UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 26, 2001

Stephan Brocoum, Assistant Manager
Office of Licensing and Regulatory Compliance
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION/U.S. DEPARTMENT OF ENERGY TECHNICAL EXCHANGE AND MANAGEMENT MEETING ON THERMAL EFFECTS ON FLOW (JANUARY 8 THROUGH 9, 2001)

Dear Mr. Brocoum:

Enclosed are the meeting summary highlights agreed upon during the January 8 through 9, 2001, Technical Exchange and Management meeting between the staff of the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy. The main purpose of the meeting was to discuss one of the Key Technical Issues, Thermal Effects on Flow (TEF). The meeting was held in Pleasanton, California.

If you have any questions regarding this letter, please contact the technical lead for TEF, Mr. Jeffrey Pohle or the Senior Project Manager for issue closure, Mr. James Andersen. Mr. Pohle can be reached at (301) 415-6703 and Mr. Andersen at (301) 415-5717.

Sincerely,

C. William Reamer, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Thermal Effects on Flow

cc: See attached distribution list

Letter to S. Brocoum from C.W. Reamer dated: January 26, 2001

cc: R. Loux, State of Nevada
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A. Brownstein, DOE/Wash, DC
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F. Marcinowski, EPA
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R. McCullum, NEI
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J. Kessler, EPRI
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R. Craig, USGS
W. Booth, Engineering Svcs, LTD
J. Curtiss, Winston & Strawn

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Technical Exchange and
Management Meeting on
Thermal Effects on Flow

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Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Thermal Effects on Flow

January 8-9, 2001
Pleasanton, California

Introduction and Objectives

This Technical Exchange and Management Meeting on Thermal Effects on Flow (TEF) is one in a series of meetings related to the U.S. Nuclear Regulatory Commission (NRC) key technical issue (KTI) and sufficiency review and the U.S. Department of Energy (DOE) site recommendation decision. Consistent with NRC regulations on prelicensing consultations and a 1992 agreement with the DOE, staff-level resolution can be achieved during prelicensing consultation. The purpose of issue resolution is to assure that sufficient information is available on an issue to enable the NRC to docket a proposed license application. Resolution at the staff level does not preclude an issue being raised and considered during the licensing proceedings, nor does it prejudge what the NRC staff evaluation of that issue will be after its licensing review. Issue resolution at the staff level, during prelicensing, is achieved when the staff has no further questions or comments at a point in time regarding how the DOE is addressing an issue. The discussions recorded here reflect NRC's current understanding of aspects of thermal effects on flow most important to repository performance. This understanding is based on all information available to date which includes limited, focused, risk-informed reviews of selected portions of recently provided DOE documents (e.g., Analysis and Model Reports (AMRs) and Process Model Reports (PMRs)). Pertinent additional information (e.g., changes in design parameters) could raise new questions or comments regarding a previously resolved issue.

Issues are "closed" if the DOE approach and available information acceptably address staff questions such that no information beyond what is currently available will likely be required for regulatory decision making at the time of any initial license application. Issues are "closed-pending" if the NRC staff has confidence that the DOE proposed approach, together with the DOE agreement to provide the NRC with additional information (through specified testing, analysis, etc.) acceptably addresses the NRC's questions such that no information beyond that provided, or agreed to, will likely be required at time of initial license application. Issues are "open" if the NRC has identified questions regarding the DOE approach or information, and the DOE has not yet acceptably addressed the questions or agreed to provide the necessary additional information in a potential license application.

The objective of this meeting is to discuss and review the progress on resolving the TEF KTI (see Attachment 1 for the description of Subissues #1 and 2). The quality assurance (QA) aspect of this KTI was determined to be outside the scope of the meeting and is being tracked in NRC's ongoing review of the DOE's QA program.

Summary of Meeting

At the close of the Technical Exchange and Management Meeting, the NRC staff stated that Subissues 1 and 2 were "closed-pending." Specific NRC/DOE agreements made at the meeting are provided as Attachment 1. The agenda and the attendance list are provided as

Attachments 2 and 3, respectively. Copies of the presenters' slides are provided as Attachment 4. Highlights from the Technical Exchange and Management Meeting are listed below.

Highlights

1) Opening Comments

The DOE stated that the intent of the meeting is to reach agreement on the current status and path forward for each of the TEF subissues (see "Thermal Effects on Flow" presentation given by Deborah Barr). In the TEF Issue Resolution Status Report (IRSR), Revision 3, the NRC stated that TEF Subissues #1 and 2 are "open." During this meeting, the DOE stated that its presentation would focus on the open items identified by the NRC in the IRSR and subsequent discussions. The DOE stated that it felt that the details provided during the current meeting would be the basis for NRC to list Subissues 1 and 2 as "closed-pending."

The DOE stated that for Subissue #2, Open Items 3, 4, and 9 would not be discussed and that documents addressing these open items would be submitted to the NRC. The NRC has identified the documents needed to resolve the open items, including the relevant concerns, in the agreements pertaining to Subissue #2.

2) Uncertainties in Total System Performance Assessment for the Site Recommendation

The DOE provided an overview of ongoing activities to identify the treatment of uncertainties in Total System Performance Assessment (TSPA) for the Site Recommendation (see "Uncertainties in Total System Performance Assessment for the Site Recommendation" presentation given by Kevin Coppersmith). The DOE discussed three ongoing activities to evaluate uncertainties: uncertainty review, conservatism assessment, and unquantified uncertainties.

Regarding the uncertainty review, the DOE stated that it would perform a bottom-up review of uncertainty treatment in process models and abstractions. The DOE stated that guidance to PMR and AMR authors was as follows: (1) if there is sufficient data, it would use a probability distribution function, and (2) if there is large uncertainty or complexity, it would provide a conservative estimate that is technically defensible. The DOE stated that the TSPA-SR is a mix of distributions and conservative estimates. The DOE asserted that, because these are conservative inputs, the TSPA-SR results are conservative, but the magnitude of the conservatism has not been assessed. The NRC replied that conservative inputs do not necessarily translate to conservative outputs in nonlinear coupled systems. The DOE agreed and stated that the intent of the ongoing uncertainties activities is to evaluate the degree of nonlinearity between conservatism in inputs and conservatism in dose estimates.

Regarding the conservatism assessment, the DOE stated the purpose was to complete a qualitative evaluation of the representativeness/conservatism of features, events, and processes (FEPs) in process models. The DOE stated that the conservatism assessment was a starting point for the unquantified uncertainties activity. The DOE further stated that the conservatism review includes all conservatisms in TSPA-SR. However, the evaluation of importance of these conservatisms to dose estimates is qualitative in the conservatism activity. The NRC noted that the conservatism report and AMRs do not evaluate all the uncertainties and their importance to dose. Thus the determination of importance to dose is subjective. The DOE agreed and stated that the unquantified uncertainties activity is intended to quantitatively evaluate the importance to dose estimates.

Regarding unquantified uncertainties, the DOE identified the key uncertainties and stated that it would evaluate the significance of these uncertainties to dose estimates. The DOE stated that currently the uncertainty review is non-Q and would be used for guidance to DOE staff/contractors for license application development. Subsequent revisions to the AMRs would be developed in accordance with guidance that is developed. The DOE stated that the evaluation complements, but does not replace, TSPA for the Site Recommendation. The NRC raised an issue regarding the QA status of the uncertainty analyses in light of the fact that these analyses are providing important guidance for license application development. The DOE responded that the present uncertainties activities will only be used to provide insight to develop guidance for treatment of uncertainties to support license application.

3) Total System Performance Assessment

The DOE provided an overview of how TEF is being incorporated into the TSPA (see "Thermal Effects on Flow - Representation in the Total System Performance Assessment" presentation given by Nicholas Francis).

The DOE stated that thermally-enhanced percolation flux above the drift crown and the in-drift thermodynamic environment are the two TSPA process level models pertinent to TEF. The NRC commented that the thermohydrologic abstractions do not include the mountain-scale coupled processes model results and large features such as faults. The DOE agreed that multi-scale model calculations used as input to TSPA do not consider effects from mountain-scale hydrologic processes or flow in faults.

Regarding the thermally enhanced percolation flux above the drift crown, the DOE stated that percolation flux at five meters above the drift crown was selected as input for the abstracted seepage model. The DOE stated that the thermal effects die out before the first climate stage, which is in approximately six hundred years. The DOE stated that thermodynamic variables are calculated for 610 locations representing waste package groups. The NRC questioned how the temperature and relative humidity responses calculated at 610 locations are reduced to the 400 waste package groups used in the corrosion models. The DOE stated the staff to answer that question were not present but that they would determine the answer. The NRC questioned whether the utilization of uncertainty in climate states represents or bounds all sources of uncertainty. The NRC asked whether the representation of variability and uncertainty in thermodynamic variables calculated from TEF models at the 610 locations needed to be propagated to other models (such as chemistry) or whether the current representation was appropriate. The DOE stated they believed the current abstraction appropriately represents variability and uncertainty.

The DOE stated that the variability and uncertainty in TEF do not have a large impact on TSPA-SR corrosion models as currently implemented. The NRC asked what the impact on the corrosion models would be with an increase in variability and uncertainty from TEF thermodynamic variables. The DOE responded that uncertainty resulting from heterogeneity can't be greater than uncertainty resulting from the no-backfill versus backfill example.

4) Technical Discussions - Subissue #1, Features, events, and processes related to thermal effects on flow

A summary of the current status of resolution was presented (see "Features, Events, and Processes for Thermal Effects on Flow and Evolution of the Near Field Environment" presentation given by Nicholas Francis). The DOE identified the NRC information needs from Revision 3 of the TEF IRSR. The DOE stated that the presentation would provide the basis for going to "closed-pending."

In its presentation, the DOE stated that the five open items would be addressed in the FEPs AMR revisions/changes and the update to the FEPs database. The NRC questioned whether the FEPs AMR updates would address all the NRC comments in Revision 3 of the IRSRs, including whether traceable references for the documentation of low-consequence calculations will be provided. The DOE stated that, in general, it believed the NRC comments were addressed, and it requested that the NRC review the updates and provide the DOE any additional comments. The DOE also addressed an NRC comment on regional hydrothermal activity. The DOE also provided a summary of the TEF and Evolution of the Near-Field Environment (ENFE) FEPs.

As a result of additional discussions, the NRC and DOE reached two agreements for Subissue #1 (see Attachment 1). With these two agreements, the NRC stated that Subissue #1 could be listed as "closed-pending".

5) Technical Discussions - Subissue #2, Thermal effects on temperature, humidity, saturation, and flux

The DOE addressed the nine open items listed in Revision 3 of the TEF IRSR (with the exception of Open Items 3, 4, and 9 as previously discussed).

<u>TEF Subissue 2, Open Item 1: Thermohydrologic Modeling for the Current Repository Design</u>:

The DOE discussed the basis for resolving Open Item #1 (see "Thermal Effects on Flow Subissue 2, Open Item 1: Thermohydrologic Modeling for the Current Repository Design" presentation given by Ernest Hardin and Tom Buscheck). The DOE stated that the presentation would provide the basis for closing the open item.

The DOE stated that multi-scale thermohydrologic model calculations have been conducted for the Enhanced Design Alternative II design with no backfill. The NRC inquired whether the design included ventilation. The DOE stated that the design included ventilation for the 50-year pre-closure period. The NRC further inquired whether the model included water removal resulting from ventilation and the DOE responded that it did not.

The DOE concluded that the thermohydrologic models incorporate relevant Enhanced Design Alternative II design features and, therefore, this open item can be closed.

TEF Subissue 2, Open Item 2: Cold Trap Effects in the Multi-scale Thermohydrologic Model:

The DOE discussed the basis for resolving Open Item #2 (see "Thermal Effects on Flow Subissue 2, Open Item 2: Cold Trap Effects in the Multi-scale Thermohydrologic Model" presentation given by Ernest Hardin and Tom Buscheck). The DOE stated that the presentation would provide the basis for going to "closed-pending" for this open item.

The DOE stated that it has identified the technical issues in modeling cold traps, key assumptions for cold traps for the Multi-scale Thermohydrologic Model, and is considering additional models, as appropriate, to represent cold trap effects in the Multi-scale Thermohydrologic Model. The DOE stated that the cold trap effects occur in emplacement drifts with water and latent heat transfer from warmer to cooler locations. The DOE stated that previous analyses indicated that drift-scale cold traps could produce condensate flux on cooler waste packages. The DOE stated: (1) it is developing a mountain-scale model to represent the repository-scale cold trap effect; (2) it is considering development of a detailed drift-scale thermohydrologic model to estimate the magnitude of the drift-scale cold trap effect; and (3) it may not incorporate the cold trap effect into TSPA unless it significantly changes the predicted dose. The NRC inquired what the DOE's standard is for a "significant" change in calculated dose. The DOE replied they would provide the NRC a response to the question.

TEF Subissue 2, Open Item 6: Data Support for the Ventilation Model:

The DOE discussed the basis for resolving Open Item #6 (see "Thermal Effects on Flow Subissue 2, Open Item 6: Data Support for the Ventilation Model" presentation given by Ernest Hardin). The DOE stated that the presentation would provide the basis for going to "closed-pending" for this open item.

The DOE presented an overview of the ventilation test. The DOE stated that the testing will be used to calibrate ventilation models based on ANSYS and Multiflux codes. During Phase 3 of the test, the DOE will simulate moisture removal by ventilation air using water injection and evaluate the effect on heat removal efficiency. The NRC questioned how the DOE would determine how much water needed to be added to adequately represent thermohydrologic coupling with the repository drift wall. The DOE stated that the ventilation test is designed to represent heat removal by ventilation air and is not designed to represent thermal-hydrologic coupling with the host rock at the drift wall.

Mr. Shettel (Nye County) questioned the evaporation and precipitation at the drift wall. The DOE responded that the precipitation occurs inside the rock and not at the drift wall. In addition, the DOE stated that calculations could be done to calculate the quantity of minerals precipitated. Mr. Shettel stated that Nye County has already done the calculations and they are presented on the Nye County webpage.

TEF Subissue 2, Open Item 5: Potential Heat Losses in Cross Drift Thermal Test:

The DOE discussed the basis for resolving Open Item #5 (see "Thermal Effects on Flow Subissue 2, Open Item 1: Potential Heat Losses in Cross Drift Thermal Test" presentation given by Mark Peters). The DOE stated that the presentation would provide the basis for closing the open item.

At the start of the presentation, the NRC asked about the status of monitoring mass and energy losses through the bulkhead of the drift-scale test. The DOE replied that a contractor proposal for monitoring losses through the bulkhead had been received and the DOE determined the proposal to not be feasible.

With respect to the cross-drift thermal test, the DOE stated that the potential for unmonitored mass and energy flow through the cross drift thermal test boundaries has been taken into account as identified in the Cross Drift Thermal Test Planning Report, Section 4.0. The DOE indicated that simulations to support test design showed that minimal mass or energy losses would occur through the boundaries of the cross drift thermal test. The NRC questioned whether these simulations were done using a stochastic representation of heterogeneity. The DOE said they were not. The NRC noted that incorporating heterogeneity into the simulations may provide different results related to potential losses through the test boundaries. The NRC stated that it would review the Cross-Drift Thermal Test Planning Report and provide the DOE comments, if any.

The DOE discussed the test design configuration. The DOE stated that the objectives of the cross drift thermal test include testing water shedding between drifts. The NRC questioned whether the water collection holes would be effective in collecting water and stated that capillary diversion needs to be taken into account. The DOE noted the NRC comment. The DOE stated that there might not be sufficient water for collection in the collection holes. The DOE acknowledged that conclusions on whether thermal seepage into emplacement drifts occurs could not be drawn solely on the basis of no water accumulating in the collection holes. Similarly, the DOE acknowledged that chemical analyses of liquid water cannot be undertaken if no water accumulates in the collection holes. The DOE stated that the Cross Drift Thermal Test Final Report is scheduled for December 2004 in the present baseline schedule.

Later in the meeting, Mr. Frishman (State of Nevada) raised three concerns about the cross drift thermal test. First, he noted that the current schedule for the test would not allow information to be used in the license application. Second, he stated that current repository design is based upon hypotheses that need to be tested. Finally, he indicated that the test would provide data to test three key hypotheses: (1) mobilized water would be shed between emplacement pillars; (2) there would be no penetration of the boiling isotherm by liquid; and (3) mobilized waters would have a benign chemistry with respect to engineered barrier performance. During the NRC review of the Cross-Drift Thermal Test Planning Report, the NRC will consider the State of Nevada's comments.

TEF Subissue 2, Open Item 7: Data Uncertainty:

The DOE discussed the basis for resolving Open Item #7 (see "Thermal Effects on Flow Subissue 2, Open Item 7: Data Uncertainty" presentation given by Bo Bodvarsson). The DOE stated that the presentation would provide the basis for going to "closed-pending" for this open item.

The NRC questioned how data uncertainty is propagated into TSPA because data uncertainty in calibrated properties used for current modeling represents only uncertainty in the boundary condition flux. The DOE responded by discussing ongoing efforts to account for other uncertainties in the calibrated properties model wherein the resulting calibrated properties would properly include a measure of uncertainty along with the sets for high, mean, and low flux boundary conditions. The NRC responded that this would provide the needed measure of uncertainty but questioned whether this would be propagated further into TSPA. The DOE asked if the NRC has a suggestion for an efficient method to do so. The NRC suggested additional runs of the Multi-Scale Thermohydrologic Model, using important parameters at their 95% confidence (including parameters, such as thermal conductivity, not determined in the calibrated properties AMR), and binning these results into the abstraction along with results for the high, mean, and low boundary fluxes. Both the DOE and NRC acknowledge that a full analysis of parameter uncertainty would require an impossibly large number of model runs and that efforts need to focus on those parameters that have the largest effect on thermohydrologic model results and ultimately performance.

The DOE stated that to address this area, it would discuss: (1) uncertainty from spatially heterogeneous properties; (2) uncertainty in measured data; (3) propagation of uncertainty in inverse modeling; and (4) upscaling.

Regarding uncertainty from spatially heterogeneous properties, the DOE stated that it is most important for site-scale flow and transport. The DOE further stated that heterogeneity within individual layers is incorporated for specific problems (e.g., seepage into drift, perched water bodies).

Regarding uncertainty in measured data, the DOE stated that measured data are upscaled to the unsaturated zone model gridblock scale common to both mountain scale simulations and inverse modeling calibration studies. The DOE further stated that upscaling is only necessary for certain parameters. The NRC suggested the methods used for upscaling be summarized and documented.

The DOE stated that measurement errors are taken into account in iTOUGH. The NRC commented that the AMR currently available to the NRC does not take into account heat dissipation probe information. The DOE stated that the future AMR will incorporate it.

Regarding propagation of uncertainty in inverse modeling, the DOE stated that iTOUGH2 utilizes a statistical minimization routine and automatic optimization algorhythm to yield best matches to the observed data. The analysis yields a statistical evaluation of the goodness of fit and the relative importance of all relevant input parameters (including the ten most sensitive ones). The DOE stated that it was going to start submitting the iTOUGH2 output on sensitivity and uncertainties of parameters to the technical database. The NRC commented that this would be a good idea.

The NRC noted that the various property sets used for thermohydrologic modeling were determined by the DOE to be equally valid based on comparisons to temperature data from the drift scale test, although saturations and fluxes obtained using these various property sets were significantly different. The NRC questioned whether additional comparisons of modeled versus measured saturations were to be done and if these comparisons would take into account uncertainties such as losses through the thermal bulkhead and in saturation measurements using ERT, GPR, and neutron probes. The DOE responded that these comparisons were being made.

TEF Subissue 2, Open Item 8: Model Uncertainty:

The DOE discussed the basis for resolving Open Item #8 (see "Thermal Effects on Flow Subissue 2, Open Item 8: Model Uncertainty" presentation given by Bo Bodvarsson). The DOE stated that the presentation would provide the basis for going to "closed-pending" for this open item.

The DOE stated that three types of uncertainties are considered in the thermohydrologic models (1) property/parameter, (2) conceptual model, and (3) numerical model uncertainty. The DOE then discussed flow conceptualization under ambient and thermal conditions. The DOE indicated there is uncertainty in conceptual models and said this uncertainty is being evaluated using alternative conceptual models such as discrete fracture models. The DOE stated that this evaluation would be discussed in the Unsaturated Zone Flow and Transport PMR, Rev. 00, ICN 02.

TEF Subissue 2, Overall Status

As a result of additional discussions, the NRC and DOE reached 13 agreements for Subissue #2 (see Attachment 1). With these 13 agreements, the NRC stated that Subissue #2 could be listed as "closed-pending."

6) Public Comments

There were no general public comments other than those discussed above.

1/11/01	1/11/2001
C. William Reamer Deputy Director Division of Waste Management Nuclear Regulatory Commission	Dennis R. Williams Deputy Assistant Manager Office of Licensing & Regulatory Compliance Department of Energy

Summary of the Resolution of the Key Technical Issue on Thermal Effects on Flow

Subissue #	Subissue Title	Status	NRC/DOE Agreements
1	Features, events, and processes related to thermal effects on flow	Closed-Pending	1) Provide the FEPs AMRs relating to TEF. The DOE will provide the following updated FEPs AMRs related to thermal effects on flow to the NRC: *Disruptive Events FEPs* (ANL-NBS-MD-000005) Rev 00 ICN 01; *Features, Events, and Processes: System Level* (ANL-WIS-MD-000019) Rev 00; *Features, Events, and Processes in UZ Flow and Transport* (ANL-NBS-MD-000001) Rev 01; *Features, Events, and Processes in SZ Flow and Transport* (ANL-NBS-MD-000002) Rev 01; *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (ANL-NBS-MD-000004) Rev 00 ICN 01; *Miscellaneous Waste Form FEPs* (ANL-WIS-MD-000009) Rev 00 ICN 01; and *Engineered Barrier System Features, Events, and Processes* (ANL-WIS-PA-000002) Rev 01. Expected availability: January 2001. 2) Provide the FEPs database. The DOE will provide the FEPs data base to the NRC during March 2001.

2	Thermal effects on temperature, humidity, saturation, and flux	Closed-Pending	1) Consider measuring losses of mass and energy through the bulkhead of the drift-scale test (DST) and provide the technical basis for any decision or method decided upon (include the intended use of the results of the DST such as verifying assumptions in FEP exclusion arguments or providing support for TSPA models. The DOE should analyze uncertainty in the fate of thermally mobilized water in the DST and evaluate the effect this uncertainty has on conclusions drawn from the DST results. The DOE's position is that measuring mass and energy losses through the bulkhead of the DST is not necessary for the intended use of the DST results. The DST results are intended for validation of models of thermally-driven coupled processes in the rock, and measurements are not directly incorporated into TSPA models. Results of the last two years of data support the validation of DST coupled-process models and the current treatment of mass and energy loss through the bulkhead. The DOE will provide the NRC a white paper on the technical basis for the DOE's understanding of heat and mass losses through the bulkhead and their effects on the results by April 2001. This white paper will include the DOE's technical basis for its decision regarding measurements of heat and mass losses through the DST bulkhead. This white paper will address uncertainty in the fate of thermally mobilized water in the DST and also the effect this uncertainty has on conclusions drawn from the DST results. The NRC will provide comments on this white paper. The DOE will provide analyses of the effects of this uncertainty on the uses of the DST in response to NRC comments. 2) Provide the location and access to the Multi-Scale Thermohydrologic Model input and output files. The output files are in the Technical Data Management System. The DTNs are LL000509112312.003, LL000509012312.002, and LL000509212312.004. The input files are located in the Project records system. The document identification number is MOL.20000706.0396. The DOE will provide the requested information to the NRC in January 2001.

2	Thermal effects on temperature, humidity, saturation, and flux - cont.		3) Provide the following references: Multi-Scale Thermohydrologic Model AMR, ICN 01; Abstraction of Near Field Environment Drift Thermodynamic and Percolation Flux AMR, ICN 01; Engineered Barrier System Degradation Flow and Transport PMR, Rev. 01; and Near Field Environment PMR, ICN 03. DOE will provide to the NRC the following documents: • *Multi-Scale Thermohydrologic Model* AMR (ANL-EBS-MD-00049) Rev 00 ICN 01 (January 2001) • *Abstraction of Near-Field Environment Drift Thermodynamic and Percolation Flux* AMR (ANL-EBS-HS-000003) Rev 00 ICN 01 (January 2001) • *Engineered Barrier System Degradation, Flow and Transport* PMR (TDR-EBS-MD-000006) Rev 01 (September 2001) • *Near-Field Environment* PMR (TDR-NBS-MD-000001) Rev 00 ICN 03 (January 2001) 4) Provide the Multi-Scale Thermohydrologic Model AMR, Rev. 01. The DOE will provide the *Multi-Scale Thermohydrologic Model* AMR (ANL-EBS-MD-00049) Rev 01 to the NRC. Expected availability is FY 02. 5) Represent the cold-trap effect in the appropriate models or provide the technical basis for exclusion of it in the various scale models (mountain, drift, etc.) considering effects on TEF and other abstraction/models (chemistry). See page 11 of the Open Item (OI) 2 presentation. The DOE will represent the "cold-trap" effect in the *Multi-Scale Thermohydrologic Model* AMR (ANL-EBS-MD-00049) Rev 01, expected to be available in FY 02. This report will provide technical support for inclusion or exclusion of the cold-trap effect in the various scale models. The analysis will consider thermal effects on flow and the in-drift geochemical environment abstraction. 6) Provide the detailed test plan for Phase III of the ventilation test, and consider NRC comments, if any. The DOE will provide a detailed test plan for the Phase III ventilation test in March 2001. The NRC comments will be provided no later than two weeks after receipt of the test plan, and will be considered by the DOE prior to test initiation.

2	Thermal effects on temperature, humidity, saturation, and flux - cont.		7) Provide the Ventilation Model AMR, Rev. 01 and the Pre-Test Predictions for Ventilation Test Calculation, Rev. 00. The DOE will provide the *Ventilation Model* AMR (ANL-EBS-MD-000030) Rev 01 to the NRC in March 2001. Note that ventilation test data will not be incorporated in the AMR until FY02. The DOE will provide the Pre-test Predictions for Ventilation Tests (CAL-EBS-MD-000013) Rev 00 to the NRC in February 2001. Test results will be provided in an update to the *Ventilation Model* AMR (ANL-EBS-MD-000030) in FY 02. 8) Provide the Mountain Scale Coupled Processes AMR, or an other appropriate AMR, documenting the results of the outlined items on page 20 of the OI 7 presentation (considering the NRC suggestion to compare model results to the O.M. Phillips analytical solution documented in Water Resources Research, 1996). The DOE will provide the updated *Mountain-Scale Coupled Processes Model* AMR (MDL-NBS-HS-000007) Rev 01 to the NRC in FY 02, documenting the results of the outlined items on page 20 of DOE's Open Item 7 presentation at this meeting. The DOE will consider the NRC suggestion of comparing the numerical model results to the O.M. Phillips analytical solution documented in WRR (1996). 9) Provide the Multi-Scale Thermohydrologic Model AMR, ICN 03. The DOE will provide the *Multi-Scale Thermohydrologic Model* AMR (ANL-EBS-MD-00049) Rev 00 ICN 03 to the NRC. Expected availability July 2001. 10) Represent the full variability/uncertainty in the results of the TEF simulations in the abstraction of thermodynamic variables to other models, or provide technical basis that a reduced representation is appropriate (considering risk significance). The DOE will discuss this issue during the TSPAI technical exchange tentatively scheduled for April 2001. 11) Provide the Calibrated Properties AMR, incorporating uncertainty from all significant sources. The DOE will provide an updated *Calibrated Properties Model* AMR (MDL-NBS-HS-000003) Rev 01 that incorporates uncertainty from significant sources to the NRC in FY 02.

2	Thermal effects on temperature, humidity, saturation, and flux - cont.		12) Provide the Unsaturated Zone Flow and Transport PMR, Rev. 00, ICN 02, documenting the resolution of issues on page 5 of the OI 8 presentation. The DOE will provide the *Unsaturated Zone Flow and Transport* PMR (TDR-NBS-HS-000002) Rev 00 ICN 02 to the NRC in February 2001. It should be noted, however, that not all of the items listed on page 5 of the DOE's Open Item 8 presentation at this meeting are included in that revision. The DOE will include all the items listed on page 5 of the DOE's Open Item 8 presentation in Revision 02 of the *Unsaturated Zone Flow and Transport* PMR, scheduled to be available in FY 02. 13) Provide the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport AMR, Rev. 01 and the Analysis of Hydrologic Properties Data AMR, Rev. 01. The DOE will provide updates to the *Conceptual and Numerical Models for UZ Flow and Transport* (MDL-NBS-HS-000005) Rev 01 and the *Analysis of Hydrologic Properties Data* (ANL-NBS-HS-000002) Rev 01 AMRs to the NRC. Scheduled availability is FY 02.

DOE-NRC TECHNICAL EXCHANGE AGENDA THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT KEY TECHNICAL ISSUES January 8-12, 2001 Pleasanton, California			
Monday, January 8, 2001			
Schedule	TEF Presentation	Time (Minutes)	
		Duration	Discussion
8:00 – 8:20 AM	Introduction/Objectives (DOE-NRC)	20	
8:20 – 8:40 AM	TEF Summary (Barr)	10	10
8:40 – 9:10 AM	Uncertainties (Coppersmith)	20	10
9:10 – 9:45 AM	TSPA for TEF (Francis)	20	15
9:45 – 10:00 AM	BREAK	15	
10:00 – 10:30 AM	TEF and ENFE FEPs (Francis)	15	15
10:30 – 11:15 AM	Caucus Subissue 1		45
11:15 – 11:45 AM	DOE-NRC Discussion of Resolution Status		30
11:45 AM – 12:45 PM	LUNCH	60	
12:45 – 4:15 PM with 15-minute break	Subissue 2 Open Item Presentations		
	Open Item 1: Repository Design (Hardin)	15	10
	Open Item 2: Cold Traps (Hardin)	15	10
	Open Item 6: Ventilation Model (Hardin)	15	10
	Open Item 5: Cross Drift Thermal Testing (Peters)	20	10
	Open Item 7: Data Uncertainty (Bodvarsson)	30	15
	Open Item 8: Model Uncertainty (Bodvarsson)	30	15
4:15 – 5:15 PM	Caucus Subissue 2	60	
5:15 – 5:45 PM	DOE-NRC Discussion of Resolution Status		30
5:45 – 6:00 PM	Closing Remarks	15	
6:00 PM	Adjourn Day 1		

ATTACHMENT 2

DOE-NRC TECHNICAL EXCHANGE AGENDA THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT KEY TECHNICAL ISSUES January 8-12, 2001 Pleasanton, California			
Tuesday, January 9, 2001			
Schedule	TEF Presentation	Time (Minutes)	
		Duration	Discussion
8:00 – 9:00 AM	Final TEF Caucus		60
9:00 – 9:15 AM	Closing Remarks	15	
9:15 AM	Adjourn TEF Technical Exchange		
9:15 – 11:30 AM	Develop TEF Meeting Minutes and Agreement Letter	135	
11:30 – 11:45 AM	BREAK	15	
ENFE Technical Exchange			
Schedule	ENFE Presentation	Time (Minutes)	
		Duration	Discussion
11:45 AM – 12:05 PM	Introduction/Objectives (DOE-NRC)	20	
12:05 – 12:30 PM	ENFE KTI Summary (Barr)	15	10
12:30 – 1:30 PM	LUNCH	60	
1:30 – 4:10 PM (15-minute break)	ENFE TSPA Treatments and Impacts		
	EBS Chemical Environments (Nowak)	25	20
	TSPA-SR Results Related to Waste Form Degradation (Rechard)	25	25
	Effects of Coupled THC Processes on Radionuclide Transport (Gross)	25	20
4:10 – 4:50 PM	Subissue 1 Seepage and Flow: Coupled THC Processes Affecting CHn (Sonnenthal)	25	15
4:50 – 5:05 PM	Closing Remarks	15	
5:05 PM	Adjourn Day 2		

DOE-NRC TECHNICAL EXCHANGE AGENDA THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT KEY TECHNICAL ISSUES January 8-12, 2001 Pleasanton, California			
Wednesday, January 10, 2001			
Schedule	ENFE Presentation	Time (Minutes)	
		Duration	Discussion
8:00 – 10:30 AM (15-minute break)	Subissue 1: Seepage and Flow (Continued)		
	Thermal Alteration of PTn (Spycher)	25	15
	Effects of Cementitious Materials (Hardin)	25	15
	Mineral Precipitation in Fractures or at Fracture-Matrix Interface (Sonnenthal)	25	20
10:30 AM – Noon	Caucus on Subissue 1	90	
Noon – 1:00 PM	LUNCH	60	
1:00 – 1:30 PM	DOE-NRC Discussion of Resolution Status of Subissue 1		30
1:30 – 2:15 PM	Subissue 4 Item: Colloidal Transport in the UZ (Houseworth)	25	20
2:15 – 3:15 PM	Caucus on Subissue 4	60	
3:15 – 3:30 PM	BREAK	15	
3:30 – 4:00 PM	DOE-NRC Discussion of Resolution Status of Subissue 4		30
4:00 – 4:55 PM	Subissue 2 THC Effects on Waste Package Environment: In-Drift Geochemical Environment (Hardin)	30	25
4:55 – 5:10 PM	Closing Remarks	10	
5:10 PM	Adjourn Day 3		

DOE-NRC TECHNICAL EXCHANGE AGENDA THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT KEY TECHNICAL ISSUES January 8-12, 2001 Pleasanton, California			
Thursday, January 11, 2001			
Schedule	ENFE Presentation	Time (Minutes)	
		Duration	Discussion
8:00 – 11:15 AM (15-minute break)	Subissue 2 THC Effects on Waste Package Environment (Continued)		
	Treatment of Coupled Processes and Model Integration (Hardin)	30	15
	Assumption of Chemical Equilibrium (Hardin)	30	15
	Range of Water Chemistry and Trace Elements in the WP Chemical Environment (Gdowski)	30	15
	Data and Model Uncertainties and Sensitivity Studies (Hardin)	30	15
11:15 AM – 12:30 PM	Caucus on Subissue 2	75	
12:30 – 1:30 PM	LUNCH	60	
1:30 – 2:00 PM	DOE-NRC Discussion of Resolution Status of Subissue 2		30
2:00 – 3:20 PM	Subissue 3 THC Effects on Radionuclide Release (Stockman)	45	35
3:20 – 3:35 PM	BREAK	15	
3:35 – 4:35 PM	Caucus on Subissue 3	60	
4:35 – 5:05 PM	DOE-NRC Discussion of Resolution Status of Subissue 3		30
5:05 – 5:15 PM	Closing Remarks	15	
5:15 PM	Adjourn Day 4		

Friday, January 12, 2001			
8:00 AM – Noon	ENFE Meeting Minutes and Agreement Letter	240	

THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT TECHNICAL EXCHANGE AND MANAGEMENT MEETINGS JANUARY 8-11, 2001 PLEASANTON, CALIFORNIA

NAME	ORGANIZATION	PHONE NUMBER
RICH MAJOR	ACNW STAFF (NRC)	(301) 415-7366
Bob Bradbury	MTCS	(702) 794-5424
MARTHA H. KOHLER	LLNL	925 4235582
John Bradbury	NRC	301-415-6597
Thomas A. Buscheck	LLNL	925-423-9390
Don L. Shettel	Nye Co., NV/GMII	702-294-3064
Mark T. Peters	M&O/LANL	702-295-3644
Darren Jolley	M&O/Duke	702-295-5525
CHARLES C. WARREN	OQA/QATSS	925-423-6863
Ken Pointer	M+O/Beckman	702-295-6191
Stephen Blair	M+O/LLNL	925-422-6467
Christine Stockman	M+O/SNL	702-295-4477
David R. Turner	CNWRA	210-522-2139
ENGLISH PEARCY	CNWRA	210-522-5540
David Pickett	CNWRA	210-522-5582
Milt Levenson	ACNW	650-322-1025
GUSTAVO CRAGNOLINO	CNWRA	210-522-5539
Lietai Yang	CNWRA	210-522-2483
Michael Gross	M+O/Beckman	415 482 8200
E. James Nowak	SNL	505-284-4810
RAYMOND WYMER	ACNW/NRC	865-483-9309
Ralph Wagner	M&O/ART/URS	702-295-4441
Peter Mast	M+O/PA	505-872-1089

ATTACHMENT 3

THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT TECHNICAL EXCHANGE AND MANAGEMENT MEETINGS JANUARY 8-11, 2001 PLEASANTON, CALIFORNIA

NAME	ORGANIZATION	PHONE NUMBER
CARL D. BELLA	NWTRB	703 235 9130
John Kessler	EPRI	650-855-2069
Jean Younker	M&O TRW	702 295 5497
Wunan Lin	LLNL	925-422-7162
Judy Treichel	NV NWTF	702-248-1127
Steve Frishman	NV NWPO	775-687-3744
Harris Greenberg	MTS/BAH	702-794-1385
Junghun (John) Leem	M&O PA/DUKE	702-295-6779
RICHARD METCALF	PAO M&O, DUKE	702-295-7086
Michael Itamura	PAO/SNL	505-284-4815
Brian Marshall	USGS	303-236-7914
ROBIN L. SWEENEY	DOE/YMP/OLRC	702/794-1417
George W. Hellstrom	DOE/YMP/OCC	702/794-5519
Anita Capoferri	DOE/HQ/OGC	202-586-8135
Patricia Campbell	Winston & Strawn	202-371-5828
STEPHEN J. CEREGHINO	BECHTEL SAIC	702-279-8284
Richard Slaydew	TRW/M&O PPEC	702-295-5465
YVONNE TSANG	LBNL	510-486-7047
Robin Datta	M&O/TID	702-295-5070
ALI HAGHI	M&O/DUKE	702-295-5318
E. VON TIESENHAUSEN	CLARK COUNTY	702 455-5184
William M. Murphy	California State Univ. Chico	530 898 6269
Lorraine DeGARMO	Lorraine DeGarmo	702/295-5488
Dale G. Wilder	LLNL	925/422-6908

THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT TECHNICAL EXCHANGE AND MANAGEMENT MEETINGS JANUARY 8-11, 2001 PLEASANTON, CALIFORNIA

NAME	ORGANIZATION	PHONE NUMBER
James Andersen	NRC/NMSS	301-415-5717
Jeffrey Pohle	NRC/NMSS	301-415-6703
David Brooks	NRC/NMSS	301-415-7284
Bret Leslie	NRC/NMSS	301-415-6654
Lauren Browning	CNWRA	210 522-6642
Dave Esh	NRC/NMSS	301-415-6705
Scott Painter	CNWRA	210 522 3348
Asad Chowdhury	CNWRA	210 522 5151
Ron Green	CNWRA	210 522 5305
Debra Hughson	CNWRA	210 522 3805
Bill Dam	NRC/NMSS	301-415-6710
Bo Bodvarsson	LBNL/M&O	510-486-4789
Andrew Orrell	M&O/SNL	702 295-5600
Nicholas Francis	M&O/SNL	505 284-3923
Kevin Coppersmith	CCI/M&O	702 295-6275
Ernest Hardin	M&O/LLNL	702 295 3897
Veronica Arnell	M&O/RSL	702 295-2954
Alan Ross	M&O/R&L	702 295 6007
Carol Hanlon	DOE/YMP	702-794-1324
Dennis R. Williams	DOE/YMP/OL&RC	702-794-5526
Deborah L. Barr	DOE/YMP/OPE	702-794-1479
David C. Sassani	MTS/GAI	702-794-5501
Michael Scott	CRWMS M&O/R&L	702-295-3016
Dave Diodato	USNWTRB	703-235-4481

THERMAL EFFECTS ON FLOW AND EVOLUTION OF THE NEAR-FIELD ENVIRONMENT TECHNICAL EXCHANGE AND MANAGEMENT MEETINGS JANUARY 8-11, 2001 PLEASANTON, CALIFORNIA

NAME	ORGANIZATION	PHONE NUMBER
Rob P Rechard	M&O/SNL	505-844-1761
ROBERT HOWARD	M&O PERFORMANCE ASSESSMENT	702-295-3097
V Pasu Pasupathi	M&O WASTE PACKAGE	702-295-4507
Rod McCullum	NEI	202-739-8082
Eric Sonnenthal	LBNL	(510)486-5866
Jim Houseworth	LBNL	(702)295-7611
Nicolas Spycher	LBNL	(510) 495-2388
Tammy Summers	M&O/LLNL	(925) 423-0531
BRIAN VIANI	LLNL	925/423-2001
David Pickett	CNWRA	210-522-5582
Richard Aguilar	M&O / SNL	505-284-4597
Greg Gdowski	LLNL	925-423-2113
Thomas J. Wolery	LLNL	925-422-5789
Tae M. Ahn	NRC	301-415-5812

ATTACHMENT 4

PRESENTER'S SLIDES

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

Thermal Effects on Flow

Presented to:
DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:
Deborah Barr
Yucca Mountain Site Characterization Office
Department of Energy

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Current Subissue Status
- Key Activities Supporting Resolution of the Thermal Effects on Flow Key Technical Issue
- Presentation Outline
- Conclusions

Presentation Objectives

- Describe how thermal effects on flow are accounted for in the Total System Performance Assessment
- Provide an overview of the treatment of model and data uncertainties
- Provide update on DOE's progress in identifying and screening features, events, and processes related to thermohydrologic models
- Provide update on DOE's progress in enhancing its thermohydrologic models and test program
- Present and agree on approaches to close-pend Subissues 1 and 2 for the Thermal Effects on Flow Key Technical Issue by addressing the associated open items

Current Subissue Status

- **Subissue 1: OPEN** — **Features, Events, and Processes Related to Thermal Effects on Flow**
  - Five (5) Open Items
- **Subissue 2: OPEN** — **Thermal Effects on Temperature, Humidity, Saturation, and Flux**
  - Nine (9) Open Items
- **DOE understands that closure of the referenced subissues and open items will result in closure of the acceptance criteria in the NRC's Thermal Effects on Flow Issue Resolution Status Report (IRSR), Revision 2**

Subissue 1 Open Item Status

Open Items	NRC IRSR Rev. 3 Status	DOE Proposed Status
1) Final List of Primary and Secondary Features, Events and Processes (FEPs)	Open	Closed-Pending
2) FEPs Screening Analysis for Thermohydrological Models	Open	Closed-Pending
3) Secondary FEPs in FEPs Screening Documentation	Open	Closed-Pending
4) Screening Argument Assumptions for FEPs Relevant to Thermohydrological Models	Open	Closed-Pending
5) Traceable References to Technical Basis for Screening Arguments for Excluded FEPs	Open	Closed-Pending

Subissue 2 Open Item Status

Open Items No Presentation for shaded items – Document submittals only		NRC IRSR Rev. 3 Status	DOE Proposed Status
1)	Complete Thermohydrologic Modeling For Current Repository Design	Open	Closed
2)	Cold Trap Effects	Open	Closed-Pending
3)	Traceable References to Multi-Scale Thermohydrologic Model	Open	Closed-Pending
4)	Mass and Energy Losses Through the Drift Scale Test Bulkhead	Open	Closed-Pending
5)	Unmonitored Mass and Energy Flow Through the Cross Drift Thermal Test Boundaries	Open	Closed
6)	Data Support for Ventilation Model	Open	Closed-Pending
7)	Data Uncertainty	Open	Closed-Pending
8)	Model Uncertainty	Open	Closed-Pending
9)	Model Support by Predicting Thermohydrologic Results of the Cross Drift Thermal Test	Open	Closed-Pending

Subissue 2 Open Item Status
(Continued)

Closed Pending Based on Document Submittals	Document Submittals
Open Item 3: Traceable References to Multi-Scale Thermohydrological Model	Multi-scale Thermohydrological Model AMR and Input and Output Files, ANL-EBS-MD-000049, Rev. 00, ICN 01 and Abstraction of Near Field Environment Drift Thermodynamic Environment and Percolation Flux AMR, ANL-EBS-HS-000003, Rev. 00, ICN 01
Open Item 4: Mass and Energy Losses through the Drift Scale Test Bulkhead	DOE Cooperative Agreement with the University of Nevada - Measurement of Heat/Mass Loss Through the Bulkhead of the Drift Scale Test
Open Item 9: Model Support by Predicting Thermohydrological Results of the Cross Drift Thermal Test	Cross-Drift Thermal Test Pre-test Plan to be developed at a later date. Document submittals will be made once the documents become available

Key Activities Supporting Resolution of Thermal Effects on Flow Issue

- **DOE has**
  - Updated the Features, Events, and Processes list and screening arguments
  - Updated project documents to include repository design without backfill
  - Enhanced work scope to ensure applicability of test results for validating/constraining models
- **DOE is**
  - Revising Analysis/Model Reports and Process Model Reports, as necessary, to reflect improvements in thermohydrologic modeling and testing to better understand coupled processes
  - Working to quantify model and data uncertainties

Presentation Outline

- **Uncertainties in the Total System Performance System Assessment for the Site Recommendation**
- **Thermal Effects on Flow representation in Total System Performance System Assessment**
- **Subissue 1: Features, Events, and Processes**
- **Subissue 2: Thermal Effects on Temperature, Humidity, Saturation and Flux**
  - Open Item 1: Thermohydrologic Modeling for Repository Design
  - Open Item 2: Cold Trap Effects
  - Open Item 6: Data Support for Ventilation Model
  - Open Item 5: Unmonitored Mass and Energy Flow Through the Cross-Drift Thermal Test Boundaries
  - Open Item 7: Data Uncertainty
  - Open Item 8: Model Uncertainty

Conclusions

- **Subissue 1: Features, Events, and Processes**
  - DOE considers that this subissue is Closed-Pending NRC review of updated Features, Events, and Processes Analysis Model Reports and the Features, Events, and Processes database
- **Subissue 2: Thermal Effects on Temperature, Humidity, Saturation and Flux**
  - DOE considers that this subissue is Closed-Pending NRC review of new analyses and test data associated with the nine open items

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

Uncertainties in Total System Performance Assessment for the Site Recommendation

Presented to:
DOE-NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:
Kevin Coppersmith
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Uncertainties in Total System Performance Assessment for the Site Recommendation
- Ongoing activities to evaluate uncertainties
- Conclusions
- References

Presentation Objectives

- Discuss ongoing activities to identify the treatment of uncertainties in Total System Performance Assessment for the Site Recommendation
- Describe how unquantified uncertainties are being evaluated
- Outline planned activities for uncertainty treatment for the license application

Uncertainties in Total System Performance Assessment for the Site Recommendation

- Ongoing activities to evaluate uncertainties
  - Uncertainty review
  - Conservatism assessment
  - Unquantified uncertainties

Uncertainties in Total System Performance Assessment for the Site Recommendation
(Continued)

- **Ongoing Activities to Evaluate Uncertainties**
  - Total System Performance Assessment for the Site Recommendation is a "defensible assessment"
    - Guidance to process modelers regarding uncertainties:
      - » If have sufficient data, develop probability distribution to quantify uncertainties
      - » If have large uncertainties or complexity, provide a conservative estimate that is defensible technically (bounds, conservative distributions)
  - Total System Performance Assessment for the Site Recommendation is a mix of probability distributions and conservative estimates
    - Because there are conservative inputs, the Total System Performance Assessment results are considered to be conservative
    - The *magnitude* of that conservatism has not yet been quantified

Uncertainties in Total System Performance Assessment for the Site Recommendation (Continued)

- **Ongoing Activities to Evaluate Uncertainties**
  - Three activities are being implemented to review and evaluate the treatment of uncertainties in Site Recommendation Consideration Report
    - Uncertainty Review: Systematic review of the manner in which uncertainties have been treated for Site Recommendation Consideration Report
    - Conservatism Assessment: Identification of conservatisms in process models for Site Recommendation Consideration Report
    - Unquantified Uncertainties: Evaluation of the significance of unquantified uncertainties in Total System Performance Assessment for the Site Recommendation
      - » "Unquantified uncertainties": Current state of knowledge is only partially represented

Uncertainties in Total System Performance Assessment for the Site Recommendation
(Continued)

- **Uncertainty Review**
  - Performing bottoms-up review of uncertainty treatment in process models and abstractions (Analysis/Model Reports, Process Model Reports), including:
    - Parameter distributions using project data or published data
    - Alternative conceptual models: choice of a preferred model using physical arguments, or through comparisons with test data
    - Temporal and spatial variability
    - Partitioning of variability and uncertainty
    - Assumptions/judgments
    - Conservative bounds
    - Conservative distributions
    - Features, events and processes screening of low-probability/low-consequence scenarios
  - Reviewing both quantified and unquantified uncertainties

Uncertainties in Total System Performance Assessment for the Site Recommendation
(Continued)

- **Conservatism Assessment**
  - Purpose: To complete a qualitative evaluation of the representativeness/conservatism of features, events, and processes in process-level models
  - Identified specific conservatisms, reasons for conservative assessments, potential to develop more representative assessments
  - Qualitative evaluation of degree of conservatism
  - Starting point for unquantified uncertainties activity

Uncertainties in Total System Performance Assessment for the Site Recommendation
(Continued)

- **Significance of Unquantified Uncertainties**
  – Unquantified uncertainties include models and parameters
    - "Conservative bounds"
    - Single point-value inputs
    - "Bounding distributions" or statistically-biased distributions
    - Conservative conceptual models
  – May include either conservative or optimistic inputs

Project Goals and Status for Managing Uncertainties

Step 1: Identify key unquantified uncertainties	Initial list developed
Step 2: Develop representative models and parameters with unquantified uncertainty	Initial meetings conducted with all technical groups; follow-on meetings in progress
Step 3: Evaluate the implications of newly quantified inputs and uncertainties	Total System Performance Assessment abstractions and analyses, sensitivity analyses planned
Step 4: Develop recommendations for uncertainty treatment for license application	Results and recommendations documented in report; Final September 2001
Step 5: Manage uncertainty treatment in license application	Ongoing during development of Total System Performance Assessment for the License Application

Identify Key Unquantified Uncertainties

Topic	Model/Parameter
Unsaturated Zone	Effects of drift degradation and rock bolts on seepage
	Thermal effects on seepage
	Engineered Barrier System release to unsaturated zone: drift shadow zone
	Matrix diffusion
Engineered Barrier System	Convection/evaporation and condensation in drift
	Transport pathway from inside waste package to invert
	Retardation for pathway out of waste package
	Invert saturation
Waste Package Degradation	Uncertainty in weld stress state following mitigation
	Geometry of defects
	General corrosion rate of Alloy 22
	Long-term stability of passive films on Alloy 22
	Aging effects on Alloy 22
	Microbiologically influenced corrosion

Identify Key Unquantified Uncertainties
(Continued)

Topic	Model/Parameter
Waste Form Degradation	In-package chemistry (high-level waste glass degradation rate, steel degradation rate, oxygen fugacity)
	Cladding degradation (mechanical perforation, unzipping, dissolution rate of fuel)
	Neptunium solubility
	Colloid concentrations
Saturated Zone	Specific discharge
	Effective diffusion coefficient in volcanics
	Fracture porosity in volcanics
	Flowing interval spacing
	Effective porosity in alluvium
	Bulk density of alluvium
	Pu colloid retardation in alluvium
	Sorption coefficients in alluvium for Np, I, Tc, U
	Sorption coefficient for Np in volcanics

Develop Representative Models and Parameters that Quantify Uncertainties

- Quantify uncertainties by having technical investigators provide representative estimates of the key uncertainties
- Iterative series of interviews followed by calculations, modeling, and analyses with five topical teams
- Investigators use their knowledge of project-specific data, literature data, analogous systems or processes, and technical judgment
- Topical teams include Total System Performance Assessment representatives to ensure compatibility with current model

Evaluate the Implications of New Models and Parameter Estimates

- **Newly quantified uncertainties will be analyzed using the Total System Performance Assessment model to gain insight into the overall degree of conservatism in the Total System Performance Assessment-Site Recommendation results**
- **A range of analyses is planned:**
  - Dose estimates over time, with all newly-quantified uncertainties incorporated
  - Peak dose estimates
  - Time to peak dose
  - Estimates of the impact of each model or parameter change on dose history and peak dose, by comparison with Total System Performance Assessment-Site Recommendation results
  - Subsystem comparisons
  - Contribution of inputs to total dose uncertainty

Evaluate the Implications of New Models and Parameter Estimates (Continued)

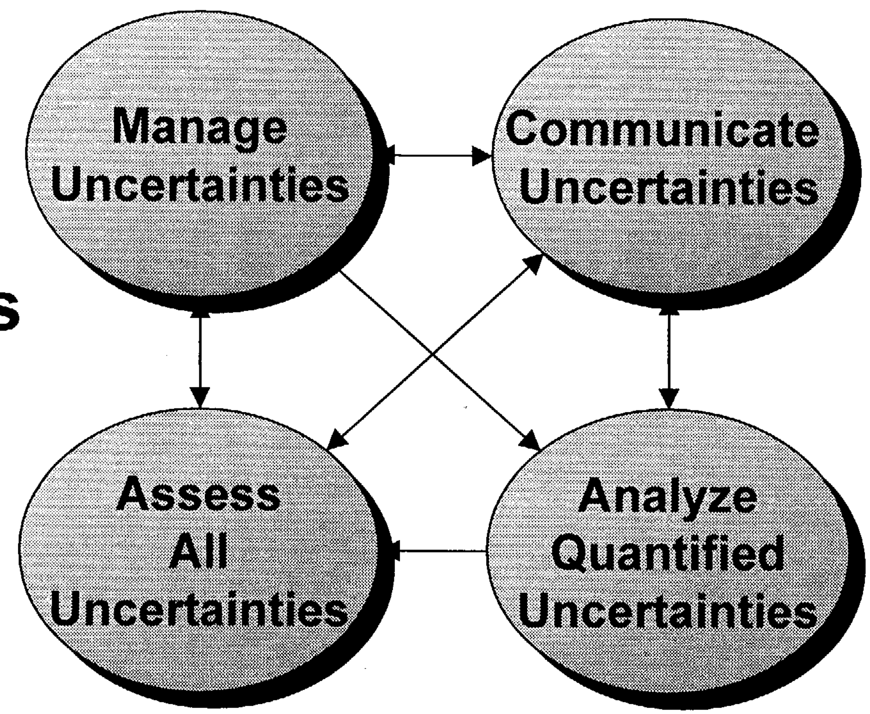
- Complements, does not replace, Total System Performance Assessment for the Site Recommendation

Develop Guidance for License Application Time-Frame

- **Insights from current projects**
  - Treatment of quantified uncertainties
  - Significance of unquantified uncertainties
- **Documented guidance on how uncertainties should be treated in license application analyses and supporting documentation**

Managing Uncertainties for the License Application

- Align uncertainty strategy with the licensing approach
- Implement DOE's overall approach to dealing with uncertainties
- Quantify those uncertainties most important to dose estimates
- Manage quantified and unquantified uncertainties to make a defensible safety argument for licensing



Conclusions

- Ongoing reviews are being conducted to understand uncertainty treatment in inputs to Total System Performance Assessment for the Site Recommendation
- Evaluations of the significance of unquantified uncertainties are in progress
- Insights from these evaluations will provide support for Total System Performance Assessment for the Site Recommendation
- Guidance will be provided for the treatment of uncertainties in the license application time-frame and for associated documentation

References

- Cline, K.M. 2000. “Transmittal of MTS Report of Conservatism in Process Models and TSPA.” Letter from K.M. Cline (MTS) to S. Brocoum (DOE/YMSCO), October 12, 2000, LV.MTS.KMC.10/00-218, with attachment
- “Integrated Report on Uncertainties in TSPA-SR”, Draft Report due April 30, 2001, Final Report due September 2001

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

Thermal Effects on Flow - Representation in the Total System Performance Assessment

Presented to:

DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:

Nicholas D. Francis
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9 2001
Pleasanton, CA

YUCCA
MOUNTAIN
PROJECT

Outline

- **Presentation Objectives**
- **Subissues/Open Items**
- **Application of thermal effects on flow in the Total System Performance Assessment for the Site Recommendation Model**
  - NRC integrated subissues applicable to thermal effects on flow
  - Thermal effects on flow abstractions of process-level models
  - Representation of thermal effects on flow in the Total System Performance Assessment
- **Conclusions**
- **References**

Presentation Objectives

- **Describe how thermal effects on flow have been accounted for in the Total System Performance Assessment for the Site Recommendation**
- **Discuss impact of thermal effects on flow on repository performance with and without backfill**
  - Waste package failure curves

Subissues/Open Items

- **Subissue 1: Features, Events, and Processes (discussed in a separate presentation)**
- **Subissue 2: Thermal Effects on Temperature, Humidity, Saturation, and Flux**
  - Open Item 7: Propagate hydrologic property set uncertainty through model abstractions
  - Open Item 8: Treatment of conceptual model uncertainty through model abstractions

Note: Open Items 7 and 8 are the subject of additional presentations in this meeting

Application of Thermal Effects on Flow

- **NRC Integrated Subissues Applicable to Thermal Effects on Flow**
  - Flow rates in the unsaturated zone
  - Degradation of engineered barriers
  - Radionuclide release rates and solubility limits
  - Quantity and chemistry of water contacting waste packages and waste forms

Application of Thermal Effects on Flow
(Continued)

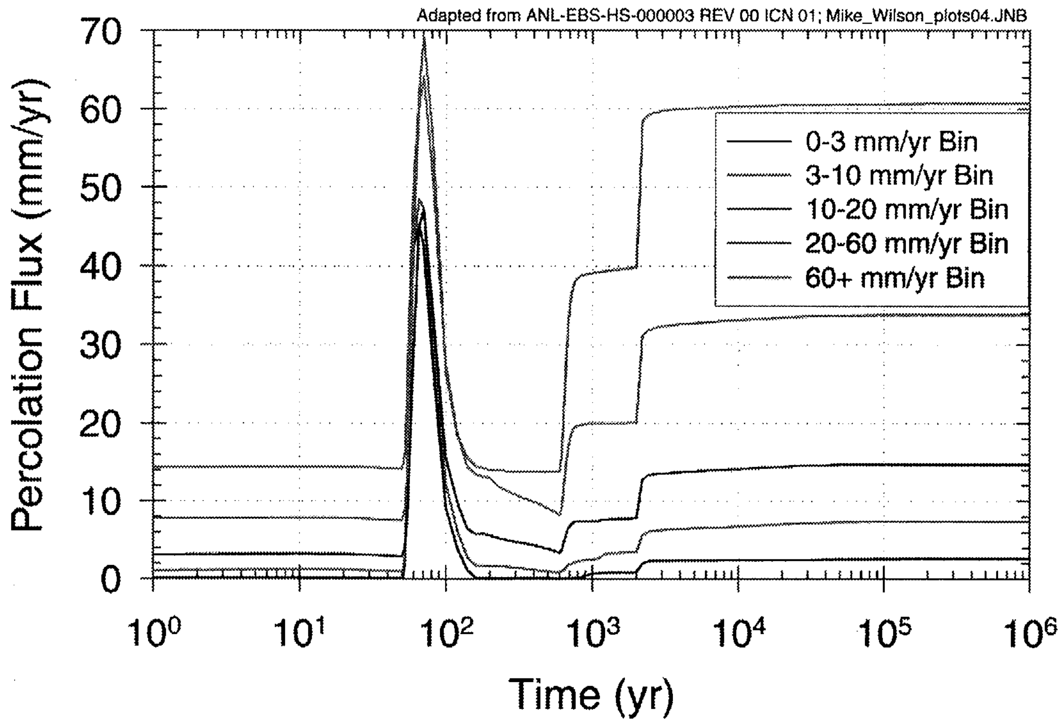
- **NRC integrated subissues for thermal effects on flow have been mapped into the following abstractions of process level models considered in the Total System Performance for the Site Recommendation**
  - Features, Events, and Processes screening arguments (discussed in a separate presentation)
  - Thermally enhanced percolation flux above the crown of the drift
  - In-drift thermodynamic environment

Thermally Enhanced Percolation Flux Above the Crown of the Drift

- **Flow Paths in the Unsaturated Zone**
  - Abstraction of the Multi-scale Thermohydrologic Model at 610 locations within the repository footprint
    - Five infiltration rate bins defined for Total System Performance Assessment
    - Uncertainty in infiltration rate
    - Two waste categories
      - » Commercial Spent Nuclear Fuel
      - » Defense High-Level Waste

Thermally Enhanced Percolation Flux Above the Crown of the Drift (Continued)

- **Flow Paths in the Unsaturated Zone (Continued)**
  - Percolation flux at 5 meters above drift crown was selected as input for the abstracted seepage model

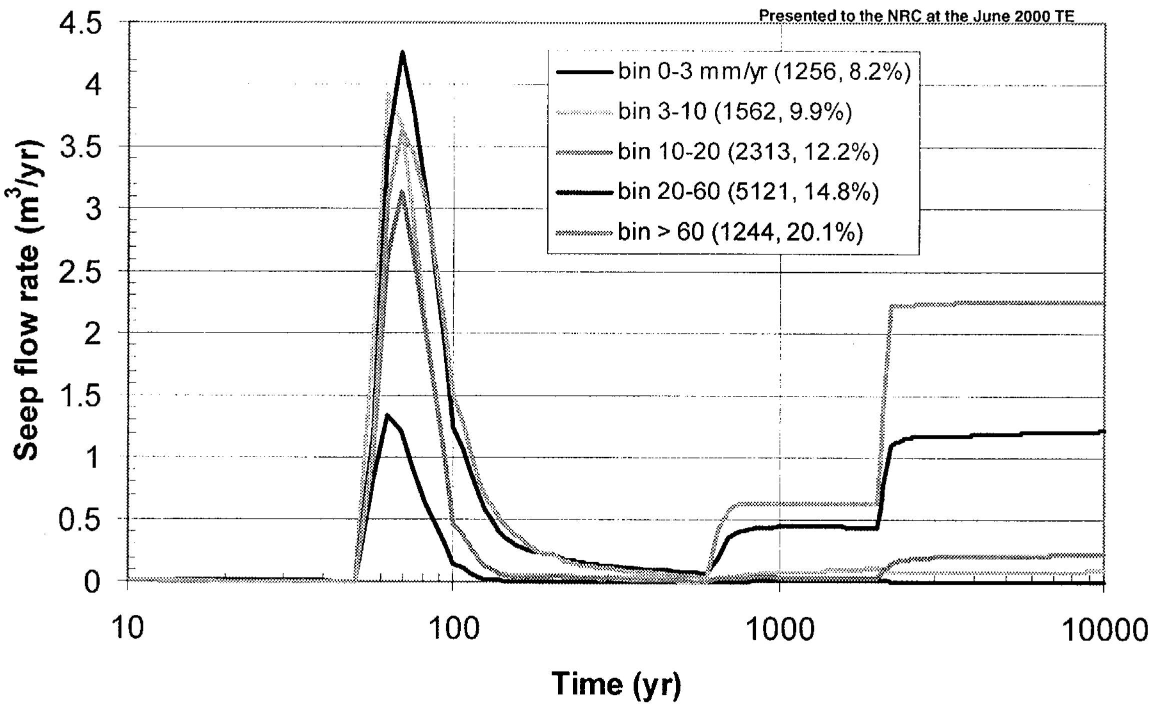


Bin averages are shown, 610 individual percolation flux curves are implemented into abstracted seepage model for a given infiltration flux case (mean flux shown) and waste type (Commercial Spent Nuclear Fuel shown)

Thermally Enhanced Percolation Flux Above the Crown of the Drift (Continued)

- **Flow Paths in the Unsaturated Zone (Continued)**
  - Seepage volume flow rates are based on percolation flux at 610 locations within the heated repository footprint

Presented to the NRC at the June 2000 Technical Exchange

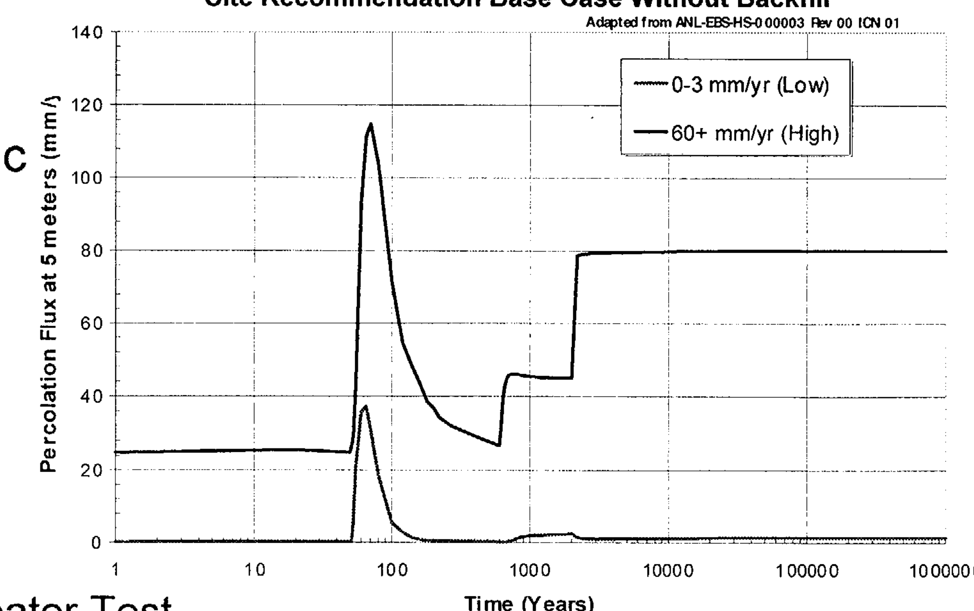


Averages for locations with seepage are shown for a given infiltration flux case (mean flux shown) and waste type (Commercial Spent Nuclear Fuel shown). Only a fraction of the 610 locations have seepage. The seepage flow rate is used in waste form degradation and Engineered Barrier System transport submodels.

Thermally Enhanced Percolation Flux Above the Crown of the Drift (Continued)

- **Flow Paths in the Unsaturated Zone (Continued)**
  - Propagation of hydrologic property set uncertainty through model abstractions
    - Analogous time-history curves are used in the Total System Performance Assessment model for the *low* and *high* infiltration flux cases
  - Treatment of conceptual model uncertainty through model abstractions
    - Multi-scale Thermohydrologic model and subsequent abstractions based on the dual permeability active fracture model
      - » Basis: Thermal test temperature results from Large Block Test, Single Heater Test, Drift Scale Heater Test

Average Commercial Spent Nuclear Fuel Percolation Flux at 5 Meters Including Infiltration Flux Uncertainty Site Recommendation Base Case Without Backfill

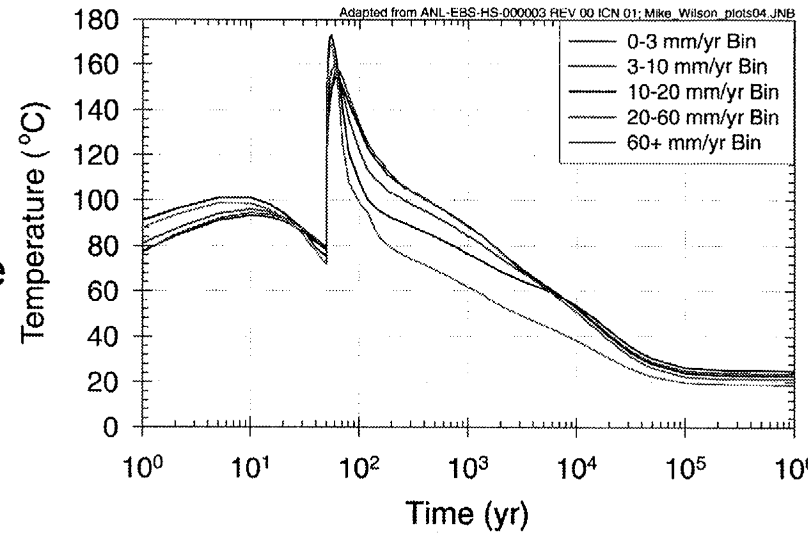


In-Drift Thermodynamic Environment

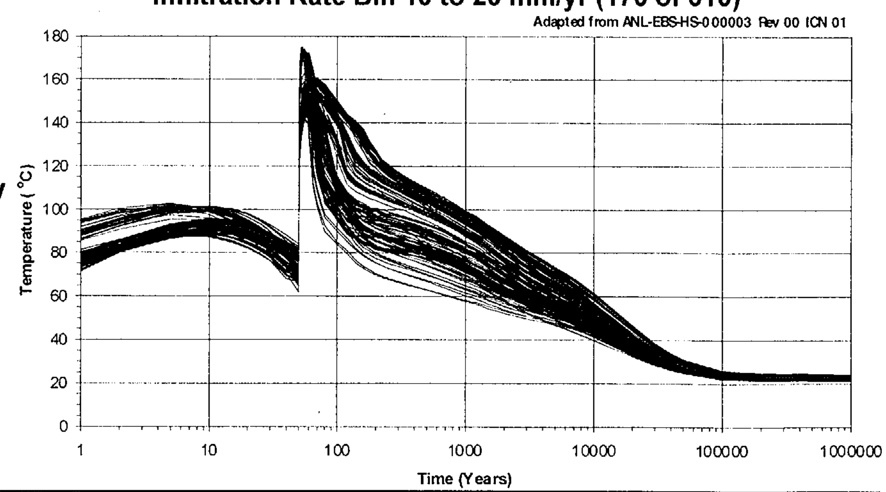
- **Degradation of Engineered Barriers**
  - Abstraction of the Multi-scale Thermohydrologic Model at 610 locations within the repository footprint
    - Five infiltration rate bins defined for Total System Performance Assessment
    - Uncertainty in infiltration rate
    - Two waste categories
      - » Commercial Spent Nuclear Fuel
      - » Defense High-Level Waste

In-Drift Thermodynamic Environment
(Continued)

- **Radionuclide Solubility Limits and Degradation of Engineered Barriers**
  - Infiltration bin averaged waste package temperatures (mean flux case shown)
    - Waste form dissolution rate and uranium solubility use bin averaged temperatures
  - Individual commercial spent nuclear fuel waste package temperatures for a single infiltration bin (10-20 millimeters/year, mean flux case shown)
    - Corrosion models use temperatures from 610 locations within the repository footprint established by the Multi-scale Thermohydrologic model

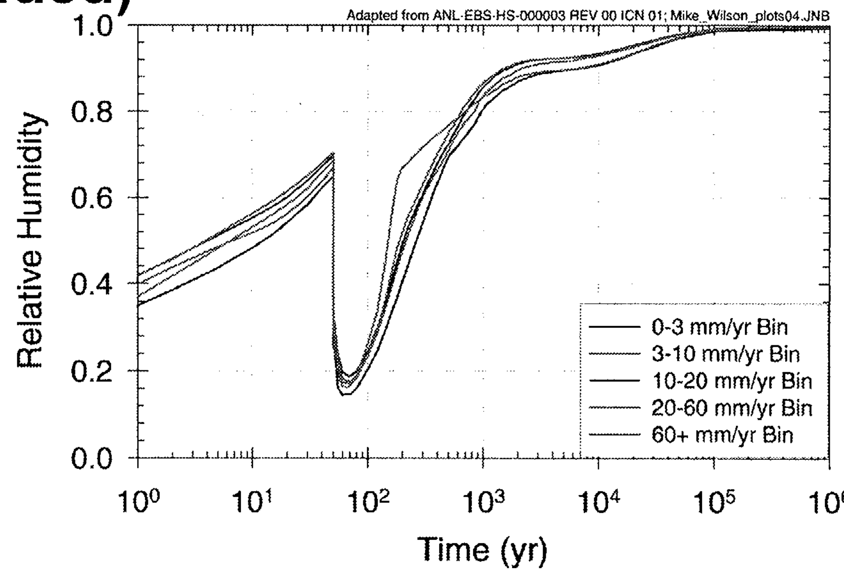


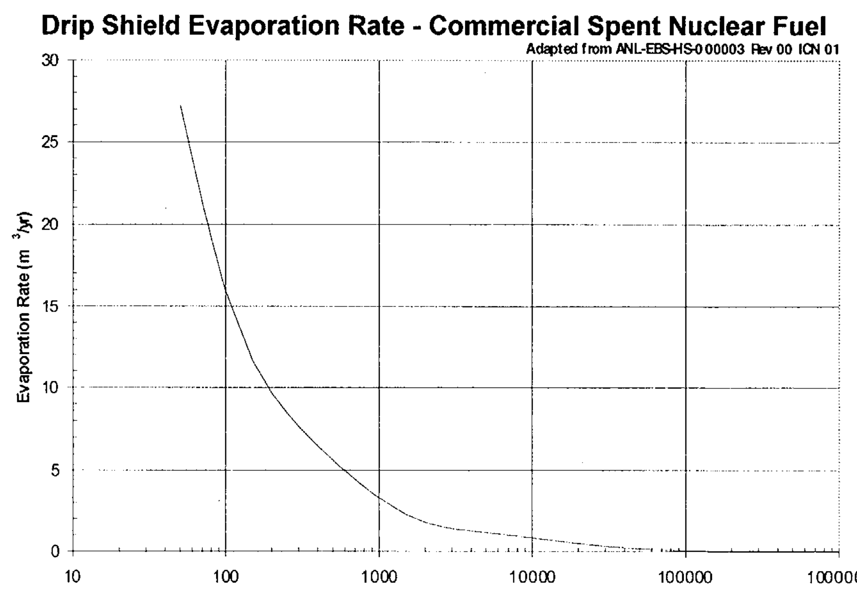
Waste Package Surface Temperature No Backfill, Medium Infiltration Flux Case
Infiltration Rate Bin 10 to 20 mm/yr (170 of 610)



In-Drift Thermodynamic Environment
(Continued)

- **Degradation of Engineered Barriers**
  - Infiltration bin averaged waste package relative humidity (mean flux case shown)
    - Illustration only, corrosion models also use relative humidity from repository locations established by the Multi-scale thermohydrologic model-analogous to second figure on slide 12
  - Heat balance applied at the drip shield surface to determine maximum potential seepage water evaporation rate
    - Drip shield corrosion model

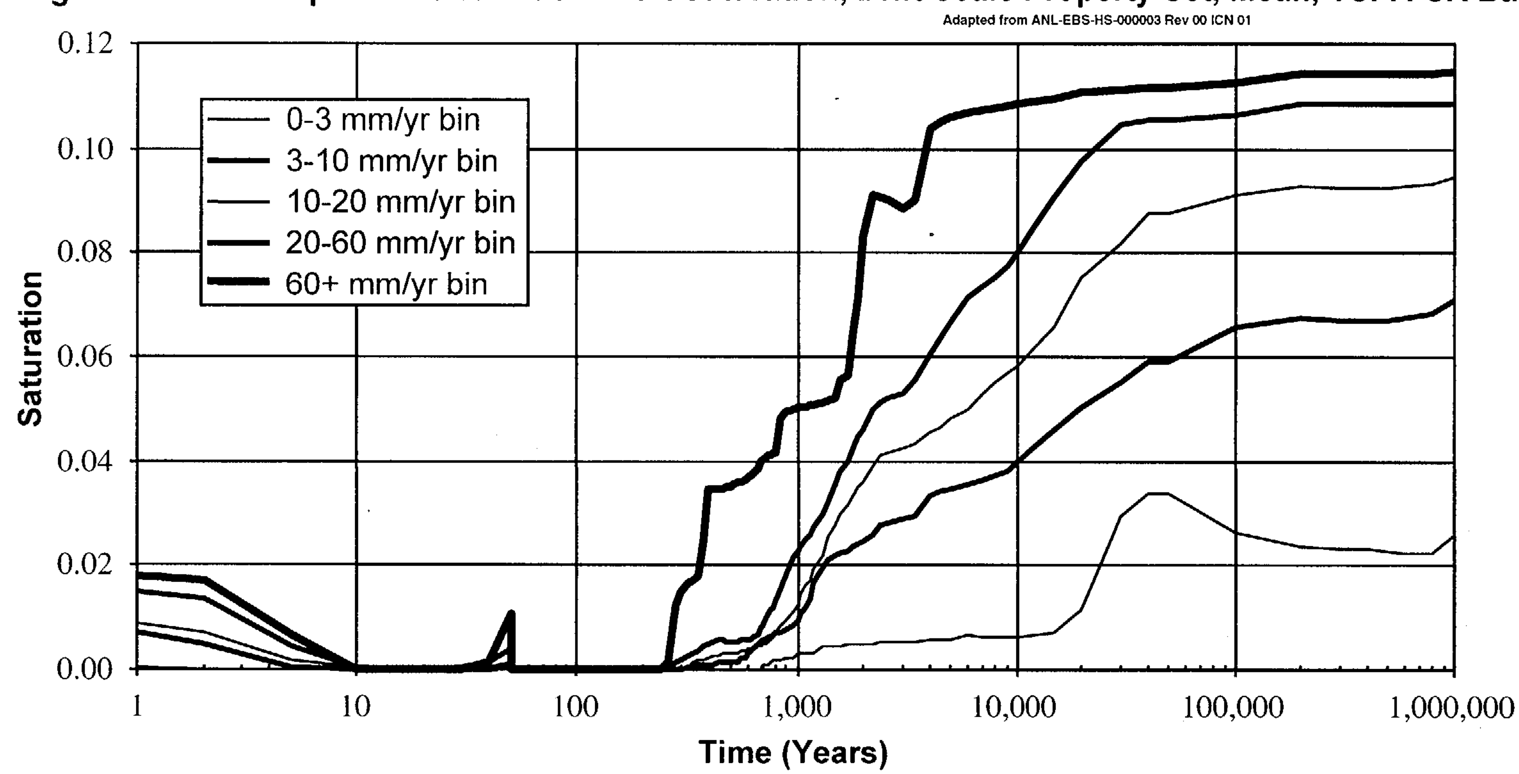




In-Drift Thermodynamic Environment
(Continued)

- **Radionuclide Release Rates**
  - Infiltration bin averaged invert liquid saturation (mean flux case shown)
    - Diffusion coefficient in the invert

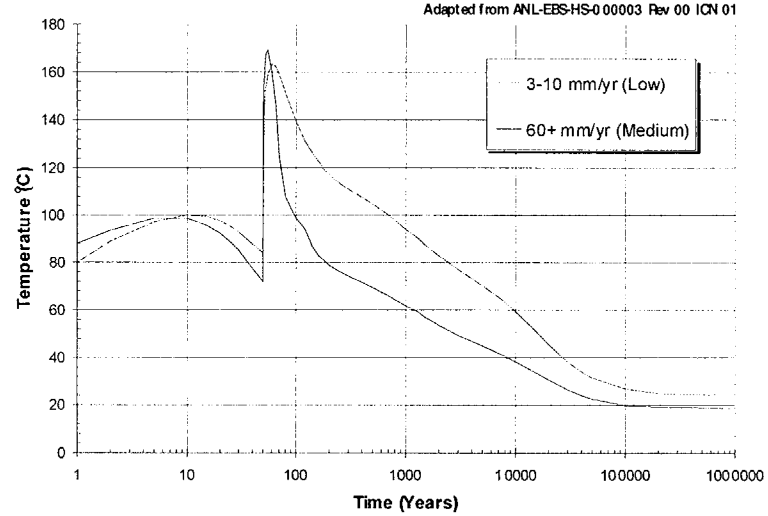
Average Commercial Spent Nuclear Fuel Invert Saturation, Drift Scale Property Set, Mean, TSPA-SR Base Case



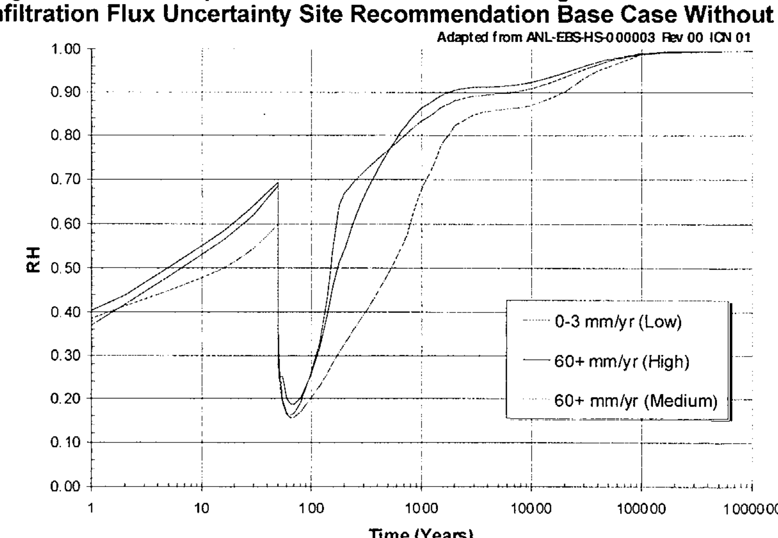
In-Drift Thermodynamic Environment
(Continued)

- **Degradation of Engineered Barriers** (Continued)
  - Propagation of hydrologic property set uncertainty through model abstractions
    - Corresponding time-history curves are used in the Total System Performance Assessment model for the low and high infiltration flux cases
  - Treatment of conceptual model uncertainty through model abstractions
    - Multi-scale Thermohydrologic model and subsequent abstractions based on the dual permeability active fracture model
      - » Basis: Thermal test temperature results from Large Block Test, Single Heater Test, Drift Scale Heater Test

Average Commercial Spent Nuclear Fuel Waste Package Temperature Including Infiltration Flux Uncertainty Site Recommendation Base Case Without Backfill



Average Commercial Spent Nuclear Fuel Waste Package Relative Humidity Including Infiltration Flux Uncertainty Site Recommendation Base Case Without Backfill



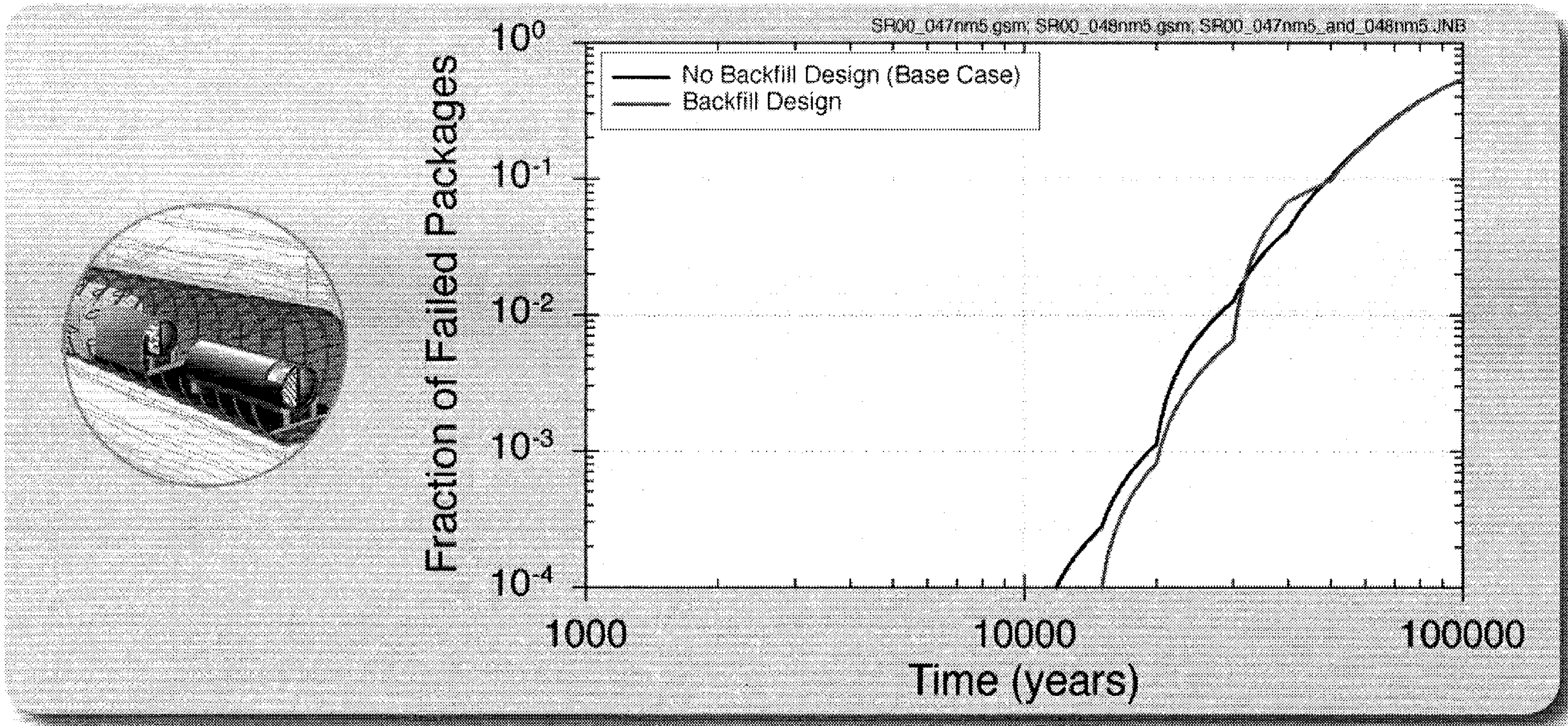
Impacts of Thermal Effects on Flow

- **Comparison of no backfill and backfill repository designs to illustrate how in-drift environment influences waste package failure**
- **In-drift temperatures and relative humidities are strong functions of emplaced engineered materials**
  - Backfill causes an increase in temperature and a decrease in relative humidity
  - No backfill results in lower temperatures and higher relative humidities

Impacts of Thermal Effects on Flow
(Continued)

- **Figure illustrates variability of waste package failure for different environmental conditions**

Adapted from TDR-WIS-PA-000001 Rev 00



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Conclusions

- **Total System Performance Assessment for the Site Recommendation models account for thermal effects on flow as applied in the following Total System Performance Assessment abstractions**
  - Chemical Environments (Engineered Barrier System environments subcomponent)
  - Unsaturated zone flow
  - Waste package and drip shield degradation
  - Waste form degradation
  - Engineered barrier system transport
- **For the designs to date, variability and uncertainty in thermal effects on flow do not have a large impact on the Total System Performance Assessment for the Site Recommendation corrosion models**

References

- Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049 Rev 00 ICN 01
- Abstraction of Near Field Environment Drift Thermodynamic Environment and Percolation Flux, ANL-EBS-HS-000003 Rev 00 ICN 01
- Features, Events, and Processes in Thermal Hydrology and Coupled Processes, Unsaturated Zone Flow and Transport, and Engineered Barrier System
  - ANL-NBS-MD-000004 Rev 00 ICN 01
  - ANL-NBS-MD-000001 Rev 00 ICN 01
  - ANL-EBS-MD-000035 Rev 00 ICN 01

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

Features, Events, and Processes for Thermal Effects on Flow and Evolution of the Near Field Environment

Presented to:
DOE/NRC Technical Exchange on the Key Technical Issues and Subissues Related to Thermal Effects on Flow and Evolution of the Near-Field Environment

Presented by:

Nicholas D. Francis
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- Presentation Objectives
- Open Items and Status
- Ongoing/Recent Revisions
- Status
- NRC Comment on Regional Hydrothermal Activity
- Summary of Results
- Conclusions
- Features, Events, and Processes Tabulation

Presentation Objectives

- **Describe the basis for revision of the Features, Events, and Processes Analysis/Model Reports relevant to Thermal Effects on Flow and Evolution of Near Field Environment and results of the analyses in these documents**
- **Identify the Thermal Effects on Flow and Evolution of Near Field Environment features, events, and processes discussed in the following Analysis/Model Reports**
  - Unsaturated Zone Flow &Transport (ANL-NBS-MD-000001)
  - Near Field Environment (ANL-NBS-MD-000004)
  - Engineered Barrier System (ANL-WIS-PA-000002)
  - Waste Package (ANL-EBS-PA-000002)
  - Waste Form (ANL-WIS-MD-000008, ANL-WIS-MD-000009, ANL-WIS-MD-000012)
  - Disruptive Events (ANL-WIS-MD-000005)
  - Saturated Zone (ANL-NBS-MD-000002)
  - Biosphere (ANL-MGR-MD-000011)
  - System Level (ANL-WIS-MD-000019)

Open Items and Status
Thermal Effects on Flow, Subissue 1: Features, Events, and Processes

- **Open Item 1: Final List of Primary and Secondary Features, Events, and Processes**
  - Status: Currently being addressed in the Analysis/Model Report revisions/changes
- **Open Items 2 and 3: Revised Features, Events, and Processes Screening Arguments (primary and secondary Features, Events, and Processes)**
  - Status: Currently being addressed in the Analysis/Model Report revisions/changes

Open Items and Status Thermal Effects on Flow, Subissue 1: Features, Events, and Processes (Continued)

- **Open Item 4: Summary of Screening Argument Assumptions**
  - Status: Currently being addressed in the Analysis/Model Report revisions/changes
- **Open Item 5: Traceable References**
  - Status: Currently being addressed in the update to the Features, Events, and Processes database

Ongoing/Recent Revisions

- Update screening arguments for features, events, and processes found in multiple Rev 00 ICNs Features, Events, and Processes Analysis/Model Reports
- Additional documentation of secondary features, events, and processes analyses and update primary features, events, and processes for no-backfill case
- Add fields for related NRC Issue Resolution Status Report subissues; treatment of secondary features, events, and processes; and related primary features, events, and processes
- Address review comments

Status

- 20 To Be Verified Assumptions in Rev 00 of Features, Events, and Processes Database
- Unsaturated Zone Flow and Transport Rev 00 ICN 01 expected to be available 1/2001
- Thermal Hydrology & Coupled Processes Rev 00 ICN 01 expected to be available 1/2001
- Engineered Barrier System Rev 01 expected to be available 1/2001
- Waste Form Revisions/Changes expected to be available 1/2001
- Waste Package Revisions/Changes expected to be available 1/2001

NRC Comment on Regional Hydrothermal Activity

- **Hydrothermal Activity Features, Events, and Processes 1.2.06.00.00: This category contains features, events, and processes associated with naturally occurring high-temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows**
- **Unsaturated Zone Flow and Transport**
  - Silicic magmatism is excluded based on low probability
    - Active at Yucca Mountain 11 to 15 million years ago
    - Recurrence of this process in the next 10,000 years is not considered credible

Reference: Characterize Framework for Igneous Activity at Yucca Mountain, Nevada. ANL-MGR-GS-000001

NRC Comment on Regional Hydrothermal Activity (Continued)

- **Unsaturated Zone Flow and Transport (Continued)**
  - Basaltic magmatism is excluded based on low consequence
    - Minimal physical and mineralogical effects on local rock properties because such activity is narrowly confined and of short duration--local and short transient
    - Studies of analog sites indicate the consequences of basaltic magmatism in terms of the amount and extent of mineral alteration are small

Reference: Valentine et al. 1998

NRC Comment on Regional Hydrothermal Activity (Continued)

- **Saturated Zone Flow and Transport**
  - No credit is taken for dilution of a contaminant plume by convective mixing of fluid in a buoyancy-driven flow field
  - Evaluation of the effect of the uncertainty in the geochemical conditions through the sorption coefficient (K_d) and effective diffusion coefficient (D_e)
    - Evaluates the effect of the uncertainty in the geochemical conditions through the sorption coefficient
      - Sorption coefficient is based on the rock type with the lowest sorption capacity
    - Diffusion coefficient dependence on temperature conservatively neglected

Summary of Results

- **53 Primary Features, Events, and Processes for Thermal Effects on Flow**
  - 18 included
  - 24 partially included/excluded
  - 11 excluded (based on low probability, low consequence and regulatory guidance)
  - 212 secondary Features, Events, and Processes

Summary of Results
(Continued)

- **151 Primary Features, Events, and Processes for Evolution of the Near-Field Environment**
  - 43 included (+Two Secondary)
  - 44 partially included/excluded
  - 63 excluded (+One Secondary) (based on low probability, low consequence and regulatory guidance)
  - One without Screening Argument (Waste Form Features, Events, and Processes)
  - 594 secondary Features, Events, and Processes

Conclusions

- List of primary and secondary features, events, and processes is complete
- All ICN 01 of Features, Events, and Processes Analysis Model Reports completed in January 2001
- Secondary features, events, and processes are addressed explicitly in Rev 01 of the Features, Events, and Processes database to be completed March 2001
- Crosswalk between features, events, and processes and Process Model Reports is provided in attached features, events, and processes tabulation

Features, Events, and Processes Process Model Reports

List of Acronyms for following tabulation

Bio	Biosphere
CNSF	Commercial Spent Nuclear Fuel
DE	Disruptive Events
DSNF	Defense Spent Nuclear Fuel
EBS	Engineered Barrier System
FEPs	Features, Events, and Processes
MIC	Microbiologically Induced Corrosion
NFE	Near-Field Environment
PMRs	Process Model Report
System	Total System Performance Assessment FEPs Analysis Model Report
SZ	Saturated Zone
TBV	To be verified
TC	Thermal-chemical
TH	Thermal-hydrologic
THC	Thermal-hydrologic-chemical
UZ&FT or UZ	Unsaturated Zone Flow & Transport
WF	Waste Form
WP	Waste Package

Features, Events, and Processes Tabulation
(Thermal Effects on Flow)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
1.1.02.00.00	Excavation/Construction	NFE – Include fracture effects/Exclude chemistry effects - Low consequences UZ F&T – Include stress relief and ground supports on seepage/Exclude chemistry effects - Low consequences EBS – Exclude - Low consequences
1.1.02.02.00	Effects of pre-closure ventilation	NFE – Include EBS – Include
1.1.07.00.00	Repository Design	System – Include for base-case design/Exclude secondary FEPs - Low Consequence & Regulatory EBS – Include base case design/Exclude deviations from design
1.2.02.01.00	Fractures	NFE – Include Seepage/Exclude permanent effects - Low Consequence UZ – Include present day/Exclude changes - Low Consequence DE – Include present day/Exclude changes - Low Consequence SZ – Exclude - Low Consequence
2.1.01.01.00	Waste Inventory	WF – Include

Features, Events, and Processes Tabulation
(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.1.01.02.00	Co-disposal/co-location of waste	WF – Include co-location & co-disposal/Exclude DSNF* canister - Low Consequence/Exclude chemical interaction – Low Probability
2.1.01.03.00	Heterogeneity of waste forms	WF – Include
2.1.08.01.00	Increased unsaturated water flux at the repository	NFE – Include climate change/Exclude water quenching waste package - Low Consequences UZ F&T – Include
2.1.08.02.00	Enhanced influx (Philip's Drips)	UZ – Include EBS – Exclude - Low Consequences NFE – Include
2.1.08.03.00	Repository dry-out due to waste heat	NFE – Include
2.1.08.04.00	Condensation forms on backs of Drift	EBS – Include
2.1.08.08.00	Induced hydrological changes in waste and EBS	WF – Include flow areas and changes to waste package, waste form in drip shield/Exclude hydrologic changes to waste form and invert - Low Consequences
2.1.08.10.00	Desaturation/dewatering of repository	NFE – Include WF – Include

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.1.08.11.00	Resaturation of the repository	NFE – Include EBS – Include
2.1.09.01.00	Properties of the potential carrier plume in the waste and EBS	NFE – Include WF – Include effects of steel corrosion/Exclude changing properties of water - Low Consequences
2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock	NFE – Include in THC model/Exclude in TH model - Low Consequences WF – Include in radionuclide mobilization/Exclude in adjacent rock - Low Consequences EBS – Include
2.1.11.01.00	Heat output/temperature in waste and EBS	NFE – Include WF – Include EBS – Include
2.1.11.02.00	Nonuniform heat distribution/edge effects in repository	NFE – Include TH effects/Exclude Thermal-Mechanical effects - Low Consequences
2.1.11.04.00	Temperature effects/coupled processes in waste and EBS	WF – Include EBS – Include

Features, Events, and Processes Tabulation
(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.1.11.07.00	Thermally-induced stress changes in the waste and EBS	WF – Include thermal stresses in NFE/Exclude thermal stresses in waste and packages - Low Consequences EBS – Include
2.1.11.09.00	Thermal effects on liquid or two-phase flow in the waste and EBS	WF – Include water reaching EBS/Exclude two-phase flow in waste and single phase flow driven flow in waste - Low Consequences EBS – Include
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	NFE – Exclude - Low Consequences UZ F&T – Include stress relief and ground support on seepage/Exclude water chemistry - Low Consequences
2.2.01.02.00	Thermal and other waste and EBS-related changes in the adjacent host rock	NFE – Exclude - Low Consequences
2.2.01.03.00	Changes in fluid saturations in the excavation disturbed zone	NFE – Exclude - Low Consequences
2.2.03.01.00	Stratigraphy	UZ F&T – Include SZ – Include

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.2.03.02.00	Rock properties of host rock and other units	UZ F&T – Include SZ – Include
2.2.06.01.00	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	NFE – Exclude - Low Consequences DE – Exclude - Low Consequences
2.2.06.02.00	Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults	UZ F&T – Exclude - Low Consequences SZ – Exclude - Low Consequences DE – Exclude - Low Consequences
2.2.07.02.00	Unsaturated groundwater flow in geosphere	UZ F&T – Include
2.2.07.04.00	Focusing of unsaturated flow (fingers, weeps)	UZ F&T – Include
2.2.07.05.00	Flow and transport in the UZ from episodic infiltration	UZ F&T – Include transient flow due to TH processes on seepage/Exclude episodic flows - Low Consequences
2.2.07.07.00	Perched water develops	UZ – Include increased flow and present day perched water/ Exclude effects of perched water below repository - Low Consequences

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.2.07.08.00	Fracture flow in the unsaturated zone	UZ F&T – Include
2.2.07.10.00	Condensation zone forms around drifts	NFE – Include UZ F&T– Include effects on seepage/Exclude mountain scale effects - Low Consequences
2.2.07.11.00	Return flow from condensation cap/resaturation of dry-out zone	NFE – Include UZ F&T – Include effects on seepage/Exclude mountain scale effects - Low Consequences
2.2.08.03.00	Geochemical interactions in geosphere (dissolution, precipitation, weathering) and effects on radionuclide transport	NFE – Include UZ – Exclude - Low Consequences SZ – Include
2.2.08.04.00	Redissolution of precipitates directs more corrosive fluid to container	NFE – Include UZ F&T – Include SZ – Include
2.2.10.01.00	Repository-induced thermal effects in geosphere	UZ – Include TC effects on seepage/Exclude mountain-scale TC effects - Low Consequences SZ – Exclude - Low Consequences & Low Probability

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.2.10.02.00	Thermal convection cell develops in saturated zone	UZ F&T – Include Thermal-Chemical effects on seepage/Exclude mountain-scale Thermal-Chemical effects - Low Consequences SZ – Exclude - Low Consequences & Low Probability
2.2.10.03.00	Natural geothermal effects	UZ F&T – Include SZ – Include
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	NFE – Exclude - Low Consequences UZ F&T – Exclude - Low Consequences
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	NFE – Exclude - Low Consequences UZ F&T - Exclude - Low Consequences
2.2.10.06.00	Thermo-chemical alteration (solubility, speciation, phase changes, precipitation/dissolution)	NFE – Include in geochemical model/Exclude in TH model - Low Consequences UZ F&T – Exclude - Low Consequences SZ – Include
2.2.10.07.00	Thermo-chemical alteration of the Calico Hills unit	UZ F&T – Exclude - Low Consequences SZ – Exclude - Low Consequences & Low Probability
2.2.10.08.00	Thermo-chemical alteration of the saturated zone	SZ – Exclude - Low Consequences & Low Probability

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name	PMR – Screening Decision - Screening Basis
2.2.10.09.00	Thermo-chemical alteration of the Topopah Spring basal vitrophyre	UZ F&T – Exclude - Low Consequences
2.2.10.10.00	Two-phase buoyant flow/heat pipes	NFE – Include UZ F&T – Include
2.2.10.11.00	Natural air flow in the unsaturated zone	UZ – Exclude - Low Consequences
2.2.10.12.00	Geosphere dry-out due to waste heat	NFE – Include
2.2.10.13.00	Density-driven groundwater flow (thermal)	NFE – Include SZ – Exclude - Low Consequences and Low Probability
2.3.11.01.00	Precipitation	UZ F&T – Include Bio – Include precipitation/Exclude recharge and climate change - Low Consequences
2.3.11.03.00	Infiltration and recharge (hydrologic and chemical effects)	UZ F&T – Include changing infiltration & water table rise/Exclude effects of changing water chemistry - Low Consequences
2.3.13.03.00	Effects of repository heat on biosphere	System – Exclude - Low Consequences

Features, Events, and Processes Tabulation

(Thermal Effects on Flow, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
1.1.02.00.00	Excavation/Construction (1,2)	NFE – Include fracture effects/Exclude chemistry effects - Low consequences UZ F&T – Include stress relief and ground supports on Seepage/ Exclude chemistry effects - Low consequences EBS – Exclude - Low consequences
1.1.02.01.00	Site Flooding (during construction and operation) (2)	UZ F&T – Exclude - Low Probability EBS – Exclude - Regulatory
1.1.02.02.00	Effects of Pre-Closure Ventilation (1)	NFE – Include EBS – Include
1.1.02.03.00	Undesirable materials left (2,3,4)	EBS – Exclude - Low Consequence
1.1.03.01.00	Error in waste or backfill emplacement (2)	WP – Exclude - Low Probability EBS – Exclude - Regulatory
1.1.07.00.00	Repository Design (1,2,3,4)	System – Include for Base case design/Exclude secondary FEPs - Low Consequence & Regulatory EBS – Include base case design/Exclude deviations from design
1.1.08.00.00	Quality Control (1,2,3,4)	System – Include primary & two secondary FEPs/Exclude rest of secondary FEPs - Low Consequence & Regulatory EBS – Include/Exclude defects & deviations

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
1.1.12.01.00	Accidents and unplanned events during operation (1,2,3,4)	System – Exclude - Low Consequence EBS – Exclude - Regulatory
1.1.13.00.00	Retrievability (1,2,3,4)	System – Include design for retrievability & emplacement/ Exclude operational & administrative considerations EBS – Include
1.2.02.01.00	Fractures (1)	NFE – Include Seepage/Exclude permanent effects - Low Consequence UZ – Include present day/Exclude changes - Low Consequence DE – Include present day/Exclude changes - Low Consequence SZ – Exclude - Low Consequence
1.2.04.02.00	Igneous activity causes changes to rock properties (1,2,4)	UZ – Exclude - Low Consequence DE – Exclude - Low Consequence
1.2.06.00.00	Hydrothermal Activity (1,2,3)	UZ – Exclude - Low Probability SZ – Exclude - Low Consequence
1.2.08.00.00	Diagenesis (1,4)	System – Exclude - Low Consequence
1.2.09.02.00	**Large-scale Dissolution (1)**	**UZ – Exclude - Low Probability** **SZ – Exclude - Low Consequence**

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.01.02.00	Co-disposal/co-location of waste (1,3)	WF – Include co-location & co-disposal/Exclude DSNF canister - Low Consequence/Exclude chemical interaction – Low Probability
2.1.01.03.00	Heterogeneity of waste form (2,3)	WF – Include
2.1.02.01.00	DSNF degradation, alteration, and dissolution (2,3)	WF – Include
2.1.02.02.00	CSNF alteration, dissolution, and radionuclide release (2,3)	WF – Include
2.1.02.03.00	Glass degradation, alteration, and dissolution (2,3)	WF – Include chemistry dependent corrosion rates & congruent dissolution/Exclude phase separation - Low Probability
2.1.02.04.00	Alpha recoil enhances dissolution (3)	WF – Exclude – Low Consequence
2.1.02.05.00	Glass cracking and surface area (3)	WF – Include
2.1.02.06.00	Glass recrystallization (3)	WF – Exclude
2.1.02.07.00	Gap and grain release of cesium, iodine (3)	WF – Include gap & grain boundary release/Exclude – some changes – Low Consequences
2.1.02.08.00	Pyrophoricity (1,2,3)	WF – Exclude - Low Consequences

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.02.09.00	Void space (in glass container) (3)	WF – Include
2.1.02.13.00	General corrosion of cladding (3)	WF – Exclude - Low Consequences
2.1.02.14.00	MIC of cladding (3)	WF – Exclude - Low Probability
2.1.02.15.00	Acid corrosion of cladding from radiolysis (3)	WF – Exclude – Low Probability
2.1.02.16.00	Localized corrosion (pitting) of cladding (3)	WF – Exclude - Low Probability
2.1.02.17.00	Localized corrosion (crevice corrosion) of cladding (3)	WF – Exclude
2.1.02.18.00	High dissolved silica content of waters enhances corrosion of cladding (3)	WF – Exclude - Low Consequences
2.1.02.19.00	Creep rupture of cladding (3)	WF – Include
2.1.02.20.00	Pressurization from helium production causes cladding failure (3)	WF – Include
2.1.02.21.00	Stress corrosion cracking of cladding (3)	WF – Include
2.1.02.22.00	Hydride embrittlement of cladding (3)	WF – Exclude - Low Probability

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.02.23.00	Cladding unzipping (3)	WF – Include - Wet Oxidation/Exclude – Dry Oxidation - Low Probability
2.1.02.24.00	Mechanical failure of cladding (3)	WF – Include
2.1.02.25.00	DSNF cladding degradation (3)	WF – Exclude - Low Consequences
2.1.03.01.00	Corrosion of waste containers (2)	WP – Include EBS – Include
2.1.03.02.00	Stress corrosion cracking of waste containers (2)	WP – Include waste container/Exclude Drip Shield – Low Consequences
2.1.03.03.00	Pitting of waste containers (2)	WP – Include
2.1.03.04.00	Hydride cracking of waste containers & drip shields (2)	WP – Exclude Drip Shield - Low Consequences/Exclude Waste Container (TBV) - Low Probability
2.1.03.05.00	Microbially mediated corrosion of waste containers & drip shields (2)	WP – Include waste container/Exclude Drip Shield (TBV) - Low Consequences
2.1.03.06.00	Internal corrosion of waste container (2,3)	WP – Exclude (TBV) - Low Consequences WF – Include after waste package failure/Exclude prior to waste package failure - Low Consequences

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.03.07.00	Mechanical impact on waste container (2)	WP – Exclude rockfall damage, mechanical damage by internal gas pressure, & swelling of corrosion products and damage by seismic events (TBV) - Low Consequences
2.1.03.10.00	Container heating (2)	WP – Exclude Corrosion - Low Consequences EBS – Include
2.1.03.11.00	Container form (2,3)	WP – Exclude - Low Consequences
2.1.03.12.00	Container failure (long-term) (2,3)	WP – Include EBS – Include
2.1.04.01.00	Preferential pathways in the backfill (2,3)	EBS – Include
2.1.04.02.00	Physical and chemical properties of backfill (2,3,4)	EBS – Include
2.1.04.03.00	Erosion or dissolution of backfill (1,2,3,4)	EBS – Exclude - Low Consequences
2.1.04.05.00	Backfill evolution (1,2,3,4)	EBS – Include
2.1.04.08.00	Diffusion in backfill (4)	EBS – Exclude - Low Consequences

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.04.09.00	Radionuclide transport through backfill (4)	EBS – Exclude - Low Consequences
2.1.05.03.00	Seal degradation (1)	UZ F&T – Exclude - Low Consequences
2.1.06.01.00	Degradation of cementitious materials in drift (1,2,3,4)	EBS – Include
2.1.06.02.00	Effects of rock reinforcement materials (1,2,4)	EBS – Include
2.1.06.03.00	Degradation of the liner (1,2,3,4)	EBS – Exclude - Low Probability
2.1.06.04.00	Flow through the liner (1,2,3,4)	EBS – Exclude - Low Probability
2.1.06.05.00	Degradation of the invert and pedestal (1,2,4)	EBS – Include
2.1.06.06.00	Effects and degradation of drip shield (1,2,3,4)	WP – Include physical & chemical degradation processes/Exclude rockfall effects, and damage from seismic events (TBV) - Low Consequences
2.1.06.07.00	Effects at material interfaces (1,2,3,4)	WP – Include EBS – Exclude - Low Consequences

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.08.01.00	Increased Unsaturated Water Flux at the Repository (1)	NFE – Include climate change/Exclude water quenching waste package - Low Consequences UZ F&T – Include
2.1.08.02.00	Enhanced Influx (Philip's Drips) (1)	UZ – Include EBS – Exclude - Low Consequences NFE – Include
2.1.08.03.00	**Repository Dry-out due to Waste Heat (1)**	**NFE – Include**
2.1.08.04.00	Condensation forms on backs of drifts (2,4)	EBS – Include
2.1.08.05.00	Flow through invert (1,4)	EBS – Include
2.1.08.06.00	Wicking in waste and engineered barriers (4)	EBS – Include
2.1.08.07.00	Pathways for unsaturated flow and transport in the waste and EBS (2,3,4)	EBS – Include WF – Include bulk transport paths/Exclude preferential paths - Low Consequences

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.08.08.00	Induced hydrological changes in the waste and EBS (1,2,3,4)	WF – Include flow areas and changes to waste package, waste form in drip shield/Exclude hydrologic changes to waste form and invert - Low Consequences
2.1.08.10.00	**DesaturationDewatering of the Repository (1)**	**NFE – Include** **WF – Include**
2.1.08.11.00	Resaturation of the Repository (1,2,3,4)	NFE – Include EBS – Include
2.1.09.01.00	**Properties of the Potential Carrier Plume in the Waste and EBS (1,2,3,4)**	**NFE – Include** **WF – Include effects of steel corrosion/Exclude changing properties of water - Low Consequences**
2.1.09.02.00	Interaction with corrosion products (2,3,4)	WF – Include rind around fuel pellets/Exclude changes to advective, diffusive, or sorptive effects on radionuclide transport EBS – Include
2.1.09.03.00	Volume increase of corrosion products (2)	WP – Exclude - Low Consequences WF – Include unzipping of clad/Exclude dry oxidation of CSNF - Low Consequences

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation
(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.09.04.00	Radionuclide solubility, solubility limits, and speciation in the waste form and EBS (3,4)	WF – Include
2.1.09.05.00	In-drift sorption (4)	WF – Include sorption on colloids/Exclude sorption within waste form & waste package - Low Consequences EBS – Exclude - Low Consequences
2.1.09.06.00	Reduction-oxidation potential in waste and EBS (2,3,4)	WF – Include EBS – Include
2.1.09.07.00	Reaction kinetics in waste and EBS (2,3,4)	WF – Include reaction kinetics in equilibrium model/Exclude reaction transients - Low Consequences EBS – Exclude - Low Consequences
2.1.09.08.00	Chemical gradients/enhanced diffusion in waste and EBS (2,3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.09.00	Electrochemical effects (electrophoresis, galvanic coupling) in waste and EBS (2)	WP – Exclude (TBV) - Low Consequences WF – Exclude - Low Consequences
2.1.09.10.00	Secondary phase effects on dissolved radionuclide concentrations at the waste form (3)	WF – Exclude - Low Probability

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.09.11.00	Waste-rock contact (3)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.12.00	Rind (Altered Zone) Formation in Waste, EBS, and Adjacent Rock (1,2,3,4)	NFE – Include in THC model/Exclude in TH model - Low Consequences WF – Include in radionuclide mobilization/Exclude in adjacent rock - Low Consequences EBS – Include
2.1.09.13.00	Complexation by organics in waste and EBS (3,4)	WF – Exclude - Low Probability EBS – Exclude - Low Consequences
2.1.09.14.00	Colloid formation in waste and EBS (3,4)	WF – Include EBS – Include
2.1.09.15.00	Formation of true colloids in waste and EBS (3)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.16.00	Formation of pseudo-colloids (natural) in waste and EBS (3,4)	WF – Include EBS – Include
2.1.09.17.00	Formation of pseudo-colloids (corrosion products) in waste and EBS (3,4)	WF – Include EBS – Include

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.09.18.00	Microbial colloid transport in the waste and EBS (3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.19.00	Colloid transport and sorption in waste and engineered barriers (4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.20.00	Colloid filtration in waste and engineered barriers (4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.09.21.00	Suspensions of particles larger than colloids (4)	SZ – Exclude - Low Consequences WF – Exclude EBS – Exclude - Low Consequences
2.1.10.01.00	Biological activity in waste and EBS (2,3,4)	WP – Include for waste container/Exclude for drip shield (TBV) - Low Consequences WF - Exclude - Low Consequences
2.1.11.01.00	**Heat Output/Temperature in Waste and EBS (1,2,3,4)**	**NFE – Include** **WF – Include** **EBS – Include**
2.1.11.02.00	Nonuniform Heat Distribution/Edge Effects in Repository (1,2,3,4)	NFE – Include TH effects/Exclude Thermal-Mechanical effects - Low Consequences

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation
(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.11.03.00	Exothermic reactions in waste and EBS (2,3)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.11.04.00	Temperature effects/coupled processes in waste and EBS (2,3,4)	WF – Include EBS – Include
2.1.11.06.00	Thermal sensitization of waste containers increases fragility (2)	WP – Include
2.1.11.08.00	Thermal effects: chemical and microbiological changes in the waste and EBS (2,3,4)	WF – Include EBS – Include
2.1.11.09.00	Thermal effects on liquid or two-phase liquid fluid flow in the waste and EBS (2,3,4)	WF – Include water reaching EBS/Exclude two-phase flow in waste and single phase flow driven flow in waste - Low Consequences EBS – Include
2.1.11.10.00	Thermal effects on diffusion (Soret effect) in waste and EBS (3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.12.01.00	**Gas Generation (1,2,3,4)**	**UZ F&T – Exclude - Low Consequences** **WF – Exclude - Low Consequences** **EBS – Exclude - Low Consequences**

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.12.02.00	Gas Generation (He) from fuel decay (3)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.12.03.00	Gas Generation (H_2) from metal corrosion (2,3,4)	WP – Exclude (TBV) - Low Consequences WF– Exclude - Low Consequences EBS -- Exclude - Low Consequences
2.1.12.04.00	Gas Generation (CO_2, CH_4, H_2S) from microbial degradation (2,3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.12.05.00	Gas generation from concrete (2)	EBS – Exclude - Low Consequences
2.1.12.06.00	Gas transport in waste and EBS (2,3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.12.07.00	Radioactive gases in waste and EBS (3,4)	WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.1.12.08.00	Gas explosions (3,4)	WF – Exclude - Low Probability EBS – Exclude - Low Consequences
2.1.13.01.00	Radiolysis (2,3,4)	WP – Exclude - Low Consequences WF – Exclude - Low Consequences EBS – Exclude

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.1.13.02.00	Radiation damage in waste and EBS (2,3)	WP – Exclude (TBV) - Low Consequences WF – Exclude - Low Consequences EBS – Exclude - Low Consequences
2.2.01.01.00	**Excavation and Construction-Related Changes in the Adjacent Host Rock (1)**	**NFE – Exclude - Low Consequences** **UZ F&T – Include stress relief & ground support on seepage/Exclude water chemistry - Low Consequences**
2.2.01.02.00	Thermal and Other Waste and EBS-Related Changes in the Adjacent Host Rock (1,4)	NFE – Exclude - Low Consequences
2.2.01.03.00	Changes in Fluid Saturations in the Excavation Disturbed Zone (1)	NFE – Exclude - Low Consequences
2.2.01.04.00	Elemental solubility in excavation disturbed zone (4)	WF – No Screening argument
2.2.01.05.00	Radionuclide transport in excavation disturbed zone (4)	UZ F&T – Exclude - Low Consequences
2.2.03.02.00	Rock properties of host rock and other units (1)	UZ F&T – Include SZ – Include

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.2.06.01.00	**Changes in Stress (Due to Thermal, Seismic, or Tectonic Effects) Change Porosity and Permeability of Rock (1)**	**NFE – Exclude - Low Consequences** **DE – Exclude - Low Consequences**
2.2.07.04.00	**Focusing of Unsaturated Flow (Fingers, Weeps) (1)**	**UZ F&T – Include**
2.2.07.05.00	Flow and Transport in the UZ from Episodic Infiltration (1)	UZ F&T – Include transient flow due to TH processes on seepage/Exclude episodic flows - Low Consequences
2.2.07.06.00	Episodic/pulse release from repository (1,3,4)	UZ F&T – Include intermittent waste package failures/ Exclude episodic flow - Low Consequences EBS – Include
2.2.07.07.00	Perched Water develops (1)	UZ – Include increased flow and present day perched water/ Exclude effects of perched water below repository - Low Consequences
2.2.07.10.00	**Condensation Zone Forms Around Drifts (1,2)**	**NFE – Include** **UZ F&T – Include effects on seepage/Exclude mountain scale effects - Low Consequences**

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Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.2.07.11.00	**Return Flow From Condensation Cap/Resaturation of Dry-Out Zone (1,2)**	**NFE – Include** **UZ F&T – Include effects on seepage/Exclude mountain scale effects - Low Consequences**
2.2.07.15.06	Convection (water transport) (1)	SZ – Primary FEP included
2.2.07.15.07	Dispersion (water transport) (1)	SZ – Primary FEP included
2.2.08.01.00	Groundwater chemistry/composition in UZ and SZ (1,2,3,4)	UZ – Included ambient water chemistry/Exclude changes to chemistry - Low Consequences SZ – Include
2.2.08.02.00	Radionuclide transport occurs in a carrier plume in geosphere (4)	UZ – Exclude - Low Consequences SZ – Include
2.2.08.03.00	**Geochemical Interactions in Geosphere (Dissolution, Precipitation, Weathering and Effects on Radionuclide Transport) (1,4)**	**NFE – Include** **UZ – Exclude - Low Consequences** **SZ – Include**
2.2.08.04.00	**Redissolution of Precipitates Directs More Corrosive Fluids to Container (1,2,4)**	**NFE – Include** **UZ F&T – Include** **SZ – Include**
2.2.08.05.00	Osmotic processes (4)	UZ F&T -- Exclude - Low Consequences

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Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.2.08.06.00	Complexation in geosphere (4)	UZ F&T – Include ambient condition complexation/Exclude changes to complexation - Low Consequences
2.2.08.07.00	Radionuclide solubility limits in geosphere (4)	UZ F&T- - Exclude - Low Consequences SZ-- Exclude - Low Consequences
2.2.08.08.00	Matrix diffusion in geosphere (4)	UZ F&T – Include SZ – Include
2.2.08.09.00	Sorption in UZ and SZ (4)	UZ F&T – Include SZ – Include
2.2.08.10.00	Colloidal transport in geosphere (4)	UZ F&T – Include SZ – Include
2.2.09.01.00	Microbial activity in geosphere (4)	UZ F&T – Exclude - Low Consequences SZ – Include
2.2.10.01.00	Repository-induced thermal effects in geosphere (1,2,4)	UZ – Include TC effects on seepage/Exclude mountain-scale TC effects - Low Consequences SZ – Exclude - Low Consequences & Low Probability
2.2.10.04.00	**Thermo-Mechanical Alteration of Fractures Near Repository (1)**	**NFE – Exclude - Low Consequences** **UZ F&T – Exclude - Low Consequences**

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.2.10.05.00	**Thermo-Mechanical Alteration of Rocks Above and Below the Repository (1)**	**NFE – Exclude - Low Consequences** **UZ F&T - Exclude - Low Consequences**
2.2.10.06.00	Thermo-Chemical Alteration (Solubility Speciation, Phase Changes, Precipitation/Dissolution) (1,4)	NFE – Include in geochemical model/Exclude in TH model - Low Consequences UZ F&T – Exclude - Low Consequences SZ – Include
2.2.10.07.00	Thermo-chemical alteration of the Calico Hills unit (1,4)	UZ F&T – Exclude - Low Consequences SZ – Exclude - Low Consequences & Low Probability
2.2.10.09.00	Thermo-chemical Alteration of Topopah Spring Basal Vitrophyre (1,4)	UZ F&T – Exclude - Low Consequences
2.2.10.10.00	Two-Phase Buoyant Flow/Heatpipes (1)	NFE – Include UZ F&T – Include
2.2.10.11.00	Natural airflow in UZ (1)	UZ – Exclude - Low Consequences
2.2.10.12.00	Geosphere Dry-out Due to Waste Heat (1)	NFE – Include
2.2.10.13.00	**Density-Driven Groundwater Flow (1)**	**NFE – Include** **SZ – Exclude - Low Consequences and Low Probability**

Shaded Features, Events, and Processes identified on the NRC Open Item list dated 11/29/00

Features, Events, and Processes Tabulation

(Evolution of Near Field Environment, Continued)

FEP Number	FEP Name (Subissue)	PMR – Screening Decision - Screening Basis
2.2.11.01.00	Naturally occurring gases in geosphere (4)	UZ F&T – Exclude - Low Consequences & Low Probability SZ – Exclude - Low Consequences
2.2.11.01.05	Gas Generation and gas sources, far-field (1,2)	SZ – Primary FEP excluded UZ F&T – Primary FEP excluded
2.2.11.02.00	Gas pressure effects (1)	UZ F&T – Exclude - Low Consequences & Low Probability EBS – Exclude - Low Consequences
2.2.11.03.00	Gas transport in geosphere (4)	UZ F&T – Exclude - Low Consequences & Low Probability
2.3.11.03.00	Infiltration and recharge (hydrologic and chemical effects) (2)	UZ F&T – Include changing infiltration & water table rise/Exclude effects of changing water chemistry - Low Consequences
3.1.01.01.00	Radioactive decay and ingrowth (1,2,3,4)	UZ F&T – Include SZ – Include WF – Include

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

Thermal Effects on Flow
Subissue 2, Open Item 1: Thermohydrologic Modeling for the Current Repository Design

Presented to:

DOE-NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:

Ernest Hardin
Tom Buscheck
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 1 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 1, Thermohydrologic Modeling for Repository Design, related to Subissue 2, in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Demonstrate that DOE has accounted for the Enhanced Design Alternative II design features in its thermohydrologic modeling

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates that Subissue 2 is OPEN**

Open Item 1

- **To close this Open Item, DOE needs to complete thermohydrologic modeling for the current repository design**

- **Basis for resolution**
  - Multi-scale Thermohydrologic Model calculations have been conducted for the Enhanced Design Alternative II design with no backfill. The design attributes are:
    - 5.5 meter diameter drifts (assumed to remain intact)
    - 50 emplacement drifts with 81 meters center-to-center spacing
    - 10 centimeter gaps between 1.67 meter diameter waste packages
    - No backfill
    - Impermeable drip shield
    - Crushed-tuff invert

Open Item 1
(Continued)

- **References**
  - Multi-scale Thermohydrologic Model Analysis/Model Report (ANL-EBS-MD-000049 Rev 00 ICN 01)
  - Abstraction of Near-Field Environment Drift Thermodynamic and Percolation Flux Analysis/Model Report (ANL-EBS-HS-000003 Rev 00 ICN 01)
  - Engineered Barrier System Degradation, Flow, and Transport Process Model Report (TDR-EBS-MD-000006 Rev 01) (under development)
  - Near Field Environment Process Model Report (TDR-NBS-MD-000001 Rev 00 ICN 03)
- **DOE considers this Open Item closed. The thermohydrologic models incorporate relevant Enhanced Design Alternative II design features**

Conclusions

- Predicted thermohydrologic behavior for the Enhanced Design Alternative II design is well understood using the Multi-scale Thermohydrologic Model, which takes into account the details of the emplacement drifts and engineered components
- DOE considers Open Item 1 Closed. This presentation supports a status of Closed-Pending for Subissue 2

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

Thermal Effects on Flow Subissue 2, Open Item 1: Thermohydrologic Modeling for the Current Repository Design

Presented to:
DOE-NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:
Ernest Hardin
Tom Buscheck
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 1 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 1, Thermohydrologic Modeling for Repository Design, related to Subissue 2, in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Demonstrate that DOE has accounted for the Enhanced Design Alternative II design features in its thermohydrologic modeling

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates that Subissue 2 is OPEN**

Open Item 1

- **To close this Open Item, DOE needs to complete thermohydrologic modeling for the current repository design**

- **Basis for resolution**
  - Multi-scale Thermohydrologic Model calculations have been conducted for the Enhanced Design Alternative II design with no backfill. The design attributes are:
    - 5.5 meter diameter drifts (assumed to remain intact)
    - 50 emplacement drifts with 81 meters center-to-center spacing
    - 10 centimeter gaps between 1.67 meter diameter waste packages
    - No backfill
    - Impermeable drip shield
    - Crushed-tuff invert

Open Item 1
(Continued)

- **References**
  - Multi-scale Thermohydrologic Model Analysis/Model Report (ANL-EBS-MD-000049 Rev 00 ICN 01)
  - Abstraction of Near-Field Environment Drift Thermodynamic and Percolation Flux Analysis/Model Report (ANL-EBS-HS-000003 Rev 00 ICN 01)
  - Engineered Barrier System Degradation, Flow, and Transport Process Model Report (TDR-EBS-MD-000006 Rev 01) (under development)
  - Near Field Environment Process Model Report (TDR-NBS-MD-000001 Rev 00 ICN 03)

- **DOE considers this Open Item closed. The thermohydrologic models incorporate relevant Enhanced Design Alternative II design features**

Conclusions

- Predicted thermohydrologic behavior for the Enhanced Design Alternative II design is well understood using the Multi-scale Thermohydrologic Model, which takes into account the details of the emplacement drifts and engineered components
- DOE considers Open Item 1 Closed. This presentation supports a status of Closed-Pending for Subissue 2

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

Thermal Effects on Flow
Subissue 2, Open Item 2: Cold Trap Effects in the Multi-scale Thermohydrologic Model

Presented to:
DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:
Ernest Hardin
Tom Buscheck
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 2 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 2, to include "cold trap effect" in the Multi-Scale Thermohydrologic Model, related to Subissue 2 in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Demonstrate DOE has identified key assumptions for the Multi-scale Thermohydrologic Model and screened features, events, and processes related to "cold trap"
- Demonstrate DOE is considering the "cold trap effect" and will incorporate important effects in the Multi-scale Thermohydrologic Model for Total System Performance Assessment for License Application

Current Subissue 2 Status

- Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates that Subissue 2 is OPEN

Open Item 2

- Include the process (Feature, Event, and Processes) referred to as the "cold trap effect" in the Multi-scale Thermohydrologic Process Model. Subsequently, provide model support for implementation of the Multi-scale Thermohydrologic Process Model "cold trap effect" model by comparison with past observation such as condensation in the Enhanced Characterization of the Repository Block under a thermal gradient imposed by the tunnel boring machine

Open Item 2
(Continued)

- **Basis for Resolution**
  - Technical issues in modeling processes related to the "cold trap effect"
  - Multi-scale model key assumptions
  - Overview of cold trap activities

Open Item 2
(Continued)

- **References**
  - Engineered Barrier System Degradation, Flow, and Transport Process Model Report, TDR-EBS-MD-000006 Rev 01 (under development)
  - Multi-scale Thermohydrologic Model, ANL-EBS- MD-000049 Rev 01 (under development)
  - Buscheck T.A. in Wilder D.G. (ed.) 1996. Volume II: Near-Field and Altered Zone Environment Report. UCRL-LR-124998
- **DOE considers this Open Item Closed-Pending NRC review of ongoing and planned Analysis/Model Report and Process Model Report revisions**

Open Item 2
(Continued)

- DOE has identified the technical issues in modeling cold traps, key assumptions for cold traps for the Multi-scale Thermohydrologic Model, and is considering additional models, as appropriate to represent cold trap effects in the Multi-scale Thermohydrologic Model

Open Item 2
(Continued)

- **Technical Issues in Modeling Cold Traps**
  - "Cold trap effects" occur in emplacement drifts with water and latent heat transfer from warmer to cooler locations. This is a potential source of condensation and dripping water in the emplacement areas
  - Drift-scale cold traps may occur between warmer and cooler waste package locations
  - Repository-scale cold traps may occur between the repository center and edges
  - Previous analysis has shown that drift-scale cold traps could produce condensate flux on cooler waste packages (Buscheck, 1996)

Open Item 2
(Continued)

- **Multi-scale Thermohydrologic Model Key Assumptions**
  - Dimensionality of thermohydrologic model (develop three-dimensional submodels; Ref. #2)
  - Use of porous-medium simulator to represent air circulation in the Engineered Barrier System (evaluate using computational fluid dynamics approach; Ref. #1)
  - Spatially uniform fracture continuum properties (evaluate heterogeneous properties in three-dimensional drift-scale thermohydrologic models; Ref. #3)

References:

1. Engineered Barrier System Process Model Report, TDR-EBS-MD-000006, revision in FY02
2. Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049, Rev 01
3. Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049 Rev 00 ICN 03

Open Item 2
(Continued)

- **Overview of Cold Trap Activities**
  - DOE is developing a mountain-scale thermohydrologic model (single drift, line source) to represent the repository-scale cold-trap effect (i.e., temperature differences and rates of water transfer)
  - DOE is considering development of a detailed drift-scale thermohydrologic model to estimate the magnitude of the drift-scale cold-trap effect (i.e., temperature differences and rates of water transfer)
  - DOE will incorporate the repository-scale and/or drift-scale models into the Multi-scale Thermohydrologic Model, only if the models lead to significant changes in the predicted dose
  - DOE intends to conduct independent analyses of heat and single-phase mass transfer in the emplacement drifts, using a computational fluid dynamics approach

Conclusions

- Multi-scale model key assumptions related to "cold traps" have been identified and the magnitude of three-dimensional moisture movement effects are currently being considered
- Cold trap Features, Events, and Processes have been screened (FEP 2.1.08.04.00)
- Cold trap effects may be included in the process model output that directly supports the Total System Performance Assessment if they are significant to system performance
- DOE considers Open Item 2 Closed-Pending NRC review of ongoing modeling activities and planned Analysis/Model Report and Process Model Report revisions. This presentation supports a status of Closed-Pending for Subissue 2

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

Thermal Effects on Flow Subissue 2, Open Item 6: Data Support for the Ventilation Model

Presented to:

DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:

Ernest Hardin

John Pye

Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001

Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 6 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will:**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 6, Data Support for the Ventilation Model, related to Subissue 2 in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Explain that DOE is continuing the ventilation test, the results of which will be compared with the ventilation model results

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates that Subissue 2 is OPEN**

Open Item 6

- **To close this Open Item, DOE needs to provide data support for the ventilation model by completing the ongoing ventilation test. Subsequently, DOE should provide model support for the ventilation model by comparisons to the test data**
- **Basis for resolution**
  - Ventilation Test Overview
    - Testing is ongoing to evaluate pre-closure ventilation models
    - Testing will provide a basis for optimizing ventilation system performance (flow rate, operation, etc.)
    - Testing is expected to confirm that evaporation increases ventilation heat removal efficiency
    - Testing will be used to calibrate ventilation models based on ANSYS and Multiflux codes

Open Item 6
(Continued)

- **Basis for resolution (Continued)**
  - Ventilation Test Features
    - Simulated drift diameter: 54 inches
    - Simulated drift length: 25 $\times$ diameter (120 feet)
    - Test heater power: 0.35 kilowatt/meter
    - Expected waste package surface temperature: ambient to 200°C
    - Air velocity: 60 to 150 feet/minute
    - Maximum drift wall temperature: 100°C

Open Item 6
(Continued)

- **Basis for resolution** (Continued)
  - Ventilation Test Key Parameters
    - Atmospheric temperature, humidity, pressure
    - Temperature, humidity, and velocity at inlet, outlet, and points between
    - Drift wall temperature
    - Power output
  - Ventilation Test Conduct
    - Perform ambient tests, then thermal tests
    - Allow for test to be performed without ventilation

Open Item 6
(Continued)

- **Basis for resolution (Continued)**
  - Ventilation Test Schedule
    - Phase 1 Simulate maintaining sub-boiling temperatures at the drift wall using ambient temperature inlet air (Complete)
    - Phase 2 Simulate maintaining sub-boiling temperatures at the drift wall using pre-heated inlet air (Ongoing)
    - Phase 3 Simulate moisture removal by ventilation air using water injection and evaluate the effect on heat removal efficiency (June 2001)

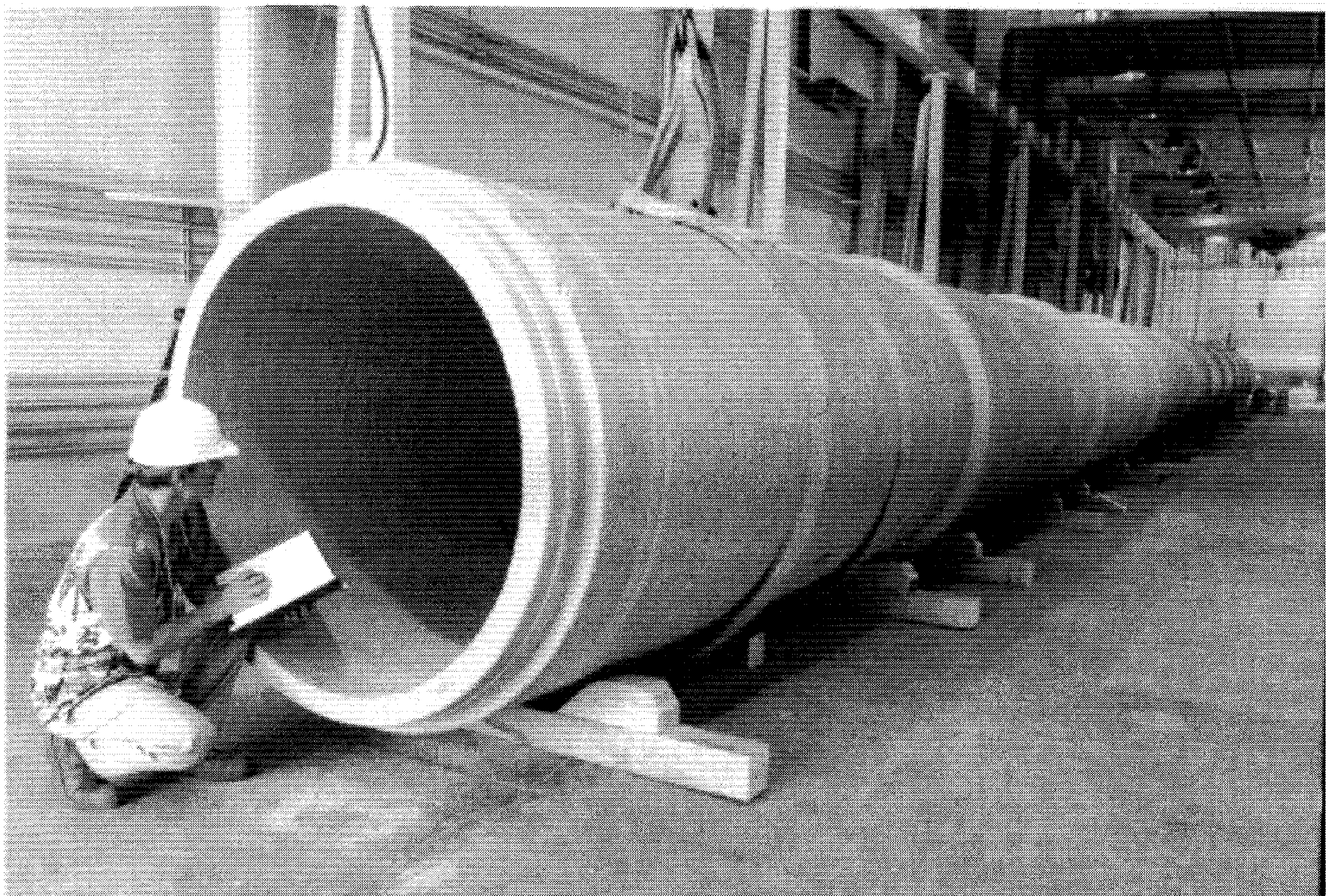
Open Item 6
(Continued)

- **References**
  - Ventilation Model, ANL-EBS-MD-000030 Rev 01 (under revision; future revisions will include ventilation test data)
  - Pre-test Predictions for Ventilation Tests, CAL-EBS-MD-000013 Rev 00 (work in progress)
- **DOE considers this Open Item Closed-Pending NRC review of the ventilation tests results that will be used to support DOE's ventilation models**

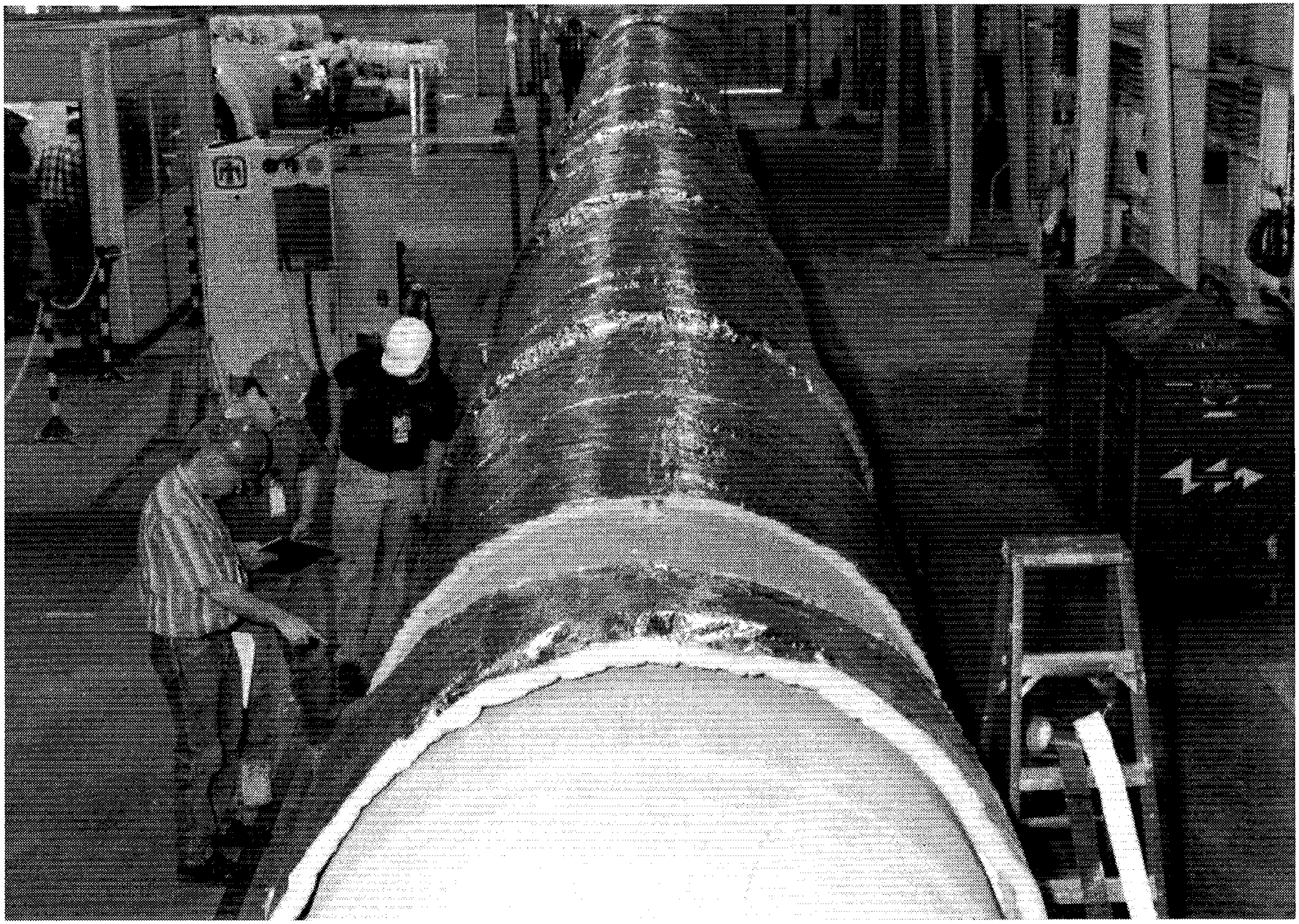
Conclusions

- Test methods and results will represent repository conditions and are expected to be sufficient to calibrate ventilation models for prediction of pre-closure ventilation system heat removal performance
- DOE considers Open Item 6 Closed-Pending completion of ventilation testing and modeling. This presentation supports a status of Closed-Pending for Subissue 2

Ventilation Test Setup - Atlas Facility

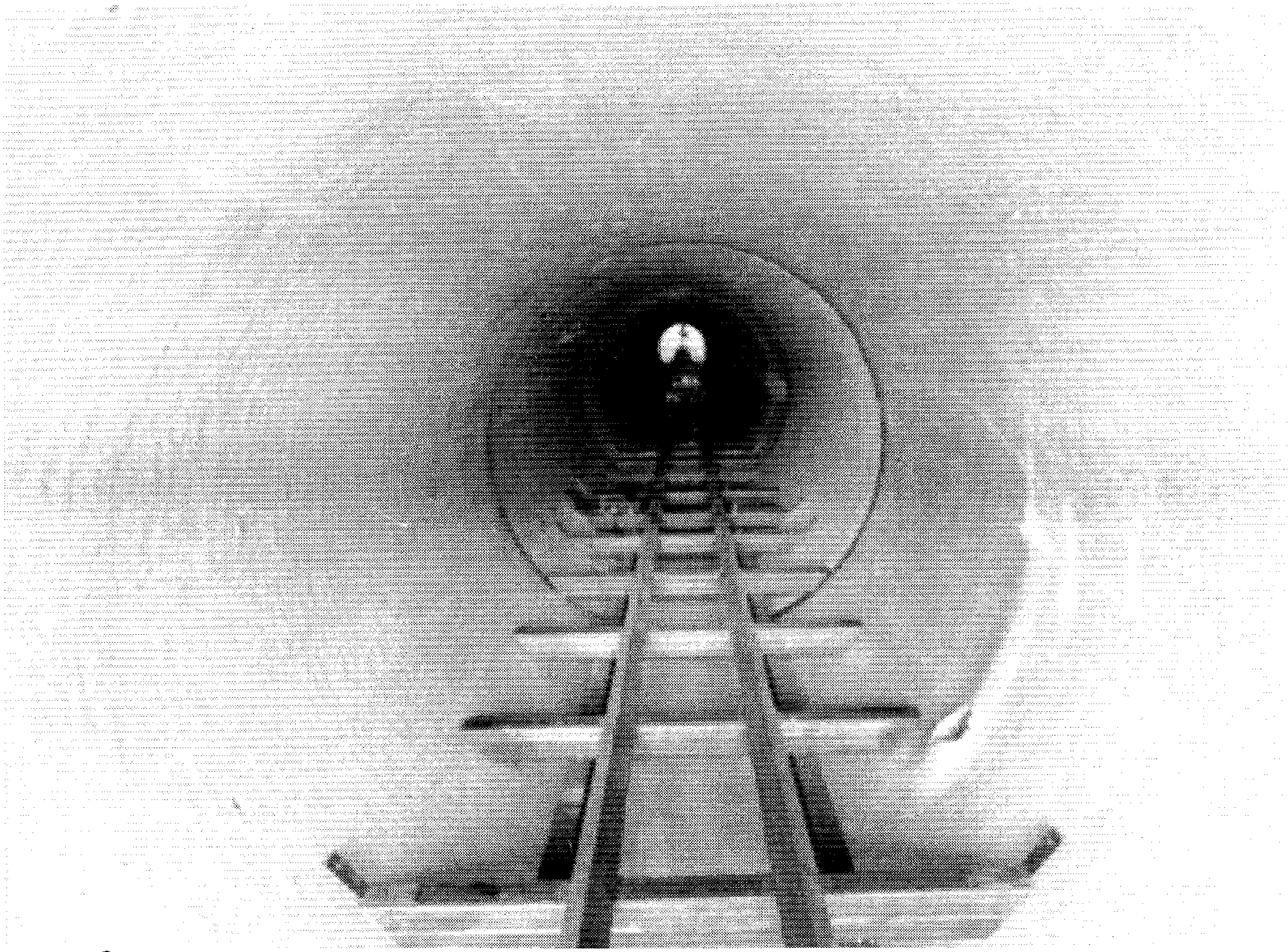


Ventilation Test Setup - Atlas Facility



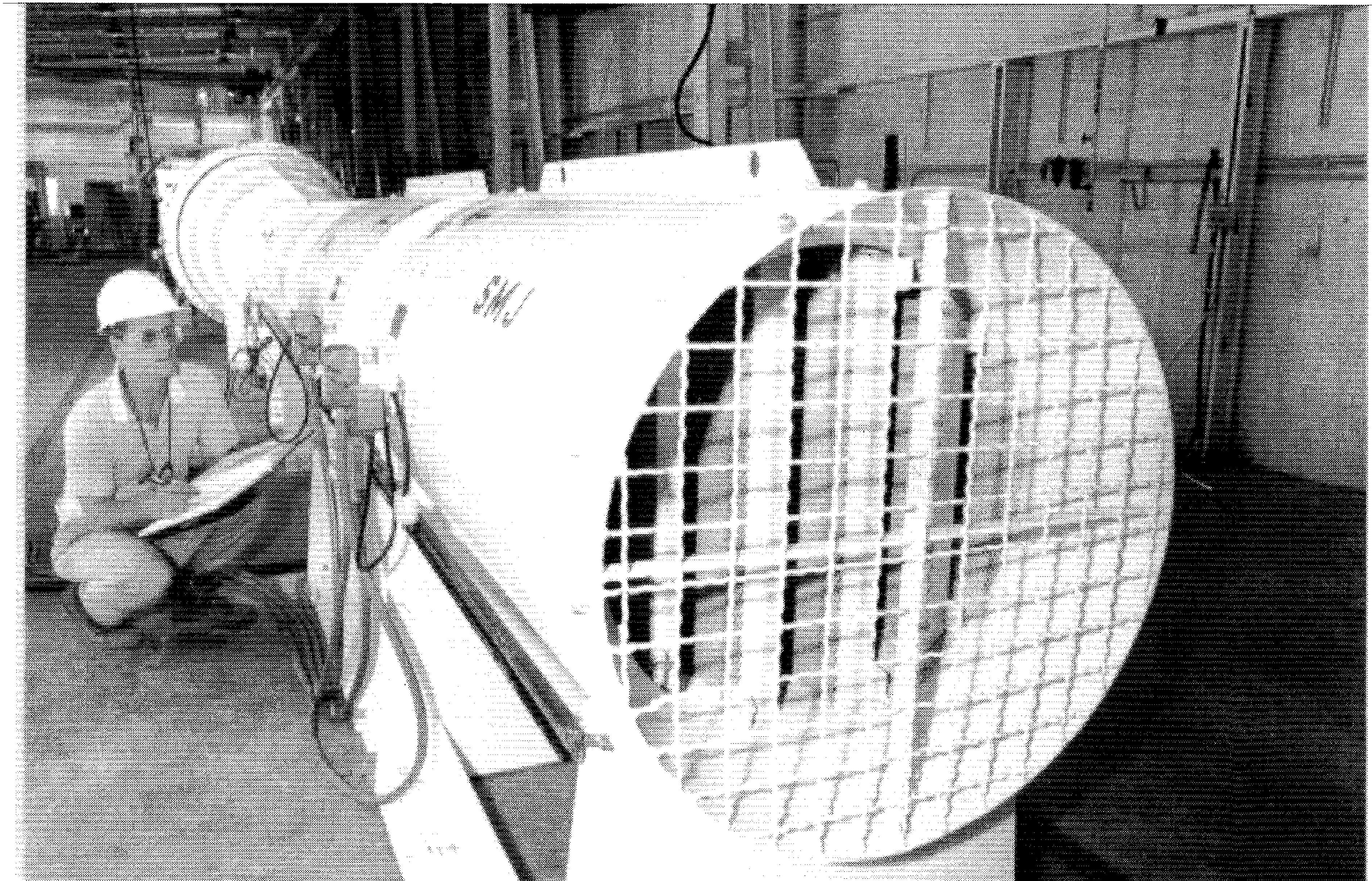
YM-20972 View of the EBS Ventilation Test at the Atlas Facility, Las Vegas.

Invert Structure, Ventilation Test - Atlas Facility



Simulated Waste Packages, Ventilation Test - Atlas Facility

Ventilation Test Fan Section - Atlas Facility



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

Thermal Effects on Flow Subissue 2, Open Item 5: Potential Heat Losses in Cross Drift Thermal Test

Presented to:
DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by:
Mark Peters
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Safety Systems Inc.

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2 Open Item 5 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 5, Unmonitored Mass and Energy Flow Through the Test Boundaries in the Cross Drift Thermal Test, related to Subissue 2 in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Demonstrate that DOE has considered and taken into account unmonitored mass and energy losses in the planned Cross Drift Thermal Test

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates Subissue 2 is OPEN**

Open Item 5

- To close this Open Item, DOE needs to address (i) the potential for unmonitored mass and energy flow through test boundaries of the Cross Drift Thermal Test and (ii) the effect of unmonitored mass and energy flow through test boundaries of the Cross Drift Thermal Test on the usefulness of the test results before the test begins. Consider designing and conducting the Cross Drift Thermal Test to avoid unmonitored mass and energy flow through test boundaries

Open Item 5
(Continued)

- **Basis for resolution**
  - Test design takes into consideration convective heat and mass movement
  - Test block is representative of the potential repository rock, and the test design will minimize heat and mass losses to the outside
  - Predictive simulations, taking into account convective movement, will be performed prior to heat-up

Open Item 5
(Continued)

- **References**
  - Cross Drift Thermal Test Planning Report, August 2000
- **DOE considers this Open Item closed. The potential for unmonitored mass and energy flow through the Cross Drift Thermal Test boundaries has been taken into account as identified in the Cross Drift Thermal Test Planning Report, Section 4.0**

Cross Drift Thermal Test Objectives

- **Investigate the hypothesis that heat-mobilized pore water will shed/drain between emplacement drifts to below the repository horizon**
- **Investigate the hypothesis that liquid water cannot penetrate through zones/regions at or above boiling temperature**
- **Measure the rock mass properties of Topopah Spring Welded Tuff (Tptpll) listed below in the following order of priority**
  - Hydrologic properties
  - Thermal and mechanical properties
  - Chemical/mineralogic/petrologic properties

Cross Drift Thermal Test Objectives
(Continued)

- Investigate the hypothesis that there would be no long-term thermally driven seepage into the emplacement drifts and that the chemistry of seepage water, if any, will be benign to the engineered components
- Investigate the hypothesis that the composition of gas in the emplacement drift will be benign to the engineered components

Cross Drift Thermal Test Objectives Baseline Schedule

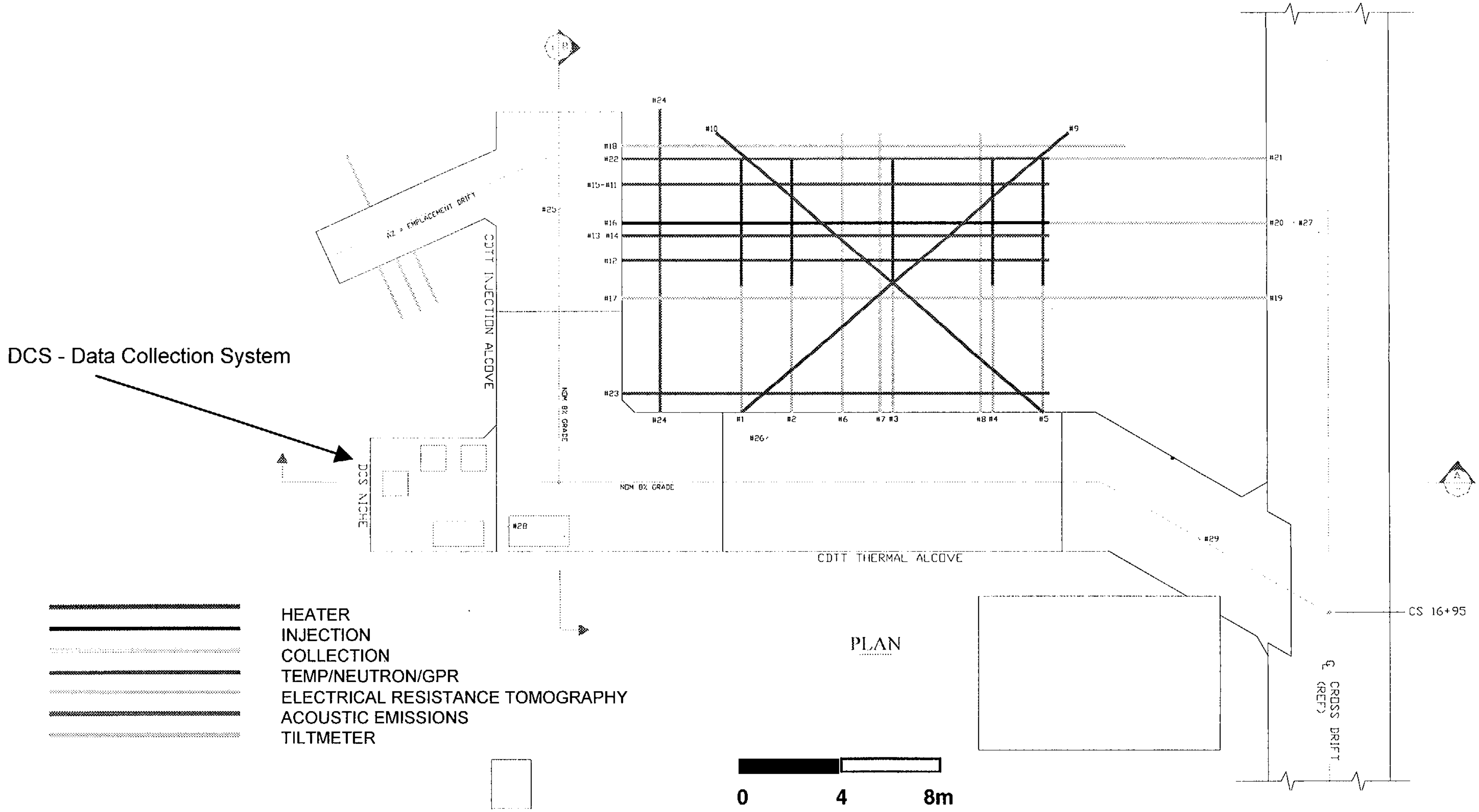
• Complete Test Facility Excavation	July 2002
• Complete Pre-test Predictive Analyses	December 2002
• Initiate Heat-up	January 2003
• Terminate Heating	September 2003
• Complete Cooling	February 2004
• Final Report	December 2004

Note: Above dates represent the current project baseline and are subject to change based on replanning

Test Design and Configuration

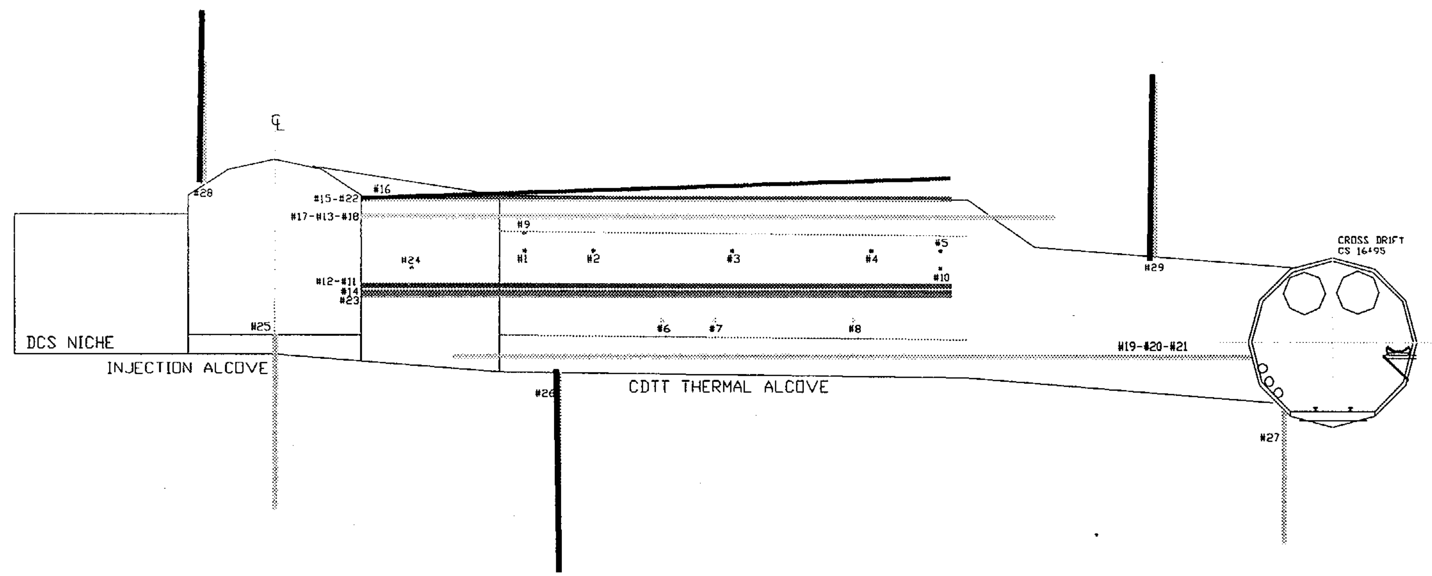
- Conducted in the lower lithophysal unit of Topopah Spring Welded Tuff
- Described in the Cross Drift Thermal Test Planning Report
- Illustrated in the following plan and elevation views

Test Design and Configuration
(Continued)
Plan View of Cross Drift Thermal Test Configuration



Test Design and Configuration
(Continued)

Elevation of Cross Drift Thermal Test Configuration



HEATER
INJECTION
COLLECTION
TEMP/NEUTRON/GPR
ELECTRICAL RESISTANCE TOMOGRAPHY
ACOUSTIC EMISSIONS
TILTMETER

0 4 8m

Test Design and Configuration
(Continued)

- Test block created by L-shaped alcove and the Cross Drift
- Five five-meter long heaters in five parallel holes in a horizontal plane; each heater capable of ~300 watts/meter
- Three inner heaters spaced four meters apart with two outer heaters two meters from their neighbors
- Minimum of five meters of rock between heater plane and exposed surfaces of test block

Test Design and Configuration
(Continued)

- **In addition to various instrument holes, there will be:**
  - One injection hole approximately 1.75 meters above the heater plane
  - Three collection holes approximately two meters below the heater plane
- **Actual heated test volume will be:**
  - Surrounded by a minimum of five meters of unheated rock
  - All holes, other than heater holes, will be lined and/or packed off
  - All holes will also be plugged at collar
- **In the predictive and subsequent thermal-hydrologic modeling of the Cross Drift Thermal Test, the heater holes will be simulated explicitly as an unlined hole, plugged at the collar**

Predictive Simulations

- Thermal-hydrologic simulations (scoping calculations) were performed in support of designing the test, as described in the Cross Drift Thermal Test Planning Report
- Guard heaters will be installed at both ends of the heater plane so that adverse impact of "edge effects" on the core test volume observations will be negligible
- Predictive simulations of thermal-hydrologic, thermal-hydrologic-chemical, and thermal-hydrologic-mechanical responses of the Cross Drift Thermal Test will be performed prior to start of heating to establish the baseline for prediction/measurement comparisons

Reference: Cross Drift Thermal Test Planning Report, August 2000

Conclusions

- Test design takes into consideration convective heat and mass movement
- Test block is representative of the potential repository rock
- Large thickness of unheated rock surrounding the heated test volume is expected to minimize heat and mass losses to the outside
- Explicit simulation of unlined heater holes plugged at collar will realistically account for convective movements within the test volume
- DOE considers Open Item 5 Closed. This presentation supports a status of Closed-Pending for Subissue 2

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

Thermal Effects on Flow
Subissue 2, Open Item 7: Data Uncertainty

Presented to:
DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by
Bo Bodvarsson
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 7 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 7, Evaluate Data Uncertainty, related to Subissue 2 in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Demonstrate that DOE has propagated data uncertainty into thermohydrologic models, and additional ongoing work will further reduce uncertainties

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates that Subissue 2 is OPEN**

Open Item 7

- To close this Open Item, DOE needs to evaluate (i) measurement error, bias, and scale-dependence in the saturation, water potential, and pneumatic pressure data used for model parameter calibration, (ii) heterogeneity and spatial variability in thermohydrologic properties, and (iii) variability in model results using the various property sets found to be valid for thermohydrologic modeling and propagate this uncertainty through the thermohydrologic model abstraction

Open Item 7
(Continued)

- **Basis for Resolution**
  - DOE has propagated data uncertainty into thermohydrologic models. Additional ongoing work will further reduce uncertainties
- **References**
  - Calibrated Properties, MDL-NBS-HS-000003, Rev 00
  - Mountain Scale Coupled Processes Model, MDL-NBS-HS-000007, Rev 00
  - Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049, Rev 00 ICN 2
- **DOE considers this Open Item Closed-Pending NRC review of analyses of thermal effects on flow and work in progress**

NRC Comment

- **Measurement error, bias, and scale-dependence in the saturation, water potential, and pneumatic pressure data used for model parameter calibration**
- **To address the NRC's Comment, this presentation will discuss:**
  - Uncertainty from spatially heterogeneous properties
  - Uncertainty in measured data
  - Propagation of uncertainty in inverse modeling
  - Upscaling

Uncertainty from Spatially Heterogeneous Properties

- **Most important for site-scale flow and transport**
  - Geologic stratigraphy
  - Inclination of layers
  - Faults
- **Calibration by inverse modeling gives properties in homogeneous layers**
- **Heterogeneity within layer is incorporated for specific problems (e.g., seepage into drift, perched water bodies)**

Uncertainty in Measured Data

- **Measured data are segregated into:**
  - Input property set for TOUGH2 simulation (e.g. matrix and fracture permeability, van Genuchten parameters)
  - Parameters to be compared to TOUGH2 output in inverse modeling with iTOUGH2 (e.g., water potential, saturation)
- **All measured data are upscaled to unsaturated zone model gridblock common to both mountain scale simulations and inverse modeling calibration studies**
- **Measurement error included as uncertainty for both input property and data to be matched by iTOUGH2**
- **Inverse modeling with iTOUGH2 to determine unsaturated zone hydrological properties**

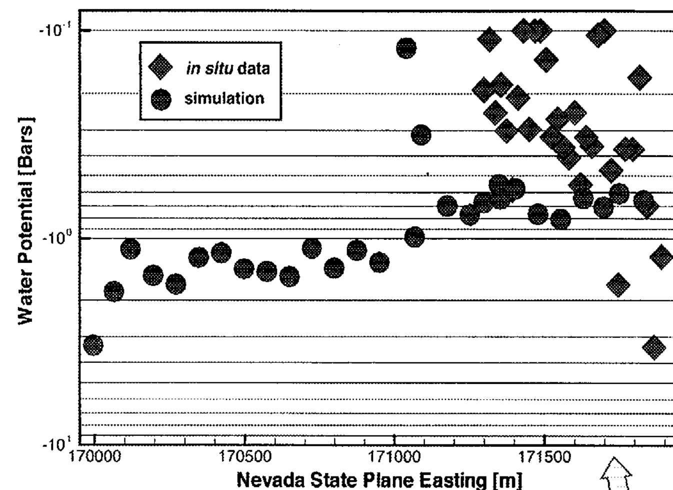
Additional NRC Comments on Measurement Errors

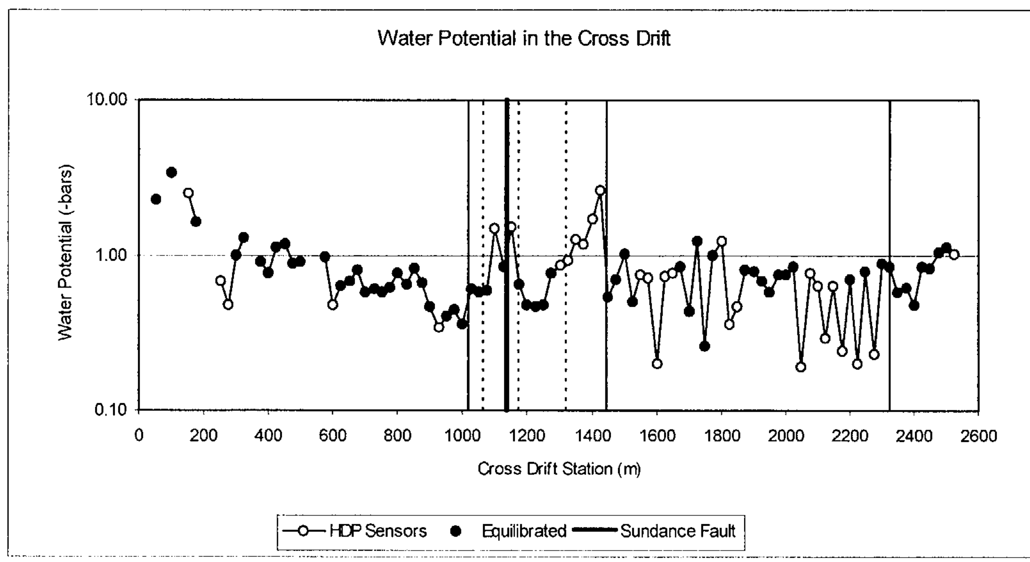
- **NRC Comment: Effects of measurement error of saturation data on resulting calibration properties**
  - See discussion of propagation of error from input parameters to calibrated properties
- **NRC Comment: Drying effects on in-situ water potential measurements were not considered**
  - Water potential measurements in borehole stabilize with time. Stabilized values in surface-based boreholes, Exploratory Study Facility boreholes and Enhanced Characterization Repository Block boreholes were used in the calibration process

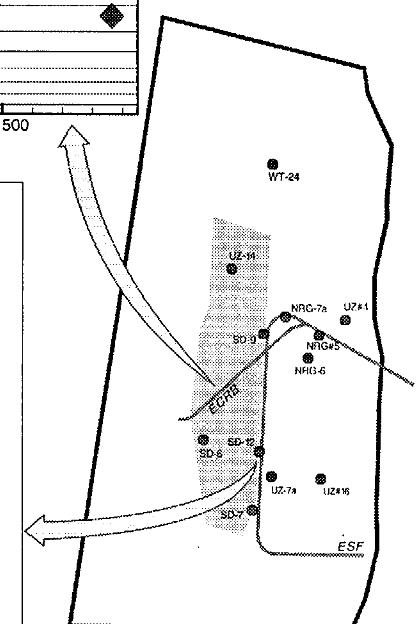
Reference: Calibrated Properties, MDL-NBS-HS-000003, Rev 00

Additional NRC Comments on Measurement Errors Water Potential Data from Cross Drift

- **Three-dimensional simulation comparison against in-situ water potential data from the Cross Drift**
- **The unsaturated zone model honors water potential data from all available sources, as they become available**



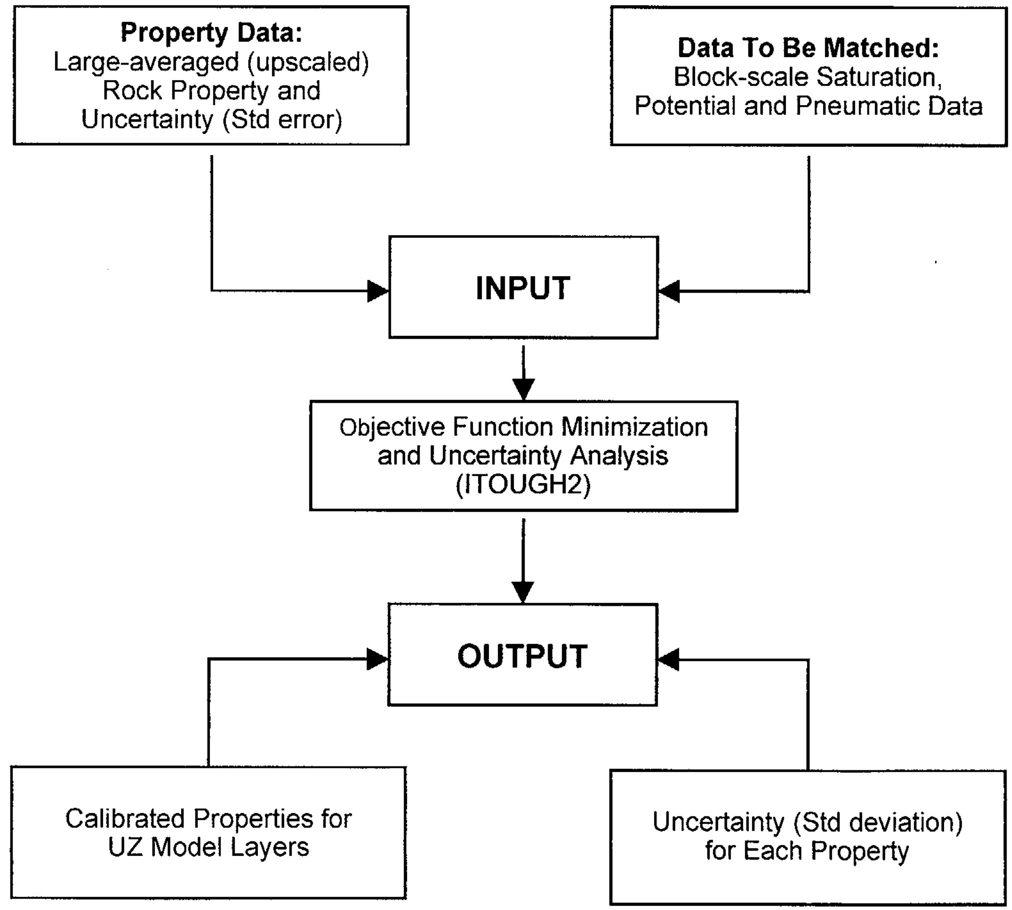




Reference: Unsaturated Zone Flow and Transport, TDR-NBS-HS-000002 Rev 00 ICN 02

Propagation of Uncertainty in Inverse Modeling from Input Parameter to Calibrated Properties

- Measurement error incorporated as uncertainty values for relevant data in inputs into iTOUGH2
- At each iTOUGH2 iteration, only sensitive rock properties are updated
- The most sensitive properties include (fracture and matrix) permeability and alpha
- iTOUGH2 output uncertainties for calibrated values included in future data submission of calibrated property sets
- Measurement errors include uncertainty resulting from scale-dependence and modeling errors



Reference: Calibrated Properties, MDL-NBS-HS-000003, Rev 00

Upscaling

Two-Step Approach

- Large-scale rock properties for each model layer are determined (upscaled) from small-scale measurements
- Upscaled properties are further refined with inverse modeling. Since the large-scale model is used to match gridblock scale measurements (e.g, matrix saturation), inverse modeling is also an upscaling procedure

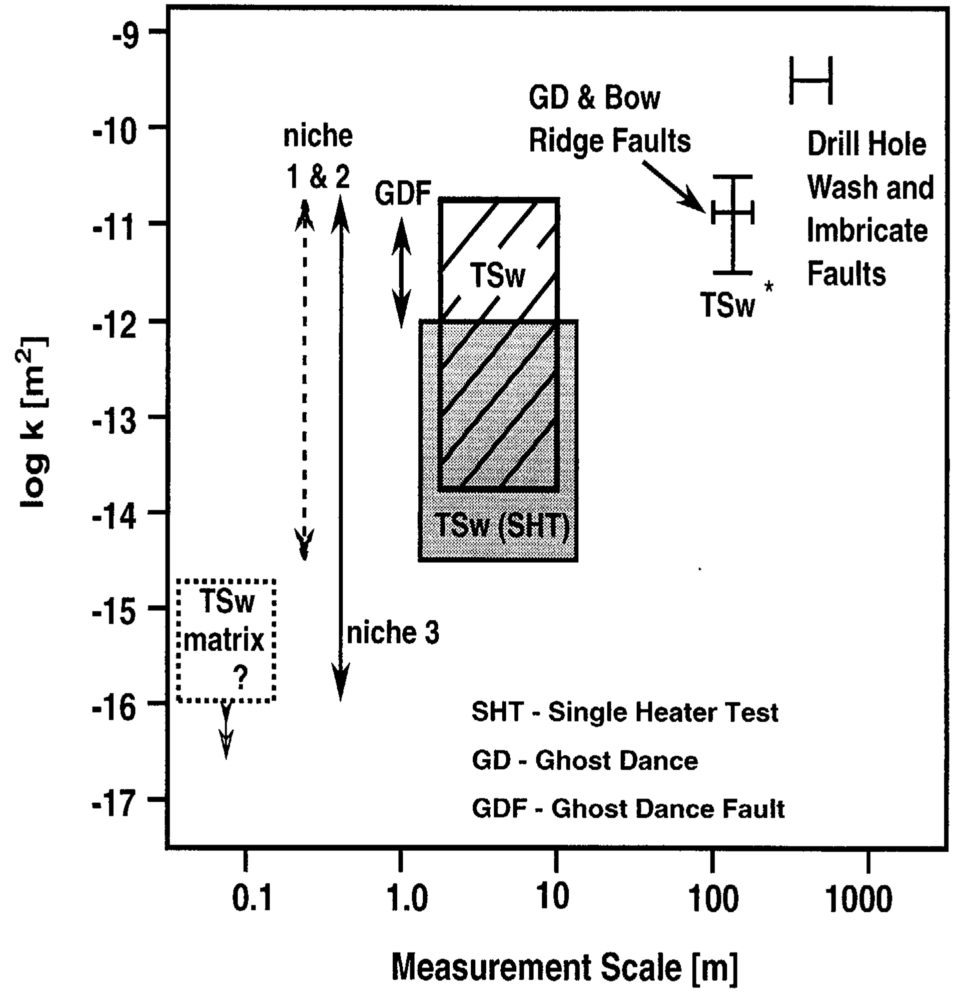
Additional NRC Comment on Scaling

- **NRC Comment: In the maximum likelihood inverse method used in iTOUGH2, measurement error should be generalized to include uncertainty resulting from scale-dependence and modeling errors**
  - In the current approach, measurement errors are included as prior information, and iTOUGH2 correctly includes this uncertainty

Additional NRC Comment on Scaling

Scale-Dependent Behavior of Pneumatic Pressure Data

- **Mountain Scale**
  - Measured data (hundreds of meter scale) in surface-based boreholes used in calibration process
- **Drift Scale**
  - Borehole measurements (less than a meter to tens of meters scale) from the Exploratory Studies Facility used in calibration process



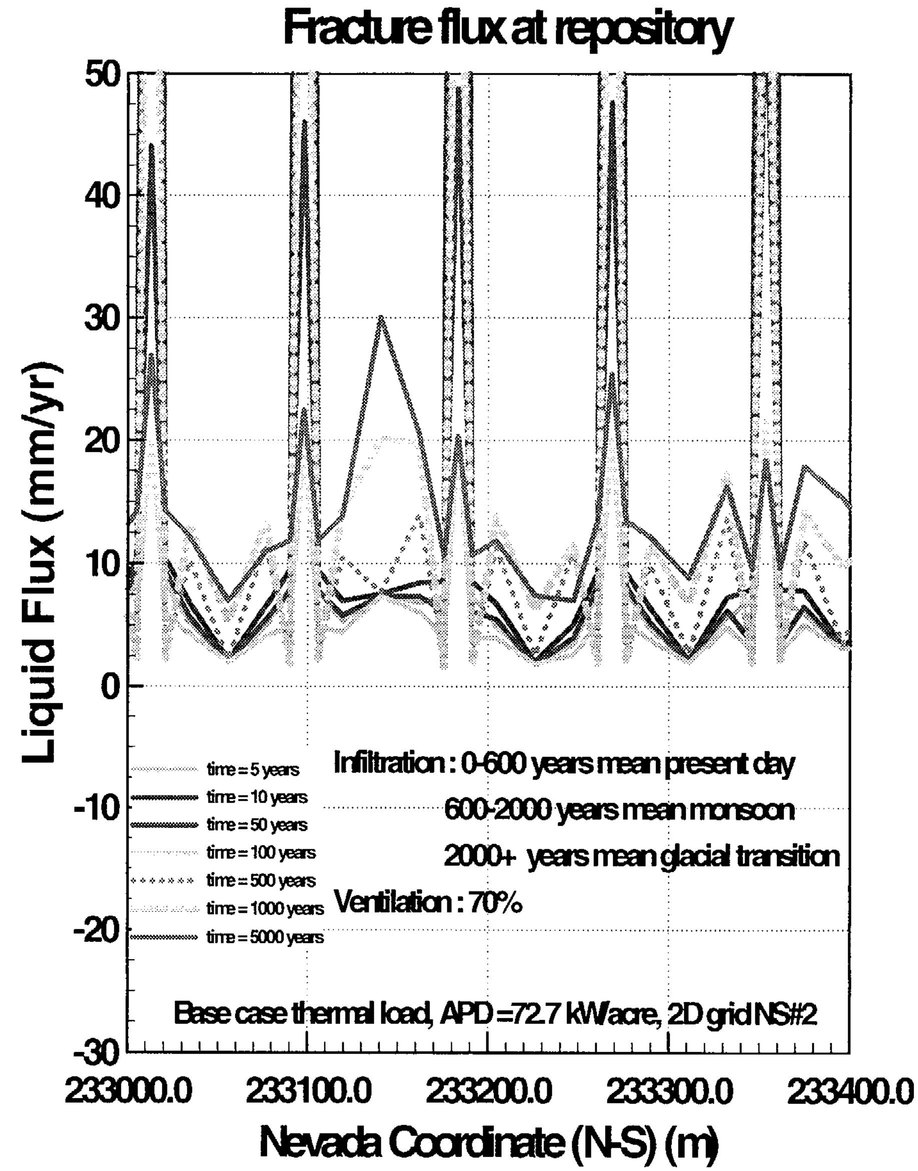
Reference: Work in Progress

NRC Comments

- **Heterogeneity and spatial variability in thermohydrologic properties, and**
- **Variability in model results using the various property sets found to be valid for thermohydrologic modeling and propagate this uncertainty through the thermohydrologic model abstraction**
- **To address these NRC comments, this presentation will discuss:**
  - Mountain Scale Thermohydrologic Model
    - More refined grids and investigation of three-dimensional effects
    - Incorporate heterogeneity to evaluate potential of liquid water breaking through above-boiling regime
  - Uncertainty in other Thermohydrologic Models
    - Multi-Scale Model
    - Thermal Test Model

Mountain Scale Model

- Figure shows fracture flux at coarse repository grid block interface (2.5 meters above heater horizon)
- Use ambient unsaturated zone model properties
- Uniform properties for each unsaturated zone model layer
- Include long-term changes in ambient infiltration flux due to changes in prevailing climate
- No major impact on flow except close to drifts
- Thermal barrier => No liquid seeps into drifts for 1000-2000 years
- Drainage in pillars



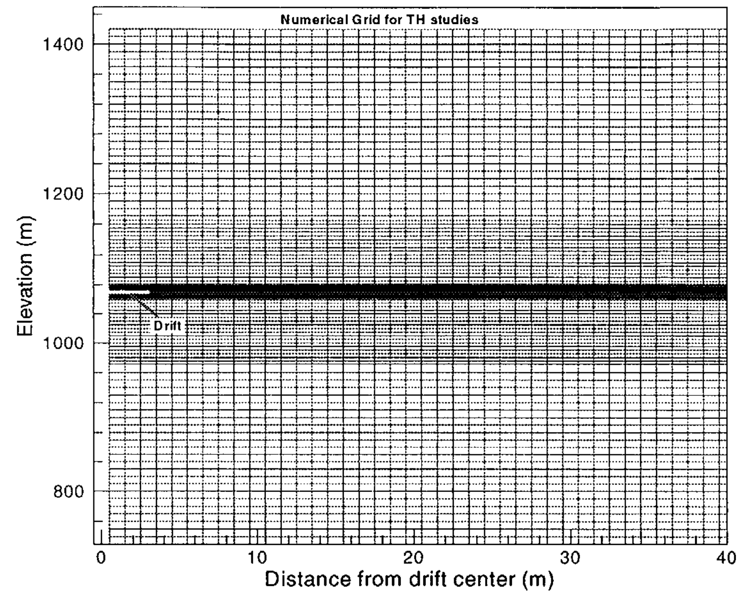
Reference: Mountain Scale Coupled Processes Model, MDL-NBS-HS-000007, Rev 00

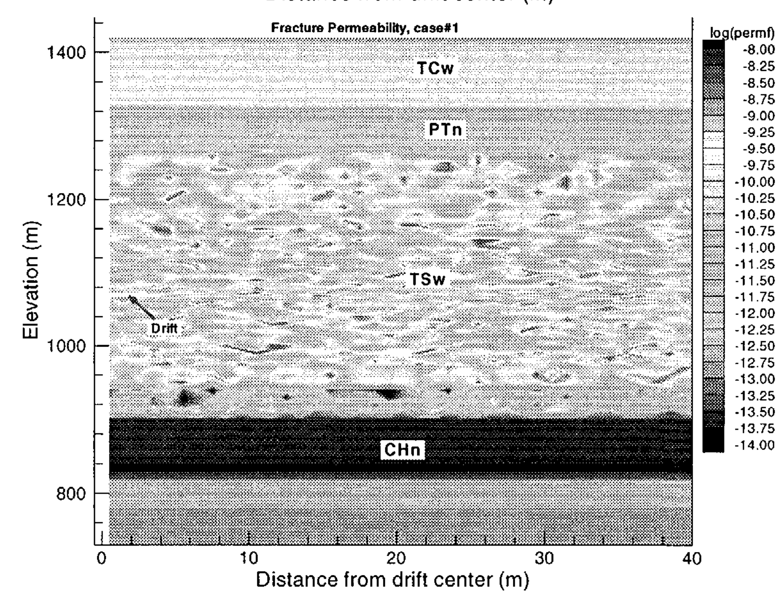
Refined Grid Case: Mountain Scale Model

Spatially Heterogeneous Fracture Permeability

- **Two-dimensional dual permeability active fracture half drift model grid, 1.0 meter spacing near drift**
- **Stochastic variation of fracture permeability in TSw unit, (4 orders magnitude range), based on distribution of measured air-permeability data in lower lithophysal unit**
- **Fracture-matrix interaction**
  - Dual-permeability active fracture model of fingering liquid flow in fractures
  - Fracture-matrix mass and heat transfer in fingered liquid flow
  - Vapor diffusion within dual-permeability model
- **Several realizations of permeability distribution completed for the above-boiling repository thermal load**

Reference: To be Incorporated in the Mountain Scale Coupled Processes Model, MDL-NBS-HS-000007, Rev 01





Refined Grid Case: Mountain Scale Model
(Continued)

Spatially Heterogeneous Fracture Permeability

- **Findings:**
  - No liquid seepage into drifts for 1000-2000 years
  - Above the drifts the fracture saturation increases and the liquid flux may exceed 250 millimeters/year, but is all vaporized by repository heat as it drains down
  - Increase in liquid flux within the drift pillars at 10-20 meters from the drift enhanced by condensate drainage
  - Dry-out zone extends to 10 meters above and up to 30 meters below drift; laterally the dry-out zone extends 10-15 meters from drift center
  - The mid-pillar between the drifts remains at near-ambient liquid saturation, but well connected fractures may dry due to vapor diffusion

Reference: To be Incorporated in the Mountain Scale Coupled Processes Model, MDL-NBS-HS-000007, Rev 01

Refined Grid Case: Mountain Scale Model
(Continued)

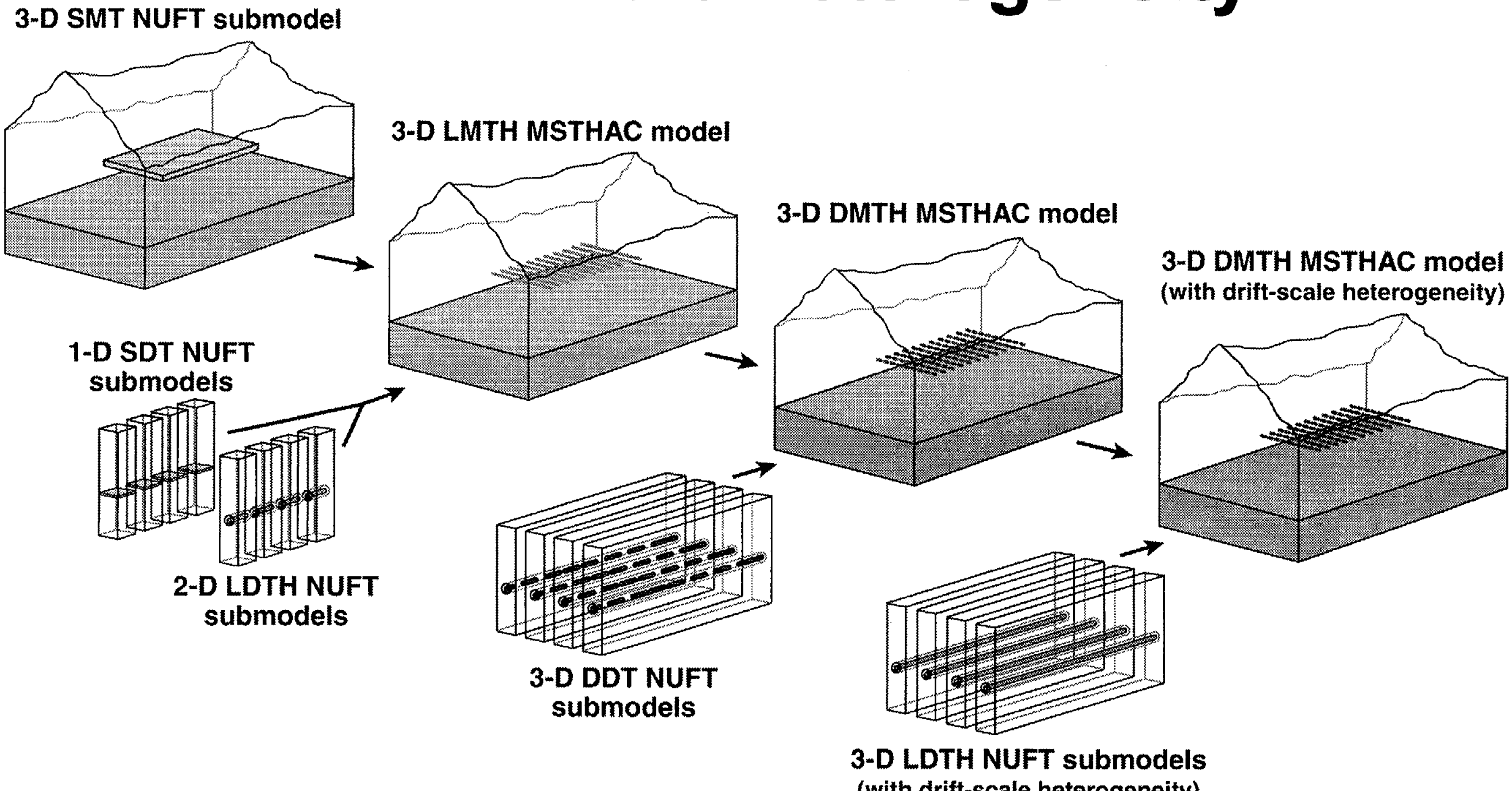
Spatially Heterogeneous Fracture Permeability

- **Work is in progress to determine the effects of heterogeneity on the potential for thermally driven seepage:**
  - Using further refinement of grid for heterogeneous field
  - Using three-dimensional effects since preliminary assessment indicates that the two-dimensional models are conservative
  - Evaluating the effect of high-permeability features (e.g., fault) crossing the drift

Data Uncertainty in Other Models

- **Multi-scale Thermohydrologic Model**
  - Incorporation of heterogeneous property set with the addition of three-dimensional drift-scale TH submodels (called three-dimensional LDTH submodels) is in progress (Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049 Rev 00 ICN 3)
- **Thermal Test Drift Scale Model**
  - Sensitivity studies using different property sets indicate no significant difference in match to measured temperature data in middle non-lithophysal unit (Thermal Test Thermal-Hydrological Model, ANL-NBS-TH-000001 Rev 00)
  - Data uncertainty in lower lithophysal unit will be investigated in the planned Cross Drift Thermal Test

Illustration of Multi-scale Thermohydrologic Model Incorporation of Drift Scale Heterogeneity



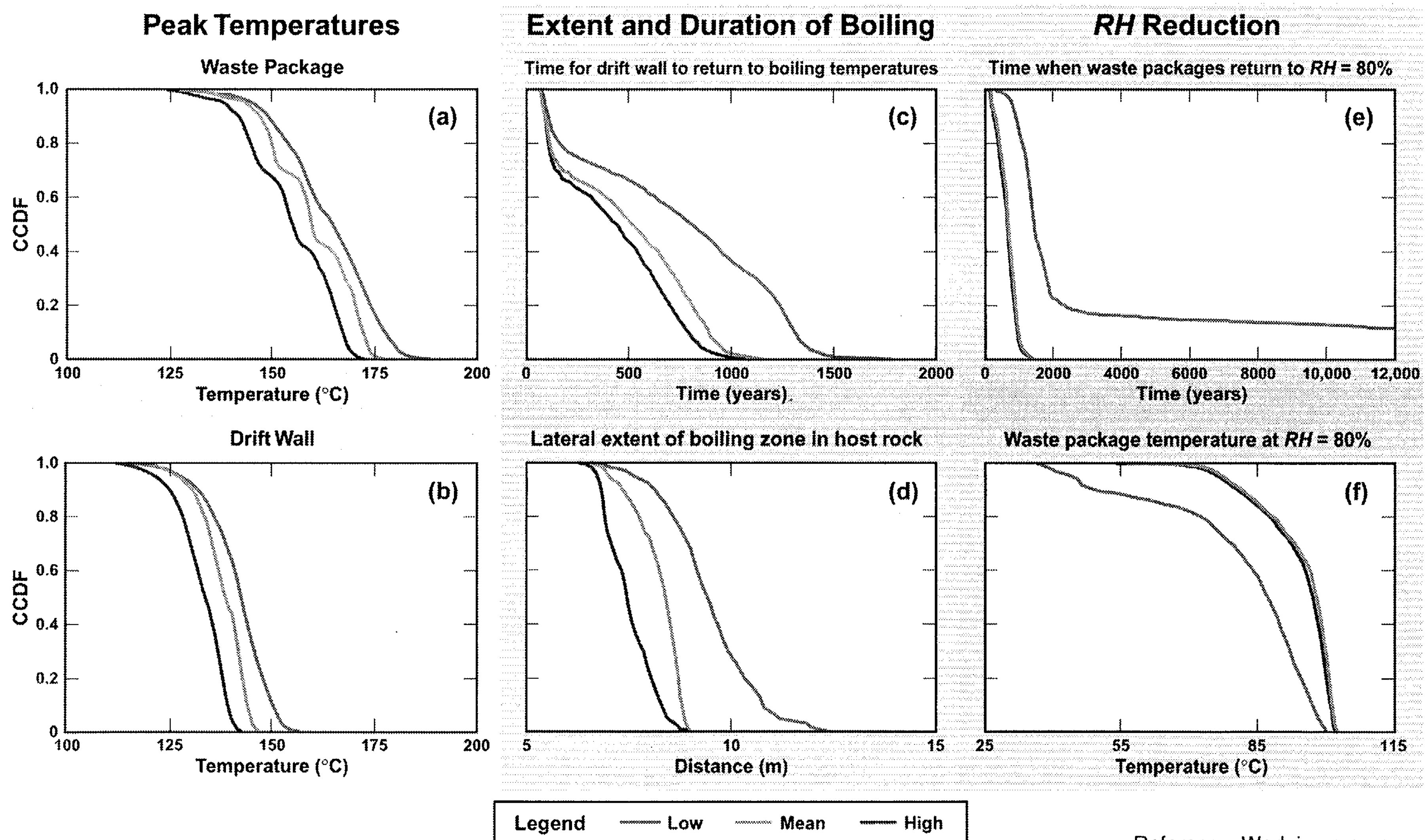
SMT-Smeared Heat-Source-Mountain-Scale-Thermal Conduction
SDT- Smeared Heat-Source-Drift-Scale-Thermal Conduction
DDT- Discrete Heat-Source-Drift-Scale-Thermal Conduction
MSTHAC-Multi-scale Thermohydrologic Abstraction Code

LDTH-Line-Average-Heat-Source-Drift-Scale Thermohydrologic
LMTH-Line-Average-Heat-Source-Mountain-Scale Thermohydrologic
DMTH- Discrete-Heat-Source-Mountain-Scale Thermohydrologic

Reference: To be incorporated in the Multi-scale Thermohydrologic Model, ANL-EBS-MD-000049 Rev 00 ICN 03

Propagation of Data Uncertainty through the Multi-scale Thermohydrologic Model for the Mean, Lower-bound, and Upper-bound Infiltration-flux Cases

RH-Relative Humidity



Reference: Work in progress

Reducing Data Uncertainty
Field Activities

- Systematic hydrological testing in the lower lithophysal unit
- Air permeability, tracer testing in seepage studies in Enhanced Characterization Repository Block
- Drift Scale Test
- Planned Cross Drift Thermal Test

Conclusions

- **Uncertainty is inherent in all measurements**
- **There is a large range of uncertainty for different data sets**
- **For the calibration processes**
  - Data are screened to reduce measurement uncertainty
  - Measurement error is included as uncertainty in input parameters
  - Propagation of uncertainty from input parameter to final calibrated property set is carried through in inverse modeling
- **Systematic hydrological testing and other testing in the lower lithophysal unit and will supply needed data to reduce uncertainty**
- **DOE considers Open Item 7 Closed-Pending completion of ongoing and planned field activities. This presentation supports a status of Closed-Pending for Subissue 2**

Backup Slides

Propagation of Uncertainty in Inverse Modeling Analysis of Measured Data

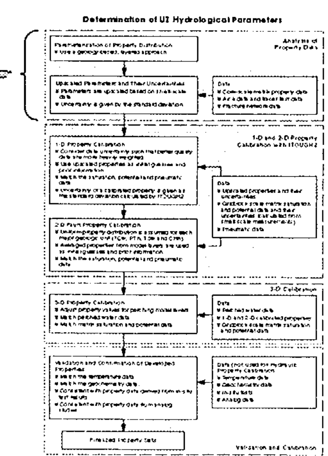
Analysis of Property Data

Parameterization of Property Distribution
- Use a geology-based, layered approach.

Upscaled Parameters and Their Uncertainties
- Parameters are upscaled based on small-scale data.
- Uncertainty is given by the standard deviation.

Data
- Core-scale matrix property data
- Air permeability data and tracer test data
- Fracture network data

1-D and 2-D Property Calibration with iTOUGH2



Reference: Unsaturated Zone Flow and Transport, TDR-NBS-HS-000002 Rev 00 ICN 02

Propagation of Uncertainty in Inverse Modeling

One- and Two-dimension Property Calibration with iTOUGH2

Analysis of Property Data

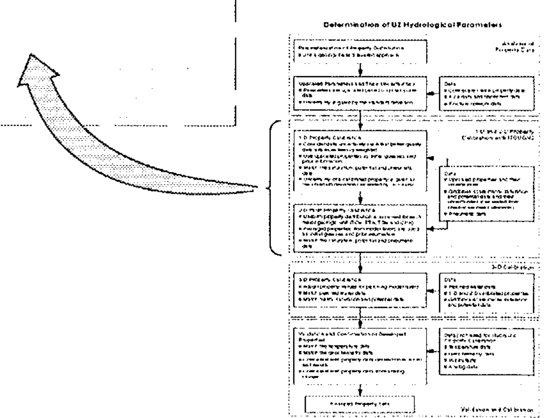
1-D and 2-D Property Calibration with iTOUGH2

1-D Property Calibration
- Consider data uncertainty such that better quality data are more heavily weighted.
- Use upscaled properties as initial guesses and prior information.
- Match the saturation, potential and pneumatic data.
- Uncertainty of a calibrated property is given as the standard deviation calculated by iTOUGH2

Data
- Upscaled properties and their uncertainties
- Gridblock-scale matrix saturation and potential data and their uncertainties (calculated from small-scale measurements)
- Pneumatic data

2-D Fault Property Calibration
- Uniform property distribution is assumed for each major geologic unit (TCw, PTn, TSw and CHn).
- Averaged properties from model layers are used as initial guesses and prior information.
- Match the saturation, potential and pneumatic data.

3-D Calibration
&
Validation and Calibration



Reference: Unsaturated Zone Flow and Transport, TDR-NBS-HS-000002 Rev 00 ICN 02

Propagation of Uncertainty in Inverse Modeling

Three-dimension Calibration Validation and Finalized Property Sets

1-D and 2-D Property Calibration with iTOUGH2

3-D Calibration

3-D Property Calibration
- Adjust property values for perching model layers.
- Match perched water data.
- Match matrix saturation and potential data.

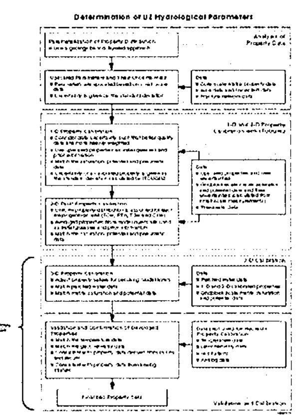
Data
- Perched water data
- 1-D and 2-D calibrated properties
- Gridblock-scale matrix saturation and potential data

Validation and Confirmation of Developed Properties
- Match the temperature data.
- Match the geochemistry data.
- Consistent with property data derived from In-situ test results.
- Consistent with property data from analog studies.

Data (not used for Hydraulic Property Calibration
- Temperature data
- Geochemistry data
- In-situ tests
- Analog data

Finalized Property Sets

Validation and Calibration

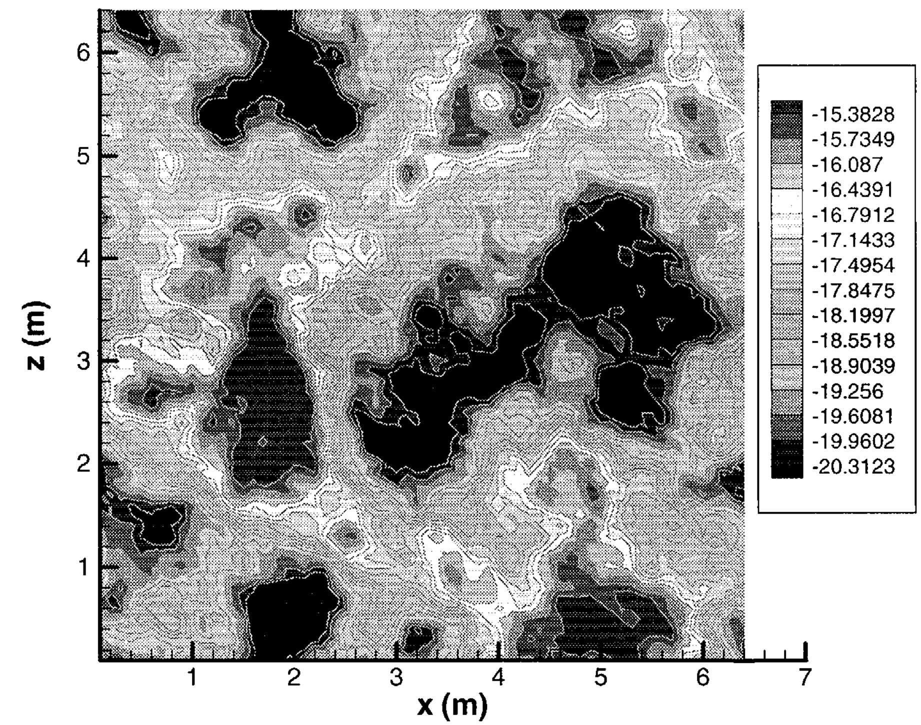


Reference: Unsaturated Zone Flow and Transport, TDR-NBS-HS-000002 Rev 00 ICN 02

Upscaling Matrix Constitutive Relations

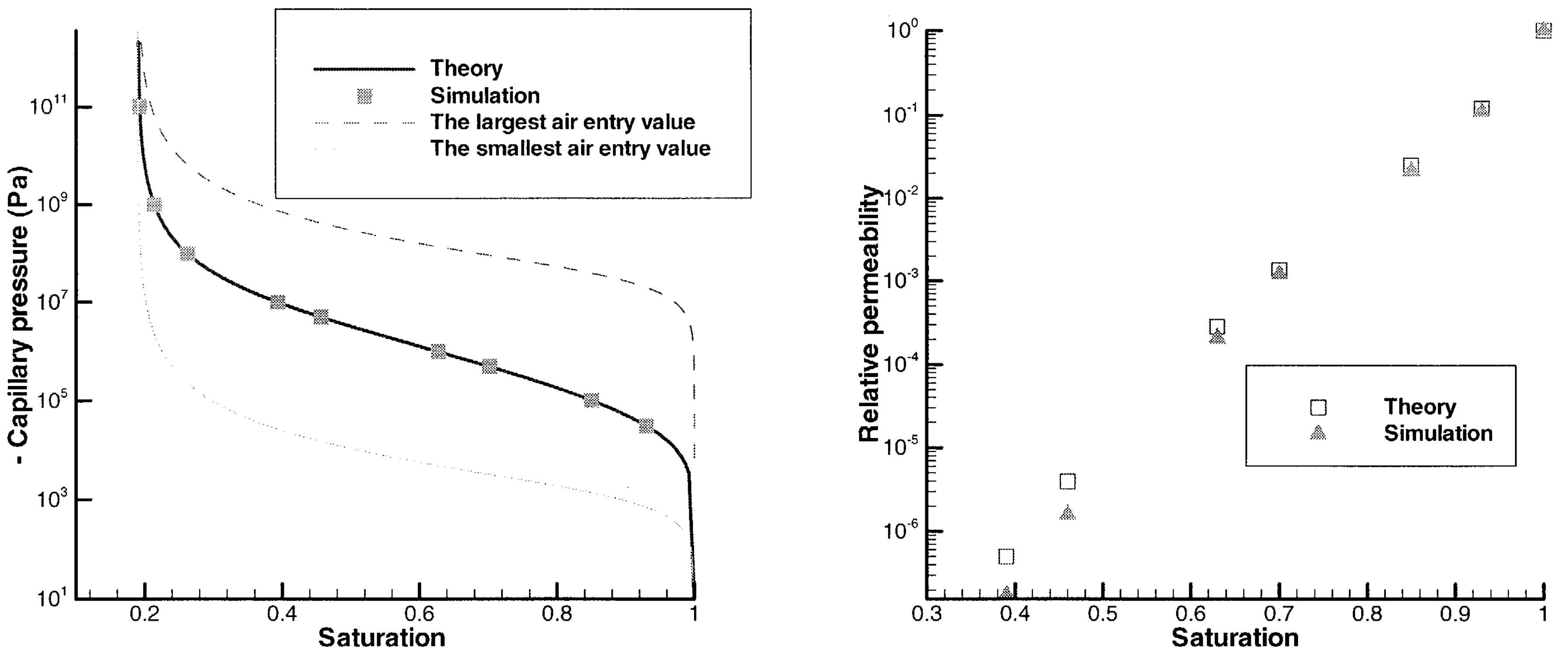
- Upscaling for constitutive relations takes advantage of large air entry values for tuff matrix
- Validate with numerical experiments using two-dimensional heterogeneous porous media

Heterogeneous Log Permeability Field



Reference: To be Incorporated in Calibrated Properties, MDL-NBS-HS-000003, Rev 01

Upscaling Matrix Constitutive Relations
(Continued)



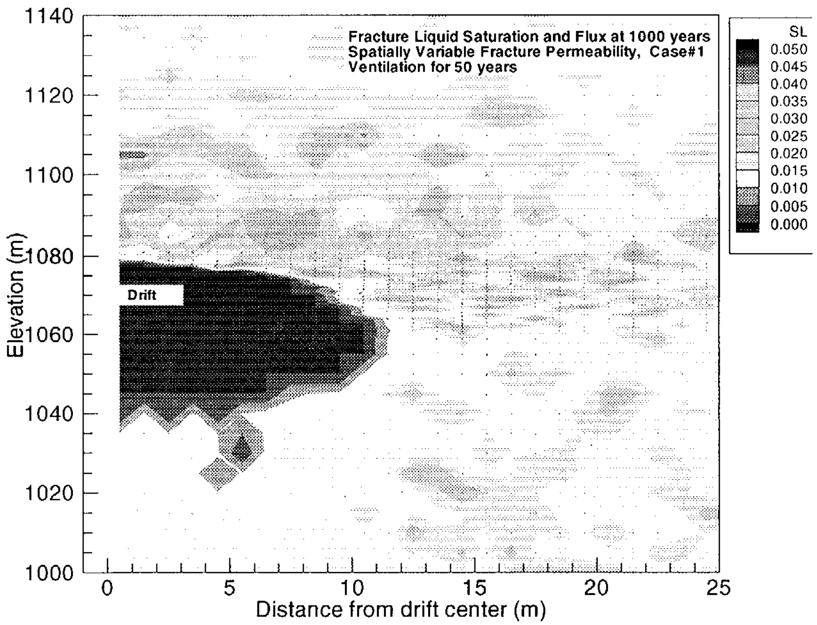
Reference: To be Incorporated in Calibrated Properties, MDL-NBS-HS-000003, Rev 01

Mountain Scale Model

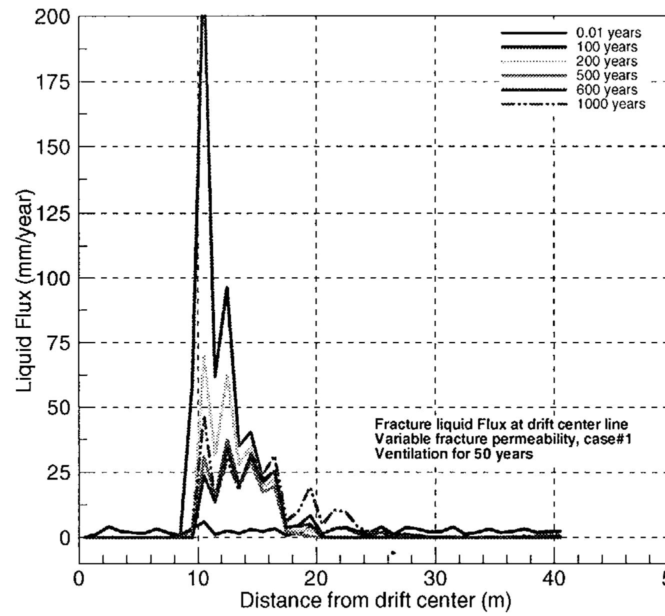
Results of Thermohydrologic Numerical Models

- Stochastic TSw fracture permeability above boiling (50 years ventilation)

a.) Liquid saturation after 1000 years



b.) Liquid flux at drift centerline



Reference: To be Incorporated in the Mountain Scale Coupled Processes Model, MDL-NBS-HS-000007, Rev 01

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

Thermal Effects on Flow
Subissue 2, Open Item 8: Model Uncertainty

Presented to:
DOE/NRC Technical Exchange on Key Technical Issue and Subissues Related to Thermal Effects on Flow

Presented by
Bo Bodvarsson
Civilian Radioactive Waste Management System Management and Operating Contractor

January 8-9, 2001
Pleasanton, CA

YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 2, Open Item 8 identified in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03, this presentation will**
  - Summarize technical basis for resolution of items
  - Identify basis documents
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- Describe the basis for resolving Open Item 8, Evaluate Model Uncertainty, related to Subissue 2 in the Thermal Effects on Flow Issue Resolution Status Report, Rev 03
- Explain how DOE has considered alternative models and how these models are utilized in conjunction with test data

Current Subissue 2 Status

- **Thermal Effects on Flow Issue Resolution Status Report, Rev 03 indicates Subissue 2 is OPEN**

Open Item 8

- **To close this Open Item, DOE needs to evaluate model uncertainty as seen in the results from various alternative conceptual models such as equivalent continuum model, dual permeability model and active fracture model and propagate this uncertainty through the thermohydrologic model abstraction**

- **Basis for Resolution**
  - DOE has considered model uncertainty, including:
    - Types of model uncertainty
    - Flow conceptualization under ambient conditions
    - Flow conceptualization under thermal conditions
    - Fracture flow under ambient and thermal conditions
    - Fracture/matrix interaction model evolution
    - Discrete fracture description
    - Reducing model uncertainty

Open Item 8

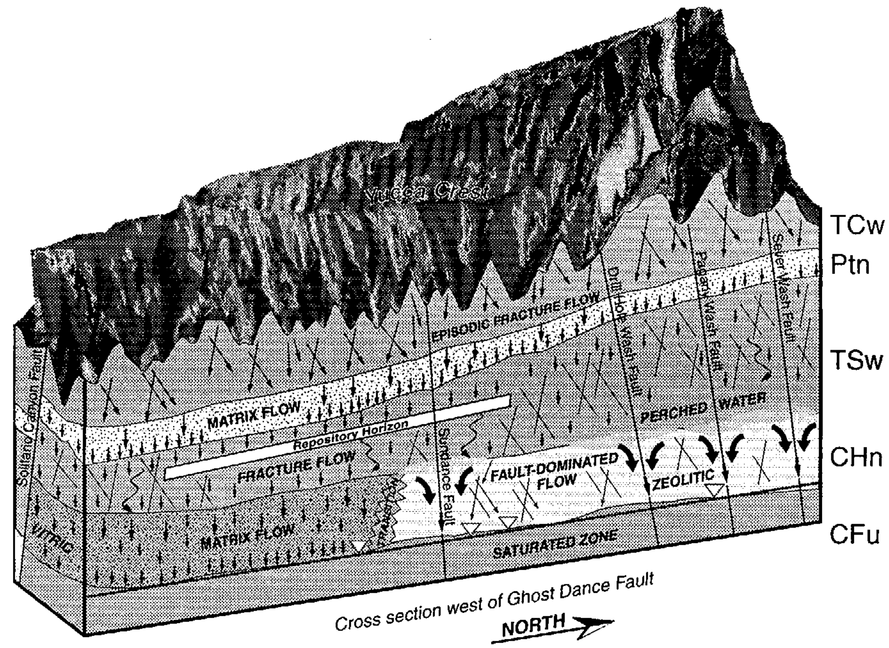
- **References**
  - Unsaturated Zone Flow and Transport Process Model Report, TDR-NBS-HS-000002 REV 00 ICN 02
- **DOE considers this Open Item Closed-Pending NRC review of the ongoing investigation of ambient and thermal testing program and modeling, and the planned thermal test in the Cross Drift**

Types of Model Uncertainty

- **Three types of uncertainties are considered in the thermohydrologic models**
  - Property/parameter uncertainty (discussed in Open Item 7)
  - Conceptual model uncertainty
  - Numerical model uncertainty

Flow Conceptualization Under Ambient Conditions

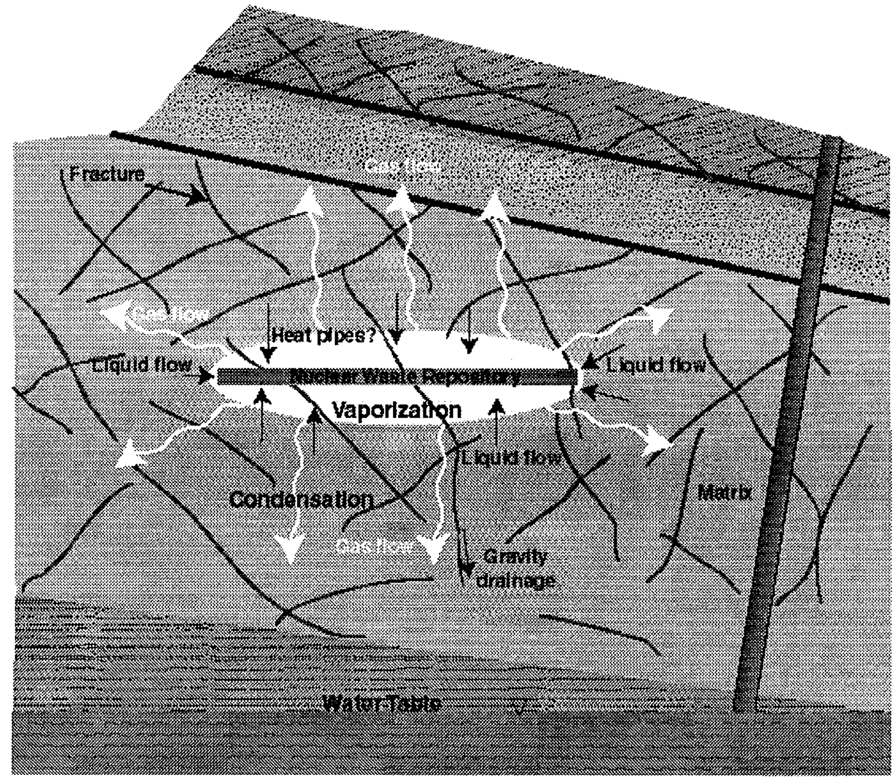
- The percolation processes below Paintbrush Tuff (PTn) are approximately in steady state
- Fracture water flow is dominant in a welded unit and matrix flow in a non-welded unit
- Many and dispersed fractures are actively conducting water. Isolated, transient and fast flow paths exist, but carry only a small amount of water
- The fracture-matrix interaction is limited in welded units
- The existence of the perched water bodies introduces three-dimensional lateral flow



Reference: Unsaturated Zone Flow and Transport PMR, Rev 00, ICN 02, TDR-NBS-HS-000002

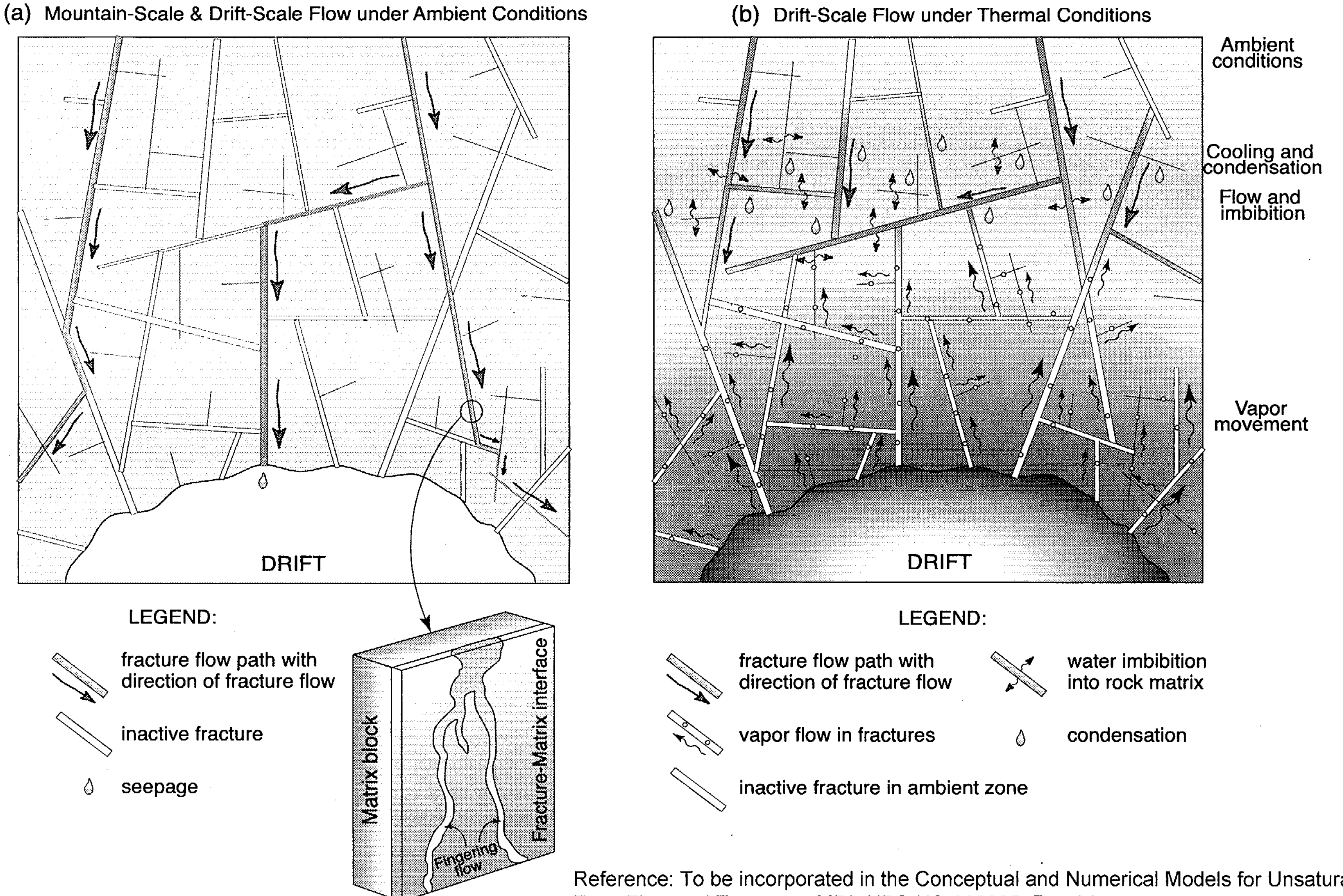
Flow Conceptualization Under Thermal Conditions

- Heat from waste induces vaporization and boiling
- Water that turns into vapor migrates from the matrix into the well-connected and permeable fractures
- Vapor moves away through fractures from emplacement drift in all directions
- Vapor condenses in cooler regions on fracture walls, where it can drain or be imbibed into the matrix
- A two-phase, nearly isothermal zone may develop between the dry-out zone and the zone of increased liquid saturation



Reference: Work in progress

Fracture Flow Under Ambient and Thermal Conditions



Reference: To be incorporated in the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport, MDL-NBS-HS-000005, Rev 01

Fracture/Matrix Interaction Model Evolution

- **Equivalent Continuum Model (Klavetter and Peters, 1986, Pruess et al. 1990)**
  - Used historically for computational efficiency, only one continuum to represent both matrix and fractures
- **Discrete fracture/matrix model (since 1988)**
  - Limited to highly simplified geometry, such as a single fracture
  - The importance of non-equilibrium fracture-matrix interaction was demonstrated (Buscheck et al., 1991; Nitao et al., 1993)
  - Thermohydrologic model of the G-Tunnel Heater Test (Nitao and Buscheck, 1995) was in much better agreement with temperature and liquid saturation measurements than a model using the equivalent continuum model; corresponding models predicted much greater condensate shedding around repository drifts than did models using the equivalent continuum model

Fracture/Matrix Interaction Model Evolution
(Continued)

- **Dual Permeability Model (preferred choice since 1997)**
  - More realistic representation of the different flow behavior in fractures and matrix
  - The Single Heater, Large Block, and Drift Scale Tests demonstrated that the equivalent continuum model is inadequate in representing the movement of heat-driven water, especially in the fractured continuum
- **Active Fracture Model (since 1999)**
  - Accounts for the fact that liquid flow occurs in only a small fraction of fractures under ambient flow conditions

Note: Only the dual permeability and active fracture models are used in the Total System Performance Assessment

Fracture/Matrix Interaction Model Evolution
(Continued)

- **Active Fracture Model (Continued)**
  - Improvement over dual permeability model because it accounts for fingering of liquid flow
  - Accounts dynamically for the matrix/fracture interface area for liquid flow
    - Under thermal perturbation, vapor flow occurs in all fractures. Therefore, in the zones of increased saturation, all rather than a small fraction of fractures may participate in liquid flow
- **Mass and heat transfer between the fractures and matrix**
  - Improved treatment of thermal conductivity takes into account finger liquid flow on the fracture/matrix interface (incorporated in present Monte Carlo simulations with fracture heterogeneity in Mountain Scale thermohydrologic model)

Discrete Fracture Model

Uncertainty from Treating Fractures as Continuum

- **Discrete fracture model feasible only at scales of ten meters or less**
  - Must be carefully designed for the processes being investigated
- **Discrete fracture modeling is in progress to evaluate**
  - Validity of assigning continuum characteristic curve for each numerical gridblock
  - Impact of discrete fracture on seepage phenomena

Reference: To be incorporated the Analysis of Hydrologic Properties Data, ANL-NBS-HS-000002, Rev 01

Reducing Model Uncertainty

- **Basic approach is predictive modeling with subsequent calibration against measured data**
- **Ambient tests in progress include**
  - Hydrological systematic testing
  - Seepage tests
  - Alcove 8/Niche 3
- **Thermal tests include**
  - Drift Scale Test (in progress)
  - Cross Drift Thermal Test (planned)

Conclusions

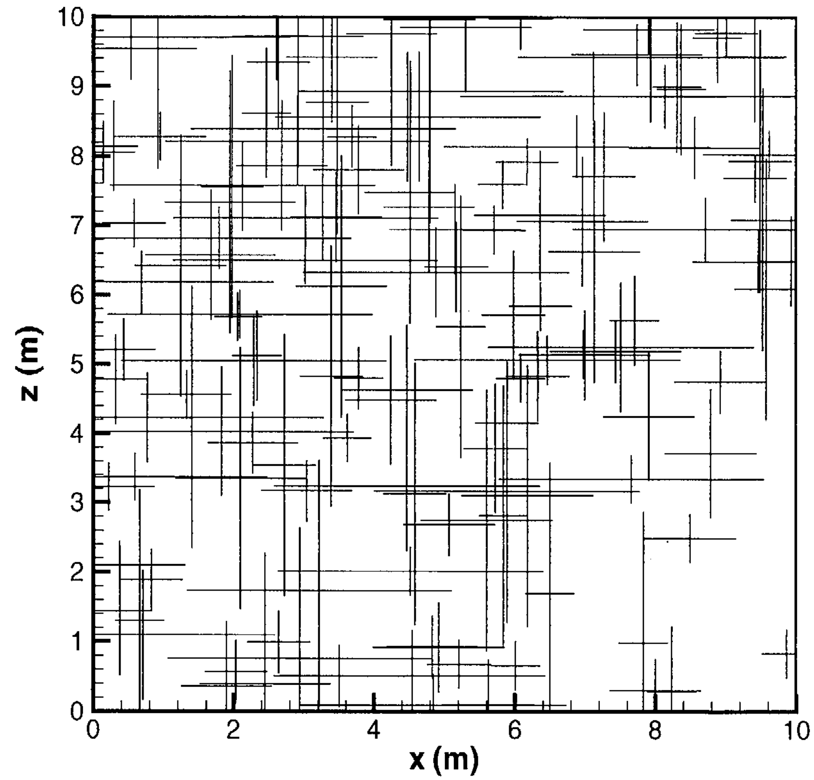
- **DOE has a good understanding of basic processes**
- **DOE has evaluated the processes against data that are relevant to thermal hydrology in the repository units**
- **Evolution of coupled models has occurred over the last ten years yielding**
  - Realistic representation of the physical system and validation against field tests
  - Sound numerical basis for evaluation of thermally driven processes
  - Investigation of the ambient and thermal testing program and modeling are ongoing. Thermal tests in the Cross Drift are planned
- **DOE considers Open Item 8 Closed-Pending completion of ambient and thermal testing. This presentation, in addition to the status of the previous Open Items, support a status of Closed-Pending for Subissue 2**

Backup Slides

Discrete Fracture Model

Are van Genuchten Relations Appropriate for Fracture Continuum?

- Two-dimensional fracture networks (10 meters x 10 meters) consisting of five types (length, aperture) of fractures are used to explicitly represent fractures at a subgrid scale
- For a given capillary pressure imposed on both the top and bottom boundaries, steady-state flow through a network is simulated with TOUGH2
- Apparent capillary pressure and unsaturated conductivity correspond to the boundary pressure and average vertical flux, respectively
- For a number of boundary pressure values, the constitutive relations for the fracture network are derived from flow simulations

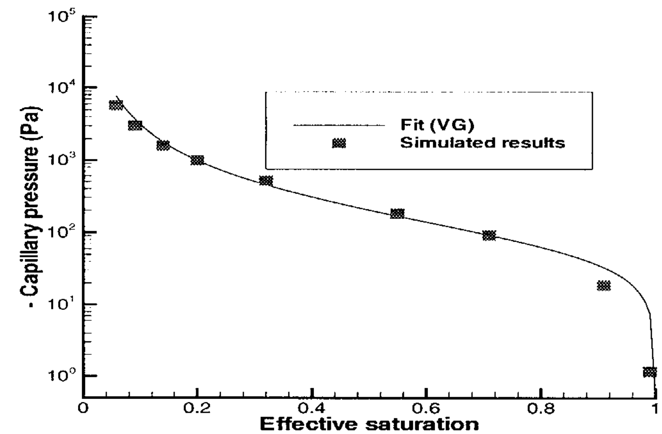


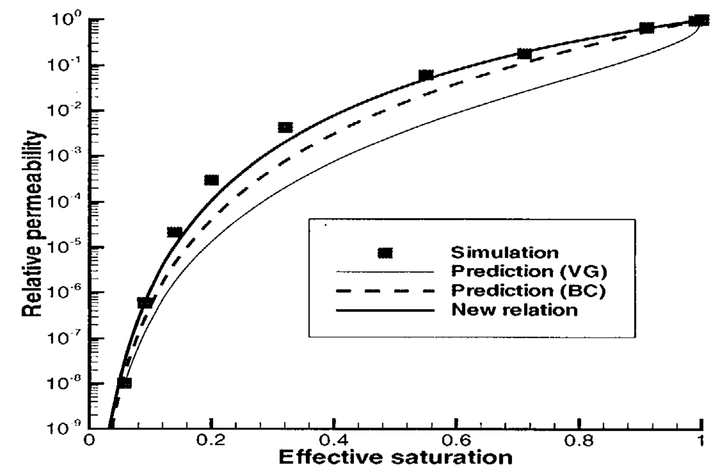
Reference: To be incorporated the Analysis of Hydrologic Properties Data, ANL-NBS-HS-000002, Rev 01

Discrete Fracture Model
(Continued)

Are van Genuchten Relations Appropriate for Fracture Continuum?

- Van Genuchten model (1980) can match the simulated water retention curve
- Both Brooks-Corey (1966) and van Genuchten (1980) models give good predictions for relative permeability at low saturations, but not at high ones
- Brooks-Corey relation is modified to have relatively high tortuosity factor values for high saturations. This new relation gives satisfactory prediction for relative permeability
- Similar results are obtained for two different realizations (fracture networks)





Reference: To be incorporated the Analysis of Hydrologic Properties Data, ANL-NBS-HS-000002, Rev 01

Discrete Fracture Model
(Continued)

Evaluation of the use of continuum approach in modeling seepage into drifts

- Two-dimensional fracture networks (about 10 meters x 10 meters) are used to simulate seepage into a drift
- Simulated results from both the continuum approach and the discrete fracture approach are compared for a number of percolation rates
- Model uncertainty for seepage calculation with the continuum approach will be considered

Draft Analysis of the Issue Resolution Status for the Key Technical Issue on Thermal Effects on Flow

Subissue 1: Is the U.S. Department of Energy thermal testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?

Importance to Performance. The influx of water as a liquid or vapor into the emplacement drifts can potentially affect repository performance by degrading the integrity of the waste package, by transporting radionuclides released from waste packages, or by altering hydraulic or transport pathways in the ground control structures, inverts, or host rock. Draft Repository Safety Strategy, Revision 4 sensitivity analyses do not show significant dependence of postclosure performance on details of the flow in the unsaturated zone. Robustness of the waste package and the drip shield mitigate the effects of the flow system, including thermal effects on the flow. Consequently, thermal effects on the flow system are not considered to be important and this factor is not identified as a principal factor.

Programmatic Acceptance Criterion (AC) 1: DOE's thermohydrologic testing program was developed under acceptable quality assurance procedures (QAP). Data were collected and documented under purview of these procedures.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Although the NRC Staff has reviewed and accepted the DOE QA program, the DOE should ensure that deficiencies are being addressed as part of the DOE program to develop a license application. Pending continued review of DOE's Quality Assurance (QA) program implementation. (NRC 1999, Section 5.1.1)	The DOE believes this criterion is **closed.** Activities associated with development of the Process Model Reports (PMRs) and their related Analyses/Model Reports (AMRs) are subject to the quality assurance program as described in the Quality Assurance Requirements and Description (QARD) (DOE 2000) document. As such, collection of related data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement quality assurance program requirements. The following Deficiency Reports related to the Thermal Effects on Flow (TEF) Key Technical Issue (KTI) has been closed. LLNL-98-D-007 (closed 9/21/99), LLNL-98-D-065 (closed 9/21/99) and LVMO-98-D-064 (closed 7/13/99)	No additional work needed.

Draft Analysis of the Issue Resolution Status for the Key Technical Issue on Thermal Effects on Flow

Subissue 1: Is the U.S. Department of Energy thermal testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?

Programmatic Acceptance Criterion (AC) 2: Expert elicitation may be used for, but not necessarily limited to, assessing if conceptual models bound the range of thermally driven refluxing expected at YM, in addition to thermohydrologic testing to provide conservative bounds to estimates. All expert elicitation are conducted and documented in accordance with NUREG -1563 (Kotra et al. 1996) or other acceptable approaches.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed DOE has conducted an expert elicitation on the near-field/altered zone, which includes TEF issues. To date, the Staff has no questions or comments regarding the use of expert elicitations in areas related to TEF. (NRC 1999, Section 5.1.2)	The DOE believes this criterion is **<u>closed.</u>** Expert elicitations associated with development of the Near Field Environment (NFE) PMR (CRWMS M&O 2000l) were determined to be subject to the quality assurance program as described in the QARD (DOE 2000) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563 (Kotra et al. 1996). Section 2.4.5 of the NFE PMR (CRWMS M&O 2000l) specifically addresses how expert elicitations were used. Expert elicitations were not used in the engineered barrier system (EBS) the unsaturated zone (UZ) areas related to thermal effects on flow.	No additional work needed.

Draft Analysis of the Issue Resolution Status for the Key Technical Issue on Thermal Effects on Flow

Subissue 1: Is the U.S. Department of Energy thermal testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?

Technical Acceptance Criterion (AC) 1.1: Thermohydrologic tests are designed and conducted with the explicit objective of testing conceptual and numerical models so that critical thermohydrologic processes can be observed and measured.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed DOE has initiated a series of niche studies conducted in the ESF to investigate seepage through partially saturated fracture rock under ambient conditions. Study results will assist in testing conceptual and numerical models ambient (isothermal) conditions. The Staff has not identified any concerns with stated test objectives; thus the Staff has no further questions at this time. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Thermohydrologic processes affecting flow and transport are described in the Unsaturated Zone Flow & Transport (UZ F&T) PMR (CRWMS M&O 2000q) Sections 3.10 and 3.12. These processes include spatial patterns and rates of flow close to waste emplacement drifts, mountain-scale flow patterns and rates above waste emplacement drifts, seepage into waste emplacement drifts, and mountain-scale flow patterns and rates between the potential repository and the water table. The DOE niche studies conducted in the Exploratory Studies Facility (ESF) will assist in testing conceptual and numerical models.	No additional work needed.

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Subissue 1: Is the U.S. Department of Energy thermal testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?

Technical Acceptance Criterion (AC) 1.2: Thermohydrologic tests are designed and conducted with the explicit consideration of TH, thermal-chemical and hydrologic-chemical couplings.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed The success of the sampling procedures and the importance of the TH, thermal-chemical, and hydrologic-chemical couplings are being evaluated after the results from these tests are made available and analyzed. The importance of these couplings should not be dismissed prior to full analysis of TH, thermal-chemical, and hydrologic-chemical data that will be provided by the LBT, SHT, and DST. The Staff has no further questions at this time. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Section 3.6 of the NFE PMR (CRWMS M&O 2000l) describes in situ and field thermohydrologic testing, including the Large Block Test (LBT) and the Drift Scale Test (DST). Section 6.1 of the *Thermal Test AMR* (CRWMS M&O 2000s) 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 Topopah Spring Welded Tuff (TSw) to observe coupled thermal-hydrological-mechanical-chemical (THMC) behavior in a representative rock unit. The heating duration of the test was designed to provide a sufficient length of time for thermal-hydrological-chemical (THC) processes to develop. The Drift Scale Coupled Processes AMR (CRWMS M&O 2000u 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 primary purpose of the Single Heater Test (SHT) was to investigate the thermal-mechanical responses of the rock mass caused by heating from a single heater in a borehole. The test confirmed the process that heat drives water away in vapor form (CRWMS M&O 2000l, Section 3.6.1.2). The EBS PMR (CRWMS M&O 2000p) 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 Rev. 01 (CRWMS M&O 2000t).	No additional work needed.

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Technical Acceptance Criterion (AC) 1.3: Thermohydrologic tests are designed and conducted at different scales to discern scale effects on observed phenomena.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed DOE is conducting thermohydrologic testing in the laboratory at a 0.5 m scale and in the field at the different scales of the LBT, SHT and DST. Results from these tests will be analyzed to discern scale effects on key heat and mass transfer processes. The Staff has no further questions at this time. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Mountain-scale TH (Section 3.12 UZ F&T PMR (CRWMS M&O 2000q)) and drift-scale THC (Section 3.10 UZ F&T PMR (CRWMS M&O 2000q)) models address the effects of heat and mass transfer processes at different scales. The mountain-scale model considers the effects of faults, perched water, and condensate drainage between drifts. The drift-scale THC model address effects of heat and mass transfer at the drift scale, including chemical reactions, mineral alteration, precipitation, and dissolution. The testing program discussed in Section 3.6 of the NFE PMR (CRWMS M&O 2000l) was designed to continue the testing at different scales. The scale dimension was extended from laboratory scale (core samples) to bench scale (small block tests) to the LBT and SHT and then to the large scale DST. Bench scale tests were succeeded by field tests with the results provided as input to the SHT, LBT, DST and Cross-Drift testing. Section 3.6 also provides a description of the thermal tests. The SHT, DST, and LBT are all different scale tests. The SHT is a small to intermediate sized field test. The DST is geometrically more complex and larger scale than the SHT or LBT. The scale of the DST allows investigation of the NFE and associated coupled thermal, hydrological, chemical, and mechanical processes on an emplacement drift scale. The size of the LBT was chosen so that the block of rock to be heated was large enough to contain several fractures, but small enough so that boundary conditions and rock heterogeneity could be adequately controlled and/or characterized. Finally, quarter-scale testing at the Atlas Facility has been used to investigate heat and mass transfer processes, and to confirm relationships for transfer of test results to the repository scale. Quarter-scale testing will be described in Rev. 01 of the EBS PMR (CRWMS M&O 2000p).	No additional work needed.

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Subissue 1: Is the U.S. Department of Energy thermal testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?

Technical Acceptance Criterion (AC) 1.4: Thermohydrologic tests are designed and conducted for temperature ranges expected under repository operating conditions.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed Pending DOE currently has three field-scale thermohydrologic tests at varying stages of implementation. The LBT and SHT have completed their heating periods. The DST is in the first year of a planned 4-year heating phase. The maximum temperature attained during the conduct of LBT was 170°C and for SHT was 165°C. The maximum planned drift wall temperature for the DST is 200°C. Planned temperatures for the DST are consistent with expected conditions for an 85 MTU thermal load. However, current design changes being considered by DOE include lower repository heat loading. The Staff has no further questions at this time. The Staff will further consider this criterion pending DOE approval of design changes currently under consideration. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Section 3.6 in the NFE PMR (CRWMS M&O 2000l) describes the thermal tests, including the DST. The DST is an ongoing test. The planned temperatures for the DST are consistent with an 85 MTU thermal load. Current design (60 MTU/acre) may lower the driftwall peak temperatures. However, the overall rock temperatures are expected to be representative, unless there is a significant lowering of the MTU loading in the repository. The quarter scale tests simulate waste package heating with a waste package heater and repository heating through peripheral heaters. Various temperature ranges have been used, up to 90°C (the approximate upper limit of the test) which is representative of repository conditions throughout much of the cooldown period, after the few hundreds to thousands of years. Quarter-scale testing will be described in Rev. 01 of the EBS PMR (CRWMS M&O 2000p).	No additional work needed.

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Technical Acceptance Criterion (AC) 1.5: Thermohydrologic tests are designed and conducted to determine if water refluxes back to the heaters during either the heating or cool-down phases of the tests.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed Pending The LBT and SHT will be monitored for water refluxing back to the heaters during the cool-down phase (scheduled for completion in January 1999 for the SHT and July 1999 for the LBT) to the extent possible. Performance of the DST will be monitored for the presence of refluxing water and the success of the refluxing water detection systems. Although the staff has no specific unresolved questions or comments regarding the design and conduct of DOE's thermohydrologic tests to determine if water refluxes back to the heaters, DOE should demonstrate that the DST instrumentation is capable of detecting water return to the heaters. Thus, the Staff will continue to monitor the results of the DST as information becomes available. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** The LBT and DST field tests reported in Section 3.6 of the NFE PMR (CRWMS M&O 2000l) were specifically designed to look at reflux issues. The LBT was an integrated test designed to maximize the conditions under which refluxing could occur. A specific goal of the LBT was observation of condensate refluxing above the boiling zone. Boundary conditions including constant temperature on the upper block surface allowed for condensation in the upper part while the heated zone below was maintained above boiling. Evidence for refluxing was observed from temperature fluctuations in the heated zone, and other indications. The wing heaters in the DST were also designed to create conditions that would be favorable to condensate buildup above the heaters and refluxing back to the heated zone. In borehole 79, there were indications of thermal refluxing as the temperature approached boiling temperature. Similar responses are seen in borehole 80. In the SHT, closely spaced temperature measurements indicated small-scale variability in the refluxing process.	No additional work needed.

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Technical Acceptance Criterion (AC) 1.6: Thermohydrologic tests are designed and conducted to evaluate the possibility for occurrences of cyclic wetting/drying on WP surfaces.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed DOE has indicated that they have started laboratory experiments on the effects of cyclic wetting/drying on the WP and that they plan to consider this item for performance confirmation (U.S. Department of Energy, 1999). Because DOE has changed the design for the WP from carbon steel to C-22, accelerated corrosion from cyclic wetting/drying is much less of a concern. DOE could revisit the topic subject to future design changes. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** The LBT results, plus similar laboratory test results, as described in the Thermally-Driven Coupled Processes Report, show that episodic refluxing is possible. This type of activity has not been strongly evident from the SHT or the DST as indicated in the Thermal Test Thermal-Hydrological AMR (CRWMS M&O 2000s).	No additional work needed.

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Technical Acceptance Criterion (AC) 1.7: Thermohydrologic tests are designed and conducted to account for all mass and energy losses/gains in the model system.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open DOE intends to use results from the DST to test conceptual and mathematical models. However, mass and energy losses through the thermal bulkhead of the heated drift are not being monitored. Unmonitored heat and mass loss through the thermal bulkhead compromises the utility of the DST in assessing thermally driven water liquid and vapor flow. This concern was recognized by the DOE during preliminary pretest modeling analysis (Buscheck and Nitao, 1995). DOE has not provided justification for either not monitoring heat and mass loss through the bulkhead or not prohibiting these losses. DOE indicated that they would evaluate methods for monitoring these losses through the bulkhead within the framework of the existing budget. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Section 3.6 of the NFE PMR (CRWMS M&O 2000l) indicated that the DST was heavily monitored to account for mass and energy losses within the measurement sections. There was only partial control or accounting for energy losses from the ends, as discussed in the Thermal Test Thermal-Hydrological AMR (CRWMS M&O 2000s). The DST was neither designed nor conducted to account for all mass and energy losses/gains in the thermal test system. Evaluation of impacts of heat and moisture losses in the DST concludes that the test is acceptable and heat losses do not invalidate the test. • DOE has accounted for the heat and moisture losses through the bulkhead in the Drift Scale Test using numerical simulations. Simulations using the dual permeability model (DKM) indicate that after the temperature around the bulkhead reached the boiling point (after about 9 months of heating), the average heat-loss rate through the bulkhead is between 20 and 35 kW and the average rate of moisture loss is between 25 and 50 kg/hr. Most recent DKM/Active fracture model (AFM) modeling explicitly simulated the open boreholes housing the wing heaters, and incorporating a reasonable representation of barometric pressure fluctuations. Although these simulations indicate small increases in the upper bound of the heat-loss, the differences between the predicted and measured temperatures narrowed considerably. • The bulkhead was intended to provide a protective and primary thermal barrier to allow personnel to observe the heated drift and to work in close proximity to the bulkhead/heated drift with minimal risk. • Analyses indicate that an assumed convective boundary condition results in good comparative agreement between measured and simulated temperatures. Thus, the lack of accurate measurements of heat loss can be offset by measures taken in numerical modeling.	No additional work needed.

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	• In a large-scale, open system test like the DST, assumptions on many factors are unavoidable. Despite these shortcomings, calculated results can be compared to corresponding measurements to allow acceptable evaluation of conceptual models. • DOE does not believe the approach to addressing heat and mass exchange through the bulkhead in the DST outlined in Wagner (1999) will significantly compromise the DST.	

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Technical Acceptance Criterion (AC) 1.8: Thermohydrologic tests are designed and conducted such that the model environment is sufficiently characterized so that the level of uncertainty in property values does not result in unacceptable uncertainty in thermal test interpretation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed DOE has measured the hydraulic and physical properties of the media present at its thermal tests. Sensitivity analyses can help determine if potential measurement error is within the variability due to natural heterogeneity. Additional assessment and analysis may be required for those variables, which indicate that the impact of measurement error on model predictions is unacceptably large. The Staff has no further questions at this time. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** One of the objectives of the DST was to evaluate the impact of different property sets and their impact on model results. Section 3.6 of the NFE PMR (CRWMS M&O 2000l) describes the thermal tests, including the SHT, LBT and the DST. Section 1 of the Thermal Tests Thermal-Hydrological AMR (CRWMS M&O 2000s) describes how analyses are performed to compare measurements from the thermal tests to results from the numerical simulations. These analyses form the bases for the conclusions presented in the AMR. Section 6.2 of the Thermal Tests Thermal-Hydrological AMR describes the results of the comparative analyses in sufficient detail to conclude that the environment is sufficiently characterized, so that the level of uncertainty in property values does not result in unacceptable uncertainty in thermal-test interpretation. Evaluation of impacts of heat and moisture losses in the DST concludes that losses do not invalidate the test.	No additional work needed.

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Technical Acceptance Criterion (AC) 1.9: Thermohydrologic tests are designed and conducted such that accuracy in the measurement of the test environment saturation is sufficient to discern the relative ability of different conceptual models to represent the TH processes in heated partially saturated, fractured porous media.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending DOE is using several instrumentation technologies to measure saturation in the medium surrounding its thermal tests. Of greatest relevance is instrumentation used to measure saturation and related changes at the DST. These measurements are not yet available for independent evaluation. The Staff has no further questions at this time. The Staff will review saturation data from the DST when available. (NRC 1999, Section 5.1.3)	The DOE believes this criterion is **closed.** Section 3.6 of the NFE PMR (CRWMS M&O 2000l) describes the thermal tests, including the SHT, the DST, and the LBT. The Thermal Test AMR (update in preparation) will compare model results using a number of property sets to measured temperature and liquid saturation data obtained from the DST. The AMR will provide a comparison of simulated and measured saturation distributions for evaluation of thermal-hydrological (TH) models. The LBT and DST produced saturation conditions that span the range that will occur in the repository host rock. From each test, the types of data collected include: • Moisture distribution in rock/fractures monitored by neutron and electrical-resistance tomography (ERT) • Temperatures monitored by permanently installed and movable resistance temperature detectors (RTDs) DOE believes that the thermal test measurements are consistent with the TH models and that the Thermal Test AMR update will provide additional information to support acceptance of this criterion.	No additional work needed.

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Technical Acceptance Criterion (AC) 2: Thermohydrologic test results from other sites and programs have been analyzed and applied, as appropriate, to the Yucca Mountain site.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed DOE is focusing on thermohydrologic testing at YM. It is unlikely that thermohydrologic test results from other sites and programs will be solely depended upon to reach conclusions about the performance of a geologic repository at YM. To date, the Staff has not raised any concerns about the applicability to YM of test results from other sites and programs and has no further questions at this time. (NRC 1999, Section 5.1.4)	The DOE believes this criterion is **closed.** Section 3.6 of the NFE PMR (CRWMS M&O 2000l) addresses thermohydrologic test results from G-Tunnel, an unsaturated site similar to Yucca Mountain in rock type (welded tuff, Grouse Canyon) and initial saturation (approximately 85%). Good agreement was observed between the TH models and field temperatures.	No additional work needed.

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Technical Acceptance Criterion (AC) 3: If the thermohydrologic testing program is not complete at the time of LA submittal, DOE has explained why the testing program does not need to be completed for the LA and identified specific plans for completion of the testing program as part of the performance confirmation program.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending The staff will continue to monitor the progress of thermohydrologic testing at YM by attending the DOE quarterly progress meetings. In addition, the staff will review those aspects of DOE's performance confirmation program related to thermohydrologic testing as the performance confirmation program evolves. To date, no specific questions or comments regarding thermohydrologic testing aspects of DOE's performance confirmation program have been raised by the staff. (NRC 1999, Section 5.1.5)	The DOE believes this criterion is **closed pending**. Information needed to support the LA will be based on testing and analysis conducted before LA and considered in the licensing review. Testing contained in the performance confirmation program is confirmatory. The performance confirmation program addresses thermal-hydrologic effects on unsaturated zone flow and seepage into emplacement drifts during the pre-emplacement period, including assessment of the thermal hydrologic response of rock mass and cooling and seepage testing under heated environments. Longer term testing for seepage and NFE THC testing and monitoring around selected emplacement drifts and under simulated postclosure conditions is also addressed. Testing of the in-drift environments is included as well. See the Performance Confirmation Plan (CRWMS M&O 2000j, Sections 5.3.1.2, 5.3.1.4, 5.3.1.5, 5.3.2, and Appendix G).	No additional work beyond planned activities is needed.

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Importance to Performance. The influx of water as a liquid or vapor into the emplacement drifts can potentially affect repository performance by degrading the integrity of the waste package, by transporting radionuclides released from waste packages, or by altering hydraulic or transport pathways in the ground control structures, inverts, or host rock. Draft RSS, Revision 4 sensitivity analyses do not show significant dependence of postclosure performance on details of the flow in the unsaturated zone. Robustness of the waste package and the drip shield mitigate the effects of the flow system, including thermal effects on the flow. Consequently, thermal effects on the flow system are not considered to be important and this factor is not identified as a principal factor.

Programmatic Acceptance Criterion (AC) 1: DOE's thermohydrologic modeling analyses were developed and documented under acceptable QA procedures.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open In the TSPA, DOE acknowledged that "analyses presented within were not performed with qualified data sets, all results within this report are considered unqualified" (TRW Environmental Safety Systems, Inc., 1998; Section 4.4.1). NRC will continue to attend DOE sponsored meetings and QA audits to ensure that this deficiency is being addressed as part of the DOE program to develop a license application. Open pending continued review of DOE's QA program implementation. (NRC 1999, Section 5.2.1)	The DOE believes this criterion is **closed.** Activities associated with development of the NFE PMR (CRWMS M&O 2000l) and its related AMRs were determined to be subject to the quality assurance program as described in the QARD (DOE 2000) document. As such, collection of related data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement quality assurance program requirements. Verification of data status and data qualification is substantially complete for thermohydrologic model inputs. Whereas some data are still under review, the procedures used for data management are considered acceptable under the QA program. The following Deficiency Reports related to the TEF KTI have been closed. LLNL-98-D-007 (closed 9/21/99), LLNL-98-D-065 (closed 9/21/99) and LVMO-98-D-064 (closed 7/13/99)	No additional work needed.

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Programmatic Acceptance Criterion (AC) 2: Expert elicitation may be used for, but not necessarily limited to, selecting a conceptual model and its parameters. All expert elicitation are conducted and documented in accordance with NUREG -1563 (Kotra et al. 1996) or other acceptable approaches		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed DOE has conducted an expert elicitation on the near-field/altered zone, which includes TEF issues. To date, the Staff has no questions or comments regarding the use of expert elicitations in areas related to TEF. (NRC 1999, Section 5.2.2)	The DOE believes this criterion is **closed.** Expert elicitations associated with development of the NFE PMR (CRWMS M&O 2000l) were determined to be subject to the quality assurance program as described in the QARD (DOE 2000) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563 (Kotra et al. 1996). Section 2.4.5 of the NFE PMR (CRWMS M&O 2000l) specifically addresses how expert elicitations were used. Expert elicitations were not used in the EBS and the UZ areas related to thermal effect on flow.	No additional work needed.

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Technical Acceptance Criterion (AC) 1.1: Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that uncertainties and variabilities in parameter values are accounted for using defensible methods. The technical bases for parameter ranges, probability distributions or bounding values used are provided. Parameter values (single values, ranges, probability distributions, or bounding values) are derived from site-specific data or an analysis is included to show the assumed parameter values lead to a conservative effect on performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending The effect of heterogeneity needs to be included in the models to capture critical heat and mass transfer mechanisms (refer to discussion in Section 3.3.7). There is insufficient evidence to demonstrate that the assumed parameter values lead to a conservative effect on performance based on the observation that acceptable and appropriate values for the base case parameters are not yet determined. It is assumed that at the time when acceptable and appropriate parameter values have been incorporated into the reference base case data set, DOE will provide appropriate results from sensitivity analyses to demonstrate that the assumed parameters values lead to a conservative effect on performance. The Staff will review the reference data set used in DOE's TSPA-LA to ensure consistency with available field data. (NRC 1999, Section 5.2.3)	The DOE believes this criterion is **closed pending.** TH modeling is described in the NFE PMR (CRWMS M&O 2000l) (Sections 3.2, 3.3, 3.4, and 3.6) and two of its supporting AMRs, Thermal Test AMR (CRWMS M&O 2000s) and Abstraction of Drift Scale Coupled Processes AMR (CRWMS M&O 2000a). The NFE PMR provides input to coupled-process-induced changes in the parameters used in those analyses. Section 3.3 addresses the drift-scale coupled-process models and abstractions used to evaluate those parameter changes. Section 3.10 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the parameter ranges and the technical basis for these ranges. Parameter values derived from site data are specified. For the EBS PMR (CRWMS M&O 2000p), parameter values and technical bases for the parameter ranges for the Water Distribution and Removal Model and the Physical and Chemical Environment Model are presented in Sections 3.1.1 through 3.1.4, respectively. In most respects, these values are the same as, and were developed by, parameter estimation described in the NFE and UZ F&T PMRs. Where appropriate, bounding calculations are used to estimate the physical effects, such as flow through the drip shields (EBS PMR Section 3.1.1) and chemical effects, such as the alteration of groundwater chemistry (EBS PMR Section 3.1.2). Analysis of the influence of drift-scale heterogeneity is being considered to determine if drift-scale heterogeneity should be explicitly represented in the Multi-scale TH Model. Incorporation of the new hydrogeologic parameter values obtained from testing in the TSw lower lithophysal into the TH process model is also being considered. Monte Carlo simulations that include spatial heterogeneity are being performed to directly assess thermal seepage and drainage of condensate in the pillars. Effects of discrete fault features are also being investigated in the Monte-Carlo analysis.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 1.2: Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed The DOE multiscale modeling approach provides an acceptable method to establish initial conditions, boundary conditions, and computational domains that are consistent with site characteristics (subject to comment noted under Subissue 2 technical acceptance criterion 5). The USFIC KTI has determined that the DOE has identified the atmospheric boundary condition with an acceptable level of uncertainty. The Staff has no further questions at this time. (NRC 1999, Section 5.2.3)	The DOE believes this criterion is **closed.** Initial and boundary conditions have been considered in the TH models. TH modeling is addressed in the NFE PMR (CRWMS M&O 2000l) (Sections 3.2, 3.3, 3.4, and 3.6) and two of its supporting AMRs, Thermal Test AMR (CRWMS M&O 2000s) and Abstraction of Drift Scale Coupled Processes AMR (CRWMS M&O 2000a). The NFE PMR provides input to coupled-process-induced changes in the parameters used in those analyses. NFE PMR Section 3.3 addresses the coupled process models and abstractions used to evaluate parameter changes within the NF that might effect the results of the TH analyses. Analyses in the UZ F&T PMR (CRWMS M&O 2000q) Section 3.10 considered site characteristics in establishing initial conditions and computational domains. In addition to the required UZ hydrologic properties, the model includes initial and boundary water and gas chemistries, initial mineralogy, mineral volume fractions, reactive surface areas, equilibrium thermodynamic data for minerals, aqueous and gaseous species, kinetic data for mineral-water reactions, and diffusion coefficients for aqueous and gaseous species as described in the UZ F&T PMR Section 3.10.2. The EBS process models for thermal hydrological effects are also based on initial conditions, boundary conditions, and computational domains consistent with site characteristics. The thermal hydrology models used in EBS PMR (CRWMS M&O 2000p) Section 3.1 are based on natural barrier system hydrologic and thermal properties developed for the UZ F&T PMR. The parameter values and technical bases for the parameter ranges for these process models are also presented in the EBS PMR Section 3.1 In addition, data on these EBS processes are being collected. Where appropriate, bounding calculations have been performed to estimate the physical effects, such as flow through the drip shields (EBS PMR Section 3.1.1) and chemical effects, such as the alteration of groundwater chemistry (EBS PMR Section 3.1.4).	No additional work needed.

Subissue 2: Is the U. S. Department of Energy thermohydrologic modeling approach sufficient to predict the nature and bounds of thermal effects on flow in the near field?

Technical Acceptance Criterion (AC) 2.1: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models are based on well-accepted principles of heat and mass transfer through partially saturated, fractured porous media. These codes are based on well-accepted principles of heat and mass transfer applicable to unsaturated geologic media.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed The NUFT and TOUGH2 codes are used by DOE to simulate heat and mass transfer through partially saturated, fractured porous media. These codes are based on well-accepted principles of heat and mass transfer applicable to unsaturated geologic media. The Staff has no further questions at this time. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed.** The NUFT and TOUGH2 codes are used by DOE to simulate heat and mass transfer through partially saturated, fractured porous media. As noted by the NRC staff (NRC 1999, Section 5.2.4) these codes are based on well accepted principles for heat and mass transfer applicable to unsaturated geologic media.	No additional work needed.

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Technical Acceptance Criterion (AC) 2.2: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE models include the processes of evaporation and condensation. DOE has not yet demonstrated that their models incorporate the effects of discrete geologic features. Discrete geologic features can be of critical importance in regions near emplacement drifts by influencing the amount of seepage into the drift causing focusing of flow through partially saturated fractured media and influencing the flow pathways of refluxing water near the drifts. Open pending review of DOE models to incorporate the effects of discrete geologic features as an influence on seepage into drifts, focusing of flow and influence on refluxing water near drifts. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Current models described in the UZ F&T PMR (CRWMS M&O 2000q) Section 3.10 include processes of evaporation and condensation. Figure 3.10-2 shows the relationship between TH and geochemical processes in zones of boiling, condensation and drainage in the rock mass outside of the drift and above the heat source. Seepage models described in the UZ F&T PMR Section 3.9 include an active fracture model to describe fracture-matrix interactions. Comparison results between the discrete fracture model seepage and the continuum model will be considered for documentation in a future AMR. The model is an isothermal, fracture only model. The EBS PMR (CRWMS M&O 2000p) relies on thermal-hydrologic models that incorporate evaporation and condensation as discussed above. The effects of seepage that could be caused by spatial heterogeneity in hydrologic properties have been addressed parametrically by introducing seepage directly into the models. The results will be documented in the Water Distribution and Removal Model AMR Rev. 01 (CRWMS M&O 2000t). The effects of extreme seepage on drainage have also been evaluated.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.3: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include, at a minimum, an evaluation of important thermohydrological phenomena, such as: (i) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Recent DOE models that include the DKM conceptualization appear to adequately predict the extent of dryout surrounding the emplacement drifts, but require results from a longer duration of the DOE's DST than currently available, or some other long-term large-scale heater test in a fractured, porous medium. In addition, lateral movement of condensate and condensate drainage through fractures has not been adequately demonstrated. The effects of discrete geologic features on rapid and episodic moisture redistribution need to be incorporated directly and indirectly into the conceptual models. Models used to predict formation of cold traps should include the effects of radiative heat transfer and ventilation. Open pending review of TH modeling results including evaluation of DKM conceptual model based on long-term large-scale heater test; simulation of lateral movement of drainage through fractures; and predictions of cold trap formation containing effects of ventilation and radiative heat transfer. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Section 3.10 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the evaluation of the extent of the dryout zone and time of rewetting for different calibrated property sets and climate scenarios. It also summarizes the TH mountain scale models and the effects of temperature changes over the mountain, including effects on flow around the drift, condensate formation and drainage in the pillars. A discrete fracture model for seepage is being developed for comparison with the continuum model. The model is an isothermal, fracture only model. The EBS Multi-scale Thermal Hydrologic Model (CRWMS M&O 2000i) provides analysis of repository thermohydrological phenomena at various locations within the repository. The degree of multi-drift dry-out zone coalescence will be a function of the thermal load specified in the final design of the repository. Recent, proposed design modifications by DOE to reduce the repository thermal load to 60 MTU/acre will minimize, if not eliminate, dry-out zone coalescence. Recent DOE models that include the active fracture model predict the extent of dry-out surrounding the emplacement drifts. (EBS PMR (CRWMS M&O 2000p) Sections 3.1.1, 3.1.2 and 3.1.4). Durable changes to hydrologic properties have been evaluated. Thus, DOE understands the magnitude of effects of rock properties importance to predicting fracture porosities. For example, calibrated rock properties used in TH models demonstrate that drainage though fractures do occur consistent with field scale test results. However, durable changes are believed to have negligible impact on repository performance and thus are not an important issue for the current design. In Total System Performance Assessment-Site Recommendation	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.3: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include, at a minimum, an evaluation of important thermohydrological phenomena, such as: (i) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.		
	(TSPA-SR), the average response of rock for predicting lateral movement of condensate was evaluated. In addition, current models in TSPA-SR indicate that heat transfer at the mountain is mostly conductive. This approach is used in the models to represent repository edge effects. Simulations of drift-scale TH behavior have been conducted with a discrete-fracture-matrix model (DFMM) and compared against simulations conducted with the DKM. These two approximations of fracture-matrix interaction were found to predict similar drift-scale TH behavior. The DFMM was also used to predict TH behavior around the G-Tunnel heater test, resulting in good agreement with measured temperatures and liquid saturations. Cold-trap effects, at the drift scale, are minimized in the current conceptual design by line load waste package (WP) spacing (i.e., end-to-end WP spacing), which promotes thermal coupling between adjacent (hot and cold) waste packages. Drift-scale cold traps effects could be more pronounced if point-load WP spacing is used (i.e., with significant gaps between WPs). Further analyses of potential cold-trap effects, with explicit representation of radiative heat transfer and ventilation, and axial movement of moisture in the open drifts are being considered. Results of this modeling effort will determine whether the influence of drift-scale cold-trap effects should be included in the Multi-scale TH Model. Cold-trap effects can also occur at the mountain scale (or repository scale). Analyses of the mountain-scale cold-trap effect are being considered. Results of this modeling effort will determine whether the influence of the mountain-scale cold-trap effect should be included in the Multi-scale TH Model.	

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Technical Acceptance Criterion (AC) 2.4: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include all significant repository design features.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Proposed modifications to the TSPA-VA repository design include use of drip shields, backfill and ventilation. The effects of such design features have been shown to have a significant effect on moisture redistribution. Therefore, these design features need to be incorporated into the models used to simulate heat and mass transfer through partially saturated fractured porous media. Open pending review of TH modeling that incorporates the effects of proposed design features on moisture redistribution. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** The EBS PMR (CRWMS M&O 2000p), NFE PMR (CRWMS M&O 2000l), and the UZ F&T PMR (CRWMS M&O 2000q) represent appropriate design features that affect TH response. For example, the Multi-scale TH model uses in-drift geometry and drift spacing and the thermal and hydrologic properties of the EBS components, such as waste package and invert, from the current design. The mountain-scale TH model considers the effects of faults, perched water, and condensate drainage between drifts. The Multi-scale TH model (CRWMS M&O 2000i) captures the repository scale variability, details of the emplacement drifts and engineered components and variability of heat output from the waste package inventory. The models are based upon the current Enhanced Design Alternative II (EDA-II) repository design features. EBS modeling activities are currently in process, or planned, which will examine heat and mass transfer under the drip shield in more detail and will supplement existing analyses of drip shield performance in the Water Distribution and Removal Model, Rev 01. In addition, work is in progress to model the details that show the importance of water removal as a result of pre-closure ventilation and the effect on rock properties that control peak temperatures during post-closure.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.5: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models are capable of accommodating variation in infiltration.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open The DOE multiscale modeling approach needs to include the effects of spatially variable infiltration coupled with the variable heat load effect of the repository edge. Open pending review of TH modeling for effects of spatially variable infiltration coupled with variable heat load of the repository edge. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** The TH models incorporate variations in infiltration as discussed in Sections 3.10 and 3.12 of the UZ F&T PMR (CRWMS M&O 2000q). In addition, the models described in the EBS PMR (CRWMS M&O 2000p) Section 3.incorporate the present day, monsoon, and glacial transition climates. The existing TH models consider stratigraphic variation, with uniform properties within each unit. Ongoing and planned analyses will consider stochastic spatial variability of fracture properties in the host rock, representing natural variability of the fracture network (This approach is already used for ambient drift seepage model). Existing TH models also represent variability of thermodynamic condition in the emplacement drifts, caused by thermal loading and proximity to the repository edges in addition to the aforementioned variability.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.6: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that conceptual model uncertainties have been defined and documented and effects on conclusions regarding performance assessed.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE has included the dual continuum conceptualization (i.e., DKM) in the NUFT and TOUGH2 codes. DOE needs to demonstrate that their models are unambiguously consistent with physical observations of the DST or some other appropriate heater test or analog site. Test cases or analog sites that do not provide adequate information to discriminate between conceptual models cannot be used to reduce conceptual model uncertainty. DOE has not yet defined and documented conceptual model uncertainty. Open pending review of TH models for consistency with physical observations, other appropriate heater test or analog site. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Each of the supporting EBS Process Models address specific issues of model uncertainty as indicated in Section 3.1 of the EBS PMR (Rev 01 is work in progress). Conceptual uncertainties in the mountain-scale TH model are addressed in the UZ F &T PMR (CRWMS M&O 2000q). In the NFE PMR (CRWMS M&O 2000l), the THC model has been shown to be consistent with physical observations of the DST (TOUGHREACT code). (See also, field test response in subissue 1, AC 1.5). Various conceptual models (e.g., equivalent-continuum model (ECM), DFMM, and DKM) have been used to predict TH behavior of field-scale thermal tests (G-Tunnel, SHT, LBT, and DST), resulting in ongoing improvements in the agreement between measured and predicted behavior. For the G-Tunnel Heater Test, the DFMM resulted in better agreement with measured temperatures and liquid saturations than the ECM. For the SHT and DST, the DKM resulted in better agreement with measured temperatures and liquid saturations than the ECM. Recent simulations of the field thermal tests using the DKM/AFM resulted in marginal improvements in the coincidence between predicted and measured behavior. Calculations are currently being considered to perform statistical evaluations of the differences between measurements and predictions.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.7: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that mathematical models are consistent with conceptual models, based on consideration of site characteristics.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed The mass balance of models need to be confirmed to ensure that mathematical and conceptual models are consistent, based on consideration of site characteristics. The mathematical models need to incorporate all significant components contained in the conceptual models. The Staff has no further questions at this time. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed.** The AP3.10Q process requires that detailed process models are consistent with conceptual models. Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000q) discuss mathematical models used to represent conceptual models and are based on site characteristics. In each EBS process models, the mathematical models are consistent with conceptual models.	No additional work needed.

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Technical Acceptance Criterion (AC) 2.8: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that alternative modeling approaches, which are consistent with available data and current scientific understanding, have been investigated, limitations defined, and results appropriately considered.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open Alternative process-level models are not provided for critical process-level heat and mass transfer mechanisms. For example, refluxing into the drift during the heating period can have profound effects on TSP; however, an alternative model of these processes has not been formulated to provide confidence in the original conceptual and mathematical models. In addition, results from an alternative model for seepage into a drift which indicates significantly higher levels of seepage are not used in subsequent models and analyses. Open pending review of TH models and alternative process-level models for critical process-level heat and mass transfer mechanisms. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** The Water Distribution and Removal Model Rev. 01 (CRWMS M&O 2000t) shows that the in-drift environment is not especially sensitive to seepage during the thermal period. The current TSPA also shows that seepage does not have a profound effect - rather it has little effect if the waste package, drip shield, and other EBS components perform their functions as expected. Various conceptual models (e.g., ECM, DFMM, and DKM) have been used to predict TH behavior of field-scale thermal tests (G-Tunnel, SHT, LBT, and DST), resulting in ongoing improvements in the agreement between measured and predicted behavior. For the G-Tunnel Heater Test, the DFMM resulted in better agreement with measured temperatures and liquid saturations than the ECM. For the SHT and DST, the DKM has resulted in better agreement with measured temperatures and liquid saturations than the ECM. Plans are underway to complete Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts. The effects of discrete fault features are also being considered in the Monte-Carlo analysis. As another example, Section 3.10.7 in the UZ F&T PMR (CRWMS M&O 2000q) discusses an alternative model proposed by Matyskiela (1997). DOE disagrees with this alternative model. The alternative model proposed by Matyskiela assumes fractures/matrix contact available in a saturated system and that dissolved silica concentrations in the fracture water are greater than in the matrix. Neither of these assumptions are representative of the Yucca Mountain system. Based on available information, it has not been demonstrated that the	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.8: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that alternative modeling approaches, which are consistent with available data and current scientific understanding, have been investigated, limitations defined, and results appropriately considered.		
	magnitude and time of the resulting expected annual dose would be significantly changed by use of alternative models that lead to greater seepage. DOE recognizes the importance of these processes and continues to investigate the potential for dripping, thermal refluxing, and seepage under isothermal conditions. DOE plans to consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding, and DOE plans to evaluate the effects that plausible alternative conceptual models may have on the performance of the geologic repository. In addition, a number of alternative models have been identified which could affect the environment for waste package corrosion, but which are not currently being investigated because the consequences appear negligible given the current model for waste package corrosion resistance. If uncertainty increases with respect to rates of waste package and drip shield corrosion, then alternative models for chemical and hydrologic processes in the EBS will be more important.	

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Technical Acceptance Criterion (AC) 2.9: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that results from different mathematical models have been compared to judge robustness of models.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Adequate data are not available to compare the ECM, G-ECM and DKM conceptual models nor the mathematical models upon which the conceptual models are based. Full comparison of the model results from different mathematical models cannot be completed in the absence of field-scale measurements taken over sufficiently long durations and large spatial distances. Open pending review of comparison of model results from different mathematical models using field-scale measurements (long duration and large spatial distances). (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed.** Much of the work on these alternative models is several years old, thus a historical summary is needed to compare models. The need to compare models is questionable because current models are more realistic. Numerical approaches that can be used for unsaturated, fractured rock have been reviewed in the Conceptual and Numerical Models for Unsaturated Zone Flow and Transport AMR (CRWMS M&O 2000b) on conceptual and numerical models for UZ flow and transport as described in the UZ F&T PMR (CRWMS M&O 2000q) Sections 3.3 and 3.4. The model is calibrated to field measurements of pneumatic pressure, water saturation and capillary pressure. Comparisons and predictions of hydrologic and geochemical conditions have been made for both unperturbed and thermally perturbed conditions.	No additional work needed.

Subissue 2: Is the U. S. Department of Energy thermohydrologic modeling approach sufficient to predict the nature and bounds of thermal effects on flow in the near field?

Technical Acceptance Criterion (AC) 2.10: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models used to predict shedding around emplacement drifts are shown to contain an adequate level of heterogeneity in media properties.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE models used to predict moisture redistribution near emplacement drifts do not have the capability to predict penetration of the boiling isotherm by water flowing down a fracture. Seepage models have not been demonstrated to predict the amount of water entering an emplacement drift with an acceptable level of uncertainty. Open pending review of TH models to adequately represent heat and mass transfer mechanisms in heterogeneous media to adequately predict shedding around emplacement drifts. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000q) summarize the approach to evaluating heterogeneities in the TH model. Seepage model calculations used by Performance Assessment have only been performed for unperturbed temperatures. Therefore, seepage during the boiling period has been included in Performance Assessment using a conservative, but unrealistic, assumption that percolation flux 5 meters above the drifts will penetrate to the drifts and potentially seep into the drifts. Calculations have been performed, however, that demonstrate shedding of percolating and condensate water around the drift during the boiling period (e.g. UZ F&T PMR Section 3.10.5.2). Monte Carlo simulations that include spatial heterogeneity are also being performed to directly assess thermal seepage and drainage of condensate in the pillars. Plans are underway to address the effects of TH processes on seepage and flow close to waste emplacement drifts. This is being done through a Monte Carlo analysis of thermal hydrology, seepage and drainage of condensate water through the pillars between emplacement drifts. Effects of discrete fault features are also being investigated in the Monte-Carlo analysis. The EBS Multi-scale TH Model (CRWMS M&O 2000i) considers 31 chimney locations within the repository. DOE believes that this model captures an adequate level of heterogeneity in percolation rates at the repository horizon (EBS PMR (CRWMS M&O 2000p) Section 3.1.4). Evidence of two events in the LBT and from boreholes 79 and 80 of the DST, show that liquid water penetrated the thermal zone. (see also, field test response in subissue 1, AC 1.5) Early pre-test TH-model simulations of the DST using the ECM predicted minimal shedding of condensate around the boiling zone,	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.10: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models used to predict shedding around emplacement drifts are shown to contain an adequate level of heterogeneity in media properties.		
	resulting in a thick zone of condensate buildup above the boiling zone. These ECM TH-model calculations showed a very pronounced flattening of the vertical temperature profile, with temperatures close to 96°C in the zone of condensate buildup. More recent TH models of the DST, which use the DKM, predict much greater condensate shedding (than the ECM TH models) around the boiling zone, resulting in a much less pronounced zone of condensate buildup above boiling zone. The DKM TH-model calculations of the DST also predict a much thinner region of flattening (near 96°C) of the vertical temperature profile, corresponding to the very thin zone of condensate buildup above the boiling zone. Temperature measurements in the DST have a similar thin region of temperature flattening, indicating similar (efficient) condensate shedding behavior as is predicted by the DKM TH models. Based on the current models for corrosion resistance of the waste package and drip shield materials (Waste Package PMR, Section 3.1, (CRWMS M&O 2000m)), the occurrence of seepage during the thermal period is expected to be inconsequential to dose.	

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Technical Acceptance Criterion (AC) 2.11: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that TH models have been demonstrated to be appropriate for the temperature regime expected at the repository.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open DOE will need to show that the TH model predictions are consistent with test results or analog site observations for the appropriate temperature regime. Once the design heat load has been finalized, DOE will have to demonstrate that heater test results of analog site observations, used to support TH models, are consistent with predicted temperature regimes. Open pending review of TH model predictions for consistency with test results or analog site observations for the appropriate temperature regime. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** The TH models incorporated the anticipated thermal load for the current repository design as described in Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000q). Comparisons of the DST results and THC modeling are given in Section 3.10.4 of the UZ F&T PMR and Section 3.6.4 of the NFE PMR (CRWMS 2000l). The thermal hydrologic calculations are appropriate for the expected temperature regime as discussed in EBS PMR (CRWMS M&O 2000p) Section 3.1. The current EDA-II design is based upon an 81-m emplacement drift spacing with line loading. EBS models are based upon the NUFT thermal hydrological code, which has been validated for this temperature regime. (EBS PMR Section 3.1). The thermal test results described in the Thermal Test AMR (CRWMS M&O 2000s) are for the nonlithophysal tuff, whereas much of the current repository design would be situated in the lower lithophysal. The Thermal Test AMR (CRWMS M&O 2000s) compares test results with model predictions using different codes and modeling approaches. Temperatures in the repository would be lower than in the DST heated drift, however, the same models would be used and the first stages of heating would be the same (e.g. warming, evaporation, near-boiling, dryout by ventilation, etc.). The Cross-Drift Thermal Test (CDTT) is planned and will be conducted in the crystal poor lower lithostratigraphic unit of the TSw hydrologic unit (Tptpll). The CDTT will investigate the premise that heat-mobilized pore water will shed/drain between emplacement drifts to below the repository horizon, and test the premise that liquid water can penetrate through zones/regions at or above boiling temperature. Data from hydrological testing of the Tptpll in the Cross-Drift will be incorporated in the predictive modeling of the CDTT, as they become available.	No additional work beyond planned activities is needed.

Draft Analysis of the Resolution Status for the Key Technical Issue on Thermal Effects on Flow

Subissue 2: Is the U. S. Department of Energy thermohydrologic modeling approach sufficient to predict the nature and bounds of thermal effects on flow in the near field?

Technical Acceptance Criterion (AC) 2.12: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include radiative heat transport unless it is shown that radiative heat loss by a WP is not significant.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed The multiscale TH models include radiative heat transfer at the drift scale. DOE model results indicate that radiative heat loss by a WP can be significant. The Staff has no further questions at this time. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed.** TH models include radiative heat transfer at the drift scale as described in Section 3.10.5.1 in the UZ F&T PMR (CRWMS M&O 2000q). The EBS Multi-scale Thermohydrologic Model includes radiative heat transfer. For thermal effects within the drift, the NUFT calculations consider radiative heat transport. The RADPRO software routine calculates view factors using a standard approach in heat transfer analysis. (EBS PMR (CRWMS M&O 2000p) 3.1.4)	No additional work needed.

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Technical Acceptance Criterion (AC) 2.13: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that models include the effects of ventilation particularly if ventilation could result in deposition or condensation of moisture on a WP surface.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open DOE has not demonstrated that ventilation is included in their models. Ventilation could remove moisture from one portion of the repository environment and deposit it elsewhere with negative consequences (i.e., inducing increased WP corrosion at the point of condensation). DOE models have not been demonstrated to include the potential negative effects of ventilation. Open pending review of TH models for inclusion of potential negative effects of ventilation on moisture condensation and effects on WP corrosion. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Ventilation analyses in preparation (Ventilation AMR Rev 01 (CRWMS M&O 2000n)) will show that relative humidity in the pre-closure ventilation period will be low, and condensation is very unlikely. Also, ventilation effects are included in the current Multi-scale TH Model (CRWMS M&O 2000i) as heat removal only. Sensitivity studies have been performed to evaluate changes in rock properties that could result from pre-closure ventilation and the consequences for peak temperatures and other conditions after closure (EBS PMR Rev 01 work in progress). Other models are under development to incorporate and evaluate postclosure 3-D gas-phase transport in the drifts. Effects of ventilation are also included in Sections 3.10.5.1 and 3.12.1 in the UZ F&T PMR (CRWMS M&O 2000q).	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.14: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that the media properties of a model contain an adequate level of heterogeneity so that mechanisms such as dripping are not neglected or misrepresented.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open DOE models have not been demonstrated to contain an adequate level of heterogeneity so that mechanisms are adequately and appropriately represented, and the appropriate heat and mass transfer mechanisms are included in the conceptual and mathematical models. Open pending review of TH models for adequate level of heterogeneity so that mechanisms such as dripping from refluxing or seepage are appropriately represented given the appropriate heat and mass transfer mechanisms are included. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** The drift seepage model has been enhanced to account for heterogeneities as described in Section 3.9.3 of the UZ F&T PMR (CRWMS M&O 2000q). The effects of heterogeneity on drift seepage have been found to be important, since the drift seepage results are sensitive to the presence of heterogeneous permeability. Model results for the drift-scale test have been validated against test results (UZ F&T PMR Section 3.10.10) and (NFE PMR Section 3.6.4 (CRWMS M&O 2000l)). The conceptual and mathematical models used to represent TH processes include convective heat and mass transfer, as well as conductive heat transfer. Diffusive mass transfer is included in THC calculations. Phase change, as represented by vaporization, boiling, and condensation is also included. A Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts is being considered. Effects of discrete fault features are also being investigated in the Monte-Carlo analysis. Based on available evidence, it has not been demonstrated that dripping or seepage into the emplacement drifts under isothermal conditions is consistent with available data and current scientific understanding. Based on available evidence, it has not been demonstrated that the magnitude and time of the resulting expected annual dose would be significantly changed by the omission of these mechanisms. Based on the current models described in the Waste Package PMR (CRWMS M&O 2000m) for corrosion resistance of the waste package and drip shield, the occurrence of seepage during the thermal period will be inconsequential to dose.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.14: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that the media properties of a model contain an adequate level of heterogeneity so that mechanisms such as dripping are not neglected or misrepresented.		
	The Water Distribution and Removal Model Rev. 01 (CRWMS M&O 2000t) will show that the in-drift environment is not especially sensitive to seepage during the thermal period. The TSPA-SR shows that seepage does not have a profound effect—rather it has little effect based on the current corrosion resistance of the waste package, drip shield, and other EBS components. Analysis of the influence of drift-scale heterogeneity is underway to determine whether drift-scale heterogeneity should be explicitly represented in the Multi-scale TH Model (CRWMS M&O 2000i).	

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Technical Acceptance Criterion (AC) 2.15: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that drift wall representations in models must contain sufficient physical detail so that processes predicted using a continuum model, such as capillary diversion, are appropriate for the geologic media at the proposed repository horizon.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE has not demonstrated that their models must contain sufficient physical detail to take credit for capillary diversion. Recent analyses (Hughson and Dodge, 1999) indicate that non-uniformity in drift wall surfaces can lead to dripping. Previous continuum models used by DOE indicated capillary diversion around drift openings when the effects of drift wall irregularities were not induced. Open pending review of TH models for sufficient detail for DOE to take credit for capillary diversion. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Models predicting seepage include partial drift collapse and multiple realizations of heterogeneous rock properties. These models are described in Sections 3.9.3.4 and 3.9.3.5 in the UZ F&T PMR (CRWMS M&O 2000q). Higher rate flows generated by the proposed mechanism of film-flow and dripping from wall surface roughness features is captured in the Niche seepage calibration data. Lower rates may not be captured due to the effects of ventilation and evaporation during the Niche tests. DOE will include the effect of the low-flow regime processes (e. g., film flow) in the seepage fraction and seepage flow, or justify that it is not needed. When conducting seepage studies, DOE will consider smaller scale tunnel irregularities in drift collapse or justify that it is not needed.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.16: Descriptions of process-level conceptual and mathematical models used in the analyses are reasonably complete. Further, DOE should demonstrate that physical mechanisms, such as penetration of the boiling isotherm by flow down a fracture are not omitted due to over-simplification of the physical medium or the conceptual model.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE conceptual models have not been demonstrated to contain all necessary mechanisms to ensure that all processes that could lead to water introduction into the drift and onto WPs are included. Mechanisms that provide for the penetration of the boiling isotherm are not included in the DOE conceptual model. Seepage and dripping into emplacement drifts under isothermal conditions have not been demonstrated to be adequately included in the DOE conceptual models. Open pending review of TH models. (NRC 1999, Section 5.2.4)	The DOE believes this criterion is **closed pending.** Section 3.9 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the drift seepage models, including enhancements, such as the evaluation of partial drift collapse and episodic percolation flux. Section 3.10 in the UZ F&T PMR describes the THC models. Penetration of the boiling isotherm is currently overestimated in the Performance Assessment model (see AC 2.10). Process-level models have not yet addressed this question. Seepage from high-rate percolation flux has been adequately addressed and verified by field experiments. DOE will include the effect of the low-flow regime processes (e. g., film flow) in the seepage fraction and seepage flow, or justify that it is not needed. Plans are underway to complete Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts. Effects of discrete fault features are also being considered in the Monte-Carlo analysis. The EBS PMR (CRWMS M&O 2000p) Rev. 01 and the Water Distribution and Removal Model will present sensitivity studies that evaluate the importance of seepage during the thermal period. Seepage has little effect based on the current corrosion resistance of the waste package, drip shield, and other EBS components. Multiple failures will be required before thermally induced seepage could directly affect dose rates.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 3.0: Coupling of processes has been evaluated using a methodology in accordance with NUREG-1466 (Nataraja and Brandshaug, 1992) or other acceptable methodology. Coupled processes may be uncoupled, if it is shown that the uncoupled model results bound the predictions of the fully-coupled model results.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open The TEF KTI focused primarily on the coupling of TH processes. Interest in the broader coupling of THMC processes is limited to the effects on water flow into or out of the WP environment that would result from permeability changes due to either TC or TM processes. (NRC 1999, Section 5.2.5)	The DOE believes this criterion is **closed-pending.** NUREG-1466 provides logical steps for the development of predictive models and their numerical representation of thermally induced THMC behavior of the host rock. Models of coupled processes in the NFE PMR (CRWMS M&O 2000l) Sections 3.2 and 3.3 present the current approach for modeling drift-scale and mountain-scale TH effects. The DOE agrees that coupled processes may be uncoupled if the models bound the effects of fully coupled processes. Additional discussion of process coupling in the emplacement drifts is provided in EBS PMR (Rev 01 work in progress). The NFE PMR (CRWMS M&O 2000l) (Sections 3.2, 3.3, 3.4, and 3.6) and two of its supporting AMRs, Thermal Test AMR (CRWMS M&O 2000s) and Abstraction of Drift Scale Coupled Processes AMR (CRWMS M&O 2000a) discuss the evaluation of coupled process effects on the conditions or parameters (e.g., porosity and permeability) that are input to the TH models. THMC processes are also discussed in DOE's status discussions for evolution of the Near Field Environment and Repository Design and Thermal Mechanical Effects Key Technical Issues.	No additional work needed.

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Technical Acceptance Criterion (AC) 4: The dimensionality of models, which include heterogeneity at appropriate scales and significant process couplings, may be reduced, if shown that the reduced dimension model bounds the predictions of the full dimension model.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open After review of the TSPA-VA, it is not clear if two-dimensional, mountain-scale, TH calculations provide the time histories for gas-phase advection that results from large-scale temperature and pressure gradients because only thermal conduction is included in DOE's mountain-scale submodel (TRW Environmental Safety Systems, Inc. 1998, pg 3-12 and 3-13). Open pending review of DOE's multiscale modeling to account for gas-phased advection due to large-scale temperature and pressure gradients. (NRC 1999, Section 5.2.6)	The DOE believes this criterion is **closed pending.** TH modeling is contained in the NFE PMR (CRWMS M&O 2000l) (Sections 3.2, 3.3, 3.4, and 3.6) and two of its supporting AMRs, Thermal Test AMR (CRWMS M&O 2000s), Abstraction of Drift Scale Coupled Processes AMR (CRWMS M&O 2000a) and the Multi-scale TH model AMR (CRWMS M&O 2000i). TH modeling has been performed for a range of scales and dimensions as described in Section 3.10 in the Drift-Scale THC Processes and Model (CRWMS M&O 2000u), and Section 3.12 in the Mountain-Scale TH Model (CRWMS M&O 2000g). Only thermal conduction is included in the mountain-scale model that is used for the Multi-scale model; however, TH processes are included explicitly in the 2-D and 3-D Mountain-scale TH models. The Multi-scale model (CRWMS M&O 2000i) incorporates spatial variation in infiltration, rock properties, repository layout, depth to surface, and other effects. Work is ongoing to include larger-scale 3-D processes, including gas-phase circulation at the repository scale. Large-scale gas convection is included in the mountain-scale TH model. These calculations were done in two and three dimensions. Drift-scale gas convection is accounted for in the two-dimensional drift-scale THC model. Comparison of gas-phase circulation results obtained with drift-scale TH models is provided in the EBS PMR (Rev 01 work in progress). In the EBS Multi-scale TH model, the potential repository-scale heterogeneity is represented by the drift scale active properties set which captures the properties for various strata. Lateral of hydrostratigraphy (not the uniform unit properties) within the potential repository footprint is represented by the 31 drift-scale-model locations used in the Multi-scale TH model.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 5: Equivalent Continuum Models (ECM) are acceptable for the rock matrix and small discrete features, if it can be demonstrated that water in small discrete features is in continuous hydraulic equilibrium with matrix water. Significant discrete features, such as fault zones, should be represented separately unless it can be shown that inclusion in the ECM produces a conservative effect on calculated overall performance.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE has not demonstrated which discrete features (i.e., faults or fracture zones) need to be modeled discretely to conservatively bound heat and mass transfer in TSPA calculations. Open pending review of models for treatment of discrete feature modeling. (NRC 1999, Section 5.2.7)	The DOE believes this criterion is **closed.** Section 3.10.3 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the approach to modeling thermal-hydrologic processes. The major faults are modeled discretely in the mountain-scale TH model. Ongoing and planned modeling will evaluate the effects of stochastic heterogeneity of fracture properties, representing natural variability in the fracture networks on seepage during the thermal period. A similar approach has already been used to simulate drift seepage. Discrete fracture modeling of TH processes has been performed in the past but is not currently used for thermal test and repository modeling because TH processes can be adequately represented by continua.	No additional work needed.

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Technical Acceptance Criterion (AC) 6: Accepted and well-documented procedures adopted to construct and calibrate numerical models used.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending DOE has not documented all procedures adopted to construct and calibrate numerical models used. The Staff has no further questions at this time. The Staff will review techniques used by DOE to construct and calibrate numerical models used when available. (NRC 1999, Section 5.2.8)	The DOE believes this criterion is **closed.** Inverse modeling is used to calibrate properties for the natural barrier system. Inverse model calibration for both the site-scale and drift-scale property sets has been performed (Section 3.6.4 UZ F&T PMR, CRWMS M&O 2000q). Calibration of TH models using results from field tests is documented in the Thermal Test AMR (CRWMS M&O 2000s).	No additional work needed.

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Technical Acceptance Criterion (AC) 7: Results of process-level models have been verified by demonstrated consistency with results/observations from field-scale, thermohydrologic test. In particular, sufficient physical evidence should exist to support the conceptual models used to predict thermally driven flow in the near field.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending The results from DOE's testing program quarterly workshops that compare TH test results to TH model simulations are not yet documented. The Staff will continue to attend these workshops and will review DOE comparisons of DST data and model simulations when available. The Staff has no further questions at this time. (NRC 1999, Section 5.2.9)	The DOE believes this criterion is **closed.** The NFE PMR (CRWMS M&O 2000l) Section 3 addresses process model confidence building or verification through comparisons with field tests. As described in that section, the DST THC model is used to predict THC processes prior to and during the DST. Measured data from the DST are used to evaluate the conceptual and numerical models. Results from DST THC simulations were compared to measured gas-phase carbon dioxide (CO_2) concentrations, and the chemistry of waters collected from hydrology boreholes during the test. The results of these comparisons provide indication of consistency with results and observations from field-scale thermal tests. Process level models have been calibrated against hydrochemical, isotopic and other site data and observations as described in Sections 3.9.4.5, 3.10.4 and 3.12.4 in the UZ F&T PMR (CRWMS M&O 2000q).	No additional work needed.

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Importance to Performance. The influx of water as a liquid or vapor into the emplacement drifts can potentially affect repository performance by degrading the integrity of the waste package, by transporting radionuclides released from waste packages, or by altering hydraulic or transport pathways in the ground control structures, inverts, or host rock. Draft RSS, Revision 4 sensitivity analyses do not show significant dependence of postclosure performance on details of the flow in the unsaturated zone. Robustness of the waste package and the drip shield mitigate the effects of the flow system, including thermal effects on the flow. Consequently, thermal effects on the flow system are not considered to be important and this factor is not identified as a principal factor.

Programmatic Acceptance Criterion (AC) 1: DOE's analyses developed and documented under acceptable QA procedures.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open In the TSPA, DOE acknowledged that "analyses presented within were not performed with qualified data sets, all results within this report are considered unqualified" (TRW Environmental Safety Systems, Inc., 1998; Section 4.4.1). NRC will continue to attend DOE sponsored meetings and QA audits to ensure that this deficiency is being addressed as part of the DOE program to develop a license application. Open pending continued review of DOE's QA program implementation. (NRC 1999, Section 5.3.1)	The DOE believes this criterion is **closed.** Activities associated with development of the PMR and related AMRs were determined to be subject to the quality assurance program as described in the QARD document. As such, collection of related data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement quality assurance program requirements. Whereas some data and models developed for SR are based on provisional inputs that are not et qualified, the processes used to manage data, software models and documentation are in place.	No additional work needed.

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Programmatic Acceptance Criterion (AC) 2: Expert elicitation may be used for, but not necessarily limited to, justifying the use of abstracted models in DOE's TSPA. All expert elicitation are conducted and documented in accordance with NUREG -1563 (Kotra et al. 1996) or other acceptable procedures.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
DOE has conducted an expert elicitation on the near-field/altered zone, which includes TEF issues. To date, the Staff has no questions or comments regarding the use of expert elicitations in areas related to TEF. (NRC 1999, Section 5.3.2)	The DOE believes this criterion is **closed.** Expert elicitations were determined to be subject to the quality assurance program as described in the QARD (DOE 2000) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563 (Kotra et al. 1996).	No additional work needed.

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Technical Acceptance Criterion (AC) 1: Abstractions of process level models may be used if predictions from the abstracted model are shown to conservatively bound process-level predictions. In particular, DOE may use an abstracted model to predict water influx into emplacement drift if the abstracted model is shown to bound process-level model predictions on the influx of water as liquid or vapor into an emplacement drift.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE process-level models do not yet incorporate all potentially important heat and mass transfer (refer to discussion in Section 5.3.8 and 3.3.7 of this IRSR). Open pending review of abstracted models. (NRC 1999, Section 5.3.3)	The DOE believes this criterion is **closed.** Section 3.9 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the abstraction of seepage into drifts. As noted in Section 3.9.6.3, distributions for the amount of seepage as a function of percolation flux are derived directly from process models results and constrained by measurements of permeability around three niches in the Exploratory Studies Facility (ESF) and calibration of seepage tests conducted in one niche in the ESF. A conservative model abstraction of drift seepage has been developed (Abstraction of Drift Seepage, CRWMS M&O 2000c). Although heat transfer mechanisms are not included in the seepage process model and abstraction for TSPA, it is conservative to neglect the effects of heat on these components. The effects of heat on percolation flux intercepting the drift are included through a separate TSPA abstraction that is an input to the seepage abstraction. The thermal seepage abstraction that is used for TSPA-SR is based on average thermally driven reflux in the host rock above the drift, calculated using the Multi-scale TH model. This flux is then used to calculate a seepage value, using the drift seepage model (supported by field-testing). The result is a conservative abstraction because the reflux magnitude in the rock is a reasonable bound on the available flux for flow into the drift, and the seepage model represents best available information on the potential for seepage. It is also noted that the thermally driven reflux magnitude in the rock represents the average balance between convective and conductive heat transfer, which is strongly related to the thermal conductivity, which has been measured or estimated. There is less uncertainty on the magnitude of the average thermally mobilized water in the rock above the drift openings, than on the physics of transient flow in fractured rock.	No additional work needed.

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Technical Acceptance Criterion (AC) 2.1: Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that uncertainties and variabilities in parameter values are accounted for using defensible methods. The technical bases for parameter ranges, probability distributions or bounding values used are provided. Parameter values (single values, ranges, probability distributions, or bounding values) are derived from site-specific data or an analysis is included to show the assumed parameter values lead to a conservative effect on performance.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed Pending The effect of heterogeneity needs to be included in the models to capture critical heat and mass transfer mechanisms (refer to discussion in Section 3.3.7). There is insufficient evidence to demonstrate that the assumed parameter values lead to a conservative effect on performance. This conclusion is based on the observation that acceptable and appropriate values for the base case parameters are not yet determined. It is assumed that at the time when acceptable and appropriate parameter values have been incorporated into the reference base case data set, DOE will provide appropriate results from sensitivity analyses to demonstrate that the assumed parameters values lead to a conservative effect on performance. The Staff has no further questions at this time. The Staff will review the reference data set used in DOE's TSPA-LA to ensure consistency with available field data. (NRC 1999, Section 5.3.4)	The DOE believes this criterion is **closed pending.** The THC abstraction of the mean filtration rate (with climate changes) includes both geochemical systems (full and calcite-silica-gypsum) considered in the THC process model as described in Section 3.10.11 in the UZ F&T PMR (CRWMS M&O 2000q). To account for infiltration uncertainties, DOE will review the modern day infiltration distribution to affirm the reasonableness of the upper bound infiltration map. If needed for the LA licensing case, any necessary adjustments will be addressed as part of the TSPA-LA. In addition, plans are underway to complete Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts. Effects of discrete fault features are also being considered in the Monte-Carlo analysis. Heterogeneity is important for hydrologic properties and chemical parameters, and less important for thermal properties. Temperatures in the EBS depend chiefly on thermal conductivity, which does not vary as much as other transport properties. TH models are readily manipulated to show and bound the effects of seepage (see the Water Distribution and Removal Model Rev. 01, (CRWMS M&O 2000t) Section 3.1.1). Chemical heterogeneity is relatively uncertain, but the EBS will perform its function for a range of chemical conditions. The hydrologic input parameters for the TH models that predict in-drift conditions for TSPA-SR are the result of parameter estimation and model calibration documented for the UZ F&T model, and field-scale thermal test models. Use of these parameters for field-test models is equivalent to their use for repository modeling. These models capture the average response of the rock mass to heating. Whereas thermal refluxing has been demonstrated to produce episodic water movement under certain conditions the abstraction of	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 2.1: Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that uncertainties and variabilities in parameter values are accounted for using defensible methods. The technical bases for parameter ranges, probability distributions or bounding values used are provided. Parameter values (single values, ranges, probability distributions, or bounding values) are derived from site-specific data or an analysis is included to show the assumed parameter values lead to a conservative effect on performance.		
	thermal seepage that is used for TSPA-SR is conservative and encompasses such refluxing. Further, process model sensitivity studies (Water Distribution and Removal Model Rev. 01, (CRWMS M&O 2000t)) have shown that the effects of thermal seepage on the in-drift environment are limited, and that the current abstraction models are appropriate.	

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Technical Acceptance Criterion (AC) 2.2: Sufficient data are available to adequately define relevant parameters, parameter values, and conceptual models. Specifically, DOE should demonstrate that analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Closed Pending The DOE multiscale modeling approach provides an acceptable method to establish initial conditions, boundary conditions, and computational domains that are consistent with site characteristics (subject to comment noted under technical acceptance criterion 5). However, there remains uncertainty in values considered appropriate for infiltration at the atmospheric boundary. Additional site characterization and sensitivity analyses will be required to resolve this uncertainty to an acceptable level. The Staff has no further questions at this time. The USFIC KTI will monitor DOE progress is determining the atmospheric boundary condition. (NRC 1999, Section 5.3.4)	The DOE believes this criterion is **closed.** DOE plans to account for uncertainties and variabilities in parameter values and to provide the technical basis for parameter ranges, probability distributions or bounding values used in the performance assessment. However, DOE does not believe that uncertainty in values necessarily requires additional site characterization or sensitivity analyses as stated in the discussion [NRC]. The "acceptable level of uncertainty will depend on a number of factors, e.g. spatial heterogeneity. Site characteristics have been considered in establishing initial conditions, boundary conditions and computational domains as described in Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000q). The thermal hydrology models used in EBS PMR (CRWMS M&O 2000p) are based upon the selection of natural barrier system hydrologic and thermal properties used in the UZ process models. The initial conditions and boundary conditions for the models for specific locations use the same infiltration rates, and temperature and pressure boundary conditions consistent with the UZ process model (EBS PMR Section 3.1).	No additional work needed.

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Technical Acceptance Criterion (AC) 3.1: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that performance affecting heat and mass transfer mechanism, including processes observed in available thermohydrologic tests and experiments, have been identified and incorporated into the TSPA. Specifically, it is necessary to either demonstrate that liquid water will not reflux into the underground facility or incorporate refluxing that liquid into the TSPA and bound the potential adverse effects of: (i) corrosion of the WP, (ii) accelerated transport of radionuclides; and (iii) alteration of hydraulic and transport pathways that result from refluxing water.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open DOE conceptual and mathematical models incorporated into the TSPA do not yet include, either directly or as an abstraction, the heat and mass transport mechanisms that could lead to water refluxing into the drift, particularly during the heating period. DOE models in the TSPA-VA assume that no water can enter the drift at all times when driftwall temperatures exceed boiling (TRW Environmental Safety Systems, Inc. 1998, pg 3-142). This assumption is not conservative. In addition, the TSPA-VA assumption of no dripping into the drift during the first 5000 years of heating is not conservative. DOE models are based on a continuum approach that assigns bulk average properties to the site media. The continuum-based models can mask the potential effects of processes that could lead to water being introduced into the drift causing accelerated corrosion of the WP, transport of radionuclides, and alteration of hydraulic and transport pathways. Sufficient natural heterogeneity is required in the models to ensure critical heat and mass transfer mechanisms are not masked. In addition, analyses and models predicated on the results of the seepage models should use the results of the "high-seepage" alternative model to be conservative. Open pending review of the models. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed pending.** Section 3.12 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes the evaluation of flow changes close to drifts and drainage in the pillars. A conservative model abstraction of drift seepage has been developed (Abstraction of Drift Seepage, CRWMS M&O 2000c). Although heat transfer mechanisms are not included in the seepage process model and abstraction for TSPA, it is conservative to neglect the effects of heat on these components. The effects of heat on percolation flux intercepting the drift are included through a separate TSPA abstraction that is an input to the seepage abstraction. A Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts is underway. Effects of discrete fault features are also being considered in the Monte-Carlo analysis. A discrete fracture model for seepage is being developed for comparison with the continuum model. The model is an isothermal, fracture only model. The EBS PMR (Rev 01 work in progress) and the Water Distribution and Removal Model Rev. 01 (CRWMS M&O 2000t) present sensitivity studies that evaluate the importance of seepage during the thermal period. Seepage has little effect based on the corrosion resistance of the waste package and drip shield. Multiple failures will be required before thermally induced seepage could directly affect dose rates. High seepage is not necessarily most aggressive for corrosion of the engineered barriers. Revision 01 of the EBS Physical and Chemical Environment AMR (CRWMS M&O 2000k) provides the calculation of water compositions that can occur as a result of humidity interaction with minerals and salts.	No additional work beyond planned activities is needed.

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Acceptance Criterion (AC) 3.2: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that significant Geologic Repository Operations Area (GROA) underground facility design features, such as the addition of backfill or drip shields, that can result in changes in TSP have been identified and incorporated into the TSPA.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending The referenced design to be used in DOE's TSPA-LA is being revised. The final reference design has not yet been approved by DOE and could be modified in the future. Therefore not all critical design features that will be included in the final design are known at this time. The effects of drip shields and backfill on system performance have not yet been completely assessed. Other design features, in addition to drip shields and backfill, may need to be evaluated in the future. The Staff has no further questions at this time. The Staff will review DOE's TSPA-LA to ensure that all significant GROA design features have been incorporated into the analysis. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed.** The EBS process models incorporate significant design features of the underground facility. Significant design features are those features that could change the thermodynamic environment, and thus are represented in sufficient detail that their thermohydrologic effects are incorporated. The process models incorporate current underground design features including the waste packages, drip shields, and steel in the EBS.	No additional work needed

Subissue 3: Does the U. S. Department of Energy Total System Performance Assessment adequately account for thermal effects on flow?

Technical Acceptance Criterion (AC) 3.3: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that conceptual model uncertainties have been defined and documented, and their effects on conclusions regarding TSP have been addressed.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Current DOE conceptual models do not incorporate heat and mass transport mechanisms that could indicate water reflux into the drift during and after the heating period. The effects of refluxed water need to be incorporated into the TSPA. Open pending review of models for incorporation of effects of refluxed water into TSPA. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed pending.** The NFE PMR (CRWMS M&O 2000l) summarizes the evaluation of flux into drifts during and after the thermal period. In addition, each of the major process models is documented in a referenced report that includes a discussion of the model uncertainties. The effects of reflux are included in the TSPA through the multi-scale TH model and corresponding model abstraction. Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts. Effects of discrete fault features are also being considered in the Monte-Carlo analysis. The NFE PMR CRWMS M&O 2000l), MSTHM AMR (CRWMS M&O 2000i), and TH Abstraction AMR (CRWMS M&O 2000u) evaluated the thermal effects on seepage. The EBS Water Distribution and Removal AMR (CRWMS M&O 2000t) evaluated the effects of bounding seepage values on the EBS environment.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 3.4: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that mathematical models are consistent with conceptual models, based on consideration of site characteristics.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open The mass balance of models need to be confirmed to ensure the mathematical and conceptual models are consistent, based on consideration of site characteristics. Open pending review of models to confirm mass balance in models. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed**. Mass balance is ensured by the mathematical and numerical approaches used in TH simulations to support TSPA.	No additional work needed.

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Technical Acceptance Criterion (AC) 3.5: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that alternative modeling approaches, which are consistent with available data and current scientific understanding, have been investigated, limitations defined, and results appropriately considered		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open Alternative process-level models are not provided for critical heat and mass transfer mechanisms. For example, refluxing into the drift during the heating period can have profound effects on TSP, however, an alternative model of such a process has not been formulated to provide confidence in the original conceptual and mathematical models. In addition, results from an alternative DOE model for seepage into a drift that indicate significantly higher levels of seepage rates should be considered in the TSPA to ensure the TSPA is conservative. Open pending review of alternative process models for critical heat and mass transfer mechanisms. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed pending.** The Water Distribution and Removal Model Rev. 01 (CRWMS M&O 2000t) shows that the in-drift environment is not especially sensitive to seepage during the thermal period. The current TSPA shows that seepage does not have a profound effect—rather it has little effect based on the corrosion resistance of the waste package and drip shield. NFE PMR (CRWMS M&O 2000l) explains how abstracted results from the Multi-scale TH model and the drift seepage model used to represent thermal seepage ensures that there is seepage into some emplacement drifts even during the peak thermal period. Alternative modeling approaches are also discussed in Section 3.10.7 in the UZ F&T PMR (CRWMS M&O 2000q). A discrete fracture model is being pursued, however, it is not aimed at achieving higher seepage. The work is intended to investigate the discrete fracture alternative model and compare with the continuum model being used. Monte Carlo simulations with heterogeneity are also being performed to directly assess thermal seepage and drainage of condensate in the pillars. Discrete fracture seepage analysis and comparison with continuum model approach is underway. In addition, a Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts is being performed. Effects of discrete fault features are also being considered in the Monte-Carlo analysis. The "upper" infiltration model is used, with conservative flux focusing factors, and other conservatisms, as part of the seepage representation in TSPA. Plans are underway to continue performing analyses to determine the seepage threshold.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 3.6: Descriptions of the conceptual and mathematical models used in DOE's TSPA are reasonably complete. Further DOE should demonstrate that results from different mathematical models have been compared to judge robustness of models

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open Expanded sensitivity analyses using the ECM, G-ECM and DKM conceptual models should provide an assessment of the robustness of the models. Open pending review sensitivity analyses for robustness of models. (NRC 1999, Section 5.3.5)	The DOE believes this criterion is **closed.** Sensitivity analyses related to TEF are included in the TSPA-SR. The dual-continuum (DKM) conceptual model encompasses any behavior that could be represented in a General-equivalent continuum model (G-ECM) or ECM model. Therefore, the use of the DKM conceptual model is always a more comprehensive treatment of processes than the G-ECM or ECM conceptual models. Comparison of these methods and more recent models would not contribute robustness. These conceptual models are just steps in an evolution of models for unsaturated fractured rock that have evolved because improvements were developed and faster computers made it possible to use them.	No additional work needed.

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Technical Acceptance Criterion (AC) 4: Coupling of thermal processes has been evaluated using a methodology in accordance with NUREG-1466 (Nataraja and Brandshaug, 1992) or other acceptable methodology. Coupled processes may be uncoupled, if it is shown that the uncoupled model results bound the predictions of the fully coupled model results.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open The TEF KTI focused primarily on the coupling of TH processes. Interest in the broader coupling of THMC processes is limited to the effects on water flow into or out of the WP environment that would result from permeability changes due to either TC or TM processes. (NRC 1999, Section 5.3.6)	The DOE believes this criterion is **closed-pending.** NUREG-1466 provides logical steps for the development of predictive models and their numerical representation of thermally induced THMC behavior of the host rock. Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000q) summarize the approach to evaluating coupled processes at the drift-scale and mountain-scale. The DOE agrees with NRC staff remarks (NRC 1999, Section 5.3.6) that the coupled processes may be uncoupled if the models bound the effects of fully coupled processes. The effects of coupled processes on flow into or out of the waste package environment are limited to changes in the invert ballast properties, and clogging of fractures that could drain water from the drifts. These are addressed in the EBS PMR Rev. 01 (CRWMS M&O 2000p) and supporting AMRs. Analyses have shown that the host rock has substantial excess drainage capacity, and that spatial variability makes ponding in the drifts even more unlikely. Invert ballast porosity changes will be a small fraction of the initial porosity, even with seepage of assumed composition.	No additional work needed.

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Technical Acceptance Criterion (AC) 5: The dimensionality of models used to assess the importance of refluxing water on repository performance may be reduced, if it is shown that the reduced dimension model bounds the predictions of the full dimension model in performance.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: Open After review of the TSPA-VA, it is not clear if two-dimensional, mountain-scale, TH calculations provide the time histories for gas-phase advection that results from large-scale temperature and pressure gradients because only thermal conduction is included in DOE's mountain-scale submodel (TRW Environmental Safety Systems, Inc. 1998, pg 3-12 and 3-13). Open pending review of DOE's multiscale modeling to account for gas-phased advection due to large-scale temperature and pressure gradients. (NRC 1999, Section 5.3.7)	The DOE believes this criterion is **closed pending.** Section 3.4.2.4 in the UZ F&T PMR (CRWMS M&O 2000q) summarizes studies of grid refinements. Section 3.12.2.2 in the UZ F&T PMR summarizes numerical grids for TH simulations. Large-scale gas convection is included in the mountain-scale TH model. These calculations were done in two and three dimensions. Only thermal conduction is included in the mountain-scale model that is used for the Multi-scale model, (clarification); however, TH processes are included explicitly (albeit at coarser resolution) in the 2-D and 3-D mountain-scale TH models. The Multi-scale model already incorporates spatial variation in infiltration, rock properties, repository layout, depth to surface, and other effects. Work is ongoing to include larger-scale 3-D processes that could influence large-scale gas circulation.	No additional work beyond planned activities is needed.

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Technical Acceptance Criterion (AC) 6: Results of the TSPA related to TEF have been verified by demonstrating consistency with results of process-level models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Open DOE process-level models do not yet incorporate all potentially important heat and mass transfer mechanisms. Seepage into the drift under isothermal conditions and refluxing into the drift during and after the heating period are two mechanisms not adequately incorporated into the DOE process-level models at this time. Therefore, in the absence of the process-level models that represent these mechanisms, results from DOE's TSPA analyses cannot be verified as consistent with the process-level models. Open pending review of process-level models for incorporation of important heat and mass transfer mechanisms. (NRC 1999, Section 5.3.8)	The DOE believes this criterion is **closed pending.** TSPA analyses related to TEF were based on the process level models. A conservative model abstraction of drift seepage has been developed (Abstraction of Drift Seepage, CRWMS M&O 2000c). Although heat transfer mechanisms are not included in the seepage process model and abstraction for TSPA, it is conservative to neglect the effects of heat on these components. The effects of heat on percolation flux intercepting the drift are included through a separate TSPA abstraction that is an input to the seepage abstraction. Plans are underway to complete Monte Carlo analysis that investigates the effects of heterogeneity on thermohydrologic processes, seepage, and drainage of condensate water through the pillars between emplacement drifts. Effects of discrete fault features are also being considered in the Monte-Carlo analysis.	No additional work beyond planned activities is needed.

Dr..t Analysis of the Resolution Statu. .or the Key Technical Issue on The...al Effects on Flow

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Technical Acceptance Criterion (AC) 7: Sensitivity and importance analyses were conducted to assess the need for additional data or information with respect to TEF.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: Closed Pending DOE has conducted sensitivity analyses in TSPA-VA to determine which changes in data result in critical impact on performance. These sensitivity analyses need to be repeated when all necessary heat and mass transfer mechanisms are adequately incorporated into the process-level models. The Staff has no further questions at this time. Results of new analyses will be reviewed when completed and made available. (NRC 1999, Section 5.3.9)	The DOE believes this criterion is **closed-pending.** Sensitivity analyses are conducted where appropriate in the EBS Process Models. Additional sensitivity analyses are ongoing and will be included in revisions of the NFE and EBS PMRs (CRWMS M&O 2000l and CRWMS M&O 2000p), and supporting AMRs.	No additional work beyond planned activities is needed.

REFERENCES

DIRS #	DOCUMENT DESCRIPTION
153193	Cline, K.M. 2000. "Transmittal of MTS Report of Conservatism in Process Models and TSPA. Letter from K.M. Cline (MTS) to S. Brocoum (DOE/YMSCO)," October 12, 2000, LV.MTS.KMC.10/00-218, with attachment. ACC: MOL.20001113.0311.
123916	CRWMS M&O 2000a. *Abstraction of Drift-Scale Coupled Processes.* ANL-NBS-HS-000029 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0371.
141187	CRWMS M&O 2000b. *Conceptual and Numerical Models for UZ Flow and Transport.* MDL-NBS-HS-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0526
142004	CRWMS M&O 2000c. *Abstraction of Drift Seepage.* ANL-NBS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000322.0671.
142945	CRWMS M&O 2000d. *Features, Events, and Processes in UZ Flow and Transport.* ANL-NBS-MD-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000502.0240
143368	CRWMS M&O 2000e. *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux.* ANL-EBS-HS-000003 REV 00, ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.200001206.0143.
144426	CRWMS M&O 2000f. *Calibrated Properties Model.* MDL-NBS-HS-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0520
144454	CRWMS M&O 2000g. *Mountain-Scale Coupled Processes (TH) Models.* MDL-NBS-HS-000007 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0528
149861	CRWMS M&O 2000h. *Features, Events, and Processes in Thermal Hydrology and Coupled Processes.* ANL-NBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. MOL.20000602.0053
149862	CRWMS M&O 2000i. *Multi-scale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. MOL.20001208.0062
150657	CRWMS M&O 2000j. *Performance Confirmation Plan.* TDR-PCS-SE-000001 REV 01 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000601.0196.
150795	CRWMS M&O 2000k. *Engineered Barrier System: Physical and Chemical Environment Model.* ANL-EBS-MD-000033 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001228.0081.
150826	CRWMS M&O 2000l. *Near Field Environment Process Model Report.* TDR-NBS-MD-000001 REV 00 ICN 03. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001121.0041.

REFERENCES

DIRS #	DOCUMENT DESCRIPTION
151624	CRWMS M&O 2000m. *Waste Package Degradation Process Model Report.* TDR-WIS-MD-000002 REV 00 ICN 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001228.0229
151634	CRWMS M&O 2000n. *Ventilation Model.* ANL-EBS-MD-000030 REV 00. Las Vegas, Nevada: CRWMS M&O. MOL.20000107.0330
151656	CRWMS M&O 2000o. *EBS FEPs/Degradation Modes Abstraction.* ANL-WIS-PA-000002 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0631
151804	CRWMS M&O 2000p. *Engineered Barrier System Degradation, Flow, and Transport Process Model Report.* TDR-EBS-MD-000006 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000724.0479
151940	CRWMS M&O 2000q. *Unsaturated Zone Flow and Transport Model Process Model Report.* TDR-NBS-HS-000002 REV 00 ICN 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000831.0280.
151942	CRWMS M&O 2000r. *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00, ICN 01. Las Vegas, Nevada: CRWMS M&O. MOL.20000727.0092
151964	CRWMS M&O 2000s. *Thermal Tests Thermal-Hydrological Analyses/Model Report.* ANL-NBS-TH-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. MOL.20000505.0231
152016	CRWMS M&O 2000t. *Water Distribution and Removal Model.* ANL-EBS-MD-000032 REV 00, ICN 01. Las Vegas, Nevada: CRWMS M&O. MOL.20000822.0006
152668	CRWMS M&O 2000u. *Drift-Scale Coupled Processes (DST and THC Seepage) Models.* MDL-NBS-HS-000001 REV 00. 1. Las Vegas, Nevada: CRWMS M&O. MOL.20000615.0296
143244	CRWMS M&O 2000X. *Analysis of Infiltration Uncertainties*. ANL-EBS-MD-000035 REV 01. Las Vegas, Nevada: CRWMS M&O.
TBD	CRWMS M&O 2000v. Pretest Predictions For Ventilation Tests, CAL-EBS-MD-000013 Rev. 00
TBD	CRWMS M&O 2000w. Cross Drift Thermal Test Planning Report, August 2000
149540	DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422
NRC 1999	NRC (U.S. Nuclear Regulatory Commission) 1999. *Issue Resolution Status Report Key Technical Issue: Thermal Effects on Flow.* Rev. 2. Washington, D.C.: U. S. Nuclear Regulatory Commission.

MOL.20001113.0311

Management and Technical Support Services
A Yucca Mountain Site Characterization Office Support Organization

LV.MTS.KMC.10/00-218
October 12, 2000

QA: N/A

Mr. Stephan Brocoum
U.S. Department of Energy
Yucca Mountain Site Characterization Office, M/S 523
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Subject: Transmittal of MTS Report of Conservatism in Process Models and TSPA

Mr. Brocoum:

Enclosed is a report entitled, "Evaluation of Process Models for their Representation of Postclosure Repository Performance" that summarizes an independent assessment of how realistic process models and model abstractions are in their representation of features, events, and processes, and events related to the performance of a potential repository at Yucca Mountain. Selected model components were evaluated for their representation, importance to the make up of the process model, and significance to repository performance. The evaluation also included an assessment of the ability to modify the process model to be more representative of expected reporting performance. The results suggest that levels of conservatism are found throughout the models and that the conservatisms are primarily driven by uncertainty. The results of this task are used as input to the Phase I: Unquantified Uncertainties Activity approved by the Project Operations Review Board in October 2000.

Sincerely,

K. Michael Cline
Management and Technical Support Services

KMC/tc

Attachment

cc: Russ Dyer, DOE/YMSCO, Las Vegas, NV
William Boyle, DOE/YMSCO, Las Vegas, NV
Suzanne Mellington, DOE/YMSCO, Las Vegas, NV
Claudia Newbury, DOE/YMSCO, Las Vegas, NV
Jim Replogle, DOE/YMSCO, Las Vegas, NV

Tim Sullivan, DOE/YMSCO, Las Vegas, NV
Dennis Williams, DOE/YMSCO, Las Vegas, NV
Abe VanLuik, DOE/YMSCO, Las Vegas, NV
Joseph Ziegler, DOE/YMSCO, Las Vegas, NV

Brenda Bowlby, MTS, Las Vegas, NV
Bob Fish, MTS, Las Vegas, NV
Bob Gamble, MTS, Las Vegas, NV
Richard Goffi, MTS, Washington, DC
Harris Greenberg, MTS, Las Vegas, NV
Ron Linden, MTS, Las Vegas, NV
Kevin Coppersmith, M&O, Las Vegas, NV
Ray Mele, MTS, Las Vegas, NV
Charles Metzger, MTS, Washington, DC
Bimal Mukhopadhyay, MTS, Las Vegas, NV
Mark Nutt, MTS, Las Vegas, NV
Ralph Rogers, MTS, Las Vegas, NV
Richard Salness, MTS, Las Vegas, NV
David Sassani, MTS, Las Vegas, NV
John Savino, MTS, Las Vegas, NV
Richard Toft, MTS, Las Vegas, NV
Frank Wong, MTS, Las Vegas, NV
Eric Zwahlen, MTS, Las Vegas, NV

EVALUATION OF PROCESS MODELS FOR THEIR REPRESENTATION OF POSTCLOSURE REPOSITORY PERFORMANCE

Introduction

This report summarizes an independent assessment of the consistency of process models with the YMSCO direction to the performing organization (DOE FY00 Planning Guidance (May 1999); Project Operations Review Board (PORB) Position Papers 00216-03, 03A, and 03B; and Technical Direction letter (Dyer to Bailey) of July 19, 2000). The objective of this activity is to complete a preliminary qualitative evaluation of how realistic the process models and model abstractions are in their representation of features, events, and processes related to repository performance. Selected model components (parameters and assumptions) were evaluated for the character of their representation (representative, conservative, or optimistic), importance to the process model, significance to repository performance, and difficulty in modifying the abstractions. The results of this task are used as input to the Phase I: Unquantified Uncertainties Activity initiated in September 2000 and approved by the PORB (October 4, 2000). It is anticipated that the results of this model representation activity will continue to be modified and refined as the uncertainty activities continue.

Summary of DOE Direction on Development of Process Models and TSPA-SR

Process models used in the evaluation of postclosure performance should, to the extent practicable, reflect a credible representation of the total system, and the natural and engineered subsystems of the total system. The reasonably expected (defined as the mean value of a probabilistic distribution) behavior of the total system and the different barriers contributing to performance should reflect the uncertainty associated with the representation of long-term performance. This approach is consistent with the regulatory framework and applicable to both the site suitability evaluation for site recommendation (SR) and the evaluation of performance to be presented in the license application (LA). Any other approach will tend to underestimate (or overestimate) repository performance, limit the ability to understand and demonstrate the relative contributions of each barrier to the total system, and reduce flexibility in the regulatory environment.

Regulatory Perspective

The Nuclear Regulatory Commission (NRC) has stated in its proposed repository licensing criteria (10 CFR Part 63) that DOE's performance assessment model should reflect a credible representation of a geologic repository and that complete assurance that the postclosure performance objective can be met is not expected (see Attachment A). The NRC further defines its postclosure performance objective in terms of the "expected annual dose" based on a credible representation of the system. The Advisory Committee on Nuclear Waste (ACNW) is of the opinion that conservatism should be applied only in evaluating the results of Total System Performance Assessment (TSPA), and that the models making up the TSPA should be as realistic as possible. The Environmental Protection Agency (EPA) has indicated in its proposed performance standard for Yucca

Mountain (40 CFR Part 197) that "reasonable expectation" can be achieved, not absolute proof. NRC and EPA statements that establish their regulatory framework and provide guidance for modeling expected performance are presented in Attachment A. This Attachment also addresses suggested appropriate use of conservative values and bounding conditions.

Approach to Evaluating Representation of Process Models and TSPA-SR

The overall approach to this evaluation of conservatism was initially developed in a workshop at Lawrence Berkeley Laboratory in May 2000, to address realistic model components in the unsaturated and saturated flow models. DOE staff and managers, principal investigators, and performance assessment (PA) analysts met for two days to identify and evaluate model components significant to the unsaturated and saturated zone flow models. At the request of DOE, the MTS Team advanced this evaluation to consider all the process models making up the TSPA-SR.

The MTS team performing this activity consisted of the Process Model Report (PMR) and Analysis and Modeling Report (AMR) review leads, PA team members, technical managers, and regulatory team representatives. The evaluations were qualitative in nature. The Team collectively selected 87 model components that were considered to be 1) important to the make up of the process models and 2) potentially significant (specific influence on the PA results) to repository performance including peak dose. The basis for this selection of model components and their subsequent evaluations was the Team's knowledge of PMRs and AMRs, contents of the TSPA-SR, the design elements, and the testing program. The model components that were selected are listed in Attachment B. These model components were evaluated for their representation of features, events and processes associated with TSPA for a potential repository at Yucca Mountain, and to assess if there was available information that could be considered in any additional near term evaluations to better reflect a more realistic representation of behavior. Attachment C is the database for these qualitative analyses. It provides the detail of the analyses and includes:

- Rationale for selecting the levels of how representative the model components are of features, events, and processes of a potential repository at Yucca Mountain.

- Evaluation of model component importance to repository performance for the regulatory time-frame (10,000 years) and peak dose

- Availability of existing information not previously considered in the development of the process model or its components

- Assessment of the schedule for modifying the model components considering specific time frames leading to major program milestones and availability of additional information

The 87 model components were comparatively evaluated for importance; therefore, the designations of "high", "medium", or "low" should be considered relative to the selected group of model components specific to the process models they make up. Attachment B summarizes these evaluations and Attachment C provides the detail. To focus on those model components most important to the process models and repository performance those components ranked "low" for importance were given no further consideration.

Evaluation Results

The overall evaluation suggests that a limited number of model components of the process models are optimistic, a few are either very conservative or representative, and most are conservative in their representation of features, events, and processes significant to a potential repository at Yucca Mountain (see Attachment B). The amount of conservative model components within each process model makes quantifying the overall assessment of how representative the results of TSPA are very difficult. Preliminary TSPA results indicates that the repository performance within the regulatory time frame is dominated by the long lasting waste package concept. Taking this into consideration, those model components of each process model that were judged to be most significant to the process models and most important to long term repository performance are addressed in the following subsections.

Biosphere Model Components

The level of conservatism embedded in the parameters making up the biosphere models is primarily driven by regulatory requirements. None of the parameters were considered to be overly conservative or given a "high" assignment of importance. Some conservatism has been built into the Biosphere model, GENII-S, although the sum total is not considered to significantly impact the biosphere dose conversion factors. The conservatism attributed to the prescriptive nature of the proposed regulations include parameters such as:

- Prescribing 100 percent of the local groundwater available in the hypothetical farming community as contaminated

- Defining the critical group as those individuals residing within a farming community and exhibiting behaviors or characteristics that will result in the highest expected annual dose

Disruptive Events Model Components

Igneous Activity – Two conceptual models for disruptive events 1) Volcanic Eruption (extrusion) Model and 2) Igneous Intrusion Model comprise the igneous activity scenario. The Analysis and Model Report for igneous consequence modeling for the TSPA-SR describes two criteria that are used to evaluate the validity of the conceptual models. One criterion states that a conceptual model is valid if it is shown to be conservative with respect to the overall performance of the system in response to igneous disruption.

Depending how the disruptive igneous event is treated in TSPA for the regulatory timeframe, the consequences of potentially conservative modeling assumptions could be significant. Since the annual probability of igneous activity is on the order of one in a million to one in ten million, estimates of mean annual consequences are inherently different than for nominal case estimates. The following model components could negatively impact repository performance particularly for the volcanic eruption model; therefore, it is important that this disruptive event be treated separately from the nominal case for TSPA.

- Ability of future igneous activity to occur independent of structural controls
- Wind direction fixed to the south toward the critical group
- All volcanic eruptions are violent strombolian for their entire duration.

While the concept of violent strombolian for the duration of the eruption is conservative compared to observations in the region, large volume ash plumes may dilute the concentration of rationuclides; therefore the assumption could be optimistic in how it is treated in TSPA.

Seismic Activity – The near-surface (i.e., approximately first 1 km of the crust) attenuation of ground motion is expressed by the parameter kappa. The average value of kappa for sites at the surface of Yucca Mountain was previously estimated based on small to moderate magnitude aftershocks of the Little Skull Mountain earthquake of June 1992. The original analyses considered data from 12 sites, only two of which are located on tuff in the immediate YM area. More recent analyses have indicated that the earlier estimate of kappa is probably too small, which results in higher levels of ground motion (acceleration and velocity) predicted at the surface and potential repository level and would result in conservative seismic design inputs and an over design for surface facilities.

Kappa also directly affects the seismic hazard curve that is used in failure analyses of key underground and waste package components (i.e., spent nuclear fuel cladding). As demonstrated in the TSPA-SR, clad failure caused by seismic ground motion is an important contributor to peak dose as currently modeled. While a consensus on the magnitude of a possible change to the kappa value used in the determination of the probabilistic seismic hazard has not been reached, it does appear that the mean kappa value may increase which would lower the hazard. Incorporating a lower seismic hazard curve in clad failure modeling could lower the peak dose estimate.

Engineered Barrier System Model Components

Distribution of Seepage in the drift - Water seeping into the drift is assumed to (a) all get onto the drip shield and (b) be able to get into and through any existing breach in the drip shield. Each of these assumptions provides about a factor of 2 conservatism because (a) the drip shield projected area is about half the drift width and (b) any existing breach in the drip shield would occur on one side or the other of the drip shield for some period of time. The first aspect should be fairly constant, whereas the latter aspect would change with time as the drip shield incurred further breaches. However, the latter aspect also ignores the extent of the drip shield breaches, which should be much less than the length of the drip shield itself. The importance to peak dose is diminished by the relatively small percentage of packages/drip shields that actually get Seepage flux (about 10%); however, peak dose could increase significantly (three times (3X)) for long term climate (after a few thousand years) in TSPA.

Diffusion inside the Waste Package – There is no model for diffusion inside the waste package to limit the release rate in the absence of advective flow; therefore the assumption is that release is instantaneous. There is no data and no conceptual model developed for this process; however, if this could be modeled it could potentially have a high impact on reducing peak dose.

Evaporation of Water from the Waste Package - Preliminary calculations suggest that there is potentially enough decay heat produced by the spent fuel in the first 10,000 years to evaporate all of the water that could drip into a waste package based on current climate without flow focusing. If this could be demonstrated it could act as an effective "drip shield" and provide defense in depth as another barrier, thus supporting arguments for potential removal of the drip shield from the design.

Near Field Environment Model Components

The identified conservative or optimistic model components of this process model are assessed to not have large potential for impacting the resulting overall performance of the system given the current TSPA models. This is in part due to the level of conservatism/optimism represented by these, as well as due to the nature of the other subsystem models that would use the information generated from these models.

Use of Pore-Water Chloride – Measured values derived from the Topohah Spring welded tuff (TSw) pore waters are used as estimates for the boundary fracture water composition in the coupled thermal-hydrologic-chemical (THC) seepage model. This THC seepage model provides the boundary conditions for gas and water compositions entering the potential drifts. This water composition appears to be an end member and bound the chloride concentration (by about a factor of 2 to 3); however, it serves to provide a somewhat conservative constraint on the chloride content of fluids that are concentrated by evaporation in the drift. The importance of the conservatism depends on the response of conversion models to chloride concentration. Currently these models are insensitive to chloride concentration until very high values of chloride. Additional water compositions are being evaluated and their relevance will be assessed relative to how well they can be used to represent the ambient site geochemistry. These additional compositions could be used to decrease this somewhat conservative chloride concentration.

Thermally Perturbed Seepage Model – This model combines the ambient seepage model with the thermally perturbed percolation flux at 5 m above the drift as generated in the multi-scale thermo-hydrology model (MSTHM). The conservatism results from the coupling of two models (the ambient seepage model and the MSTHM) for use in the TSPA and the lack of fracture heterogeneity in the MSTHM representation. It is not currently demonstrated that heterogeneity in the geologic system will not lead to cases of seepage even during the thermal period. Therefore, the results of such homogeneous TH models (which indicate fracture dry out at the drift wall) are not used directly to drive the seepage model during the thermal period. This is somewhat conservative and should not have major impacts to dose consequences for two reasons. First, the effect is transient such that any discrepancy between fracture saturation at the drift wall versus 5 meters away decays as the peak thermal pulse decays. Any difference is gone after a few hundred (to about one thousand) years. Second, this enhanced seepage applies only for about 10 to 20% of the waste package locations.. The localized, transient nature of this model component decreases its capacity to have a major impact to the performance of the system. Additional analyses are being performed to incorporate the relevant scale of fracture heterogeneity into the thermal-hydrologic models. These analyses will be used to assess how much more realistic the thermal seepage model could be made within the SR to LA time frame.

THC Effects - There appear to be no lasting THC effects for the fracture permeability distribution in the system. This model component is neither conservative nor optimistic in contributing to performance given the large range of uncertainty; however, the values selected are at the optimistic end of the range. Based on the current THC model, this is the representative result. However, further THC sensitivity analyses will provide additional results that may indicate some changes to permeability. Because of the large changes needed to decrease the fracture permeability and the large margin (in terms of fluid flux capacity) in the permeability of the geologic system, this is not expected to have a major impact on the release of radionuclides to the accessible environment.

THC Alteration – Currently, there is no modeled THC alteration of the zeolitic units below the repository based on the thermal perturbation of the repository. Alteration of zeolites would release additional water and decrease the sorption path length. Not including such effects provides a somewhat optimistic view of the evolving unsaturated flow and transport pathway. However, for the current design this is expected to be a minor impact because of the temporal and spatial extent of the heating of the zeolitic zones. Duration of heating of zeolitic units will be relatively short and only a small part of the upper portion of the units will be affected above the lower temperature limit for such conversions. In addition, such alteration has been shown to be endothermic (requires heat) and therefore should result in even less propagation of the limiting temperature into the zeolitic zone. Therefore, this is not expected to lead to significant change to radionuclide transport, but ignoring any changes is somewhat optimistic. Analyses to assess the path lengths affected and the degree to which they are altered are being performed to quantify this within the SR to LA timeframe.

Unsaturated and Saturated Zone Model Components

Unsaturated zone (UZ) and saturated zone (SZ) groundwater flow had not been identified as principal factors in the Viability Assessment; hence the model components were developed using bounding rather than realistic parameters. The use of these bounding values resulted in groundwater travel times and the amount of water flowing through the UZ and SZ are perceived to be very conservative and considered by many Project participants (PIs) to not be defensible. The model components identified in this report are principally the result of principal investigator and DOE staff workshops held in May of 2000. In some cases actions have been taken by the Project to address those model components to develop a more realistic representation of UZ and SZ behavior (CR-M&O-00-084, "revise Project Baseline Work Scope for Development of an Expected Case Model for UZ and SZ Transport Behavior").

The list below contains the conservative conditions that affect TSPA as developed by the workshops. Of particular note are the flow and transport properties of faults and fractures in the Calico Hills non-welded (CHn) unit. The project's conceptual model of flow and transport views the hydrology in this unit as matrix-dominated leading to slow travel times and enhanced geochemical interaction with the rock mass. Lack of detailed understanding concerning the degree of fracturing led to the conservative position that this unit be considered fractured, which greatly increased the groundwater flow velocity though the unit. Similar conservatism was used for faults and fault properties especially in the CHn.

The following prioritized list summarizes the parameters for the unsaturated zone (UZ) that are conservatively applied in the respective process models. These parameters are predominately used in groundwater travel time calculations and will be re-evaluated for the expected case scenario. The expected case scenario is defined as a representation of the combined natural and engineered system that is judged to reflect the reasonably expected behavior of the system and its components. The list for the SZ is prioritized by the parameters that would affect the TSPA calculations the most if the uncertainty in each were reduced accordingly. Consideration of representative parameters would increase transport time and would push peak dose out in time. The UZ parameters are:

- Fracture flow in the Calico Hills nonwelded vitric tuff unit
- Different flow and transport computational methods
- Perched water models and lateral diversion
- Fault properties in the Calico Hills
- Synthesis of geochemical information
- Spatial distribution of infiltration and percolation
- Effects of drift degradation on drift seepage
- Effects of flow focusing on drift seepage
- Effects of episodic flow on drift seepage
- Gridding methods for the dual-permeability model

A similar list of model components was drawn up for the saturated zone models. The workshops were held prior to the reviews of the SZ PMR and subsequent reviews identified an additional conservatism that strongly affects groundwater travel times. The current SZ model consists of Monte Carlo simulations where the properties that are randomly sampled from distributions are assigned homogeneously to each layer. A more defensible approach would involve assigning properties heterogeneously to elements within each layer. When properties are assigned heterogeneously to each layer realization that produces a set of values that are all on the high or low side of mean porosity will result in an extreme high or low travel time. Consequently, individual realizations in the SZ model vary from a few years to several thousand years for breakthrough. This potentially non-representative approach does not likely affect the median travel times, but it does create extremes of high or low rates. In addition to this consideration the following model components were identified by the PI workshops for creating more realistic models. The SZ parameters are:

- Uncertainty distribution for specific discharge (groundwater flux).
- Effective diffusion coefficient.
- Implementation in the SZ flow and transport model;
  - conceptual model of colloid filtration,
  - Kc model parameter for colloid-facilitated transport,
  - only fracture flow in volcanic units (no matrix flow), and
  - no sorption in fractures.
- Uncertainty in the northern and western boundary of the alluvium.
- Sorption coefficients in the alluvium and volcanic units.
- Flowing interval porosity and spacing.

Waste Form Model Components

Secondary Phase or Recurring Conditions - The abstracted CSNF (commercial spent nuclear fuel) dissolution model was based on a large set of qualified flow-through experiments. This model was compared to unsaturated drip tests, batch tests, and a range of literature results. The model and uncertainty range adequately accounted for, or overestimated, all dissolution rate data. In addition, a comparison of the phases produced in the unsaturated drip tests compare well with that of natural analogs (from WF PMR, Section 3.3.2).

Fast rates are used to bound the upper end of uncertainties. Secondary phases were excluded because experimental results were inconclusive with regard to effect of such phases on degradation mechanisms. The PA Peer Review Panel (Budnitz et al. 1999) conservative approach since secondary phases would retard radionuclide release from CSNF that in turn may reduce peak dose.

Waste Form Solubility – Considerable discussion has focused on Np-bearing phase(s) that could form under repository conditions. Thermodynamically, NpO_2 is the stable phase. However, it has not been observed in solubility experiments, except for some unusual conditions. It is believed that a kinetic barrier prevents NpO_2 from precipitating.

Analysis of the stability field for Np(V) solid phases concluded that Np_2O_5 is the solubility controlling phase in J-13 well water (From Summary of Dissolved Concentration Limits AMR, Section 6.4.2). Using high Np solubility bounds uncertainties and is conservative, since using a low solubility value (if shown to be the case) will retard Np release and hence, may reduce peak dose. The present approach resulted from analyses of the currently available data on Np-bearing phases and solubility. Further analyses would be required to reduce conservatism in this bounding approach.

Waste Form Colloids - The abstractions are based on laboratory results from waste form corrosion testing and testing of adsorption and de-sorption properties of Pu and Am on clay and iron-(hydr)oxide colloids. To the extent that the laboratory tests and test conditions represent anticipated repository conditions, the abstraction is valid for calculating the colloid-associated radionuclide concentrations and colloid mass concentrations. The approach for the colloidal-radionuclide source term is based on YM-specific field and laboratory studies and results from YM-relevant studies.

The colloids formed from CSNF and DSNF are assumed to have reversibly attached radionuclides; and this assumption is potentially non-conservative and remains to be verified when results from on-going tests become available (Section 3.8.2.2 of the WF PMR).

Cladding fragility - The basis for matrix exposure analysis are measurements of gap inventories, experimental measurements of the release of radionuclides from damaged cladding, and intrinsic dissolution measurements. Although unzipping has not been observed for rods in storage pools for the past 40 years, the unzipping analysis is consistent with dry unzipping experiments. Uncertainties have been defined that are based on both experiments and extremes in the analysis. Therefore, this analysis is appropriate for TSPA-SR. Although it is conservative, it is not as conservative as the assumption of instantaneous unzipping to expose the CSNF that was used in TSPA -VA (From WF PMR, Section 3.4.2.7).

Seismic clad failure estimates include conservative inputs in order to simplify the analysis. Recent peak dose estimates (post 10,000 years) indicate that clad failure from strong ground motions is a significant contributor (about 25%) in determining peak dose. Reduction in clad failure estimates could significantly reduce peak dose estimates.

Waste Package Model Components

The waste package degradation process model components are based on limited testing and our basic understanding of material engineering; however, no information (analogs) exists on the performance of engineered materials for the necessary time frames of performance. In addition, no non-mechanistic, pre-specified number of waste package early breaches were included in the SR base case models (TSPA-SR does include a non-mechanistic waste package early breach as a sensitivity study). Projecting the performance of engineered materials for thousands of years is unprecedented; therefore, considerable uncertainty may exist in this model. The following are model components identified as conservative in this process model.

Waste Package Materials - The level of conservatism in the model components making up the Waste Package Degradation models is primarily used to bound uncertainties in degradation phenomena. None of the parameters were considered to be overly conservative or given a "high" assignment of importance. Reducing conservatism in these parameters would increase the expected life of the waste package.

The waste package model components were generally judged as conservative by the MTS Team members; however, it is conceivable that the performance projections are less conservative than suggested. The evaluation concluded that considerable uncertainty may exist in waste package performance with the unprecedented projections of long-term performance and limited available information. Non-mechanistic juvenile failure was not explicitly considered in TSPA and therefore is not evaluated as a model component in this report. While it is assumed that waste packages may have manufacturing defects and may be damaged during emplacement and operations; however, there is no mechanism for failure. The inability to identify juvenile failure may lead to optimistic projections of waste package performance.

Conclusions

Many of the model components making up the process models and expected to be significant to repository performance are conservative. The selection of conservative representations appears to have been driven by uncertainty in the amount of relevant data, data analyses and modeling results.

The use of conservatism in the process models appears to be compounded in the model abstractions and TSPA-SR. This may lead to system model results that are unrealistically conservative (i.e., the model significantly underestimates performance). The most significant impact to the process models and TSPA are summarized below.

- TSPA-SR results may mask performance sensitivities and the relative importance of identified uncertainties with compounded conservatism. Such a lack of sensitivity may result in model components or features, events, and processes being characterized as not important to waste isolation.

- Lack of quantifiable model component uncertainties contributes to the inability to clearly understand how representative TSPA results are. This could have a significant impact on the ability to demonstrate the existence and contributions of multiple engineered and natural barriers to overall system performance.

- Ability to move to more conservative model components may not be possible during the regulatory process if the DOE adopts overly conservative models going into LA. Regardless of the level of conservatism adopted by the DOE, the NRC will have a different perspective and may lead to the DOE going to greater levels of conservatism.

- Compounded conservatism or overly conservative performance assessments may lead to the perception among external parties that the natural and engineered systems are not sufficiently understood to accurately represent repository performance.

- Some of the model components were identified as having a potentially significant affect on long term performance (peak dose). In addition, some model components of the Disruptive Events Process Model were identified as affecting dose in the regulatory time frame. Reduction in the conservative representation of these model components could positively enhance long term performance in time and magnitude, and further reduce dose in the igneous disruptive event scenario. Those model components that may affect long term performance are summarized as follows:

- Assumption that all seepage begins at the crown of the drift is conservative and should be reassessed – modify for LA by December 2002

- All waste is wetted from any seepage into the waste package is very conservative; however there are not planned activities to address this – identify work and address by LA in December 2002

- Determine secondary phases for waste form – analyses can be completed by December 2002 for LA.

- Re-evaluate data to determine more representative values for Np and other radionuclide solubilities – analyses can be complete by December 2000.

- Determine more reasonable waste form colloid conditions (high sorption coefficients and irreversibility) – analyses can be completed by December 2002.

- Re-evaluate seismic clad failure estimates using more representative system modeling – analyses can be completed by April 2001 for inclusion in TSPA for SR.

Model components of the igneous disruptive events scenario that most significantly impact dose are summarized as follows:

- Large eruptive volume may result in dilution of radionuclide concentration is optimistic assumption in terms of dose – re-evaluate models to remove optimisim by December 2000

- Waste packages next to dike fail completely is somewhat conservative – there are no plans to modify this assumption

- Centering the eruptive scenario on the drift is conservative – reconsider more random distribution by December 2000

- Fixed wind direction to compensate for surface redistribution may be conservative, but is an indirect way of addressing contaminated soil redistribution – consider better definition of these scenarios by SR in April 2001.

The evaluation also identified optimism in some model components. These model components should be carefully re-evaluated and a more representative condition may want to be considered. The optimistic model components identified in this assessment are listed below.

- Volcanic disruptive event ash plume height, dispersion speed, and potential for higher dose to critical group – re-evaluate this by December 2000.

- No alteration of the zeolites under the thermal pulse is of low importance; therefore, no further consideration is necessary.

- No lasting changes to the fracture permeability in the UZ, due to coupled THC, is an optimistic assumption, but there are no plans to re-evaluate.

- Higher infiltration rates and episodic infiltration for extreme climate conditions should be considered – modify assumptions for December 2000.

- Although not explicitly addressed in this evaluation, it is conceivable that waste package performance projections may be less conservative than currently estimated because of the absence of juvenile failure mechanisms – explore mechanisms for juvenile failure by LA in 2002.

Recommendations

The approach to PA modeling to demonstrate compliance with the postclosure criteria for site suitability and licensing should consider the NRC's and EPA's positions (Attachment A) that TSPA should, to the extent possible, include a "credible representation" of the geologic repository system with "representative parameter distributions."

Models used to evaluate compliance with regulatory requirements for repository system performance after closure should reflect a credible representation of the natural and engineered system unless the uncertainty is so great that only a conservative representation can be made. In such a case the uncertainty should to the extent possible be quantified. This approach should be followed for both the postclosure site suitability evaluation performed for SR and the postclosure compliance evaluation presented in the LA. To the extent possible, the goal should be to present the most representative analysis of system performance that is permitted by the data that are available and the models that are consistent with and supported by these data and a quantified assessment of associated uncertainties.

The levels of conservatism associated with the component models most significant to long term performance should be reassessed in an attempt to achieve more realistic representations. Those model components recognized as optimistic should also be considered in any reassessment of their representation. Serious consideration should be given to explicitly considering juvenile failure of waste packages in TSPA. This should include a review of the current work activities and available information related to these model components. This assessment suggests that many of the model components can be addressed prior to LA and in some cases prior to SR.

The results of this report should form the basis for the follow on task to address unquantified uncertainties. The identification of model components important to the make up of the process models and repository performance should be given further consideration as candidates for the analysis of unquantified uncertainties, particularly those assessed as having high importance and conservative.

Attachment A

REGULATORY STATEMENTS AND APPROPRIATE USE OF CONSERVATIVE REPRESENTATIONS

Statements from NRC and EPA Documents Establishing the Framework and Providing Guidance for Performance Assessment Models

The Nuclear Regulatory Commission (NRC) stated its expectation for the DOE's performance assessment model in the Supplementary Information for its proposed repository licensing criteria at 10 CFR Part 63 (64 FR 8651):

> *"To the extent that DOE's performance assessment provides a credible representation of a geologic repository, the Commission expects no more than that and believes that no more is needed."*

The NRC describes its regulatory approach to decision-making in section 63.101 of its proposed rule (64 FR 8674):

> *Although the performance objective for the geologic repository after permanent closure . . . is generally stated in unqualified terms, it is not expected that complete assurance that the requirement will be met can be presented. A reasonable assurance, on the basis of the record before the Commission, that the performance objective will be met is the general standard that is required. Proof that the geologic repository will be in conformance with the objective for postclosure performance is not to be had in the ordinary sense of the word because of the uncertainties inherent in the understanding of the evolution of the geologic setting, biosphere, and engineered barrier system. For such long-term performance, what is required is reasonable assurance, making allowance for the time period, hazards, and uncertainties involved, that the outcome will be in conformance with the objective for postclosure performance of the geologic repository. Demonstrating compliance will involve the use of complex predictive models that are supported by limited data from field and laboratory tests, site-specific monitoring, and natural analog studies that may be supplemented with prevalent expert judgment. Further, in reaching a determination of reasonable assurance, the Commission may supplement numerical analyses with qualitative judgments including, for example, consideration of the degree of diversity among the multiple barriers as a measure of the resiliency of the geologic repository.*

The NRC defines its postclosure performance objective in terms of the "expected annual dose," which is defined as:

> *. . . the expected value of the annual dose considering the probability of the occurrence of the events and the uncertainty, or variability, in parameter values used to describe the behavior of the geologic repository.* [section 63.2, 64 FR 8664]

In an April 8, 1999 letter to the Commission commenting on the NRC staff review of the DOE's Viability Assessment (VA), the Advisory Committee on Nuclear Waste (ACNW) made a relevant observation (page 5) about the appropriate place for the application of conservatism in regulating nuclear facilities:

> *". . . the appropriate place for conservatism is in the choice of a probability of exceedence of a risk standard.*
>
> *"In the case of a PA for a geological repository, we believe that the analysis should be performed with as nearly realistic assumptions, models, and parameters as possible, including the uncertainty involved. The resultant* [cumulative probability distribution function for annual dose] *derived from the PA would show explicitly the probability that a standard would be exceeded.*
>
> *". . . a licensing decision would not be based exclusively on the probability (i.e., the* [proposed] *regulation is risk-informed rather than risk-based), but the decision about conservatism is made with the clearest view of the issues after the best information available has been used in an analysis."*

The EPA explains its regulatory approach regarding the basis for determining compliance with the proposed standards:

> *. . . we are proposing the concept of "reasonable expectation" to reflect our intent regarding the level of "proof" necessary for NRC to determine whether the projected performance of the Yucca Mountain disposal system complies with the standards . . . . We intend for this term to convey our position and intent that unequivocal numerical proof of compliance is neither necessary nor likely to be obtainable.* [64 FR 46997]
>
> *In carrying out performance assessments under a "reasonable expectation" approach, all parameters that significantly affect performance would be identified and included in the assessments. The distribution of values for these parameters would be made to the limits of confidence possible for the expected conditions in the natural and engineered barriers and the inherent uncertainties involved in estimating those values. Selecting parameter values for quantitative performance assessments would focus upon the full range of defensible and reasonable parameter distributions rather than focusing only upon the tails of the distributions . . . . The "reasonable expectation" approach also would not exclude*

important parameters from the assessments because they are difficult to quantify to a high degree of confidence. . . . Overestimating or underestimating the values of parameters, or ignoring the positive effects upon performance for other processes and parameters because they cannot be precisely estimated, would essentially result in the performance assessments actually being analyses of extreme performance scenarios. These extreme assessments have a high probability of being unrealistic or of such low probability that they would not represent the range of likely performance for the disposal system. [64 FR 46997-46998]

The proposed EPA standard at 40 CFR part 197 requires the following:

> *The DOE must demonstrate to NRC that there is a reasonable expectation of compliance with* [the environmental standards for disposal] *before NRC can issue a license.* [section 197.13, 64 FR 47014]
>
> *Reasonable expectation means that the Commission is satisfied that compliance will be achieved based upon the full record before it. Reasonable expectation:*
>
> *(a) Requires less than absolute proof because absolute proof is impossible to attain for disposal due to the uncertainty of projecting long-term performance;*
>
> . . .
>
> *(c) Takes into account the inherently greater uncertainties in making long-term projections of the performance of the Yucca Mountain disposal system;*
>
> *(d) Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify to a high degree of confidence; and*
>
> *(e) Focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values.* [section 197.14, 64 FR 47014]

Appropriate Use of Bounding/Conservative Representations for Modeling

If the data are limited, or models cannot otherwise be constrained, a bounding or appropriately conservative approach is likely to provide the only credible representation for modeling the behavior of a particular system component. This approach should be the exception, not the rule in modeling for performance analyses.

If the results and conclusions of the performance analysis are not significantly affected by the use of a bounding/conservative approach in representing a particular system component or process (i.e., performance is insensitive to whether a credible or a conservative representation is used), the use of such an approach could simplify the analysis. However, such simplification should only be applied after there is a clear understanding of the potential contribution of each system component or process independent of the other elements of the system. Such an understanding is necessary because the potential contribution of one component or process to overall system performance may be masked by the contribution of other components or processes. To identify those components and related processes that individually (or collectively) have the potential to significantly affect performance, each component or process must be modeled using a credible representation and appropriate steps taken to ensure that masking effects are accounted for in the analyses. Only then can appropriate simplifications be introduced in the system model and defensible conclusions about compliance be drawn from the results.

Where data are available and models can be developed based on these data that will provide a credible representation of anticipated/reasonably expected system behavior, conservative/bounding representations should be avoided for the reasons noted above. It is also not appropriate to use conservative/bounding approaches to limit the range of factors considered in the performance assessment model in order to avoid areas of uncertainty or because the factors are difficult to characterize and quantify. A probabilistic analysis, which is required by the regulations for a demonstration of compliance, provides the greatest information for decision-making when it is based on a credible representation of system behavior and uncertainty is appropriately quantified in the ranges of input parameters used. Selection of conservative representations focuses on the tails of the probability distributions and misrepresents both the reasonably expected behavior and the significance of the uncertainty.

For the purpose of the performance assessment that will support the postclosure site suitability determination and the SR, it is important to distinguish between using the best available data and models to provide a credible representation of the system, and the qualification/validation status of these data and models. Although the goal is to have a substantial portion of the data qualified and the models validated for the site suitability determination and SR, the more important goal is to have a credible, defensible, and traceable basis for the performance analysis. It is therefore inappropriate to employ conservative/bounding approaches in an effort to simplify the process for the qualification of data, or the verification of its qualification status, and the validation of the models that are the basis for the system performance analysis.

Attachment B

Work Prioritization Tables for Conservative Process Model Parameters

Importance to Repository Performance:
1. High
2. Medium
3. Low

PD – Important to peak dose
RMD – Important to regulatory time frame maximum dose
* - Currently being re-evaluated as part of representative case

Ability to Modify Model Based on Availability of Needed Information
A. Choose – Data and analysis exist
B. Analyze – Data exists, needs re-analysis
C. Collect – Data being collected, needs analysis
D. Plan Analyses – Data analyses need to be planned
E. Plan Tests – Needs to be executed or planned for data collection
F. Regulatory Requirements - Constrained by regulatory requirement

Availability of Results (Schedule)
I. By DOE/HQ review of the SRCR (September 30, 2000)
II. By release of the SRCR (Dec., '00)
III. By HQ review of the SR (April, '01)
IV. For input into the LA (Oct.-Dec., '02)
V. Can't be done

PMR and Assumption or Parameter	Level	Import.	Ability to Mod.	Results
Biosphere				
Disruptive Volcanic Event Scenario assumes that volcanic eruption would result in a thin ash deposition on surface	Representative	L	-	-
Drinking Water Treatment and Holdup Time	Representative	L	-	-
Depth of Surface Soil	Representative	L	-	-
Population Statistics	Representative	L	-	-
Annual Groundwater Usage	Representative	M	F	V
Site Specific Data vs. Literature Findings	Representative	L	-	-
RMEI vs. Average Member of the Critical Group	Somewhat Conservative	L	-	-
Fraction of Water that is Contaminated	Conservative	M	F	V
GENII-S Code and Input Parameters	Conservative	L	-	-
Dose Conversion Factors (DCF's) for Internal Exposure	Conservative	M	F	V
The Disruptive Volcanic Event Scenario	Optimistic	L	-	-

Disruptive Events				
Ash particle distribution used in TSPA	Representative	M	D	V
Assumed that only those waste packages located partially or entirely within the area of the eruptive conduit contribute to the radionuclide source term for the dispersal calculation	Representative	M	D	V
Intrusions that come within 300m of the surface are assumed to erupt somewhere along the length of the dike	Representative	M	-	-
Igneous Event Probabilities – Assumption that the event probabilities established in the AMR Char Igneous Activity pertain to the formation of a new volcano	Representative	H	-	-
Intrusive scenario – Any waste packages, drip shields, and other components of the EBS that are adjacent to an intrusive dike (3 packages on either side) fail completely	Somewhat Conservative	M(RMD)	B	V
Possible structural control (fault capture) and lateral diversion of ascending basaltic dikes from the repository block is not considered. Lack of detailed information on near-surface structural features	Somewhat Conservative	M	B	IV
Wind direction fixed in base case toward the critical group. While this assumption overestimates the dose, it is intended to compensate for surface redistribution processes not explicitly accounted for in TSPA. The representativeness of this assumption depends on how it treats surface redistribution.	Conservative	H(RMD)	A	II
Extrusive eruptive conduits that partially intersect drifts are assumed to be centered on the drifts. This mathematical simplification results in affecting more waste packages	Conservative	M(RMD)	B	II
All eruptions are violent strombolian for their entire duration (dependent on eruptive volume) with fragmentation of the ascending magma occurring below the repository horizon.	Conservative	M	B	III
Seismic Kappa – near surface attenuation parameter assigned a relatively conservative value based on limited data	Conservative	M	B & C	III
All waste is assumed to be unaltered commercial spent fuel for the purpose of estimating waste particle diameters in the eruptive environment. Reduced to small grain sizes.	Conservative	L	-	-
Erupted volume is assumed based on a combination of YM and very large modern volcanoes.	Eruption – Very Conservative	H(RMD)	A	III
Sensitivity analyses to date indicate that the inclusion of very large eruptive volumes may in fact lower the mean dose. More definitive results depend on incorporation of higher altitude wind data corresponding to heights of ash plumes associated with the larger volume eruptions.	Calculated Dose – Somewhat Optimistic	M(RMD)	A	II

EBS				
Invert diffusion – Uses a curve fit through the data and uncertainty, with a conservative adjustment of 30% to the mean of that fit for D as a function of porosity and saturation in the invert	Representative	H (PD)	A	I
Thermal expansion, floor heave, rock fall, seismic response, and emplacement pallet failure screened out	Representative	L	-	-
Sorption in WP and invert ignored	Somewhat Conservative	L	-	-
Diffusion in WP – Starts when Stress Corrosion Cracking exists because of assumed liquid pathway	Somewhat Conservative	L	-	-
Seepage in Drift – All seepage assumed to start at the crown of drift or drip shield so it all falls on drip shield or WP and has greatest probability of entering a hole	Somewhat Conservative	L (PD)	-	-
EBS Diffusion – Pallet is ignored and waste package is in intimate contact with invert	Somewhat Conservative	L	-	-
All mass moved to inner surface of WP – All mass is contacted by any seepage flux into the WP	Very Conservative	H (PD)	D	V
Evaporation of water from WP is neglected	Very Conservative	H	D	III
Near Field				
Seepage – No dryout during ventilation period and no dryout during thermal period (input to seepage model is 5 meters above the drift)	Somewhat Conservative	M	B & C	IV
Use of the pore-water CL-composition to represent the infiltration water provides an upper bound to the starting chloride concentration of ambient fluids moving potentially through the fractures	Somewhat Conservative	L	-	-
No alteration of zeolitic units under the repository calculated based on the thermal perturbation	Somewhat Optimistic	L (PD)	-	-
No lasting changes to the fracture permeability in the UZ due to coupled THC processes	Somewhat Optimistic	M	A-D	V
SZ – From May 11-12, 2000 Assessments at LBL				
Specific Discharge (Groundwater Flux)	Conservative	H*	C	II
Effective Diffusion Coefficient	Conservative	M	A	II
Sorption Coefficients for Alluvium	Conservative	H	C	IV
Flowing Interval Porosity (Fracture Porosity)	Conservative	H*	A & B	II
Conceptual Model of Colloid Filtration	Conservative	M	D	IV
Kc Model Parameters for Colloid-Facilitated Transport	Conservative	M	D	IV
Sorption Coefficients for Volcanic Units	Very Conservative	L	-	-
Homogeneous properties of hydrologic units used in Monte Carlo simulations	Very Conservative	H	B	II
Flowing Interval Spacing	Very Conservative	M*	B	IV

SZ - From May 11-12, 2000 Assessments at LBL				
Western boundary of Alluvial Uncertainty Zone. Short Term Long Term	Very Conservative	H*	C	II
Northern Boundary of the Alluvial Uncertainty Zone	Very Conservative	H*	A	II
No Sorption in Fractures	Very Conservative	L	-	-
Only Fracture Flow in Volcanic Units (no matrix flow)	Very Conservative	L	-	-
UZ - From May 11-12, 2000 Assessments at LBL				
Fracture porosity set to about 1%	Representative	-	-	-
Thermo-mechanical effects on seepage neglected	Somewhat Conservative	L	-	-
Thermal effects on Flow/transport are neglected	Somewhat Conservative	M	B & C	IV
Coupled process effects on flow/transport are neglected	Conservative	H*	B & C	II
Thermal effects on flow properties are neglected	Conservative	M	B	IV
Fracture-matrix interaction (and fracture velocities) determined by active fracture model	Conservative	H*	B	II
Broad Uncertainty and variability distributions used for K/alpha parameter	Conservative	M	B	II
Divetsion of flow and transport around the perched water rather than through it might be conservative	Conservative	H*	B	II
Broad Uncertainty distributions used for flow-focusing factor	Conservative	H*	B	II
Colloid concentration and Kd's used to calculate Kc	Conservative	M	E	IV
FEHM particle-tracking method appears to be conservative compared to the DCPT or T2R3D methods	Conservative	H*	B	II
Seepage into drift specified seepage abstraction when drift wall is above boiling	Conservative	H*	B & C	II
All seepage into drift is counted (not just seepage above waste package) Consider allowance for film flow in drifts	Conservative	H*	B	II
Mountain scale TMH	Conservative	M	B & C	IV
Physical colloid filtration is neglected in most situations; in particular it is always neglected for transport in fractures	Conservative	M	E	IV
All host units treated the same in seepage abstraction	Conservative	H*	C	IV
Rc is neglected for reversible colloids in the SZ and for all colloids in the UZ	Conservative	M	E	III
Uncertainty distributions for Diffusion coefficient are higher in UZ than SZ	Conservative	M	B	III
Lithophysal porosity	Conservative	H	C	IV
All nuclides introduced into fractures	Conservative	M	A	I
Seep flux increased by 10% to account for possible correlation of k and alpha	Conservative	L	-	-
Thermal effect on Kd	Conservative	M	B	III
Single grid matrix	Conservative	H*	B & C	II
Fault Properties in CHn	Conservative	H*	E	IV

UZ – From May 11-12, 2000 Assessments at LBL-Cont.				
Flow models may have a significant amount of Fracture flow through the CHnv unit	**Very Conservative**	**H***	**B & C**	**II**
Episodic flow/seepage neglected	**Somewhat Optimistic**	**H**	**B**	**I**
High Infiltration case should be higher	**Optimistic**	**H***	**B**	**II**
Waste Form				
Colloid stability	**Representative**	**M**	**-**	**-**
DSNF degradation: No cladding credit is assumed, and characteristics of N-reactor fuel are assumed (dissolution occurs in one time step of TSPA) Cladding is not as robust or thick as that for CSNF	**Representative**	**L**	**-**	**-**
Local corrosion and unzipping of cladding are assumed to occur.	**Conservative**	**M**	**E**	**V**
HLW degradation: Fast degradation rates are assumed	**Conservative**	**L**	**-**	**-**
Waste form solubility: High Np solubility assumed to be controlled by Np205.	**Conservative**	**H (PD)**	**B & C**	**II**
Waste form colloids: High sorption coefficients are used and some colloids assumed to be highly irreversible	**Conservative**	**M (PD)**	**C**	**IV**
No secondary phases are assumed for CSNF degradation, which results in a fast degradation rate	**Conservative**	**M (PD)**	**C**	**IV**
Clad failure due to low probability seismic event contributes significantly to peak dose calculation	**Very Conservative**	**H(PD)**	**B & C**	**III**
Waste Package				
To address the effects of microbiological induced corrosion (MIC), an enhancement factor of 2.0 is applied to the corrosion rate of the waste package	**Representative**	**L**	**-**	**-**
Welded regions of the waste package are assumed to be 100% aged, and as a result, an enhancement factor of 2.5 is applied to the corrosion rate	**Representative**	**L**	**-**	**-**
Drift assumed to be wet at 50% relative humidity. This controls the chemical composition of water reacting with waste form	**Somewhat Conservative**	**L**	**-**	**-**
Environments for general/local corrosion and SCC tests are aggressive, yet plausible under repository conditions	**Conservative**	**L**	**-**	**-**
No credit is taken for crack initiation in stress corrosion cracking (SCC) modeling	**Conservative**	**L**	**-**	**-**

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