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August 2006

BECHTEL SAIC COMPANY LLC

Technical Work Plan for:

Additional Multiscale Thermohydrologic Modeling

Prepared for:
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CHANGE HISTORY

Revision Number	ICN Number	Date of Change	Description of Change
00	00	10/21/2006	Initial Issue.
01	00	05/23/2006	This technical work plan supersedes TWP-MGR-PA-000036, REV 00, *Technical Work Plan for: Additional Multiscale Thermohydrologic Modeling*. Revision addresses the following: CRs 5154, 6543, 6521, and 6730; updated IED information; and the development, implementation, and validation of a revised methodology for generating thermal-hydrologic submodels. Revised methodology will conduct MSTHM calculations out to 1,000,000 years. Change bars were not used because changes to this revision were too extensive.
02	00	08/24/2006	Revision describes the use of a version of the updated calibrated hydrologic properties; the use of interpolation among a set of generic thermal-hydrologic submodels that are run for a range of percolation flux histories that cover a sufficiently broad range of infiltration flux uncertainty for four host-rock units and three thermal property sets; and development of a set of appropriately averaged thermal property values for the non-host-rock units. Validation activities for the multiscale thermohydrologic model will involve the validation of the model as a whole, and the validation and testing of certain submodels, or components.

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TABLE

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ACRONYMS

CPU	central processing unit
CR	Condition Report
DDT	three-dimensional discrete-heat-source, drift-scale, thermal-conduction (submodel)
DST	Drift Scale Test
EBS	engineered barrier system
FEP	feature, event, and process
IED	information exchange drawing
LDTH	line-averaged-heat-source, drift-scale, thermal-hydrologic (submodel)
MSTHM	multiscale thermohydrologic model
QA	quality assurance
QARD	*Quality Assurance Requirements and Description*
RH	relative humidity
RPC	Records Processing Center
SDT	smeared-heat-source, drift-scale, thermal-conduction (submodel)
SMT	smeared-heat-source, mountain-scale, thermal-conduction (submodel)
TAD	transport, aging, and disposal (canister)
TDMS	Technical Data Management System
TH	thermal-hydrologic
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
TWP	technical work plan
UZ	unsaturated zone

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1. WORK SCOPE

This technical work plan (TWP) addresses additional activities for the model developed in *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The additional activities will incorporate updated parameters, such as percolation flux and the calibrated hydrologic properties, and information, including information exchange drawings (IEDs) utilized by the multiscale thermohydrologic model (MSTHM), and will extend the MSTHM analyses out to 1,000,000 years. The applied calibrated hydrologic properties will be an updated version of those available in *Calibrated Properties Model* (BSC 2004 [DIRS 169857]). These updated properties will be documented in an Appendix of Revision 03 of *UZ Flow Models and Submodels* (BSC 2004 [DIRS 169861]). The updated calibrated properties are applied because they represent the latest available information. The reasonableness of applying the updated calibrated properties to the prediction of near-field/in-drift thermal-hydrologic (TH) conditions will be evaluated and justified. Some of this evaluation will be conducted in conjunction with the post-model development validation activity involving comparisons of predicted TH conditions with measured TH conditions in the Drift Scale Test (DST).

Other planned activities are related to the development, implementation, and testing of a revised TH submodel-construction approach. This new approach utilizes interpolation among a set of generic TH submodels that are run for a range of percolation flux histories that cover a sufficiently broad range of infiltration flux uncertainty, as well as for four host-rock units (two lithophysal units and two nonlithophysal units), and for three thermal property sets (low, mean, and high). In addition, planned activities include developing a set of appropriately averaged thermal property values for non-host-rock (i.e., non-repository) units. The use of effective averages for the non-host-rock thermal properties results in the same predicted near-field TH behavior as that resulting from a detailed representation of far-field thermal properties. The reduction in the degree of complexity in the thermal property distributions will facilitate the defense of the TH submodels.

Validation of the MSTHM involves the validation of the MSTHM as a whole, and the validation and testing of certain submodels, or components, used in the MSTHM. While most of these testing and validation activities were completed for Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 7), all validation and testing activities will be redone for Revision 04 of this report. Moreover, model development testing activities have been added that specifically pertain to the revised construction approach for the line-averaged-heat-source, drift-scale, thermal-hydrologic (LDTH) submodel.

Additional activities are also required to address Condition Reports (CRs) 5154, 6521, 6543 and 6730. These additional activities in terms of work scope are described in Section 1.2.1.

The condition description in CR 5154 states that the hydrologic properties of the intergranular porosity of the invert ballast used in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) are inconsistent with the grading-compaction given in the current design (BSC 2004 [DIRS 168138]; BSC 2004 [DIRS 168489]).

The condition description for CR 6521 pertains to the heat-generation tables used in two out of the eight waste packages represented in the three-dimensional discrete-heat-source, drift-scale, thermal-conduction (DDT) submodel of the MSTHM (BSC 2005 [DIRS 173944], Section 6.2.8). Revision 04 of the MSTHM report will generate a revised set of repository-wide MSTHM results that will incorporate the necessary heat-generation corrections identified in CR 6521.

The condition description for CR 6543 pertains to an incompatibility between the software routine reformat_EXT_to_TSPA v1.0 (LLNL 2003 [DIRS 164272], STN: 11061-1.0-00) and output from MSTHAC v7.0 (LLNL 2002 [DIRS 164274], STN: 10419-7.0-00). This incompatibility only affected total system performance assessment (TSPA) bin files generated from Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), which are being replaced by TSPA bin files that will be generated for the updated set of repository-wide MSTHM results created for Revision 04 of the MSTHM report. This incompatibility will be corrected in a new revision to software routine reformat_EXT_to_TSPA, which will be qualified (as Version 2.0) and applied to generate revised TSPA bin files for the updated set of repository-wide MSTHM results generated for Revision 04 of the MSTHM report.

The condition description for CR 6730 pertains to the 50 representative TSPA bins that are provided to the TSPA model with the intention of being representative of the broad spectrum of TH histories across the repository and for the five uncertainty cases. The number of bins arises from two waste package types (CSNF and DHLW), five percolation flux bins, and five percolation flux/host-rock thermal conductivity uncertainty cases. The current approach is to generate, using software routine reformat_EXT_to_TSPA v1.0, only the 50th percentile waste package with respect to peak temperature and boiling duration. This approach does not sample waste packages at either the hotter/longer-boiling-period or cooler/shorter-boiling-period ends of the spectrum. To address CR 6730, after revision of software routine reformat_EXT_to_TSPA v1.0 (as discussed above, resulting in Version 2.0), the software will provide the option of selecting additional TSPA bins with respect to temperature/boiling duration, such as the 10th and 90th percentiles. Additional TSPA bins can then be generated, in collaboration with TSPA, for impact analyses and/or performance assessment. Note that the addition of any percentile bins will only occur after collaboration with TSPA to assure that the intended data are provided in an appropriate manner. Information describing the shape/type of the probability density functions of temperature for the entire waste package inventory, and for the various uncertainty cases, will be passed on to TSPA to assist in the selection of percentiles.

The process to identify and describe parameters that are used in the TSPA model, and subsequently enter and maintain theses parameters in the TSPA input database, is presented in PA-DSK-1002, *TSPA Model Parameter Entry Forms Process*. The use of this process ensures that the selected percentiles (there will be one or more) are used in an appropriate manner as documented in the parameter entry form controlling MSTHM feeds to TSPA.

This TWP, which was prepared in accordance with LP-2.29Q-BSC, *Planning for Scientific Activities*, covers the plans for Revision 04 of the MSTHM report. This TWP plans the development, implementation, and testing of a revised TH submodel-construction approach for the MSTHM, which is designed to more efficiently address a wide range of updated percolation flux distributions. This TWP also addresses the above noted CRs, updates to information pertaining to features, events, and processes (FEPs), and partial rewriting and editing where necessary.

1.1 OBJECTIVES

The primary objective of Revision 04 of the MSTHM report is to provide TSPA with revised repository-wide MSTHM analyses that incorporate updated percolation flux distributions, revised hydrologic properties, updated IEDs, and information pertaining to the emplacement of transport, aging, and disposal (TAD) canisters. The updated design information is primarily related to the incorporation of TAD canisters, but also includes updates related to superseded IEDs describing emplacement drift cross-sectional geometry and layout. The intended use of the results of Revision 04 of the MSTHM report, as described in this TWP, is to predict the evolution of TH conditions (temperature, relative humidity, liquid-phase saturation, and liquid-phase flux) at specified locations within emplacement drifts and in the adjoining near-field host rock along all emplacement drifts throughout the repository. This information directly supports the TSPA for the nominal and seismic scenarios.

The revised repository-wide analyses are required to incorporate updated parameters and design information and to extend those analyses out to 1,000,000 years. Note that the previous MSTHM analyses reported in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) only extend out to 20,000 years. The updated parameters are the percolation flux distributions, including incorporation of post-10,000-year distributions, and updated calibrated hydrologic property values for the host-rock units. The applied calibrated hydrologic properties will be an updated version of those available in *Calibrated Properties Model* (BSC 2004 [DIRS 169857]). These updated properties will be documented in an Appendix of Revision 03 of *UZ Flow Models and Submodels* (BSC 2004 [DIRS 169861]). The updated calibrated properties are applied because they represent the latest available information. The reasonableness of applying the updated calibrated properties to the prediction of near-field/in-drift TH conditions will be evaluated and justified. Some of this evaluation will be conducted in conjunction with the post-model development validation activity involving comparisons of predicted TH conditions with measured TH conditions in the DST. The expected result is that, consistent with what was found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.9), near-field/in-drift TH behavior is insensitive to a wide range of host-rock hydrologic property values.

It is the intention of the work described in this TWP to propagate the new infiltration fluxes from the replacement infiltration model, by using the percolation fluxes from the revised site-scale unsaturated zone (UZ) flow model that has applied those new infiltration fluxes. The percolation flux distributions will be obtained from the updated site-scale UZ flow model, which has applied updated infiltration flux maps.

Another objective of the work scope is to develop, implement, and validate a revised TH submodel-construction approach. This revised approach utilizes interpolation among a set of generic LDTH submodels that are run for a range of percolation flux histories that cover a sufficiently broad range of infiltration flux uncertainty, as well as for four host-rock units (two lithophysal units and two nonlithophysal units), and for three thermal property sets (low, mean, and high). A key motivation for this revised LDTH submodel-construction approach is to enable the MSTHM to be more flexible in addressing a broad range of infiltration flux cases. This approach allows the generic LDTH submodel simulations to be conducted prior to receiving percolation flux maps. Provided that the generic LDTH submodel simulations needed to sufficiently span percolation flux conditions for a given percolation flux realization have already been conducted, the revised TH submodel-construction approach can be deployed much more quickly than the previous MSTHM approach, described in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]), which requires discrete LDTH submodels, with discrete time-dependent percolation flux conditions, distributed across the repository. Therefore, repository-wide MSTHM analyses can quickly be conducted once updated percolation flux maps become available. Another benefit of this revised approach is that repository-wide MSTHM analyses can be conducted for various stochastic percolation flux distributions and compared with corresponding MSTHM analyses conducted for specific percolation flux distributions generated by the upstream site-scale UZ flow model (BSC 2004 [DIRS 169861]). If the stochastic MSTHM analyses produce results similar to those from corresponding MSTHM analyses utilizing specific discrete percolation flux realizations, this could be used to justify why specific percolation flux distributions do not need to be propagated through the MSTHM. This outcome could improve model confidence and defensibility.

The ranges of updated percolation flux conditions that will be implemented in the generic LDTH submodel runs can be adequately informed by a number of sources. If available in time, these ranges can be obtained directly from the revised site-scale UZ flow model. Another percolation flux distribution source could be the updated infiltration flux maps, which will be available prior to the availability of the updated percolation flux maps from the updated site-scale UZ flow model. The use of the infiltration flux maps would necessitate an assumption that the range in infiltration flux across the repository footprint is equal to or greater than the range of percolation flux. This assumption will be justified by comparing the infiltration flux and percolation flux maps that were used in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Other objectives of the work scope covered in this TWP are to address CRs 5154, 6521, 6543, and 6730.

The revision described in this TWP will be prepared in accordance with LP-SIII.10Q-BSC, *Models*.

1.2 PRIMARY TASKS

To accomplish the objectives stated in Section 1.1, the following tasks are detailed.

Preparing Revision 04 of the MSTHM report includes the following subtasks for each of the indicated condition reports.

1.2.1 Tasks to Address Condition Reports

1.2.1.1. Tasks to Address CR 5154

CR 5154 concerns the hydrologic properties of intergranular porosity of the crushed-tuff gravel in the invert. Updated hydrologic property values for the invert, obtained from *Analysis of Invert Hydrologic Properties* (ANL-NBS-HS-000053), will be used in the updated repository-wide MSTHM analyses conducted for Revision 04 of the MSTHM report. Using updated hydrologic property values responds directly to CR 5154.

1.2.1.2 Tasks to Address CR 6521

The DDT submodels of the MSTHM (BSC 2005 [DIRS 173944], Section 6.2.8) will be implemented with the correct heat loadings for the first and eighth waste packages in Revision 04 of the MSTHM report. Using the correct heat loadings responds directly to CR 6521.

1.2.1.3 Tasks to Address CR 6543 and CR 6730

The correction in the software routine reformat_EXT_to_TSPA v1.0, which entails changing "T_WP_waste-package-type" to "T_wp_waste-package-type," will be implemented in software routine reformat_EXT_to_TSPA v2.0, which will be qualified and baselined per IT-PRO-0011, *Software Management*. The revised software routine will be used to generate the bin files that will be provided to TSPA. These TSPA bin files will be assembled under a new data tracking number. Correcting and qualifying the software routine reformat_EXT_to_TSPA responds directly to CR 6543.

To address CR 6730, an option is included in software routine reformat_EXT_to_TSPA v2.0 that allows the selection of additional TSPA bins with respect to temperature, such as the 10th and 90th percentile waste package, within a given percolation flux/waste package group bin, with respect to peak temperature. Additional TSPA bins can then be generated from the updated repository-wide MSTHM analyses, in collaboration with TSPA, for impact analyses and/or performance assessment. Thus, revising and qualifying the software routine reformat_EXT_to_TSPA responds directly to CR 6730.

1.2.2 Apply Updated Calibrated Hydrologic Properties for the Host-Rock Units

Updated calibrated hydrologic properties will be applied to the repository host-rock units in the LDTH submodels. The applied calibrated properties of the host-rock units will be an updated version of those available in *Calibrated Properties Model* (BSC 2004 [DIRS 169857]), and will be documented in Revision 03 of that report. The updated calibrated properties are applied because they represent the latest available information. The reasonableness of applying the updated calibrated properties to the prediction of near-field/in-drift TH conditions will be evaluated and justified. Some of this evaluation will be conducted in conjunction with the post-model development validation activity involving comparisons of predicted TH conditions with measured TH conditions in the DST. The expected result is that, consistent with what was found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.9), near-field/in-drift TH behavior is insensitive to a wide range of host-rock hydrologic property values.

With respect to hydrologic properties, the repository host rock will be broken into two groups: lithophysal (consisting of the Tptpul and Tptpll units) and nonlithophysal (consisting of the Tptpmn and Tptpln units). The thermal properties for each of the four host-rock units (Tptpul, Tptpmn, Tptpll, and Tptpln) will be the same as those used in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The two lithophysal units (Tptpul and Tptpll) will share the same (Tptpll) hydrologic properties, but each will have its own set of thermal properties. The two nonlithophysal units (Tptpmn and Tptpln) will share the same

(Tptpmn) hydrologic properties, but each will have its own set of thermal properties. Note that this approach is similar to that applied in Section 6.7 of *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131]), wherein the two lithophysal host-rock units are treated as having the same hydrologic properties and the two nonlithophysal units are treated as having the same hydrologic properties. The calibrated properties of the Tptpll and Tptpmn units are used because they are better informed with site data and because those two units comprise more than 90% of the repository area, as shown in Table 6.3-3 of Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). In the case of this TWP, the *matrix* hydrologic properties, as well as the *fracture* hydrologic properties, will be demonstrated to yield similar TH behavior in the two nonlithophysal units, as well as within the two lithophysal units.

1.2.3 Develop Effective Averages for Thermal Properties of the Non-Host-Rock Units

For the generic LDTH submodels, and for the corresponding smeared-heat-source, drift-scale, thermal-conduction (SDT) submodels, effective averages will be developed for the thermal properties of the non-host-rock (i.e., nonrepository) units. The nonrepository units will be grouped for the upper UZ and the lower UZ, and effective averages will be developed for each group. It is important to note that the smeared-heat-source, mountain-scale, thermal (SMT) submodel will continue to represent the entire stratigraphic column of both non-host-rock and host-rock units that is consistent with the site-scale UZ flow model (BSC 2004 [DIRS 169861]). Because of the manner in which the MSTHM combines the results from its family of submodels, the representation of mountain-scale heat flow in the revised MSTHM analyses will be consistent with the corresponding analyses in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). Results of LDTH submodels that utilize the effective averages for the thermal properties of the non-host-rock units will be compared against LDTH submodels that discretely utilize the entire vertical sequence of hydrostratigraphic units to demonstrate the adequacy of the effective averages.

1.2.4 Develop and Test Revised LDTH Submodel-Construction Approach

A revised LDTH submodel-construction approach will be developed and tested and applied to the revised MSTHM analyses. This revised approach utilizes interpolation among a set of generic TH submodels that are run for a range of percolation flux histories that cover a sufficiently broad range of infiltration flux uncertainty, as well as for four host-rock units: two lithophysal units and two nonlithophysal units (see Section 1.2.2); and for three thermal property sets: low, mean, and high. The revised LDTH submodel-construction approach requires the use of a single ventilation heat-removal efficiency, which is applicable to the entire heated footprint of the repository area (see Section 1.2.5). The revised LDTH submodel-construction approach requires the development of a new interpolation routine, LDTH_interpolater v1.0.

A grid-block and timestep resolution study will be conducted, using the LDTH submodels. The expected outcome is that the LDTH submodel results will not significantly change as a consequence of additional grid-block and timestep refinement.

The revised LDTH submodel-construction approach will be tested in two model development testing tasks, which will be conducted during model development. Note that the entire MSTHM, which utilizes the revised LDTH submodel-construction approach, will be validated for a post-model development validation test problem of a single emplacement drift, by comparing the results of the MSTHM against the results of an alternative three-dimensional TH model. This post-model development validation activity will also build confidence in the revised approach.

In the first model development testing task, an interpolated LDTH submodel output file will be interpolated from an array of generic LDTH submodels, which are run for different percolation flux histories, and for different vertical locations within the host-rock unit sequence. The accuracy of the interpolation approach will be tested against an LDTH submodel that explicitly represents a discrete percolation flux history at a discrete vertical location within the host-rock unit sequence.

In the second model development testing task, the revised interpolation approach will be used to generate MSTHM results for the mean infiltration flux, mean host-rock thermal conductivity case found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The MSTHM results using the revised LDTH submodel-construction approach will be compared with the corresponding MSTHM analyses in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

A post-model development validation task will involve modifying the three-drift repository validation test case described in Section 7.5 of Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The modifications will include varying the overburden thickness and percolation flux in the longitudinal direction of the emplacement drifts of the test problem. The modifications will also include changing the model geometry to represent one emplacement drift that is much longer than that of the three-drift repository test case. The new LDTH submodel-construction approach will be applied in generating MSTHM results at edge and center locations. These results will be compared with corresponding results from the three-dimensional monolithic TH model, which is a process-level mathematical model, of the single-drift repository validation test case.

The size of the numerical mesh of the three-dimensional monolithic TH model of the single-drift repository validation test case necessitates running the TH model simulations on a parallel central processing unit (CPU) cluster. To do this, existing unqualified software NUFT v4.0, which can function in either a single-CPU or a multiple-CPU mode, will be qualified and baselined per IT-PRO-0011.

1.2.5 Revise MSTHM to Address Updated IEDs and TAD Canisters

The MSTHM will be revised to incorporate updated design and repository layout information from updated IEDs, including available information pertaining to the TAD canisters. The revisions to the MSTHM will include the following:

- Representation of the repository will be revised to be consistent with the updated IED (BSC 2005 [DIRS 176805]).

- Representation of waste packages in the DDT submodels will be revised to incorporate the updated IED (BSC 2005 [DIRS 173501], Table 1) and to be consistent with the maximum TAD canister dimensions.

- Representation of drip shields in the DDT and LDTH submodels will be revised to incorporate the updated IED (BSC 2005 [DIRS 173303], Table 1) and to be consistent with the maximum TAD canister dimensions.

- To address the increased waste-package lengths consistent with the maximum TAD canister dimensions, the heated footprint of the repository will be increased to include the entire southern repository panel (Panel 2). This will increase the total heated area of the repository and increase the number of geographic locations (from the current value of 2,874) for which MSTHM output is provided. Note that the revised (increased) heated footprint area will be accommodated by using the former contingency drifts in Panel 2.

- Revised invert depth, according to the updated IED (BSC 2004 [DIRS 169503]), will be incorporated in the LDTH and DDT submodels.

- Revised waste-package dimensions, consistent with maximum TAD canister dimensions, will be incorporated in the DDT submodels.

- Revised line-averaged thermal load, which is called the Lineal Power Density (expressed in kW/m), will be incorporated into the LDTH submodel, as well as into the SDT and SMT submodels.

- A single constant value of the ventilation heat-removal efficiency, which is temporally and spatially averaged along an emplacement drift in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]), will be applied uniformly across the entire heated footprint of the repository. This ventilation heat-removal efficiency value will be applied to the LDTH, SDT, DDT, and SMT submodels (see Section 1.2.4).

1.2.6 Revise MSTHM to Incorporate Updated Percolation Flux Distributions

The revised MSTHM analyses will incorporate updated percolation flux distributions. The revisions to the MSTHM will include the following:

- Incorporate updated PTn-to-TSw percolation flux values for the lower-bound, mean, and upper-bound infiltration flux sensitivity cases.

- Revise the temporal representation of the influence of climate change on percolation flux, by shortening the glacial-transition period from 2,000 to 20,000 years, down to 2,000 to 10,000 years, and add a post-10,000-year climate state that pertains from 10,000 to 1,000,000 years, in consultation with the TSPA Department. All four of the post-10,000-year percolation flux maps will be addressed. This work includes incorporating percolation flux maps from the updated site-scale UZ flow model for post-10,000-year percolation fluxes.

- Implement the revised LDTH submodel-construction approach described in Section 1.2.4.

- Extend the MSTHM analyses out to 1,000,000 years.

1.2.7 Revise MSTHM to Incorporate Updated Calibrated Hydrologic Properties

The revised MSTHM will incorporate the updated calibrated hydrologic properties (see Section 1.2.2). The revisions to the MSTHM will include the following:

- Incorporate updated calibrated hydrologic properties for the host-rock units used in the LDTH submodels. The applied calibrated hydrologic properties will be an updated version of those available in *Calibrated Properties Model* (BSC 2004 [DIRS 169857]). These updated properties will be documented in an Appendix of Revision 03 of *UZ Flow Models and Submodels* (BSC 2004 [DIRS 169861]). The reasonableness of applying the updated calibrated properties to the prediction of near-field/in-drift TH conditions will be evaluated and justified. Some of this evaluation will be conducted in conjunction with the post-model development validation activity involving comparisons of predicted TH conditions with measured TH conditions in the DST. The expected result is that, consistent with what was found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.9), near-field/in-drift TH behavior is insensitive to a wide range of host-rock hydrologic property values. Two host-rock groups will be established with respect to hydrologic properties, including a lithophysal group (representing the Tptpul and Tptpll units) and a nonlithophysal group (representing the Tptpmn and Tptpln units).

- Develop effective average values of the thermal property values for the non-host-rock (i.e., nonrepository) units incorporated in the LDTH, SDT, and DDT submodels. Note that the SMT submodel maintains the full representation of the hydrostratigraphic units with respect to thermal properties. Therefore, given the manner in which the MSTHM combines the results of its submodels, the representation of mountain-scale heat flow is fully consistent with stratigraphy of the site-scale UZ flow model (BSC 2004 [DIRS 169861]).

- Implement the revised LDTH submodel-construction approach described in Section 1.2.4.

1.2.8 Revise Binning Software to Accommodate Revisions to TSPA Binning Process

To address CR 6730, the process of generating the TSPA bins will be modified as follows:

- Revise the manner in which TSPA bins are established by adding the option for low and high temperature bins (e.g., 10th and 90th percentile), as well as the current 50th percentile bins, using software routine reformat_EXT_to_TSPA v2.0. Information describing the shape/type of the probability density functions of temperature for the entire waste package inventory, and for the various uncertainty cases, will be passed onto to TSPA to assist in the selection of percentiles.

1.2.9 Revise Low-Probability-Seismic Drift-Collapse Cases

The MSTHM analyses described in Section 6.3.7 of Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) will be revised such that they are consistent with the nominal MSTHM analyses of Revision 04 of the MSTHM report. The revised analyses will include a low and high thermal conductivity case for the rubble, as was done in Revision 03. These analyses will provide TSPA with temperature differences (called temperature deltas) between the collapsed-drift case and the corresponding nominal case. The temperature deltas can be used by TSPA to calculate the relative humidity (*RH*) on the waste package for the seismic case, using the *RH* ratio approach as follows:

$$RH_{wp,seismic} = RH_{wp,nominal} (P_{sat} (T_{wp,nominal}))/(P_{sat}(T_{wp,seismic}))$$

where

$$T_{wp,seismic} = T_{wp,nominal} + \Delta T$$

and P_{sat} is equal to the saturation vapor pressure and ΔT is the delta temperature between the seismic and corresponding nominal case.

1.3 RESPONSIBLE ORGANIZATIONS

The Near-Field Environment team is responsible for the execution of the work identified in this plan.

1.4 TESTING AND PRETEST PREDICTIONS

The requirement to address scientific testing in activities and products is not applicable because there is no scientific testing associated with this TWP.

2. SCIENTIFIC APPROACH AND TECHNICAL METHODS

This section establishes the implementation plan and work controls to perform the primary tasks.

2.1 WORK ACTIVITIES

Users of the results from Revision 04 of the MSTHM report will be the TSPA Department. The requirement to identify items to be tested, test requirements, and instructions for performing the test is not applicable because there are no items to be tested associated with this TWP.

The intended use of the results of Revision 04 of the MSTHM report, as described in this TWP, is to predict the evolution of thermohydrologic conditions (temperature, relative humidity, liquid-phase saturation, and liquid-phase flux) at specified locations within emplacement drifts and in the adjoining near-field host rock along all emplacement drifts throughout the repository. This information directly supports the TSPA for the nominal and seismic scenarios.

The CRs related to this TWP, which include CRs 5154, 6521, 6543, and 6730, will all be addressed by completing the tasks outlined in Sections 1.2.1.1, 1.2.1.2, and 1.2.1.3, respectively. The completion of these tasks responds directly to the indicated CRs and will be reflected in the updated repository-wide MSTHM results produced by Revision 04 of the MSTHM report.

2.1.1 Scientific Approach and Technical Methods

Many of the tasks described in Section 1.2 utilize the same scientific approach and technical methods, such as model building methods, that were applied in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). This section describes only those tasks that apply scientific approaches or new technical methods that are not described in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

2.1.1.1 Incorporate Updated Calibrated Hydrologic Properties for the Host-Rock Units

Updated calibrated hydrologic properties will be applied for the repository host-rock units in the LDTH submodels. The calibrated properties will be updated, relative to those available in *Calibrated Properties Model* (BSC 2004 [DIRS 169857]), which will be documented in Revision 03 of that report. The updated calibrated properties are applied because they represent the latest available information. The reasonableness of applying the updated calibrated properties to the prediction of near-field/in-drift TH conditions will be evaluated and justified. Some of this evaluation will be conducted in conjunction with the post-model development validation activity involving comparisons of predicted TH conditions with measured TH conditions in the DST. The expected result is that, consistent with what was found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 6.3.9), TH behavior is insensitive to a wide range of host-rock hydrologic property values.

The repository host rock will be represented as four lithostratigraphic units. The two lithophysal units (Tptpul and Tptpll) will share the same (Tptpll) hydrologic properties, but each will have its own set of thermal properties. The two nonlithophysal units (Tptpmn and Tptpln) will share the same (Tptpmn) hydrologic properties, but each will have its own set of thermal properties. The calibrated properties of the Tptpll and Tptpmn units are used because they are better informed with site data and because those two units comprise more than 90% of the repository area, as shown in Table 6.3-3 of Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

2.1.1.2 Develop Effective Averages for Thermal Properties of the Non-Host-Rock Units

For the generic LDTH submodels, and for the corresponding SDT submodels, effective averages will be developed for the non-host rock (i.e., non-repository) units. The non-host-rock units will be grouped for the upper UZ and the lower UZ, and effective averages will be developed for each group. It is important to note that the SMT submodel will continue to represent the entire stratigraphic column of both non-host-rock and host-rock units, consistent with the site-scale UZ flow model (BSC 2004 [DIRS 169861]). Because of the manner in which the MSTHM combines the results from its family of submodels, the representation of mountain-scale heat flow in the revised MSTHM analyses will be consistent with the corresponding analyses in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]. Results of LDTH submodels that utilize the effective averages for the thermal properties of the non-host-rock units will be compared against LDTH submodels that discretely represent the entire vertical sequence of hydrostratigraphic units to demonstrate the adequacy of the effective averages.

2.1.1.3 Develop and Test Revised LDTH Submodel-Construction Approach

A revised LDTH submodel-construction approach will be developed and tested. This revised approach utilizes interpolation among a set of generic TH submodels that are run for a range of percolation flux histories that cover a sufficiently broad range of infiltration flux uncertainty, as well as for four host-rock units: two lithophysal units and two nonlithophysal units (see Section 1.2.2); and for three thermal property sets: low, mean, and high. This revised approach does not alter the form of any of the MSTHM output; neither does it alter the number of parameter-uncertainty cases that are provided to TSPA. Note that five percolation flux/host-rock thermal conductivity uncertainty cases were provided to TSPA in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944])

This revised approach utilizes generic LDTH submodels for a repository-wide-averaged overburden thickness and distance above the water table. Note that the effects of overburden thickness and distance above the water table are represented in the MSTHM by the SMT mountain-scale submodel. The generic submodels are run for the three host-rock thermal conductivity cases: low, mean, and high, which were addressed in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). These generic models are run for a matrix of percolation flux cases described below, which include the influence of climate change. They will include the influence of four climate states: present-day, monsoonal, glacial-transition, and post-10,000-year. Note that the post-10,000-year percolation fluxes will accommodate the values specified in the draft U.S. Environmental Protection Agency regulation at 40 CFR 197. Because of similarities in the temporal evolution of percolation flux (as it is affected by climate change) for the mean and upper-bound infiltration flux cases, a generic set of percolation fluxes can address both the mean and upper-bound infiltration flux cases. Because the temporal trend of the lower-bound infiltration flux case is different, it may be necessary to build a separate matrix of generic LDTH submodels to address that case.

The revised LDTH submodel-construction approach, which will be conducted separately for the respective three host-rock thermal conductivity cases, consists of two primary steps: (1) percolation flux interpolation and (2) host-rock-type interpolation. The percolation flux interpolation discretely accounts for the temporal evolution of present-day, monsoonal, glacial-transition, and post-10,000-year climate-state percolation fluxes.

The percolation flux interpolation approach, which is conducted in four steps (for the four primary climate states), requires a $P \times M \times G \times K$ matrix of LDTH submodel runs, where P stands for present-day, M stands for monsoonal, G stands for glacial-transition, and K stands for post-10,000-year. For example, a matrix of cases could involve five present-day percolation fluxes, two monsoonal percolation fluxes per present-day flux, two glacial-transition percolation fluxes per monsoonal flux, and two post-10,000-year percolation fluxes per glacial-transition flux, resulting in a total of $5 \times 2 \times 2 \times 2 = 40$ generic LDTH submodels. These 40 submodels are required to represent the four host-rock units, resulting in a total of $4 \times 40 = 160$ generic LDTH submodels. The four Areal Mass Loadings required by the MSTHM (see BSC 2005 [DIRS 173944], Section 6.2.4) result in a total of $4 \times 160 = 640$ LDTH submodels. Note that these 640 LDTH submodels are applicable to both the mean and upper-bound infiltration flux cases with the mean host-rock thermal conductivity in representing all four climate states. An additional 640 LDTH submodels would be required to address the high host-rock thermal conductivity case, which could be applied to either the mean or upper-bound infiltration flux cases to represent all four climate states.

If the lower-bound infiltration flux case requires the same number of present-day percolation flux values, 640 LDTH submodels would be required to address the lower-bound infiltration flux case for the mean host-rock thermal conductivity case in representing all four climate states. An additional 640 LDTH submodels would be required to address the low host-rock thermal conductivity case to represent all four climate states.

The revised LDTH submodel-construction approach will be tested in two model development testing tasks. Note that the entire MSTHM, which utilizes the revised LDTH submodel-construction approach, will be validated for a post-model development validation test problem of a single emplacement drift, by comparing the results of the MSTHM against the results of an alternative three-dimensional TH model. This post-model development validation activity will also build confidence in the revised approach.

In the first model development testing task, an interpolated LDTH submodel output file will be interpolated from an array of generic LDTH submodels, which are run for different percolation flux histories, and for different vertical locations within the host-rock unit sequence. The accuracy of the interpolation approach will be tested against an LDTH submodel that explicitly represents a discrete percolation flux history at a discrete vertical location within the host-rock unit sequence.

For the second model development testing task, the revised approach will be applied to generate MSTHM results for the mean infiltration flux, mean host-rock thermal conductivity case found in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The MSTHM results using the revised LDTH submodel-construction approach will be compared with the corresponding MSTHM results in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]) to determine whether the interpolation approach adequately captures the range of TH conditions across the repository for that case.

A post-model development validation task will involve modifying the three-drift repository validation test case, described in Section 7.5 of Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). The modifications will include revising the model geometry to represent one emplacement drift with adiabatic no-flow boundaries at the vertical planes along the drift and mid-pillar centerlines. This modification will allow the model to represent a longer emplacement drift than represented in the three-drift repository validation test case in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 7.5). The revised LDTH submodel-construction approach will be used to generate MSTHM results at two locations in the test problem, including an edge and center location. These results will be compared with corresponding results from the three-dimensional monolithic TH model, which is an alternative mathematical model, of the single-drift validation test case.

The size of the numerical mesh of the three-dimensional monolithic TH model of the single-drift repository validation test case necessitates running the TH model simulations on a parallel CPU cluster. To do this, existing unqualified software NUFT v4.0, which can function in either a single-CPU or a multiple-CPU mode, will be qualified and baselined per IT-PRO-0011.

2.1.2 Data Collection, Reduction, and Recording Methodology

The requirement to identify methods for data collection, data reduction, and recording results is not applicable because there is no data collection associated with this TWP.

2.1.3 Unexpected Test Results, Test Conditions, or Off-Normal Event Occurrence

The requirement to address provisions for handling unexpected test results, unanticipated test conditions, or occurrence of off-normal events during testing is not applicable because there is no testing associated with this TWP and no off-normal events are associated with this TWP.

2.1.4 Features, Events, and Processes

The current list of included FEPs that pertain to the MSTHM report is obtained from *Engineered Barrier System Features, Events and Processes* (BSC 2005 [DIRS 175014]). The total system performance assessment for the license application (TSPA-LA) FEPs listed in Table 1 include all those FEPs listed in the previous TWP (BSC 2005 [DIRS 173377]), with the following exceptions:

- FEP 2.1.06.06.0A, Effects of Drip Shield on Flow, has been removed because the MSTHM report is not referenced by this FEP in *Engineered Barrier System Features, Events, and Processes* (BSC 2005 [DIRS 175014])
- FEP 2.1.08.04.0B, Condensation Forms at Repository Edges (Repository-Scale Cold Traps), has been added because the MSTHM report is referenced by this FEP.
- FEP 1.1.02.02.0A, Preclosure Ventilation, has been added.
- FEP 2.1.11.09.0C, Thermally Driven Flow (Convection) in Drifts, has been added.

Table 1. Included TSPA-LA FEPs Associated with the MSTHM Report

FEPs No.	FEPs Subject	Scope or Context
1.1.02.02.0A	Preclosure Ventilation	The duration of preclosure ventilation acts together with waste package spacing (as per design) to control the extent of the boiling zone front (zone of reduced water content).
2.1.08.03.0A	Repository dry-out due to waste heat	Repository heat evaporates water from the UZ rocks near the drifts, as the temperature exceeds the vaporization temperature. This zone of reduced water content (reduced saturation) migrates outward during the heat phase and then migrates back to the containers as the heat diffuses throughout the mountain and the radioactive heat sources decay. The FEP addresses the effects of dry-out within the repository drifts.
2.1.08.04.0A	Condensation forms on roofs of drifts (drift-scale cold traps)	Emplacement of waste in drifts creates thermal gradients within the repository. Such thermal gradients can lead to drift-scale cold traps characterized by latent heat transfer from warmer to cooler locations. This mechanism can result in condensation forming on the roof or other parts of the drifts, leading to enhanced dripping on the drip shields, waste packages, or exposed waste materials.

Table 1. Included TSPA-LA FEPs Associated with the MSTHM Report (Continued)

FEPs No.	FEPs Subject	Scope or Context
2.1.08.04.0B	Condensation forms at repository edges (repository-scale cold traps)	Emplacement of waste in drifts creates thermal gradients within the repository. Such thermal gradients can lead to repository-scale cold traps characterized by latent heat transfer from warmer to cooler locations. This mechanism can result in condensation forming at repository edges or elsewhere in the engineered barrier system (EBS), leading to enhanced dripping on the drip shields, waste packages, or exposed waste material.
2.1.08.05.0A	Flow through invert	The invert, a porous material consisting of crushed tuff, separates the waste package from the bottom of the drift. Flow and transport through and bypassing the invert can influence radionuclide release to the UZ.
2.1.08.06.0A	Capillary effects (wicking) in the EBS	Capillary rise, or wicking, is a potential mechanism for water to move through the waste and EBS.
2.1.08.11.0A	Repository desaturation due to waste cooling	Following the peak thermal period, water in the condensation cap may flow downward, resaturating the geosphere dry-out zone and flowing into the drifts. This may lead to an increase in water content and/or resaturation in the repository.
2.1.11.01.0A	Heat generation in EBS	Temperature in the waste and EBS will vary through time. Heat from radioactive decay will be the primary cause of temperature change, but other factors to be considered in determining the temperature history include the in situ geothermal gradient, thermal properties of the rock, EBS, and waste materials, hydrological effects, and the possibility of exothermic reactions. Considerations of the heat generated by radioactive decay should take different properties of different waste types, including defense spent nuclear fuel, into account.
2.1.11.02.0A	Non-uniform heat distribution in EBS	Uneven heating and cooling at edges of the repository lead to non-uniform thermal effects during both the thermal peak and cool-down period.
2.1.11.09.0A	Thermal effects on flow in the EBS	High temperatures in the EBS may influence seepage into and flow within waste and the EBS. Thermally induced changes to fluid saturation and/or relative humidity could influence in-package chemistry. Thermal gradients in the repository lead to localized accumulation of moisture. Wet zones form below the areas of moisture accumulation.
2.1.11.09.0C	Thermally Driven Flow (Convection) in Drifts	Temperature differentials may result in convective flow in the EBS. Convective flow within drifts could influence in-drift chemistry.

2.2 MODELING AND SCIENTIFIC ANALYSIS ACTIVITIES

Development of the MSTHM was largely completed for previous versions of the MSTHM report. Much of that documentation will be preserved in the planned revision, as needed for traceability and transparency. Model validation will be redone to accommodate new features of the MSTHM and include them in the validation comparisons. The description below is thus for the full extent of validation planned for the revised report.

2.2.1 Model Validation

Validation of the MSTHM involves the validation of the MSTHM as a whole, and the validation and testing of certain submodels, or components, used in the MSTHM. While most of these validation activities were completed for Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 7), all validation and testing activities will be redone for Revision 04 of this report. The post-model development validation activities include:

- Comparison of LDTH submodel results, adapted to represent the DST, with measurements from the DST (see discussion below)
- Comparison of MSTHM results against those of a corresponding alternative three-dimensional TH model (see discussion below).

The model development testing activities include:

- Testing the effective thermal properties determined for the non-host-rock units
- Testing the percolation flux and host-rock-type interpolation approaches used for LDTH submodels
- Testing the application of updated calibrated hydrologic properties for the Tptpll to the lithophysal units (Tptpul and Tptpll)
- Testing the application of updated calibrated hydrologic properties for the Tptpmn to the nonlithophysal units (Tptpmn and Tptpln).

The LDTH submodel, which is the TH submodel of the MSTHM, is validated by corroboration, using comparison between measured data from the DST and a TH simulation of the DST. The TH model of the DST uses the same conceptualization, mathematical basis, and parameter values used in the LDTH submodels for the MSTHM. The comparisons are between simulated vs. measured changes in rock temperature and matrix liquid-phase saturation, at representative locations in the DST. Some differences between simulated vs. measured changes are expected; explicit criteria for acceptance of temperature comparisons are given in Section 2.2.4. The main phenomenon of TH coupling is the redistribution of water in the rock mass. Matrix water content was periodically surveyed in the DST, using a geophysical method that effectively detects changes, but is inherently statistical and does not measure the absolute liquid-phase saturation. Also, these data may exhibit transient instrument responses that do not represent significant rock responses. Trends and relative changes in the data show where there are zones of wetting and drying in the test, and then they are appropriately used for qualitative comparison with TH model simulations, as stated in Section 2.2.4.

The MSTHM, as a whole, is validated by corroboration against an alternative mathematical model, a validation test case consisting of a three-dimensional TH simulation including an emplacement drift, the surrounding host rock, and the over- and underlying non-host-rock units between the water table and the ground surface. The geometric representation of the emplacement drift in the test case is a simplification of an emplacement drift in the southern repository panel (see Panel 2 of Figure 4-1 in BSC 2005 [DIRS 173944]). The test case is designed to validate the assembly steps in the MSTHM for predicting TH conditions at various locations in the repository. The locations for comparison include one representing the repository center, and one representing the repository edge. The term "representative" in this context is intended to mean that together these two locations are typical in terms of the potential for prediction uncertainty brought about by the assumptions and approximations specific to the MSTHM approach, for both the repository center and edge locations.

The maximum model-to-model comparison differences for changes in temperature or relative humidity at either of these locations, at any time during the simulation, must be reasonably comparable to the range of uncertainty in the same measures, which is generated by the MSTHM results provided to TSPA. The approach used to compare the magnitude of model uncertainty to that of parametric uncertainty described in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 7.5.4) will be used. Wherever applicable, the differences in the predicted parameter (e.g., temperature) between the MSTHM prediction and the corresponding three-dimensional monolithic TH model will be determined and compared with the predicted range of that parameter, arising from parametric uncertainty, which is propagated to TSPA for specific locations in the repository. An example of this is Figure 7.5-9 in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). When a parameter in question (e.g., liquid-phase saturation) changes abruptly with time, an alternative means of model-to-model comparison will be used, which is to compare the time required to attain a given value of that parameter. An example of this alternative means of model-to-model comparison is given in Table 7.5-14 in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

Note that the work described in this TWP includes revised model development tasks (see Section 2.1.1) and new during-development model validation tasks (see Section 2.1.1.3) that specifically support the model features associated with those revised model development tasks.

There are no additional model validation activities required to validate the MSTHM analyses out beyond 10,000 years for the reasons listed below:

- There are no changes to the fundamental TH flow processes for the period beyond 10,000 years. These fundamental flow processes are not altered by disruptive events.
- Host-rock thermal conductivity, which is one of the two most important parameters affecting TH behavior, is not expected to change significantly for the period beyond 10,000 years.
- The values of percolation flux, which is the other key parameter affecting TH behavior, that will be applied to the MSTHM for the post-10,000-year period will be consistent with the values specified in the draft U.S. Environmental Protection Agency regulation at 40 CFR 197.

2.2.2 Establishment of Validation Criteria and Level of Confidence Requirement

The criteria for ensuring that the appropriate level of confidence has been obtained for the MSTHM report as required by LP-SIII.10Q-BSC are based on a position that the outputs of this model may directly impact the TSPA dose results, and are therefore used for demonstration of regulatory compliance. Variation in the output of the MSTHM is estimated to have a small effect (less than 0.1 mrem/yr) on the estimated mean annual dose because of the long-term postclosure emplacement drift environment parameters predicted. Therefore, the appropriate level of confidence identified for the MSTHM report is Level II. The validation criteria are given in Section 2.2.4.

2.2.3 Justification of Model Validation Approaches

Post-development activities for the MSTHM consist of two primary tasks, one corresponding to the MSTHM itself and the other corresponding to the LDTH submodel of the MSTHM.

The maximum model-to-model comparison differences for changes in temperature or relative humidity at either of these locations, at any time during the simulation, must be reasonably comparable to the range of uncertainty in the same measures, which is generated by the MSTHM results provided to TSPA. The approach used to compare the magnitude of model uncertainty to that of parametric uncertainty described in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944], Section 7.5.4) will be used. Wherever applicable, the differences in the predicted parameter (e.g., temperature) between the MSTHM prediction and the corresponding three-dimensional monolithic TH model will be determined and compared with the predicted range of that parameter, arising from parametric uncertainty, which is propagated to TSPA for specific locations in the repository. An example of this is Figure 7.5-9 in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]). When a parameter in question (e.g., liquid-phase saturation) changes abruptly with time, an alternative means of model-to-model comparison will be used, which is to compare the time required to attain a given value of that parameter. An example of this alternative means of model-to-model comparison is given in Table 7.5-14 in Revision 03 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

The LDTH submodel, which is the TH submodel of the MSTHM, is validated by corroboration, using comparison between measured data from the DST and a three-dimensional TH simulation of the DST. The three-dimensional TH model of the DST uses the same conceptualization, mathematical basis, and parameter values used in the LDTH submodels for the MSTHM. The corroboration description includes a comparison between the DST measurements and the three-dimensional TH model results. The comparisons are between simulated vs. measured changes in rock temperature and matrix liquid-phase saturation, at representative locations in the DST. Some differences between simulated vs. measured changes are expected; quantitative criteria for acceptance of temperature comparisons are given in Section 2.2.4. The main phenomenon of TH coupling is the redistribution of water in the rock mass. Matrix water content was periodically surveyed in the DST, using a geophysical method that effectively detects changes, but is inherently statistical and does not measure the absolute liquid-phase saturation. Also, these data may exhibit transient instrument responses that do not represent significant rock responses. Trends and relative changes in the data show where there are zones of wetting and drying in the test, and then they are appropriately used for qualitative comparison with TH model simulations, as stated in Section 2.2.4.

2.2.4 Meeting Validation Criteria

The validation criteria are based on LP-SIII.10Q-BSC, Section 5.3.2(a)(1), corroboration of model results with data acquired from field experiments, and Section 5.3.2(a)(2), corroboration of results with other alternative mathematical models.

For validation by corroboration of results with an alternative three-dimensional TH mathematical model, the maximum model-to-model comparison differences for changes in temperature or relative humidity at either of two representative locations (representing the repository center and edge), at any time during the simulation, must be smaller than the range of uncertainty in the same measures, which is generated by the MSTHM for ranges of percolation flux and host-rock thermal conductivity in the repository-wide MSTHM simulations propagated to TSPA. Corroboration of MSTHM-predicted results against an alternative mathematical model demonstrates that the MSTHM-predicted results are sufficiently accurate.

For corroboration by comparison of TH simulations with DST data, comparison of the temperature changes should agree within 30% or better for the DST heating phase; this value is smaller than the range of peak waste package temperatures predicted for the repository. There are thousands of channels of temperature instrumentation in the DST, and differences greater than 30% may be accepted if it can be shown that they resulted from short-term (compared to the duration of the test) or localized transients in the test conditions, or from spurious instrument response. Comparison of the matrix liquid saturation changes will be qualitative; the DST simulation should show the same trends with respect to location and duration. Corroboration against measured results provides sufficient confidence about the adequacy of the scientific basis of the MSTHM.

2.2.5 Analyses Using Previously Developed and Validated Model(s)

The requirement to provide justification of previously developed and validated models to complete scientific analysis, as required by LP-SIII.9Q-BSC, *Scientific Analyses*, is not applicable because no previously developed and validated models external to the identified models are associated with the work described in this TWP.

2.2.6 Use of Previously Developed Models

The requirement to provide justification for and validation plans for previously developed models outside of the intended use, limitations, or range of validity, as required by LP-SIII.10Q-BSC, is not applicable because models will be used within their intended use, limitations, and range of validity.

Models that are adequately validated for 10,000-year assessments shall be assumed to be valid for assessments for the period after 10,000 years (70 FR 173).

2.2.7 Schedule of Review Sessions

In accordance with LP-2.29Q-BSC, the Responsible Manager will schedule separate meetings as appropriate to review model validation quality issues with (a) the model report Originator prior to starting the work, (b) the Checker prior to the document going into checking before or concurrent with the document entering checking, and (c) the Independent Technical Reviewer.

3. INDUSTRY STANDARDS, FEDERAL REGULATIONS, U.S. DEPARTMENT OF ENERGY ORDERS, REQUIREMENTS, AND ACCEPTANCE/COMPLETION CRITERIA

This section discusses applicable standards, criteria from *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]), level of accuracy of activity results, acceptance criteria, and other requirements as they apply to the model report described in this TWP.

3.1 STANDARDS

The requirement to identify industry standards is not applicable because there are none identified.

3.2 REGULATORY REQUIREMENTS

The applicable federal regulations and technical requirements related to the work activities associated with this TWP are generally implemented through the appropriate implementing procedures identified in Section 4. In particular, the requirements identified in 10 CFR 63.114 (a), (b), (c), and (g) are implemented through LP-SIII.10Q-BSC. The requirements identified in 10 CFR 63.114 (d), (e), and (f) are implemented in the appropriate FEPs screening analyses, which are discussed in *Engineered Barrier System Features, Events and Processes* (BSC 2005 [DIRS 175014]). There are no U.S. Department of Energy orders applicable to the scope of work identified in this TWP.

3.3 ACCEPTANCE CRITERIA

The MSTHM report predicts results that directly pertain to quantity of water contacting the engineered barriers and waste forms (NRC 2003 [DIRS 163274], Section 2.2.1.3.3.3). The Acceptance Criteria for this category are:

- **Acceptance Criterion 1**—System Description and Model Integration Are Adequate:

  (1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the quantity and chemistry of water contacting engineered barriers and waste forms abstraction process.

  (2) The abstraction of the quantity and chemistry of water contacting engineered barriers and waste forms uses assumptions, technical bases, data, and models, that are appropriate and consistent with other related U.S. Department of Energy abstractions.

  (3) Important design features, such as waste package design and material selection, backfill, drip shield, ground support, thermal loading strategy, and degradation processes, are adequate to determine the initial and boundary conditions for

calculations of the quantity and chemistry of water contacting engineered barriers and waste forms.

(4) Spatial and temporal abstractions appropriately address physical couplings (thermal-hydrologic-mechanical-chemical).

(5) Sufficient technical bases and justification are provided for total system performance assessment assumptions and approximations for modeling coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, the waste package chemical environment, and the chemical environment for radionuclide release. The effects of distribution of flow on the amount of water contacting the engineered barriers and waste forms are consistently addressed, in all relevant abstractions.

(6) The expected ranges of environmental conditions within the waste package emplacement drifts, inside the breached waste packages, and contacting the waste forms and their evolution with time are identified.

(7) The model abstraction for quantity and chemistry of water contacting engineered barriers and waste forms is consistent with the detailed information on engineered barrier design and other engineered features.

(8) Adequate technical bases are provided, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for inclusion of any thermal-hydrologic-mechanical-chemical couplings and features, events, and processes.

(9) Performance-affecting processes that have been observed in thermal-hydrologic tests and experiments are included into the performance assessment.

(12) Guidance in NUREG–1297 and NUREG-1298 (Altman et al. 1988 [DIRS 103597]; Altman et al. 1988 [DIRS 103750]), or other acceptable approaches, is followed.

- **Acceptance Criterion 2**—Data Are Sufficient for Model Justification:

(1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

(2) Sufficient data were collected on the characteristics of the natural system and engineered materials to establish initial and boundary conditions for conceptual models of thermal-hydrological-mechanical-chemical coupled processes, that affect seepage and flow and the engineered barrier chemical environment.

(3) Thermal-hydrologic tests were designed and conducted with the explicit objectives of observing thermal-hydrologic processes for the temperature ranges expected for repository conditions and making measurements for mathematical

models. Data are sufficient to verify that thermal-hydrologic conceptual models address important thermal-hydrologic phenomena.

(4) Sufficient information to formulate the conceptual approach(es) for analyzing water contact with the drip shield, engineered barriers, and waste forms is provided.

- **Acceptance Criterion 3**—Data Uncertainty Is Characterized and Propagated Through the Model Abstraction:

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

(2) Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.

(3) Input values used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers (e.g., drip shield and waste package) are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the Yucca Mountain site. Correlations between input values are appropriately established in the U.S. Department of Energy total system performance assessment. Parameters used to define initial conditions, boundary conditions, and computational domain in sensitivity analyses involving coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, the waste package chemical environment, and the chemical environment for radionuclide release, are consistent with available data. Reasonable or conservative ranges of parameters or functional relations are established.

(4) Adequate representation of uncertainties in the characteristics of the natural system and engineered materials is provided in parameter development for conceptual models, process-level models, and alternative conceptual models. The U.S. Department of Energy may constrain these uncertainties using sensitivity analyses or conservative limits. For example, the U.S. Department of Energy demonstrates how parameters used to describe flow through the engineered barrier system bound the effects of backfill and excavation-induced changes.

- **Acceptance Criterion 4**—Model Uncertainty Is Characterized and Propagated Through the Model Abstraction:

  (1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.

  (2) Alternative modeling approaches are considered and the selected modeling approach is consistent with available data and current scientific understanding. A description that includes a discussion of alternative modeling approaches not considered in the final analysis and the limitations and uncertainties of the chosen model is provided.

  (3) Consideration of conceptual-model uncertainty is consistent with available site characterization data, laboratory experiments, field measurements, natural analog information and process-level modeling studies; and the treatment of conceptual-model uncertainty does not result in an under-representation of the risk estimate.

  (4) Adequate consideration is given to effects of thermal-hydrologic-mechanical-chemical coupled processes in the assessment of alternative conceptual models.

  (5) If the U.S. Department of Energy uses an equivalent continuum model for the total system performance assessment abstraction, the models produce conservative estimates of the effects of coupled thermal-hydrologic-mechanical-chemical processes on calculated compliance with the postclosure public health and environmental standards.

- **Acceptance Criterion 5**—Model Abstraction Output Is Supported by Objective Comparisons:

  (1) The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs).

  (3) Accepted and well-documented procedures are used to construct and test the numerical models that simulate coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow, engineered barrier chemical environment, and the chemical environment for radionuclide release. Analytical and numerical models are appropriately supported. Abstracted model results are compared with different mathematical models, to judge robustness of results.

3.4 LEVEL OF ACCURACY, PRECISION, AND REPRESENTATIVENESS OF RESULTS

The required level of accuracy, precision, and representativeness of the results of the MSTHM must be specified in light of the purpose of the MSTHM, which is to predict a reasonable range of relevant TH parameters in the emplacement drifts and adjoining host rock. The purpose of the

MSTHM is to predict a reasonable range of TH conditions, resulting from parametric uncertainty and variability, and from the influence of waste package heat-output variability. Thus, the goal is to predict the range of possible TH responses across the repository; this is quite different from predicting a single expected TH response. This range in TH conditions must capture the influence of the key processes and conditions, including the uncertainty and variability associated with those processes and conditions. Thus, the required level of accuracy, precision, and representativeness of the MSTHM results must be judged relative to the influence of parametric uncertainty on the range of predicted TH responses. This is analogous to determining the relative significance of conceptual model uncertainty, which is done by comparing the influence of conceptual model uncertainty with the influence of parametric uncertainty and waste package heat-output variability, as is done in Section 7.5.4 of *Multiscale Thermohydrologic Model* (BSC 2005 [DIRS 173944]).

3.5 COMPLETION CRITERIA

The requirement to state any sections of the Code of Federal Regulations, U.S. Department of Energy orders, Key Technical Issues, and additional information is not applicable because there are none identified. Section 3.3 identifies the requirement to address acceptance criteria from *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]).

This work satisfies the requirements of AP-16.1Q, *Condition Reporting and Resolution*, to enable closure of the CRs, if any, generated as a result of the Corrective Action Program.

3.6 OTHER REQUIREMENTS

The need to list any requirements allocated or derived per the Requirements Management System as required by LP-2.29Q-BSC, in performance assessment, or other source documents, is not applicable because there are none identified. The requirements identified in engineering are discussed in Section 1.2.5 through the noted IEDs.

Deliverables will be submitted to the U.S. Department of Energy in accordance with AP-7.5Q.

4. IMPLEMENTING DOCUMENTS

Current versions of the following procedures, as appropriate to individual tasks within the work packages, will be used to perform the work described in this TWP:

- AP-7.5Q, *Establishing Deliverable Acceptance Criteria and Submitting and Reviewing Deliverables*
- AP-16.1Q, *Condition Reporting and Resolution*
- AP-17.1Q, *Records Management*
- AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*
- IT-PRO-0011, *Software Management*

- LP-2.9Q-BSC, *Establishment and Verification of Required Education and Experience of Personnel*
- LP-2.29Q-BSC, *Planning for Science Activities*
- LP-3.15Q-BSC, *Managing Technical Product Inputs*
- LP-6.3Q-BSC, *Document Control*
- LP-SIII.2Q-BSC, *Qualification of Unqualified Data*
- LP-SIII.9Q-BSC, S*cientific Analyses*
- LP-SIII.10Q-BSC, *Models*
- PA-PRO-0601, *Document Review*
- TQ-PRO-1001, *Personnel Training and Qualification.*

There are no additional implementing documents to be developed to control and perform the activity. Refer to Section 8.2 regarding non-Q activities.

5. EQUIPMENT

The technical products (analyses, reports, and calculations) are prepared using project standard desktop computers. No field or laboratory work is conducted as part of this plan. No calibration or other test equipment is used.

6. RECORDS

Records generated as a result of implementing procedures listed in Section 4 will be collected and submitted to the Records Processing Center in accordance with AP-17.1Q.

7. QUALITY VERIFICATIONS

No quality assurance verification, other than regularly scheduled audits and surveillances, is required during the execution of the work packages. Quality verifications may include quality engineering work monitoring activities.

8. PREREQUISITES, SPECIAL CONTROLS, ENVIRONMENTAL CONDITIONS, PROCESSES, OR SKILLS

This section discusses *Quality Assurance Requirements and Description* (QARD) (DOE 2006 [DIRS 176927]), IT-PRO-0009, and training requirements as they apply to this work.

8.1 QARD REQUIREMENTS

The work scope described in this TWP was determined to be subject to the requirements of the QARD since it involves the analysis of data to support performance assessment and is relevant to investigations of items or barriers catalogued in *Q-List* (BSC 2005 [DIRS 175539]).

8.2 NON-Q WORK

This TWP does not describe the conduct of non-Q activities. Therefore, the requirement to determine whether each non-Q activity is subject to the Augmented Quality Assurance Program (DOE 2006 [DIRS 177173]) is not applicable.

8.3 PREREQUISITES

Data inputs to the report described in this TWP include data for the purpose of model validation. These data are available from the Technical Data Management System (TDMS).

Pre-job briefings may be conducted by Near-Field Environment team management for coordination of upcoming activities and associated requirements at the following junctures:

1. Before starting work

   - What procedures will be used? Are these expected to change during production?
   - Who will be working on the change/revision? Do they have position descriptions, verification of education and experience, and updated training?
   - What software will be used? If baselined software will be used, an appropriate Software User Request must be implemented prior to software use.
   - Which input data will be used? State differences from previous versions.
   - Does project scheduling accurately capture the work, with contingency for delays and time off, and with activities defined so they can be effectively statused? Author/checker should own the schedule from day one.
   - Have laboratory/subcontractor Subcontract Change Requests and Statements of Work been updated and approved?
   - Have the Quality Engineer and publications support staff been notified of the schedule?

2. Before checking starts

   - Check the Document Input Reference System for completion and unverified references.
   - Provide copies of any sources not in the Technical Information Center catalog

- Is data qualification completed and documented?
- Are output document tracking numbers submitted?

3. Before review

   - Review list of action items to complete for final approval.
   - Identify the reviewers. To whom will comments be escalated?
   - Have appropriate review criteria been developed? Will output data be included in the review?
   - Who is the Review Coordinator, and what is the schedule for completion of the review?

4. Before a concurrence draft is circulated

   - Have all comments been responded to with positive verbal responses from the reviewers?
   - Are there any unresolved issues, and have they been escalated?
   - Are there changes in output since checking?
   - Have any references been cancelled or superseded since checking?

5. At approval

   - Check that procedures are the same versions in effect at start.
   - Check for To Be Verified items in the Document Input Reference System (there should be none).

8.4 IT-PRO-0009 (QARD SUPPLEMENT V) REQUIREMENTS

A process control evaluation for work activities under this TWP was conducted in accordance with IT-PRO-0009 through the use of the IT-PRO-0009 Attachment 3 checklist. As a result, the following methods are used for the control of electronic management of information:

1. Upon completion of work activities, quality assurance (QA) and non-QA records are submitted to the Records Processing Center (RPC) in accordance with applicable implementing procedures. These records are retained, protected, and dispositioned in accordance with the requirements of LP-6.3Q-BSC.

2. During the conduct of work activities, electronic information is backed up and readily available on network drives. Model reports are available in InfoWorks with restricted write privileges. Data are maintained and available in the TDMS and/or Record

Information System. Electronic information on personal computers and on network drives can be retrieved instantly.

3. The model reports, data, and software are retained on network drives. Electronic information that may be stored on password-protected personal computers during the conduct of work activities is retained until the QA and non-QA information associated with the work activity becomes part of the record system. Information on personal computers is backed up on network drives.

4. Electronic information that may be stored on hard drives on password-protected personal computers is transferred to the RPC on compact disks, per AP-17.1Q, Attachment 1, Section B(2)(b). Disks and all other removable backup media are labeled with the following: generating program, originator, date, document number, and content description. This information is retained on the password-protected personal computers until confirmation by the RPC that the information has become part of the record system.

5. Completeness and accuracy of the input information is assured through compliance with the checking, quality engineering review, and technical review requirements of the applicable procedure controlling the work activity (LP-SIII.10Q-BSC). Changes to this information are made in accordance with the revision requirements given in LP-SIII.10Q-BSC.

6. Security and integrity of the electronic information developed during the work activity is maintained by storing the information on network drives and on hard drives of password-protected personal computers, and by limiting write access. After transfer to the RPC and/or TDMS, integrity is maintained by RPC access controls.

7. Minimization of errors resulting from the transfer of electronic information from one type of media to another is accomplished through originator review of the transferred information prior to transmittal. Developed data submitted to the TDMS is checked for consistency in accordance with TDMS procedures.

8.5 ENVIRONMENTAL CONTROLS

The analytical work is performed in the Summerlin office complex and at national laboratory office locations. Special environmental conditions are not required for this work.

8.6 TRAINING

Training requirements are established in the training requirements matrix in the Licensing and Nuclear Safety Training Program (TDP-ORGAD-001) and administered for compliance by the same. If the staff member is affiliated with one of the national laboratories currently working on the Yucca Mountain Project, his or her training requirements are established by the national laboratory in accordance with the laboratory's contract to Bechtel SAIC Company, LLC. Compliance with the training requirements is met through the contractual mechanisms associated with the contract. Additionally, personnel performing the work activity are subject to verification of education and experience in accordance with LP-2.9Q-BSC.

9. SOFTWARE

Off-the-shelf commercial software, such as Microsoft Word and Microsoft Excel, is employed to carry out this work. The work is conducted using project-standard desktop computers. The controlled software for planned use to conduct the work identified in this TWP is listed below. Each of the following software programs is qualified:

- NUFT v3.0s, STN: 10088-3.0s-02
- NUFT v3.0.1s, STN: 10130-3.0.1s-01
- RADPRO v4.0, STN:10204-4.0-00
- XTOOL v10.1, STN:10208-10.1-00
- MSTHAC v7.0, STN:10419-7.0-00
- readsUnits v1.0, STN:10602-1.0-00
- YMESH v1.54, STN: 10172-1.54-00
- boundary_conditions v1.0, STN: 11042-1.0-00
- heatgen_ventTable_emplace v1.0, STN:11039-1.0-00
- rme6 v1.2, STN: 10617-1.2-00
- xw v1.0, STN: 11035-1.0-00
- colCen v1.0, STN: 11043-1.0-00
- repository_percolation_calculator v1.0, STN: 11041-1.0-00
- extractBlocks_EXT v1.0, STN: 11040-1.0-00
- chimney_interpolate v1.0, STN: 11038-1.0-00.

Each of the following software programs will be qualified:

- reformat_EXT_to_TSPA v2.0
- NUFT v4.0.

The use of continuous-use software is not planned in this report.

10. ORGANIZATIONAL INTERFACES

The work scope identified in this TWP is being performed by the Near-Field Environment team within the Post Closure Activities organization. The identification of organizational interfaces, including input and customer organizations, in addition to those internal to the implementing department, and the roles and responsibilities, is not applicable because there are none. All upstream and downstream products are within the Post Closure Activities organization.

The MSTHM uses data obtained from the following upstream reports or from updated revisions of these reports:

- *UZ Flow Model and Submodels* (BSC 2004 [DIRS 169861])
- *Development of Numerical Grids for UZ Flow and Transport Modeling* (BSC 2004 [DIRS 169855])
- *Calibrated Properties Model* (BSC 2004 [DIRS 169857])

- *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854])
- *Thermal Conductivity of the Non-Repository Lithostratigraphic Layers* (BSC 2004 [DIRS 170033])
- *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862])
- *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]).

The MSTHM simulations provide TSPA-LA with the TH parameters (as a function of time) that influence the evolution of in-drift coupled flow and transport processes. The TSPA-LA then uses those TH parameters as part of its integrated assessment of system performance.

Analysis and model reports that are directly downstream of this report include:

- *Drift Degradation Analysis*
- *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model*

Total System Performance Assessment (TSPA) Model/Analysis for the License Application.

If results of the work described in this TWP supersede direct inputs in downstream reports, an impact review will be carried out in accordance with AP-SIII.3Q.

The License Application organization will coordinate the use of work described in this plan, in responding to Key Technical Issue agreements and preparing sections of the license application.

11. PROCUREMENT

Procurement activities are not associated with the work scope of this TWP.

12. REFERENCES

10 CFR (Code of Federal Regulations) 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

40 CFR 197. Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada. Readily available.

70 FR (Federal Register) 173. Implementation of a Dose Standard After 10,000 Years. Proposed rule 10 CFR 63. Readily available.

103597 Altman, W.D.; Donnelly, J.P.; and Kennedy, J.E. 1988. *Peer Review for High-Level Nuclear Waste Repositories: Generic Technical Position.* NUREG-1297. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 200651.

103750 Altman, W.D.; Donnelly, J.P.; and Kennedy, J.E. 1988. *Qualification of Existing Data for High-Level Nuclear Waste Repositories: Generic Technical Position.* NUREG-1298. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 200652.

169131 BSC (Bechtel SAIC Company) 2004. *Abstraction of Drift Seepage.* MDL-NBS-HS-000019, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041103.0003.

169857 BSC 2004. *Calibrated Properties Model.* MDL-NBS-HS-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041006.0004.

169855 BSC 2004. *Development of Numerical Grids for UZ Flow and Transport Modeling.* ANL-NBS-HS-000015 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040901.0001.

168489 BSC 2004. *D&E / PA/C IED Emplacement Drift Configuration and Environment.* 800-IED-MGR0-00201-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040326.0001.

168138 BSC 2004. *Estimation of Mechanical Properties of Crushed Tuff for Use as Ballast Material in Emplacement Drifts.* 800-CYC-SSE0-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040309.0023; ENG.20050817.0009; ENG.20050829.0017.

170003 BSC 2004. *Heat Capacity Analysis Report.* ANL-NBS-GS-000013 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041101.0003.

169503 BSC 2004. *Repository Subsurface Emplacement Drifts Steel Invert Structure Plan & Elevation.* 800-SS0-SSE0-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040520.0004.

170033 BSC 2004. *Thermal Conductivity of Non-Repository Lithostratigraphic Layers.* MDL-NBS-GS-000006 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041022.0004.

169854 BSC 2004. *Thermal Conductivity of the Potential Repository Horizon.* MDL-NBS-GS-000005 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040928.0006.

169861 BSC 2004. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041101.0004; DOC.20050629.0003.

169862 BSC 2004. *Ventilation Model and Analysis Report.* ANL-EBS-MD-000030, Rev. 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041025.0002.

175014 BSC 2005. *Engineered Barrier System Features, Events, and Processes.* ANL-WIS-PA-000002 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050829.0003.

173303 BSC 2005. *IED Interlocking Drip Shield and Emplacement Pallet [Sheet 1 of 1].* 800-IED-WIS0-00401-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050301.0007.

176805 BSC 2005. *IED Subsurface Facilities Layout Geographical Data [Sheet 1 of 1].* 800-IED-WIS0-01701-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20051103.0003.

173501 BSC 2005. *IED Waste Package Configuration [Sheet 1 of 1].* 800-IED-WIS0-00601-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050406.0005.

173944 BSC 2005. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050711.0001.

175539 BSC 2005. *Q-List.* 000-30R-MGR0-00500-000-003. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050929.0008.

173377 BSC 2005. *Technical Work Plan for: Near-Field Environment and Transport In-Drift Heat and Mass Transfer Model and Analysis Reports Integration.* TWP-MGR-PA-000018 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050413.0003.

177173 DOE (U.S. Department of Energy) 2006. *Augmented Quality Assurance Program (AQAP).* DOE/RW-0565, Rev. 1. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20060626.0002.

176927 DOE 2006. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 17. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20060504.0008.

164274 LLNL (Lawrence Livermore National Laboratory) 2002. *Software Code: MSTHAC.* V7.0. Sun, SUN O.S. 5.8. 10419-7.0-00.

164272 LLNL 2003. *Software Code: reformat_EXT_to_TSPA.* V1.0. Sun, Sun OS 5.8. 11061-1.0-00.

163274 NRC (U.S. Nuclear Regulatory Commission) 2003. *Yucca Mountain Review Plan, Final Report.* NUREG-1804, Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 254568.