BSC	**Model Administrative Change Notice** *Complete only applicable items.*	QA: QA Page 1 of 8

1. Document Number:	ANL-EBS-MD-000027	**2. Revision:**	03	**3. ACN:**	01
4. Title:	Drift Degradation Analysis				
5. No. of Pages Attached	26				

6. Approvals:

Preparer:	G.H. Nieder-Westermann (signature) Print name and sign	04/14/2005 Date
Checker:	Dwayne Kicker (signature) Print name and sign	04/14/2005 Date
QER:	Judy Gebhart (signature) Print name and sign	4/18/05 Date
Independent Technical Reviewer:	Jean Younker (signature) Print name and sign	4-18-05 Date
Responsible Manager:	Mark Board (signature) Print name and sign	4/18/05 Date

7. Affected Pages	8. Description of Change:
1-2	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
1-3	Citation update (Correct DIRS as appropriate) Replace Citation, change: *Williams 2002 [DIRS 159916]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
1-10	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Drift Degradation Analysis				

3-3	Deleted a citation Table 3-1, 5th row, delete entire row: ***UNWEDGE V2.3 (CRWMS M&O 1998 [DIRS 145366]*** This error was identified in CR 4729
4-3	Citation update Table 4-1 “Input Data and Parameters for the Drift Degradation Analysis”, 4th column “Source/Supporting Information”, 4th cell, 2nd line, change font to Italic to indicate an Indirect Input, change: Olsson and Brown 1997 [DIRS 106453] To ***Olsson and Brown 1997 [DIRS 106453]*** This error was identified in CR 5000
4-3	Citation update Table 4-1 “Input Data and Parameters for the Drift Degradation Analysis”, 4th column “Source/Supporting Information”, 4th cell, 4th line, change font to Italic to indicate an Indirect Input, change: SNL 1996 [DIRS 165408] To ***SNL 1996 [DIRS 165408]*** This error was identified in CR 5000
4-3	Citation update Table 4-1 “Input Data and Parameters for the Drift Degradation Analysis”, 4th column “Source/Supporting Information”, 4th cell, 6th line, change font to Italic to indicate an Indirect Input, change: SNL-1996 [DIRS 165410] To ***SNL-1996 [DIRS 165410]*** This error was identified in CR 5000

Complete only applicable items.

1. Document Number:	ANL-EBS-MD-000027	2. Revision:	03	3. ACN:	01
4. Title:	Drift Degradation Analysis				

4-6	Citation update Table 4-1 "Input Data and Parameters for the Drift Degradation Analysis", 4th column "Source/Supporting Information", cell number 14, 2nd line, change font from regular to Italic to indicate an Indirect Input, change: USGS 1997 [DIRS 169040] To ***USGS 1997 [DIRS 169040]*** This error was identified in CR 5000
4-8	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
4-9	Clarification to a footnote Table 4-1 "Input Data and Parameters for the Drift Degradation Analysis", footnote "a", change: *"The italicized supplemental references listed along with the source DTNs provide either summary or supporting information that is linked to the source DTN, and provide direct input for this analysis and model report."* To ***"The italicized supplemental references listed along with the source DTNs provide either summary or supporting information that is linked to the source DTN, and therefore provide indirect input for this model report."*** This error was identified in CR 5000
4-13	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Drift Degradation Analysis				

4-13	Correct text as indicated below to address CR 4734-010 Last paragraph on page 4-13, delete reference to YMRP criteria 2.2.1.3.1.3 and text as shown: **4.2 CRITERIA** This model report addresses acceptance criteria from Section ~~Sections 2.2.1.3.1.3 and~~ 2.2.1.3.2.3 of Yucca Mountain Review Plan, Final Report (NRC 2003 [DIRS 163274]) regarding the ~~degradation of engineered barriers and the~~ mechanical disruption of engineered barriers.
5-1	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
6-47	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
6-239	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2004 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
6-247	Added information Table 6-53"Repository Design and Thermal-Mechanical Effects DTI Agreement items Addressed in This Model Report", 2nd column "Approach and Section Reference". 7th cell, 2nd sentence, change: *The approach of varying the joint geometry input to UNWEDGE is no longer applied.* To ***The approach of varying the joint geometry input to UNWEDGE (Carvalho, Hoek, and Li 1992 [DIRS 172800]) is no longer applied.*** This error was identified in CR 4729

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01

4. Title: Drift Degradation Analysis

9-3	Citation update (Correct DIRS as appropriate) Section 9.1, replace reference (164519) with reference (172801), change: *BSC 2004. D&E / PA/C IED Subsurface Facilities. 800-IED-WIS0-00101-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC:ENG.20040309.0026* *To* ***BSC 2004. D&E/RIT IED Subsurface Facilities [Sheet 1 of 4]. 800-IED-WIS0-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC:ENG.20041130.0002*** This Correction is associated with TBV-5343
9-4	Citation update (Correct DIRS as appropriate) Section 9.1, replace reference (168970) with reference (172334), change: *BSC 2004. Lithophysal Rock Mass Mechanical Properties of the Repository Host Horizon. 800-K0C-SS00-00200-000-00Aa Las Vegas, Nevada: Bechtel SAIC Company. ACC:MOL020040510.0200* *To* ***BSC 2004. Lithophysal Rock Mass Mechanical Properties of the Repository Host Horizon. 800-K0C-SS00-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC:ENG.20041111.0001*** This correction is associated with TBV-5811 Additional page 9-4a was added.
9-6	Citation update (correct DIRs as appropriate) Added new reference (172800) to Section 9.1: ***"Carvalho, J.; Hoek, E.; and Li, B. 1992. Unwedge User's Guide, Version 2.3. [Toronto, Ontario, Canada: Rocscience]. TIC: 243850.*** Additional page 9-6a was added. This error was identified in CR 4729
9-17	Deleted reference (Correct DIRs as appropriate) Deleted the following reference (159916) from section 9.1: ***Williams, N.H. 2002. Thermal Imputs for Evaluations Supporting TSPA LA." Interoffice memorandum from N.H. Williams (BSC) to Distribution, September 16, 2002, 0911024159, with enclosures. ACC: MOL.20021008.0141*** This correction is associated with TBV-5343

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Drift Degradation Analysis				

9-18	Deleted reference (correct DIRs as appropriate) Deleted the following reference (145366) from section 9.1: ***"CRWMS M&O 1998. Software Code: UNWEDGE V2.3. V2.3. 30053 V2.3."*** This error was identified in CR 4729
C-1	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2003 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343
D-1	Added information Appendix D, 1st section "DRKBA Analysis of Nonlithophysal Rock", 9th line, change: *"The UNWEDGE software (UNWEDGE V2.3, 30053 V2.3) is an example of a deterministic method that calculates the maximum block size given the spacing and orientation of three joint sets, and the excavation size and orientation."* To ***"The UNWEDGE software (Carvalho, Hoek, and Li 1992 [DIRS 172800]) is an example of a deterministic method that calculates the maximum block size given the spacing and orientation of three joint sets, and the excavation size and orientation."*** This error was identified in CR 4729
E-2	Citation update (Correct DIRS as appropriate) Table E-1 "Density Data for Various Thermal Mechanical Units and Associated Lithostratigraphic Units", footnote "b", 2nd line, change: *BSC 2004 [DIRS 169854], Table 7-10* To ***BSC 2004 [DIRS 169854], Table 6-6*** This correction is associated with TBV-6387

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Drift Degradation Analysis				

E-16	Citation update (Correct DIRS as appropriate) ***Appendix E, Section E4.1.1, last line, change:*** *BSC 2004 [DIRS 168970]* To ***BSC 2004 [DIRS 172334]*** This correction is associated with TBV-5811
E-28	Citation update (Correct DIRS as appropriate) *Table E-10 "Suggested Range of Mechanical Properties Developed from 11.5-in. Core Testing, Selected for Base-Case Design and Performance Analyses", footnote "b", change:* *BSC 2004 [DIRS 168970], Table 6.6-1* To ***BSC 2004 [DIRS 172334], Table 6.4-1*** This correction is associated with TBV-5811
E-39	Citation update (Correct DIRS as appropriate) Table E-11 "Base Case and Lower Bound Strength Values for Rock Categories Used in UDEC Analyses of Spatial Variability", footnote "b", change: *BSC 2004 [DIRS 168970], Table 6.6-1* To ***BSC 2004 [DIRS 172334], Table 6.4-1*** This correction is associated with TBV-5811
E-39	Citation update (Correct DIRS as appropriate) Table E-11 "Base Case and Lower Bound Strength Values for Rock Categories Used in UDEC Analyses of Spatial Variability", add footnote "c" to read: *"Lower bound unconfinecd compressive strength data are based on BSC 2004 [172334], Table 6.6-1* This correction is associated with TBV-5811
E-55	Citation update (Correct DIRS as appropriate) Table E-18 "Thermal Conductivity for Various Thermal Mechanical Units and Associated Lithostratigraphic Units", footnote "c", change: *BSC 2004 [DIRS 169854], Table 7-10* To ***BSC 2004 [DIRS 169854], Table 6-6*** This correction is associated with TBV-6387

1. Document Number:	ANL-EBS-MD-000027	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Drift Degradation Analysis				

Q-1	Citation update (Correct DIRS as appropriate) Replace Citation, change: *BSC 2003 [DIRS 164519]* To ***BSC 2004 [DIRS 172801]*** This correction is associated with TBV-5343

The outputs from the drift degradation analysis support scientific analyses, models, and design calculations, including the following:

- *Abstraction of Drift Seepage*
- *Seismic Consequence Abstraction*
- *Structural Stability of a Drip Shield Under Quasi-Static Pressure*
- *Drip Shield Structural Response to Rock Fall*.

This report has been developed in accordance with *Technical Work Plan for: Regulatory Integration Modeling of Drift Degradation, Waste Package and Drip Shield Vibratory Motion and Seismic Consequences* (BSC 2004 [DIRS 171520]). The drift degradation analysis includes the development and validation of rockfall models that approximate phenomenon associated with various components of rock mass behavior anticipated within the repository horizon. Two drift degradation rockfall models have been developed: the rockfall model for nonlithophysal rock and the rockfall model for lithophysal rock. These models reflect the two distinct types of tuffaceous rock at Yucca Mountain. The output of this modeling and analysis activity documents the expected drift deterioration for drifts constructed in accordance with the repository layout configuration (BSC 2004 [DIRS 172801]).

1.1 BACKGROUND

Information on the Geologic Setting and Repository Subsurface Design–The repository site at Yucca Mountain is located approximately 300 m below ground surface within the Topopah Spring formation—a densely welded, laterally-expansive tuff unit comprised of a number of subunits that dip gently from west to east (BSC 2004 [DIRS 170029], Section 6.5.1.4). These subunits can be divided into two broad physical and mechanical categories: nonlithophysal and lithophysal[1] welded tuffs. The basic matrix material of these two subunits is similar in most respects (mineralogical, textural, mechanical properties). However, due to varying cooling histories and as a result of position within the flow, they are, structurally (and therefore thermomechanically), significantly different in character. The nonlithophysal rocks (the middle and lower nonlithophysal units) are hard, strong, fine-grained and fractured volcanic rocks whose mechanical behavior is strongly controlled by the geometry and surface characteristics of its fracturing. The lithophysal rocks (the upper and lower lithophysal units) are composed of the same strong, hard matrix material, but have porosity in the form of lithophysal cavities ranging from about 10 percent to 30 percent by volume. The presence of these cavities results in significantly different mechanical behavior (i.e., in the deformability and strength) of the rock mass.

[1] Lithophysae–A hollow, bubble like cavity in a volcanic rock that is surrounded by a porous rim formed by fine-grained alkali feldspar, quartz, and other minerals. Lithophysae are typically a few centimeters to a few decimeters in diameter; however, they can be as small as 1 mm in diameter or less to as large as 1 m or more in diameter (BSC 2003 [DIRS 166660]).

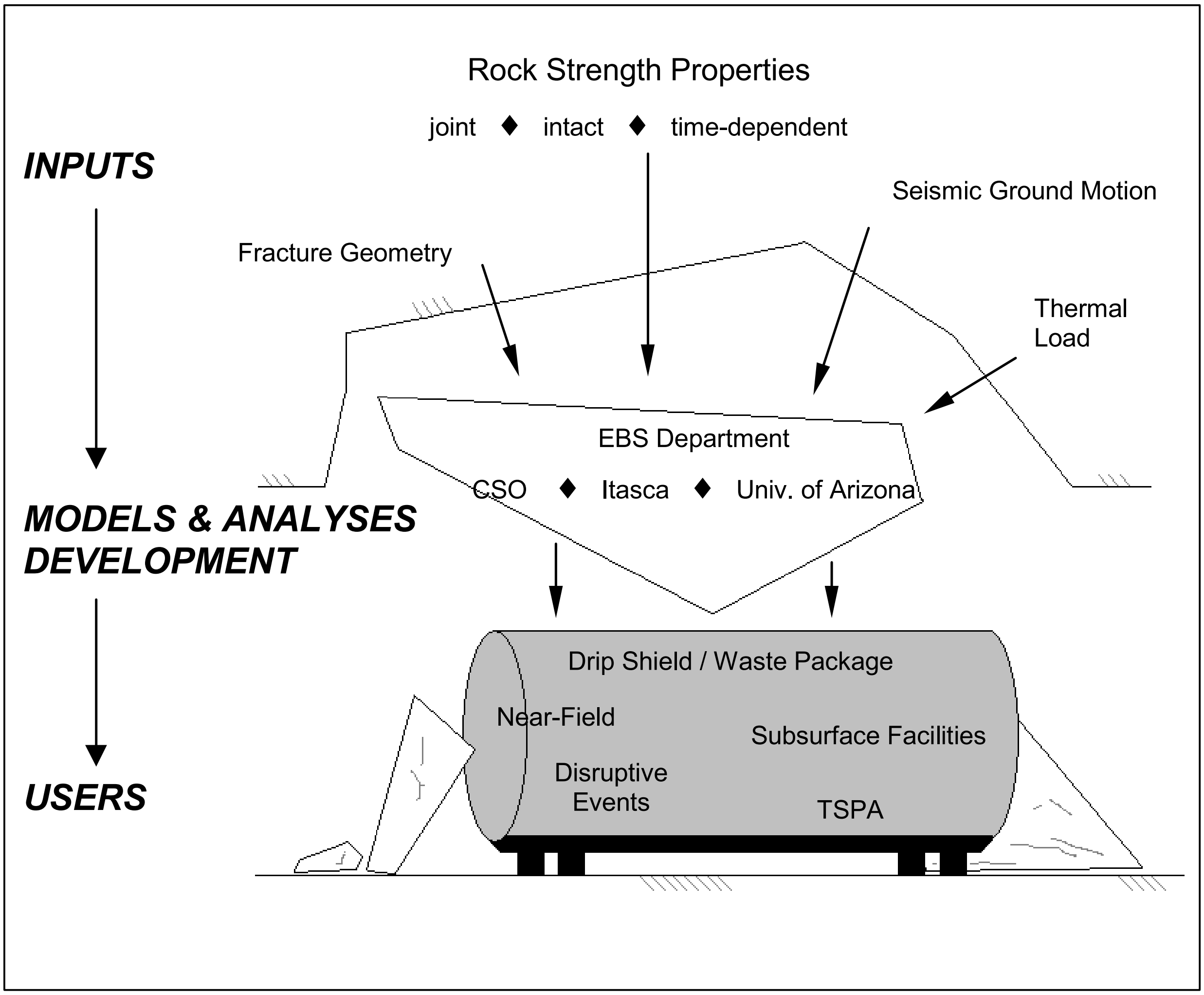

Figure 1-1. Drift Degradation Analysis

The proposed repository layout and the Topopah Spring Tuff subunits within which the excavations are located are shown in Figure 1-2. The repository consists of a series of emplacement panels that are accessed via ramps and access mains from the ground surface. The emplacement drifts are circular in the cross-section with a diameter of 5.5 m (BSC 2003 [DIRS 165572], Table 8), and driven at 81-m spacing (BSC 2004 [DIRS 172801]). This layout results in approximately 85 percent of the emplacement area to be within the lithophysal rocks, and about 15 percent within the nonlithophysal units (BSC 2003 [DIRS 165572], Table II-2).

Waste packages will be delivered to the emplacement drift from the surface facilities on steel pallets. The waste package assembly will be placed, using remote handling equipment, on a steel framework and crushed tuff drift invert at a nominal 10 cm end-to-end spacing. The nominal waste package heat output and spacing result in a maximum thermal loading density of 1.45 kW/m of drift length (BSC 2004 [DIRS 167369]). The waste packages will be ventilated for a minimum of 50 years using forced ventilation air at a nominal delivery rate of 15 m^3/sec per emplacement drift (BSC 2004 [DIRS 169862], Section 4.1.10). This ventilation air removes

1.3 SCOPE OF MODEL DOCUMENTATION

Activities documented in this report involve developing models, using analytical methods, and performing calculations and statistical analyses to determine the expected quantities, locations, size distributions, and frequencies of rockfall, based on the repository layout configuration (BSC 2004 [DIRS 172801]). Drift profiles, including the predicted deterioration as a result of rockfall, have been determined. This analysis has examined unsupported drifts with no backfill, and applied static, thermal, and seismic loading conditions.

The scope of model documentation required for analyzing the degradation anticipated in the repository emplacement drifts includes the following activities:

- Conduct a thermal-mechanical assessment of the repository block at Yucca Mountain to determine thermal stress inputs to the drift degradation models.
- Conduct a fracture degradation assessment to account for long-term strength degradation. This assessment provides strength degradation inputs to the drift degradation models.
- Develop a drift degradation structural model for nonlithophysal rock that includes thermal and seismic loading.
- Develop a drift degradation lithophysal model that includes thermal and seismic loading.

Revision 1 ICN 1 of this analysis (BSC 2001 [DIRS 156304]) considered various emplacement drift orientations, with the drift azimuth varied in appropriate increments to examine the effect of orientation on key block size and frequency. The results from this drift orientation study have not been included in this revision, and only the current emplacement drift orientation (BSC 2004 [DIRS 172801]) has been considered in this report.

1.4 ANALYSIS/MODEL APPLICABILITY AND LIMITATIONS

The drift degradation results with seismic and thermal consideration, including the drift profiles, are applicable for 5.5-m-diameter emplacement drifts oriented at an azimuth of 72º in accordance with the repository underground layout configuration (BSC 2004 [DIRS 172801]; BSC 2004 [DIRS 168489]; BSC 2003 [DIRS 165572]). The model results presented in this report are applicable to the lithophysal and nonlithophysal rock units of the repository host horizon. Uncertainties associated with the data available for model development are described in Section 6.5. The rockfall models presented in this report are valid for conditions anticipated within the repository over the 10,000-year regulatory period for both preclosure and postclosure performance, including increased loads due to seismic ground motion and thermal stress, and decreased rock strength due to time-dependent strength degradation.

Table 3-1. List of Qualified Software Supporting the Drift Degradation Analysis (Continued)

Software Title/Version	Software Tracking Number	Operating Environment (Platform/Operating System)	Brief Description of Software (Range of Use/Selection/Limitations)
DRKBA Version 3.31 (BSC 2002 [DIRS 161946])	10071-3.31-00	PC/Windows 2000	DRKBA was used to analyze block development and failure in the nonlithophysal rock units (Appendix D). DRKBA was selected to assess the impact of small-scale fractures on rockfall because it has an efficient key-block simulation algorithm. DRKBA was also selected as an alternative numerical code to verify the results from 3DEC. DRKBA does not directly apply seismic and thermal loads, and therefore was not selected as the primary code for rockfall analyses.
FracMan V2.512 (USGS 1999 [DIRS 160577])	10114-2.511-00	PC/Windows NT	FracMan was used to replicate the fracture geometry observed in the ESF to develop a representative volume of jointed rock mass (Section 6.1.6). FracMan was selected for its capability of discrete fracture data analysis, geologic fracture network construction, spatial analysis, and visualization. There are no known limitations on outputs.
NUFT V3.0s (LLNL 2002 [DIRS 157280])	10088-3.0s-01	SUN/SUN O.S. 5.7	NUFT was used to simulate heat transfer around the emplacement drift (Section 6.2). NUFT was selected for its capability of modeling thermal-hydrology of an unsaturated zone including subsurface heat and fluid flow. There are no known limitations on outputs from NUFT.
EarthVision V.5.1 (Dynamic Graphics 2000 [DIRS 167994])	10174-5.1-00	SGI/IRIX 6.5	EarthVision was used to extract stratigraphic unit thickness and cross-sections from the Geological Framework Model (GFM2000) (Appendix M). EarthVision was selected for its capability of extracting specific data from GFM2000 and presenting the data in a common graphical format. EarthVision was not used to perform data manipulation in this report. There are no known limitations on outputs based on the range of use in this report.
Clustran V.1.1 (BSC 2004 [DIRS 169203])	11162-1.1-00	PC/Windows 2000	Clustran was used to analyze fracture data in Section 6.1.6. Clustran was selected for its common usage on fracture orientation analysis for the geotechnical and mining industries. There are no known limitations on outputs.

Table 4-1. Input Data and Parameters for the Drift Degradation Analysis (Continued)

Parameter			Value	Range	Source/*Supporting Information* [a]	Application
Fracture strength	Rotary shear tests	Joint normal stress, σ (MPa); Joint peak shear stress, τ_p (MPa); Joint dilation (deg)	See Appendix E, Table E-3	See Appendix E, Table E-3	SNL02112293001.003 [DIRS 108412], *Olsson and Brown 1997 [DIRS 106453]*; SNL02112293001.005 [DIRS 108413], *SNL 1996 [DIRS 165408]*; SNL02112293001.007 [DIRS 108414], *SNL 1996 [DIRS 165410]*	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.1, 6.3.1.6.2; Appendix E, Section E2)
		Joint normal stiffness, K_n (MPa/mm); Joint shear stiffness, K_s (MPa/mm)	See Appendix E, Table E-4	See Appendix E, Table E-4		
Fracture strength	Direct shear tests	Joint cohesion (MPa); Joint friction angle (deg); Joint dilation (deg); Joint shear stiffness, K_s (MPa/mm)	See Appendix E, Table E-5	See Appendix E, Table E-5	BSC 2003 [DIRS 166660], Tables 8-47 and 8-52	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.6.2; Appendix E, Section E2)

Table 4-1. Input Data and Parameters for the Drift Degradation Analysis (Continued)

Parameter			Value	Range	Source/*Supporting Information* [a]	Application
Rock mass strength for thermal-mechanical units	Intact unconfined compressive strength for thermal-mechanical units, σ_{ci} (MPa) (also referred to as intact rock uniaxial compressive strength or ultimate differential strength)		See Appendix A, calculation file, *rock mass strength v2.xls*, worksheet "Intact Strength"	See Appendix A, calculation file, *rock mass strength v2.xls*, worksheet "Intact Strength"	MO0311RCKPRPCS.003 [DIRS 166073] SNL02030193001.001 [DIRS 120572] SN0306L0207502.008 [DIRS 165015]	Thermal-Mechanical Calculation (Section 6.2; Appendix C; Appendix E, Section E4.3)
	Intact Poisson's ratio for thermal-mechanical units; Intact Young's modulus for thermal-mechanical units (GPa)		See Appendix A, calculation file, *rock mass strength v2.xls*, worksheet "Intact Strength"	See Appendix A, calculation file, *rock mass strength v2.xls*, worksheet "Intact Strength"	MO0402DQRIRPPR.003 [DIRS 168901]] SN0306L0207502.008 [DIRS 165015]	
Rock mass strength in the Heated Drift	Q system input parameters from tunnel mapping in the Heated Drift	RQD, J_n, J_r, J_a	See Appendix E, Table E-13	See Appendix E, Table E-13	GS970608314224.007 [DIRS 158430], *USGS 1997 [DIRS 169040]*	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.6.4; Appendix E, Section E4.2)
	Ultimate differential strength (MPa) (also referred to as compressive strength, intact rock triaxial compressive strength, or intact rock uniaxial compressive strength)		See Appendix E, Table E-14	See Appendix E, Table E-14	MO0311RCKPRPCS.003 [DIRS 166073]	
	material constant for intact rock, m_i		33.87	—	BSC 2003 [DIRS 166660], Table 8-39	
Block strength for nonlithophysal rock	Uniaxial compressive strength $(\sigma_{ax})_u$ (MPa) (also referred to as intact rock uniaxial compressive strength or ultimate differential strength)		See Appendix E, Table E-17	See Appendix E, Table E-17	MO0311RCKPRPCS.003 [DIRS 166073]	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.6.4; Appendix E, Section E4.4)

Table 4-1. Input Data and Parameters for the Drift Degradation Analysis (Continued)

Parameter		Value	Range	Source/*Supporting Information* [a]	Application
Regional geology - stratigraphic thickness		See Appendix E, Tables E-1, E-18, E-19	—	MO0012MWDGFM02.002 [DIRS 153777]	Thermal-Mechanical Calculation (Appendix C; Appendix E, Sections E1 and E5)
Repository layout		See Appendix C, Sections C2 and C3	See Appendix C, Sections C2 and C3	BSC 2004 [DIRS 172801], BSC 2003 [DIRS 165572]	Thermal-Mechanical Calculation (Appendix C)
Emplacement drift orientation		72° drift azimuth	—	BSC 2004 [DIRS 172801], BSC 2003 [DIRS 165572]	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.1) Rockfall Model for Lithophysal Rock (Section 6.4.2.2, Appendix Y)
Emplacement drift diameter (m)		5.5 m	—	BSC 2004 [DIRS 168489]	
Drip shield, waste package, and invert geometry		See Appendix Y, Table Y-1; Appendix A, calculation file, *impact velocity bounding cal for preclosure rockfall rev1.mcd*	—	BSC 2004 [DIRS 169220], BSC 2004 [DIRS 168489], BSC 2004 [DIRS 169472], BSC 2004 [DIRS 169503]	
Seismic ground motion	5×10^{-4} per year	See Section 6.3.1.2.1 (Tables 6-5, 6-6, 6-7; Figure 6-36), Appendix X	See Section 6.3.1.2.1 (Tables 6-5, 6-6, 6-7; Figure 6-36), Appendix X	MO0407TMHIS104.003 [DIRS 170599]	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.2, Appendix X) Rockfall Model for Lithophysal Rock (Section 6.4.2.2)
	1×10^{-4} per year			MO0306SDSAVDTH.000 [DIRS 164033]	
	1×10^{-5} per year			MO0402AVDTM105.001 [DIRS 168890]	
	1×10^{-6} per year [c]			MO0403AVDSC106.001 [DIRS 168891] MO0301TMHIS106.001 [DIRS 161868];	
	1×10^{-7} per year			MO0403AVTMH107.003 [DIRS 168892]	

Table 4-1. Input Data and Parameters for the Drift Degradation Analysis (Continued)

Parameter	Value	Range	Source/*Supporting Information* [a]	Application
Sampling of Stochastic Input Parameters	See Section 6.3.1.2.2 (Table 6-8) and Section 6.4.2.2 (Table 6-44)	See Section 6.3.1.2.2 (Table 6-8) and Section 6.4.2.2 (Table 6-44)	MO0301SPASIP27.004 [DIRS 161869]	Rockfall Model for Nonlithophysal Rock (Section 6.3.1.2) Rockfall Model for Lithophysal Rock (Section 6.4.2.2)
Lithophysal abundance	See Appendix O	See Appendix O	GS021008314224.002 [DIRS 161910] GS040608314224.001 [DIRS 171367]	Rockfall Model for Lithophysal Rock (Section 6.4)

[a] The italicized supplemental references listed along with the source DTNs provide either summary or supporting information that is linked to the source DTN, and therefore provide indirect input for this model report.

[b] Long-term strength data are provided by outside sources and qualified for use in this report (Appendix S, Section S2.1.2) in accordance with the requirements of AP-SIII.10Q, Section 5.2.

[c] Note that two sets of 1×10^{-6} time histories are provided. The difference in these sets is described in DTN: MO0403AVDSC106.001 [DIRS 168891], file *10-6 TH memo.doc*. The original set (i.e., DTN: MO0301TMHIS106.001 [DIRS 161868]) is used in Section 6.4.2.2. Since this ground motion results in complete drift collapse for lithophysal rock, it was not necessary to repeat the analyses using the revised set (i.e., DTN: MO0403AVDSC106.001 [DIRS 168891].

4.1.6 Rock Thermal Properties Data

A regional thermal-mechanical calculation has been developed as part of this drift degradation analysis (Section 6.2), and uses the following thermal properties data (see Table 4-1 and Appendix E, Section E5 for parameter values and source DTNs):

- Thermal conductivity (W/m°K)
- Rock specific heat (J/kg°K)
- Thermal expansion (/°C)
- Heat decay curve.

4.1.7 Repository Layout Information

Repository layout information (Table 4-1), including emplacement drift diameter and azimuth, is provided by repository design and performance assessment information exchange drawings (BSC 2004 [DIRS 172801]; BSC 2004 [DIRS 168489]) and *Underground Layout Configuration* (BSC 2003 [DIRS 165572], Sections 5.1.4 and 8.7).

4.1.8 Matrix and Fracture Hydrologic Properties Data

A temperature-history calculation has been developed as part of this analysis (Section 6.2) based on a two-dimensional drift scale thermohydrologic model from *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]) and DTN: LL030808623122.036 [DIRS 165790]. Matrix and fracture hydrologic properties data used in the calculation are provided in DTN: LL030808623122.036 [DIRS 165790] as a part of the NUFT input files (i.e., file *dkm-afc-1Dds-mc-mi-04*). Summaries of the matrix and fracture hydrologic properties data are also available in DTN: LB0205REVUZPRP.001 [DIRS 159525] and DTN: LB0208UZDSCPMI.002 [DIRS 161243].

4.1.9 In Situ Stress Data

In situ stress data were determined by hydraulic fracturing in a borehole located in the Tptpmn unit in the Thermal Test Facility in the ESF (DTN: SNF37100195002.001 [DIRS 131356]; CRWMS M&O 1997 [DIRS 147458], pp. 15, 19, and 20). The in situ stress measurements included a series of five hydraulic fracturing tests, resulting in an estimate of the state of stress in the ESF as shown in Table 4-1. The vertical stress shown in Table 4-1 was calculated based on the depth of cover in the Thermal Test Facility at the test borehole location. The in situ stress for each emplacement drift will vary depending on the cover depth on top of the drift. The approximated values assigned for the in situ stress for the rockfall modeling activities in Sections 6.3 and 6.4 are adequate and insensitive to the results judging the magnitude of the induced seismic and thermal stress.

4.2 CRITERIA

This model report addresses acceptance criteria from Section 2.2.1.3.2.3 of *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) regarding the mechanical disruption of engineered barriers.

5. ASSUMPTIONS

The following assumptions have been used in this drift degradation analysis.

5.1 THERMAL-MECHANICAL CALCULATION

5.1.1 Simultaneous Emplacement

Assumption: The thermal-mechanical calculation in this report assumes that generation of heat from the waste packages occurs simultaneously throughout the repository. The entire repository begins heating at the same time because sequential emplacement of waste packages has not been considered.

Basis: This assumption is necessary because design information is available only for the emplacement drift layout (BSC 2004 [DIRS 172801]), and not for the emplacement schedule.

Confirmation Status: This assumption does not require further confirmation, because results from the thermal-mechanical calculation should be the most conservative based on this assumption (i.e., the assumption produces increased heat and greater stresses in the rock mass). Sequential emplacement may cause an additional internal stress between the emplacement drifts and the remaining drifts. This internal stress will be insignificant during the preclosure period, because the majority of the heat load will be removed from the emplacement drifts due to ventilation (Section 5.1.2). The effects of the internal stress are expected to be minor during the postclosure period, because the waste packages will cool down significantly during the preclosure period, and the repository temperature is expected to be homogenized due to heat conduction between the drifts during the preclosure period. A range of temperatures has been considered in the rockfall analyses presented in this report (Sections 6.3.1.3 and 6.4.2.3), and the rockfall results are relatively insensitive to the temperature changes evaluated.

Use in the Analysis/Model: This assumption is used in the thermal-mechanical calculation of regional (repository-scale) and local (drift scale) temperature and thermal stress (Sections 6.2, 6.3.1, and 6.4.2; Appendix C).

5.1.2 Ventilation Heat Removal Ratio

Assumption: During the ventilated preclosure period, 90 percent of the decay heat output is removed from the emplacement drift system.

Basis: The basis of this assumption is provided from the ventilation model supporting a license application (BSC 2004 [DIRS 169862]), which has integrated heat removal ratios (averaged spatially and temporally) of 88 percent and 90 percent for the 50-year preclosure ventilation period and 600-m long drifts (MO0306MWDASLCV.001 [DIRS 165695] and MO0306MWDALAFV.000 [DIRS 163961], respectively).

Confirmation Status: No further confirmation is needed for this assumption because sensitivity calculation regarding the heat removal ratio was conducted covering the heat removal ratio down and stresses as calculated by the drift scale and the coupled regional and drift scale calculations is presented at the end of this section.

The thermal part of the drift scale calculation was performed by the NUFT thermohydrology software, applying a two-dimensional line-averaged heat source, drift scale, thermohydrologic (LDTH) sub-model, which is described in *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]). The LDTH sub-model is a part of the multiscale thermohydrologic model that is created by the NUFT software. The LDTH sub-model accounts for hydrologic effects in the rock mass, and conductive and radioactive heat transfer mechanisms around the drift. Effects of the preclosure forced ventilation are accounted for by removing a percentage of the heat given off by the waste package (Section 5.1.2). A non-backfilled and mean infiltration version of the LDTH sub-model L2C3 (coordinates: E170731, N234973) was selected and extracted among the 31 LDTH sub-models. The L2C3 LDTH sub-model is used to compute temperature history of the emplacement drift and surrounding areas throughout the preclosure and postclosure periods.

The L2C3 LDTH sub-model location selected has the following characteristics of interest:

- Approximately the geometric center of the license application reference repository layout (BSC 2004 [DIRS 172801]).

- The repository horizon is located approximately 281 m below the ground surface and 327 m above the water table. This elevation puts the repository horizon at approximately 1057 m above sea level.

- The repository horizon is located in the Tptpll with approximately 34 m of Tptpll above the repository horizon and 68 m of Tptpll below the repository horizon.

- The mean infiltration conditions have surface infiltration rates of 12.0 mm/year during the first 600 years of emplacement (present day climate), 40.8 mm/year from 600 years to 2000 years (monsoonal climate), and 63.2 mm/year from 2,000 years on (glacial transition climate).

- The ground surface temperature is fixed at 16.9°C, and the water table temperature is fixed at 29.2°C.

In addition to the LDTH sub-model, updated thermal and hydrologic properties were used for the repository and non-repository rock units. The thermal and hydrologic properties are presented in Section 4.1.6 and 4.1.8, respectively. Details of the data preparation for input files of the LDTH sub-model are described in *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]).

Three major cases of the drift scale thermal calculation were carried out, including:

- Case 1: Base case calculation with 1.45 kW/m initial heat load and 50 years preclosure ventilation (90 percent heat removal ratio, Section 5.1).

- Case 2: Sensitivity calculation for thermal properties of repository rock material (Tptpll) with 1.45 kW/m initial heat load, 50 years preclosure ventilation, and 90 percent

Rock Thermal Properties Data–A sufficient amount of rock thermal properties data has been collected for the nonlithophysal rock units. The epistemic uncertainty associated with this thermal properties data for nonlithophysal rock is assessed to be low. Conversely, the amount of rock thermal properties data for the lithophysal units is limited. Therefore, the epistemic uncertainty associated with this thermal properties data for lithophysal rock is assessed to be high. Uncertainty assessments are provided in the data source documentation identified in Table 4-1 and in Appendix E (Section E5). Sensitivity calculations for thermal properties were conducted with one standard deviation less values used for thermal conductivity and specific heat as described in Section 6.2, Section 6.3.1.3, and Section 6.4.2.3. The sensitivity case results in approximately 23°C higher peak temperature comparing with the base case but with minor impact to the rockfall prediction.

Repository Layout Information–The repository layout data are based on design information, which is currently in the preliminary design stage. This design information is subject to change before being finalized. The model results documented in this report are applicable for the emplacement drift diameter and emplacement drift alignment provided by repository design and performance assessment information exchange drawings (BSC 2004 [DIRS 172801]; BSC 2004 [DIRS 168489]) and Section 5.1.4 and 8.7 of *Underground Layout Configuration* (BSC 2003 [DIRS 165572]). The rockfall models are sensitive to both emplacement drift diameter and alignment. While no changes are expected to the emplacement drift diameter and alignment, and any change to this design information would require reevaluation.

6.6 DRIFT DEGRADATION FEPS

The development of a comprehensive list of features, events, and processes (FEPs) potentially relevant to postclosure of the repository is an ongoing, iterative process based on site-specific information, design, and regulations. The approach for developing an initial list of FEPs was documented by *The Development of Information Catalogued in REV00 of the YMP FEP Database* (Freeze et al. 2001 [DIRS 154365]). To support TSPA-LA, the FEP list was re-evaluated and is provided by DTN: MO0407SEPFEPLA.000 [DIRS 170760]. Table 6-50 provides a list of FEPs addressed in this model document that have been included in TSPA-LA (based on MO0407SEPFEPLA.000 [DIRS 170760]), and provides specific references to sections within this document. Additionally, Table 6-51 provides a list of FEPs addressed in this model document that have been excluded in TSPA-LA (based on MO0407SEPFEPLA.000 [DIRS 170760]).

Table 6-53. Repository Design and Thermal-Mechanical Effects KTI Agreement Items Addressed in This Model Report (Continued)

Agreement Item	Approach and Section Reference	Status of Agreement
RDTME 3.17	The approach for determining the effective maximum rock size has been revised in this model report. The approach of varying the joint geometry input to UNWEDGE (Carvalho, Hoek, and Li 1992 [DIRS 172800]) is no longer applied. The maximum rock size and shape is taken directly from the 3DEC output, which includes the variation in joint strike, dip, spacing, and persistence. The variation of joint geometry parameters is based on field mapping data from the ESF, which has been input into the rockfall model (Sections 6.1.6 and 6.3).	The data and information provided in this model report are intended to fully address the requirements of this agreement.
RDTME 3.19	(1) In this revision of this model report, the DRKBA analyses provide a confirmatory role in the assessment of drift degradation. The primary analysis for degradation of nonlithophysal rock is provided using 3DEC (Section 6.3), while lithophysal rock is analyzed using UDEC (Section 6.4). An appropriate range of joint strength properties has been applied as documented in Section 6.3.1.6. Long-term degradation has been accounted for as documented in Section 6.3.1.5. (2) An analysis of block sizes based on the full distribution of joint trace length data has been included in this report (Sections 6.1.4 and 6.1.6), including the available small joint trace length data (Section 6.3.3). (3) As indicated above, the DRKBA results now provide a confirmatory role in the assessment of drift degradation. 3DEC has replaced DRKBA as the primary code for analyzing structural block development in the nonlithophysal rock units. The 3DEC and DRKBA results are in good agreement (Section 7.7.5). (a) Appropriate boundary conditions for thermal and seismic loading have been included in 3DEC as documented in Section 6.3.1.1. (b) A total of 50 fracture patterns have been analyzed, which were drawn from the same fracture population used in the DRKBA analyses (Section 6.3.1.1). (c) Thermal and mechanical properties for rock blocks and joints are available in the Technical Data Management System as documented in Section 4.1. (d) Long-term degradation of joint strength has been included as documented in Section 6.3.1.5. (e) Site-specific ground motion time histories appropriate for postclosure period have been modeled as documented in Sections 6.3.1.2 and 6.4.2.2.	The data and information provided in this model report are intended to fully address the requirements of this agreement.

BSC 2003. *Heat Capacity and Thermal Expansion Coefficients Analysis Report*. ANL-NBS-GS-000013 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030820.0002. 164670

BSC 2003. *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability*. 800-K0C-TEG0-00600-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031125.0002. 166183

BSC 2003. *Subsurface Geotechnical Parameters Report*. 800-K0C-WIS0-00400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040108.0001. 166660

BSC 2003. *Underground Layout Configuration*. 800-P0C-MGR0-00100-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031002.0007. 165572

BSC 2004. *Abstraction of Drift Seepage*. MDL-NBS-HS-000019 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. 169131

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 168489

BSC 2004. *D&E / PA/C IED Interlocking Drip Shield and Emplacement Pallet*. 800-IED-WIS0-00401-000-00D. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040503.0018. 169220

BSC 2004. *D&E/RIT IED Subsurface Facilities [Sheet 1 of 4]*. 800-IED-WIS0-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20041130.0002. 172801

BSC 2004. *D&E / PA/C IED Typical Waste Package Components Assembly*. 800-IED-WIS0-00204-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040202.0012. 167369

BSC 2004. *D&E/PA/C IED Typical Waste Package Components Assembly*. 800-IED-WIS0-00202-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040517.0008. 169472

BSC 2004. *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, NV*. MDL-MGR-GS-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. 170027

BSC 2004. *Drip Shield Structural Response to Rock Fall*. 000-00C-SSE0-00300-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040405.0019. 168993

BSC 2004. *Geologic Framework Model (GFM2000)*. MDL-NBS-GS-000002 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040827.0008. 170029

BSC 2004. *Ground Control for Emplacement Drifts for LA*. 800-K0C-SSE0-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040712.0019. 170292

BSC 2004. *Lithophysal Rock Mass Mechanical Properties of the Repository Host Horizon*. 800-K0C-SS00-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20041111.0001. 172334

BSC 2004. *Multiscale Thermohydrologic Model*. ANL-EBS-MD-000049 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. 169565

BSC 2004. *Peak Ground Velocities for Seismic Events at Yucca Mountain, Nevada*. ANL-MGR-GS-000004 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. 170137

BSC 2004. *Q-List*. 000-30R-MGR0-00500-000-000 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040721.0007. 168361

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. 169503

BSC 2004. *Sampling of Stochastic Input Parameters for Rockfall Calculations and for Structural Response Calculations Under Vibratory Ground Motion*. ANL-EBS-PA-000009 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040901.0004. 169999

BSC 2004. *Seismic Consequence Abstraction*. MDL-WIS-PA-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. 169183

BSC 2004. *Structural Calculations of Waste Package Exposed to Vibratory Ground Motion*. 000-00C-WIS0-01400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040217.0008. 167083

BSC 2004. *Technical Work Plan for: Regulatory Integration Modeling of Drift Degradation, Waste Package and Drip Shield Vibratory Motion and Seismic Consequences*. TWP-MGR-GS-000003 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040810.0003. 171520

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

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

Byrne, P.M.; Srithar, T.; and Kern, C.B. 1990. "Field Measurements and Analysis of a Large Diameter Flexible Culvert." *Structural Performance of Flexible Pipes, Proceedings of the First National Conference on Flexible Pipes, Columbus, Ohio, 21-23 October, 1990*. Sargand, S.M; Mitchell, G.F.; and Hurd, J.O., eds. Pages 27-37. Brookfield, Vermont: A.A. Balkema. TIC: 255970. 168921

Canori, G.F. and Leitner, M.M. 2003. *Project Requirements Document*. TER-MGR-MD-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031222.0006. 166275

Carlos, B.A.; Chipera, S.J.; and Bish, D.L. 1995. *Distribution and Chemistry of Fracture-Lining Minerals at Yucca Mountain, Nevada*. LA-12977-MS. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL.19960306.0564. 101326

Carvalho, J.; Hoek, E.; and Li, B. 1992. *Unwedge User's Guide, Version 2.3.* [Toronto, Ontario, Canada: Rocscience]. TIC: 243850. 172800

Charles, R.J. 1959. "The Strength of Silicate Glasses and Some Crystalline Oxides." *Fracture, Proceedings of an International Conference on the Atomic Mechanisms of Fracture held in Swampscott, Massachusetts, April 12-16, 1959*. Averback, B.L.; Felbeck, D.K.; Hahn, G.T.; and Thomas, D.A., eds. Chapter 12, 225–249. New York, New York: John Wiley & Sons. TIC: 236240. 170308

Chen, E.P. 1987. *A Computational Model for Jointed Media with Orthogonal Sets of Joints*. SAND86-1122. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19991116.0419. 101800

Christiansen, R.L.; Lipman, P.W.; Carr, W.J.; Byers, F.M., Jr.; Orkild, P.P.; and Sargent, K.A. 1977. "The Timber Mountain-Oasis Valley Caldera Complex of Southern Nevada." *Geological Society of America Bulletin*, *88*, (7), 943-959. [Boulder, Colorado]: Geological Society of America. TIC: 201802. 157236

CRWMS M&O 1997. *Data Transmittal Package (DTP) for "Hydraulic Fracturing Stress Measurements in Test Hole: ESF-AOD-HDFR#1, Thermal Test Facility, Exploratory Studies Facility at Yucca Mountain*. DTN: SNF37100195002.001, TDIF 305878. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970717.0005; MOL.19970717.0006; MOL.19970717.0007; MOL.19970717.0008. 147458

CRWMS M&O 1997. *Yucca Mountain Site Geotechnical Report*. B00000000-01717-5705-00043 REV 01. Two volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971017.0736; MOL.19971017.0737. 103564

CRWMS M&O 1998. *Geology of the Exploratory Studies Facility Topopah Spring Loop*. BAB000000-01717-0200-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980415.0283. 102679

CRWMS M&O 1998. *Preliminary Block Size Calculation*. BCAA00000-01717-0210-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981106.0282. 102723

Wiederhorn, S.M. 1968. "Moisture Assisted Crack Growth in Ceramics." *International Journal of Fracture Mechanics*, *4*, (2), 171-177. Groningen, The Netherlands: Wolters–Noordhoff Publishing. TIC: 256161. 170309

Williams, N.H. 2001. "Contract #: DE-AC08-01NV12101 - Drift Scale Test (DST) White Paper: Scaling Along the Roof of the Heated Drift." Letter from N.H. Williams (BSC) to S.P. Mellington (DOE/YMSCO), May 15, 2001, PROJ.05/01.033, with enclosure. ACC: MOL.20010622.0252. 159516

9.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available. 156605

AP-2.22Q, Rev. 1, ICN 1. *Classification Analyses and Maintenance of the Q-List*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040714.0002.

AP-3.15Q, Rev. 4, ICN 5. *Managing Technical Product Inputs*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040812.0004.

AP-SIII.9Q, Rev. 1, ICN 6. *Scientific Analyses*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040805.0003.

AP-SIII.10Q, Rev. 2, ICN 6. *Models*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040805.0005.

AP-SIII.2Q, Rev. 1, ICN 2. *Qualification of Unqualified Data*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040127.0008.

AP-SIII.3Q, Rev. 2, ICN 1. *Submittal and Incorporation of Data to the Technical Data Management System*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040226.0001.

LP-SI.11Q-BSC, Rev. 0. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040225.0007.

YMP-USGS-GP-20, Rev. 1. *Estimating Abundance of Fractures in Core and in Outcrops, Including Lithophysae, Spots, Clasts, and Fractures.* Denver, Colorado: U.S. Geological Survey. ACC: MOL.19960129.0372.

9.3 SOFTWARE

BSC 2002. Software Code: 3DEC. V2.01. PC WINDOWS 2000/NT 4.0. 10025-2.01-00. 161930

BSC 2002. Software Code: DRKBA. V3.31. PC WINDOWS 2000/NT 4.0. 10071-3.31-00. 161946

BSC 2002. Software Code: F LAC. V4.0. PC WINDOWS 2000/NT 4.0 10167-4.0-00. 161953

BSC 2002. Software Code: FLAC3D. V2.1. PC WINDOWS 2000/NT 4.0. 10502-2.1-00. 161947

BSC 2002. Software Code: PFC2D. V2.0. PC WINDOWS 2000/NT 4.0. 10828-2.0-00. 161950

BSC 2002. *Software Code: PFC3D*. V.2.0. PC. 10830-2.0-00. 160612

BSC 2002. *Software Code: UDEC*. V3.1. PC WINDOWS 2000/NT 4.0. 10173-3.1-00. 161949

BSC 2004. *Software Code: Clustran*. V. 1.1. PC, Windows 2000. 11162-1.1-00. 169203

BSC 2004. *Software Code: PFC2D*. V 2.0. PC, Windows 2000. 10828-2.0-01. 169930

BSC 2004. *Software Code: PFC3D*. V 2.0. PC, Windows 2000. 10830-2.0-01. 169931

BSC 2004. *Software Code: Read DXF*. V. 1.0. PC, Windows 2000. 11159-1.0-00. 169204

CRWMS M&O 1997. *Software Code: DIPS*. V4.03. 30017 V4.03. 149839

Dynamic Graphics 2000. *Software Code: EARTHVISION*. 5.1. SGI/IRIX 6.5. 10174-5.1-00. 167994

LLNL (Lawrence Livermore National Laboratory) 2002. *Software Code: NUFT*. V3.0s. Sun, SunO.S. 5.6 & 5.7. 10088-3.0s-01. 157280

USGS 1999. *Software Code: FracMAN*. V.2.512. PC, Windows NT. 10114-2.511-00. 160577

9.4 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

GS000608314224.004. Provisional Results: Geotechnical Data for Station 35+00 to Station 40+00, Main Drift of the ESF. Submittal date: 06/20/2000. 152573

REGIONAL AND LOCAL SCALE THERMAL-MECHANICAL ANALYSIS OF THE ROCK MASS SURROUNDING WASTE EMPLACEMENT DRIFTS AT YUCCA MOUNTAIN

C1. INTRODUCTION

This appendix summarizes the results of a three-dimensional thermal-mechanical analysis of the repository site at Yucca Mountain using the finite difference code FLAC3D.

The analysis supports the NUFT drift-scale thermal calculation and to evaluate the edge effect described in Section 6.2 by defining the distribution of stresses around drifts due to progressive heating of the repository area. Unlike the NUFT calculation that simulated complex heat transfer physics (Section 6.2), only the thermal conduction into the rock mass was considered in the analysis in order to compute the thermal stresses around the drifts. Simulation of the rock mass behavior due to excavation and heating of the drifts has been carried out in two steps.

First, a regional scale (small-scale, for instance 1/10,000) calculation of the Yucca Mountain site was constructed. This calculation includes details of topography, stratigraphy and two structural faults. Figure C-1a shows an aerial view of Yucca Mountain, together with a digital elevation calculation generated for the purposes of this calculation. Figure C-1b shows the FLAC3D mesh constructed from the digital elevation calculation and available geological information. In the regional calculation, the heat sources act uniformly distributed over the area delimited by the repository boundaries (see Figure C-1).

Second, a detailed local scale (large-scale, for instance 1/100) calculation has been constructed at the specified locations at the center (considered to be the hottest) and edge within the proposed repository area (see Figure C-2). This local scale calculation allows the study of induced stresses and displacements on the rock mass surrounding a central drift due to simultaneous application of heat sources in this drift and in neighboring ones.

C2. DESCRIPTION OF THE REGIONAL (SMALL) SCALE CALCULATION

A topographical plan shown of the Yucca Mountain site (the coordinates in the plan view correspond to N-S and W-E geographical system in meters) is seen in Figure C-3. The figure indicates the location of the proposed repository area (red lines), access tunnels (blue lines) and location of available geological cross-sections (black lines). The location of boreholes from where thickness of the strata and in situ stresses have been measured is also shown on this figure.

In the regional scale calculation, the repository area is considered to lie on a horizontal plane at an elevation of 1073 meters (averaged from BSC 2004 [DIRS 172801]). From the available geological information, the two faults, the Solitario Canyon fault in the west and the Ghost Dance fault in the east, have been outlined (the green lines in Figure C-3 represent the traces of the faults on the horizontal plane containing the repository at the 1,073 meter elevation). The spatial location of the faults, as measured and interpreted from the available geological maps (BSC 2004 [DIRS 170029]) and cross-sections extracted from DTN: MO0012MWDGFM02.002 [DIRS 153777] (i.e., Figures M-1, M-2 and M-3), is defined in Table C-1 and depicted in Figure C-4. The details of the cross-section extraction are provided in Appendix M.

DRKBA ANALYSIS OF NONLITHOPHYSAL ROCK

The DRKBA analysis approach involves the use of probabilistic key-block theory through the numerical code, DRKBA V3.31 (see Section 3.1). This method is based on an industry-accepted approach for analyzing geotechnical problems. Prior to initially purchasing the DRKBA software, technical literature sources were reviewed for the purpose of determining the most appropriate approach to be used in the development of a key-block analysis for the YMP. In summary, the issue of key-block analysis in underground excavations located in jointed rock masses has been considered in a number of design situations. Deterministic methods of block theory in rock engineering were advanced by Warburton (1981 [DIRS 150093]) and Goodman and Shi (1985 [DIRS 150094]). The UNWEDGE software (Carvalho, Hoek, and Li 1992 [DIRS 172800]) is an example of a deterministic method that calculates the maximum block size given the spacing and orientation of three joint sets, and the excavation size and orientation. Subsequently Hoerger and Young (1990 [DIRS 151814]), Tyler et al. (1991 [DIRS 151818]), Kuszmaul and Goodman (1995 [DIRS 151816]) and Stone et al. (1996 [DIRS 150437]) have been orientated toward probabilistic risk assessment of key-block failure. Stone et al. (1996 [DIRS 150437]) reports on the use of DRKBA. These latest methods are considered suitable for the analysis of densely jointed and faulted rock masses where planar joint surfaces can reasonably be considered. These conditions typically exist at the YMP.

D1. DRKBA APPROACH

DRKBA is a commercially available acquired software product (described in Section 3). The software simulates structural discontinuities as circular discs placed in the rock mass according to probabilistic distributions determined from tunnel mapping data. Joint planes are simulated by a Monte Carlo technique from probability distributions representing the orientation, spacing, and trace length of the corresponding joint set. DRKBA determines where joint planes intersect to form blocks, and then analyzes these blocks to determine if they are geometrically feasible (i.e., the shape of the block is such that it is physically possible to slide or fall into the tunnel opening). If the blocks are geometrically feasible, DRKBA then determines if they are mechanically stable (i.e., the gravitational forces that cause the block to move into the tunnel opening are less than the frictional forces on the block sliding surfaces). DRKBA does not include a ground support element.

A probabilistic key-block analysis using DRKBA requires four sets of data. The required data are stored in data files having extensions *.mkg*, *.exc*, *.den*, and *.prb*, and contain information for the grid, excavation, rock density, and joint sets, respectively. The make grid file (*.mkg*) includes the information required for building a grid of nodal points for the mesh. The excavation data file (*.exc*) contains the information for defining an excavation in three-dimensional space. The density file (*.den*) holds the information for the rock density data. The probabilistic joint data file (*.prb*) includes the required information for generating fracture space from the given fracture probability distributions.

The DRKBA software employs a bipolar Watson distribution for joint orientation data. The principal axis orientation and a concentration factor k are the required inputs for the bipolar Watson distribution. The concentration factor k is an index of the concentration. The larger the value of k, the more the distribution is concentrated towards the principal axis orientation. Joints

Table E-1. Density Data for Various Thermal Mechanical Units and Associated Lithostratigraphic Units

Thermal Mechanical Unit	Stratigraphic Unit	Thickness[a] (m)	Dry Bulk Density (kg/m^3)	DTN[b]
TCw / PTn	Tpcpv3	0.0	2310	SN0303T0503102.008 [DIRS 162401]
	Tpcpv2	5.1	1460	
	Tpcpv1	2.4	1460	
	Tpbt4	0.5	1460	
	Tpy	3.8	1460	
	Tpbt3	3.8	1460	
	Tpp	5.1	1460	
	Tpbt2	8.3	1460	
	Tptrv3	1.9	1460	
	Tptrv2	1.2	1460	
	Mean (weighted by unit thickness)		*1460*	
TSw1	Tptrv1	1.2	2310	
	Tptrn	35.6	2190	
	Tptrl	6.1	2190	
	Tptpul	66.8	1834	SN0404T0503102.011 [DIRS 169129]
	Mean (weighted by unit thickness)		*1974*	
TSw2 / TSw3	Tptpmn	38.3	2148	
	Tptpll	95.6	1979	
	Tptpln	55.1	2211	
	Tptpv3	12.0	2310	SN0303T0503102.008 [DIRS 162401]
	Mean (weighted by unit thickness)		2095	
CHn1 / CHn2	Tptpv2	4.7	1460	
	Tptpv1	15.4	1460	
	Tpbt1	2.0	1460	
	Calico	45.5	1670	
	Calicobt	15.9	1670	
	Mean (weighted by unit thickness)		1614	

[a] Thickness of units extracted from DTN: MO0012MWDGFM02.002 [DIRS 153777]. The details of this extraction are provided in Appendix M.

[b] Mean values are calculated in this report and not provided by the DTNs listed in this table. Data extracted from DTN: SN0404T0503102.11 [DIRS 169129] are summarized in BSC 2004 [DIRS 169854], Table 6-6. Data extracted from DTN: SN0303T0503102.008 [DIRS 162401] are summarized in BSC 2004 [DIRS 170033], Table 6-13.

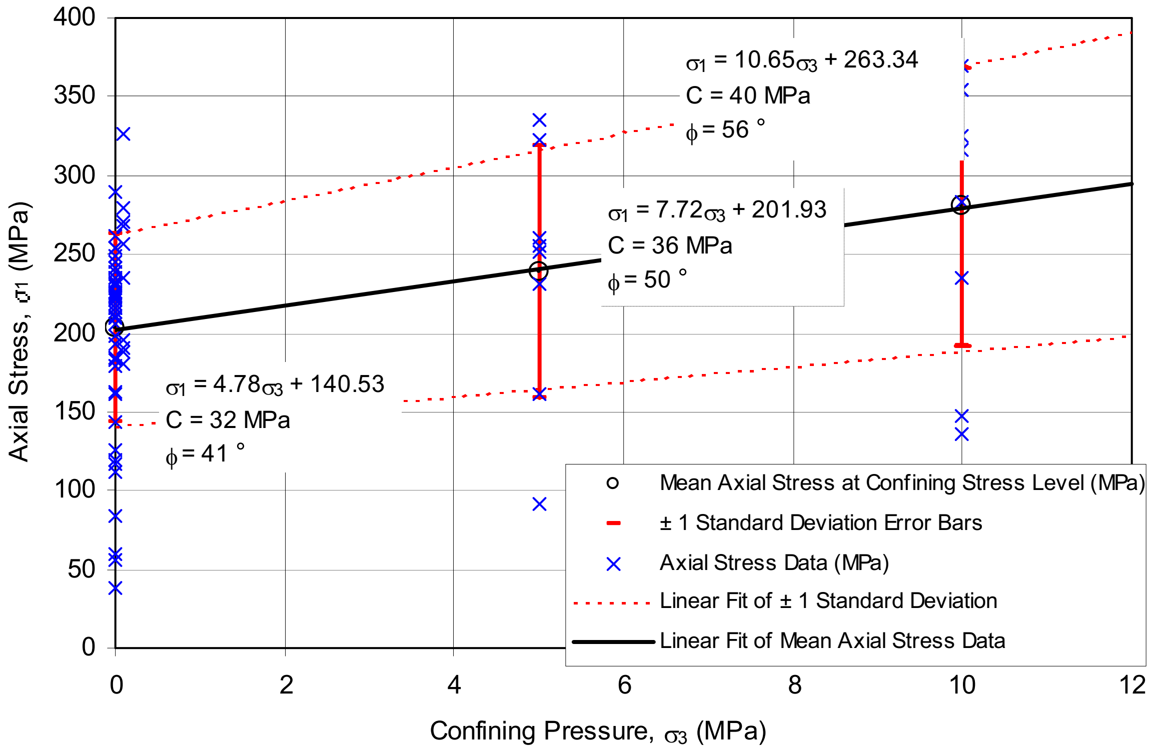

Figure E-2. Uniaxial and Triaxial Test Data from Borehole Samples Near the ESF for the Tptpmn Lithostratigraphic Unit

E4. ROCK MASS PROPERTIES

E4.1 ASSESSMENT OF LITHOPHYSAL ROCK STRENGTH

E4.1.1 Introduction

The following section provides a discussion of the development of estimates of the rock mass mechanical properties of the lithophysal units of the Topopah Spring tuff. A description of the small and large core laboratory testing database is provided. The large core mechanical testing (including room dry and saturated conditions) was used to relate strength and modulus to lithophysal porosity, which is the primary factor in control of variability of mechanical properties in this rock. An initial set of base case strength and modulus values (termed rock strength "categories") are developed as from the most-recent large core testing that span the entire range of lithophysal porosity conditions observed in the ECRB Cross-Drift. These base case values are used as a basis for a series of parametric analyses of emplacement drift stability under in situ, thermal and seismic loading described in Section 6.4. These analyses consider homogenous rock properties for each rock strength category with the lower strength categories leading to conservative results. Additional discussion on lithophysal rock strength is provided in *Lithophysal Rock Mass Mechanical Properties of the Repository Host Horizon* (BSC 2004 [DIRS 172334]).

Table E-10. Suggested Range of Mechanical Properties Developed from 11.5-in. Core Testing, Selected for Base-Case Design and Performance Analyses

Rock Mass Category	Unconfined Compressive Strength (MPa)	Estimated Young's Modulus[a] (GPa)	Cohesion[c] (MPa)			Bulk Modulus[c], K (GPa)	Shear Modulus[c], G (GPa)	Approximate Lithophysal Porosity From Laboratory Tests[b] (%)
			ϕ=50	ϕ=45	ϕ=40			
1	10	1.9	1.82	2.07	2.33	1.07	0.80	35 ± 8
2	15	6.4	2.73	3.11	3.50	3.54	2.65	28 ± 6
3	20	10.8	3.64	4.14	4.66	6.01	4.51	21 ± 4
4	25	15.3	4.55	5.18	5.83	8.48	6.36	13 ± 5
5	30	19.7	5.46	6.21	7.00	10.95	8.21	7 ± 7

Source: DTNs provided in Table E-9.

[a] Young's Modulus estimated from linear fit to 11.5-in. core data given in Figure E-8.

[b] Approximated lithophysal porosity and ranges are from BSC 2004 [DIRS 172334], Table 6.4-1.

[c] Cohesion is calculated using Equation E-8. Bulk and shear modulus values are calculated based on Equations E-2 and E-3.

UDEC simulations of compression tests were conducted for 30 samples from each of the upper and lower cross sections. For each sample, for rock mass strengths for each strength category were defined by two sets of values – the base case properties, and the lower bound rock mass properties, both illustrated in Figure E-16 and summarized in Table E-11. The upper bound values are not examined as they are irrelevant since the base case analyses of drift stability presented in Section 6.4 are conservative – higher strengths will only result in greater stability.

Table E-11. Base Case and Lower Bound Strength Values for Rock Categories Used in UDEC Analyses of Spatial Variability

Rock Mass Category	Unconfined Compressive Strength (MPa)		Estimated Young's Modulus[a] (GPa)	Approximate Lithophysal Porosity From Laboratory Tests[b] (%)
	Base Case	Lower Bound[c]		
1	10	2.0	1.9	35 ± 8
2	15	5.6	6.4	28 ± 6
3	20	9.2	10.8	21 ± 4
4	25	12.8	15.3	13 ± 5
5	30	16.3	19.7	7 ± 7

Source: DTNs provided in Table E-9.

[a] Young's Modulus estimated from linear fit to 11.5-in. core data given in Figure E-8

[b] Estimated from correlations of strength and modulus to lithophysal porosity in Figure E-6. Porosity ranges are based on BSC 2004 [DIRS 172334], Table 6.4-1.

[c] Lower bound unconfined compressive strength data are based on BSC 2004 [DIRS 172334], Table 6.6-1.

The numerical compression tests typically show that the samples fail as expected in an axial splitting mode (Figure E-17). The results of these analyses are summarized in Figure E-18 in terms of the relationship of UCS and Young's Modulus. Here, the laboratory and PFC shape study analyses are plotted along with the results of the numerical compression experiments for base case and lower bound properties. Several conclusions from this work can be made, including:

1. The variability in porosity distribution inherent in the samples results in UCS values that roughly equal or exceed 10 MPa. As seen in Figure E-18, the spatial variability in rock mass strength naturally results in sample strengths that gravitate toward that of the average porosity (i.e., around 15 percent). It is difficult, considering variable rock mass porosity, to produce average rock mass strength values that are at the low end of the category range. This agrees with observations in the ESF main loop and ECRB Cross-Drift of stable, lightly supported excavations in the lithophysal units that show little or no signs of instability.

Table E-18. Thermal Conductivity for Various Thermal Mechanical Units and Associated Lithostratigraphic Units

Thermal Mechanical Unit	Stratigraphic Unit	Thickness[a] (m)	Thermal Conductivity[b] (W/m°K) T ≤ 100° C	T > 100° C	DTN[c]
TCw / PTn	Tpcpv3	0.0	0.80	0.69	SN0303T0503102.008 [DIRS 162401]
	Tpcpv2	5.1	1.06	0.49	
	Tpcpv1	2.4	1.06	0.49	
	Tpbt4	0.5	1.06	0.49	
	Tpy	3.8	1.06	0.49	
	Tpbt3	3.8	1.06	0.49	
	Tpp	5.1	1.06	0.49	
	Tpbt2	8.3	1.06	0.49	
	Tptrv3	1.9	1.06	0.49	
	Tptrv2	1.2	1.06	0.49	
	Mean (weighted by unit thickness)		*1.06*	*0.49*	
TSw1	Tptrv1	1.2	0.80	0.69	
	Tptrn	35.6	1.81	1.30	
	Tptrl	6.1	1.81	1.30	
	Tptpul	66.8	1.77	1.18	SN0404T0503102.011 [DIRS 169129]
	Mean (weighted by unit thickness)		*1.77*	*1.22*	
TSw2 / TSw3	Tptpmn	38.3	2.07	1.42	
	Tptpll	95.6	1.89	1.28	
	Tptpln	55.1	2.13	1.49	
	Tptpv3	12.0	0.80	0.69	SN0303T0503102.008 [DIRS 162401]
	Mean (weighted by unit thickness)		*1.92*	*1.33*	
CHn1 / CHn2	Tptpv2	4.7	1.06	0.49	
	Tptpv1	15.4	1.06	0.49	
	Tpbt1	2.0	1.06	0.49	
	Calico	45.5	1.26	0.60	
	Calicobt	15.9	1.26	0.60	
	Mean (weighted by unit thickness)		*1.21*	*0.57*	

[a] Thickness of units extracted from DTN: MO0012MWDGFM02.002 [DIRS 153777]. The details of this extraction are provided in Appendix M.
[b] T = temperature.
[c] Mean values are calculated in this report and not provided by the DTNs listed in this table. Data extracted from DTN: SN0404T0503102.11 [DIRS 169129] are summarized in BSC 2004 [DIRS 169854] , Table 6-6. Data extracted from DTN: SN0303T0503102.008 [DIRS 162401] are summarized in BSC 2004 [DIRS 170033], Table 6-13.

IMPACT ANALYSES

Q1. IMPACT ANALYSES ON LDTH (LINE-AVERAGED HEAT SOURCE, DRIFT-SCALE, THERMOHYDROLOGIC) SUB-MODEL

An impact analysis was conducted for the drift-scale thermal calculation performed by the NUFT thermohydrology software employing a two-dimensional, line-averaged heat source, drift-scale, thermohydrologic (LDTH) sub-model. The LDTH sub-model is a part of the multiscale thermohydrologic model created by the NUFT software, which is described in *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 163056]). An LDTH sub-model, P2WR5C10 (coordinates: E 170730, N 234913), was selected from the new 108 LDTH sub-models (DTN: LL030808623122.036 [DIRS 165790]) for this impact review. The P2WR5C10 LDTH sub-model location selected has the following characteristics of interest compared to the L2C3 LDTH sub-model (Section 6.2):

- Approximately the geometric center of the license application reference repository layout (BSC 2004 [DIRS 172801]).
- The repository horizon is located approximately 310 m below the ground surface and 279 m above the water table. This elevation puts the repository horizon at approximately 1053 m above sea level (DTN: LL030808623122.036 [DIRS 165790]).
- The repository horizon is located in the Tptpll with approximately 45 m of Tptpll above the repository horizon and 59 m of Tptpll below the repository horizon (DTN: LL030808623122.036 [DIRS 165790]).
- The mean infiltration conditions have surface infiltration rates of 4.7 mm/year during the first 600 years of emplacement (present day climate), 14.6 mm/year from 600 years to 2000 years (monsoonal climate), and 22.1 mm/year from 2000 years on (glacial transition climate) (DTN: LL030808623122.036 [DIRS 165790]).
- The ground surface temperature is fixed at 16.9°C, and the water table temperature is fixed at 28.3°C (DTN: LL030808623122.036 [DIRS 165790]).

The preclosure forced ventilation has a varying heat removal capacity from the air inlet to exit of an emplacement drift due to temperature change of the airflow. The heat removal ratio is also a function of time as the waste package power output and rock mass temperature changes (BSC 2004 [DIRS 169862]). The heat removal ratio at 600 m from inlet[1], as shown in Table Q-1, was obtained from DTN: MO0306MWDALAFV.000 [DIRS 163961] and was used for calculating temperature during the preclosure period.

[1] Emplacement drifts in the repository average approximately 600 m in length (BSC 2003 [DIRS 165572]).