BSC	Model Administrative Change Notice *Complete only applicable items.*	QA: QA Page 1 of 6

1. Document Number:	MDL-NBS-HS-000002	2. Revision:	03	3. ACN:	01
4. Title:	Seepage Model for PA Including Drift Collapse				
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6. Approvals:		
Preparer:	Jens Birkholzer Print name and sign	12/1/05 Date
Checker:	Peter Persoff Print name and sign	12/01/05 Date
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Independent Technical Reviewer:	Jean Younker Print name and sign	12-1-05 Date
Responsible Manager:	Ming Zhu Print name and sign	12/1/05 Date

7. Affected Pages	8. Description of Change:
4-1	Citation update Table 4-2 "Geometric Parameters Used", 2nd column "Input Source", 2nd cell, change: 800-IED-WIS0-00205-000-00C (BSC 2004 [DIRS 167758]) To **800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])** This error was identified in CR 5307
4-2	Added clarification Table 4-3 "Parameters Used in THM Study", add Note to read: **Note: Figures are used as indirect input.** This change was identified in CR-5600

1. Document Number:	MDL-NBS-HS-000002	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Seepage Model for PA Including Drift Collapse				

4-2	Added clarification Section 4.1 “DIRECT INPUT”, 1st paragraph on page 4-2, change: Information and data used in this report for establishing parameter ranges are given in Table 4-4. The appropriateness of the data is discussed in Section 6.3. To **Information and data used in this report for establishing parameter ranges are given in Table 4-4. The appropriateness of the data is discussed in Section 6.3. Figures cited in Table 4-4 were developed using qualified software and inputs.** This change is associated with CR-5600
4-2	Citation update Table 4-4 “Data and Information Used in This Report for Establishing Parameter Ranges”, 3rd column “Comments”, 7th row, change: “Degraded drift profiles for Tptpmn and Tptpll units.” To **“Degraded drift profiles for lithophysal units.”** This change is self-identified
4-2	Citation update Table 4-4 “Data and Information Used in This Report for Establishing Parameter Ranges”, last row, change: Collapsed Drift Diameter | BSC (2004 [DIRS 166107], Figures 6-112, 6-113, 6-114, 6-115, 6-116, 6-128, 6-154, S-46) | Simulated drift geometry after postclosure seismic event To **Collapsed Drift Profiles** | **BSC (2004 [DIRS 166107], Figures 6-89, 6-90, and 6-108 through 6-114)** | **Degraded drift profiles for non-lithophysal units** This change is associated with TBV-6026

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1. Document Number:	MDL-NBS-HS-000002	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Seepage Model for PA Including Drift Collapse				

6-6	Citation update Section 6.3.1 "Drift Geometry and Grid Design", 1st paragraph, 2nd line, change: 800-IED-WIS0-00205-000-00C (BSC 2004 [DIRS 167758]) To **800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])** This change was identified in CR 5307
6-23 and 6-24	Citation update (Correct DIRS as appropriate) Section 6.6.3 "Results for Degraded-Drift Scenario", Last line of page 6-23 and 1st line of page 6-24, change: BSC 2004 [DIRS 166107], Figures 6-112 through 6-116 To **BSC 2004 [DIRS 166107], Figures 6-108 through 6-114** This change was identified in CR 5345 and is associated with TBV-6026
6-24	Change text for clarification Section 6.6.3 "Results for Degraded-Drift Scenario", 1st paragraph, second, third, fourth, and fifth sentences on page 6-24, change: "Note that some of the extreme seismic cases lead to very high stresses that may exceed the compressive strength of the intact rock mass in the nonlithophysal units (BSC 2004 [DIRS 166107], Section 6.3.1.6.4). In such cases, severe spalling or even drift collapse would occur, as the intact rock blocks would essentially be crushed. However, as such extreme events are extremely unlikely, given the 11-million-year lifetime of the Yucca Mountain, the *Seismic Consequences Abstraction* (BSC 2004 [DIRS 169183], Section 6.8.1) determines that complete collapse of drifts in nonlithophysal units is not to be considered in the TSPA-LA. The effect of wedge-type rockfall in nonlithophysal units, on the other hand, is implicitly accounted for in the TSPA-LA." To **"It was also evaluated whether the extreme seismic cases would possibly lead to very high stresses exceeding the compressive strength of the intact rock mass in the nonlithophysal units (BSC 2004 [DIRS 166107], Section 6.3.1.6.4). In such cases, severe fracturing of the intact rock blocks would occur, which in turn could lead to severe drift damage. The impact of fracturing of solid rock blocks in response to extreme seismic events was examined via a sensitivity study of the shear and tensile strength of solid rock bridges (BSC 2004 [DIRS 166107], Section 6.3.1.6.4). This sensitivity study showed that the expected rock bridge failure of between 5 and 20 percent (for the 1×10^{-6} and 1×10^{-7} hazard levels, respectively) would increase local wedge-type rockfall, but would not lead to drift collapse (BSC 2004 [DIRS 166107], Figures 6-89 and 6-90). The effect of such wedge-type rockfall in nonlithophysal units is implicitly accounted for in TSPA-LA. As discussed in Section 6.4.2.4.2 below, changes in the drift profile caused by wedge-type rockfall (local breakouts along the wall or the crown) do not significantly affect seepage."** This change was identified in CR 5345 and is associated with TBV-6026

1. Document Number:	MDL-NBS-HS-000002	**2. Revision**:	03	**3. ACN**:	01
4. Title:	Seepage Model for PA Including Drift Collapse				

6-24	Editorial Correction Section 6.6.3 "Results for Degraded-Drift Scenario", 2nd paragraph, 6th line, change: "As discussed in Section 6.4.2.4.2, complete collapse of emplacement drifts leads to a significant increase in seepage compared to nondegraded or slightly degraded drifts." To **"Complete collapse of emplacement drifts leads to a significant increase in seepage compared to nondegraded or slightly degraded drifts."** This change was identified in CR 5345 and is associated with TBV-6026
6-24	Citation update (Correct DIRS as appropriate) Section 6.6.3 "Results for Degraded-Drift Scenario", 2nd paragraph, line 9, change: Figure 6-128 in BSC (2004 [DIRS 166107]) To **Figure 6-125 in BSC (2004 [DIRS 166107])** This error was identified in CR 5345 and is associated with TBV-6026
6-24	Citation update Section 6.6.3 "Results for Degraded-Drift Scenario", 3rd paragraph, line 3 and 4, change: BSC 2004 [DIRS 166107], Sections 6.4.2.4, 8.1 and Appendix S3.4.2, Figures S-41 through S-43 To **BSC 2004 [DIRS 166107], Sections 6.4.2.3, 6.4.2.4, 8.1, and S3.4.2, Figures S-42 through S-44** This error was identified in CR 5345 and is associated with TBV-6026
6-24	Citation update (Correct DIRS as appropriate) Section 6.6.3 "Results for Degraded-Drift Scenario", 3rd paragraph, line 9, change: Appendix S3.4.3 of BSC (2004 [DIRS 166107]) To **Section S3.4.3 of BSC (2004 [DIRS 166107])** This error was identified in CR 5345 and is associated with TBV-6026

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4. Title:	Seepage Model for PA Including Drift Collapse				

6-24	Citation update (Correct DIRS as appropriate) Section 6.6.3 "Results for Degraded-Drift Scenario", 3rd paragraph, line 14, change: Figure 6-154 and Figure S-46 in BSC 2004 [DIRS 166107] To **Figure 6-161 and Figure S-47 in BSC 2004 [DIRS 166107]** This error was identified in CR 5345 and is associated with TBV-6026
6-29	Editorial Correction Section 6.6.3 "Results for Degraded-Drift Scenario", 1st paragraph on page 6-29, line 12, delete: **(see Section 6.4.4.1.2)** This error was identified in CR 5345 and is associated with TBV-6026
6-29	Editorial Correction Section 6.6.3 "Results for Degraded-Drift Scenario", last paragraph on page 6-29, line 4, delete: **(These are the same parameter cases as simulated for the nondegraded drift in Section 6.4.2.3).** This error was identified in CR 5345 and is associated with TBV-6026
9-2	Citation update (Correct DIRS as appropriate) Section 9.1 "Documents Cited", replace reference (167758) with reference (173501), change: BSC 2004. *D&E / PA/C IED Typical Waste Package Components Assembly.* 800-IED-WIS0-00205-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040202.0013. To **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.** This error was identified in CR 5307

Complete only applicable items.

1. Document Number:	MDL-NBS-HS-000002	2. Revision:	03	3. ACN:	01
4. Title:	Seepage Model for PA Including Drift Collapse				

B-1	Citation update Appendix B, 1st paragraph, line 7, change: 800-IED-WIS0-00205-000-00C (BSC 2004 [DIRS 167758]) To **800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])** This error was identified in CR 5307
C-1	Citation update Appendix C, 1st paragraph, line 6, change: *800-IED-WIS0-00205-000-00C (BSC 2004 [DIRS 167758])* To **800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])** This error was identified in CR 5307
D-1	Citation update Appendix D, 1st paragraph, line 5, change: *800-IED-WIS0-00205-000-00C (BSC 2004 [DIRS 167758])* To **800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])** This error was identified in CR 5307

4. INPUTS

4.1 DIRECT INPUT

This report presents calculated potential seepage rates over ranges of parameter values. The PA abstraction and evaluation will be presented in a separate report in which probability weighting factors will be discussed for parameter values and scenarios that are appropriate to the repository horizon at Yucca Mountain (see BSC 2004 [DIRS 169131]). Hence, for this report, while some data are used as direct input to model calculations, other data are used mainly to establish the limits of the parameter ranges to be used. Also, information on rockfall scenarios is taken to design special cases to study their potential impact on the seepage results. Tables 4-1 through 4-3 and Table 4-5 present direct-input data, and Table 4-4 presents data used to establish parameter ranges and scenarios used in the current report. These data are also considered to be direct-input data. Discussions of parameter ranges, scenarios, and uncertainties are given in Section 6. No unqualified project data are qualified under this report.

First, the hydrologic parameters used as direct input are the van Genuchten parameter *m*, residual liquid saturation S_{lr} in the fracture continuum, and satiated saturation S_{ls}. These values and their sources are given in Table 4-1.

Table 4-1. Hydrogeologic Input Parameters

Description	Input Source	Value	Units
Fracture Properties for Tptpmn Unit, tsw34			
van Genuchten Parameter, *m*	LB0208UZDSCPMI.002 [DIRS 161243]	0.633	[dimensionless]
Residual Liquid Saturation, S_{lr}	LB0208UZDSCPMI.002 [DIRS 161243]	0.01	[dimensionless]
Satiated Saturation S_{ls}	LB0208UZDSCPMI.002 [DIRS 161243]	1.0	[dimensionless]
Fracture Properties for Tptpll Unit, tsw35			
van Genuchten Parameter, *m*	LB0208UZDSCPMI.002 [DIRS 161243]	0.633	[dimensionless]
Residual Liquid Saturation, S_{lr}	LB0208UZDSCPMI.002 [DIRS 161243]	0.01	[dimensionless]
Satiated Saturation S_{ls}	LB0208UZDSCPMI.002 [DIRS 161243]	1.0	[dimensionless]

Note that the parameter values for Tptpmn and Tptpll are the same. Geometric parameters used in the present report are given in Table 4-2.

Table 4-2. Geometric Parameters Used

Description	Input Source	Value	Units
Emplacement Drift Diameter	800-IED-MGRO-00201-000-00B (BSC 2004 [DIRS 168489])	5.5	meters
Waste Package Length (average over 44-BWR, 24-BWR, 12-PWR, and 21-PWR packages)	800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])	5.1	meters

In Section 6.7, a sensitivity study of the THM effect on seepage is conducted. Input data required for this study are listed in Table 4-3.

Table 4-3. Parameters Used in THM Study

Description	Input Source	Value/Results
van Genuchten Parameter, $1/\alpha$	LB0302SCMREV02.002 [DIRS 162273]	604.3 Pa
Fracture Permeability Field	LB0306DRSCLTHM.001 [DIRS 169733], File *tmn1_10ky.out*	Figures 6.5.1-1, 6.5.4-3 (d), and 6.5.4-4 (d) of BSC 2004 (DIRS 169864)

NOTE: Figures are used as indirect input.

Information and data used in this report for establishing parameter ranges are given in Table 4-4. The appropriateness of the data is discussed in Section 6.3. Figures cited in Table 4-4 were developed using qualified software and inputs.

Table 4-4. Data and Information Used in This Report for Establishing Parameter Ranges

Description	Input Source	Comments
Results from Seepage Calibration Model: K_{FC}, $1/\alpha$	DTN: LB0302SCMREV02.002 [DIRS 162273]	Statistics of postexcavation air permeabilities and calibrated $1/\alpha$ parameter for niches and systematic testing boreholes in both Tptpmn and Tptpll units.
Air-Permeability Data: K_{FC}	DTN: LB0012AIRKTEST.001 [DIRS 154586]	Pre-excavation air-permeability data from Niche 1620 in the Tptpll unit (also referred to as Niche 5).
	DTN: LB980901233124.101 [DIRS 136593]	Pre-excavation air-permeability data from Niches 3107 (Niche 3) and 4788 (Niche 4) in the Tptpmn unit.
	DTN: LB0011AIRKTEST.001 [DIRS 153155]	Pre-excavation air-permeability data from Niche 3650 (Niche 2) and 3566 (Niche 1) in the Tptpmn unit.
	DTN: LB0205REVUZPRP.001 [DIRS 159525]	Air permeability analysis.
Flow Field Simulations for Infiltration Scenarios: Q_p	DTN: LB0302PTNTSW9I.001 [DIRS 162277]	Present-day, monsoon, and glacial transition low-, median-, and high-infiltration flow fields from unsaturated zone model. Fluxes are given at the PTn/TSw interface.
Degraded Drift Profiles	DTN: MO0306MWDDPPDR.000 [DIRS 164736]	Degraded drift profiles for lithophysal units.
Collapsed Drift Profiles	BSC 2004 [DIRS 166107], Figures 6-89, 6-90, and 6-108 through 6-114	Degraded drift profiles for non-lithophysal units.

PTn=Paintbrush nonwelded unit; Tptpll=lower lithophysal zone of Topopah Spring Tuff; Tptpmn=middle nonlithophysal zone of Topopah Spring Tuff; TSw= Topopah Spring welded unit

Fracture hydrologic properties used for the flow focusing study discussed in Section 6.8 are listed in Table 4-5.

combination of extreme choices of these two parameters that may represent a nonphysical condition.

Within the SMPA, the flux exchange between fractures and matrix in a steady-state fracture-matrix system is negligible and does not need to be modeled explicitly in the SMPA. In general, matrix permeability is low, and the potential for imbibition of substantial amounts of water into the matrix is limited because of its relatively low porosity and relatively high initial liquid saturation. In a fracture-matrix system, the transient flow between fracture and matrix is restricted to intermediate times; i.e., they are insignificant (1) for a short-term liquid-release test with insufficient time for matrix imbibition, and (2) for a long-term seepage experiment, in which near-steady late-time data are no longer affected by matrix imbibition. The ability of a single fracture-continuum model to reproduce and predict average seepage from a discrete fracture-matrix system has been demonstrated by Finsterle (2000 [DIRS 151875]) using synthetic data.

Also within the SMPA, the effect of lithophysal cavities on seepage is represented through the use of an effective capillary-strength parameter, without the explicit inclusion of lithophysal cavities into the process model. This approach is considered appropriate for the following reasons: (1) the effect of lithophysal cavities is included by the SCM (BSC 2004 [DIRS 170034], Section 5.7) in the calibration conditioned to data from Tptpll testing; (2) because of capillary effects, flow will be mainly through fractures rather than the cavities; and (3) omitting lithophysal cavities is consistent with the SCM, and consistency between the calibration model (the SCM) and the prediction model (the SMPA) removes the impact of a potential bias.

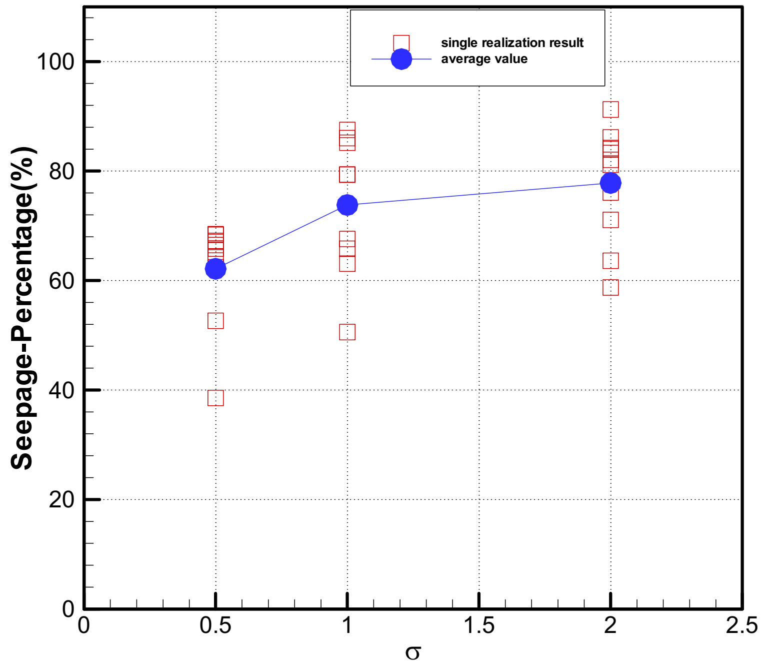
6.3.1 Drift Geometry and Grid Design

As provided in design drawings 800-IED-MGR0-00201-000-00B (BSC 2004 [DIRS 168489]) and 800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501]) respectively, the drift diameter is 5.5 m and the waste package length is 5.1 m. The three-dimensional calculational domain for this report is chosen to be 10 m high, 4 m wide, and 2.4384 m long, covering the upper left-hand half of the drift with a diameter of 5.5 m (See Figure 6-1). Thus, a vertical plane through the axis of the drift forms the right-hand boundary, and the drift axis is 0.5 m above the lower boundary. The length along the drift axis is chosen to be 8 ft (2.4384 m), which is 8 grid cells of 1 foot (0.3048 m) length. Thus, the calculated seepage will be over an area of half the drift (cut along its axis) and the length of 2.4384 m, which amounts to an area of $(5.5/2) \times 2.4384 = 6.706\ m^2$. On the other hand, the cross-sectional area of the drift containing one waste package is $5.1 \times 5.5 = 28.05\ m^2$. Consequently, the seepage rate at steady state calculated in the simulation domain needs to be scaled-up by a factor of (28.05/6.706 = 4.183) to obtain the seepage rate for the full drift per waste package, expressed as m^3 of water per year per waste package (m^3/year/wp). Seepage percentage is defined as this seepage rate divided by the product of percolation flux (m/year), the diameter of the drift (5.5 m), and the length of the waste package (5.1 m). This product is the amount of percolation water incident on the footprint of the drift section with one waste package. The calculation of seepage percentage does not require consideration of the scale-up factor of 4.183 if the calculated seepage from this model is divided by the total percolation water incident on the model area of $6.706\ m^2$.

Figure 6-13 presents the results of sensitivity to the standard deviation, σ, in log k_{FC} of the heterogeneous permeability field, using the same notation as before. Three values were used:

σ = 0.5
σ = 1 (base case)
σ = 2

The Figure shows that results for the base case are comparable to those for σ = 2, but are higher (thus more conservative) than those for σ = 0.5.



Output DTN: LB0304SMDCREV2.002.

Figure 6-13. Seepage Percentage as a Function of Standard Deviation σ, with $\log_{10}(k_{FC}\ [m^2]) = -12$, Q_p = 200 mm/year, 1/α = 600 Pa

6.6.3 Results for Degraded-Drift Scenario

Results on seepage based on calculated degraded drift profiles are discussed in this section firstly for the nonlithophysal and then for the lithophysal rocks. Drift degradation in the hard, strong, jointed rock of the nonlithophysal units is mostly limited to local gravitational drop of rock blocks (wedge-type rockfall) at the drift ceiling. As summarized in BSC (2004 [DIRS 166107], Section 8.1), minor damage due to wedge-type rockfall (i.e., controlled by the geological structure) is expected in nonlithophysal units from (1) all seismic events (BSC 2004 [DIRS 166107], Section 6.3.1.2), (2) thermal stress (BSC 2004 [DIRS 166107], Section 6.3.1.3), and (3) time-dependent strength degradation (BSC 2004 [DIRS 166107], Section 6.3.1.5). Except for local wedge-type rockfall, the drifts in nonlithophysal units remain intact openings with the horizontal extent essentially unchanged (BSC 2004 [DIRS 166107], Figures 6-108 through 6-114), similar to the results obtained in the earlier Revision 01 of the report *Drift Degradation Analysis* (BSC 2001 [DIRS 156304], compare with profiles in Figures 39 and 40). It was also evaluated whether the extreme seismic cases would possibly lead to very high stresses exceeding the compressive strength of the intact rock mass in the nonlithophysal units (BSC 2004 [DIRS 166107], Section 6.3.1.6.4). In such cases, severe fracturing of the intact rock blocks would occur, which in turn could lead to severe drift damage. The impact of fracturing of solid rock blocks in response to extreme seismic events was examined via a sensitivity study of the shear and tensile strength of solid rock bridges (BSC 2004 [DIRS 166107], Section 6.3.1.6.4). This sensitivity study showed that the expected rock bridge failure of between 5 and 20 percent (for the 1×10^{-6} and 1×10^{-7} hazard levels, respectively) would increase local wedge-type rockfall, but would not lead to drift collapse (BSC 2004 [DIRS 166107], Figures 6-89 and 6-90). The effect of such wedge-type rockfall in nonlithophysal units is implicitly accounted for in TSPA-LA. As discussed in Section 6.4.2.4.2 below, changes in the drift profile caused by wedge-type rockfall (local breakouts along the wall or the crown) do not significantly affect seepage.

More significant drift degradation than in the nonlithophysal units is predicted for the relatively deformable lithophysal rock. In lithophysal units, all seismic events with peak ground motions greater than about 2 m/s lead to complete collapse of emplacement drifts, as discussed in BSC (2004 [DIRS 166107], Sections 6.4.2.2). Peak ground motions larger than 2 m/s occur, for example, in some of the 1×10^{-5} seismic hazard levels and in all 1×10^{-6} and the 1×10^{-7} seismic hazard levels. Complete collapse of emplacement drifts leads to a significant increase in seepage compared to nondegraded or slightly degraded drifts. For all other seismic events with smaller peak ground motions, the extent of drift damage in lithophysal rocks is less significant. For example, according to Figure 6-125 in BSC (2004 [DIRS 166107]), partial drift collapse will occur for a peak ground motion of 1.04 m/s for low-strength rock of Category 1, while only minor damage is expected for all other rock strength categories at the same peak ground motion. Independent of the rock category, no or very minor rock damage from local rockfall is predicted for the seismic cases with annual occurrence of 5×10^{-4} and the 1×10^{-4}, with the drifts remaining essentially intact. Based on these results (and other considerations), the *Seismic Consequences Abstraction* (BSC 2004 [DIRS 169183], Section 6.8.1) recommends for the TSPA-LA that all peak ground motions equal or greater than 0.384 m/s should be considered large enough to collapse the drift in the lithophysal zones. This threshold value for collapse includes all seismic events with annual occurrence probability equal to or lower than 1×10^{-4}.

In contrast to the impact of seismic events, thermal effects and time-dependent rock strength degradation result in minor drift damage in the lithophysal units, limited to small breakouts in the wall and the crown (BSC 2004 [DIRS 166107], Sections 6.4.2.3, 6.4.2.4, 8.1, and S3.4.2, Figures S-42 through S-44). Over a 20,000-year time span, the reduction in rock strength is estimated on the order of 40 percent from the initial cohesive strength. This reduction is not significant enough to allow for major damage or even complete collapse (see also profiles predicted from quasistatic simulations for 40 percent cohesion reduction in Appendix R of BSC (2004 [DIRS 166107])). More damage is expected from a combination of seismic, thermal, and time-dependent effects. As shown for the 1×10^{-4} seismic hazard level in Section S3.4.3 of BSC (2004 [DIRS 166107]), the extent of rockfall is affected by the timing of the seismic event (effects are stronger at later stages when cohesive strength has reduced) and by the rock category (effects are stronger for low-quality rock). The most significant damage for these cases is predicted for rock of Categories 1 and 2 (about 10 percent of the rock mass in the Tptpll unit) and the seismic event occurring after 10,000 years (Figures 6-161 and S-47 in BSC 2004 [DIRS 166107]), with partial wall breakouts and a 50 percent diameter increase.

Scenario 2 involves seepage into completely collapsed drifts in the lithophysal rocks. During collapse, either sudden or gradual, the rock mass above an underground opening disintegrates into a number of fragments that fall down and begin to fill the open space. Because there are large voids between the rock fragments, the bulk porosity of the fragmented rubble is much larger than the intact rock. As a result, the open space of the original excavation plus the collapsed portion of rock above are completely filled with rubble at a certain stage. When this occurs, the broken rock provides backpressure, which prevents further collapse of the rock mass (BSC 2004 [DIRS 166107], Section 6.4.2.5). The final situation after complete drift collapse can be categorized as follows: the original opening has increased in size, but is filled with fragmented rubble with large voids. The solid wall rock surrounding the rubble-filled opening is intact, but may have increased permeability and reduced capillary strength because of the dynamic motion and the stress redistribution. For convenience, we refer to the rubble-filled opening as a "collapsed drift", although technically there is no drift after collapse. The size and the shape of a collapsed drift mainly depend on the porosity of the rubble material and on the type of caving mechanism as collapse occurs. The collapsed drift profiles provided in DTN: MO0306MWDDPPDR.000 [DIRS 164736] are all similar, independent of the event leading to collapse. (Note that these profiles are also depicted in Appendix R of BSC (2004 [DIRS 166107]). In this reference, collapsed drifts are shown for Scenarios 2 through 5, 11, 12, 17, 18, 23, 24, 28, 29, and 30.) All drifts remain approximately circular after complete collapse. However, the size of the collapsed drifts increases considerably, with the largest drifts having a diameter of approximately 11 m after collapse.

Though complete drift collapse may lead to significantly different seepage behavior, capillary barrier effects still give rise to considerable flow diversion at the interface between the solid rock and the rubble-filled drift opening. This is because of the large scattered voids between the rock fragments (block sizes on the order of centimeters and decimeters (BSC 2004 [DIRS 166107], Section 8.1)), suggesting that the capillary strength parameter in the rubble filled drift is very small, most likely close to the zero capillary strength of an air-filled opening. Also, a small gap can be expected between the solid rock at the ceiling and the collapsed rubble material as a result of consolidation. Therefore, capillary-driven flow diversion remains an important mechanism in reducing seepage in collapsed drifts, which should be included in the seepage abstraction model. Additional simulation cases were conducted with the SMPA to study seepage into collapsed drifts. A worst-case drift profile for seepage was selected as representative of the complete drift collapse scenarios depicted in MO0306MWDDPPDR.000 [DIRS 164736] (see also Appendix R of BSC (2004 [DIRS 166107])). The chosen profile has a circular shape with a diameter of 11 m, which is the largest diameter predicted. The larger the drift size, the more seepage can be expected because (1) the total amount of percolation flux arriving at the drift increases with the horizontal size, and (2) flow diversion is less effective for a larger drift. A capillary strength parameter of 100 Pa was used for the fragmented rock material within the collapsed drift (Section 5). This value is considered a conservative choice for seepage calculations, because the capillary strength of the rubble material is most likely smaller.

Systematic seepage simulations for the collapsed drift case were conducted for the full set of parameter combinations, with capillary strength values ranging from 100 Pa to 1,000 Pa, mean permeability values ranging from –14 to –10 (in $\log_{10}$), and percolation flux values ranging from 1 mm/year to 1,000 mm/year. The resulting seepage values are provided in a seepage

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

BSC 2004. *Analysis of Hydrologic Properties Data.* ANL-NBS-HS-000042, Rev. 00. Las Vegas, Nevada: Bechtel SAIC Company. 170038

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

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 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. 173501

BSC 2004. *Drift Degradation Analysis.* ANL-EBS-MD-000027, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company. 166107

BSC 2004. *Drift Scale THM Model.* MDL-NBS-HS-000017, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company. 169864

BSC 2004. *Drift-Scale THC Seepage Model.* MDL-NBS-HS-000001, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company. 169856

BSC 2004. *Seepage Calibration Model and Seepage Testing Data.* MDL-NBS-HS-000004, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company 170034

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

BSC 2004. *Technical Work Plan for: Regulatory Integration Evaluation of Analysis and Model Reports Supporting the TSPA-LA.* TWP-MGR-PA-000014 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040603.0001. 169653

BSC 2004. *Technical Work Plan for: Unsaturated Zone Flow Analysis and Model Report Integration.* TWP-MGR-HS-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040701.0005. 169654

BSC 2004. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006, Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company. 169861

Section 6.6.1 discusses the seepage results. The seepage percentage is defined as the ratio of the seepage rate into a drift section to the percolation rate applied to the top of the model over the projected cross-sectional area of that drift section. The seepage rate for model calculation is transformed to response surface of seepage into drift in kilograms of water per year per waste package (kg/year/wp) of 5.5 m diameter and 5.1 m length (design drawings 800-IED-MGR0-00201-000-00B (BSC 2004 [DIRS 168489]) and 800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])). An excerpt is shown in Table B-1. The data reductions were performed using standard functions of the exempt software EXCEL (2000 SR-1). Detailed simulation results for all 20 realizations with every combination of $k_{FC,}$ $1/\alpha$, and Q_p values were submitted to the Technical Data Management System (Output-DTN: LB0304SMDCREV2.002). The following steps explain the data reduction to obtain *ResponseSurfaceSMPA.dat*.

Steps:

1. In *SMPAi.out**, delete all lines containing word "MESSAGE" and the empty line that follows it.

2. Copy *SMPAi.out* to *ResponseSurfaceSMPA.dat.*

3. Remove all lines with "MESSAGE" and surrounding empty lines.

4. Remove lines 1-227 and 2778-end of file; remove columns 5 and 6.

5. Copy column 5 between lines 228 and 2777 from files *SMPAi.out2* to *SMPAi.out20* and add as column 5-23 to file *ResponseSurfaceSMPA.dat.*

6. Open file *ResponseSurfaceSMPA.dat* in EXCEL and sort rows according to first three columns.

7. Insert new columns 4-7; column 1 is log(k), column 2 is 1/alpha, column 3 is percolation flux, columns 8-27 are the seep flow rates for 20 realizations. In file SMPAi, an adjustment factor of 10 should be imposed as part of unit conversion.

8. Column 4 = (average of columns 8-27)*10; this is the average seepage flux (kg/year/wp); the adjustment factor of 10 is multiplied to results.

9. Column 5 = (std. dev. of columns 8-27)*10; this is the standard deviation of the seepage flux.

10. Column 6 = column 4 / (5.5*5.1*column 3) * 100; this is the average seepage percentage.

11. Column 7 = column 5 / (5.5*5.1*column 3) * 100; this is the seepage percentage standard deviation.

12. Save Columns 1-7 as formatted text file to *ResponseSurfaceSMPA.prn.*

Figures 6-9 to 6-11 discuss the seepage results in the form of seepage percentage. The seepage percentage is defined as the ratio of the seepage rate into a drift section to the percolation rate applied to the top of the model over the projected cross-sectional area of that drift section. It corresponds to simulated total seepage rates into a drift of 5.5 m diameter and 5.1 m length (design drawings 800-IED-MGR0-00201-000-00B (BSC 2004 [DIRS 168489]) and 800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])). The data reductions were performed using standard functions of the exempt software EXCEL (2000 SR-1). Detailed simulation results were submitted to TDMS (Output-DTN: LB0304SMDCREV2.002). The following steps explain the data reduction for seepage results, using worksheets *fig6-10_1.xls* and *fig6-10_2.xls* as examples; excerpts are shown in Tables C-1 and C-2.

Steps:

1. Generate a new file *qq** from *SMPAi.out** by using command " grep "-0.1200000E+02 0.5000000E+03" *SMPAi.out** > qq*."
2. Copy qq* to *qqq.dat.*
3. Open file *qqq.dat* and save as *fig6-10_1* in EXCEL and delete columns A, B, E, and F.
4. Insert new column 2; column 1 is log(k), column 3 is the seepage flow rate.
5. Insert new row 1 and add header.
6. Column 2 = column 2 *10 / (5.5*5.1* 200) * 100; this is the seepage percentage; the factor of 10 is an adjustment factor as part of scaling specification required in the ITOUGH code, and 200 is the percolation flux.
7. Save *fig6-10_1* as formatted text file.
8. Open EXCEL file *fig6-10_1* and save as *fig6-10_2* in EXCEL.
9. Copy rows C17 to C31 as D2 to D16; C32 to C46 as E2 to E16; … C287 to C301 as V2 to V16; columns C to V are 20 realizations.
10. Column 2 = (average of columns C-V)*10 / (5.5*5.1*200) * 100; this is the average seepage percentage.
11. Save *fig6-10_2* as formatted text file.
12. Keep columns 1 and 2 in the text files *fig6-10_1* and *fig6-10_2* and save together as a *fig6-10* for Tecplot plotting.

Section 6.6.3 discusses the seepage results of rockfall. The seepage percentage is defined as the ratio of the seepage rate into a drift section to the percolation rate applied to the top of the model over the projected cross-sectional area of that drift section. It corresponds to simulated total seepage rates into a drift of 5.5 m diameter and 5.1 m length (design drawings 800-IED-MGR0-00201-000-00B (BSC 2004 [DIRS 168489]) and 800-IED-WIS0-00601-000-00A (BSC 2005 [DIRS 173501])). The data reductions were performed using standard functions of the exempt software EXCEL (2000 SR-1). Detailed simulation results were submitted to TDMS (Output-DTN: LB0304SMDCREV2.002). The following steps explain the data reduction for seepage results, using worksheets *fig6-17_1.xls* and *fig6-17_2.xls* as examples; excerpts are shown in Tables D-1 and D-2.

Steps:

1. In *SMPAi.outmnw**, delete all lines containing word "MESSAGE" and the empty line that follows it and only keep the seepage results.

2. Copy *SMPAi.outmnw** to *SMPAioutmnw.dat.*

3. Open file to *SMPAioutmnw.dat* and save as *fig6-17_1* in EXCEL and delete columns 1, 2, 5, and 6.

4. Insert new column 2; column 1 is log(k), column 3 is the seepage flow rate.

5. Insert row 1 and add header.

6. Column 2 = column 3 *10 / (5.5*5.1* 200) * 100; this is the seepage percentage; the factor of 10 is an adjustment factor as part of scaling specification required in the ITOUGH code, and 200 is the percolation flux.

7. Save *fig6-17_1* as formatted text file.

8. Open EXCEL file *fig6-17_1* and save as *fig6-17_2* in EXCEL.

9. Open EXCEL file *fig6-17_2* and copy rows C17 to C31 as D2 to D16; C32 to C46 as E2 to E16; … C137 to C151 as L2 to L16; columns C to L are 10 realizations.

10. Column 2 = (average of columns C-L)*10 / (5.5*5.1*200) * 100; this is the average seepage percentage.

11. Save *fig6-17_2* as formatted text file.

12. Use above steps to calculate the average seepage percentage for base case on data *SMPAimnb.dat* and get formatted text file *fig_mnbmean*.

13. Keep columns A and B in the text files *fig6-17_1*, *fig6-17_2*, and *fig_mnbmean* and save together as a *fig6-17* for Tecplot plotting.