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Number of Waste Packages Hit by Igneous Intrusion

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Number of Waste Packages Hit by Igneous Intrusion

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2. Scientific Analysis Title

Number of Waste Packages Hit by Igneous Intrusion

3. DI (Including Revision Number)

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4. Total Appendices		5. Number of Pages in Each Appendix	
Six		A-8, B-4, C-4, D-8, E-16, F-4	
	Printed Name	Signature	Date
6. Originator	Michael Wallace	Signature on file	10-13-04
7. Checker	Charles Harrington	Signature on file	10-13-04
8. QER	Darrell Svalstad	Signature on file	10-13-04
9. Responsible Manager/Lead	Suzette Payne	Signature on file / S. Payne	10/13/04
10. Responsible Manager	Mike Cline	Signature on file	10/13/04

11. Remarks

CR 2839 indicated the model for the number of dikes intersecting the repository should be coupled with the model for the number of conduits formed. This issue should be considered if the work scope for this AMR is revisited in the future.

Contributing author: Frank Perry.

Change History

12. Revision No.	13. Description of Change
00	Initial issue
01	This document has been revised to include the latest backfill analysis, repository layout, sensitivity studies on dike spacing, and management approved recommendations from the evaluation phase of the Regulatory Integration Team. These comments focused on regulatory implications, transparency, and traceability. This document is a complete revision; therefore, change bars are not used.

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ACRONYMS AND ABBREVIATIONS

CDF	cumulative distribution function
FEPs	features, events, and processes
IED	Information Exchange Drawing
LHS	Latin Hypercube Sampling
PDF	probability distribution factor
TSPA	Total System Performance Assessment
TSPA-LA	Total System Performance Assessment for the License Application
TSPA-SR	Total System Performance Assessment for the Site Recommendation
TWP	technical work plan
YMP	Yucca Mountain Project

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1. PURPOSE

The purpose of this scientific analysis report is to document calculations of the number of waste packages that could be damaged in a potential future igneous event through a repository at Yucca Mountain. The analyses include disruption from an intrusive igneous event and from an extrusive volcanic event. This analysis supports the evaluation of the potential consequences of future igneous activity as part of the total system performance assessment for the license application (TSPA-LA) for the Yucca Mountain Project (YMP).

Igneous activity is a disruptive event that is included in the TSPA-LA analyses. Two igneous activity scenarios are considered:

- The igneous intrusion groundwater release scenario (also called the igneous intrusion scenario) considers the in situ damage to waste packages or failure of waste packages that occurs if they are engulfed or otherwise affected by magma as a result of an igneous intrusion.

- The volcanic eruption scenario depicts the direct release of radioactive waste due to an intrusion that intersects the repository followed by a volcanic eruption at the surface.

An igneous intrusion is defined as the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to repository level, where it intersects drifts. Magma that does reach the surface from igneous activity is an eruption (or extrusive activity) (Jackson 1997 [DIRS 109119], pp. 224, 333). The objective of this analysis is to develop a probabilistic measure of the number of waste packages that could be affected by each of the two scenarios.

The following are direct users of output from this analysis report:

- *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada*

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

- *Screening Analysis for Criticality Features, Events, and Processes for License Application*

- *Features, Events and Processes: Disruptive Events*

- *Features, Events, and Processes in SZ Flow and Transport.*

The following analysis reports are direct sources to this report:

- *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*
- *Characterize Eruptive Processes at Yucca Mountain, Nevada.*

The following analysis report is a significant indirect source to this report:

Dike/Drift Interactions.

These analyses are limited to the specific contexts in which they are used. The contexts are described in detail in the sections and appendices where the analyses are described.

The numbers in square brackets after a citation is used throughout this report represent entries in the Document Input Reference System (DIRS), which is a detailed electronic index to this and other documents.

2. QUALITY ASSURANCE

The results of this report are important to the demonstration of compliance with the postclosure performance objectives prescribed in 10 CFR 63.113 [DIRS 156605]. As such, this work is determined to be important to waste isolation, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List* and controlled by approved procedures subject to the Yucca Mountain Project (YMP) quality assurance program, as documented in Section 8.1 of the technical work plan (TWP) (BSC 2004 [DIRS 171403]).

The conduct of activities described in this report is documented in the *Technical Work Plan: Igneous Activity Assessment for Disruptive Events* (BSC 2004 [DIRS 171403]). The TWP states that this documentation will provide an update and revision to *Number of Waste Packages Hit by Igneous Intrusion*. While this report provides an update and revision to the calculation of the number of waste packages hit documented in the previous version of this report (CRWMS M&O 2000 [DIRS 153097]), it was developed under AP-SIII.9Q, *Scientific Analyses* instead of AP-3.12Q, *Design Calculations and Analyses*. The technical work plan also identifies the methods used to control the electronic management of data (BSC 2004 [DIRS 171403], Section 8.4).

This report documents calculations of the number of waste packages that could be damaged in a potential future igneous event through a repository at Yucca Mountain. Waste packages are classified in the *Q-List* (BSC 2004 [DIRS 168361]) as SC because of their importance to waste isolation, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*.

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3. USE OF SOFTWARE

This analysis uses two software packages that reside in the Yucca Mountain software baseline:

- LHS Version 2.51 STN: 10205-2.51-00 (SNL 2004 [DIRS 167794])
- DIRECT V 1.0 STN: 11121-1.0-00 (SNL 2004 [DIRS 167795]).

Computer code LHS (Latin Hypercube Sampling) (SNL 2004 [DIRS 167794]), is a FORTRAN code that provides a method to simultaneously bin multiple parameter distributions for use by subsequent models or calculations. The LHS technique is used for this binning method. A general treatment of the LHS method, upon which the computer code is based, can be reviewed in Helton and Davis (2002 [DIRS 163475]). This technique approximates the Monte Carlo method without missing representative distribution tail values. For this analysis, LHS was used to develop a distribution of realizations of the required input parameters. The parameterization is described in detail in Sections 4 and 6 of this report. LHS was used within its intended purposes and its range of validation. LHS was run on a DEC Alpha microprocessor with the Open VMS AXP, Version 7.3-1 operating system. The software was selected because it was suitable for the tasks of binning multiple parameter distributions and combining them. No alternate software programs were found that offered superior performance. The software use is limited to the ranges of values that the input data represents.

Computer code DIRECT (Dike Interaction with Repository, Explicit Characterization & Tabulation) (SNL 2004 [DIRS 167795]) is a geometric analysis package written using Torque Game Engine (www.garagegames.com), which is a commercial open-source software development kit employing C++ coding and a separate scripting language. DIRECT was specifically built to incorporate binned probability distributions of igneous parameters into calculations of the numbers of waste packages hit for this analysis (specific to dike - repository intersections only). DIRECT was used within its intended purposes and its range of validation. DIRECT was run on a Dell Precision 330 workstation with a Windows 2000 operating system. The software was selected because it was suitable for the tasks of calculating intersections between igneous dikes and repository drifts. A general search of alternate commercial off-the-shelf software was conducted and no alternates were found to be capable of performing these specific custom tasks. The software use is limited to the ranges of values that the input data represents.

Commercial software used in this report is not required to be qualified according to the procedure *Software Management,* LP-SI.11Q-BSC. The following commercial software was used in this report:

- Microsoft Excel 2000 (9.0.5121 SR-1)
- Rhinoceros 3.0
- MilkShape 3D.

Only standard Excel functions were used in the calculations prepared using Microsoft Excel 2000. Electronic output files from Excel are included as Appendices A through C.

Rhinoceros is a computer-aided design package that was used to help visualize and scale base-unit geometry inputs that eventually were transformed to represent volcanic dikes and the repository drifts in DIRECT (SNL 2004 [DIRS 167795]). MilkShape 3D is a general-purpose 3-D geometry file format translator and pre-processor. MilkShape 3D was used to convert the unit Rhinoceros-generated geometry files into a format suitable for input to DIRECT.

All software programs were run using appropriate computer platforms and operating systems, as required by LP-SI.11Q-BSC, *Software Management.* Except for Microsoft Excel, which is used for many separate activities, the software applications are used in the following order:

1. Run LHS to establish the igneous inputs to DIRECT.

2. Run Rhino 3D to establish the repository geometry.

3. Run MilkShape to convert Rhino geometry output to format suitable for input to DIRECT.

4. Run DIRECT using the inputs produced in the previous steps.

4. INPUTS

This section identifies data, parameters, criteria, and codes and standards associated with the scientific analysis. Uncertainties in input data and parameters are addressed in Section 6.5.

4.1 DIRECT INPUTS

Table 4-1 summarizes the inputs and input sources used for this analysis. Conditional probabilities for dike length, azimuth angle, and number of eruptive centers (conduits) on a dike (DTN: LA0302BY831811.001 [DIRS 162670]) are used as input to this analysis. The file consists of 4032 points in a parameter space for dike length and azimuth angle. The data cover angles from 0 degrees (north) to 175 degrees (south-southeast) in 5 degree increments and lengths from 0 km to 5.55 km in 0.05 km increments. Details of this parameter development are discussed in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Section 6.5.3). That analysis summarizes and builds upon the *Probabilistic Volcanic Hazards Assessment for Yucca Mountain, Nevada* (CRWMS M&O 1996 [DIRS 100116]), in which the interpretations of 10 members of an expert panel were used to compute a probability distribution of the annual frequency of intersection of a basaltic dike or dike set with the repository footprint. The analysis assumes an origin for the igneous event (also called a volcanic event) and a dike with a given length and direction extending away from the origin. Points of origin have been used throughout the region around the repository based on the probabilistic volcanic hazards assessment experts' interpretations. Although similar in concept, these points of origin are not to be confused with anchor points described later in this report. This input information is used in the calculations for the number of waste packages hit for both the igneous intrusion scenario (Section 6.3) and the volcanic eruption scenario (Section 6.4). However, the points of origin in this case should not be confused with descriptions of dike swarm origin points in Section 6.3, which are focused on implementation of the dike geometry on a local scale.

Characterize Framework for Igneous Activity at Yucca Mountain (BSC 2004 [DIRS 169989], Table 19) develops the final composite conditional probability distribution for number of eruptive centers, also known as conduits. The data source for this information is DTN: LA0307BY831811.001 [DIRS 164713]. That distribution is used as input to this calculation for determining the cumulative distribution function (CDF) for number of waste packages hit, given a maximum of 13 eruptive centers associated with a volcanic event.

Independent probabilities for the distribution of dike azimuth angles are also developed in *Characterize Framework for Igneous Activity at Yucca Mountain*, BSC (2004 [DIRS 169989]), highlighted by Figure 22 of that report and the pertinent section shown in Figure 6-3 of this report. The data source for this information is DTN: LA0303BY831811.001 [DIRS 163985].

Repository design input information is taken from several information exchange drawings (IED):

D&E / PA/C IED Subsurface Facilities (BSC 2004 [DIRS 164519]), Figure 6-1 provides information on the underground layout configuration.

D&E / PA/C IED Subsurface Facilities (BSC 2004 [DIRS 168370]) provides several important parameters. Figure 2 and Table 7 from this source provide information on the underground layout configuration and the repository areas, respectively. Table 7 refers to the Roman numeral panel designations illustrated in the overlying Figure 2. Note that the contingency area is considered a separate panel in this illustration. The circled numbers in Figure 2 represent the panel designations used to organize Universal Transverse Mercator projection coordinates and other information. In that figure, it can be seen by hand counting that the contingency area starts at drift number 18 of Panel 2. Ignoring the contingency area, the total number of active drifts is 96.

Table 2 of *D&E / PA/C IED Subsurface Facilities* ((BSC 2004 [DIRS 164519]) provides information on the Universal Transverse Mercator projection coordinates of each emplacement drift endpoint. This information is used to determine the lengths of each emplacement drift and to compute the average drift azimuth angle of 72 degrees.

Drift diameter and average spacing between drifts were taken from *D&E / PA/C IED Emplacement Drift Configuration and Environment* (BSC 2004 [DIRS 168489], Table 1).

Information on the expected total number of waste packages was taken from *D&E/PA/C IED Typical Waste Package Components Assembly* (BSC 2004 [DIRS 169472], Table 11). This information was used along with knowledge of each emplacement drift length to estimate the number of waste packages per drift.

D&E / PA/C IED Subsurface Facilities (BSC 2004 [DIRS 168370], Table 7) is the source of repository area information. The table includes a contingency area that is not used in the calculation of area. This information is used in conjunction with the number of waste packages to compute an average waste package density factor in the analysis of Section 6.4.

Probabilities for dike spacing, number of dikes in a swarm, and eruptive conduit diameter are taken from DTN: LA0407DK831811.001 [DIRS 170768]. The two latter probabilities have been transformed into discrete cumulative distribution functions (CDF). The CDF for conduit diameter is used in the calculations for the number of waste packages hit for the volcanic eruption scenario (Section 6.4). The CDF distributions for number of dikes in a swarm are used in the calculation for number of waste packages hit for the igneous intrusion scenario (Section 6.3).

The dike spacing distribution has been abstracted in this analysis. The wider range of a minimum of 1 m and a maximum of 1500 m has been reduced to a minimum of 100 m and a maximum of 690 m. The narrower range used has a conservative bias, as demonstrated in Section 6.5.

A previously developed and validated model was not used in this analysis.

Table 4-1. Summary of Calculation Inputs

Input Information	Source for Input Information (including DTN or IED number)	Value
Final composite conditional probability distribution for number of conduits (eruptive centers) intersecting repository	DTN: LA0307BY831811.001 [DIRS 164713] File: *PECDIST-LA.xls*, worksheet Table 19, Column I	Table of values
Marginal distribution of dike azimuth angles	DTN: LA0303BY831811.001 [DIRS 163985] File: *MLA-AZM.CDF*	Graphical and tabular representation of distribution
Conditional probabilities for dike length, dike azimuth angle, and number of conduits on a dike	DTN: LA0302BY831811.001 [DIRS 162670] File: *CCSM-LA.CMP*	Table of values
Drift layout	IED: 800-IED-WIS0-00101-000-00A (BSC 2004 [DIRS 164519], Figure 1) and IED: 800-IED-WIS0-00103-000-00A (BSC 2004 [DIRS 168370], Figure 2)	Graphical
Repository areas (active)	IED: 800-IED-WIS0-00103-000-00A (BSC 2004 [DIRS 168370], Table 7)	Table of values Total = 5,419,074 m^2
Drift coordinates	IED: 800-IED-WIS0-00101-000-00A (BSC 2004 [DIRS 164519], Table 2)	Table of values
Drift spacing and diameter	IED: 800-IED-MGR0-00201-000-00B (BSC 2004 [DIRS 168489], Table labeled "Thermal Inputs for Supporting TSPA-LA")	81-m spacing (between drift center lines) 5.5-m diameter
Planned total number of waste packages	IED: 800-IED-WIS0-00202-000-00C (BSC 2004 [DIRS 169472], Table 11)	11,184
Total number of active (noncontingency drifts)	IED: 800-IED-WIS0-00103-000-00A (BSC 2004 [DIRS 168370], Figure 2)	96
Dike thickness ("width" as used in cited document)	DTN: LA0407DK831811.001 [DIRS 170768], single file; 2nd parameter row	95th percentile = 4.5 m
Number of dikes in a swarm (truncated log-normal distribution)	DTN: LA0407DK831811.001 [DIRS 170768], single file; 3rd parameter row	Minimum = 1. Mode = 3 95th percentile = 6
Conduit diameter (triangular distribution)	DTN: LA0407DK831811.001 [DIRS 170768], single file; see 1st and 2nd parameter rows	Minimum = 4.5 m. Mode = 50 m. Maximum = 150 m.
Dike spacing (random uniform distribution)	DTN: LA0407DK831811.001 [DIRS 170768], single file; 4th parameter row	Minimum = 100 m; Maximum = 690 m Note: This range is adapted from the source range of minimum = 1 m, maximum = 1500 m.
Maximum expected magma density	DTN: LA0407DK831811.001 [DIRS 170768], single file, 9th parameter row	2663 kg/m^3
Dimensions and weights of different types of waste packages	IED: 800-IED-WIS0-00202-000-00C (BSC 2004 [DIRS 169472], Tables 1 and 11)	Tables of values
FEP list	DTN: MO0407SEPFEPLA.000 LA FEP List [DIRS 170760]	Tables

4.2 CRITERIA

The general requirements to be satisfied by the performance assessment for a license application are stated in 10 CFR 63.114 [DIRS 156605]. Technical requirements to be satisfied by the total system performance assessment are identified in the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 5-4). The acceptance criteria that will be used by the Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Final* Report (NRC 2003 [DIRS 163274]). This analysis constitutes a subcomponent of the TSPA-LA, and the pertinent requirements and criteria for this report are summarized in Appendix E.

This scientific analysis report provides documentation that acceptance criteria described in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Sections 2.2.1.3.2.3 and 2.2.1.3.10.3) have been addressed. The *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) acceptance criteria associated with the integrated subissue of Mechanical Disruption of Engineered Barriers are intended to ensure that the requirements of 10 CFR 63.114(a)-(c) and (e)-(g) have been met. Descriptions of information in this report that addresses the acceptance criteria associated with the integrated subissue of Mechanical Disruption of Engineered Barriers (NRC 2003 [DIRS 163274], Section 2.2.1.3.2.3) are provided in Appendix E. Similarly, the *Yucca Mountain Review Plan, Final Report* acceptance criteria associated with the integrated subissue of *Volcanic Disruption of Waste Packages* are intended to ensure that the requirements at 10 CFR 63.114(a)-(c) and (e)-(g) are met. Descriptions of how information in this report addresses the acceptance criteria associated with the integrated subissue of *Volcanic Disruption of Waste Packages* (NRC 2003 [DIRS 163274], Section 2.2.1.3.10.3) are provided in Appendix E.

4.3 CODES, STANDARDS, AND REGULATIONS

Other than the citations discussed in Section 4.2, there are no specific formally established codes, standards, or regulations that have been identified as applying to this scientific analysis activity.

5. ASSUMPTIONS

This section identifies assumptions that are used in this analysis. The discussion of each assumption includes four elements:

- A statement of the assumption
- The rationale for the assumption
- A statement on the need for further confirmation, if any, of the assumption
- A statement about where the assumption is used in the calculation.

5.1 TREATMENT OF WASTE PACKAGES IN DRIFTS INTERSECTED BY A DIKE AND IN DRIFTS NOT INTERSECTED BY A DIKE (IGNEOUS INTRUSION SCENARIO)

Assumption:

1. It is assumed that for any drift intersected by a dike, all of the waste packages located in that drift will fail. In other words, they will provide no further protection for the waste.

2. It is assumed that for any drift not intersected by a dike, none of the waste packages located in that drift will fail.

Rationale:

1. Since the emplacement drifts will not be backfilled, there are no credible mechanisms to block or mitigate the resulting effects from the dike intrusion upon the waste packages.

2. The presence of backfill in ventilation drifts, access drifts, and turnouts will serve as credible mechanisms, provided sufficient engineering and construction quality control are implemented, to protect waste packages in emplacement drifts which are not exposed directly to magma (i.e., drifts that are not intersected by a dike).

Confirmation Status: One analysis, *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Sections 6 and 8) and a design analysis, *Magma Bulkhead Analysis* (800-K0C-SSP0-00100-000-00A; Mrugala 2004 [DIRS 171070]), include evaluation of possible effects on waste packages in drifts that are not directly intersected by a dike, but that are adjacent to drifts that are intersected by a dike. Such effects include the penetration of magma into backfilled locations (800 K0C-SSP0-00100-000-00A; Mrugala 2004 [DIRS 171070]) and penetration of corrosive gases into backfilled locations or through pillars to drifts, which are not (initially) intersected by a dike, as well as effects of elevated temperatures (BSC 2004 [DIRS 170028], Section 6). For Part 1 of this assumption, the *Dike/Drift Interactions* model report (BSC 2004 [DIRS 170028], Section 6) concludes that waste packages in drifts that are intersected by dikes will provide no further protection to the waste. For Part 2 of this assumption, results of scoping calculations show that the combination of backfill, plus an engineered plug or bulkhead can be designed to limit the flow of magma between drifts (BSC 2004 [DIRS 170028], Section 6).

Finally, no credit is taken for the presence of rockfall in the drifts. Such drift degradation is expected to occur as a result of seismic ground motion at estimated frequencies (approximately 10^{-6} to 10^{-7} per year) much greater than the estimated frequency of dike intersection (approximately 10^{-8} per year) (BSC 2004 [DIRS 169183], Section 6.5.5).

No further confirmation is necessary.

Use Within the Analysis: This assumption set is used in Section 6.3.

5.2 CONSTANT CONDUIT DIAMETER PER REALIZATION (VOLCANIC ERUPTION SCENARIO)

Assumption: It is assumed that all conduits have the same diameter for any particular realization.

Rationale: This is a simplifying assumption. A distribution of conduit diameters is sampled in this analysis. The assumption only refers to the fact that for each realization, the conduit diameter that is sampled from the distribution is held constant. In other words, conduit diameters do vary from one realization to the next, but within any particular realization, the diameter is held constant.

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.4 to simplify the calculation of the number of waste packages hit by an eruptive conduit.

5.3 WASTE PACKAGES DAMAGED BY A CONDUIT (VOLCANIC ERUPTION SCENARIO)

Assumption: The number of waste packages within an eruptive conduit is assumed to be simply a function of conduit area and the average waste package density within the repository. No attempt is made to specifically determine or assign where a conduit occurs in the repository. If the conduit occurs in the repository, the number of waste packages hit is determined by multiplying the conduit area by the calculated waste package density factor, which is the total number of waste packages divided by the total repository area. Although magma associated with an eruption may contact other packages along the drift, the magma moving with sufficient vertical velocity to entrain waste in an eruption is assumed to be located only within the conduit because if additional waste packages outside of the conduit profile fail, then this simplified calculation approach would not be viable.

Rationale: The average waste package density is calculated by dividing the total planned number of waste packages by the total planned active repository area, including pillars. That approach is supported in part by the facts that the waste packages are uniformly distributed along each emplacement drift and those emplacement drifts are evenly spaced within the repository footprint. In other words, the waste packages are relatively evenly spaced in two different directions throughout the repository. Considered over the scale of the entire repository, this leads to a relatively uniform waste package density, which supports the use of an average value.

The net effect of the assumption is that any conduit that penetrates the repository will damage some number of waste packages to a sufficient degree that they provide no further protection for the waste. If, instead of this approach, the analysis were to explicitly overlay conduit profiles onto the repository and calculate intersections along the lines of the igneous intrusion scenario (described in detail in Section 6.3), there would be many cases in which conduits never actually intersect with drifts at all. However, the reverse is true as well. In other words, for explicit overlay of conduits, there would likely be cases where the conduits would be calculated to intersect more waste packages than in the analysis presented in this report. The approach in this report leads to an answer between these two extremes and allows for simplification of the analysis.

The second part of the assumption has been termed the cookie-cutter approach. Conduits are secondary features that evolve after a dike has penetrated the surface; thus, the repository will have already been penetrated by dikes and intersected drifts filled with magma before a conduit forms. Magma in the conduit will have a greater pressure than magma already in the drifts. This creates conditions that minimize flow into the conduit. The pressure gradient favors flow from the conduit to the drift and not the reverse. Additionally, the expected maximum density of the magma of approximately 2663 kg/m^3 (DTN: LA0407DK831811.001 [DIRS 170768]), is somewhat less than the density of any single waste package and is roughly 25 percent less than the average waste package density of approximately 3,350 kg/ m^3. The waste package density values are derived in this report. They are found under the heading “Auxiliary” in the Auxiliary worksheet of Excel spreadsheet *RepGeometry.xls* (Appendix A provides a pointer to this file).

An analysis in the *Dike/Drift Interactions* report (BSC 2004 [DIRS 170028], Section 6.4.8.2) evaluates the possibility that magma could somehow move waste packages that are initially outside of a conduit towards that conduit. This analysis considers expected magma velocities, pressures, and viscosities, as well as waste package dimensions and densities. The analysis concludes that waste package movement outside of a conduit profile is not expected under these conditions. It also concludes that the conditions are appropriate for waste packages that are initially within a conduit profile to be lifted up to the surface. Therefore, it is assumed there will be no significant interaction of magma in the conduit with waste packages outside of the conduit boundary. In addition, the range of conduit diameters used in this analysis includes a conservative upper bound of 150 m (DTN: LA0407DK831811.001 [DIRS 170768]), which likely accounts for the uncertainty in physical processes that could possibly entrain packages beyond the most likely conduit diameter of 50 m.

The *Dike/Drift Interactions* report (BSC 2004 [DIRS 170028], Section 6.4.8.2)) also found that fissure eruptions (in which dikes instead of conduits reach the surface) do not possess sufficient force to move waste packages from the drifts, primarily due to their low velocities and densities.

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.4 for the calculation of the number of waste packages hit by an eruptive conduit.

5.4 DIKES IN A SWARM OCCUR IN PARALLEL

Assumption: It is assumed that for any scenario case in which more than one dike is sampled, all dikes are parallel to each other. The sampled azimuth value therefore applies to all dikes in the swarm.

Rationale: This is the general case in nature. Vertical tabular dikes propagate in a direction generally perpendicular to the direction of minimum compressive stress in the host rock formation, as discussed in Pollard (1973 ([DIRS 166923], p. 254).

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.3 as part of the geometric simulation of dike swarms.

6. SCIENTIFIC ANALYSIS DISCUSSION

This analysis differs from the previous calculation (CRWMS M&O 2000 [DIRS 153097]) in a number of important ways, as summarized in the list below:

- New parameter distributions calculated in *Characterize Eruptive Processes at Yucca Mountain, Nevada.* (BSC 2004 [DIRS 169980]) are used.
- New parameter distributions calculated in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Section 6.5.3) are used.
- New supporting information contained in *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 6) is used.
- New repository footprint layout documented in Sections 4 and 6 is used.
- New assumptions for both igneous scenarios are used.
- New calculation approaches for both scenarios are applied.

The new calculation approach toward igneous intrusion improves the approach used in the previous version of this report (CRWMS M&O 2000 [DIRS 153097]) in support of the site recommendation, primarily because it can utilize a more comprehensive sampling of igneous parameters. Moreover, the approach is more explicit in its determination of actual intersections between dike and drift. The approach is easily replicated and verifiable by simple hand calculations. Therefore, these calculations qualify as analyses per AP-SIII.9Q.

6.1 ANALYSIS OBJECTIVES

The objectives for these analyses are to develop predictive distributions for the number of waste packages hit (damaged) for igneous intrusions (dikes) or eruptive events (conduits). These distributions are provided as CDFs and will be inputs to the source term determination for the igneous intrusion scenario and for the volcanic eruption scenario in the TSPA-LA.

Corroborating and related information to this study that is not classified as direct input is listed below by data type and then source. See Section 8 for detailed references:

Statistical equations:	Guttman, I.; Wilks, S.S.; and Hunter, J.S. 1982 [DIRS 141885] Haan, C.T. 1977. [DIRS 100579] Mishra, S. 2002. [DIRS 163603]
LHS method reference:	Helton, J.C. and Davis, F.J. 2002. [DIRS 163475]
Geologic term reference:	Jackson, J.A., ed. 1997. [DIRS 109119]

The software packages used in this analysis were selected because they were suitable for binning and combining multiple parameter distributions and calculating intersections between igneous dikes and repository drifts. No alternate software programs were found that offered superior performance. The software use is limited to the ranges of values that the input data represents.

6.2 FEATURES, EVENTS, AND PROCESSES INCLUDED IN THE ANALYSIS

The development of a comprehensive list of features, events, and processes (FEPs) potentially relevant to postclosure performance of the potential Yucca Mountain repository is an iterative process based onsite-specific information, design, and regulations. Table 6-1 provides a list of igneous-related FEPs (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) that are included in the TSPA-LA through the use of the results of the calculation described in this document. Detailed discussion of inclusion or exclusion of the Disruptive Events FEPs is discussed in *Features, Events, and Processes: Disruptive Events* [DIRS 170017].

One or more dikes in the subsurface can be accompanied by formation of scoria cones, spatter cones, ash and lapilli fall, and/or lava flows on the surface (BSC 2004 Section 6.3.3 [DIRS 169980]). The TSPA-LA treats an intrusive and an extrusive event simultaneously, but computationally separated. In the intrusive event, waste packages are damaged by the dike intrusions, but eruptive conduits do not form and radionuclides are released from the cooled intrusion to the subsurface by groundwater flow and transport processes. This event is called the igneous intrusion scenario in this report and is described in Section 6.3. In the extrusive event, magma enters the repository drifts and magma and ash, potentially with entrained waste, are released to the surface by an eruptive conduit. This event is called the volcanic eruption scenario in this report and is described in Section 6.4. The parameters and distributions developed in this analysis report are used directly in the TSPA-LA. The FEPs listed in Table 6-1 are part of the conceptual basis for such a scenario.

Table 6-1. Included FEPs for this Scientific Analysis Report

TSPA-LA FEP Number	TSPA-LA FEP Name	Section Where Disposition is Described
1.2.04.04.0A	Igneous Intrusion Interacts with EBS Components	Sec. 4, 6.3, and 7
1.2.04.06.0A	Eruptive Conduit to Surface Intersects Repository	Sections 4, 6.4, and 7

DTN: MO0407SEPFEPLA.000 LA FEP List [DIRS 170760].

6.3 NUMBER OF WASTE PACKAGES HIT BY IGNEOUS INTRUSION (IGNEOUS INTRUSION SCENARIO)

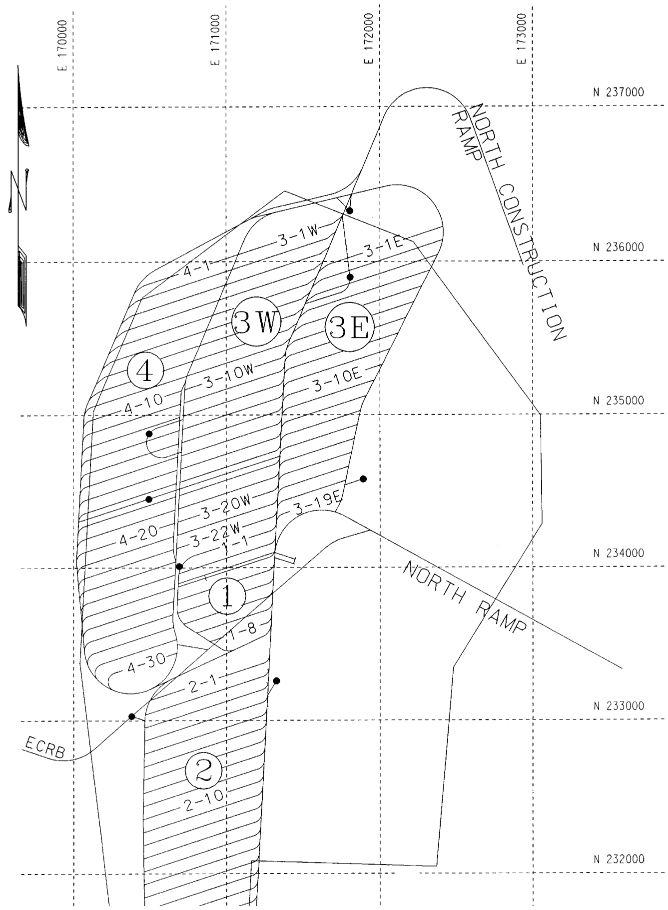
6.3.1 Problem Definition and Approach

The igneous intrusion groundwater release scenario (also called the igneous intrusion scenario,) considers the number of waste packages damaged if they were to be engulfed by magma as a result of an igneous intrusion. The variables that affect this scenario include geologic and geometric elements. The geologic elements are largely stochastic parameters. The geometric elements concern both geologic features and the current repository design.

The primary geologic elements considered are associated with volcanic dikes. Dikes are elongate, vertically oriented tabular bodies of magma that ascend through the earth's crust from a melt zone in the mantle. At or near the earth's surface, dikes are observed to extend on the order of kilometers in length and vary in azimuth, depending on the regional stress orientation (BSC 2004 [DIRS 169989], Section 6). Multiple dikes can be intruded during the same magmatic event and are observed to be oriented parallel to each other (BSC 2004 [DIRS 169980], Section 6). A group of one or more dikes resulting from the same magmatic event is called a swarm. If such dikes were formed below the repository and they reached the near-surface environment, a number of drifts in the repository could be intersected and a number of waste packages could fail. For the analysis, dikes are assumed to be oriented in a parallel manner within a hypothetical swarm of dikes (Assumption 5.4). Dikes are described using input parameters for length, thickness (or width), azimuth, spacing between the dikes, and the number of dikes in a swarm (Table 4-1). The LHS (SNL 2004 [DIRS 167794]) technique is used to develop a series of dike swarm configurations for the range of input parameters (see Appendix A; file *dikedata.txt*).

The primary geometric elements for the igneous intrusion scenario include the features of dikes just described, as well as the layout of the repository. The repository design used in this analysis is depicted in Figure 6-1. The figure shows four major panel areas, numbered 1, 2, 3 (W and E), and 4, covering a total area of 5,419,074 square meters, and consisting of 96 individual drifts (800-IED-WIS0-00103-000-00A, BSC 2004 [DIRS 168370], Figure 2 and Table 7). In addition to the extensive pillars between each drift, there are access and ventilation drifts, which are generally oriented north–south. There is also a north–south oriented rock wall, which separates panel 4 from panel 1 and the southern half of panel 3W. This analysis utilizes the current information that access drifts, ventilation drifts, and turnouts will be backfilled, and those backfilled parts will serve as effective barriers to lava flow (but not to dike propagation), as described in Assumption 5.1. The main section of each drift, which contains the waste packages, will not be backfilled. Therefore, it is assumed that for any drift intersected by a dike, all waste packages in the drift will fail (see Assumption 5.1). The essential repository geometric features to capture for this analysis are the repository perimeter and drift coordinate information. The center endpoint coordinates for each drift are included in Appendix A (original worksheet of *RepGeometry.xls* spreadsheet). The approximate perimeter coordinates for the entire repository are also included in Appendix A (perimeter worksheet of the same spreadsheet).

The analyses in this report are conditional upon the current repository design shown in Figure 6-1. The southern half of panel 2, below drift number 2-17 (which is the seventh drift below the drift labeled '2-10' in the figure) is a contingency area. This contingency area is considered in the design, but not in the calculations for this report. The design reflects a concentrated arrangement of waste packages, which leads to elevated temperatures in the drifts compared to a less concentrated arrangement.



Input Data: The total number of drifts (96) was determined by counting the active drifts.
IED: 800-IED-WIS0-00101-00A (BSC 2004 [DIRS 164519]).

NOTE: Coordinates are Nevada State Plane coordinates in meters. Circled numbers refer to panel designations.

Figure 6-1. Repository Plan View

Waste package spacing refers to the combined length of one waste package and the distance to the next adjacent package within a drift. The value of average waste package spacing must be determined to estimate the number of waste packages in each drift (the value is developed towards the bottom of the original worksheet of the *RepGeometry.xls* spreadsheet in Appendix A). The total length of emplacement drift in the repository is divided by the total number of waste packages. After rounding, the value of average waste package spacing is 5.2 m per waste package.

The calculation approach consists of the following steps:

A. Use LHS (SNL 2004 [DIRS 167794]) to develop 3000 realizations of dike swarm configurations that could intersect the repository. Each realization must honor all input constraints and rules (Appendix D).

B. Calculate the total number of drifts intersected for each realization by overlaying the dike-swarm configurations onto the repository layout geometry and summing up the number of drifts intersected.

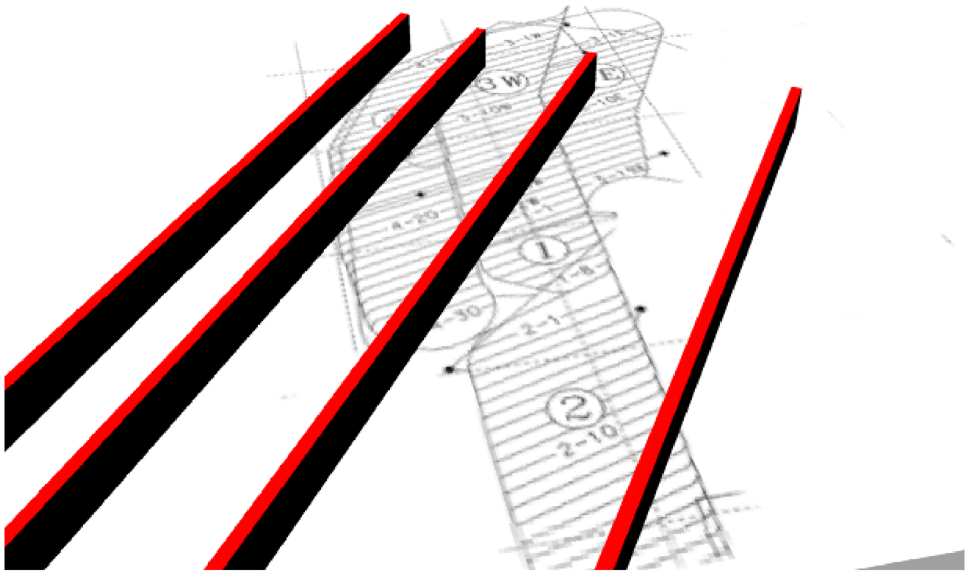
C. Given an average working value for the spacing of waste packages, determine the total number of waste packages hit for each realization.

D. Develop average CDFs for the numbers of waste packages hit using the 3000 realizations.

6.3.2 Calculation Step A – Dike Swarm Configurations and Repository Intersections

The first calculation step is facilitated primarily through the use of the LHS code (SNL 2004 [DIRS 167794]) and the parameter distributions in accordance with the rules (listed in Appendix D) for dike configurations. LHS is a FORTRAN code that provides simultaneous binning of multiple parameter distributions for use by subsequent calculations. LHS can generate correlated or uncorrelated parameter sets that are representative of distributions generated by more resource- and time-intensive methods, such as the Monte Carlo method. A general treatment of the LHS method, upon which the code is based, can be reviewed in Helton and Davis (2002 [DIRS 163475]).

The number of waste packages damaged is a function of constant values and several variables. The dike thickness and repository layout and dimensions are held constant while the following parameters vary: dike length, the number of dikes in the swarm, the spacing between each dike, the angles at which the dikes intersect the repository, and the dike entry locations along the repository perimeter. The analysis takes all of these factors into account through multiple parameter distribution sampling using LHS (SNL 2004 [DIRS 167794]). The analysis depends heavily on the probabilistic treatments of many of these variables contained in two analysis reports: *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]) and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980]). Figure 6-2 shows a hypothetical swarm of dikes, depicted as red vertical slabs, intersecting the repository.



NOTE: For illustration purposes only. Not to scale. Oblique view.

Figure 6-2. Conceptualization of a Swarm of Dikes Penetrating the Repository Footprint

An input file was prepared for LHS (SNL 2004 [DIRS 167794]) (Appendix A; file *lhs2_uif$input.dat*) that contains the following distribution parameter sets:

1. Dike length within repository. Sampled dike lengths can range from near 0 m to over 5,000 m (Table 4-1, row 3). One value is sampled for each realization. However, the length of each dike in that realization can vary from this value according to the rules described in Appendix D (part A). These rules are intended to prevent logical inconsistencies when the sampled dike lengths are incorporated with the multiple dike distributions and overlaid onto the repository plan.

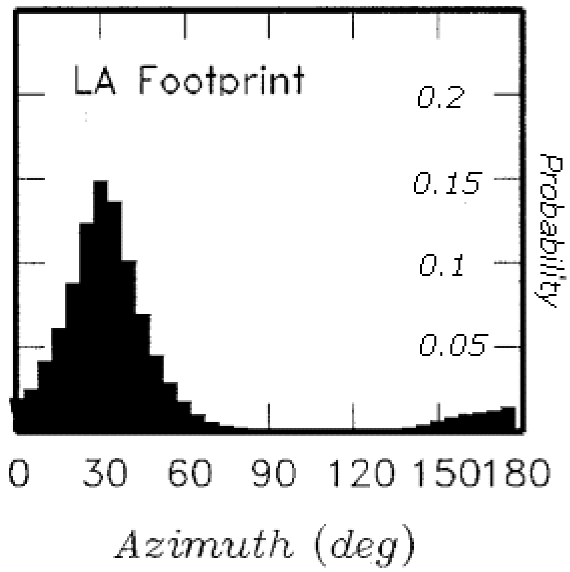
2. Dike azimuth angle. One value is sampled for each realization. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Figure 22) developed the distributions of possible azimuth angles through the repository that is used in this analysis (Table 4-1, row 3). Azimuth angles are measured in degrees, going clockwise, from due north. Figure 6-3 shows a relatively narrow distribution clustered around the modal value of 30 degrees. The sampled angle applies to all dikes in that realization.

3. Number of dikes per realization. This is a truncated log-normal distribution with a minimum value of 1 and a modal value of 3. The 95th percentile is set at 6 (Table 4-1, row 11). Given the LHS (SNL 2004 [DIRS 167794]) setting to produce 1000 realizations, this distribution leads to a small population of cases where the number of dikes can run from 7 to roughly 15.

4. Spacing between dikes. Dike spacing ranges from 1 m to 1490 m (Table 4-1, row 13). The range used in this analysis has a minimum value of 100 m and a maximum possible spacing of 690 m. This range is demonstrated to be conservative and is

discussed further in Section 6.5.1. The spacing values are calculated independently for each pairing of adjacent dikes. In other words, for any given realization, there can be many unique inter-dike spacing values. The total width of the swarm will be the sum of the dike spacings.

5. Central dike swarm entry location. This position is termed an ‘anchor point’. The anchor point is assigned to a random location along the repository perimeter for each realization. The variable position of entry locations is assigned a uniform distribution.



Data Source: Figure 22 (BSC 2004, [DIRS 169989]). Data in DTN: LA0303BY831811.001 [DIRS 163985].

Figure 6-3. Mean Probability Distribution for Dike Intersection Azimuth Angle

Parameters that are not treated as uncertain variables include dike thickness and repository layout and dimensions. The repository is treated as a configuration that does not change. Dike thicknesses do vary, but the maximum expected thickness of 4.5 m (DTN: LA0407DK831811.001 [DIRS 170768]) at Yucca Mountain is still small compared to the 81 m spacing between repository emplacement drifts and the average drift length of over 600 m (800-IED-MGR0-00201-000-00B BSC 2004 [DIRS 168489]). A maximum dike thickness is hard-coded into DIRECT (SNL 2004 [DIRS 167795]) by bounding box algorithms with additional thickness above the maximum value of 4.5 m. This additional thickness adds an element of conservatism because the greater the thickness of each dike, the greater the area occupied by each dike. Within the limited repository area, these greater dike areas proportionately increase the opportunities for intersections with drifts. This increased thickness treatment is discussed in more detail in Section 6.3.3.

Figures 6-4 and 6-5 illustrate the basic conceptual rules, and the type and variety of outcomes that can be realized. After conducting an LHS (SNL 2004 [DIRS 167794]) run with the proper sampling and distribution criteria, a set of 1000 parameter combination realizations is produced (this set is captured in the file *LHS.dat*, which is input to the DIRECT code (SNL 2004 [DIRS 167795])). This set is called a replicate and it contains its own unique random seed to generate the 1000 realizations. This approach appears to sufficiently capture the range of uncertainty. The DIRECT code uses the anchor point and samples azimuth angle (in these figures represented by the anchor extension line) as preliminary building blocks. The code builds a geometric representation of each realization and explicitly computes the intersections between each dike and drift. Because three replicates were conducted, there are three *lhs.dat* type input files (files *lhs_1.dat*, *lhs_2.dat*, and *lhs_3.dat* in Appendix A).

In the example realization shown in Figure 6-4, five dikes (red lines) having a northeast bearing intersect the repository and a number of internal waste emplacement drifts. The orange semi-transparent zones identify repository drifts that have been intersected by these dikes. The green dot represents the sampled anchor entry point. The anchor entry point can occur anywhere along the repository perimeter, according to a sampled value. The green anchor extension line represents both the sampled azimuth angle and the sampled dike length (the dike portion penetrating the repository only).

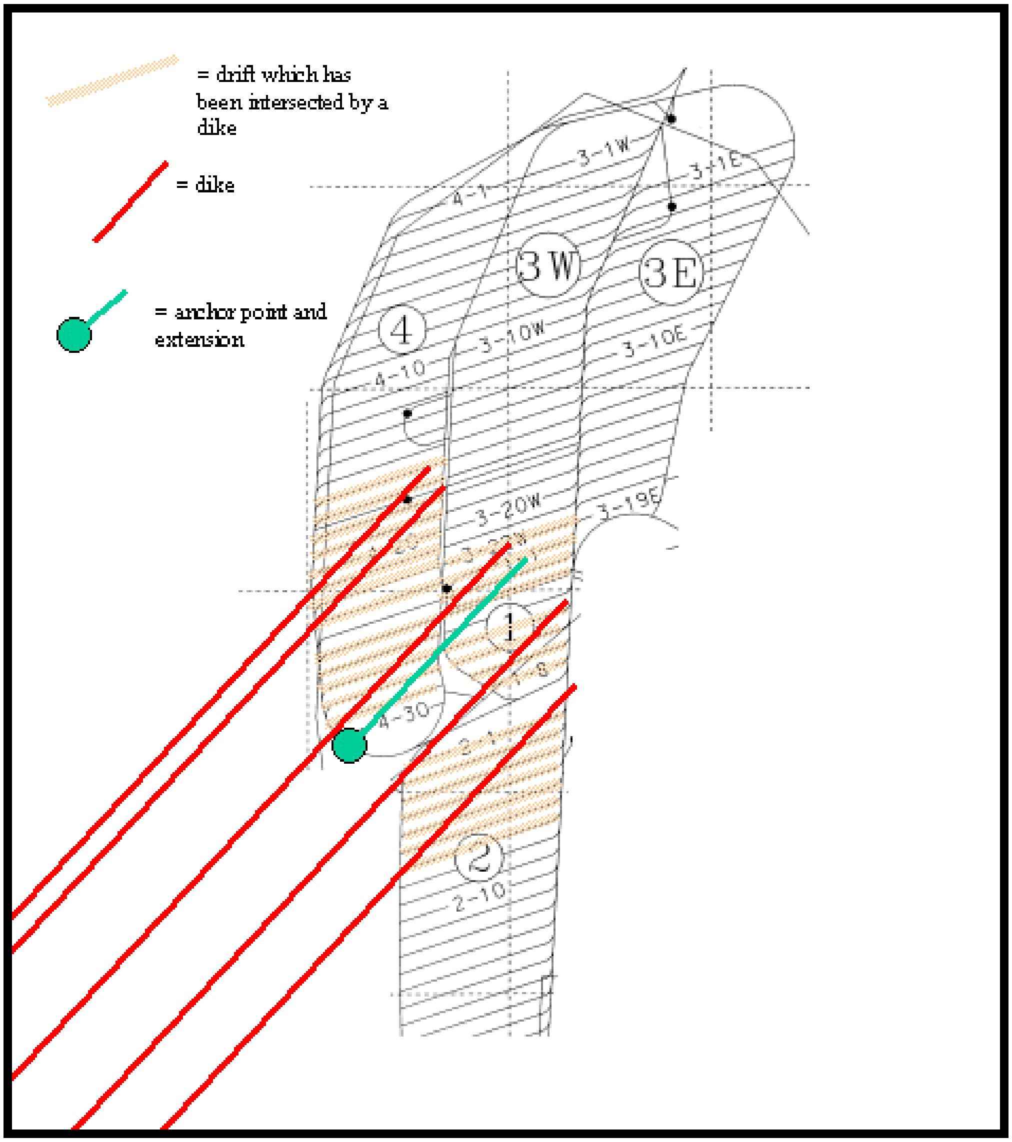
All dikes are parallel to the anchor extension line, but have variable spacing (via sampling) between them. The anchor point does not correspond to any particular dike. Rather, the anchor point and extension are positioned at the middle of the entire dike swarm. These anchor features have the limited role of facilitating the positioning and layout of all dikes as determined by the sampled factors. Anchor features alone are not factored in the tally or determination of dike drift intersections. In other words, if no dikes intersect a drift, but an anchor extension line does, the drift will not be included in the tally.

Figure 6-5 shows an alternate sampled realization. In this case, there are only two dikes that now have an easterly bearing and enter the repository from a more northerly position than the previous figure. The anchor point and extension are positioned at the middle of the dike swarm. Clearly the variations in dike swarm configuration can, and will lead to significant differences in the calculated number of drifts intersected.

The realizations illustrated in Figures 6-4 and 6-5 represent only two of many possible dike swarm configurations. The nature and extent of possibilities are controlled by features that fall into two distinct categories. One category represents the sampled (and generated) distributions described earlier. The other category represents rules used to control specific aspects of the dike swarms. Four rules were developed for use with the LHS code (SNL 2004 [DIRS 167794]) to prevent logical inconsistencies when the sampled dike lengths are incorporated with the multiple dike distributions and overlaid onto the repository plan. The rules primarily involve the lengths and spacings of dikes (see Appendix C, part A for details).

6.3.3 Calculation Step B – Determining Number of Drifts Intersected

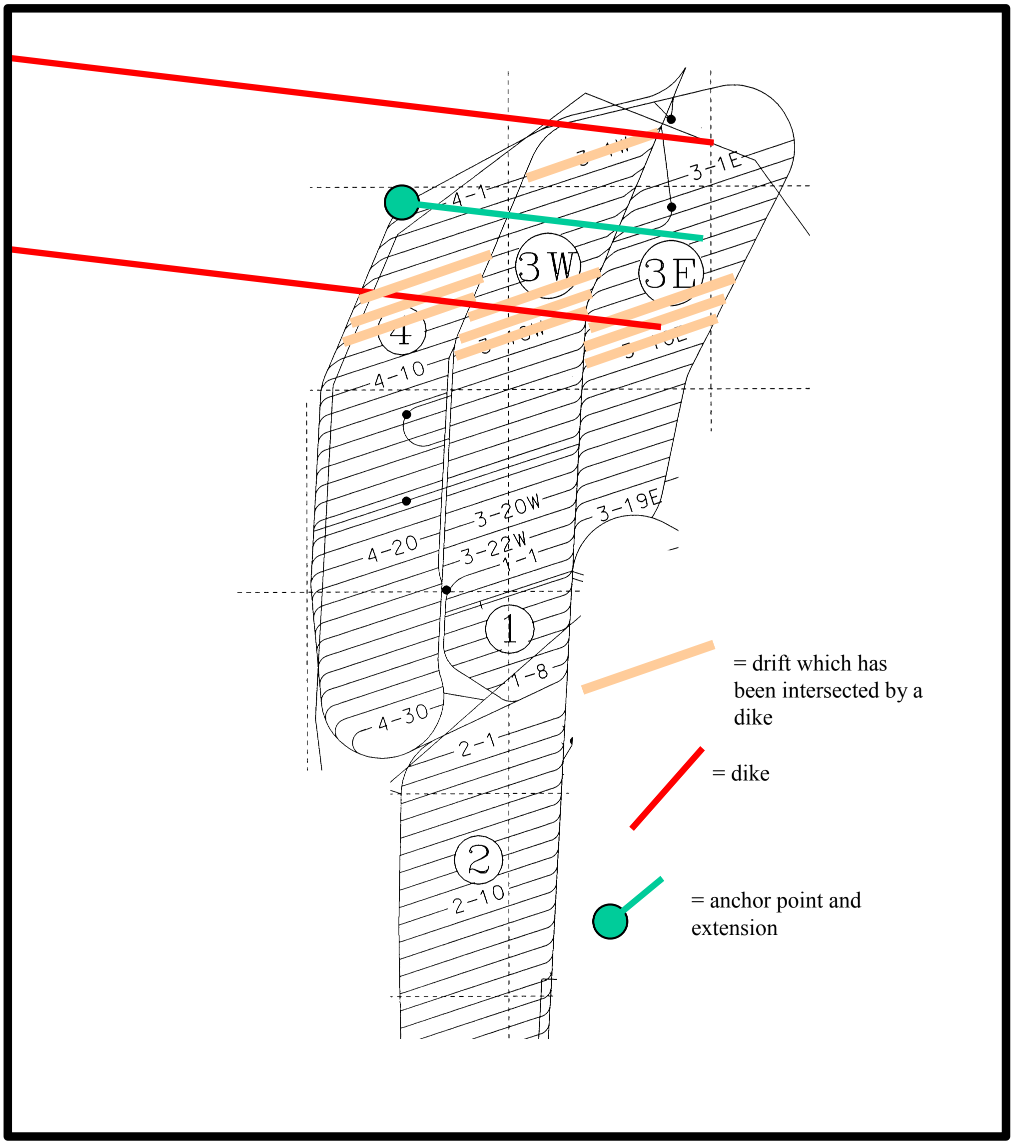
This step involves overlaying the dike swarm configurations onto the repository layout geometry and tallying the number of drifts intersected for each realization. This procedure involves several substeps. Both the repository layout geometry and the sampled dike geometry must be realized within the DIRECT code (SNL 2004 [DIRS 167795]) for intersections to be calculated automatically. Therefore, the first substeps are to determine these geometries and import them into the DIRECT environment.



NOTE: For illustration purposes only. Not to scale.

Figure 6-4. Example of a Dike Swarm Configuration

DIRECT (SNL 2004 [DIRS 167795]) is based on the underlying Torque Game Engine (www.garagegames.com), which, with few exceptions, requires that geometric objects be initially imported into the system as binary objects, called shape files, having a .dts extension. Moreover, the DIRECT geometric coordinate space has a different scale and orientation than the Nevada State Plane Coordinates space used to define the repository layout. Therefore, geometric transformations must be employed. Note however, that as subsequently shown, the final graphics of DIRECT results are easily measured and comparable against input values and original drawings. Additional details of the production of the proper geometry files are contained in Appendix D (Part B).



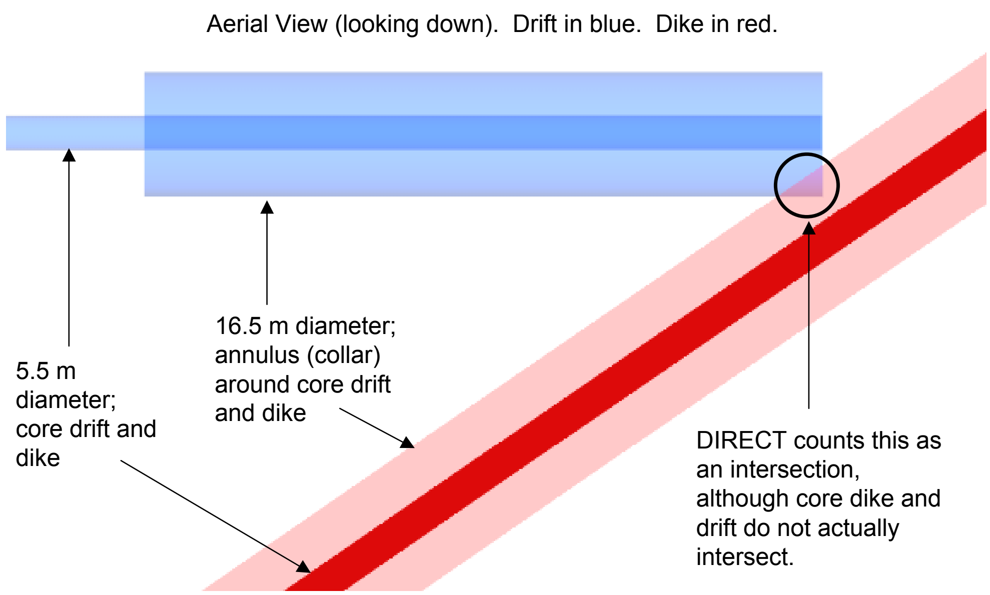
NOTE: For illustration purposes only. Not to scale.

Figure 6-5. Second Example of a Dike Swarm Configuration

After the inputs have been properly developed and entered, DIRECT (SNL 2004 [DIRS 167795]) builds the dike-drift geometry for each realization. The resulting dikes and drifts have the proper lengths at this point and their cross-sectional thicknesses initially retain the 4.5-m and 5.5-m dimensions, respectively. These cross sectional thicknesses are expanded later within DIRECT in order to produce bounding boxes (also called buffer zones) for collision intersection calculations, as illustrated in Figure 6-6. DIRECT assigns bounding box thicknesses of 16.5 m for both drifts and dikes. This thickness is three times greater than the planned emplacement drift widths of 5.5 m and is also more than three times greater than the anticipated maximum dike thicknesses of 4.5 m.

This buffer zone approach leads to the counting of more intersections than if original sampled dike and drift thicknesses were used because wider dikes and drifts are more likely to overlap than narrower ones. The bias is not large because of the high aspect ratios of dike and drift lengths to their thicknesses. For example, dikes can be greater than 5000 m long and drifts up to over 700 m long, compared to only 16.5 meters wide. As Figure 6-6 suggests, this bias generally only comes into play when dikes occur near the tip of a drift or vice versa.

The buffer zone approach addresses potential uncertainties in dike and drift positions. The analysis report, *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980], p. 6-9), describes dikes potentially having irregular features, such as subplanar geometry, off-shoot dikes, or minor variations in width and strike direction. These variations can be accounted for through the buffer zone approach. In other words, although dikes at any point have a certain thickness, there is another, effective thickness caused by these other variable factors that the buffer zone approach is intended to capture. Also, as stated in Assumption 5.1, drift degradation can lead to the thickening of a drift profile over its original dimensions and can also be addressed by the buffer zone for drifts.



NOTE: For illustration purposes only.

Figure 6-6. Illustration of Bounding Box (Buffer Zone) Setup

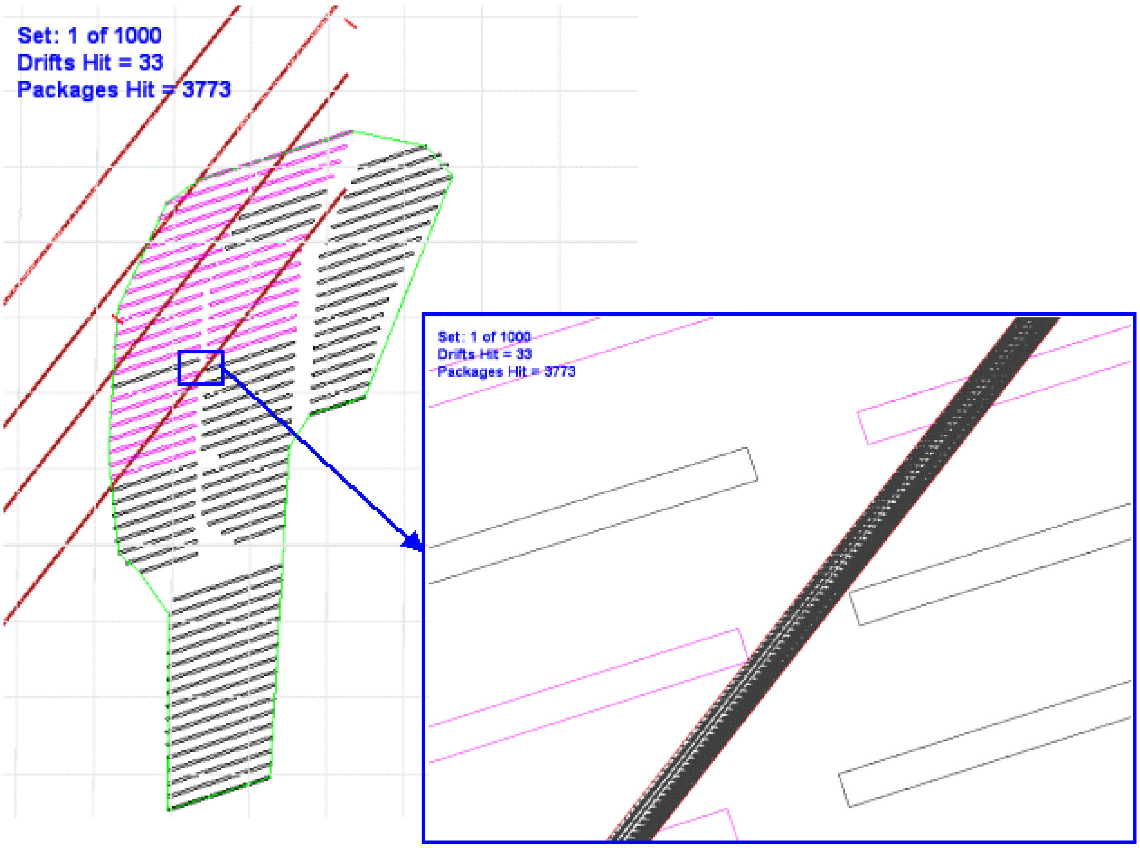
6.3.4 Calculation Steps C and D – Number of Waste Packages Damaged

The collision detection is done in DIRECT (SNL 2004 [DIRS 167795]) by a series of internal algorithms that test for line intersections. For each realization, all possible intersections between every dike and every drift are evaluated. For drifts that are intersected by a dike, the number of waste packages for that drift are added to the total (documented in Appendix A, column F of the original worksheet of the *RepGeometry.xls* spreadsheet). After DIRECT has calculated the total number of waste packages hit for a realization, the result is written to a separate row in the output file, *results.txt*. The output spreadsheet contains one row per realization, leading to 1,000 rows of data. Three replicate sets of 1000 each were computed, resulting in 3000 realizations.

Figures 6-7 through 6-13 were produced from DIRECT (SNL 2004 [DIRS 167795]) in this fashion. They were selected from the third replicate to show a representative sampling from the wide variety of results. The predicted values for each case are shown in the upper left hand corner of each figure. These figures, and any other DIRECT graphic output can be verified by comparing the observed and tabulated values shown in the graphic against the associated input values (found in files *lhs.dat*, *dikedata.txt*, *driftdata.txt*) and using the rules for dike overlay described in the previous section.

Figures 6-7 through 6-13 have special features that require consideration prior to result checking or other review. The grid overlay in each figure has an even spacing of 500 m in both directions. It can be used to help confirm sampled geometry parameters. Dikes are pictured in red and drifts are shown in gray. Drifts shown in magenta indicate intersection by a dike. In addition, the thicknesses of the pictured dikes and drifts are all set at 16.5 m, in accordance with the previous discussion on bounding boxes. Due to the small scale, figures as shown may be misleading. For each of the sample figures below, a zoomed image is shown to clarify areas of ambiguity (DIRECT allows the user to look in detail at any location of interest).

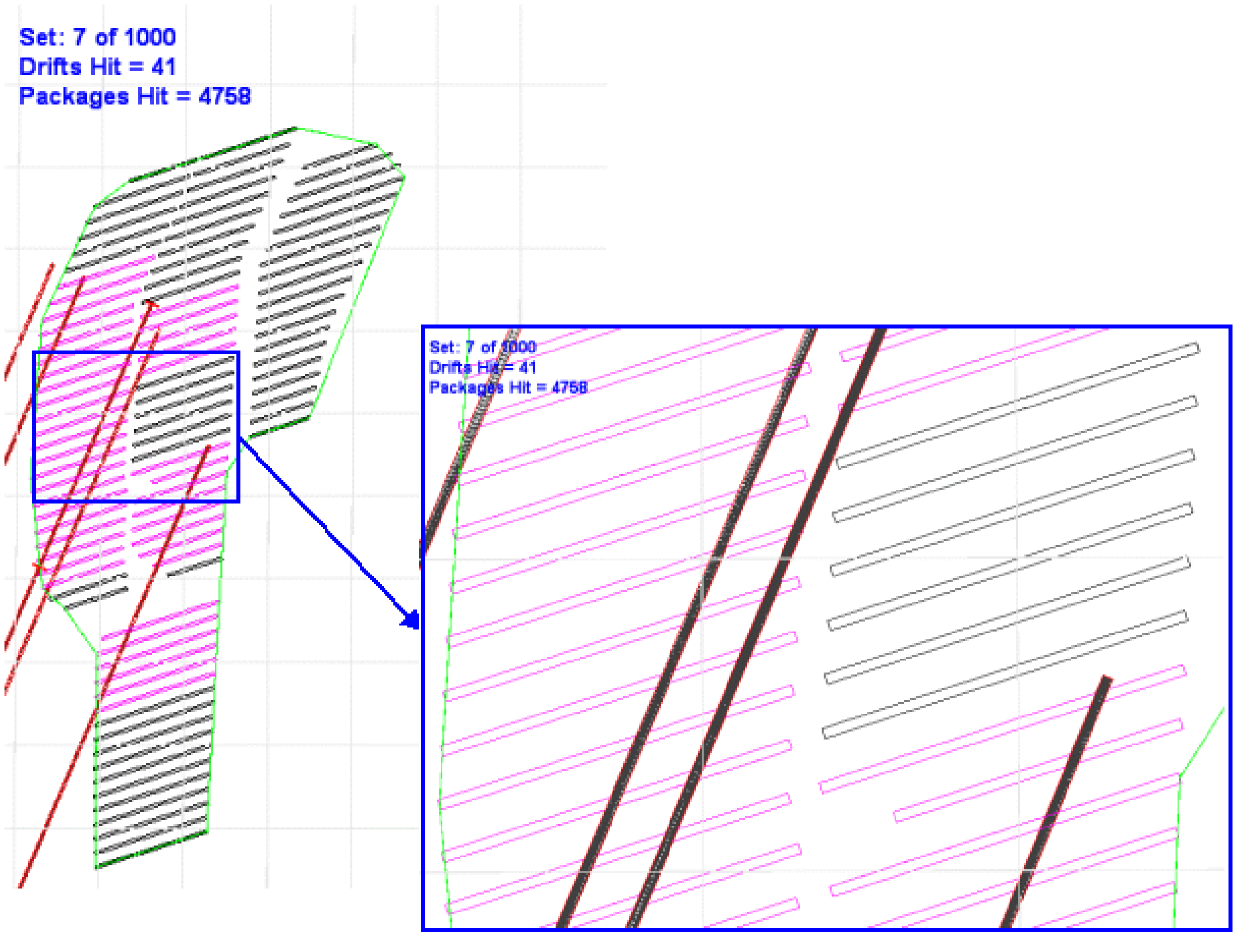
The green line represents the perimeter of the repository that was input to DIRECT (SNL 2004 [DIRS 167795]). This line is not intended to represent any formal perimeter boundary. It simply represents the track along which the anchor point position is placed, following LHS (SNL 2004 [DIRS 167794]) sampling. The two short red lines indicate the anchor features (see Appendix D).



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

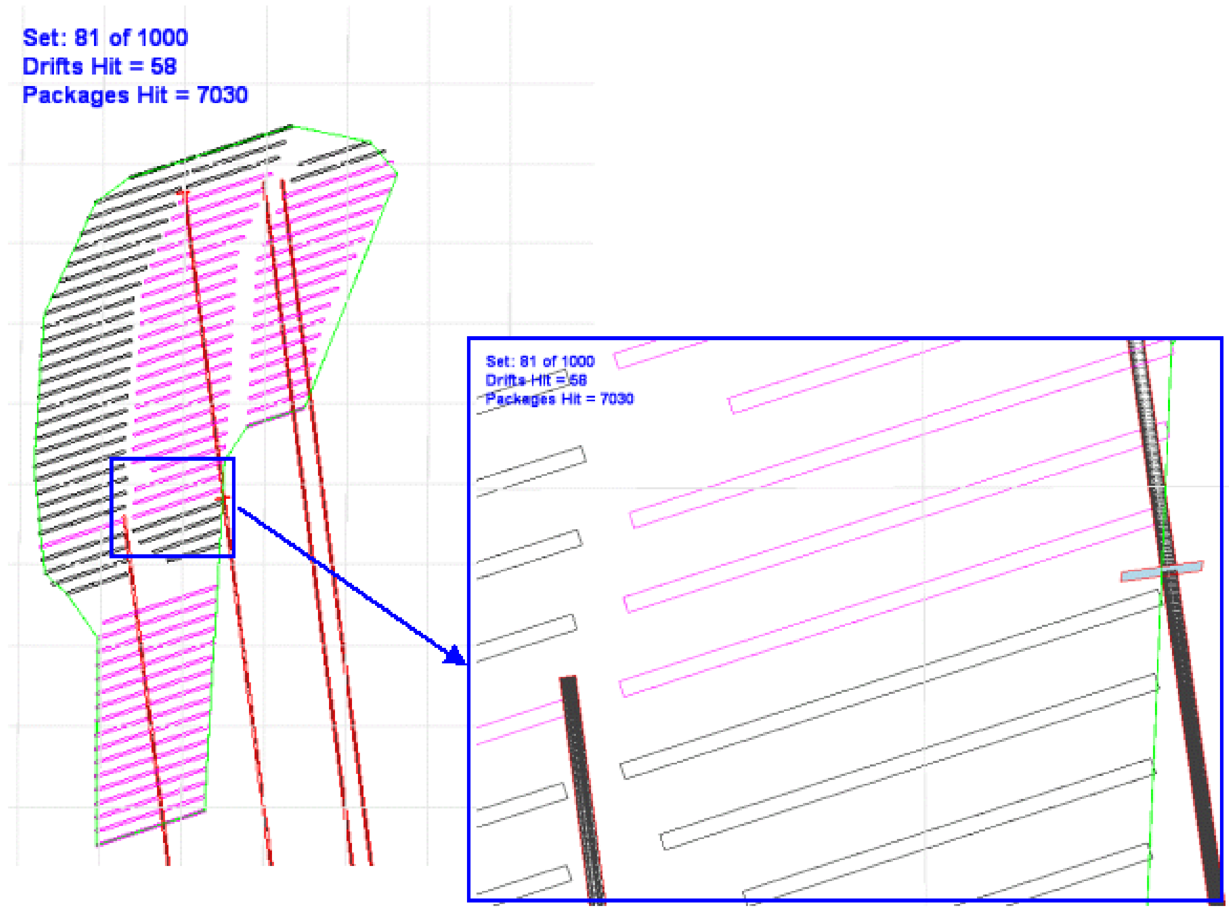
Figure 6-7. Selected Screen Captures of DIRECT Results for Replicate 3, Set 1



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

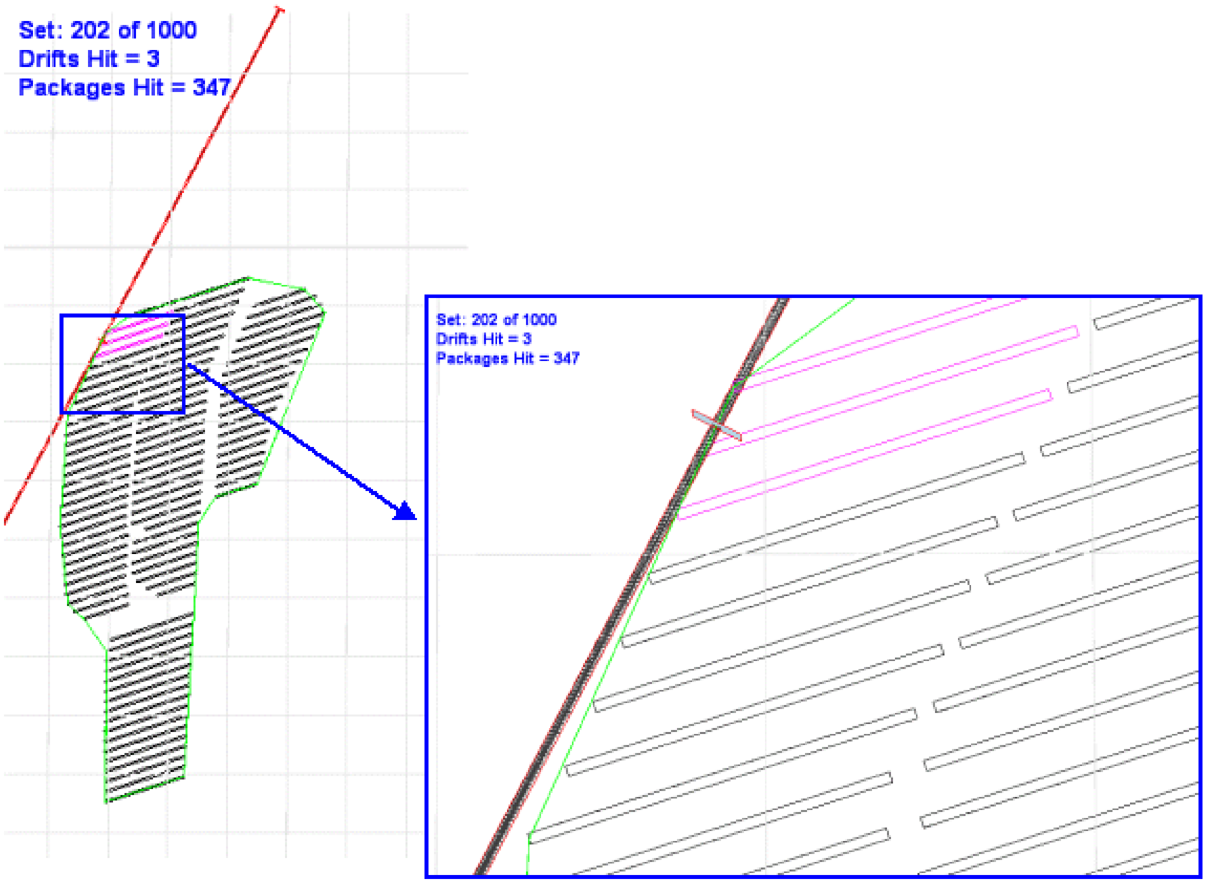
Figure 6-8. Selected Screen Captures of DIRECT Results for Replicate 3, Set 7



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

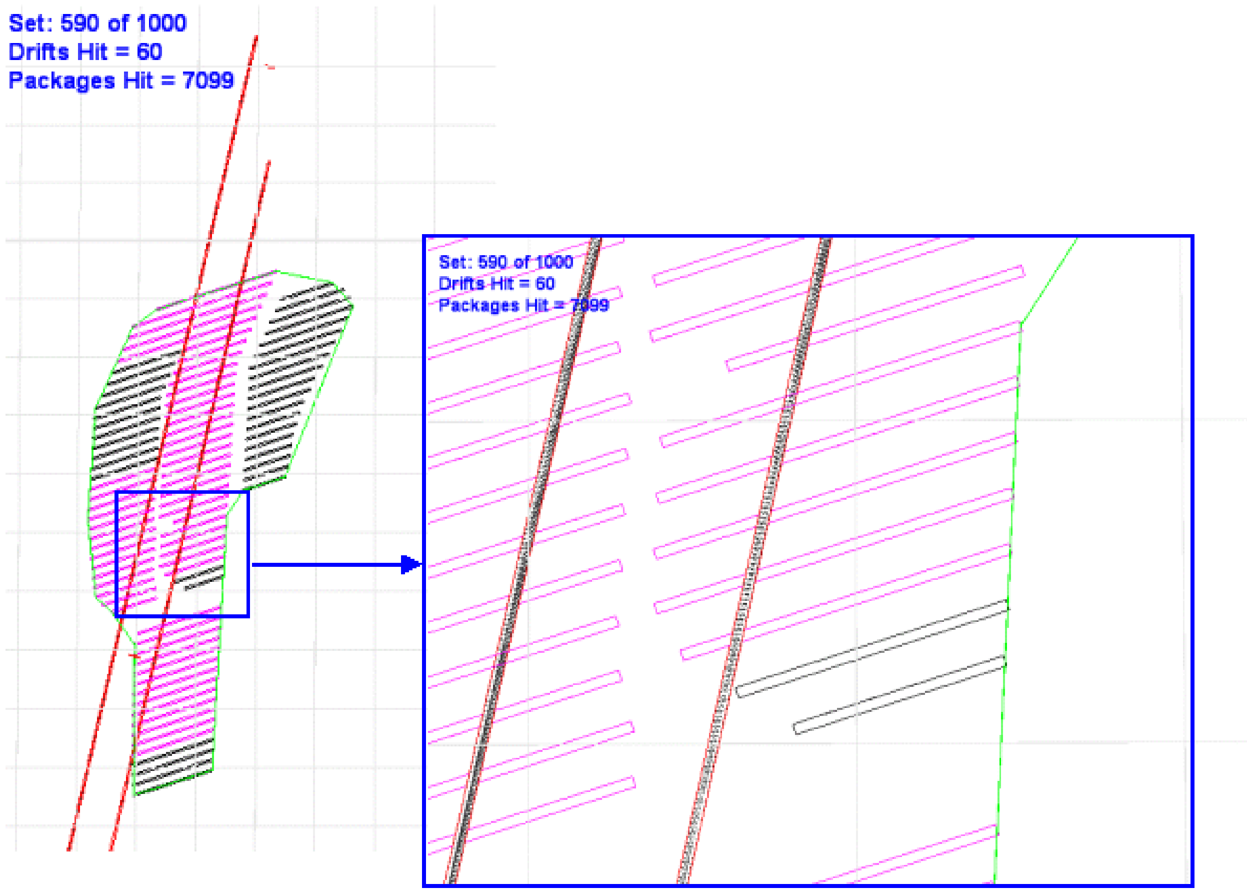
Figure 6-9. Selected Screen Captures of DIRECT Results for Replicate 3, Set 81



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

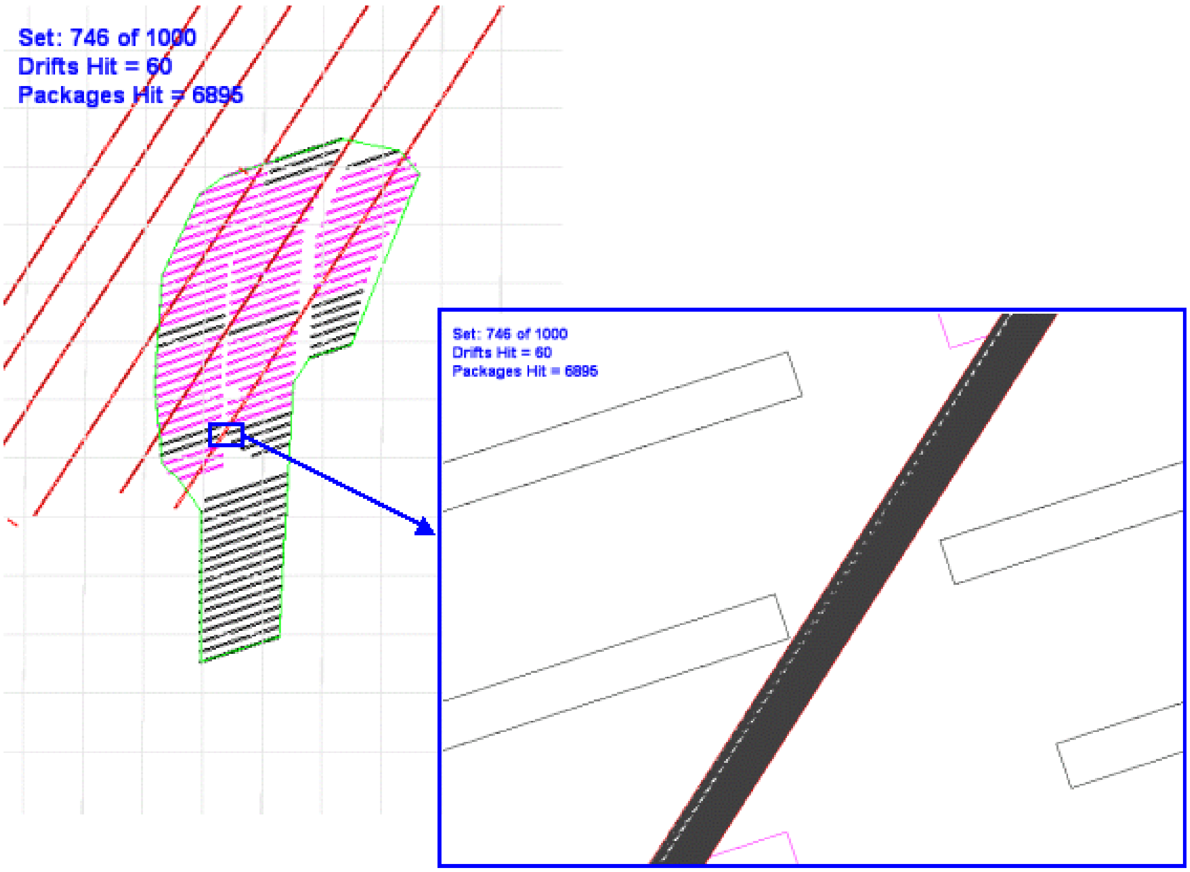
Figure 6-10. Selected Screen Captures of DIRECT Results for Replicate 3, Set 202



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

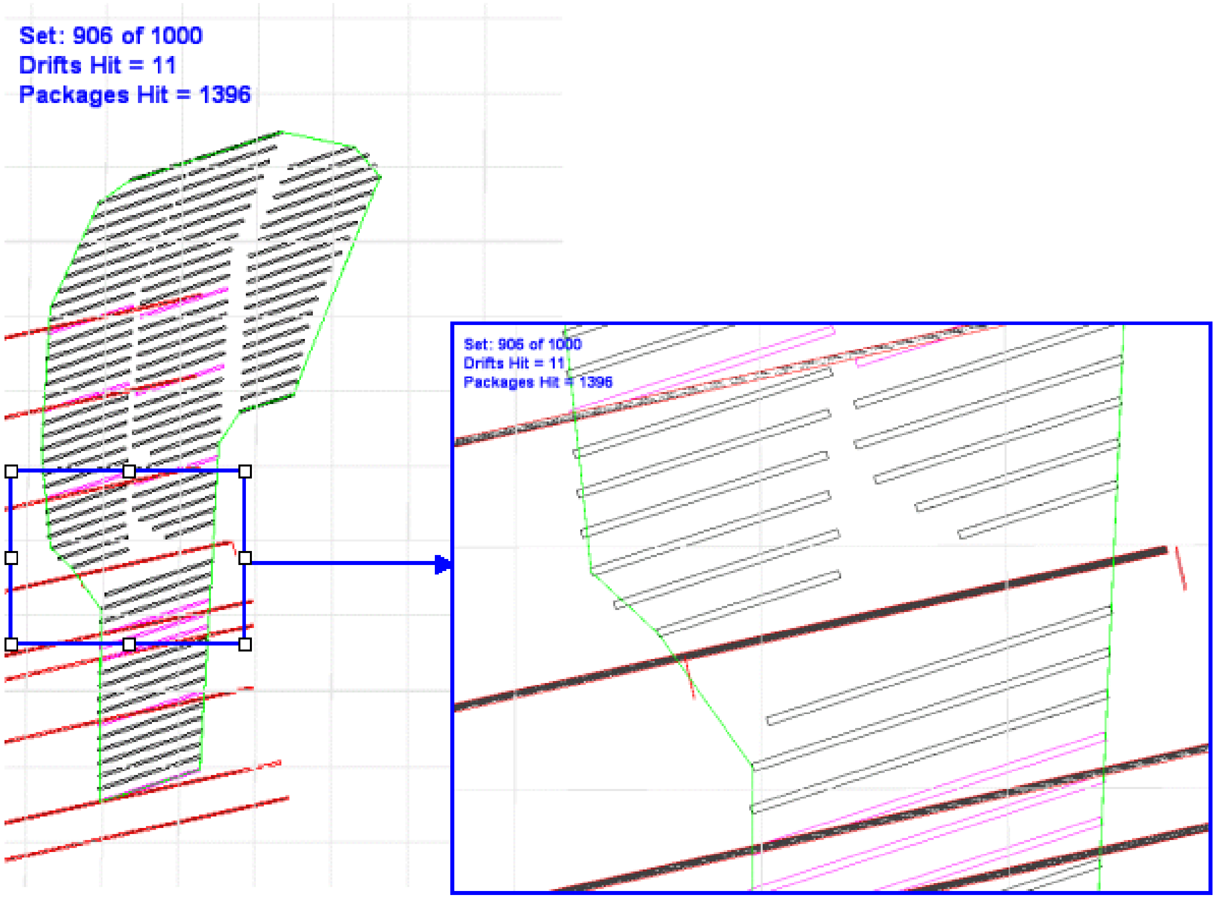
Figure 6-11. Selected Screen Captures of DIRECT Results for Replicate 3, Set 590



Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

Figure 6-12. Selected Screen Captures of DIRECT Results for Replicate 3, Set 746



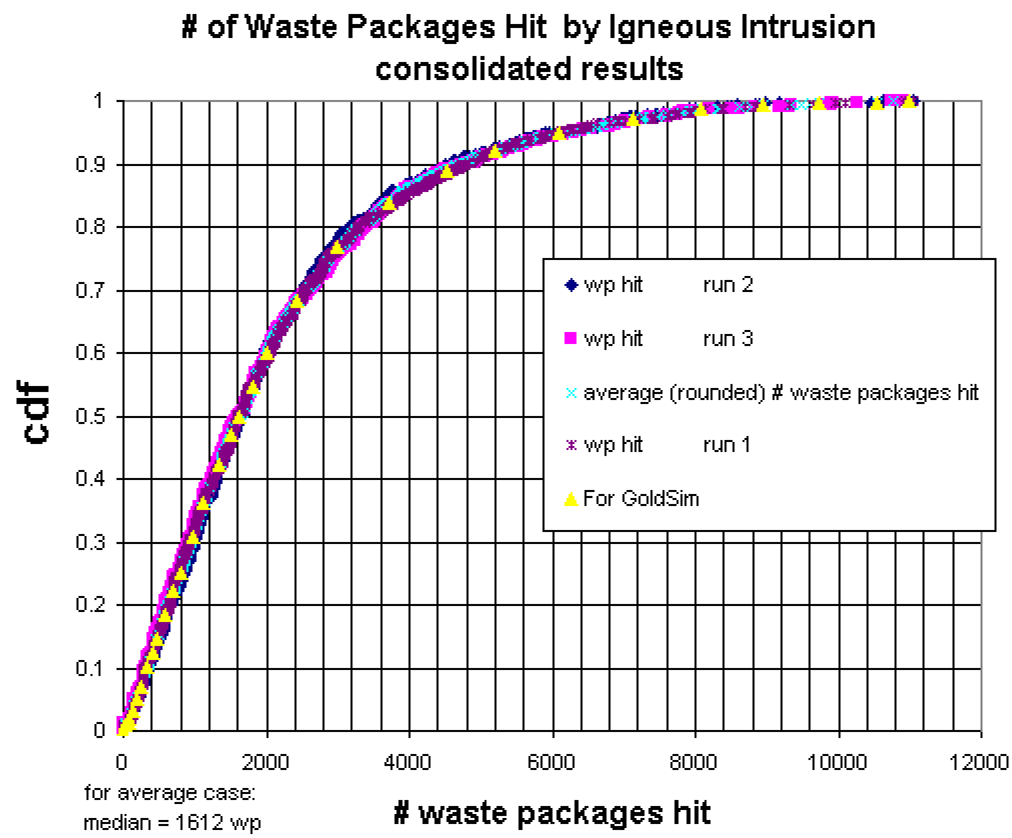
Output DTN: SN0402T0503303.004 (from file *graphs_set3.zip*).

NOTE: Modified output data for illustration.

Figure 6-13. Selected Screen Captures of DIRECT Results for Replicate 3, Set 906

The results from three runs of DIRECT (SNL 2004 [DIRS 167795]) (using the three different LHS (SNL 2004 [DIRS 167794]) replicate files) are included in the files, *results_1.txt*, *results_2.txt* and *results_3.txt* described in Appendix A, as well as in output DTN: SN0402T0503303.004. A complete set of graphics for all 3,000 runs is included in the same source.

The results from the three replicates are combined and integrated by direct averaging into a single CDF, as shown in Figure 6-14 below. The results nearly overlay each other in a coarse sense. Details are documented in the *DikeSwarmCDF* worksheet of the *ANL-MGR-GS-000003_results.xls* spreadsheet, included in DTN: SN0402T0503303.004. The median value is 1,612 waste packages hit out of a wide range of results, from essentially zero to nearly the entire waste package inventory of 11,184 packages. The For Goldsim category is a CDF extracted for use by Goldsim users from the integrated CDF.



Output DTN: SN0402T0503303.004 (in file *ANL-MGR-GS-000003_results.xls*).

Figure 6-14. CDF Results for Igneous Intrusion Case

6.4 NUMBER OF WASTE PACKAGES HIT BY VOLCANIC ERUPTION

A volcanic eruption could occur through the repository and result in the development of eruptive conduits. As described in Section 6.3 of *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980]) and augmented by the discussion in Section 5.4 of this report, a volcanic eruption process could follow these steps:

1. A tabular dike vertically penetrates upward through the repository and reaches the surface.

2. Irregularities in the dike and/or the materials through which the dike projects promote the evolution of one or more conduits.

3. The conduit transmits all material in its path upward to the surface. This material includes waste from failed packages if they are intersected by the conduit. This step is supported in Assumption 5.3.

The analysis of the number of waste packages hit resulting from a volcanic eruption considers a distribution of volcanic conduits that are associated with a single volcanic event, which affects the repository. Each conduit creates a circular profile through the repository, damaging any intersected waste packages and transferring waste to the surface.

The distribution of conduit diameters is characterized by a minimum of 4.5 m, a mode equal to 50 m, and a maximum value equal to 150 m (Table 4-1, row 1; DTN: LA0407DK831811.001 [DIRS 170768]). For simplicity of binning in the distribution process, the minimum conduit diameter used in this analysis is set to 5.0 m. This diameter also adds a slight conservative bias to the results.

As described in Section 5.2, all conduits in the same realization have the same sampled diameter. The minimum spacing between conduits, as discussed in *Characterize Framework for Igneous Activity at Yucca Mountain,* there is no possibility within this abstraction for conduit overlap.

In this abstraction, and as discussed in Section 5.3, the number of waste packages intersected by an eruptive conduit is treated as the product of conduit area times the average waste package density within the repository. The average waste package density is calculated by dividing the total planned number of waste packages by the total planned repository area, including pillars. This approach is supported in part by the facts that the waste packages are uniformly distributed along each emplacement drift and those emplacement drifts are evenly spaced within the repository footprint. In other words, the waste packages are relatively evenly spaced in two different directions throughout the repository. When considered over the scale of the entire repository, this spacing leads to a relatively uniform waste package density, which supports the use of an average value.

This abstraction allows for simplifications to the analysis. The most important simplification is that there is no need to specifically consider the actual location of any particular emplacement drift, pillar, or waste package.

The number of waste packages damaged by a system of eruptive conduits is treated as a joint probability, dependent on both the number of conduits and the diameter of the conduits. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Table 19) contains various distributions based on different approaches for the number of conduits associated with a dike system intersecting the repository. The approaches differ in several respects, including the degree of randomness versus the tendency toward a constant conduit spacing and the degree of correlation between conduit number and dike characteristics. The distribution for the mean hazard, final composite conditional probability represents a composite of these different approaches, and is used in this analysis. The term, hazard, is a term of art, that simply means probability. Table 6-2 shows this distribution, which has 14 bins ranging from 0 to 13 conduits and a maximum at 1 conduit.

Table 6-2 . Mean Hazard, Final Composite Conditional Probability for Number of Eruptive Centers

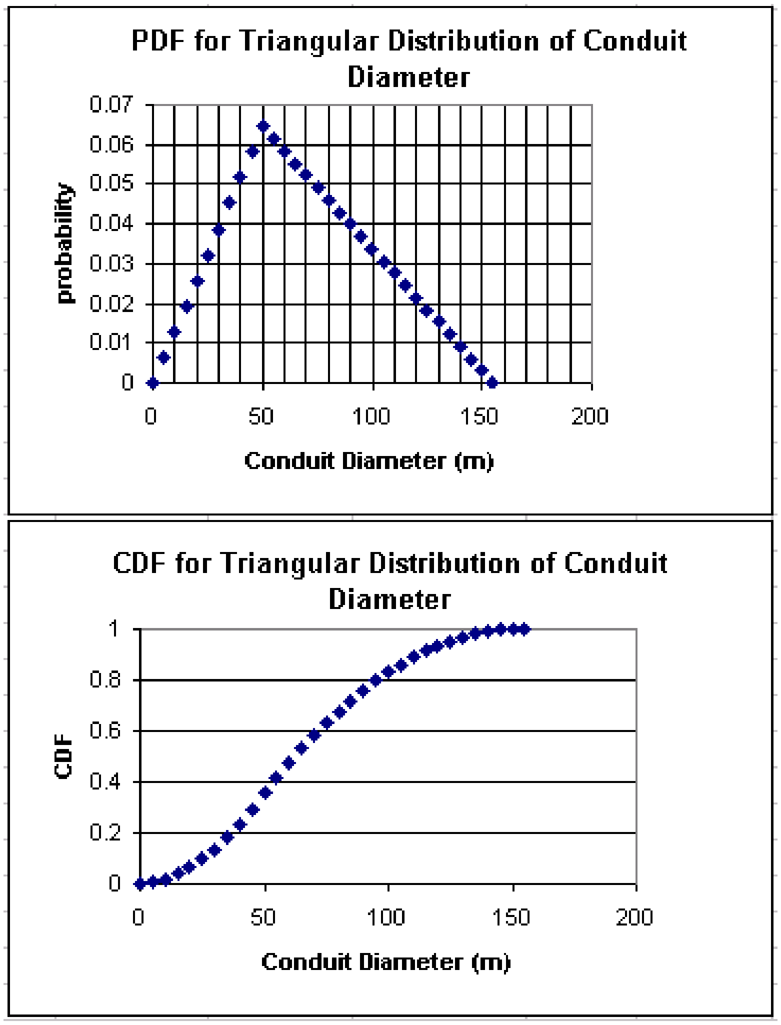
Number of Eruptive Centers within Repository	Final Composite Conditional Probability
0	0.218
1	0.567
2	0.108
3	0.0430
4	0.0238
5	0.0163
6	0.0101
7	0.00699
8	0.00335
9	0.00144
10	0.00092
11	0.00080
12	0.00045
13	0.00005

Source: BSC 2004 [DIRS 169989], Table 19; DTN: LA0307BY831811.001 [DIRS 164713].

As documented in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Figure 19 and accompanying text), the results of the PVHA generally specify that less than five eruptive centers would form during a single volcanic event, regardless of the number of associated dikes (CRWMS M&O 1996, *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* [DIRS 100116]. To capture the full range of uncertainty, the distribution shown in Table 6-2 allows as many as 13 conduits to penetrate the repository.

The distribution for conduit diameters is taken from the DTN LA0407DK831811.001 [DIRS 170768]. It is described as a triangular distribution with a most-likely (mode) value of 50 m, a minimum value equal to the host dike thickness of 4.5 m, and a maximum value of 150 m. The development of this distribution is detailed in the work area titled Auxiliary 1, starting on row 75 in the auxiliary worksheet of the *ANL-MGR-GS-000003_results.xls* spreadsheet. Appendix B of this document explains how to acquire this spreadsheet from the

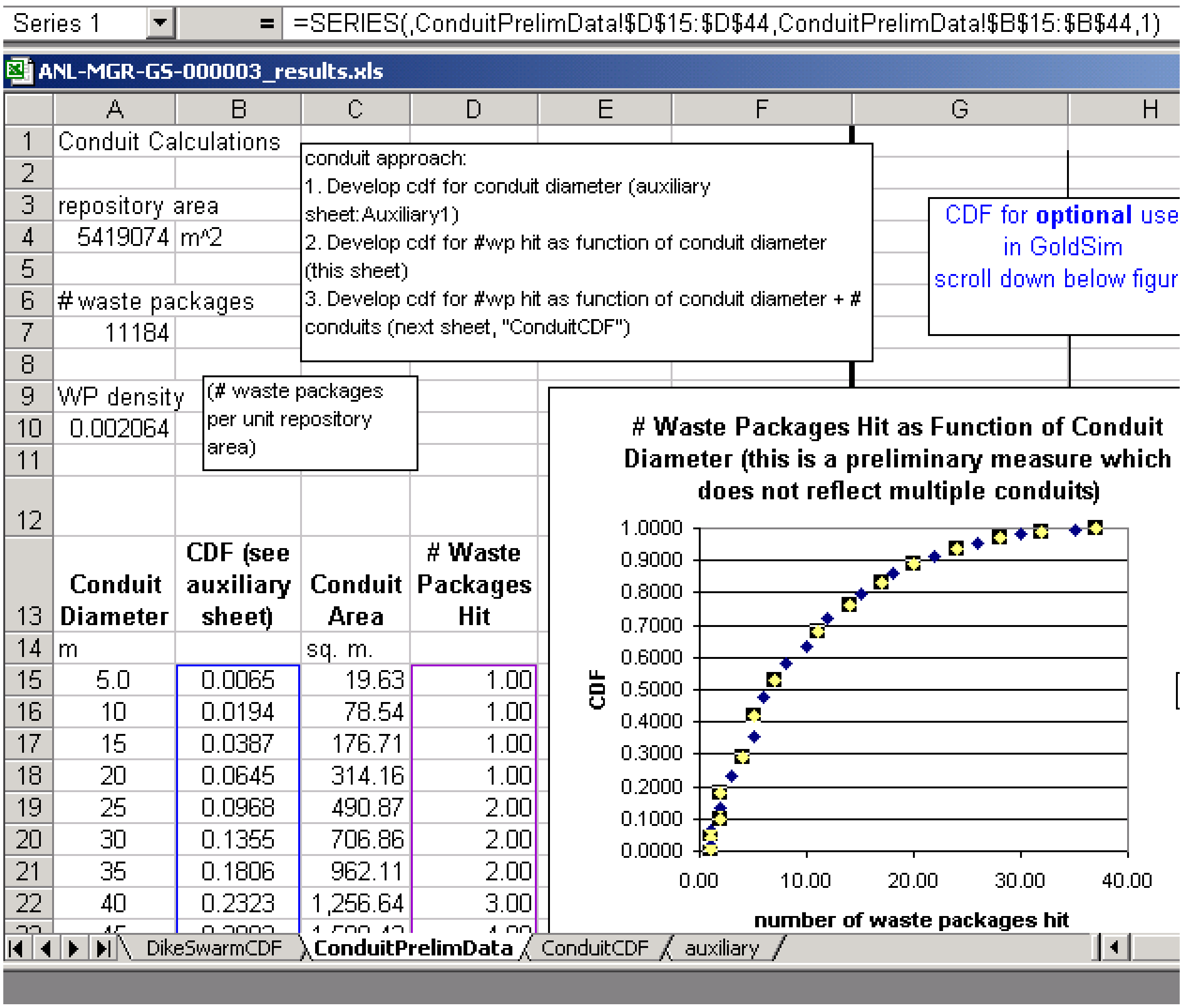
Technical Data Management System. The distribution has been modified slightly from the above guidelines so that the minimum diameter is set at 5 m instead of 4.5 m. The change facilitates a more even distribution of bins and also has a mild bias towards overestimation of the number of waste packages hit, as described previously. Bins are set at constant 5 m increments. This distribution for conduit diameters is shown in Figure 6-15.



Output DTN: SN0402T0503303.004.

Figure 6-15. Probability Distribution Function and Cumulative Distribution Function of Conduit Diameter Distribution

A preliminary CDF was calculated that addressed only the number of waste packages hit as a function of conduit diameter. The calculations for this distribution are detailed in the ConduitPrelimData worksheet of the *ANL-MGR-GS-000003_results.xls* spreadsheet. Appendix B of this document explains how to acquire this spreadsheet from the Technical Data Management System. Figure 6-16 shows a portion of that spreadsheet. Column A of the spreadsheet lists the conduit diameter bins. Column B contains the CDF values, which were calculated in Auxiliary1 and described earlier. Column C contains the calculations of conduit area, given the diameter value from column A. Column D calculates the number of waste packages hit and column E computes the probability distribution factor (PDF) for each bin (not used). The resulting CDF is displayed in the adjoining graph on that worksheet. That graph shows a median percentile value of less than 10 packages. It is important to note that this CDF only considers the effect of one conduit.



Output DTN: SN0402T0503303.004.

Figure 6-16. Excerpt of Preliminary Conduit Worksheet

The analysis considers an integration of the two distributions for conduit diameter and number of conduits. Integration of the two distributions results in a joint probability distribution. The CDF for a joint probability distribution is presented as equation 2.32 (page 29) in Haan (1977 [DIRS 100579]) and reproduced below:

$$F_{X,Y}(x,y) = prob(X \le x \text{ and } Y \le y) = \sum_{x_i \le X} \sum_{y_j \le Y} f_{X,Y}(x_i y_j) \qquad \text{(Eq. 6-1)}$$

where x and y are two independent random variables, i and j are indices for those variables, X and Y are samples from the distributions of those variables, *F()* is the cumulative joint probability function and *f()* is the joint probability.

Because the random variables are independent, Guttman et al. (1982 [DIRS 141885]) shows in equation 6.7.3 (page 90 and paraphrased below to match previous notation) that the joint probability of any combination of the two variables is equal to the product of the independent probabilities of each variable:

$$f(x_i, y_j) = f_x(x_i) f_y(y_j) \qquad \text{(Eq. 6-2)}$$

The combined effects of multiple conduits added to the effects of different conduit diameters are developed according to the above two equations in the ConduitCDF worksheet of the *ANL-MGR-GS-000003_results.xls* spreadsheet. Appendix B of this document explains how to acquire this spreadsheet from the Technical Data Management System. Figure 6-17 provides an excerpt from that spreadsheet. Column A contains the bins for conduit diameter. As before, there are 30 bins, all in constant 5 m increments. Columns B and C contain the CDFs and PDFs respectively for the conduit diameter distribution. This set of conduit diameter bins is repeated 14 times because the distribution is integrated with the distribution for the number of conduits. The sum of probabilities in column C is therefore equal to 14.

Column D contains the elements for the number of conduits. As stated earlier, this distribution consists of 14 members with a constant incremental bin spacing of 1. Column E contains the corresponding PDF values. Because each component is added 30 times through the integration with the conduit diameter distribution, the sum of the probabilities is approximately 30.

Column F contains the bins for the calculated numbers of waste packages damaged. These numbers are calculated by multiplying the corresponding conduit areas by the corresponding number of conduits and by the waste package density factor. Column G contains the associated joint probabilities PDF, calculated by multiplying the values in columns C and E by each other, as defined by Equation 6-2. Columns I through K represent a rank ordering of the previous information so that a composite CDF can be created.

ANL-MGR-GS-000003_results.xls

	A	B	C	D	E	F	G	H	I	J	K
11	Conduit Diameter	CDF for Conduit Diameter	conduit diameter pdf	Number of Conduits	# conduits PDF	# waste packages destroyed	combined probability		# waste packages destroyed (rank ordered)	c c n k	**Composite CDF**
95	120	2.9355	0.0215	2	0.108000	47	0.0023226		5		0.4831232
96	125	2.9539	0.0184	2	0.108000	51	0.0019908		5		0.483891
97	130	2.9693	0.0154	2	0.108000	55	0.001659		5		0.4840714
98	135	2.9816	0.0123	2	0.108000	60	0.0013272		5		0.4840868
99	140	2.9908	0.0092	2	0.108000	64	0.0009954		5		0.4840955
100	145	2.9969	0.0061	2	0.108000	69	0.0006636		5		0.4840965
101	150	3.0000	0.0031	2	0.108000	73	0.0003318		6		0.5171933
102	5	3.0065	0.00645	3	0.043	1	0.0002774		6		0.5227675
103	10	3.0194	0.0129	3	0.043	1	0.0005548		6		0.5247094
104	15	3.0387	0.0194	3	0.043	2	0.0008323		6		0.5256307

DikeSwarmCDF / ConduitPrelimData / **ConduitCDF** / auxiliary

Output DTN : SN0402T0503303.004.

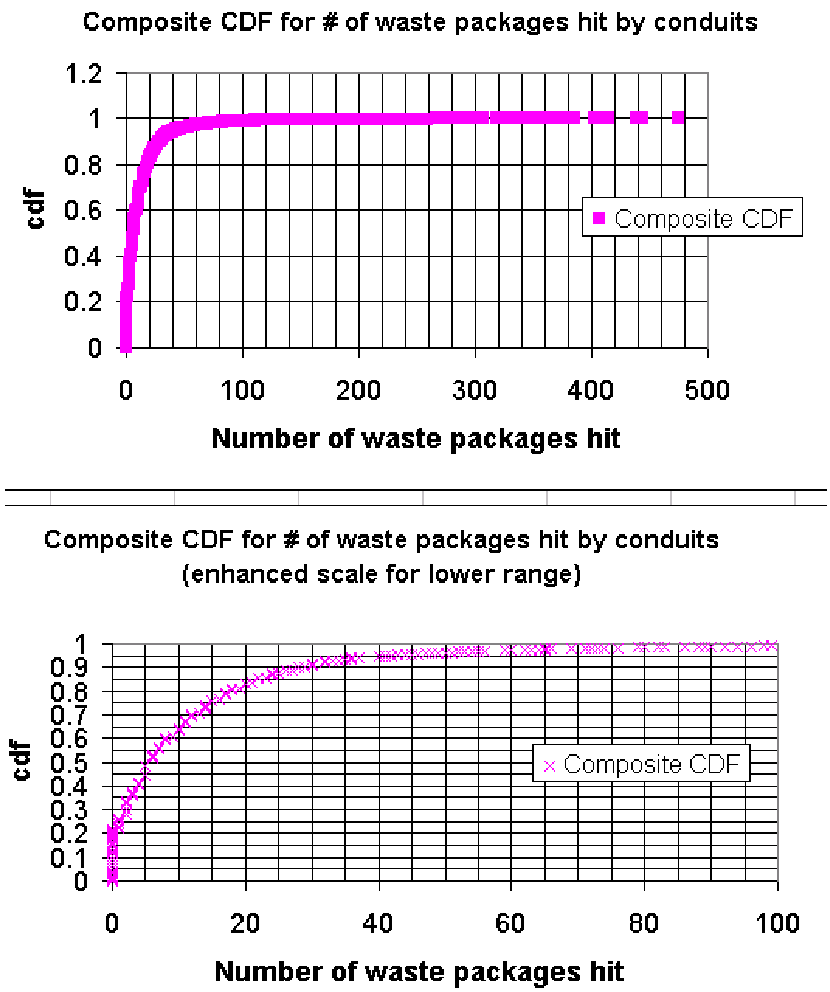
Figure 6-17. Excerpt from the Spreadsheet Development of Conduit CDF

The graph in Figure 6-18 depicts the resulting joint CDF. Less than 10 waste packages are damaged out of the median percentile of this distribution. The median value is approximately 5 waste packages. The median value is also indicated by Figure 6-17 at the confluence of rows 100 and 101 with columns I and K (highlighted). That graph is reproduced in Figure 6-18 with an expanded scale excerpt for the high slope, early portion of the curve.

Not considered in this analysis, is the phenomenon of secondary dike propagation and conduit formation (also known as the dog-leg scenario. In this scenario, as magma from a dike penetrates and pressurizes a drift, another vertical fracture is triggered at some distance down the drift. Magma could intrude along this fracture and an eruptive conduit could develop, carrying waste to the surface. The amount of waste could be considerable because there are generally more than 100 waste packages per drift. The secondary dike scenario is eliminated from consideration in TSPA-LA and in this model report because an extensive analysis (BSC 2004, Dike/Drift Interactions [DIRS 170028], Section 6.5.4) showed that the necessary conditions would be unlikely to develop.

6.5 UNCERTAINTY STUDIES

In the current analyses (Sections 6.3 and 6.4), uncertainties have been intrinsically accounted for by the nature of the Latin Hypercube Sampling approach (in the LHS (SNL 2004 [DIRS 167794]) software step). LHS incorporates the probability distributions for the parameters of concern to generate thousands of realizations. Each realization consists of a different combination of parameter values, all of which honor the defined ranges for each parameter. This approach explores both uncertainty (in outcomes due to variable combinations) and sensitivity (in outcomes due to ranges of parameter values).



Output DTN: SN0402T0503303.004.

Figure 6-18. Composite CDF for Number of Waste Packages Hit by Conduits

In addition, drifts and dikes have both been treated as if they were more than three times wider (16.5 m) than their sampled or assigned values. This treatment generates a conservative bias in which more intersections are tallied than otherwise would be the case. This collar approach addresses potential additional minor uncertainties in dike positions and the extent of drift degradation, and helps enforce the reasonable goal that the study does not rely upon-precise specifications for dike positions relative to each drift.

The collar abstraction is also conservative because the original distribution for dike thickness as developed in DTN: LA0407DK831811.001 [DIRS 170768] provides a range from as low as 0.5 m to 4.5 m. Using the larger values of the collar abstraction provide more potential for dike drift intersections than using the original range. However, the dike spacing parameter (spacing between each dike) has also been abstracted from the original source (DTN: LA0407DK831811.001 [DIRS 170768]) and an additional uncertainty has been implemented to demonstrate that the abstracted approach has a conservative bias (Section 6.5.1).

6.5.1 Dike Spacing Uncertainty and Sensitivity

As discussed in Section 4.1, the dike spacing that was considered in the base analysis was adapted from the wider range of 1 m to 1490 m (DTN: LA0407DK831811.001 [DIRS 170768]) to a range of 100 m to 690 m. For every realization, the spacing between any two dikes can vary within this range with a uniform probability. However, the source of the dike spacing parameter actually specifies a broader range of 1 m to 1500 m. The impact of this broader dike spacing range on predicted numbers of waste packages hit is evaluated in this section.

Dike spacing impacts will be dependent upon relative positions and orientations within the repository footprint. If the dikes are oriented along a generally north to south axis, then dike spacings smaller than 100 m (the base case minimum) may have little impact, given that drifts can be over 600 m long (from east to west). The impact may be small because it only takes one dike intersection to count all waste packages in the drift as ‘hit’. Any additional dikes hitting that drift won’t increase the count. If the orientation is again north to south, but the spacing is pushed beyond 690 m (the base case maximum), then it is conceivable that more drifts could be accessed, but the reverse is also true. Less drifts may be accessed if the spacing is less than 690 m because dikes might ‘leapfrog’ over entire drifts or end up outside of the repository footprint entirely.

Consideration of other dike orientations, such as east to west brings up different complications, because the drifts would be relatively parallel to the dikes. In these cases, the absolute position of each dike is much more important. For all cases, discussion of anticipated results, while helpful, is not sufficient to reach any conclusions with regard to sensitivities or uncertainties.

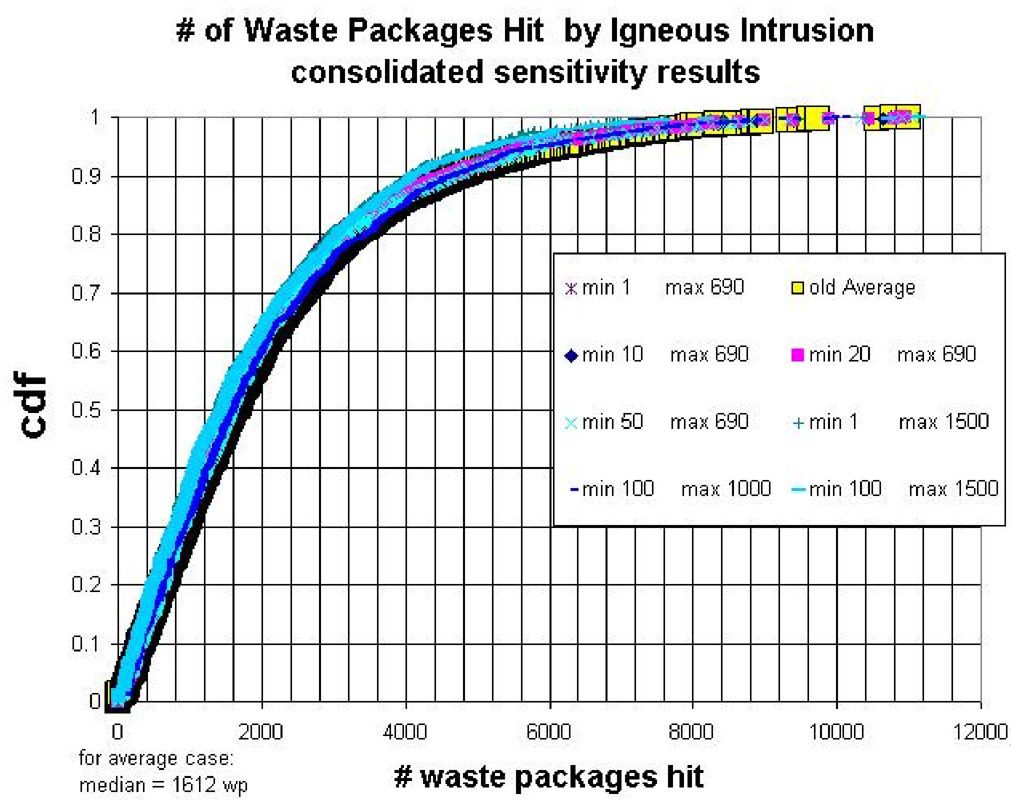
This impact is therefore evaluated by performing additional runs of the LHS (SNL 2004 [DIRS 167794]) and DIRECT (SNL 2004 [DIRS 167795]) codes. The additional runs cover the case of the 0 m to 1500 m range and include intermediate range cases. These runs address the question of whether or not the abstracted range used in the base case was conservative. These runs also help to produce a coarse graphic estimate of sensitivity to dike spacing ranges.

Details of this run set are included in Appendix C. All runs were modified from the first replicate of the base case run set and therefore utilized the same random seed. Using the same random seed ensured that all inputs to DIRECT (SNL 2004 [DIRS 167795]) for each realization, such as dike azimuth angle and number of dikes, were identical to their base case counterparts, with the exception of spacing between each dike.

Table 6-3 summarizes the run cases and the results for the median number of waste packages hit. Figure 6-19 presents the CDFs for each case, along with the base case. Note that all results nearly overlay each other on a coarse level. Figure 6-20 is a bar chart that compares the median number of waste packages hit graphically for each case. As the table and figures show, the base case is more conservative than all other cases considered. Moreover, the results do not appear to be extremely sensitive to the dike spacing parameter.

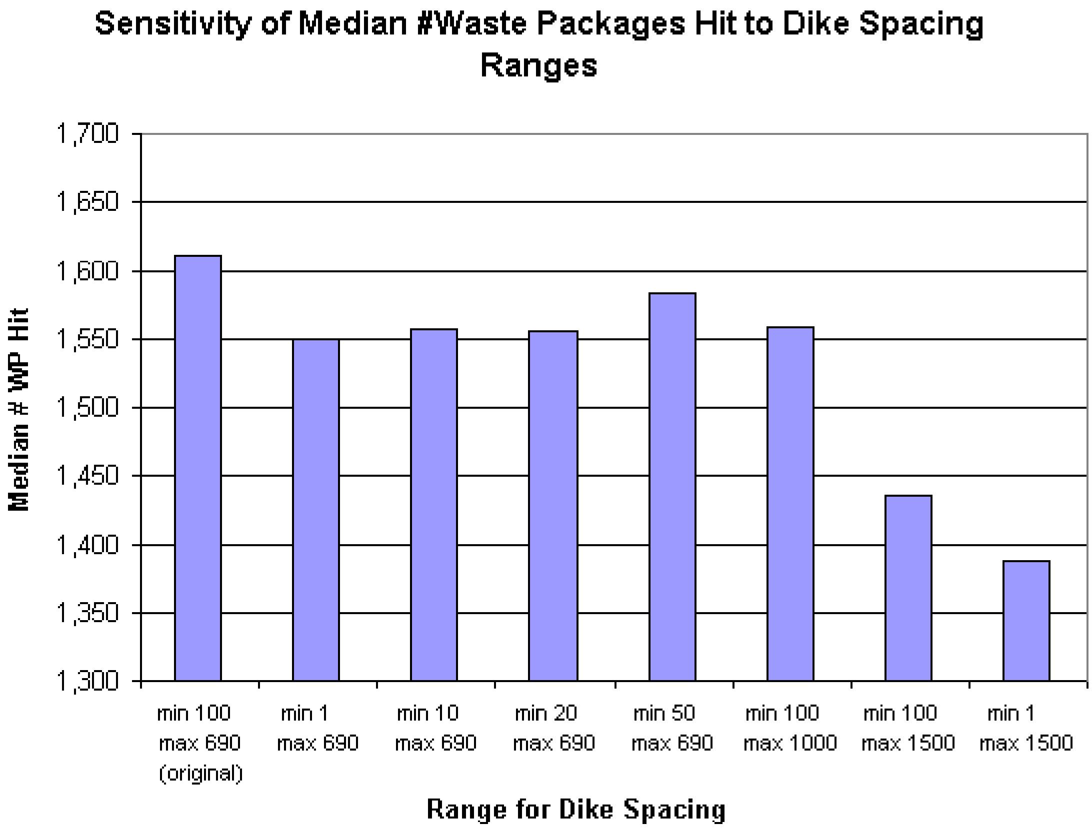
Table 6-3. Results of Uncertainty Study for Dike Spacing Parameter

Case #	Min Spacing (m)	Max Spacing (m)	Median # Waste Packages Hit
1 (Base Case)	100	690	1612
2	1	690	1550
3	10	690	1557
4	20	690	1556
5	50	690	1583
6	100	1000	1559
7	100	1500	1436
8	1	1500	1388



Sensitivity output data. See Appendix C for mapping to data archive.

Figure 6-19. Number of Waste Packages Hit by Igneous Intrusion, Consolidated Sensitivity Results



Sensitivity output data. See Appendix C for mapping to data archive.

Figure 6-20. Sensitivity of Median Number of Waste Packages Hit to Dike Spacing Ranges

6.5.2 Conclusions Regarding Uncertainty and Sensitivity Analyses

None of the results led to median values from CDFs that were more than the base case result of a median of 1612 waste packages hit. Therefore, these alternate studies will not supersede the base analysis (Section 6.3). Rather, they simply clarify the conservative nature of the abstracted range for dike spacing and illustrate the relative sensitivity of the estimates of the number of waste packages damaged to variations in dike spacing inputs.

6.6 COMPARISON WITH SITE RECOMMENDATION RESULTS

In the previous version of this analysis for the site recommendation effort (CRWMS M&O 2000 [DIRS 153097]), two CDFs were developed for the case of swarms of dikes intersecting the repository. Neither is directly comparable to the results in this analysis package because they utilized different assumptions, approaches, repository geometries and abstractions. For the first of those CDF calculations, among other important differences, it was assumed that damage to waste packages was limited to the area of the dike intersections plus a small, adjacent marginal area on both sides of the dike. In that case, the median number of waste packages hit was 200. The second CDF calculation employed a similar assumption as in Section 5.1 of this analysis, which states that all waste packages in a drift that is intersected by a dike will be damaged. In that CDF, the median value of 1,970 is similar in magnitude to the median value of the base result in this analysis (approximately 1,610 packages). Differences can be attributed to different repository designs and to the different approaches used to evaluate the problem.

The site recommendation analysis did not directly calculate number of waste packages hit due to eruptive conduits. Therefore no direct comparison with the current analysis is possible. The previous analysis did develop a CDF for the number of waste packages hit, based solely on a distribution of conduit diameters, but that CDF was integrated into a different approach that is not comparable to the current one.

However the current analysis also developed a preliminary distribution for the number of waste packages hit based solely on a distribution of conduit diameters. That preliminary step is documented in the ConduitPrelimData worksheet of the *ANL-MGR-GS-000003_results.xls* spreadsheet. Appendix B links this document to the appropriate DTN. Figure 6-21 is an excerpt from that spreadsheet, which shows the approximate 50th percentile value (0.53) matched to a value of seven for the median number of waste packages hit for this preliminary step. That value is only slightly lower than the previous version (calculation) median value of 10 waste packages (CRWMS M&O 2000 [DIRS 153097], Table III-2).

	A	B	C	D	E
13	Conduit Diameter	CDF (see auxiliary sheet)	Conduit Area	# Waste Packages Hit	pdf for conduit diameter
14	m		sq. m.		
26	60	0.4747	2,827.43	6.00	0.0584
27	65	0.5300	3,318.31	7.00	0.0553
28	70	0.5822	3,848.45	8.00	0.0522
29	75	0.6313	4,417.86	10.00	0.0492

Output DTN: SN0402T0503303.004 worksheet ConduitPrelimData.

Figure 6-21. Preliminary Median Number of Waste Packages Hit as a Function of Conduit Diameter Only

The earlier calculation also anticipated a different treatment of its output. For the site recommendation, given a no-backfill scenario, it was assumed that only three packages on either side of a dike would be fully damaged and that any remaining packages in the drift would only be slightly damaged (CRWMS M&O 2000, [DIRS 153097]). The resulting source terms for the numbers of damaged waste packages are therefore much less than the estimates that would result if all of the waste packages contacted by magma were considered to provide no further protection for the waste, as in this analysis. However, the current analysis feeds into a treatment in which all waste packages hit are considered to be damaged. The rationale for this consideration is contained in *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 6.4.8). The resulting source terms for the numbers of damaged waste packages are correspondingly greater in this analysis.

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7. CONCLUSIONS

The following sections provide summary details on analysis results and direct mapping to exact locations in output spreadsheets. Conclusions are also described with some comparison to previous results.

7.1 SUMMARY

An analysis was conducted to estimate the number of waste packages that would be damaged by igneous events using two scenarios. The first scenario, igneous intrusion, investigated the case where one or more igneous dikes intersect the repository. A swarm of dikes was characterized by distributions of length, spacing, and azimuths from which mathematical relationships were built between those parameters and the number of waste packages hit. Corresponding CDFs for the number of waste packages hit were calculated. The igneous intrusion analysis involved an explicit characterization of dike—drift intersections, built upon various distributions that reflect the uncertainties associated with the inputs. The second igneous scenario, volcanic eruption (eruptive conduits), considered the case where conduits formed in association with a volcanic eruption through the repository. Mathematical relationships were built between the resulting conduit areas and the fraction of the repository area occupied by waste packages. This relation was used in conjunction with a joint distribution incorporating variability in eruptive conduit diameters and in the number of eruptive conduits that could intersect the repository. The eruptive conduit approach involved a simplified abstraction. Additional alternate calculations and uncertainties associated with this approach were addressed in Section 6.5.

Primary outputs from this analysis report are a CDF for the number of waste packages hit by an igneous intrusion for use in TSPA-LA analyses of the igneous intrusion scenario and a CDF for the number of waste packages hit by an eruptive conduit for use in the volcanic eruption scenario. Mapping to these CDFs is provided in the previous section. The primary technical product output listed in Table 7-1 is also documented in Output DTN: SN0402T0503303.004 (see Appendix B).

The secondary technical product output of this analysis activity consists of the subsequent sensitivity analyses. The spreadsheet covering these results is labeled: *SensCDFs.xls*. All related files from these runs are described and mapped in Appendix C of this report. The actual CDF outputs of concern are mapped in Figure 6-19 in Section 6.5.

7.2 CONCLUSIONS

The igneous intrusion scenario shows a range of consequences extending from virtually no waste packages damaged to nearly all waste packages damaged in the repository. The 50th percentile value indicates approximately 1610 waste packages impacted out of over 11,000 waste packages in the repository. This number of impacted waste packages is less than the equivalent value from the previous version of this analysis (CRWMS M&O 2000 [DIRS 153097], Section 6.2) by approximately 360 waste packages. Differences can be attributed to a new repository design and to the new approaches used to evaluate the problem.

Table 7-1. Mapping of CDF Technical Product Outputs from ANL-MGR-GS-000003 to the *ANL-MGR-GS-000003_results.xls* Spreadsheet

CDF Description	Worksheet Subsection	Row and Column Mapping
Number of Waste Packages Hit: Igneous Intrusion Scenario (Section 6.3)	DikeSwarmCDF	start at row 6, column R finish at row 38, column S
Number of Waste Packages Hit: Volcanic Eruption (eruptive conduit) Scenario (Section 6.4)	ConduitCDF	start at row 11, column T finish at row 31, column U
Number of Waste Packages Hit: Preliminary CDF Based on Distribution of Eruptive Conduit Diameters, but not Integrated with Distribution for Number of Eruptive Conduits (Section 6.4) This CDF is similar to the primary output eruptive conduit CDF that was provided to TSPA-LA for the site recommendation	ConduitPrelimData	see columns B and D

Output DTN: SN0402T0503303.004.

The prior report did not develop a CDF for number of waste packages impacted by eruptive conduits; therefore, no exhaustive comparisons can be made for that scenario. For this analysis, the median number of waste packages hit for the volcanic eruption scenario is five.

8. INPUTS AND REFERENCES

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AP-SIII.9Q, Rev. 1 ICN 7. *Scientific Analyses*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040920.0001.

LP-SI.11Q-BSC, Rev. 0 ICN 1. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20041005.0008.

8.3 SOFTWARE

SNL (Sandia National Laboratories) 2004. *Software Code: LHS.* V2.51. DEC ALPHA OPEN VMS AXP 7.3-1. 10205-2.51-00. 167794

SNL 2004. *Software Code: DIRECT.* V 1.0. PC, Windows 2000. 11121-1.0-00. 167795

8.4 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

LA0302BY831811.001. Characterize Igneous Framework and Probability. Submittal date: 02/05/2003. 162670

LA0303BY831811.001. Characterize Igneous Framework Figures and Tables. Submittal date: 04/07/2003. 163985

LA0307BY831811.001. Characterize Igneous Framework Additional Output. Submittal date: 07/29/2003. 164713

LA0407DK831811.001. Physical Parameters of Basaltic Magma and Eruption Phenomena. Submittal date: 07/15/2004. 170768

MO0407SEPFEPLA.000. LA FEP List. Submittal date: 07/20/2004. 170760

8.5 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

SN0402T0503303.004. Number of Waste Packages Hit by Igneous Intrusion. Submittal date: 02/13/2004.

SN0410T0503303.009. Intermediate and Sensitivity Files Associated with Number of Waste Packages Hit by Igneous Intrusion. Submittal date: 10/12/04.

APPENDIX A
INTERMEDIATE FILES

This Appendix describes supporting files used in the development of inputs to the DIRECT code (SNL 2004 [DIRS 167795]), as well as DIRECT output, which feeds into a spreadsheet. These data are archived in Output DTN: SN0410T0503303.009.

Table A-1. Intermediate Files

File Names	Description
RepGeometry.xls	Microsoft Excel spreadsheet. Defines geometry of drifts for eventual inclusion into DIRECT. Extensive annotation within document. Includes a waste package density calculation.
driftData.txt	Input file for DIRECT containing geometric transformation information for each repository emplacement drift.
repositorydata.txt	Input file for DIRECT containing geometric information on the perimeter of the repository in the DIRECT coordinate system.
boundingtest1.dts *diketest1.dts*	Shape files that are read by DIRECT. They are the base shapes that are then extruded and reoriented to represent objects in the scene.
lnnormal03a.xls	Microsoft Excel spreadsheet. Defines the discrete, truncated, lognormal dike count probability distribution. The values are then cut and pasted into the input files to LHS (see next row of this table).
lhs_input1.dat, *lhs_input2.dat*, *lhs_input3.dat*	Input file to LHS. Rename to lhs2_uif$input.dat prior to running on each case.
lhs_1.dat, lhs_2.dat, *lhs_3.dat*	Renamed output from LHS, provides only the numeric data without any text headings or descriptions. Used by DIRECT.
results_1.txt, *results_2.txt*, *results_3.txt*	Renamed output from DIRECT, provides only the numeric data without any text headings or descriptions.

DIRECT FILES

Note that for each run of DIRECT, a copy of the corresponding *lhs_1.dat*, *lhs_2.dat*, and *lhs_3.dat* must be first renamed to *lhs.dat*.

In the renamed DIRECT output files, each row stands for a separate realization. The number represents the number of waste packages hit for that case. Note that DIRECT only produces an output file called *results.txt*. The user must rename the file so the file does not get inadvertently overwritten.

Descriptions for *RepGeometry.xls*

The original worksheet contains a tabulation of the bounding endpoint, Nevada State Plane coordinates for each repository drift, as well as calculations of drift length (m). This worksheet contains a reference to the sources, IED: 800-IED-WIS0-00101-000-00A (BSC 2004 [DIRS 164519]) and IED: 800-IED-WIS0-00202-000-00C (BSC 2004 [DIRS 169472]).

The scaled down worksheet contains tabulations of the previous worksheet values scaled down by 100 and translated 1,710 m west and 2,310 m south. Also, the midpoint of each drift in these transformed coordinates is tabulated.

The drift export worksheet contains geometric descriptions suitable (if directions are followed) for input to the DIRECT code.

The perimeter worksheet contains coordinates in transformed DIRECT space that define a perimeter around the collection of drifts.

The auxiliary worksheet contains a separate set of calculations to determine the mass density of the different types of waste packaging. This set was developed in support of Assumption 5.3.

Descriptions for *lhs_#.dat*

line 1, entry 1	realization number, not used
line 1, entry 2	number of sampled variables
line 1, entry 3	concatenation of dike length interval with azimuth angle after decimal point
line 1, entry 4	number of dikes in the swarm
line 1, entry 5	fraction of the perimeter length at which anchor point is set

The remaining lines (three) in the set are dike spacings, even though all entries may not be used. This set of 4 lines is repeated (although values change) for each realization.

Description for *driftData.txt*

Each row defines a single dike or drift

The first three numbers in a row represent the x, y, and z coordinates, respectively, of the center of the drift.

The next three numbers in the row represent the scaling to be applied in the x, y, and z directions, respectively, for the drift.

The final four numbers define rotations. The first three numbers are logical flags for the x, y, or z axes, respectively. The fourth number is rotation in degrees. If any flag is labeled 1 instead of zero, then the drift is rotated clockwise about that axis by the stated number of degrees.

The entire sequence is repeated until all drifts are addressed

Description for *dikeData.txt*

The first row has a single entry, N, defining the number of dikes for the first realization.

The second row has two sets of x, y, and z coordinates (in game engine space) that define the two endpoints of the anchor extension line.

The next N lines each contain the standard game engine format of data to define each dike.

> The first three numbers represent the x, y, and z coordinates, respectively, of the center of the dike.
>
> The next three numbers represent the scaling to be applied in the x, y, and z directions, respectively, for the dike.

The final four numbers define rotations. The first three numbers are logical flags for the x, y, or z axes, respectively. The fourth number is rotation in degrees. If any flag is labeled 1 instead of zero, then the dike is rotated clockwise about that axis by the stated number of degrees.

The entire sequence is repeated until all realizations are addressed.

Description for *repositorydata.txt*

The first row has a single entry, listing the number of rows that follow.

The remaining rows contain the x and y coordinate of a vertex in the repository outline perimeter polygon. The last row repeats the first x-y coordinate row, to define a closed polygon.

LHS FILES

INPUT FILE:
The input data file uses keywords starting in the first column of a line to identify the line or lines of data for each block of input data. The input file starts with two lines of title information with the keyword TITLE at the start of each line. The title information is followed by the number of samples or observations following the keyword NOBS. The fourth line of input is a seed for the random number generator following the keywords RANDOM SEED.

The probability distributions follow the first four lines of input. Each distribution type is identified by one of the following keywords:

BETA, EXPONENTIAL, LOGNORMAL, LOGSTUDENT, LOGUNIFORM, NORMAL, RAYLEIGH, RAYLEXP, STUDENT, TRIANGULAR, UNIFORM, or USER DISTRIBUTION.

The distribution type is followed by two words that uniquely identify the variable. A distribution is sampled by choosing NOBS values from NOBS equally sized intervals for the cumulative probability distribution. Each sampled value is chosen randomly from within each interval.

The first distribution used for DIRECT is the joint probability distribution of the dike lengths and azimuths. The distribution is a USER DISTRIBUTION and the variable name is DIKE LENAZIM. The second line of the USER DISTRIBUTION gives the number of data points (2218), specifies whether the probability data is equally spaced (EQUAL and therefore not listed or specified individually for each line of data (SPECIFIED), and specifies whether the distribution is discrete (DISCRETE) or continuous (CONTINUOUS).

For a discrete distribution, only the specified values are possible sampled values. For a continuous distribution all values between the starting and ending values are possible sampled values. For the DIKE LENAZIM distribution, each length, azimuth pair has its own specified probability (SPECIFIED) and there is no interpolation allowed between these values (DISCRETE). Because LHS allows only one value followed by its probability, the dike length and azimuth are combined into one value using the length as the whole number part of the value and the angle in degrees divided by 1000 as the fraction part of the value. Because DISCRETE is specified, no interpolation is allowed and the length and azimuth can be recovered without change from the sampled value. For example, if the value chosen in one of the NOBS intervals is 500.160, the dike length is 500 m and the dike angle is 160 degrees. Because the length value is actually the start of a 50-m interval, 25 meters is added to the length in DIRECT to give the center of the 50-m interval. The azimuth angle is the start of a 5-degree interval, so 2.5 degrees is added to the azimuth in DIRECT. The values entered for this stage come from the DTN: LA0302BY831811.001 [DIRS 162670] file: *CCSM-LA.CMP*.

The second sampled variable is the number of dikes. The distribution is identified by the line, USER DISTRIBUTION DIKE COUNT. The dike count distribution consists of 18 specified discrete values of dike count and probability. The distribution is a lognormal distribution with a mean of 3 that has been truncated to integer values between 1 and 18 and renormalized. The standard deviation of the distribution is chosen so that the 95th percentile point falls at 6 dikes. The median dike count remains 3 after the renormalization. The sampling usually produces one maximum dike count of 13 or 14 in 1000 sample values. The development of this tabular information was fairly extensive, so it is described in detail as the last item of this Appendix under the heading, "Procedure for generating the discrete, truncated, lognormal dike count probability distribution."

The third distribution is a uniform distribution for the anchor point position. The distribution is identified by the line UNIFORM ANCHOR POINT. The following line indicates that the uniform distribution is between 0 and 1. The sampled value represents the fraction of the 11302-meter repository perimeter at which the anchor point falls.

The next 13 distributions give the spacings of the dikes. Since the three samplings used for DIRECT have at most 14 dikes, 13 spacings are needed. The first spacing distribution is identified by the line UNIFORM DIKE SPACING1. The final spacing distribution is identified by the line UNIFORM DIKE SPACING13. The second line of each distribution indicates that the spacing is sampled uniformly on the interval from 100 to 690 meters.

The distributions are followed by a line of output options started by the keyword OUTPUT. The three output options specified are CORR (correlations), HIST (histograms), and DATA (sampled data listings). The correlation output gives rank correlations of the sampled variables. The rank correlations range from –1 to 1, and values near zero (typically between –0.2 and 0.2) indicate that the grouping of sampled variables show no strong rank correlations. Strong rank correlations would indicate that the sampled variables are not really independent and at least one of them should not be used.

The LHS input data ends with a repetition of the two title lines.

OUTPUT DATA

The DBG output file (renamed in this appendix to *lhs_#.dat*) contains the following data for each of the NOBS sampled sets: a sequence number (1 to 1000 for the DIRECT data), the number of sampled variables (16), the LENAZIM value, the dike count, the anchor point perimeter fraction, and 13 dike spacings. These values are read by DIRECT to generate the dike configurations for the igneous intrusions.

Procedure for generating the discrete, truncated, lognormal dike count probability distribution

This procedure is mapped to the *lnnormal03a.xls* spreadsheet. That spreadsheet is included as part of the electronic media associated with the records package for this Analysis Report revision.

1. It was intended that the dike count distribution have a median of 3 (cells G3, J3) and its 95-percentile point at a count of 6 dikes (cells G7, J7). The mean (cell A2) and standard deviation (cell B2) of the lognormal distribution (column D) are the only adjustable parameters available that allow the distribution to meet these requirements. Values of mean = 1.0986 (cell A2) and standard deviation = 0.47 (cell B2) were found by trial and error.

2. Column C contains values of ln(x). The range of -1.9 through 2.99 is adequate to cover the desired range of x = 1 through x = 18.

3. Column D contains probabilities for the normal distribution of the values in column C, i.e., the lognormal distribution of x, for the mean in cell A2 and the standard deviation in cell B2.

4. Column E contains the cumulative probabilities for column D, calculated by a trapezoidal integration over two values in column C. The area of the trapezoid (the increment in cumulative probability) is the difference in ln(x) times the average of the previous and current probability value. The cumulative probability for the first point (ln(x) = -1.9) is set to zero. Since the cumulative probability is actually of order 1e11 (it would be roughly of the order of the next increment (cell E3), this approximation will not adversely affect the results.

5. Column F contains values of x (which will eventually be the dike count). Column F = exponent (column E).

6. Column G contains the dike counts. It was found that a range of 1 through 18 dikes was adequate for the DIRECT simulations.

7. Column H contains the cumulative probability from x (dike count in column G) – 0.5 to x + 0.5 for values of x between 1 and 18. This calculation assigns a discrete cumulative probability to dike count x based on an interval of width 1 surrounding the dike count x. The cumulative probability of 0 dikes is about 7×10^{-5}, but because distribution will be truncated to exclude dike counts below 1 and above 18, the cumulative probability of 0 dikes is omitted. The cumulative probabilities of x-.5 and x+.5 are found by linear interpolation. This requires visual inspection of column F (values of x) to find the intervals surrounding x-.5 and x+.5. For example, x = 0.5 occurs between lines 42 and 43 of column F and x = 1.5 occurs between lines 78 and 79 of column F, so these values are entered in the formula in column H cell 2. Note that these discrete probabilities are not normalized yet.

8. The normalized cumulative probabilities of discrete dike counts are computed by dividing the discrete probability in column H by the sum of all probabilities in column H. The result is placed in column I. These are the discrete, truncated, normalized probabilities used in LHS for the dike count distribution. The mode of the distribution is 3, satisfying one of the initial goals.

9. Column J is the cumulative probability for column I. The choice of mean (cell A2) and standard deviation (cell B2) have made the 95 percentile point fall at a dike count of 6, satisfying the other initial goal.

10. Column L shows the values actually used in LHS. These values were calculated on a DEC Alpha computer and differ from the values in column I in the third or later significant digit. The differences are due to hardware and software differences between the DEC Alpha and the PC on which the Excel spreadsheet was evaluated. There is no difference in the output from LHS, whether the DEC values are used or the PC values are used.

lnnormal03a.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	mean	stddev	ln(x)	normal(ln(x))	cumulative	x	#dikes	cum(#dikes+.5)-cum(#dikes-.5)	prob(#dikes)	cum prob # dikes		used in LHS	cum prob	difference in cum
2	1.09851	0.46986	-1.9	1.21667E-09	0.000E+00	1.496E-01	1	7.0137E-02	0.070146	0.070146		0.070146	0.070146	0.000000
3			-1.87	1.82495E-09	4.562E-11	1.541E-01	2	2.7891E-01	0.278946	0.349092		0.278924	0.34907	0.000022
4			-1.84	2.7262E-09	1.139E-10	1.588E-01	3	2.7945E-01	0.279480	0.628572		0.279443	0.628513	0.000059
5			-1.81	4.05598E-09	2.156E-10	1.637E-01	4	1.7715E-01	0.177172	0.805744		0.17729	0.805803	-0.000059
6			-1.78	6.00983E-09	3.666E-10	1.686E-01	5	9.5650E-02	0.095662	0.901406		0.095581	0.901384	0.000022
7			-1.75	8.86866E-09	5.898E-10	1.738E-01	6	4.8589E-02	0.048595	0.950000		0.048633	0.950017	-0.000017
8			-1.72	1.30342E-08	9.183E-10	1.791E-01	7	2.4370E-02	0.024373	0.974373		0.024381	0.974398	-0.000025
9			-1.69	1.90783E-08	1.400E-09	1.845E-01	8	1.2291E-02	0.012293	0.986666		0.012279	0.986677	-0.000011
10			-1.66	2.78114E-08	2.103E-09	1.901E-01	9	6.2700E-03	0.006271	0.992936		0.006267	0.992944	-0.000008
11			-1.63	4.03773E-08	3.126E-09	1.959E-01	10	3.2596E-03	0.003260	0.996196		0.003255	0.996199	-0.000003
12			-1.6	5.83822E-08	4.608E-09	2.019E-01	11	1.7252E-03	0.001725	0.997922		0.001723	0.997922	0.000000
13			-1.57	8.40724E-08	6.744E-09	2.080E-01	12	9.2920E-04	0.000929	0.998851		0.00093	0.998852	-0.000001
14			-1.54	1.20575E-07	9.814E-09	2.144E-01	13	5.1580E-04	0.000516	0.999367		0.000512	0.999364	0.000003
15			-1.51	1.72222E-07	1.421E-08	2.209E-01	14	2.8435E-04	0.000284	0.999651		0.000287	0.999651	0.000000
16			-1.48	2.44991E-07	2.046E-08	2.276E-01	15	1.6418E-04	0.000164	0.999815		0.000164	0.999815	0.000000
17			-1.45	3.47089E-07	2.935E-08	2.346E-01	16	9.5230E-05	0.000095	0.999911		0.000095	0.99991	0.000001
18			-1.42	4.89735E-07	4.190E-08	2.417E-01	17	5.5903E-05	0.000056	0.999967		0.000056	0.999966	0.000001
19			-1.39	6.88194E-07	5.957E-08	2.491E-01	18	3.3413E-05	0.000033	1.000000		0.000034	1	0.000000
20			-1.36	9.63142E-07	8.434E-08	2.567E-01								

Output DTN: SN0410T0503303.009.

Figure A-1. Excerpt from *lnnormal03a.xls* Spreadsheet

APPENDIX B
OUTPUT FILES

This Appendix lists files associated with outputs from the DIRECT code (SNL 2004 [DIRS 167795]) and some supporting work in the included spreadsheet.

The following files are archived in Output DTN: SN0402T0503303.004:

- Microsoft Excel spreadsheet: *ANL-MGR-GS-000003_results.xls*.

- Three folders, graphs_set1, graphs_set2, and graphs_set3, each containing a set of 1,000 png graphics files corresponding to each replicate case. The folders are compressed as *graphs_set1.zip*, *graphs_set2.zip*, *graphs_set3.zip*, respectively. Note that Figures 6-7 through 6-13 are excerpts from files in *graphs_set3.zip*. The headers of these files also refer to 'sets.' However, those sets are internal to the replicate.

The Excel spreadsheet references the following sources:

- DTN: LA0407DK831811.001 [DIRS 170768]
- DTN: LA0307BY831811.001 [DIRS 164713]

Tables 1 and 11 of 800-IED-WIS0-00202-000-00C (BSC 2004 [DIRS 169472]).

Mishra, S. 2002. *Assigning Probability Distributions to Input Parameters of Performance Assessment Models.* SKB TR-02-11. Stockholm, Sweden: Svensk Kärnbränsleförsörjning A.B. TIC: 252794. [DIRS 163603]

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APPENDIX C
SENSITIVITY FILES

This appendix lists only files associated with Section 6.5 of this report. The archive is compressed into a single file named *WPHRev01Sensitivity.zip*. This file is also archived in the same DTN described in Appendix A, DTN: SN0410T0503303.009.

The following files discussed in Section 6.5 are included in this archive:

- Microsoft Excel spreadsheet: SensCDFs.xls
- Files associated with LHS (SNL 2004 [DIRS 167794]) and DIRECT (SNL 2004 [DIRS 167795]) runs:

Case	Input File to LHS	Input File to DIRECT	Output File from DIRECT
1	*Lhs_input_ds_1_690m.dat*	*lhs_1mds.dat*	*ResultsDSMin1Max690.txt*
2	*Lhs_input_ds_10_690m.dat*	*lhs_10mds.dat*	*ResultsDSMin10Max690.txt*
3	*Lhs_input_ds_20_690m.dat*	*lhs_20mds.dat*	*ResultsDSMin20Max690.txt*
4	*Lhs_input_ds_50_690m.dat*	*lhs_50mds.dat*	*ResultsDSMin50Max690.txt*
5	*Lhs_input_ds_100_1000m.dat*	*lhs_ds_100_1000m.dat*	*ResultsDSMin100Max1000.txt*
6	*Lhs_input_ds_100_1500m.dat*	*lhs_ds_100_1500m.dat*	*ResultsDSMin100Max1500.txt*
7	*Lhs_input_ds_1_1500m.dat*	*lhs_ds_1_1500m.dat*	*ResultsDSMin1Max1500.txt*

- Seven folders, each containing a set of 1,000 .png graphics files corresponding to each case. The folders are compressed into one file: *SensGraphs.zip*.

  DS_1to690
  DS_10to690
  DS_20to690
  DS_50to690
  DS_100to1000
  DS_100to1500
  DS_1to1500

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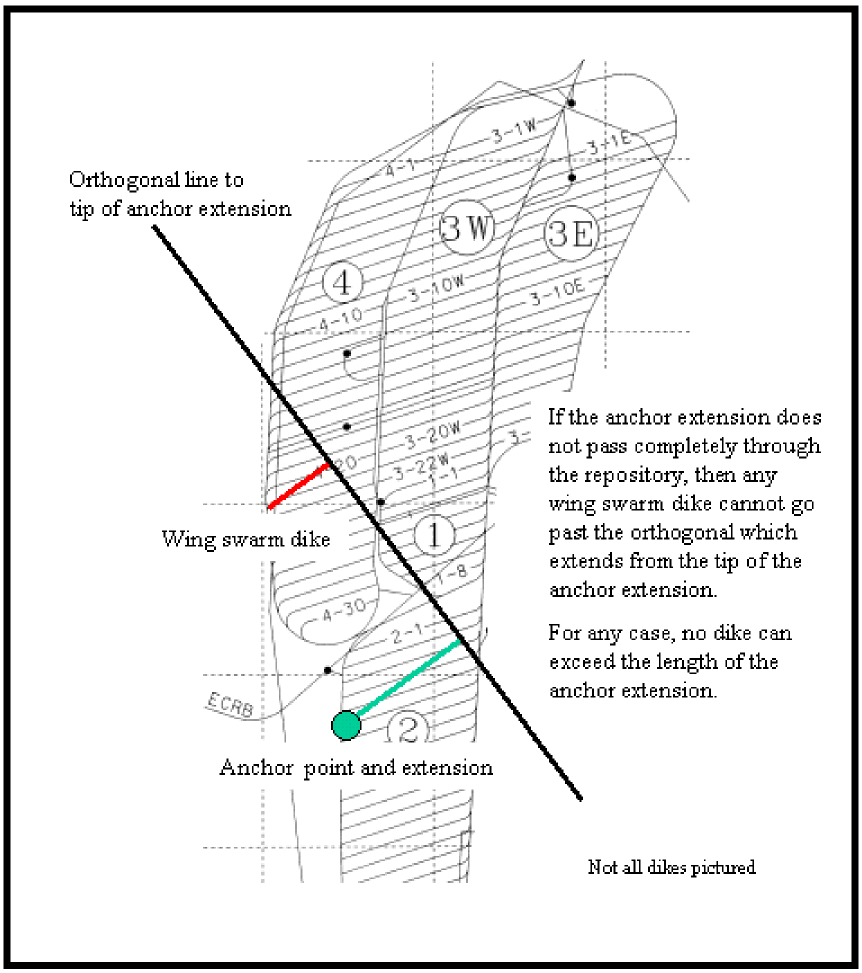
APPENDIX D
INTERMEDIATE STEPS IN THE DEVELOPMENT OF DIRECT SIMULATIONS

PART A. SUPPLEMENTAL DETAILS ON GEOMETRY RULES AND CONSTRAINTS

The rules primarily involve the lengths and spacings of dikes, as determined by their geometric relationships to the anchor extension. Figures D-1 and D-2 illustrate the most important of these length rules. Note that nonpertinent features, such as the portions of dikes outside the repository, are left out in these figures. In the figures, the anchor point extension identifies the starting position for the midpoint of the dike swarm. The wing swarm dike graphically represents any dike position in the dike swarm. The anchor extension line helps define the additional parameters, such as azimuth and dike length, according to the rules.

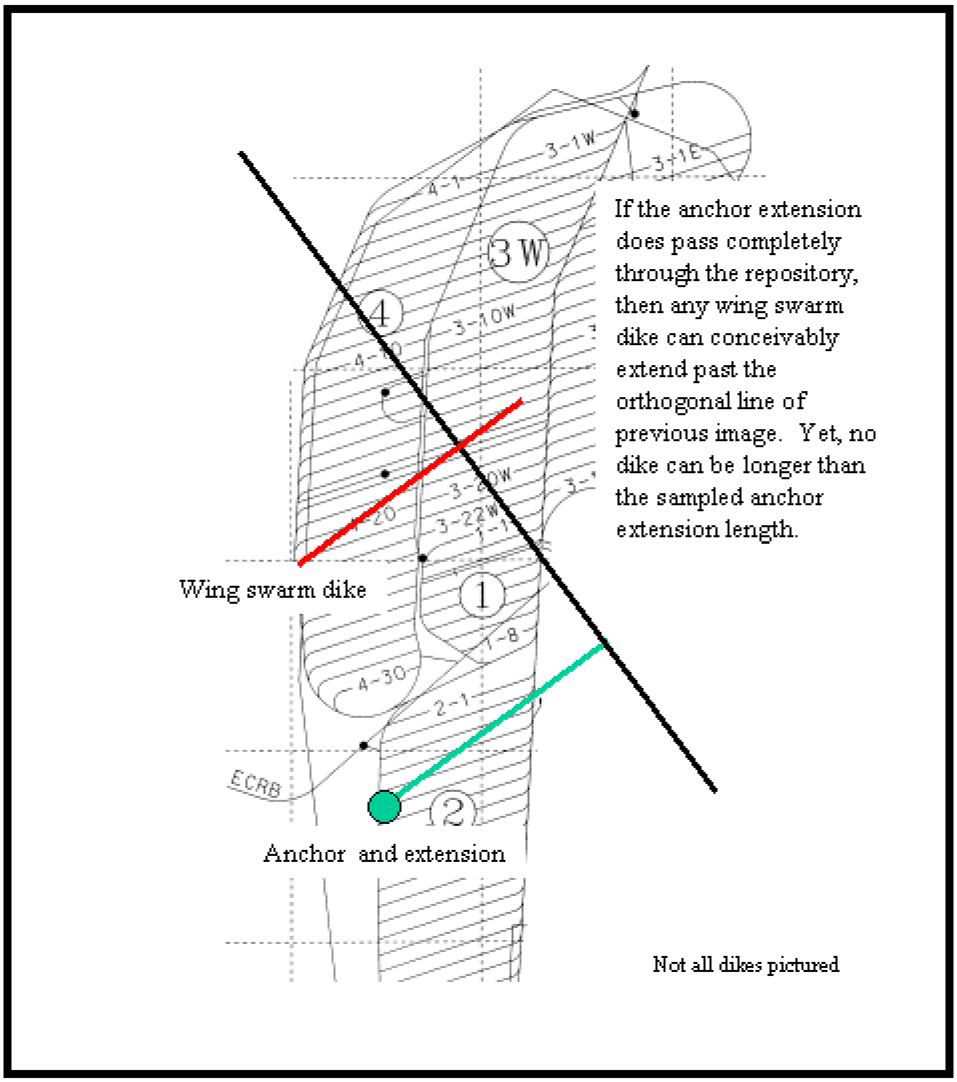
Rule 1. For cases in which the anchor extension does not project all the way through the repository, no dike can extend beyond a line that is adjacent and orthogonal to the tip of the extension line–This rule generally complies with the constraints that the sampled dike length represents the intended maximum repository intersection length of dikes for that realization. In Figure D-1, a dike (thick red line) is shown to the northwest of the anchor extension. That dike is shorter than the anchor extension because of this rule.



NOTE: For illustration purposes only. Not to scale. North is top of diagram.

Figure D-1. Illustration of Dike Configuration Rule 1

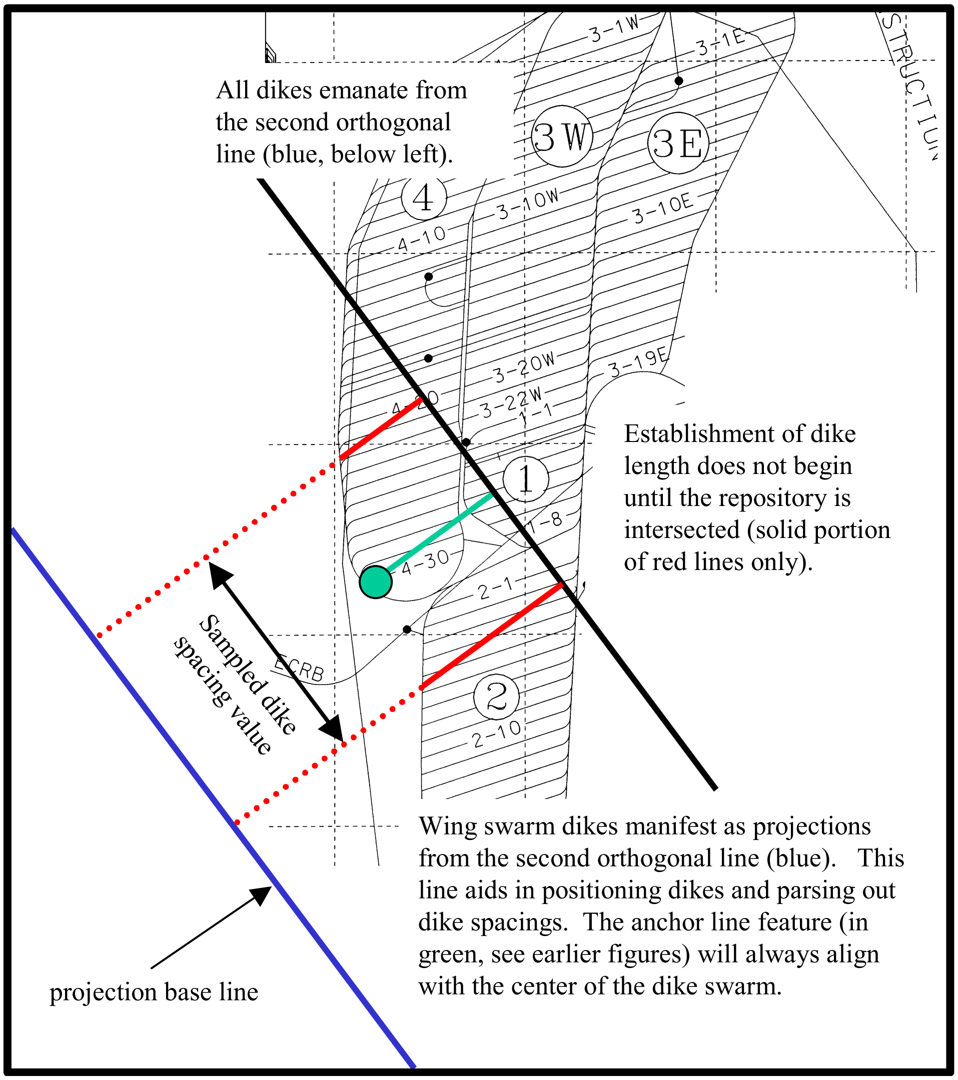
Rule 2. All dikes that penetrate the repository will be no longer than the length of the sampled anchor extension–This rule complies with the fact that the sampled dike length (represented by the dike extension line) represents the intended maximum repository intersection length of dikes for that realization. This rule covers dike configurations for cases in which the anchor extension does project all of the way through the repository. An illustration of this rule is shown in Figure D-2. The figure indicates that for this case, all dikes that penetrate the repository will be no longer than the length of the sampled anchor extension. Such dikes can be shorter in length due to possible cut-offs, depending upon their origination point. For both rules 1 and 2 an added requirement is that no dike exceeds the length of the anchor extension.



NOTE: For illustration purposes only. North is top of diagram.

Figure D-2. Illustration of Dike Configuration Rule 2

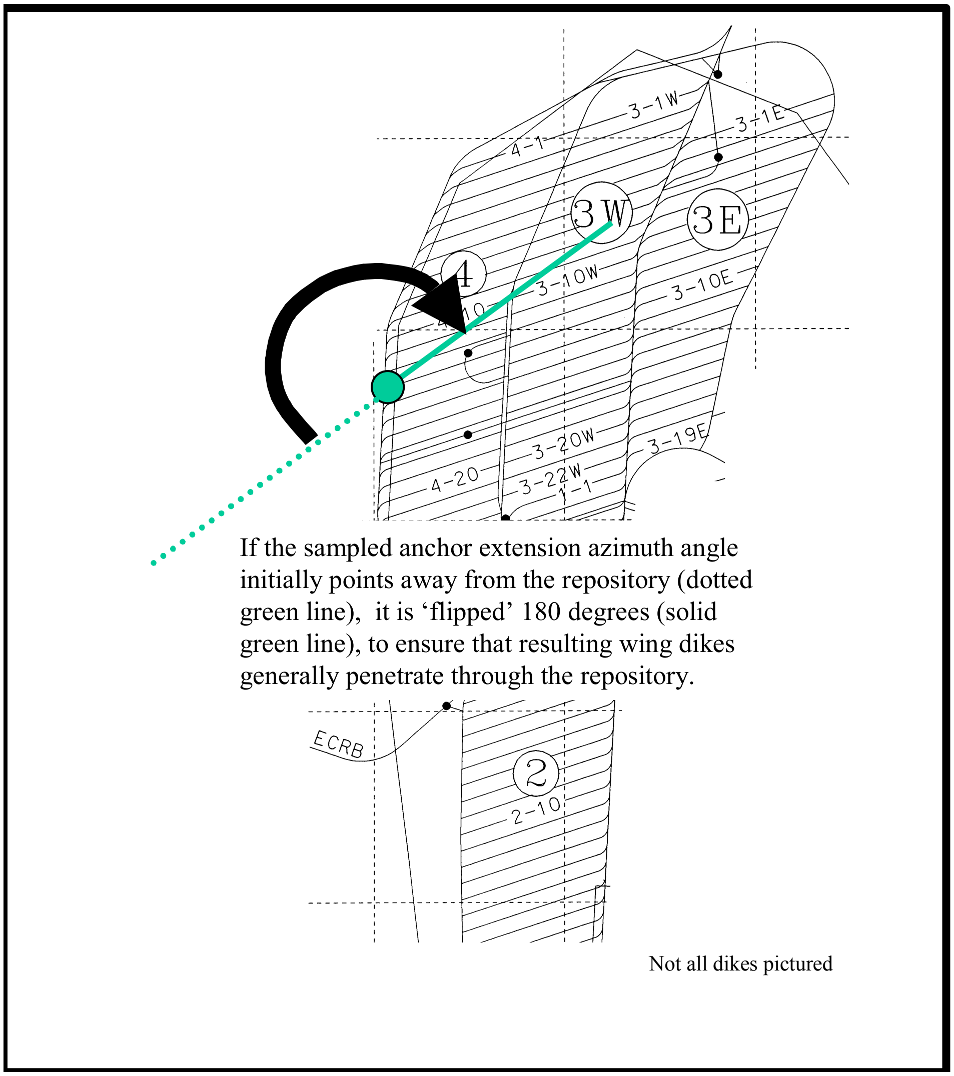
Rule 3. A second orthogonal line serves as the launching border for all of the dikes–The third rule, shown in Figure D-3, concerns the entry point, or lack thereof, for all dikes. The code has to account for proper alignment and overlay of all dikes, based upon the initial anchor feature setting and the other constraints already described. Proper overlay includes the specification that all dikes that intersect the repository must have a starting point along the repository border. To help meet these criteria, a projection base line is constructed. From a sufficient distance set back from the anchor point, a projection base line (blue), parallel to the orthogonal line just described extends in both directions (a T intersection). The sampled dike spacings are initially registered to this line. For each dike spacing, a dike extension line is then projected (dotted red lines) in the same direction as the anchor point extension line. If the dike extension line intersects the repository perimeter, then the dike is drawn into the repository according to the previous rules. If the dike extension line does not penetrate the repository perimeter, then, although the dike is registered, no further attempt is made to constrain the dike to penetrate the repository.



NOTE: For illustration purposes only. North is top of diagram.

Figure D-3. Illustration of Dike Configuration Rule 3

Rule 4. Any sampled azimuth angle has to intersect the repository–The fourth rule ensures that any selected azimuth angle will be transformed into an angle that allows intersection of the dike into the repository (Figure D-4). For example, in the case where a sampled anchor point position places the dike at the west end of the repository and the sampled anchor extension azimuth angle points to the southwest, the dike would not intersect the repository. To ensure all dikes intersect the repository, the rule reverses (or rotates) the azimuth angle into the repository.



NOTE: For illustration purposes only. North is top of diagram.

Figure D-4. Illustration of Dike Configuration Rule 4

PART B. SUPPLEMENTAL DETAILS ON DIRECT INPUT FILES AND RUNTIME PARAMETERS

Input Files

DIRECT (SNL 2004 [DIRS 167795]) expects every object to be defined by its initial shape file definition, the midpoint coordinates of the shapefile object, the scaling in the x, y, and/or z axis of the shapefile object, and the rotations of the shapefile object around the x, y, and/or z axes, centered at its midpoint. For drifts, the shape definitions are set up in the *RepGeometry.xls* worksheet (Appendix A) and realized in the DIRECT input file, *driftData.txt* (Appendix A). For dikes, the shape definitions are set up in the output file from the LHS run, which is input into DIRECT to produce a separate input file, *dikeData.txt* (Appendix A).

Production of shapefiles is a multistep process:

1. In the 3-D computer-aided design program, Rhinoceros, or an alternate computer-aided design program, construct a unit prism for initial drift geometry.

2. Export the unit prism as an Alias|Wavefront .obj file (this is simply a format that Rhinoceros can write and MilkShape can read).

3. Import the .obj file into MilkShape. (MilkShape has its own drawing capability, but does not offer the degree of precision control that Rhinoceros does.).

4. Export the file from MilkShape into the dts format (*boundingtest1.dts*), also known as a shapefile. The object's initial orientation and dimensions are such that it has a unit length in the y axis direction.

5. Place the shapefile object into the appropriate directory (example\data\shapes\organic).

6. Repeat the process to produce a unit prism for all sampled dikes. (*boundingtest1.dts*, into same directory as above)

The development of the transformation parameters that are applied to the drift shapefile is another multistep process:

1. Start with original IED-supplied drift coordinates (original worksheet of the *RepGeometry.xls* spreadsheet, Appendix A).

2. Transform scale and position (by first dividing both coordinates by 100, then subtracting 1710 from the x coordinate and 2320 from the y coordinate) and confirm the 72 degree azimuth angle (scaled down worksheet of *RepGeometry.xls* spreadsheet) (Appendix A).

3. Produce a transformation instruction file (*driftData.txt*) for input to DIRECT. (DriftExport worksheet of the *RepGeometry.xls* spreadsheet) (Appendix A).

For all dike sets, DIRECT automatically produces the appropriate transformation parameters and the transformation instruction file based on the file from the LHS step.

Runtime Parameters

DIRECT has automatic and custom viewing features. In automatic mode, DIRECT produces a single file containing all results, but no figures for verification assistance. To set the runs for automatic mode, the user currently must enter the command line: direct.exe -dedicated in an MS-DOS window that is set to the same directory as the DIRECT executable.

In custom mode, which is the default setup, the user can examine one case at a time. When the code is launched, the first set is shown on the screen. The user can advance one set at a time by pressing the right arrow key. The user can go backward one step at a time by pressing the left arrow key. The user can skip to any of the steps (out of 1,000) by pressing the ctrl + j keys simultaneously and entering the desired step number.

The graphic from that case can then be saved as a .png file for storage and/or printing. The file is saved by simultaneously pressing the ctrl and p keys to create an image file in .png format in the examples directory. Within DIRECT (SNL 2004 [DIRS 167795]), the image can be zoomed in or out by pressing the w and s keys respectively. The image can be panned right or left by pressing the d and a keys respectively. The image can be panned up or down by pressing the o and l keys respectively. The user can set DIRECT to automatically produce a sequential series of step plots for the current view by pressing the space bar. Pressing the space bar again will toggle out of that mode.

APPENDIX E
MAPPING YMRP ACCEPTANCE ASSESSMENT CRITERIA

The information provided by this analysis report addresses the number of waste packages that could be impacted by volcanic conduits or contacted by magma if a basaltic dike intersects the repository at Yucca Mountain. The analyses documented in this report assume that a dike intersects the repository; therefore the analysis provides conditional probabilities as probability distribution functions for the number of waste packages hit by igneous intrusion and the number of waste packages that are impacted by eruptive conduits.

The outputs of this analysis are used to describe the source term for TSPA-LA analyses related to the igneous activity volcanic (direct) release and intrusion-groundwater (indirect) release scenarios. The analyses do not address the amount of damage to waste packages or contents. Of specific interest are the number of waste packages that could be damaged as a result of either the:

- Intrusion of a basaltic dike into one or more repository drifts
- Eruption of a small basaltic volcano through the repository resulting in intersection of waste packages by volcanic conduits.

E1. YUCCA MOUNTAIN REVIEW PLAN CRITERIA ASSESSMENT

The NRC has identified two integrated subissues (NRC 2003 [DIRS 163274]) that are at least partially addressed by information in this report, mechanical disruption of engineered barriers and volcanic disruption of waste packages.

The *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) provides the review methods and acceptance criteria that the NRC staff will use to evaluate the technical adequacy of the license application. The applicable acceptance criteria, which may also be addressed in other analysis and model reports, are fully addressed when this report is considered in conjunction with those reports. Although not clearly described in the *Yucca Mountain Review Plan, Final Report*, the Integrated Issue Resolution Status Report (NUREG-1762, NRC 2002 [DIRS 159538]) specifically notes (Section 3.3.10.1, Paragraph 1), "Interactions between basaltic magma and waste packages not located along a subvolcanic conduit to the surface are evaluated in the Mechanical Disruption of Engineered Barriers Integrated Subissue" (Section 2.2.1.3.2).

E1.1 Integrated Subissue: Mechanical Disruption of Engineered Barriers

The following description identifies information from this report that addresses *Yucca Mountain Review Plan, Final Report* acceptance criteria and/or review methods related to the integrated subissue of mechanical disruption of engineered barriers (NRC 2003 [DIRS 163274], Section 2.2.1.3.2.3).

Acceptance Criterion 1: System Description and Model Integration Are Adequate

The objectives for calculating the number of waste package hit are described in Section 6.1 of the analysis report. The purpose of the analysis and integration of the analysis into TSPA-LA is described in Section 1. This analysis develops a probabilistic measure of the number of waste packages that could be affected by a basaltic igneous event in each of the two TSPA-LA igneous activity scenarios.

1. TSPA-LA adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the mechanical disruption of the engineered barrier abstraction process.

   This analysis describes the number of drifts intersected by a dike or swarm of dikes. Consequently, through a direct relationship of drifts and numbers of waste packages per drift, this analysis also estimates the number of waste packages contacted by magma in the indirect release scenario (also termed igneous intrusion scenario in this report). Similarly, for the direct release scenario (also termed eruptive conduit scenario in this report), the numbers and diameters of conduits that could form within the repository are used to estimate the number of waste packages that would be damaged to the extent that they would provide no further protection for the waste and would be erupted to the surface.

   The primary geologic and geometric elements used in the analysis (the volcanic dike(s) and any conduits, and the repository layout) are identified and summarized in Sections 6.3 through 6.4. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not directly intersected are described in Section 5.1. An assumption about constant conduit diameters used in the analysis is described in Section 5.2 and assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in Section 5.4. The number of waste packages damaged by an igneous intrusion are described in Section 6.3 and summarized in Figure 6-14. The number of waste packages hit by volcanic eruption are described in Section 6.4 and summarized in Figure 6-18. Results of the analysis are summarized in Section 7.1, and conclusions are presented in Section 7.2. The principal output of the analysis are CDFs for the number of waste packages hit by an igneous intrusion and by an eruptive conduit. The DTN outputs are referenced in Section 8.5.

   It is important to note that this analysis provides only the number of waste packages damaged by igneous intrusion into the repository or by development of one or more eruptive conduits through the repository. The analysis does not address the nature and extent of damage to waste packages; that assessment is provided in a model report, *Dike-Drift Interactions* (BSC 2004 [DIRS 170028]).

2. The description of geological and engineering aspects of design features, physical phenomena, and couplings that may affect mechanical disruption of engineered barriers is adequate. For example, the description may include materials used in the construction of engineered barrier components, environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) on these materials, and mechanical failure processes and concomitant failure criteria used to assess the performance capabilities of these materials. Conditions and assumptions in the abstraction of mechanical disruption of engineered barriers are readily identified and consistent with the body of data presented in the description.

   The primary geologic and geometric elements used in the analysis (the volcanic dike(s) and any conduits, and the repository layout) are identified and summarized in

Sections 6.3 through 6.4. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not directly intersected are described in Section 5.1. An assumption about constant conduit diameters used in the analysis is described in Section 5.2, and assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in Section 5.4.

This analysis provides the number of waste packages damaged by igneous intrusion into the repository or by development of one or more eruptive conduits through the repository. The analysis does not address the nature and extent of damage to waste packages or environmental conditions that might affect the extent of damage. The assessment of waste package damage and identification of environmental parameters used in the damage analysis are provided in a model report, *Dike-Drift Interactions* (BSC 2004 [DIRS 170028]).

3. The abstraction of mechanical disruption of engineered barriers uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for mechanical disruption of engineered barriers are consistent with the abstraction of degradation of engineered barriers (Section 2.2.1.3.1 of the *Yucca Mountain Review Plan, Final Report*). The descriptions and technical bases provide transparent and traceable support for the abstraction of mechanical disruption of engineered barriers.

   Data and parameters used in this analysis are traced to related documents listed in Table 4-1, Section 4. Appropriateness and consistency are addressed in Section 4.1. Assumptions used in the analysis are described in Section 5. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not intersected by a dike are described in Section 5.1. An assumption about constant conduit diameters is described in Section 5.2. Assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in Section 5.4. Section 6.3 describes the analysis of the number of waste packages hit by igneous intrusion, and Section 6.4 describes the analysis of the number of waste packages hit by conduits associated with a volcanic eruption through the repository.

4. Boundary and initial conditions used in the total system performance assessment for license application abstraction of mechanical disruption of engineered barriers are propagated throughout the abstraction approaches.

   Geologic and geometric variables affect the consideration of the number of waste package that could be affected by igneous intrusion into the repository or volcanic eruption through the repository. As described in Section 6.3.1, the geologic variables are mostly stochastic parameters that include dike length and orientation and geometric elements that include locations of geologic features and repository design elements. Methods to propagate the geologic and geometric variables through the analysis of the number of waste packages hit by igneous intrusion are described in

Section 6.3.2 and 6.3.3. The alternate analyses considered in this report, including sensitivity and uncertainty studies, are described in Section 6.5.

5. Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided.

   Features, events, and processes (FEPs) that are specifically addressed by information in this analysis report are identified in Section 6.2 and Table 6-1. Table 6-1 also identifies sections of the report in which the FEPs are addressed. The outputs of the analysis are CDFs for the number of waste packages hit by an igneous intrusion into the repository and included in conduits that develop as results of a volcanic eruption through the repository (Figures 6-14 and 6-18, respectively).

6. The conclusion, with respect to the impact of transient criticality on the integrity of the engineered barriers, is defensible.

   This analysis report does not address the impact of transient criticality on the integrity of the engineered barriers.

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

   NUREG-1297 describes the generic technical position with respect to the use of peer reviews on high-level waste repository programs. Peer review was not used in the development of this analysis. NUREG-1298 describes the generic technical position with respect to qualification of existing data. This report does not document the results of qualification of existing data.

Acceptance Criterion 2: Data Are Sufficient for Model Justification

1. Geological and engineering values used in the license application to evaluate mechanical disruption of engineered barriers are adequately justified. Adequate descriptions of how the data were used and appropriately synthesized into the parameters are provided.

   Geologic and geometric variables affect the consideration of the number of waste packages that could be affected by igneous intrusion into the repository or volcanic eruption through the repository. Input data are justified in Section 4.1, and their synthesis into parameters is described in Section 6.3. As described in Section 6.3.1, the geologic variables are mostly stochastic parameters that include dike length and orientation and geometric elements that include locations of geologic features and repository design elements. Methods to propagate the geologic and geometric variables through the analysis of the number of waste packages hit by igneous intrusion are described in Section 6.3.2 and 6.3.3. The alternate analyses considered in this report, including sensitivity and uncertainty studies, are described in Section 6.5. The outputs of the analysis are CDFs for the number of waste packages hit by an igneous intrusion into the repository and included in conduits that develop as results of a volcanic eruption through the repository (Figures 6-14 and 6-18, respectively).

2. Sufficient data have been collected on the geology of the natural system, engineering materials, and initial manufacturing defects to establish initial and boundary conditions for the total system performance abstraction of mechanical disruption of engineered barriers.

   This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain region (BSC 2004 [DIRS 169989]). Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 4-1. Table 4-1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Sections 5.1 through 5.4 include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

3. Data on geology of the natural system, engineering materials, and initial manufacturing defects used in the total system performance assessment for license application abstraction are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analogue research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment for license application abstraction are adequate to determine the possible need for additional data.

   This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain region (BSC 2004 [DIRS 169989]). Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 4-1. Table 4-1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Those sections include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

   Consideration of alternatives, with sensitivity and uncertainty studies, that were conducted as part of this analysis are described in Section 6.5.

4. Engineered barrier mechanical failure models for disruption events are adequate. For example, these models may consider effects of prolonged exposure to the expected emplacement drift environment, material test results not specifically designed or performed for the Yucca Mountain site, and engineered barrier component fabrication flaws.

This analysis does not evaluate failure modes for engineered barrier components or damage that could result from exposure of waste packages and waste forms to magmatic conditions. Assessments of damage to waste packages and waste forms associated with intrusion of a dike into the repository or eruption of a volcano through the repository are provided in the model report, *Dike-Drift Interactions* (BSC 2004 [DIRS 170028]).

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

Data and parameters used for the analysis of magma-waste package and magma-waste form interactions are described in Section 4.1.

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

   This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain region (BSC 2003 [DIRS 169989]). Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 4-1. Table 4-1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Sections 5.1 through 5.4 include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

   Consideration of alternatives, with sensitivity and uncertainty studies, that were conducted as part of this analysis are described in Section 6.5. The representation of risk is a TSPA-LA responsibility. This report describes no results that could be used to evaluate the representation of risk from magma drift and magma waste package interactions.

2. Process-level models used to represent mechanically disruptive events within the emplacement drifts at the proposed Yucca Mountain repository are adequate. Parameter values are adequately constrained by Yucca Mountain site data, such that the estimates of mechanically disruptive events on engineered barrier integrity are not underestimated. Parameters within conceptual models for mechanically disruptive events are consistent with the range of characteristics observed at Yucca Mountain.

   This analysis examines the number of waste packages that could be damaged by intersection of the repository by a basaltic volcanic dike or by eruption of a basaltic volcano through the repository (Figures 6-14 and 6-18). Sources of inputs for the analysis are listed in Table 4-1. Consistency of parameter values with observed ranges of characteristics (e.g., frequency of intersection of the repository by a basalt dike,

dike length and orientation, and the CDF for number of conduits that could form within the repository) are described in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]). Table 8 presents a mapping of CDF technical product outputs from this report to the results spreadsheet. Table 9 presents a similar mapping for alternative CDF results and Table 10 presents a mapping of auxiliary CDF outputs for the two previously identified spreadsheets. This analysis does not evaluate failure modes for engineered barrier components or damage that could result from exposure of waste packages and waste forms to magmatic conditions. Assessments of damage to waste packages and waste forms associated with intrusion of a dike into the repository or eruption of a volcano through the repository are provided in the model report, *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]).

3. Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the assessment abstraction of mechanical disruption of engineered barriers. This may be done either through sensitivity analyses or use of conservative limits.

   Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube Sampling approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Section 6.5. Alternate analyses, and sensitivity and uncertainty studies that were included to examine sensitivities to specific parameters are described in Section 6.5. Conservatism adopted in the analyses ensures that the risk is not under-represented and that they are discussed in Sections 6.3.3, 6.4, and 6.5. Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG-1563 (Kotra et al 1996 [DIRS 100909]). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

   Expert elicitation was not directly used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository. However, expert elicitation was used in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]) and data resulting from that elicitation are used in this report.

Acceptance Criterion 4: Model uncertainty is characterized and propagated through the model abstraction

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

   Features, events, and processes that are included in this report are described in Section 6.2 and summarized in Table 6-1. Table 6-1 also summarizes the TSPA-LA description of each included FEP and includes references to sections of the report in which the TSPA-LA disposition is described. Analysis of alternates and sensitivity and uncertainty analyses are described in Section 6.5 (also see Acceptance Criterion 3, Item 4). Consideration of the effects of an alternate abstraction approach is described in Section 6.5.1. Consistency of analytical results with process-level models and/or empirical observations is ensured by the use of results from such sources as inputs defining model parameters.

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

   Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube Sampling approach with use of conditional probability distributions for key inputs as described in Section 4.1. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Section 6.3.3 and Section 6.5 (also see Acceptance Criterion 3, Item 4). The representation of risk is a TSPA-LA responsibility. This report describes the number of waste packages hit by igneous intrusion into the repository (Figure 6-14) and eruption of a volcano through the repository (Figure 6-18). No results that could be used to evaluate the representation of risk from the abstractions for number of waste packages are developed in this report. Conservatisms adopted to ensure that risk is not under-represented are discussed in Sections 6.3.3, 6.4 and 6.5.

3. Appropriate alternative modeling approaches that are consistent with available data and current scientific knowledge and appropriately consider their results and limitations using tests and analyses sensitive to the processes modeled are investigated.

   Alternate analyses and sensitivity and uncertainty analyses are described in Section 6.5 (also see Acceptance Criterion 3, Item 4). Sensitivity studies examined effects of dike spacing consistent with parameter distributions reported Section 6.3 of analysis report *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980]). Conclusions from the alternate and sensitivity studies are presented in Section 6.5.4.

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

1. Models implemented in this total system performance assessment for license application abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field tests and/or natural analogues).

   The bases for the analysis of number of waste packages damaged by igneous intrusion into the repository or volcanic eruption through the repository are presented in Sections 6.3 and 6.4. The abstraction of the number of waste packages damaged by an intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 6-14. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 6-18. Comparisons with the site recommendation results are presented in Section 6.6. Consideration of the effects of an alternate abstraction approach is described in Section 6.5.1.

2. Outputs of mechanical disruption of engineered barrier abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both.

   The outputs of this analysis are distributions for the number of waste packages hit by igneous intrusion (Figure 6-14) or included in volcanic conduits (Figure 6-18). Also documented, are median numbers of waste packages hit or included. There are no corresponding process-level models or empirical observations to compare with these analyses.

3. Well-documented procedures, which have been accepted by the scientific community to construct and test the mathematical and numerical models, are used to simulate mechanical disruption of engineered barriers.

   The outputs of the abstraction of number of waste packages damaged by igneous intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 6-14. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 6-18. The results are CDFs for the number of waste packages damaged for the intrusion scenario and the volcanic scenario. The results include the assumptions described in Section 5 and analysis inputs for data and parameters described in Section 4.1. Well-documented procedures that have been accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate mechanical disruption of engineered barriers.

   Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube Sampling approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Sections 6.3.3 and 6.5. Alternate analyses and sensitivity and uncertainty analyses are described in Section 6.5 (also see Acceptance Criterion 3, Item 4). Sensitivity studies examined effects of dike spacing consistent with parameter distributions reported in Section 6.3 of the analysis report, *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980]). Conclusions from the alternate and sensitivity studies are presented in Section 6.5.4.

4. Sensitivity analyses or bounding analyses are provided to support the total system performance assessment for license application abstraction of mechanical disruption of engineered barriers that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analogue research.

The outputs of the abstraction of number of waste packages damaged by igneous intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 6-14. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 6-18. The results are CDFs for the number of waste packages damaged for the intrusion scenario and the volcanic scenario. The results include the assumptions described in Section 5 and analysis inputs for data and parameters described in Section 4.1. In addition, uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube Sampling approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Sections 6.3.3 and 6.5.

E1.2 Integrated Subissue: Volcanic Disruption of Waste Packages

The following information addresses the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) acceptance criteria related to volcanic disruption of waste packages (Section 2.2.1.3.10.3).

Acceptance Criterion 1: System Description and Model Integration Are Adequate

1. Total system performance assessment for license application adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the volcanic disruption of waste package abstraction process.

   The intersection of one or more repository drifts by a basaltic dike and subsequent damage to waste packages by magma or by inclusion in a volcanic conduit are coupled processes whose characteristics depend on the nature of the processes that are associated with the intersection and subsequent evolution of the magma drift system. This analysis describes the number of drifts intersected by a dike and the number of waste packages contacted by magma in the indirect release scenario. Similarly, for the direct release scenario, the number of conduits that could form within the repository is used to estimate the number of waste packages that would be damaged to the extent that they would provide no further protection for the waste. The results of these analyses are presented in Sections 6.3 and 6.4. The methods used to propagate uncertainties in the number and diameters of conduits are described in Section 6.4. Assumptions supporting the analysis are described in Sections 5.2 through 5.4. The uses of information from this analysis, in terms of FEPs issues by subsequent analyses are summarized in Table 6-1.

   This analyses incorporates design features as documented in Table 4-1 and reflects the analyses and models used as input and with companion analysis reports and model reports, including the *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]), *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169980]), and *Dike Drift Interactions* (BSC 2004 [DIRS 170028]). This analysis also provides the source term for the igneous groundwater transport model implemented in TSPA-LA through the *Saturated*

Zone Flow and Transport Model Abstraction (BSC 2004 [DIRS 170042]) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [DIRS 170026]).

2. Models used to assess volcanic disruption of waste packages are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region and/or observed at active igneous systems.

   No models were used in the analysis documented in this report. However, the analyses used to develop parameters for TSPA-LA is related to this criterion. The analyses documented in this report are limited to estimating the number of waste packages included in eruptive conduits (direct release scenario) or contacted by magma (indirect release scenario). These analyses do not examine waste package damage caused by, or damage processes related to, volcanic disruption of the repository. Models that assess damage to waste packages and waste forms are documented in a model report, *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]). Other pertinent physical processes are assessed in *Characterize Eruptive Processes at Yucca Mountain Nevada* (BSC 2004 [DIRS 169980]), and the processes are investigated in *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]). Igneous features in the Yucca Mountain region and/or observed at active igneous systems considered in these other disruptive event analyses or model reports support the features included in this analyses (Section 6.3 and 6.4).

3. Models account for changes in igneous processes that may occur from interactions with engineered repository systems.

   The report does not consider changes in igneous processes that could result from interactions with engineered repository systems. Models of the interactions between a basalt dike(s) and the engineered repository system are documented in Dike*/Drift Interaction* (BSC 2004 [DIRS 170028]). Results of these models support this analysis.

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

   Guidance in NUREG-1297 and NUREG-1298 is not applicable to this analysis. NUREG-1297 describes the generic technical position with respect to the use of peer reviews on high-level waste repository programs. Peer review was not used in the development of this analysis. NUREG-1298 describes the generic technical position with respect to qualification of existing data. This report does not document the results of qualification of existing data.

Acceptance Criterion 2: Data Are Sufficient for Model Justification

1. Parameter values used in the license application to evaluate volcanic disruption of waste packages are sufficient and adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

   This analysis derives parameters that are sampled as direct feeds to the TSPA-LA (Section 6.3 and 6.4). Design features and developed parameters based on analogue data are identified in Table 4-1. Data used in the analysis are described and justified and the bases for the values are documented in the references cited in this report (Sections 4.1, 6.3, 6.4).

2. Data used to model processes affecting volcanic disruption of waste packages are derived from appropriate techniques. These techniques may include site-specific field measurements, natural analogue investigations, and laboratory experiments.

   The analysis of the number of waste packages hit does not include any modeling of processes affecting volcanic disruption of waste packages. Upstream analyses provide inputs for this analysis and the bases for the values used in this analysis are documented in the references cited in this report (Sections 4.1, 6.3, 6.4).

3. Sufficient data are available to integrate features, events, and processes, relevant to volcanic disruption of waste packages into process-level models, including determination of appropriate interrelationships and parameter correlations.

   Features, events, and processes related to this analysis and included in TSPA-LA are identified in Table 6-1 and Section 6.2.

4. Where sufficient data do not exist, the definition of parameter values and associated conceptual models is based on appropriate use of expert elicitation conducted in accordance with NUREG-1563 (Kotra et al. 1996 [DIRS 100909]). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

   Expert elicitation was not used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository or volcanic eruption through the repository. Use of the results of the probabilistic volcanic hazard analysis expert elicitation to characterize data uncertainties are described below, under Acceptance Criterion 3, Item 3.

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

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

The data, parameter values, assumed ranges, and probability distributions that are used as inputs for this analysis are identified in Section 4.1 and Table 4-1. Justifications for the use of the various forms of input information are provided in Sections 6.3 and 6.4. The bases for the values are documented in the references cited in this report.

2. Parameter uncertainty accounts quantitatively for the uncertainty in parameter values observed in site data and the available literature (i.e., data precision) and the uncertainty in abstracting parameter values to process-level models (i.e., data accuracy).

   Methods to include uncertainties in the various input parameters needed for this analysis are described in Sections 6.3, 6.4 and Section 6.5. The technical bases for the input values are provided in the documents that have been cited in this analysis report. Outputs of the analysis are described in terms of cumulative distribution functions (Figures 6-14 and 6-18) and/or conditional probabilities that capture the uncertainties associated with the parameters.

3. Where sufficient data do not exist, the definition of parameter values and associated uncertainty is based on appropriate use of expert elicitation conducted in accordance with NUREG-1563 (Kotra et al. 1996 [DIRS 100909]). If other approaches are used, the U. S. Department of Energy adequately justifies their use.

   Expert elicitation was not used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository or volcanic eruption through the repository. However, expert elicitation results were documented in the analysis report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]), which was used to provide relevant inputs to the current analysis. Examples of inputs from *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989]), which were used in this analysis, include distributions for dike length, orientation, and number of conduits.

Acceptance Criterion 4: Model Uncertainty Is Characterized and Propagated Through The Model Abstraction

Parameter distributions developed in this analysis are utilized in TSPA-LA to propagate epistemic uncertainty related to input parameter distributions. Disruptive event models used to analyze interactions between a basalt dike(s) and engineered repository systems are documented in the *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]).

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

The analysis documented in this report provides the number of waste packages that could be included in volcanic conduits (Section 6.4 and Figure 6-18) or contacted by magma if a basaltic dike intersects the repository at Yucca Mountain (Section 6.3.3 and Figure 6-14).

Models used to analyze interactions between a basalt dike(s) and engineered repository systems are documented in the update of the *Dike/Drift Interaction* (BSC 2004 [DIRS 170028]).

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APPENDIX F
GLOSSARY

conduit–The vertical or subvertical, essentially cylindrical, tube that brings magmatic material to land surface. Conduit is the appropriate term regarding the subsurface, and PA conceptual models emphasize the interactions that occur at the intersection of a conduit with the repository.

dike–A tabular subplanar magma-filled crack that cuts across local geologic contacts, such as bedding planes. Length and width (or thickness) describe the size of a dike, although minor variations in width and strike direction can be expected along the length of any one dike.

dike system–One or more dikes that are closely related in space and time. Dike systems may include multiple dikes that share a common magmatic source with a single volcano. This definition does not preclude the possibility that a dike system may feed more than one volcano.

eruptive event (with respect to repository performance)–The formation of a volcano that includes at least one subsurface conduit that intersects a drift containing waste packages.

extrusive event (with respect to repository performance)–Synonymous with eruptive event.

igneous activity–Any process associated with the generation, movement, emplacement, or cooling of molten rock within the earth or on the earth's surface.

intrusive event (with respect to repository performance)–An igneous structure (such as a dike, dike system, or other magmatic body in the subsurface) that intersects the repository footprint at the repository elevation.

magma–Partially or completely molten rock within the earth's crust or mantle.

volcanic event–The formation of a volcano (with one or more vents) resulting from the ascent of basaltic magma through the crust as a dike or system of dikes.

volcano–A geologic feature than includes an edifice of magmatic material erupted on the land surface, one or more conduits that feed the eruption, and a dike or dike system that feeds the conduit or conduits.

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