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Enclosure 2

**OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT**
**ANALYSIS/MODEL COVER SHEET**
***Complete Only Applicable Items***

1. QA: QA



2. ☒ Analysis — Check all that apply

| | |
|---|---|
| Type of Analysis | ☐ Engineering<br>☒ Performance Assessment<br>☐ Scientific |
| Intended Use of Analysis | ☐ Input to Calculation<br>☐ Input to another Analysis or Model<br>☒ Input to Technical Document<br>☐ Input to other Technical Products |

Describe use:

Provides Input Data for use in TSPA-SR

3. ☒ Model — Check all that apply

| | |
|---|---|
| Type of Model | ☒ Conceptual Model<br>☐ Abstraction Model<br>☐ Mathematical Model<br>☐ System Model<br>☐ Process Model |
| Intended Use of Model | ☐ Input to Calculation<br>☐ Input to another Model or Analysis<br>☒ Input to Technical Document<br>☐ Input to other Technical Products |

Describe use:

Provides Input Data for use in TSPA-SR

4. Title:

Igneous Consequence Modeling for the TSPA-SR

5. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-WIS-MD-000017 Rev 00

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# OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
## ANALYSIS/MODEL REVISION RECORD

***Complete Only Applicable Items***



2. Analysis or Model Title:

Igneous Consequence Modeling for the TSPA-SR

3. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-WIS-MD-000017 Rev 00

| 4. Revision/Change No. | 5. Description of Revision/Change |
|---|---|
| Revision 00 | Initial Issue |

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# ACRONYMS

| | |
|---|---|
| AMR | Analysis and Model Report |
| BDCF | Biosphere Dose Conversion Factor |
| CDF | Cumulative Distribution Function |
| CNWRA | Center for Nuclear Waste Regulatory Analyses |
| CRWMS M&O | Civilian Radioactive Waste Management System, Management and Operating Contractor |
| DOE | U.S. Department of Energy |
| FEPs | Features, Events, and Processes |
| IRSR | Issue Resolution Status Report |
| NRC | Nuclear Regulatory Commission |
| OCRWM | Office of Civilian Radioactive Waste Management |
| PDF | Probability Density Function |
| PMR | Process Model Report |
| PVHA | Probabilistic Volcanic Hazard Analysis |
| QA | Quality Assurance |
| QAP | Quality Administrative Procedure (M&O) |
| QARD | Quality Assurance Requirements and Description |
| SR/LA | Site Recommendation/License Application |
| SZ | Saturated Zone |
| TBV | To Be Verified |
| TPO | Technical Product Output |
| TSPA | Total System Performance Assessment |
| TSPA-SR | Total System Performance Assessment Site Recommendation |
| TSPA-VA | Total System Performance Assessment Viability Assessment |
| UZ | Unsaturated Zone |
| VA | Viability Assessment |

# 1. PURPOSE

The purpose of this technical report is to develop credible, defendable, substantiated models for the consequences of igneous activity for the SR/LA. The effort will build on the TSPA-VA and improve the quality of scenarios and depth of the technical basis underlying disruptive events modeling.

The scope of this work as defined in the development plan (CRWMS M&O 1999b) involves using data that has been extracted from existing sources to design and support the TSPA models for the transport of radionuclides following igneous disruption of the repository. Computational models for both volcanic eruptive releases (this is an event that results in ash containing waste being ejected from Yucca Mountain) and igneous intrusion groundwater releases (this is an event that reaches the repository level, impacts the waste packages, and produces releases from waste packages damaged by igneous activity) will be included directly in the TSPA calculations as part of the the TSPA. Calculation of any doses resulting from igneous releases will also be done within the TSPA model, as will the probabilistic weighting of these doses. Calculation and analysis of the TSPA results for igneous disruption are therefore outside the scope of this activity.

The objectives of the work are to:

1. Develop TSPA conceptual models for volcanic eruptive and igneous intrusive groundwater transport releases from igneous activity consistent with the available conceptual models and data.
2. Document support from conceptual models and data.
3. Deliver conceptual model parameter inputs to the TSPA-SR.
4. Provide appropriate documentation for conceptual models, data, and parameters to relevant project databases.

More specifically, this AMR addresses conceptual models for two types of igneous disruption of the repository: volcanic eruptions that intersect drifts and bring waste to the surface, and igneous intrusions that damage waste packages and expose radionuclides for groundwater transport processes. These two types of disruption were described in the 1998 Viability Assessment (DOE 1998, Vol. 3, Section 4.4) as the "direct release scenario" and the "enhanced source term scenario," respectively. Descriptive terms recommended here for these scenarios are "volcanic eruption" and "igneous intrusion groundwater transport," respectively. This AMR does not address indirect effects of igneous activity that does not intersect the repository: as described in CRWMS M&O 2000g, "Disruptive Events Features, Events, and Processes" indirect effects of igneous activity are shown to have sufficiently small consequences that they are not included in the TSPA-SR estimates of overall system performance.

Implementation of the conceptual models and parameters and the calculation of the estimated performance of the repository following igneous disruption are outside the scope of this AMR. The TSPA-SR calculations of radionuclide releases and the resulting doses to the critical group will be conducted within the TSPA model as part of the overall TSPA-SR analysis (see Development Plan CRWMS M&O 1999c, Total System Performance Assessment—Site Recommendation Methods and Assumptions, Rev. 00). This AMR, therefore, does not include implementation of the conceptual models or analysis of model results. This AMR documents the conceptual igneous consequence models and the associated input parameters that support simulations of igneous disruption of the repository that are conducted within the TSPA-SR model.

This AMR relies upon other AMRs and Calculations (CRWMS M&O 1999e, CRWMS 2000a, CRWMS M&O 2000b, CRWMS M&O 2000c, CRWMS M&O 2000d, CRWMS M&O 2000e, DTN:LA9912GV831811.001, DTN:SN0001T0801500.001, DTN:SN0004ERUPTION.000, DTN:SN0004WINDDATA.000) to establish the values to be utilized as input parameters within the igneous consequence model. The model that has been chosen to depict/simulate the volcanic eruption only depicts/simulates the atmospheric transport and deposition of the ash containing waste and does not accommodate the modeling of subsurface phenomena.

This analysis is governed by the OCRWM Work Direction and Planning Document entitled "Coordinate Modeling of Consequences of Igneous Activity for TSPA-SR" (CRWMS M&O 1999b).

## 2. QUALITY ASSURANCE

An activity evaluation (CRWMS M&O 1999d) in accordance with QAP-2-0, *Conduct of Activities* (CRWMS M&O 1999g), has determined that the Quality Assurance (QA) program applies to this analysis because activities to be conducted in this analysis are subject to requirements described in the *Quality Assurance Requirements and Description* (QARD) document (DOE 2000). The analysis does not involve any items on the Q-List (YMP 1998). This AMR has been prepared in accordance with Procedure AP3-3.10Q, *Analysis and Models* (AP-3.10Q).

## 3. COMPUTER SOFTWARE AND MODEL USAGE

The software used in this AMR, and the AMRs and Calculations that this AMR utilizes, are listed in Table 1. No codes were utilized within this AMR.

### 3.1. MICROSOFT EXCEL

Microsoft Excel was used in this AMR in the development of input values for the igneous consequence model in accordance with section 2.0 of AP-SI.1Q Rev 2, ICN 4, *Software*

*Management.* No routines or macros were developed for this AMR. Cumulative distribution functions (CDF) or probability density functions (PDF) were used in Excel for the input parameters and only standard Excel functions were used. Some of the parameters required additional pre or post processing of the data obtained from the data sources to place them in a suitable form for use in the models. The parameters that were developed utilizing Excel are listed below. These parameters and the associated values are discussed in more detail in Sections 4 and 6.

- Event Eruptive Volume — CDF
- Ash Mean Particle Diameter — CDF
- Ash Mean Particle Diameter Standard Deviation — CDF
- Event Power — CDF
- Ash Dispersion Controlling Constant — CDF
- Vent Diameter — CDF
- Initial Eruptive Velocity — CDF
- Wind Speed — CDF
- Wind Direction — PDF
- Number of Packages Hit Per Drift — CDF
- Number of Drifts Hit Per Vent — CDF
- Number of Conduits Intersecting Waste — PDF
- Event Probability — CDF

Table 1: Software Used in the Igneous Consequences Modeling and Supporting AMRs and Calculations

| Computer Code | Version | Code Source | Computer Type |
|---|---|---|---|
| Microsoft Excel | 97-SR-1 | Acquired | Windows 95 PC |
| Microsoft Word | 97-SR-1 | Acquired | Windows 95 PC |

## 3.2. MICROSOFT WORD

Microsoft Word was utilized in preparation of this document.

# 4. INPUTS

This analysis draws extensively on other AMRs done within disruptive events Process Model Report (PMR) (CRWMS M&O 2000f) to help define the events to be modeled in the TSPA and to provide the probability distributions assigned to parameters. In some cases, this AMR simply reports the results of other activities without further analysis.

Full implementation of the igneous consequence conceptual models in the TSPA-SR simulations will also require information from many other groups within the project that are outside the disruptive events report. For example, TSPA-SR calculations of radionuclide concentrations in groundwater resulting from igneous intrusion will require estimates from this AMR of the amount of waste exposed by igneous activity and will also require waste dissolution models and unsaturated and saturated zone flow and transport models that will be developed by other groups. Similarly, TSPA-SR calculations of radiation doses incurred by the critical group as a result of both volcanic eruptions and igneous intrusive groundwater transport events will require biosphere dose conversion factors (BDCFs) that are developed outside of the disruptive events PMR (CRWMS M&O 2000f). Although models and parameter values that are external to the disruptive events report are discussed in this AMR as is necessary for clarity, their derivation and justification is outside the scope of this AMR.

Figure 1 shows the relationship between the major products of the disruptive events PMR (CRWMS M&O 2000f) that are relevant to igneous consequence modeling, and shows how these products support each other and the TSPA-SR analysis. AMR and calculation titles are shown in the figure in abbreviated form: full titles are given in the following text. Activities external to the disruptive events report are shown in boxes with dashed lines. This AMR, Igneous Consequence Modeling, is shown in the right center of the figure.

Broadly, information flows from left to right across the figure, culminating in support for the TSPA-SR. Most activities directly or indirectly support the TSPA model that calculates the overall performance of the system. CRWMS M&O 2000b, "Characterize Framework for Igneous Activity at Yucca Mountain, Nevada," provides basic information about volcanic activity in the Yucca Mountain Region and derives the probability of future volcanic activity from information provided in the *Probabilistic Volcanic Hazard Analysis* (PVHA) (CRWMS M&O 1996, Appendix E). Information about the general nature of volcanic activity in the Yucca Mountain Region is used by CRWMS M&O 2000a, "Characterize Eruptive Processes at Yucca Mountain, Nevada," to support that AMR's detailed characterization of the events and processes associated with a volcanic eruption. Information about the probability of future eruptions is used by CRWMS M&O 2000d, "Number of Waste Packages Hit by Igneous Intrusion" to support the calculation of cumulative distribution functions (CDFs) characterizing the number of waste packages affected by intrusions and eruptions. Distribution for the probability of future eruptions is developed within this AMR and will be utilized in the TSPA-SR model. CRWMS M&O 2000c, "Dike Propagation Near Drifts," provides an estimate of the distance magma flows down drifts, supporting CRWMS M&O 2000d. CRWMS M&O 2000d also draws information from DTN:LA9912GV831811.001 to calculate the number of waste packages damaged by igneous events. As shown in the figure, this AMR, "Igneous Consequence Modeling for the TSPA-SR" (ANL-WIS-MD-000017) draws information from the Calculation "Number of Waste Packages Hit by Igneous Intrusion" (CAL-WIS-PA-000001) (CRWMS M&O 2000d), DTN "Volcanic Eruption

Parameters" (DTN:LA9912GV831811.001), AMR "Characterize Framework for Igneous Activity at Yucca Mountain, Nevada" (ANL-MGR-GS-000001) (CRWMS M&O 2000b), and several activities outside the disruptive events PMR (CRWMS M&O 2000f) to develop its products supporting the TSPA analysis.

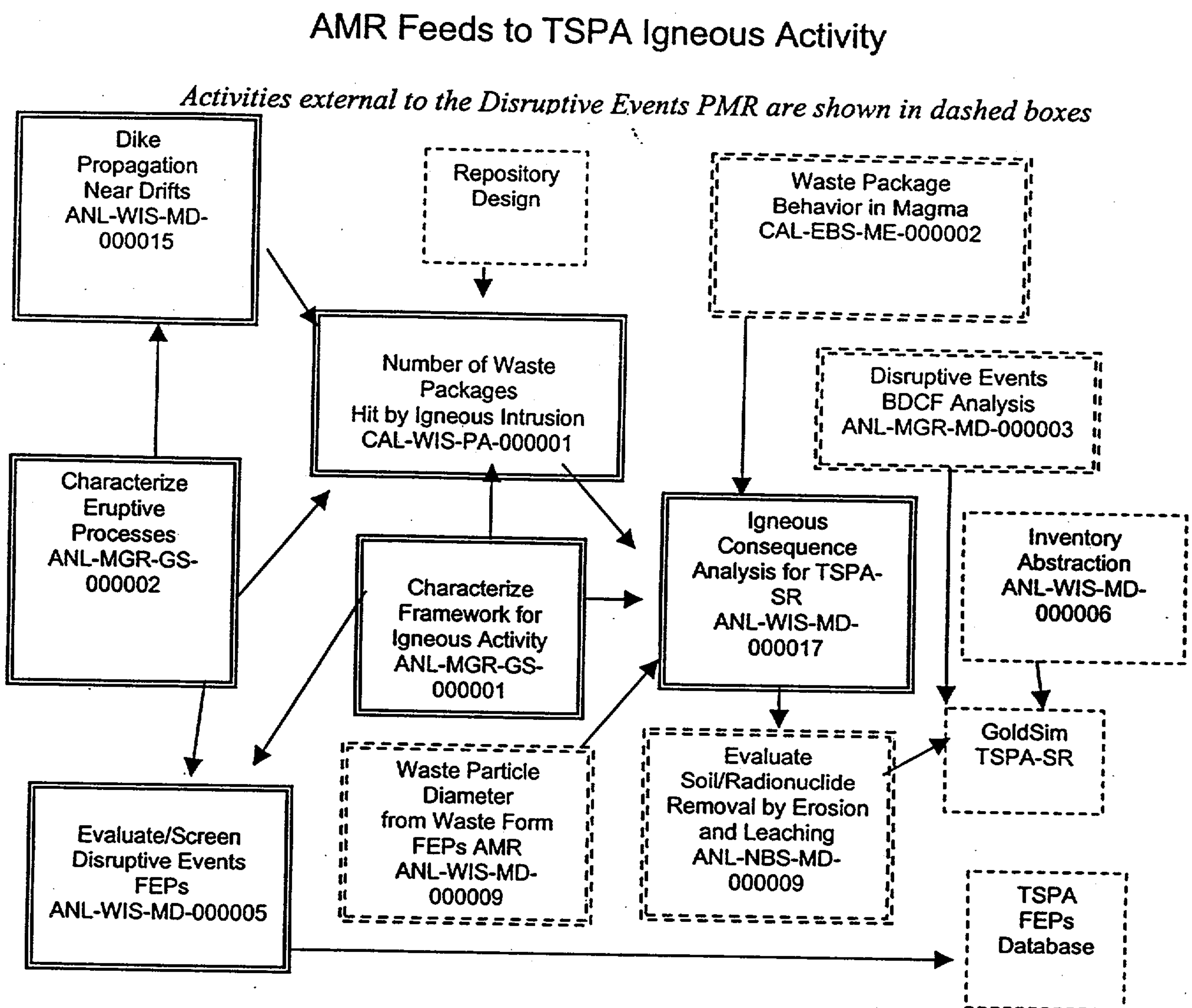


Figure 1: Information Feeds to Igneous Consequence Modeling in the TSPA-SR. Activities external to the Disruptive Events Report are shown in dashed boxes.

One AMR shown in Figure 1, "Disruptive Events Features, Events, and Processes" (ANL-WIS-MD-000005) (CRWMS M&O 2000g) supports the TSPA Features, Events, and Processes (FEPs) database. In addition, this AMR supports the TSPA-SR analysis by providing a selection process to identify model elements. As described in the TSPA

FEPs database development plan (CRWMS M&O 1999a), the FEPs database will provide summary documentation of the treatment of all FEPs that have not been included in the TSPA-SR simulation, as well as providing references to the appropriate documentation describing detailed treatment of FEPs that are included in the TSPA and justification for the exclusion of those that have been omitted. CRWMS M&O 2000g addresses a range of FEPs relevant to disruptive events in general.

## 4.1. DATA AND PARAMETERS

Two igneous events are addressed in this AMR. The first event is a hypothetical volcanic eruption that intersects the repository. In this scenario an igneous dike rises to the repository level and intersects one or more waste-containing drifts in the repository. The dike then continues to rise towards the surface, and at some depth a conduit forms to the surface resulting in a volcanic eruption. Each conduit that reaches the surface contains a corresponding vent at the surface. Each dike may result in as many as five conduits being formed that could potentially intersect the waste containing drifts. The conduits erupt to the surface entraining any waste that was intersected in the magma (ash). This event is modeled within the TSPA model utilizing the software code ASHPLUME (Jarzemba et al. 1997) which is an implementation of the Suzuki model (Suzuki 1983). This model requires values to be defined for several input parameters. These values are obtained from various sources and are listed in Table 2.

Table 2 Volcanic Eruption Event (ASHPLUME) Input Data

| Input Parameter | Data Source | DTN Number/Input Transmittal Number | Data Status |
|---|---|---|---|
| Particle Shape Factor | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO (Tech. Prod. Output) |
| Air Density | Lide 1994, Handbook | N/A | Fact |
| Air Viscosity | Lide 1994, Handbook | N/A | Fact |
| Ash Settled Density | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Ash Particle Densities at Min/Max Particle Sizes | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Ash Min/Max Particle Sizes for Densities | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Waste Particle Size | CRWMS M&O 2000e | 00178.T | TPO |
| Event Eruptive Volume | CRWMS M&O 2000b, Reamer 1999 (p. 87) | N/A | TPO |
| Ash Mean Particle Diameter | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Ash Particle Size Standard Deviation | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Event Power | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |

| | | | |
|---|---|---|---|
| Conduit Diameters | DTN:LA9912GV831811.001 | DTN:LA9912GV831811.001 | TPO |
| Initial Eruption Velocity | Wilson and Head, 1981, p. 2977 | DTN:SN0004ERUPTION.000 | TBV |
| Wind Speed | Quiring 1968, p. VI-1 – VI-21 | DTN:SN0004WINDDATA.000 | TBV |
| Wind Direction | Quiring 1968, p. VI-1 – VI-21 | DTN:SN0004WINDDATA.000 | TBV |
| Number of Packages Hit per Drift (Volcanic Eruption) | CRWMS M&O 2000d | 00158.T | TPO |
| Number of Drifts Hit per Conduit | DTN:SN0001T0801500.001 | DTN:SN0001T0801500.001 | TPO |
| Number of Conduits Intersecting Waste | CRWMS M&O 2000d | 00158.T | TPO |
| Event Probability | CRWMS M&O 2000b | 00157.T | TPO |
| Probability of >0 Conduits | DTN:SN0001T0801500.001 | DTN:SN0001T0801500.001 | TPO |

The second event is a hypothetical igneous intrusion that results in exposing the waste for groundwater transport away from the repository. This event is characterized by an igneous dike rising to the repository level and intersecting one or more waste-containing drifts in the repository. The magma from the dike damages the waste packages in the intersected drifts. These affected waste packages are breached and the contents are then available for transport in groundwater. Groundwater transport is modeled within the TSPA model using the unsaturated zone and saturated zone (UZ/SZ) models. This model requires values to be defined for some input parameters. These values are obtained from other AMRs and Calculations, and are listed in Table 3. The input parameters for these two models and the development of the parameter values will be discussed in more detail in Section 6.

Table 3: Igneous Intrusion Groundwater Transport Event Input Parameters

| Input Parameter | Data Source | DTN Number | Data Status |
|---|---|---|---|
| Event Probability | CRWMS M&O 2000b | 00157.T | TPO |
| Number of Packages Hit (Igneous Intrusion) | DTN:SN0001T0801500.001 | DTN:SN0001T0801500 .001 | TPO |

## 4.2. CRITERIA

There are no specific criteria identified in the project requirements documents (i.e. System Description Documents). This AMR was prepared to comply with the DOE interim guidance (Dyer 1999) which directs the use of specified Subparts/Sections of the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640). Subparts of this proposed rule that are particularly applicable to data include Subpart B, Section 15 (Site Characterization) and Subpart E, Section 114 (Requirements for Performance Assessment). Subparts applicable to models are outlined in Subpart E, Sections 114

(Requirements for Performance Assessment) and 115 (Characteristics of the Reference Biosphere and Critical Group).

## 4.3. CODES AND STANDARDS

No codes and standards are utilized in the preparation and completion of this document.

# 5. ASSUMPTIONS

This section identifies assumptions that are essential to the formulation of the conceptual model and associated parameter values described in Section 6.

Assumptions are grouped within this section according to general areas of the conceptual model and analyses that they affect. Discussion of each assumption includes four sections: 1) a statement of the assumption; 2) the rationale (basis) as to why it is valid for the purposes of this analysis; 3) a statement of the need for further confirmation, if any, of the assumption (i.e., the "to-be-verified" [TBV] status); and 4) a statement of how the assumption is used in the analysis described in Section 6.

## 5.1. ASSUMPTIONS REGARDING THE TRANSPORT MECHANISMS FROM THE REPOSITORY TO THE CRITICAL GROUP LOCATION

### 5.1.1. Future Wind Speed and Direction

**Assumption:** The available data characterizing variability in wind speed and direction in the Yucca Mountain region under present climatic conditions (e.g., Quiring, 1968, p. VI-1 – VI-21, as described in Section 6) are an acceptable approximation of variability in wind speed and direction for future wind conditions.

Conceptually, this assumption corresponds to an assumption that climatic change will not materially affect wind speed and direction. The magnitude of short-term variability in wind speed and direction, which is included in the data that characterizes present wind conditions, it is presumed to be significantly greater than long-term variability introduced by potential future climatic changes.

**Rationale:** There are no data available directly relevant to wind speed and direction during future climatic conditions. Unlike other climate-related parameters like mean annual precipitation and temperature, there are essentially no data directly relevant to wind speeds and directions under past climates that could be used as the basis for future climates. Justification for this assumption is based on the observation that the magnitude of short-term variability in meteorological phenomena is great compared to changes in long-term averages. Emphasis for relatively brief volcanic events is correctly placed on the short-term variability rather than on long-term averages in wind patterns.

Additional support for the reasonableness of this assumption comes from examination of published modeling studies of past climatic conditions that may be reasonable analogs for future climatic conditions at Yucca Mountain. Kutzbach et al. (1993) have modeled global climates at 3,000 year intervals during the last 18,000 years, using general circulation models with available paleoclimatic information used to define boundary conditions. Resolution of the model is extremely coarse (grid blocks are 4.4 degrees latitude by 7.5 degrees longitude; Kutzbach et al., 1993, page 60), and results are not intended to be interpreted at local scales. However, model results are presented at a regional scale that provides qualitative information about modeled wind speeds and directions for the southwestern United States. Model results are provided for 18,000 years ago, at the end of the last major glaciation of northern North America, and also at 12,000, 9,000, and 6,000 years ago, and also for present conditions. Climatic conditions at these times span the range of conditions that might reasonably occur during a future transition from the present climate to a glacial climate.

Modeled surface winds for the southwestern United States in winter (January) and summer show a slightly stronger westerly component (away from the critical group south of the repository) 18,000 years ago than at present, and are essentially unchanged from the present at 12,000, 9,000, and 6,000 years ago (Kutzbach et al, 1993, figure 4.6 and 4.8). Modeled winter (January) winds at the 500 millibar pressure isobars (about 5.5 km elevation) blow strongly from the west at all times, and are somewhat stronger at 18,000 years ago than at present (Kutzbach et al., 1993, Figure 4.14). Modeled summer (July) winds at 500 millibars are weaker and less consistent, blowing from the southwest and west at 18,000 and 12,000 years ago and at the present and from the northwest 9,000 and 6,000 years ago (Kutzbach et al., 1993, Figure 4.15).

Relevant to the assumption discussed here, it is significant that changes in the Kutzbach et al.'s (1993) modeled wind speeds and directions in the southwestern United States are not dramatic during the modeled transition from glacial to interglacial climates. The largest changes, occurring during full glacial conditions 18,000 years ago, appear qualitatively to correspond to a decrease in the relative frequency of winds blowing toward the critical group location south of Yucca Mountain. These changes are reasonably and conservatively neglected, and variability in present wind conditions is assumed to adequately characterize variability in future conditions.

**Confirmation Status:** No testing or modeling activities are planned to provide further confirmation of this assumption because this assumption is not identified as requiring further work to be verified. It is possible to design sensitivity analyses within the TSPA-SR model that can test sensitivity of overall performance to different assumptions about future wind conditions. Such analyses are outside the scope of this AMR, however.

**Use within Analysis:** This assumption is used in Section 6 to justify the distributions of future wind speed and direction that are recommended for use in the TSPA-SR analyses. Functionally, the assumption means that individual values of wind speed and direction can be sampled for time zero from distributions based on present data, and the same values can then be used for all time steps for each realization.

### 5.1.2. Treating Wind Speed and Wind Direction as Independent Parameters

**Assumption:** Wind speed and wind direction data from Quiring (1968, p. VI-1 – VI-21, as described in Section 6) are treated as uncorrelated parameters, even though they were collected as paired, fully-correlated parameters (i.e., each measurement of wind velocity included components of speed and direction.)

**Rationale:** This assumption allows sampling of variability in both speed and direction independently, assuring that the full range of reported speeds have the possibility of occurring in a southerly direction, toward the critical group. This also has the benefit of allowing the wind speed to be fixed towards the critical group if desired without affecting the wind speed distribution. Although the assumption does insure that the highest wind speeds reported (regardless of direction in the available data set) may coincide with winds blowing toward the critical group, the assumption should not be viewed as necessarily conservative. There is no *a priori* reason to assume that high wind speeds toward the critical group will result in larger doses (although intuitively that seems a likely outcome), and the assumption also allows for the lowest wind speeds to coincide with winds blowing to the south. The assumption is best viewed as a reasonable approach to expand the range of uncertainty observable in the available data set to ensure that the full range of reasonably foreseeable conditions are included in the analysis.

**Confirmation status:** The data supporting this assumption is TBV and will need to be verified. However, this assumption simply indicates how the data was utilized and requires no further verification. It is possible to design sensitivity analyses within the TSPA-SR model that can test sensitivity of overall performance to different assumptions about future wind conditions. Such analyses are outside the scope of this AMR, however.

**Use within Analysis:** This assumption is used in Section 6 to justify the lack of correlation in the distributions of future wind speed and direction that are recommended for use in the TSPA-SR analyses.

### 5.1.3. Combining Wind Speeds and Directions from Different Altitudes

**Assumption:** Wind speeds and directions reported by Quiring (1968, p. VI-1 – VI-21, as described in Section 6) are combined into single distributions for each parameter, regardless of the altitude (data were reported from 5,000-16,000 feet above sea level, which is approximately 1,500-5,000 meters above sea level) from which the data was collected.

**Rationale:** In part, this assumption is made to accommodate the input requirements of ASHPLUME. As described in Section 6, the ASHPLUME code, proposed for use in atmospheric transport of waste following a volcanic eruption, does not incorporate vertical heterogeneity in either wind speed or direction. This assumption prevents dispersion due to vertically-varying wind velocities. Were ASHPLUME capable of including vertical heterogeneity in wind velocity, individual realizations could result in greater longitudinal and transverse dispersion in the dimensions of the calculated ash plume. By omitting dispersion due to altitudinal variability in wind velocity, the analysis will tend to overestimate extreme values of ash fall thickness and waste concentrations at the location of the critical group. This "spreading" of the distribution of model outcomes will help ensure that extreme conditions have been included in the analysis.

**Confirmation status:** The data supporting this assumption is TBV and will need to be verified. However, this assumption simply indicates how the data was utilized and requires no further verification. If future modifications to the ASHPLUME code allow, sensitivity analyses can be designed and executed within the TSPA-SR model that will test sensitivity of overall performance to different assumptions about vertical heterogeneity of wind velocity. Such analyses are outside the scope of this AMR, however.

**Use within Analysis:** This assumption is used in Section 6 to justify the distributions of future wind speed and direction that are recommended for use in the TSPA-SR analyses.

## 5.2. ASSUMPTIONS REGARDING THE NATURE OF THE IGNEOUS EVENT

### 5.2.1. Fragmentation Depth and Type of Eruption (Violent or Nonviolent)

**Assumption:** All eruptions include a violent strombolian phase with fragmentation of the ascending magma into pyroclasts occurring below the repository horizon.

**Rationale:** The assumption is considered to be conservative. As discussed in Section 6, uncertainty associated with the nature of the violent phase, including its duration (the length of time that the volcanic eruption is occurring) and the volume (the amount of material that is expelled from the volcano during the event) of material erupted, is included in the analysis through the development of a distribution function characterizing uncertainty in the volume of erupted material.

**Confirmation Status:** This assumption is not identified as requiring further work to be verified. It is conservative to assume that every volcanic event has a violent strombolian phase.

**Use in Analysis:** This assumption is used in Section 6 to support the conceptual model for the volcanic eruption release.

## 5.3. ASSUMPTIONS REGARDING THE BEHAVIOR OF WASTE, WASTE PACKAGES AND OTHER COMPONENTS OF THE ENGINEERED BARRIER SYSTEM IN A MAGMATIC ENVIRONMENT

### 5.3.1. Behavior of the Waste Package and Drip Shield in an Eruptive Conduit

**Assumption:** Any waste packages, drip shields, and other components of the engineered barrier system that are partially or completely intersected by an eruptive conduit are fully destroyed. All waste within waste packages that are fully or partially intersected by an eruptive conduit is available to be entrained in the eruption.

**Rationale:** The assumption is considered to be conservative. Actual conditions in eruptive magmatic environments and the response of the waste packages and other components of the engineered barrier system are uncertain. Waste packages directly intersected by an eruptive conduit may be subjected to a range of conditions characteristic of rapid pyroclastic flow during violent strombolian eruptions, or to less extreme conditions during less violent eruptions.

Bounding information that provides support for concluding that the assumption of complete failure is not unreasonably conservative comes from CRWMS M&O 1999e, which reports maximum stresses in the waste package shell as a function of wall thickness and temperature. Results of this calculation show failure of the intact, undegraded waste package is likely to occur slightly above 1200 degrees C by deformation of the junction of the shell and the lid. Failure of waste packages that are already partially degraded by corrosion from seepage or other means will occur at lower temperatures. These calculations do not consider dynamic loads that may be imposed by flowing magma or pyroclastic material, nor do they consider possible corrosive effects in the aggressive chemical environment. It is concluded that it is reasonable to assume that partial failure (although not complete failure) of waste packages will occur at temperatures below those reported in this calculation. CRWMS M&O 2000b reports that temperatures above 1100 degrees C are possible for magmatic environments like those considered here, and all waste packages subjected to magmatic heat and dynamic stresses of eruption are therefore assumed to fail.

Alternative, and less bounding, conceptual models for the behavior of the damaged packages in the eruptive conduit can be proposed, but data are not available to support them. For example, some waste packages intersected by eruptive conduits could be pushed aside into the drifts, rather than being entrained in the eruption. Other waste packages could be brought to the surface partially or largely intact, rafted in flowing lava or carried as large particles in a pyroclastic eruption. Even if brought to the surface, waste remaining in large fragments of waste packages would not be entrained with ash and transported downwind to the critical group.

**Confirmation Status:** No additional work is planned to verify this assumption. This assumption is adequately conservative such that additional confirmation is not needed.

**Use in Analysis:** This assumption is used in Section 6 to support the conceptual model for the volcanic eruption release.

### 5.3.2. Behavior of the Waste Package and Drip Shield in Proximity to an Igneous Intrusion Groundwater Transport Event

**Assumption:** Any waste packages, drip shields, and other components of the engineered barrier system that are partially or completely intersected by an intrusive dike are fully destroyed. Furthermore, three waste packages on either side of the dike are also assumed to be fully destroyed.

**Rationale:** The assumption that the affected waste packages are fully destroyed is considered to be conservative. The determination that three waste packages on either side of the dike are affected by the intrusion is not an assumption: it is an input to CRWMS M&O 2000d and is listed here only for clarity.

**Confirmation Status:** No activities are planned at this time to verify this assumption, nor are any necessary: the assumption is conservative. It is acknowledged that for packages damaged due to proximity to an intrusive dike (rather than by direct intersection) the assumption describes a physically unlikely, and perhaps impossible, set of conditions. However, there is no defensible technical basis for choosing a less conservative model at this time. It is presumed that further analyses of the behavior of the waste package in a magmatic environment and modeling of water flow and radionuclide transport in the drift following magmatic disruption have the potential to support less conservative and more realistic assumptions.

**Use in Analysis:** This assumption is used in Section 6 to support the conceptual model for the igneous intrusion groundwater release.

### 5.3.3. Behavior of the Waste Form in an Eruptive Conduit

**Assumption:** The waste package, drip shield, and other components of the engineered barrier system provide no protection to the waste form during the eruptive event. Waste particle diameter (CRWMS M&O 2000e) in the eruptive environment has been estimated assuming that the waste form is directly exposed to the magmatic environment.

**Rationale:** The assumption is conservative, and is consistent with the assumptions made regarding the behavior of the waste package and engineered barrier system.

**Confirmation Status:** This assumption is adequately conservative such that additional confirmation is not needed.

**Use in Analysis:** This assumption is not used directly in this analysis: rather, it was used in the analysis reported in CRWMS M&O 2000e (Waste Form FEPs AMR) that characterized uncertainty in the waste particle diameter in an eruptive environment. The assumption is included here only for clarity and completeness. See Section 6 for a discussion of waste particle diameter.

### 5.3.4. Behavior of the Waste Form in Proximity to an Igneous Intrusion Groundwater Transport Event

**Assumption:** All waste material in waste packages damaged as a result of proximity to an igneous intrusion is assumed to be available for incorporation in the unsaturated zone transport model, dependent on solubility limits and the availability of water.

Availability of water should be determined using the seepage model for nominal performance, neglecting the thermal, mechanical, and chemical effects of the intrusion on the drift environment. No credit is taken for water diversion by the remnants of the drip shield or waste package, and cladding should be assumed to be fully degraded.

**Rationale:** The assumption is considered to be conservative in its overall effect. The actual thermal, chemical, hydrological, and mechanical conditions within a drift following igneous intrusion are unknown, but the conservatism of assuming that the remnants of the waste package and engineered barriers provide no protection is considered to be sufficient to compensate for uncertainty associated with conditions in the drift.

**Confirmation Status:** This assumption is adequately conservative such that additional confirmation is not needed.

**Use in Analysis:** This assumption is used in Section 6 to support the conceptual model for the igneous intrusion groundwater release.

### 5.3.5. Type of waste

**Assumption:** For the purposes of estimating waste particle diameters in the eruptive environment, all waste is assumed to be unaltered commercial spent fuel.

**Rationale:** The assumption is considered reasonable for analyses of the 10,000-year post-closure performance period specified in the DOE Interim Guidance (Dyer 1999).

CRWMS M&O 2000e notes waste forms may have different particle diameters in the eruptive environment, depending both on the initial type of the waste (commercial spent fuel or glass waste) and the degree and type of alteration of the waste. The assumption to treat all waste as unaltered commercial spent fuel is conservative with respect to the unaltered glass waste forms that make up most of the waste volume (CRWMS M&O 2000e), and which are likely to have particle diameters comparable to those of the ash itself (see Section 6.1.1.13), larger than the values used for spent fuel. The assumption that the waste form is unaltered is reasonable for analyses of the 10,000-year post-closure performance period, given the relatively small number of waste packages expected to fail under nominal conditions during that period and the expected stability of the waste form within the undisturbed waste packages.

**Confirmation status:** This assumption is considered realistic for analyses of 10,000-year performance, as described above. Sensitivity analyses can be designed and executed using the TSPA-SR model to test sensitivity of overall performance to the assumption that waste remains unaltered. However, such analyses are outside the scope of this AMR.

## 5.4. ASSUMPTIONS REGARDING INPUTS TO THE ASHPLUME MODEL

### 5.4.1. Treatment of the Incorporation Ratio

**Assumption:** The incorporation ratio is assumed to be 0.3.

**Rationale:** The incorporation ratio describes the ratio of ash/waste particle sizes that can be attached together. The incorporation ratio $\rho_c$ is given by equation 1.

$$\rho_c = \log_{10}\left(\frac{d^a_{\min}}{d^w}\right) \qquad \text{(eqn. 1)}$$

where $d^a_{\min}$ is the minimum ash particle size needed for incorporation and $d^w$ is the waste particle size to be incorporated. An incorporation ratio of 0.3 was utilized by Jarzemba et al. (1997, p. 2-6), and is utilized within this AMR. This corresponds to a maximum waste particle size being incorporated to half the diameter of the ash particle (i.e., any waste particles larger than half the ash particle diameter cannot be incorporated into the ash).

The mathematics of the ASHPLUME model make the simplifying assumption that all waste particles corresponding to values below the incorporation ratio are attached to ash particles for transport. The code also contains the assumption that any waste particles larger than this size are not transported downwind.

The waste particles are incorporated into the ash particles for transport. This combined ash/waste particle is treated as an ash-only particle during transport within the code to simplify the atmospheric dispersal code. The code maintains an inventory of the amount of waste that is attached to ash particles and then calculates how much waste is deposited at each grid location, directly proportional to the mass of ash that is deposited at that location. For example, a certain volume of ash is erupted into the atmosphere and all the waste mass is incorporated into this ash. Thus, at a grid point downwind where 1% of the total ash was calculated by ASHPLUME to be deposited, a corresponding 1% of the total waste would also be deposited at that same grid point. Changes in the ash particle density due to incorporation of potentially denser waste particles could affect the transport dynamics of the combined ash/waste particles. However, the inclusion of this complicating effect would tend to reduce the atmospheric transport time of the combined particles. This complication would be non-conservative with respect to the amount of waste transported relatively greater distances from the repository.

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

### 5.4.2. Treatment of the Maximum Particle Diameter for Transport

**Assumption:** The maximum particle diameter available to be transported downwind is assumed to be 10 cm.

**Rationale:** This parameter is a simple check within the code to limit the maximum size of particles that are considered for transport in the model. This value is chosen as 10 cm and is consistent with the intended usage of the ASHPLUME model (Jarzemba et al. 1997). This is a large enough particle size that transport of particles larger than this size 20 kilometers downwind is not physically realizable.

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

### 5.4.3. Treatment of Minimum Height on Eruption Column Considered During Transport

**Assumption:** The minimum eruption column height to be considered during transport is assumed to be 1 meter.

**Rationale:** This parameter allows the modeler to determine a lower cut-off height below which particle transport is not calculated within the code. The value for this parameter was chosen to be 1 meter which is essentially ground level. This has the effect of including all the particles that are below the Maximum Particle Diameter for Transport in the analysis. This is a conservative choice for this input value since the full eruptive column height is being considered in the analysis (from ground level to the maximum column height).

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

### 5.4.4. Treatment of Threshold Limit on Ash Accumulation

**Assumption:** The threshold limit on ash accumulation is assumed to be $10^{-10}$.

**Rationale:** This defines any ash concentrations ($g/cm^2$) below $10^{-10}$ as zero. This is a reasonable assumption since any values below this limit will have a negligible impact on the overall average dose for 100 simulations of the model.

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

### 5.4.5. Treatment of Constant (C) Relating Eddy Diffusivity and Particle Fall Time

**Assumption:** The value for Constant (C) Relating Eddy Diffusivity and Particle Fall Time was assumed to be 400 $cm^2/sec^{5/2}$.

**Rationale:** The constant (C) controlling eddy diffusivity relative to particle fall time was modeled by Suzuki (1983, p. 99). The eddy diffusivity (K) of the particles is expressed in equation 2 as a function of the particle fall time.

$$K = Ct^{3/2} \qquad \text{(eqn. 2)}$$

Where t is the particle fall time. This equation assumes turbulent particle diffusion and that the particle diffusion time equals the particle fall time (i.e., time to settle to the ground in seconds). The above equation is obtained from Suzuki (1983) via the assumption that eddy turbulent diffusion occurs over large-scale eddies and can thus be related to the particle fall times. The apparent eddy diffusivity in $cm^2/s$ ($A_L$) of particles in the atmosphere is related to the scale of diffusion in cm (L) by equation 3.

$$A_L = 0.08073\, C^{2/5} L^{6/5} \qquad \text{(eqn. 3)}$$

Figure 2 in Suzuki 1983 (p. 99) shows a linear relationship between log ($A_L$) and log (L) in the atmosphere given by equation 4.

$$A_L = 0.887\, L^{6/5} \qquad \text{(eqn. 4)}$$

Combining these equations yields a constant value for C of 400 $cm^2/sec^{5/2}$, which is used in the current analysis. This usage is consistent with the usage in the ASHPLUME model (Jarzemba et al. 1997).

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

### 5.4.6. Treatment of Ash Dispersion Controlling Constant

**Assumption:** The Ash Dispersion Controlling Constant is assumed to be a log-uniform distribution that has a minimum value of 0.01 and a maximum value of 0.5.

**Rationale:** The ash dispersion controlling constant (beta) was defined by Suzuki (1983, p. 104-107). This parameter affects the distribution of particles vertically in the ash column. The erupted ash cloud is assumed (by Suzuki) to spread axially at a rate of half the height. Thus, when the column reaches 5 km in height it will have spread to a total lateral width of 2.5 km, or 1.25 km in all directions from the vent. The ASHPLUME code takes a beta value and determines the vertical profile of particle sizes in the erupted column that will then be transported downwind. Suzuki discussed beta values of 0.01, 0.1, and 0.5. The larger beta becomes, the more the particle distribution becomes skewed towards the top of the column. Therefore, a value of 0.5 generates a column particle distribution that contains very few particles in the lower 70% of the column, while a beta value of 0.01 gives an upwardly decreasing distribution that contains the most particles lower in the column. Suzuki states that beta values of 0.5 or greater are possible, but are not very likely to occur. Jarzemba et al. (1997, p. 4-1) utilizes a log-uniform distribution for beta that has a minimum value of 0.01 and a maximum value of 0.5. This range of values spans over an order of magnitude and encompasses the range that is valid for the ASHPLUME model.

**Confirmation Status:** This assumption is considered reasonable and consistent with the intended use of the ASHPLUME model. No further confirmation is needed.

**Use in Analysis:** This assumption is utilized in Section 6 to support the model for volcanic eruption releases.

## 6. ANALYSIS/MODEL

Two igneous events will be modeled within the TSPA-SR. The first is the volcanic eruption and the second is the igneous intrusion groundwater transport event. These two events are discussed in detail in the following sections and the input parameters and corresponding input values for these models are presented below. Section 6.1 discusses the volcanic eruption while section 6.2 details the igneous intrusion groundwater transport event. Depending on the magnitude, geometry, and type of an igneous event, the result could range from a non-impact on the waste packages (dike does not intersect the repository) to a severe impact (multiple large conduits from a repository-long dike form directly over drifts).

This AMR uses various TBV data and N/A Technical Product Output data (Section 4). Should problems processing any of these TBV data be encountered, then an alternative analysis and documentation for the impacted data would need to be completed.

## 6.1. VOLCANIC ERUPTION CONCEPTUAL MODEL

The igneous volcanic eruption is modeled utilizing the code ASHPLUME (Jarzemba et al., 1997) which was developed at the Center for Nuclear Waste Regulatory Analyses (CNWRA). This model is an implementation of the Suzuki igneous model (Suzuki 1983). The Suzuki model is a mathematical implementation of an atmospheric dispersal model. The Suzuki model inputs basic physical parameters about the igneous event and then utilizes an atmospheric dispersal model to correlate the ash particles settling to the surface with the atmospheric downwind transport of these ash particles. It is important to note that the Suzuki model does not attempt to model the subsurface physics of the igneous event, but instead relies on expert inputs for the physical characteristics of the volcano and then models the atmospheric dispersal of the ash particles downwind until the ash settles on the ground. The CNWRA (Jarzemba et al. 1997) modified the Suzuki model by adding the coupling of waste particles to the ash particles in order to model a volcanic igneous event through the Yucca Mountain Repository. The resulting code was ASHPLUME version 1.0 and maintained all the physical characteristics of the Suzuki model (Jarzemba et al., 1997).

The ASHPLUME version 1.0 model was modified to version 1.3 for use in the TSPA Viability Assessment (VA) (DOE 1998a, Volume 3, Section 4.4). The 1.0 version of ASHPLUME utilized inputs of event duration and event power (the average power at which the eruptive magma is expelled from the volcano). From these inputs the model calculated the event volume; the column height (the maximum height to which the eruptive column rises above the volcano). The 1.3 version of ASHPLUME was modified to input the event volume as an independent variable and the event duration and column height were calculated within the code.

The ASHPLUME code discussed in this AMR utilizes the same physics as those in the model used for the TSPA-VA. The current AMR implementation however, represents a major improvement over the TSPA-VA model due to improvements in the input parameter values. The input parameter values for the current implementation were obtained from several supporting AMRs, calculations, and references (CRWMS M&O 1999e, CRWMS M&O 2000b, DTN:LA9912GV831811.001, CRWMS M&O 2000e, CRWMS M&O 2000d, DTN:SN0001T0801500.001, Jarzemba et al. 1997, Lide 1994, Suzuki 1983, Reamer 1999, Wilson and Head 1981, Quiring 1968, DTN:SN0004ERUPTION.000, DTN:SN0004WINDDATA.000) and represents a hypothetical volcanic eruption at Yucca Mountain. An additional improvement is the utilization of supporting Calculations (CRWMS M&O 2000d and CRWMS M&O 1999e) to model the intersection of a dike with the repository drifts. These provide an improved technical basis for analysis of how many drifts and subsequent waste packages will be intersected by the igneous dike. The added detail and technical justification to the input parameter values provides a means of tracing the justifications behind the input values that are utilized within this AMR and allows for an improved accountability for the use of model input values. The input parameters and their associated values are discussed in more detail in the following subsections.

The use of ASHPLUME to model a volcanic eruption at Yucca Mountain is considered reasonable for this event. This is due to the acceptance of the underlying Suzuki model for modeling volcanic events using the Suzuki model as it was implemented by the CNWRA coupled with sound estimates for the input values to the model provides a reasonable first order estimate of the igneous event. Thus, this AMR recommends utilizing this model for the TSPA-SR.

PUFF, an alternative model was evaluated for the volcanic eruptive event (Searcy et al. 1998). This model was evaluated conceptually based on descriptions in the scientific literature, but no working version of the model could be obtained from the originators to test because the developers did not consider the code ready for general release. Another alternative model considered was the gas-thrust model that was proposed in the NRC's Igneous Activity Issue Resolution Status Report (IRSR), Rev. 2, Section 4.2.2.3 (Reamer 1999). After evaluating this model, it was concluded that the ash dispersion controlling constant (beta) within ASHPLUME had a similar effect as the proposed model. The parameter beta has the effect of generating a vertical distribution of particles above the volcano. The gas-thrust model appears to be a variation on that concept and within the uncertainties of the input parameter values, it is not certain which approach is more conservative. Thus, we chose to maintain the current treatment of the vertical particle distribution within ASHPLUME.

### 6.1.1. Direct Feeds to ASHPLUME

The twenty input parameters listed below are defined as either point values or are pre-defined within the code as simple distributions and are passed directly into the ASHPLUME code as defined without any sampling within the TSPA model. These parameters are:

- Minimum Grid Location on X-Axis
- Maximum Grid Location on X-Axis
- Minimum Grid Location on Y-Axis
- Maximum Grid Location on Y-Axis

- Number of Grid Locations on X-Axis
- Number of Grid Locations on Y-Axis
- Maximum Particle Diameter for Transport
- Minimum Height on Eruption Column Considered in Transport
- Threshold Limit on Ash Accumulation
- ASHPLUME Run Type: Deterministic or Stochastic
- Option to Save Particle Size Information at the Dose Point
- Particle Shape Factor
- Air Density
- Air Viscosity
- Constant (C) Relating Eddy Diffusivity and Particle Fall Time
- Incorporation Ratio
- Ash Settled Density
- Ash Particle Densities
- Ash Particle Sizes Corresponding to Densities
- Waste Particle Diameter

These parameters (except for the waste particle size) represent model settings within the code and basic physical parameters. These parameters are important to the ASHPLUME model because they set the conditions under which the model will be run.

#### 6.1.1.1. Grid Location and Spacing for X-Axis and Y-Axis

The grid location and spacing for the ASHPLUME code simulations is chosen to correspond to a deterministic simulation (single volcanic eruption event) with the critical group located 20 kilometers south of the volcanic center. The grid location is independent of the actual site geography and is modeled relative to the volcanic center. Thus, a minimum x and y axis grid spacing each defined as 0 corresponds to the volcanic center or source of the event. A maximum x-axis grid location of 0 corresponds to the centerline of the event (i.e., the event is directed straight at the critical group for the purposes of defining the grid locations). The maximum y-axis grid location is –20, which corresponds to a location 20 kilometers due south from the volcanic center. The number of grid spacings on both the x and y-axis is defined as 1. This facilitates faster model simulations since we are only interested in reporting the results at the critical group location 20 kilometers due south.

#### 6.1.1.2. Maximum Particle Diameter for Transport

This parameter is a simple check within the code to limit the maximum size of particles that are considered for transport in the model. This value is chosen as 10 cm (Section 5.4.2), which is a large enough particle size that transport of particles larger than this size 20 kilometers downwind is not physically realizable.

6.1.1.3. Minimum Height of Eruption Column Considered in Transport

This parameter allows the modeler to determine a lower cut-off height below which particle transport is not calculated within the code. The value for this parameter was chosen to be 1 meter (Section 5.4.3), which is essentially ground level. This has the effect of including all the particles that are below the Maximum Particle Diameter for Transport in the analysis. This is a conservative choice for this input value since the full eruptive column height is being considered in the analysis (from ground level to the maximum column height).

6.1.1.4. Threshold Limit on Ash Accumulation

This defines any ash concentrations ($g/cm^2$) below $10^{-10}$ as zero (Section 5.). This is a reasonable assumption since any values below this limit will have a negligible impact on the overall average dose for 100 simulations of the model.

6.1.1.5. ASHPLUME Run Type: Deterministic or Stochastic

The ASHPLUME code has the option of being run in either a deterministic or a stochastic mode. The deterministic mode allows parameters that are distributions to be sampled outside of ASHPLUME (within the TSPA) and then to pass the sampled point values for each parameter into ASHPLUME code. Each realization in the deterministic mode simulates only one volcanic event at a time. In contrast, the stochastic mode allows the user to input distributions for the parameters directly into ASHPLUME and then to execute the code up to 1000 times (simulating a new volcanic event with each simulation). The parameters are sampled directly within the ASHPLUME code in this mode. ASHPLUME will be run in deterministic mode with the TSPA model to allow GoldSim to control sampling and the simulation of multiple realizations.

6.1.1.6. Option to Save Particle Size Information at the Dose Point

The ash particle size information at the dose point will not be saved. Saving this information would have the effect of slowing down the model execution.

6.1.1.7. Particle Shape Factor

The particle shape factor is a parameter that is used to describe the shape of the ash particles being transported in the model. The shape factor is defined as $F=(b+c)/2a$, where $a$, $b$, and $c$ are the length of the longest, middle, and shortest axes of the particles. DTN:LA9912GV831811.001 defines the ash shape factor to be 0.5. This is the default shape factor that was utilized by Jarzemba et al. (1997) and was determined in CRWMS M&O 2000a to be a reasonable value for this parameter. This parameter only applies to the ash and does not apply to the waste. The waste is incorporated onto ash particles in order to be transported downwind and even though some ash particles have attached waste particles, the simplifying assumption is made in the ASHPLUME code to treat all the ash (and ash/waste) particles as having the same shape factor to simplify the code.

6.1.1.8. Air Density and Air Viscosity

The air density and air viscosity are constants within this model. Because the density and viscosity of air do not vary much within the altitude range of interest, this should be a reasonable approximation. The density and viscosity were selected at an altitude of 1000 meters above sea level and at ambient temperature (25 °C). Because the model does not take into account thermal effects, the ASHPLUME code implicitly assumes that the ash plume is instantaneously changed to ambient temperature. These parameter values for air at 1000 meters above sea level (approximate elevation at ground surface) and at 25 °C are 0.001117 $g/cm^3$ (density) and 0.0001758 g/m-s (viscosity) (Lide 1994).

6.1.1.9. Constant (C) Controlling Eddy Diffusivity Relative to Particle Fall Time

The constant (C) controlling eddy diffusivity relative to particle fall time is assumed to be 400 $cm^2/sec^{5/2}$ (Section 5.4.5).

6.1.1.10. Incorporation Ratio

The incorporation ratio was defined in Section 5.4.1 and was assumed to have a value of 0.3.

6.1.1.11. Ash Settled Density

The ash settled density is provided in DTN:LA9912GV831811.001 as 1.0 $g/cm^3$. This density is the bulk density of the ash that settles on the ground after eruption.

6.1.1.12. Ash Particle Densities and Corresponding Particle Sizes

The ASHPLUME code requires inputs for the densities of large and small ash particles. DTN:LA9912GV831811.001 defines the densities of ash particles as a function of the magma density. This AMR utilizes a magma density of 2.6 $g/cm^3$ which is within the range of magma densities reported in CRWMS M&O 2000a (the magma density distribution does not vary much within the region of interest). DTN:LA9912GV831811.001 defines the density of a 0.001 cm ash particle to be 80% of the magma density (2.08 $g/cm^3$), while a 1.0 cm ash particle has a density of 40% of the magma density (1.04 $g/cm^3$). The model calculates the density of the actual mean ash particle size that is used for each realization by using linear interpolation for the ash density between these two extremes.

#### 6.1.1.13. Waste Particle Diameter

The waste particle diameter for unaltered commercial spent nuclear fuel in a magmatic environment is defined by CRWMS M&O 2000e. The distribution defined in that document is utilized as a log triangular distribution with a minimum value of 0.0001 cm, a mode value of 0.002 cm, and a maximum value of 0.05 cm. The log-triangular distribution is currently presribed by the ASHPLUME code. This is the only distribution that is programmed into the code. All the remaining distributions will be sampled within the TSPA model and fed into the ASHPLUME code as point values for a particular simulation. As discussed in Section 5.3.5, it is assumed for the purposes of this analysis that this is an acceptable approximation for the waste particle diameter for all waste types.

### 6.1.2. ASHPLUME Feeds Sampled in the TSPA Model

The inputs identified below are defined as distributions (except mass of waste per package and percentage of hit packages that fail). These parameters will be sampled in the TSPA model and the sampled value for the parameter will then be fed into the ASHPLUME code as a point value input. These parameters are:

- Event Eruptive Volume
- Ash Mean Particle Diameter
- Ash Mean Particle Diameter Standard Deviation
- Event Power
- Ash Dispersion Controlling Constant
- Vent Diameter
- Initial Eruption Velocity
- Wind Speed
- Wind Direction
- Mass of Waste Released
  - Mass of Waste per Package
  - Number of Packages Hit per Drift
  - Number of Drifts Hit per Vent
  - Number of Conduits Intersecting Waste
  - Percentage of Hit Packages that Fail

#### 6.1.2.1. Event Eruptive Volume

A range for the event eruptive volume is defined in CRWMS M&O 2000b as 0.002 – 0.14 $km^3$. The NRC IRSR for Igneous Activity, Rev. 2 (Reamer 1999, p. 129) defines an eruptive volume range that spans 0.004 – 0.44 $km^3$. This AMR defines the eruptive volume as a log-uniform distribution that spans the range defined by these two documents (0.002 – 0.44 $km^3$). By incorporating the IRSR range, the higher eruptive-volume events are incorporated into the ASHPLUME model. The CDF for event eruptive volume is provided in Figure 2 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

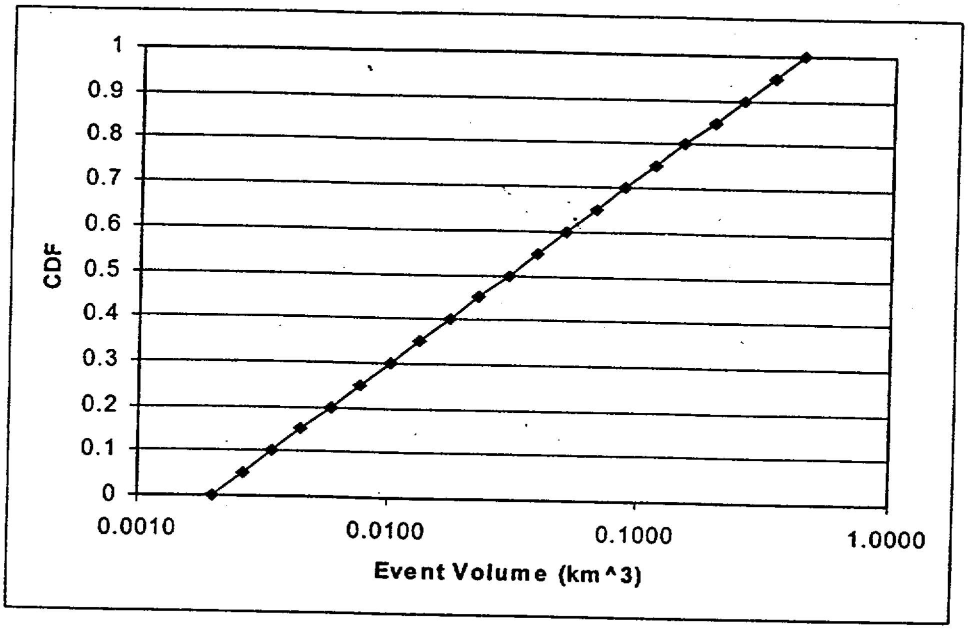


Figure 2: Event Eruptive Volume CDF

6.1.2.2. Ash Mean Particle Diameter

The ash mean particle diameter is obtained from DTN:LA9912GV831811.001. A log triangular distribution is defined with a minimum value of 0.001 cm, a mode value of 0.01 cm, and a maximum value of 0.1 cm. The ash mean particle diameter is sampled within the TSPA model and fed into ASHPLUME as a point value for each realization. The CDF for the mean ash particle diameter is given in Figure 3 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

6.1.2.3. Ash Mean Particle Diameter Standard Deviation

The ash mean particle standard deviation is provided in DTN:LA9912GV831811.001 as a uniform distribution from 1-3 (phi units, which are defined to be the negative logarithm in base 2 of the particle diameter in millimeters). The CDF for the mean ash particle diameter standard deviation is given in Figure 4 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

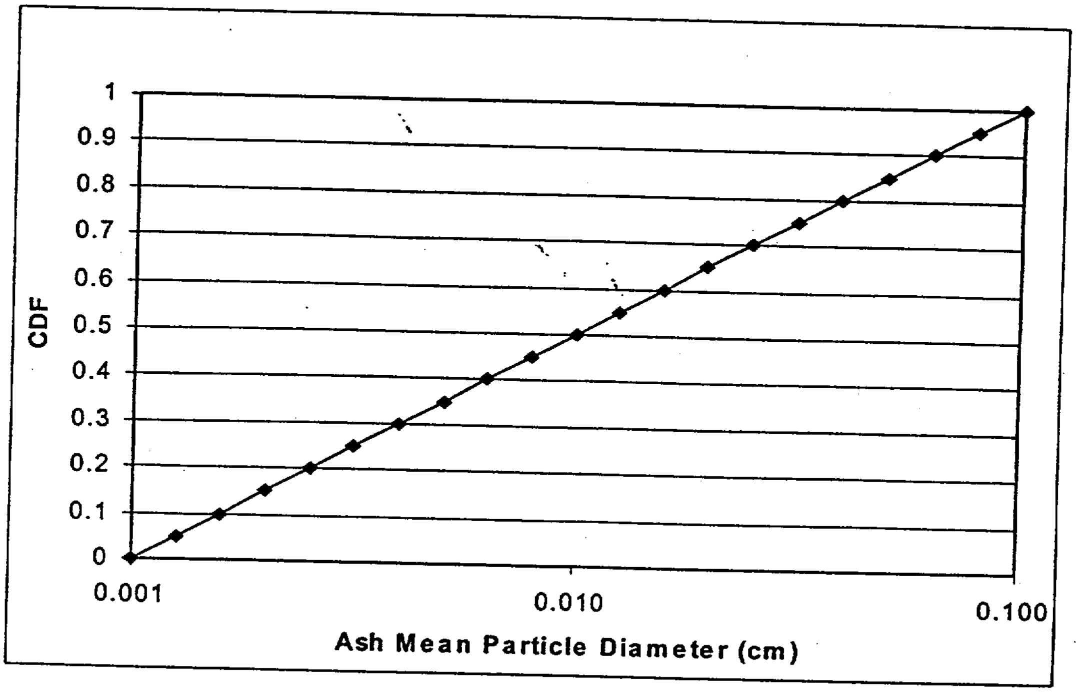


Figure 3: Ash Mean Particle Diameter CDF

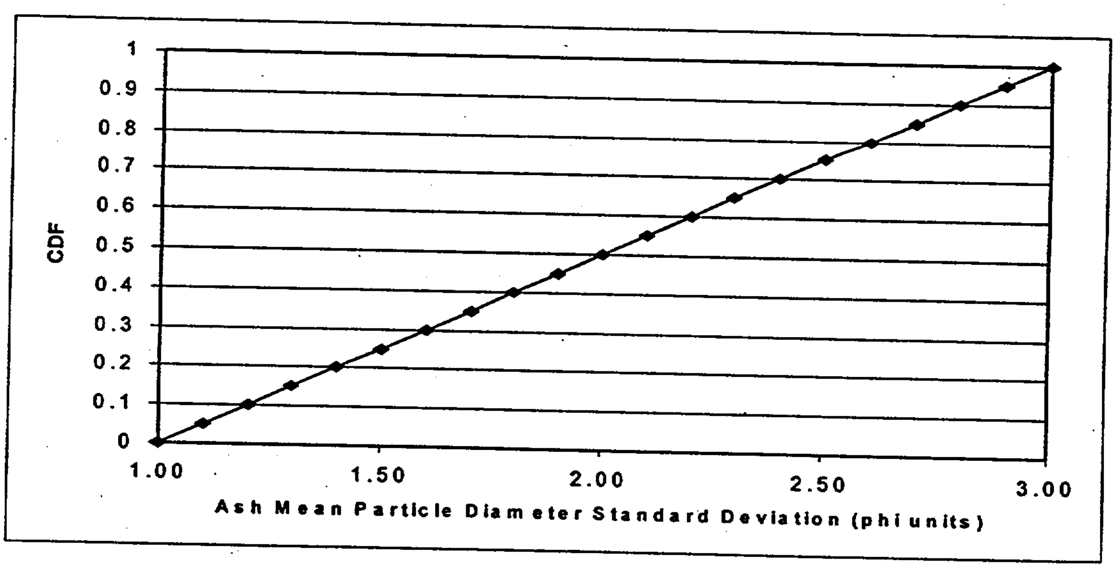


Figure 4: Ash Mean Particle Diameter Standard Deviation CDF

#### 6.1.2.4. Event Power

The event power is provided by DTN:LA9912GV831811.001. The eruptive power for eight representative events is utilized to form a CDF. These eight events span the expected range of events that could be expected at Yucca Mountain (CRWMS M&O 2000a). A CDF is formed from these eight events by assuming the power of each event is equally likely to occur and thus each representative event is equally weighted. The CDF for the event power is given in Figure 5 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model. Note that in the current version of ASHPLUME (Version 1.4LV), the role of the event power parameter in determining eruption height has been superseded by the modification that derives eruption height from event volume. The code still requires a value for the parameter, however, and it is recommended that the distribution reported here be used for all Yucca Mountain applications of ASHPLUME, including any future applications that may use modified versions of the code.

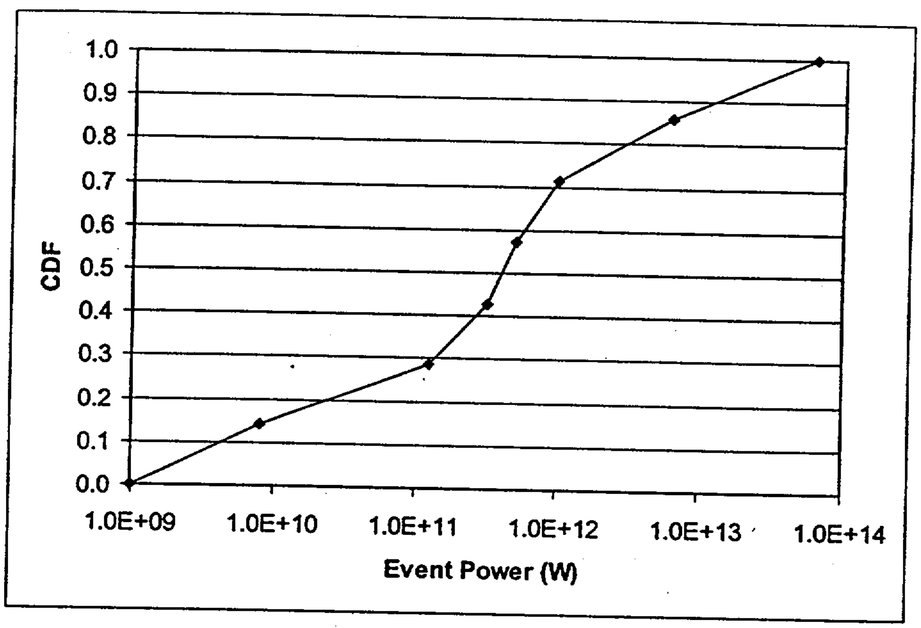


Figure 5: Event Power CDF

#### 6.1.2.5. Ash Dispersion Controlling Constant

The ash dispersion controlling constant (beta) was a log-uniform distribution that has a minimum value of 0.01 and a maximum value of 0.5 (Section 5.4.6). The CDF for the ash dispersion controlling constant is given in Figure 6 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

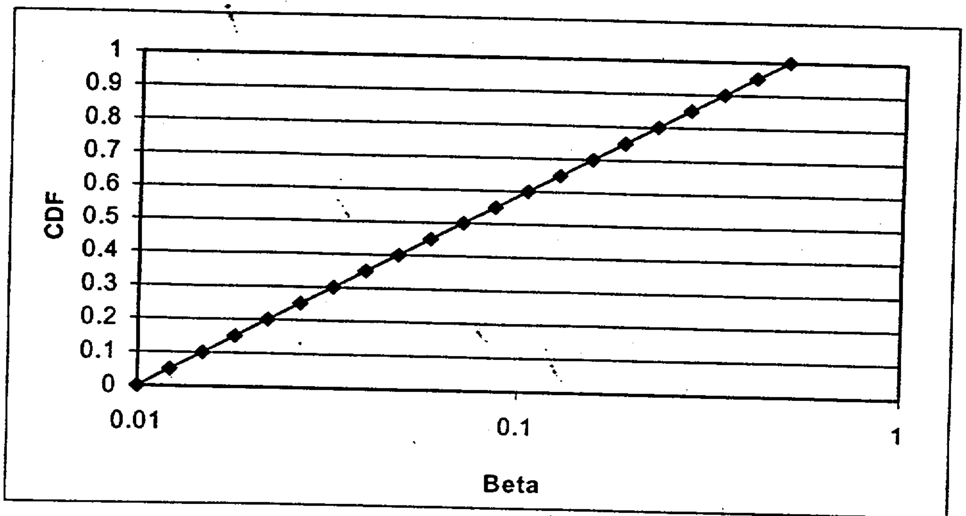


Figure 6: Ash Dispersion Controlling Constant CDF

### 6.1.2.6. Initial Eruptive Velocity and Conduit Diameter

The initial eruptive velocity of the event is defined from Wilson and Head (1981, p. 2977) as a function of the conduit radius. Table 3 (Wilson and Head 1981, p. 2977) shows a nearly linear relationship between the conduit radius and the initial eruption velocity for conduit radii of 0.2 – 30 meters and eruptive velocities of 0.033 – 86.2 m/s. This AMR utilizes conduit diameters up to 150 meters (DTN:LA9912GV831811.001). A linear least squares regression hand calculation on the data from Wilson and Head was done and the resulting linear equation extrapolated up to 150-meter conduit diameter. The resulting eruptive velocities were conditioned on the CDF for conduit diameter that is defined below.

The conduit diameter of an eruptive event is defined in DTN:LA9912GV831811.001. This distribution is defined in (CRWMS M&O 2000d) with a minimum value of 15 meters, a median value of 50 meters, and a maximum value of 150 meters. The CDF for the conduit diameter is given in Figure 7. This CDF is provided by this AMR and is sampled within the TSPA model.

The initial eruptive velocity is sampled in the TSPA model by first sampling the conduit diameter CDF and then choosing the corresponding value for the initial eruptive velocity. The CDFs for the conduit diameter and initial eruptive velocity are given in Figures 7 and 8 and in Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

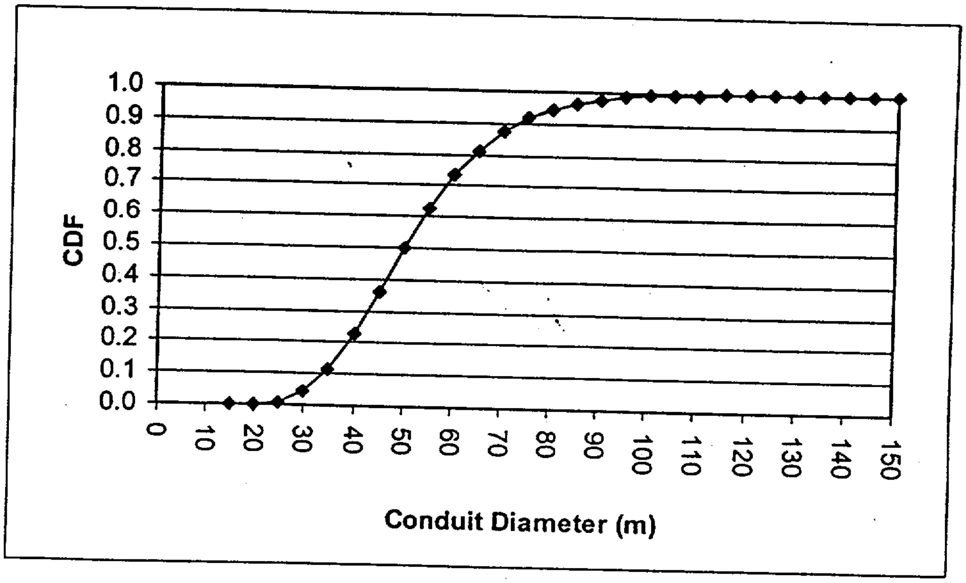


Figure 7: Conduit Diameter CDF

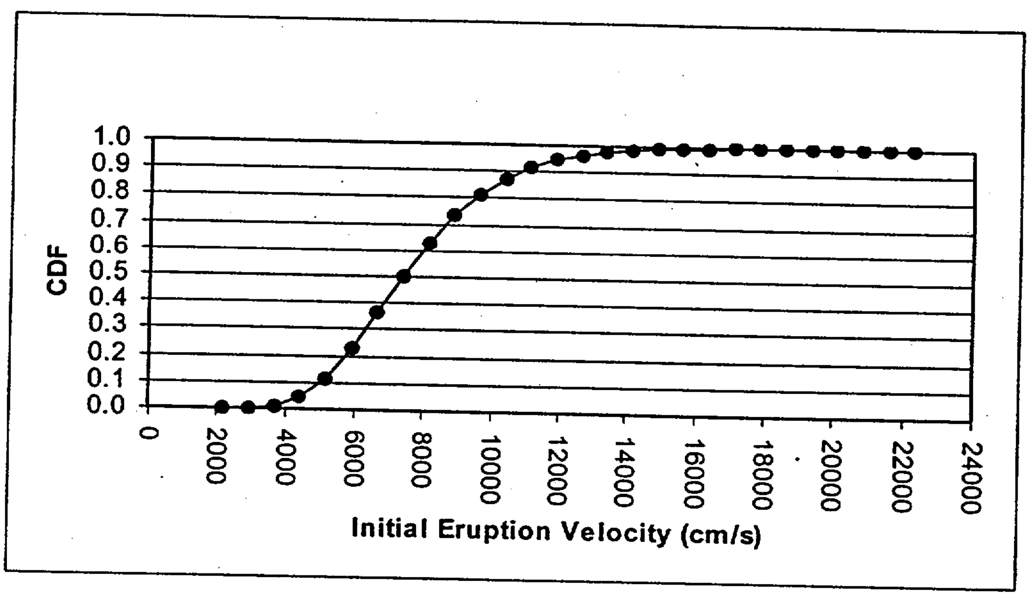


Figure 8: Initial Eruption Velocity CDF

6.1.2.7. Wind Speed

DTN:SN0004WINDDATA.001 provides wind speed data for the Yucca Mountain region for a seven year period (1957-1964). Data are reported from 5,000-16,000 feet (approximately 1,500-5,000 meters) above sea level for four different months of the year and as a function of wind direction. All wind speed data were averaged (time of year, elevation, and direction) to yield an overall bulk distribution for Yucca Mountain. The data were grouped into wind speed intervals (50 cm/s intervals) in a spreadsheet and a CDF was developed based on the number of wind speed occurrences within each group. The CDF for the wind speed is given in Figure 9 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA model.

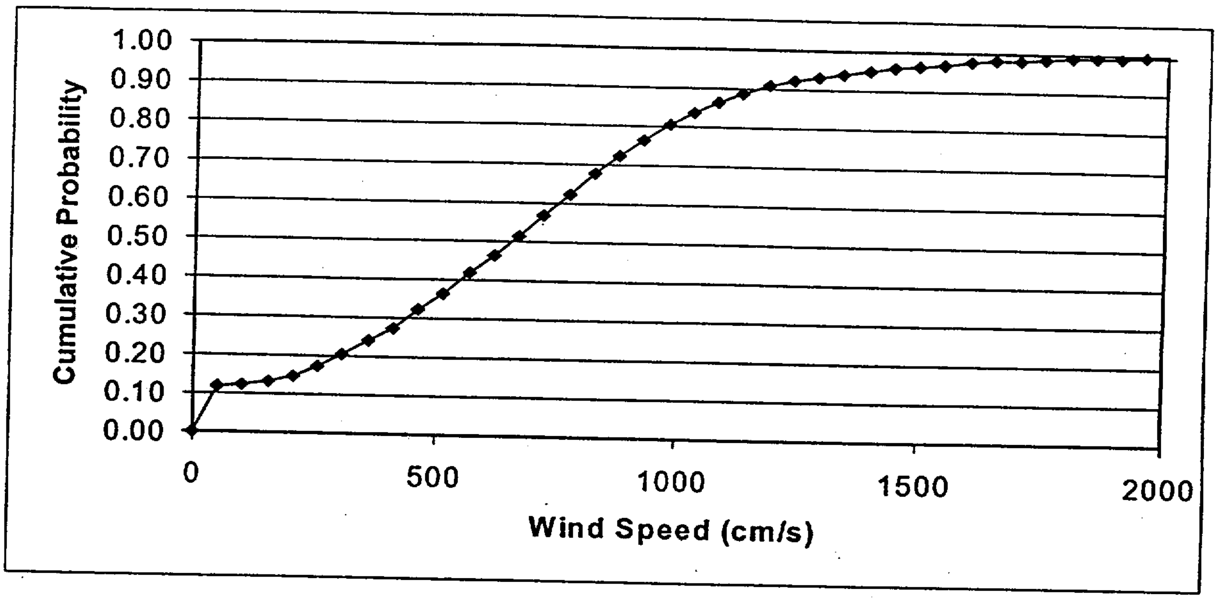


Figure 9: Wind Speed CDF

6.1.2.8. Wind Direction

DTN:SN0004WINDDATA.001 provides wind direction data for the Yucca Mountain region for a seven year period (1957-1964). The wind direction data ranged from 5,000-16,000 feet above sea level and was reported over four different months of the year and as a function of wind speed. All wind direction data were averaged together (time of year, elevation, and wind speed) to yield an overall bulk distribution for Yucca Mountain. The data were grouped into 30 degree intervals in a spreadsheet and a PDF was developed based on the number of wind direction occurrences within each group. The wind rose is given in Figure 10 and the PDF for the wind direction is given in Attachment I. This PDF is provided by this AMR and is sampled within the TSPA model.

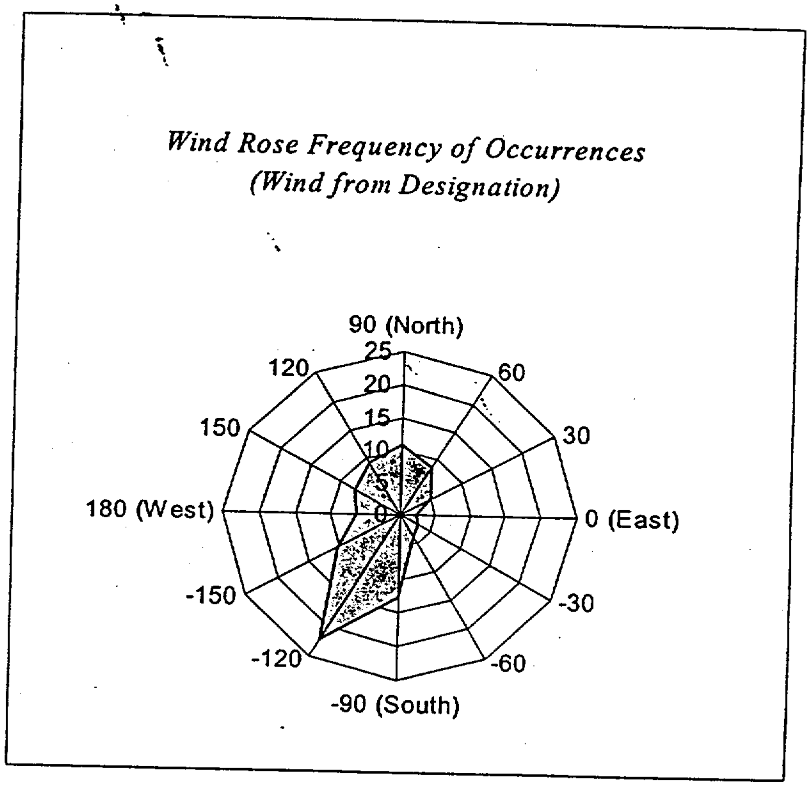


Figure 10: Wind Rose

6.1.2.9. Mass of Waste Released

The mass of waste released is calculated by utilizing several parameters. These parameters are the mass of waste per package (point value), number of packages hit per drift (CDF), number of drifts hit per conduit (CDF), number of conduits intersecting waste (PDF), and the percentage of hit packages that fail (point value). These five parameters are combined utilizing equation 5 that is calculated within the TSPA model to generate the mass of waste released for each realization.

Mass of Waste Released = (Mass of Waste per Package) (eqn. 5)
x (Number of Packages Hit per Drift)
x (Number of Drifts Hit per Vent)
x (Number of Vents Intersecting Waste)
x (% of Hit Packages that Fail)

The mass of selected radionuclides per waste package is provided directly within the TSPA model and is based on the repository inventory. The number of packages hit per drift, the drift spacing, and the associated design that was utilized is provided by

CRWMS M&O 2000d. This parameter is conditioned on the conduit diameter for the event (identical to conduit diameter used in the initial eruptive velocity derivation in Section 6.1.2.6). The CDF for the number of packages hit per drift is given in Figure 11 and in Attachment I and is sampled based on the conduit diameter that was sampled earlier. The number of drifts hit per conduit is a CDF that is dependent on the conduit diameter for the simulation. Conduit diameters 75 meters or smaller can only intersect

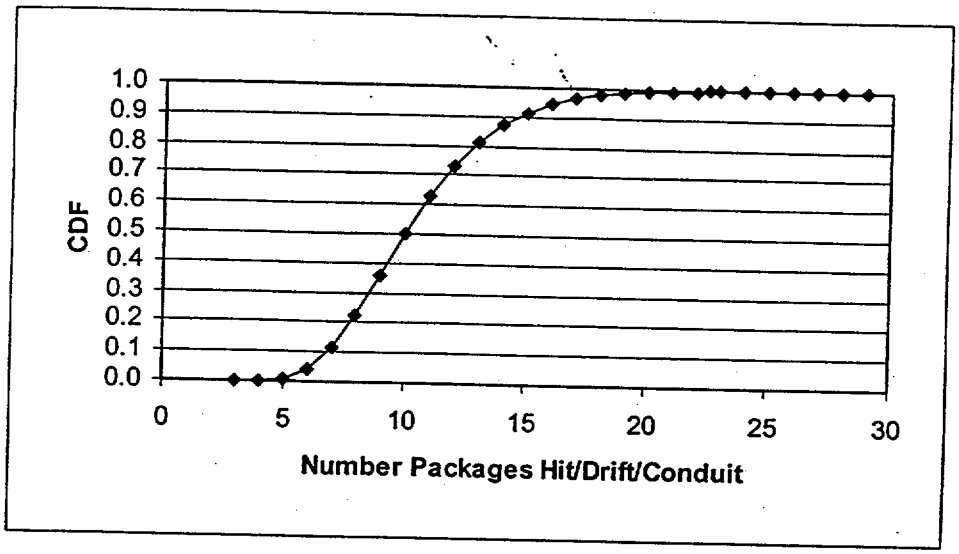


Figure 11: Number of Packages Hit per Drift per Conduit CDF Sampled on Conduit Diameter

one drift, while conduit diameters 80 meters or larger can intersect either one or two drifts. The larger the conduit, the higher the probability of intersecting two drifts and the more packages that are hit. In the calculation above, the simplifying assumption is that compared to the intersection with a single drift, intersecting two drifts results in twice the number of packages hit. This is a conservative assumption since it assumes that the conduit is centered on both drifts at the same time, which is not physically realizable. The CDF for the number of drifts hit per conduit as a function of conduit diameter is given in Figure 12 and Attachment I. The CDF values are unique to each conduit diameter. Reviewing Figure 12 shows that a CDF value of 0 means there is zero probability of 2 drifts being hit, while a CDF value of 0.325 means there is a 32.5% chance of hitting 2 drifts.

The number of conduits intersecting the waste is provided by CRWMS M&O 2000d and is normalized for 1-5 conduits. Thus, the zero conduit probabilities have been removed so that all the simulations will result in doses to the critical group. The results are then combined with the probability of zero conduits occurring; this results in a reduction in the final dose values. Accounting of the probability of zero conduits intersecting the waste is done in the post processing of the ASHPLUME results within the TSPA model and is

0.3643. The conditional PDF for the number of conduits intersecting waste drifts is given in Figure 13 and Attachment I.

The percentage of packages hit by magma that fail is described in Section 5.3.1. The assumption is made that 100% of packages hit by the conduit fail and the full contents of those intersected waste packages are available for input into the ASHPLUME model.

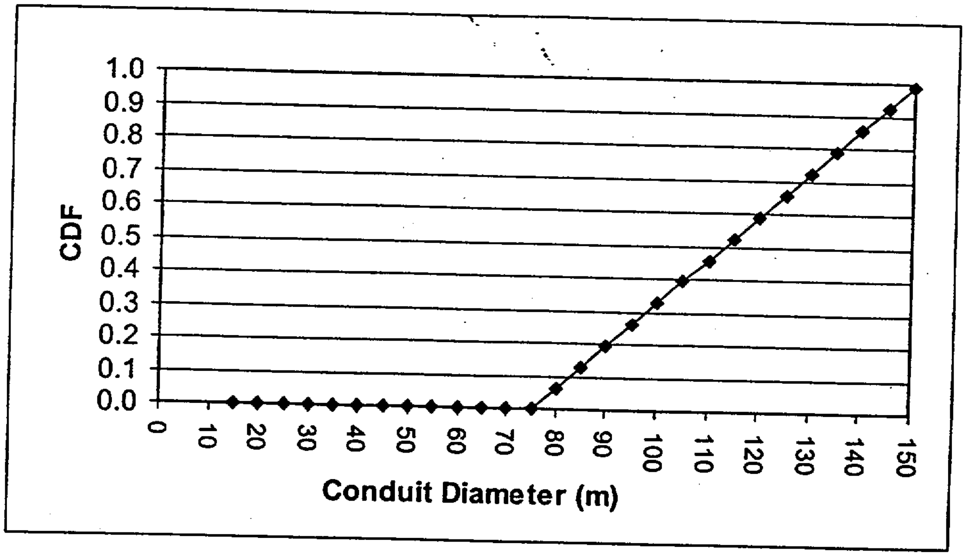


Figure 12: Conditional Probability of Intersecting 2 Drifts CDF Sampled on Conduit Diameter

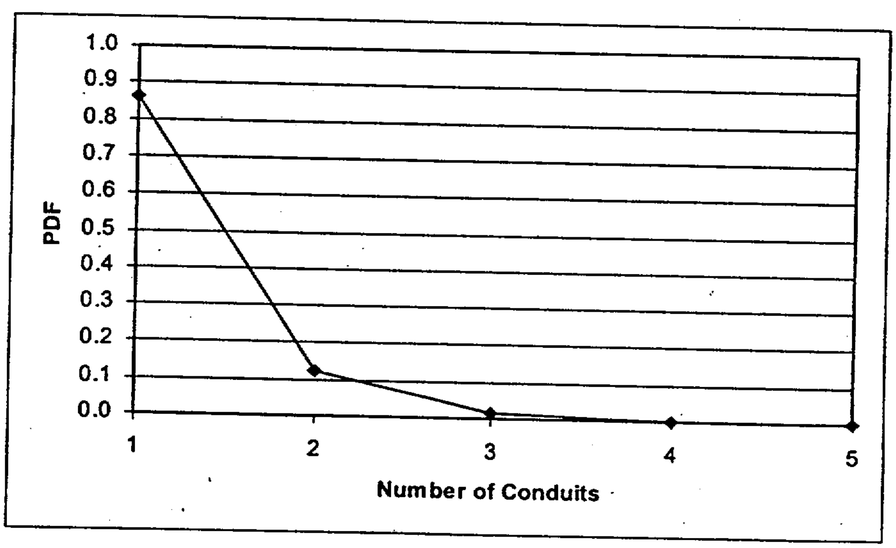


Figure 13: Number of Conduits Intersecting Waste Drifts PDF

### 6.1.3. Volcanic Eruption Inputs External to ASHPLUME

Two parameters for the volcanic eruption event are used in post processing of ASHPLUME results. These parameters are applied within the TSPA model and are combined with the waste surface concentration (g/cm$^2$) at the critical group located 20 kilometers south of the repository. This ASHPLUME output when combined with the parameters presented in this section along with the biosphere dose conversion factors (BDCFs), soil removal factors, and waste package material inventory is used within the TSPA model to calculate dose (CRWMS M&O 1999b). The igneous volcanic eruption event parameters that are defined here for use in the TSPA model are:

- Event Probability
- Probability of >0 Vents

6.1.3.1. Event Probability

"Event" is defined here to be an igneous intrusion that intersects the repository footprint, consistent with the way the term is used in CRWMS M&O 2000b, CRWMS M&O 2000a, and CRWMS M&O 2000d. The event probability is obtained from CRWMS M&O 2000b. This probability is used within the TSPA model in calculating the expected annual for the critical group. The CDF for event probability is given in Figure 14 and Attachment I. The median value for the CDF is 8.51E-9. This CDF utilizes probabilities that were taken from the values provided by CRWMS M&O 2000b for the full repository layout, including the primary and contingency blocks. This has the effect of slightly overestimating the probabilities that would result if only the primary block were used.

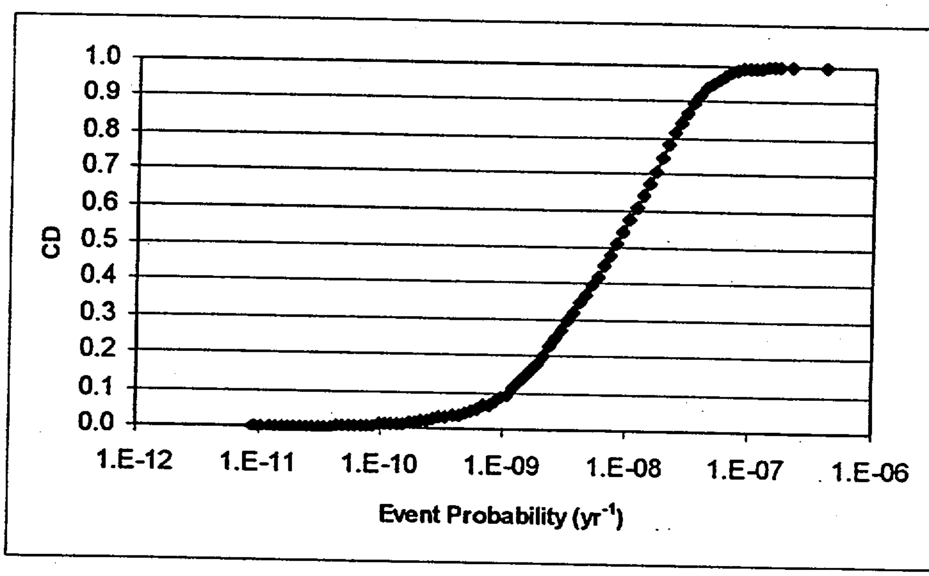


Figure 14: Event Probability CDF

6.1.3.2. Probability of more than Zero Vents Intersecting Waste

Given that intersection of the repository footprint occurs, the probability of a number of vents >0 intersecting the waste during igneous volcanic eruptive event, conditional on the occurrence of an igneous intrusion that intersects the repository, was obtained from DTN:SN0001T0801500.001. This parameter is used in conjunction with the event probability described in 6.1.3.1 to post process the ASHPLUME results. The zero conduit cases result in no ashfall dose for the critical group because no waste is entrained by the volcanic eruption. Eliminating these cases in the ASHPLUME runs provides improved statistical results because all 100 simulations have the potential to result in a dose. These results are then conditioned by multiplying the event probability above by the probability of at least one conduit occurring. This probability is 0.3643. Thus, in 36.43% of the cases at least one conduit intersects the waste, while the remaining 63.57% of the cases result in no conduits through the waste and no dose at the critical group due to a volcanic eruption. Conceptually, these cases represent igneous intrusive groundwater events in which the conduit formed outside the repository footprint and did not intersect waste. The median event probability modified by the probability of at least one conduit through the waste is 3.10E-9. This CDF utilizes probabilities that were taken from the values provided by CRWMS M&O 2000b for the full repository layout, including the primary and contingency blocks. This has the effect of slightly overestimating the probabilities that would result if only the primary block were used.

## 6.2. IGNEOUS INTRUSION GROUNDWATER TRANSPORT CONCEPTUAL MODEL

The igneous intrusion groundwater transport event conceptual model describes what could happen if waste packages in the drifts are affected by a magmatic intrusion. It is assumed that the affected waste packages provide no protection to the waste, which is treated as if it is all available after the magma cools for transport in groundwater flow through the unsaturated zone with the flow characteristics and transport properties described in the Unsaturated Zone (UZ) (TSPA model) Flow Model. Upon reaching the water table the transport continues under the conditions described by the Saturated Zone (SZ) (TSPA model) Flow and Transport Model. The igneous intrusion groundwater transport event input parameters developed in this AMR are discussed in the sections below.

### 6.2.1. Event Probability

The event probability is a compilation of the CRWMS M&O (1996) expert elicitation's and is obtained from CRWMS M&O 2000b. This probability is used within the TSPA model in calculating the expected annual dose for the critical group. The CDF for event probability is given in Figure 14 and Attachment I. The median value for the CDF is

8.51E-9. This event probability CDF is the same for the volcanic eruption and igneous intrusion groundwater events.

### 6.2.2. Mass of Waste Per Package

The mass of radionuclides per waste package is provided directly within the TSPA model and is based on the repository inventory. Discussion of this parameter is outside the scope of this AMR.

### 6.2.3. Percentage of Hit Packages that Fail

All waste packages contacted by magma are assumed to fail. As discussed in Section 5.3.1, support for this assumption is provided by CRWMS M&O 1999e.

### 6.2.4. Number of Packages Hit

The number of packages hit by an intrusive event was provided by DTN:SN0001T0801500.001. The CDF for this parameter is given in Figure 15 and Attachment I. This distribution was developed in an Excel spreadsheet by combining possible combinations of dike lengths and azimuth angles (CRWMS M&O 2000b) for each set of "dike widths/number of dikes" (DTN:LA9912GV831811.001) combinations. The resulting number of packages hit for each "dike length/number of dikes" combination is a weighted average number of packages hit for that realization. This means that for every "dike width/number of dikes" combination all possible azimuth angles and dike lengths are considered. The number of packages hit by each of these possible azimuth angle, dike length pairs is coupled with the probability that that azimuth angle, dike length occurs. The number of packages hit for the "dike width/number of dikes" combination is then calculated as the weighted average over all the azimuth angles and dike lengths. This has the effect of providing a median value for the number of packages hit and eliminating the high and low end tails from the distribution for the number of packages hit.

## 6.3. MODEL VALIDATION

The models developed in this report consist of conceptual models for the response of the repository to igneous intrusion and volcanic eruption. For volcanic eruption, the model includes recommendation of specific software (ASHPLUME version 1.4LV) to implement portions of the model and the development of output parameter distributions appropriate for use as input in both ASHPLUME and the overall TSPA modeling conducted using GoldSim. For groundwater transport resulting from igneous intrusion,

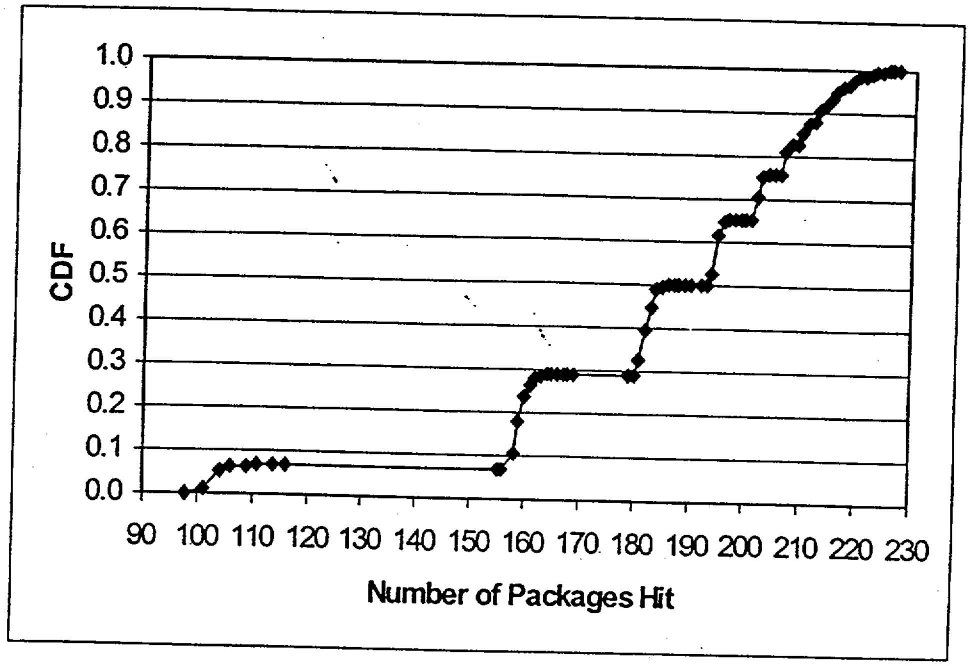


Figure 15: Number of Packages Hit for the Igneous Intrusive Groundwater Transport Event CDF (DTN:SN0001T0801500.001)

the model does not include specification of software (nor does implementation of the model require additional software beyond that contained in GoldSim), but the model does require development of parameter distributions for use in GoldSim. For both eruption and intrusion, the conceptual models developed in this report are defined in part by assumptions described in Section 5.

Because this report does not document the computational implementation of the conceptual models it develops, quantitative validation cannot be provided by comparison of overall analysis results against data acquired from experiments or analog studies. Instead, validation of the conceptual models is provided here by discussion of the validity of the individual components of the models: i.e., the defining assumptions, the parameters, and, for the volcanic eruption conceptual model, the recommended software.

### 6.3.1. Validation of model assumptions

Model assumptions are described in Section 5. Two basic criteria are used to evaluate the validity of the assumptions. 1) Assumptions are valid if they are shown to be conservative with respect to the overall performance of the system in response to igneous disruption. 2) Assumptions are valid if they are shown to be reasonable simplifications that are consistent with available information and do not introduce nonconservative biases into the analysis. These criteria are justified on the basis that they allow the development of a model that does not under-represent the potential negative impacts of igneous disruption.

As described in the "justification" sections associated with each assumption described in Section 5, all assumptions used in the development of these conceptual models are identified as either conservative or reasonable, and are valid consistent with the criteria described above.

### 6.3.2. Validation of model parameters

Parameter values and distributions that are part of the conceptual models developed in this report are described as output parameters in Sections 6.1 and 6.2. For purposes of validation, output parameters are divided into three types:

1) Parameter distributions (e.g, wind speed and direction) that are developed by analysis from the input data described in Section 4.

2) Parameter values and distributions (e.g., conduit diameter) that are simply direct restatements of input data, with no analysis.

3) Parameter values that are specific to the implementation of the code (e.g., grid locations) and do not require input data.

Table 4 summarizes the categorization of the output parameters and the approach taken to their validation. Validation criteria differ for each type of output parameter.

For the first category, in which parameters have been developed by analysis, validation is based on comparison of analysis results (the parameter distribution) with the input data described in Section 4. Output parameters in this category are considered valid if they meet the criterion of being consistent with the input data from which they are derived. As discussed in the context of the individual parameters in Sections 6.1 and 6.2, analyses used to develop the distributions are simple and straightforward, and validation of parameter distributions has therefore been done by direct visual comparison. All parameter distributions developed by analysis are found to be valid by comparison with the input data.

For the second category, in which parameters have simply been restated directly from the input data described in Section 4, validation is based on comparison of the output parameters to the input data. Output parameters in this category are considered valid if they meet the criterion of being the same as the input data. All parameter distributions restated directly from the input data are found to be valid by comparison with the input data.

Table 4 Validation of Model Parameters

| Output Parameter | Validation Category | Section in Which Output Parameter is Discussed | Validation Criteria |
|---|---|---|---|
| Minimum grid location on x-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Maximum grid location on x-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Minimum grid location on y-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Maximum grid location on x-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Number of grid locations on x-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Number of grid locations on y-axis | Model Implementation Parameter | 6.1.1.1 | Allows code to display output in desired form |
| Maximum particle diameter for transport | Model Implementation Parameter | 6.1.1.2 | Negligible impact on model implementation |
| Minimum height on eruption column considered in transport | Model Implementation Parameter | 6.1.1.3 | Negligible impact on model implementation |
| Threshold limit on ash accumulation | Model Implementation Parameter | 6.1.1.4 | Negligible impact on model implementation |
| ASHPLUME run type: deterministic or stochastic | Model Implementation Parameter | 6.1.1.5 | Allows code to display output in desired form |
| Option to save particle size information at the dose point | Model Implementation Parameter | 6.1.1.6 | Allows code to display output in desired form |
| Particle Shape Factor | Input Data | 6.1.1.7 | Directly restated from input data |
| Air Density | Input Data | 6.1.1.8 | Directly restated from input data |
| Air Viscosity | Input Data | 6.1.1.8 | Directly restated from input data |
| Constant (C) Relating Eddy Diffusivity and Particle Fall Time | Assumption | 6.1.1.9 | Consistent with model usage |
| Incorporation Ratio | Assumption | 6.1.1.10 | Consistent with model usage |
| Ash Settled Density | Input Data | 6.1.1.11 | Directly restated from input data |
| Ash Particle Densities at Min/Max Particle Sizes | Derived from Input Data | 6.1.1.12 | Consistent with input data |
| Ash Min/Max Particle Sizes for Densities | Input Data | 6.1.1.12 | Directly restated from input data |
| Waste Particle Size | Input Data | 6.1.1.13 | Consistent with input data |
| Event Eruptive Volume | Derived from Input Data | 6.1.2.1 | Consistent with input data |
| Ash Mean Particle Diameter | Input Data | 6.1.2.2 | Consistent with input data |
| Ash Particle Size Standard Deviation | Input Data | 6.1.2.3 | Consistent with input data |
| Event Power | Input Data | 6.1.2.4 | Consistent with input data |
| Ash Dispersion Controlling Constant | Assumption | 6.1.2.5 | Consistent with model usage |

| | | | |
|---|---|---|---|
| Conduit Diameters | Input Data | 6.1.2.6 | Directly restated from input data |
| Initial Eruption Velocity | Derived from Input Data | 6.1.2.6 | Consistent with input data |
| Wind Speed | Derived from Input Data | 6.1.2.7 | Consistent with input data |
| Wind Direction | Derived from Input Data | 6.1.2.8 | Consistent with input data |
| Number of Packages Hit per Drift | Input Data | 6.1.2.9 | Directly restated from input data |
| Number of Drifts Hit per Conduit | Input Data | 6.1.2.9 | Consistent with input data |
| Number of Conduits Intersecting Waste | Input Data | 6.1.2.9 | Directly restated from input data |
| Percent of Hit Packages that Fail (Volcanic Eruption) | Assumption | 6.1.2.9, see also 5.3.1 | Conservative |
| Event Probability (Volcanic Eruption) | Derived from Input Data | 6.1.3.1 | Consistent with input data |
| Probability of >0 Conduit | Derived from Input Data | 6.1.3.2 | Consistent with input data |
| Event Probability (Volcanic Eruption) | Derived from Input Data | 6.2.1 | Consistent with input data |
| Percent of Hit Packages that Fail (Igneous Intrusion) | Assumption | 6.2.3, see also 5.3.2 | Conservative |
| Number of Packages Hit (Igneous Intrusion) | Input Data | 6.2.4 | Directly restated from input data |

For the third category, in which parameters are defined specific to the implementation of the ASHPLUME model, validation is based on qualitative consideration of the impacts of the parameter value on the model implementation. Output parameters in this category are considered valid if they meet the criteria of either 1) allowing the code to display output in the desired form (e.g., specification of the grid location corresponding to the critical group location), or 2) having a conservative or negligible impact on the model implementation. As discussed in Section 6.1, all output parameters in this category have been found to be valid by evaluation against these criteria.

### 6.3.3. Validation of the conceptual models

The conceptual models developed in this report are described in Section 6.1, Volcanic Eruption Conceptual Model and Section 6.2, Igneous Intrusion Groundwater Transport Conceptual Model. Two criteria are used to evaluate the validity of these conceptual models. 1) A conceptual model is valid if it is shown to be conservative with respect to the overall performance of the system in response to igneous disruption. 2) A conceptual model is valid if it is shown to provide a representation of the physical processes of interest that is consistent with available technical information and adequate for the purposes of the analysis. In addition to these criteria, determination of the validity of a conceptual model also requires the determination that its underlying parameters and assumptions are valid. Because the development of the conceptual models described in this report does not include quantitative implementation of the computational models, validation does not include direct comparison of model results to experimental or observational data or analog information.

6.3.3.1. Validation of the volcanic eruption conceptual model

The volcanic eruption conceptual model is determined to be valid based on its consistency with available technical information and adequacy for its intended purpose. As discussed in Section 6.1, the conceptual model is derived directly from work published in the scientific literature and adopted by other workers, including the CNWRA. Alternative conceptual models were considered during its selection, and it was determined to be the most suitable model available for the purpose of estimating the release and transport of ash and waste during a volcanic eruption at Yucca Mountain. As discussed in Sections 6.3.1 and 6.3.2, the assumptions and parameter values and distributions used in the implementation of this conceptual model have also been determined to be valid for the purposes of the analysis.

6.3.3.2. Validation of the igneous intrusion groundwater transport conceptual model

The igneous intrusion groundwater transport conceptual model is determined to be valid based on its conservatism with respect to overall performance. As discussed in Sections 5.3.2, 6.2, and 6.3.2, the model includes the assumption that all waste packages affected by intrusion fail, and provide no further protection for the waste. This assumption over-estimates the amount of waste available for groundwater transport following an igneous intrusion. As discussed in Section 6.3.2, the parameter values and distributions used in the implementation of this conceptual model have also been determined to be valid for the purposes of the analysis.

## 6.4. VALIDATION OF SOFTWARE

As discussed in Section 6.1, implementation of the volcanic eruption conceptual model in GoldSim requires the use of the ASHPLUME version 1.4LV code. This code has been qualified in accordance with AP-SI.1Q, Rev. 2, ICN 3, *Software Management* (STN 10022-1.4LV-00). Verification and validation of the ASHPLUME code is outside the scope of this report, and is demonstrated through the software qualification process.

As discussed in Section 6.2, implementation of the igneous intrusion groundwater transport conceptual model in GoldSim requires no additional software beyond that developed by the TSPA for simulations of the nominal performance of the repository. Validation of the software for simulation of the nominal performance of the repository is outside the scope of this report.

# 7. CONCLUSIONS

This AMR provides the technical basis for parameters that will be used by TSPA-SR in the igneous consequence models. Two igneous events will be modeled within the TSPA-SR. The first event is a hypothetical volcanic eruption that intersects the repository and the second is an igneous intrusion groundwater transport event. Both of these events result from the intersection of a dike(s) with the repository. Both of these hypothetical events are modeled as resulting in exposing waste stored in the repository to transport processes.

It is recommended by this AMR that ASHPLUME version 1.4LV be utilized within the TSPA-SR to model potential volcanic eruption events at the Yucca Mountain repository. The parameters that are required to execute the ASHPLUME code within the TSPA-SR are summarized in Table 5 below. This table also provides a reference to the section within this AMR that discusses each parameter and the recommended values for each parameter in more detail.

The igneous intrusion groundwater event models what could happen if waste packages in the drifts are contacted by magma during an intrusion. It is recommended that this event be modeled by assuming that the waste packages have been compromised to the extent that all of the waste in the affected packages is exposed and that after the magma cools, groundwater begins to flow through the zone with the flow characteristics and transport properties described in the Unsaturated Zone Model and upon reaching the water table the transport continues under the conditions described by the Saturated Zone Flow and Transport Model. The UZ/SZ models are run within the TSPA-SR. The igneous specific parameters that are required simulate this event within the TSPA-SR are summarized in Table 6 below. This Table also provides a pointer to the section within this AMR that discusses each parameter and the recommended values for each parameter in more detail.

Table 5 Volcanic Eruption Event Input Parameters

| Output Parameter | Output Parameter Format | Section in Which Output Parameter is Discussed |
|---|---|---|
| Minimum grid location on x-axis | Point Value | 6.1.1.1 |
| Maximum grid location on x-axis | Point Value | 6.1.1.1 |
| Minimum grid location on y-axis | Point Value | 6.1.1.1 |
| Maximum grid location on x-axis | Point Value | 6.1.1.1 |
| Number of grid locations on x-axis | Point Value | 6.1.1.1 |
| Number of grid locations on y-axis | Point Value | 6.1.1.1 |
| Maximum particle diameter for transport | Point Value | 6.1.1.2 |
| Minimum height on eruption column considered in transport | Point Value | 6.1.1.3 |
| Threshold limit on ash accumulation | Point Value | 6.1.1.4 |
| ASHPLUME run type: deterministic or stochastic | Point Value | 6.1.1.5 |

| | | |
|---|---|---|
| Option to save particle size information at the dose point | Point Value | 6.1.1.6 |
| Particle Shape Factor | Point Value | 6.1.1.7 |
| Air Density | Point Value | 6.1.1.8 |
| Air Viscosity | Point Value | 6.1.1.8 |
| Constant (C) Relating Eddy Diffusivity and Particle Fall Time | Point Value | 6.1.1.9 |
| Incorporation Ratio | Point Value | 6.1.1.10 |
| Ash Settled Density | Point Value | 6.1.1.11 |
| Ash Particle Densities at Min/Max Particle Sizes | Point Values | 6.1.1.12 |
| Ash Min/Max Particle Sizes for Densities | Point Values | 6.1.1.12 |
| Waste Particle Size | Log-Triangular | 6.1.1.13 |
| Event Eruptive Volume | CDF | 6.1.2.1 |
| Ash Mean Particle Diameter | CDF | 6.1.2.2 |
| Ash Particle Size Standard Deviation | CDF | 6.1.2.3 |
| Event Power | CDF | 6.1.2.4 |
| Ash Dispersion Controlling Constant | CDF | 6.1.2.5 |
| Conduit Diameters | CDF | 6.1.2.6 |
| Initial Eruption Velocity | CDF | 6.1.2.6 |
| Wind Speed | CDF | 6.1.2.7 |
| Wind Direction | PDF | 6.1.2.8 |
| Number of Packages Hit per Drift (Volcanic Eruption) | CDF | 6.1.2.9 |
| Number of Drifts Hit per Conduit | CDF | 6.1.2.9 |
| Number of Conduits Intersecting Waste | PDF | 6.1.2.9 |
| Percent of Hit Packages that Fail (Volcanic Eruption) | Point Value | 6.1.2.9 |
| Event Probability | CDF | 6.1.3.1 |
| Probability of >0 Conduit | Point Value | 6.1.3.2 |

Table 6 Igneous Intrusive Groundwater Transport Event Input Parameters

| Output Parameter | Output Parameter Format | Section in Which Output Parameter is Discussed |
|---|---|---|
| Event Probability | CDF | 6.2.1 |
| Percent of Hit Packages that Fail (Igneous Intrusion) | Point Value | 6.2.3 |
| Number of Packages Hit (Igneous Intrusion) | CDF | 6.2.4 |

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

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# 9. ATTACHMENTS

| Attachment | Title |
|---|---|
| I | Distributions From Document |

# ATTACHMENT I

## DISTRIBUTIONS FROM DOCUMENT

(All distributions in this attachment were generated during the development of this AMR except Vent Diameter and the Number of Packages Hit for the Igneous Intrusive Groundwater Transport Event)

**Eruptive Volume CDF**

| Eruptive Volume ($km^3$) | CDF |
|---|---|
| 0.0020 | 0 |
| 0.0026 | 0.05 |
| 0.0034 | 0.10 |
| 0.0045 | 0.15 |
| 0.0059 | 0.20 |
| 0.0077 | 0.25 |
| 0.0101 | 0.30 |
| 0.0132 | 0.35 |
| 0.0173 | 0.40 |
| 0.0227 | 0.45 |
| 0.0297 | 0.50 |
| 0.0388 | 0.55 |
| 0.0509 | 0.60 |
| 0.0666 | 0.65 |
| 0.0872 | 0.70 |
| 0.1142 | 0.75 |
| 0.1496 | 0.80 |
| 0.1959 | 0.85 |
| 0.2566 | 0.90 |
| 0.3360 | 0.95 |
| 0.4400 | 1 |

**Ash Mean Particle Diameter CDF**

| Ash Mean Particle Diameter (cm) | CDF |
|---|---|
| 0.0010 | 0.00 |
| 0.0013 | 0.05 |
| 0.0016 | 0.10 |
| 0.0020 | 0.15 |
| 0.0025 | 0.20 |
| 0.0032 | 0.25 |
| 0.0040 | 0.30 |
| 0.0050 | 0.35 |
| 0.0063 | 0.40 |
| 0.0079 | 0.45 |
| 0.0100 | 0.50 |
| 0.0126 | 0.55 |
| 0.0158 | 0.60 |
| 0.0200 | 0.65 |
| 0.0251 | 0.70 |
| 0.0316 | 0.75 |
| 0.0398 | 0.80 |
| 0.0501 | 0.85 |
| 0.0631 | 0.90 |
| 0.0794 | 0.95 |
| 0.1000 | 1.00 |

**Ash Mean Particle Diameter Standard Deviation CDF**

| Ash Mean Particle Diameter Standard Deviation | CDF |
|---|---|
| 1.00 | 0 |
| 1.10 | 0.05 |
| 1.20 | 0.10 |
| 1.30 | 0.15 |
| 1.40 | 0.20 |
| 1.50 | 0.25 |
| 1.60 | 0.30 |
| 1.70 | 0.35 |
| 1.80 | 0.40 |
| 1.90 | 0.45 |
| 2.00 | 0.50 |
| 2.10 | 0.55 |
| 2.20 | 0.60 |
| 2.30 | 0.65 |
| 2.40 | 0.70 |
| 2.50 | 0.75 |
| 2.60 | 0.80 |
| 2.70 | 0.85 |
| 2.80 | 0.90 |
| 2.90 | 0.95 |
| 3.00 | 1 |

**Event Power CDF**

| Event Power (W) | CDF |
|---|---|
| $1.000 \times 10^{9}$ | 0 |
| $7.943 \times 10^{9}$ | 0.143 |
| $1.259 \times 10^{11}$ | 0.286 |
| $3.162 \times 10^{11}$ | 0.429 |
| $5.012 \times 10^{11}$ | 0.572 |
| $1.000 \times 10^{12}$ | 0.715 |
| $6.310 \times 10^{12}$ | 0.858 |
| $6.310 \times 10^{13}$ | 1 |

**Ash Dispersion Controlling Constant CDF**

| Ash Dispersion Controlling Constant | CDF |
|---|---|
| 0.010 | 0 |
| 0.012 | 0.05 |
| 0.015 | 0.10 |
| 0.018 | 0.15 |
| 0.022 | 0.20 |
| 0.027 | 0.25 |
| 0.032 | 0.30 |

| | |
|---|---|
| 0.039 | 0.35 |
| 0.048 | 0.40 |
| 0.058 | 0.45 |
| 0.071 | 0.50 |
| 0.086 | 0.55 |
| 0.105 | 0.60 |
| 0.127 | 0.65 |
| 0.155 | 0.70 |
| 0.188 | 0.75 |
| 0.229 | 0.80 |
| 0.278 | 0.85 |
| 0.338 | 0.90 |
| 0.411 | 0.95 |
| 0.500 | 1 |

**Vent Diameter and Initial Eruptive Velocity CDF**

| Vent Diameter (m) | Initial Eruption Velocity (cm/s) | CDF |
|---|---|---|
| 15 | 2196 | 0 |
| 20 | 2940 | 0.0009 |
| 25 | 3685 | 0.0094 |
| 30 | 4429 | 0.0417 |
| 35 | 5174 | 0.1133 |
| 40 | 5918 | 0.2247 |
| 45 | 6662 | 0.3605 |
| 50 | 7407 | 0.5000 |
| 55 | 8151 | 0.6267 |
| 60 | 8895 | 0.7317 |
| 65 | 9640 | 0.8131 |
| 70 | 10384 | 0.8730 |
| 75 | 11128 | 0.9154 |
| 80 | 11873 | 0.9444 |
| 85 | 12617 | 0.9640 |
| 90 | 13362 | 0.9768 |
| 95 | 14106 | 0.9852 |
| 100 | 14850 | 0.9906 |
| 105 | 15595 | 0.9940 |
| 110 | 16339 | 0.9962 |
| 115 | 17083 | 0.9976 |
| 120 | 17828 | 0.9985 |
| 125 | 18572 | 0.9991 |
| 130 | 19316 | 0.9994 |
| 135 | 20061 | 0.9996 |
| 140 | 20805 | 0.9998 |
| 145 | 21550 | 0.9999 |
| 150 | 22294 | 1 |

**Wind Speed CDF**

| Wind Speed (cm/s) | CDF |
|---|---|
| 0.00 | 0 |
| 51.44 | 0.1190 |
| 102.89 | 0.1231 |
| 154.33 | 0.1329 |
| 205.78 | 0.1449 |
| 257.22 | 0.1718 |
| 308.67 | 0.2056 |
| 360.11 | 0.2403 |
| 411.56 | 0.2750 |
| 463.00 | 0.3208 |
| 514.44 | 0.3648 |
| 565.89 | 0.4194 |
| 617.33 | 0.4653 |
| 668.78 | 0.5157 |
| 720.22 | 0.5685 |
| 771.67 | 0.6208 |
| 823.11 | 0.6792 |
| 874.56 | 0.7250 |
| 926.00 | 0.7653 |
| 977.45 | 0.8060 |
| 1028.89 | 0.8352 |
| 1080.33 | 0.8653 |
| 1131.78 | 0.8875 |
| 1183.22 | 0.9097 |
| 1234.67 | 0.9236 |
| 1286.11 | 0.9324 |
| 1337.56 | 0.9417 |
| 1389.00 | 0.9505 |
| 1440.45 | 0.9579 |
| 1491.89 | 0.9634 |
| 1543.33 | 0.9699 |
| 1594.78 | 0.9755 |
| 1646.22 | 0.9796 |
| 1697.67 | 0.9833 |
| 1749.11 | 0.9861 |
| 1800.56 | 0.9889 |
| 1852.00 | 0.9907 |
| 1903.45 | 0.9921 |
| 1954.89 | 0.9935 |
| 2006.33 | 0.9949 |
| 2057.78 | 0.9968 |
| 2160.67 | 0.9986 |
| 2263.56 | 0.9991 |
| 2366.45 | 1 |

**Wind Direction PDF**

| Wind Direction (Blowing Towards) | Wind Direction (ASHPLUME Degrees) | PDF |
|---|---|---|
| West-South | -150 | 0.073 |
| South-West | -120 | 0.092 |
| South | -90 | 0.109 |
| South-East | -60 | 0.084 |
| East-South | -30 | 0.047 |
| East | 0 | 0.063 |
| East-North | 30 | 0.101 |
| North-East | 60 | 0.218 |
| North | 90 | 0.126 |
| North-West | 120 | 0.037 |
| West-North | 150 | 0.027 |
| West | 180 | 0.023 |

**Number of Packages Hit per Drift per Vent CDF Sampled on Vent Diameter**

| Vent Diameter (m) | Number of Packages Hit per Drift per Vent | CDF |
|---|---|---|
| 15 | 3 | 0 |
| 20 | 4 | 0.0009 |
| 25 | 5 | 0.0094 |
| 30 | 6 | 0.0417 |
| 35 | 7 | 0.1133 |
| 40 | 8 | 0.2247 |
| 45 | 9 | 0.3605 |
| 50 | 10 | 0.5000 |
| 55 | 11 | 0.6267 |
| 60 | 12 | 0.7317 |
| 65 | 13 | 0.8131 |
| 70 | 14 | 0.8730 |
| 75 | 15 | 0.9154 |
| 80 | 16 | 0.9444 |
| 85 | 17 | 0.9640 |
| 90 | 18 | 0.9768 |
| 95 | 19 | 0.9852 |
| 100 | 20 | 0.9906 |
| 105 | 21 | 0.9940 |
| 110 | 22 | 0.9962 |
| 115 | 22.5 | 0.9976 |
| 120 | 23 | 0.9985 |
| 125 | 24 | 0.9991 |
| 130 | 25 | 0.9994 |
| 135 | 26 | 0.9996 |
| 140 | 27 | 0.9998 |
| 145 | 28 | 0.9999 |
| 150 | 29 | 1 |

**Number of Drifts Hit per Vent CDF Sampled on Vent Diameter**

| Vent Diameter (m) | Number of Drifts Hit per Vent | CDF |
|---|---|---|
| 15 | 1 | 0 |
| 20 | 1 | 0 |
| 25 | 1 | 0 |
| 30 | 1 | 0 |
| 35 | 1 | 0 |
| 40 | 1 | 0 |
| 45 | 1 | 0 |
| 50 | 1 | 0 |
| 55 | 1 | 0 |
| 60 | 1 | 0 |
| 65 | 1 | 0 |
| 70 | 1 | 0 |
| 75 | 1 | 0 |
| 80 | 1 | 0.060 |
| 85 | 1 | 0.126 |
| 90 | 1 | 0.192 |
| 95 | 1 | 0.258 |
| 100 | 1 | 0.325 |
| 105 | 1 | 0.391 |
| 110 | 1 | 0.457 |
| 115 | 1 | 0.523 |
| 120 | 1 | 0.589 |
| 125 | 1 | 0.656 |
| 130 | 1 | 0.722 |
| 135 | 1 | 0.788 |
| 140 | 1 | 0.854 |
| 145 | 1 | 0.921 |
| 150 | 1 | 0.987 |

**Number of Vents Intersecting Waste Drifts PDF**

| Number of Vents Intersecting Waste Drifts | PDF |
|---|---|
| 1 | 0.8606 |
| 2 | 0.1232 |
| 3 | 0.0124 |
| 4 | 0.0019 |
| 5 | 0.0019 |

**Event Probability CDF**

| Frequency ($yr^{-1}$) | CDF |
|---|---|
| 8.91300E-12 | 4.14485E-26 |
| 9.55500E-12 | 1.43798E-21 |
| 1.07200E-11 | 8.17170E-07 |
| 1.20280E-11 | 4.56989E-05 |
| 1.34960E-11 | 2.35820E-04 |
| 1.51440E-11 | 2.56313E-04 |
| 1.69920E-11 | 2.75967E-04 |
| 1.90640E-11 | 3.02403E-04 |
| 2.13920E-11 | 3.39549E-04 |
| 2.40020E-11 | 4.94913E-04 |
| 2.69280E-11 | 9.21993E-04 |
| 3.02140E-11 | 1.64580E-03 |
| 3.39000E-11 | 1.72342E-03 |
| 3.80380E-11 | 1.88771E-03 |
| 4.26820E-11 | 2.83633E-03 |
| 4.78880E-11 | 3.06944E-03 |
| 5.37300E-11 | 3.25478E-03 |
| 6.02880E-11 | 3.42150E-03 |
| 6.76440E-11 | 4.75419E-03 |
| 7.58960E-11 | 5.09198E-03 |
| 8.51600E-11 | 7.68157E-03 |
| 9.55500E-11 | 8.54944E-03 |
| 1.07200E-10 | 9.81512E-03 |
| 1.20280E-10 | 1.01521E-02 |
| 1.34960E-10 | 1.05781E-02 |
| 1.51440E-10 | 1.25944E-02 |
| 1.69920E-10 | 1.56189E-02 |
| 1.90640E-10 | 1.60594E-02 |
| 2.13920E-10 | 1.96527E-02 |
| 2.40020E-10 | 2.05899E-02 |
| 2.69280E-10 | 2.88359E-02 |
| 3.02140E-10 | 3.26450E-02 |
| 3.39000E-10 | 3.39195E-02 |
| 3.80380E-10 | 3.77270E-02 |
| 4.26820E-10 | 3.99210E-02 |
| 4.78880E-10 | 4.50245E-02 |
| 5.37300E-10 | 4.93939E-02 |
| 6.02880E-10 | 5.40941E-02 |
| 6.76440E-10 | 6.30893E-02 |
| 7.58960E-10 | 6.77652E-02 |
| 8.51600E-10 | 7.34717E-02 |
| 9.55500E-10 | 8.77999E-02 |
| 1.07200E-09 | 9.41527E-02 |
| 1.20280E-09 | 1.14478E-01 |
| 1.34960E-09 | 1.32916E-01 |
| 1.51440E-09 | 1.46238E-01 |
| 1.69920E-09 | 1.62961E-01 |
| 1.90640E-09 | 1.80037E-01 |
| 2.13920E-09 | 2.02377E-01 |

| | |
|---|---|
| 2.40020E-09 | 2.26202E-01 |
| 2.69280E-09 | 2.52160E-01 |
| 3.02140E-09 | 2.73543E-01 |
| 3.39000E-09 | 3.00125E-01 |
| 3.80380E-09 | 3.22626E-01 |
| 4.26820E-09 | 3.49793E-01 |
| 4.78880E-09 | 3.72131E-01 |
| 5.37300E-09 | 3.94744E-01 |
| 6.02880E-09 | 4.20510E-01 |
| 6.76440E-09 | 4.48491E-01 |
| 7.58960E-09 | 4.77451E-01 |
| 8.51600E-09 | 5.12031E-01 |
| 9.55500E-09 | 5.42171E-01 |
| 1.07200E-08 | 5.77740E-01 |
| 1.20280E-08 | 6.10988E-01 |
| 1.34960E-08 | 6.42040E-01 |
| 1.51440E-08 | 6.74726E-01 |
| 1.69920E-08 | 7.07644E-01 |
| 1.90640E-08 | 7.46418E-01 |
| 2.13920E-08 | 7.82949E-01 |
| 2.40020E-08 | 8.13209E-01 |
| 2.69280E-08 | 8.43987E-01 |
| 3.02140E-08 | 8.71226E-01 |
| 3.39000E-08 | 8.95031E-01 |
| 3.80380E-08 | 9.17926E-01 |
| 4.26820E-08 | 9.38355E-01 |
| 4.78880E-08 | 9.52171E-01 |
| 5.37300E-08 | 9.64017E-01 |
| 6.02880E-08 | 9.73003E-01 |
| 6.76440E-08 | 9.81574E-01 |
| 7.58960E-08 | 9.88703E-01 |
| 8.51600E-08 | 9.92176E-01 |
| 9.55500E-08 | 9.94948E-01 |
| 1.07200E-07 | 9.96120E-01 |
| 1.20280E-07 | 9.97221E-01 |
| 1.34960E-07 | 9.98862E-01 |
| 1.51440E-07 | 9.99479E-01 |
| 1.69920E-07 | 9.99767E-01 |
| 2.14860E-07 | 9.99994E-01 |
| 4.06574E-07 | 1.00000E+00 |

**Number of Packages Hit CDF (Igneous Intrusive Groundwater Transport Event)**

| Number of Packages Hit | CDF |
|---|---|
| 98 | 0 |
| 101 | 0.01087 |
| 104 | 0.05002 |
| 106 | 0.06303 |
| 109 | 0.06557 |
| 111 | 0.06605 |
| 114 | 0.06614 |
| 116 | 0.06616 |
| 155 | 0.06617 |
| 156 | 0.06707 |
| 158 | 0.10282 |
| 159 | 0.17773 |
| 160 | 0.23484 |
| 161 | 0.26494 |
| 162 | 0.27872 |
| 163 | 0.28471 |
| 164 | 0.28728 |
| 165 | 0.28888 |
| 166 | 0.28911 |
| 167 | 0.28921 |
| 168 | 0.28925 |
| 169 | 0.28928 |
| 179 | 0.28930 |
| 180 | 0.28930 |
| 181 | 0.32391 |
| 182 | 0.39465 |
| 183 | 0.44857 |
| 184 | 0.49001 |
| 185 | 0.49566 |
| 186 | 0.49809 |
| 187 | 0.49961 |
| 188 | 0.49991 |
| 189 | 0.49998 |
| 190 | 0.49999 |
| 192 | 0.50000 |
| 193 | 0.50062 |
| 194 | 0.52517 |
| 195 | 0.61584 |
| 196 | 0.64597 |
| 197 | 0.65185 |
| 198 | 0.65296 |
| 199 | 0.65318 |
| 200 | 0.65323 |
| 201 | 0.65367 |
| 202 | 0.70560 |
| 203 | 0.75299 |
| 204 | 0.75701 |
| 205 | 0.75787 |

| | |
|---|---|
| 206 | 0.75824 |
| 207 | 0.81153 |
| 208 | 0.82736 |
| 209 | 0.82869 |
| 210 | 0.85295 |
| 211 | 0.87482 |
| 212 | 0.87716 |
| 213 | 0.90682 |
| 214 | 0.91417 |
| 215 | 0.93272 |
| 216 | 0.94638 |
| 217 | 0.95638 |
| 218 | 0.96378 |
| 219 | 0.97443 |
| 220 | 0.98204 |
| 221 | 0.98655 |
| 222 | 0.99070 |
| 223 | 0.99473 |
| 224 | 0.99532 |
| 225 | 0.99813 |
| 226 | 0.99915 |
| 227 | 1.00000 |