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

1. QA: QA
Page: 1 of: 60

2. ☐ Analysis — Check all that apply	3. x Model — Check all that apply
Type of Analysis: ☐ Engineering; ☐ Performance Assessment; ☐ Scientific	Type of Model: x Conceptual Model; ☐ Abstraction Model; ☐ Mathematical Model; ☐ System Model; ☐ Process Model
Intended Use of Analysis: ☐ Input to Calculation; ☐ Input to another Analysis or Model; ☐ Input to Technical Document; ☐ Input to other Technical Products	Intended Use of Model: ☐ Input to Calculation; x Input to another Model or Analysis; x Input to Technical Document; ☐ Input to other Technical Products
Describe use:	Describe use: Provides the conceptual models for the igneous consequence models and the parameter values that will be used in the supporting mathematical model implemented in TSPA-SR model.

4. Title:
Igneous Consequence Modeling for the TSPA-SR

5. Document Identifier (including Rev. No. and Change No., if applicable):
-WIS-MD-000017 Rev 00 ICN 01

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Enclosure 2

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 ICN 01

4. Revision/Change No.	5. Description of Revision/Change
Revision 00	Initial Release
Revision 00/ICN 01	ICN includes updating AMR to account for revised thermal design considering "no-backfill design" change described by Technical Change Request: "Site Recommendation Design Baseline" (CRWMS M&O 2000k). In addition, this AMR update includes: • new input probabilities calculated in CRWMS M&O 2000b for the repository footprint and for the number of eruptive centers within the repository footprint; • revised input information related to the probability distribution for and number of dikes in a swarm (CRWMS M&O 2000a); • revised input information related conduit diameter; • revised inputs for number of packages hit and the damage to these packages to address a "no backfill" repository design; • corrected Figure 8; • miscellaneous editorial changes including clarification of the conceptual models; • and changes made to address issues related to DR LVMO-00-D-151.

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ACRONYMS AND ABBREVIATIONS

AMR	Analysis 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
DIRS	Document Information Reference System
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 TSPA-SR Model. The effort will build on the TSPA-VA and improve the quality of scenarios and depth of the technical basis underlying disruptive events modeling.

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 TSPA-SR Model. This Analysis Model Report (AMR) is limited to development of the conceptual models for these two scenarios. The mathematical implementation of these conceptual models will be done within the TSPA-SR Model. Thus, this AMR will not include any model results or sensitivity analyses. Calculation of any doses resulting from igneous releases will also be done within the TSPA-SR model, as will the probabilistic weighting of these doses. Calculation and analysis of the TSPA-SR Model results for igneous disruption are, therefore, outside the scope of this activity. The reason for not running the mathematical models as part of this AMR is that the models are integrated within the TSPA-SR model and, thus, any model simulations and the corresponding results are out of the scope of this AMR.

The scope of this work as defined in the development plan (CRWMS M&O 2000j) involves using data that has been extracted from existing sources to design and support the TSPA-SR models for the transport of radionuclides following igneous disruption of the repository. The development plan states "applications of the code in this analysis will be limited to testing of the code and sensitivity analyses during analysis design." In contrast to the development plan, the ASHPLUME code is not run within this AMR and any sensitivity runs will be performed within the TSPA-SR. This change has no impact on the technical output from this AMR.

The objectives of the work are to:

1. Develop TSPA-SR conceptual models for volcanic eruptive and igneous intrusion 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 Model.

4. Provide appropriate documentation for conceptual models, data, and parameters to relevant project databases.

5. Recommend an appropriate mathematical model for the volcanic eruption release scenario and provide appropriate parameter values for this model which will be run within the TSPA-SR Model.

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 Model 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 Model calculations of radionuclide releases and the resulting doses to the critical group will be conducted within the TSPA-SR model as part of the overall TSPA-SR analysis (CRWMS M&O 2000i). 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 and their values 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 1999b, CRWMS M&O 2000a, CRWMS M&O 2000b, CRWMS M&O 2000c, CRWMS M&O 2000d, CRWMS M&O 2000e, and CRWMS M&O 2000g) to establish the values to be utilized as input parameters within the igneous consequence models. The model that has been chosen to quantify volcanic eruption effects calculates the atmospheric transport and deposition of the ash containing waste and accounts for the relevant subsurface phenomena through the selection of appropriate parameter input values. This analysis is governed by the OCRWM Work Direction and Planning Document entitled "Igneous Consequence Modeling for the TSPA-SR" (CRWMS M&O 2000j).

On January 26, 2000 a design change was initiated to resolve certain thermal design issues. This design change would result in a greater ability of the waste packages to dissipate heat after closure of the repository, thereby maintaining the two thermal requirements. The first requirement is protective of the fuel cladding, and the second requires that a section of the rock pillar between drifts remain below the boiling temperature of water, providing a path for water drainage. This design change is described in CRWMS M&O 2000k, *Technical Change Request: "Site Recommendation*

Design Baseline". This current baseline specifying a no-backfill design repository is also specified in the Monitored Geologic Repository Project Description Document (CRWMS M&O 2000p).

This design change requires changes to documents that utilized the previous design. Among the documents requiring changes is Revision 00 of this AMR (CRWMS M&O 2000l). Differences between the initial issue of this AMR (Revision 00) which addressed a repository design that included "backfill" and this revision which addresses a repository design with "no backfill" are described in Section 6.0 Results.

In addition to the design change ICN 01 includes:

- used new inputs for number of packages hit and number of eruptive centers for the volcanic eruption conceptual model;
- used new inputs for the conduit diameter CDF, number of conduits intersecting waste CDF, and probability of greater than zero conduits;
- corrected the CDF for mean ash particle diameter;
- revised the CDFs for initial eruptive velocity, event probability, number of packages hit for the volcanic eruption, number of packages hit and the damage to those packages for the groundwater enhancement event based on revised inputs;
- revised calculation approach for the igneous intrusion groundwater release scenario; miscellaneous editorial changes including changes made to clarify the conceptual models and accommodate the revised inputs.

2. QUALITY ASSURANCE

An activity evaluation (CRWMS M&O 1999a) in accordance with QAP-2-0, *Conduct of Activities*, 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*.

The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information*, were not specified in the Development Plan (CRWMS M&O 2000j). With regard to the development of this AMR, the control of electronic management of data was evaluated in accordance with YAP-SV.1Q, *Control of the Electronic Management of Data*. The evaluation (CRWMS M&O 2000n) determined that current work processes and procedures are adequate for the control of the electronic management of data for this activity. Though YAP-SV.1Q has been replaced by AP-SV.1Q, this evaluation remains in effect.

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 software codes required to be qualified or controlled in accordance with AP-SI.1Q, *Software Management*, were used within this AMR.

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

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

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, *Software Management*. No routines or macros were developed for this AMR. Cumulative distribution functions (CDFs) or probability density functions (PDFs) were used in Excel for the input parameters and only standard Excel functions were used. Some of the parameters required additional pre-processing 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.

- Volume of Ash Erupted — CDF
- Mean Ash Particle Diameter — CDF
- Ash Mean Particle Diameter Standard Deviation — CDF
- Power of Eruption Column — CDF
- Ash Dispersion Controlling Constant — CDF
- Initial Eruptive Velocity — CDF
- Wind Speed — CDF
- Wind Direction — PDF
- Number of Waste Packages Intersected Per Eruptive Conduit — CDF
- Number of Eruptive Conduits — PDF
- Event Probability — CDF
- Number of Packages Intersected Zone 1 — CDF

3.2. MICROSOFT WORD

Microsoft Word was utilized in preparation of this document.

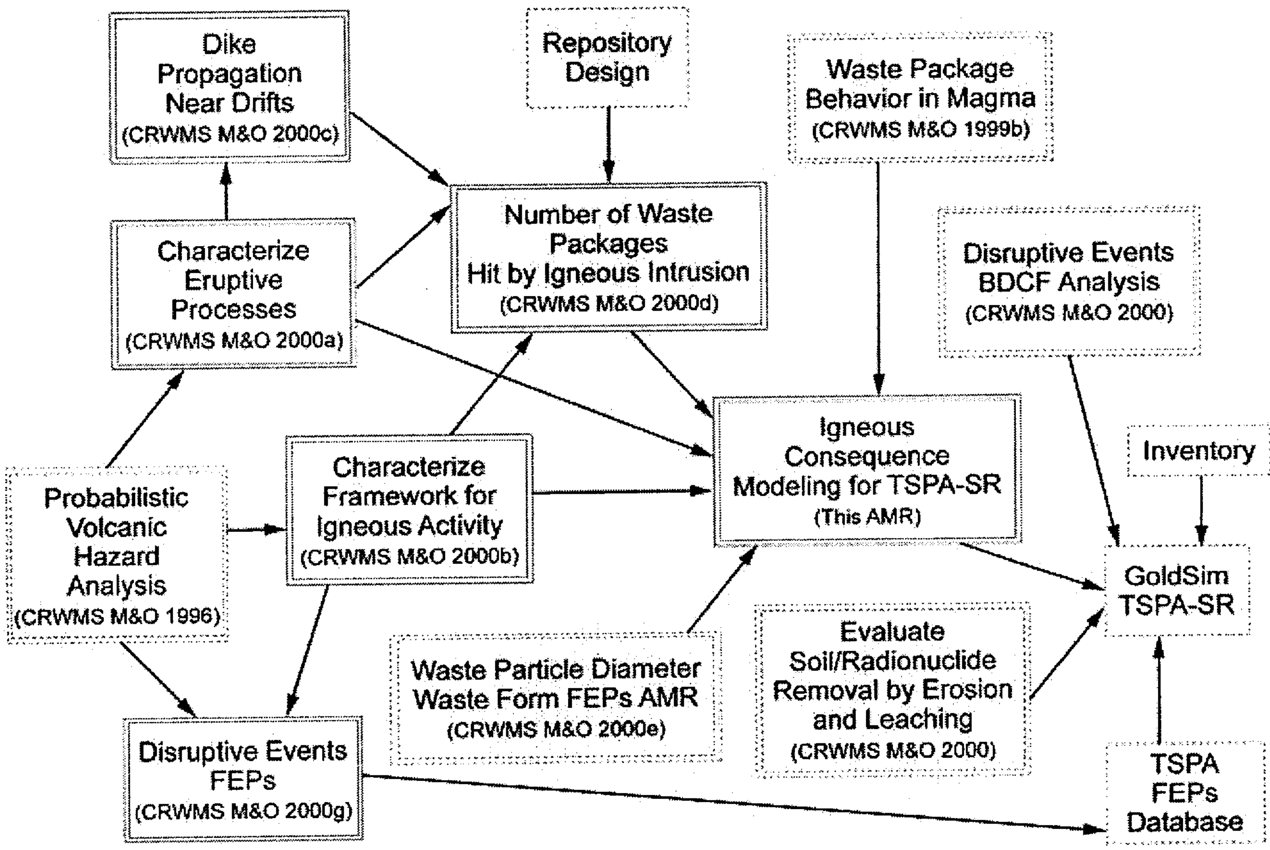
4. INPUTS

This analysis draws extensively on the results of other AMRs done to support the disruptive events Process Model Report (PMR) (CRWMS M&O 2000f) to define the events to be modeled in the TSPA-SR Model 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 Model simulations will also require information from many other groups within the Project that are outside the disruptive events group of analysts. For example, TSPA-SR Model 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 Model calculations of doses incurred by the critical group as a result of both volcanic eruption and igneous intrusion groundwater transport events will require biosphere dose conversion factors (BDCFs) that are developed outside of the disruptive events group of analyses PMR (CRWMS M&O 2000f). Although models and parameter values from sources external to the disruptive events group of analyses 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 flow of information among disruptive events AMRs and Calulations and to the TSPA-SR Model. This AMR receives inputs from the three AMRs that provide conceptual models and parameters characterizing igneous events and receives in. This AMR uses inputs from analyses outside of the disruptive events group and prepares parameter suites for input for TSPA-SR modeling. The general flow of information is described in the following paragraphs.

The AMR *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000b) summarizes the geologic framework significant to volcanism in the Yucca Mountain region based largely on the Probabilistic Volcanic Hazard Analysis (PVHA) (CRWMS M&O 1996). The AMR also provides a summary of the PVHA process and results including the probability of igneous disruption that is used in TSPA-SR Model. The AMR *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000a) provides detailed information on eruptive processes including the nature of dike systems, magma properties during intrusion and eruption. Together these two AMRs provide the framework conceptual information and parameter values for volcanic FEPs analysis (CRWMS M&O 2000h) that were used by the downstream AMRs.



Note: Titles of documents may be abbreviated in the flow chart. This figure is a schematic diagram showing the various documents that support this AMR and the TSPA-SR. Only the references relevant to this AMR are discussed in the text and included in the reference section.

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Figure 1: Information Feeds to Igneous Consequence Modeling in the TSPA-SR Model

The AMR *Dike Propagation Near Drifts* (CRWMS M&O 2000c) develops an analysis for the interaction of a hypothetical basaltic dike with an emplacement drift, drip shields, and waste packages. The analysis also examines the nature of a potential shock wave into the drift from the gases exsolving from the magma as it first encounters the relatively lower pressure of the drift environment. This AMR provides a description of three zones of waste package damage for a no backfill design.

All three of the disruptive events AMRs just described provide input to the calculation *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000d). Specifically, these AMRs provide results outputs relevant to dikes, conduits, number of eruptive centers, and the number of packages hit on either side of an intrusive dike.

The outputs from the disruptive events AMRs just discussed become inputs to this AMR, either through a direct input or as inputs that go through other AMRs first. The primary activity of the igneous consequence AMR is to receive outputs from the disruptive events volcanism AMRs and some other YMP data and, if necessary, perform operations that output the data in a suitable form for use in TSPA-SR models. Some data are passed through without being further reduced. In the process of organizing data and turning it into suitable parameter form, this AMR develops two conceptual models, one for volcanic eruptive release and the other for igneous intrusive groundwater release. These models are the "modeling concept" conceptual models and are compatible with the geologic conceptual models developed by the disruptive events framework and eruptive processes AMRs.

4.1. DATA AND PARAMETERS

Two igneous conceptual model scenarios are addressed in this AMR. The first scenario is a hypothetical volcanic eruption that intersects the repository. In this scenario an igneous dike rises to the repository level, intersects one or more waste-containing drifts in the repository, and erupts into the atmosphere. This conceptual model is implemented within the TSPA-SR Model and requires values to be defined for several input parameters. These values are obtained from various sources and are listed in Table 2. Section 6.1 provides more details of the conceptual model.

The second scenario is a hypothetical igneous intrusion that results in exposing the waste for groundwater transport away from the repository. This scenario is characterized by an igneous dike rising to the repository level and intersecting one or more waste-containing drifts, and exposing waste to groundwater flow. 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. This conceptual 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 6.2.

The data qualification status of the data in Tables 2 and 3 is identified in the DIRs.

Table 2. Volcanic Eruption Event Input Feeds to AMR

Input Parameter	Data Source	DTN Number/Technical Information Ref.
Particle Shape Factor	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Air Density	Lide 1994, Handbook	N/A
Air Viscosity	Lide 1994, Handbook	N/A
Ash Settled Density	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Ash Particle Densities at Min/Max Particle Sizes	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Ash Min/Max Particle Sizes for Densities	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Waste Particle Size	CRWMS M&O 2000e, Attachment I	DTN: LL000404551021.134
Ash Mean Particle Diameter	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Ash Particle Size Standard Deviation	CRWMS M&O 2000a, Section 7	CRWMS M&O 2000a
Eruption Column Power	CRWMS M&O 2000a	CRWMS M&O 2000a
Conduit Diameters	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002
Wind Speed	Quiring 1968, p. VI-1 – VI-21	Quiring 1968
Wind Direction	Quiring 1968, p. VI-1 – VI-21	Quiring 1968
Number of Packages Hit per Conduit (Volcanic Eruption)	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002
Number of Conduits Intersecting Waste	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002
Event Probability	CRWMS M&O 2000b	DTN:LA0009FP831811.004
Probability of >0 Conduits	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002

Table 3. Igneous Intrusion Groundwater Transport Event Input Feeds to AMR

Input Parameter	Data Source	DTN Number
Event Probability	CRWMS M&O 2000b	DTN:LA0009FP831811.004
Number of Packages Intersected Zone 1 (Igneous Intrusion)	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002
Number of Packages Intersected Combined Zones 1 and 2 (Igneous Intrusion)	CRWMS M&O 2000d	DTN: MO0010SPAOUT01.002

4.2. CRITERIA

The following criterion was identified in the development plan (CRWMS M&O 2000j):

- Ensure all necessary input values have been established for the ASHPLUME code and for the TSPA-SR Model igneous activity groundwater release simulation.

There are no other 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 provides regulatory guidance to be used until NRC's proposed site-specific, high level waste disposal regulation 10 CFR Part 63 (64 FR 8640) is promulgated. Subparts of this guidance 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 models 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 6.1.2.2) 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 predicting 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. (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.

Use within Analysis: This assumption is used in Section 6.1.2.2 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 6.1.2.2) 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 being paired with 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 are accepted data. However, this assumption simply indicates how the data was utilized and requires no further verification.

Use within Analysis: This assumption is used in Section 6.1.2.2 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 6.1.2.2) 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 code. As described in Section 6.1.1, 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 are accepted data. This assumption simply indicates how the data was utilized and requires no further verification.

Use within Analysis: This assumption is used in Section 6.1.2 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 and Type of Eruption (Violent or Nonviolent)

Assumption: All eruptions include a violent strombolian phase with fragmentation of the ascending magma into pyroclasts occurring when magma encounters 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 6.1 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 sufficiently damaged that they provide no further protection. 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 reasonably 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 1999b, 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 conservative, 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 reasonably conservative such that additional confirmation is not needed.

Use in Analysis: This assumption is used in Section 6.1 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 damaged. Furthermore, three waste packages on either side of the dike are also assumed to be sufficiently damaged such that they provide no further protection.

Rationale: The assumption that the affected waste packages are sufficiently damaged such that they provide no further protection is considered to be conservative. The determination that three waste packages on either side of the dike are affected by the intrusion is taken from CRWMS M&O 2000c.

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 6.2 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 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 (Miscellaneous 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 6.1.2.1 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 reasonably 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 compensates for uncertainty associated with conditions in the drift.

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

Use in Analysis: This assumption is used in Section 6.2 to support the conceptual model for the igneous intrusion groundwater release.

5.3.5. Waste Particle Size

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 reasonable with respect to the unaltered glass waste forms that make up most of the waste volume (CRWMS M&O 2000e). The unaltered waste glass forms that make up most of the waste volume are likely to have particle diameters comparable to those of the ash itself (see Section 6.1), which are 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 reasonable for analyses of 10,000-year performance, as described above.

5.4. ASSUMPTIONS REGARDING INPUTS TO THE ASHPLUME CODE

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 ρ_c is given by equation 1.

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

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, Table 5-1), and is utilized within this AMR. This corresponds to a maximum waste particle size being incorporated equal 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) (Jarzemba et al. 1997). A sensitivity run for this parameter will be done within TSPA-SR Model.

The mathematics of the ASHPLUME code 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 too large for incorporation are not transported downwind (Jarzemba et al. 1997).

The waste mass is distributed among the ash mass based on relative particle sizes. It is not divided equally among the ash particles. Incorporation of waste particles requires ash particles of a certain size or larger. Thus, larger ash particles will carry more waste mass and smaller ash particles will carry less or maybe even no waste mass. This is done by determining a "fuel fraction" or FF for particles as in Eqn.(2-8) of Jarzemba, et. al., 1997.

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

Use in Analysis: This assumption is utilized in Section 6.1.2 to support the model for volcanic eruption releases.

5.4.2. Treatment of the Maximum Particle Diameter for Transport

Assumption: The maximum particle diameter that can 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 reasonably conservative and consistent with the intended usage of the ASHPLUME code (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 reasonably conservative and consistent with the intended use of the ASHPLUME code. No further confirmation is needed.

Use in Analysis: This assumption is utilized in Section 6.1.2 to support the model for volcanic eruption releases.

5.4.3. Treatment of Minimum Height of 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 reasonably 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 reasonably conservative and consistent with the intended use of the ASHPLUME code. No further confirmation is needed.

Use in Analysis: This assumption is utilized in Section 6.1.2 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 code. No further confirmation is needed.

Use in Analysis: This assumption is utilized in Section 6.1.2 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 code (Jarzemba et al. 1997).

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

Use in Analysis: This assumption is utilized in Section 6.1.2 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 a distance 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 code.

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

Use in Analysis: This assumption is utilized in Section 6.1.2 to support the model for volcanic eruption releases.

5.4.7. Treatment of the Initial Eruptive Velocity

Assumption: The initial eruptive velocity is assumed to follow the relationship with the conduit radius defined in Wilson and Head et al. (1981) for the conduit radii of interest in this AMR.

Rationale: 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 of 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 (CRWMS M&O 2000a). 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 above. This linear extrapolation of the treatment of the initial eruptive velocity is a reasonable engineering treatment of the available information and allows the anticipated range of values to be captured in the CDF. Wilson and Head (Figure 6a) show an alternative linear relationship on a log-log scale between conduit radius and mass discharge rate up to conduit radii on the order of 200 meters. This is beyond the maximum range of 75 meter conduit radii defined for TSPA-SR Model analysis. For example, Wilson and Head, Figure 6a (1981) shows a mass discharge rate of about 5×10^7 kg/s (corresponding to an eruptive velocity of about 630 cm/s) for a conduit radius of 30 meters, while the relationship used in this AMR defines the eruptive velocity to be 8895 cm/s for a conduit radius of 30 meters.

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

Use in Analysis: This assumption is utilized in Section 6.1.2 to support the model for volcanic eruption releases.

6. ANALYSIS/MODEL

Two igneous event conceptual models will be modeled mathematically within the TSPA-SR Model. This AMR describes these conceptual models, and defines the parameters and the associated values for these models. The first conceptual model is a volcanic eruption through the repository. The second conceptual model is an igneous dike that intersects the repository resulting in the potential for enhancing groundwater transport of radionuclides. The coding of the mathematical models is not a part of this AMR. This AMR is limited to presentation of the conceptual models.

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 potential exists at Yucca Mountain, Nevada for a volcanic eruption to occur through the repository. An event of this type could be the violent phase of a strombolian event (see Assumption Section 5.2.1) (CRWMS M&O 2000a). A violent strombolian event in the Yucca Mountain Region would result in ash being ejected into the atmosphere. This ash would then be transported downwind and would settle and be deposited onto the ground. If this violent strombolian event intersects one or more repository drifts that contain waste packages then the potential exists for the radionuclide waste from the intersected waste packages to be entrained in the eruption column and transported in the atmosphere. If the wind is blowing towards the critical group then radionuclides could be deposited in the vicinity of the critical group. These radionuclides could then be incorporated into the biosphere resulting in a potential dose to the critical group. The task of this section is to present a conceptual model that facilitates the modeling of this event within the TSPA-SR Model.

The conceptual model for a volcanic eruption at Yucca Mountain can be broken into three components. The first component is the modeling of the subsurface physics and eruption of a volcano through the repository. This component includes the physics of the erupting column. The second component is the atmospheric transport and surface deposition of the erupted material. Finally, the third component is the incorporation and uptake of the radionuclides within the biosphere that ultimately leads to potential doses within humans. This AMR will not address the biosphere component of the volcanic eruption conceptual model. The other two components will be discussed here.

The subsurface and eruption column conceptual model for the volcanic eruption may be broken up into several pieces. The goal of this component of the model is to establish the boundary conditions that adequately define the nature of a volcanic eruption through the repository. This includes the parameters to define how much waste is intersected and entrained into the erupting column. Physical parameters associated with the erupting ash are defined including the treatment of the vertical contaminated ash column. The goal of the subsurface component of the model is not to attempt a rigorous modeling of the phenomena, but instead to define the boundary conditions. For example, instead of numerically modeling the subsurface effects of a vertically rising eruption column intersecting the repository, the conceptual model will instead focus on defining how much ash and waste are erupted and the energy associated with this erupting column. Once the masses (volumes) of the eruption are defined and the associated energies are defined, then the vertical column can be modeled. The most important component of the overall model is how much radionuclide contamination is transported to the critical group. In order to calculate this atmospheric transport, the height and composition of the vertical eruption column must be known. A detailed modeling of this column is less important than having an accurate accounting of the amount of ash and radionuclides that are in the column and at what height they are present. This information is then sufficient to feed into an atmospheric dispersal/transport model. Thus, the decision was made to capture the range of expected values for the subsurface model parameters listed below. This has the effect of capturing the range of expected results for the vertical column dynamics and for the mass (volume) of ash and waste that are erupted.

The parameters for the subsurface and eruption components of the volcanic eruption conceptual model are:

- Mass/Volume of Ash Erupted
- Mass of Waste Entrained in Eruption Column
- Power of Eruption Column
- Velocity of Eruption Column
- Height of Eruption Column
- Diameter of Eruption Vent/Conduit

- Distribution of Ash/Waste in Vertical Eruption Column
- Physical Characteristics of Ash and Waste

These parameters for the subsurface conceptual model are inputs into the atmospheric transport and surface deposition conceptual model. The atmospheric transport model needs takes in the subsurface model parameters and then models the atmospheric dispersion downwind and particle settling of the ash and waste particles. This is conceptually a simple model. Particles are ejected into the atmosphere (this is included in the subsurface model) where they are transported downwind. As the particles disperse downwind they also settle due to gravity. This combination of transport and settling results in particles being deposited on the ground downwind from the vent with the larger, denser particles lower in the eruption column being deposited closer to the vent than the smaller, less dense particles that erupted higher in the column.

The parameters of interest for the atmospheric transport and dispersal component of the volcanic eruption model are:

- Wind Speed and Direction
- Air Physical Characteristics
- Atmospheric Dispersal Properties
- Particle (Ash and Waste) Physical Characteristics

The properties of the ash and waste that are deposited on the ground are the final outputs for the model. These parameters are then utilized elsewhere to calculate doses to the critical group when coupled with the biosphere model. These models along with the models described above are modeled within the TSPA-SR Model.

Three potential mathematical codes were considered for the volcanic eruption model. These are ASHPLUME (Jarzemba et al. 1997), Puff (Searcy et al. 1998), and the Gas-Thrust code (Reamer 1999). The ASHPLUME code was chosen as the code to mathematically model the volcanic eruption scenario within the TSPA-SR. ASHPLUME was chosen because it contained all the necessary components of the conceptual model that were discussed above. These included treatment of both the subsurface and atmospheric transport and dispersal components of the conceptual model. Each of the components of the conceptual model consists of several parameters that need to be addressed in the computational model. ASHPLUME code contains both components of the conceptual model and contains the necessary complexity to adequately model the volcanic eruption scenario for the purposes of the TSPA-SR.

PUFF was evaluated conceptually based on descriptions in the scientific literature, but no working version of the code could be obtained from the originators to test because the developers did not consider the code ready for general release. However, based on the description of the code in the literature the originator concluded that it was not designed to model the atmospheric transport and settling of ash and waste and thus was not appropriate for the current needs.

Another alternative code considered was the gas-thrust code that was proposed in the NRC's Igneous Activity Issue Resolution Status Report (IRSR), Rev. 2, Section 4.2.2.3 (Reamer 1999). Although this code may have been useful in modeling the vertical plume, it was decided that the increased complexity of having to either develop an atmospheric transport model to couple to the gas-thrust code or developing code to retrofit this gas-thrust code to an existing atmospheric transport model was unnecessary. It was determined that using the ash dispersion controlling constant (beta) within ASHPLUME code had a similar effect as the proposed code. The parameter beta has the effect of generating a vertical distribution of particles above the volcano. The gas-thrust code appears to be a variation on this concept and falls within the uncertainties associated with the input parameter values used in forming the beta distribution. Thus, we chose to maintain the treatment of the vertical particle distribution within ASHPLUME code.

6.1.1. Selection of ASHPLUME as the Computational Model for the Volcanic Eruption Event

The igneous volcanic eruption conceptual model must be represented mathematically represented for inclusion in the TSPA-SR Model. The mathematical model must adequately cover the subsurface and atmospheric transport and dispersal components of the model. The parameters that must be defined for each model component are listed above.

The parameters of defining the subsurface and eruption component and the atmospheric transport and dispersal component of the model were listed in Section 6.1. The subsurface model and atmospheric transport model are both modeled mathematically utilizing the code ASHPLUME (Jarzemba et al., 1997) which was developed at the Center for Nuclear Waste Regulatory Analyses (CNWRA). This code is an implementation of the Suzuki igneous model (Suzuki 1983). The Suzuki model is a mathematical implementation of an atmospheric transport and dispersal model. The Suzuki model treats the subsurface parameters as inputs and then utilizes an atmospheric transport and 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 potential Yucca Mountain repository. The resulting code was ASHPLUME version 1.0 and which maintained all the physical characteristics of the Suzuki model (Jarzemba et al. 1997).

The ASHPLUME version 1.0 code was modified to version 1.3 for use in the TSPA Viability Assessment (VA) (DOE 1998, Volume 3, Section 4.4). The 1.0 version of

ASHPLUME code 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 and column height (the maximum height to which the eruptive column rises above the volcano). The 1.3 version of ASHPLUME code inputs the event volume as an independent variable and the event duration and column height are calculated within the code. The ASHPLUME code (version 1.4LV) that is utilized within TSPA-SR Model utilizes the same mathematical equations as those in the model used for the TSPA-VA (ASHPLUME v1.3). The difference between version 1.3 and 1.4LV are the platforms on which the codes are run; version 1.3 is run on a Unix platform while version 1.4LV is run on the PC platform and is executed within the TSPA-SR model as a dll file. This implementation is beyond the scope of this AMR. ASHPLUME version 2.0 is in development and the differences between version 2.0 and previous versions are presented elsewhere (CRWMS M&O 2000m). The 2.0 version of the code is currently in the process of being qualified using AP-SI.1Q. Since the most recent qualified version of the ASHPLUME code is version 1.4LV, this version is utilized within the TSPA-SR.

An important component of the ASHPLUME code is how the incorporation of waste and ash particles is modeled. The waste mass is distributed among the ash mass based on relative particle sizes. It is not divided equally among the ash particles. Incorporation of waste particles require ash particles of a certain size or larger. Thus, larger ash particles will carry more waste mass and smaller ash particles will carry less or maybe even no waste mass. This is done by determining a "fuel fraction" or FF for particles as in Eqn.# (2-8) of Jarzemba et al. (1997).

The actual density, i.e. mass per unit volume, of the particles being transported only comes into play in determining particle terminal velocity, V0, in Eqn.# (2-3) of Jarzemba et al. (1997). The particle density ("psi" sub p) used in Eqn.# (2-3) of Jarzemba et al. 1997 is modified to account for fuel mass when making the combined particle calculation. The combined particle densities are adjusted by the fuel fraction incorporated into the ash particle by the statement (ashden = ashden*{1+fuel fraction}) which is located in subroutine "ashden" of the ASHPLUME code. ASHPLUME code versions 1.0 (original CNWRA version), 1.3 (VA version) 1.4LV (TSPA-SR version), and 2.0 (in development) all implement the particle density adjustment the same.

6.1.2. ASHPLUME v1.4LV Code Parameters

The sub-sections below describe the parameters and parameter values needed for ASHPLUME V1.4LV code and how these relate to the parameters identified above. The specific values for these parameters will be described in the following sub-sections.

6.1.2.1. Subsurface and Eruption Components of the Volcanic Eruption Model

This section describes the parameters and values for the subsurface component of the model.

6.1.2.1.1. Mass/Volume of Ash Erupted

The mass/volume of ash that is erupted from a volcanic event needs to be defined. The mathematical model (implemented within ASHPLUME v1.4LV) uses the volume of erupted ash as an input parameter. The range for the event eruptive volume to be expected in the Yucca Mountain area 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 combining these two ranges (0.002 – 0.44 km^3). Incorporating both the IRSR range and the range from CRWMS M&O (2000b), the appropriate range of eruptive-volume for two models are incorporated into the ASHPLUME v1.4LV calculation. The CDF for event eruptive volume is provided in Figure 2 and Attachment I of this AMR. This CDF is calculated by this AMR and is sampled within the TSPA-SR model.

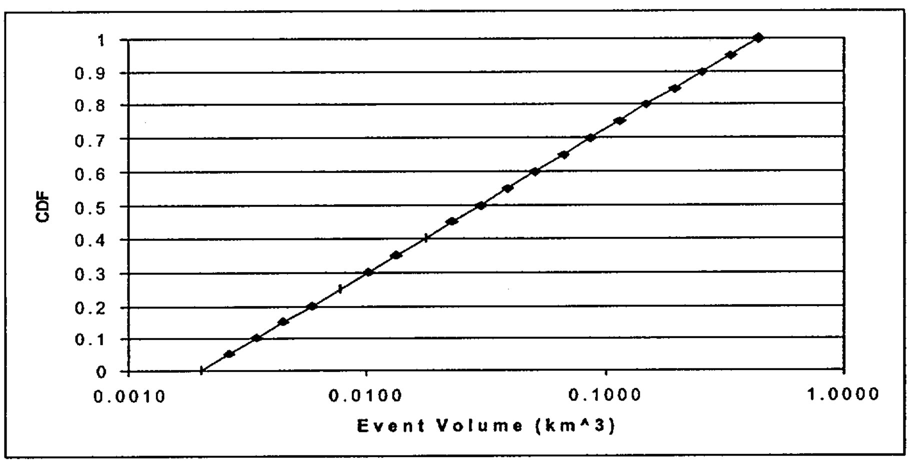

Figure 2: Event Eruptive Volume CDF (DTN: SN0010T0502900.003)

6.1.2.1.2. Mass of Waste Entrained in Eruption Column

The mass of waste entrained in the eruption column is calculated within ASHPLUME v1.4LV code and the TSPA-SR Model using several parameters. These parameters are the incorporation ratio, mass of waste per package, number of waste packages intersected by volcanic eruption, number of eruptive conduits intersecting repository, and percentage of intersected packages that fail.

The equation that describes the mass of waste released is given by:

Mass of Waste Released = (Mass of Waste per Package)
x (Number of Packages Hit per Conduit)
x (Number of Conduits Intersecting Waste)
x (% of Hit Packages that Fail) (eqn. 5)

To obtain the mass of waste entrained the result is multiplied by the incorporation ratio is utilized. The mass of waste entrained is a function of the mass of waste released and the incorporation ratio (Jarzemba et al. 1997). This has the effect of screening the size of waste particles that can be entrained within the rising ash plume as described in Section 6.1.

6.1.2.1.3. Incorporation Ratio

The incorporation ratio and supporting assumptions were defined in Section 5.4.1 and further described in Section 6.1 and a value of 0.3 is assumed.

6.1.2.1.4. Mass of Waste Per Package

The mass of selected radionuclides per waste package is provided directly within the TSPA-SR model and is based on the repository inventory.

6.1.2.1.5. Number of Waste Packages Intersected Per Eruptive Conduit

The CDF for the number of packages hit per conduit is obtained from CRWMS M&O 2000d. This CDF is given in Figure 3 and in Attachment I of this AMR and is sampled based on the conduit diameter. CRWMS M&O 2000d calculates geometrically how many waste packages are intersected for each conduit diameter (ranging from 4.5 – 150m) for 2 extreme cases: 1. If the conduit is centered on the drift or 2. The conduit is centered on the pillar between the drifts. For conduits with diameters larger than 90 meters more packages are intersected by centering the conduit on the pillar which allows the conduit to intersect a smaller portion of 2 drifts. CRWMS M&O 2000d and this AMR then take the maximum number of packages that can be intersected conditional on the conduit diameter. This means that for each conduit diameter and for each conduit that intersects the repository the maximum number of waste packages are intersected.

6.1.2.1.6. Number of Eruptive Conduits

The number of conduits intersecting the waste is provided by CRWMS M&O 2000b and CDFs and PDFs for this parameter are developed in CRWMS M&O 2000d. The probability of zero conduits forming is 22.6%. This probability is normalized out of the resulting PDFs and CDFs so that the distributions cover 1-13 conduits. 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 (0.226); this results in a reduction in the final probability weighted dose values. Accounting of the probability of zero conduits intersecting the waste is done in the post processing of the ASHPLUME code results within the TSPA-SR model and is outside the scope of this AMR. The conditional PDF for the number of conduits intersecting waste drifts is given in Figure 4 and Attachment I.

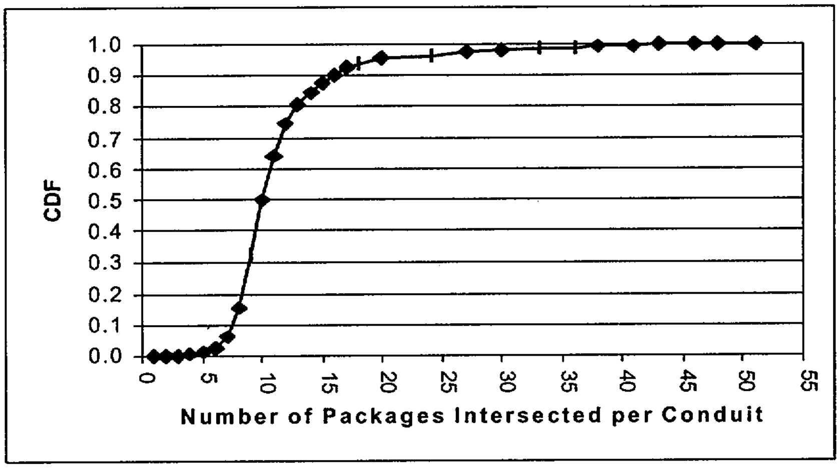

Figure 3: Number of Packages Intersected per Conduit CDF Sampled on Conduit Diameter (DTN: SN0010T0502900.003)

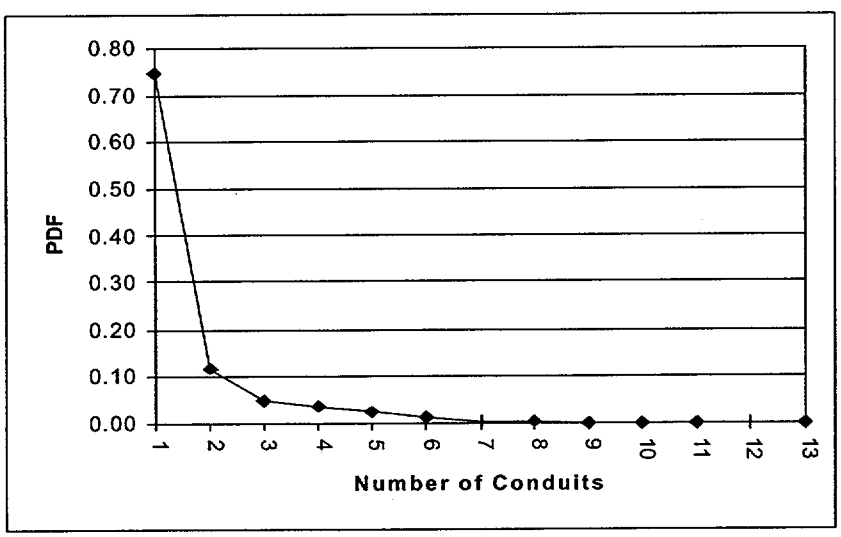

Figure 4: Number of Conduits Intersecting Waste Drifts PDF (DTN: SN0010T0502900.003)

6.1.2.1.7. Percentage of Intersected Packages that Fail

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 code. See Sections 5.3.1 and 5.3.3 for Assumptions related to this parameter.

6.1.2.1.8. Power of Eruption Column

The event power is provided by CRWMS M&O 2000a. 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 since 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-SR model. Note that in the current version of ASHPLUME code (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 code, including any future applications that may use modified versions of the code.

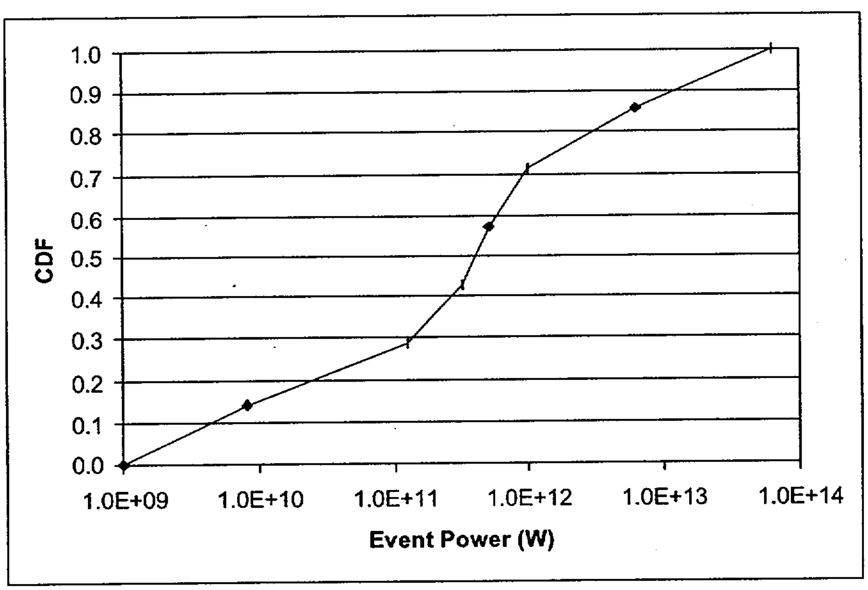

Figure 5: Event Power CDF (DTN: SN0010T0502900.003)

6.1.2.1.9. Diameter of Eruption Column Vent/Conduit

The conduit diameter distribution is defined in (CRWMS M&O 2000d) with a minimum value of 4.5 meters, a median value of 50 meters, and a maximum value of 150 meters. The CDF for the conduit diameter is given in Figure 6 and in Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model.

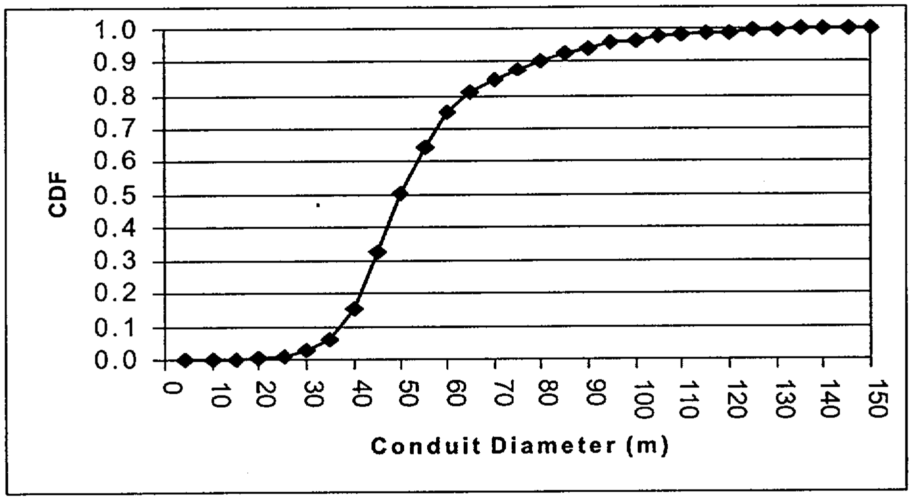

Figure 6: Conduit Diameter CDF (DTN: SN0010T0502900.003)

6.1.2.1.10. Velocity of Eruption Column

The initial eruptive velocity and supporting assumption are defined in Section 5.4.7. The initial eruptive velocity is sampled in the TSPA-SR 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 6 and 7 and in Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model.

6.1.2.1.11. Height of Eruption Column

The height of the eruption column is calculated internal to the ASHPLUME code and is not an input parameter.

6.1.2.1.12. Physical Characteristics of Ash/Waste

The physical characteristics of the ash and waste are defined within ASHPLUME v1.4LV code by several parameters. These are ash particle diameter, waste particle diameter, ash particle shape factor, ash particle densities, and settled density of ash blankets on the surface.

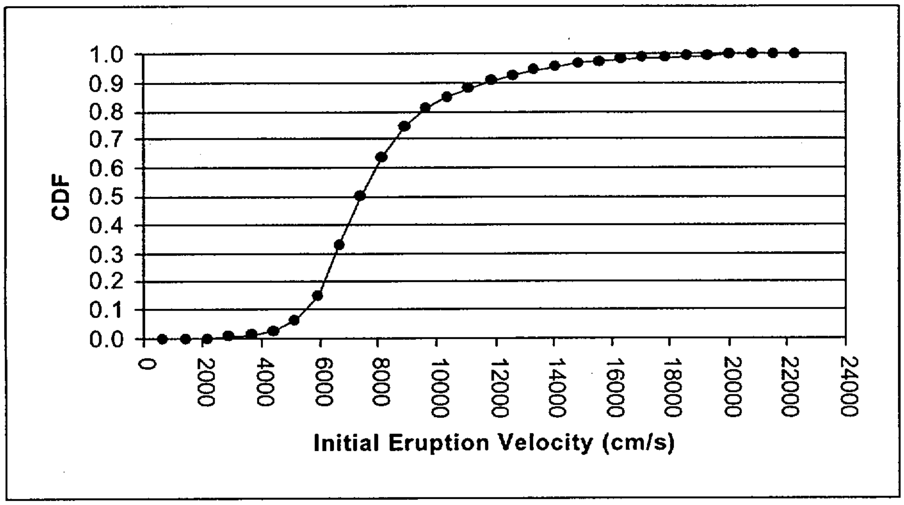

Figure 7: Initial Eruption Velocity CDF (DTN: SN0010T0502900.003)

The ash particle diameter is defined within ASHPLUME v1.4LV code by two parameters: the mean ash particle diameter and the mean ash particle diameter standard deviation. The mean ash particle diameter for the volcanic eruption vent is defined by CRWMS M&O 2000a as a log triangular distribution 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-SR model and fed into ASHPLUME code as a point value for each realization. The CDF for the mean ash particle diameter is given in Figure 8 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model. The ash mean particle standard deviation is provided in CRWMS M&O 2000a 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 9 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model.

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 prescribed by the ASHPLUME code. This is the only distribution that is programmed into the code. All other distributions assigned to ASHPLUME parameters will be sampled within the TSPA-SR 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.

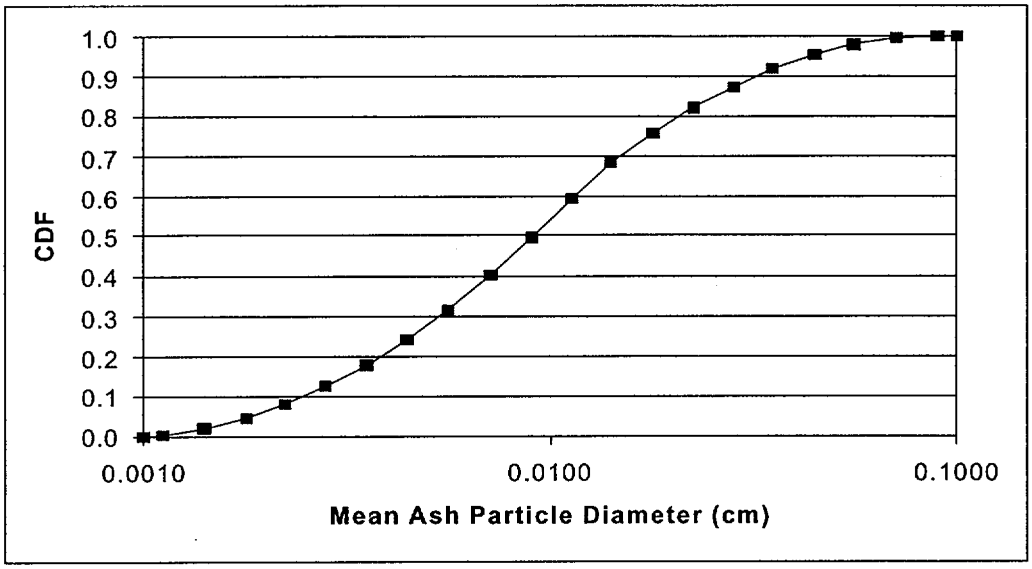

Figure 8: Ash Mean Particle Diameter CDF (DTN: SN0010T0502900.003)

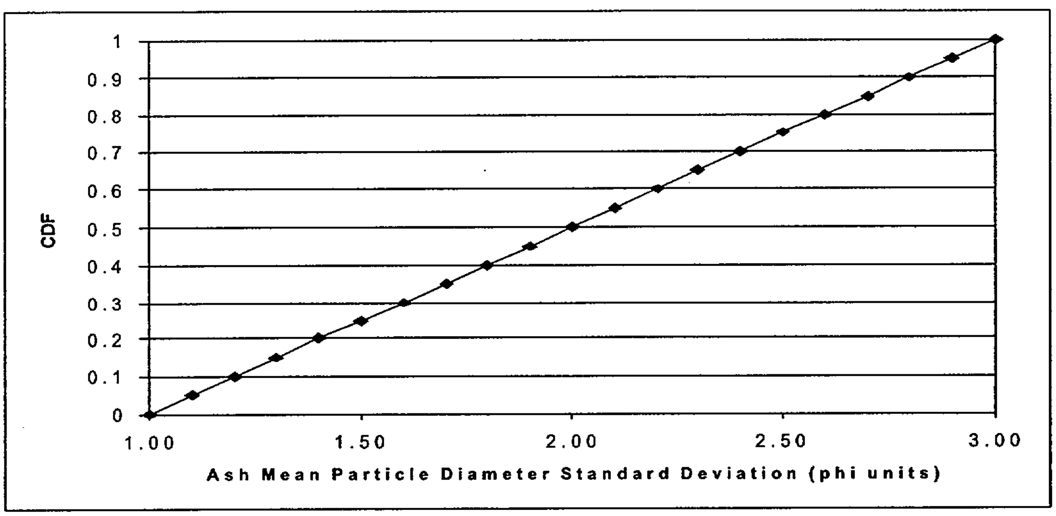

Figure 9: Ash Mean Particle Diameter Standard Deviation CDF (DTN: SN0010T0502900.003)

The ash 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. CRWMS M&O 2000a 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.

The ASHPLUME code requires inputs for the densities of large and small ash particles. CRWMS M&O 2000a 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). CRWMS M&O 2000a 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.

The ash settled density is provided in CRWMS M&O 2000a as 1.0 g/cm^3. This density is the bulk density of the ash that settles on the ground after eruption.

6.1.2.1.13. Distribution of Ash/Waste in Vertical Eruption Column

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 10 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model.

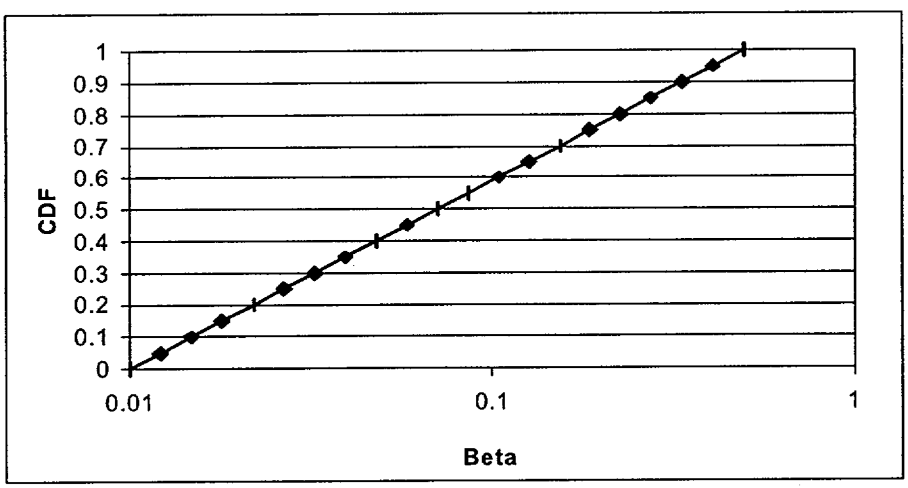

Figure 10: Ash Dispersion Controlling Constant CDF (DTN: SN0010T0502900.003)

6.1.2.2. Atmospheric Transport and Dispersal Model Parameters

6.1.2.2.1. Wind Speed and Wind Direction

Assumptions used in formulating the wind speed and direction CDFs are discussed in Sections 5.1.1, 5.1.2, and 5.1.3.

Quiring (1968) 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 11 and Attachment I. This CDF is provided by this AMR and is sampled within the TSPA-SR model.

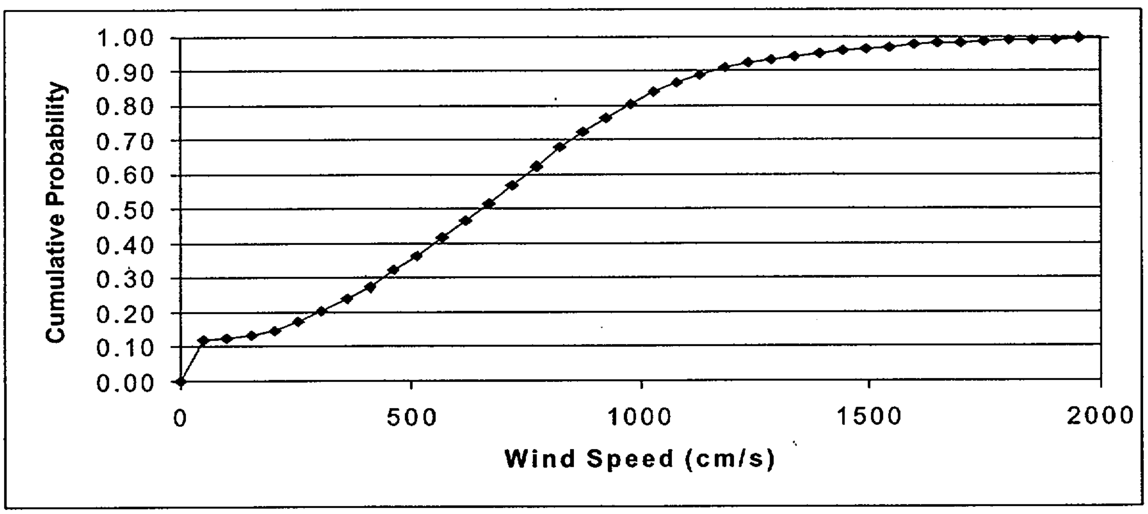

Figure 11: Wind Speed CDF (DTN: SN0010T0502900.003)

Quiring (1968) 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 12 and the PDF for the wind direction is given in Attachment I. This PDF is provided by this AMR and is available for sampling within the TSPA-SR model.

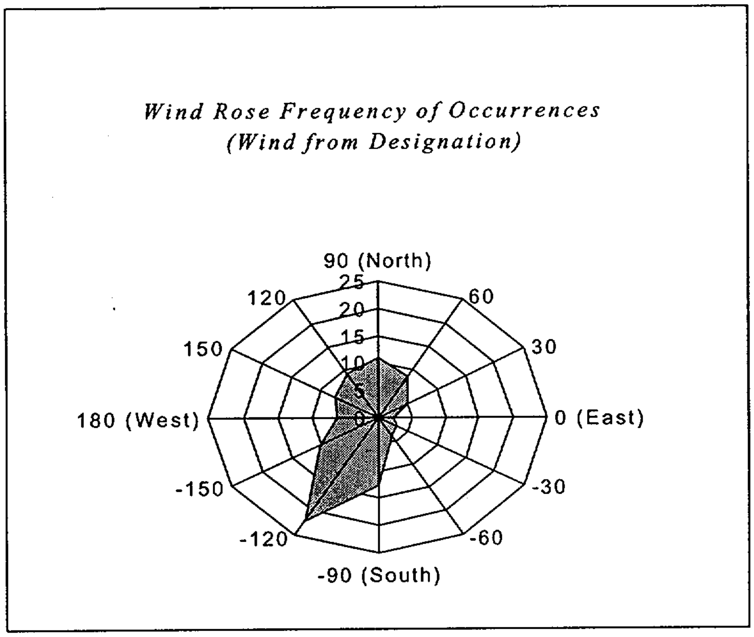

Figure 12: Wind Rose (DTN: SN0010T0502900.003)

6.1.2.2.2. Air Physical Characteristics

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).

6.1.2.2.3. Atmospheric Dispersal Parameters

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).

6.1.2.3. Model Specific Parameters

There are several model specific parameters that need to be defined in order to run the ASHPLUME v1.4LV code. These parameters are grid locations and grid spacing, maximum particle diameter for transport, minimum height of eruption column considered in transport, threshold limit on ash accumulation, ASHPLUME run type, and option of whether to save particle size information discussed below.

6.1.2.3.1. 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.

6.1.2.3.2. 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.

6.1.2.3.3. 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).

6.1.2.3.4. Threshold Limit on Ash Accumulation

This defines any ash concentrations (g/cm^2) below 10^{-10} as zero (Section 5.4.4). 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.

6.1.2.3.5. 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 code (within the TSPA-SR Model) 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 code 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 code will be run in deterministic mode with the TSPA-SR model to control sampling and the simulation of multiple realizations.

6.1.2.3.6. 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.

6.1.3. Supplementary Probability Parameters

Two additional probability parameters for the volcanic eruption event are needed to calculate probability weighted doses within the TSPA-SR Model. These parameters are combined with the ASHPLUME v1.4LV code output results. These parameters are applied within the TSPA-SR model and are combined with the ASHPLUME code determined waste surface concentration (g/cm^2) at the critical group located 20 kilometers south of the repository. The ASHPLUME code output combined with the probability-based parameters in this section along with the biosphere dose conversion factors (BDCFs), soil removal factors, and waste package material inventory are used within the TSPA-SR model to calculate dose (CRWMS M&O 2000i). The igneous volcanic eruption event parameters that are defined here for use in the TSPA-SR model are:

- Igneous Event Probability
- Probability of >0 Vents

The BDCFs, soil removal factors and waste package material inventory are beyond the scope of this AMR.

6.1.3.1. Igneous 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 igneous event probability is obtained from CRWMS M&O 2000b. This probability is used within the TSPA-SR model in calculating the expected annual dose for the critical group. The CDF for the igneous event probability is given in Figure 13 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.

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 CRWMS M&O 2000d. This parameter is used in conjunction with the event probability described above and is combined with the ASHPLUME v1.4LV code results and other factors in the calculation of an expected annual dose. 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 v1.4LV code runs provides improved statistical results because all simulations have the potential to result in a dose. These results are then conditioned by multiplying the igneous event probability above by the probability of at least one conduit occurring. This probability is 0.77. Thus, in 77% of the cases at least one conduit intersects the waste, while the remaining 23% 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 intrusion events in which the conduit formed outside the repository footprint and did not intersect waste. The median igneous event probability modified by the probability of at least one conduit through the waste is 1.2E-8. 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.

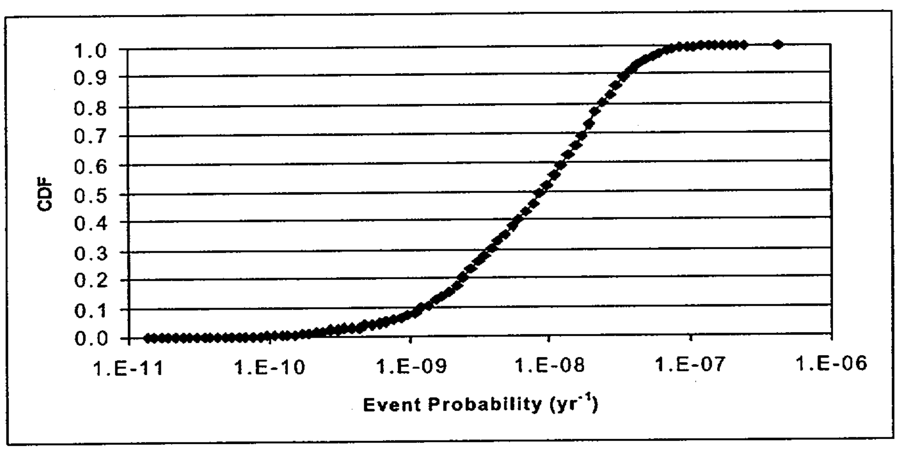

Figure 13: Event Probability CDF (DTN: SN0010T0502900.003)

6.1.4. Implementing ASHPLUME within the TSPA-SR Model

The use of ASHPLUME v1.4LV code for 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 (Suzuki 1983) 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 Model

In addition, this AMR provides 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 1999b, CRWMS M&O 2000a, CRWMS M&O 2000b, CRWMS M&O 2000e, CRWMS M&O 2000d, DTN: MO0010SPAOUT01.002, Jarzemba et al. 1997, Lide 1994, Suzuki 1983, Reamer 1999, Wilson and Head 1981, Quiring 1968). An additional improvement is the utilization of supporting Calculations (CRWMS M&O 2000d and CRWMS M&O 1999b) 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.

6.2. IGNEOUS INTRUSION GROUNDWATER TRANSPORT CONCEPTUAL MODEL

The possibility exists at Yucca Mountain, Nevada for an igneous intrusion to intersect the potential repository. The igneous intrusion groundwater transport event conceptual model describes what could potentially happen if waste packages in drifts are affected by a magmatic intrusion. This conceptual model can be divided into several model components. These are dike propagation to repository level, dike/drift interactions, number of waste packages intersected and the waste package response, transport of radionuclides in the groundwater unsaturated and saturated zones, and the biosphere response to these radionuclides in calculating doses to the critical group.

- The dike propagation to repository level is not discussed in detail, but is instead bounded. The assumption is made that each igneous event that occurs below the repository footprint rises to the repository level.
- The conceptual model for dike/drift interactions is beyond the scope of this AMR and is discussed in CRWMS M&O 2000c.
- The modeling of the transport of radionuclides in the unsaturated and saturated zones is beyond the scope of this AMR. The assumption is made that the igneous intrusion does not affect the groundwater flow characteristics and thus the nominal scenario groundwater transport models are utilized.
- The biosphere component of the model is beyond the scope of this AMR.

- The only component of the conceptual model for igneous intrusion groundwater transport that is within the scope of this AMR is the number of waste packages intersected by an igneous intrusion and the waste package response to this intrusion.

Revision 00 of this AMR (CRWMS M&O 2000l) addressed the igneous consequence modeling for the backfill design. This ICN presents the igneous consequence modeling for the no-backfill design. The two different designs result in some similarities in the igneous models. The number of packages intersected within the backfill design is the same as the number of packages damaged within zone 1 of the no-backfill design model. The differences between the igneous models for the two designs is realized in the addition of zone 2 packages into the model. Zone 1 consists of three packages on either side of the point at which the intrusive dike intersects the affected drift. Zone 2 is made up of all the remaining packages in the intersected drifts that are not in zone 1. Packages in zone 1 are assumed to be sufficiently damaged such that no further protection is provided (see Section 5.3.2). Zone 2 packages are defined to have no drift shields or cladding remaining for protection and have sustained waste package end cap weld failure (modeled as an aperture opening in the end cap of the waste package).

CRWMS M&O 2000c describes what occurs when magma enters a drift that contains waste packages. CRWMS M&O 2000d utilizes this information to develop a CDF for the number of waste packages intersected. This document defines two zones of damage within the intersected drifts. Zone 1 packages are the packages in the immediate vicinity of the dike intersection and zone 2 packages are the remaining packages in an intersected drift. As described in CRWMS M&O 2000d, the CDFs defined for the number of packages hit in zones 1 and 2 take into account dike orientation, length, width, and the number of dikes in a swarm. These CDFs are shown in Figures 14 and 15 and are listed in Attachment I. These CDFs are sampled directly within the TSPA-SR Model to determine how many packages are intersected by the igneous intrusion. The methodology for sampling these CDFs is to first sample from the zone 1 only CDF and the combined zones 1 and 2 CDF. The number of packages affected in Zone 2 is simply the number of packages intersected in the combined zones 1 and 2 CDF minus the number of packages intersected in zone 1.

The final component to the model is the waste package response in zones 1 and 2. Assumptions used in determining the waste package and waste form response to an igneous intrusion in given in Sections 5.3.2 and 5.3.4. The zone 1 waste packages are assumed to be sufficiently damaged as to provide no further protection. Magma entering the drift will undergo rapid depressurization as the confining pressure drops from lithostatic to atmospheric. For most of the range of water contents estimated for Yucca Mountain region basaltic magmas depressurization may be accompanied by rapid exsolution of volatile phases and explosive fragmentation of the magma. As discussed in *Dike Propagation Near Drifts* (CRWMS M&O 2000c), damage to the packages immediately adjacent to the point of intrusion is likely to be extensive. The force of the shock wave resulting from the fragmentation will be sufficient to move packages off their emplacement pallets, and to cause displacement of three or four packages on either side of the dike. The TSPA-SR Model input is therefore based on a calculation in which three packages on either side of an intrusive dike are fully damaged in each drift that is intersected. Multiple dikes in a swarm are conservatively assumed to be sufficiently far apart that they behave independently, with six packages damaged between them.

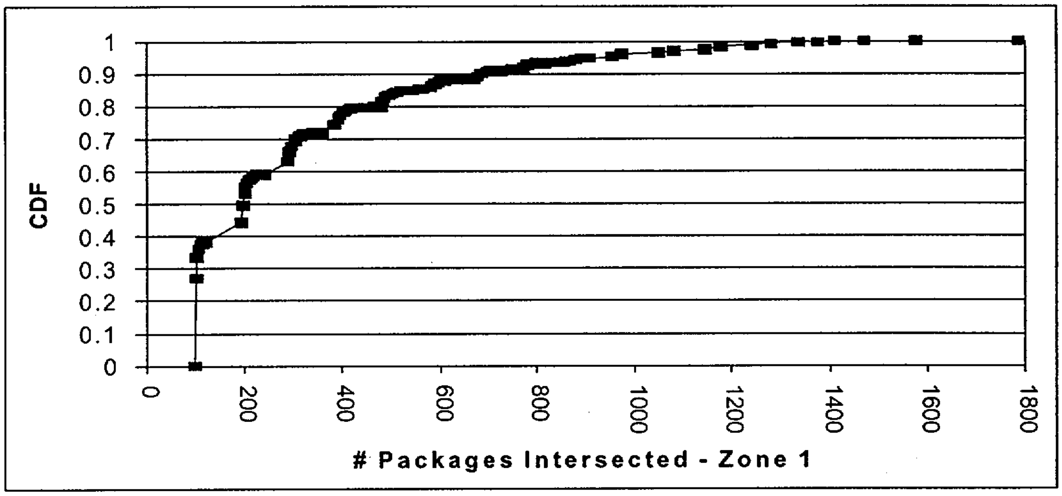

Figure 14: Number of Zone 1 Packages Intersected CDF (DTN: SN0010T0502900.003)

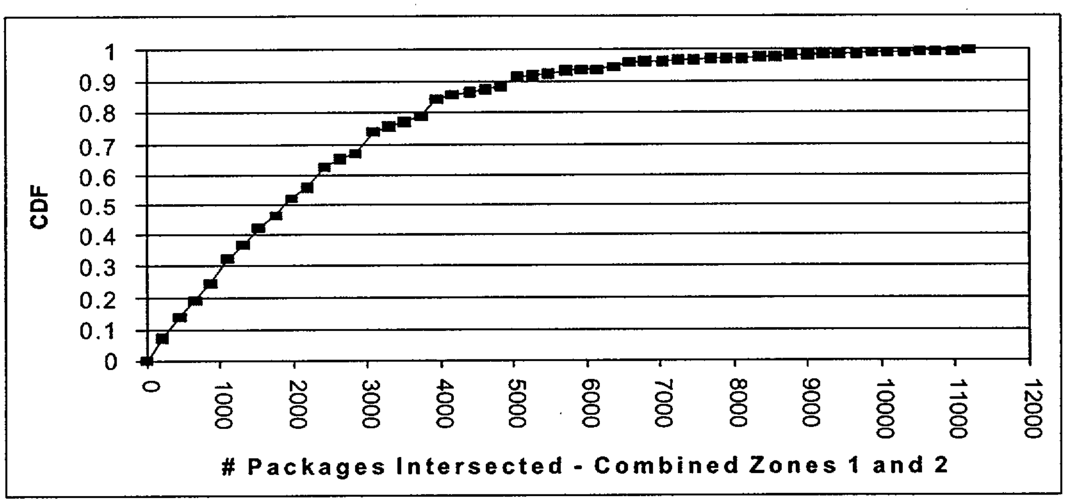

Figure 15: Number of Combined Zones 1 and 2 Packages Intersected CDF (DTN:MO0010SPAOUT01.002; DTN: SN0010T0502900.003)

For a repository design which does not include backfill, damage to waste packages within the drift will be more extensive. Actual conditions are uncertain, but the shock wave following decompression of the magma could propagate the full length of the affected drift. Immediate mechanical damage from displacement of waste packages may be limited to the region adjacent to the point of intrusion, as in the backfill model, but damage to the drip shield and ground support will occur throughout the drift. More importantly, debris from remains of the engineered barrier system will likely not be sufficient to create a plug anywhere before the right angle intersections at the ends of the drifts. Pyroclastic material (or liquid lava, in the possible case of an extremely dry magma) will quickly fill the entire length of the drift, and pressure will rise from atmospheric to lithostatic before the dike can continue to propagate upward. The combination of high temperature (approximately 1040 – 1170 degrees C) and high pressure (approaching the magmatic lithostatic pressure of 7.5 MPa at the repository depth) will be more than sufficient to cause failure of the packages (CRWMS M&O 2000c). Therefore, for the no-backfill design, the assumption is made that all packages in drifts that are intersected by intrusive dikes are damaged by the intrusion event. As discussed in the following section, three packages on either side of the dike are assumed to be damaged such that they provide no further protection, as in the backfill case, and the remaining packages in each intersected drift are assumed to undergo end cap weld failure.

Waste package behavior in immediate vicinity of the intrusion is bounded by the conservative assumption that three packages on either side of dike plus one package in the path of the dike (seven total packages) are sufficiently damaged that they provide no further protection for the waste. As is the case for the eruptive environment, actual conditions are uncertain, and damage is likely to range from moderate to extensive. Complete destruction of these waste packages seems unlikely, but thermal stresses alone may be sufficient to cause failure of the end caps (CRWMS M&O 1999b), and there is insufficient evidence to support a less conservative approach to the package behavior given the likely mechanical stresses and elevated pressures. Drip shields and cladding are also assumed to provide no further protection for the waste in the region adjacent to the dike.

If backfill is present, damage is assumed to be limited to region containing the three packages on either side of the dike. For the SR reference repository design without backfill, all remaining waste packages in all drifts intersected by a dike are assumed to be breached with a hole of uncertain cross-sectional area, and all drip shields and cladding in the intersected dikes are assumed to be fully destroyed. Breaching of the waste packages is consistent with the analysis reported in *Dike Propagation Near Drifts* (CRWMS M&O 2000c) which concludes that end cap welds will fail on these packages due to high temperatures and pressures. The area of the hole created by end cap weld failure represents the cross-sectional area that might open in a failed weld before gas flow into the failed package equalizes internal and external pressures, halting the propagation of the crack. This value is uncertain, and is sampled from a log-normal distribution with a mean value of $10\ cm^2$. The minimum value of the distribution is $1\ cm^2$, and the maximum is $1.9 \times 10^4\ cm^2$, which is an approximation of the full-cross-sectional area of a representative end cap with a radius of 77 cm. Although the mean value can be thought of conceptually as corresponding to a 1-mm-wide crack that propagates for 1 m along a weld, or a 2-mm-wide crack that extends 50 cm, it was not chosen to represent any specific dimensions of a weld failure. Rather, it was chosen as an approximation of the size of opening necessary to permit rapid gas flow and pressure equilibration. Sampling the area of the breach from a distribution that includes much larger hole sizes is intended to account for both uncertainty regarding the nature of the magmatic fluids and the package response and spatial variability in the extent of damage within the drifts.

Thus, the model for the igneous intrusion groundwater transport model within this AMR is limited to defining the number of waste packages intersected, the damage to the waste packages, and the probability associated with this event. The probability for this event was defined above in Figure 13 and in Attachment I.

6.3. CONCEPTUAL MODEL CONFIDENCE

This AMR addresses two conceptual models and thus formal validation was not performed at this time.

The conceptual models developed in this report consist of two conceptual models for the response of the repository to a volcanic eruption and to an igneous intrusion. For the volcanic eruption, the conceptual model includes a recommendation of specific computational code (ASHPLUME version 1.4LV) to implement portions of the conceptual model and the development of parameter distributions appropriate for use as input in both ASHPLUME v1.4LV code and within the TSPA-SR model. The ASHPLUME v1.4LV code is implemented as a dll file directly within the TSPA-SR model. For groundwater transport resulting from igneous intrusion, the conceptual model does not include specification of software (nor does implementation of the model require additional software beyond that contained in the TSPA-SR model), but the model does require the development of parameter distributions. 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 is beyond the scope of this AMR.

6.3.1. 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, and 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, no formal validation is done within this AMR.

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 6.3.2 and 6.3.3, 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.

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 and 6.2, the model includes the assumption that zone 1 waste packages affected by intrusion are damaged such that they provide no further protection for the waste, while zone 2 packages sustain end cap lid weld failure. This assumption over-estimates the amount of waste available for groundwater transport following an igneous intrusion. As discussed in Section 6.3.3, 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.

6.3.2. 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, and 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.

6.3.3. 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 confidence building, 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 taken from other sources, 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.

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	6.1.1.3	Allows code to display output in desired form
Maximum grid location on x-axis	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Minimum grid location on y-axis	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Maximum grid location on x-axis	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Number of grid locations on x-axis	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Number of grid locations on y-axis	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Maximum particle diameter for transport	Model Implementation Parameter	6.1.1.3	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	6.1.1.3	Negligible impact on model implementation
ASHPLUME run type: deterministic or stochastic	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form
Option to save particle size information at the dose point	Model Implementation Parameter	6.1.1.3	Allows code to display output in desired form

Particle Shape Factor	Input Data	6.1.1.1	Directly restated from input data
Air Density	Input Data	6.1.1.2	Directly restated from input data
Air Viscosity	Input Data	6.1.1.2	Directly restated from input data
Constant (C) Relating Eddy Diffusivity and Particle Fall Time	Assumption	6.1.1.2	Consistent with model usage
Incorporation Ratio	Assumption	6.1.1.1	Consistent with model usage
Ash Settled Density	Input Data	6.1.1.1	Directly restated from input data
Ash Particle Densities at Min/Max Particle Sizes	Derived from Input Data	6.1.1.1	Consistent with input data
Ash Min/Max Particle Sizes for Densities	Input Data	6.1.1.1	Directly restated from input data
Waste Particle Size	Input Data	6.1.1.1	Consistent with input data
Event Eruptive Volume	Derived from Input Data	6.1.1.1	Consistent with input data
Ash Mean Particle Diameter	Input Data	6.1.1.1	Consistent with input data
Ash Particle Size Standard Deviation	Input Data	6.1.1.1	Consistent with input data
Event Power	Input Data	6.1.1.1	Consistent with input data
Ash Dispersion Controlling Constant	Assumption	6.1.1.1	Consistent with model usage
Conduit Diameters	Input Data	6.1.1.1	Directly restated from input data
Initial Eruption Velocity	Derived from Input Data	6.1.1.1	Consistent with input data
Wind Speed	Derived from Input Data	6.1.1.2	Consistent with input data
Wind Direction	Derived from Input Data	6.1.1.2	Consistent with input data
Number of Packages Hit per Conduit	Input Data	6.1.1.1	Directly restated from input data
Number of Conduits Intersecting Waste	Input Data	6.1.1.1	Directly restated from input data
Percent of Hit Packages that Fail (Volcanic Eruption)	Assumption	6.1.1.1, see also 5.3.1	Conservative
Event Probability (Volcanic Eruption)	Derived from Input Data	6.1.2	Consistent with input data
Probability of >0 Conduits	Derived from Input Data	6.1.2	Consistent with input data
Event Probability (Volcanic Eruption)	Derived from Input Data	6.1.2	Consistent with input data
Number of Packages Intersected in Zone 1 (Igneous Intrusion)	Input Data	6.2	Directly restated from input data
Number of Packages Intersected in Combined Zones 1 and 2 (Igneous Intrusion)	Input Data	6.2	Directly restated from input data

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 taken from other sources (see Section 4), validation is based on comparison of the output parameters provided by this AMR to the input data from the referenced sources. Output parameters in this category are considered valid if they meet the criterion of being the same as the referenced input data.

For the third category, in which parameters are defined specific to the implementation of the ASHPLUME v1.4LV code, 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.

6.3.4. Validation and Verification of ASHPLUME v1.4LV Code

Quantitative validation of ASHPLUME v1.4LV code is beyond the scope of this AMR. However, this quantitative validation has been documented elsewhere. The comparison of ASHPLUME v1.4LV and ASHPLUME v2.0 codes to field measurements documented in Hill et al. (1998) are documented in CRWMS M&O 2000m. This work is a comparison of the ash distribution results only.

The software qualification of ASHPLUME v1.4LV code following AP SI.1Q, *Software Management*, required the development of a Validation Test Plan and Validation Test Report. Documented within these reports are mass balance tests of the ASHPLUME v1.4LV code to verify that the amount of ash and waste that are input into the model are deposited downwind by the model implementation. The results of these tests showed that the code accounted for all the mass of both ash and waste that was available for transport.

6.4. JUSTIFICATION OF SOFTWARE SELECTION

As discussed in Section 6.1, implementation of the volcanic eruption conceptual model in the TSPA-SR Model requires the use of the ASHPLUME v1.4LV code. This code has been qualified in accordance with AP-SI.1Q, *Software Management* (CRWMS M&O 2000o). Verification and validation of the ASHPLUME code is outside the scope of this report, and is demonstrated through the software qualification process (CRWMS M&O 2000o).

As discussed in Section 6.2, implementation of the igneous intrusion groundwater transport conceptual model in the TSPA-SR Model requires no additional software beyond that developed by the TSPA-SR Model 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 selection of parameters and parameter values that will be used by TSPA-SR Model in the igneous consequence models. Two igneous scenarios will be modeled within the TSPA-SR Model. The first scenario is a hypothetical volcanic eruption that intersects the repository and the second include igneous intrusion and groundwater transport. Both of these scenarios result from the intersection of a dike(s) with the repository and are modeled as resulting in exposing waste stored in the repository to transport processes.

It is recommended by this AMR that ASHPLUME v1.4LV code be utilized within the TSPA-SR Model to model potential volcanic eruption events at the Yucca Mountain repository. The parameters that are required to execute the ASHPLUME v1.4LV code within the TSPA-SR Model are summarized in Table 5 below. This table also provides a reference to the section within this AMR that discusses each parameter.

The igneous intrusion groundwater scenario 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 packages in close proximity to the point of intrusion is exposed. Waste in packages further from the point of intrusion have lid weld damage. After the magma cools, groundwater begins to flow through the zone with the flow characteristics and transport properties described in the Unsaturated Zone Flow and Transport Model (CRWMS M&O 2000r). Upon reaching the water table the transport continues under the conditions described by the Saturated Zone Flow and Transport Model Report (CRWMS M&O 2000q). The UZ/SZ models are run within the TSPA-SR Model. The igneous specific parameters that are required to simulate this scenario within the TSPA-SR Model 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. The output DTN for this AMR is DTN: SN0010T0502900.003.

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 technical product input information quality may be confirmed by review of the DIRS database.

Table 5. Volcanic Eruption Event Input Parameters to TSPA-SR Model

Output Parameter	**Output Parameter Format**	Section in Which Output Parameter is Discussed
Minimum grid location on x-axis	Point Value	6.1.1.3
Maximum grid location on x-axis	Point Value	6.1.1.3
Minimum grid location on y-axis	Point Value	6.1.1.3
Maximum grid location on x-axis	Point Value	6.1.1.3
Number of grid locations on x-axis	Point Value	6.1.1.3
Number of grid locations on y-axis	Point Value	6.1.1.3
Maximum particle diameter for transport	Point Value	6.1.1.3
Minimum height on eruption column considered in transport	Point Value	6.1.1.3
Threshold limit on ash accumulation	Point Value	6.1.1.3
ASHPLUME run type: deterministic or stochastic	Point Value	6.1.1.3
Option to save particle size information at the dose point	Point Value	6.1.1.3
Particle Shape Factor	Point Value	6.1.1.1
Air Density	Point Value	6.1.1.2
Air Viscosity	Point Value	6.1.1.2
Constant (C) Relating Eddy Diffusivity and Particle Fall Time	Point Value	6.1.1.2
Incorporation Ratio	Point Value	6.1.1.1
Ash Settled Density	Point Value	6.1.1.1
Ash Particle Densities at Min/Max Particle Sizes	Point Values	6.1.1.1
Ash Min/Max Particle Sizes for Densities	Point Values	6.1.1.1
Waste Particle Size	Log-Triangular	6.1.1.1
Event Eruptive Volume	CDF	6.1.1.1
Ash Mean Particle Diameter	CDF	6.1.1.1
Ash Particle Size Standard Deviation	CDF	6.1.1.1
Event Power	CDF	6.1.1.1
Ash Dispersion Controlling Constant	CDF	6.1.1.1
Conduit Diameters	CDF	6.1.1.1
Initial Eruption Velocity	CDF	6.1.1.1
Wind Speed	CDF	6.1.1.2
Wind Direction	PDF	6.1.1.2
Number of Packages Hit per Conduit(Volcanic Eruption)	CDF	6.1.1.1
Number of Conduits Intersecting Waste	PDF	6.1.1.1
Percent of Hit Packages that Fail (Volcanic Eruption)	Point Value	6.1.1.1
Event Probability	CDF	6.1.2
Probability of >0 Conduit	Point Value	6.1.2

Table 6. Igneous Intrusion Groundwater Transport Event Input Parameters to TSPA-SR Model

Output Parameter	Output Parameter Format	Section in Which Output Parameter is Discussed
Event Probability	CDF	6.1.2
Damage to Zone 1 Packages	Point Value	6.2
Damage to Zone 2 Packages	Log-normal	6.2
Number of Zone 1 Packages Intersected (Igneous Intrusion)	CDF	6.2
Number of Combined Zones 1 and 2 Packages Intersected(Igneous Intrusion)	CDF	6.2

8. INPUTS AND REFERENCES

8.1. DOCUMENTS CITED

CRWMS M&O 1996. *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada.* BA0000000-01717-2200-00082 REV 0. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971201.0221.

CRWMS M&O 1999a. *Conduct of Performance Assessment.* Activity Evaluation, September 30, 1999. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991028.0092.

CRWMS M&O 1999b. *Waste Package Behavior in Magma.* CAL-EBS-ME-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991022.0201.

CRWMS M&O 2000a. *Characterize Eruptive Processes at Yucca Mountain, Nevada.* ANL-MGR-GS-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000517.0259.

CRWMS M&O 2000b. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada.* ANL-MGR-GS-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. URN-0614.

CRWMS M&O 2000c. *Dike Propagation Near Drifts.* ANL-WIS-MD-000015 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. URN-0637.

CRWMS M&O 2000d. *Number of Waste Packages Hit by Igneous Intrusion.* CAL-WIS-PA-000001 REV 01. Las Vegas, Nevada: CRWMS M&O. URN-0652.

CRWMS M&O 2000e. *Miscellaneous Waste-Form FEPs.* ANL-WIS-MD-000009 Rev 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000526.0339.

CRWMS M&O 2000f. *Disruptive Events Process Model Report.* TDR-NBS-MD-000002 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000727.0085.

CRWMS M&O 2000g. *Features, Events, and Processes: Disruptive Events.* ANL-WIS-MD-000005 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. URN-0638.

CRWMS M&O 2000h. *The Development of Information Catalogued in Rev00 of the YMP FEP Database.* Development Plan TDP-WIS-MD-000001 Rev 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000630.0053.

CRWMS M&O 2000i. *Total System Performance Assessment-Site Recommendation Methods and Assumptions.* TDR-MGR-MD-000001 REV 00 ICN 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000307.0384.

CRWMS M&O 2000j. *Igneous Consequence Modeling for the TSPA-SR.* Development Plan TDP-WIS-MD-000023 REV 01, Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000810.0004.

CRWMS M&O 2000k. Site Recommendation Design Baseline. Technical Change Request T2000-0133. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000503.0159.

CRWMS M&O 2000l. *Igneous Consequence Modeling for the TSPA-SR.* ANL-WIS-MD-000017 Rev 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000501.0225.

CRWMS M&O 2000m. *Comparison of ASHPLUME Model Results to Representative Tephra Fall Deposits.* CAL-WIS-PA-000011 REV 00. Las Vegas, Nevada: CRWMS M&O. URN-0651.

CRWMS M&O 2000n. Process Control Evaluation for Supplement V: "Performance Assessment Operations. (Reference QAP-2-0 Activity Evaluation Form. Conduct of Performance Assessment, November 9, 1999)". Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000128.0236.

CRWMS M&O 2000p. *Monitored Geologic Repository Project Description Document.* TDR-MGR-SE-000004 REV 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001031.0062.

CRWMS M&O 2000q. *Saturated Zone Flow and Transport Process Model Report.* TDR-NBS-HS-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000821.0359.

CRWMS M&O 2000r. *Unsaturated Zone Flow and Transport Process Model Report.* TDR-NBS-HS-000002 REV 00 ICN 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000831.0280.

DOE (U.S. Department of Energy) 1998. *Total System Performance Assessment.* Volume 3 of *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0030.

DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J.R. Dyer (DOE/YMSCO) to D.R. Wilkins (CRWMS M&O), September 3, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New NRC Regulations for Yucca Mountain (Revision 01)." ACC: MOL.19990910.0079.

Jarzemba, M.S.; LaPlante, P.A.; and Poor, K.J. 1997. *ASHPLUME Version 1.0 - A Code for Contaminated Ash Dispersal and Deposition, Technical Description and User's Guide.* CNWRA 97-004, Rev. 1. San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. TIC: 239303.

Kutzbach, J.E.; Guetter, P.J.; Behling, P.J.; and Selin, R. 1993. "Simulated Climatic Changes: Results of the COHMAP Climate-Model Experiments." Chapter 4 of *Global Climates Since the Last Glacial Maximum.* Wright, H.E., Jr.; Kutzbach, J.E.; Webb, T., III; Ruddiman, W.F.; Street-Perrott, F.A.; et. al., eds. Minneapolis, Minnesota: University of Minnesota Press. TIC: 234248.

Lide, D.R., ed. 1994. *CRC Handbook of Chemistry and Physics, A Ready-Reference Book of Chemical and Physical Data.* 75th Edition. Boca Raton, Florida: CRC Press. TIC: 102972.

Quiring, R.F. 1968. *Climatological Data Nevada Test Site and Nuclear Rocket Development Station.* ESSA Research Laboratories Technical Memorandum - ARL 7. Las Vegas, Nevada: U.S. Department of Commerce, Environmental Science Services Administration Research Laboratories. ACC: NNA.19870406.0047.

Reamer, C.W. 1999. "Issue Resolution Status Report (Key Technical Issue: Igneous Activity, Revision 2)." Letter from C.W. Reamer (NRC) to Dr. S. Brocoum (DOE), July 16, 1999, with enclosure. ACC: MOL.19990810.0639.

Searcy, C.; Dean, K.; and Stringer, W. 1998. "PUFF: A High-Resolution Volcanic Ash Tracking Model." *Journal of Volcanology and Geothermal Research, 80,* 1-16. Amsterdam, The Netherlands: Elsevier Science B.V. TIC: 238696.

Suzuki, T. 1983. "A Theoretical Model for Dispersion of Tephra." *Arc Volcanism: Physics and Tectonics, Proceedings of a 1981 IAVCEI Symposium, August-September, 1981, Tokyo and Hakone.* Shimozuru, D. and Yokoyama, I., eds. Pages 95-113. Tokyo, Japan: Terra Scientific Publishing Company. TIC: 238307.

Wilson, L. and Head, J.W., III. 1981. "Ascent and Eruption of Basaltic Magma on the Earth and Moon." *Journal of Geophysical Research, 86,* (B4), 2971-3001. Washington, D.C.: American Geophysical Union. TIC: 225185.

YMP (Yucca Mountain Site Characterization Project) 1998. *Q-List.* YMP/90-55Q, Rev. 5. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19980513.0132.

8.2. CODES, STANDARDS, REGULATIONS, AND PROCEDURES

64 FR (Federal Register) 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Readily available.

AP-3.10Q, Rev. 2, ICN 3. *Analyses and Models.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000918.0282.

AP-SI.1Q, Rev. 2, ICN 4, ECN 1. *Software Management.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001019.0023.

AP-SV1.Q Rev.0 ICN 2. *Control of the Electronic Management of Information.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL. 20000831.0065.

QAP-2-0, Rev. 5. ICN 1, *Conduct of Activities.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991109.0221.

YAP-SV.1Q REV 0 ICN 1. *Control of the Electronic Management of Data.* Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL. 19991008.0209.

8.3. SOURCE DATA IDENTIFIED BY DTN TRACKING NUMBER

LA0009FP831811.004. Data Summaries Supporting Computation of Volcanic Event Intersection Frequencies for the 70,000 MTU Repository Layout. Submittal date: 09/14/2000.

LL000404551021.134. An Estimate of Fuel-Particle Sizes for Physically Degraded Spent Fuel Following a Disruptive Volcanic Event Through the Repository. Submittal Date: 04/20/2000.

MO0010SPAOUT01.002. CAL-WIS-PA-000001 REV00 ICN1 OUTPUT_OCT-00.XLS. Submittal date: 10/17/2000. URN-0653.

8.4. SOFTWARE

CRWMS M&O 2000o. *Software Code: ASHPLUME.* V1.4LV. SUN. 10022-1.4LV-00. (Reference Only)

9. ATTACHMENTS

Attachment	Title
I	Distributions From Document

ATTACHMENT I

DISTRIBUTIONS FROM DOCUMENT

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

Number of Packages Hit per Conduit CDF Sampled on Conduit Diameter

Conduit Diameter (m)	Number of Packages Hit per Conduit	CDF
4.5	1	0.0000
10	2	0.0004
15	3	0.0022
20	4	0.0066
25	5	0.0145
30	6	0.0277
35	7	0.0623
40	8	0.1541
45	9	0.3262
50	10	0.5008
55	11	0.6413
60	12	0.7467
65	13	0.8082
70	14	0.8477
75	15	0.8776
80	16	0.9026
85	17	0.9237
90	18	0.9412
95	20	0.9549
100	24	0.9654
105	27	0.9733
110	30	0.9799

115	33	0.9853
120	36	0.9897
125	38	0.9933
130	41	0.9960
135	43	0.9978
140	46	0.9989
145	48	0.9996
150	51	1.0000

Number of Conduits Intersecting Waste Drifts PDF

Number of Conduits Intersecting Waste Drifts	PDF
1	0.74796
2	0.11766
3	0.05075
4	0.03717
5	0.02457
6	0.01099
7	0.00524
8	0.00272
9	0.00131
10	0.00084
11	0.00058
12	0.00021
13	0.00001

Event Power CDF

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

Conduit Diameter and Initial Eruptive Velocity CDF

Conduit Diameter (m)	Initial Eruption Velocity (cm/s)	CDF
4.5	633	0.0000
10	1452	0.0004
15	2196	0.0022
20	2940	0.0066
25	3685	0.0145
30	4429	0.0277
35	5174	0.0623
40	5918	0.1541

45	6662	0.3262
50	7407	0.5008
55	8151	0.6413
60	8895	0.7467
65	9640	0.8082
70	10384	0.8477
75	11128	0.8776
80	11873	0.9026
85	12617	0.9237
90	13362	0.9412
95	14106	0.9549
100	14850	0.9654
105	15595	0.9733
110	16339	0.9799
115	17083	0.9853
120	17828	0.9897
125	18572	0.9933
130	19316	0.9960
135	20061	0.9978
140	20805	0.9989
145	21550	0.9996
150	22294	1.0000

Mean Ash Particle Diameter CDF

Mean Ash Particle Diameter (cm)	CDF
0.0010	0.0000
0.0011	0.0049
0.0014	0.0205
0.0018	0.0462
0.0022	0.0798
0.0028	0.1237
0.0035	0.1778
0.0045	0.2412
0.0056	0.3175
0.0071	0.4054
0.0089	0.5000
0.0112	0.5946
0.0141	0.6825
0.0178	0.7588
0.0224	0.8222
0.0282	0.8763
0.0355	0.9202
0.0447	0.9538
0.0562	0.9795
0.0708	0.9951
0.1000	1.0000

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

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

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

Event Probability CDF

Frequency yr-1	CDF
1.380E-11	8.6360E-08
1.508E-11	2.6570E-07
1.699E-11	3.5450E-06
1.906E-11	5.3391E-06
2.139E-11	8.8985E-06
2.400E-11	1.4794E-05
2.693E-11	6.1981E-05
3.021E-11	2.6176E-04
3.390E-11	2.7972E-04
3.804E-11	3.0687E-04
4.268E-11	3.4396E-04
4.789E-11	3.8650E-04
5.373E-11	9.1897E-04
6.029E-11	1.0328E-03
6.764E-11	1.1673E-03
7.590E-11	1.3850E-03
8.516E-11	2.6265E-03
9.555E-11	3.5421E-03
1.072E-10	5.6652E-03
1.203E-10	6.1123E-03
1.350E-10	6.4345E-03
1.514E-10	7.4780E-03
1.699E-10	9.5272E-03
1.906E-10	9.8907E-03
2.139E-10	1.4566E-02
2.400E-10	1.5217E-02
2.693E-10	1.9961E-02
3.021E-10	2.0548E-02
3.390E-10	2.6674E-02
3.804E-10	2.7605E-02

4.268E-10	2.9126E-02
4.789E-10	3.6339E-02
5.373E-10	3.9556E-02
6.029E-10	4.3044E-02
6.764E-10	4.8786E-02
7.590E-10	5.6212E-02
8.516E-10	5.9884E-02
9.555E-10	7.2759E-02
1.072E-09	7.8402E-02
1.203E-09	9.6084E-02
1.350E-09	1.0410E-01
1.514E-09	1.2437E-01
1.699E-09	1.3711E-01
1.906E-09	1.5409E-01
2.139E-09	1.7502E-01
2.400E-09	1.9993E-01
2.693E-09	2.2727E-01
3.021E-09	2.5491E-01
3.390E-09	2.7766E-01
3.804E-09	3.0552E-01
4.268E-09	3.3116E-01
4.789E-09	3.5510E-01
5.373E-09	3.7842E-01
6.029E-09	4.0193E-01
6.764E-09	4.2934E-01
7.590E-09	4.5783E-01
8.516E-09	4.9217E-01
9.555E-09	5.2155E-01
1.072E-08	5.5498E-01
1.203E-08	5.8938E-01
1.350E-08	6.2290E-01
1.514E-08	6.5631E-01
1.699E-08	6.8989E-01
1.906E-08	7.2977E-01
2.139E-08	7.6916E-01
2.400E-08	8.0298E-01
2.693E-08	8.3197E-01
3.021E-08	8.6445E-01
3.390E-08	8.9156E-01
3.804E-08	9.1464E-01
4.268E-08	9.3586E-01
4.789E-08	9.5025E-01
5.373E-08	9.6105E-01
6.029E-08	9.7504E-01
6.764E-08	9.8369E-01
7.590E-08	9.8873E-01
8.516E-08	9.9268E-01
9.555E-08	9.9493E-01
1.072E-07	9.9653E-01
1.203E-07	9.9842E-01
1.350E-07	9.9917E-01
1.514E-07	9.9964E-01

1.699E-07	9.9991E-01
1.906E-07	9.9996E-01
2.139E-07	9.9998E-01
2.400E-07	9.9999E-01
4.283E-07	1.0000E+00

Number of Packages Intersected – Zone 1 CDF

Number of Packages Intersected	CDF
98	0.0000
101	0.2690
104	0.3362
107	0.3602
110	0.3720
113	0.3783
116	0.3813
122	0.3822
194	0.4454
197	0.4953
200	0.5296
203	0.5532
207	0.5664
210	0.5743
213	0.5795
216	0.5832
219	0.5860
222	0.5880
225	0.5895
228	0.5905
235	0.5914
241	0.5916
287	0.6294
294	0.6594
297	0.6798
303	0.6940
306	0.7019
312	0.7066
316	0.7098
322	0.7120
325	0.7136
331	0.7149
340	0.7163
359	0.7170
384	0.7416
390	0.7610
396	0.7744
403	0.7836
409	0.7887
415	0.7918

421	0.7938
428	0.7952
434	0.7963
440	0.7971
465	0.7984
477	0.7985
481	0.8143
487	0.8268
496	0.8354
502	0.8413
512	0.8446
518	0.8466
527	0.8479
543	0.8495
558	0.8504
565	0.8506
580	0.8608
590	0.8686
596	0.8740
602	0.8777
611	0.8798
621	0.8810
639	0.8824
649	0.8828
667	0.8834
677	0.8922
686	0.8991
695	0.9038
705	0.9071
714	0.9089
726	0.9099
748	0.9112
758	0.9115
770	0.9190
779	0.9249
801	0.9290
814	0.9317
823	0.9332
835	0.9341
854	0.9351
860	0.9402
867	0.9406
879	0.9448
891	0.9478
904	0.9498
954	0.9520
972	0.9594
1050	0.9650
1081	0.9715
1144	0.9760
1175	0.9820

1240	0.9861
1278	0.9909
1334	0.9941
1371	0.9974
1409	0.9989
1468	0.9995
1574	0.9999
1785	1.0000

Number of Packages Intersected – Combined Zones 1 and 2 CDF

# Packages Intersected	CDF
0	0.0000
219	0.0717
439	0.1381
658	0.1923
877	0.2475
1096	0.3224
1316	0.3672
1535	0.4219
1754	0.4646
1974	0.5242
2193	0.5590
2412	0.6248
2632	0.6525
2851	0.6730
3070	0.7384
3289	0.7554
3509	0.7712
3728	0.7899
3947	0.8412
4167	0.8541
4386	0.8635
4605	0.8732
4824	0.8813
5044	0.9145
5263	0.9197
5482	0.9250
5702	0.9306
5921	0.9350
6140	0.9391
6360	0.9438
6579	0.9588
6798	0.9620
7017	0.9644
7237	0.9668
7456	0.9688
7675	0.9709
7895	0.9729
8114	0.9748

8333	0.9770
8552	0.9785
8772	0.9800
8991	0.9815
9210	0.9864
9430	0.9872
9649	0.9887
9868	0.9899
10088	0.9906
10307	0.9913
10526	0.9950
10745	0.9954
10965	0.9977
11184	1.0000