DRAFT DESCRIPTION OF ABSTRACTED MODELS FOR TEPHRA REDISTRIBUTION AND RESUSPENSION IN THE TPA VERSION 5.1BETA CODE

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ABSTRACT

A total-system performance assessment code has been developed to independently evaluate uncertainties in risk-significant features, events, and processes related to a potential geologic repository for high-level waste at Yucca Mountain, Nevada. Abstracted models were developed for the code to provide fundamental insights into consequences of a volcanic eruption intersecting the potential repository. This report describes two abstracted models, one new and one old, for tephra redistribution and resuspension used to estimate inhalation doses to the reasonably maximally exposed individual in the TPA Version 5.1beta code. Both models are retained to provide flexibility in the calculations.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: The CNWRA-generated data referenced in this report meet the quality assurance requirements described in the Geosciences and Engineering Division Quality Assurance Manual. Data from other sources are included with references to their source. Sources of these non-CNWRA data should be consulted for determining levels of quality assurance.

ANALYSES AND CODES: This report does not present new CNWRA analyses. The report describes portions of the TPA Version 5.1beta code. The TPA Version 5.1beta code is being developed following the procedures in Geosciences and Engineering Division Technical Operating Procedure (TOP–018), Development and Control of Scientific and Engineering Software.

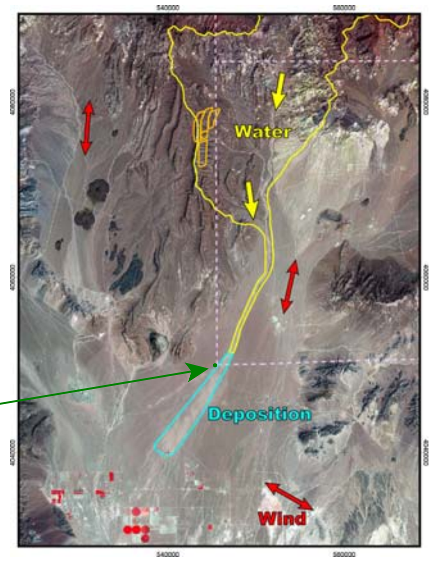
1 INTRODUCTION

The U.S. Department of Energy (DOE) is preparing a license application for a potential geologic repository for high-level waste disposal at Yucca Mountain, Nevada. A performance assessment would be submitted as part of the license application to be reviewed by the U.S. Nuclear Regulatory Commission (NRC). NRC would conduct a risk-informed performance-based review, in which in-depth technical evaluations will focus on technical areas significant to waste isolation. In preparation for a regulatory review of a potential DOE license application and its associated performance assessment, the Center for Nuclear Waste Regulatory Analyses (CNWRA) and NRC staffs developed the Total-system Performance Assessment (TPA) code to provide the capability to independently evaluate uncertainties in risk-significant features, events, and processes.

Consequences of a low probability, extrusive volcanic event are modeled assuming a subsurface volcanic conduit directly intersects the potential repository at Yucca Mountain. In this modeling scenario, waste package entrainment by the potential conduit results in the release of high-level waste as trace contamination of the erupting tephra, with subsequent atmospheric transport and deposition on the ground surface. Following initial deposition from the plume, redistribution (or remobilization) occurs through the long-term transport of tephra by wind and surficial water drainage in Fortymile Wash, referred to as eolian and fluvial remobilization, respectively. Figure 1-1 illustrates that the direction of fluvial remobilization of contaminated tephra in the model is toward the hypothetical receptor location south of the potential repository. Resuspension of ash particles {i.e., tephra < 2 mm [0.08 in]} produces airborne concentrations of ash and associated high-level waste, referred to as the airborne mass load. The estimated total dose for extrusive volcanism, which is dominated by the inhalation of resuspended volcanic ash, is significantly influenced by the amount of ash particles in the air (NRC, 2005). Ash redistribution processes may have a significant effect on the estimated proportion of contaminated ash in the airborne mass load used for calculating inhalation dose to the reasonably maximally exposed individual.

As outlined in the Yucca Mountain Review Plan (NRC, 2003), consequence modeling of a volcanic eruption conduit that intersects the potential repository should consider: volcanic disruption of waste packages, including the entrainment of high-level waste in the eruption conduit; airborne transport of radionuclides; redistribution of radionuclides in soil; and biosphere characteristics. These essential components are included in the NRC TPA code. The general focus of this report is the abstraction for redistribution of radionuclides in soil. The objective of this report is to describe the abstracted models for tephra redistribution and resuspension in the TPA Version 5.1beta code for estimating inhalation doses to the reasonably maximally exposed individual. The TPA Version 5.1beta code was underdevelopment during the preparation of this report. This report reflects the current status of the abstracted models and their inputs in the TPA Version 5.1beta code. Abstracted models and their inputs may change in revised versions of the TPA code. Descriptions of the modeling for volcanic disruption of waste packages and airborne transport of radionuclides are beyond the scope of this report and, therefore, are not discussed in detail.

With the intention of gaining fundamental insights into tephra redistribution processes and their effect on risk to the reasonably maximally exposed individual (also referred to hereafter as the receptor), the CNWRA developed and implemented a new abstracted model (Mohanty, et al., 2005) for the revised TPA code. Additional capabilities were developed in the new abstracted



Point for determining any initial tephra deposit at the receptor location

Figure 1-1. Satellite Image Showing the Fortymile Wash Catchment Basin (Yellow Line), Direction of Surface Water Flow Within Fortymile Wash (Yellow Arrows), Depositional Fan (Blue Shape), Potential Repository Site (Set of Adjacent Orange Shapes), and Nevada Test Site Boundary (Dashed Magenta Line). General Trends of Near-Surface Winds are Shown by Red Arrows.

model to provide more realistic estimates of volcanic eruption consequences. Primary capabilities of the new abstraction are (i) modeling of wind-field variations along the height of the eruption column, which affect the initial deposition of tephra, and (ii) modeling of the first-order processes affecting fluvial and eolian redistribution of tephra. Based on the insight that the estimated total dose for extrusive volcanism is dominated by the inhalation of resuspended volcanic ash (NRC, 2005), the current version of this abstracted model was developed to calculate doses only for the inhalation pathway, as described in Chapter 2 (ASHREMOB Module).

Another abstracted model, developed for previous versions of the TPA code, is described in Chapter 3. This model assumes a single wind direction and a single wind speed for calculating the atmospheric transport of tephra contaminated with high-level radioactive waste and deposition of tephra at a point on the ground surface near the reasonably maximally exposed individual. Radiological doses to the reasonably maximally exposed individual are estimated based on biopshere modeling for inhalation, ingestion, and ground surface exposure pathways. Because the resuspension of contaminated ash is directly coupled to inhalation modeling and considering its importance to total dose estimates, inhalation pathway modeling is the only biosphere modeling included with the description of this abstracted model in Chapter 3 (DCAGS Module).

The parameter AshEvolutionMode in the TPA code input file is the flag used to choose between the two abstracted modeling approaches for estimating consequences from a volcanic eruption. Allowed values of the AshEvolutionMode flag are either 1, to account for a stratified wind field and estimate the effects of ash remobilization within the Yucca Mountain region (Chapter 2), or 0, to fix the wind direction toward the receptor and neglect the effects of ash remobilization (Chapter 3). Figure 1-2 displays simplified flow charts of volcanic eruption consequence modules for the TPA code and their relationship to the AshEvolutionMode flag.

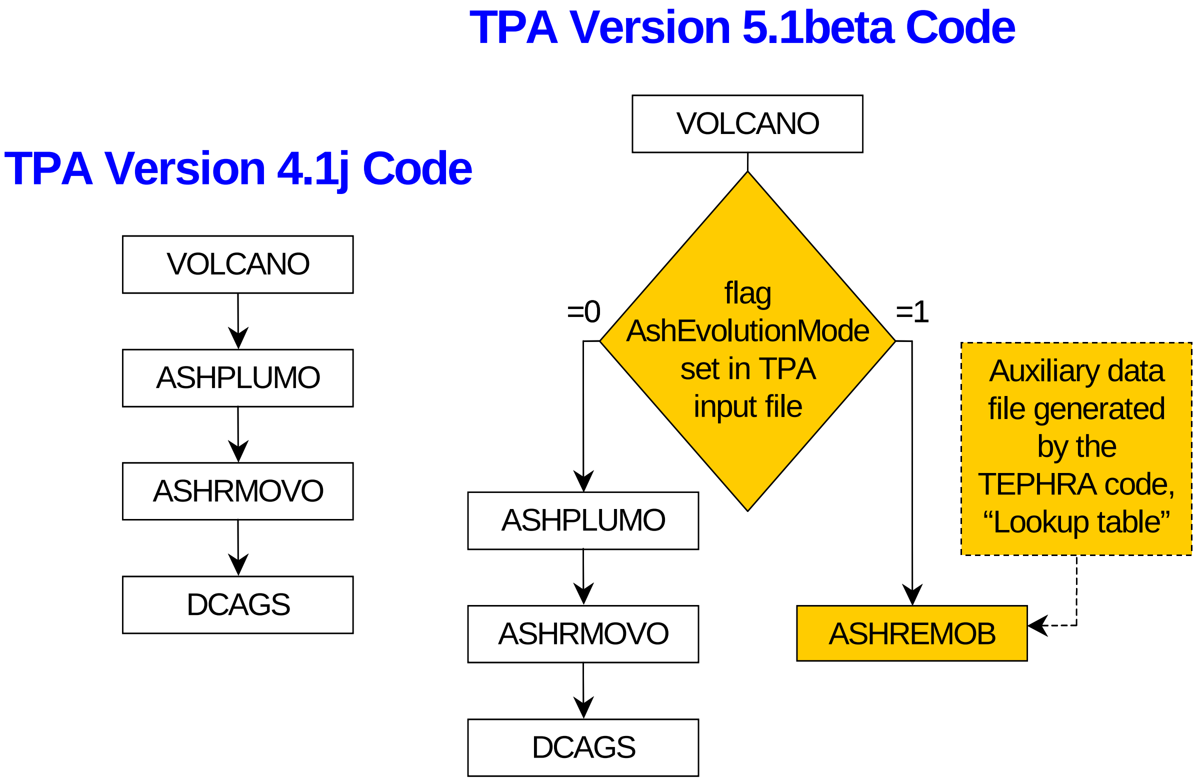


Figure 1-2. Simplified Flow Chart of Volcanic Eruption Consequence Modules for the TPA Code. The New Abstracted Model Is Highlighted in Gold. Figures 2-1 and 3-1 Provide Additional Information On the General Function of Each Consequence Module.

2 ABSTRACTED MODEL FOR TEHPRA REDISTRIBUTION AND RESUSPENSION IN THE YUCCA MOUNTAIN REGION (ASHREMOB)

A new abstracted model was developed and implemented as a new module (ASHREMOB) for the TPA Version 5.1beta code to enhance realism in extrusive volcanic consequence modeling. This model captures the main effects of surficial transport processes on the airborne concentration of high-level waste at the receptor location as a function of time after an eruption. This chapter describes the new model, which can account for wind-field variations along the height of the tephra column that affect the initial deposition of ash and the first-order processes affecting fluvial and eolian remobilizations of ash. Results from process-level conceptual model development and detailed analyses (Hooper, 2005) are directly factored into the development of this abstracted model for the TPA code (Benke, et al., 2006; Hooper and Benke, 2006). The outputs of this model are the temporal evolutions of the airborne concentration of high-level waste at the receptor location and the resulting inhalation dose following a volcanic eruption intersecting the potential repository at Yucca Mountain. The model uses a lookup table, which contains parameter values determined from detailed offline analyses, to estimate time evolutions of the airborne concentration of high-level waste at the receptor location from the initial deposit and fluvial and eolian remobilizations of ash. Detailed analyses calculate the three-dimensional deposition of ash with a stratified wind field and provide data for the lookup table and the values for other input parameters used in the model. The purpose of the ASHREMOB module is to convert initial characteristics of the contaminated tephra-fall deposit within the Yucca Mountain region into a time history of annual effective dose equivalent (or annual effective dose) for the inhalation of resuspended contaminated ash by the receptor.

High-level waste refers to highly radioactive material and irradiated reactor fuel regulated for geologic disposal under 10 CFR Part 63. Previous versions of the TPA code employed a single mass quantity for high-level waste because it provides a convenient means to account for the bulk transport of radioactive material in erupting tephra and resuspended ash. In the new abstracted model, use of the quantity for mass of high-level waste also includes transport via fluvial remobilization and eolian remobilization. The high-level waste quantity accounts for all waste forms in the potential repository by representing an average waste form in the repository. For example when averaged over the entire repository on a mass basis, one gram of high-level waste may represent 0.98 grams of commercial spent nuclear fuel, 0.01 grams of vitrified plutonium waste, and 0.01 grams of DOE spent nuclear fuel. Actual mass fractions depend on TPA code inputs. The total airborne concentration of high-level waste is combined with radionuclide activities per unit mass of high-level waste to estimate doses from each radionuclide and all radionuclides. A separate module, INVENT, calculates time-dependent radionuclide activities on a per mass basis for two types of representative waste packages, containing either commercial spent nuclear fuel or both vitrified plutonium waste and DOE spent nuclear fuel. Details of the radionuclide activity calculations are beyond the scope of this report and are not discussed further.

2.1 Inputs Supplied to the ASHREMOB Module

Figure 2-1 shows the flow of information in the TPA code when the new abstracted model is selected by the user for the volcanic eruption scenario (i.e., when AshEvolutionMode is set to 1). The passing of information from one TPA code module or component to the next is denoted with arrows. In addition to information transferred from other modules and components, each

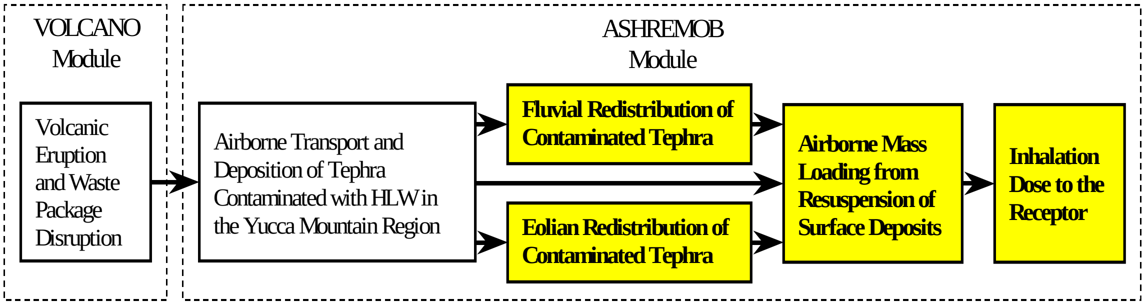


Figure 2-1. Flow Chart of Individual Modeling Components for Estimating Consequences of a Volcanic Eruption By Accounting for Fluvial and Eolian Redistribution of Contaminated Tephra in the Yucca Mountain Region. The Focus of this Report Is On the Four Modeling Components Highlighted in Yellow.

module component may have specific inputs. TPA code inputs can be specified as parameters in the master *tpa.inp* input file or in auxiliary files of input data.

The modeling component for airborne transport and deposition of contaminated tephra in the Yucca Mountain region is abstracted into the TPA code with an auxiliary data file (named *remob_lut.dat)*, referred to as the lookup table, that is generated from offline analyses using the TEPHRA code for airborne transport of radionuclides during a volcanic eruption. Based on the modeling approach in Connor, et al. (2001), the TEPHRA code generates three-dimensional plots of the tephra deposit and includes modifications for a stratified wind field and for high-level waste incorporation with erupting tephra.

The lookup table is generated using stochastic sampling of Yucca Mountain-specific volcanic parameters. Table 2-1 provides a description of the parameters in the lookup table. Table 2-2 shows the format for the lookup table. In the TPA Version 5.1 code, lookup table parameters for high-level waste are based on 1 metric ton of high-level waste entrained in erupted tephra, and ASHREMOB calculations are scaled by the total metric tons of high-level waste erupted, as determined from the VOLCANO module.

Table 2-3 presents the key input file parameters (i.e., parameters specified in the TPA code input file, *tpa.inp*) used by the ASHREMOB module for estimating inhalation dose from a potential eruption. To serve as a reference guide, Table 2-3 also presents the symbols used for each of the input file parameters in the equations of this chapter. Additional reference information pertaining to the input file parameters is contained in Appendix A of this report. Dose coefficients per unit intake [Sv/Bq], used to calculate whole body doses (effective dose or effective dose equivalent) for each pathway, are specified in the auxiliary data file, *gnewdf.dat*.

2.2 Conceptual Model Description

A conceptual model was formulated to address the potential remobilization and redistribution of contaminated tephra (i.e., ash) in the Fortymile Wash drainage system (Hooper, 2005). Although sediment erosion, transport, and deposition rates in arid regions such as Yucca Mountain are not well constrained, a sediment budget was constructed to account for long-term

Table 2-1. Parameters in the ASHREMOB Lookup Table (*remob_lut.dat*). In the TPA Version 5.1beta Code, Lookup Table Parameters Values for High-Level Waste Are Based on 1 Metric Ton of High-Level Waste Entrained in Erupted Tephra. The Symbols *i*, *f*, *e* Represent the Three Source Regions.

Parameter	Description
$c_{\mathrm{HLW},i}$	Mass of high-level waste for the initial deposit at the receptor location per unit area [g/m^2]
$C_{\mathrm{ash},i}$	Mass of ash for the initial deposit at the receptor location per unit area [g/m^2]
$m_{\mathrm{HLW},f}$	Mass of high-level waste deposited in the Fortymile Wash catchment basin from the eruption [g]
$m_{\mathrm{ash},f}$	Mass of ash deposited in the Fortymile Wash catchment basin from the eruption [g]
$a_{\mathrm{ash},f}$	Area of the Fortymile Wash catchment basin with an ash deposit from the eruption [m^2]
$m_{\mathrm{HLW},e}$	Mass of high-level waste deposited in the eolian source region from the eruption [g]
$m_{\mathrm{ash},e}$	Mass of ash deposited in the eolian source region from the eruption [g]
$a_{\mathrm{ash},e}$	Area of the eolian source region with an initial ash deposit from the eruption [m^2]

Table 2-2. Format for the Lookup Table Consisting of *n* Realizations of the TEPHRA Code*

$c_{\mathrm{HLW},i,1}$	$c_{\mathrm{ash},i,1}$	$m_{\mathrm{HLW},f,1}$	$m_{\mathrm{ash},f,1}$	$a_{\mathrm{ash},f,1}$	$m_{\mathrm{HLW},e,1}$	$m_{\mathrm{ash},e,1}$	$a_{\mathrm{ash},e,1}$
$c_{\mathrm{HLW},i,2}$	$c_{\mathrm{ash},i,2}$	$m_{\mathrm{HLW},f,2}$	$m_{\mathrm{ash},f,2}$	$a_{\mathrm{ash},f,2}$	$m_{\mathrm{HLW},e,2}$	$m_{\mathrm{ash},e,2}$	$a_{\mathrm{ash},e,2}$
. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .

Table 2-2. Format for the Lookup Table Consisting of *n* Realizations of the TEPHRA Code* (continued)

$c_{\mathrm{HLW},i,n}$	$c_{\mathrm{ash},i,n}$	$m_{\mathrm{HLW},f,n}$	$m_{\mathrm{ash},f,n}$	$a_{\mathrm{ash},f,n}$	$m_{\mathrm{HLW},e,n}$	$m_{\mathrm{ash},e,n}$	$a_{\mathrm{ash},e,n}$

* Each row corresponds to the results from a single realization of the TEPHRA code, denoted by the indices (1, 2, ..., *n*). A description of the lookup table parameters is provided in Table 2-1.

Table 2-3. Key Input File Parameters Used in the ASHREMOB Module

Symbol	Input Parameter Name
(none)	Age&Dosimetry[1=Inf,2=Todl,3=PTeen,4=Teen,5=Adlt, 6=AdltFG11]
B	InhalationRate5 [cm3/s]
λ_b	RelativeRateOfBlanketRemoval[1/yr]
$\rho_{\mathrm{ash},f}$	AshBulkDensity[g/cm3]
d_r	DepthOfResuspendibleLayer[cm]
λ_r	RateOfReductionOfMassLoadingFactor[1/yr]
$S_{\mathrm{ash,out}-H}$	AirborneMassLoadAboveFreshAshBlanketHeavyDisturbance[g/m3]
$S_{\mathrm{ash,out}-L}$	AirborneMassLoadAboveFreshAshBlanketLightDisturbance[g/m3]
$S_{\mathrm{out}-H}$	AirborneMassLoadOutsideHeavyDisturbance[g/m3]
$S_{\mathrm{out}-L}$	AirborneMassLoadOutsideLightDisturbance[g/m3]
$S_{\mathrm{in}-H}$	AirborneMassLoadInsideHeavyDisturbance[g/m3]
$S_{\mathrm{in}-L}$	AirborneMassLoadInsideLightDisturbance[g/m3]
S_{offsite}	AirborneMassLoadOffsite[g/m3]
$f_{\mathrm{out}-H}$	OccupancyFractionOutsideHeavyDisturbance[]
$f_{\mathrm{out}-L}$	OccupancyFractionOutsideLightDisturbance[]

Table 2-3. Key Input File Parameters Used in ASHREMOB Module Inhalation Dose Calculations (continued)

Symbol	Input Parameter Name
$f_{\text{in}-H}$	OccupancyFractionInsideHeavyDisturbance[]
$f_{\text{in}-L}$	OccupancyFractionInsideLightDisturbance[]
f_{offsite}	OccupancyFractionOffsite[]
(none)	AshEvolutionMode[0=no_ashremob,1=ashremob]
(none)	AshPlumeRealizationIndex[]
w_i	WeightingFactorInitialDeposit[]
w_f	WeightingFactorFluvial[]
$Y_{\text{sediment},f}$	AmbientSedimentYieldVolumePerBasinAreaPerEvent[m/event]
$A_{\text{basin},f}$	AreaDrainageBasinFluvial[m2]
T_f	TimeBetweenFlowEvents[yr]
$Y_{\text{ash},f}$	PostEruptionFluvialAshYieldVolumePerAreaPerEvent[m/event]
w_e	WeightingFactorEolian[]
$\rho_{\text{ash},e}$	DensityOfDistalAsh[g/m3]
A_{eolian}	AreaEolianSourceRegion[m2]

redistribution processes in the Fortymile Wash drainage system (Hooper, 2005). Following a potential volcanic eruption, a submillimeter-to-meter thick deposit of tephra may be deposited on the hillslopes around Yucca Mountain that are part of the Fortymile Wash watershed. Surface processes subsequently may remobilize and redistribute the tephra deposit. The significance to waste isolation of these processes is that, through time, potentially significant amounts of resuspendible particles containing high-level waste may be transported to the general area of the reasonably maximally exposed individual.

Previous model abstractions in the TPA code for tephra resuspension and airbone mass loading applied an exponential rate of reduction from an elevated mass load for fresh ash to a long-term mass load as time increased following the year of eruption [Eq. (17-2) in Mohanty, et al., 2002]. Simple mass-balance scoping calculations indicate the accumulation rate of remobilized tephra may result in significant fresh deposits of remobilized tephra (Hill and Connor, 2000; Hooper, 2005), which may be more susceptible to resuspension than stationary aged tephra originally deposited from the eruption plume. Remobilization of tephra deposits, therefore, may sustain estimated airborne mass loads, airborne concentrations of high-level waste, and associated inhalation doses for longer periods of time than suggested by simple decay relationships for the initial volcanic deposits (e.g., Bechtel SAIC Company, LLC, 2003a,b). In general, the risk from a volcanic eruption increases when estimated inhalation doses persist for longer times after the eruption (NRC, 2005, Appendix D, Figure 4-39).

Process-level modeling estimates accounting for remobilization and redistribution suggest that sediment yield is initially much higher than preeruption rates in the first few years following a potential eruption (Hooper, 2005). The modeling indicates that, within a few decades, sediment yield may return to the preeruption rate, but remobilized tephra in an arid climate may likely account for the bulk of the transported sediment in the drainage system. Thus, only minor to negligible amounts of tephra dilution are likely to occur in the first decades following a potential eruption. This process-level model appears most sensitive to the erosion rate, thickness, and volume of dispersed tephra in the watershed. Model results, however, estimate the flux of redistributed tephra in Fortymile Wash near the receptor location is higher than fluxes estimated in Bechtel SAIC Company, LLC (2003a,b).

The ASHREMOB module of the TPA code accounts for three components of the airborne concentration of high-level waste through time at the receptor location. The first component is the contribution from any ash initially deposited at the receptor location. The second component is the contribution from the later fluvial remobilization of ash. The third component is the contribution from the later eolian remobilization of ash. The airborne concentration of high-level waste through time at the receptor location is determined as the sum of these three contributions. Figure 2-2 presents a schematic representation of the three components and the sum for an example eruption that deposits ash in each of the three source regions. Because modeled eruptions may not always deposit ash in all three source regions, there may be some TPA code realizations in which at least one of the three contributions is zero. The remainder of this section describes the abstracted model for tephra redistribution and resuspension in the Yucca Mountain region (i.e., ASHREMOB module, invoked when the AshEvolutionMode flag is set to 1). For this mode, the ASHPLUMO, ASHRMOVO, and DCAGS modules are not used in the TPA code calculations. As mentioned previously, the ASHREMOB module is used to calculate inhalation doses only.

On execution of the modified TPA code, when the AshEvolutionMode flag is set to a value of 1, each realization of the TPA code selects a set of parameter values from the lookup table (Table 2-2). The lookup table contains 1,024 parameter sets, which is large compared with the typical number of realizations used in a TPA code simulation. Thus, the selection is typically performed without repetition of lookup table values within the same TPA code simulation. Repetition can occur, however, if the number of TPA code realizations exceeds the number of parameter sets in the lookup table. Using the parameter values selected for each realization, the ASHREMOB module calculations presented in the following equations estimate the airborne concentration of high-level waste through time at the receptor location and the resulting inhalation dose through time.

The inhalation dose per year (rem/yr) in ASHREMOB for the j th radionuclide is calculated as:

$$D_{inh,j}(t) = \left[B \cdot I_j \cdot \eta_{\mathrm{HLW},j}(t) \cdot \; H_{\mathrm{RMEI}}(t)\right] \times \left(1.166832 \times 10^{14}\ \frac{\mathrm{rem}}{Ci}\ \frac{Bq}{Sv}\ \frac{m^3}{cm^3}\ \frac{s}{\mathrm{yr}}\right) \qquad \text{(2-1)}$$

where

B — Breathing rate[cm^3/s], refer to the first two rows of Table 2-3

I_j — Inhalation dose coefficient per unit intake [Sv/Bq] for the j th radionuclide provided in the auxiliary data file, *gnewdf.dat*

$\eta_{\mathrm{HLW},j}(t)$ — Time-dependent activity of the j^{th} radionuclide per gram of high-level waste [Ci/g] provided by INVENT module calculations

$H_{\mathrm{RMEI}}(t)$ — Total airborne concentration of high-level waste available for inhalation by the receptor [g/m^3]

The total inhalation dose is calculated as the sum of all radionuclide inhalation doses. The total airborne concentration of high-level waste available for inhalation by the receptor is calculated as the sum of the outdoor, indoor, and offsite contributions

$$H_{\mathrm{RMEI}}(t) = H_{\mathrm{RMEI,outdoor}}(t) + H_{\mathrm{RMEI,indoor}}(t) + H_{\mathrm{RMEI,offsite}}(t) \qquad \text{(2-2)}$$

where

$H_{\mathrm{RMEI,outdoor}}(t)$ — Outdoor airborne concentration of high-level waste at the receptor location [g/m^3]

$H_{\mathrm{RMEI,indoor}}(t)$ — Indoor airborne concentration of high-level waste available for inhalation by the receptor [g/m^3]

$H_{\mathrm{RMEI,offsite}}(t)$ — Offsite airborne concentration of high-level waste available for inhalation by the receptor [g/m^3]

Inhalation of resuspended radioactive material is modeled for exposure outdoors, indoors, and offsite. The next sections present the mathematical relationships used to determine the airborne concentration of high-level waste for outdoor, indoor, and offsite exposure.

2.2.1 Outdoor Exposure

The outdoor airborne concentration of high-level waste [g/m^3] at the receptor location, $H_{\mathrm{RMEI,outdoor}}(t)$, is calculated as

$$H_{\mathrm{RMEI,outdoor}}(t) = f_{\mathrm{out}-H}\, H_{i-H}(t) + f_{\mathrm{out}-L}\, H_{i-L}(t) + \left(f_{\mathrm{out}-H} + f_{\mathrm{out}-L}\right) H_f(t) + \left(f_{\mathrm{out}-H} + f_{\mathrm{out}-L}\right) H_e(t) \qquad \text{(2-3)}$$

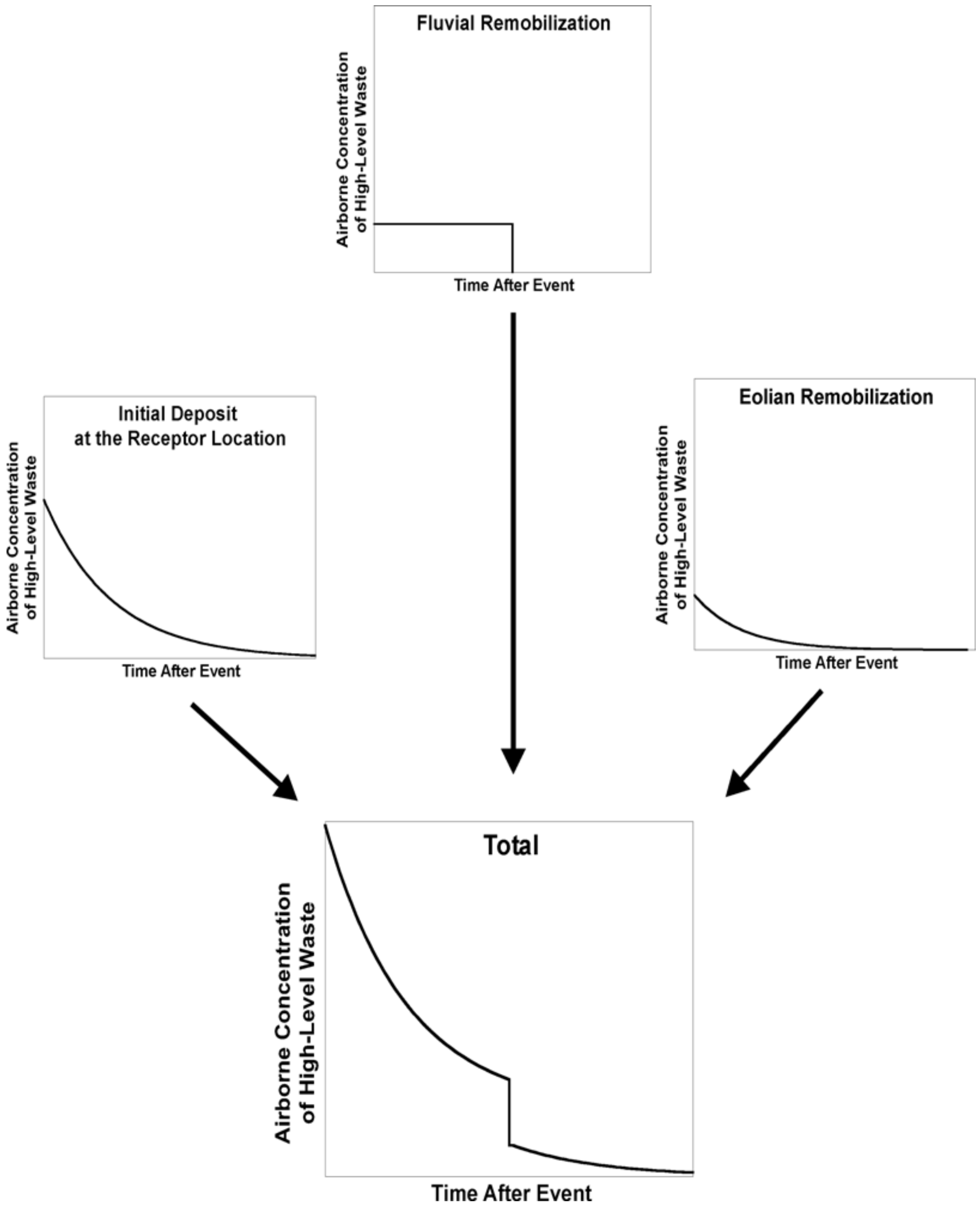


Figure 2-2. Schematic Representation of the Time Evolution of the Total Airborne Concentration of High-Level Waste at the Receptor Location Resulting from Contributions from the Initial Deposit at the Receptor Location, Fluvial Remobilization, and Eolian Remobilization. The Example Shown Cooresponds to an Eruption that Deposits Ash in Each of the Three Source Regions.

where

$H_{i\text{-}H}(t)$ — Airborne concentration of high-level waste from the initial ash deposit at the receptor location during heavy distrubance [g/m^3]

$H_{i-L}(t)$ — Airborne concentration of high-level waste from the initial ash deposit at the receptor location during light disturbance [g/m^3]

$H_f(t)$ — Airborne concentration of high-level waste from the fluvial remobilization of ash [g/m^3]

$H_e(t)$ — Airborne concentration of high-level waste from the eolian remobilization of ash [g/m^3]

$f_{\text{out}-H}$ — Fraction of time receptor spends outdoors with heavy disturbance [unitless] {OccupancyFractionOutsideHeavyDisturbance[-]}

$f_{\text{out}-L}$ — Fraction of time receptor spends outdoors with light disturbance [unitless] {OccupancyFractionOutsideLightDisturbance[-]}

t — Time following volcanic eruption [yr]

For each TPA code realization, the calculated tephra deposit is partitioned into three source regions that represent (i) initial deposits (if any) at the receptor location denoted by the symbol *i*, (ii) potential deposits in the Fortymile Wash drainage system subject to fluvial redistribution denoted by the symbol *f*, and (iii) potential deposits in areas subject to eolian redistribution denoted by the symbol *e*. A discussion on each of the calculations follows separately.

2.2.1.1 Airborne Concentration of High-Level Waste From the Initial Deposit at the Receptor Location

The airborne concentration of high-level waste from the initial deposit addresses heavy and light disturbances separately. The airborne concentration from the initial deposit during heavy disturbance is calculated as

$$H_{i\text{-}H}(t) = c_i \times S_{\text{ash,out-}H} \times f_R(t) \times e^{-\lambda_r t} \tag{2-4}$$

where

c_i — Concentration factor for high-level waste in ash for the initial deposit at the receptor location (grams of high-level waste per unit area/grams of ash per unit area) [g$_{\text{HLW}}$/g$_{\text{ash}}$]

$S_{\text{ash,out-}H}$ — Outdoor mass load above fresh ash with heavy distrubance [g/m^3] {AirborneMassLoadAboveFreshAshBlanketHeavyDisturbance[g/m3]}

$f_R(t)$ — Time-dependent fraction of resuspended mass emanated from contaminated volcanic layer [unitless]

λ_r — Rate of reduction of airborne mass load [1/yr] {RateOfReductionOfMassLoadingFactor[1/yr]}

The contribution from the initial deposit during light disturbance is calculated as

$$H_{i-L}(t) = w_i \times c_i \times S_{\text{ash,out}-L} \times f_R(t) \times e^{-\lambda_r t} \tag{2-5}$$

where

w_i — Weighting factor for the contribution of the airborne mass load above the initial deposit to the total airborne particle concentration at the receptor location [unitless]

$S_{\text{ash,out}-L}$ — Outdoor mass load above fresh ash with light disturbance [g/m^3] {AirborneMassLoadAboveFreshAshBlanketLightDisturbance[g/m3]}

The weighting factor, W_i, is a TPA code input parameter. Heavy disturbance activities and outdoor mass loads during heavy disturbances do not apply to the contributions from fluvial and eolian remobilizations (refer to additional discussion in Section 2.4). Because the outdoor mass load during heavy disturbances is assumed to result from surface-disturbing activities at the receptor location, a weighting factor is not included in Eq. (2-4). The concentration factor, c_i, is a value calculated from lookup table parameters (Table 2-1) in the following manner

$$c_i = \frac{c_{\text{HLW},i}}{c_{\text{ash},i}} \tag{2-6}$$

where

$c_{\text{HLW},i}$ — Mass of high-level waste per unit area for the initial deposit at the receptor location [g/m^2]

$c_{\text{ash},i}$ — Mass of ash per unit area for the initial deposit at the receptor location [g/m^2]

Checks are included to avoid division by zero errors. For thin ash deposits, the time-dependent resuspension factor, $f_R(t)$, accounts for the dilution of resuspended contaminated ash with noncontaminated soil. If the ash deposit is thicker than or equal to the resuspendible layer thickness hereinafter referred to as d_r, $f_R(t)$ equals unity. If the ash deposit is thinner than the resuspendible layer thickness, $f_R(t)$ equals the ratio of the ash deposit thickness to the thickness of the resuspendible layer (< 1).

2.2.1.2 Airborne Concentration of High-Level Waste At the Receptor Location From Fluvial Remobilization

The airborne concentration of high-level waste at the receptor location from fluvial remobilization is calculated as

$$H_f(t) = w_f \times c_f \times d_f \times S_f(t) \tag{2-7}$$

where

w_f — Weighting factor for the contribution of the airborne mass load above the sediment deposit from fluvial remobilization to the total airborne particle concentration at the receptor location [unitless]

c_f — Concentration factor for high-level waste in the sediment [$g_{HLW}/g_{sediment}$]

d_f — Dilution factor for mixing noncontaminated and contaminated sediments during fluvial remobilization [unitless]

$S_f(t)$ — Airborne mass load above the sediment deposit [g/m^3]

Although ash remains in the Fortymile Wash catchment basin, the airborne mass load above the sediment deposit, $S_f(t)$, is set equal to the value of the TPA code input parameter for the outdoor airborne mass load of ash above a fresh deposit for light disturbance {AirborneMassLoadAboveFreshAshBlanketLightDisturbance[g/m3]}. After the ash has been depleted from the Fortymile Wash catchment basin, $S_f(t)$ is set equal to zero (refer to additional discussion in Section 2.4).

The weighting factor, w_f, is a parameter specified in the TPA code input file. The concentration factor, c_f, is a value calculated from lookup table parameters (Table 2-1) in the following manner

$$c_f = \frac{m_{\text{HLW},f}}{m_{\text{ash},f}} \tag{2-8}$$

where

$m_{\text{HLW},f}$ — Mass of high-level waste deposited in the Fortymile Wash catchment basin from the eruption [g]

$m_{\text{ash},f}$ — Mass of ash deposited in the Fortymile Wash catchment basin from the eruption [g]

Checks are included to avoid division by zero errors.

The dilution factor, d_f, is calculated as

$$d_f = \frac{v_{\text{ash},f}}{v_{\text{sediment},f} + v_{\text{ash},f}} \tag{2-9}$$

where

$v_{\text{ash},f}$ — Total volume of ash deposited in the Fortymile Wash catchment basin [m^3]

$v_{\text{sediment},f}$ — Total volume of noncontaminated sediment yielded by the Fortymile Wash drainage system during the time period of fluvial ash remobilization [m^3]

The ash volume is calculated from parameters in the lookup table and TPA code input file as

$$V_{\text{ash},f} = \frac{m_{\text{ash},f}}{\rho_{\text{ash},f}} \tag{2-10}$$

where $\rho_{\text{ash},f}$ represents the density of ash [g/m^3] and equals the value for the TPA code ash density parameter AshBulkDensity[g/cm3] multiplied by a unit conversion factor of 1,000,000 cm^3/m^3.

The sediment volume, $V_{\text{sediment},f}$, also is calculated from parameters in the lookup table and TPA code input file as

$$v_{\text{sediment},f} = Y_{\text{sediment},f}\left(A_{\text{basin},f} - a_{\text{ash},f}\right)n_{\text{deplete}} \tag{2-11}$$

where

$Y_{\text{sediment},f}$ — Preeruption sediment volume from the drainage basin that discharges through Fortymile Wash per unit area per discharge event [m/event]

$A_{\text{basin},f}$ — Total area of the drainage basin that discharges through Fortymile Wash [m^2]

$a_{\text{ash},f}$ — Area of the Fortymile Wash catchment basin with an ash deposit from the eruption [m^2]

n_{deplete} — Number of significant flow events required to deplete the Fortymile Wash catchment basin of ash [unitless]

The number of significant flow events required to deplete the Fortymile Wash catchment basin of ash is determined from the following relationship

$$n_{\text{deplete}} = \frac{v_{\text{ash},f}}{Y_{\text{ash},f}\,a_{\text{ash},f}} \tag{2-12}$$

where $Y_{\text{ash},f}$ represents the posteruption volume of fluvial remobilized ash yielded from the Fortymile Wash catchment basin per unit area per discharge event [m/event].

The duration of fluvial remobilization component, $t_{\text{duration},f}$, depends on the timing of the fluvial remobilization events and is computed as

$$t_{\text{duration},f} = n_{\text{deplete}} T_f \tag{2-13}$$

where T_f represents the average time between significant flow events [yr/event].

2.2.1.3 Airborne Concentration of High-Level Waste At the Receptor Location From Eolian Remobilization

The airborne concentration of high-level waste at the receptor location from eolian remobilization is calculated as

$$H_e(t) = w_e \times c_e \times d_e \times S_e(t) \tag{2-14}$$

where

w_e	—	Weighting factor for the contribution of the airborne mass load above the initial ash deposit in the eolian source area to the total airborne particle concentration at the receptor location [unitless]
c_e	—	Concentration factor for high-level waste in the eolian ash deposit [g_{HLW} /g_{ash}]
d_e	—	Dilution factor for the eolian sediments [unitless]
$S_e(t)$	—	Airborne mass load above the eolian deposit [g/m^3]

Initially, $S_e(t)$ is set equal to the value of the TPA code input parameter for the outdoor airborne mass load of ash above a fresh deposit for light disturbance {AirborneMassLoadAboveFreshAshBlanketLightDisturbance[g/m3]}. The reduction in the airborne particle mass load above the eolian deposit with time is modeled with an exponential decay function dependent on the value of the TPA code input parameter {RateOfReductionOfMassLoadingFactor[1/yr]}, which is the same approach used to model the reduction in the airborne particle mass load above the initial deposit at the receptor location.

The weighting factor, w_e, is a TPA code input parameter. The concentration factor, c_e, is a value calculated from lookup table parameters (Table 2-1) in the following manner

$$c_e = \frac{m_{\text{HLW},e}}{m_{\text{ash},e}} \tag{2-15}$$

where

$m_{\text{HLW},e}$	—	Mass of high-level waste deposited in the eolian source region from the eruption [g]
$m_{\text{ash},e}$	—	Mass of ash deposited in the eolian source region from the eruption [g]

Checks are included to avoid division by zero errors. The dilution factor, d_e, is calculated from values in the lookup table and the TPA code input parameters as

$$d_e = \begin{cases} \dfrac{a_{\text{ash},e}}{A_{\text{eolian}}} & \text{if} \quad \dfrac{m_{\text{ash},e}\left(100\,\frac{\text{cm}}{\text{m}}\right)}{a_{\text{ash},e}\rho_{\text{ash},e}} > d_r \\ \dfrac{m_{\text{ash},e}}{a_{\text{ash},e}\rho_{\text{ash},e}} \cdot \dfrac{a_{\text{ash},e}}{A_{\text{eolian}}} \cdot \dfrac{100\,\frac{\text{cm}}{\text{m}}}{d_r} & \text{if} \quad \dfrac{m_{\text{ash},e}\left(100\,\frac{\text{cm}}{\text{m}}\right)}{a_{\text{ash},e}\rho_{\text{ash},e}} \le d_r \end{cases} \tag{2-16}$$

where

$a_{\text{ash},e}$ — Area of the eolian source region with an initial ash deposit from the eruption [m^2]
d_r — Resuspendible layer thickness [cm] {DepthOfResuspendibleLayer[cm]}
$\rho_{\text{ash},e}$ — Density of the distal ash deposit [g/m^3]
A_{eolian} — Total area of the eolian source region [m^2]

2.2.2 Indoor Exposure

Estimates of the total concentration of high-level waste in indoor ash account for different high-level waste concentrations from the three source regions (i.e., initial deposit at the receptor location, fluvial remobilization, and eolian remobilization). Calculations of the indoor airborne concentration of high-level waste use the same proportions from each of three source regions for the total outdoor airborne particle concentration to which the receptor is exposed. In other words, the proportion of the total airborne particle concentration from the three components is the same indoors and outdoors. The term proportion is used in these calculations instead of the term fraction to avoid confusion with the occupancy fractions.

During heavy disturbance outdoors, the total airborne particle concentration (g/m^3) at the receptor location is calculated as

$$P_{\text{out}-H}(t) = S_{\text{ash,out}-H}e^{-\lambda_r t} + w_f S_f(t) + w_e S_{\text{ash,out}-L}e^{-\lambda_r t} \tag{2-17}$$

Heavy disturbance activities are assumed to occur only on the initial deposit at the receptor location. In other words, heavy disturbance activities and outdoor mass loads during heavy disturbance do not apply to the contributions from fluvial and eolian remobilization. For this reason, a weighting factor is not included in the first term of the right-hand side of Eq. (2-17).

The proportions of the particle concentration from the three source regions (i.e., initial deposition at the receptor location, fluvial remobilization, and eolian remobilization) when the receptor is engaged in heavy disturbance activities outdoors are

$$p_{i-H}(t) = \frac{S_{\text{ash,out}-H}\, e^{-\lambda_r t}}{P_{\text{out}-H}(t)}$$

$$p_{f-H}(t) = \frac{w_f\, S_f(t)}{P_{out-H}(t)} \tag{2-18}$$

$$p_{e-H}(t) = \frac{w_e\, S_{\text{ash,out}-L}\, e^{-\lambda_r t}}{P_{\text{out}-H}(t)}$$

During light disturbance outdoors, the total airborne particle concentration (g/m^3) at the receptor location is calculated as

$$P_{\text{out}-L}(t) = w_i S_{\text{ash,out}-L} e^{-\lambda_r t} + w_f S_f(t) + w_e S_{\text{ash,out}-L} e^{-\lambda_r t} \tag{2-19}$$

The proportions of the particle concentration from the three source regions (i.e., initial deposition at the receptor location, fluvial remobilization, and eolian remobilization) when the receptor is engaged in light disturbance activities outdoors are equal to

$$p_{i-L}(t) = \frac{w_i S_{\text{ash,out}-L} e^{-\lambda_r t}}{P_{\text{out}-L}(t)}$$

$$p_{f-L}(t) = \frac{w_f S_f(t)}{P_{\text{out}-L}(t)} \tag{2-20}$$

$$p_{e-L}(t) = \frac{w_e S_{\text{ash,out}-L} e^{-\lambda_r t}}{P_{\text{out}-L}(t)}$$

The final proportions for the three source regions are calculated as the weighted sum of the proportions and occupancy fractions for heavy and light disturbance divided by the total fraction of time exposed outdoors

$$p_i(t) = \frac{p_{i-H}(t) f_{\text{out}-H} + p_{i-L}(t) f_{\text{out}-L}}{f_{\text{out}-H} + f_{\text{out}-L}}$$

$$p_f(t) = \frac{p_{f-H}(t) f_{\text{out}-H} + p_{f-L}(t) f_{\text{out}-L}}{f_{\text{out}-H} + f_{out-L}} \tag{2-21}$$

$$p_e(t) = \frac{p_{e-H}(t) f_{\text{out}-H} + p_{e-L}(t) f_{\text{out}-L}}{f_{\text{out}-H} + f_{\text{out}-L}}$$

These proportions account for the total outdoor particle load to which the receptor is exposed outdoors and are used to calculate the airborne concentration of high-level waste indoors.

The indoor airborne concentration of high-level waste (g/m^3) available for inhalation by the receptor, $H_{\text{RMEI,indoor}}(t)$, is calculated as

$$\begin{aligned} H_{\text{RMEI,indoor}}(t) &= f_{\text{in}-H}\left[p_i(t)\times c_i \times f_R(t) + p_f(t)\times c_f \times d_f + p_e(t)\times c_e \times d_e\right]S_{in-H} \\ &+ f_{\text{in}-L}\left[p_i(t)\times c_i \times f_R(t) + p_f(t)\times c_f \times d_f + p_e(t)\times c_e \times d_e\right]S_{\text{in}-L} \end{aligned} \qquad (2\text{-}22)$$

where

$S_{\text{in}-H}$ — Indoor mass load for dust with heavy disturbance (g/m^3) = AirborneMassLoadInsideHeavyDisturbance[g/m3]
$S_{\text{in}-\text{L}}$ — Indoor mass load for dust with light disturbance (g/m^3) = AirborneMassLoadInsideLightDisturbance[g/m3]
$f_{\text{in}-H}$ — Fraction of time receptor spends indoors with heavy disturbance = OccupancyFractionInsideHeavyDisturbance[-]
$f_{\text{in}-L}$ — Fraction of time receptor spends indoors with light disturbance = OccupancyFractionInsideLightDisturbance[-].

2.2.3 Offsite Exposure

The offsite occupancy fraction is included only for completeness to allow for a fraction of time the receptor may spend far away from Amargosa Valley and the Yucca Mountain region. It is assumed that the offsite locations are free of contamination. The default offsite airborne mass load is thus set to zero. Although its contribution is intended to be nil, a relationship still is established for the offsite airborne concentration of high-level waste that is similar to the relationships presented previously. Since unique concentration and dilution factors are not explicitly derived for offsite locations, the concentration and dilution factors for the eolian contribution are included as proxies in the relationship for the offsite airborne concentration of high-level waste available for inhalation by the receptor

$$H_{\text{RMEI,offsite}} = f_{\text{offsite}} \times c_e \times d_e \times S_{\text{offsite}} \qquad (2\text{-}23)$$

where

S_{offsite} — Offsite mass load (g/m^3) = AirborneMassLoadOffsite[g/m3]
f_{offsite} — Fraction of time receptor spends offsite = OccupancyFractionOffsite[-].

2.3 Outputs Associated With the ASHREMOB Module

The ASHREMOB module computes radionuclide doses for the igneous eruption scenario at every simulation time step. Intermediate outputs are reported in the *ashremob.out* output file. The *ashremob.out* file presents time histories for (i) airborne mass loads for each source region (any initial deposit at receptor location during light and heavy disturbance activities, fluvial remobilization, and eolian remobilization); (ii) airborne concentrations of high-level waste for the following parameters:

$$H_{i-H}(t),\ H_{i-L}(t),\ H_f(t),\ H_e(t),\ H_{\text{RMEI, outdoor}}(t),\ H_{\text{RMEI, indoor}}(t),\ \text{and}\ H_{\text{RMEI, offsite}}(t)$$

and (iii) total outdoor particle loads during light and heavy disturbance activities. General output files for dose are described in Section 3.3 of this report. Since the ASHREMOB module only computes dose for the inhalation pathway, all general output files for total dose actually report inhalation doses when igneous eruptions are simulated using the ASHREMOB module (i.e., the AshEvolutionMode flag set to a value of 1).

2.4 Modeling Assumptions of the ASHREMOB Approach

The new abstracted model for tephra redistribution and resuspension accounts for only the inhalation pathway. There are no calculations for other pathways (such as groundshine). Because leaching is considered to be of low significance to waste isolation (NRC, 2005, Appendix D, Section 4.3.13.1), explicit treatment for leaching was not included in the abstracted model for tephra redistribution and resuspension within the Yucca Mountain region. The other main assumptions are related to the three contributions to the airborne concentration of high-level waste available for inhalation by the receptor and the modeling component for airborne mass loading.

In the calculation of the airborne concentration of high-level waste at the receptor location, weighting factors are used to account for contributions from the three source regions (i.e., initial deposit at the receptor location, fluvial remobilization, and eolian remobilization). The weighting factors are applied as translocation factors that convert the airborne concentration of high-level waste above each source region to an airborne concentration available for inhalation by the receptor.

For the contribution from the initial deposit at the receptor location, it is assumed that inhalation doses following the volcanic event are dominated by the airborne mass load from ash (i.e., the effects on the airborne concentration of high-level waste from the resuspension of contaminated soil are neglected). Heavy disturbance activities during a portion of each year are assumed to occur on the initial deposit at the receptor location only and not on the source regions for fluvial and eolian remobilization. For the source region of the ASHREMOB module pertaining to an initial deposit at the receptor location, the airborne mass loading model is similar to the model used in the DCAGS module described in Chapter 3.

For the fluvial remobilization contribution, data suggest that fluvial remobilization events are frequent enough to replenish the deposition region of Fortymile Wash with fresh sediment. Considering that fresh deposits of remobilized tephra could be more susceptible to resuspension than stationary aged tephra originally deposited from the eruption plume, the estimated mass load for ash in the Fortymile Wash catchment basin may remain approximately constant with time. Thus, the airborne mass load at the deposition region of Fortymile Wash is assumed constant between the time of the eruption and the time, $t_{\text{duration},f}$, for fluvial remobilization to deplete the ash from the Fortymile Wash catchment basin [Eq. (2-13)]. Because the abstraction does not model individual flood events, delays between the year of eruption and the year of the first fluvial remobilization event are not accounted for explicitly. Uniform mixing of remobilized ash and clean sediment is assumed. At times greater than $t_{\text{duration},f}$, it is assumed further fluvial remobilization in Fortymile Wash results in the deposition of noncontaminated sediment over the older contaminated sediment deposit. By not accounting for dilution of thin fresh fluvial deposits with older underlying deposits, each fluvial deposit is assumed effectively to have a thickness greater than the resuspendible layer thickness. For times greater than $t_{\text{duration},f}$, the airborne particle load is artificially set to zero to represent no contribution from fluvial remobilization to the airborne concentration of high-level waste at the receptor location. Specific assumptions for the first-order conceptual model for fluvial remobilization of ash are presented in Hooper (2005). Figure 4-4 of Hooper (2005) displays a significant increase in posteruption sediment yield followed by a gradual decrease with time. For times between the time of the eruption and $t_{\text{duration},f}$, this simplified treatment of a constant posteruption sediment yield may overestimate the duration that Fortymile Wash yields contaminated sediment deposits with thicknesses greater than the resuspendible layer thickness $\left(t_{\text{duration},f}\right)$, the period of airborne concentration of high-level waste at the receptor location from the resuspension of contaminated fluvial deposits, and, subsequently, the risk resulting from long-term fluvial redistribution of tephra.

For the eolian remobilization contribution, a factor equal to the fraction of the eolian source region covered by the initial deposit is used to account for dilution by noncontaminated sediment originating from areas without an initial ash deposit. An average thickness of the tephra-fall deposit in the eolian source region is used to estimate any dilution of the airborne particle concentration resulting from the resuspension of clean soil underneath thin ash layers. The reduction with time in the particle mass load over the source deposit for eolian remobilization is assumed to be similar to the reduction associated with the initial deposit at the receptor location. A simple exponential decay function is used to model the reduction in the particle mass load with time for both the initial deposit at the receptor location and the averaged deposit for eolian remobilization.

For both the primary tephra-fall deposit at the receptor location and eolian deposits in the Yucca Mountain region, the airborne mass load reduction with time following the eruption is assumed to follow a simple exponential decay relationship. Because fluvial deposits are assumed to age differently in the environment than both primary tephra-fall and eolian deposits, the exponential reduction of the airborne mass load with time is not applied to fluvial deposits. The duration that fluvial deposits contribute to the airborne concentration of high-level waste is limited to the time period that Fortymile Wash yields contaminated sediment. After Fortymile Wash is depleted of contamined tephra, the modeled fluvial component no longer contributes to the airborne concentration of high-level waste. Because long-term heavy disturbance of fluvial deposits in the Fortymile Wash is not expected, the product of the airborne mass load of ash for light disturbance and a weighting factor is used to determine the contribution for fluvial redistribution. The assumption is that the approach of using a weighting factor with the airborne mass load from resuspended fluvial deposits adequately captures the general effect of the detailed processes for fluvial remobilization on performance estimates.

For estimating annual-average airborne particle mass loads, resuspension from heavy surface-disturbing activities is modeled only for the initial deposit at the receptor location and not for the fluvial and eolian source regions. Outdoor mass loads during heavy disturbance conditions are assumed to result from the surface-disturbing activities at the receptor location. Heavy-disturbance mass loading conditions outdoors at the receptor location correspond to the outdoor occupancy time fraction for receptor during heavy surface-disturbing activities. Since heavy disturbance conditions tend to result from human-induced activities, outdoor mass loads for heavy disturbance are applied only on the initial deposit at the receptor location. Large-scale heavy disturbance conditions in the fluvial and eolian source regions, such as sand storms, are neglected because those conditions are unlikely to affect annual dose estimates significantly because the probability of occurrence is low and the duration of exposure is short relative to the annual time frame. Small-scale heavy disturbance conditions in those regions, such as plowing fields, are neglected because the surface area affected by increased surface-disturbing activity, at any given time, is likely a small fraction of the total surface area for the source region. Additionally, localized increases in surface-disturbance of the fluvial and eolian source regions are expected to have little effect on the annual-average airborne mass load at the receptor location because (i) the airborne concentration is reduced by dispersion as the resuspension plume migrates downwind and (ii) the wind blows the plume from the localized surface-disturbing activities directly toward the receptor only part of the time.

The modeling component for mass loading consists of two categories for surface-disturbing activities: heavy and light. As described in Chapter 5 of Mohanty, et al. (2005), a larger number of activity categories, such as sleeping, sedentary, light work, moderate work, and hard work, could be conceptualized. However, limitation of the model to only two categories is a reasonably conservative simplification because time spent during little or no disturbance is coupled with a general airborne mass load for light disturbance (i.e., the model does not include a separate category for ambient airborne mass load). The abstracted modeling component for mass loading in the TPA code was developed to account for both differences in mass loads from surface-disturbing activities as well as the fraction of time that the receptor spends outdoors, indoors, and offsite. The implied modeling assumption is that number of categories for mass loads (seven in Table 2-3) and occupancy fraction (five in Table 2-3) provides sufficient flexibility and transparency to estimate annual-average concentrations of airborne particulates for inhalation calculations.

Calculations of the indoor airborne concentration of high-level waste assume the same proportions from each of three source regions (i.e., initial deposit at the receptor location, fluvial remobilization, and eolian remobilization) for the total outdoor airborne particle concentration. In other words, the proportion of the total airborne particle concentration from the three source regions is assumed the same indoors and outdoors. The concentration of high-level waste in indoor ash and the resulting indoor airborne concentration of high-level waste are influenced by outdoor surface-disturbing activities.

3 ABSTRACTED MODEL FOR RESUSPENSION OF TEPHRA DEPOSITED AT THE RECEPTOR LOCATION (DCAGS MODULE)

The purpose of the DCAGS module is to convert the areal radionuclide activity concentration (in Ci/m^2) on the ground surface calculated by the ASHRMOVO module into annual total effective dose equivalent or effective dose (in rem).

3.1 Inputs Supplied to the DCAGS Module

Figure 3-1 shows the flow of information in the TPA code for estimating inhalation doses from a potential volcanic eruption when the AshEvolutionMode flag is set to 0. Time-varying areal activity concentrations (in Ci/m^2) on the ground surface from the ASHRMOVO module for each radionuclide, and the areal concentration (in g/cm^2) of ash on the ground surface from the ASHPLUMO module are provided to the DCAGS module for calculating radionuclide doses (annual total effective dose equivalent or effective dose) using biosphere dose conversion factors in two auxiliary data files, *gs_cb_ad.dat*, and *gs_pb_ad.dat,* for current and pluvial climates, respectively. The time evolution of average annual precipitation and temperature from the UZFLOW module determines the time when the current condition will switch to pluvial conditions. The dose coefficients per unit intake in *gnewdf.dat* serve as inputs to calculations of the biosphere dose conversion factors for inhalation. Other DCAGS input parameters, such as the resuspendible depth and values for categories of airborne mass load and occupancy fraction, are specified in the Mass Loading and Occupancy Factor section of the *tpa.inp* file. Section 3.2 presents the individual inputs used in the DCAGS calculations.

3.2 Conceptual Model Description

The conceptual framework for the DCAGS module includes processes that follow the airborne transport and deposition of contaminated tephra on the ground surface at the receptor location. The DCAGS module is invoked when the AshEvolutionMode flag is set to 0. The pathways accounted for by the DCAGS module are the airborne resuspension of deposited contamination and subsequent inhalation, direct exposure, and ingestion of contaminated plant and animal

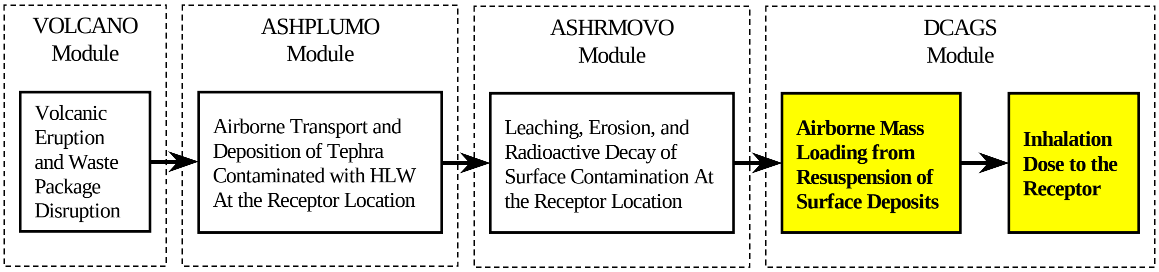


Figure 3-1. Flow Chart of Individual Modeling Components for Estimating Consequences of a Volcanic Eruption Due to Contaminated Tephra Deposited At the Receptor Location. Aspects of the DCAGS Module Associated with Pathways Other Than the Inhalation Pathway Are Not Depicted. The Focus of this Report Is On the Two Modeling Components Highlighted in Yellow.

food products. Ingestion of contaminated water is not considered. The DCAGS module uses simple exponential decay functions to account for the erosion of the initial ash deposit and an assumed reduction of airborne particle loading with time after an eruption.

A detailed description of the abstracted model calculations are presented in this section for the inhalation pathway. Other than the inhalation pathway, the biosphere dose conversion factors (rem/yr per Ci/m^2) are calculated by the GENTPA module, which is based on the GENII-S pathway/dose assessment code (Leigh, et al., 1993; Napier, et al., 1988). Biosphere dose conversion factors are calculated for each noninhalation pathway and radionuclide as an annual effective dose equivalent (or annual effective dose) per unit areal radionuclide activity concentration on the ground surface. In general, these calculations are based on unit radionuclide concentrations in the soil and a combination of site-specific and generic input parameters previously documented in LaPlante and Poor (1997). Average or median values (depending on the specified distribution type) are generally used for input parameters that describe the characteristics of the receptor. For each total-system performance assessment realization, the DCAGS module multiplies areal radionuclide activity concentrations by radionuclide-specific biosphere dose conversion factors for the exposure pathway and climate. For each time step, the products of each areal radionuclide activity and biosphere dose conversion factor are summed within and among exposure pathways and radionuclides to calculate total dose.

In the DCAGS module, the inhalation dose per year (rem/yr) for the j th radionuclide is calculated as:

$$D_{\text{inh},j}(t) = \left(315576 \frac{\text{m}^3}{\text{yr}} \frac{s}{\text{cm}^3}\right) B \cdot I_j \cdot \eta_j(t) \cdot f_R(t) \cdot \left[C_1 \times \text{e}^{-\lambda_r t} + C_2\right] \tag{3-1}$$

with

$$\begin{aligned} C_1 = {} & f_{\text{out}-H}\left(S_{\text{ash,out}-H} - S_{\text{out}-H}\right) + f_{\text{out}-L}\left(S_{\text{ash,out}-L} - S_{\text{out}-L}\right) \\ & + f_{\text{in}-H} S_{\text{in}-H} + f_{\text{in}-L} S_{\text{in}-L} + f_{\text{offsite}} S_{\text{offsite}} \end{aligned} \tag{3-2}$$

and

$$C_2 = f_{\text{out}-H} S_{\text{out}-H} + f_{\text{out}-L} S_{\text{out}-L} \tag{3-3}$$

where the individual parameters are described in Tables 2-3 and 3-1. Because leaching is considered to be of low significance to waste isolation (NRC, 2005, Appendix D, Section 4.3.13.1) and estimates of inhalation dose with the previous model have been more sensitive to the reduction rate in the airborne mass load than to the erosion rate, details of the ASHRMOVO module are not presented. For details on the modeling of leaching, erosion, and radioactive decay in the previous model, the reader is referred to Jarzemba and Manteufel (1997). The total inhalation dose is calculated as the sum of all radionuclide inhalation doses.

3.3 Outputs Associated With the DCAGS Module

The DCAGS module computes radionuclide doses for the igneous eruption scenario at every simulation time step. Doses for all radionuclides are reported in the *airpkds.res, arpkds_c.res, totdose.res,* and *totdos_c.res* files. Table 3-2 describes the contents of the *airpkdos.res, arpkds_c.res, totdose.res,* and *totdos_c.res* output files. Volcanic dose refers to the estimated

Table 3-1. Terms Used in the DCAGS Module Calculation of Radionuclide Inhalation Doses

Symbol	Description	Source Or Calculation
B	Breathing rate [cm^3/s]	Breathing rate is specified by two TPA input file parameters (see the first two rows of Table 2-3) within the GENTPA block of the input file, *tpa.inp*.
I_j	Inhalation dose coefficient per unit intake [rem/Ci]	Inhalation dose coefficients per unit intake [rem/Ci] are derived from the inhalation dose coefficients [Sv/Bq] specified in the *gnewdf.dat* auxiliary data file, which are selected using the age and dosimetry flag (see Table 2-3) within the GENTPA block of the input file, *tpa.inp*.
$\eta_j(t)$	Time-dependent activity of the j^{th} radionuclide per gram of ash near the receptor location [Ci/g]	$$\eta_j(t) = \left(\frac{\mathrm{m}^2}{10^4\,\mathrm{cm}^2}\right)\frac{R_j(t)}{X}$$ where $R_j(t)$ — Time-dependent activity of the j^{th} radionuclide per unit area deposited at a point location near the receptor (Ci/m^2) as determined in the ASHRMOVO module X — Mass of ash per unit area initially deposited at a point location near the receptor (g/cm^2) as determined in the ASHPLUMO module
$f_R(t)$	Fraction of airborne particulate mass resuspended from the contaminated volcanic ash layer [unitless]. This term accounts for the dilution of resuspended contaminated ash with noncontaminated soil for thin ash layers with a thickness less than the resuspendible layer thickness and the reduction in the thickness of the deposit due to erosion over time.	$$f_R(t) = \begin{cases} \dfrac{X}{\rho \cdot d_r} e^{-k\,t} & \text{if} \quad \dfrac{X}{\rho \cdot d_r} e^{-k\,t} < 1 \\ 1 & \text{if} \quad \dfrac{X}{\rho \cdot d_r} e^{-k\,t} \geq 1 \end{cases}$$ where ρ — Density of ash (g/cm^3) as specified by the input parameter AshBulkDensity[g/cm3] d_r — Resuspendible layer thickness (cm) as specified by the input parameter DepthOfResuspendibleLayer[cm] k — Erosion rate of the tephra deposit at the receptor location (1/yr) as specified by the input parameter RelativeRateOfBlanketRemoval[1/yr] t — Erosion rate of the tephra deposit at the receptor location (1/yr) as specified by the input parameter RelativeRateOfBlanketRemoval[1/yr]

Table 3-2. Description of Output File Contents Related to the DCAGS Module

Output File	Contents
airpkdos.res	Total peak volcanic dose from all nuclides, the time of the peak volcanic dose, and the contribution to the peak volcanic dose from each radionuclide
arpkds_c.res	Total peak volcanic dose from all nuclides, the time of the peak volcanic dose, and the contribution to the peak volcanic dose from each radionuclide for the compliance period
totdose.res	Time history of total dose from both groundwater transport pathway for igneous intrusion and atmospheric transport pathway for a volcanic eruption
totdos_c.res	Time history of total dose from both groundwater transport pathway for igneous intrusion and atmospheric transport pathway for a volcanic eruption associated with the compliance period

dose for all biosphere pathways associated with the disruptive scenario where an igneous eruption conduit intersects the repository and results in the release of high-level waste directly into the atmosphere as contaminated tephra.

When the append option [see Appendix A of Mohanty, et al. (2002)] is turned on in the *tpa.inp* file to create additional intermediate outputs, DCAGS inputs are written to the *dcags.ech* file and outputs are written to the *dcags.rlt* file. The areal radionuclide activity concentration on the ground surface for all times and the areal concentration of ash are included in *dcags.ech* file. The time history of doses for all radionuclides is available in the *dcags.rlt* file. Table 3-3 presents the contents of the *rgsna.tpa, rgsnr.tpa, rgssa.tpa, rgssr.tpa,* and *rgwgssa.tpa* output files, generated when the append option is selected.

Table 3-3. Description of Contents in Other Output Files Related to the DCAGS Module When the Append Option Is Selected

Output File	Contents
rgsna.tpa	Time history of volcanic dose for each radionuclide averaged over all realizations
rgsnr.tpa	Time history of volcanic dose for each radionuclide and realization
rgssa.tpa	Time history of volcanic dose summed for all radionuclides and averaged over all realizations
rgssr.tpa	Time history of volcanic dose for each radionuclide and igneous scenario pathway averaged over all realizations
rgwgssa.tpa	Time history of igneous intrusion, volcanic eruption, and total doses summed for all radionuclides and averaged over all realizations

3.4 Modeling Assumptions of the DCAGS Approach

DCAGS is an abstraction of complex and uncertain processes occurring in the biosphere. The conversion of soil radionuclide concentrations to receptor dose involves assumptions about the processes that determine fate and transport of contaminants in the biosphere and the estimation of human doses from exposure to contaminated media in the biosphere. Assumptions related to dosimetric models and dose coefficients, provided in auxiliary data files (such as *gnewdf.dat*), are beyond the scope of this report.

The receptor location is constrained by the regulation at 10 CFR Part 63 and based in part on the assumption that present physical constraints (topography, depth to water table, and soil conditions), which limit present farming in Amargosa Valley, will continue to limit farming south of Yucca Mountain. The areal concentration of ash on the ground surface represents an input to the DCAGS module and is provided by the ASHPLUMO module for a point location. The nominal value selected for this point is approximately 18 km south of the volcanic conduit. For the 18-km point location, the point approximation of tehpra-fall overestimates the average tephra-fall thickness that would be expected over the general area, located more than 18 km south of the potential repository. The overestimation of tephra thickness associated with an estimate at a single point introduces a reasonable degree of conservatism in the consequence calculations. For this reason, the point location for ASHPLUMO calculations of tephra thickness (when the AshEvolutionMode flag is set to 0) remains unchanged from previous versions of the TPA code. It is important to note, however, that the new model, described in Chapter 2, uses calculations of tephra-fall thicknesses within the Yucca Mountain region and can be selected by setting the AshEvolutionMode flag to a value of 1.

Airborne concentrations of radionuclides from resuspended contamination are calculated by applying a mass loading model, which effectively converts radionuclide concentrations on the ground surface into airborne concentrations. The resuspension process is highly uncertain and is influenced by a number of factors including surface ground cover (e.g., vegetation), soil moisture content, surface roughness, wind speed, physical disturbance, and resuspended particle size, density, and shape. The mass loading model for inhalation used in DCAGS was developed to be more applicable to site conditions than the available models in GENII-S (Leigh, et al., 1993; Napier, et al., 1988). This mass loading model estimates the airborne concentration of radionuclides above the ash deposit after the volcanic eruption. The model accounts for the effect of deposit thickness variation over time on the amount of contaminated material available for resuspension, and the reduction in the mass load with time after the initial tephra deposition. The implicit assumption is that this mass load model is reasonable for estimating annual-average airborne particle concentrations at the receptor location. Additional discussion on the modeling assumptions for airborne mass loading is presented in Section 2.4 of this report.

For the modeling of an igneous eruption releasing contaminated tephra directly into the atmosphere, contamination spread on the ground surface is the sole source of contamination. Radionuclides leached from the tehpra deposit to deeper soil layers and possibly to the saturated zone are treated as being removed from the biosphere. In other words, radionuclide leaching is assumed to not result in significant ground water contamination and dose contributions via the ingestion of contaminated ground water. The most significant contributors to dose for the extrusive volcanism scenario are actinides, such as Am and Pu (NRC, 2005, Figure 4-45), which are not expected to be leached easily from ground surface soil/ash layers.

This modeling assumption, therefore, is not expected to lead to a significant underestimation of dose.

4 SUMMARY AND CONCLUSION

Progress by staff toward developing independent modeling capabilities for evaluating uncertainties in risk-significant features, events, and processes related to airborne transport of radionuclides and redistribution of radionuclides in soil has culminated into a new abstracted model in the TPA Version 5.1beta code, which can be used to gain fundamental insights into tephra redistribution processes and risk to the reasonably maximally exposed individual. The new approach is intended to provide more realistic estimates of volcanic eruption consequences by accounting for (i) wind-field variations along the height of the eruption column, which affect the initial deposition of tephra, and (ii) first-order processes affecting fluvial and eolian redistribution of tephra. Results from detailed analytical work on airborne transport of radionuclides and redistribution of radionuclides in soil are assimilated into the TPA code as an input data file (i.e., lookup table) and as TPA code input parameter values for the new model. The new approach computes time histories of airborne concentrations of high-level waste and inhalation doses. In contrast, the abstracted model developed for previous versions of the TPA code assumes a single wind direction and a single wind speed for calculating the atmospheric transport of tephra contaminated with high-level waste and deposition of tephra at a point on the ground surface near the reasonably maximally exposed individual. The previous approach is still retained in the code, and users may choose whether to use the new approach or the previous approach by setting a flag in the input file. With a general emphasis on aspects related to the redistribution of radionuclides in soil, this report describes both the new and previous abstracted models for tephra redistribution and resuspension used to estimate inhalation doses to the reasonably maximally exposed individual in the TPA Version 5.1beta code.

5 REFERENCES

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APPENDIX

REFERENCE DATA SET

REFERENCE DATA SHEET

This appendix provides information about the input parameters for the TPA code in a format that is consistent with the module descriptions and user's guide (Mohanty, et al., 2002, Appendix A). As mentioned previously in the body of this report, the focus of the report and this appendix is on the estimation of radiological dose to the receptor via the inhalation pathway resulting from a potential volcanic eruption that intersects the potential repository at Yucca Mountain.

Table A–1 presents the key input parameters for the inhalation dose pathway from the *tpa.inp* input file. The numerous input parameters, such as elemental distribution coefficients and solubilities in volcanic ash, associated with leaching from surface soils are not included in this appendix, because leaching is considered to be of low significance to waste isolation (U.S. Nuclear Regulatory Commission, 2005, Appendix D, Section 4.3.13.1) and is not expected to significantly affect inhalation dose estimates.

A summary of values for the parameters in the ASHREMOB lookup table, an auxiliary data file named *remob_lut.dat,* is documented[1]. The lookup table is generated from 1,024 realizations of the TEPHRA code. The format of the lookup table is presented in Table 2-2.

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[1] Hooper,D.M., N. Franklin, B. Winfrey, and B. Hill. "Realistic Modeling of Volcanic Eruption Plumes With the Tephra Code." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. March 2006.

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)	Remarks	Parameter Used For The Following AshEvolutionMode Values*
GENTPA	Age&Dosimetry[1=Inf,2=Todl,3=PTeen,4=Teen,5=Adlt,6=AdltFG11]	Flag to select the receptor age group and the internal dosimetry methodology	iconstant	5	Adult receptor is required for Yucca Mountain calculations by 10 CFR 63.312(e). Default is set to International Commission on Radiological Protection Publication 72 (International Commission on Radiological Protection, 1996, 2002) internal dosimetry and adult receptor. Federal Guidance No. 11 (U.S. Environmental Protection Agency, 1988) adult dosimetry values are a user-selectable option. If flag is set to pre-adult age group, user is responsible for uncommenting, entering, and justifying related age dependent input parameters in DCAGW and DCAGS or ASHREMOB.	0, 1
GENTPA	InhalationRate5[cm3/s]**	Inhalation rate for Adult: ICRP72 receptor age group (Only used if Age&Dosimetry flag is set to 5)	constant	270	Default adult chronic inhalation rate in GENII 1.485 code (Napier, et al., 1988). Magnitude of breathing rate is influenced by the level of human activity. Value used is between light and moderate work activities discussed in Kennedy and Strenge (1992).	0, 1
ASHRMOVO	RelativeRateOfBlanketRemoval[1/yr]	Bulk removal rate from blanket (1/yr)	constant	0.0007	Parameter is used when AshEvolutionMode flag is set to 0 (no ash remobilization). Only traces of the tephra-fall deposit are preserved at the youngest Yucca Mountain region volcano, Lathrop Wells, which is around 100,000 years old. Recent work by Delgado-Granados et al. (1998) at Xitle volcano, Mexico, has shown that substantial amounts of basaltic tephra-fall deposits are preserved from this 2,000-year old eruption. The area around Xitle volcano receives around 500-700 mm of annual rainfall, in contrast to the roughly 100-mm annual rainfall in the Yucca Mountain region. Although many factors, such as topographic slope, degree of incision, and eolian sedimentation, affect tephra-fall erosion, areas of greater annual rainfall should experience higher erosion rates of nonconsolidated fall deposits than areas of lower annual rainfall. Thus, tephra-fall deposits in the Yucca Mountain region likely are significantly preserved for around 10,000 years. Therefore, use a removal half-life of 1,000 years.	0
ASHRMOVO	AshBulkDensity[g/cm3]	Bulk density for volcanic ash (g/cm3)	constant	1.2	Data based on in situ measurements of tephra deposits during the 1995 Cerro Negro eruption made at 1 km from the vent (Hill et al., 1998, p.1232).	0, 1
DCAGS	DepthOfResuspendibleLayer[cm]	Thickness of the upper soil layer that is available for resuspension (cm)	constant	0.3	Wiggs (1997) supports a 0.1-1cm range, with 1 cm being for poorly sorted, coarse-grained deposits (i.e., grain size on order of 1 cm). The 0.3 cm value seems reasonable, given that the tephra will likely have an average grain size on the order of 0.1 cm. Since the maximum entrainable particle size is 0.01 cm, the 0.1 cm-size ash will form an unentrainable lag deposit that shields finer particles from turbulent win entrainment unless they can escape between the 0.1 cm particle interstices.	0, 1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)	Remarks	Parameter Used For The Following AshEvolutionMode Values*
DCAGS	RateOfReductionOfMassLoadingFactor[1/yr]	Rate at which the airborne mass load factor decreases with time from the initial value after the eruption (1/yr)	constant	0.07	Limited reduction in airborne mass loads measured on deposits 4 years after 1995 Cerro Negro eruption (Hill, et al., 2000). Assuming exponential decay (e.g., Anspaugh, et al., 1975), this relationship indicates a half-life for reduction in mass load on the order of 10 years.	0, 1
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadAboveFreshAshBlanketHeavyDisturbance[g/m3]	Outdoor airborne mass load of resuspended ash due to heavy disturbance activities (g/m3)	uniform	1.0e-3, 1.0e-2	Outdoor mass loads over ash deposits for heavy disturbance activities have been measured within this range. Measurements were taken four years after the 1995 Cerro Negro eruption in Nicaragua at a height of 1.5 m above the tephra deposits located about 5 km from the vent (Hill et al., 2000). Digging and driving over deposits resulted in airborne mass loads of $\sim10^{-2}$ g/m3, which was assigned as the maximum value. Walking over deposits resulted in airborne mass loads of $\sim10^{-3}$ g/m3, which was assigned as the minimum value. Range also supported by post-eruption meaurements near Montserrat volcano by Searl et al. (2002).	0, 1
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadAboveFreshAshBlanketLightDisturbance[g/m3]	Outdoor airborne mass load of resuspended ash due to light disturbance activities (g/m3)	uniform	1.0e-4, 1.0e-3	Outdoor mass loads over ash deposits for light disturbance activities have been measured within this range. Measurements were taken four years after the 1995 Cerro Negro eruption in Nicaragua at a height of 1.5 m above the tephra deposits located about 5 km from the vent (Hill et al., 2000). Walking over deposits resulted in airborne mass loads of $\sim10^{-3}$ g/m3, which was assigned as the maximum value. Airborne mass loads over undisturbed deposits were $\sim10^{-4}$ g/m3 in 4±2 m/s winds, which was assigned as the minimum value. Range also supported by post-eruption meaurements near Montserrat volcano by Searl et al. (2002).	0, 1
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadOutsideHeavyDisturbance[g/m3]	Outdoor airborne mass load of resuspended soil due to heavy disturbance activities (g/m3)	constant	0.0	Inhalation doses following the volcanic event are assumed to be dominated by the airborne mass load from the ash deposit. Setting this parameter to zero neglects contributions to the airborne mass load from soil during the depletion of the ash deposit.	0, 1
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadOutsideLightDisturbance[g/m3]	Outdoor airborne mass load of resuspended soil due to light disturbance activities (g/m3)	constant	0.0	Inhalation doses following the volcanic event are assumed to be dominated by the airborne mass load from the ash deposit. Setting this parameter to zero neglects contributions to the airborne mass load from soil during the depletion of the ash deposit.	0, 1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)	Remarks	Parameter Used For The Following AshEvolutionMode Values*
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadInsideHeavyDisturbance[g/m3]	Indoor airborne mass load of resuspended soil and ash due to heavy disturbance activities (g/m3)	triangular	1.0e-4, 5.0e-4, 1.0e-3	Indoor mass loads recommended for NRC screening dose calculations involving building renovation and residential exposure scenarios are discussed in a literature summary by Kennedy and Strenge (1992). They describe a range of 0.00005 to 0.0001 g/m3 as representing longer-term average concentrations that account for airborne dust from nonradioactive sources. They further consider the range a prudently conservative estimate for radioactive dust loadings in the workplace or household. Because fine ash particles are expected to elevate normal dust loadings and this parameter is for heavy disturbance conditions, we take the recommendation of 0.0001 g/m3 as the lower end of a triangular distribution that extends to a maximum value that is equal to the low end of outdoor mass loading for fresh ash (0.001 g/m3) described above, with the midpoint of this range 0.0005 g/m3 assumed to be a reasonably conservative mode of a triangular distribution, selected to avoid over emphasizing the extreme high and low ends of the range.	0, 1
DCAGS	AirborneMassLoadInsideLightDisturbance[g/m3]	Indoor airborne mass load of resuspended soil and ash due to light disturbance activities (g/m3)	triangular	1.0e-5, 5.0e-5, 1.0e-4	Indoor mass loads recommended for NRC screening dose calculations involving building renovation and residential exposure scenarios are discussed in a literature summary by Kennedy and Strenge (1992). They describe a range of 0.00005 to 0.0001 g/m3 as representing longer-term average concentrations that account for airborne dust from nonradioactive sources. They further consider the range a prudently conservative estimate for radioactive dust loadings in the workplace or household. Because this parameter is for light disturbance conditions that spans a range of disturbance conditions (including no disturbance at all), the recommendation in Kennedy and Strenge (1992) of 0.0001 g/m3 is selected as the upper end of a triangular distribution that extends to a minimum value (0.00001 g/m3) that encompasses a dust loading representing relatively clean air (0.00002 g/m3) (Kennedy and Strenge, 1992), with the midpoint of this range 0.00005 g/m3 assumed to be a reasonably conservative mode of a triangular distribution, selected to avoid over emphasizing the extreme high and low ends of the range.	0, 1
MASS LOADING AND OCCUPANCY FACTORS	AirborneMassLoadOffsite[g/m3]	Offsite airborne mass load of contaminated particles (g/m3)	constant	0.0	Offsite locations are assumed to be free of contamination.	0.1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)	Remarks	Parameter Used For The Following AshEvolutionMode Values*
MASS LOADING AND OCCUPANCY	FactorsOccupancyFractionOutsideHeavyDisturbance[]	Fraction of time receptor spends outdoors with heavy disturbance (unitless)	constant	0.125	Based on an assumption of 2.75 hr/day of moderate work and 0.25 hr/day of hard work outdoors (Mohanty, et al., 2005, Chapter 5)	
MASS LOADING AND OCCUPANCY FACTORS	OccupancyFractionOutsideLightDisturbance[]	Fraction of time receptor spends outdoors with light disturbance (unitless)	constant	0.084	Based on an assumption of 2 hr/day of light work outdoors (Mohanty, et al., 2005, Chapter 5)	0, 1
MASS LOADING AND OCCUPANCY FACTORS	OccupancyFractionInsideHeavyDisturbance[]	Fraction of time receptor spends indoors with heavy disturbance (unitless)	constant	0.104	Based on an assumption of 2 hr/day of moderate work and 0.5 hr/day of hard work indoors (Mohanty et al., 2005, Chapter 5)	0, 1
MASS LOADING AND OCCUPANCY FACTORS	OccupancyFractionInsideLightDisturbance[]	Fraction of time receptor spends indoors with light disturbance (unitless)	constant	0.583	Based on an assumption of 8 hr/day sleeping, 3 hr/day sedentary, and 3 hr/day of light work indoors (Mohanty et al., 2005, Chapter 5)	0, 1
MASS LOADING AND OCCUPANCY FACTORS	OccupancyFractionOffsite[]	Fraction of time receptor spends offsite (unitless)	constant	0.104	Based on an assumption of 1.25 hr/day outdoors and 1.25 hr/day indoors offsite (Mohanty et al., 2005, Chapter 5)	0, 1
ASHREMOB	AshEvolutionMode[0=no_ashremob,1=ashremob]	User selected mode for calculating evolution of ash at receptor location (0 implies wind direction fixed toward receptor without ash remobilization, 1 implies wind direction sampled and ash remobilization effects included)	iconstant	1		0, 1
ASHREMOB	AshPlumeRealizationIndex[]	Index counter for sampling from the remob_lut.dat look-up table	iuniform	1, 1024	Produces random sampling from the 1,024 realizations of the remob_lut.dat lookup table for atmospheric transport and deposition of tephra in a stratified wind field (Mohanty et al., 2005, Chapter 6). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	**Parameter Name**	**Description**	**Distribution Type**	**Parameter Value(s)**		**Remarks**	**Parameter Used For The Following AshEvolutionMode Values***
ASHREMOB	WeightingFactorInitialDeposit[]	Weighting factor for how much the airborne mass load above the initial deposit contributes to the total airborne particle concentration at the receptor location (unitless)	constant	0.3334		Value selected for near equal contributions from each of the three components (Mohanty et al., 2005, Chapter 6). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
ASHREMOB	WeightingFactorFluvial[]	Weighting factor for how much the airborne mass load above the sediment deposit from fluvial remobilization contributes to the total airborne particle concentration at the receptor location (unitless)	constant	0.3333		Value selected for near equal contributions from each of the three components (Mohanty et al., 2005, Chapter 6). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
ASHREMOB	AmbientSedimentYieldVolumePerBasinAreaPerEvent[m/event]	Preeruption sediment volume yield per unit drainage basin area that discharges through Fortymile Wash per discharge event (m/event)	usersuppliedpwisecdf	27 values,	cumulative probability	Derived from site-specific estimates for ranges of sediment thickness, age of sediments, and depositional area, whereby uncertainties were propagated using uniform distributions for each range {Sediment thickness = U[1,2] m; Age of sediments = U[4,10] kyr; Depositional area = U[22,26] km2} in Hooper and Benke (2006). The resulting distribution for ambient sediment yield, in units of m3/m2-yr, was converted to units of m3/m2-event with a multiplication by 4 yr/event (i.e., value of the parameter TimeBetweenFlowEvents[yr]). The parameter PostEruptionFluvialAshYieldVolumePerAreaPerEvent[m/event] is coorelated to the sampled value of this parameter. Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
				0.00001	0		
				0.000012	0.0015		
				0.000014	0.0244		

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)		Remarks	Parameter Used For The Following AshEvolutionMode Values*
				0.000016	0.0747		
				0.000018	0.1442		
				0.00002	0.2346		
				0.000022	0.3346		
				0.000024	0.4375		
				0.000026	0.5351		
				0.000028	0.6076		
				0.00003	0.6778		
				0.000032	0.7377		
				0.000034	0.7886		
				0.000036	0.828		
				0.000038	0.8616		
				0.00004	0.8875		
				0.000042	0.9127		
				0.000044	0.9349		
				0.000046	0.9521		
				0.000048	0.9666		
				0.00005	0.9779		
				0.000052	0.9862		
				0.000054	0.9928		
				0.000056	0.9976		
				0.000058	0.9992		
				0.00006	0.9999		
				0.000062	1		
ASHREMOB	AreaDrainageBasinFluvial[m2]	Total area of the drainage basin (m2) that discharges through Fortymile Wash	constant	8.15e8		Standard spatial attribute for the watershed area derived from geographic information system and planimetric methods (Hooper and Benke, 2006). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)		Remarks	Parameter Used For The Following AshEvolutionMode Values*
ASHREMOB	TimeBetweenFlowEvents[yr]	Average time between significant flow events	constant	4.0		Based on peak sediment discharge measurements at Fortymile Wash from 1969 to 1998 (Hooper and Benke, 2006). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
ASHREMOB	PostEruptionFluvialAshYieldVolumePerAreaPerEvent[m/event]	Posteruption volume yield of fluvial remobilized ash at the Fortymile Wash depositional region per unit drainage basin area per discharge event (m/event)	usersuppliedpwisecdf	27 values,	cumulative probability	Coorelated parameter with a value set to twice the sampled value of AmbientSedimentYield VolumePerBasinAreaPerEvent[m/event] (Hooper and Benke, 2006). Tephra is easily eroded compared to most other surface materials. Sediment yield from a tephra-covered drainage basin is greater per unit area than the sediment yield from an ambient drainage basin (Segerstrom, 1950). To account for accelerated erosion, the mean of the calculated posteruption sediment yield is two times the ambient sediment yield over the lifetime of the potential tephra deposit. This parameter affects (i) the time period that fluvial remobilization contributes contaminated airborne particulates to the inhalation dose and (ii) dilution of fluvial deposits due to mixing with clean sediment. Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
				0.00002	0		
				0.000024	0.0015		
				0.000028	0.0244		
				0.000032	0.0747		
				0.000036	0.1442		
				0.00004	0.2346		
				0.000044	0.3346		
				0.000048	0.4375		
				0.000052	0.5351		
				0.000056	0.6076		
				0.00006	0.6778		
				0.000064	0.7377		
				0.000068	0.7886		

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)		Remarks	Parameter Used For The Following AshEvolutionMode Values*
				0.000072	0.828		
				0.000076	0.8616		
				0.00008	0.8875		
				0.000084	0.9127		
				0.000088	0.9349		
				0.000092	0.9521		
				0.000096	0.9666		
				0.0001	0.9779		
				0.000104	0.9862		
				0.000108	0.9928		
				0.000112	0.9976		
				0.000116	0.9992		
				0.00012	0.9999		
				0.000124	1		
ASHREMOB	WeightingFactorEolian[]	Weighting factor for how much the particle mass load above the initial ash deposit in the eolian source area contributes to the total airborne particle concentration at the receptor location (unitless)	constant	0.3333		Value selected for near equal contributions from each of the three components (Mohanty et al., 2005, Chapter 6). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
ASHREMOB	DensityOfDistalAsh[g/m3]	Density (g/m3) of the distal ash deposit	constant	8.0e5		Derived from 1995 Cerro Negro eruption (Hill et al., 1998). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1
ASHREMOB	AreaEolianSourceRegion[m2]	Area of the eolian source region (m2) with an initial ash deposit from the eruption	constant	2.1e9		Generalized area surrounding the receptor location for the source of ambient airborne particulates. This parameter is used in the calculation of the dilution factor for eolian remobilization (Mohanty et al., 2005). Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1

Table A–1. Reference Data for Key Input Parameters of the *tpa.inp* Input File Associated with the Pathway for Inhalation of Resuspended Volcanic Ash Contaminated with High-Level Waste (continued)

Input Block In Tpa.inp	Parameter Name	Description	Distribution Type	Parameter Value(s)	Remarks	Parameter Used For The Following AshEvolutionMode Values*
CORRELATED PARAMETERS	Independent variable: AmbientSedimentYieldVolumePerBasinAreaPerEvent[m/event] Dependent variable: PostEruptionFluvialAshYieldVolumePerAreaPerEvent[m/event]	Correlation between AmbientSedimentYieldVolumePerBasinAreaPerEvent[m/event] and PostEruptionFluvialAshYield VolumePerAreaPerEvent[m/event]	correlateinputs	0.99	The value of the PostEruptionFluvialAshYieldVolumePerAreaPerEvent[m/event] parameter is coorelated to the sampled value of the AmbientSedimentYield VolumePerBasinAreaPerEvent[m/event] parameter. The value of 0.99 is selected because a value of 1.0 is not allowed by the Latin Hypercube Sampling routine. Note: ASHREMOB parameters are used when AshEvolutionMode[0=no_ashremob,1=ashremob] equals 1.	1

*Either 0=no_ashremob or 1=ashremob or both
**Only the input parameter for inhalation rate corresponding to the default selection of receptor age and dosimetry is presented in this table.

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