RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 5:

> Provide a technical basis to support the assumption that radionuclide diffusion characteristics are the same in basaltic tephra as in ambient soils. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: For conditions after a potential future volcanic eruption that intersects the repository and entrains waste, radionuclides on the ground surface originate as radionuclide contamination in basaltic tephra deposits. The applicant uses site-specific data from the deposition and migration of fine radionuclide particulates into current surface soils of the Fortymile Wash alluvial fan, which lack discernable basaltic tephra, to support its model for the downward migration of radionuclides following tephra deposition in the volcanic ash exposure scenario (SAR Section 2.3.11.4.2.3; SNL, 2007a).
>
> Initial concentrations and thicknesses of contaminated tephra on interchannel divides and in fluvial channels are determined prior to calculating the downward migration of radionuclides, as summarized in SNL (2007a), Figure 6.3.3-11, Steps 5 and 6. The DOE downward migration model accounts for current soil characteristics without the presence of fresh basaltic tephra. Basaltic tephra can have different surface characteristics than typical epiclastic particles in ambient soils, which may have the potential to affect radionuclide migration processes. DOE should provide a technical basis to demonstrate that the presence of basaltic tephra will not significantly affect soil characteristics relevant to radionuclide migration.

1. RESPONSE

The Fortymile Wash ash redistribution (FAR) model estimates vertical (or downward) migration of radionuclides into the soil at the reasonably maximally exposed individual (RMEI) location using a one-dimensional diffusion model applied to the channel and interchannel divide subdomains at the RMEI location (SNL 2007, Section 6.5.8). The term *diffusion* in this context represents radionuclide bulk physical redistribution processes in soils (e.g., erosion-deposition, freeze-thaw, percolation, etc.) rather than processes that represent redistribution in response to the presence of chemical potential gradients. The bulk nature of the diffusivity parameter reflects both the net representation character of the parameter as well as the fact that the parameter is based on ^{137}Cs concentrations from interval samples. Advective transportation processes are not included in the model because the maximum concentration of radionuclides in all of the published literature considered was at the surface (consistent with zero advection). The modeling assumption of no advection is appropriate because it will tend to overestimate radionuclide concentrations near the surface (SNL 2007, Section 5.3.1).

In the distributary channel subdomain, contaminated tephra is mixed with uncontaminated sediments to the depth of scouring. Because of the mixing, a single diffusivity is appropriate for the mixed material, and separate diffusivities for contaminated tephra fraction and the uncontaminated sediment fraction are not needed. On interchannel divides at the RMEI location, a single range of diffusivities is appropriate because the expected tephra thicknesses are small fractions of the permeable depth of sediment.

1.1 BACKGROUND

Following deposition of contaminated tephra on the ground surface, hillslope processes begin redistribution of material (SNL 2007, Section 6.2.1). Fluvial entrainment of both the material initially deposited in the regional channels and the material moved to the channels by hillslope mobilization thoroughly mixes the material (SNL 2007, Section 5.2.5) and transports the contaminated tephra downstream toward the RMEI location. The transport mode depends on the hydraulic characteristics of the contaminated tephra versus that of the channel sediment; based on observations in Fortymile Wash, grain size appears to be the most important physical characteristic affecting tephra transport. The mixed contaminant and channel-bed material are transported primarily as bed-load material (SNL 2007, Section 6.2.1). Overall, the effect of mixing and transport of the mixed channel sediments is that the concentration of contaminants decreases as distance from the contaminant source (taken as the vent location for modeling purposes) increases.

In the model, contaminated tephra reaches the RMEI location instantaneously (SNL 2007, Section 5.2.1), and vertical movement of radionuclides in soil materials at the RMEI location is modeled as a one-dimensional diffusion process (SNL 2007, Section 6.2.2). The same diffusion process is applied to material in channels and on divides, but differences in initial thicknesses of contaminated tephra and waste concentration in the channel and interchannel subdomains are modeled (SNL 2007, Section 5.3.2), and separate diffusivity values are based on radionuclide diffusion occurring in channels or on interchannel divides at the RMEI location.

The depths of permeable soil are used to specify the depth over which diffusion is modeled (SNL 2007, Section 6.3.3, Step 6). Diffusivity values vary between the divides and channels and are based on fitting near-surface ^{137}Cs profiles measured on the alluvial fan with a one-dimensional diffusion equation. Diffusion within the channels is likely to occur faster because of the higher permeability of channel-bed sediments (which increases the rate of fine-particle transport by suspension and redeposition). On interchannel divides, contaminated tephra is deposited only from primary fallout, which is calculated directly by the ASHPLUME model (SNL 2007). In channels, the initial waste concentration includes the primary fallout as well as the waste redistributed from the Fortymile Wash drainage basin (SNL 2007, Section 6.2.2).

Effective radionuclide diffusivities for geomorphic subdomains of channels and divides are provided as parameters for the tephra redistribution model. The diffusivities are based on measured ^{137}Cs profiles in soils collected from distributary channels and on interchannel divides (SNL 2007, Sections 6.5.8.1 and 6.5.8.2). The tephra redistribution model estimates vertical migration of radionuclides into the soil at the RMEI location using a one-dimensional diffusion model that is applied separately to the channel and interchannel divide subdomains at the RMEI location (SNL 2007, Section 6.5.8). The ^{137}Cs profiles represent measurements of ^{137}Cs in bulk samples collected at depths of 0 to 3 cm and 3 to 6 cm. Little of the ^{137}Cs has diffused below 6 cm in these profiles (Pelletier et al. 2005, p. 2), and most of the ^{137}Cs is contained in the 0- to

3-cm sample interval (Pelletier et al. 2005, Table 1; SNL 2007, Table 6.5.8-1). The utility of ^{137}Cs as an analogue for migration of radionuclides in soil is supported by several studies (e.g., Anspaugh et al. 2002; He and Walling 1997).

In the tephra redistribution model, diffusion is applied to the channel subdomain and interchannel divide subdomain at the RMEI location but the values for the respective diffusivities and the permeable depths are different for the two subdomains. The diffusion process represents physical transport processes, including suspension and redeposition of fine particles by infiltration, mixing of soil particles by freeze-thaw cycles and bioturbation (SNL 2007, Section 6.5.8), but the modeled diffusion does not include chemical diffusion. Since the diffusivities used in this model are calculated from measured ^{137}Cs profiles, the diffusivities represent the *in situ* transport rates and need not be adjusted for soil conditions and porosity (SNL 2007, Section 6.5.8). In addition, in the model the radionuclides are retained in the permeable soil interval and are not permitted to exit the lower boundary of the interval. The result is that radionuclide concentrations eventually become uniformly distributed throughout the permeable interval (SNL 2007, Section 6.3.3, Step 6).

1.2 CHANNEL SUBDOMAIN

The intensity of sediment mixing represented in the channel sediments indicates separate diffusion rates for the basaltic tephra portion of channel sediments would not be appropriate. Soil horizons do not form in channels because the channel sediments are continuously reworked by floods (SNL 2007, Section 6.3.3, Step 6). Thorough mixing of contaminated tephra with uncontaminated channel sediments occurs over distances of less than 2 km from the source of contamination (SNL 2007, Section 7.3.1.5), and a single diffusivity value is appropriate for the mixed channel sediments. In channels, the primary fallout and the tephra redistributed from upstream are added together and uniformly mixed from the surface to a depth equal to that of the Fortymile Wash fan apex (SNL 2007, Section 6.3.3, Step 6).

Field observations at the Lathrop Wells volcanic center (1) show that basaltic and non-basaltic sediments in the drainages are of similar grain size so that contaminants are well mixed with and transported at rates similar to uncontaminated channel sediments (SNL 2007, Section 7.3.1.1), and (2) indicate that small outcrops of pure tephra can enrich adjacent channels over channel lengths of as much as 100 m (SNL 2007, p. 7-53). In fact, data about basalt tephra concentration as a function of distance from the channel head shows that concentration is reduced by more than 50% within 1 km from the point where a channel leaves the tephra sheet (SNL 2007, p. 7-44 and Table 7.3.1-1).

The tephra redistribution model treats all of the tephra from the eruption as coarse-grained sediment, or bed material load (SNL 2007, Section 5.2.3), for the purposes of fluvial transport (SNL 2007, p. 7-54). By considering all of the tephra as bed load, the model predicts that contaminants will persist longer in the system than would be the case if the model explicitly distinguished suspended load from bed load. The model, therefore, focuses on the least mobile, most persistent component of the load (SNL 2007, p. 7-55).

A review of model results shows that, of the total mass of contaminated tephra deposited in the upper drainage domain, most will be stored on the relatively flat areas classified as gradual hillslopes. Of the total tephra mass transported to the channel system within the drainage domain, approximately half is available to channels that are connected to the main Fortymile Wash channel. This tephra mass becomes diluted during transport to the outlet (apex of Fortymile Wash fan). The tephra concentration at the outlet varies from about 0.1 to 0.16 (10% to 16%) for the runs presented (SNL 2007, Section 7.2.8.4). These tephra concentration fractions at the outlet also demonstrate that tephra is less than 20% of the total mass transported in channels and support the use of a range of channel diffusivity values that do not differentiate among channel materials.

Because of the intensity of sediment mixing represented in the channel sediments, separate diffusion rates for the basaltic tephra portion of channel sediments would not be appropriate. Therefore, the channel diffusivity, D_c, is represented as a uniform distribution with values of 0.035 to 0.266 cm^2/yr (SNL 2007, Section 6.5.8.2).

1.3 INTERCHANNEL DIVIDE SUBDOMAIN

The expected thinness of a tephra layer and the similarity in grain size range for tephra and soils indicate that differences in diffusivities for tephra soils on divides would be negligible. Review of simulated primary tephra thicknesses on interchannel divides near the RMEI location shows that 90% of the values are less than about 0.3 cm and the mean is less than 0.7 cm. The mean value is dominated by a few very large values. Separate diffusivities for the basaltic tephra and the ambient soils on divides were not developed because the tephra thickness is very small compared to the sampled thickness of the ambient soil. Given the thinness of a tephra layer and the similarity in grain size range for tephra and divide soils, differences in diffusivities would be negligible. In addition, the diffusivities are based on concentrations of ^{137}Cs in bulk samples collected over the upper 6 cm of soil (SNL 2007, Table 6.5.8-1). The ^{137}Cs sample results showed that activity is generally greater in the upper 3 cm of the divide soils (SNL 2007, Table 6.5.8-1). However, the sampling did not differentiate variations in activity within the sample intervals. The combination of the thinness of expected tephra deposits on divides at the RMEI location and the bulk character of the samples from which the ^{137}Cs concentrations were determined indicate that differences in diffusivities would be negligible for tephra and ambient soils. Comparison of the expected thickness of tephra and the permeable depth (SNL 2007, Section 6.5.5.1) of the ambient soil indicates that separate diffusivities are not needed.

The radionuclide diffusivity for the divide subdomain was determined by first computing the fraction of ^{137}Cs total activity at 3 cm by dividing the activity from 0 to 3 cm by the total activity from 0 to 6 cm. The base values of D_d varied from 0.004 to 0.064 cm^2/yr. Considering the full range of errors associated with the measurements (e.g., repeatability of the measured value, total propagated uncertainty, and minimum detectability limits), the range of divide diffusivities increases from 0.001 to 0.095 cm^2/yr. Therefore, a uniform distribution from 0.001 to 0.095 cm^2/yr was used in the tephra redistribution model (SNL 2007, Section 6.5.8.1).

1.4 SUMMARY

For the channel subdomain, soil horizons do not form in channels because the channel sediments are repeatedly reworked by floods (SNL 2007, Section 6.3.3, Step 6); that is the ambient soil or surface soil in channels is a mixture of continuously reworked contaminated tephra and uncontaminated channel sediments. Thorough mixing of contaminated tephra with uncontaminated channel sediments occurs over distances of less than 2 km from the source of contamination (SNL 2007, Section 7.3.1.5), and a single diffusivity value is appropriate for the mixed channel sediments.

For the interchannel divide subdomain, the large fraction of ^{137}Cs contained in the upper sample interval and the restriction of virtually all of the ^{137}Cs to the upper 6 cm of the profiles (Pelletier et al. 2005, p. 2) indicate that the transport characteristics of ^{137}Cs are consistent with assumptions contained in the diffusion equation and are adequately represented by the range of effective diffusivities developed for the channel and divide subdomains. In addition, about 90% of the simulations of primary tephra fall near the RMEI location resulted in tephra thicknesses less than about a third of a centimeter. The combined result of concentration of radionuclides in the upper 3 cm of soils (SNL 2007, Table 6.5.8-1) and the thinness of expected primary tephra deposits indicates that separate diffusion rates are not needed for the basaltic tephra and the ambient soil portions of the divide sediments.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 6:

> Provide additional information on airborne waste-contaminated particle concentrations over replenished fluvial deposits to justify the parameter values for long-term airborne mass loads at the Fortymile Wash alluvial fan. Provide information to demonstrate that the exposure times for active outdoor conditions includes time spent by the reasonably maximally exposed individual (RMEI) walking outdoors on undisturbed deposits. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: Inhalation of resuspended volcanic ash is the dominant dose pathway for the volcanic ash exposure scenario. Inhalation doses are influenced by short-term and long-term airborne mass loads in the DOE Total System Performance Assessment. After an eruption, the short-term airborne mass load contribution decreases with time, while the long-term mass load remains constant (SAR Section 2.3.10.3.2.2; SAR Equations 2.3.10-2 and 2.3.10-4). In the DOE model, inhalation exposure is modeled from airborne waste, resuspended from surfaces of the Fortymile Wash alluvial fan. Compared to primary tephra-fall and eolian deposits at an analog volcanic site, fluvial deposits exhibited a finer grain-size distribution (Benke et al., 2009) and may be more susceptible to airborne resuspension during some types of surface disturbing activity. The airborne mass loads immediately following the eruption are approximately three times greater than long-term airborne mass loads (BSC, 2006). For time spent outside, about 80 percent of the RMEI time is modeled as inactive (BSC, 2005, Tables 7-1 and 7-2). Given that DOE models estimate resuspension and inhalation exposure at the alluvial fan of Fortymile Wash, it is not clear how (i) resuspension over active fan deposits and replenishment with new fluvial deposits and (ii) specific information related to walking on tephra deposits (NRC, 2007) were accounted for in the DOE technical basis for airborne mass loading.

1. RESPONSE

1.1 APPLICABILITY OF AIRBORNE PARTICLE CONCENTRATIONS USED IN THE BIOSPHERE PROCESS MODEL TO FLUVIAL DEPOSITS

Concentrations of airborne contaminated particles (mass loading) are used in the biosphere process model (SNL 2007) to calculate concentrations of radionuclides in air inhaled by the reasonably maximally exposed individual (RMEI) and radionuclide concentration in air surrounding crops. This response addresses the former. Radionuclide concentrations in air are used together with the characteristics of the RMEI exposure, such as the exposure time in various receptor environments, to calculate dose contribution from inhalation of contaminated airborne particles. For the volcanic eruption modeling case, particle concentration in air is the sum of the long-term, nominal values (long-term mass loading) and the incremental increase in the concentrations expected after a volcanic eruption (short-term mass loading). The nominal concentrations are representative of the conditions in the reference biosphere not measurably affected by a volcanic eruption at Yucca Mountain. The focus of this RAI response is primarily on these long-term airborne particle concentrations consistent with the subject of the NRC request.

1.1.1 Airborne Particle Concentrations in Outdoor Environments

To account for variation and uncertainty in the characteristics of the RMEI and concentrations of radionuclides in air throughout the reference biosphere, the biosphere process model used a microenvironmental modeling approach to calculate inhalation exposure. To assess inhalation exposure, the total modeled exposure environment (i.e., the reference biosphere) was divided into five mutually exclusive receptor environments, characterized by different behavioral and environmental conditions of inhalation exposure. Total inhalation exposure was then calculated as a sum of exposures in all receptor environments. The mutually exclusive environments include two outdoor environments (active outdoors and inactive outdoors), two indoor environments (active indoors and asleep indoors), and the environment away from the potentially contaminated area (BSC 2006, Section 6.1.1). Addressed in this RAI are the two outdoor environments.

1.1.1.1 Active Outdoors Environment

The active outdoors environment is representative of conditions that occur when a person is outdoors in the contaminated environment conducting dust-generating activities. It encompasses potentially contaminated locations outdoors where the RMEI would conduct activities that would resuspend soil, including dust-generating activities while working, driving on unpaved roads, and performing other outdoor recreational activities, including walking on uncompacted surfaces (soil and ash). The time spent in this environment was developed by considering all of dust-generating activities together for the individual population groups considered in developing exposure parameters for the RMEI, based on the available surveys and other information (BSC 2005, Section 6.3.2.1). Walking on uncompacted surfaces, such as tephra, is not evaluated separately, but is combined with the other activities that may occur in the active outdoor environment.

The average annual mass loading in the active outdoors environment was estimated to range from 1.0 to 10 mg/m^3 for the nominal (long-term) conditions and from 0.0 to 5.0 mg/m^3 for the post-volcanic (short-term) mass loading increase over the nominal level (BSC 2006, Section 7.1) during the first year following a volcanic eruption. The average first-year post-eruption mass loading, calculated as the sum of the averages of the short-term and the long-term mass loading distributions, was 7.3 mg/m^3.

The distribution of airborne particle concentration for the active outdoors environment was developed based on the experimental site-specific data and applicable analogue data and published measurements of personal exposure to resuspended dust during soil-disturbing activities such as farming (BSC 2006, Sections 6.2.1 and 6.3.1). The analogue data were considered applicable if they: (1) reported particle concentrations resulting from behaviors consistent with those conducted outdoors in Amargosa Valley while soil is being disturbed, (2) were conducted in an arid to semi-arid environment, and (3) measured personal exposure, rather than ambient conditions. The data also included measurements taken after volcanic eruptions, which were used to develop a distribution of airborne particle concentration following a volcanic eruption. The pertinent measurements (1) represented a wide range of relevant soil-disturbing activities, (2) were conducted at a variety of analogue locations, and (3) represented activities occurring not only seasonally, such as some farming activities, but also activities occurring off-season and throughout the year.

Between the site-specific measurements and the measurements reported in the literature for the analogue locations, the pool of data used to develop the distributions of airborne particle concentration for the nominal conditions included hundreds of measurements taken at more than 10 farms located in arid and semi-arid climates, representing over 30 different farming activities, collected during the measurement campaigns that included long-term measurements taken over the entire growing season and over more than a year (BSC 2006, Sections 6.2.1 and 6.3.1). Additional data for non-farming activities were also used.

The data representing post-volcanic conditions were collected following volcanic eruptions at several locations (BSC 2006, Section 6.3.1.1), including Cerro Negro, which is representative of basaltic tephra deposits. The types of activities monitored included activities known to or expected to occur in the Yucca Mountain region, including removal of ash by hand and with machinery, agricultural work, gardening, and outdoor play. An interesting observation was that the measurements of personal airborne particulate exposure during those activities on tephra deposits were similar to measurements taken under nominal conditions in areas without tephra (BSC 2006, Tables 6-6 and 6-12), except that most maximum post-volcanic measurements were lower than those from nominal conditions (BSC 2006, Figure 6-7). Therefore, based strictly on the literature data, it would appear that the distribution of airborne particle concentration for the active outdoors environment under nominal conditions sufficiently represents post-volcanic concentrations in the active outdoors environment. However, there are additional considerations that need to be taken into account when developing a distribution for this parameter. These considerations include various sources of uncertainty, such as the uncertainty in the type and timing of a volcanic eruption, as well as the physical conditions affecting mass loading between the analogue locations and the RMEI location. The distribution of short-term airborne particulate concentration for post-volcanic conditions reflects those additional sources of uncertainty (BSC 2006, Section 6.3.1.2).

The large pool of measurements described above encompasses a wide range of behavioral and environmental conditions relevant to the active outdoors environment. Based on these data, distributions of mass loading in the active outdoors environment were developed such that they were representative of average annual conditions while the RMEI would be in that environment. The developed distributions thus represent a range of uncertainty in the estimate of the annual average mass loading for the environment (i.e., are not meant to represent individual soil surface-disturbing activities) and do not include infrequent or unusually high or low concentrations, which could occur over short periods, because such concentrations are episodic at unpredictable times and levels.

Overall, the mass loading data, collected in various environments where the soil or ash were being actively disturbed, span more than two orders of magnitude. The distributions of annual average mass loading developed based on these data represent annual average conditions expected in the active outdoors environment, not individual activities, and thus their range is narrower. Because these distributions are based on a diverse set of relevant data, they are thus appropriate for a variety of environmental conditions, including a range of soil textures. As described in the response to RAI 3.2.2.1.3.13-005, tephra grain sizes are about the same as the dominant particle sizes in channel and divide materials (i.e., sand-sized material). Because of the textural similarity between the native soil and tephra, airborne particle concentrations over replenished fluvial deposits would not significantly differ from those for the underlying older deposits and would already be included in the distribution representative of the long-term airborne mass loads at the Fortymile Wash alluvial fan. Furthermore, the analysis of the possible factors contributing to the mass loading levels indicated that the intensity of soil disturbance was a much more important indicator of the mass loading levels than any environmental factors, such as the amount of precipitation, wind, or the soil type (BSC 2006, Sections 6.1.3 to 6.1.5).

The same observation was made by the scientists who measured airborne particle concentrations at volcanic and non-volcanic sites near the Sunset Crater volcano in northern Arizona (Benke et al. 2009). During those measurements, under the surface-disturbing conditions, "[t]he level of surface-disturbing activity was found to be the most influential factor affecting the measured airborne particle concentrations" (Benke et al. 2009, p. 97). The measurements relevant to the active outdoors environments were taken under light and heavy disturbance conditions. For the heavy disturbance conditions, the individual activities produced airborne particle concentrations ranging from 2 to 100 mg/m^3 for volcanic deposits, and from about 2 to 10 mg/m^3 for non-volcanic deposits (Benke et al. 2009, p. 109). For the light disturbance conditions, the measured values, if the results for all types of surfaces are included, ranged from about 0.2 to 5 mg/m^3 (Benke et al. 2009, p. 108). With respect to the types of surfaces, the measurements at the non-volcanic sites yielded higher measurements than for the volcanic sites. Although the measurements at the fluvial sites generally produced higher values compared with the non-reworked and eolian sites, the results did not conclusively demonstrate that fluvial deposits were more susceptible to airborne resuspension (Benke et al. 2009, p. 112). In summary, the airborne particle concentrations at the Sunset Crater sites agree with the range of values for individual soil-disturbing activities considered for the development of the distribution of annual average mass loading for the active outdoors environment under the nominal conditions (BSC 2006, Table 6-6). In the biosphere process model, the active outdoors environment encompasses all surface-disturbing activities, regardless of their level. The results further confirm that the distribution of mass loading is appropriate for long-term mass loads at the Fortymile Wash alluvial fan, including those from the replenished fluvial deposits.

1.1.1.2 Inactive Outdoors Environment

The inactive outdoor environment includes outdoor locations within potentially contaminated areas where the RMEI is not conducting soil-disturbing activities. In this environment, the RMEI would spend time outdoors engaged in activities that would not resuspend soil, including sitting, walking on turf or compacted/covered surfaces, and driving on paved roads in areas where radionuclides may be present. This environment also included time spent commuting within the contaminated area because the major roads in Amargosa Valley are paved. The distribution of average annual mass loading in the inactive outdoor environment ranged from 0.025 to 0.10 mg/m^3 for the nominal (long-term) conditions and from 0.025 to 0.20 mg/m^3 for the post-volcanic (short-term) mass loading increase over the nominal level (BSC 2006, Section 7.1) during the year after a volcanic eruption. The average first-year post-eruption mass loading for the inactive outdoors environment, calculated as the sum of the averages of the short-term and the long-term mass loading distributions, is 0.16 mg/m^3.

The distribution of airborne particle concentration for the inactive outdoors environment under the nominal (long-term) conditions was developed from annual average airborne particle concentrations measured at 21 static air-quality monitoring stations located in rural, agricultural settings in arid to semiarid environments. These data were obtained from the EPA Office of Air and Radiation AirData database. The data were used because the measurements were taken at stationary, outdoor sites and, therefore, would be representative of mass loading that would be experienced by a person in a rural agricultural setting such as Amargosa Valley who is outdoors and not conducting activities that resuspend substantial amounts of dust (BSC 2006, Section 6.2.2). Rural agricultural sites were selected to ensure that the level of human activity and the surface-disturbing conditions at the sites were consistent with the conditions in the Yucca Mountain region. Because the number and size of agricultural and other disturbed sites in Amargosa Valley is small relative to the size of the inhabited area (BSC 2006, Section 6.2), and parts of the Amargosa Valley have a desert pavement surface, which is generally not susceptible to soil resuspension, the ambient measurements at the rural agricultural sites are considered to be appropriate for the inactive outdoors environment.

As in the case with the active outdoors environment, the mass loading distributions for the inactive outdoors environment are representative of the average annual concentrations of resuspended particles in air while the RMEI would be in that environment. Therefore, those distributions do not include unusually high concentrations that occur during infrequent, short-duration events such as dust storms, or unusually low concentrations that occur after recent precipitation, or when the wind speed is low (BSC 2006, Section 6.1.2). The distributions were developed based on the data from many arid and semi-arid sites and represent a range of ambient conditions, including different soil textures. Therefore, the distributions are appropriate to represent the long-term airborne particle concentrations on the Fortymile Wash alluvial fan.

The measurements of airborne particle concentrations near the Sunset Crater volcano included the measurement of ambient conditions. The concentrations ranged from 0.1 to 0.4 mg/m^3, which is comparable but somewhat higher than the range of long-term (nominal) values for the inactive outdoors environment. The difference could be explained by the measurement durations (hours versus years in the case of AirData database), number of samples taken, site representativeness, and seasonality.

1.2 WALKING ON TEPHRA

As noted in Section 1.1, the biosphere process model used a microenvironmental modeling approach to calculate inhalation exposure. The reference biosphere was divided into environments, each one characterized by a unique set of parameters describing the conditions of inhalation exposure. For the inhalation exposure pathway, these parameters included particle concentrations in air (mass loading), time spent in each environment, and breathing rates. Using this method, estimates of mass loading could be clearly associated with the types of surface-disturbing activities expected at the location of the RMEI (BSC 2006, Section 6.1), and consideration of the expected duration of those activities could be incorporated into estimates of exposure times (BSC 2005, Section 6.3.2).

The time spent in this environment is the time people would spend conducting dust-generating activities, such as plowing, livestock operations, gardening, riding motorbikes, and walking on uncompacted soil or tephra, and was developed for all of these activities together, with no preference given to any specific activity. (The remainder of the time outdoors in the contaminated area was spent in the inactive outdoors environment, i.e., conducting activities that do not actively generate dust, such as walking on pavement or compacted surfaces and driving on paved roads.) The exposure time in the active outdoors environment, as for other environments, was developed by examining potential behaviors of four mutually exclusive groups within the Amargosa Valley population: local outdoor workers, commuters, local indoor workers, and nonworkers (BSC 2005, Sections 6.3.1 and 6.3.2). The proportion of the adult Amargosa Valley population in each of these four groups was based on a Bureau of the Census survey of the residents of Amargosa Valley conducted in 2000.

Walking on tephra, as an activity that disturbs the soil surface, is included in the biosphere process model, together with the other soil surface-disturbing activities, in the active outdoors receptor environment, an environment associated with elevated airborne particle concentrations. This environment encompasses all activities that could cause elevated airborne particle concentrations. In the years following a volcanic eruption, and especially in the long-term, people would not be expected to modify their behavior and spend significantly more time than before the eruption walking on uncompacted surfaces. It is not expected that the availability of the uncompacted surfaces significantly increases, and thereby affects the distribution of annual average time spent in the active outdoors environment, especially considering the relatively low expected thicknesses of deposited tephra. (Review of simulated primary tephra thicknesses on interchannel divides near the RMEI location shows that 90% of the values are less than one-third of a centimeter.) It is, however, expected, and thus included in the model, that following a volcanic eruption the airborne particle concentrations associated with walking on uncompacted surfaces will be higher than under the nominal conditions.

In summary, the elevated inhalation exposure while walking on tephra is included in the model through the elevated airborne particle concentrations rather than through the exposure times associated with this activity.

1.3 INHALATION DOSE AND ITS IMPORTANCE IN THE PERFORMANCE ASSESSMENT

The importance of the inhalation dose in the performance assessment can be put into perspective by evaluating the relative contribution to dose from inhalation of airborne particles and from the remaining exposure pathways. The annual dose to the RMEI from a volcanic eruption, conditional upon an eruption occurring, is calculated as a sum of doses from inhalation of airborne particles and from all the remaining inhalation, ingestion, and external exposure pathways included in the biosphere process model (SAR Section 2.3.10.5.2.2). The inhalation of airborne particles is further divided into short-term inhalation and long-term inhalation pathway.

The short-term component is used together with the time function to calculate the short-term increase in inhalation exposure due to elevated levels of airborne particles after a volcanic eruption. With time, mass loading returns to the pre-eruption level as prescribed by the mass loading decay function. The long-term component describes inhalation exposure to resuspended particles under nominal conditions (i.e., when the mass loading is not elevated as the result of volcanic eruption) (SNL 2007, Section 6.12.3). Annual dose to the RMEI is averaged over aleatory uncertainty in the characteristics of the eruption as well as epistemic uncertainty in the system model to obtain mean annual dose to the RMEI, as described in SAR Section 2.4.2.1.5.3.

Figure 1 compares the mean annual dose from inhalation of airborne particles to the mean annual dose from the remaining pathways (ingestion of foods, external exposure, and inhalation of radon decay products) for 10,000 years (Figure 1(a)) and 1,000,000 years (Figure 1(b)). For 10,000 years, inhalation of airborne particles is a dominant contributor to mean annual dose because of the relatively high levels of radionuclides, such as isotopes of plutonium and americium, which have a high inhalation dose contribution. With time, the concentration of these radionuclides decreases because of their relatively short half-lives, and the dose contribution from other radionuclides, such as ^{226}Ra ^{229}Th, ^{237}Np, and ^{126}Sn, becomes more important.

1.4 SUMMARY

Distributions of mass loading in the outdoors environments were developed based on the large pool of data representing a wide range of behavioral and environmental conditions relevant to the outdoors environments in the reference biosphere, and are thus appropriate for a range of soil textures, including the replenished fluvial deposits. Furthermore, tephra grain sizes are about the same as the particle sizes in channel and divide materials. Because of this similarity, airborne particle concentrations over replenished fluvial deposits would not significantly differ from those for the underlying older deposits, and are included in the distributions of airborne mass loads used in the biosphere process model.

Walking on uncompacted surfaces, such as tephra, is not evaluated separately, but rather it is combined with the other soil surface-disturbing activities that may occur in the active outdoors environment. The elevated inhalation exposure while walking on tephra is included in the model through the elevated airborne particle concentrations rather than through the exposure times associated with this activity. It is not expected that the availability of the uncompacted surfaces significantly increases, and thereby affects the distribution of annual average time spent in the active outdoors environment, especially considering the relatively low expected thicknesses of deposited tephra. It is, however, expected, and thus included in the model, that following a volcanic eruption the airborne particle concentrations associated with walking on uncompacted surfaces will be higher than under the nominal conditions.

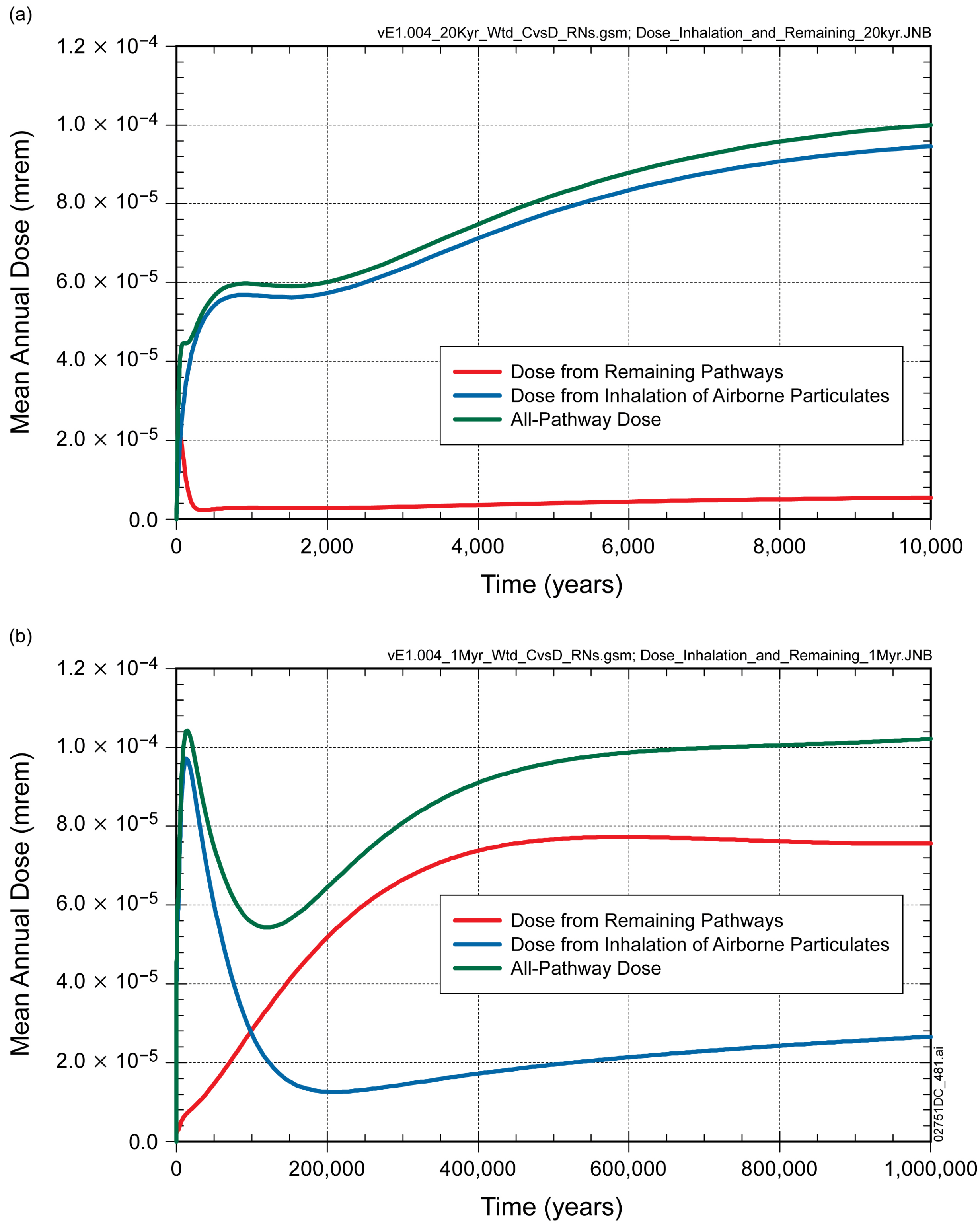

Figure 1. Contribution to Mean Annual Dose from the Inhalation of Airborne Particles and the Remaining Exposure Pathways for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

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RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 7:

Provide information on airborne resuspension of waste-contaminated particles from distributary channels and interchannel deposits and surfaces at the Fortymile Wash alluvial fan. Justify the assumption that inhalation exposure to radionuclides in channels and on interchannel divides is proportional to their respective fractions of the total fan surface area. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).

Basis: Inhalation of resuspended volcanic ash is the dominant dose pathway for the volcanic ash exposure scenario. In SAR Section 2.3.11.4.5.3 and the report on redistribution of tephra and waste (SNL, 2007a, p. 5-9), the applicant discusses exposure of the reasonably maximally exposed individual to the airborne resuspension of radionuclides in soil on interchannel divides and in sediment within distributary channels at the Fortymile Wash alluvial fan. In the DOE model, dose contributions from these two surface types are assumed to be proportional to their respective fractions of the total area of the alluvial fan. This assumption is used to convert airborne mass loads to airborne waste concentrations for inhalation dose calculations. Thus, when tephra fall is not deposited directly on interchannel divides, interchannel divides represent stable surfaces that may be relatively depleted in resuspendable particulates, and the interchannel divides may provide lower contributions of resuspendable particles than fresh channel sediments. DOE has not addressed how this uncertainty in airborne particle concentration above these two surfaces has been accounted for by assuming a direct proportionality between total mass load and areal extent of surface type.

1. RESPONSE

Eruptive events caused by an eruptive conduit intersecting the repository could result in atmospheric release of contaminated tephra from the repository, followed by atmospheric transport and deposition of waste-contaminated tephra downwind from the conduit location, and redistribution of the contaminated tephra by fluvial processes to the reasonably maximally exposed individual (RMEI) location. The annual dose resulting from volcanic eruptions is calculated in the total system performance assessment (TSPA) model using the volcanic eruption modeling case. Relative contribution of the volcanic eruption modeling case to the total mean annual dose for 10,000 years and for 1,000,000 years after repository closure is insignificant (SAR Figure 2.4-18).

For the volcanic eruption modeling case, the RMEI location is assumed to be on the alluvial fan of the Fortymile Wash. The initial contamination at the RMEI location from a volcanic eruption has a distinct spatial extent. The dose to the RMEI results from radiation exposure within the contaminated area and is influenced by the physical characteristics of that area, particularly as they affect the redistribution of contaminated tephra, as well as the spatial extent of human activities. It can be assumed that the location where the RMEI receives radiation exposure within the domain of the upper part of the alluvial fan is random. This random RMEI location on the upper part of the alluvial fan further justifies the airborne particle concentration levels developed to represent distributary channels and interchannel divides, as well as supports the assumption that inhalation exposure to radionuclides in distributary channels and on interchannel divides is proportional to their respective fractions of the total alluvial fan surface area.

1.1 FORTYMILE WASH ALLUVIAL FAN – REPRESENTATION OF THE TOPOGRAPHY AND HUMAN ACTIVITIES

Location of Distributary Channels and Interchannel Divides within the Fortymile Wash Alluvial Fan—Alluvial fans are dynamic landforms and their topography can evolve over both long and short timescales. At the RMEI location, fluvially redistributed contaminated tephra is combined with the primary contaminated tephra from the initial tephra fall (if any) that was deposited directly on the RMEI location during an eruption. Fluvial redistribution of waste-contaminated tephra is modeled using the Fortymile Wash ash redistribution (FAR) model. The RMEI location is represented in that model as two separate subdomains of the alluvial fan of the Fortymile Wash, specifically shallow distributary channels and the interchannel divides. Distributary channels represent the alluvial fan area that is subject to active fluvial deposition and redistribution. In distributary channels, the radionuclide concentration includes the primary contaminated tephra fall deposition as well as the radionuclides redistributed from the upper basin by fluvial processes. The interchannel divides separate active distributary channels. On interchannel divides, tephra is only deposited by direct volcanic tephra fall (i.e., eruption plume directed toward the south), with no contribution from the remobilization and fluvial transport processes (SAR Section 2.3.11.4.1.1.3). Radionuclides in the primary tephra deposit are initially concentrated at the surface but then diffuse within the soil profile.

The concentration of radionuclides in the soil is calculated by taking into account the fraction of land occupied by distributary channels and interchannel divides (SNL 2007a, Section 6.12.3). The fraction of the RMEI location treated as distributary channels is controlled by a model input parameter. The interchannel divides are the remaining fraction of the RMEI location not subject to fluvial deposition. The fraction of the Fortymile Wash alluvial fan subject to fluvial deposition is assumed to be equal to the fraction of area deposited in the last 10,000 years. It is represented by a probability density function with a lower bound of 0.09 and the upper bound of 0.54 (SNL 2007b, Appendix A). Because of the long-term geologic dynamics of the alluvial fan, the locations of distributary channels and interchannel divides can vary within the alluvial fan area.

Location of Agricultural Activities—Characteristics of the community that includes the RMEI are based on the characteristics of the Amargosa Valley population. The land use characteristics of the Amargosa Valley population were evaluated to determine whether there were any distinct temporal or spatial patterns of agricultural land use (SNL 2007c, Sections 6.7.2 and 6.7.3). The analysis did not identify such patterns; however, it was concluded that there were limitations on farming in the Yucca Mountain region, including physical limitations to agricultural land and the evidence of degradation of agricultural land quality in arid regions, as well as socioeconomic limitations to continuous land use. There was also evidence that large plots of agricultural land are not in continuous use, or that the fields have been relocated. Satellite images for the same area of Amargosa Valley that were acquired at different times show different patterns of central-pivot-irrigated fields, indicating that field locations vary with time (SNL 2007c, Section 6.7.3). Furthermore, based on the aerial imagery of the Amargosa Valley obtained by the U.S. Department of Agriculture National Agriculture Imagery Program, the location of the agricultural fields relative to ephemeral streams and other water drainage features discernable from the photographs do not appear to follow a pattern and thus can be considered random (USDA 2009).

Location of the RMEI within the Contaminated Area—For the volcanic eruption modeling case, the potential contamination of the area occupied by the hypothetical community that includes the RMEI is from radionuclides deposited within the Fortymile Wash alluvial fan from a volcanic eruption, or by later redistribution of contaminated volcanic tephra to that location. The RMEI has lifestyle and dietary characteristics that are representative of the entire hypothetical community and may be exposed at any location within that community. Therefore, the radiation environment of the RMEI does not have a defined location within that community. In other words, the location within the hypothetical community, where the RMEI may be exposed to radionuclides from a volcanic eruption, is random.

Exposure of the RMEI within the Contaminated Area—Because of different soil-mixing mechanisms on cultivated and noncultivated lands, and because of the different contributions of these areas to human radiation exposure, the consequences of volcanic tephra deposition and redistribution are calculated differently for cultivated and noncultivated lands. On cultivated lands, volcanic tephra would be uniformly mixed with surface soils to the tillage depth. The contaminated surface soil is the source of contamination for crops and animal products, and it is the source for inadvertent soil ingestion. On noncultivated land, tephra would be partially mixed with native soil, particularly in the distributary channels, but the distribution of radionuclide concentration with the surface soil depth initially would not be uniform and may be greater in the top layer of surface soil that may become resuspended. Radionuclide concentration in the top resuspendable layer is used to evaluate radionuclide concentration in the air in the receptor environments and, subsequently, the inhalation exposure (SNL 2007a, Section 6.3.2.6). Such an approach is conservative and maximizes the inhalation exposure because the model uses the higher radionuclide concentration in the resuspendable layer of noncultivated soil to calculate radionuclide concentration in the soil and in the air for all locations.

The inhalation exposure includes contributions from all the receptor environments within the contaminated area (SAR Section 2.3.10.3.1.2) and is representative of all the population groups whose characteristics were used to define the RMEI (SAR Section 2.3.10.3.1.7). Therefore, the inhalation exposure outdoors can occur at any location on noncultivated land, irrespective of the position of distributary channels and interchannel divides. As described in the preceding paragraphs of this section, the location of the distributary channels and the interchannel divides on the alluvial fan is dynamic and the activities of the hypothetical community and the RMEI are invariant to where the distributary channels and the interchannel divides are located.

1.2 RESUSPENSION OF PARTICLES FROM SURFACES AT THE FORTYMILE WASH ALLUVIAL FAN

As discussed in the response to RAI 3.2.2.1.3.13-006, the distributions of the airborne particle concentrations used in the biosphere process model for the volcanic eruption modeling case were developed by considering a wide range of the applicable environmental and behavioral conditions. Therefore, the airborne particle concentration levels are inclusive of the long-term and short-term levels predicted to occur following a volcanic eruption and are appropriate to characterize airborne resuspension of contaminated particles from distributary channel and interchannel deposits and surfaces at the Fortymile Wash alluvial fan.

The concept of the RMEI and the associated hypothetical community supports an assumption that the location for RMEI exposure within the Fortymile Wash is random. Furthermore, because the alluvial fans are dynamic landforms, the location of the distributary channels and interchannel divides will change over time, as will the fraction of the alluvial fan area occupied by these landforms. Therefore, it is appropriate to use the distribution of airborne contaminated particle concentrations encompassing a wide range of annually averaged exposure circumstances to describe the environmental conditions at the RMEI location.

1.3 INHALATION EXPOSURE TO RADIONUCLIDES IN DISTRIBUTARY CHANNELS AND ON INTERCHANNEL DIVIDES

The relative contributions to the mean annual dose for the volcanic eruption modeling case from redistribution of contaminated tephra in the distributary channels and from direct tephra deposition on the interchannel divides were evaluated and the results are shown in Figure 1(a) for 10,000 years and in Figure 1(b) for 1,000,000 years after the repository closure. Again, relative contribution of the volcanic eruption modeling case to the total mean annual dose is minor (SAR Figure 2.4-18).

For the 10,000-year time period, dose calculated from interchannel divides is greater than dose calculated from distributary channels. Both dose components are dominated by the inhalation of contaminated airborne particles (see response to RAI 3.2.2.1.3.13-006, Figure 1). The inhalation dose on the interchannel divides is greater than in the distributary channels due to the higher radionuclide concentration in the resuspendable layer of soil on the divides. For the 10,000-year time period (Figure 1(a)), radionuclide concentration in the resuspendable layer, which contributes to the inhalation dose, is greater on the interchannel divides. The primary reason for this is that the redistribution of initial contaminated tephra into the soil on the divides is only through diffusion; whereas in the distributary channels, mixing of contaminated tephra with uncontaminated channel sediments by fluvial scour results in lower initial concentrations of radionuclides in the resuspendable layer of soil, and thus lower inhalation dose. The differences in the radionuclide concentration with soil depth in the distributary channels and on the interchannel divides result from the different initial deposition (by tephra fall and redistribution) and different values of parameters affecting the transport within the soil (e.g., scour depth in distributary channels compared to permeable depth on interchannel divides). On interchannel divides, contaminated tephra is considered to be deposited only from primary tephra fall. Radionuclides within this tephra fall are initially concentrated at the surface, but then diffuse within the soil profile. In distributary channels, the initial radionuclide concentration includes the primary tephra fall as well as the radionuclides redistributed from the upper basin by fluvial processes. Both of these components will be mixed with channel sediments by fluvial scour and deposition (SNL 2007b, Section 6.2). Radionuclides in distributary channels at the RMEI location are also subject to diffusion in the soil, although the parameters controlling diffusive transport, such as the permeable depth of soil and the diffusivity constant, are different than for the interchannel divides, further contributing to the differences in radionuclide concentration with soil depth.

After 10,000 years (Figure 1(b)), dose from distributary channels becomes a major contributor to the total annual dose. The reason is the same as that for the decreased importance of the inhalation exposure pathway in the long term, discussed in the response to RAI 3.2.2.1.3.13-006. For 10,000 years, inhalation of airborne particles is a dominant contributor to mean annual dose because of the relatively high levels of radionuclides, such as ^{239}Pu, ^{240}Pu, and ^{243}Am, which have a high inhalation dose contribution. With time, the concentration of these radionuclides decreases because of their relatively short half-lives and the absence of ingrowth, and the dose contribution from other radionuclides, such as ^{226}Ra ^{229}Th, and ^{237}Np, becomes much more important in part because of the ingrowth of these radionuclides from their long-lived parents. There is more ^{226}Ra in the surface soil layer (within the tillage depth) in the distributary channels than on the interchannel divides because the channels receive fluvially redistributed radionuclides in addition to the primary tephra fall, and the biosphere process model conservatively assumes that all ^{222}Rn produced from ^{226}Ra decay in this layer is released from the soil (SNL 2007, Section 6.5.2.2). Therefore, the long-term dose associated the channels will be higher.

Inhalation exposure of the RMEI, conditional on a volcanic eruption, is calculated in the biosphere process model as a product of radionuclide concentrations in the soil, airborne particle concentrations (mass loading), resuspension enhancement factor, inhalation exposure time, and the breathing rate (SNL 2007a, Sections 6.5.2.1 and 6.5.6). Because of the random location of the RMEI relative to distributary channels and interchannel divides (here the randomness is taken to be a characteristic of both the RMEI and geomorphology of the area), these parameters inherently include the inhalation exposure conditions in all areas at the Fortymile Wash alluvial fan, and do not give preference to any specific location. Therefore, it is appropriate to assume that inhalation exposure to radionuclides in distributary channels and on interchannel divides is proportional to their respective fractions of the total alluvial fan surface area. Similar to the inhalation pathway, because of the undetermined, random location of the RMEI relative to distributary channels and interchannel divides, it is also appropriate to calculate the annual dose from the other pathways by taking into account the proportion of land represented by distributary channels and interchannel divides.

1.4 SUMMARY

The distributions of the airborne particle concentrations used for the volcanic eruption modeling case were developed by considering a wide range of the applicable environmental and behavioral conditions and are appropriate to characterize airborne resuspension of contaminated particles from distributary channel and interchannel deposits and surfaces at the Fortymile Wash alluvial fan. The concept of the RMEI and the associated hypothetical community supports the assumption that the location of the RMEI exposure within the Fortymile Wash is random. Furthermore, because the alluvial fans are dynamic landforms, the location of the distributary channels and interchannel divides will change over time, as will the fraction of the alluvial fan area occupied by these landforms. Because of the random location of the RMEI exposure relative to distributary channels and interchannel divides, where the randomness is a characteristic of both the RMEI and geomorphology of the area, it is appropriate to assume that inhalation exposure to radionuclides in distributary channels and on interchannel divides is proportional to their respective fractions of the total alluvial fan surface area.

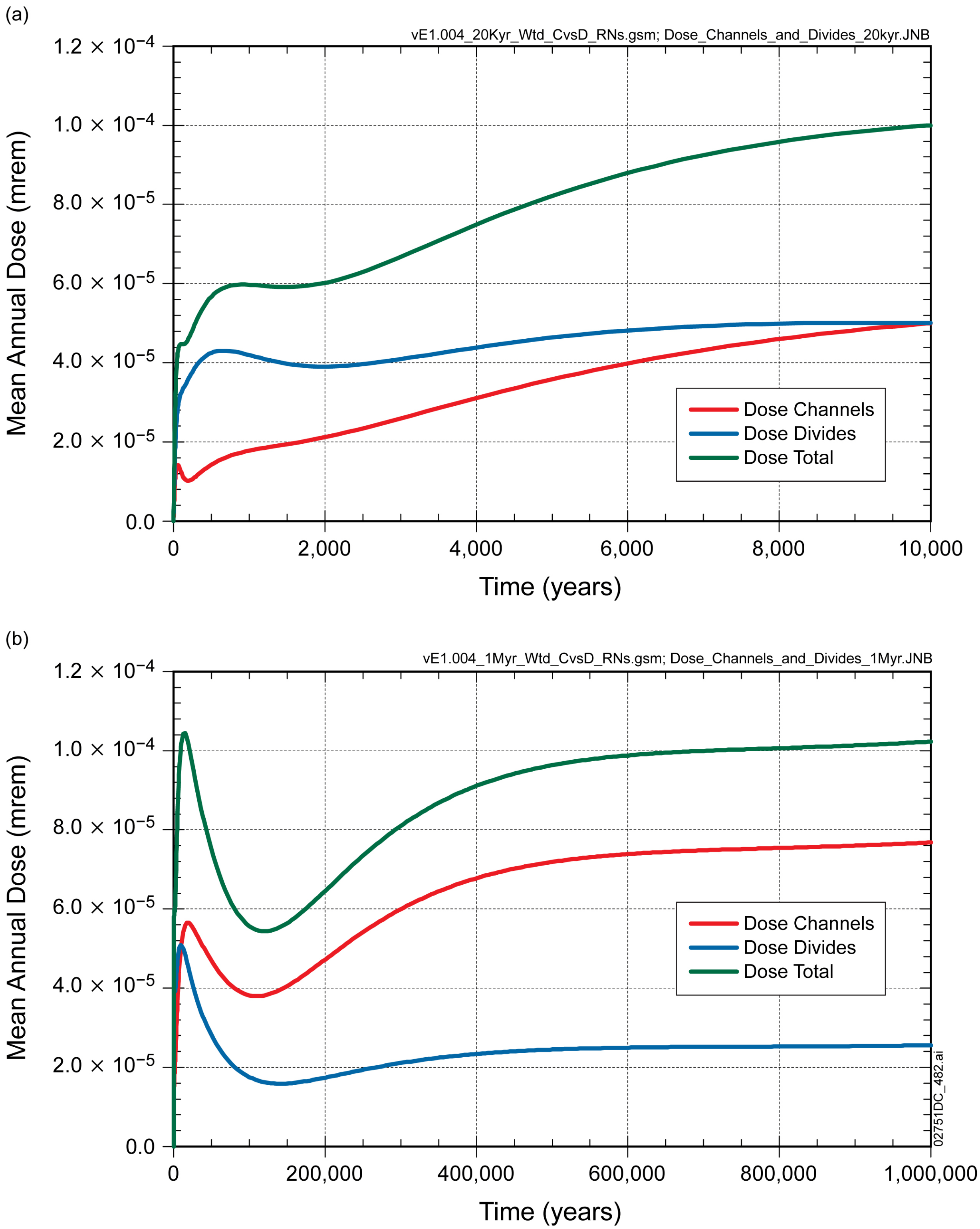

Figure 1. Relative Contribution to Total Mean Annual Dose from Direct Deposition on Interchannel Divides and from Redistribution of Contaminated Tephra in Distributary Channels for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 8:

> Explain how spatial grid sizes in the abstracted model adequately account for variations in the actual topography and do not smooth out steeper slopes, thereby reducing the potential for tephra mobilization. Provide additional information on how data from the selected analog sites and their incorporation into the DOE model account for uncertainty in potential future conditions for tephra erosion at Yucca Mountain. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: Critical slope is a sensitive parameter in the DOE Fortymile Wash Ash Redistribution model for the volcanic ash exposure scenario (SNL, 2007a, Section 6.6.3). Critical slope defines the amount of tephra mobilized and mixed into fluvial sediments. Use of an average slope for a grid area may underestimate the amount of tephra mobilized from local areas with steeper slopes within the grid spacing of the DOE abstracted model. It appears that DOE determined critical slope values from field measurements acquired long after the measured tephra fall occurred, when effects from rapid, immediately post-depositional erosion may no longer be observable. It is thus not clear if the critical slope determination (SNL, 2007a, Table 6.5.2-1) is representative of the erosion of fresh tephra fall deposits and accounts for the variability observed at historical deposits, including erosion outside active channels immediately following tephra-fall deposition. Periods of early rapid erosion have been observed at analog volcanic sites (e.g., Segerstrom, 1950, 1961; Hooper and Hill, 2004). Additional information is needed to support how DOE critical slope values and modeling of tephra mobility for average, long-term conditions account for uncertainties in the immediate post-depositional erosional characteristics of tephra deposits. Such early effects may result in short-term increases in annual dose that could influence the peak expected dose.

1. RESPONSE

The Fortymile Wash ash redistribution (FAR) model is used to evaluate the redistribution of contaminated tephra from hillslopes and channels in the upper part of the Fortymile Wash drainage basin to the location of the reasonable maximally exposed individual (RMEI). This tephra redistribution model accounts for variations in topography and does not smooth steeper slopes. An inverse relationship that exists between the critical slope value and the amount of tephra mobilized.

A digital elevation model (DEM) developed for the tephra redistribution model for Yucca Mountain distinguishes features such as channels and divides within the upper drainage basin domain. A typical hillslope in the Fortymile Wash drainage basin contains approximately 30 pixels above each channel head, and hillslopes are well resolved in the 30 m/pixel DEM. The resolution of these features is the basis for the use of the DEM and the conclusion that its resolution is sufficient for the purposes of the tephra redistribution model.

The critical slope parameter is defined as the minimum slope resulting in erosional tephra mobilization. In other words, tephra is mobilized from all grid cells with a slope greater or equal to the critical slope. Sensitivity studies have shown that the greater the critical slope the less the amount of material mobilized, because as the critical slope value increases, the area of active slopes decreases, and if the active slope area decreases, the amount of material mobilized from active slope areas decreases.

Volcanic cone erosion analogue studies at the Quaternary volcanoes in Crater Flat and in the Sunset Crater area, Arizona were used in developing the tephra redistribution model for Yucca Mountain. The Crater Flat studies describe filling of pore spaces and reductions in the permeability of the surface deposits as precursors to the onset of rilling and cone erosion. For Quaternary Crater Flat cones, whose development included closing stages of violent Strombolian activity, and at Sunset Crater, long periods of time are needed to fill pore spaces and reduce the permeability of the surface deposits, such that rilling and cone erosion can begin. In contrast to the Quaternary cones in Crater Flat, Parícutin volcano showed very rapid erosion of ash deposits, which is attributed to very high rainfall in the region, and "crusting" of the top of the tephra layer. Although the "crusting" might be similar to processes that reduce permeability at volcanoes in Crater Flat and at Sunset Crater, the amount of precipitation and character of cone slope erosion makes Parícutin inappropriate as an analogue for the development of cone erosion features following an eruption at Yucca Mountain.

1.1 DIGITAL ELEVATION MODEL FOR YUCCA MOUNTAIN AREA

A DEM is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. The local DEM slope for each grid cell is calculated from the elevations of the surrounding grid cells. Local slope values are compared with the critical slope to determine whether tephra from each grid cell is mobilized (SNL 2007, Section 6.3.3, Step 3). Mathematically, the local slope is defined in terms of local elevation gradients in the *x* (east and west) and *y* (north and south) directions that are implemented in the model using centered derivatives (SNL 2007, Section 6.3.3, Step 3, Equations. 6.3-5 and 6.3-6). As shown in Equation 6.3-6, the local slope is calculated using a 5-cell configuration shaped like a cross; the cell for which the local slope is to be calculated is in the center of the cross. The cells to the right and left of the center cell provide elevations for the terms h_{i+1} and h_{i-1} in Equation 6.3-6. Similarly, the cells above and below the center cell provide elevations for the terms h_{j+1} and h_{j-1} in Equation 6.3-6, which assumes the DEM grid cell resolution is the same in the *x* and *y* directions ($\Delta x = \Delta y$) (SNL 2007, p. 6-15). The slope calculated by this method is described as a "four-neighbor slope" (SNL 2007, Section 7.2.3).

The method for calculating DEM slopes was evaluated during model development (SNL 2007, Section 7.2.3). The four-neighbor slope calculated by the code was verified by hand calculation on a small 5 × 5 subset of the grid. In addition, an alternative method for calculating local slopes was compared with the method used in the FAR model. This alternative considers the local slope to be equal to the steepest gradient between the grid cell and the eight neighboring grid cells (includes diagonals). The comparison demonstrated that the differences in slopes estimated by the two methods were very small (SNL 2007, Figure 7.2.3-1). The mean slope difference for all grid cells in the upper basin is approximately 4×10^{-3}, with a standard deviation equal to 0.02. This difference is very small when compared with the uncertainty in the critical slope parameter (SNL 2007, Section 7.2.3), which includes slope process uncertainties, and variations in slope angle and slope materials.

Local slope measurements are sensitive to the measurement scale. For this reason, care was taken to ensure that the slopes estimated from the DEM are comparable to slopes measured in the field for the purpose of estimating the critical slope parameter (Section 1.2). Slope angles at Sunset Crater were measured incrementally using two Jacobs staffs (SNL 2007, Section 6.5.2). The purpose of the measurements was to identify the slope angles (at hillslope scale) necessary for erosion to completely strip the tephra from a hillslope. For this purpose, measuring slopes on a large scale (tens of meters) is appropriate since slope variations at smaller scales (e.g., rills) would be affected by the larger-scale processes.

The 30 m × 30 m DEM grid is appropriate for estimating slope values at Yucca Mountain that are compared to critical slope because the critical slope were based on slope measurements at a similar scale. In addition, given the drainage density in the Fortymile Wash drainage basin, a typical hillslope contains approximately 30 pixels above each channel head. As such, hillslopes are well resolved in the 30 m/pixel DEM (SNL 2007, Section 7.1.2), and the DEM resolution of slopes is appropriate for comparison with critical slope values based on measured slope values at Sunset Crater, Arizona.

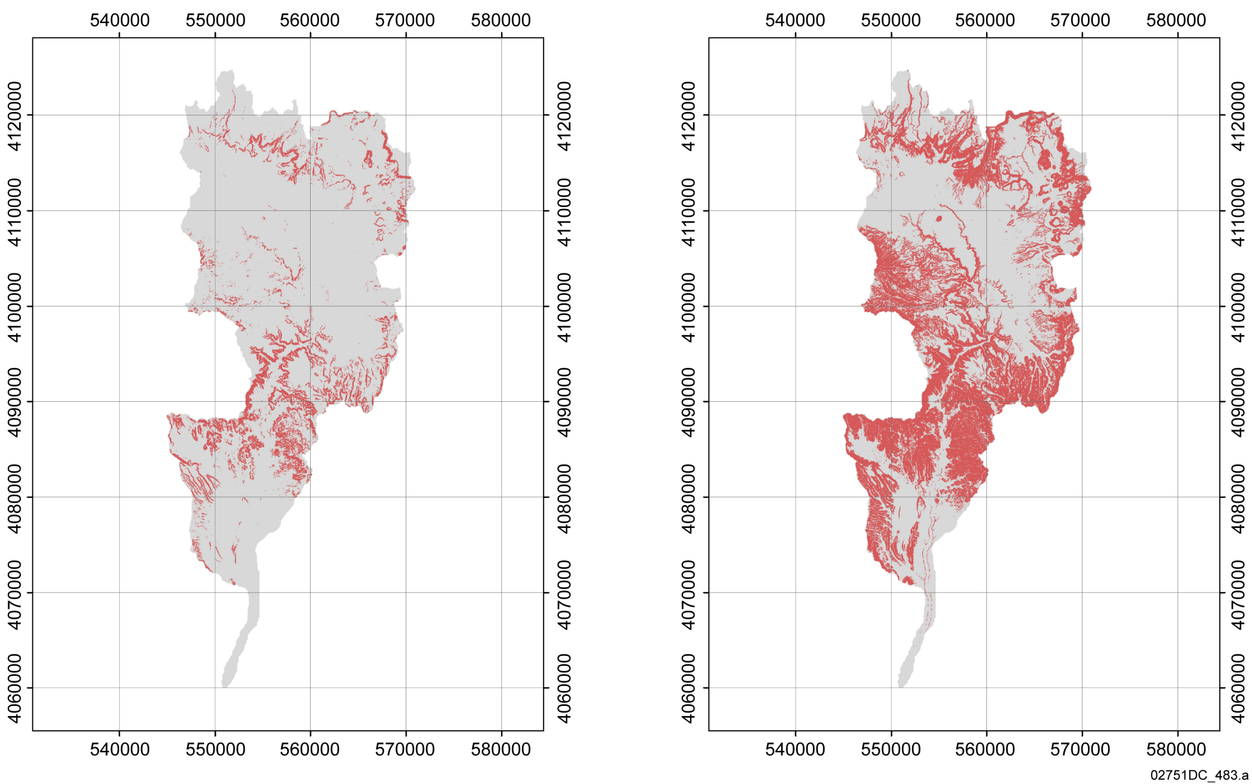
1.2 CRITICAL SLOPE PARAMETER AND MOBILIZATION OF SLOPE MATERIAL

The critical slope parameter is a fraction (the tangent of the slope angle) that represents the steepest stable slope for tephra-blanketed hillslopes. The parameter range is based on hillslopes measured at their steepest stable angles, based on observed indicators for tephra mobilization such as incipient rilling and presence of debris lobes (SNL 2007, Section 6.5.2).

The Sunset Crater area was selected for slope studies supporting the development of the critical slope because of the presence of erosional features on a widespread tephra deposit that is about 1,000 years old and occurs in a region that shares similar climatic features with Yucca Mountain. Field observations indicate that dry slope processes predominate for at least a few hundred years following tephra deposition (SNL 2007, Table 6.5.2-1), and that conditions permitting the sheetwash and rilling needed for erosion and redistribution of the cone and tephra deposits require more time to develop, perhaps many tens of thousands of years (Valentine et al. 2006, p. 1,327). Slope measurement data from the Sunset Crater area were used as the basis for estimating the critical slope parameter used by the FAR model to predict whether or not tephra that initially falls on slopes will be mobilized and transported downstream (SNL 2007, Section 4.1.3). Field observations (SNL 2007, Table 4.1-3 and Section 6.5.2) indicate that slope values less than or equal to 10° (tan = 0.18) were areas of deposition. Slopes between 12° (tan = 0.21) and 19° (tan = 0.34) were stable but had some gullies in the tephra. Slopes between 20° (tan = 0.36) and 25° (tan = 0.47) were transitional, being stable in some areas but stripped of tephra in others. Areas with slopes greater than or equal to 26° (tan = 0.49) were stripped of tephra.

The range of slope, or tangent, values used to define the critical slope parameter (0.21≤tan θ≤0.47) was developed from field slope measurements (SNL 2007, Section 6.5.2). The minimum value of the slope range is based on slopes showing incipient incision (SNL 2007, Section 6.5.2). Within this range of critical slope values, between about 6% and 21% of the upper drainage basin, DEM exceeds the critical slope (SNL 2007, p. 6-39 and Figure 6.5.2-1), depending on the specified value for the critical slope. From this relationship, it is apparent that lower critical slope values result in a greater fraction of the basin surface area being included in a mobilization source zone (SNL 2007, Figure 6.5.2-2).

This relationship occurs because as the critical slope value decreases, the area of the basin whose slopes are greater than the critical slope, increases (SNL 2007, Figure 6.5.2-2; Figure 1), and the amount of material mobilized increases. That is, Figure 1 shows that the amount of mobilized tephra is controlled by the active slope area of the drainage basin, which increases as the critical slope decreases.



Source: SNL 2007, Figure 6.5.2.-2.

NOTE: Map is based on sample model output and is for illustrative purposes only. Specified critical slope values exceed (a) 0.47 (slope angle of 25 degrees) and (b) 0.21 (slope angle of 12 degrees).

Figure 1. Maps Showing Areas (red) Where the Local Slope Exceeds a Critical Slope Value for the Upper Drainage Basin Domain

1.3 CONE EROSION ANALOGUE STUDIES

Analogue studies have been performed to describe erosion of Quaternary basaltic cones near Yucca Mountain (Valentine et al. 2006) and to develop the technical basis for estimating the critical slope parameter for the tephra redistribution model (SNL 2007, Section 6.5.2). Based on published descriptions (Segerstrom 1950, 1961; Hooper and Hill 2004), Paricutin volcano in Mexico has been identified by the Nuclear Regulatory Commission staff as a possible analogue for rapid cone erosion and tephra remobilization associated with periods of early rapid erosion at young basaltic volcanoes. Three potential analogues are reviewed and evaluated in the following subsections.

1.3.1 Yucca Mountain, Nevada and Sunset Crater, Arizona

Recent field studies have shown that cone erosion near Yucca Mountain is a gradual process that begins with development of rills on cone surfaces. Initiation of rilling, in turn, requires that low permeability areas exist on the cone surface to enable runoff rather than simple infiltration into loose scoria (Valentine et al. 2006, p. 1327). At cones whose late stages have been described as violent Strombolian (such as Lathrop Wells volcano), periods of perhaps several thousand years could be required for eolian material and carbonate to clog pores and reduce the permeability, thereby limiting infiltration and promoting runoff (Valentine et al. 2006, p. 1,327).

The conditions identified for slope erosion of tephra deposits near Yucca Mountain can be extended to the analogue area of Sunset Crater in northern Arizona where a tephra deposit associated with the 10 ka eruption of Sunset Crater covered the land surface. Slope modification processes vary from dry slope processes, which include tephra ravel and creep, to erosional processes like gullying. Field observations show that ravel and creep processes are more common on steeper slopes (typical range 20° to 30°), whereas gullying is more common on slopes of 12° to 20°. Generally, the cone erosion process begins with the development of rills on cone slopes. Initiation of rilling requires the existence of low permeability areas on the cone surface that enable runoff of rainwaters rather than simple infiltration into loose scoria (Valentine et al. 2006, p. 1,327). This distribution of processes is consistent with the model for slope modification described by Valentine et al. (2006, p. 1,327), which moves material to the base of the cone and forms debris lobes. Because of the time required for onset of sheetwash and rilling, erosion of fresh tephra fall, in the years immediately following deposition, would not be expected at Yucca Mountain.

1.3.2 Parícutin, Mexico

Cone slope modification at Parícutin in the years immediately following the 1943 eruption has been attributed primarily to daily heavy rainfall during the summer and fall rainy season (Ort et al. 2008, pp. 478 and 479), and attributed to a lesser extent to the high permeabilities of the primary tephra deposits and steep slope angles (Segerstrom 1950, pp. 52 to 68). Segerstrom (1950, pp. 74 and 77) included descriptions that could be interpreted as describing some control of slope deposits by the slope angle, and recognized the dependence of rill-channel formation and sheet erosion on length and steepness of slope and the resistance of the surface to erosion (Segerstrom 1950, pp. 77 and 82). Erosion at Parícutin has been related to rilling and sheetwash that result from "crusting" of the top of the tephra layer and the effects of rain impact (Segerstrom 1950, p. 56), but the crusting mechanism is not clearly described. In contrast to rilling and sheetwash, mudflows at Parícutin were attributed to slope angle and the presence of fine-grained or more poorly sorted, relatively less permeable material beneath the mudflow layer (Segerstrom 1950, p. 62). Segerstrom (1950, p. 74) includes descriptions that could be interpreted as describing local control of erosion slope deposits by the slope angle, but in this instance the relationship, if recognized, was not clearly described. Finally, creep was recognized in areas of loose, permeable ash (Segerstrom 1950, p. 60), and the areas of creep are generally consistent with observations in the Sunset Crater area in Arizona (SNL 2007, Section 6.5.2).

Overall, the early studies at Parícutin attributed initiation of erosion to very high amounts of precipitation and the existence of "crusty" areas of reduced permeability. Filling of interstitial spaces in the surface of ash deposits by precipitated salts was specifically discounted by Segerstrom (1950, p. 52). The inhibition of sheet erosion on the Parícutin cone was at least partially attributed to the existence of new, highly permeable, coarse ash deposits (Segerstrom 1950, p. 84) and high slope angles (Segerstrom 1950, p. 79). The common association of sheet erosion and rilling at Parícutin is consistent with descriptions of conditions needed for initiation of rilling described in the Yucca Mountain area (Valentine et al. 2006, p. 1,327). In addition, upward migration of channel heads was observed at Parícutin (Segerstrom 1950, p. 82) and was attributed to the thickness of the non-resistant ash across ridge crests and between rill heads; in the Yucca Mountain area, the process is attributed to upward migration of channel heads and nucleation of rills.

Decreases in the rate of erosion at Parícutin are described by Segerstrom (1961) and are attributed to removal of ash deposits from the steepest slopes and main stream channels, and to rapid development of vegetation (Segerstrom 1961, p. D-225). Hooper and Hill (2004) also focused on the erosion rates at Parícutin using a simplified mass balance model. Assuming a constant erosion rate, their (Hooper and Hill 2004, abstract) sediment budget model suggests that at least 2,200 years of additional erosion is needed to remove the Parícutin fall deposit, and that at Lathrop Wells volcano, 100% of the deposit would be eroded in 29,000 years (Hooper and Hill 2004, Poster Conclusions). Based on other existing descriptions (Valentine et al. 2006, p. 1,327; SNL 2007, Appendix C), the periods described by Hooper and Hill (2004) would be unrealistically short for significant modification, much less removal, of the Lathrop Wells cone and by extension, for erosion of future cone deposits in the Yucca Mountain region.

As noted, mobilization of tephra at Parícutin is primarily controlled by the amount of rainfall. Parícutin receives about 1,500 mm/yr (about 59 in./yr), which is about three times the rainfall that is received by Sunset Crater (Ort et al. 2008, p. 483), and about 6 times the annual precipitation at Yucca Mountain (DOE 2002, Section 3.1.2.2). The current precipitation at Parícutin is also more than 5 times the expected average annual precipitation at Yucca Mountain under projected future glacial-transition climatic conditions (SAR 2.3.1.1). Because of the differences in precipitation between Parícutin and Yucca Mountain, Parícutin is not well-suited as an analogue for tephra erosion following an eruption at Yucca Mountain.

FAR modeling of tephra redistribution assumes instantaneous removal of all tephra on slopes greater than the critical slope (SNL 2007, Section 5.2.1). This assumption overestimates the waste concentration at the RMEI location immediately following the eruption when radionuclide activity is greatest. However, the RMEI domain is assumed not to be a perfect "depozone" (SNL 2007, Section 5.2.4), which means that tephra and contaminants can be transported through the RMEI domain. Since the FAR model mobilizes and deposits tephra at the RMEI location instantaneously following the eruption (SNL 2007, Section 5.2.1), contaminated material contributes immediately to the concentrations predicted at the RMEI location. The model does not allow further dilution of the contaminants after the initial redistribution. Also, contaminants are not allowed to diffuse across the lower boundary of the permeable interval (see the response to RAI 3.2.2.1.3.12-005), and soil concentrations of contaminants tend to become uniformly distributed through the permeable interval of soils at the RMEI location (SNL 2007, Section 6.3.3, Step 6).

1.4 TREATMENT OF UNCERTAINTIES IN POTENTIAL FUTURE CONDITIONS

Uncertainties in potential geomorphic processes at Yucca Mountain and associated with the tephra redistribution model are addressed by the selection of appropriate analogues for evaluation of cone slope erosion processes and the selection of appropriate parameter ranges.

Selection of Appropriate Analogues for Evaluation of Future Cone Slope Erosion Processes

Analogues were carefully selected to be representative of tephra redistribution processes that are expected to be associated with the volcanic eruption modeling case at Yucca Mountain. Cone modification processes were described at Quaternary basaltic volcanoes in Crater Flat, and around Sunset Crater, Arizona. The characteristics of the tephra deposits and cones at these analogue sites are similar to those that would be expected at Yucca Mountain. Annual precipitation amounts at Sunset Crater are similar to, but greater than, the precipitation in the Yucca Mountain area. However, on the basis of climatic and meteorological differences, Paricutin is not considered an appropriate analogue for erosional cone modification and tephra redistribution processes at Yucca Mountain.

Field observations in the Sunset Crater area, Arizona, suggest that dry slope processes predominate immediately following tephra deposition (SNL 2007, Table 6.5.2-1), and that conditions that permit sheetwash and rilling needed for erosion and redistribution of the cone and tephra do not exist immediately following deposition (SNL 2007, Table 6.5.2-1). As shown by the Crater Flat Quaternary analogues, initiation of sheetwash and rilling requires sufficient time (perhaps thousands of years) for eolian sediment and carbonate to clog the pore spaces in loose scoria and reduce the permeability sufficiently to limit infiltration and thereby initiate cone erosion processes caused by precipitation runoff (Valentine et al. 2006, p. 1,327). Despite the expected delay of many years in the initiation of tephra erosion, the FAR tephra redistribution model features remobilization of tephra immediately following deposition; so the model overestimates contaminant concentrations at the RMEI location during the period when total radionuclide activity is greatest.

Selection of Appropriate Parameter Ranges

The range for critical slope was described as a uniform distribution between 0.21 and 0.47. As described in Section 1.2, slope values less than or equal to 10° (tan = 0.18) were areas of deposition. Slopes between 12° (tan = 0.21) and 19° (tan = 0.34) were stable but had some gullies in the tephra. Slopes between 20° (tan = 0.36) and 25° (tan = 0.47) were transitional, being stable in some areas but stripped of tephra in others. Areas with slopes greater than or equal to 26° (tan = 0.49) were stripped of tephra (SNL 2007, Section 6.5.2). Therefore, the geomorphic basis for range of the critical slope parameter included those slopes on which incipient incision was observed near Sunset Crater (SNL 2007, Section 6.5.2) as well as slopes stripped of tephra. The lower limit of the range is based on the lowest slope angles that show incipient erosional effects. Inclusion of these lowest slope angles in the parameter range is particularly important because of the inverse relationship between the critical slope value and the amount of material mobilized.

1.5 SUMMARY

The slope values used to define the critical slope range ($0.21 \leq \tan\theta \leq 0.47$) for the FAR tephra redistribution model were developed from field slope measurements near Sunset Crater, Arizona (SNL 2007, Section 6.5.2). As the critical slope value decreases greater fractions of the basin domain are included in the active slope area, which is the source for mobilized tephra (SNL 2007, Figure 6.5.2-2).

The development of the critical slope value is based on the presence of erosional features on the tephra surfaces. Analogue studies at the Quaternary basalt volcanoes in Crater Flat indicate that erosion of cone scoria deposits is gradual and is associated with pedogenic processes that deposit sand and silt (Valentine et al. 2006, p. 1,319). For cones that are characterized by closing states of violent Strombolian activity, such as Lathrop Wells volcano, a significant period of time, hundreds to perhaps many tens of thousands of years, might be required for eolian sediment and carbonate to clog the pore spaces in loose scoria and reduce the permeability sufficiently to limit infiltration and thereby initiate rilling and cone erosion (Valentine et al. 2006, p. 1,327). The studies at Sunset Crater show that immediate post-depositional cone modification effects are related to dry slope processes and are relatively minor in terms of intensity and extent compared to the erosion effects associated with sheetwash and rilling. Therefore, the RAI concern that "effects from rapid, immediately post-depositional erosion may no longer be observable" is not consistent with the significant amounts of time (hundreds of years or longer) needed for pedogenic processes to alter the permeability of the cone materials sufficiently for cone erosion processes to begin.

Climatic differences between the region containing Yucca Mountain and that containing Parícutin are significant. The average annual precipitation (Segerstrom 1950, pp. 11 and 12; Ort et al. 2008, p. 483) and the resulting amount and character of cone slope erosion at Parícutin does not represent an appropriate analogue for the development of cone erosion features that have been used to support the range of values for the critical slope parameter developed for the FAR model.

Uncertainties in potential future conditions associated with possible tephra redistribution following an eruptive event are addressed by ensuring the slopes estimated by the DEM are representative of hillslopes at Yucca Mountain, selection of appropriate analogues to evaluate slope processes, selection of values for the critical slope parameter that capture the range of slope angles indicative of the transition from stable to active slopes, and the assumption of instantaneous mobilization and transport of tephra on hillslopes that are greater than the critical slope value.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None

4. REFERENCES

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RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 11:

> Provide a technical basis to support the exclusion of a standard sediment dilution-mixing model from consideration as a valid alternative conceptual model in SAR section (2.3.11.4.4.3). This information is needed to determine compliance with 10 CFR 63.114(a)(3).
>
> Basis: Although SAR Section 2.3.11.4.4.3 and SNL (2007a) discuss several different numerical methods considered in implementing the Fortymile Wash Ash Redistribution (FAR) model, the applicant does not discuss consideration of alternative conceptual models for representing potential tephra redistribution processes. A dilution-mixing model (Hawkes, 1976; Marcus, 1987) has been commonly used to represent surface redistribution processes (Pelletier et al., 2008). This model appears to represent an alternative conceptual model to the scour-dilution-mixing approach used by the applicant. DOE has not provided a technical basis to exclude this model from consideration as an alternative conceptual model in the SAR.

1. RESPONSE

Dilution-mixing models such as those described by Hawkes (1976) and Marcus (1987) have commonly been used to represent surface redistribution processes and were evaluated for representing potential tephra redistribution processes. The evaluation showed that dilution-mixing models are deficient for modeling tephra redistribution in the Yucca Mountain region. These models do not consider vertical distribution of contamination and do not explicitly differentiate between dilution of contaminants that results from mixing with uncontaminated channel-bed sediments or from mixing with uncontaminated sediments from upstream. Dilution-mixing models are appropriate only for tributary systems but are not well suited for tributary-distributary drainage systems such as Fortymile Wash. The dilution-mixing models assume that contaminant concentration at a point downstream is a function of source and nonsource concentrations weighted by the relative basin areas upstream of the point. Since the dilution-mixing models do not differentiate the cause(s) of contaminant dilution that are relevant to the igneous scenario for Yucca Mountain, they were not further considered as alternative conceptual models to the scour-dilution-mixing approach used in the tephra redistribution model.

The tephra redistribution model used in the SAR includes two components: a scour-dilution-mixing model, the topic of this response and a diffusion model, addressed in the response to RAI 3.2.2.1.3.13-005. The scour-dilution-mixing model mobilizes contaminated tephra to the reasonably maximally exposed individual (RMEI) location and was selected for use because it represents the process of mixing of tephra and clean sediment as they are transported down the Fortymile Wash drainage. The scour-dilution-mixing model is conceptually similar to the dilution-mixing model used in mineral exploration and contaminant transport studies (Hawkes 1976; Helgen and Moore 1996; Marcus 1987) in that the contaminant concentrations downstream are a weighted average of upstream concentrations. In addition, the scour-dilution-mixing model explicitly includes the vertical component of mixing (Pelletier et al. 2008, Section 3). Broader comparisons of the two models provide the basis for selecting the scour-dilution-mixing model in favor of the dilution-mixing models that have been widely used in mineral exploration and contaminant-transport studies.

1.1 SCOUR-DILUTION-MIXING COMPONENT

The process of vertical scour-dilution-mixing is the predominant mode of dilution in many fluvial systems dominated by bed-material load and is represented in the tephra redistribution model by the scour-dilution-mixing model. In contrast, widely used geochemical dilution-mixing models emphasize the process of lateral mixing, but do not explicitly account for vertical-scour-dilution mixing. As a first example, an analysis of downstream radionuclide concentrations following a tailings pond failure showed that the observed concentrations are consistent with a scour-dilution-mixing model (e.g., Pelletier et al. 2008, Section 3). In this example, observed radionuclide concentrations are consistent with the scour-dilution-mixing model because scour depth is proportional to the square root of unit discharge, which is proportional to the unit stream power for channel reaches of nearly uniform slope. Another example based on dilution and mixing at large and small scales near tributary junctions showed that local minimum concentrations observed immediately downstream of tributary junctions are associated with maximum scour depths immediately downstream of channel confluences as a result of local hydraulic effects (Pelletier et al. 2008, Section 3).

More strictly applicable to the landforms at Yucca Mountain, Pelletier et al. (2008, Section 6) applied the scour-dilution-mixing model to the Lathrop Wells volcanic area. The model successfully predicted the changes in basaltic tephra concentrations associated with the tributary influxes along channels on each side of the Lathrop Wells volcano. The Lathrop Wells volcano has hillslope and fluvial processes that occur in an environment very similar to that described in the total system performance assessment volcanic eruption modeling case for Yucca Mountain (SAR Section 2.3.11.4). In addition, the scour-dilution-mixing model permits tracking of tephra mass in calculations and thereby demonstrates that all tephra in the system has been accounted for (SNL 2007, Section 7.2.8). Similarly, sensitivity studies related to three parameters (critical slope, drainage density, and scour depth) have demonstrated that the model responds as expected (SNL 2007, Section 7.2.9). The selected model incorporates the effects of scour depth on mixing and dilution of contaminated tephra and thereby provides a model that more accurately represents processes observed in the vicinity of the RMEI location (SNL 2007, p. 7-25). The result of the mixing process is that waste concentrations become diluted as sediment is transported by fluvial processes toward the RMEI location.

1.2 COMPARISON OF SCOUR-DILUTION-MIXING MODEL TO DILUTION-MIXING MODELS

Hawkes (1976) and Marcus (1987) describe commonly used geochemical dilution-mixing models. Pelletier et al. (2008) compared the scour-dilution-mixing model to dilution-mixing models described by Hawkes (1976) and Helgen and Moore (1996) that are widely used in mineral exploration and contaminant-transport studies (SNL 2007, p. 6-7). In the dilution-mixing models, contaminant concentration at a point downstream is a function of source and nonsource concentrations weighted by the relative basin areas upstream of the point. That is, the dilution-mixing model is based on the concept of lateral mixing of contaminants with uncontaminated sediment delivered from upstream. The cause of the dilution is ambiguous because no means exist to discriminate between dilution from mixing with uncontaminated channel-bed sediments or from mixing by transport of sediments from upstream. An alternative dilution-mixing model (Marcus 1987) represents some improvement relative to the Hawkes (1976) model. The improvement generally relates to an improved ability to incorporate changes in concentrations caused by tributary influxes (Marcus 1987, p. 225). However, the modeled concentrations still rely on uniform mixing of sediments as the major control on concentration, and sporadic stream flow was shown to adversely affect model predictions (Marcus 1987, p. 225), such that the model was shown to be unsuitable for heavy metal dispersion and sediment movement in ephemeral streams (Marcus 1987, p. 227). The scour-dilution-mixing approach provides an improvement from the earlier models by incorporating additional processes into the model for mixing and dilution of channel sediments. The method is volumetric because contaminant concentration at each point is the ratio of the total contaminant volume from upstream to the total volume of the upstream scour zone (SNL 2007, p. 6-8)

The scour-dilution-mixing model estimates scour depth as a function of contributing area (SNL 2007, pp. 7-21 and 7-22), which results in an estimate of sediment volume available for mixing (SAR Section 2.3.11.4.4.3). Since the Fortymile Wash drainage basin includes tributary and distributary channel geometries, the dilution-mixing models that are appropriate in tributary drainage networks are not directly applicable (Pelletier et al. 2008, p. 228). A dilution-mixing model considers only the contributing area in the dilution calculation (SAR Section 2.3.11.4.4.3) and is therefore less appropriate than the scour-dilution-mixing model. Unlike the scour-dilution-mixing model, the dilution-model does not capture abrupt concentration decreases associated with large abrupt tributary influxes of uncontaminated sediment (Pelletier et al. 2008, p. 229). The Marcus (1987, pp. 225 and 227) model accommodates variations in concentration associated with tributary influxes, but the model is not appropriate for evaluating contaminant dispersion and sediment movement in ephemeral streams.

1.3 SUMMARY

The scour-dilution-mixing model is applicable to tributary-distributary channel systems that are characteristic of the Yucca Mountain region. The model estimates scour depth as a function of contributing area (SNL 2007, pp. 7-21 and 7-22), which results in an estimate of sediment volume available for mixing (Pelletier et al. 2008, Section 3; SAR Section 2.3.11.4.4.3). Conversely, the dilution-mixing models are not directly applicable because they are appropriate only in tributary drainage networks (Pelletier et al. 2008, p. 228), and dilution-mixing models consider only the contributing area in the dilution calculation (SAR Section 2.3.11.4.4.3). In addition, the dilution-mixing model does not capture abrupt concentration decreases associated with large abrupt tributary influxes of uncontaminated sediment (Pelletier et al. 2008, p. 229). The Marcus (1987, p. 227) model accommodates variations in concentration associated with tributary influxes, but even the Marcus model is not appropriate for evaluating contaminant dispersion and sediment movement in ephemeral streams. Based on comparisons of models, DOE determined that dilution-mixing models were not appropriate alternative conceptual models for use in developing the tephra redistribution model for Yucca Mountain.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

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RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 1:

Provide additional justification for the parameter distributions used for the column diffusion coefficient and the magma partitioning factor in the DOE Ashplume model. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).

Basis: DOE performance assessment results for the volcanic ash exposure scenario are sensitive to the amount of high-level waste contamination in tephra deposited directly at the receptor location and in the catchment basin of Fortymile Wash. In DOE's model, two factors influence the amount of waste that is dispersed in tephra by violent Strombolian eruption columns, the column diffusion coefficient and the magma partitioning factor (SAR Section 2.3.11.4.2.2.2).

For the first, the DOE Ashplume model for calculating the initial distribution of erupted tephra uses a coefficient for eruption column diffusion, β, that ranges from 0.01 to 0.5. However, based on model comparison (SNL, 2007, Appendix J, Section J4.5), DOE indicate that the column diffusion coefficient should range from 0.3 to 0.5. Sensitivity analyses in SNL (2007, Figure C-4) show that selection of values of β less than 0.3 decreases the waste concentration in the tephra deposit, which is expected to decrease radiological dose.

For the second factor, eruptive products resulting from violent Strombolian activity are divided between volcanic cone, lava flows, and tephra-fall deposit. The Ashplume model assumes that only waste deposited in the tephra-fall deposit contributes to dose. DOE applies the magma partitioning factor to the mass of mixed-in waste to account for the proportion that is incorporated with the tephra-fall deposit. The amount of waste in tephra, and radiological dose, are linearly proportional to the magma partitioning factor. DOE uses data from eight analog volcanic eruptions to determine a range of 0.1 to 0.5 for the magma partitioning factor (BSC, 2003; SNL, 2007). However, not all the analog eruptions showed violent Strombolian behavior and those that did have a magma partitioning factor greater than 0.3.

DOE should justify the use of a column diffusion coefficient and magma partitioning factor with values less than 0.3 and explain how values less than 0.3 are consistent with the DOE conceptual model of a violent Strombolian eruption column and downwind plume.

1. RESPONSE

1.1 COLUMN DIFFUSION COEFFICIENT

The development of the range of values for the column diffusion coefficient is described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 6.5.2.3). The range of values used in the Ashplume submodel in the total system performance assessment (TSPA) (0.01 to 0.5) was derived from the range of values used previously by the author of the mathematical model, Suzuki (1983, p. 104), and the authors of the ASHPLUME numerical code, Jarzemba et al. (1997). The column diffusion coefficient, β, is used as a multiplier for the source term for Ashplume (SNL 2007a, Equation 6-3) to produce a vertical profile of tephra particles in the eruption column. This vertical particle distribution in the eruptive column is represented by the function $p(z)$, which defines the probability density distribution as a function of height, z, for particle diffusion out of the eruption column (SNL 2007a, Equation 6-3). Variation in the distribution of particle loading in the eruption column for various values of β is shown by Suzuki (1983, Figure 6a), and an example of this particle distribution for $\beta = 0.5$ (for central tendency of other Ashplume parameters) is shown in the spreadsheet calculation and plot in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, p. J-31). These plots demonstrate the concentration of particles near the top of the eruption column (at higher values of height, z, forming an 'anvil cloud'-shaped distribution of particles) that is considered representative of conditions in a violent Strombolian eruption.

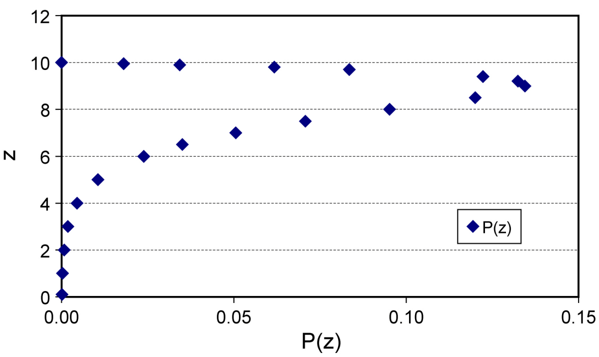
This anvil-cloud distribution can also result from small values of β for combinations of other Ashplume input parameters. The plot in Figure 1 illustrates the profile of particle mass in the initial eruption column vs. height (z, in km), as represented by the probability density function for particle diffusion out of the eruption column, $p(z)$ (SNL 2007a, p. 6-11). Referring to Ashplume input parameter ranges provided in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Table 8-2), for small tephra particle diameters (e.g., 0.005 cm) and relatively high initial rise velocities (e.g., 9,000 cm/s), the use of values of β at the low end of its range (e.g., 0.01) is appropriate to develop the upward-concentrated particle distribution (Figure 1). Therefore, the low end of the range originally used by Suzuki (1983) and Jarzemba et al. (1997) is appropriate for use in Ashplume realizations for Yucca Mountain to develop mass loading for model eruptive columns representing violent Strombolian eruptions.

Sensitivity analyses reported in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Figure C-4 and Table C-5), indicate that, for central tendency in other parameters, the variation in β from 0.5 to 0.01 reduces the calculated value of fuel (waste) concentration at the reasonably maximally exposed individual (RMEI) location (maximum 3.45×10^{-5} g/cm^2 for $\beta = 0.5$) by less than 30% and reduces tephra concentration by less than 4%.

Ashplume
CGS Terms (Red terms are variable, black ones are calculated)

part. diam	part. dens.	shape F	Beta	Wo	Vo	Yo
0.005	1.5	0.5	0.01	9000	8.6634	10.3886

Air Density = 0.001734
Air Visosity = 0.000185



H(z)	W(z)	Y	P(z)	P(z) normalized	t (s)
10.0000	0.0000	0.0000	0.0000	0.0000	5.0091E+04
9.9500	45.0000	0.0519	0.0512	0.0180	4.9923E+04
9.9000	90.0000	0.1039	0.0973	0.0343	4.9755E+04
9.8000	180.0000	0.2078	0.1754	0.0617	4.9418E+04
9.7000	270.0000	0.3117	0.2372	0.0835	4.9079E+04
9.4000	540.0000	0.6233	0.3473	0.1222	4.8046E+04
9.2000	720.0000	0.8311	0.3762	0.1324	4.7345E+04
9.0000	900.0000	1.0389	0.3820	0.1345	4.6635E+04
8.5000	1350.0000	1.5583	0.3409	0.1200	4.4817E+04
8.0000	1800.0000	2.0777	0.2704	0.0952	4.2935E+04
7.5000	2250.0000	2.5971	0.2010	0.0708	4.0986E+04
7.0000	2700.0000	3.1166	0.1435	0.0505	3.8967E+04
6.5000	3150.0000	3.6360	0.0996	0.0351	3.6875E+04
6.0000	3600.0000	4.1554	0.0677	0.0238	3.4707E+04
5.0000	4500.0000	5.1943	0.0299	0.0105	3.0127E+04
4.0000	5400.0000	6.2331	0.0127	0.0045	2.5188E+04
3.0000	6300.0000	7.2720	0.0053	0.0018	1.9843E+04
2.0000	7200.0000	8.3109	0.0021	0.0007	1.4021E+04
1.0000	8100.0000	9.3497	0.0008	0.0003	7.5928E+03
0.1000	8910.0000	10.2847	0.0004	0.0001	9.2395E+02
			2.8410		

$$Y = \frac{\beta W(z)}{V_0} \qquad t = 0.752 \times 10^6 \left[\frac{1 - e^{-0.0625z}}{V_0}\right]^{0.926}$$

$$Yo = \frac{\beta W_0}{V_0} \qquad W(z) = W_0\left(1 - \frac{z}{H}\right) \qquad p(z) = \frac{\beta W_0 Y e^{-Y}}{V_0 H\left\{1 - (1+Y_0)e^{-Y_0}\right\}}$$

02751DC_493.ai

NOTE: Source for formulas in spreadsheet: SNL 2007a, Figure J-14. Constant values were chosen (as described in text) from Ashplume input values for TSPA in SNL 2007a, Table 8-2: "part. diam" from line 23, "part. dens." from lines 8 and 9, "shape F" from line 12, "Beta" from line 22, "Wo" from line 29, "air density" from line 13, "air viscosity" from line 14. Equations and parameter relationships are described in SNL 2007a, pp. 6-11 to 6-13.

Figure 1. Upward-Concentrated Particle Distribution from ASHPLUME

1.1.1 ASHPLUME-ASHFALL Code Comparison Study

The use of the values of 0.3 and 0.5 as limits to the range for the column diffusion coefficient in the ASHPLUME-ASHFALL code comparison study (discussed in the RAI Basis statement) is described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Appendix J). The study was conducted as part of confidence building for the Ashplume model. As described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 7.5), the code comparison was carried out by configuring the inputs to the ASHPLUME code to simulate conditions of the 1995-96 eruptions of Ruapehu volcano in New Zealand. The Ashplume inputs were developed to be equivalent to the inputs used by Hurst and Turner (1999) for the ASHFALL modeling study of these eruptions, and the results of the two models were compared to evaluate whether the ASHPLUME code could simulate the eruption using reasonable parameter ranges. It should be noted that Ruapehu is an andesitic stratovolcano (Smithsonian Institution 2009) and is not considered to be an analogue for potential small-volume basaltic eruptions in the Yucca Mountain region (SNL 2007b), and the input parameters used to match the ASHFALL model of the Ruapehu eruptions do not correspond to the ranges of Ashplume input parameters used for the Yucca Mountain region. In particular, the values of 0.3 and 0.5 used for the column diffusion coefficient were developed by considering measured settling velocities for Ruapehu tephra and ASHFALL coefficient values (SNL 2007a, pp. J-9 to J-12). Although the study demonstrated that the ASHPLUME code performed acceptably in the model validation exercise, the Ruapehu data used in that study do not provide a technical basis for developing input parameters to the Ashplume model for Yucca Mountain, which is described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a).

1.2 MAGMA PARTITIONING FACTOR

The development of the range of values for the magma partitioning factor is described in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 6.5.2.22). The Ashplume conceptual model assumes that waste enters the magma at the repository depth and is well-mixed with the rising, fragmenting magma in the conduit. At the vent, only a part of the waste-containing magma enters the eruption column and is transported downwind and deposited in the tephra blanket; the remaining part of the waste-containing magma is deposited in geologically persistent landforms of the scoria cone and lava flows. Therefore, a "magma partitioning factor" is required to adjust the volume of waste available for transport in the Ashplume submodel of the TSPA. This parameter reduces the waste available for transport by a factor of 0.1 to 0.5, based on the proportion of erupted mass deposited in the tephra blanket relative to mass deposited in scoria cones and lava flows at analogous, small-volume basaltic volcanoes around the world.

The range of erupted mass in tephra blankets reported for analogue basaltic volcanoes is listed, along with a collaborative case, in Table 1. In some cases, volcanoes exhibiting violent Stromblian eruptive activity produce relatively high tephra proportion values (e.g., Paricutin – 0.50, Cerro Negro – 0.36, Lathrop Wells – 0.38, Tolbachik – 0.32). Tephra proportion values for Ferrarias and Pico do Boi are lower (0.04 and 0.16, respectively), and result from poorly described eruptions. However, the corroborative data entry for Cinder Cone in Table 1 lists the ashfall proportion (and hence "magma partitioning factor" value) of 0.05 from an eruption which, from detailed granulometric data, was described as having "very energetic Strombolian" phases by Heiken (1978, p. 128). This corroborative value indicates that the lower limit of the range for magma partitioning factor (0.1) is reasonable and representative of violent Strombolian eruptions.

1.3 SUMMARY

The range of values of the Ashplume input parameter, β or column diffusion coefficient (0.01 to 0.5) produces an upward-concentrated particle distribution in the eruptive column. While the use of values at the upper end of the range (e.g., 0.5) was discussed by the authors of the mathematical model (Suzuki 1983) and the computer code (Jarzemba et al. 1997), the appropriateness of the use of values at the lower end of the range (0.01) is demonstrated graphically in this response through the use of small tephra particle diameters (e.g., 0.005 cm) and relatively high initial rise velocities (e.g., 9,000 cm/s).

The use of the values, 0.3 and 0.5, as limits to the range for the column diffusion coefficient in the ASHPLUME-ASHFALL code comparison study do not correspond to the ranges of Ashplume input parameters used for the Yucca Mountain region. These values were developed by considering measured settling velocities for Ruapehu tephra and ASHFALL coefficient values. Although the study demonstrated that the ASHPLUME code performed acceptably in the model validation exercise, the Ruapehu data used in that study do not provide a technical basis for developing input parameters to the Ashplume model for Yucca Mountain.

The lower limit of the range of values for the magma partitioning factor (0.1) is supported by discussion of eruptive volume proportions at an additional corroborative analogue volcano.

Table 1. Range of Erupted Mass in Tephra Blankets Reported for Analogue Basaltic Volcanoes

	Volume (measured)			**Volume (DRE)**				**Proportion (DRE)**			
Volcano (age or eruption date)	**Cone (km^3)**	**Ashfall (km^3)**	**Lava (km^3)**	**Cone (km^3)**	**Ashfall (km^3)**	**Lava (km^3)**	**Total (km^3)**	**Cone**	**Ashfall**	**Lava**	**Notes**
Data											(1)
Cerro Negro, Nicaragua (1850-1995 AD)	—	—	—	0.0615	0.0574	0.0397	0.1586	0.39	0.36	0.25	
Serra Gorda, Sao Miguel, Azores (<5 ka)	0.030	0.060	0.015	0.0133	0.0267	0.0138	0.0538	0.25	0.50	0.26	(2)
Ferrarias, Sao Miguel, Azores (< 5ka)	0.001	0.006	0.070	0.0004	0.0027	0.0646	0.0677	0.01	0.04	0.95	
Carvao "C", Sao Miguel, Azores (<5 ka)	0.011	0.020	0.015	0.0049	0.0089	0.0138	0.0276	0.18	0.32	0.50	
Pico do Boi, Sao Miguel, Azores (<5 ka)	0.010	0.005	0.008	0.0044	0.0022	0.0074	0.0140	0.31	0.16	0.53	
Paricutin, Mexico (1943-1951 AD)	0.157	1.152	0.700	0.1027	0.7532	0.6462	1.5020	0.07	0.50	0.43	
Tolbachik Cones 1-3, Kamchatka (1975 AD)	0.200	0.420	0.260	0.1692	0.1938	0.2400	0.6031	0.28	0.32	0.40	
Lathrop Wells, NV (77 ka)	0.02	0.07	0.03	0.02	0.03	0.03	0.08	0.25	0.38	0.38	(2)
Corroborative											
Cinder Cone, CA (1650 AD)	0.0379	0.0324	0.25	0.032	0.015	0.23	0.277	0.12	0.05	0.83	(3)

NOTES: (1) Magma density assumed 2,600 kg/m^3 for all analyses unless otherwise noted. Cone density is assumed to be 2,200 kg/m^3. Lava density assumed to be 2,400 kg/m^3. Tephra density is assumed to be 1,200 kg/m^3.

(2) Mass proportions do not total to 1.0 due to rounding.

(3) Cone and ashfall volumes measured for Cinder Cone are from Heiken (1978, Table 1). Lava volume is derived from mapped lava extent of 8.3 km^2 (MacDonald 1964) and average flow margin thickness of 30 m.

DRE = dense rock equivalent.

2. COMMITMENTS TO NRC

None

3. DESCRIPTION OF PROPOSED LA CHANGE

None

4. REFERENCES

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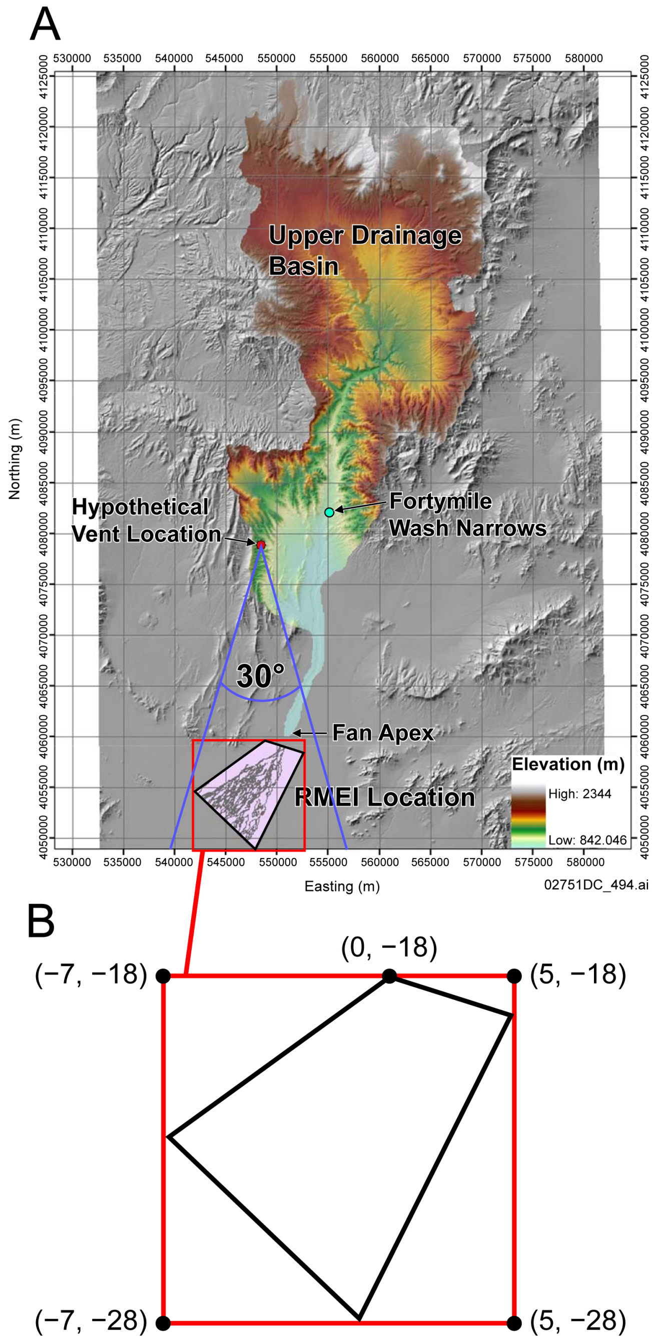
Provide additional information to show that using a point to model tephra deposition at the reasonably maximally exposed individual (receptor) location does not underestimate radiological dose. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).

Basis: SAR Section 2.3.11.4.2.2.3 and a DOE report (SNL 2007a, Section 6.5.2.1.17 and Table 8-2) indicate that tephra and waste at the receptor location are calculated for a point located 18 km south of the volcanic vent. However, the tephra redistribution model uses an area to represent the location of the receptor (SAR Section 2.3.11.4.1.1.3 and Figure 2.3.11-13; SNL, 2007b, Figure 1-2 and Table 6.5.10-1). DOE performance assessment results are influenced by the amount of contaminated tephra deposited at the receptor location. Because of variation in wind speed and direction, the likelihood of tephra being deposited at a single point appears to be less than the likelihood of tephra being deposited within an area, such as that shown in SAR Figure 2.3.11-13. DOE should provide additional information to indicate that tephra fall calculated at a point in the Ashplume model appropriately represents the likelihood and characteristics of a tephra-fall deposit in the area used to represent the dose receptor in the tephra redistribution model.

1. RESPONSE

Although the source of contamination at the reasonably maximally exposed individual (RMEI) location for the volcanic eruption modeling case has a spatially distributed nature as a result of the tephra dispersal process, it is appropriate to use a representative point estimate to calculate radiological dose to the RMEI. Tephra and waste areal concentrations (in g/cm^2) at a single point location are used to represent primary tephra deposition as input to the Fortymile Wash ash redistribution (FAR) model, but it is not assumed that all tephra and waste are being deposited at a single point. The results of supplemental Ashplume model runs demonstrate that the single point values of tephra/waste areal concentration located 18 km south of the repository typically represent the maximum concentrations that will be deposited on the RMEI location, as represented by the FAR model (Figure 1) for a given model realization with south-directed winds. Therefore, the areal concentration inputs to the FAR model will tend to overestimate waste deposition by primary tephra fall elsewhere on the alluvial fan surfaces.



NOTE: The upper part of the figure (A) is reproduced from SNL 2007a, Figure 1-2, in which the model areas for the FAR model are defined. The polygon outlining the "RMEI Location" for the FAR model has been enlarged in (B) to illustrate the extent of the Ashplume model grid (red box) that circumscribes this RMEI location polygon. Grid spacing is 1 km, producing 143 data points. Coordinates in (B) are given in kilometers relative to the "Hypothetical Vent location" shown in (A). The point at coordinates (0, −18) corresponds to the single point location used by the FAR submodel in the TSPA model to calculate tephra and waste concentrations for the RMEI location.

Figure 1. Schematic of Extent of Ashplume Model Study Area for This RAI Response

The appropriateness of a single point calculation of tephra deposition to represent conditions in the 33 km^2 RMEI location used in the FAR model (SNL 2007a, Section 6.5.4.1) is demonstrated here through the use of supplementary Ashplume model runs. These model runs are taken from the validated total system performance assessment (TSPA) model realizations (SNL 2008) in which the ASHPLUME code calculated tephra and waste concentrations for a single point located 18 km south of the hypothetical eruption vent (Figure 1). The Ashplume realizations were repeated to assess concentrations at a grid of points that circumscribes the upper Fortymile Wash alluvial fan defined as the RMEI location for the purposes of the FAR model (Figure 1). The point at coordinates (0, −18), where TSPA model point values of tephra/waste areal concentrations were calculated, is included in this grid for comparison purposes. (The location of the RMEI is specified with respect to the groundwater transport of radionuclides as approximately 18 km due south of the repository along Fortymile Wash, as described in SNL 2007b, p. 6-32.)

Three Ashplume model runs were chosen from the TSPA model realizations (SNL 2008) to investigate the distribution of tephra and waste concentrations across the RMEI location on the alluvial fan (Table 1). These model runs represent moderate eruption volume, low and medium eruptive column heights, light and moderate wind speeds, and due south- and southeast-directed winds. These existing TSPA model realizations were rerun using a 12-km by 10-km grid with 1-km grid spacing that covers the upper alluvial fan (equivalent to the RMEI location for the FAR model, Figure 1B). The results of the south-directed eruption cases (runs 102 and 179) indicate that the single point (0, −18) received the highest concentration of tephra (Figure 2A and B) and waste (Figure 3A and B) for the upper alluvial fan area for medium and low column heights and light to moderate wind speeds. The farthest removed areas in the western or southern corner of the FAR RMEI location received less than 30% of the maximum tephra concentration at (0, −18) for light winds (run 102) and received less than 1% of the maximum for higher winds (run 179). Therefore, the concentration inputs to the FAR model will tend to overestimate waste deposition by primary tephra fall on the alluvial fan surfaces.

The single-point tephra and waste concentrations are also appropriate for eruptive plumes oriented away from due south. The highest tephra/waste concentrations for the south-southeast-directed plume (run 130, comparable to south-directed run 179) were deposited on the northeast corner of the alluvial fan, as shown in Figures 2C and 3C. The range of concentrations deposited on the FAR RMEI location for this wind orientation was three orders of magnitude lower than the south-directed winds for tephra (Figure 2B and C) and two orders of magnitude lower for waste (Figure 3B and C). For this south-southeast wind direction, the single-point value (0, −18) represents conditions over about 95% of the upper alluvial fan (RMEI location as represented by the FAR model), which receives negligible tephra deposition. For winds directed further east and northeast, the difference in deposited tephra/waste across the RMEI location further decreases.

Wind directions for Ashplume realizations in the TSPA model are sampled from twelve 30-degree-wide bins. The model results for due-south (−90 degrees) directed winds are representative of wind directions from −75 degrees to −105 degrees (south-southeast to south-southwest). (Ashplume wind directions are measured relative to due east, with positive values moving in a counter-clockwise direction.) The wind direction bin centered on −90 degrees encompasses the entire FAR RMEI location (Figure 1A, blue lines). Therefore, the 33 km^2 FAR RMEI location shares an equal likelihood of tephra deposition for a given Ashplume realization.

Summary

The use of a single point calculation of tephra/waste deposition does not underestimate the concentration of waste deposited in the 33 km^2 RMEI location used in the FAR model (SNL 2007a, Section 6.5.4.1). As demonstrated by supplemental Ashplume model runs for winds directed due south, the single point location at coordinates (0, −18 km) typically receives the maximum areal concentration of tephra and waste compared to the rest of the FAR RMEI location. For wind directions other than due south, the areal tephra/waste concentrations calculated for the coordinates (0, −18 km) represent conditions over about 95% of the area of the FAR RMEI location, which receives negligible tephra deposition. For winds directed further east and northeast, the difference in deposited tephra/waste across the RMEI location further decreases. Because wind directions for the Ashplume model are sampled from 30-degree-wide bins, the 33 km^2 FAR RMEI location shares an equal likelihood of tephra deposition for a given Ashplume realization. This approach appropriately represents the likelihood and characteristics of tephra and waste deposition at the RMEI location because the use of tephra/waste concentration values at a single point tends to overestimate concentrations in the 33 km^2 RMEI location used in the FAR model.

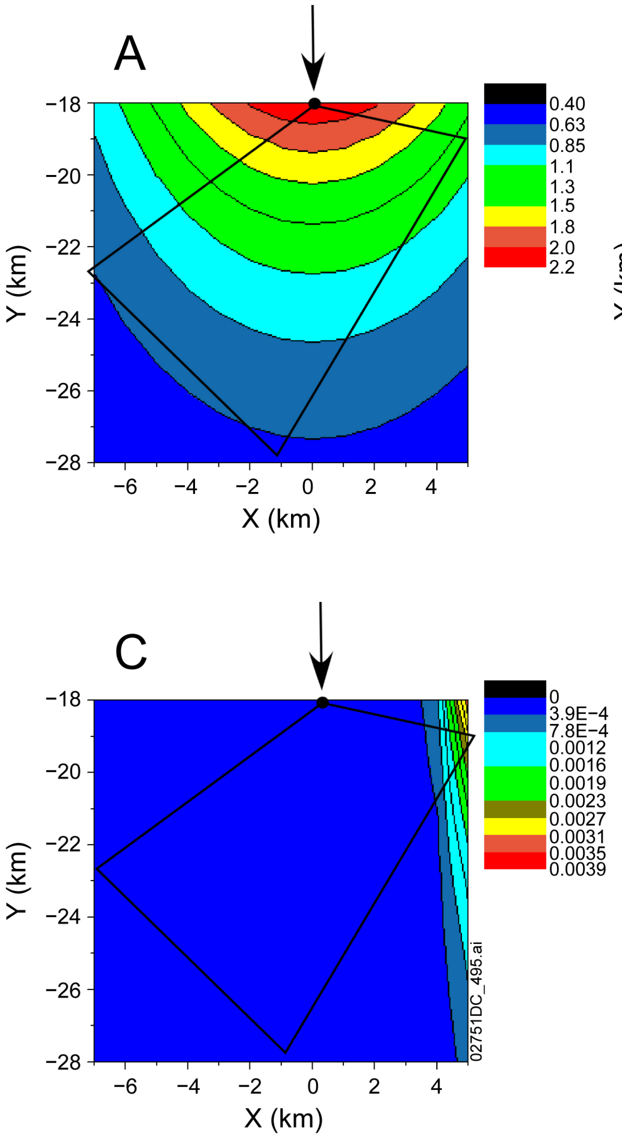
Table 1. Summary of Supplemental Ashplume Model Runs Based on TSPA Model Realizations

Realization	Beta	Mean Ash Particle Diameter (cm)	Ash Particle Diameter Standard Deviation (cm)	Eruptive Power (W)	Eruption Duration (s)	Initial Rise Velocity (cm/s)	Wind Direction (degrees counter-clockwise from East)	Wind Speed (cm/s)	Eruption Volume[a] (km^3)	Column Height[b] (km)	Comments
102	0.4792	0.0458	0.5982	3.93×10^{9}	1.03×10^{7}	8,899	−90	442	0.040	2	South-directed plume, low column, moderate volume, light windspeed
179	0.1069	0.0024	0.5923	1.27×10^{11}	3.18×10^{5}	7,176	−90	2,018	0.040	5	South-directed plume, moderate column, moderate volume, moderate windspeed
130	0.1981	0.0046	0.3570	1.05×10^{11}	3.31×10^{5}	7,504	−60	1,746	0.035	5	Southeast-directed plume, moderate column, moderate volume, moderate windspeed

[a] Eruption volume (V, km^3) is calculated from the relationship $V = P^*T_d / 10^{18}$, where P is eruptive power (W) and T_d is eruption duration (s) (SNL 2007b, Equation 8-1).

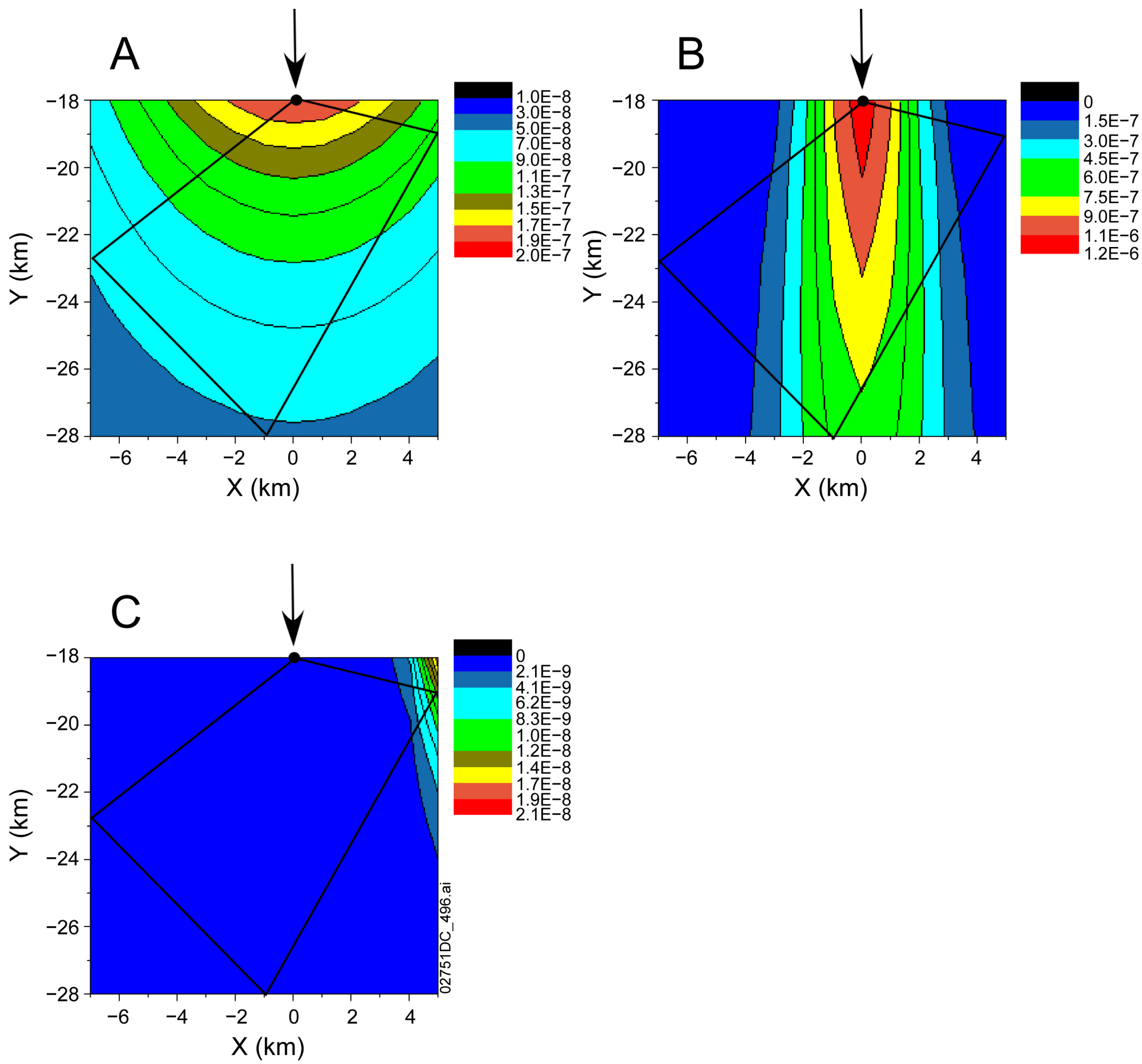
[b] Column height (H, km) is calculated from the relationship $H = 0.0082^*P^{0.25}$, where P is eruptive power (W) (SNL 2007b, Equation 6-7a).

NOTE: Column headers Beta, Mean Ash Particle Diameter, Eruptive Power, Eruption Duration, Initial Rise Velocity, Wind Direction, and Wind Speed refer to input values for the Ashplume model (SNL 2007b, Table 8-2).



NOTE: Black polygon overlays represent the approximate "RMEI location" for the FAR model depicted in Figure 1. Color contours in g/cm^2; note variable contour interval. The position of single-point concentration calculations (0, −18) is shown by the black dot and arrow. (A) ASHPLUME run 102, south-directed wind; (B) run 179, south-directed wind; (C) run 130, southeast-directed wind.

Figure 2. Three ASHPLUME Realizations of Tephra Concentration across the Upper Fortymile Wash Alluvial Fan



NOTE: Black polygon overlays represent the approximate “RMEI location” for the FAR model depicted in Figure 1. Color contours in g/cm^2; note variable contour interval. The position of single-point concentration calculations (0, −18) is shown by the black dot and arrow. (A) ASHPLUME run 102, south-directed wind; (B) run 179, south-directed wind; (C) run 130, southeast-directed wind.

Figure 3. Three ASHPLUME Realizations of Waste Concentration across the Upper Fortymile Wash Alluvial Fan

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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SNL 2008. *Total System Performance Assessment Model/Analysis for the Yucca Mountain License Application*. MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001.

RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 9:

> Justify scour depth for conditions when fresh basaltic tephra deposits may exist in Fortymile Wash, where scour depth estimates could be influenced by tephra-rich channel material and differ with those determined from current conditions. Provide information to indicate that the parameter range for scour depth does not overestimate dilution with non-basaltic, underlying sediment and underestimate the resulting waste concentration at the reasonably maximally exposed individual location. Address other available scour data for Fortymile Wash (e.g., U.S. Geological Survey Station 10251258). This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: Tephra deposited on hillslopes after a volcanic eruption is susceptible to erosion and subsequent remobilization and redistribution. Scour depth is one of the most sensitive parameters in the DOE Fortymile Wash Ash Redistribution model for the volcanic ash exposure scenario (SNL, 2007a, Section 6.6.3). The applicant bases its determination of the parameter range for scour depth on a site-specific field measurement of Fortymile Wash for current conditions without the presence of a tephra deposit. DOE utilized scour chain data only at the Narrows (U.S. Geological Survey Station 10251250). Other field data from Fortymile Wash (e.g., U.S. Geological Survey Station 10251258) may be relevant and should be addressed by DOE.
>
> In SNL (2007a, page 7-7), the applicant provides a rationale to justify the range of scour depth that is based on the mass of tephra remobilized and associates slightly overestimating scour depth with a larger mass of remobilized tephra. Because Figures 6.6.1-2 and 7.1.3-1 in the same report indicate that greater scour depths correspond to smaller initial waste concentrations in fluvial sediment at the receptor location, additional information is needed on how the treatment of uncertainty for scour depth affects the dilution of waste in fluvial sediment and DOE dose estimates.

1. RESPONSE

The scour depth parameter was developed as a function of the contributing area and stream discharge, and it is quantitatively independent of the proportion of tephra in stream channels. Validation studies have confirmed that shallower scour depths in the upper parts of the drainage basin result in higher initial tephra concentrations in channel sediments on the alluvial fan, which is the location of the reasonably maximally exposed individual (RMEI) (SNL 2007a, Figure 6.6.1-2 and Section 7.1.3). These studies indicate that the values used for the limits of the range of scour depth (73 to 122 cm; SNL 2007a, Table 6.5.10-1) tend to underestimate potential dilution and overestimate initial tephra concentrations in channel sediments at the RMEI location.

The Fortymile Wash ash redistribution (FAR) model assumes that the hydraulic properties of the fresh tephra are reasonably similar to those of the channel bed material (i.e., background sediment) and that the contaminated tephra is transported primarily as bed-load material (SNL 2007a, p. 6-7). The expected range in grain size for tephra (0.01 to 1.0 mm; SNL 2007b, Section 6.5.2.4) is mostly sand-sized, similar to the observed range in grain size for channel-bed material in the Yucca Mountain region (fine to medium sand) (SNL 2007a, Sections 5.2.3 and 7.3.1.1). Based on these textural similarities, hydraulic conditions and channel-bed processes are not expected to be different for tephra-rich conditions (SNL 2007a, Section 5.2.3; Pelletier et al. 2008, p. 236). An analogue study of fluvial transport of basaltic tephra around Lathrop Wells volcano (about 77 ka) confirms that basaltic tephra is well-mixed with non-basaltic sediment (tuff and carbonate) in channels (SNL 2007a, Sections 7.3.1.1 and 7.3.1.2). Therefore, the development of scour depth (as a function of contributing area and discharge; SNL 2007a, pp. 6-18 to 6-21) is quantitatively independent of the proportion of tephra in the stream channel.

Based on a digital elevation model grid, scour depth for channel pixels in the upper drainage basin of Fortymile Wash (as defined in SNL 2007a, Section 6.2.2) is calculated based on values of contributing area and channel width, relative to values measured at the Narrows stream gauge following a 1995 flood (SNL 2007a, Section 6.3.3 and Equation 6.3-14). In the upper drainage basin of Fortymile Wash, the FAR model defines the contaminant concentration at each point to be equal to the ratio of the total contaminant volume from upstream to the total volume of the upstream scour zone (SNL 2007a, p. 6-8). The model results show an inverse relationship between the depth of scour and the concentration of contaminated tephra being transported downstream by the mixing/dilution process. In the upper drainage basin, deeper scour depths involve greater amounts of uncontaminated sediments. The greater amounts of uncontaminated sediment result in greater dilution of the contaminated tephra (SNL 2007a, Figure 6.6.1-2).

Once the tephra has been redistributed to the RMEI area, further dispersion of the radionuclide material in the tephra is modeled as a vertical diffusion process. The FAR model uses the concentration of tephra in channel sediments at the outlet of the upper drainage basin (via the dilution factor) to specify initial conditions for concentration of tephra above the scour depth in all channels on the alluvial fan (RMEI location). The thickness of the contaminated tephra in the active channels is set to the values of scour depth at the Fortymile Wash fan apex. In channels, the primary fallout and the tephra redistributed from upstream are added together and uniformly mixed from the surface to a depth equal to the scour depth at the fan apex. The diffusion process moves the initial concentration of contaminants in the sediment above the scour depth downward throughout the total permeable sediment column. The redistributed contaminant mass available in the system for vertical diffusion is proportional to the initial concentration and scour depth at the drainage basin outlet. The diffusion is assumed to occur within a finite thickness corresponding to the distance from the surface to a zone of reduced permeability (i.e., within the depth of the permeable layer).

For early, nonequilibrium model conditions, shallower scour depths result in higher concentrations of contaminants in the upper part of the channel sediment profile (SNL 2007a, Figure 7.1.3-1). Higher concentrations in the resuspendable soil layer in channels contribute to a higher mean dose from inhalation of airborne particulates, which is a dominant exposure pathway in the initial 10,000 years (see discussion on inhalation dose and related figures in the responses to RAIs 3.2.2.1.3.13-006 and 3.2.2.1.3.13-007). After about 100,000 years, other pathways become more important, particularly the inhalation of radon (^{222}Rn) decay products. The mean dose from these pathways depends on the amount of contaminant within the surface soil (tillage depth). Because the scour depth exceeds the tillage depth, the mean dose from the pathways other than inhalation is also proportional to the concentrations of contaminated tephra in the upper part of the channel sediment profile, and decreases as the scour depth increases.

With time, the concentration of contaminants reaches equilibrium within the permeable layers of the channels and the divides. Equilibrium times in the channels vary according to the difference between the scour depth and the thickness of the permeable soil layer and are on the order of 460,000 years for shallower scour depth (73 cm) and 250,000 years for deeper scour depth (107 cm) (SNL 2007a, p. 7-5). Although deeper scour depth results in a lower initial concentration, at equilibrium conditions the competing effects of scour depth on the lower and upper drainage basins cancel each other out, and the resulting concentration in the channel is independent of scour depth. Thus, scour depth only influences the concentration profiles, and consequently the dose to the RMEI, for nonequilibrium times (SNL 2007, p. 7-5).

The basis section of this RAI requests clarification of the statement (in SNL 2007a, p. 7-7 versus Figures 6.6.1-2 and 7.1.3-1) that, by applying scour depth measurements at the Narrows to the channels on the alluvial fan, the model may slightly overestimate scour depth and overestimate the mass of contaminated tephra at the RMEI location. This statement refers to equilibrium model conditions, as described above, at which time the normalized concentration in RMEI channel sediments approaches the ratio of the scour depth to the total permeable depth of the channel.

The development of the range of values for the scour depth parameter is based on field observations, as described in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 6.5.6). Observed scour depths from the March 11, 1995, flood event at the Narrows location in Fortymile Wash provide the upper and lower bounds for this parameter distribution (73 to 122 cm). The use of the scour chain observations from the Narrows gauge station provides the most accurate representation of flood-induced scour in the upper Fortymile Wash watershed. The constricted channel geometry at this location ensures bank-to-bank flow conditions, and few tributaries enter Fortymile Wash downstream of this location (i.e., its contributing area for the wash does not increase significantly below this point) (SNL 2007a, Section 6.5.6). Other stream flow data from the U.S. Geological Survey are not well located for use in calibrating discharge and scour depth in the upper drainage basin; for example, station 10251258 (Amargosa Valley) is located on the distributary Fortymile Wash alluvial fan, and the location does not represent tributary conditions in the upper drainage basin that are necessary to calibrate the FAR model.

The magnitude of the 1995 flood event was less than a 100-year event, and larger floods would be expected on a 10,000-year timescale. Since tephra transport and mixing are controlled by large floods in the basin, greater scour depths are expected to result from these larger floods during the model time period; for example, expected scour depths for 100- and 500-year floods in the Fortymile Wash basin are 140 and 310 cm (SNL 2007a, Section 7.1.3). Validation studies have confirmed that shallower scour depths in the upper parts of the drainage basin result in higher initial tephra concentrations in channel sediments on the alluvial fan (RMEI location), as described in the previous paragraph (SNL 2007a, Figure 6.6.1-2 and Section 7.1.3). These studies indicate that the values used for the limits of the range of scour depth (73 to 122 cm; SNL 2007a, Table 6.5.10-1) tend to underestimate potential dilution and overestimate the initial concentrations of contaminated tephra in channel sediments at the RMEI location.

The scour-dilution-mixing approach improves on the earlier models (e.g., dilution-mixing models discussed in the response to RAI 3.2.2.1.3.13-005) by making the channel mixing and dilution models more process-based. A volumetric approach is taken, by allowing the contaminant concentration at each point to be equal to the ratio of the total contaminant volume from upstream to the total volume of the upstream scour zone (all transported sediment). A parameter sensitivity analysis showed that the scour depth at the fan apex accounts for nearly 40% of the variation in waste concentrations in channels at the RMEI location (SNL 2007a, Section 6.6.1). The scour depth used in the tephra redistribution model determined an average or effective scour depth associated with many large floods over hundreds or even thousands of years and is based on scour chain measurements at the Narrows in Fortymile Wash (SNL 2007a, Section 6.5.6). The range of effective scour depths is taken to be a uniform distribution between 73 and 122 cm. The upper bound value of 122 cm was selected instead of the maximum scour recorded at the Narrows site, 152 cm, because the lesser value tends to overestimate initial concentration in the channels at the RMEI location (SNL 2007a, Section 6.5.6). Therefore, an overestimate of the initial waste concentration in fluvial sediments at the RMEI location would be expected to result in an overestimate of the dose to the RMEI for early, nonequilibrium model time.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

Pelletier, J.D.; DeLong, S.B.; Cline, M.L.; Harrington, C.D.; and Keating, G.N. 2008. "Dispersion of Channel-Sediment Contaminants in Distributary Fluvial Systems: Application to Fluvial Tephra and Radionuclide Redistribution Following a Potential Volcanic Eruption at Yucca Mountain." *Geomorphology, 94*, 226-246. New York, New York: Elsevier.

SNL (Sandia National Laboratories) 2007a. *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada.* MDL-MGR-GS-000006 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071220.0004.

SNL 2007b. *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada.* MDL-MGR-GS-000002 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071010.0003.

RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 10:

> Clarify how much tephra, is stored in channels, including tephra mobilized from surrounding hillslopes into channels. If the total amount of tephra stored in channels is significant with respect to the amount of tephra routed to the receptor location, provide a basis for storing significant amounts of tephra in channels. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: Tephra deposited on hillslopes after a volcanic eruption is susceptible to erosion and subsequent remobilization and redistribution. Scour depth is one of the most sensitive parameters in the DOE Fortymile Wash Ash Redistribution model for the volcanic ash exposure scenario (SNL, 2007a, Section 6.6.3). In the DOE model, tephra can be stored below the scour depth in channels and not routed to the Fortymile Wash alluvial fan (SAR Section 2.3.11.4.1.1.3; SNL, 2007a, p. 6-24). The applicant states initial tephra-fall thicknesses in channels that exceed the scour depth are not very common and tephra sequestered below the scour depth is a very small fraction of the mobilized tephra (SNL, 2007a, p. C-15). However, it does not comment on the potentially greater amount of tephra mobilized from surrounding hillslopes into the channels and stored. If the DOE model stores significant amounts of tephra in channels, additional supporting information is needed to account for uncertainties in the application of the scour depth approach, and may include presentation of suitable analogs that exhibit the modeled behavior.

1. RESPONSE

The scour depth parameter represents the combined effects of large flood events during the model time period (SNL 2007, p. 6-49). While scour-dilution-mixing transport of tephra (both primary deposit in channels and eroded from hillslopes) is considered an instantaneous process in the model, tephra remaining on hillslopes and in channels below the scour depth is representative of long-term storage of material that does not contribute to the mass of contaminated tephra in the alluvial fan channels at the reasonably maximally exposed individual (RMEI) location. Analogue studies of basaltic tephra in channel sediments near Lathrop Wells volcano indicate that primary tephra deposits stored below scour depth can persist for at least 77,000 years (SNL 2007, Section 7.3.1.2).

The mass balance analysis in the Fortymile Wash ash redistribution (FAR) model (SNL 2007, Section 7.2.8) provides the means to quantitatively assess the amount of tephra stored in channels in the upper Fortymile Wash drainage basin below the scour depths. For six FAR realizations (varying values of critical slope, drainage density, and scour depth), the proportion of primary tephra deposit in the drainage basin stored in channels below scour depth ranges from 0.8% to 3.6% (SNL 2007, Table 7.2.8-2). The amount of tephra eroded from steep hillslopes (combined with primary tephra fall in channels) and stored beneath scour depth is not reported. The effect of this value on overall model results of the model is not significant.

As demonstrated in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007, Section 7.2.8 and tables therein), 81% to 85% of total tephra deposited on the upper Fortymile Wash watershed is stored on gradual hillslopes and is therefore not redistributed to the RMEI area. Of the remaining 15% to 19% of the tephra, approximately half is routed to the main channel of Fortymile Wash (see *ashmobilized* column in SNL 2007, Table 7.2.8-3). The other half amounts to approximately 7% to 10% of the total tephra deposit and is the result of tephra storage by three mechanisms: (1) primary channel tephra deposit stored below scour depth, (2) local fluvial deposition in unconnected channels (SNL 2007, Figure 7.2.4-1), and (3) storage of eroded hillslope tephra in channels beneath the scour depth. Primary tephra deposits in channels stored below the scour depth amount to 0.8% to 3.6% of total tephra (SNL 2007, Table 7.2.8-2), or up to about one-third of the basin storage. A qualitative comparison of Figures 7.2.4-1 and 7.2.4-2 in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007) indicates that the quantity of tephra stored by local deposition in unconnected channels is equal to or exceeds the quantity of primary tephra deposited in channels and stored below scour depth. The quantity of tephra stored by local deposition in unconnected channels therefore can be estimated at about one-third of basin storage. Therefore, the quantity of tephra eroded from steep slopes and stored below the scour depth is not more than one-third of basin storage, or 2% to 3% of the total tephra deposit in the watershed.

The total tephra (both primary fall and mobilized tephra from steep slopes) stored below the scour depth comprises a small proportion of the overall tephra fall in the watershed – on the order of 3% to 7% – and it is localized in channel cells that lie directly under the path of the tephra plume (SNL 2007, p. 7-24). This total tephra stored below the scour depth comprises a larger proportion of mobilized tephra (not stored on gradual hillslopes) – up to 30%. However, the potential effect of this total tephra stored below the scour depth is not significant. As demonstrated in the response to RAI 3.2.2.1.3.13-009, were this stored tephra mobilized by deeper scour depths throughout the watershed, the effect would be to increase the incorporation of non-tephra sediment, enhance dilution, and reduce the tephra concentrations at the outlet of Fortymile Wash.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2007. *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada.* MDL-MGR-GS-000006 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071220.0004.

RAI Volume 3, Chapter 2.2.1.3.13, First Set, Number 12:

> Provide additional support for not including the potential effects of eolian redistribution of tephra in the performance assessment. This information is needed to determine compliance with 10 CFR 63.114(a)(1, 2).
>
> Basis: The DOE Fortymile Wash Ash Redistribution model explicitly accounts for fluvial redistribution of tephra but does not consider potential effects of eolian redistribution (SAR Section 2.3.11.4.1.1.3; SNL, 2007a, Sections 1.2 and 5.2.2). DOE considers the eolian transport of primary tephra in the Fortymile Wash drainage basin to the receptor location to be negligible, based on its characterization of the prevailing direction for strong surface winds as predominantly from the south (SNL, 2007b, Appendix D; Pelletier and Cook, 2005). However, surface-wind data in, for example, CRWMS M&O (1997, site 9) show both southerly and northerly components in response to diurnal and seasonal effects. These data show that eolian transport of tephra from north of the RMEI location cannot be excluded based on wind direction. Additional support is needed for not considering the potential effects of eolian transport.

1. RESPONSE

For four potential pathways, eolian transport of contaminated tephra to the reasonably maximally exposed individual (RMEI) location is either shown to be negligible compared with direct deposition and fluvial redistribution, or the effects of eolian mobilization and transport processes are considered through the selection of parameter value ranges in the tephra redistribution model and through the selection of biosphere model parameters.

Four potential pathways for eolian transport of contaminated tephra to the RMEI area are identified in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 5.2.2):

1. Eolian redistribution of primary fallout at the RMEI location
2. Eolian transport from the Fortymile Wash drainage basin in the north to the RMEI location
3. Eolian transport from channels to divides at the RMEI location
4. Eolian transport from Franklin Lake Playa in the south to the RMEI location.

The following discussion of each of these four transport pathways provides information on how each pathway is accounted for in the TSPA model through the selection of parameter value ranges in the tephra redistribution or biosphere models, or provides support for not explicitly modeling each pathway.

1.1 EOLIAN REDISTRIBUTION AT THE RMEI LOCATION

Wind blowing toward the south could result in direct deposition of contaminated tephra at the RMEI location in the event of a volcanic eruption through the repository. Resuspension of top soil layer, including primary tephra fallout, at the RMEI location due to wind, human activity, or other disturbances is included in the biosphere air submodel of the TSPA volcanic eruption modeling case. Deposition of resuspended particles onto plant surfaces with subsequent ingestion and direct inhalation of resuspended particles is considered in the biosphere plant and inhalation submodels (SNL 2007b, Sections 6.5.1.2, 6.5.6.1, and 6.5.3.2). Radionuclide concentration within the surface tillage depth (0.05 to 0.30 m) is used to calculate dose due to ingestion, external exposure, and inhalation of radon decay products (SNL 2007b, Section 6.5.1.1). Radionuclide-dependent biosphere dose conversion factors (BDCFs) for the ingestion and external exposure pathways are multiplied by the activity concentration per unit area of tillage soil to obtain dose for these pathways. Radionuclide concentration in the relatively thin (1 to 3 mm) resuspendable layer at the surface of the soil is used to calculate inhalation dose from exposure to suspended particulates. Depending on the thickness of the tephra deposit, the resuspendable layer may consist of soil mixed with ash or of ash only. This pathway is included in the TSPA model through the specification of appropriate BDCFs for short-term and long-term inhalation exposure. Radionuclide dependent inhalation BDCFs are multiplied by the activity concentration per unit mass of soil in the resuspendable layer to obtain an inhalation dose. Thus, eolian redistribution of contaminated tephra and soil locally at the RMEI location is included in the TSPA volcanic eruption modeling case through this treatment of the resuspension of contaminated particles.

1.2 EOLIAN TRANSPORT FROM THE FORTYMILE WASH DRAINAGE BASIN

Wind blowing toward the east or northeast direction could result in contaminated tephra deposits in the Fortymile Wash drainage basin. Wind blowing from the north could subsequently transport the contaminated tephra from the drainage basin to the RMEI location. This transport pathway is considered to be negligible in the TSPA volcanic eruption modeling case based on the prevailing direction of the highest velocity winds, which are generally from the south in the vicinity of Yucca Mountain (SNL 2007a, Section 5.2.2). This wind direction is not expected to result in significant eolian transport from the upper drainage basin domain to the RMEI location (SNL 2007a, Figure 1-2).

The basis for this RAI cites *Regional and Local Wind Patterns Near Yucca Mountain* (CRWMS M&O 1997) (Site 9) as an example of significant northerly winds due to diurnal and seasonal effects. That report describes regional and local airflow patterns that occur near Yucca Mountain based, in part, on nine meteorological stations. The meteorological station identified as Site 9 is located near the center of lower Jackass Flats, immediately north of the Amargosa Valley area, and can be considered to be in an area representative of the drainage basin domain and the RMEI location (SNL 2007a, Figure 1-1). Wind data for all hours sampled at Site 9 is displayed as a wind rose plot in Figure 3-2 of *Regional and Local Wind Patterns Near Yucca Mountain* (CRWMS M&O 1997, Section 3.1.1). The data show a bimodal distribution of wind between the two general directions of south and northeast due to diurnal effects and topographic channeling. The wind direction distribution results from the regular diurnal wind cycle of airflow upslope toward higher terrain in the daytime and downslope away from higher terrain at night. The wind rose diagram for Site 9 also includes information on the wind speed distribution represented by the relative lengths of the segments composing each direction line in the diagram. The Site 9 data clearly indicate that winds from the south have a significantly higher wind speed distribution than winds from the northeast. Figure 3-9 in *Regional and Local Wind Patterns Near Yucca Mountain* (CRWMS M&O 1997, Section 3.1.2) shows wind rose plots for Site 9 separated into daytime and nighttime winds. That figure shows that winds from the south, or upslope, occur mostly in the daytime, and winds from the northeast, or downslope, occur mostly at night. The daytime plot shows that winds from the south have a significant number of speeds greater than 5.4 m/s, with wind speeds ranging to greater than 11 m/s, while the nighttime plot shows that winds from the north have speeds that are mostly less than 5.4 m/s.

The Site 9 data (CRWMS M&O 1997, Sections 3.1.1 and 3.1.2) supports the previously stated basis for neglecting winds from the north because the highest velocity winds in the area are from the south. Within a single day-night cycle of winds, higher southerly daytime wind velocities relative to northerly nighttime wind velocities would result in net transport of contaminated tephra initially deposited in the drainage basin towards the north, away from the RMEI location. Over the long term, it is unlikely that any significant redistribution of tephra from the drainage basin to the RMEI location could occur due to this wind pattern. For contaminated tephra initially deposited directly at the RMEI location, the net transport of material in a northerly direction and dilution from material brought in from the south would reduce waste concentrations at the RMEI location over time. Choosing not to simulate these effects explicitly in the TSPA model will tend to overestimate tephra and waste concentration at the RMEI location.

1.3 EOLIAN TRANSPORT FROM CHANNELS TO DIVIDES

The third transport pathway deals with eolian transport of sand-sized particles from the channels of Fortymile Wash to the divides. Transport of this type occurs in the present, but deposition is primarily localized within a narrow margin along the active channels, with minor amounts of deposition extending for several hundred meters downwind from the channel. Figure 5-1 from *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a) is an orthophoto mosaic of the Fortymile Wash alluvial fan. The figure identifies the locations of several sand streaks originating in the channel and extending in a north to northwest direction, consistent with the prevailing regional wind direction. Sand streaks are created as sand is blown from the channel bed up onto divides. These sand streaks are composed of continuous sand (covered by sand ripples) within approximately 10 to 20 m of the active channel. The continuous sand cover transitions to disturbed desert pavement, and eventually to undisturbed desert pavement, with increasing distance from the channel. Eolian sand and silt is found within the top tens of centimeters on the older alluvial fan units; however, these surfaces are significantly older than 10,000 years, and deposition has occurred gradually over this time. The consequence of not explicitly including this localized redistribution within the RMEI domain is expected to be insignificant (SNL 2007a, Section 5.2.2). To calculate the dose to the RMEI for the volcanic eruption modeling case, the TSPA model sums the waste concentrations from active channels and interchannel divides weighted by the fraction of the fan composed of active channels and interchannel divides, respectively. As discussed in the response to RAI 3.2.2.1.3.13-007, this approach is equivalent to assuming that the RMEI is exposed to radionuclides from the channels and divides proportional to their area. Since most scenarios result in greater concentrations within the channel sediments (due to prevailing wind direction being opposite to the direction of fluvial transport), eolian redistribution of tephra from the channels to the divides at the RMEI location can be approximated by increasing the fraction of area comprised of active channels, *F*. The current active channel covers less than 5% of the fan area. However, the active channel fraction parameter, *F*, in the TSPA model is sampled from a significantly larger uniform distribution of values between 0.09 and 0.54. Therefore, the effect of this eolian transport pathway is implicitly accounted for in the model by the very large range in the *F* parameter being used (SNL 2007a, Section 5.2.2).

1.4 EOLIAN TRANSPORT FROM FRANKLIN LAKE PLAYA

Fine particles transported from the Fortymile Wash drainage basin as suspended load during large floods could be deposited south of the RMEI location in Franklin Lake Playa. The possibility that these deposits could be transported by eolian processes to the RMEI location was considered in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 5.2.2). In this scenario, silt- and clay-sized particles are carried as suspended load during large floods from the Fortymile Wash drainage basin into the Amargosa River. The primary location for silt and clay deposition from Fortymile Wash is Franklin Lake Playa, which is about 30 km south of the RMEI location. Silt accumulation rates near Franklin Lake Playa have been observed to decrease rapidly with distance from playa sources. The thickness of eolian deposits on divides 1 to 2 km downwind of Franklin Lake Playa were found to be 0.5 to 3.0 cm on early Holocene to late Pleistocene surfaces. This implies a deposition rate of approximately 1 cm in 10,000 years, which can be considered to be a maximum value for eolian deposition from a localized source in this region. In the event of a volcanic eruption at Yucca Mountain, fines redistributed from Franklin Lake Playa will require longer transport distances of approximately 20 km or greater to reach the RMEI location and will entrain clean material along the way, resulting in an overall dilution effect of material deposited at the RMEI location. For this reason, eolian transport from Franklin Lake Playa was excluded from the TSPA volcanic eruption modeling case.

1.5 SUMMARY

Four potential pathways for eolian transport of contaminated tephra to the RMEI area are identified in *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007a, Section 5.2.2). Two of these transport processes are accounted for in the TSPA volcanic eruption modeling case, and two are considered to have negligible effect and are consequently neglected. Consideration of resuspension of contaminated tephra locally at the RMEI location due to wind and other processes is included in the model through BDCFs in the biosphere submodel. Eolian redistribution of contaminated tephra from the north in Fortymile Wash basin to the RMEI location is neglected because wind data, including data presented in *Regional and Local Wind Patterns Near Yucca Mountain* (CRWMS M&O 1997), indicates that higher velocity winds in the area are from south to north. This would likely result in a net reduction of concentration at the RMEI location. The effect of eolian redistribution of tephra from the channels to the divides at the RMEI location is included by increasing the fraction of area comprised of active channels, F. Eolian redistribution from the south in the Franklin Lake Playa area to the RMEI location is excluded based on the extended transport distance compared to observed transport distances from the Franklin Lake Playa, as well as the dilution effect resulting from entrained uncontaminated material during transport.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

CRWMS M&O 1997. *Regional and Local Wind Patterns Near Yucca Mountain.* B00000000-01717-5705-00081 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980204.0319.

SNL (Sandia National Laboratories) 2007a. *Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada.* MDL-MGR-GS-000006 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071220.0004; LLR.20080423.0011.

SNL 2007b. *Biosphere Model Report.* MDL-MGR-MD-000001 REV 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070830.0007; LLR.20080328.0002.