flow rate. The model also accounted for parameter uncertainty and spatial variability, and effects caused by such things as drift degradation and the presence of rock bolts.

- Chemical environment models represented the chemistry of seepage water that would move into the drifts as well as the composition of the gas phase in the drifts. Water and gas compositions would be affected by the heat generated by the emplaced waste. The chemistry of the water and gas, which would evolve over time, would affect the potential for *corrosion* of the waste packages and the mobility of radionuclides released from degraded packages.

- An Engineered Barrier System radionuclide transport abstraction model determined the rate of radionuclide releases from the Engineered Barrier System to the unsaturated zone. This conceptual model consisted of a flow model and a transport model (DIRS 177407-SNL 2007, p. 1-1). Input to the flow model included the seepage flux into the drift and the model defined pathways for water flow in the Engineered Barrier System. As described in the Repository SEIS (DIRS 180751-DOE 2008, pp. F-13 and F-14), this flow model addressed eight pathways by which water could move through the drifts, going around or through the drip shields, waste packages, and inverts to the unsaturated zone below the repository. The transport model considered both advective and diffusive transport of radionuclides from a breached waste package and included colloid-facilitated transport (DIRS 177407-SNL 2007, p. 1-1).

There are a number of other models associated with the repository zone and with the behavior of the components of the associated Engineered Barrier System. These included models to address the degradation of waste packages and drip shields over time, as well as the degradation and mobilization of the waste form within the waste packages.

The final element of this discussion is the unsaturated zone transport model, which DOE used to represent the movement of released contaminants from the repository level down to the water table. This model incorporated the flow fields from the unsaturated zone flow model and considered flow through welded and nonwelded tuff and through fractures and the rock matrix. It also accounted for some regions having zeolitic tuffs, which have low permeability and enhanced radionuclide absorption. The model addressed the transport of dissolved species and of colloids, the small particles that can remain suspended in groundwater for indefinite periods and to which radionuclides could sorb.

As described in the Repository SEIS (DIRS 180751-DOE 2008, pp. F-18 and F-19), the five basic processes that would affect the movement of dissolved or colloidal radionuclides, and which are represented in the unsaturated zone transport model, are described as follows:

1. Water flux and advection. The radionuclides are carried along with the water moving through the unsaturated zone. The total water flux and the amount of water moving relatively fast through fractures are significant factors in this transport process.

2. Matrix diffusion. This is the exchange of solute mass (the dissolved radionuclides) between fluid in the fractures and fluid in the rock matrix. Water movement is generally much slower in the matrix than in the fractures and there is more rock surface available for *sorption*. As a result, for water moving through the rock matrix, diffusion can be an efficient retarding mechanism.

3. Sorption. This is the process by which radionuclides are sorbed onto the rock. The various radionuclides have different retardation characteristics; that is, some are sorbed more readily than others. If there is significant matrix diffusion or flow into the rock matrix from the fractures, then there can be significant retardation in the movement of specific radionuclides.

4. Colloidal Transport. Several specific radionuclides could move as, or sorbed onto, colloidal particles. The transport model addresses this mechanism as well as retardation of colloids at fracture-rock matrix interfaces.

5. Radioactive *decay* and ingrowth. As radionuclides move along flow paths in the unsaturated zone, they would decay, and in some cases the decay would be into other radionuclides of potential concern (ingrowth). The model included decay and ingrowth processes for dissolved and colloidal radionuclides.

The output from the unsaturated zone radionuclide transport model provided the rate and spatial distribution of radionuclide releases, which was then the input to the saturated zone flow and transport model.

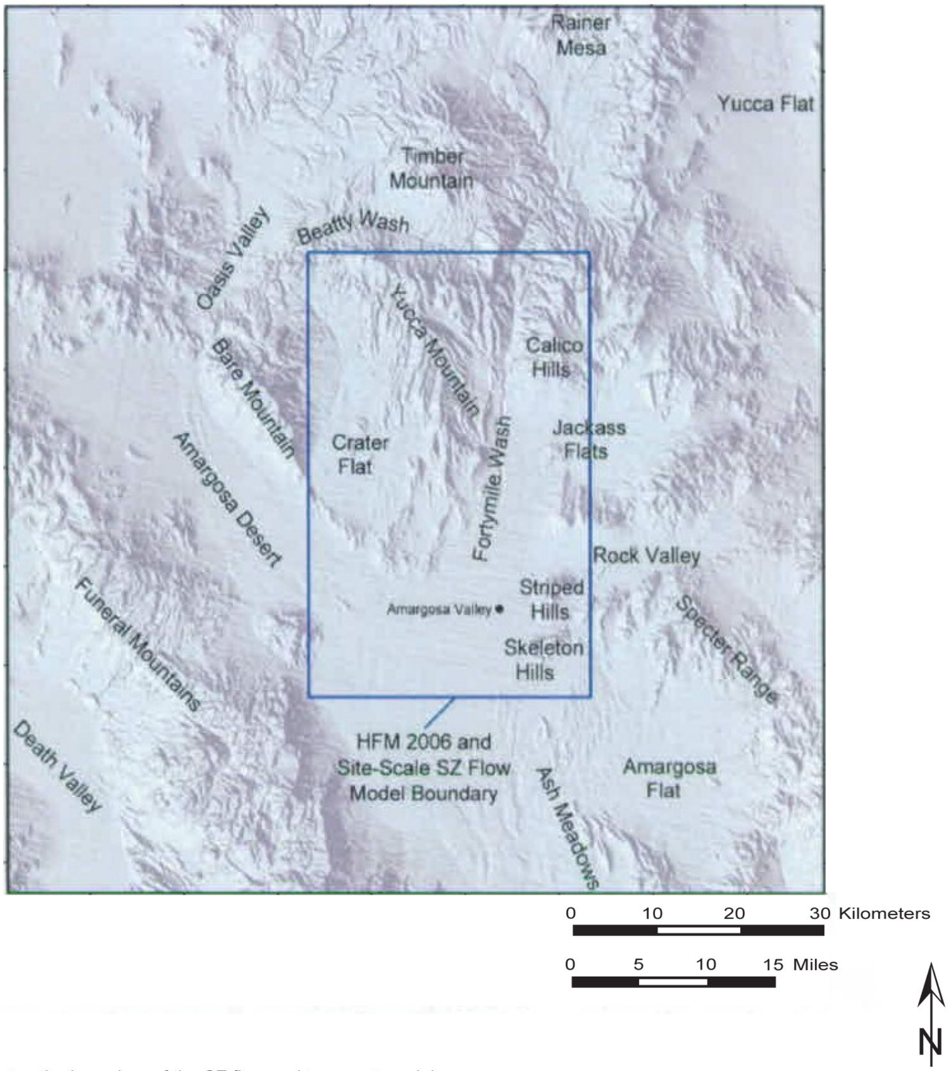
2.4.2 GROUNDWATER MOVEMENT IN THE SATURATED ZONE

The TSPA-LA modeled the flow of groundwater and the transport of radionuclides within the saturated zone from beneath Yucca Mountain. As with the movement of water and radionuclides in the unsaturated zone, the saturated zone involved both a flow model and a transport model.

DOE developed the site-scale saturated zone flow model to determine the groundwater flow field at Yucca Mountain. This model was designed to have an optimal size for being able to capture flow fields near Yucca Mountain and to assess groundwater flow at distances beyond (but close to) the RMEI location at 18 kilometers (11 miles) from the repository, while still being small enough to incorporate the necessary structural detail and have reasonable computational efficiency (DIRS 177391-SNL 2007, p. 6-3). Figure 2-7 shows the horizontal boundaries of the site-scale saturated zone flow model incorporated by the TSPA-LA. Also shown in the figure, for reference, are nearby surface features.

The site-scale saturated zone flow model received input from the unsaturated zone flow model (described above). The model incorporated geologic and hydrologic data collected from investigations in the Yucca Mountain area and used a three-dimensional numerical grid to describe flow in the saturated zone. The model included flow in the fractured volcanic rock in the areas near Yucca Mountain and in the alluvium of Amargosa Desert, as well as discrete flow features (for example, faults and high- and low-permeability regions) in the fractured tuff units that would affect transport of radionuclides. The calibrated flow field that the site-scale saturated zone flow model generated formed the basis for the site-scale saturated zone transport model (DIRS 180751-DOE, 2008, p. F-20).

The site-scale saturated zone transport model received input from the unsaturated zone transport model in the form of radionuclide mass fluxes at the water table beneath Yucca Mountain. Output from the model was also in the form of radionuclide mass fluxes, but these were at the location of the RMEI where they provided input to the biosphere model, which the next section addresses further. Simulating advection as the principal transport mechanism, DOE used the model to represent the transport of radionuclides, both



Note: The square indicates the boundary of the SZ flow and transport models.

HFM = Hydrogeologic Framework Model; SZ = saturated zone; UTM = Universal Transverse Mercator

Source: Modified from DIRS 177391-SNL 2007, Figure 6-1, p. 6-4.
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Figure 2-7. Boundaries of the site-scale saturated zone flow model and nearby surface features.

dissolved and sorbed onto colloids, along the groundwater flow path from beneath Yucca Mountain to the southeast, then to the south toward the Amargosa Desert. The model also accounted for the water-rock and water-soil interactions along the flow path. The saturated zone transport model represented transport in the volcanic rock by including flow and advective transport in the fractures and diffusive transport between the fractures and the surrounding rock matrix, where water moves more slowly. Flow at greater distances from Yucca Mountain is primarily through the basin-fill (alluvial) materials, and these were simulated as more uniformly porous materials. A three-dimensional particle-tracking model was the primary transport component of the saturated zone analysis. The particle-tracking model generated a library of breakthrough curves, which determined the timing for radionuclides reaching the accessible environment. During implementation of the TSPA-LA model, output from the unsaturated zone transport model, in the form of radionuclide mass fluxes, was combined with this library of breakthrough curves to determine the radionuclide mass fluxes at the location of the RMEI where they provided input to the biosphere model, which was developed, as described in Section 2.4.3, to generate estimates of annual radiation exposures, or doses, to the RMEI.

For purposes of the evaluations addressed by this Analysis of Postclosure Groundwater Impacts, it is important to understand that the site-scale saturated zone flow model (and the site-scale transport model) was designed to integrate with the Death Valley regional groundwater flow model, introduced in Section 2.1 above. DOE used the USGS's documentation of that model (DIRS 173179-Belcher 2004, all) as a primary source for describing the regional groundwater flow system. One of the reasons for developing the regional groundwater flow system model was to characterize the groundwater system in the vicinity of the proposed repository at Yucca Mountain and one of the ultimate objectives was to provide target boundary conditions for the site-scale saturated zone model (DIRS 173179-Belcher 2004, p. 7).

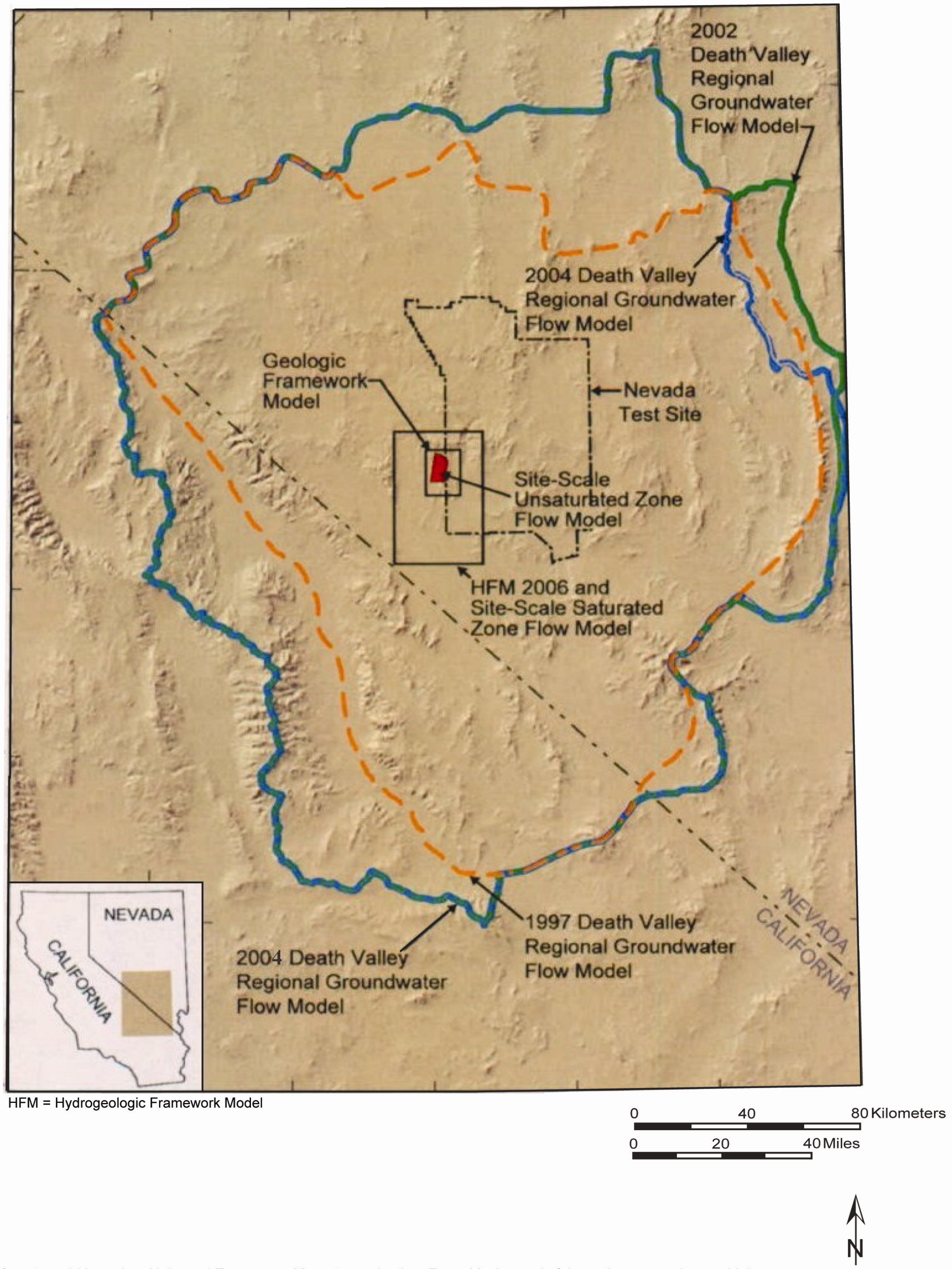
Correspondingly, DOE designed the site-scale model to mesh, or nest, within the larger regional model to take advantage of the great amount of regional geologic information. Figure 2-8 shows the domains, or boundaries, of the regional groundwater flow system model and those of the site-scale model inside the larger one. The figure also shows the domains of the site-scale geologic framework model (not discussed in this document) and the unsaturated zone flow model (Section 2.3.1.1).

The vertical scales of the regional groundwater flow system and site-scale models also closely match; both extend from the land surface down to a depth of 4,000 meters (13,000 feet) below sea level and, as applicable, incorporate the same hydrogeologic units (DIRS 177391-SNL 2007, p. 6-29). Examples of ways in which the site-scale flow model incorporated data from the regional groundwater flow system model include the following:

- The regional groundwater flow system model provided the volumetric and mass flow rates through the lateral boundaries of the site-scale model. Specifically, the cell-by-cell fluxes from the regional groundwater flow system model were set as the target values for boundary conditions during calibration of the site-scale model (DIRS 177391-SNL 2007, pp. 6-5 and 6-17).

- The regional groundwater flow system model, as well as other sources, provided the recharge to the site-scale flow model (DIRS 177391-SNL 2007, pp. 6-17 and 6-18).

This discussion of the manner in which the regional groundwater flow system and site-scale models were designed to be integrated and used together is provided as a background for evaluations described in Chapter 3. A primary objective of this Analysis of Postclosure Groundwater Impacts, as stated in the NRC staff Adoption Report, is the evaluation "of the impacts on soils and surface materials from the processes involved in surface discharges of contaminated groundwater." Considering the groundwater flow path from Yucca Mountain, the potential locations of surface discharges are beyond the southern boundary of the site-scale flow model used in the TSPA-LA. To perform this evaluation, the regional groundwater flow system model used output from the site-scale model to develop pathways farther to the south.



Notes: 50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Image is false-color composite combining LANDSAT 7 spectral bands 2, 5, and 7 on shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon. The figure's keystone shape reflects the spherical shape of the earth.

Source: Modified from DIRS 174109-SNL 2007, Figure 6-1, p. 6-11.
00250-S3_010.4.ai

Figure 2-8. Locations of the Death Valley regional groundwater flow system and site-scale saturated zone flow model domains.

2.4.3 GROUNDWATER USE AND EXPOSURES AT THE RMEI LOCATION

DOE used the saturated zone site-scale flow and transport models described in Section 2.4.2 to develop estimates of groundwater flux at the RMEI location and to determine the distribution of travel times for radionuclides released from the repository to reach the RMEI location. This section briefly describes how the TSPA-LA model then derived estimates of radioactive dose to a hypothetical individual at the RMEI location. Key elements of the TSPA-LA methodology included the manner in which the RMEI was defined and the manner in which that hypothetical individual would be exposed to contaminants in the groundwater moving beneath the RMEI location. This section discusses these elements in terms of the regulations developed by the EPA and the NRC to establish defining criteria for the RMEI and DOE's subsequent efforts to define specific exposure mechanisms within the framework set by NRC and EPA. DOE developed the biosphere model as part of the TSPA-LA model to characterize the exposure mechanisms and generate estimates of annual radiation exposures, or doses, to the RMEI. The biosphere model characterizes results of individual exposure mechanisms in terms of *biosphere dose conversion factors*, which are used to calculate doses.

In addition to being integrated with the saturated zone flow and transport models, the biosphere model was integrated with the volcanic eruption model used to simulate a volcanic eruption modeling case. The biosphere model was also used to calculate annual radiation exposures from this scenario, but this Analysis of Postclosure Groundwater Impacts does not address this portion of the model. It should also be noted that the biosphere model was not used to evaluate impacts from potential exposures to chemically toxic materials; rather, DOE used separate analyses to compare concentrations of these materials with available regulatory standards (DIRS 180751-DOE 2008, p. F-22).

2.4.3.1 Regulatory Structure of Exposure Scenario

DOE developed the exposure scenarios used to assess impacts to the RMEI in accordance with regulations that establish specific characteristics for that hypothetical individual. The EPA set public health and environmental standards for the proposed repository at Yucca Mountain in 40 CFR Part 197. The NRC is responsible for implementing the EPA standards and, as part of its role, the NRC issued corresponding, implementing regulations in 10 CFR Part 63. The primary requirements that define the RMEI are the following criteria [from 10 CFR 63.312(a)-(e)]:

a) Lives in the accessible environment at a location above the highest concentration of radionuclides in the plume of contamination [where the accessible environment is defined as any point outside the controlled area and the definition of controlled area includes locations no further south than 36° 40' 13.6661" North latitude, in the predominant direction of groundwater flow (10 CFR 63.302)];

b) Has a diet and living style representative of people currently living in Amargosa Valley;

c) Uses well water with average concentrations of radionuclides based on an annual water demand of 3,000 acre-feet;

d) Drinks 2 liters of water per day from the above well; and

e) Is an adult with metabolic and physiological considerations consistent with present knowledge.

With respect to item b above, both the EPA regulations and the implementing NRC regulations require that DOE determine the current diets and living styles based upon surveys of the people residing in the town of Amargosa Valley [40 CFR 21(b) and 10 CFR 63.312(b)]. DOE met this requirement by collecting dietary and lifestyle data in a 1997 survey that included adults living in Amargosa Valley. Of the 900 adults estimated to live in Amargosa Valley at the time of the survey, data from 187 respondents were included in the evaluations. The evaluations also incorporated data from the 2000 Census along with regional and national information on behavioral patterns, food intake, and potential exposure parameters (DIRS 172827-BSC 2005, pp. 4-1 to 4-9). DOE documented the results of the evaluations in *Characteristics of the Receptor for the Biosphere Model* (DIRS 172827-BSC 2005, all) and included estimates of activity distributions (for example, percent of time away, active outdoors, and asleep), consumption of locally produced food, and proportions of the representative population in various occupation categories. Parameters developed through this effort provided input to the biosphere model.

The EPA's public health and environmental standards for the repository establish a two-tiered compliance standard: one tier for the first 10,000 years after disposal and the other tier for the period from 10,000 to 1,000,000 years [40 CFR 197.20(a)]. The 1 million years after disposal is termed the period of *geologic stability*. The characteristics of the RMEI remain the same for both compliance periods. The EPA regulations specify that DOE may not assume that future geologic, hydrologic, and climate conditions will be the same as they are at present, but that "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge to technology" during the period of geologic stability (40 CFR 197.15). Holding societal and biosphere conditions constant during the entire 1-million-year performance period was a result of recommendations from the National Academy of Sciences to use biosphere assumptions that reflect current technologies and living patterns because of the unlimited possible future states of society. As described in the preamble to EPA's final rule of June 13, 2001 (66 FR 32074), "we *(EPA)* believe there may be an essentially unlimited number of predictions that could be made about future human societies, with an unlimited number of potential impacts on the significance of future risk and dose effects. Regulatory decision making involving many speculative scenarios for future societies and impacts would become extraordinarily difficult without any demonstrable improvement in public health and safety and should be avoided as much as possible."

2.4.3.2 Biosphere Dose Conversion Factors

Continuing to address the groundwater flow path as it was represented in the TSPA-LA model, DOE used the site-scale saturated zone flow and transport models to characterize movement of the simulated contamination plume to a point where the groundwater was accessible to inhabitants of the area. At the RMEI location, this would involve the use of one or more wells, and considering the diet and lifestyles of the residents of the town of Amargosa Valley, human exposures would result from using the contaminated groundwater for domestic and agricultural purposes. DOE developed the biosphere model, as described previously, to support calculation of estimated annual radiation doses to the RMEI from the use and consumption of this pumped groundwater.

Once radionuclides in the groundwater are brought to the surface, they would move through various environmental components of the biosphere and could result in dose to the RMEI through three exposure pathways: inhalation, ingestion, and external exposure. DOE addressed and modeled each of these exposure pathways using the diet, lifestyle, and other characteristics established for the hypothetical RMEI. The five environmental components, or submodels, considered in the groundwater exposure case of the biosphere model were soil, air, plant, animal, and fish (DIRS 183478-SNL 2008, pp. 6.3.11-3 and

6.3.11-4). The environmental transport processes explicitly included in the biosphere model are as follows (DIRS 183478-SNL 2008, pp. 6.3.11-4 and 6.3.11-5):

- Radionuclide accumulation in surface soil layers as a result of continuous long-term cultivation using contaminated water;
- Resuspension of contaminated soil;
- Radionuclide deposition on crop surfaces by dry processes (resuspension of contaminated soil and subsequent adhesion of soil particles onto vegetation surfaces);
- Radionuclide deposition on crop surfaces by interception of contaminated irrigation water;
- Removal of surface contamination by weathering processes;
- Translocation and retention of contaminants from the deposition site to the edible tissues of vegetation;
- Radionuclide uptake from soil by plants through the roots;
- Release of radionuclides in gaseous phases, radon-222 and carbon dioxide-14, from the soil into the air with subsequent inhalation;
- Photosynthesis by crops of carbon dioxide-14 from the atmosphere;
- Radionuclide intake from animals through consumption of contaminated feed, water, and soil, followed by transfer to animal products;
- Radionuclide transfer from water to air through use of evaporative coolers (a type of air conditioner); and
- Radionuclide transfer from water to fish.

The interrelationships among the identified transport pathways, environmental components (or media), and exposure pathways can be conceptualized, as shown in Figure 2-9.

DOE developed the biosphere model to generate a catalog of biosphere dose conversion factors. These conversion factors were generated in terms of dose per year to the RMEI per unit of *radioactivity* in a volume of groundwater (that is, concentration of radioactivity in the groundwater). In this manner, the TSPA-LA could generate an annual dose by applying the applicable biosphere dose conversion factors to the concentration of radionuclides estimated for the groundwater. Because the radionuclides have different radiological characteristics (they emit different types and levels of energy), the conversion factors are unique to a specific radionuclide, and the corresponding groundwater concentration to which they are applied also has to be radionuclide specific. For the groundwater scenario, the biosphere model developed conversion factors for 30 different radionuclides plus several decay products either considered separately or with their parent radionuclides (DIRS 177399-SNL 2007, pp. 6-13, 6-68 and 6-69).

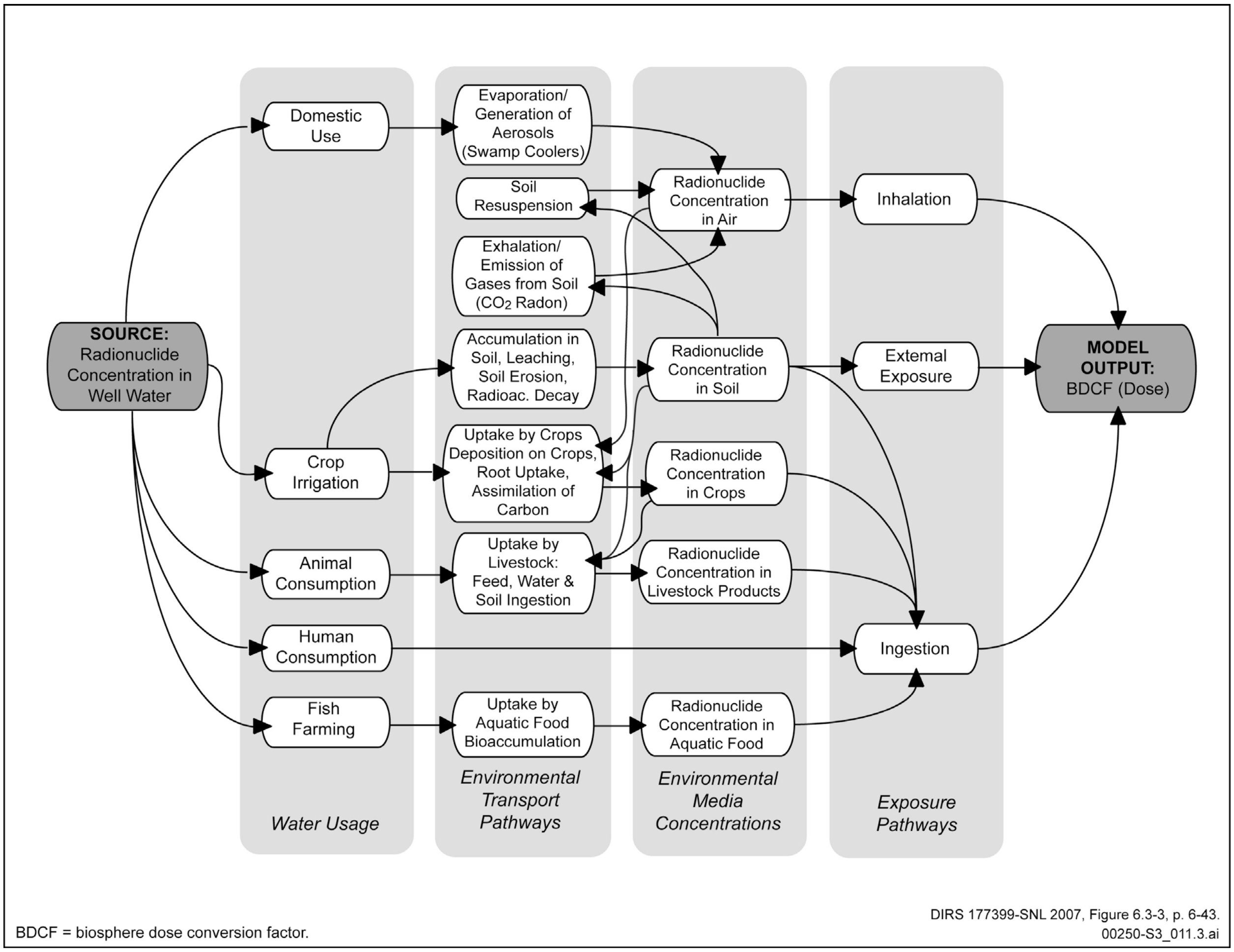


Figure 2-9. Conceptual representation of the biosphere model for the groundwater exposure scenario.

Table 2-5 provides an example of the exposure pathway contributions to an all-pathway biosphere dose conversion factor for one radionuclide, plutonium-239. The all-pathway biosphere dose conversion factor is the sum of the factors for the three exposure pathways: external, inhalation, and ingestion. The table describes the various parameters that contribute to each of the potential exposure pathways. As applicable, a pathway biosphere dose conversion factor is the sum of the contributing factors. The contributing dose conversion factors are additive because they each have a linear relationship with the radionuclide concentration in the groundwater. Not shown in the table is any indication of the numerous submodels developed to support each of the contributing groups and subgroups. The submodels incorporate a wide range of diet and lifestyle characteristics of the residents as well as exposure and dose relationships.

Development of the biosphere model included the calculation of biosphere dose conversion factors for different climates. As might be expected, groundwater use and resulting exposures vary with climate changes. For example, a wetter climate requires less irrigation and thus a lower concentration of radionuclides in fields due to use of less irrigation water. However, the biosphere dose conversion factors for the different climates ultimately were not used for the TSPA-LA. Because the present-day climate is characterized as the driest of any of the anticipated climates, it had the highest biosphere dose conversion factors. DOE used the present-day biosphere dose conversion factors for all of the climate scenarios to be conservative and to simplify the calculations.

Table 2-5. Summary of the elements contributing to an example (in this case for plutonium-239) all-pathway biosphere dose conversion factor.

Exposure pathway	Dose contributing parameters: Group	Dose contributing parameters: Subgroup	Example dose factors for one radionuclide – Pu-239 [in (mrem/yr)/(pCi/L)][a,b]: Contributor	Total
External				2.40×10^{-5}
	Environmental-specific exposure time (hours/day)	Active outdoors (0.45) Inactive outdoors (1.45) Active indoors (9.45) Asleep indoors (8.30) Away (4.35)		
Inhalation				1.95
	Inhalation dose, soil particles		1.31	
	Inhalation dose, evaporative cooler		6.37×10^{-1}	
Ingestion				7.85×10^{-1}
	Ingestion dose for water		6.78×10^{-1}	
	Ingestion dose for crops	Leafy vegetables	1.91×10^{-2}	
		Other vegetables	3.81×10^{-3}	
		Fruit	1.22×10^{-2}	
		Grain	1.54×10^{-3}	
	Ingestion dose for animal products	Meat	6.74×10^{-5}	
		Milk	2.57×10^{-6}	
		Poultry	1.01×10^{-5}	
		Eggs	1.80×10^{-4}	
	Ingestion dose for fish		3.64×10^{-2}	
	Ingestion dose for soil		3.26×10^{-2}	
All pathway dose conversion factor ($BDCF_{Pu-239}$)				2.73

Source: DIRS 177399-SNL 2007, pp. 6-261 to 6-264, Table 6.10-1.

a. The biosphere dose conversion factors shown here are in terms of dose in millirem per year per a unit groundwater concentration of pico-curries per liter. The biosphere model presents these values in terms of dose in sieverts per year (Sv/yr) per unit groundwater concentration of becquerels per cubic meter (Bq/m^3). The conversion was made by multiplying the (Sv/yr) per (Bq/m^3) units by 3.70×10^6.

b. The biosphere dose conversion factor values shown here were derived through a deterministic calculation to check the biosphere model. Actual output from the model (values used in calculation of dose impacts) is the result of stochastic calculations done to generate uncertainties associated with the ranges of values that could fit the various model parameters. For example, the mean all-pathway $BDCF_{Pu-239}$ from the model is $(3.54 \pm 1.25) \times 10^0$ (DIRS 177399-SNL 2007, p. 6-284) compared with the value at the bottom of the table. The plus or minus value (±1.25) represents the standard deviation of the values generated by the biosphere model.

BDCF = biosphere dose conversion factor.

mrem/yr = millirem per year.

pCi/L = picocuries per liter.

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177399	SNL 2007	SNL (Sandia National Laboratories) 2007. *Biosphere Model Report.* MDL-MGR-MD-000001 REV 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070830.0007; LLR.20080328.0002.
177407	SNL 2007	SNL (Sandia National Laboratories) 2007. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071004.0001; LLR.20080414.0023.
184614	SNL 2007	SNL (Sandia National Laboratories) 2007. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006 REV 03 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080108.0003; DOC.20080114.0001; LLR.20080414.0007; LLR.20080414.0033; LLR.20080522.0086; DOC.20090330.0026.
183478	SNL 2008	SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001.
186186	SNL 2009	SNL (Sandia National Laboratories) 2009. *Inputs to Jason Associates Corporation in Support of the Postclosure Repository Supplemental Environmental Impact Statement (SEIS-3).* LSA-AR-037. Las Vegas, Nevada: Sandia National Laboratories.
186145	Taylor 2008	Taylor, T. 2008. "State of Nevada Order 1197, Applications to Appropriate Additional Underground Water and any Application to Change the Point of Diversion of an Existing Ground-Water Right to Point of Diversion Closer to Devils Hole." Carson City, Nevada: State of Nevada, Office of the State Engineer. ACC: MOL.20090324.0118.
186227	USGS 2006	USGS (U.S. Geological Survey) 2006. Ground-Water Modeling of the Death Valley Region, Nevada and California. Fact Sheet 2006-3120. Henderson, Nevada: U.S. Geological Survey. ACC: MOL.20061218.0202.

186229	USGS 2009	USGS (U.S. Geological Survey) 2009. "Water Quality Samples for the Nation, Nevares Spring." Denver, Colorado: U.S. Geological Survey. Accessed April 8, 2009. ACC: MOL.20090422.0063. URL: http://nwis.waterdata.usgs.gov/usa/nwis/qwdata
186230	USGS 2009	USGS (U.S. Geological Survey) 2009. "Water Quality Samples for the Nation, Navel Spring (DV-2)." Denver, Colorado: U.S. Geological Survey. Accessed April 8, 2009. ACC: MOL.20090422.0062. URL: http://nwis.waterdata.usgs.gov/usa/nwis/qwdata

3. ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

This chapter describes assessments and analysis of potential environmental impacts resulting from postclosure *repository* performance and its effect on the *groundwater* environment described in Chapter 2. The assessments focus on the effects of long-term transport of radiological and nonradiological contaminants. The analysis estimates flow and accumulation of contaminants throughout the *affected environment* for the *postclosure* period. Environmental impacts resulting from surface *discharges* of contaminated water (including impacts to groundwater quality), health and safety, and *biota* are assessed.

The *Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE/EIS-0250F-S1; DIRS 180751-DOE 2008, all) (Repository SEIS) analyzed the transport of *radionuclides* from the repository to the *Regulatory Compliance Point* south of the repository where a hypothetical *reasonably maximally exposed individual* (RMEI) used water from a hypothetical well. The Repository SEIS reported results of an assessment of the radiologic doses to the RMEI. That assessment was guided by U.S. Environmental Protection Agency (EPA) and U. S. Nuclear Regulatory Commission (NRC) regulations. Chapter 2, Section 2.4 of this document details the nature of the Repository SEIS radiological analysis. The Repository SEIS also assessed the release of *nonradiological contaminants*, transport to the Regulatory Compliance Point (the location of the RMEI), and impacts. The Repository SEIS analysis provided a qualitative evaluation of radiological and nonradiological impacts that might occur beyond the Regulatory Compliance Point.

REGULATORY COMPLIANCE POINT

This point is defined as the location over the highest concentration of contaminants in the plume as required by the U.S. Nuclear Regulatory Commission at 10 CFR 63.312(a). The TSPA-LA calculates radiologic dose to a reasonably maximally exposed individual located at a point on the Nevada Test Site boundary (36°40'13.66661" North Latitude) that is approximately 18 kilometers south of the repository. In this Analysis of Postclosure Groundwater Impacts, this location is referred to as the Regulatory Compliance Point.

The NRC staff identified a need for a more extensive description of the affected environment, assessment of the transport of *contaminants* throughout the affected environment beyond the Regulatory Compliance Point, and assessment of associated impacts (see Chapter 1).

The work described in this chapter responds to the NRC staff by performing the following analyses:

- Trace the release and movement of contaminants from the repository into the *aquifer* system up to and beyond the Regulatory Compliance Point, including releases at natural discharge sites. Assess the cumulative amounts entering and leaving the aquifer system and the accumulation within the system; and

- Assess the impacts resulting from the release, movement, and accumulation of contaminants throughout the region.

CONTAMINANTS

This Postclosure Groundwater SEIS discusses two types of contaminants: radiological contaminants (also referred to as radionuclides) and nonradiological contaminants (such as toxic metals with a nonradiological toxicity). When the word "contaminants" is used by itself, then the reference is to both types of contaminants.

The analyses discussed in this chapter followed these steps:

- Used a regional groundwater flow model to define the potential paths contaminants could take after exiting the repository, transporting to the Regulatory Compliance Point, and beyond into the region. This modeling also identified natural discharge points (DIRS 173179-Belcher et al. 2004, all; DIRS 177391-SNL 2007, all);

- Performed transport analyses of radionuclides starting with the release of radionuclides from the Regulatory Compliance Point as previously analyzed using the *Total System Performance Assessment Model/Analysis for the License Application* (DIRS 183478-SNL 2008, all; TSPA-LA) (see Chapter 2, Section 2.4);

- Performed the transport analyses of nonradiologic contaminants starting with the release of the contaminants at the *unsaturated zone-saturated zone* interface. DOE estimated release at the unsaturated zone-saturated zone interface using an extension of the bounding release calculations performed in the Repository SEIS (DIRS 180751-DOE 2008, Appendix F, Section F.4);

- Analyzed transport of contaminants along the flow paths developed from the *Death Valley regional groundwater flow model* to natural discharge or pumped withdrawal points;

- Analyzed doses and associated health effects from radiological contaminants;

- Analyzed human health impacts from nonradiologic contaminants at points where contaminants interact with the *biosphere* (that is, natural discharge and pumped withdrawal points);

- Analyzed soil concentrations of contaminants at natural discharge and pumped withdrawal sites; and

- Evaluated *processes* that could occur at the natural discharge sites.

3.1 Analytical Framework for the Analysis of Postclosure Groundwater Impacts

This section describes the development of an analytical framework for this Analysis of Postclosure Groundwater Impacts. DOE developed this framework based on variables or assumptions regarding the future in the region and results of the regional flow modeling.

3.1.1 CONSIDERATION OF UNCERTAINTIES ABOUT THE FUTURE

The analyses of postclosure groundwater impacts include the following assumptions:

- The current population and its distribution will continue for the period of *geologic stability* [1 million years, as prescribed by Title 40 of the Code of Federal Regulations (CFR), Part 197], and

- The current range of human activities will continue for the period of geologic stability.

The analyses use these two assumptions based on guidance in the EPA regulations (at 40 CFR 197.15) regarding avoidance of speculation about future populations and human activities. As described in the preamble to EPA's final rule of June 13, 2001 [Volume 66 of the *Federal Register* (FR) 32074], avoiding such speculation is recommended because the future is unknown and the analyses would be open to limitless possibilities. Consistent with the amended EPA regulations at 40 CFR Part 197 (73 FR 61256) and the amended NRC regulations at 10 CFR Part 63 (74 FR 10811), which incorporate the National Academy of Sciences guidance for the period of geologic stability, this Analysis of Postclosure Groundwater Impacts analyzes a 1-million-year postclosure period.

The other primary variables considered are:

- Future climate conditions, and
- Future groundwater withdrawals (pumping).

3.1.1.1 Future Climate Conditions

In its *U.S. Nuclear Regulatory Commission Staff's Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain* (NRC staff's Adoption Report), the NRC staff specifically mentioned that the requested analyses should be performed for the present and a future, wetter climate (DIRS 186113-NRC 2008, p. 3-12). Therefore, DOE analyzed two separate climate conditions: the present climate and a future, wetter climate. The wetter climate DOE considered for this Analysis of Postclosure Groundwater Impacts is the same as the post-10,000-year climate used in the TSPA-LA. Chapter 2, Section 2.2 of this analysis, has a detailed discussion of past climates and their influence on regional *geohydrology*. The intent of the approach in this analysis is to bound the possibilities by offering results for a continued present day climate and a future, wetter climate.

In this Analysis of Postclosure Groundwater Impacts, DOE conducted the analysis with the climate constant for the entire 1-million-year postclosure period. The analysis was repeated for the present climate and the future, wetter climate. This analysis uses radionuclide *fluxes* derived from previous TSPA-LA model runs as input (for example the radionuclide fluxes at the Regulatory Compliance Point). When the TSPA-LA model produced these fluxes, it was run with four climate changes occurring during the 1-million-year period. The climate changes in the TSPA-LA are primarily drivers to the *infiltration* into the repository rather than regional transport. Reprogramming and rerunning the TSPA-LA twice with a fixed climate for 1-million years solely to match each of the climate assumptions in this document would be unnecessary for the following reasons: (1) it would input conservative results for the present climate scenario and (2) it would input essentially the same results for the wetter climate (the TSPA-LA maintained the present climate for only 600 years and then the climate became progressively wetter). This Analysis of Postclosure Groundwater Impacts used the TSPA-LA results as input to both the present and future, wetter climates for the regional analysis.

3.1.1.2 Future Groundwater Pumping

Groundwater pumping can lead to changes in the *hydraulic gradient*s and therefore alter the direction and rate of groundwater flow in the region. As is shown below, groundwater modeling demonstrates that different flow paths result from different *pumping scenarios*. This Analysis of Postclosure Groundwater Impacts used the TSPA-LA model to develop characteristics of the contaminant plume at the Regulatory Compliance Point. To evaluate the results of a range of pumping scenarios, DOE extended flow and transport simulations to areas physically beyond those addressed in the TSPA-LA model. DOE used output from the TSPA-LA model as input to the Death Valley regional groundwater flow system model to develop contaminant flow paths beyond the Regulatory Compliance Point.

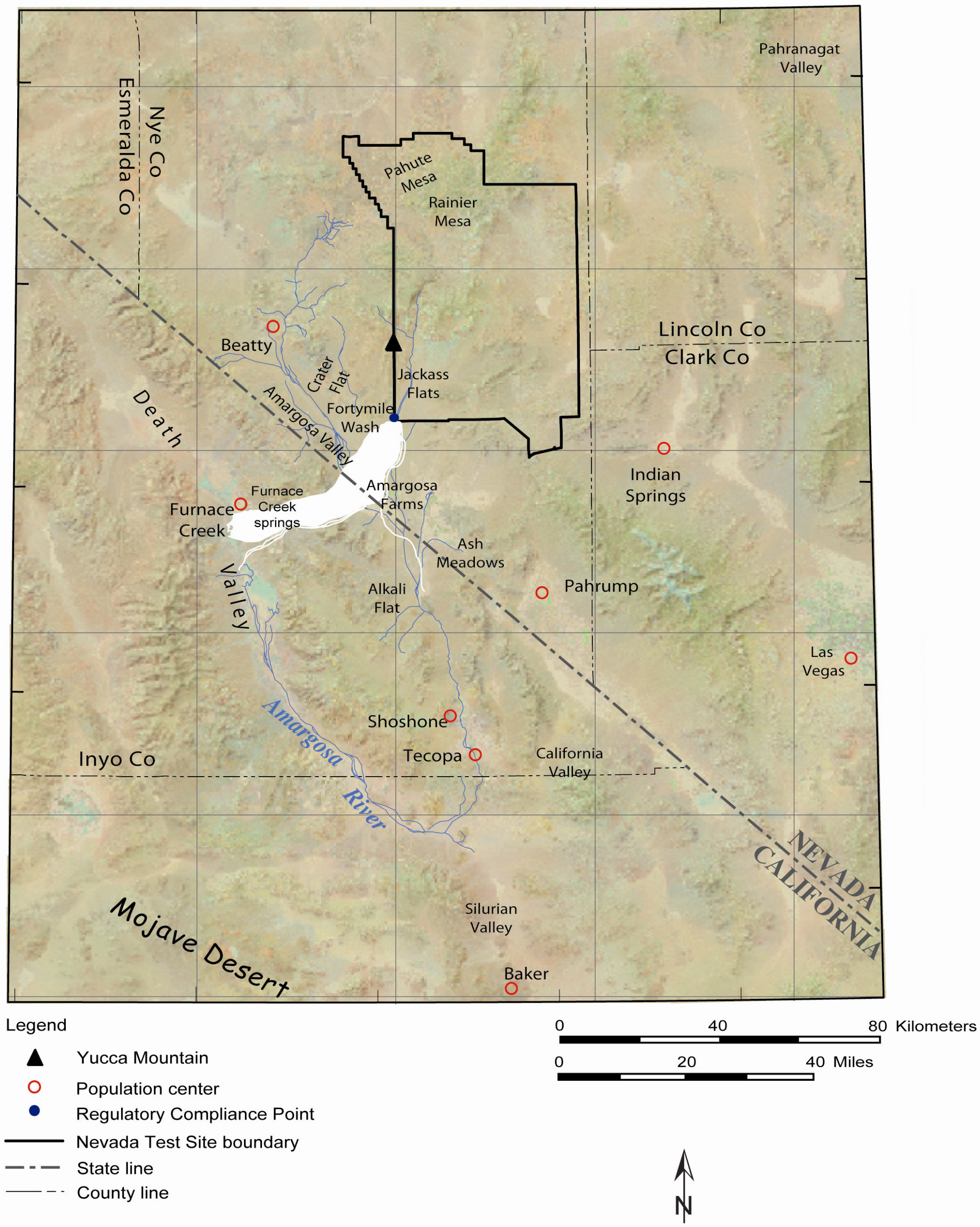
Both the site-scale saturated zone flow model and the Death Valley regional groundwater flow system model include particle-tracking capabilities. This allowed a simulation of adding particles to track where they would go as they moved with the groundwater (that is, assuming there is no *adsorption*, filtering, *decay*, or other mechanisms that would prohibit the particles from moving with the water). As Chapter 2 of this document explains, the site-scale saturated zone flow model only extends to the Amargosa Farms area (see Figure 2-8). The Death Valley regional groundwater flow system model extends farther south to encompass the entire Death Valley flow region. Therefore, the particle-tracking effort required the application of both models. DOE began with particle locations obtained from the site-scale saturated zone flow model as input to the Death Valley regional groundwater flow system model at the Regulatory Compliance Point. DOE then used the particle-tracking capabilities of the regional model to determine where those particles would move in the regional flow system. DOE repeated this process for two pumping scenarios to determine how the flow paths would change under differing conditions imposed on the model. The *no-pumping scenario* simulated conditions of the regional flow system before any significant groundwater pumping had started (or the equilibrium conditions if all pumping were to cease). The pumping scenario simulated *steady-state* conditions with 2003 groundwater pumping locations and rates reported by the U.S. Geological Survey (USGS; DIRS 185968-Moreo and Justet 2008, all) (see Chapter 2, Section 2.1.1.1.2 for a discussion of the choice of pumping rates). In the modeling, most of the pumping was at the Amargosa Farms area, which represents the majority of all the pumping in the region.

Under the no-pumping scenario (Figure 3-1), the model shows the particles initially traveling to the south from the Regulatory Compliance Point. Then essentially all of the particles flow to the west to exit the groundwater flow system at the *floor of Death Valley* in the Furnace Creek area on or near the saltpan at Middle Basin. There is a small particle trace that continues to the south to Alkali Flat. This track represents only 2 particles out of the total 8,024 particles. There is also a minor particle track near the west end of the main particle track extending farther south into Death Valley toward Badwater Basin. This track also represents 2 particles out of the 8,024.

Under the pumping scenario (Figure 3-2), no particles go farther than the central portion of the Amargosa Desert. The model indicates that the groundwater pumping in the Amargosa Farms area draws in all the particles.

The endpoints of the groundwater flow pathways in Figures 3-1 and 3-2 represent the range of locations where contaminants could be released from the proposed repository under present climate conditions. Under future, wetter climates, these flow paths would still be followed because studies have shown that the same paths are followed under wetter climates (DIRS 185814-DOE 2008, Section 2.3.9). However, as Chapter 2, Section 2.2.2 of this document describes, higher groundwater levels under wetter and cooler conditions could result in groundwater discharge locations closer to the boundary of the *accessible environment* than would occur under present-day conditions (see Section 3.2.1.8 for an analysis of this situation).

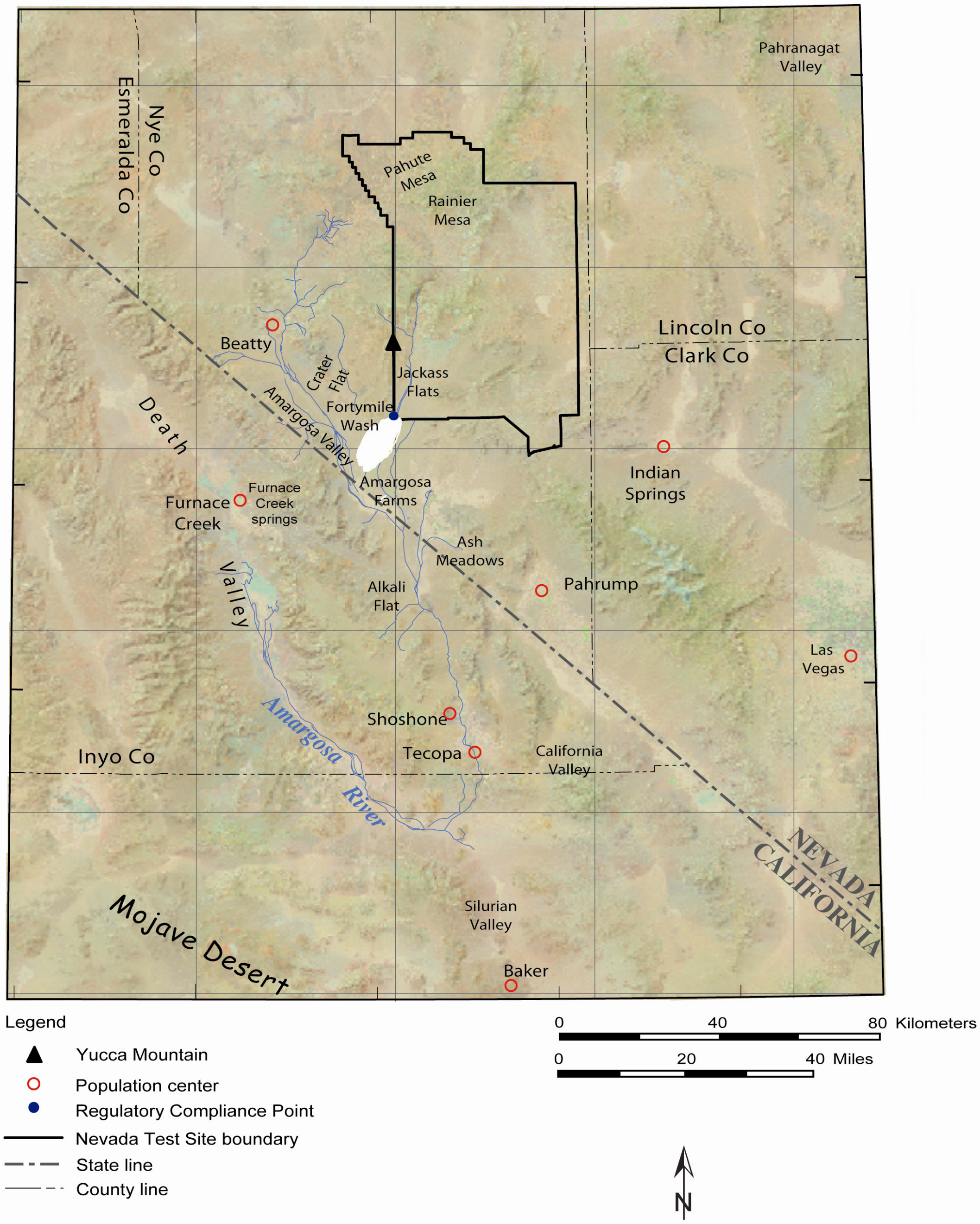
These particle-tracker results illustrate that an analytical framework that includes pumping and no-pumping scenarios would capture the range of potential impacts at both the groundwater pumping and natural discharge locations. The analysis therefore focused on the floor of Death Valley in the Furnace



Note: The white area represents the particle tracks from the regional flow modeling. The small tail that extends to Alkali Flat represents 2 of 8,024 particles. The small tail that goes farther south into Death Valley represents 2 of 8,024 particles. The figure's keystone shape reflects the spherical shape of the earth.

Source: DIRS 186186-SNL 2009, Fig. 11.
00250-S3_013.11.ai

Figure 3-1. Groundwater flow paths for the no-pumping scenario.



Notes: The white area represents the particle tracks from the regional flow modeling.
The figure's keystone shape reflects the spherical shape of the earth.

Source: DIRS 186186-SNL 2009, Fig. 13.
00250-S3_014.8.ai

Figure 3-2. Groundwater flow paths for the pumping scenario.

Creek area and Amargosa Farms area. Although the regional flow model predicts that natural discharge would exit the flow system through *evapotranspiration* from the alluvium on the floor of Death Valley at Middle Basin, DOE cannot preclude the possibility that contaminants could mix with carbonate waters and discharge at the springs in the Furnace Creek area. To evaluate the consequences of this possibility, DOE analyzed two scenarios for the discharge of contaminants in Death Valley: (1) that all discharge of contaminants would occur via evapotranspiration at the floor of Death Valley and (2) that all discharge of contaminants would occur at the springs in the Furnace Creek area. In addition, because the particle track analysis indicates that some particles could flow to Alkali Flat, DOE also assessed the possibility of discharges at that location.

Note that in the no-pumping scenario, natural discharges in Death Valley (Furnace Creek springs area and Middle Basin) and Alkali Flat are the only sources of potential exposure considered because DOE assumes groundwater pumping in Amargosa Desert would not occur in this scenario. Conversely, in the pumping scenario, use of groundwater in the Amargosa Farms area is the only source of potential exposure considered because particle-tracker results indicate that no particles would bypass the Amargosa Farms area. Although it is likely that future events would be a combination of these two scenarios, the analysis of the two extremes ensures this Analysis of Postclosure Groundwater Impacts does not underestimate the impacts at these locations.

3.1.2 FINAL SELECTION OF ANALYTICAL FRAMEWORK

The inputs required for the analysis of radiological contaminants involved outputs from the TSPA-LA model. In the Repository SEIS, DOE used the TSPA-LA model to analyze four scenario classes. For this Analysis of Postclosure Groundwater Impacts, the summation of fluxes from the Repository SEIS combined case were used as the input. The combined scenario case included the following scenario classes:

- The Nominal Scenario Class: undisturbed case where normal degradation processes, such as *corrosion* of *waste packages*, proceed over time and result in releases;
- Early Failure Scenario Class: failure of *drip shields* or waste packages caused by manufacturing defects;
- Igneous Scenario Class: events and processes initiated by eruption through the repository or intrusion of igneous material into the repository; and
- Seismic Scenario Class: events and processes initiated by ground motion or fault displacement.

DOE used the radiological release results from this combined case as input for this Analysis of Postclosure Groundwater Impacts.

The estimated waste package failures in the combined scenario were used to develop the release rates for the nonradiological contaminants, which were then used as input to the transport analysis for those contaminants (see Section 3.2.1.3).

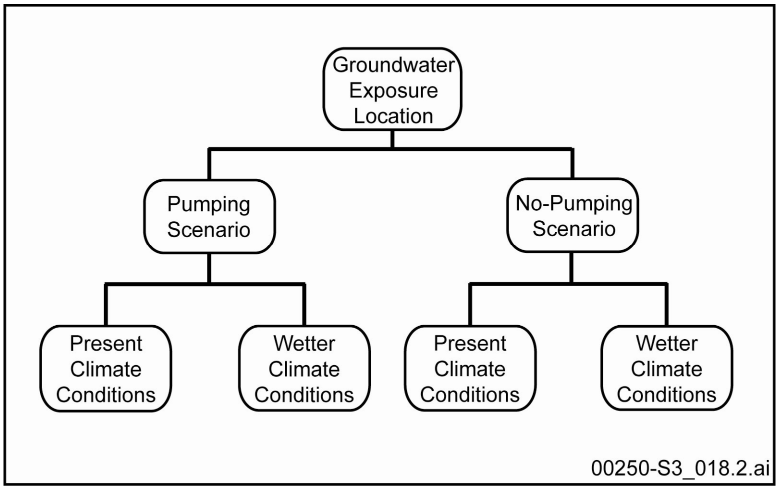


Figure 3-3. Analytical framework for each potential groundwater exposure location.

Considering the treatment of uncertainties discussed in the previous section and the potential exposure pathways, Figure 3-3 illustrates the analytical framework for analysis of all of the contaminants.

There would be no contaminants at the natural discharge locations for the pumping scenario and no contaminants at the Amargosa Farms area (the site of the predominant groundwater withdrawals under the pumping scenario) under the no-pumping scenario.

The list of analytical constructs that provide the expected range of potential impacts is:

- Path to the Amargosa Farms area, pumping, present climate
- Path to the Amargosa Farms area, pumping, wetter climate
- Path to the Furnace Creek springs area, no-pumping, present climate
- Path to the Furnace Creek springs area, no-pumping, wetter climate
- Path to the *Death Valley floor* (Middle Basin), no-pumping, present climate
- Path to the Death Valley floor (Middle Basin), no-pumping, wetter climate.

Note that full results were not developed for Alkali Flat; Section 3.3.1 below includes a discussion for purposes of comparing the results for Middle Basin.

As mentioned above, DOE analyzed this framework for a 1-million-year postclosure period (Section 3.3). Section 3.3 also provides results for a 10,000-year period to allow comparison with results provided in the Repository SEIS for 10,000 years after *closure* at the Regulatory Compliance Point.

3.2 Analysis Methods

This section discusses the methods used in the analysis, the flow of data between the various types of models, and some of the inherent conservatisms in the approach.

3.2.1 DESCRIPTION OF METHODS

This section summarizes the methods used in this Analysis of Postclosure Groundwater Impacts long-term performance analysis. Appendix B has more detailed descriptions of the conceptual and numerical models. Figure 3-4 diagrams the interrelationships of the models/techniques used in the analysis. Section 3.1.1.2 discusses how DOE used the Death Valley regional groundwater flow system model to identify and quantify flow paths. The following sections discuss the remainder of the elements in Figure 3-4.

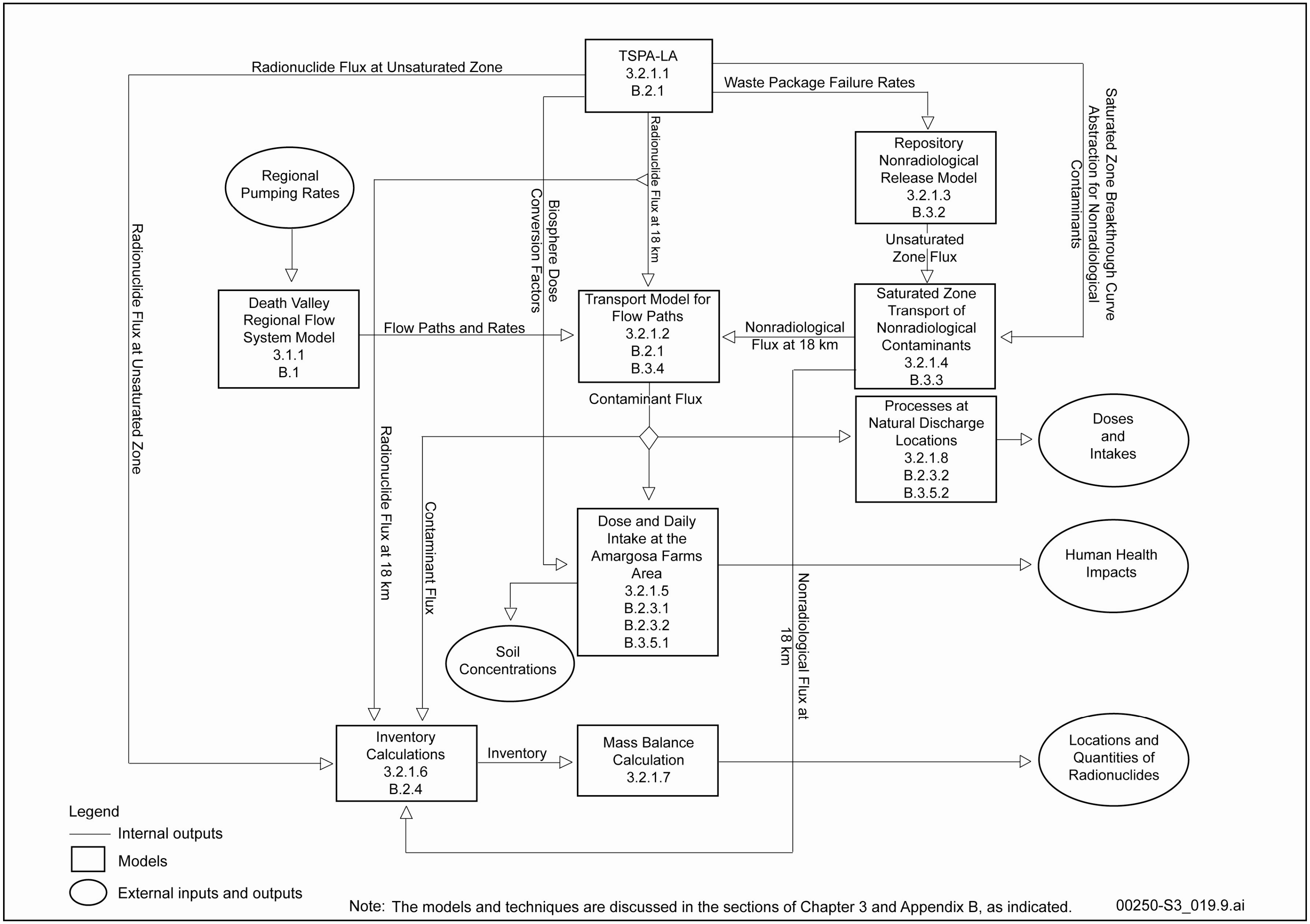


Figure 3-4. Diagram of the interrelationships of the models/techniques used in this Analysis of Postclosure Groundwater Impacts.

3.2.1.1 TSPA-LA

Chapter 2, Section 2.4 provides a summary of the TSPA-LA, its objectives, and how DOE applied it to the Repository SEIS. The analysis of postclosure groundwater impacts used five types of output from the TSPA-LA, as follows:

1. Radionuclide flux at the unsaturated zone-saturated zone interface,
2. Radionuclide flux at the 18-kilometer Regulatory Compliance Point,
3. Saturated zone breakthrough curves,
4. Waste package failure rates for the combined case, and
5. *Biosphere dose conversion factors*.

The primary type of outputs used from the TSPA-LA were the sets of mass release rates (fluxes) at the unsaturated zone-saturated zone interface under the repository and at the saturated zone at the Regulatory Compliance Point. The fluxes at the Regulatory Compliance Point were the primary input to the radionuclide transport modeling in the region beyond the Regulatory Compliance Point. The other outputs relate to uses by other analysis components (from Figure 3-4) and are discussed below with those components.

3.2.1.2 Transport Model for Flow Paths

The transport model used a one-dimensional pipe model with *longitudinal dispersion* (mixing) and equilibrium adsorption of dissolved contaminants on surfaces of a porous solid contained within the pipe. DOE assumes the pipe contains the entire plume (that is, all of the mass flux) moving in a certain direction. This pipe concept is appropriate for modeling the transport along the paths because there would be little horizontal or vertical mixing (dispersivity) in the aquifer and along the flow paths (DIRS 184806-SNL 2008, p. 4-13). This model took the contaminant flux at the Regulatory Compliance Point as input and generated the flux at the output of the pipe. For radionuclides, the TSPA-LA output provided the input flux. For this deterministic analysis, all cases used the *mean value* outputs from TSPA-LA. For nonradiological contaminants, DOE developed the input flux from the saturated zone transport model for nonradiological contaminants described below in Section 3.2.1.4.

3.2.1.3 Repository Nonradiological Release Model

Since the TSPA-LA model did not analyze the release of the nonradiological contaminants molybdenum, nickel, and vanadium, DOE developed a means for estimating the releases of these metals at the unsaturated zone-saturated zone interface (see Appendix B for a more detailed discussion on the choice of nonradiological contaminants for this analysis). DOE used a modified version of the bounding release analysis of these contaminants from the Repository SEIS (DIRS 180751-DOE 2008, Appendix F, Section F.4). Such an analysis was not needed for uranium, as uranium results are available directly from the TSPA-LA results by summing all uranium isotopes. The Repository SEIS analysis of nonradiological contaminants was for 10,000 years (before a significant number of packages would be expected to fail) and therefore did not consider potential releases of nonradiological contaminants from the inside of waste packages. Using package failure rates from the TSPA-LA model output enabled DOE to extend the release analysis to 1 million years and account for materials inside the packages. The output of the nonradiological contaminant release model was the mass flux of the nonradiological contaminants at the unsaturated zone-saturated zone interface, which became the input to the saturated zone transport model for nonradiological contaminants molybdenum, nickel, and vanadium.

3.2.1.4 Saturated Zone Transport of Nonradiological Contaminants

This model used breakthrough curves developed by running the TSPA-LA site-scale saturated zone transport model for species with transport properties equal to those of molybdenum, nickel, and vanadium to estimate the transport of nonradiological materials to the Regulatory Compliance Point. The fluxes developed as output were then the input to the transport model described above in Section 3.2.1.3, which then produced the fluxes of nonradiological contaminants at the potential exposure locations.

3.2.1.5 Dose and Daily Intake at Amargosa Farms

The radiological dose and nonradiological daily intake calculations used the fluxes at the Amargosa Farms area as input and generated human health impacts and soil concentrations. If water was to be pumped at high rates from a large number of widely distributed wells (unlike the limited water use from a single or a small number of hypothetical wells at the RMEI location), the contaminants distributed over the irrigated fields would tend to percolate back into the groundwater system where they could be recaptured by the wells. DOE developed well water concentrations of contaminants using a special case of the *Irrigation Recycle Model* (DIRS 182130-SNL 2007, p. 7-1). The special-case version of the *Irrigation Recycle Model* is one in which there is no decay or *sorption* of the contaminants. This provides a very conservative result because it does not include holdup of contaminants and decay of radionuclides in the soil column after they have infiltrated back into the aquifer. The special-case model generates water concentration as a function of input mass flux, pumping rate, and two fractions: (1) the fraction of contaminants recycled (not lost outside of the irrigation system) and (2) the fraction of contaminants recaptured by the wells. DOE conservatively assumed the recapture fraction to be 1 (meaning that all of the contaminants would be recaptured by the well). DOE developed the recycle fraction from consideration of usage of the pumped water (irrigation versus other uses) and consideration of diversion of some contaminants from being reintroduced into the soil. The value developed for the recycle fraction was 0.86, as further detailed in Appendix B, Section B.2.3.1.

The biosphere dose conversion factors for the TSPA-LA were developed based upon the characteristics of agricultural production in Amargosa Valley and the behaviors and lifestyle of the residents of that area. Thus, as appropriate, DOE calculated doses at the Amargosa Farms area using those biosphere dose conversion factors (see Chapter 2, Section 2.4.3.2). DOE also calculated daily intakes of nonradiological contaminants for a 70-kilogram person, drinking 2 liters of water per day (see Section 3.3.2 for more details).

3.2.1.6 Inventory Calculations

The mass flux of contaminants resulted in an inventory at each location analyzed in the transport analysis. This inventory was a decay- and growth-adjusted measure of the total amount of material arriving at the specific location as a function of time. DOE calculated the inventory for a contaminant from the flux by integrating the flux as a function of time as modified for radionuclides by decay of each radionuclide and growth equations for the radionuclide chains. This decay/growth-adjusted time integral of the flux-time curve is a quantitative measurement of the cumulative release of material adjusted for decay and growth at a specific location at specific times during the 1-million-year period.

3.2.1.7 Mass Balance Calculation

DOE developed *mass balances* for contaminants using the inventories. For example, the amount of a radionuclide in the saturated zone path between the Regulatory Compliance Point and the Amargosa Farms area is the difference between the inventory released beyond that point and the inventory accumulated at the Amargosa Farms area. The mass balances provide an overall accounting of where contaminants have been transported and where they have accumulated.

3.2.1.8 Processes at Natural Discharge Locations

As identified in Section 3.1.1.2 under the no-pumping scenario, the regional flow model predicts that natural discharge would exit the flow system through evapotranspiration from the alluvium on the floor of Death Valley at Middle Basin. As previously mentioned, DOE cannot preclude the possibility that contaminants could mix with carbonate waters and discharge at the springs in the Furnace Creek area. Therefore, DOE analyzed both potential natural discharge locations.

3.2.1.8.1 *Furnace Creek Springs Area*

To calculate the annual dose resulting from the use of potentially contaminated water discharged from springs in the Furnace Creek area, DOE used the biosphere dose conversion factors developed for the TSPA-LA. Because there is no large-scale irrigation of agricultural fields in that area, the irrigation recycle model was not used to calculate radionuclide concentrations in the soil. The *receptors* considered for this analysis include full-time residents in the Furnace Creek area, such as local members of the Timbisha Shoshone Tribe and employees of the National Park Service. Those persons would receive external exposure from contaminants deposited in soil from spring flows or use of spring water for landscaping, and from inhalation and inadvertent ingestion of contaminated soil particles. They also could be exposed by drinking spring water or using that water in evaporative coolers in their residences and offices. The biosphere dose conversion factors developed for the TSPA-LA, and used in this analysis, include these pathways and were developed based on exposure rates for full-time residents of the Amargosa Farms area. Because there is little agricultural production or other local production of foodstuffs in the Furnace Creek area, DOE did not include food ingestion pathways in the Furnace Creek springs analysis. This resulted in reductions of the biosphere dose conversion factors by 40 to 60 percent for the radionuclides that are the principal contributors to dose. Because the biosphere dose conversion factors were developed based on year-round exposure to soil and groundwater by residents, the calculated dose substantially overestimates the risk to visitors to Death Valley National Park or other non-residents in the area (see details in Appendix B, Section B.2.3.2.1).

3.2.1.8.2 *Middle Basin and Alkali Flat*

The Middle Basin at the Death Valley floor near the springs at Furnace Creek is a playa. The Franklin Lake Playa is a major feature at Alkali Flat.

Playas have been classified as wet playas and dry playas (DIRS 186240-Reynolds et al. 2007, p. 1811). Wet playas are characterized as having groundwater less than 5 meters below the surface. Middle Basin and Franklin Lake Playa currently are wet playas. In a wet playa, capillary action brings water to the surface, resulting in evaporation from the shallow groundwater. This action produces a soft surface of *evaporite* minerals that are typically rich in minerals such as calcium carbonate, hydrated calcium sulfate, sodium chloride (common salt), and sodium sulfate. The deposits originate from the total-dissolved-solids in the groundwater and are found in the capillary fringe area and on the surface. Often the deposits are described as "fluffy" with large pore space and low density (DIRS 186240-Reynolds et al. 2007, p. 1812). As the evaporite mineral crystals form, they displace the rock-derived *clastic* minerals, expanding the sediments upward (DIRS 186240-Reynolds et al. 2007, p. 1812). Sometimes a more compact, but still *friable*, material forms, which contains a lower fraction of evaporites. These deposits are associated with lower rates of evaporation or lower salinity in the groundwater.

At times, durable, wind-resistant crusts of evaporite minerals can form a protective layer about 1 centimeter thick on top of unconsolidated and dry, fine-grained sediment that might be as much as 10 centimeters thick. Breaking this crust can release material that is easily carried by the wind (DIRS 186240-Reynolds et al. 2007, p. 1823). It has been observed that changes occur in evaporite sediments due to wind deflation, rainfall events, and water table fluctuations (DIRS 186240-Reynolds et al. 2007, p. 1816). Thus, the deposits may take on many forms; some very susceptible to resuspension and some not.

If radiological and nonradiological contaminants from a repository at Yucca Mountain were transported to Middle Basin, they would occur as trace amounts in the dissolved solids. As the surface evaporite minerals form, trace contaminants (such as radionuclides or other nonradiological contaminants) would also precipitate. There is no mechanism for preferential precipitation, so the ratio of trace contaminants to evaporites is reflective of the ratio or concentration of trace contaminants to concentration of all dissolved minerals in the groundwater that is evaporating. Based on this principle, DOE estimated the concentration of contaminants in the evaporite minerals (see Appendix B, Section B.2.3.2.2). DOE assumed that the surface materials would be made up entirely of these evaporite mineral deposits. This is a conservative assumption because rock-based clastic soils would make up some of the material and thus reduce the effective concentration of contaminants. Doses and intakes would be proportional to this concentration.

An additional potential natural discharge location under the future, wetter climate was identified in Chapter 2, Figure 2-5. The potential impacts at this location are discussed qualitatively in Section 3.3.5.

3.2.1.8.3 *Doses and Intakes at Wet Playas*

Estimates of doses and intakes at the floor of Death Valley (Middle Basin) were based on the scenario that the wet playa condition continues to exist for the entire analysis period. Occasional dust storms, rain storms, and runoff may alter the evaporite deposits, causing erosion, silt coverage, compaction, and consolidation. Some of these alterations would cause increased concentration of resuspended particulates in the air, while others, such as compaction and consolidation, would reduce air emissions. A relatively high annual average concentration of resuspended particles, associated with conducting activities outdoors while not significantly disturbing soil, was used in the analysis to account for these processes. Occasional flooding of the playa would reduce, if not eliminate, exposure to contaminants in the deposits. Any standing water or runoff water would be extremely brackish and non-potable; therefore, ingestion of this water would be unlikely and was not included. Most municipalities define potable water as having less than 250 milligrams per liter total-dissolved-solids. Brackish water is considered to have 500 to 3,000 milligrams per liter total-dissolved-solids, and saline water is classified as greater than 30,000 milligrams per liter total-dissolved-solids. At the Franklin Lake Playa (Alkali Flat), stagnant water has total-dissolved-solids of 70,000 to 80,000 milligrams per liter and drainage paths have water with total-dissolved-solids of 6,000 to 20,000 milligrams per liter (DIRS 186240-Reynolds et al. 2007, p. 1814).

Inhalation exposure may be eliminated during the wetter climate if the playa was covered by standing water.

The receptor that was considered for the Furnace Creek springs area [a full-time resident of Death Valley (see Section 3.2.1.8.1)], was also considered in the analysis of health impacts at Middle Basin from the deposition of contaminated evaporites on the soil surface. Three potential exposure pathways (external exposure to evaporite minerals, inhalation of resuspended evaporites, and ingestion of evaporites) were evaluated in the analysis. Ingestion of water, and other uses of contaminated water, was not included because it is more likely that residents would continue to rely upon water obtained from nearby, existing springs and wells than from any mineral-laden seeps or other standing water that may occur in the valley bottom. As described in Section 3.2.1.8.1, DOE included the exposure pathways of ingesting water from springs and using that water for other purposes (for example, evaporative cooling) in the calculation of impacts in the Furnace Creek springs area.

To calculate external exposure and inhalation exposure of contaminated evaporites, DOE assumed that the receptor would always be outdoors, where contaminants would be present, and that they would be engaged in activities that would not significantly resuspend soil. It was also assumed that all particulates inhaled and inadvertently ingested would be contaminated evaporites. Thus, the analysis very conservatively estimates exposure because it does not account for time spent indoors, where concentrations of resuspended particles would be lower and the receptor would be shielded from some radiation, or time spent away from the area of potential surface contamination. Because there are no residences and few other permanent facilities (such as parking lots, overlooks, and nature paths for tourists visiting Death Valley National Park) on or immediately adjacent to the saltpan at Middle Basin, it is likely that residents would spend substantially less time in areas directly contaminated by evapotranspiration of groundwater. In addition, contaminated evaporites would only be a portion of the total amount of particulates inhaled or inadvertently ingested, which is not discounted in the exposure estimates (see details in Appendix B, Section B.2.3.2.2).

The mass concentration of contaminants in the soil at the discharge site on the floor of Death Valley would not increase over time due to accumulation because contaminants would continue to precipitate along with the same or similar mass of other dissolved solids. Evaporite minerals deposited on the surface of wet playas in this region often are deflated, or eroded, by wind (Reynolds et al. 2007, pp. 1815 through 1820). Similarly, over time, contaminants and the evaporite minerals would be removed from the playa surface by *eolian processes* and dispersed over a large area within and surrounding Death Valley. The mass concentration of contaminants at those sites would be less than that on the floor of Death Valley (at Middle Basin) because the contaminants and associated evaporites would be mixed with uncontaminated, rock-based clastic soils and uncontaminated evaporites blown or washed in from other locations. Thus, even after many years of dispersal, the dose or intake at locations surrounding the playa where contaminants may be redeposited would be less than that estimated for Middle Basin on the floor of Death Valley.

3.2.2 CONSERVATISMS IN THE APPROACH

As mentioned previously, DOE selected the analytical framework developed for this Analysis of Postclosure Groundwater Impacts to provide the range of potential impacts at the groundwater exposure locations while considering the various uncertainties discussed in Section 3.1.1. Therefore, the following conservatisms were inherent in the analytical framework.

1. DOE developed an analytical framework based on a scenario that a relatively high rate of pumping would continue for 1 million years, regardless of climate or other factors. The long-term pumping would result in collection and recycling of all contaminants in one limited area. This scenario is very conservative for the estimates of potential impacts in the Amargosa Farms area.

2. *Glacial* climate conditions generally occur periodically in 10,000- to 100,000-year cycles (see Section 2.2.1.2.4). For example, very wet conditions are postulated to have occurred during the Illinoian glacial stage of about 140,000 to 170,000 years ago, and a full glacial wet condition is evidenced around 21,000 years ago (DIRS 120425-D'Agnese et al.1999, p. 4). These glacial conditions are characterized by significantly cooler and wetter climate conditions. Periodic glacial climate conditions would result in high *recharge* rates at the recharge areas and cause a general rise in the water table. The result would be increased discharge of surface water at locations where contaminants are released, which could dilute and disperse many of the contaminants over a very large area such that accumulation at natural discharge points would be unlikely over 1 million years.

3. DOE used present day discharge flow rates at natural discharge locations because there is no sure way to predict these flow rates when there is no pumping. Actual discharge rates presently observed were used at the Middle Basin (in this case evapotranspiration), the springs at Furnace Creek, and Alkali Flat (also an evapotranspiration site). Currently, there is regional pumping so these rates will not match what might be expected if there were no pumping. Thus, the flow rates are likely underestimated for the no-pumping scenario. While higher flows tend to move contaminants to the location faster, the *attenuating* effect of delay is not nearly as important in the calculation of the concentrations of radionuclides and other contaminants as dilution (especially for radionuclides with long half-lives, stable metals, and contaminants with low or zero *partition coefficients*). The results below show that higher flow rates at the natural discharge locations during the wetter climate result in lower doses even though more contaminants arrive earlier. Therefore, use of present day flow rates likely resulted in overestimation of doses at the natural discharge locations.

The techniques DOE used in this analysis were suitable for characterizing the regional releases and impacts identified by NRC staff. In such an approach, some specific details need not be included. For example, the interaction of contaminants with the solids (rocks and soils) through which the water flows is a very complex set of processes. The TSPA-LA model accounted for a wide variety of processes with a large body of research and computational complexity. The modeling with the Death Valley regional groundwater flow model accounted for heterogeneities in the flow system, and this was reflected in the transport analysis. Many other simplifications were used. Whenever simplifications were used, DOE applied them in a conservative manner to avoid underestimation of impacts. For example, when comprehensive knowledge of complexities of transport were not know, DOE selected partition coefficients with low values compared with literature values (especially for the nonradiological contaminants).

For this Analysis of Postclosure Groundwater Impacts, DOE used a fairly large time step in the flux-versus-time curves. To ensure conservatism, discrete steps were taken in such a way so that the stepped curve was generally higher and occurred sooner than the continuous flux curve being represented. This approach maximizes both the flux (during a period of rising flux) and the cumulative release.

The release rates for the nonradiological contaminants from the repository are conservative because DOE assumed that all surfaces are constantly corroding and in constant contact with water flowing through the repository. This is different from the seepage models in the TSPA-LA model, which estimate intermittent drips at various locations in the repository. The nonradiological contaminants release rate model also does not consider that all of the *Alloy 22* (the major source of molybdenum) is initially under drip shields, protected from infiltrating water.

The estimate of doses and intakes at Middle Basin on the Death Valley floor included the following conservatisms:

- In the estimate of concentration of contaminants in the solids, DOE used a low level of total-dissolved-solids found in local groundwater. Higher values of total-dissolved-solids would reduce the estimated concentration and therefore dose and intakes.

- In the calculation of exposure from inhalation of airborne particulates:

  - DOE assumed that all resuspended particulates that the receptor breathes in are evaporite minerals. Inclusion of rock-based clastic soils would reduce the estimated concentration and therefore doses and intakes;

  - DOE used the maximum value for the concentration of resuspended particles for the environment considered in the analysis;

  - DOE assumed that the receptor would inhale air containing the estimated concentration of contaminants for the entire year; and

  - The single value of breathing rate used ignores the fact that people spend 8 or so hours asleep when their breathing rate would drop by at least half the assumed value.

- For ingestion of contaminated soil:

  - DOE assumed that all material that is inadvertently ingested consists of evaporite minerals, and

  - The daily ingestion rate is relatively high at 100 milligram per day (for example, the EPA recommends 50 milligrams per day for adults and 100 milligrams per day for children (DIRS 152549-EPA 1997, Table 4-23).

- For external exposure to radionuclides in soil:

  - DOE used dose coefficients developed for soil contaminated to an infinite depth, although most evaporites would be on or near the soil surface. Dose coefficients for a lesser depth would be lower and would reduce the estimate of dose; and

  - DOE assumed that the receptor would be outdoors and exposed to contaminated evaporites year-round.

The above detailed summary shows that the analysis DOE carried out is, overall, very conservative so as not to underestimate impacts from the scenarios analyzed.

3.3 Results

This section describes the results of release and accumulation analyses. Section 3.1 describes the framework for the analysis and Section 3.2 describes the analytical method. Appendix B contains more details of the technical approach and the results.

3.3.1 RADIOLOGICAL CONTAMINANTS

DOE estimated dose as a function of time for the 1-million-year postclosure period. Table 3-1 summarizes the estimated peak annual doses during this time for the radiological contaminants. This table also gives the *probability* of a *latent cancer fatality* associated with these individual doses. As recommended by the Interagency Steering Committee on Radiation Standards, this Analysis of Postclosure Groundwater Impacts uses a conversion factor of 0.0006 probability of latent cancer fatality per rem of dose, for members of the public, to estimate the health effects of radiologic doses (DIRS 174559-Lawrence 2002, p. 2).

Table 3-1. Peak annual dose and probability of latent cancer fatalities for six exposure scenarios.

	Peak annual dose (millirem per year)		Probability of latent cancer fatality	
Scenario	10,000 years after closure	1,000,000 years after closure	10,000 years after closure	1,000,000 years after closure
Amargosa Farms area, pumping, present climate	2.1×10^{-1}	1.1	1.2×10^{-7}	6.7×10^{-7}
Amargosa Farms area, pumping, wetter climate	2.5×10^{-1}	1.3	1.5×10^{-7}	8.0×10^{-7}
Middle Basin, no-pumping, present climate	0.0	1.6×10^{-1}	0.0	9.5×10^{-8}
Middle Basin, no-pumping, wetter climate	1.5×10^{-2}	4.2×10^{-2}	8.9×10^{-9}	2.5×10^{-8}
Furnace Creek springs area, no-pumping, present climate	0.0	3.4×10^{-1}	0.0	2.1×10^{-7}
Furnace Creek springs area, no-pumping, wetter climate	2.3×10^{-2}	8.9×10^{-2}	1.4×10^{-8}	5.4×10^{-8}

As a point of comparison, the mean peak annual dose for 10,000 years after closure reported in the Repository SEIS for the RMEI at the Regulatory Compliance Point was 2.4×10^{-1} millirem per year, and the mean peak annual dose during 1 million years after closure was 2.0 millirem per year (DIRS 180751-DOE 2008, p. 5-27). Note that the Repository SEIS results during the 10,000-year dose were for a dry climate for the first 600 years and a progressively wetter climate for the remaining 9,400 years. The wetter climate result in this Analysis of Postclosure Groundwater Impacts at the Amargosa Farms area would tend to be somewhat higher because the wetter climate was imposed for the entire period. Also, the doses estimated at the Amargosa Farms area were based on recycling of contaminants back into the groundwater. A calculation of recycling for the RMEI location showed an 11-percent increase in dose when recycling was applied (DIRS 182130-SNL 2007, all). All of the doses in Table 3-1 are less than or about equal to the doses the TSPA-LA presented for the Regulatory Compliance Point. For further comparison, the regulations require that the mean RMEI annual dose be less than 15 millirem per year for the first 10,000 years and the mean RMEI peak annual dose be less than 100 millirem per year for 1 million years (10 CFR Part 63).

Figures 3-5 to 3-8 present the estimate of doses over time at the Amargosa Farms area, the Furnace Creek springs area, and the floor of Death Valley. Appendix B provides plots of dose contributions by individual radionuclides. The long-term risk to area residents and visitors to the *Death Valley region* from groundwater contamination would be very low based on the annual dose calculations presented above.

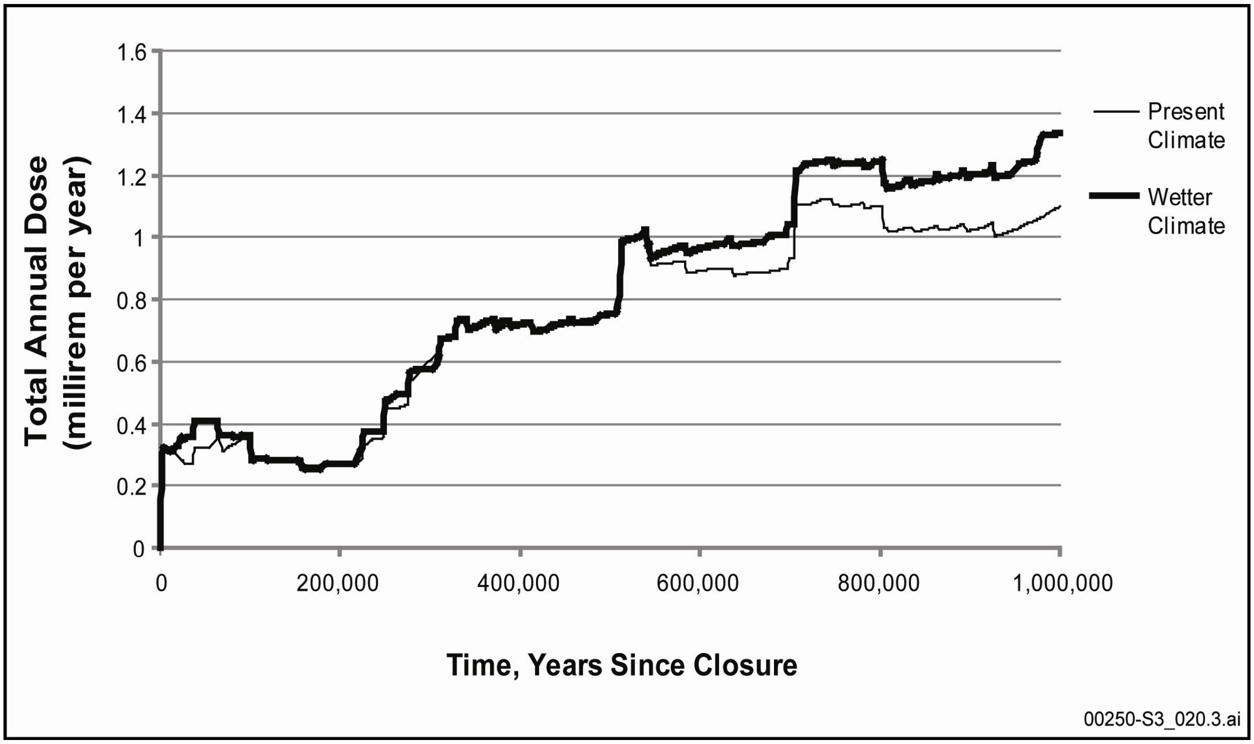


Figure 3-5. Total annual dose at the Amargosa Farms area.

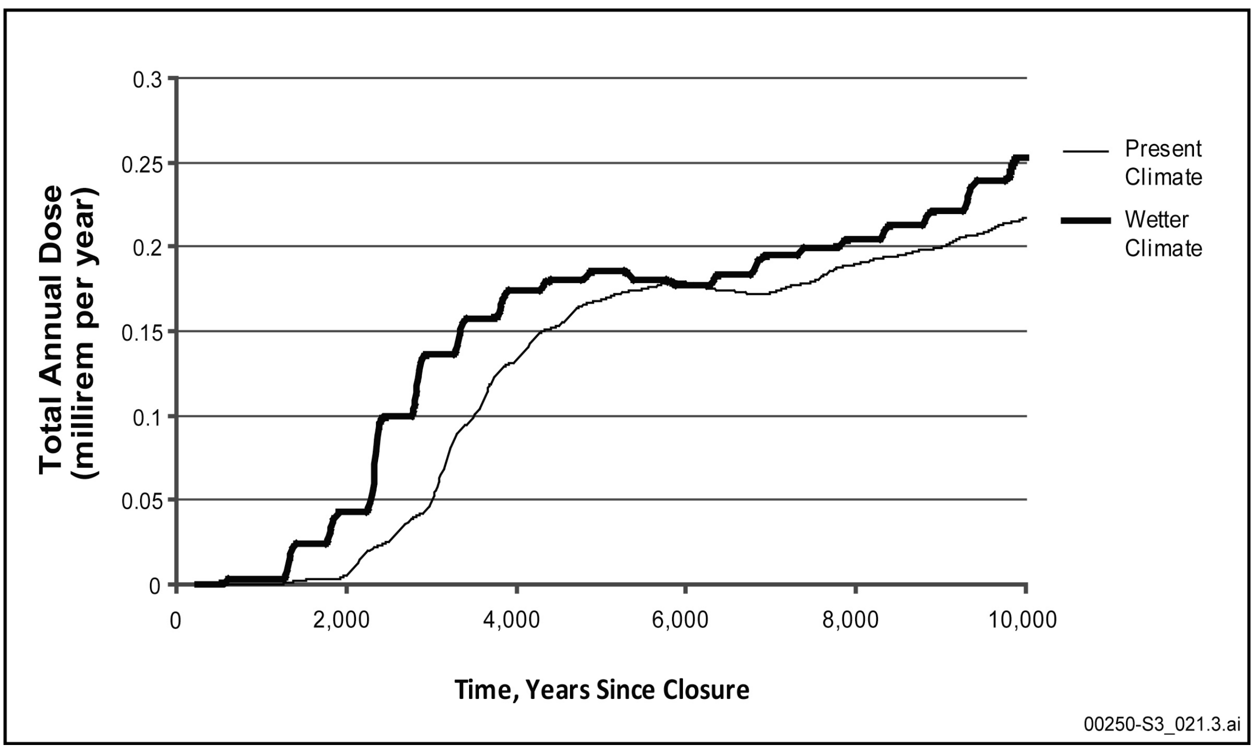


Figure 3-6. Total annual dose at the Amargosa Farms area for the first 10,000 years.

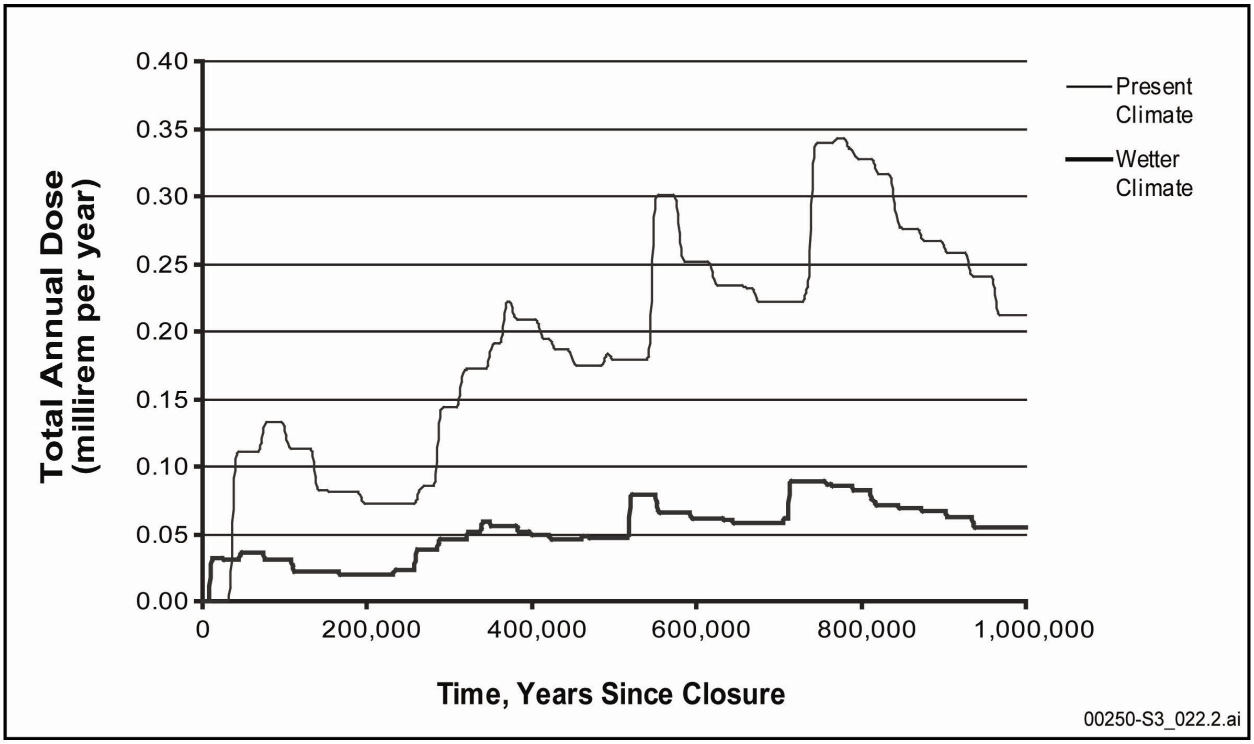


Figure 3-7. Total annual dose at the Furnace Creek springs area.

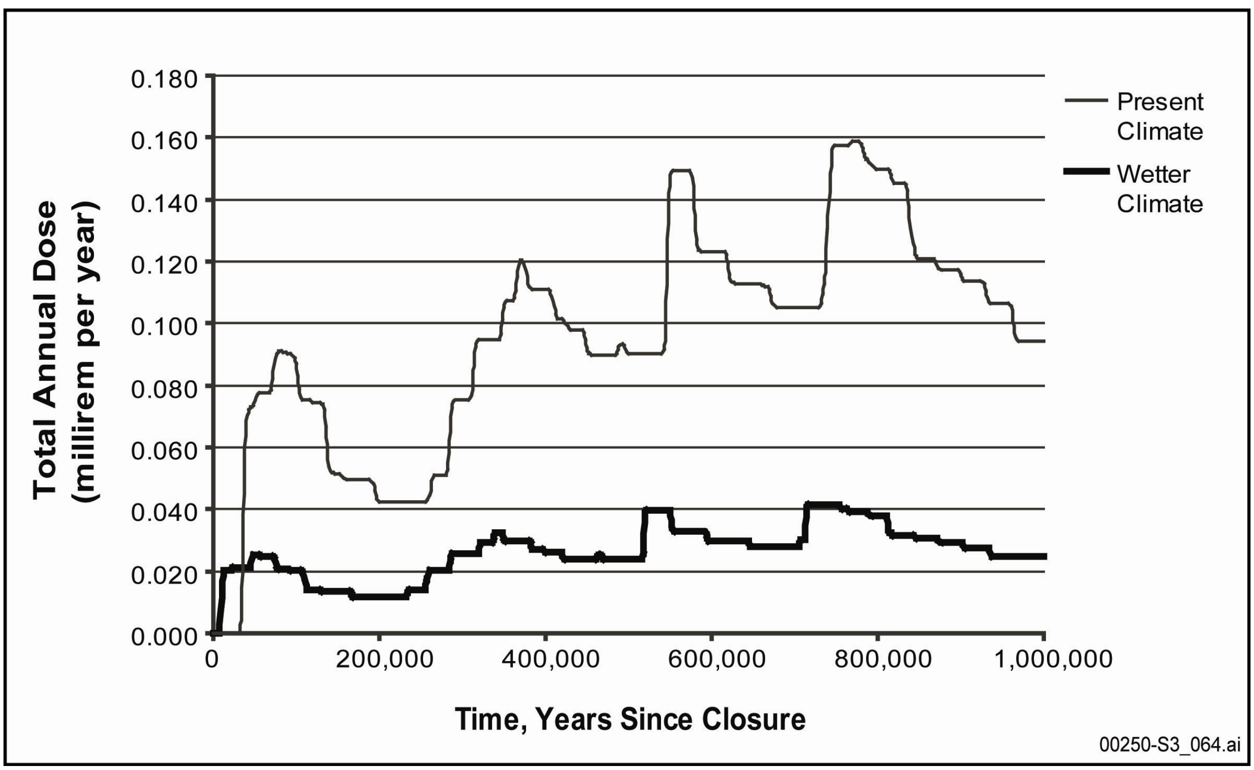


Figure 3-8. Total annual dose at the Middle Basin.

Because the human health consequences are so low, DOE would not expect any harm to flora or fauna. Dose rates to plants and animals are expected to result in radiation absorption levels much less than 100 millirad per day. A rad is a unit of radiation absorption by any object, living tissue or otherwise. In people, rads are converted to rem (roentgen-equivalent-man). For radiation such as gamma or x-rays, one rad equals one rem in a person. For flora and fauna, a radiation unit for humans (rem) would be inappropriate, so radiation absorption is expressed in rad or millirad. The International Atomic Energy Agency concluded that chronic radiation absorption of less than 100 millirad per day is unlikely to cause measurable detrimental effects in populations of the more radiosensitive species in terrestrial ecosystems (DIRS 103277-IAEA 1992, p. 53). While not directly comparable, the fact that annual radiation doses at exposure locations evaluated in this Analysis of Postclosure Groundwater Impacts are all less than 2 millirem (0.002 rem), it can be concluded that radiation effects to flora and fauna would be several orders of magnitude below 100 millirad.

WHY ARE THE DOSE PLOTS SO JAGGED?

Anyone used to viewing plots of dose histories from the TSPA-LA might wonder why the dose histories in this Analysis of Postclosure Groundwater Impacts appear so jagged. There are two basic reasons:

1. The TSPA-LA model resulted in similar abrupt changes in dose histories per time step, but those changes were less apparent because of the use in TSPA-LA reports of logarithmic-scaled plots that depicted changes over long time periods. The results of the TSPA-LA model used as input to the modeling for this document have similar abrupt changes per time step, but those changes are more evident in this analysis because a linear, rather than logarithmic, scale is used for the total dose plots. Logarithmic scales are used to present results that vary by several orders of magnitude.

2. The coarser (that is, longer) time step used in the analyses for this document resulted in curves having a jagged appearance. This longer time step was appropriate for the purposes of these analyses. Using a shorter time step would have resulted in smoother curves, but would not have changed any of the results or conclusions of the analyses.

For the present climate condition, radionuclides that have no adsorption to slow down their travel dominate dose at the Amargosa Farms area; that is, iodine-129 and technetium-99. During the wetter climate condition, some slower-moving radionuclides, such as plutonium-242, contribute significantly to the total dose (at least for a limited time). In the Furnace Creek springs area plot (Figure 3-7), the wetter-climate dose is higher than the drier-climate dose for about the first 30,000 years. This is a good demonstration of the relative effects of delay and dilution. The wetter climate doses are reduced by more dilution from the higher flow rates so that they are generally lower than the dry climate. However, the increased flow of groundwater during the wetter climate causes radionuclides to arrive earlier.

There is also a degree of uncertainty for the actual percentage of flow that could divert to Alkali Flat as opposed to the floor of Death Valley. If all of the flow were to divert to Alkali Flat, then the dose could be as much as twice that calculated for the floor of Death Valley. Franklin Lake Playa at Alkali Flat is also a wet playa and the radionuclide flux would be estimated to be about the same as Middle Basin if all the flow were diverted to Alkali Flat. The analytical difference is that the evapotranspiration rate at Franklin Lake Playa is about half of that at Middle Basin and dose is inversely proportional to evapotranspiration rate. This estimated result applies a very conservative assumption, in that if all of the contaminants were to divert to Alkali Flat, the evapotranspiration rate at that location would not increase from its current measured value. It would be very likely that any diversion of contaminants would be the result of increased groundwater flow in the direction of Alkali Flat and that there would be increases in the evapotranspiration rate at the playa. Since these parameters are not known, DOE made this conservative, qualitative estimate.

3.3.2 NONRADIOLOGICAL CONTAMINANTS

The nonradiological contaminants considered include molybdenum, nickel, vanadium, and uranium. Uranium is included in both radiological and nonradiological contaminants because uranium has a notable toxicity as a heavy metal. The uranium concentrations are a sum of the uranium isotopes from the radionuclide calculations. DOE assessed human health impacts of the nonradiological materials by comparing daily intakes with EPA's *Oral Reference Dose* standard (DIRS 148228-EPA 1999, all; DIRS 148229-EPA 1999, all; DIRS 103705-EPA 1997, all; DIRS 102173 EPA-1994, all). For exposure locations involving ingestion of potentially contaminated water (that is, the Amargosa Farms and Furnace Creek springs areas), DOE calculated the daily intake for a 70-kilogram person drinking 2 liters of water daily. For exposures at the Death Valley floor, the daily intakes are due to dust ingestion and inhalation in milligrams per day for a 70-kilogram person. Table 3-2 summarizes the estimated daily intakes of the nonradiological contaminants. The bottom row of the table shows EPA's Oral Reference Doses.

ORAL REFERENCE DOSE

The Oral Reference Dose is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. It is expressed in units of milligrams per kilograms per day. In general, the Oral Reference Dose is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Table 3-2. Peak daily intakes of the nonradiological contaminants.

Scenario	Peak daily intakes (mg/kg body wt.-day) of metals during 1 million years after closure			
	Molybdenum	Nickel	Vanadium	Uranium
Amargosa Farms area, pumping, present climate[a]	3.00×10^{-3}	1.37×10^{-2}	6.04×10^{-6}	3.47×10^{-6}
Amargosa Farms area, pumping, wetter climate[a]	3.00×10^{-3}	1.37×10^{-2}	6.04×10^{-6}	3.84×10^{-6}
Middle Basin, no-pumping, present climate[b]	6.80×10^{-4}	0.0	0.0	0.0
Middle Basin, no-pumping, wetter climate[b]	1.74×10^{-4}	0.0	0.0	0.0
Furnace Creek springs area, no-pumping, present climate[a]	2.99×10^{-3}	0.0	0.0	0.0
Furnace Creek springs area, no-pumping, wetter climate[a]	7.67×10^{-4}	0.0	0.0	0.0
Oral Reference Dose (mg/kg body-wt/day)	5.00×10^{-3}	2.00×10^{-2}	7.00×10^{-3}	3.00×10^{-3}

Sources: DIRS 148228-EPA 1999, all; DIRS 148229-EPA 1999, all; DIRS 103705-EPA 1997, all; DIRS 102173-EPA 1994, all.

a. Based on a 70-kilogram person drinking 2 liters of water per day.

b. Based on a 70-kilogram person ingesting and inhaling a given amount of contaminant per day (milligrams).

mg/kg body-wt/day = milligram per kilogram body-weight per day.

All intakes are below the Oral Reference Dose. Note that there are a number of zeros in the table. The zero values signify when a contaminant is estimated to not reach the discharge area during the 1-million years.

Figures 3-9 and 3-10 present detailed plots of the daily intakes of nonradiological contaminants for the Amargosa Farms area location.

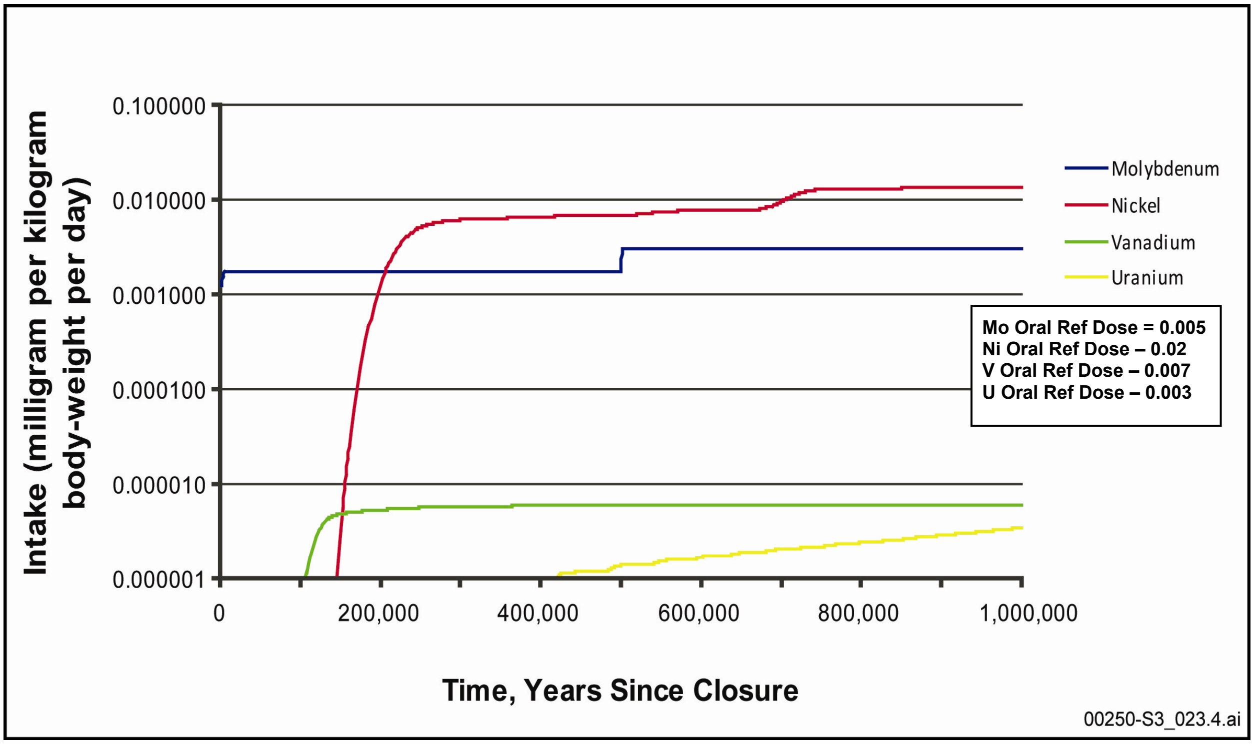


Figure 3-9. Daily intakes of nonradiological contaminants at the Amargosa Farms area, present climate.

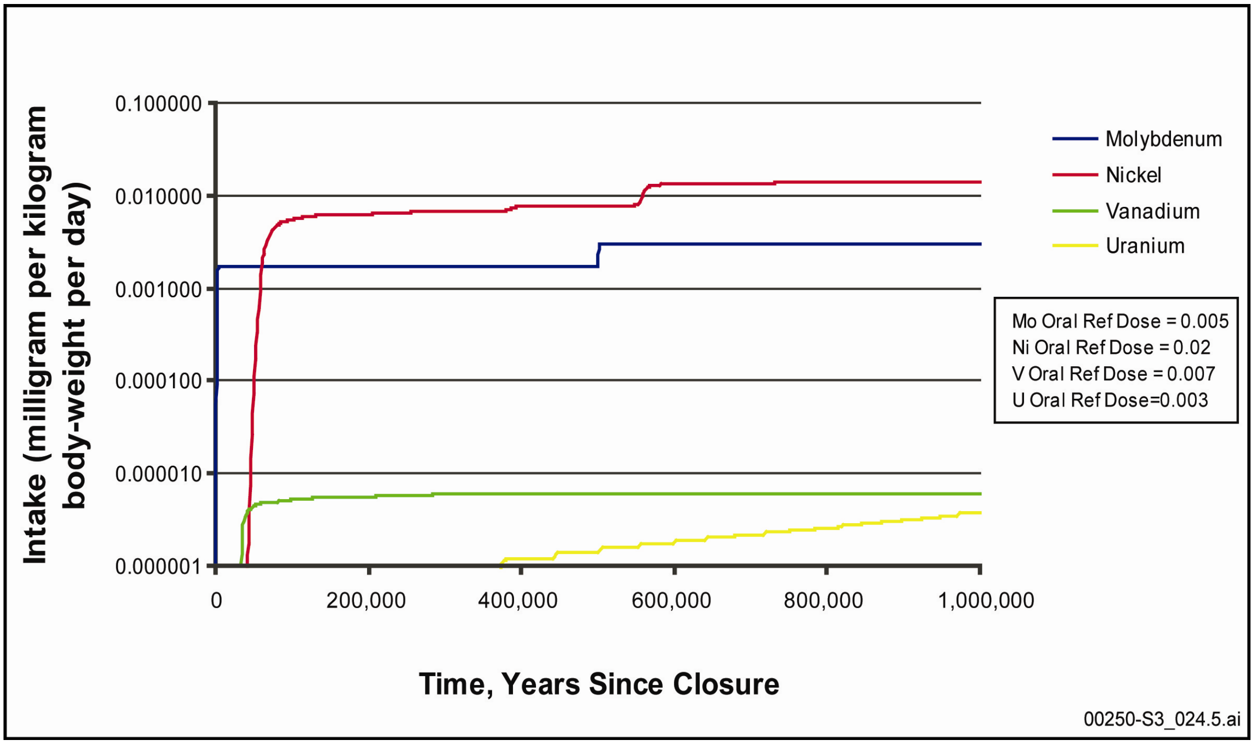


Figure 3-10. Daily intakes of nonradiological contaminants at the Amargosa Farms area, wetter climate.

Figures 3-11 and 3-12 show estimated daily intakes of molybdenum at the Furnace Creek springs area. Molybdenum is the only nonradiological contaminant that would reach the Death Valley natural discharge locations during the 1-million-year period. Figure 3-13 shows the estimated daily intakes of molybdenum at the Death Valley floor (Middle Basin).

Just as with the radionuclides, if all of the contaminants were to divert to Alkali Flat, then intakes would be approximately double those of the Death Valley floor. As explained in Section 3.3.1, this approximation is made using very conservative assumptions.

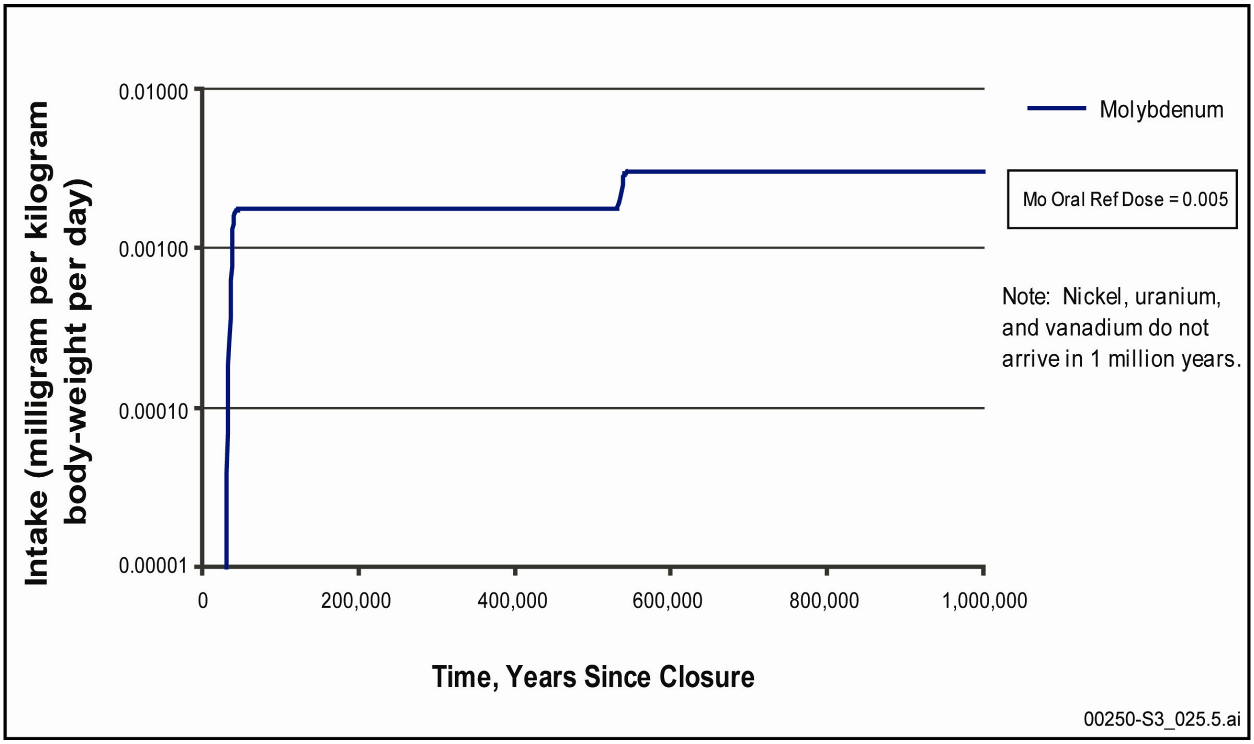


Figure 3-11. Molybdenum daily intake at the Furnace Creek springs area, no-pumping, present climate.

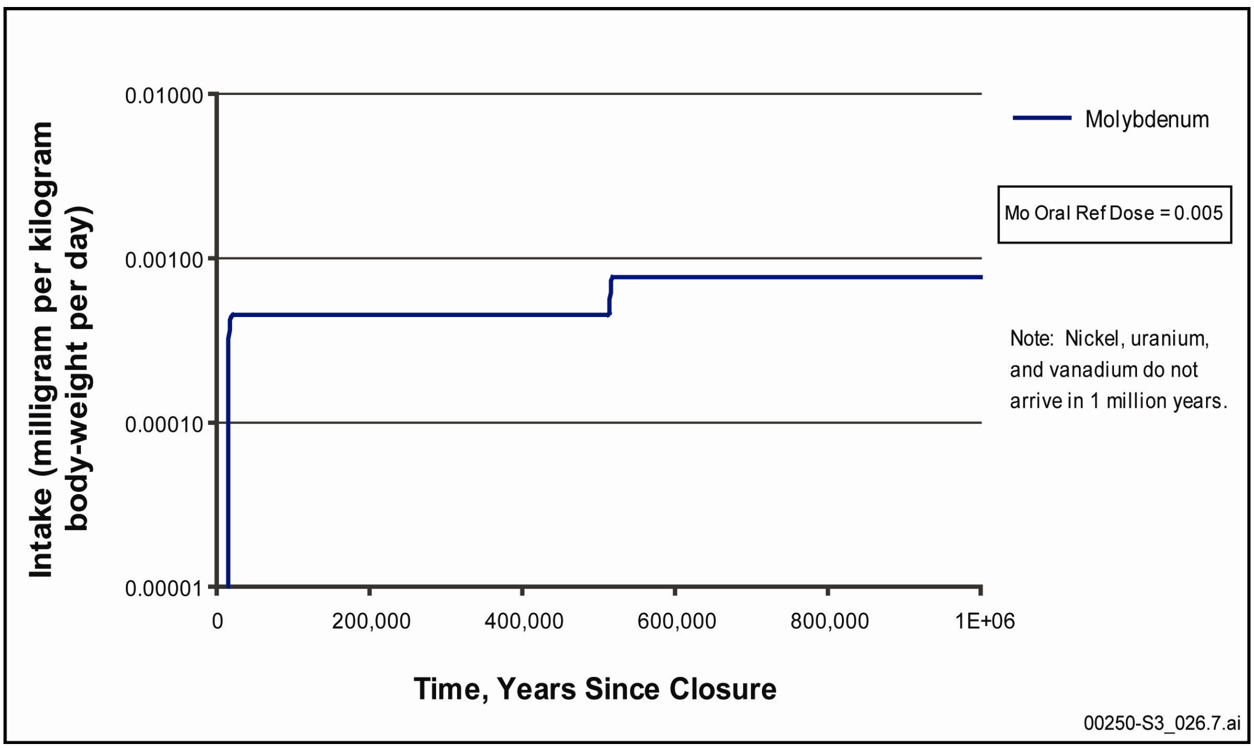


Figure 3-12. Molybdenum daily intake at the Furnace Creek springs area, no-pumping, wetter climate.

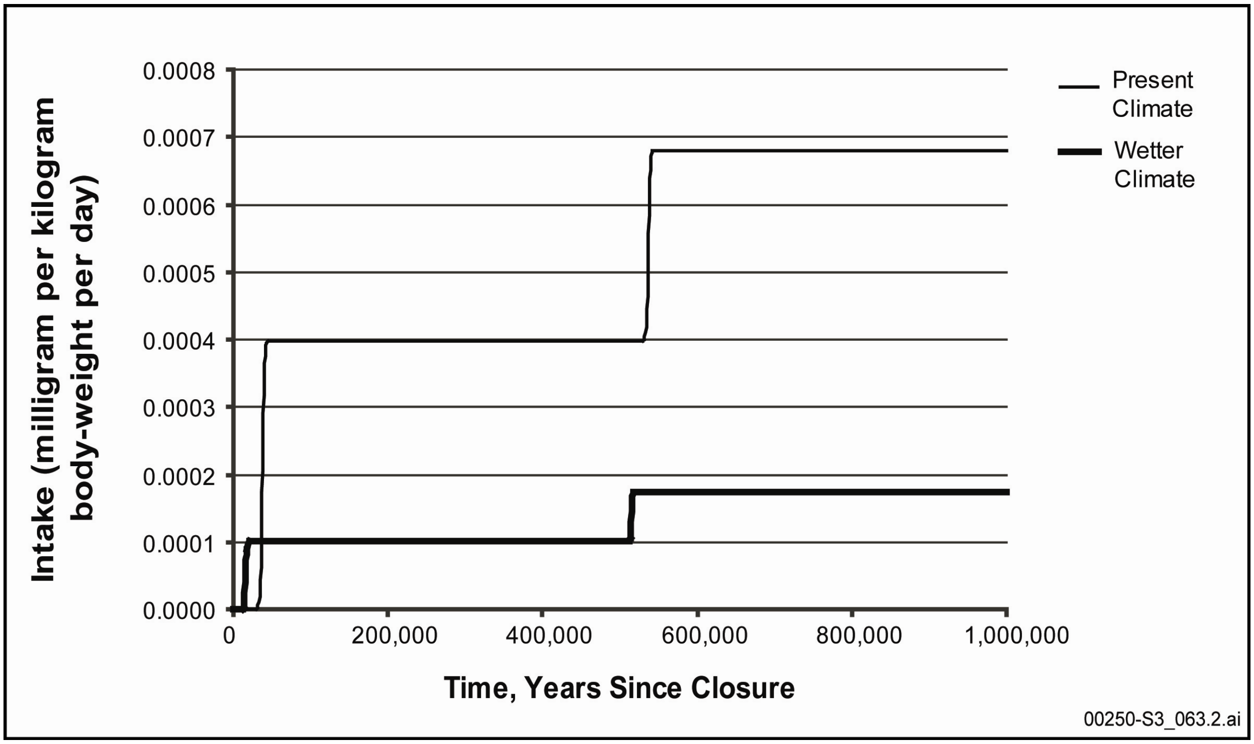


Figure 3-13. Molybdenum daily intake at Middle Basin, no-pumping.

3.3.3 MASS BALANCES

DOE used the fluxes of contaminants to develop inventories at the Amargosa Farms area, Furnace Creek springs, and Middle Basin on the floor of Death Valley. These inventories represent the decay- and growth-adjusted cumulative release. DOE then used the cumulative releases to develop an overall mass balance for individual contaminants. Appendix B provides detailed mass balances.

3.3.4 SOIL CONCENTRATIONS

Under the pumping scenario, the analysis includes the irrigation of fields with potentially contaminated groundwater. As irrigation water containing contaminants dispenses over the fields, contaminants would infiltrate the soil, and water would seep into the soil and also evaporate. Some contaminants (especially those with strong bonding to the soil; that is, high adsorption or high partition coefficients) would remain in a surface layer. DOE estimated soil concentrations as part of the transport and dose calculations. Soil concentrations at the Amargosa Farms area are reported in Appendix B, Section B.4.3. Different processes drive soil concentrations at the natural discharge points; Section 3.2.1.8 discusses these processes. Soil concentrations at Middle Basin are reported in Appendix B, Section B.4.4.

3.3.5 ADDITIONAL POTENTIAL DISCHARGE LOCATIONS

In addition to Furnace Creek springs, the Death Valley floor, and Alkali Flat, contaminants might also discharge at the area of the State Line Deposits during the wetter climate (Chapter 2, Figure 2-5). As described in Section 2.2.2.2, USGS' 1999 groundwater model simulations of the past wetter (full-glacial) climate depict groundwater discharges associated with the State Line Deposits extending northward along the path of Fortymile Wash (DIRS 120425-D'Agnese et. al. 1999, pp. 22 and 23). The report on DOE's Irrigation Recycling Model considered the USGS' 1999 simulations of past and future wetter climates and identified one of these simulated discharge points as being located on the flow path from the repository and a few kilometers north of the Amargosa Farms area (DIRS 182130-SNL 2007, p. 6-47 and Figure 5.1-1). The USGS identified this area as a discharging area during a future climate similar to the wetter climate analyzed in this Analysis of Postclosure Groundwater Impacts. It is not clear what discharge rate might occur at this site, but it is reasonable to assume that it might be approximately 2,000 acre-feet per year during a wetter climate (estimates show Furnace Creek springs' discharge to be over 2,300 acre-feet in the present climate). If some portion of the contaminant plume were to flow to this discharge area, then the dose and intake estimates could be somewhere between those estimated for the Amargosa Farms area (pumped with recycle) and those for the Regulatory Compliance Point with a water supply of 3,000 acre-feet per year. This diversion would somewhat reduce the doses and intakes at Death Valley if there were no pumping. If there were full pumping, the water from the discharge site could contain concentrations of contaminants less than those at Regulatory Compliance Point but somewhat higher than those at the Amargosa Farms area. If the site were a spring, then the discharging water would flow down Fortymile Wash and the Amargosa River in a generally southerly direction. Assuming this surface water might be used for farming, the doses resulting from its use could be somewhere between those estimated for the Amargosa Farms area and those estimated in the Repository SEIS for the Regulatory Compliance Point. The existence of this additional natural discharge site and possible presence of surface water could lead to less pumping, which could result in less groundwater flow, and therefore contaminants, toward the Amargosa Farms area and therefore more flow, and contaminants, toward natural discharge points. Reduced pumping falls within the framework analyzed previously and would result in decreasing doses at the Amargosa Farms area while increasing doses at natural discharge points to levels somewhere in between those reported in Table 3-1 for full pumping at the Amargosa Farms area and those for no pumping at the natural discharge sites in Death Valley.

DOE believes the groundwater levels predicted for past and future wetter climates in the USGS 1999 report may be overestimated based on physical evidence of ancient groundwater elevations beneath Yucca Mountain (Repository SEIS, Section 3.1.4.2.2, page 3-44). However, the information was used in the Irrigation Recycling Report to evaluate conservatively high estimates of groundwater elevation (representing a worse-case in the effects of recycling contaminants back to groundwater from irrigation). Likewise, these high groundwater elevations are qualitatively analyzed here to evaluate a potential future, wetter climate groundwater discharge location closer to the repository site where contaminant concentrations could be higher than those presented for Amargosa Farms. Realistically, potential groundwater discharge locations would be more likely to occur within the primary area of the State Line Deposits, located to the south of Amargosa Farms. This location would experience lower contaminant concentrations than were evaluated for Amargosa Farms and thus, impacts in this area would be expected to be less than those presented for the Amargosa Farms area.

3.4 Cumulative Impacts

The Repository SEIS analyzed the potential environmental impacts of the reasonably foreseeable action of disposing of Inventory Modules 1 and 2 beyond that of the *Proposed Action* (70,000 *metric tons of heavy metal*) (DIRS 180751-DOE 2008, Section 8.3.1). These inventory modules represent the total projected amount of *spent nuclear fuel* and *high-level radioactive waste* (Module 1) and the additional inventory of other *radioactive* materials such as Greater-Than-Class C low-level radioactive wastes (Module 2). The Repository SEIS developed scale factors for how the addition of Modules 1 and 2 to the proposed repository inventory would affect the dose and nonradiological impacts at the Regulatory

Compliance Point. DOE found that impacts of the modules would increase linearly relative to the increased number of waste packages. Because the regional impacts reported in this Analysis of Postclosure Groundwater Impacts depended directly on the fluxes at the Regulatory Compliance Point, it is reasonable to assume that the cumulative impacts of the inventory modules on the regional radiological impacts would also increase by the linear relationship identified in the Repository SEIS. The scale factors for the nonradiological contaminants molybdenum, nickel, and vanadium would be likewise. Because the estimated 1-million-year regional impacts at the various exposure locations Section 3.3 evaluated are all less than the dose estimates the Repository SEIS presented for the Regulatory Compliance Point, the estimated doses at these locations would also be less than the estimated doses presented in the Repository SEIS for the inventory modules. Likewise, the intakes of toxic metals would be less than or about equal to those presented in the Repository SEIS.

The Repository SEIS also evaluated the cumulative impact from Nevada Test Site activities, primarily as a result of past underground weapons testing (DIRS 180751-DOE 2008, p. 8-36). After evaluation, the estimated total potential cumulative impact (Yucca Mountain impact plus Nevada Test Site impact) would be 0.24 millirem per year to the RMEI for the 1-million-year period. It would be reasonable to expect that the same effect applies to the regional dose impacts in this Analysis of Postclosure Groundwater Impacts and would therefore contribute an insignificant amount to the 1-million-year dose.

3.5 American Indian Concerns

The analyses of potential impacts to cultural resources from construction, operation and monitoring, and eventual closure of a repository that were included in the Yucca Mountain FEIS (DIRS 155970-DOE 2002, Section 4.1.5.2) and Repository SEIS (DIRS 180751-DOE 2008, Section 4.1.5.1) focused on resources within and near the land withdrawal area. Those analyses were based in part on a Native American Interaction Program conducted by the DOE since the late 1980s to obtain input and perspectives from American Indian tribes. In addition, consultation between DOE and the tribes, including the Timbisha Shoshone Tribe, has occurred at tribal locations over the years. During preparation of the Yucca Mountain FEIS, DOE interacted with American Indian tribes on a range of topics to assess their viewpoints and perspectives. DOE supported the American Indian Writers Subgroup of the Consolidated Group of Tribes and Organizations in its preparation of American Indian Perspectives on the *Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (DIRS 102043-AIWS 1998, all) and discussed that document in the above environmental impact statements.

Neither the Yucca Mountain FEIS nor Repository SEIS included a specific analysis of potential effects of a change in groundwater quality on the use of springs and associated cultural resources in the Furnace Creek area or elsewhere in the Yucca Mountain region. This is because DOE concluded that groundwater flowing under Yucca Mountain likely would discharge at Alkali Flat (DIRS 180751-DOE 2008, Section 5.4) and that concentrations of radionuclides and associated health effects at downgradient locations would be no greater than those estimated in the Repository SEIS for the Regulatory Compliance Point (DIRS 180751-DOE 2008, Section 5.1.1.4 and Appendix F). This Analysis of Postclosure Groundwater Impacts describes the possibility that groundwater that flows under Yucca Mountain could discharge via evapotranspiration at the floor of Death Valley or at springs in the Furnace Creek area of Death Valley (Section 3.1.1.2); therefore, DOE has further considered potential impacts to cultural resources and American Indian concerns.

Members of the Timbisha Shoshone Tribe reside on a 314-acre parcel of trust land located in the Furnace Creek area of Death Valley. The tribe has federally appropriated rights to 92 acre-feet per year of surface and groundwater in the area (16 U.S.C. 410aaa). The springs in the Furnace Creek area, including the Furnace Creek, Texas, Travertine, and Salt springs, are of traditional and cultural importance to members of the Timbisha Shoshone Tribe, and the purity of water in those springs is important to Tribal spiritual beliefs, culture, and heritage. Members of the Tribe have stated that even small amounts of contaminants would be disrespectful to the springs and to the earth (DIRS 186231-NRC 2009, pp. 28 to 30).

To evaluate changes in groundwater quality during the postclosure period, and potential impacts to American Indians and other residents of Death Valley, DOE estimated annual doses of radiological contaminants and daily intakes of nonradiological contaminants that would result from the use of the springs in the Furnace Creek area. As described in Section 3.3.1, if all radionuclides were to discharge at the springs in the Furnace Creek area, the estimated peak annual doses during the 1-million-year period after *repository closure* would be 0.34 millirem for the present climate and 0.09 millirem for the wetter climate. The corresponding probabilities of a latent cancer fatality are less than 1 chance in 1 million (Table 3-1). Those dose estimates include contributions from the most likely pathways by which residents of Death Valley would be exposed to radionuclides discharged from the springs, including external exposure, ingestion and inhalation of soil, ingestion of water, and use of evaporative coolers (a type of air conditioner). Ingestion of locally produced foodstuffs was not included because there is limited production of food products in Death Valley National Park.

Even if the Department had assumed that fruits, vegetables, and animal products were locally produced using the spring water, following agricultural practices and consumed at rates similar to those of the residents of Amargosa Valley (where locally produced foodstuffs are readily available), the estimated peak annual doses during the 1-million-year period would only increase to 0.61 millirem for the present climate and 0.19 millirem for the wetter climate. These dose estimates account for the potential dose to Death Valley residents that may periodically consume locally produced garden products irrigated with spring water or native plants and animals living at the springs. These estimates also account for external exposure to mineral deposits in the immediate vicinity of the springs and native plant or animal material obtained from the springs and used to construct crafts or other products. This is because DOE based the biosphere dose conversion factors used to calculate the external exposure rates on the assumption that receptors would be exposed year-round and throughout the local environment to soil contaminated by the use of groundwater for irrigation. In Death Valley, people would be exposed to contaminated soil only when they would be within or near the limited areas with flowing or standing water around and downstream of the springs, and where groundwater would be used for gardens and residential landscaping. Thus, the model assumed that the period of external exposure to contaminated soil would exceed the period of exposure to products made with contaminated plant and animal materials. The concentration of radionuclides in those products also would likely be less than in soil contaminated by irrigation because the soil is where most of the radionuclides in the biosphere would remain, and because only a portion of the contaminants in the groundwater would be taken up by plants and animals, especially for those radionuclides that build up in the soil (DIRS 183041-SNL 2008, Section 3.3.03.01.0A).

If all of the radiological contaminants were to discharge at Middle Basin at the floor of Death Valley, which is near trust land of the Timbisha Shoshone Tribe, the peak total annual doses to a person living year-round outdoors on the playa during the 1-million-year period after repository closure would be 0.16 millirem per year for the present climate and 0.04 millirem per year for the wetter climate.

The only nonradiological contaminant that would reach Death Valley in an appreciable concentration by 1 million years is molybdenum. The estimated intake for molybdenum at that location is below the Oral Reference Dose (Section 3.3.2).

In the Yucca Mountain FEIS and Repository SEIS, DOE conducted an analysis of environmental justice as required by Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations." This Executive Order directs agencies to identify and consider disproportionately high and adverse human health, social, economic, or environmental effects of their actions on minority and low-income communities and American Indian tribes and provide opportunities for community input to the process, which includes input on potential effects and mitigation measures. See Section 4.1.13 of the Repository SEIS for an explanation of the requirements of that Executive Order and the methods the Department used to analyze environmental justice. In the Yucca Mountain FEIS and Repository EIS, DOE concluded that there would be no high or adverse impacts on members of the public, including minority and low-income communities or American Indian tribes.

In this Analysis of Postclosure Groundwater Impacts, DOE has identified no high and adverse potential impacts to members of the general public associated with exposure to contaminants that may occur in groundwater following closure of a repository at Yucca Mountain. Further, DOE has not identified subsections of the population, including minority or low-income populations, that would receive disproportionate impacts. Likewise, DOE has identified no unique exposure pathways that would expose minority or low-income populations to disproportionately high and adverse impacts. The Department acknowledges the sensitivities and cultural practices of the Timbisha Shoshone Tribe concerning the use and purity of springs in the Funeral Creek area; however, the analysis included in this Analysis of Postclosure Groundwater Impacts demonstrates that the potential concentrations of contaminants in those springs would be so low that there would be virtually no potential health effects associated with the use of those springs. Thus, this document supports the Department's previous conclusion that no disproportionately high and adverse impacts would result from the proposed repository.

3.6 Summary

DOE's Analysis of Postclosure Groundwater Impacts indicates that while radionuclides would distribute into one or more of several locations and could discharge from springs, the estimated human health consequences would be minimal and would be below the 1-million-year peak annual doses reported in the Repository SEIS assessments for the Regulatory Compliance Point. The analysis also indicates that the human health consequences of the nonradiological contaminants would be below established guidelines. Based on the low human health effects, no impacts to flora or fauna would be expected.

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4. GLOSSARY

The U.S. Department of Energy (DOE or the Department) has provided this glossary to assist readers in the interpretation of this *Analysis of Postclosure Groundwater Impacts for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (Analysis of Postclosure Groundwater Impacts). The Glossary includes definitions of technical and regulatory terms and explains these terms with their meanings in the context of this Analysis of Postclosure Groundwater Impacts. DOE derived the definitions in this Glossary from the most authoritative sources available (for example, a statute, regulation, DOE directive, dictionary, or technical reference book) and checked each definition against other authorities. Glossary terms are presented in *italics* the first time they appear in each chapter or appendix of this document. In this Glossary, the convention is to italicize other glossary terms when they appear in a definition, but only once per definition.

abstraction model	A model of reduced complexity developed by taking specific elements or results from a more-complicated system model for use in a specific application.
accessible environment	For this analysis, all points on the earth outside the surface and *subsurface* area controlled over the long term for the proposed *repository*, including the atmosphere above the controlled area. The closest point of the accessible environment is generally considered to be the location of the *reasonably maximally exposed individual* who, by regulatory definition, lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination.
actinide	Any one of a series of chemically similar elements of atomic numbers 89 (actinium) through 103 (lawrencium). All actinides are *radioactive*.
adsorption	The *process* of a dissolved chemical species attaching to the surface of a solid exposed to the solution containing the chemical species.
affected environment	The physical, biological, and human-related environment that is sensitive to changes resulting from the *Proposed Action*. The extent of the affected environment may not be the same for all potentially affected resource areas. For example, traffic may increase within 4 miles of a hypothetical site from which waste would be removed to a nearby landfill (the extent of the affected environment with respect to transportation impacts). In contrast, *groundwater* extending 2 miles from the hypothetical site may be affected (the extent of the affected environment with respect to groundwater impacts).

Alloy 22	A corrosion-resistant, high-nickel alloy DOE would use for the outer shell of the *waste package*, for rails that support the *drip shields*, and for the parts of the *emplacement pallet* that would contact the waste package.
alluvial aquifer	Alluvial deposits (materials deposited by running water) that qualify as an *aquifer*. For purposes of this analysis, alluvial aquifer is used as a general term applying to aquifers in basin-fill deposits independent of the specific origin of those deposits.
aquifer	A subsurface, saturated rock unit (formation, group of formations, or part of a formation) of sufficient *permeability* to transmit *groundwater* and yield usable quantities of water to wells and springs.
astronomical changes (climate)	Extraterrestrial changes that affect the *solar radiance* received by the earth and include changes in the amount of solar radiance given off by the sun and changes in the angle and proximity of the earth in relation to the sun when receiving that radiance.
attenuation	A *process* that tends to slow down or stop the transport of a *contaminant* in a natural or *engineered system*.
barrier	Any material, structure, or condition (as a thermal barrier) that prevents or substantially delays the movement of water or *radionuclides*. See *natural barrier*.
biosphere	The "life" zone of Earth, which includes all living organisms, including man, and all organic matter that has not yet decomposed.
biosphere dose conversion factor	For purposes of this analysis, the factor that is multiplied by the concentration of radiological *contaminants* in *groundwater* to calculate the annual dose to the *reasonably maximally exposed individual,* or other *receptor* with similar characteristics, due to a specific *radionuclide*.
biota	The living organisms of a geographic region or a time period considered as a group.
borosilicate glass	*High-level radioactive waste* matrix material in which boron takes the place of the lime used in ordinary glass mixtures. See *vitrification*.
calcite deposit	Residues of calcium carbonate left as a result of evaporating water.