

# 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



U.S. Department of Energy  
Office of Civilian Radioactive Waste Management

RWEV-REP-001

July 2009

## ACRONYMS, ABBREVIATIONS, AND SYMBOLS

To ensure a more reader-friendly document, the U.S. Department of Energy (DOE) limited the use of acronyms and abbreviations in this Analysis of Postclosure Groundwater SEIS Impacts. In addition, acronyms and abbreviations are defined the first time they are used in each chapter or appendix. The acronyms, abbreviations, and symbols used in the text of this document are listed below. Acronyms and abbreviations used in tables and figures are listed in footnotes to the tables and figures.

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy (also called the Department)
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FEIS	final environmental impact statement
FR	<i>Federal Register</i>
$K_d$	partition coefficient
NEPA	<i>National Environmental Policy Act</i>
NRC	U.S. Nuclear Regulatory Commission
NWPA	<i>Nuclear Waste Policy Act</i> , as amended
RMEI	reasonably maximally exposed individual
SEIS	supplemental environmental impact statement
TAD	transportation, aging, and disposal (canister)
TSPA-LA	Total System Performance Assessment model for the License Application
U.S.C.	United States Code
USGS	U.S. Geological Survey

## TERMS AND DEFINITIONS

In this document, DOE has italicized terms that appear in the Glossary (Chapter 4) the first time they appear in a chapter.

## UNDERSTANDING SCIENTIFIC NOTATION

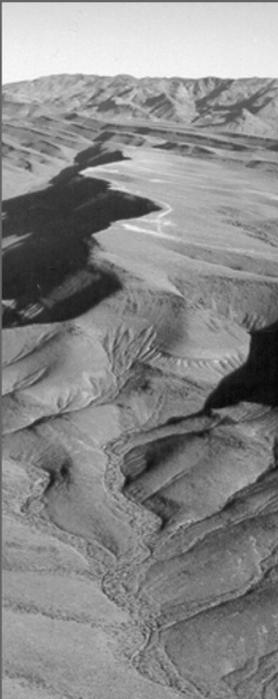
DOE has used scientific notation in this Analysis of Postclosure Groundwater SEIS Impacts to express numbers that are so large or so small that they can be difficult to read or write. Scientific notation is based on the use of positive and negative powers of 10. The number written in scientific notation is expressed as the product of a number between 1 and 10 and a positive or negative power of 10. Examples include the following:

Positive Powers of 10	Negative Powers of 10
$10^1 = 10 \times 1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1/100 = 0.01$
and so on, therefore,	and so on, therefore,
$10^6 = 1,000,000$ (or 1 million)	$10^{-6} = 0.000001$ (or 1 in 1 million)

Probability is expressed as a number between 0 and 1 (0 to 100 percent likelihood of the occurrence of an event). The notation  $3 \times 10^{-6}$  can be read 0.000003, which means that there are 3 chances in 1 million that the associated result (for example, a fatal cancer) will occur in the period covered by the analysis.

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## S. SUMMARY

### S.1 Introduction

#### S.1.1 BACKGROUND INFORMATION

The U.S. Department of Energy (DOE or the Department) completed the *Final 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) (Yucca Mountain FEIS) in February 2002. In June 2008, DOE issued 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) (Repository SEIS), which addressed modifications to repository design and operational plans.

The Yucca Mountain FEIS addressed the Proposed Action to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain in Nye County, Nevada, for the disposal of spent nuclear fuel and high-level radioactive waste. The FEIS considered the potential environmental impacts of a repository design for surface and subsurface facilities; a range of canister packaging scenarios, repository thermal operating modes, and repository sizes; and plans for the construction, operation, monitoring, and eventual closure of the repository.

The basic elements of the Proposed Action the Repository SEIS evaluated did not change from those evaluated in the Yucca Mountain FEIS. As described in the Repository SEIS, the surface and subsurface facilities would allow DOE to operate the repository following a primarily canistered approach in which most commercial spent nuclear fuel would be packaged at the reactor sites in transportation, aging, and disposal canisters. The Department would construct the surface and subsurface facilities over a period of several years (referred to as phased construction) to accommodate an increase in spent nuclear fuel and high-level radioactive waste receipt rates as repository operational capability reached its design capacity. The Repository SEIS evaluated potential environmental impacts of the repository design and operational plans as described in the application that DOE submitted on June 3, 2008, to the U.S. Nuclear Regulatory Commission seeking authorization to construct the repository, as required by Section 114(b) of the *Nuclear Waste Policy Act*, as amended.

On September 8, 2008, the NRC staff issued a Notice of Acceptance to the Department informing that the License Application had been accepted for docketing. Included with this notice was the *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*, dated September 5, 2008 (<http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app/nrc-eis-adr.pdf>). In its Adoption Report, the NRC staff conducted a review to determine if it was practicable to adopt the environmental impact statements in accordance with 10 CFR 51.109. Based on its review, the NRC staff concluded that it was practicable to adopt the Yucca Mountain FEIS and supplements prepared by DOE, but that additional supplementation was needed to address the potential impacts of the proposed action on groundwater and from surface discharges of groundwater.

In response to the NRC staff's Adoption Report, DOE has prepared 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).

### **S.1.2 SCOPE OF THE POSTCLOSURE GROUNDWATER SEIS**

This Analysis of Postclosure Groundwater impacts addresses the information identified by the NRC staff as needed to supplement DOE's environmental impact statements. It expands on the analysis of postclosure impacts that could arise from potentially contaminated groundwater by considering impacts in areas of the accessible environment farther from Yucca Mountain than that considered in the Repository SEIS.

The NRC staff's Adoption Report identified two areas for supplementation: (1) impacts on groundwater and (2) impacts from surface discharges of groundwater. Within these areas, the NRC specifically identified a need for the following information:

- A description of the full extent of the volcanic-alluvial aquifer, particularly those parts that could become contaminated, and how water (and potential contaminants) can leave the flow system. For example, the DOE license application describes potential groundwater flow farther to the south of Alkali Flats, into the Southern Death Valley subregion of the regional model domain. This component of the groundwater flow system is not discussed in the EISs.
- An analysis of the cumulative amount of radiological and non-radiological contaminants that can be reasonably expected to enter the aquifer from the repository, and the amount that could reasonably remain over time. In its license application, for example, DOE provides calculated cumulative releases of some radionuclides at different stages within the repository system, as intermediate results in TSPA. This type of information, for radiological and non-radiological contaminants could be used in the analysis.
- Estimates of contamination in the groundwater, given potential accumulation of radiological and non-radiological contaminants. One way to analyze the overall impacts on groundwater may be a mass-balance approach that accounts for mass released, the part of the groundwater flow system affected by potential releases, and the expected processes that could affect released contaminants. Such an approach would also show the extent of contamination and possible impacts on water quality.
- A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods.
- A description of the physical processes at the surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants.
- Estimates of the amount of contaminants that could be deposited at or near the surface. This involves estimates of the amount of groundwater involved in discharge or near-surface evaporation, the amounts of radiological and non-radiological

contaminants in that water, contaminant concentrations in the resulting deposits, and potential environmental impacts (e.g., effects on biota).

## S.2 Affected Environment

In the late 1990s, DOE directed the U.S. Geological Survey to improve its groundwater flow model of the Death Valley regional flow system to support DOE programs at the Nevada Test Site and Yucca Mountain. The results of the Survey's work are presented in *Death Valley Regional Ground-Water Flow System, Nevada and California – Hydrogeologic Framework and Transient Ground-Water Flow Model*, and much of the information in this Analysis of Postclosure Groundwater Impacts describing the regional flow system was obtained from that document. It includes a conceptual model of the groundwater flow system within the Death Valley region and describes how the Survey used that information to construct a computer-based numerical model to simulate that flow system. Figure S-1 shows the flow system boundaries (as depicted in the model). In addition, DOE has further developed a site-scale flow model, which represents a smaller area (including Yucca Mountain) at a greater level of detail. This site-scale model was used in the *Total System Performance Assessment Model/Analysis for the License Application (TSPA-LA)*.

**DEATH VALLEY REGION**

In this Analysis of Postclosure Groundwater Impacts, Death Valley region refers to the area described by the outer boundaries in Figure S-2; Death Valley subregion refers to one of the three areas that make up the region. Death Valley or the floor of Death Valley refers to the topographic low area, or structural trough running roughly northwest-to-southeast that is labeled in the western (California) side of the region and is a central element of Death Valley National Park.

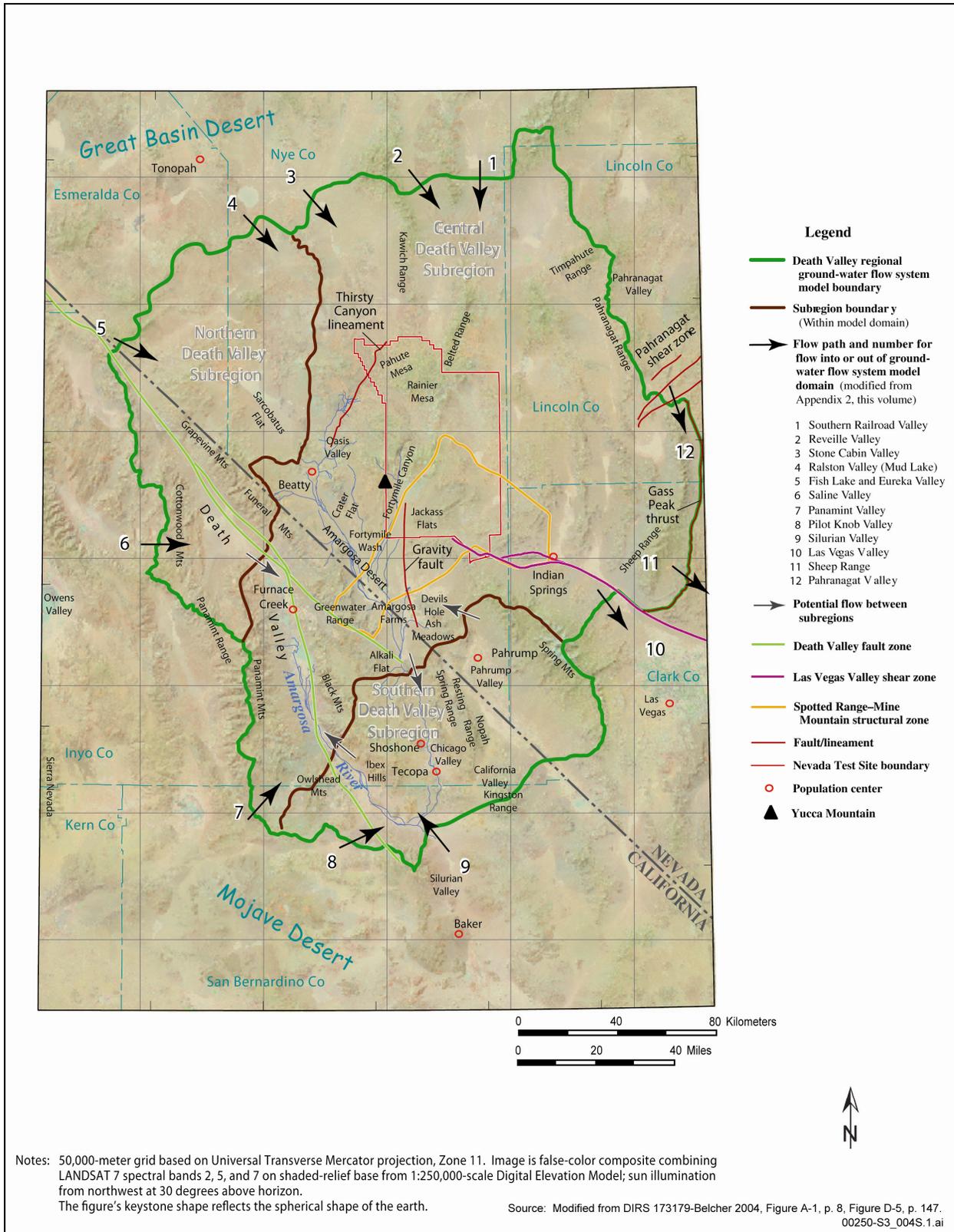
The source of groundwater flow in the region is predominantly from recharge due to infiltration of precipitation that falls within the boundaries of the region, most of which originates in the mountainous areas. Water also enters the regional flow system as throughflow from adjoining groundwater basins, predominantly from the north, west, and south, but the amount of water coming into the system laterally is estimated to be relatively small (roughly 10 percent) in comparison with that coming in as recharge from the surface.

The overall direction of groundwater movement is from the source areas (that is, those primary areas of recharge that are often near the margins of the regional flow system) toward the regional hydrologic sink in the floor of Death Valley. The largest volume of groundwater loss in the region is also in Death Valley in the form of spring discharges and evapotranspiration.

**EVAPOTRANSPIRATION**

Evapotranspiration is the loss of water by evaporation from the soil and other surfaces, including evaporation of moisture emitted or transpired from plants.

The regional flow system is best described in hierarchical terms, which include subregions, basins, and sections, to facilitate discussion and delineate general areas of groundwater recharge, discharge, and movement within the boundaries of the overall flow system. Within the region (Figure S-2), recharge entering the system at Yucca Mountain would be within the central Death Valley subregion.



**Figure S-1.** Boundaries and prominent topographic features of the Death Valley regional groundwater flow system.

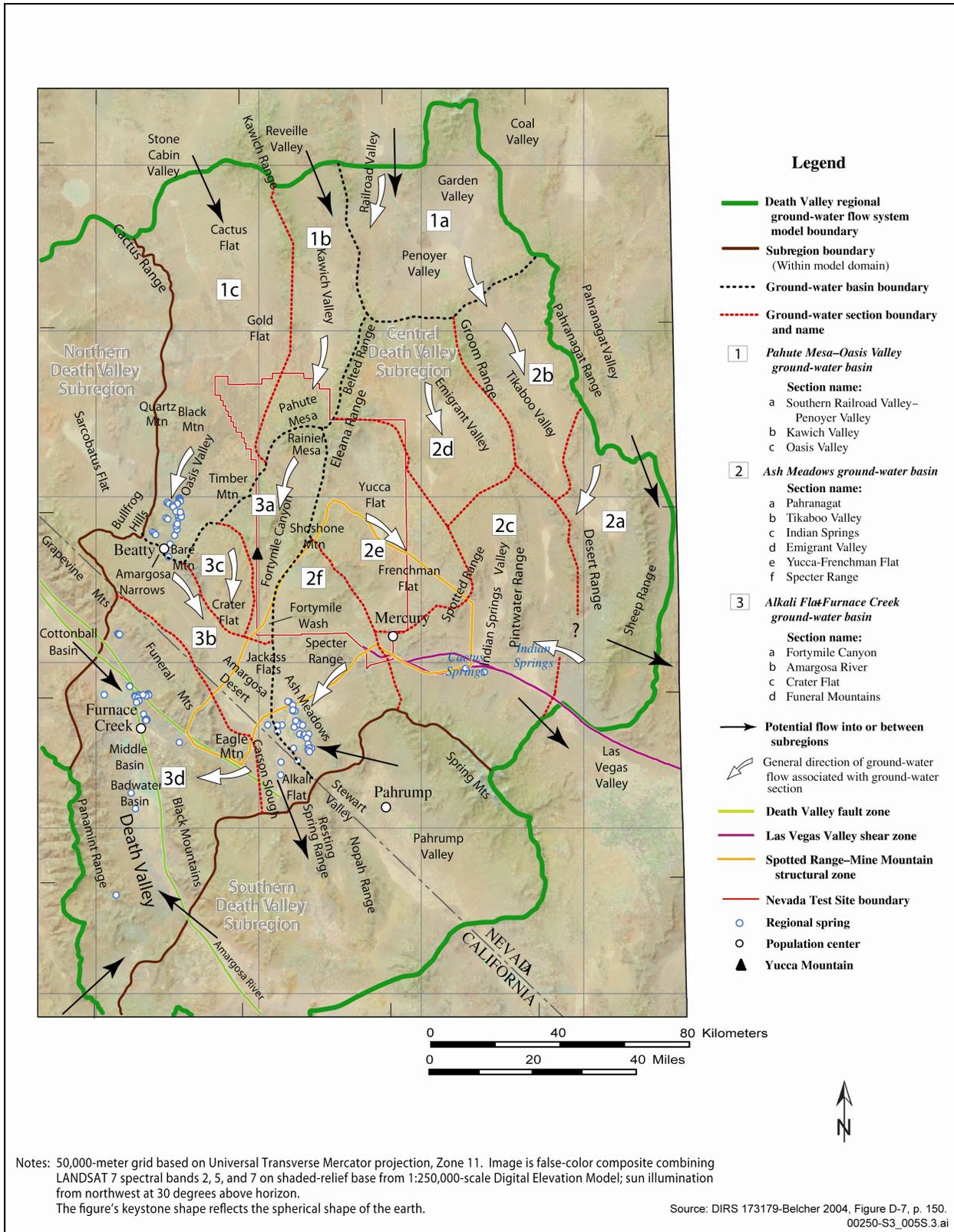
The central Death Valley subregion (Figure S-3) is further divided into three basins: (1) the Pahute Mesa – Oasis Valley groundwater basin; (2) the Ash Meadows groundwater basin; and (3) the Alkali Flat – Furnace Creek groundwater basin, located in the central area of the subregion between the other two basins and extending to the south-southwest. Groundwater in the first two basins generally flows in a southerly direction (and to the southwest in the case of the Ash Meadows groundwater basin), contributing to the Alkali Flat – Furnace Creek groundwater basin, which also generally flows in a southerly direction toward the hydrologic sink that is Death Valley. Yucca Mountain and water infiltrating through the area of the proposed Yucca Mountain Repository are within the Alkali Flat – Furnace Creek basin.

The Alkali Flat – Furnace Creek basin is further divided into four sections (identified by their numbers in Figure S-2): (3a) Fortymile Canyon, (3b) Amargosa River, (3c) Crater Flat, and (3d) Funeral Mountains. The repository at Yucca Mountain would be located within the Fortymile Canyon section, and the natural groundwater flow path from beneath the repository is from that section to the Amargosa River section.

Infiltrating water at Yucca Mountain that reaches the saturated zone, or water table, reaches a volcanic aquifer in the Fortymile Canyon section. The saturated zone at Yucca Mountain is roughly 300 meters (980 feet) below the level of the proposed repository. The lower carbonate aquifer is also present beneath the repository site, but is more than 1,250 meters (4,100 feet) below the repository level. Thus, there is about 950 meters (3,100 feet) between the top of the saturated zone and the top of the lower carbonate aquifer. A well completed to the lower carbonate aquifer at Yucca Mountain indicated a water level, or potentiometric head, in that aquifer about 20 meters (66 feet) higher than the water level in the overlying volcanic aquifer. This demonstrates an upward hydraulic gradient between the lower carbonate aquifer and the volcanic aquifer at this location. The upward gradient, along with the great depth and the intervening confining unit(s), which hinder flow between the aquifers and allow the upward gradient to exist, would prevent any releases from the repository from reaching the lower carbonate aquifer in the area of the repository. Similarly, two other wells, which are farther south than the first well, have been completed to the lower carbonate aquifer. Both of these wells also indicate an upward hydraulic gradient.

At Yucca Mountain, the groundwater in the volcanic aquifer flows to the southeast; then shifts more to the south toward the Amargosa River section. A fault line, the Highway 95 Fault, runs east-to-west in the same general area where the flow system transitions from the Fortymile Canyon section to the Amargosa River section. Subsurface investigations in this area indicate that the Highway 95 Fault is the southern boundary of the volcanic aquifer in the flow path from Yucca Mountain. The volcanic aquifers on the north side of the fault appear to line up with less-permeable Tertiary sedimentary rocks on the south side; thus forcing the southward-flowing groundwater up into the overlying alluvial aquifer system.

Groundwater (both in the alluvial aquifer and in the underlying carbonate aquifer) from the Fortymile Canyon section enters the central part of the Amargosa River section and flows in a southward direction. The majority of the annual groundwater withdrawals in the region (17,600 acre-feet in 2003) occur in the Amargosa River section and are primarily used for irrigation. The largest natural pathway by which groundwater throughflow leaves the Amargosa River section is to the southwest through fractures in the carbonate rocks at the southeastern end of the Funeral Mountains. Throughflow leaving by this route moves into the Funeral Mountains section of the Alkali Flat – Furnace Creek basin, primarily toward the



**Figure S-2.** Central Death Valley subregion of the Death Valley regional groundwater flow system.

springs in the Furnace Creek area of Death Valley or beyond to the floor of Death Valley. The second largest pathway for groundwater losses in the Amargosa River section is through evapotranspiration, primarily in the area of Alkali Flat and including losses along the Amargosa River and Carson Slough in the same general area.

The Funeral Mountains section encompasses the central, lowest portion of Death Valley (Badwater Basin), the Funeral and Black mountains along the northeast boundary of the section, and the eastern slope of the Panamint Range along the southwest boundary. Since Badwater Basin is the low spot of the regional sink that is Death Valley, groundwater throughflow can reach the section from all directions. This includes groundwater moving in from both the northern and southern Death Valley subregions; however, the primary source of groundwater coming into the section is from throughflow in the lower carbonate aquifer in the southern part of the Funeral Mountains.

Along the primary flowpath, throughflow from beneath the Funeral Mountains first encounters the springs of the Furnace Creek area of Death Valley. Groundwater not discharged at the springs, or discharged and reinfiltreated, then moves southwest toward the floor of Death Valley. There, groundwater is either transpired by stands of mesquite on the lower part of the Furnace Creek fan or evaporated from the playas on the floor of Death Valley. The lowest and largest of these playas is Badwater Basin. Other named playas within the Funeral Mountains section include Middle Basin, which is immediately north of Badwater Basin, and Cottonball Basin, which is north of Furnace Creek.

The largest spring discharges for the Funeral Mountains section, as well as for the Alkali Flat – Furnace Creek basin, are those of the Furnace Creek area and include the Texas, Travertine, and Nevares springs. The estimated combined discharge of these springs is 2,300 acre-feet (2.8 million cubic meters) per year, of which more than half is from the Travertine Springs. By far the largest groundwater loss in the section, however, is by evapotranspiration. The estimated annual evapotranspiration loss from the floor of Death Valley is 35,000 acre-feet (43.2 million cubic meters). This estimated quantity, however, includes areas of the Death Valley floor that are within the northern and southern Death Valley subregions as well as the central Death Valley subregion.

Groundwater in the Funeral Mountains section supports federal facilities and those of the Timbisha Shoshone Tribe within Death Valley National Park. Most of the water used to support the Tribe and operations within the park comes from the springs in the Furnace Creek area; some water comes from a single production well. Death Valley is within the traditional homeland of the Timbisha Shoshone Tribe, and some members of that Tribe reside on a 314-acre parcel of trust land located on the floor of Death Valley near Furnace Creek. The springs in the Furnace Creek area are of traditional and cultural importance to members of the Tribe, and the purity of water in those springs is important to tribal spiritual beliefs, culture, and heritage.

Under a climate that was cooler and wetter than today, the groundwater flow paths would be basically the same as for the present day. Because of potentially higher water levels, however, there would likely be additional natural discharge locations consistent with identified paleodischarge sites.

### **S.3 Environmental Impacts of Postclosure Repository Performance**

**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 Repository SEIS analyzed the transport of radionuclides out of the repository to a location 18 kilometers south of the repository and reported impacts to a hypothetical reasonably maximally exposed individual. The assessments of environmental impacts in this Analysis of Postclosure Groundwater Impacts focus on the effects of long-term transport of radiological and nonradiological contaminants beyond this Regulatory Compliance Point. The analysis starts at the point where contaminants would be released from the unsaturated zone to the saturated zone underneath the repository. For the radionuclides, DOE used results from TSPA-LA to characterize

the release from the unsaturated zone, transport of radionuclides in the saturated zone to the Regulatory Compliance Point, and release of the radionuclides into the volcanic-alluvial aquifer beyond the Regulatory Compliance Point. From the Regulatory Compliance Point, DOE performed further analysis to track radionuclides out into the Amargosa Desert and Death Valley. For nonradiological contaminants, DOE used a modified version of the bounding release analysis of these contaminants from the Repository SEIS and used the same methods for saturated zone transport beyond the Regulatory Compliance Point as those used for the radiological contaminants.

The U.S. Nuclear Regulatory Commission staff identified a need for additional evaluations of the impacts of contaminants released from the repository at locations beyond this Regulatory Compliance Point. In response, DOE performed the following analyses:

- Traced the release and movement of contaminants from the repository into the aquifer system up to and beyond the Regulatory Compliance Point, including releases at discharge sites. Assessed the cumulative amounts entering and leaving the aquifer system and the accumulation within the system; and
- Assessed the impacts resulting from the release, movement, and accumulation of contaminants throughout the region;

The analyses followed these steps:

- Used the regional groundwater flow model to define the potential paths contaminants could take after exiting the repository and transporting to the Regulatory Compliance Point and beyond into the region. This modeling also identified natural discharge points;
- Performed transport analyses of contaminants along the flow paths developed from the regional groundwater model to natural discharge or pumped withdrawal points;
- Analyzed human health impacts from radiological and nonradiological contaminants at points where contaminants interact with the biosphere (that is, natural discharge and pumped withdrawal points);
- Analyzed soil concentrations at pumped discharge sites; and

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

### **3.3.1 ANALYTICAL FRAMEWORK FOR THE ANALYSIS OF POSTCLOSURE GROUNDWATER IMPACTS**

DOE developed an analytical method for this document to evaluate the potential range of environmental impacts that could occur within a 1-million-year postclosure period. The analyses assumed that the current population, its distribution, and current land uses would all remain as they are today.

DOE also evaluated other primary variables, such as future climatic conditions and groundwater withdrawals, by establishing a reasonable range of possibilities and preparing a set of analytical constructs that, when evaluated, provide a perspective on the range of impacts that could occur to the environment over the 1-million-year period.

DOE analyzed two separate climate conditions: the present climate and a future, wetter climate. The wetter climate considered in this analysis is consistent with the post-10,000-year climate used in the TSPA-LA, which is almost four times wetter than the present climate. In this Analysis of Postclosure Groundwater Impacts, for each climate condition, DOE held the climate constant for the entire 1 million years.

Groundwater pumping can lead to changes in the hydraulic gradients and therefore alter the direction and rate of groundwater flow in the region. The results of the groundwater modeling show that different flow paths result from different pumping scenarios. In this Analysis of Postclosure Groundwater Impacts, DOE evaluated two pumping scenarios: (1) a pumping scenario that continues the 2003 pumping rates in the Amargosa Farms area for the entire 1-million-year postclosure period, and (2) a no-pumping scenario that analyzes the cessation of all pumping in the region for the entire 1-million-year postclosure period.

To evaluate the effects of these two pumping scenarios, DOE extended flow and transport simulations to physical locations beyond those the TSPA-LA model addressed. Output from the TSPA-LA model was used 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 capability allowed a simulation of adding particles (representing contaminants) at locations within the model and then tracking the particles 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). DOE 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 the two pumping scenarios to determine how the flow paths would change under differing conditions imposed on the model.

Under the pumping scenario, the model predicts that all of the particles would be withdrawn from the wells at the Amargosa Farms area (Figure S-3). Under the no-pumping scenario, the model shows the particles initially traveling to the south from the Regulatory Compliance Point and essentially all of the particles eventually 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 Middle Basin playa (Figure S-4). There is a small particle trace that continues to the south to discharge at Alkali Flat (also referred to as Franklin Lake Playa) and another

small particle trace that travels farther south in Death Valley toward Badwater Basin. While the model predicts discharge from the alluvial aquifer on the floor of Death Valley, it cannot be precluded that contaminants could mix with carbonate waters and discharge at the springs in the Furnace Creek area; therefore, this Analysis of Postclosure Groundwater Impacts also evaluates the potential impacts of the complete contaminant plume discharging into these springs.

Considering the variables described above, this document evaluates potential environmental impacts for the following analytical constructs:

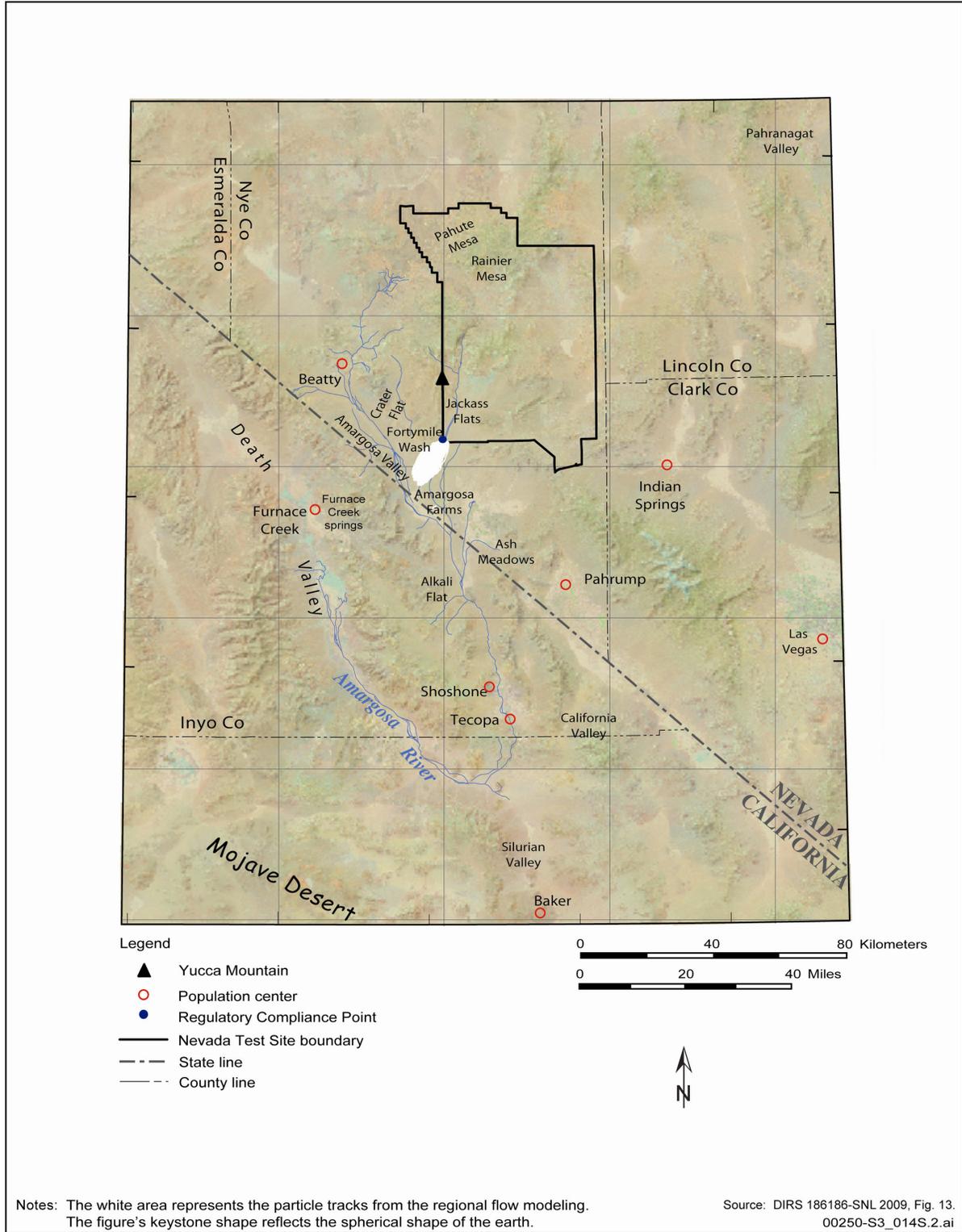
- Pumping scenario, present climate, Amargosa Farms area
- Pumping scenario, wetter climate, Amargosa Farms area
- No-pumping scenario, present climate, floor of Death Valley at Middle Basin
- No-pumping scenario, wetter climate, floor of Death Valley at Middle Basin
- No-pumping scenario, present climate, Furnace Creek springs area
- No-pumping scenario, wetter climate, Furnace Creek springs area

In addition, because the particle-tracking analysis indicates that some particles could flow to Alkali Flat, DOE assessed the potential impacts of discharges at that location. These results are presented in comparison with those at Middle Basin.

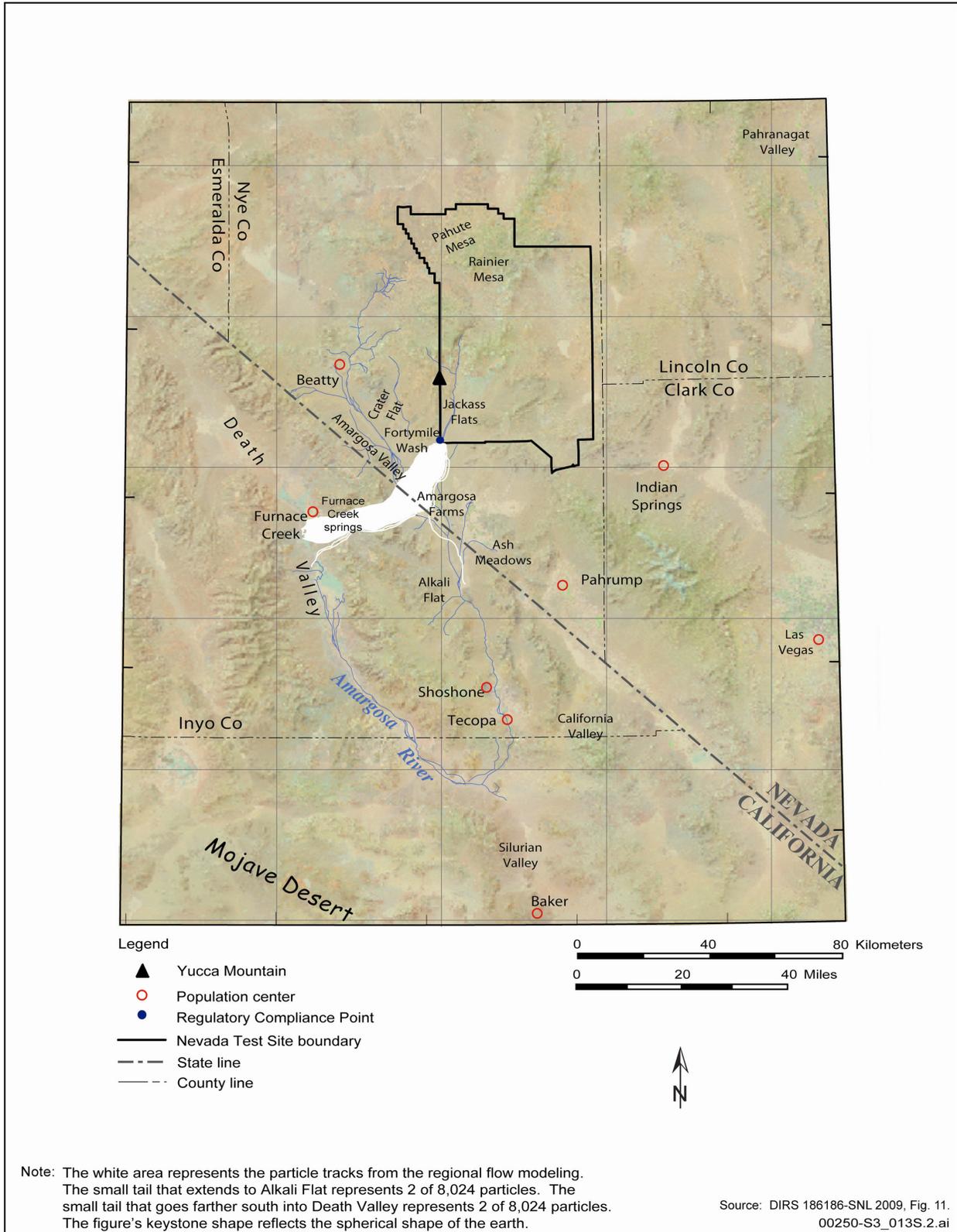
Under these constructs and the assumptions behind them, there would be no natural discharge of contaminants under the pumping scenario; therefore, there would be no impacts at Death Valley. Similarly, under the no-pumping scenario, there would be no withdrawals and, therefore, no impacts in the Amargosa 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.

For each scenario, DOE estimated the total annual dose from exposure to radionuclides and daily intake of nonradiological contaminants for a full-time resident living at the discharge area. DOE further estimated the annual dose and daily intake for a resident near the Amargosa Farms area for the pumping scenario based on the characteristics of agricultural production in Amargosa Valley and the behaviors and lifestyles of the residents in that area. DOE used similar methods to estimate dose and intake for a resident of Death Valley resulting from the discharge of contaminants at springs in the Furnace Creek area, but did not include exposure pathways related to ingestion of contaminated foodstuffs. These pathways were not included because there is no large-scale agricultural production in Death Valley.

To estimate the annual dose and daily intake for a resident of Death Valley resulting from the discharge of contaminants at the Death Valley floor, DOE calculated the concentration of contaminants in evaporite minerals that would precipitate onto the surface of the wet playa in Middle Basin. At wet playas in Death Valley and the surrounding region (that is, playas where groundwater is near the ground surface), capillary action brings water to the surface, resulting in evaporation of groundwater and deposition of the minerals in that groundwater. Radiological and nonradiological contaminants from a repository at Yucca Mountain would occur as trace amounts in the dissolved solids in groundwater and would precipitate with those dissolved solids. Because there would be no mechanism for preferential precipitation of



**Figure S-3.** Groundwater flow paths for the pumping scenario.



**Figure S-4.** Groundwater flow paths for the no-pumping scenario.

contaminants, DOE estimated the concentration of contaminants in the evaporite minerals based on the ratio of contaminants to total-dissolved-solids in the groundwater. To estimate the health impact from exposure to contaminants in the evaporite material, DOE considered three pathways: external exposure, inhalation of resuspended particulates, and inadvertent ingestion of soil. The consequences of ingesting water from Middle Basin and using that water for other purposes were not included because that water would be brackish, and better-quality water would be available from the springs and wells in the Furnace Creek area.

### **S.3.2 ANALYTICAL RESULTS**

The results in this Analysis of Postclosure Repository Impacts are segregated by radiological and nonradiological contaminants.

#### **S.3.2.1 Radiological Impacts Health Impacts**

DOE estimated the total annual dose for a full-time resident as a function of time for the 1-million-year postclosure period. Table S-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 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. This probability represents the chance that a person exposed to the dose for 70 years would die from a cancer induced by that dose. Note that the probabilities in Table S-1 are very small (on the order of 1 chance in a million at the highest level).

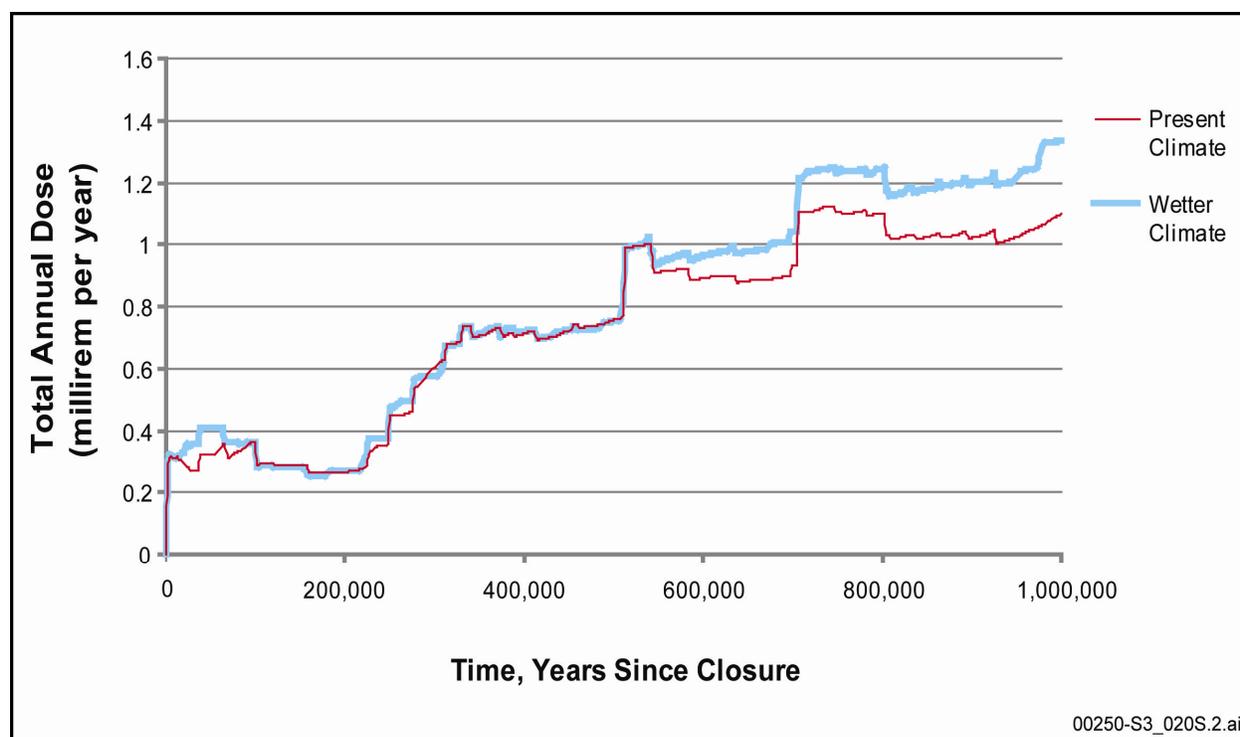
As a point of comparison, the mean peak annual dose during 10,000 years after closure presented in the Repository SEIS for the reasonably maximally exposed individual at the Regulatory Compliance Point was 0.24 millirem per year, and the mean peak annual dose during 1 million years after closure was 2.0 millirem per year. All of the doses in Table S-1 are less than or about equal to these doses.

Figures S-5 to S-8 summarize the trends of the total annual dose over time at the three locations; that is, the Amargosa Farms area, Middle Basin, and Furnace Creek springs. In the present climate, radionuclides that have no adsorption to slow their travel (specifically, iodine-129 and technetium-99) dominate dose at the Amargosa Farms area. During the wetter climate, some slower-moving radionuclides, such as plutonium-242, contribute significantly to the total dose at that area (at least for a limited time).

If, for the no-pumping scenario, the entire flow of contaminants were to divert to Alkali Flat, the total annual dose could be as much as twice that calculated for the Middle Basin because the current, measured rate of evapotranspiration at Alkali Flat is about half that at Middle Basin, and the dose would be inversely proportional to the evapotranspiration rate. This qualitative approach is very conservative because if all of the contaminants were to divert to Alkali Flat, the evapotranspiration rate at that location would likely have increased from its current value.

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

Scenario	Peak annual dose (millirem per year)		Probability of a latent cancer fatality (per year)	
	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	$2.2 \times 10^{-1}$	1.1	$1.3 \times 10^{-7}$	$6.7 \times 10^{-7}$
Amargosa Farms area, pumping, wetter climate	$2.5 \times 10^{-1}$	1.3	$1.5 \times 10^{-7}$	$8.0 \times 10^{-7}$
Middle Basin, no-pumping, present climate	0.0	$1.6 \times 10^{-1}$	0.0	$9.5 \times 10^{-8}$
Middle Basin, no-pumping, wetter climate	$1.5 \times 10^{-2}$	$4.2 \times 10^{-2}$	$8.9 \times 10^{-9}$	$2.5 \times 10^{-8}$
Furnace Creek springs area, no-pumping, present climate	0.0	$3.4 \times 10^{-1}$	0.0	$2.1 \times 10^{-7}$
Furnace Creek springs area, no-pumping, wetter climate	$2.3 \times 10^{-2}$	$8.9 \times 10^{-2}$	$1.4 \times 10^{-8}$	$5.4 \times 10^{-8}$



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

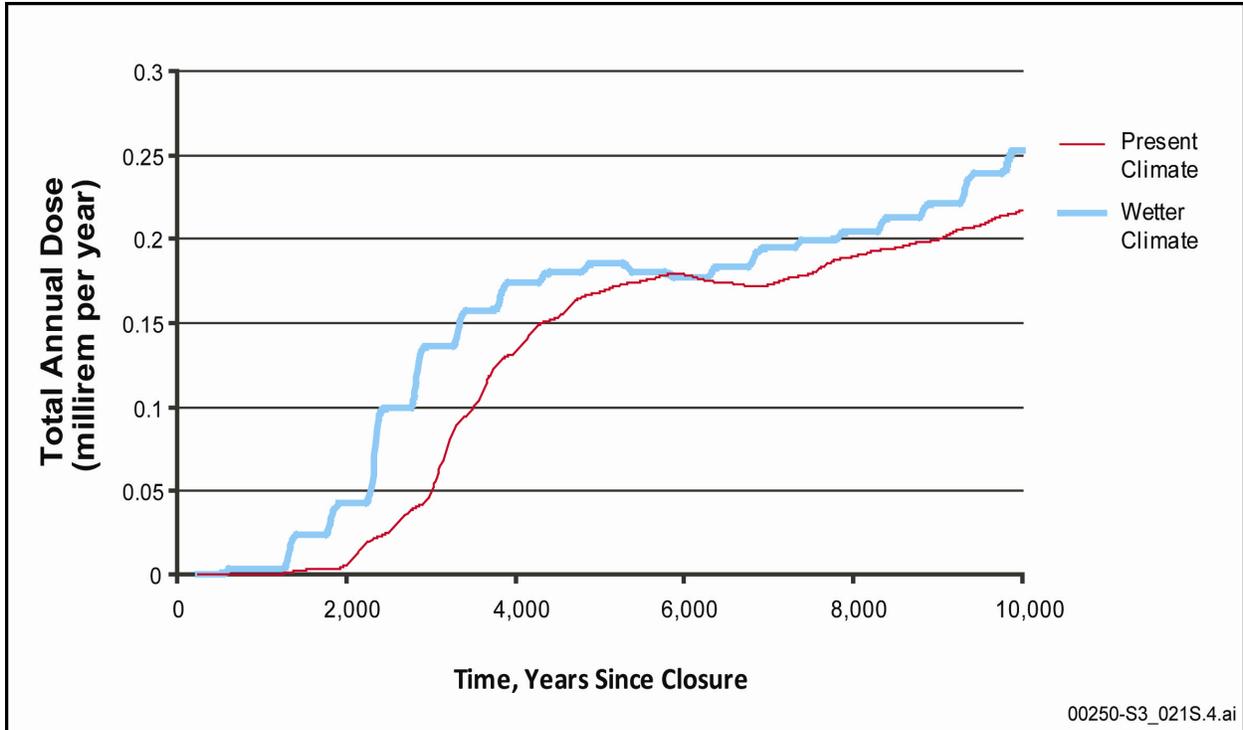


Figure S-6. Total annual dose at the Amargosa Farms area for the first 10,000 years.

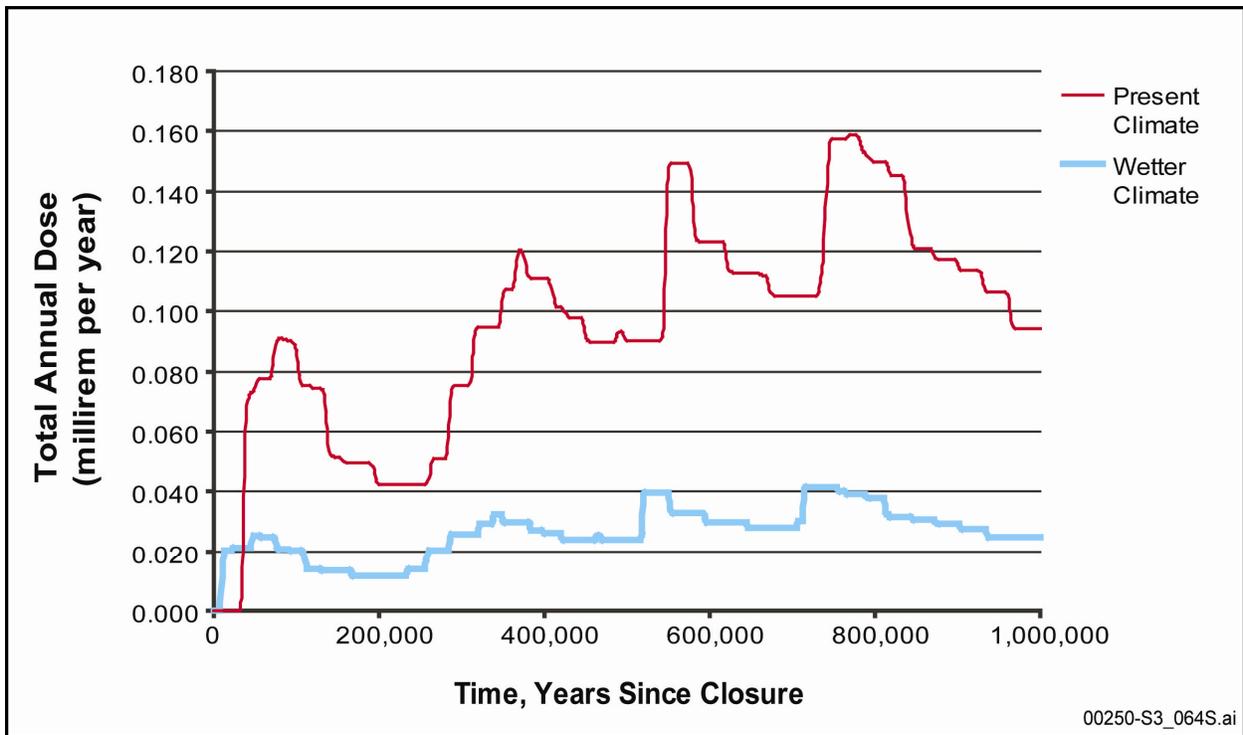


Figure S-7. Total annual dose at Middle Basin.

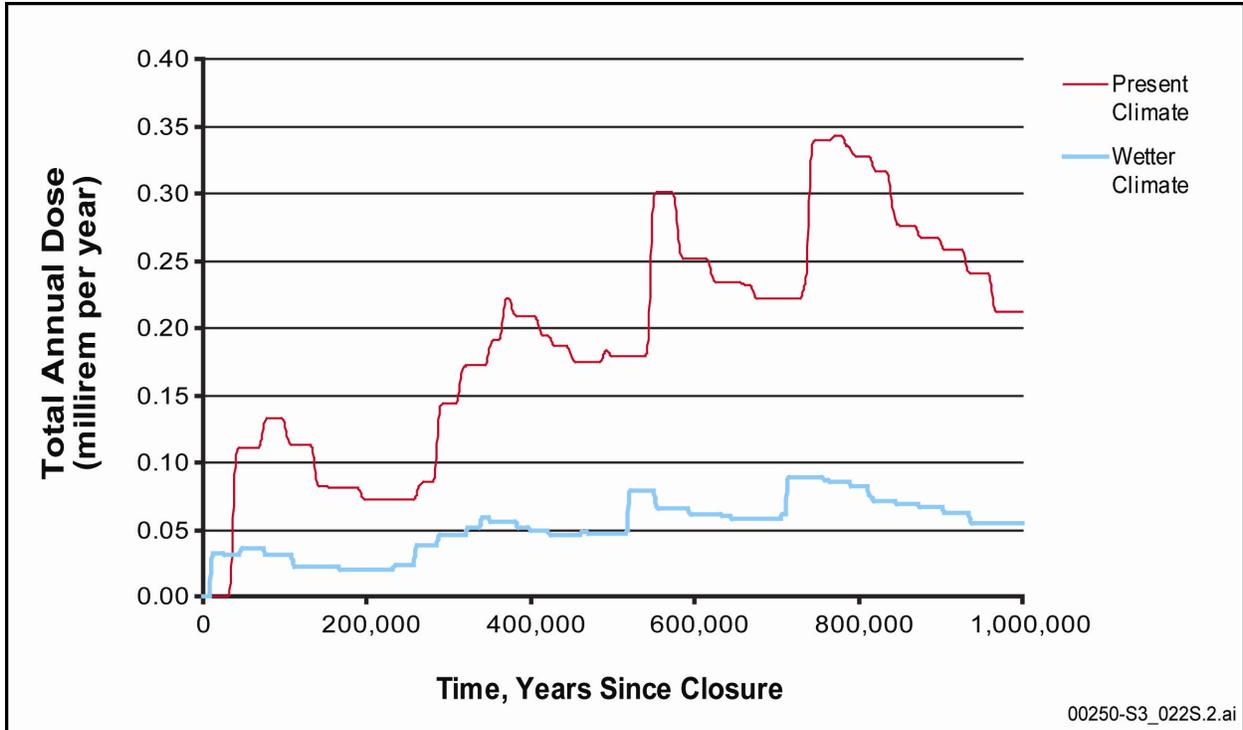


Figure S-8. Total annual dose at the Furnace Creek springs area.

**S.3.2.2 Nonradiological Health Impacts**

The nonradiological contaminants this Analysis of Postclosure Groundwater Impacts considered include molybdenum, nickel, vanadium, and uranium. Uranium is included as both a radiological and nonradiological contaminant 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 the U.S. Environmental Protection Agency’s Oral Reference Dose standard. 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 per day. For exposure at Middle Basin, DOE calculated the daily intake due to inhalation and inadvertent ingestion of soil. Table S-2 summarizes the estimated daily intakes of the nonradiological contaminants. The bottom row of the table shows EPA’s Oral Reference Doses. All intakes are below their associated Oral Reference Dose.

Figures S-9 and S-10 present detailed plots of the daily intakes of nonradiological contaminants for the Amargosa Farms area for the present and wetter climates, respectively. Figures S-11 and S-12 show estimated daily intakes of molybdenum at the Furnace Creek springs area for the present and wetter climates, respectively.

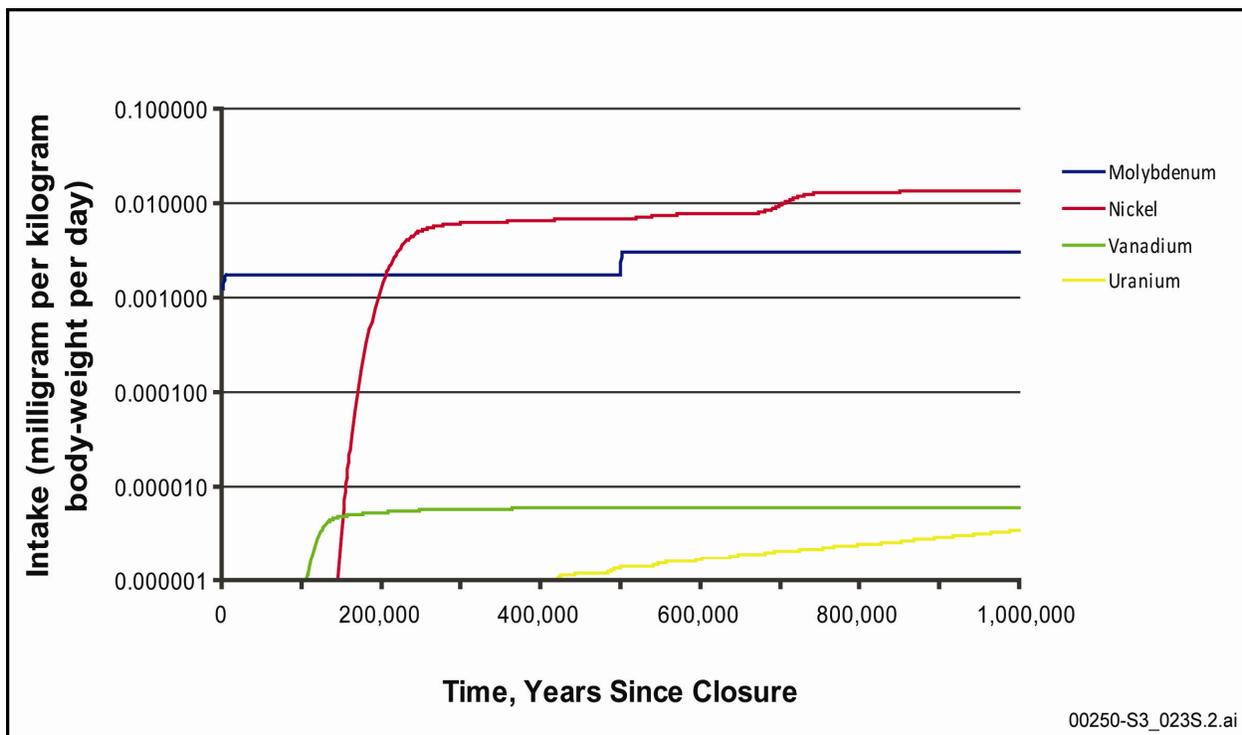
**Table S-2.** Daily intakes of the nonradiological contaminants.

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

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.

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



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

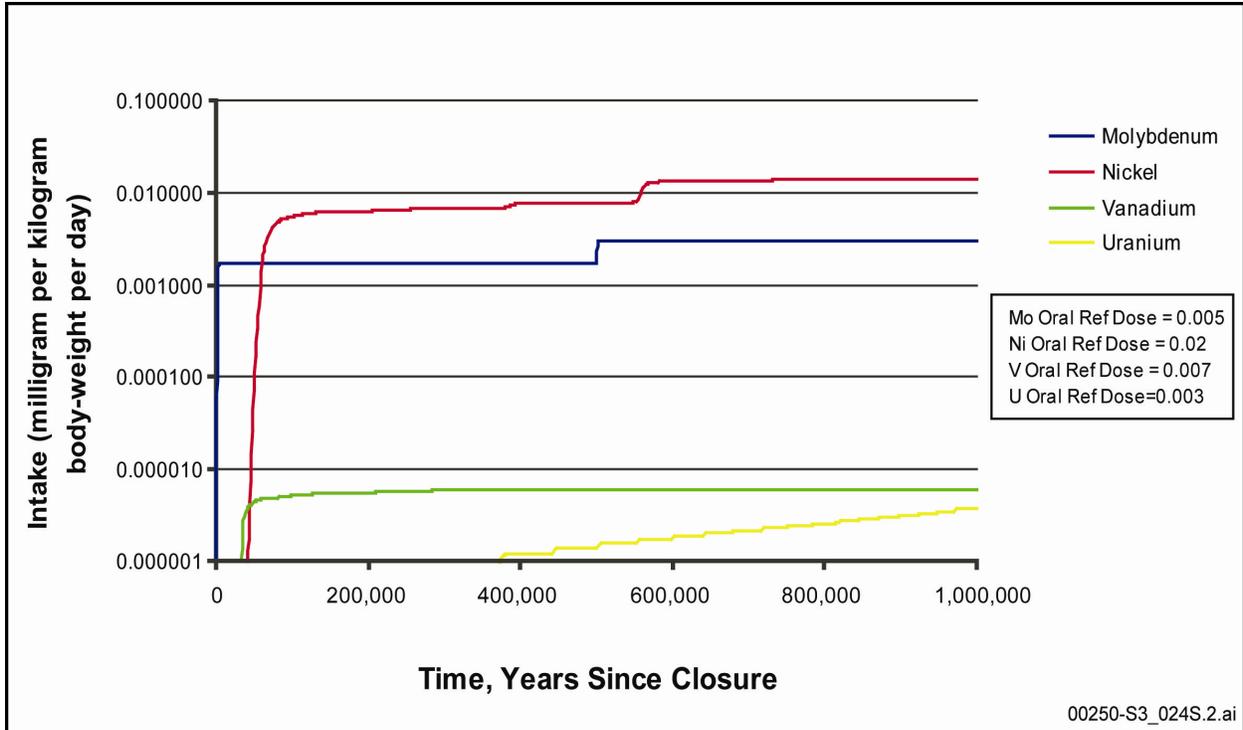


Figure S-10. Daily intakes of nonradiological contaminants at the Amargosa Farms area, wetter climate.

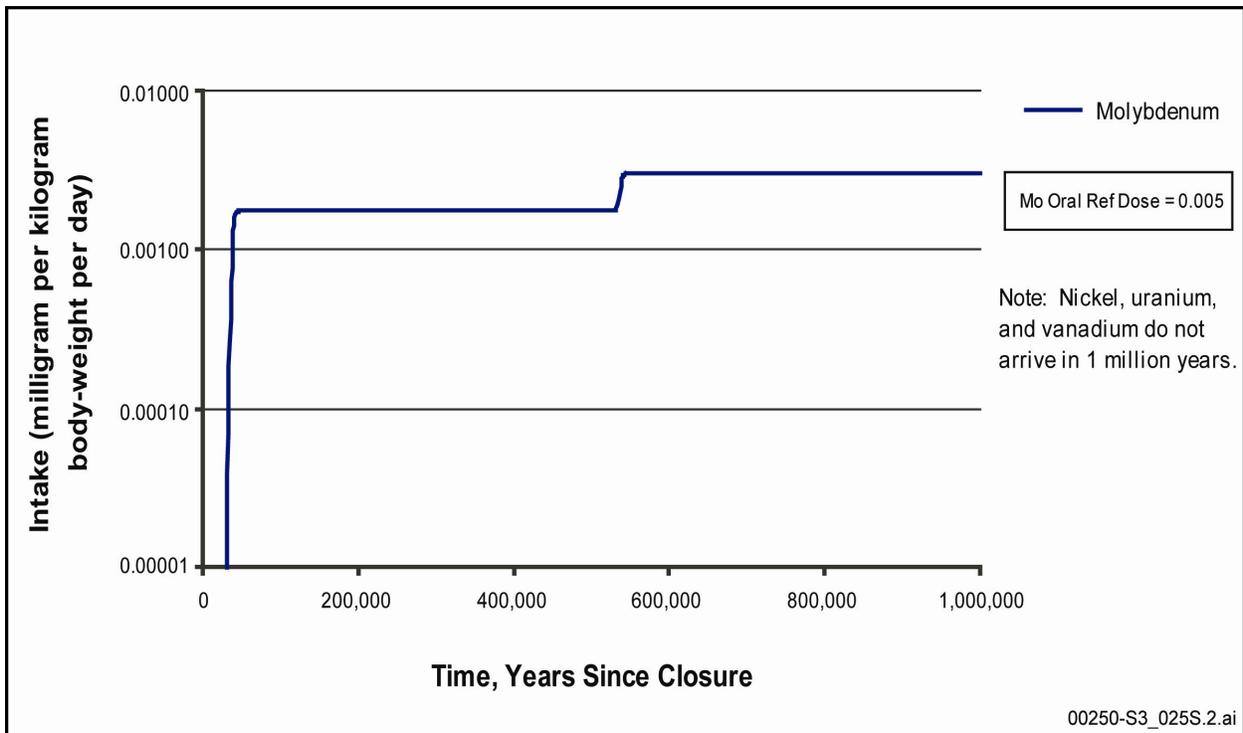
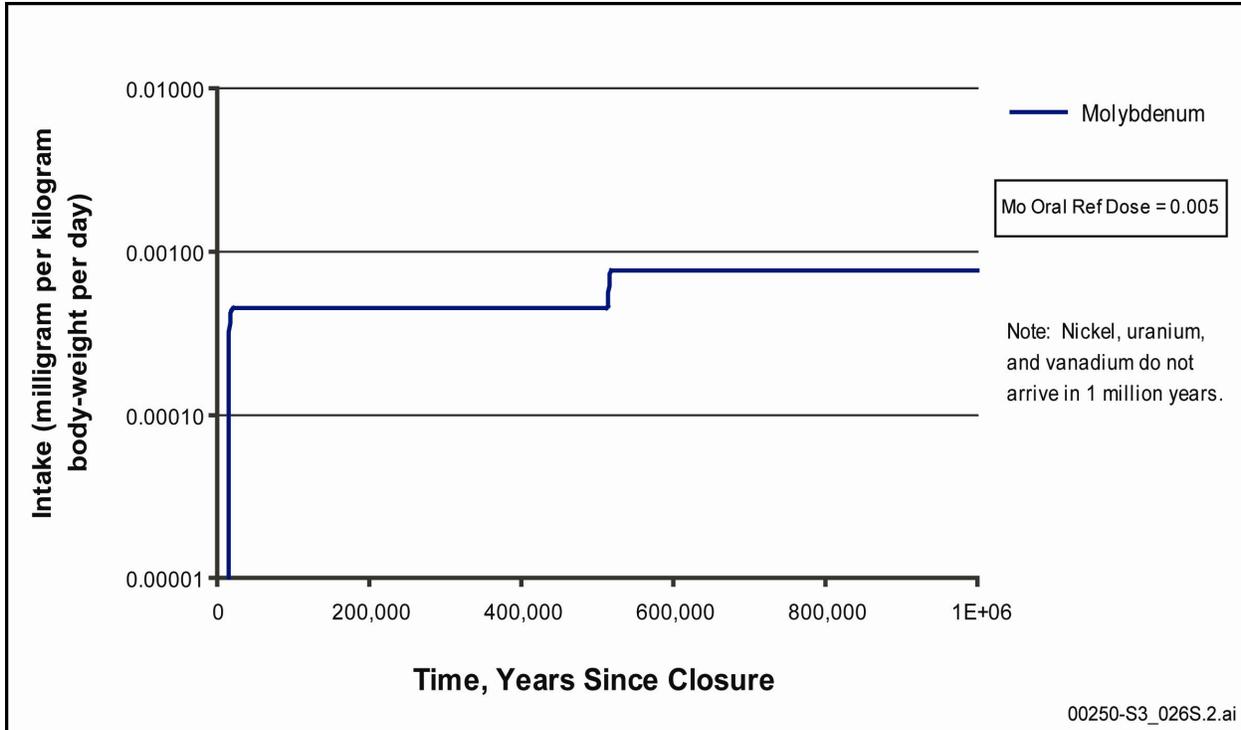


Figure S-11. Molybdenum daily intakes at Furnace Creek springs, no-pumping, present climate.



**Figure S-12.** Molybdenum daily intakes at Furnace Creek springs, no-pumping, wetter climate.

### S.3.3 AMERICAN INDIAN CONCERNS

This Analysis of Postclosure Groundwater Impacts describes the possibility that groundwater that flows under Yucca Mountain could discharge at the floor of Death Valley or at springs in the Furnace Creek area of Death Valley. The springs in the Furnace Creek area 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. Therefore, DOE has further considered potential impacts to cultural resources and American Indian concerns.

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 analyses contained in this document demonstrate 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 the springs. Thus, this document supports the Department’s previous conclusion that no disproportionately high and adverse impacts would result from the proposed repository.

### S.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). 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