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

SUMMARY

U.S. DEPARTMENT OF ENERGY

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S.1 Introduction

S.1.1 BACKGROUND INFORMATION

The *Nuclear Waste Policy Act*, as amended (NWPA) directed the Department of Energy (DOE) to evaluate the Yucca Mountain site in Nye County, Nevada as a potential location for a geologic repository. A geologic repository for spent nuclear fuel and high-level radioactive waste would permanently isolate radioactive materials in a deep subsurface location to limit risk to the health and safety of the public.

The NWPA also directed the Secretary of Energy, if the Secretary were to decide to recommend approval of the Yucca Mountain site for development of a repository, to submit a final environmental impact statement (EIS) with a recommendation to the President of the United States. DOE 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 to fulfill that requirement. 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 Final SEIS), which addressed modifications to repository design and operational plans.

The Yucca Mountain 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 a repository.

The basic elements of the Proposed Action that the Repository Final SEIS evaluated did not change from those evaluated in the Yucca Mountain FEIS. As described in the Repository Final SEIS, the surface and subsurface facilities would allow DOE to operate a 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. Under the Proposed Action, 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.

On June 16, 2008, DOE submitted the Repository Final SEIS to the U.S. Nuclear Regulatory Commission (NRC), and on July 11, 2008, the U.S. Environmental Protection Agency announced in the *Federal Register* the availability of the Repository Final SEIS (73 FR 39958).

On September 8, 2008, the NRC staff issued a Notice of Acceptance to the DOE, 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 (NRC staff's Adoption Determination Report). In its Adoption Determination 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 neither the Yucca Mountain FEIS nor the Repository Final SEIS adequately addressed impacts on groundwater or from surface discharges of groundwater from contaminants that may enter the groundwater over time from a repository at Yucca Mountain.

In response to the NRC staff's Adoption Determination Report, DOE prepared an *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 Analysis of Postclosure Groundwater Impacts was submitted to the NRC on July 30, 2009.

In September 2011, the Yucca Mountain licensing proceedings were suspended, at NRC's direction, due to budgetary limitations.

On August 13, 2013, the U.S. Court of Appeals for the District of Columbia Circuit ordered the NRC to continue with the licensing process for the Yucca Mountain application. The NRC issued an order on November 18, 2013, setting forth the agency's plans for responding to the D.C. Circuit order.

On February 28, 2014, DOE notified the NRC that DOE would prepare an updated version of the *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,* submitted to the NRC in July 2009.

DOE undertook a review of the data and analyses used to prepare the Analysis of Postclosure Groundwater Impacts in 2009. The following bullets identify the primary changes that were included in this update to the 2009 Analysis as a result of that review:

- Chapter 1
    - Update of the history leading to this revision to the technical report.
- Chapter 2
    - The USGS re-issued its Scientific Investigations Report from 2004 on the Death Valley regional groundwater flow system model under the same title, *Death Valley Regional Groundwater Flow System, Nevada and California – Hydrogeologic Framework and Transient Groundwater Flow Model*. It was issued as Professional Paper 1711 in 2010. There were no technical changes to the model, however, this Analysis of Postclosure Groundwater Impacts refers to both documents.
    - Minor updates of pumping data and clarifications of text.
- Chapter 3 and Appendix B
    - Minor changes in the Yucca Mountain TSPA-LA biosphere model methodology applied at the Regulatory Compliance Point, arising from a response to an NRC Request for Additional Information
    - DOE reviewed more recent international research on sorption of non-radiological contaminants onto soil.
    - Minor corrections.

S.1.2 SCOPE OF THE POSTCLOSURE GROUNDWATER IMPACT ANALYSIS

This Analysis of Postclosure Groundwater impacts addresses the information identified by the NRC staff as needed to supplement DOE's Yucca Mountain FEIS and Repository Final SEIS. 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 Final SEIS.

The NRC staff's Adoption Determination 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 Yucca Mountain FEIS and Repository Final SEIS.

- 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 the 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 (now the Nevada National Security 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 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-1; *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.

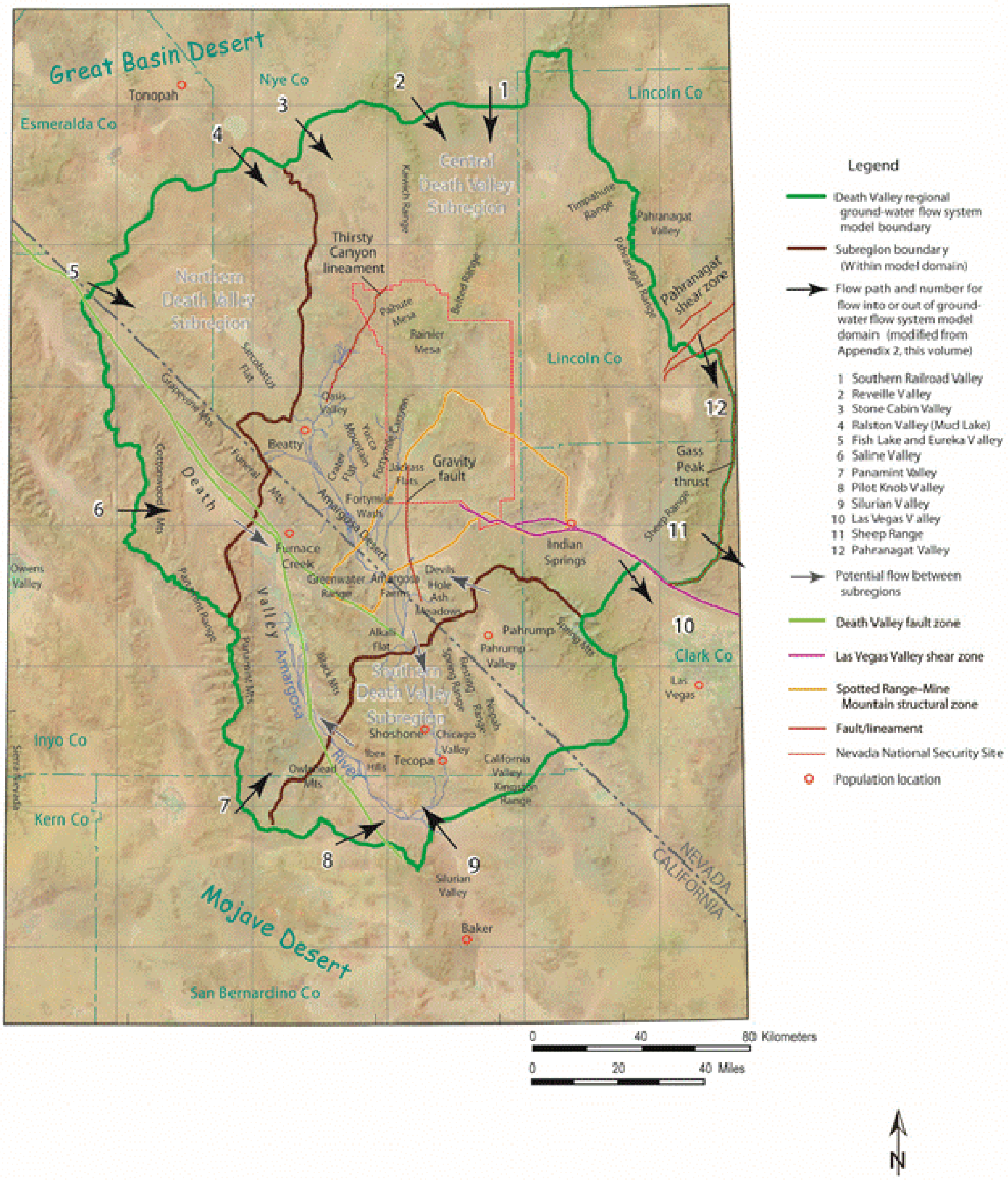
The overall direction of groundwater movement is from the source areas (that is, those primary areas of recharge that are often near the margins of the regional flow system) toward the regional hydrologic sink in the floor of Death Valley. The largest volume of groundwater loss in the region is also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

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.

EVAPOTRANSPIRATION

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

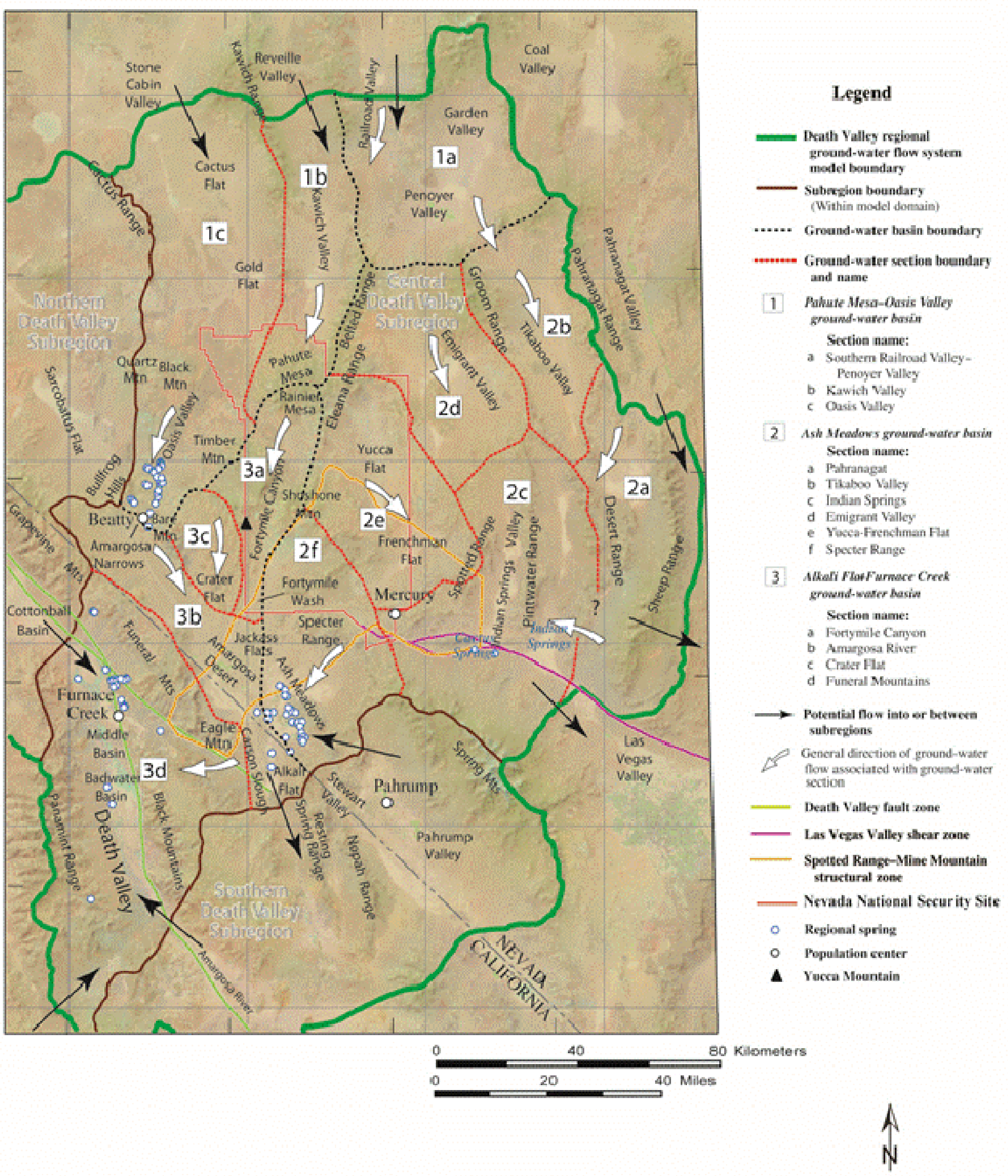
The central Death Valley subregion (Figure S-2) is further divided into three basins: (1) the Pahute Mesa – Oasis Valley groundwater basin; (2) the Ash Meadows groundwater basin; and (3) the Alkali Flat – Furnace Creek groundwater basin, located in the central area of the subregion between the other 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 a repository at Yucca Mountain are within the Alkali Flat – Furnace Creek basin.



Note: 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.

Source: Belcher 2004, Figure A-1, p. 8, Figure D-5, p. 147.

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



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: Belcher 2004, Figure D-7, p. 150.

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

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 analyzed repository at Yucca Mountain would be located within the Fortymile Canyon section, and the natural groundwater flow path from beneath the analyzed 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 analyzed repository. The lower carbonate aquifer is also present beneath the analyzed 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 analyzed repository from reaching the lower carbonate aquifer in the area. 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 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 reinfiltrated, 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 by the EPA and indicated by NRC at 10 CFR 63.312(a) as the point of compliance for calculating dose with respect to the postclosure individual protection, human intrusion, and groundwater protection standards, based on the definition of the controlled area in 10 CFR 63.302. The TSPA-LA calculates radiological dose to a reasonably maximally exposed individual located at a point on the Nevada National Security Site boundary (36°40’13.66661” North Latitude) that is approximately 18 kilometers south of the analyzed repository footprint in the predominant direction of groundwater flow.

The Repository Final SEIS analyzed the transport of radionuclides out of the analyzed 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 non-radiological 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 analyzed 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 non-radiological contaminants, DOE used a modified version of the bounding release analysis of these contaminants from the Repository Final SEIS and used the same methods for saturated zone transport beyond the Regulatory Compliance Point as those used for the radiological contaminants.

The NRC staff identified a need for additional evaluations of the impacts of contaminants at locations beyond this Regulatory Compliance Point. In response, DOE performed the following analyses:

- Traced the release and movement of contaminants from the analyzed 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;

The analyses followed these steps:

- Used the regional groundwater flow model to define the potential paths contaminants could take after exiting the analyzed 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 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.

S.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.

The site-scale saturated zone flow model and the Death Valley regional groundwater flow system model both include particle-tracking capabilities. This capability allows a simulation of adding particles (representing contaminants) at locations within the model and then tracking the particles as they move 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.

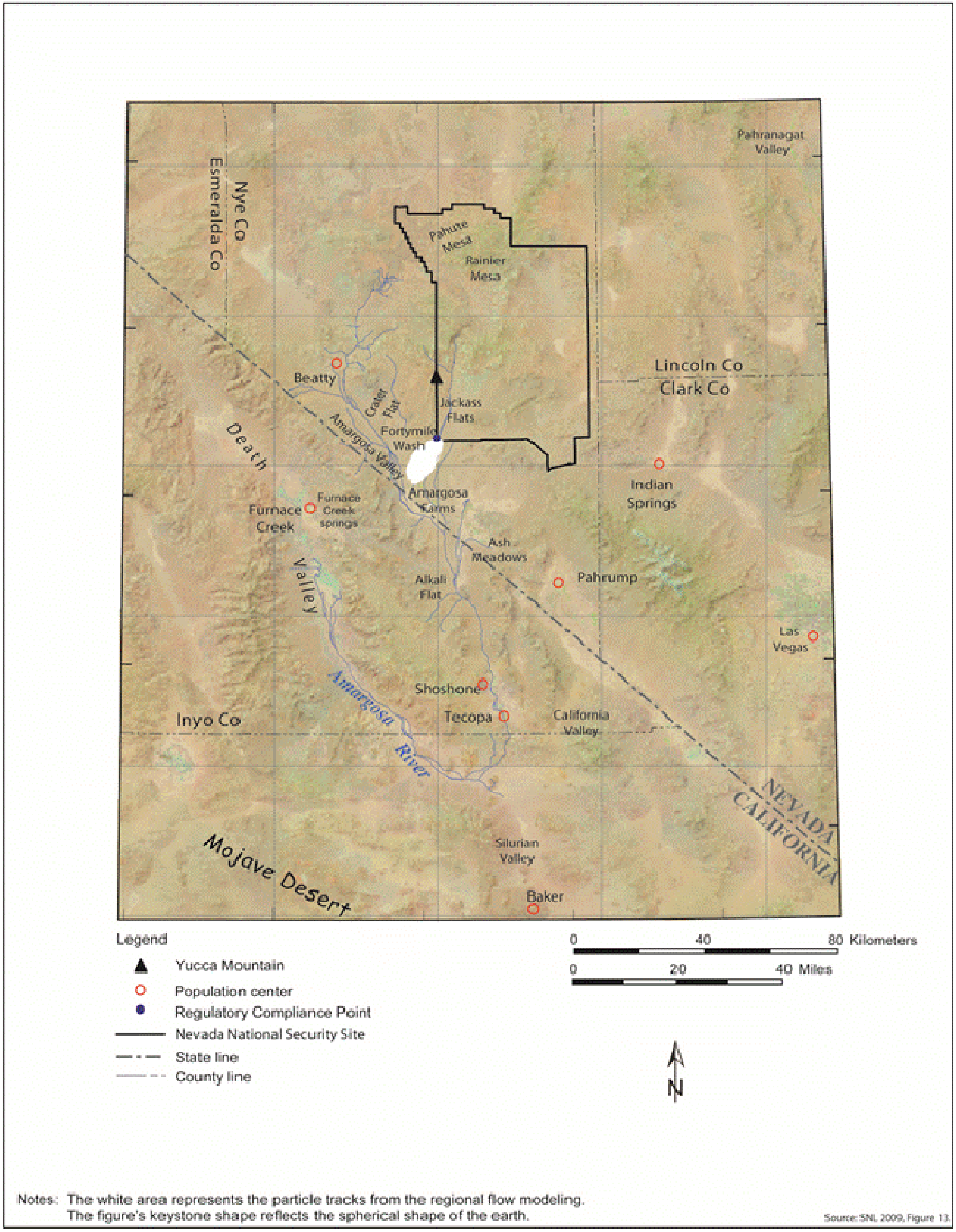
Under the pumping scenario, the model predicts that all of the particles would be withdrawn from the wells at the Amargosa Farms area (Figure S-3). Under the no-pumping scenario, the model shows the particles initially traveling to the south from the Regulatory Compliance Point and essentially all of 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

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. Because it is likely that future events would lie on a spectrum between the two end member scenarios, the analysis of the two scenarios ensures this Analysis of Postclosure Groundwater Impacts does not underestimate the impacts at these locations.

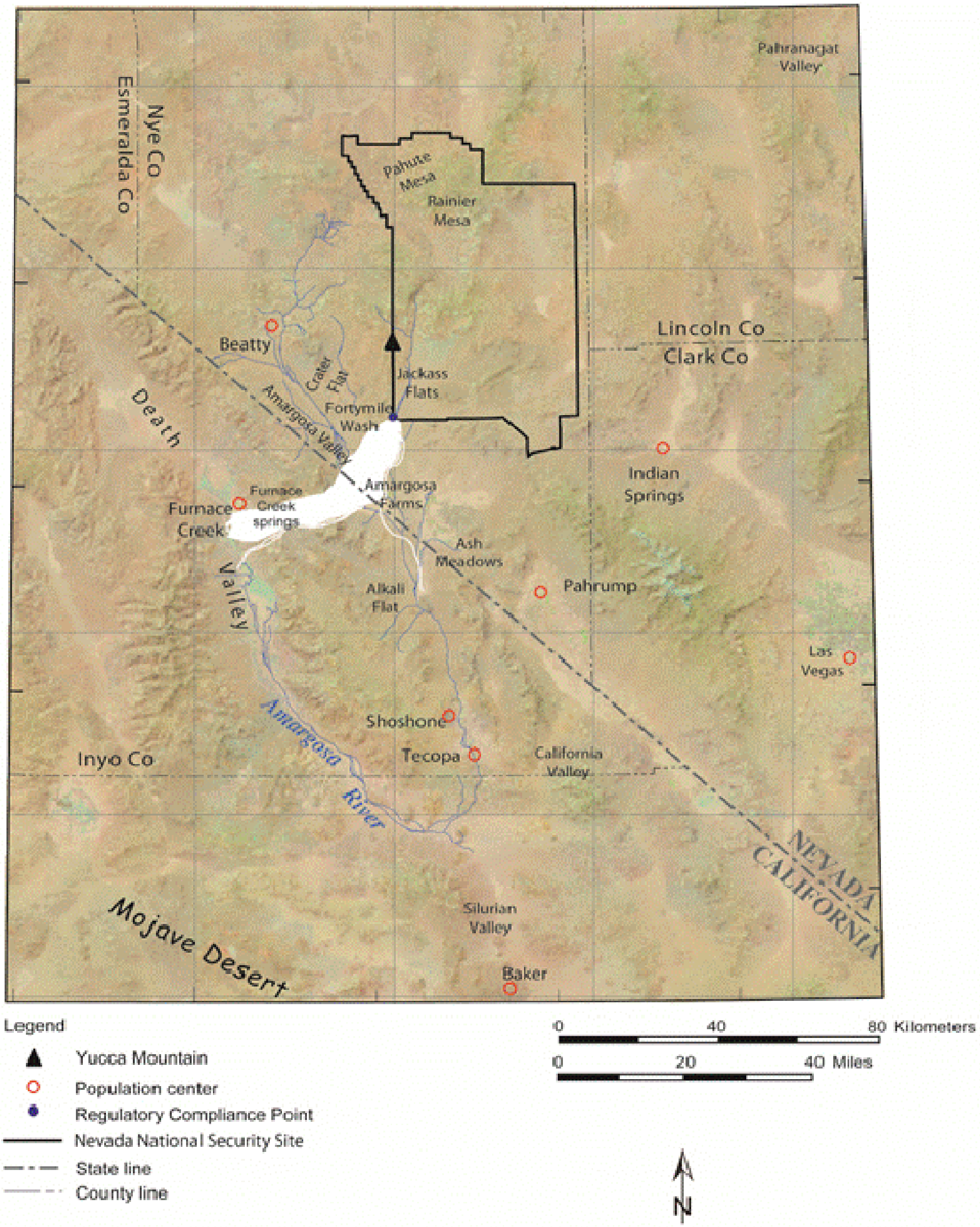
For each scenario, DOE estimated the total annual dose from exposure to radionuclides and daily intake of non-radiological contaminants for a full-time resident living at the discharge area. DOE further estimated the annual dose and daily intake for a resident near the Amargosa Farms area for the pumping 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.



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: SNL 2009, Figure 13.

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



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: SNL 2009, Figure 11.

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

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 non-radiological 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 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 non-radiological 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 radiological 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 Final 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).

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

Scenario	Peak annual dose (millirem per year): 10,000 years after closure	Peak annual dose (millirem per year): 1,000,000 years after closure	Probability of latent cancer fatality (per year): 10,000 years after closure	Probability of latent cancer fatality (per year): 1,000,000 years after closure
Amargosa Farms area, pumping, present climate	2.2×10^{-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}
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}
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}

There is uncertainty in the percentage of flow that could divert to Alkali Flat as opposed to the floor of Death Valley. The flow simulations showed 2 of 8,024 particles reached Alkali Flat in the no-pumping scenario (none reach this area in the pumping scenario). There are no permanent residents in this area compared to Death Valley where Native Americans reside as well as temporary park visitors. If some small fraction of flow, as indicated by the particle tracks, were to reach this area in the no-pumping scenario, then the doses and intakes would be very much smaller than those found for Death Valley Middle Basin.

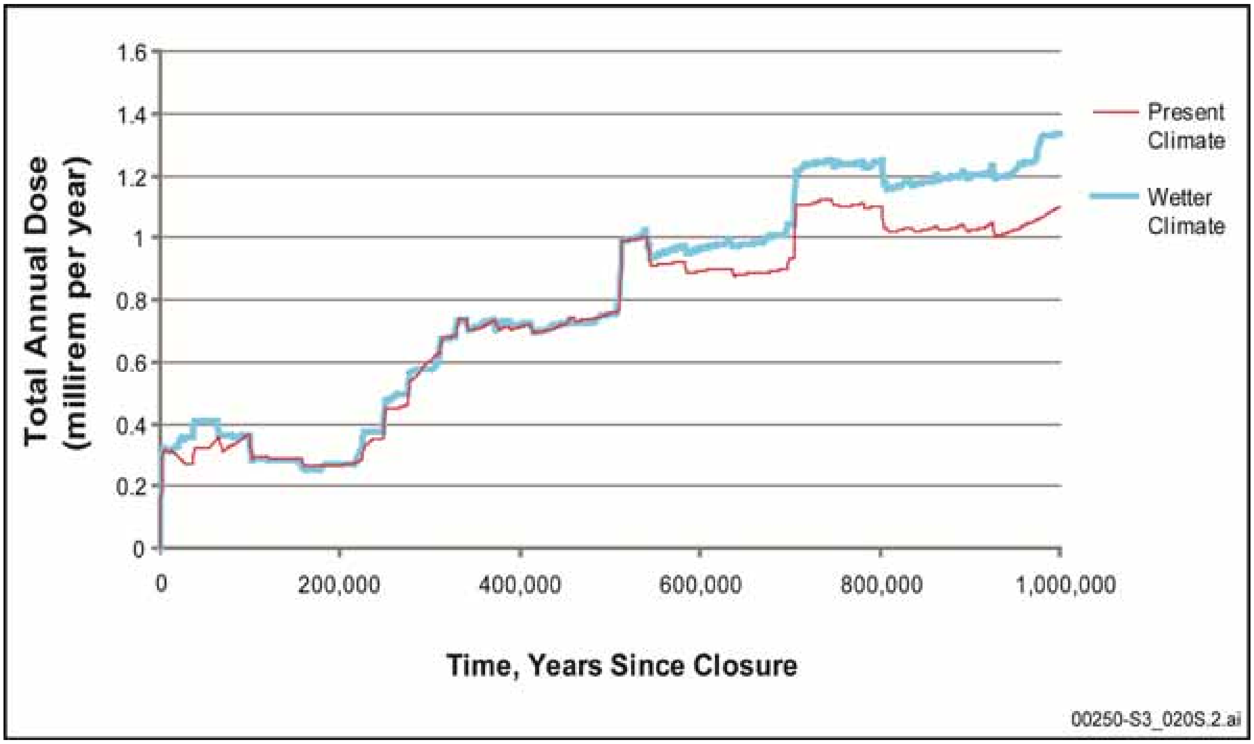


Figure S-5. Total annual dose at the Amargosa Farms area.

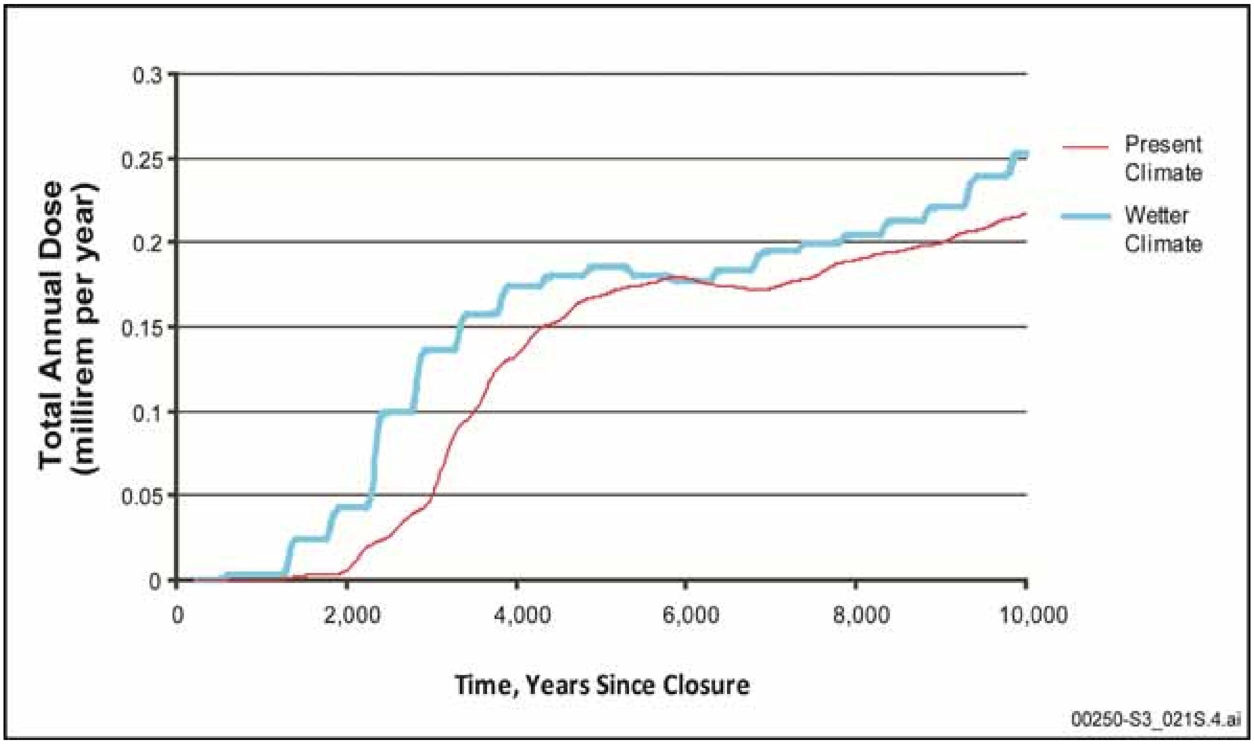


Figure S-6. Total annual dose at the Amargosa Farms area for the first 10,000 years.

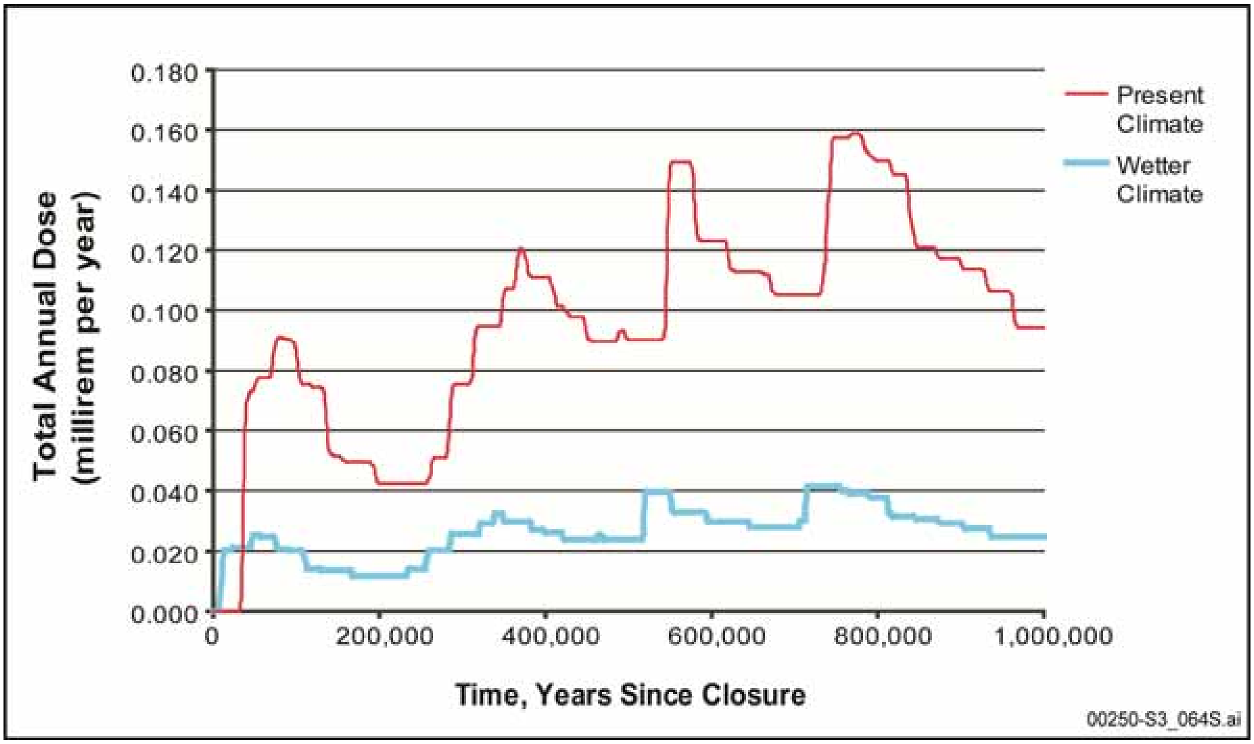


Figure S-7. Total annual dose at Middle Basin.

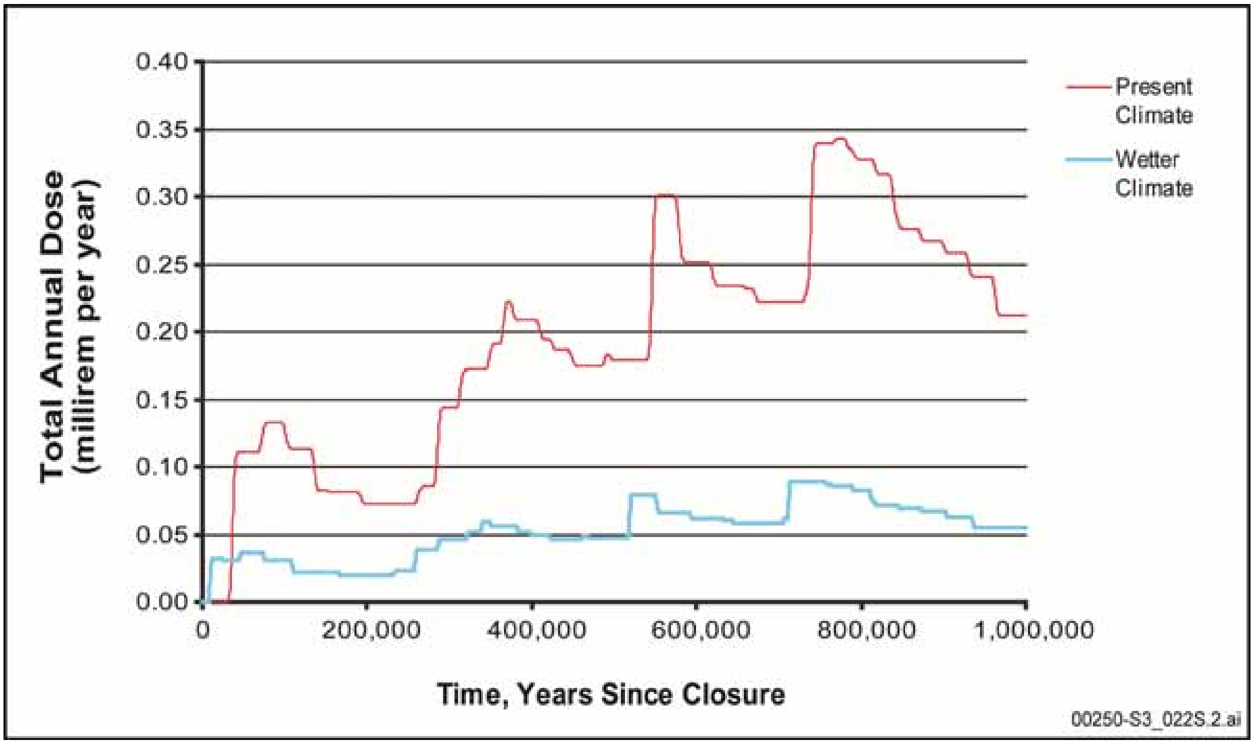


Figure S-8. Total annual dose at the Furnace Creek springs area.

S.3.2.2 Non-Radiological Health Impacts

The non-radiological contaminants this Analysis of Postclosure Groundwater Impacts considered include molybdenum, nickel, vanadium, and uranium. Uranium is included as both a radiological and non-radiological 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 non-radiological materials by comparing daily intakes with the U.S. Environmental Protection Agency's Oral Reference Dose standard. Oral Reference Doses are levels below which no detectable health effects would occur. 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 non-radiological 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 non-radiological 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 non-radiological contaminants.

	Peak intakes[a] (mg/kg body wt.-day) of metals during 1 million years after closure			
Scenario	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}
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
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
Oral Reference Dose (mg/kg body-wt/day)	5.00×10^{-3}	2.00×10^{-2}	9.00×10^{-3}	3.00×10^{-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.

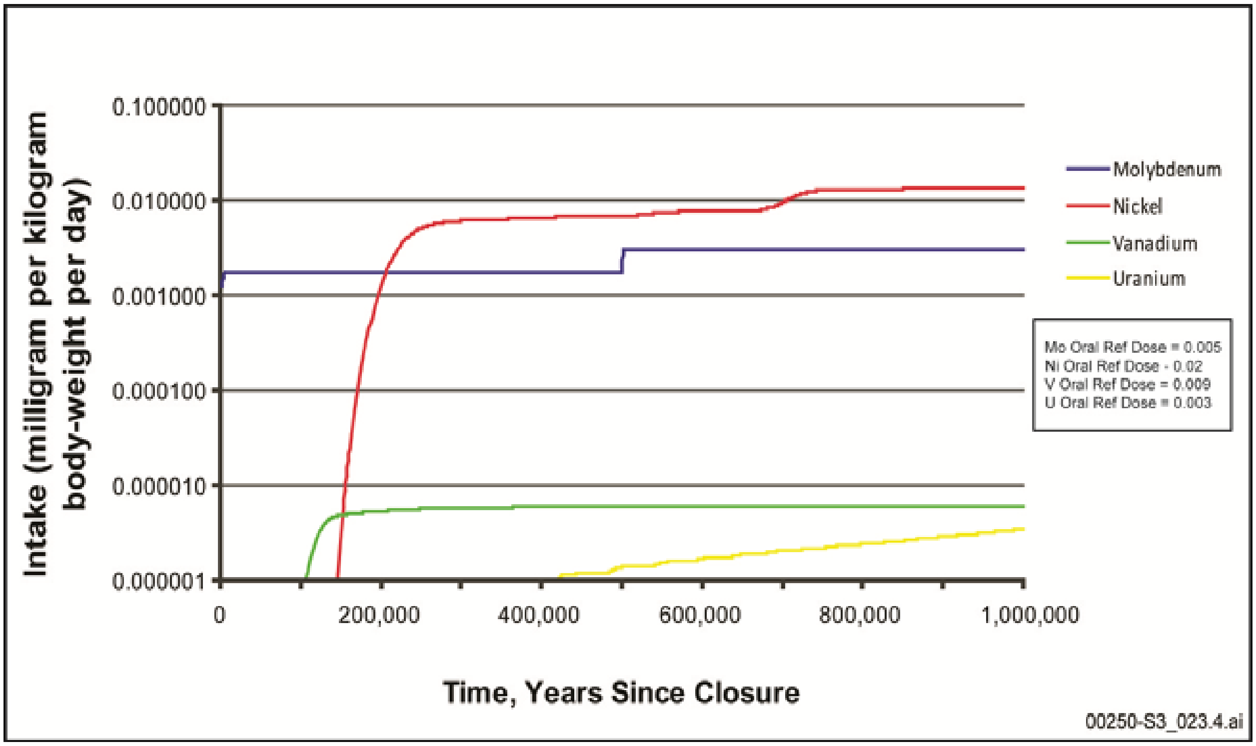


Figure S-9. Daily intakes of non-radiological contaminants at the Amargosa Farms area, present climate.

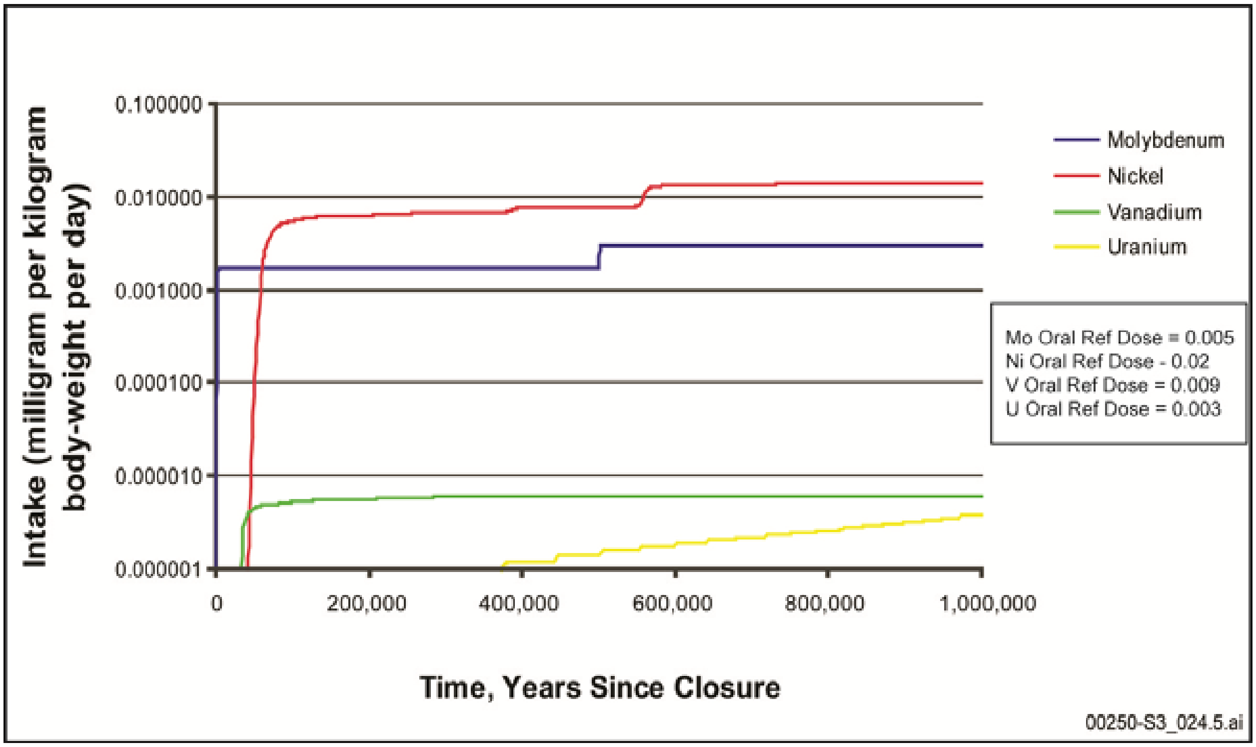


Figure S-10. Daily intakes of non-radiological contaminants at the Amargosa Farms area, wetter climate.

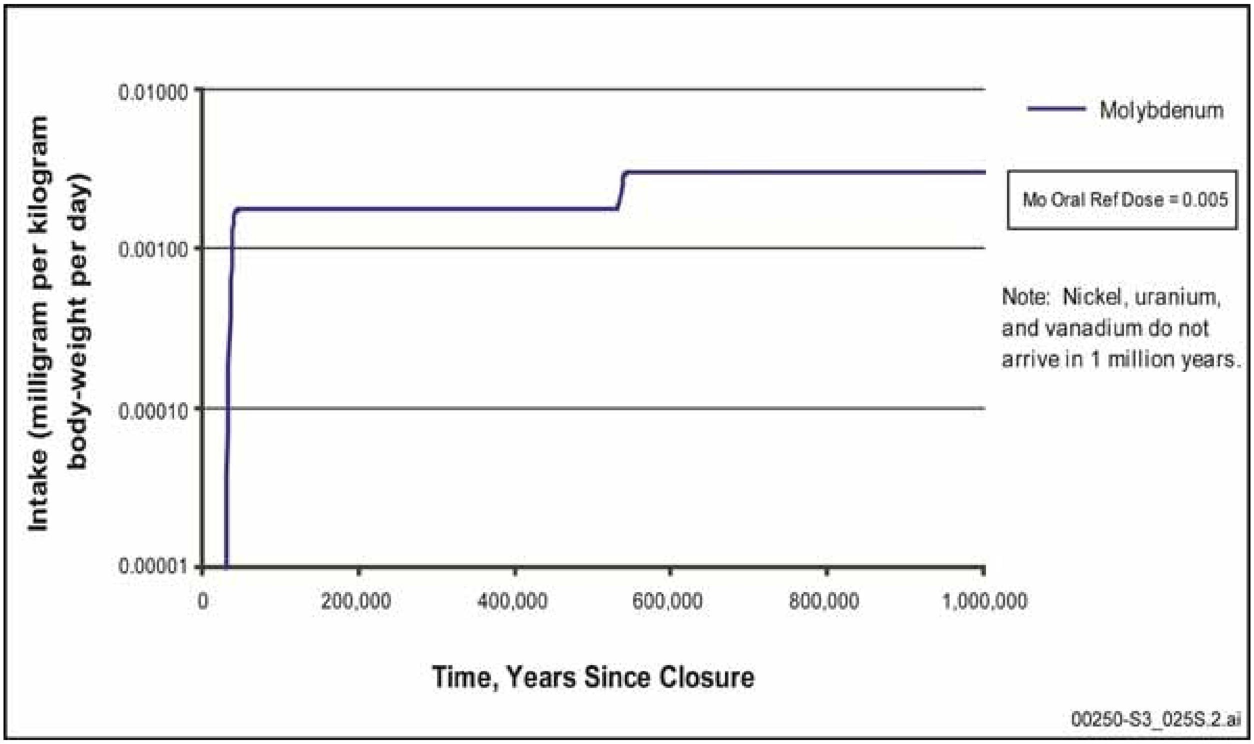


Figure S-11. Molybdenum daily intakes at Furnace Creek springs, no-pumping, present climate.

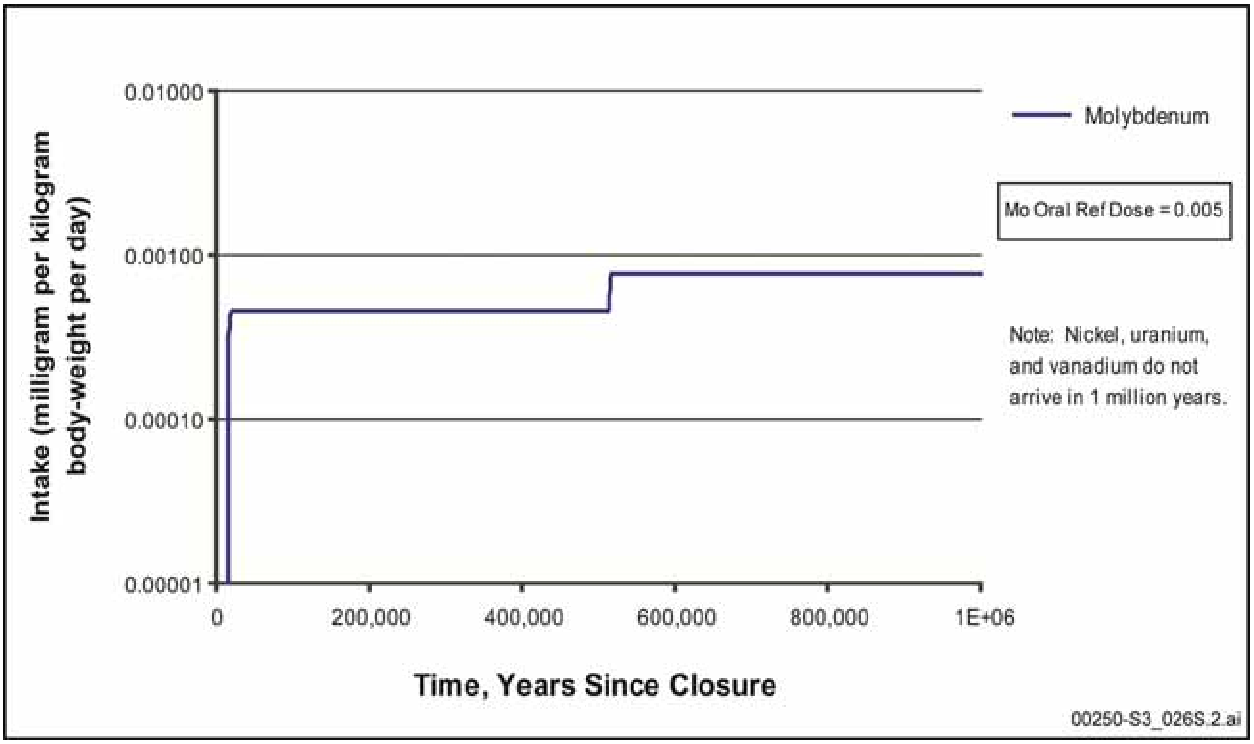


Figure S-12. Molybdenum daily intakes at Furnace Creek springs, no-pumping, wetter climate.

S.3.3 TRIBAL GOVERNMENT 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 Tribal Government concerns.

DOE acknowledges the sensitivities and cultural practices of the Timbisha Shoshone Tribe concerning the use and purity of springs in the Furnace 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 analyzed repository.

S.3.4 CUMULATIVE IMPACTS

The Repository Final 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 Final SEIS developed scale factors for how the addition of Modules 1 and 2 to the analyzed repository inventory would affect the dose and non-radiological impacts at the Regulatory Compliance Point. DOE found that impacts of the modules would increase linearly relative to the increased number of waste packages. The scale factors identified in the Repository Final SEIS were as follows: Module 1 impacts would increase by a factor of

2; Module 2 impacts would increase by an additional factor of 1.01 over Module 1. Potential impacts of the Proposed Action at groundwater discharge locations in the region depend directly on the mass release rates at the Regulatory Compliance Point; therefore, it is reasonable to assume that the cumulative impacts of the inventory modules at the regional discharge locations would also increase by the linear relationship identified in the Repository Final SEIS. The scale factors for non-radiological contaminants would be likewise.

The most recent sitewide EIS for the Nevada National Security Site indicates that there is a potential for impacts to springs and seeps from radioactive contamination from past underground testing; however, it is unlikely that any radioactive contamination from the Nevada National Security Site would reach Death Valley in the foreseeable future. There is not enough detailed data to quantitatively evaluate any incremental contribution from the Nevada National Security Site on the results presented in this Analysis of Postclosure Groundwater Impacts.

S.4 Conclusions

S.4.1 MAJOR CONCLUSIONS OF THE ANALYSIS

This Analysis of Postclosure Groundwater Impacts expands the analyses of postclosure impacts from those presented in the Repository Final SEIS, to include:

- A description of the full extent of the volcanic-alluvial aquifer, particularly those parts that could become contaminated, and how water (and potential contaminants) could leave the flow system;
- An analysis of the cumulative amount of radiological and non-radiological contaminants that could be reasonably expected to enter the aquifer from the analyzed repository, and the amount that could reasonably remain over time;
- Estimates of contamination in the groundwater, given potential accumulation of radiological and non-radiological contaminants;
- 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 could affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants; and
- Estimates of the amount of contaminants that could be deposited at or near the surface;

This analysis provides estimates of health impacts from exposures to contaminants in Amargosa Valley. DOE found that these exposures would result in very small health impacts, which are about the same as those at the Regulatory Compliance Point. This analysis also provides estimates of health impacts from exposures to contaminants in Death Valley, either from evapotranspiration from the floor of Death Valley or from the springs at Furnace Creek. DOE found that these exposures would be so low that virtually no potential health effects would be expected.

Based on the above, DOE concludes it has provided the information identified by the U.S. Nuclear Regulatory Commission as needed to supplement the Yucca Mountain FEIS and Repository Final SEIS and, therefore, has adequately addressed impacts on groundwater, or from surface discharges of groundwater, from a repository at Yucca Mountain. This 2014 update confirms the conclusion of the 2009 Analysis.

S.4.2 AREAS OF CONTROVERSY

In both the Yucca Mountain FEIS and the Repository Final SEIS, DOE acknowledged that areas of controversy exist regarding the analyzed repository and the analyses of its impacts. For this Analysis of Postclosure Groundwater Impacts, DOE identified the areas of controversy that are related to postclosure groundwater impacts and are addressed in this document. These areas reflect differing points of view or irreducible uncertainties.

S.4.2.1 Evaluation of the Lower Carbonate Aquifer

The Inyo County Yucca Mountain Repository Assessment Office raised concerns that DOE has not properly evaluated the full extent of the lower carbonate aquifer, the importance of maintaining the upward hydraulic gradient between the lower carbonate aquifer and the volcanic-alluvial aquifer, and the effects of continued or increased pumping on these aquifers. DOE has addressed these concerns in Appendix A.

S.4.2.2 Impacts to Timbisha Shoshone Tribe

As mentioned in Section S.4.3, the Timbisha Shoshone Tribe considers the waters of the Furnace Creek springs to be of traditional and cultural importance and believes that any effects on the purity of these waters would be detrimental to the Tribe’s culture. The analysis DOE included in this document 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 the springs.

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

RWEV-REP-001-Update

October 2014

CONVERSION FACTORS

Metric to English			English to Metric		
Multiply	**by**	**To get**	**Multiply**	**by**	**To get**
Area					
square kilometers	247.1	acres	acres	0.0040469	square kilometers
square kilometers	0.3861	square miles	square miles	2.59	square kilometers
square meters	10.764	square feet	square feet	0.092903	square meters
Concentration					
kilograms/square meter	0.16667	tons/acre	tons/acre	0.5999	kilograms/square meter
milligrams/liter	1[a]	parts/million	parts/million	1[a]	milligrams/liter
micrograms/liter	1[a]	parts/billion	parts/billion	1[a]	micrograms/liter
micrograms/cubic meter	1[a]	parts/trillion	parts/trillion	1[a]	micrograms/cubic meter
Density					
grams/cubic centimeter	62.428	pounds/cubic feet	pounds/cubic feet	0.016018	grams/cubic centimeter
grams/cubic meter	0.0000624	pounds/cubic feet	pounds/cubic feet	16,025.6	grams/cubic meter
Length					
centimeters	0.3937	inches	inches	2.54	centimeters
meters	3.2808	feet	feet	0.3048	meters
micrometers	0.00003937	inches	inches	25,400	micrometers
millimeters	0.03937	inches	inches	25.40	millimeters
kilometers	0.62137	miles	miles	1.6093	kilometers
Temperature					
Absolute					
degrees Celsius × 1.8	+32	degrees Fahrenheit	degrees Fahrenheit−32	0.55556	degrees Celsius
Relative					
degrees Celsius	1.8	degrees Fahrenheit	degrees Fahrenheit	0.55556	degrees Celsius
Velocity or Rate					
cubic meters/second	2,118.9	cubic feet/minute	cubic feet/minute	0.00047195	cubic meters/second
meters/second	2.237	miles/hour	miles/hour	0.44704	meters/second
Volume					
cubic meters	264.17	gallons	gallons	0.0037854	cubic meters
cubic meters	35.314	cubic feet	cubic feet	0.028317	cubic meters
cubic meters	1.3079	cubic yards	cubic yards	0.76456	cubic meters
cubic meters	0.0008107	acre-feet	acre-feet	1,233.49	cubic meters
liters	0.26418	gallons	gallons	3.78533	liters
liters	0.035316	cubic feet	cubic feet	28.316	liters
liters	0.001308	cubic yards	cubic yards	764.54	liters
Weight/Mass					
grams	0.035274	ounces	ounces	28.35	grams
kilograms	2.2046	pounds	pounds	0.45359	kilograms
kilograms	0.0011023	tons (short)	tons (short)	907.18	kilograms
metric tons	1.1023	tons (short)	tons (short)	0.90718	metric tons

English to English

acre-feet	325,850.7	gallons	gallons	0.000003046	acre-feet
acres	43,560	square feet	square feet	0.000022957	acres
square miles	640	acres	acres	0.0015625	square miles

[a] This conversion factor is only valid for concentrations of contaminants (or other materials) in water.

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ACRONYMS AND ABBREVIATIONS

DOE	U.S. Department of Energy
CFR	Code of Federal Regulations
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FR	Federal Register
NEPA	*National Environmental Policy Act*
NOI	Notice of Intent
NRC	U.S. Nuclear Regulatory Commission
NWPA	*Nuclear Waste Policy Act*
RMEI	reasonably maximally exposed individual
U.S.C.	United States Code
USGS	U.S. Geological Survey

UNDERSTANDING SCIENTIFIC NOTATION

DOE has used scientific notation in this Analysis of Postclosure Groundwater 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 and a positive or negative power of 10. Examples include the following:

Positive powers of 10	Negative powers of 10
$10^1 = 10 \times 1 = 10$	$10^{-1} = 1 \div 10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1 \div 100 = 0.01$
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 3×10^{-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.

METRIC PREFIXES

Prefix	Symbol	Multiplication factor		Scientific notation
tera-	T	1,000,000,000,000	=	1×10^{12}
giga-	G	1,000,000,000	=	1×10^{9}
mega-	M	1,000,000	=	1×10^{6}
kilo-	k	1,000	=	1×10^{3}
deca-	D	10	=	1×10^{1}
deci-	d	0.1	=	1×10^{-1}
centi-	c	0.01	=	1×10^{-2}
milli-	m	0.001	=	1×10^{-3}
micro-	μ	0.000001	=	1×10^{-6}
nano-	n	0.000000001	=	1×10^{-9}
pico-	p	0.000000000001	=	1×10^{-12}

Chapter 1

INTRODUCTION

CONTENTS

Section Page

1 INTRODUCTION

Spent nuclear fuel and *high-level radioactive waste* are long-lived, highly *radioactive* materials that result from certain nuclear activities. For more than 60 years, these materials have accumulated at commercial power plants and U.S. Department of Energy (DOE) facilities across the United States. Because of their nature, spent nuclear fuel and high-level radioactive waste must be isolated from the human environment and monitored for long periods. Through the passage of the *Nuclear Waste Policy Act*, as amended (NWPA) (42 U.S.C. 10101 et seq., 1987), Congress found that:

- The Federal Government has the responsibility to provide for the permanent disposal of high-level radioactive waste and spent nuclear fuel to protect the public health and safety and the environment.
- Appropriate precautions must be taken to ensure that these materials do not adversely affect the public health and safety and the environment for this or future generations.

1.1 Background

The NWPA directed DOE to evaluate the *Yucca Mountain site* in Nye County, Nevada as a potential location for a *geologic* repository. A geologic repository for spent nuclear fuel and high-level radioactive waste would permanently isolate radioactive materials in a deep *subsurface* location to limit risk to the health and safety of the public.

The NWPA also directed the Secretary of Energy, if the Secretary were to decide to recommend approval of the Yucca Mountain site for development of a repository, to submit a final environmental impact statement (EIS) with a recommendation to the President. DOE 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; DOE 2002) (Yucca Mountain FEIS) in February 2002 to fulfill that requirement. The Yucca Mountain 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 a repository.

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; DOE 2008a) (Repository Final SEIS). The basic elements of the *Proposed Action* evaluated in the SEIS did not change from those evaluated in the Yucca Mountain FEIS. As described in the Repository Final SEIS, the surface and subsurface facilities would allow DOE to operate the analyzed 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*. Under the Proposed Action, DOE 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.

On June 16, 2008, DOE submitted the Repository Final SEIS to the U.S. Nuclear Regulatory Commission (NRC), and on July 11, 2008, the U.S. Environmental Protection Agency (EPA) announced in the *Federal Register* the availability of the Repository Final SEIS (73 FR 39958).

On September 8, 2008, the NRC issued a Notice of Acceptance (letter) to DOE (Weber 2008) 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 (NRC 2008) (NRC staff's Adoption Determination Report), dated September 5, 2008. The NRC staff's Adoption Determination Report described the review the NRC staff conducted to determine if it was practicable to adopt the EISs in accordance with 10 CFR 51.109, "Public hearings in proceedings for issuance of materials license with respect to a geologic repository." The NRC staff concluded that neither the Yucca Mountain FEIS nor the Repository Final SEIS adequately addressed impacts on *groundwater* or from surface *discharges* of groundwater from contaminants that may enter the groundwater over time from a repository at Yucca Mountain. The basis for the NRC staff's position is contained in the NRC staff's Adoption Determination Report and summarized in Section 1.2 of this chapter.

In response to the NRC staff's Adoption Determination Report, DOE announced in the *Federal Register* its intent to prepare a supplement to the Yucca Mountain FEIS and the Repository Final SEIS (73 FR 63463, October 24, 2008). In that Notice of Intent (NOI), DOE described the nature of the environmental analyses to be included in the supplement and invited public comment during a 30-day period, which ended on November 24, 2008 (see Section 1.2.2 for a description of the public comments). On July 30, 2009, DOE submitted to the NRC the *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*.

In September 2011, the Yucca Mountain licensing proceedings were suspended, at NRC's direction, due to budgetary limitations (NRC 2011).

On August 13, 2013, the U.S. Court of Appeals for the District of Columbia Circuit ordered the NRC to continue with the licensing process for the Yucca Mountain application "…unless and until Congress authoritatively says otherwise or there are no appropriated funds remaining…" [In re Aiken County, 725 F.3d 255, 267 (D.C. Cir. 2013)]. The NRC issued an order on November 18, 2013, setting forth the agency's plans for responding to the D.C. Circuit order.

On February 28, 2014, DOE notified the NRC (Boyle 2014) that DOE would prepare an updated version of the *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*, submitted to the NRC in July 2009.

1.2 Scope of the Postclosure Groundwater Impact Analysis

This section discusses the NRC staff's Adoption Determination Report and the nature of public comments received in response to DOE's 2008 NOI to prepare a supplement to the Yucca Mountain FEIS and Repository Final SEIS (73 FR 63463, October 24, 2008).

1.2.1 NRC STAFF'S ADOPTION DETERMINATION REPORT

This Analysis addresses the information identified by the NRC staff as needed to supplement DOE's Yucca Mountain FEIS and Repository Final SEIS. Specifically, the NRC staff's Adoption Determination Report identified two areas that needed supplementation, as quoted below (NRC 2008, Section 3.2.1.4.2.2, pp. 3-10 through 3-12):

> *Need for Supplementation 1: Impacts on Groundwater*
>
> The EISs have not provided complete and adequate discussion of the nature and extent of the repository's cumulative impact on groundwater in the volcanic-alluvial aquifer. A supplement should include 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 (DOE 2008b, General Information, Section 5.2.2.2). 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 its Total System Performance Assessment (e.g., DOE 2008b, Section 2.4.2.2.3). 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.

Need for Supplementation 2: Impacts from Surface Discharges of Groundwater

The EISs have not provided a complete and adequate discussion of the impacts on soils and surface materials from the processes involved in surface discharges of contaminated groundwater. A supplement should include the following additional information:

- A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods (for example, as discussed in DOE 2008b, Safety Analysis Report, Section 2.3.1.2).

- 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*).

1.2.2 2008 NOTICE OF INTENT

The Council on Environmental Quality and DOE regulations do not require public scoping for the preparation of a supplemental EIS. However, in its October 2008 NOI, DOE invited comments on the scope of the analysis (73 FR 63463, October 24, 2008). The NOI described the scope as follows:

> The requested supplement will analyze further the repository-related impacts on groundwater, and from surface discharges of groundwater. More specifically, the supplement will describe the extent of the volcanic-alluvial aquifer, particularly those parts that could become contaminated, and how water (and potential contaminants) can leave the flow system. In

> addition, the supplement will provide 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. This information will be used to estimate contamination in the groundwater, given potential accumulation of radiological and non-radiological contaminants.
>
> The supplement also will provide a discussion of the impacts on soils and surface materials from the processes involved in surface discharges of contaminated groundwater. A description of locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods will be included, as will a description of the physical processes at surface discharge locations that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants. This information will be used to develop estimates of the amount of contaminants that could be deposited at or near the surface, and potential environmental impacts.

In the NOI, DOE announced a 30-day public comment period, which ended on November 24, 2008. During the 30-day period, DOE received comments from (1) the Inyo County Yucca Mountain Repository Assessment Office, (2) the Lincoln County Board of County Commissioners, (3) the White Pine County Nuclear Waste Project Office, and (4) the Timbisha Shoshone Tribe. The primary nature of the comments focused on the following:

- Inyo County – Requested expansion and/or refinement of the scope of the supplement as defined by the NRC staff. Specifically, the County requested that DOE evaluate perceived flaws in the model used to analyze long-term performance, impacts from continued regional groundwater pumping, impacts to endangered species in springs in Death Valley, and that DOE address cleanup and remediation measures.

- Lincoln County – Requested an expansion of the scope of the supplement to include an additional analysis of the potential impacts of a volcanic eruption, specifically addressing how the release of volcanic tephra and radioactive gases might impact human health and the environment in counties northeast of Yucca Mountain.

- White Pine County – Requested an expansion of the scope of the supplement to include an additional analysis of the potential impacts of a volcanic eruption, specifically addressing how the release of volcanic tephra and radioactive gases might impact human health and the environment in counties northeast of Yucca Mountain.

- Timbisha Shoshone Tribe – Requested that the supplement include analyses of several topics related to groundwater flow, potential transport of nuclear waste, and possible effects to the Death Valley National Monument.

The above comments received on the 2008 NOI and DOE’s responses are contained in Appendix A.

A public comment period is not required in connection with submission of this updated Analysis to the NRC.

1.3 Document Organization and Contents

This Analysis of Postclosure Groundwater Impacts is organized to address the supplementation needs identified by the NRC staff as described in Section 1.2.1. Chapter 2 provides descriptions of the volcanic-alluvial aquifer, including the current groundwater flow system and evidence of past climates and associated flow systems. Chapter 2 also provides summary information from the modeling of the groundwater flow system and how the Repository Final SEIS and the *Yucca Mountain Repository License Application* (DOE 2008b) used that modeling. Finally, Chapter 2 describes any changes to the information that was initially presented in the 2009 Analysis of Postclosure Groundwater Impacts.

Chapter 3 of this Analysis presents the analytical methodology and results for the estimation of impacts from contaminated groundwater and surface discharges in the accessible environment. Chapter 3 also includes a discussion of potential postclosure impacts to Tribal Governments in the *Death Valley region*.

Chapter 4 is a Glossary of those terms italicized in the body of this Analysis.

Appendix A presents the comment documents received after DOE's publication of the 2008 NOI to prepare a supplement to the Yucca Mountain FEIS and Repository Final SEIS, and DOE's responses to those comments. Appendix B provides analytical details that support the results provided in Chapter 3.

1.4 References

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Chapter 2

AFFECTED ENVIRONMENT

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2 AFFECTED ENVIRONMENT

This chapter presents baseline environmental conditions associated with the supplemental evaluation needs posed by U.S. Nuclear Regulatory Commission (NRC) staff in 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* (NRC staff's Adoption Report) (NRC 2008). The topical areas identified by NRC staff include elements of baseline environmental conditions as well as additional impact evaluations. The supplemental environmental conditions identified in the NRC staff's Adoption Report are: (1) 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; and (2) a description of the locations of potential natural *discharge* of contaminated *groundwater* for present and expected future wetter periods. Chapter 1of this Analysis of Postclosure Groundwater Impacts provides more information about the NRC staff's requests. The scope of this chapter is to provide the supplemental information on baseline environmental conditions and to provide information needed to understand the supplemental impact evaluations presented in Chapter 3 of this analysis.

The environmental conditions described in this chapter and the impact evaluations of Chapter 3 are supplemental to those presented in 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; DOE 2002) (Yucca Mountain FEIS) and 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; DOE 2008a) (Repository Final SEIS) for the long-term performance of a *repository* at Yucca Mountain. In order to support the impact evaluations in Chapter 3, this chapter includes the following additional descriptive information on the *affected environment*:

- A description of the current groundwater flow system, addressing each of the groundwater basins or sections through which groundwater from beneath Yucca Mountain could pass. The basin or section descriptions include identification of the aquifers, locations of natural discharge, and direction of *subsurface* flow.

- A discussion of past (ancient) climates and hydrological conditions that provide the basis for possible future conditions as addressed in the Yucca Mountain FEIS, Repository Final SEIS, and in Chapter 3 of this analysis.

- A description of the numerical modeling performed to simulate the regional groundwater flow system for past, present, and future climate conditions.

- A discussion of the groundwater modeling performed in the local area of Yucca Mountain and the associated evaluations of impact for the *reasonably maximally exposed individual* (RMEI) as was presented in the Repository Final SEIS. This discussion, along with the descriptions of the regional flow system modeling efforts, provides the basis for the current modeling and evaluation approach described in Chapter 3 of this analysis, which evaluates potential contaminant flow paths and potential impacts beyond the RMEI location.

2.1 Current Groundwater Flow System

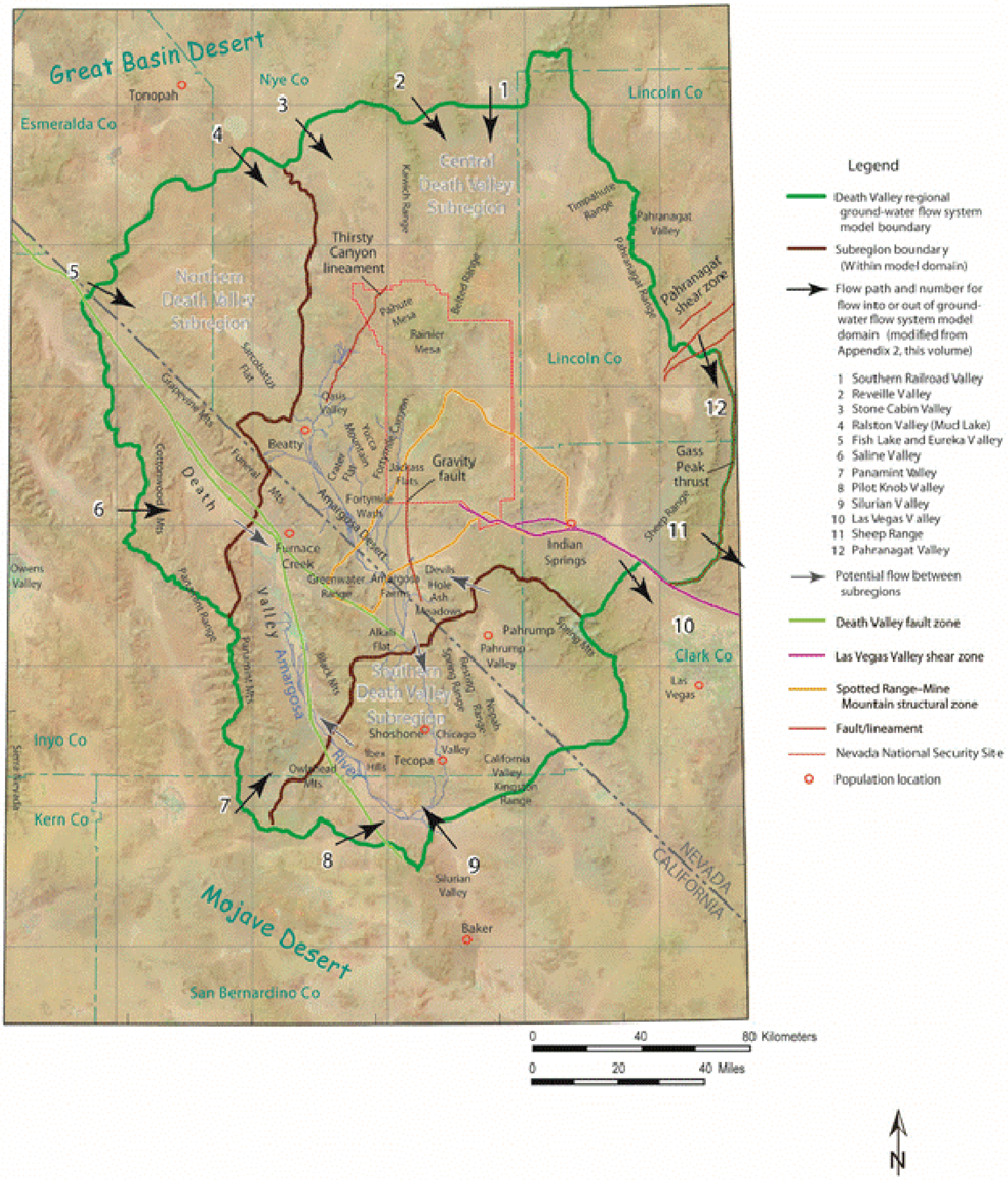
DEATH VALLEY REGION

In this section, Death Valley region refers to the area described by the outer boundaries in Figure 2-1; 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.

This section presents general information on the *Death Valley regional groundwater flow system*, illustrated in Figure 2-1, which is then followed by more specific detail on the portions of the regional flow system that a repository at Yucca Mountain could affect.

In the late 1990s, DOE directed the U.S. Geological Survey (USGS) to improve its groundwater flow model of the Death Valley regional flow system to support DOE programs at the Nevada Test Site (now the Nevada National Security Site) and Yucca Mountain. The results of the USGS's work are presented in *Death Valley Regional Ground-Water Flow System, Nevada and California – Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher 2004; Belcher and Sweetkind 2010), and much of the information in this section comes from that document. The USGS technical report presents a hydrologic conceptual model of the groundwater flow system within the *Death Valley region* as well as a description of the construction of a computer-based numerical model to simulate that flow system. The conceptual model is an interpretation or working description of how the flow system works. It was developed based on data that had been measured (such as *water table* elevations), calculated (for instance, estimates of *recharge* and discharge), or otherwise collected (such as groundwater hydrochemistry characteristics) to represent the regional flow system. The numerical model was then developed to simulate flow in the regional system and provide additional information. The flow paths for groundwater from beneath Yucca Mountain are contained within the flow system boundaries of the numerical model. The information presented in this section, unless specifically noted as coming from the numerical model, is based on the conceptual model of the Death Valley regional groundwater flow system. Modeling results are left primarily for discussion in Chapter 3.

The source of groundwater flow in the region is predominantly from recharge due to *infiltration* of precipitation that falls within the boundaries, and most of the recharge originates in the mountainous areas. The major recharge areas include: (1) along the eastern boundary (the Timpahute, Pahranagut, and Sheep ranges and the Spring Mountains); (2) along the western part of the boundary (Panamint Range and the Cottonwood Mountains); (3) the northern area of the Nevada National Security Site (Kawich and Belted ranges and Rainier Mesa), and (4) along the eastern margin of Death Valley (Grapevine and Funeral mountains) (Belcher 2004, pp. 117 and 118; Belcher and Sweetkind 2010, p. 114). Areas of recharge are generally reflected by mounds in the water table or *potentiometric surface*, and the largest mound in the region is associated with the Spring Mountains (BSC 2004, pp. 8-9 and 8-10), located southeast of Yucca Mountain. 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 (Belcher 2004, pp. 330 and 331; Belcher and Sweetkind 2010, pp. 322 and 323; BSC 2004, p. 8-42).



Note: 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.

Source: Belcher 2004, Figure A-1, p. 8, Figure D-5, p. 147.

Figure 2-1. Boundaries and prominent topographic features of the Death Valley regional groundwater flow system.

One can conceptualize groundwater flow in the region as including a set of relatively shallow, localized flow systems superimposed on deeper intermediate and regional flow systems. A localized flow system can be visualized as consisting of a single basin or valley between mountain ridges; an intermediate flow system would be at a greater depth, supporting flow beneath two or more valleys. The overall direction of groundwater movement is from the source areas (that is, those primary areas of recharge generally near the margins of the regional flow system) toward the regional hydrologic sink (that is, the area to which groundwater flows) in the *floor of Death Valley*.

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 largest volume of groundwater loss in the region is also in Death Valley in the form of spring discharges and *evapotranspiration*. In this discussion, sites of evapotranspiration losses are locations where groundwater is naturally at or close enough to the surface of the ground to be susceptible to evaporation or uptake by plants. Losses from pumping and subsequent use of the water are identified separately. There are numerous additional discharge locations along flow paths toward Death Valley. By volume of water lost, the largest of these is represented by the spring discharges and evapotranspiration at Ash Meadows. Other areas of notable water loss (all by evapotranspiration and occasionally with spring discharges) include Sarcobatus Flat, Oasis Valley, Pahrump Valley, and Tecopa Basin (Belcher 2004, pp. 330 and 331; Belcher and Sweetkind 2010, pp. 322 and 323). As with water coming laterally into the regional flow system, there is throughflow that leaves the system laterally into adjoining groundwater systems. Again, the amount of water that leaves the regional flow system in this manner, primarily along the east and southeast boundaries, is estimated to be relatively small (less than 10 percent) in comparison with the volume lost within the boundaries (Belcher 2004, pp. 330 and 331; Belcher and Sweetkind 2010, pp. 323 and 324; BSC 2004, p. 8-42).

Another pertinent factor in describing the general nature of groundwater in the regional flow system is the nature of the *geologic* material through which it passes. The eastern and southern parts of the region lie within the carbonate-rock province of the Great Basin, which is characterized by thick sequences of carbonate rock. The northwest part of the region generally is underlain by volcanic rocks that are part of the southwest Nevada volcanic field (BSC 2004, p. 8-4). In characterizing this region, the USGS identified 25 different hydrogeologic units in five different groupings that begin with the youngest unconsolidated Cenozoic basin-fill (or alluvial) deposits along with younger volcanic rocks. The groupings then incorporate the consolidated Cenozoic basin-fill deposits; the Cenozoic volcanic rocks of the southwestern Nevada volcanic field; the Mesozoic, Paleozoic, and late Proterozoic sedimentary rocks (including the carbonate rock); and finally the lowest units, the crystalline metamorphic rocks of the Proterozoic Era and the intrusive rocks of all ages. Units within these groupings can be aquifers or *confining units*. A confining unit is a rock or sediment unit of relatively low *permeability* that retards the movement of water in or out of adjacent aquifers, whereas an aquifer is a permeable water-bearing unit of rock or sediment that yields water in a usable quantity to a well or spring. Within the 25 hydrogeologic units, the USGS characterized 9 as aquifers, 8 as confining units, and another 8 as units that can function either as aquifers or confining units. It is noted that these are general characterizations because the hydrogeologic units vary in material and hydraulic properties over the extent of the regional groundwater flow system (Belcher 2004, pp. 39 and 40; Belcher and Sweetkind 2010, pp. 35 and 36), which is the reason some units are identified as either aquifers or confining units.

Simplifying the hydrogeologic units presented in the USGS model (and in almost any other groundwater study of the region), the principal aquifers of the region can be characterized as basin-fill (or alluvial), volcanic, and carbonate. The basin-fill is the eroded, or otherwise broken down material deposited in between mountains and ridges. These bodies of sand, silt, gravel, and other materials can be very thick, and when they extend below the water table, permeable portions serve as aquifers. *Volcanic aquifers* are in permeable units of igneous rock (of volcanic origin), and *carbonate aquifers* are in permeable units of limestone or dolomite (carbonate rock). (The carbonate aquifer is more appropriately termed the carbonate-rock aquifer, but this document refers to it as simply the carbonate aquifer and uses “carbonate rock” to reference the geologic strata.) Consistent with the location of the southwest Nevada volcanic field identified previously, the mountainous area of the north-central portion of the Death Valley region is often underlain by volcanic rocks and the associated volcanic aquifers. Consistent with the location of the carbonate-rock province of the Great Basin, carbonate aquifers are regionally extensive, particularly in the east and southern portions of the region, and are often at great depths below volcanic and *alluvial aquifers*. When all three aquifers are present, the volcanic rocks are generally in hydraulic connection with the overlying basin-fill and may be in hydraulic connection with underlying carbonate rocks as well as laterally from one basin to another (BSC 2004, p. 8-4). It should be noted that two carbonate aquifers are recognized in the region: the *upper* and *lower carbonate aquifer*s. The upper unit is generally only of local importance (that is, it is not significant in the regional flow system) and is not present in the flow path from Yucca Mountain, and, accordingly, is not discussed further.

The regional flow system is divided into 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 2-1) are the northern *Death Valley subregion*, the central Death Valley subregion, and the southern Death Valley subregion. The regional flow system is divided into these subregions for descriptive purposes only, with delineation of the subregion boundaries based on several different physical attributes including discharge locations in Death Valley.

The focus of the discussion in this Analysis of Postclosure Groundwater Impacts is the central Death Valley subregion because it contains the primary groundwater flow paths from Yucca Mountain. Recharge entering the system at Yucca Mountain is in the central Death Valley subregion, and since the primary discharge locations are within that subregion, recharge is not likely to leave the central Death Valley subregion as groundwater. Although the focus is on the central subregion, this discussion also includes the southern Death Valley subregion because it is possible that some throughflow, including flow paths from Yucca Mountain, occurs between the central and southern subregions. Flow paths from Yucca Mountain do not extend toward the northern Death Valley subregion, but throughflow from the northern subregion into the central subregion does occur.

The subsections that follow begin with descriptions of the applicable subregions and provide a broad view of the overall subregion before moving to the discussion of the applicable basin, the next category down in the hierarchy used to define the flow system. Similarly, the basin is discussed in broad terms before focusing on the applicable groundwater section, the lowest category in the hierarchy. In this manner, each of the groundwater sections through which groundwater from Yucca Mountain could pass is addressed beginning beneath Yucca Mountain and following the general flow path to the low point of the regional flow system, which is Death Valley. Death Valley extends in a northwest-to-southeast direction across all three of the subregions (that is, the northern, central, and southern Death Valley subregions). The lowest area of Death Valley, Badwater Basin, is within the central Death Valley subregion.

Defining the Death Valley regional groundwater flow system included estimating the amount of water moving through the system. In most cases, the USGS’s technical report (Belcher 2004; Belcher and Sweetkind 2010) presents this information in the form of estimates of quantities of water lost from the system through spring discharges, evapotranspiration, and pumping. Thus the report does not generally provide estimates for quantities of groundwater moving through any specific location within the flow system. However, if it is assumed that the system is reasonably in balance (that is, there are no areas where reservoirs of surface or subsurface water are growing or being depleted), then the estimates of water losses along the flow paths provide an indication of at least the minimum amount of groundwater that is moving along those flow paths. It is recognized that some portions of the regional system are currently not in balance (for example, as indicated by lowered water levels in some areas due to pumping), but the water loss values are still of use in describing the movement in the system. Table 2-1 provides estimates of water losses along the sections of the regional flow system that are described in the discussions that follow. That is, the table presents information for those sections of the flow system that could involve flow paths for groundwater that originates beneath Yucca Mountain. The USGS's technical report identifies and describes numerous other significant areas of the flow system where groundwater is lost from the system, which are not included in Table 2-1 since they are not applicable to the analysis in this Analysis of Postclosure Groundwater Impacts.

Table 2-1. Estimates of water losses along select sections of the regional flow system.

	Annual groundwater losses/discharges (acre-feet)		
Flow path section	Specific spring discharges[a]	Losses from evapotranspiration[b]	Groundwater pumping in 2003[c]
Central Death Valley subregion			
Alkali Flat – Furnace Creek basin			
Fortymile Canyon section			92
Amargosa River section		1,350[d]	17,600
Funeral Mountains section	2,300[e]	23,700[f]	55
Southern Death Valley subregion			
Shoshone – Tecopa section		2,530[g]	27[h]
California Valley section		6,400	(h)
Ibex Hills section		3,420[i]	

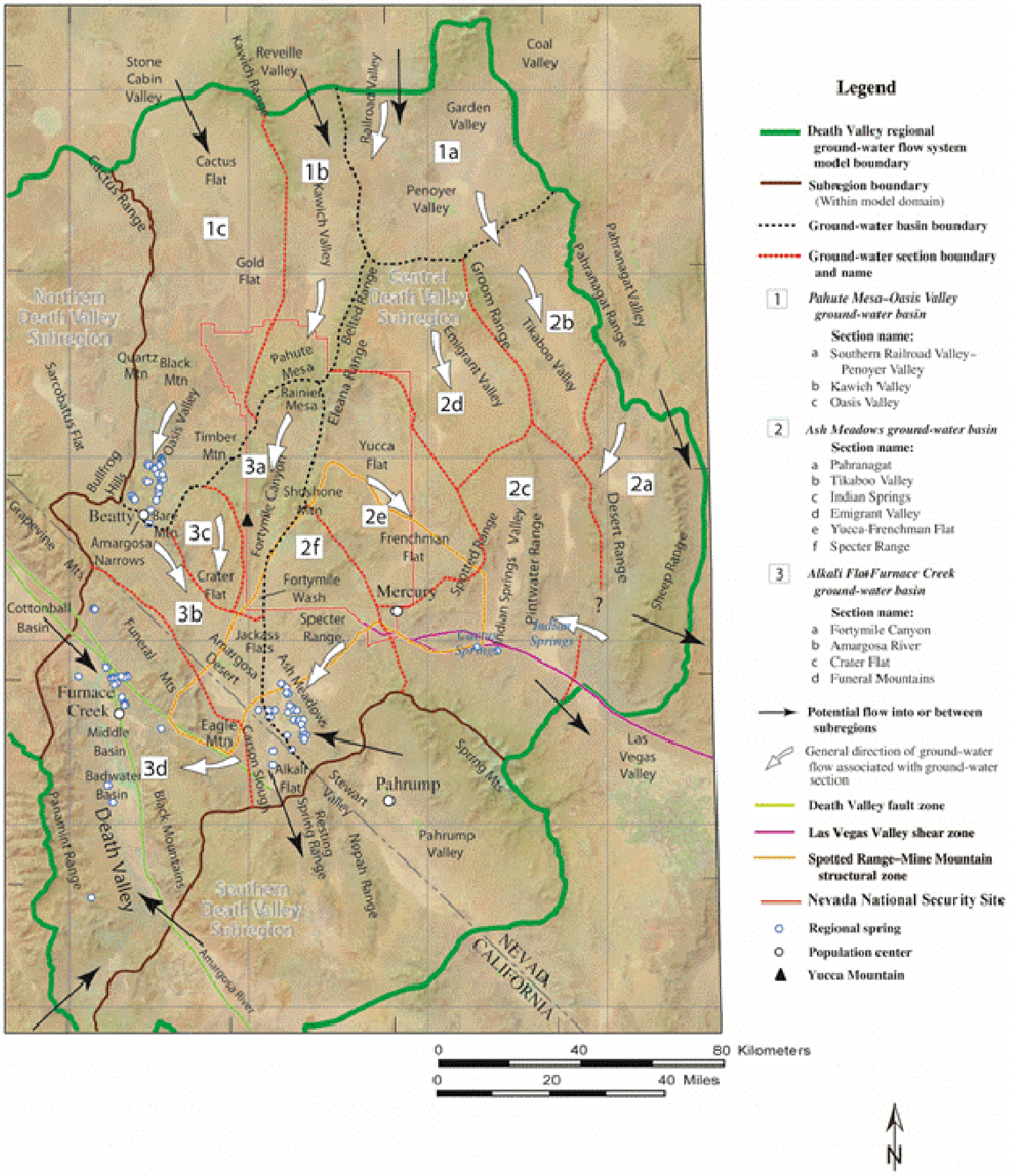
Notes: 1. To convert acre-feet to cubic meters, multiply by 1,233.49.
2. Blank cells indicate data are not available or not applicable.
3. As applicable, losses from evapotranspiration may include discharges from small, local springs.

a. Source: Belcher 2004, p. 109; Belcher and Sweetkind 2010, p. 105.
b. Source: Belcher 2004, pp. 107 and 276; Belcher and Sweetkind 2010, pp. 103 and 268.
c. Source: Moreo and Justet 2008, database.
d. Evapotranspiration losses from the Amargosa River section include those from the Franklin Well area and those from the Alkali Flat (also known as Franklin Lake Playa) area.
e. The spring discharge shown for the Funeral Mountains section is the total for the Texas, Travertine, and Nevares springs. The data source describes the discharge value for Travertine Springs (1,370 acre-feet per year) as being the total of 10 springs in the same area, and the discharge for Nevares Spring (560 acre-feet per year) is described as including nearby Cow and Salt springs.
f. The evapotranspiration loss shown for the Funeral Mountains section is the total annual loss from the following areas (from north to south): Cottonball Basin (3,030 acre-feet per year), Furnace Creek Ranch (3,410 acre-feet per year), Middle Basin (1,960 acre-feet per year), Badwater Basin (5,950 acre-feet per year), west side vegetation (5,390 acre-feet per year), and Mormon Point (3,950 acre-feet per year).
g. Evapotranspiration losses from the Shoshone – Tecopa section include those from areas along the Amargosa River bed and those from the Chicago Valley playa.
h. The groundwater pumpage volume for the Shoshone – Tecopa section includes pumpage from the California Valley section. The data source does not provide a breakdown of the two sections.
i. The evapotranspiration loss shown for the Ibex Hills section is the total annual loss from the following areas (from north to south): Confidence Mill site (960 acre-feet per year) and Saratoga Springs (2,460 acre-feet per year).

Table 2-1 does not present pumping values more recent than 2003 because the values in the table are those used in modeling efforts described in Section 3.1.1.2. However, more recent groundwater pumping values are discussed for comparison purposes in Sections 2.1.1.1.1 and 2.1.1.1.2 below.

2.1.1 CENTRAL DEATH VALLEY SUBREGION

The central Death Valley subregion (Figure 2-2) is divided into three basins: (1) the Pahute Mesa – Oasis Valley groundwater basin, which incorporates northern and northwestern portions of the subregion; (2) the Ash Meadows groundwater basin, which consists of the east portion of the subregion; and (3) the Alkali Flat – Furnace Creek groundwater basin, located in the central area of the subregion between the



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: Belcher 2004, Figure D-7, p. 150.

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

other two basins and extending to the south-southwest. In general terms, groundwater in the first two basins flows southward (and to the southwest in the case of the Ash Meadows groundwater basin), contributing flow to the Alkali Flat – Furnace Creek groundwater basin. Conversely, groundwater in the Alkali Flat – Furnace Creek basin does not move into either of the other two basins of the Central Death Valley subregion.

The three basins of the central Death Valley subregion were named based on major discharge areas. As Figure 2-2 shows, groundwater flow in the Pahute Mesa – Oasis Valley basin is generally toward an area having spring discharges and evapotranspiration losses in Oasis Valley near Beatty. Some of the flow may also go west toward Sarcobatus Flat in the northern Death Valley subregion, and some may flow to the east toward Crater Flat. Finally, groundwater not discharging within Oasis Valley flows through the thin layer of alluvium or the low-permeability basement rocks at Amargosa Narrows and into the Alkali Flat – Furnace Creek basin (Belcher 2004, p. 150; Belcher and Sweetkind 2010, p. 146).

Groundwater flow in the Ash Meadows basin, the largest of the basins in the central Death Valley subregion, generally moves toward the discharge area of Ash Meadows. In Ash Meadows, groundwater encounters a northwest-to-southeast trending fault where water coming in primarily from the east in the lower carbonate aquifer hits less permeable fine-grained basin-fill sediments. The result is about 30 springs along a 16-kilometer (10-mile) long spring line that generally follows the trace of the fault (Belcher 2004, p. 152; Belcher and Sweetkind 2010, p. 148). Although earlier conceptual models of the Ash Meadows basin had much of the flow at Ash Meadows originating in Pahranagat Valley, more recent evidence suggests that most, if not all, of the water discharging at Ash Meadows originated in the Spring Mountains. Most of the discharged water likely infiltrates and recharges the alluvial aquifers, with much of this discharging as evapotranspiration along the Amargosa River, Carson Slough, and Alkali Flat (Belcher 2004, p. 152; Belcher and Sweetkind 2010; p. 148), located just to the south-southwest of Ash Meadows (Alkali Flat is also referred to as Franklin Lake Playa.)

Yucca Mountain and water infiltrating through the area of a repository at Yucca Mountain are within the Alkali Flat – Furnace Creek basin. Since groundwater in this basin does not contribute flow to either of the other two basins in the central Death Valley subregion, and because of the significance of this basin with respect to groundwater flow from a repository at Yucca Mountain, the remaining discussion of this subregion is limited to the Alkali Flat – Furnace Creek basin.

2.1.1.1 Alkali Flat – Furnace Creek Groundwater Basin

The northern boundary of the Alkali Flat – Furnace Creek groundwater basin is in the area of Pahute Mesa in the central area of the regional flow system. The basin extends to the southwest, encompassing Fortymile Canyon, Crater Flat, the Amargosa Desert, the Funeral Mountains, the central portion of Death Valley, and the eastern slope of the Panamint Range (on the west side of Death Valley) (Figure 2-2). Groundwater in the basin moves through volcanic aquifers in the north and alluvial and carbonate aquifers in the south. As with the regional flow system in general, the direction of flow is toward the regional sink of Death Valley.

The primary recharge areas for the Alkali Flat – Furnace Creek basin are Pahute Mesa and the Timber and Shoshone mountains in the north, the Grapevine and Funeral mountains (separating Amargosa Desert from Death Valley) in the center, and the Panamint Range on the southwestern boundary. Additional water sources for the Alkali Flat – Furnace Creek basin are in the form of groundwater throughflow, possibly from the Sarcobatus Flat and Oasis Valley areas in the north and from the Ash Meadows area in the east.

The main surface discharge area in the basin is the springs in Death Valley, specifically those in the Furnace Creek area, including the Texas Springs, Travertine Springs, and Nevares Springs. The largest losses in the basin, however, are attributed to evapotranspiration losses over the floor of Death Valley. In the south-central part of the basin, near the Nevada-California border, there are also discharge areas along the Amargosa River, Carson Slough, and Alkali Flat. Throughflow may also result in groundwater leaving the basin and entering the southern Death Valley subregion by following the general course of the Amargosa River past Alkali Flat and through a veneer of alluvium near Eagle Mountain.

The Yucca Mountain FEIS described the flow in the alluvial aquifer of the southern Amargosa Desert as moving toward the primary discharge area of Alkali Flat, with a small portion potentially moving toward the springs in the Furnace Creek area of Death Valley (DOE 2002, pp. 3-40 and 3-46). The subsequent Repository Final SEIS also described the predominant flow in the alluvial aquifer of the southern Amargosa Desert as moving toward Alkali Flat, but the SEIS cited more recent studies as showing evidence that a portion of the flow likely goes to the Furnace Creek area, with some minor amounts also potentially going beyond Alkali Flat and following the general course of the Amargosa River into Death Valley (DOE 2008a, pp. 3-34 and 3-35). These are relatively minor changes in the conceptual model of the groundwater flow system in the Amargosa Desert. However, this Analysis of Postclosure Groundwater Impacts reaches different conclusions about the direction of flow. As Chapter 3 of this analysis describes, DOE used the Death Valley regional flow system model to simulate flow conditions in the absence of any significant pumping in the region, so the simulation included no effects from pumping in the Amargosa Desert on flow paths from Yucca Mountain. Results of the simulation for this *no-pumping scenario* show flow paths from Yucca Mountain going primarily toward the Furnace Creek area and the floor of Death Valley beyond, with only a small portion going to Alkali Flat. Although the Death Valley regional groundwater flow system model is considered the best representation of the regional flow system developed to date, there are still uncertainties inherent in its use. Since the model predicts a portion (albeit small) of the flow going to Alkali Flat, it does not preclude that flow path as a possibility. Further, groundwater reaching as far south as Alkali Flat might, under at least some conditions, continue southward into the southern Death Valley subregion. As a result, even though the modeling scenario in this case predicts a dominant flow path toward the Furnace Creek area, the conceptual model for purposes of this evaluation conservatively continues to identify other possible flow paths to the south, toward Alkali Flat and beyond.

The Alkali Flat – Furnace Creek basin is divided into four sections (identified by their numbers in Figure 2-2): (3a) Fortymile Canyon, (3b) Amargosa River, (3c) Crater Flat, and (3d) Funeral Mountains. The analyzed 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. In the southern portion of the Amargosa River section, groundwater moves to the west to discharge points in the Funeral Mountains section, further south to discharge in the area of Alkali Flat, or past Alkali Flat into the southern Death Valley subregion. The following sections describe in more detail the groundwater pathway from the Yucca Mountain area.

Table 2-2 provides a summary of the sample results from a series of water quality samples collected from springs in the Furnace Creek area and from wells in the Amargosa Farms area. These are primary areas of impact Chapter 3 evaluates, so the data are presented here to provide an indication of the baseline condition of groundwater in these two areas. The table also shows drinking water standards for comparison purposes. It is recognized that these samples represent groundwater and were not collected from drinking water systems, so the standards are not directly applicable. However, the standards do provide a recognized benchmark. As can be seen in Table 2-2, with the exception of arsenic in four locations, and lead and fluoride in one location (indicated by shading in the table), the groundwater

Table 2-2. Water quality of springs in the Furnace Creek area and of wells in the Amargosa Farms area.

Constituent	Units	Drinking water standard	Select springs of the Furnace Creek area[a]			Select wells of the Amargosa Farms area	
			Navel Spring[a,b]	Texas Spring[a]	Nevares Spring[c]	NDOT Well[d]	Gilgans South Well[d]
Number of observations			2 to 3	1 to 4	1	1	1
Inorganics							
Arsenic	mg/L	0.010	0.190	0.024	Not analyzed	0.022	0.011
Barium	mg/L	2	0.032	0.039[c]	0.042	0.010	0.0022
Beryllium	mg/L	0.004	Not analyzed	(0.003)[e]	0.0006	(0.001)[e]	(0.001)[e]
Cadmium	mg/L	0.005	(0.01)[e]	0.0038[f]	(0.001)[e]	(0.001)[e]	(0.001)[e]
Chloride (secondary)[g]	mg/L	250[g]	75[c]	37.3	37	13	7.2
Chromium (total)	mg/L	0.1	0.0035	0.00075[f]	(0.005)[e]	0.0065	0.0043
Copper	mg/L	1.3[h]	(0.01)[e]	0.0083[f]	(0.001)[e]	(0.001)[e]	(0.001)[e]
Fluoride	mg/L	4.0	1.7	4.7	3.2	1.8	1.6
Iron (secondary)[g]	mg/L	0.3[g]	0.098[c]	0.0039[f]	0.004	0.0064	(0.003)[e]
Lead	mg/L	0.015[h]	(0.10)[e]	0.038[f]	(0.001)[e]	(0.001)[e]	(0.001)[e]
Manganese (secondary)[g]	mg/L	0.05[g]	(0.001)[e]	0.0016[f]	0.004	(0.001)[e]	(0.001)[e]
Mercury	mg/L	0.002	(0.0001)[e]	(0.0001)[e]	Not analyzed	(0.001)[e]	(0.001)[e]
Molybdenum	mg/L	None	Not analyzed	(0.030)[e]	0.018	0.007	0.0032
Nitrate (as N)	mg/L	10	6.6	0.2	(0.050)[e]	2.17	1.68
Nitrite (as N)	mg/L	1	(0.01)[e]	(0.01)[e]	(0.050)[e]	(0.01)[e]	(0.01)[e]
Selenium	mg/L	0.05	(0.001)[e]	(0.001)[e]	Not analyzed	(0.001)[e]	(0.001)[e]
Silver (secondary)[g]	mg/L	0.10[g]	(0.001)[e]	(0.001)[e]	(0.001)[e]	(0.001)[e]	(0.001)[e]
Sulfate (secondary)[g]	mg/L	250[g]	113	160	170	110	28
Vanadium	mg/L	None	Not analyzed	(0.01)[e]	(0.001)[e]	Not analyzed	Not analyzed
Zinc (secondary)[g]	mg/L	5[g]	0.0115	0.0093[f]	0.004	0.027	0.0016
Organics							
Organochlorine and organonitrogen compounds		Varies	(varies)[e]	(varies)[e]	Not Analyzed	(varies)[e]	(varies)[e]
Volatile organic compounds		Varies	(varies)[e]	(varies)[e]	Not Analyzed	(varies)[e]	(varies)[e]
Semi-volatile organic compounds		Varies	(varies)[e]	(varies)[e]	Not Analyzed	(varies)[e]	(varies)[e]

Table 2-2. Water quality of springs in the Furnace Creek area and of wells in the Amargosa Farms area (continued).

Constituent	Units	Drinking water standard	Select springs of the Furnace Creek area[a]			Select wells of the Amargosa Farms area	
			Navel Spring[a,b]	Texas Spring[a]	Nevares Spring[c]	NDOT Well[d]	Gilgans South Well[d]
Number of observations			2 to 3	1 to 4	1	1	1
Radionuclides							
Alpha particles	pCi/L	15	3.4	3.15	Not analyzed	(3.0)[e]	(3.0)[e]
Radium 226 and Radium 228	pCi/L	5	0.37	0.47	Not analyzed	0.04	0.03
Uranium	ug/L	30	2.4	5.1	Not analyzed	2.6	(1.0)[e]
Gross beta[i]	pCi/L	None[i]	13	16	Not analyzed	5.7	6.1
Radon-222	pCi/L	None	37	38.5	Not analyzed	612	600

Note: Shaded areas designate sample results that exceed the applicable drinking water standard. “None” indicates there is no applicable standard.

a. Source: NPS 1994, pp. 113 to 116, 127 to 130

b. Source: USGS 2009a.

c. Source: USGS 2009b.

d. Source: Covay 1997.

e. This constituent was not detected at the detection limit shown in parentheses. As applicable, the *Baseline Water Quality Data Inventory and Analysis Death Valley National Monument* (NPS 1994) reported a value in these cases, but also reported that the average value was computed with 50 percent or more of the total observations that were half the detection limit (that is, half or more of the observations were reported as not detected, so the “half the detection limit” convention was employed). If there were only two observations in such cases and the minimum and maximum values were the same, then both observations were reported as not detected.

f. This average value was computed with 50 percent or more of the total observations that were half the detection limit. Use of half of the detection limit is a common convention when a value is reported as not being detected.

g. This constituent and the applicable drinking water standard are not from the primary drinking water standards (that is not from 40 CFR Part 141); rather, they are secondary standards from 40 CFR Part 143, which were set to ensure the aesthetic quality of the drinking water. The secondary standards are not federally enforceable.

h. Values shown for copper and lead are action levels that, when exceeded, require the water distribution system to take additional steps to control the corrosiveness of their water (that is, copper and lead are primary concerns with respect to those elements being leached from the distribution system materials).

i. Primary drinking water standards include a standard for beta particles and photon emitters, albeit in terms of dose per year (specifically, 4 millirem per year) from average exposure rates. In order to calculate the dose, speciation of the beta particles is required and the analytical results here are only in terms of gross beta values.

mg/L = milligrams per liter.
NDOT = Nevada Department of Transportation.
pCi/L = picocuries per liter.
ug/L = micrograms per liter.

samples represent water of good quality. Relatively high concentrations of natural arsenic are a recognized problem for groundwater in this area, and since the EPA lowered the drinking water standard from 0.05 to 0.01 milligrams per liter in 2006, many of the groundwater sources in the area exceed the standard.

2.1.1.1.1 Fortymile Canyon Section

Recharge and Movement

Recharge and throughflow from volcanic rocks of the eastern Pahute Mesa and the western part of Rainier Mesa are the sources for groundwater flow in the Fortymile Canyon section. Infiltration of runoff in the upper reaches of Fortymile Canyon and Fortymile Wash during moderate to intense precipitation events may also be a significant source of recharge in the section (Belcher 2004, p. 152; Belcher and Sweetkind 2010, p. 150). The amount of water infiltrating at Yucca Mountain is small in comparison with these other areas and is not a significant contributor to recharge. Infiltrating water at Yucca Mountain that reaches the *saturated zone* reaches a volcanic aquifer. As indicated in the Repository Final SEIS (DOE 2008a, p. 3-42), the saturated zone at Yucca Mountain is roughly 300 meters (980 feet) below the level of the analyzed repository. The lower carbonate aquifer is also present beneath the repository site, but it is more than 1,250 meters (4,100 feet) below the repository level (DOE 2008a, p. 3-42). Thus, there is about 950 meters (3,100 feet) between the top of the saturated zone, or water table, and the top of the lower carbonate aquifer. As noted in the Repository Final SEIS, a well (well UE-25 p-1) 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, affects the movement of groundwater in this area. Infiltrating water (and potential releases from the analyzed repository) that reached the saturated zone in this area would remain in the overlying volcanic aquifer and move laterally rather than down into the lower carbonate aquifer. At Yucca Mountain, the groundwater in the volcanic aquifer flows to the southeast. This condition is localized, in that by the time the flow reaches the Fortymile Wash area, the general direction of flow shifts to the south and into the Amargosa River section.

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 performed by Nye County in this area led the County to conclude that the Highway 95 Fault is the southern boundary of the volcanic aquifer in the flow path from Yucca Mountain (Nye County 2005, p. 70). Drilling results show volcanic aquifers on the north side of the fault lining up with less-permeable Tertiary sedimentary rocks on the south side. The Nye County evaluation suggests that the contact with the less-permeable rocks forces the southward-flowing groundwater up into the overlying alluvial aquifer system. DOE incorporated data from Nye County's investigations into its development of the site-scale groundwater flow model used in the evaluation of a repository at Yucca Mountain (SNL 2007a, pp. 6-28 and 6-29). (The site-scale model is described in Section 2.4.2.)

Nye County installed another exploratory well (well NC-EWDP-2DB) to the lower carbonate aquifer in the same area of the boundary between the Fortymile Canyon and Amargosa River sections, just south of the Highway 95 Fault and about 19 kilometers (12 miles) south of the analyzed repository site. This well also shows an upward gradient from the lower carbonate aquifer to the overlying alluvial aquifers. In this case, water in the deep well rose 7.2 meters (24 feet) higher than the surrounding water table (BSC 2004, p. T8-11). At this location, the Paleozoic rock of the lower carbonate aquifer is at a depth of about 820 to 910 meters (2,700 to 3,000 feet) below the ground surface (Nye County 2001, pp. 31 and 32). (The range in depth below ground surface is the result of different interpretations of the *lithology* in the well and the depth at which the Paleozoic rock was first encountered.) Since the water table is about 80 meters (260 feet) below the surface in this area, the top of the lower carbonate aquifer is about 740 to 830 meters (2,400 to 2,700 feet) below the top of the water table.

Discharges or Losses

There are no identified natural discharges of groundwater (springs or evapotranspiration sites) within the Fortymile Canyon section of the flow system (Table 2-1). Pumping occurs in the section, but the quantity removed is relatively minor. Water supply wells are located near Yucca Mountain in the portion of Jackass Flats that is adjacent to Fortymile Wash. As described in the Yucca Mountain FEIS (DOE 2002, p. 3-66), water withdrawals from 1992 through 1997 were as high as 400 acre-feet (490,000 cubic meters) per year in this section. As described in the Repository Final SEIS (DOE 2008a, p. 3-50), water use in this area has decreased since that time. By the years 2000 and 2001, the quantity used had dropped to about 140 acre-feet (170,000 cubic meters) per year, and from 2002 through 2004, withdrawals dropped further, ranging from 46 to 67 acre-feet (57,000 to 83,000 cubic meters) per year. The latest update to the groundwater withdrawal rates developed for the regional flow system (Moreo and Justet 2008) estimates the total groundwater withdrawal in 2003 from both Jackass Flats and the Buckboard Mesa area to the north to be 93 acre-feet (114,000 cubic meters) (Table 2-1). From 2005 through 2009, the total amount of water pumped from the two wells adjacent to Fortymile Wash averaged about 78 acre-feet (97,000 cubic meters) per year (DOE 2013, p. 4-86). (As noted in Section 2.1, the modeling efforts described in Section 3.1.1.2 rely on Moreo and Justet 2008; more recent groundwater pumping values are discussed for comparison purposes.)

2.1.1.1.2 Amargosa River Section

Recharge and Movement

Recharge to the Amargosa River section is primarily by throughflow from adjoining sections. The alluvial aquifer receives flow from the Oasis Valley, Crater Flat, and Fortymile Canyon sections to the north and from the Ash Meadows area (labeled as the Specter Range section in Figure 2-2) to the east. The underlying lower carbonate aquifer also receives throughflow from the Fortymile Canyon section and from the Ash Meadows area.

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. In the northwestern part of the section (and northwest of the flow path from Yucca Mountain), the USGS described groundwater movement in the alluvial aquifer as being dominantly lateral and downward toward the regional, lower carbonate aquifer flow paths. In the south-central part of the section, near the Nevada-California border, flow characteristics change and become dominated by upward flow from the carbonate rocks (Belcher 2004, p. 155; Belcher and Sweetkind 2010, pp. 150 and 151).

Since the Death Valley regional groundwater flow system report (Belcher 2004; Belcher and Sweetkind 2010) was completed, Inyo County installed an additional well to the lower carbonate aquifer. The County installed this deep well on the California portion of the Amargosa River section, almost directly west of Ash Meadows, and it also has an upward hydraulic gradient from the lower carbonate aquifer to the overlying alluvial aquifer. The well is about 50 kilometers (31 miles) south of the deep well at Yucca Mountain and about 31 kilometers (19 miles) south of the deep well Nye County installed. Water in the Inyo County well rose to an elevation 3.3 meters (almost 11 feet) higher than in an adjacent well [only 6 meters (20 feet) away] installed in the overlying alluvial aquifer (Inyo County 2008, pp. 4 to 8). Assuming that the bottom of the cased portion of the well represents about the top of the lower carbonate aquifer, the depth to the lower carbonate aquifer in this area is about 750 meters (2,500 feet) below the ground surface (Inyo County 2008, p. 8). The water table in this area is at about 32 meters (105 feet) below the ground surface, so the top of the lower carbonate aquifer is about 720 meters (2,400 feet) below the top of the water table.

The *hydrogeology* of the southern portion of the Amargosa River section is particularly complex. On the east side of the section, the lower carbonate aquifer is close to the surface and feeds springs in Ash Meadows. On the west side, the carbonate rocks are lifted and exposed in the southern end of the Funeral Mountains. Moving to the south, the basin-fill deposits narrow (laterally) and become thinner as they encounter hills and mountains. In addition to the thinned basin-fill deposits in this area, groundwater flow to the south is hindered, or at least deflected, by the low-permeability quartzites of the Resting Spring Range (Belcher 2004, p. 155; Belcher and Sweetkind 2010, p. 151).

The Ash Meadows area is not included in Table 2-1 because it is not part of the flow path from Yucca Mountain, but groundwater movement in Ash Meadows is significant to the Amargosa River section. As noted in Section 2.1, the estimated amount of water discharged and lost to evapotranspiration at Ash Meadows is second only to the amount lost from the floor of Death Valley within the entire regional flow system. Estimates put groundwater losses from the Ash Meadows area at over 18,000 acre-feet (22.2 million cubic meters) per year (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103). Most of the spring discharge (not lost to evapotranspiration) reinfiltrates and recharges the alluvial aquifer of the Amargosa River section; however, much of this is believed to discharge as evapotranspiration from the alluvium along the Amargosa River bed, Carson Slough, and Alkali Flat (Belcher 2004, p. 152; Belcher and Sweetkind 2010, p. 148).

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 springs in the Furnace Creek area of Death Valley or beyond to the floor of Death Valley. As described in the Repository Final SEIS (DOE 2008a, pp. 3-34 and 3-35), the evaluation of naturally occurring chemical and isotopic constituents in the water of the Furnace Creek springs link those discharges to the lower carbonate aquifer and, further, have shown them to be very similar to the water in springs in Ash Meadows. This suggests that groundwater in the lower carbonate aquifer that feeds Ash Meadows is the primary source of the spring discharge in the Furnace Creek area almost directly to the west. However, these same studies suggest there are other contributors to the Death Valley spring discharges, including the volcanic aquifers to the north of Amargosa Desert that contribute to the alluvial aquifer. The evidence indicates the carbonate rocks beneath the Funeral Mountains provide conduits for flow from both the alluvial and lower carbonate aquifers beneath the Amargosa Desert toward the springs in the Furnace Creek area and beyond to the floor of Death Valley.

In summary, groundwater can reach the southern area of the Amargosa River section from several pathways. In the lower carbonate aquifer, groundwater flows in from the north, as well as from the east by way of throughflow from beneath Ash Meadows. In the overlying alluvial aquifer, groundwater can move in as throughflow from the north, as recharge from spring or near surface flows at Ash Meadows, and as upward flow from the lower carbonate aquifer. Once groundwater reaches the southern area of the Amargosa River section, it can leave by one of three identified routes. From the largest to smallest, based on the estimated volume of water involved, these exit routes are as follows: (1) as throughflow to the west via the fractured carbonate rocks beneath the southern Funeral Mountains and into the Funeral Mountains section of the Alkali Flat – Furnace Creek basin; (2) as evapotranspiration, primarily in the area of Alkali Flat and including losses along the Amargosa River and Carson Slough in the same general area; and (3) as throughflow to the south, following the general course of the Amargosa River and through a thin layer of alluvium near Eagle Mountain and into the southern Death Valley subregion (Belcher 2004, p. 154; Belcher and Sweetkind 2010, p. 150). The USGS regional flow model (Belcher 2004; Belcher and Sweetkind 2010) does not characterize the quantity of flow that might move into the southern Death Valley subregion, other than describing it as minor. The amount of groundwater and quantity of contaminants that could bypass Alkali Flat, while characterized as minor, is not critical for purposes of this Analysis of Postclosure Groundwater Impacts. This is because Chapter 3 of this analysis evaluates discharge areas closer to the analyzed repository and assumes discharge of the entire contaminant plume at those areas. Since the types of discharges, water usage, and associated exposure pathways in the southern Death Valley subregion would reasonably be expected to be similar to those Chapter 3 evaluates, exposure scenarios would be the same but with a lower quantity of contaminants. As a result, if some amount of contaminants were to bypass Alkali Flat, there would be a decrease of impacts from those that Chapter 3 presents for the floor of Death Valley and the springs of the Furnace Creek area.

Discharges or Losses

Natural discharges within the Amargosa River section are characterized as the evapotranspiration resulting from groundwater seeps and near-surface water in the Franklin Well area of the Amargosa River bed and the evapotranspiration from Alkali Flat. The Franklin Well area is an 8-kilometer (5-mile) stretch of the Amargosa River bed in California that runs on the west side of California State Highway 127 (that joins Nevada State Highway 373) near the south end of the Funeral Mountains (Laczniak et al. 2001, pp. 14 and 20). It is estimated that 350 acre-feet (432,000 cubic meters) of groundwater are lost each year from the Franklin Well area of the Amargosa River (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103). Alkali Flat is a large playa area located near the southern boundary of the Amargosa River section. Estimates of evapotranspiration losses from this area include not only standing water or near-surface water in the main playa area, but also aboveground flow and groundwater seeps along Carson Slough from where the slough leaves the Ash Meadows area to where it joins the Amargosa River bed at the main playa (Laczniak et al. 2001, p. 19). It is estimated that 1,000 acre-feet (1.23 million cubic meters) of groundwater are lost each year from the Alkali Flat area (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103).

There are also significant groundwater losses in the Amargosa River section as a result of pumping. Notable irrigation activities began in the Amargosa Desert in the 1970s and continue in the western Amargosa Desert. Groundwater withdrawals in the Amargosa River section have caused local water level declines. This includes the farmed area of Amargosa Desert in the central portion of the section as well as in the northwest portion of the section as a result of mining operations south of Beatty. In the Yucca Mountain FEIS (DOE 2002, p. 3-48) groundwater withdrawals in the Amargosa Desert were reported to average about 14,000 acre-feet (17 million cubic meters) per year from 1995 to 1997. The Repository Final SEIS (DOE 2008a, p. 3-37) reported that this yearly withdrawal rate decreased to an average of about 13,000 acre-feet (16 million cubic meters) per year from 2000 to 2004. The USGS regional flow model incorporates groundwater withdrawal rates that are slightly different than those reported in the FEIS and SEIS. For example, the latest update to the groundwater withdrawal rates developed for the regional flow system (Moreo and Justet 2008) estimates a total groundwater withdrawal from the Amargosa Desert of 17,600 acre-feet (21.7 million cubic meters) in 2003. This is compared with a 2003 groundwater withdrawal of about 13,800 acre-feet (17 million cubic meters) from the reference (La Camera et al. 2005, pp. 72 and 73) the Repository Final SEIS cited. Based on State of Nevada records, which are comparable to the values reported in the FEIS and SEIS, groundwater withdrawal from the Amargosa Desert averaged about 16,200 acre-feet (20 million cubic meters) per year from 2005 through 2012 (Nevada DWR 2013). Accurate pumping records are not available for all irrigation activities in the area and the differences in published values are attributed to differences in the factors used to generate estimates for unavailable data.

DIFFERENCES IN GROUNDWATER PUMPING ESTIMATES

Groundwater pumping estimates for the Amargosa Desert, as identified in previous DOE environmental impact evaluations, are different from those the USGS used in developing the Death Valley regional groundwater flow system model. The primary groundwater use in the area is irrigation. Both estimates are based on documents published by the USGS, but those cited in the earlier DOE documents used irrigation estimates the State of Nevada generated, whereas the regional flow system model used irrigation estimates the USGS generated. Both estimates are based on reliable data on the amount of land under irrigation, but when pumping data are missing, there are differing opinions on what water application rate (amount per acre) should be used to generate an estimate. The regional groundwater flow system model incorporates the larger values of the two approaches. Total annual groundwater withdrawals, as used in the model, averaged 16,800 acre-feet (20.7 million cubic meters) from 1994 through 2003, with a minimum and maximum of 14,100 and 21,200 acre-feet (17.4 and 26 million cubic meters) (Moreo and Justet 2008, p.4).

Groundwater pumping described in the preceding paragraph is limited primarily to the west-central portion of the Amargosa Desert. As described in the Repository Final SEIS (DOE 2008a, p. 3-38), a 1976 U.S. Supreme Court decision (Cappaert et al. v. United States et al. 1976) restricted groundwater withdrawal in the Ash Meadows area to protect the water level in Devils Hole and the endangered Devils Hole pupfish. In November 2008, the Nevada State Engineer took further action to protect the federally reserved water rights at Devils Hole. According to Nevada State Engineer Order 1197, any water rights applications within 25 miles (40 kilometers) of Devils Hole, and change applications that place the point of diversion to within 25 miles of Devils Hole, will be denied (with some exceptions) (Taylor 2008). This 25-mile radius incorporates the Amargosa Farms area of the Amargosa River section and, as a result, the State Engineer’s order could curtail future pumping rates in areas more distant from Devils Hole than Ash Meadows. As a result of these actions and restrictions, current pumping rates at the Amargosa Farms area may not be sustainable in the long term.

On an annual basis, the natural groundwater discharges in and near the Amargosa River section consist of the 1,350 acre-feet (1.66 million cubic meters) lost to evapotranspiration within the section, over 18,000 acre-feet (22.2 million cubic meters) lost to evapotranspiration at Ash Meadows, and the minimum of 2,300 acre-feet (2.8 million cubic meters) of throughflow to the Furnace Creek section (discussed further in Section 2.1.1.1.3 below). Based on these values and, more importantly, on the fact that groundwater levels are declining, it is reasonable to conclude that 17,600 acre-feet (21.7 million cubic meters) of annual groundwater pumping in the Amargosa Desert (primarily in the Amargosa Farms area) plays a significant role in the water budget of the section and of the central Alkali Flat – Furnace Creek basin.

2.1.1.1.3 Funeral Mountains Section

Recharge and Movement

As Figure 2-2 shows, the Funeral Mountains section encompasses the central, lowest portion of Death Valley (that is, 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. Recharge to the section from precipitation is primarily from these mountainous areas, but surface runoff can reach Badwater Basin via Salt Creek from the north or Amargosa River from the south during large precipitation or runoff events within the drainage systems. 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, but a primary source of groundwater coming into the section is from throughflow in the lower carbonate aquifer in the southern part of the Funeral Mountains (Belcher 2004, p. 155; Belcher and Sweetkind 2010, p. 151).

Based on the flow paths described previously for the southern portion of the Amargosa River section, the most likely flow path for groundwater originating from beneath Yucca Mountain to reach the Funeral Mountains section would be through the southern part of the Funeral Mountains. A much less likely route would be a round-about way through the southern Death Valley subregions along the general path of the Amargosa River. Along the primary route, throughflow from beneath the Funeral Mountains would first encounter the springs of the Furnace Creek area of Death Valley. Groundwater not discharged at the springs, or discharged and reinfiltrated, then moves in a southwesterly direction 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 (Belcher 2004, p. 154; Belcher and Sweetkind 2010, p. 151). The lowest, and largest, of these playas is Badwater Basin. Other named playas within the Funeral Mountains section include Middle Basin, which is immediately to the north of Badwater Basin, and Cottonball Basin, which is north of Furnace Creek.

The Death Valley floor is surrounded by alluvial fans and numerous springs fringed with vegetation. Groundwater is generally shallow at the bottoms of the fans sloping from the mountains that ring Death Valley. The source of the water in these fans is often local recharge from the mountains, but as in the case of the Furnace Creek area, the source may also be throughflow from adjacent basins.

Discharges or Losses

Natural groundwater losses in the Funeral Mountains section are in the form of spring discharges and evapotranspiration. The largest spring discharges of the 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 combined discharge of these springs is estimated at 2,300 acre-feet (2.8 million cubic meters) per year (Table 2-1), of which more than half is from the Travertine springs (Belcher 2004, p. 109; Belcher and Sweetkind 2010, p. 105). By far the largest groundwater loss in the section, however, is by evapotranspiration. The estimated annual evapotranspiration loss from the portion of the *Death Valley floor* within the Funeral Mountains section is 23,700 acre-feet (29.2 million cubic meters) (Belcher 2004, p. 276; Belcher and Sweetkind 2010, p. 268) (see Table 2-1 above). This value for the central portion of the Death Valley floor represents 68 percent of the 35,000 acre-feet (43.2 million cubic meters) per year of evapotranspiration losses estimated for the entire Death Valley floor (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103).

Groundwater in the Funeral Mountains section supports federal facilities and those of the Timbisha Shoshone Tribe within Death Valley National Park. Most of this water is obtained from the springs of the Furnace Creek area, but there is also a single production well (Moreo et al. 2003, p. 20) near the northwestern boundary of the section, in the Stovepipe Wells Village area of Death Valley. The amount of groundwater withdrawn from this well is minor; the 2003 withdrawal was about 55 acre-feet (68,000 cubic meters) (Moreo and Justet 2008, database) (Table 2-1).

Death Valley Springs and the Timbisha Shoshone Tribe

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 (NRC 2009, pp. 28 to 30). Representatives of the Timbisha Shoshone Tribe have stated that the DOE should evaluate the impacts of the contamination of the Death Valley springs on Timbisha cultural, historic, religious, and other interests, including the Tribe's rights to continued traditional tribal religious and cultural activities associated with the springs and on the consumptive water rights granted by the *Timbisha Homeland Act of 2000* (16 U.S.C. 410aaa) (NRC 2009, p. 5). Section 3.5 of this Analysis of Postclosure Groundwater Impacts evaluates the potential impacts to cultural resources and Tribal Government concerns in that area.

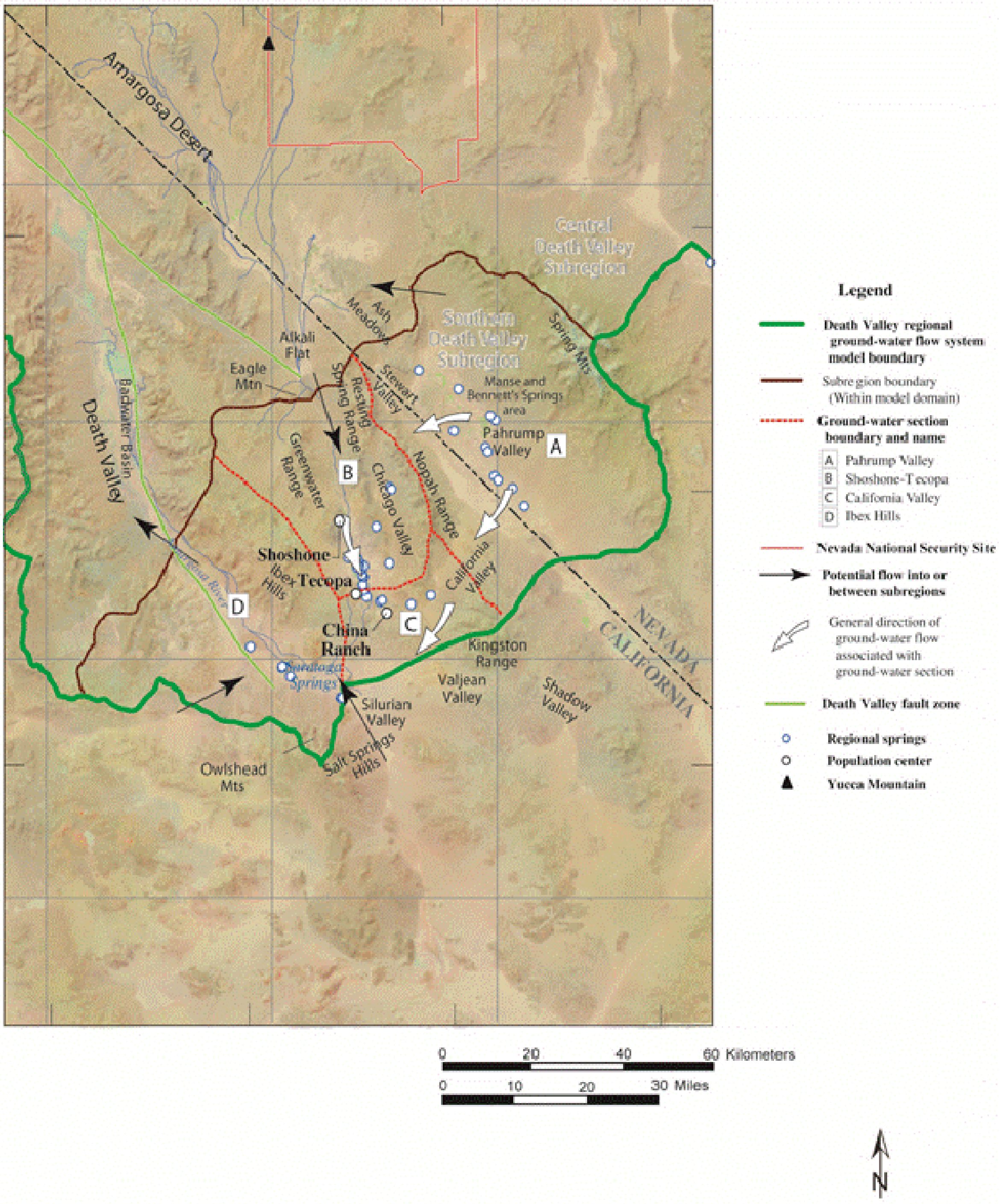
2.1.2 SOUTHERN DEATH VALLEY SUBREGION

The southern Death Valley subregion (Figure 2-3) is divided into four sections, with no basins. The four sections are: (A) the Pahrump Valley section making up the northeast portion of the subregion, (B) the Shoshone-Tecopa section in the north-central portion of the subregion, (C) the California Valley section in the south-central portion, and (D) the Ibex Hills section making up the southwest portion of the subregion. Recharge from the Spring Mountains at the northeast boundary provides groundwater flow in the subregion. Precipitation in the Nopah and Greenwater ranges within the central area of the subregion and in the Kingston Range on the southeastern boundary contribute recharge to a lesser degree (Belcher 2004, p. 155; Belcher and Sweetkind 2010, p. 151). Groundwater throughflow may also enter the southern boundary of the subregion by way of the basin-fill materials in Silurian Valley and in valleys adjacent to the Owlshead Mountains. A small amount of throughflow into the subregion may also occur across the boundary with the Alkali Flat – Furnace Creek basin of the central Death Valley subregion. As described in Section 2.1.1.1.2, this area of possible groundwater inflow is through a thin layer of alluvium near Eagle Mountain, south of Alkali Flat.

As with the rest of the regional flow system, groundwater in the southern Death Valley subregion generally moves toward the low floor area of Death Valley. Most of the subregion’s land area is to the northeast of the Death Valley floor (Figure 2-3), so groundwater in most of the region moves generally in a southwesterly direction. A portion of the subregion’s land area, however, is on the southwest side of the Death Valley floor; in this area, groundwater flows generally toward the north and northeast.

Pahrump Valley is the largest discharge area in the subregion. Before extensive development in the Pahrump Valley, the broad playa area had several springs, and the Manse Springs and Bennetts Springs discharged at the base of the broad alluvial fans at the foot of the Spring Mountains. This area now has by far the largest pumping withdrawals in the subregion and flow has ceased in many of the springs. Other areas of natural discharge are along the Amargosa River in the Shoshone and Tecopa areas and in the Saratoga Springs area of Death Valley. Some groundwater may leave the subregion in the northernmost portion, contributing flow to Ash Meadows, and in the southwestern portion, moving past the Saratoga Springs area toward Badwater Basin of the central Death Valley subregion (Belcher 2004, p. 155; Belcher and Sweetkind 2010, p. 152).

The only potential groundwater flow path from beneath Yucca Mountain to the southern Death Valley subregion is across the boundary with the Alkali Flat – Furnace Creek basin in the area south of Alkali Flat and into the Shoshone-Tecopa section of the southern subregion. From the Shoshone-Tecopa section, the primary groundwater flow path basically follows the bed of the Amargosa River to the south into the California Valley section, then to the west into the Ibex Hills section. Since the potential pathway from Yucca Mountain does not include the Pahrump Valley section, that section is not discussed further. The discussion that follows provides additional detail on the three sections of the southern Death Valley subregion that could be involved in the groundwater flow path from Yucca Mountain.



Notes: 50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Image is false-color composite combining LANDSAT 6 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.

Sources: Belcher 2004, Figure D-8, p. 151; Belcher and Sweetkind 2010.

Figure 2-3. Southern Death Valley subregion of the Death Valley regional groundwater flow system.

2.1.2.1 Shoshone – Tecopa Section

Recharge and Movement

Groundwater flow in the Shoshone – Tecopa section is primarily a result of throughflow from adjacent sections with some contribution from recharge in the Nopah Range on the northeastern boundary of the section. Groundwater in the Pahrump Valley section that is not lost in that section moves either to the north of the Nopah Range and into the Shoshone – Tecopa section, or to the south of the Nopah Range and into the California Valley section. That groundwater entering the Shoshone – Tecopa section at the northern end of Chicago Valley joins with groundwater flowing south from the Alkali Flat area and moves southward following the path of the Amargosa River.

Discharges or Losses

Groundwater discharge in the Shoshone – Tecopa section is primarily from springs and evapotranspiration along the floodplain of the Amargosa River between the towns of Shoshone and Tecopa, California. Springs in this section are small, local features, as opposed to the regional-scale, named springs shown in Table 2-1. Estimates of the amount of groundwater lost to spring discharges and evapotranspiration in the area are about 2,100 acre-feet (2.6 million cubic meters) per year (Table 2-1). The Chicago Valley playa on the east side of the Shoshone – Tecopa section also has evapotranspiration losses. It is estimated that about 430 acre-feet (530,000 cubic meters) of groundwater are lost each year from the Chicago Valley playa (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103).

Documentation for the regional flow system model also identifies some minor pumping withdrawals from the area. Estimates for the Shoshone – Tecopa and California Valley sections are minor and involve only 27 acre-feet (33,000 cubic meters) from two wells in 2003 (Moreo and Justet 2008, database; Belcher 2004, p. 111; Belcher and Sweetkind 2010, p. 108) (Table 2-1).

Groundwater not lost to spring discharges, evapotranspiration, or pumping continues flowing south in the alluvium along the Amargosa River and into the California Valley section. Some of the throughflow may also move to the southwest through faulted and fractured crystalline rocks into the Ibex Hills section (Belcher 2004, p. 156; Belcher and Sweetkind 2010, p. 152).

2.1.2.2 California Valley Section

Recharge and Movement

Sources of groundwater flow in the California Valley section are attributed to throughflow from the Shoshone – Tecopa section to the north and from the Pahrump Valley section to the northeast. Recharge from precipitation also occurs on the Kingston Range on the southeast boundary of the section. Groundwater movement in the section is primarily to the south and southwest into the Ibex Hills section.

Discharges or Losses

A structural uplift south of Tecopa brings groundwater to the surface, feeding a *perennial* stretch of the Amargosa River. As a result, water leaves the section both as surface flow in the Amargosa River and as throughflow in the alluvium along the river. The annual water loss estimate resulting from spring discharges and evapotranspiration along the Amargosa River in the California Valley section is 6,400 acre-feet (7.89 million cubic meters) (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103) (Table 2-1). The minor amount of pumping that occurs in this section was included in the Shoshone – Tecopa section above.

2.1.2.3 Ibex Hills Section

Recharge and Movement

The Ibex Hills section receives groundwater from several directions. In addition to receiving throughflow from the Shoshone – Tecopa section to the north and the California Valley section to the east, the Ibex Hills section likely receives throughflow from outside the regional flow system. As described in Section 2.1.2, groundwater throughflow can enter the southern boundary of the section by way of the basin-fill materials in Silurian Valley to the southeast and in valleys adjacent to the Owlshead Mountains to the south. Groundwater discharge from the lower carbonate aquifer also feeds the area of Saratoga Springs at the southern tip of the Ibex Hills. Groundwater movement is toward the low central area of the section where the Amargosa River bed runs from the southeast to the northwest.

Discharges or Losses

Groundwater discharge in the Ibex Hills section is primarily in the form of spring discharges in the Saratoga Springs area, from evapotranspiration along the Amargosa River and shallow groundwater (that is, groundwater close enough to the land surface that it is subject to evapotranspiration) along the flood plain of the river. A minor amount of groundwater may also leave the Ibex Hills section as throughflow into the central Death Valley subregion to the north, toward the discharge area of Badwater Basin (Belcher 2004, p. 156; Belcher and Sweetkind 2010, p. 152). The estimate of total annual evapotranspiration losses from the portion of the Death Valley floor within the Ibex Hills section is 3,420 acre-feet (4.2 million cubic meters) (Belcher 2004, p. 277; Belcher and Sweetkind 2010, p. 269) (see Table 2-1 above). This value for the southern portion of the Death Valley floor includes losses from Saratoga Springs and is only a minor portion (about 10 percent) of the 35,000 acre-feet (43.2 million cubic meters) per year of evapotranspiration losses estimated for the entire Death Valley floor (Belcher 2004, p. 107; Belcher and Sweetkind 2010, p. 103).

2.2 Evidence of Past Climates and the Associated Groundwater Flow System

2.2.1 PALEOCLIMATOLOGY

The Yucca Mountain FEIS briefly described DOE’s study and analysis of the evidence of ancient climates (DOE 2002, pp. 3-15 and 3-16) in order to gain insight into potential future climates. This study of ancient climates is termed *paleoclimatology*. DOE’s efforts have looked at time scales in the hundreds of thousands of years. This section briefly describes the natural phenomena that drive long-term climate changes. It then describes results of efforts to characterize past climates in the Yucca Mountain region based on these natural phenomena and on evidence of past climates found in geologic evidence in the region.

2.2.1.1 Forcing Mechanisms

To understand how climate has changed over this geologic time scale, DOE’s evaluations, along with those of other investigators, have looked at the forcing mechanisms that drive climate changes. Two of the primary forcing mechanisms have been characterized as *astronomical changes* and *terrestrial changes*.

Astronomical changes are extraterrestrial changes that affect the *solar radiance* received by the earth and include changes in the solar radiance put out by the sun and those due to changes in the way the earth receives that radiance due to its proximity and tilt in relation to the sun. Changes in solar radiance are attributed to sunspot cycles and increasing and decreasing radiance trends of low magnitude over long periods (BSC 2004, pp. 6-4 and 6-5). Earth changes are attributed to slight changes in the shape of its orbit around the sun and to changes in the earth's axis in relation to the plane of the orbit. These cyclical changes in the amount and manner in which the earth receives solar radiance are small, but based on long-term climate records, they show a relationship with *glacial* and *interglacial* periods.

Terrestrial changes refer to the manner in which the earth's components, consisting of the atmosphere, the water bodies, the solid earth, and life forms, respond to the changes in solar radiance the earth receives. Among these components, the primary forcing mechanisms for climate change, in simple terms, are the interactions between the atmosphere and the oceans as they attempt to minimize temperature differences caused by unequal solar radiance. These interactions and other terrestrial forcing mechanisms, including unpredictable events such as volcanism and asteroid impacts, represent additional critical elements in characterizing ancient climates (BSC 2004, pp. 6-7 to 6-9).

Developing an understanding of the natural mechanisms that drive climate changes coupled with physical evidence of past climates has allowed DOE to develop estimates of the climates that could occur in the future and how those climates could affect the performance of a repository at Yucca Mountain.

2.2.1.2 Characterization of Past Climates

A variety of information sources have contributed to an understanding of the paleoclimate in the Yucca Mountain area. The primary sources consist of stratigraphic successions of plant and animal fossils, and the presence of stable isotopes of oxygen and carbon that can be measured and dated. Paleoclimatology studies routinely incorporate numerous other contributing information sets that are not specifically mentioned here. These sources of information of interest are often referred to as climate proxy data because some climate-related parameter, or parameters, can be interpreted.

Information sources, or natural records, covering long periods of time within the Yucca Mountain region consist primarily of Devils Hole in Ash Meadows, Nevada and Owens Lake and Death Valley in California—all within about 160 kilometers (100 miles) of Yucca Mountain. Other sources of information used in the evaluations include plant *macrofossil* data collected from packrat middens and wetland and spring deposits, which often provide significant information detail, even if it is only applicable to relatively short periods of time (BSC 2004, p. 6-26).

DOE evaluated other climate evidence that shows climate episodes similar in magnitude and timing to the Owens Lake and Death Valley data. These included lake and glacial records in the region and records as far away as Greenland, Antarctica, Siberia, and Europe. These records show that climate varied substantially over time and that the timing of those changes is strikingly similar, which provides added support to the concept that climate responds to global forcing mechanisms (BSC 2004, pp. 6-40 to 6-44). One of the other records, mentioned below, is the ice core recovered from the Russian Vostok station in East Antarctica. This was a 1998 joint effort among Russia, the United States, and France and resulted in the deepest ice core ever recovered, reaching a depth of 3,623 meters (2.25 miles). Evaluation of data from the ice core indicated that the ice is slightly older than 400,000 years and represents a record extending through four climate cycles (Petit et al. 1999).

2.2.1.2.1 Devils Hole

Devils Hole, Nevada, is a large fracture within the lower carbonate aquifer that has existed over the past 600,000 years. Calcite that precipitated on rock surfaces over time has left a stable isotope record of the water in the aquifer. The concentrations of isotopes of hydrogen and oxygen deposited in calcite have been shown to vary depending on temperature. As a result, measurements of the isotopes in the calcite provide a climate change chronology, tracking a progression of glacial and interglacial climates. The Devils Hole isotopic data compare well with similar data, including composite records from global oceans and values in ice from cores taken in Antarctica and Greenland. The Devils Hole data provide a good indication of the timing for global climate changes, but do not provide a clear picture of the magnitude of the changes in air temperature and precipitation that were associated with the climate changes (BSC 2004, pp. 6-28 and 6-29).

2.2.1.2.2 Owens Lake

Owens Lake is a present-day playa in Inyo County, California, about 160 kilometers (100 miles) west-southwest of Yucca Mountain. Over its long history, Owens Lake has varied between being a flow through lake; a stagnant, saline lake; and a primarily dry playa bed. The playa contains a thick sequence of lake deposits, which include several plant, animal, and geochemical proxies (that is, they provide evidence for specific conditions) for both *paleohydrology* and climate, and which have been studied extensively in the form of several drill cores collected from the lake bed. These lake deposits provide a record of snow pack in the Sierra Nevada mountains and a measure of the nature, rate of change, and duration of past glacial and interglacial periods (BSC 2004, p. 6-30). The chronology of the sediment layers, estimated to span 850,000 years, is derived primarily from a model of the sediment accumulation rate. This chronology was subsequently augmented with a radiometric evaluation of pollen profiles that covered 230,000 years of the lake sediment history (BSC 2004, p. 6-30).

The geochemistry of the Owens Lake sediments provides significant information on the water that moved through the system. In simple terms, water moving through the system had low concentrations of chemical constituents during glacial periods when runoff was dominated by melt from an extensive snowpack and was higher in geochemical concentrations during interglacial periods (BSC 2004, p. 6-31). Fossil diatoms and ostracodes (tiny crustaceans whose remains are commonly preserved in aquatic environments) in the sediments also reflect the range of water chemistry that was in the drainage feeding Owens Lake. The *microfossil* record shows a chronological progression of climate-induced changes in the hydrochemistry as well as in plant and animal life. One set of species becomes rare or disappears and another set appears and becomes common. Following these relationships, stratigraphic distributions and abundance of five key ostracode species were used to track climate-induced changes in water chemistry and temperature for the past 400,000 years (BSC 2004, p. 6-33). The Owens Lake record is relatively continuous and can be interpreted in terms of the global climate changes that are correlated with *orbital parameters* (BSC 2004, p. 6-37).

INTERGLACIAL CLIMATE

In the cyclic nature of climate, interglacial refers to the relatively dry, warm climate (as in the present day) that is at the opposite end of the spectrum from the cooler and wetter glacial climate.

2.2.1.2.3 Death Valley

Sediments in Death Valley, California, also provide evidence of past climate events. During glacial periods, there was a deep lake present in Death Valley and based on evaluations of sediments there and in nearby areas, the Amargosa River was a primary source for that lake. Since flow in the Amargosa River is not supported by runoff from high mountains like the Sierra Nevada, the very presence of the ancient lake at Death Valley appears to support the likelihood that Fortymile Wash, a primary contributor to the Amargosa River, was a permanent stream requiring a groundwater system to support it (BSC 2004, p. 6-37). Silver Lake Playa, to the south of Death Valley, was another Pleistocene lake in the region and provides additional evidence that storm tracks may have been displaced southward (compared with the current climate) during glacial episodes.

Other paleohydrologic and paleoclimatic data from Death Valley have been obtained primarily from a 186-meter (610-foot) core taken from the lowest area (Badwater Basin) of the Death Valley floor. The core consists of sediments and evaporites deposited over the last 200,000 years. The core layers were dated using isotopic dating techniques and evaluated for various geochemical constituents to gain an understanding of the physical and climatic conditions under which they were deposited. The core contains halite crystals with fluid inclusions that can be evaluated for the temperature at which the halite precipitated. Based on the strata dating and the fluid inclusion evaluations, investigators have been able to identify periods of time when maximum summer and winter temperatures were similar and how those temperatures compare with those of the current climate. For example, investigators have been able to conclude that temperatures for the majority of the last 100,000 years were lower than temperatures for the modern climate (BSC 2004, p. 6-40), which began about 12,000 years ago (BSC 2004, p. T6-30).

2.2.1.2.4 Conclusion

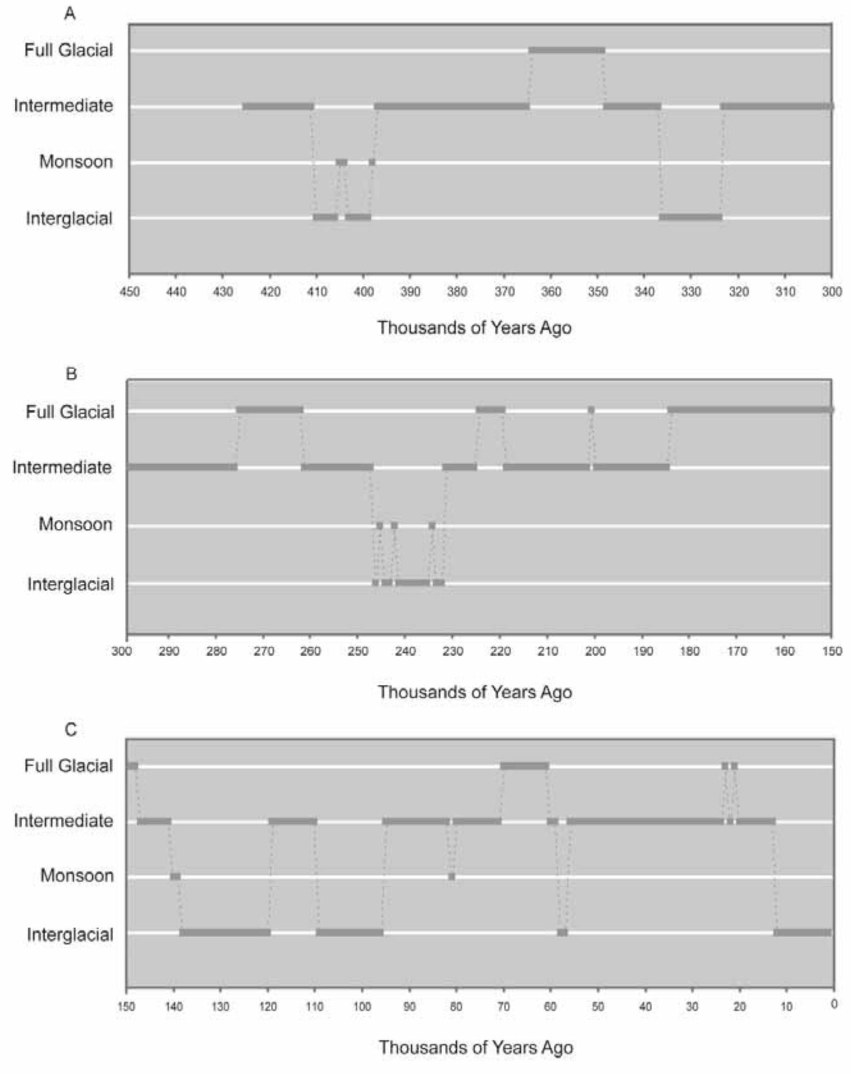
DOE’s evaluation of paleoclimatology focused on the relatively short-term history of climate of the tens and hundreds of millennia because that is the time scale of significance to the performance of a repository at Yucca Mountain. The forcing mechanisms described above are expected to function in the future in the same manner as they functioned during the past. Conditions that existed during extremely different climates (such as global aridity during the Triassic period or tropical humidity during the Cretaceous period) involved very different land and ocean configurations. These types of changes in land, mountain, and ocean configurations have not occurred over the past 500,000 years and are expected to change little over the next 500,000 years (BSC 2004, p. 6-26); climate swings or perturbations during the past 500,000-year time frame were suppressed in comparison with what the earth experienced during times even further removed from the present, and the climates typical of the recent past likely are representative of those in the future. There is some evidence of earlier (before 500,000 years ago) climate shifts that suggests the long-term earth-based (terrestrial) climate-forcing functions have remained relatively constant only over the past 500,000 years (BSC 2004, pp. 6-57 to 6-60).

The various sets of paleoclimatology data collected from the local Yucca Mountain region have been compared with each other to develop the best possible picture of what climate types affected the area and when. These data have also been compared with records of the southwestern United States beyond the Owens Lake – Death Valley region and with various locations around the world, including Greenland, Antarctica, Siberia, and Europe. The evaluations have shown that climate has changed significantly over time and that major changes around the world were synchronized (BSC 2004, p. 6-40). The paleoclimatology studies have identified four basic climate types as occurring within the period represented by the more than 400,000-year record of Owens Lake record (BSC 2004, p. 6-54). These climate types, or states, are as follows:

- Interglacial – A climate comparable to the present, relatively warm climate.
- *Monsoon* – A climate characterized by hotter summers with increased summer rainfall relative to today.
- *Intermediate* – A climate (sometimes referred to as the glacial-transition climate) that has cooler and wetter summers and winters relative to today.
- Glacial – A climate that is substantially cooler and wetter relative to today.

The sequencing of these climate states is cyclical, moving from interglacial to glacial and back again. Climate periods between the interglacial and glacial extremes are termed the *intermediate climate state*. Monsoonal activity occurs as relatively short bursts within the longer periods of interglacial or intermediate climates.

Figure 2-4 provides a graphical representation of the different climate states and when they occurred during the past 425,000 years. The climate states are largely based on the Owens Lake climate proxies because of the quality of record and the proximity of Owens Lake to Yucca Mountain. However, information from Devils Hole and the Vostok (Antarctica) ice core, which shows a strong similarity to the Devils Hole data, was used extensively to help set the timing of the climate changes depicted in the figure (BSC 2004, p. 6-55).



Note: Consistent with the source of the information in the table, climate swings with durations of less than 500 years are not shown. For example, the data show a climate swing from intermediate to glacial and back during the timeframe from 18,000 to 19,000 years ago. Because the duration of the glacial climate state was less than 500 years, the table does not show it, and the timeframe is depicted as remaining in the intermediate climate state during that time period.

Source: BSC 2004, pp. T6-29 and T6-30 (Table 6-28).

Figure 2-4. Summary of climate occurrences during the past 425,000 years as derived from Owens Lake climate proxies.

Table 2-3 provides a summary of the information presented in Figure 2-4 in terms of the total duration of each climate state. As can be seen in the figure and the table, the Yucca Mountain region experienced the intermediate climate state for the greatest amount of time at almost 60 percent of the past 425,000 years.

Table 2-3. Summary of years and percentage for each climate state.

Climate State	Total duration during the past 425,000 years	Percentage[a]
Interglacial	82,000	19
Monsoon	9,000	2
Intermediate	248,000	58
Glacial	86,000	20

Sources: BSC 2004, pp. T6-29 and T6-30, and Figure 2-4 of this Analysis of Postclosure Groundwater Impacts.

a. The percentage total does not sum to 100 percent due to rounding of the individual percentage values.

The data linked well with global circulation patterns and orbital parameters, thus demonstrating the cyclic nature, *process*, timing, and potential drivers of past climate. The climate proxy data suggest the following (from BSC 2004, p. 6-52):

- Numerous climate states occurred during the last 500,000 years ranging from warm interglacial periods (modern climate) to cool or cold and wet glacial periods. The half-million-year span contained glacial periods of different magnitudes ranging from cold and very wet to cool and dry. The maximum temperature during the glacial states of 20,000 to 22,000 years ago is estimated to have been between 4 and 8 degrees Celsius (7 to 14 degrees Fahrenheit) colder than present, with a mean annual precipitation between 1.8 to 2.4 times that of present. This glacial period is considered to have been cool and dry compared with previous glacial periods.

- Past climate states contained periods of high variability with warmer periods occurring in glacial states and cool episodes occurring in warm climate states.

- The modern climate has less *effective-moisture* compared with other climate states.

- Past climates resulted in infiltration and percolation within Yucca Mountain.

2.2.2 PALEOHYDROLOGY

Concurrent with its evaluation of paleoclimates, DOE evaluated paleohydrologic evidence. This evaluation of ancient hydrologic conditions in the region of Yucca Mountain has, like the paleoclimatic data, provided insight for assessing the long-term performance of a repository. The paleoclimatology studies described above identified periods of higher effective-moisture (compared with modern conditions) that dominated the last 425,000 years. Similarly, the paleohydrology studies have shown that the low groundwater levels of today might be typical for only the relatively short, drier interglacial periods and that the water table has been higher in the past and would likely rise during future glacial cycles.

The higher effective-moisture of past climate states resulted in the Death Valley region’s lakes, perennial drainage systems, some large wetlands, and many small seeps and minor wetlands (D’Agnese et al. 1999, p. 5). Shallow lakes existed in the Gold Flat, Kawich, and Emigrant basins to the north and northeast of the Nevada National Security Site. Both the Amargosa River and its major tributary, Fortymile Wash, were likely perennial streams helping supply the ancient Lake Manly in Death Valley. Cactus Springs, Corn Creek Springs, and Tule Springs, all on the northeast, Las Vegas side of the Spring Mountains, were supported by both groundwater and surface water systems. The higher amounts of recharge in the Spring

Mountains and the Sheep Range likely resulted in spring discharge from the alluvial fans at the foot of the mountains (D'Agnese et al. 1999, p. 5). This picture of past hydrologic conditions has been obtained through the evaluation of natural features, isotopic data, and mineralogical data, all of which provide evidence of past groundwater levels.

The paleohydrologic information of interest for this Analysis of Postclosure Groundwater Impacts is the identification of areas along potential groundwater flow paths from Yucca Mountain where past conditions may have resulted in groundwater discharge locations not considered in the Section 2.1 discussion of the current groundwater flow system.

2.2.2.1 Ancient Groundwater Discharge Locations

Evidence of ancient, or fossil, spring discharges can take several forms in the southern Great Basin. In areas where water from the lower carbonate aquifer fed the springs, fossil spring deposits are in the form of calcite that forms tufa mounds, travertine terraces, and stratiform deposits. These are all calcium carbonate deposits typical of the Ash Meadows basin and eastern Death Valley, where current discharges are from the lower carbonate aquifer. Deposits in Crater Flat and the Amargosa Desert are from discharges of the alluvial aquifer that were derived primarily from volcanic aquifers, and the amount of carbonate materials is less. Based on the evaluation of fossil spring deposits, it is estimated the water table was from 15 to 70 meters (50 to 230 feet) higher during the Pleistocene (the epoch that lasted from about 2.58 million to 11,700 years ago[1]) than at present (BSC 2004, p. 8-97). The discussions that follow address the various *paleodischarge* sites found in the Yucca Mountain region. Figure 2-5 depicts these ancient discharge sites.

2.2.2.1.1 Ash Meadows

At Devils Hole, evaluation of *calcite deposits* has shown that the water level was more than 5 meters (16 feet) higher than at present between 116,000 and 53,000 years ago, and fluctuated between about 5 and 9 meters (16 to 30 feet) higher than at present during the period between about 44,000 and 20,000 years ago (BSC 2004, p. 8-97). Based on the information in Figure 2-4, both of these time periods included extensive periods of the intermediate climate and some periods of the glacial climate. Investigators have found paleodischarge paths lined with calcite deposits in areas up to 14 kilometers (8.7 miles) north and northeast of Devils Hole in the area often referred to as Amargosa Flat (or Peters Playa), which is the northeast extension of the Ash Meadows paleodischarge area shown in Figure 2-5. Searches for these deposits have shown that they occur at scattered, isolated locations on the surface that coincide with known or suspected faults. They have not been found at similar elevations elsewhere within the basin or along its margin. It is believed that the upward hydraulic gradient in the lower carbonate aquifer may have been even greater during the Pleistocene than at present, and that the scattered evidence of paleodischarges in the Amargosa Flats area was due to upflow along the faults (BSC 2004, p. 8-98).

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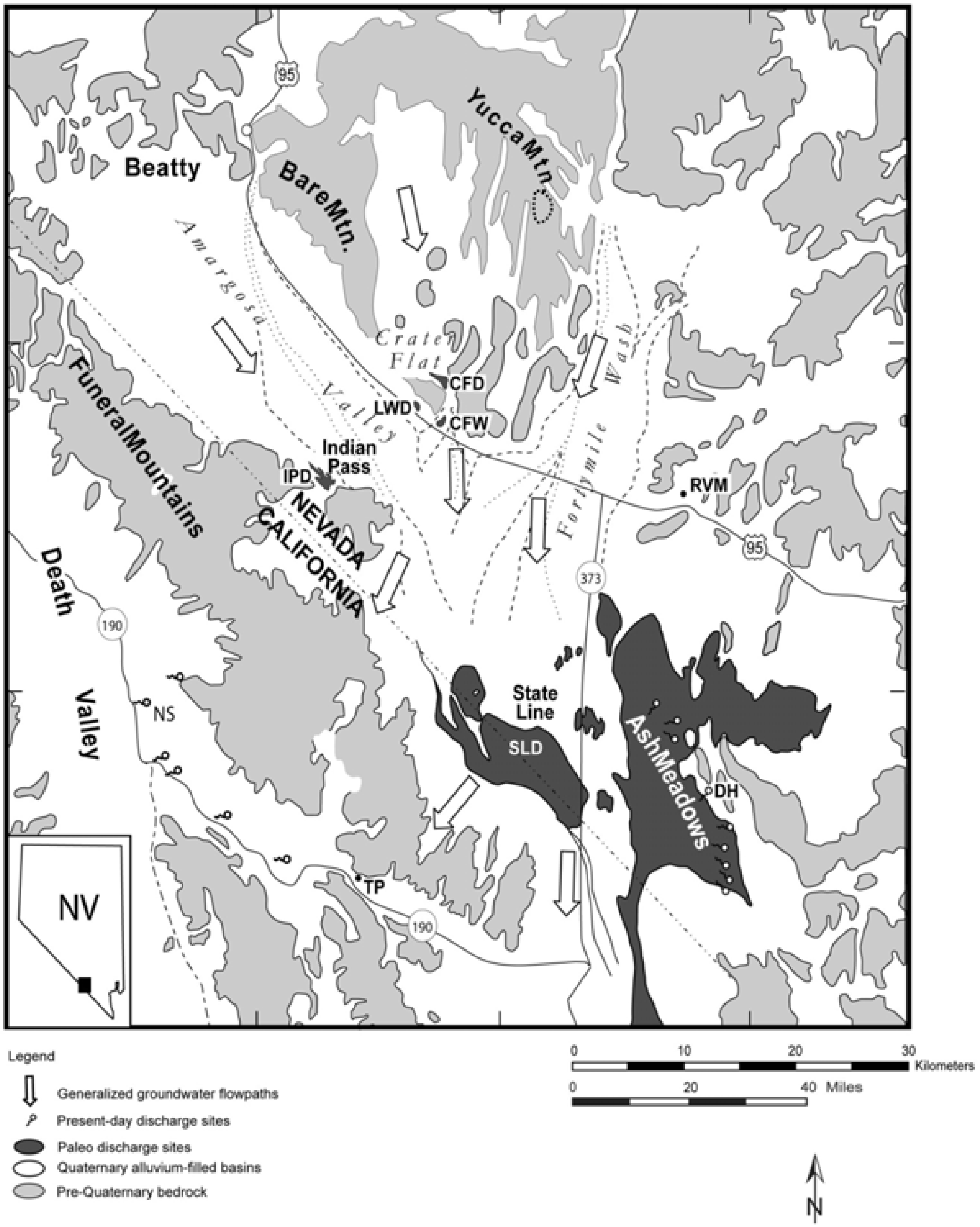
[1] During 2009, the age range of the Pleistocene was redefined and confirmed by the International Union of Geological Sciences (see Cohen and Gibbard 2011).



Note: CFD = Crater Flat Deposit; LWD = Lathrop Wells Diatomite; CFW = Crater Flat Wash; DH = Devils Hole; RVM = Rock Valley Mound; SLD = State Line Deposits; IPD = Indian Pass Deposit; TP = Traverine Point; NS = Nevares Spring; GS = Grapevine Spring

Source: BSC 2004, p. F8-29 (Figure 8-29).

Figure 2-5. Paleodischarge areas in the Yucca Mountain region.

2.2.2.1.2 Southern Crater Flat Area

Investigators found deposits from ancient springs on both the north and south side of the unnamed ridge that defines the southern boundary of Crater Flat. This ridge, or band of hills, extends to the southeast from Bare Mountain, almost reaching the hills extending south from Yucca Mountain. On the north side of the ridge, the Crater Flat Deposit occurs at an elevation of about 840 meters (2,760 feet) above present sea level. There are two deposits on the south side of the ridge: The Lathrop Wells Diatomite site occurs at elevations between 790 and 800 meters (2,590 and 2,620 feet) and the Crater Flat Wash deposit occurs at an elevation of about 790 meters.

Evidence of ancient springs at the Crater Flat sites consists of various mineral deposits, casts of insect burrows, and petrified plants. The Lathrop Wells Diatomite site includes a 1- to 2-meter (3- to 7-foot)-thick bed of *diatomite* (a soft, chalk-like sedimentary rock rich in the skeletons of diatoms) that is not present at the other sites (BSC 2004, p. 8-98). Efforts to date the spring deposits indicate they formed beginning about 60,000 years ago and continued until about 15,000 years ago. It is estimated that the water table needed to be 17 to 30 meters (56 to 100 feet) higher than at present to support the southern springs and 10 to 70 meters (30 to 230 feet) higher at the Crater Flat site (BSC 2004, p. 8-99). The compositions of the spring deposits indicate that water from the volcanic and alluvial aquifers generated them. Possibly, but less likely, the composition of the deposits also suggests that they could have been formed by the lower carbonate aquifer (BSC 2004, p. 8-100). Current groundwater temperatures in the area indicate there may be upward contributions from the lower carbonate aquifer, possibly along faults in the local area. Thus, there could have been similar contributions in the past.

2.2.2.1.3 State Line Deposits

Ancient spring deposits similar to those at the Crater Flat sites occur along the Nevada-California state line, adjacent to the south end of the Funeral Mountains. The general area starts about where the Amargosa River first enters California, and continues to the southeast to the area where Fortymile Wash joins the riverbed. The present water table is shallow along this reach of the river, which is consistent with it being identified in Section 2.1.1.1.2 as an area with notable evapotranspiration losses. Carbonate-capped terrace deposits indicate that ancient spring discharges occurred as much as 6 meters (20 feet) above the river bottom. Dating of the deposits indicate these high elevation discharges occurred for a span of 30,000 to 50,000 years. Other samples indicate deposit ages as old as 100,000 years and as young as about 10,000 years. These findings are consistent with the belief that the Amargosa River was a major contributor to Lake Manly in Death Valley (Section 2.2.1.2) and appear to show an interplay of surface flow and spring discharge (Belcher 2004, p. 158; Belcher and Sweetkind 2010, p. 154) in a large area where flow from Fortymile Wash joined the Amargosa River.

As with the Crater Flat sites, composition of the State Line deposits indicate water from the volcanic and alluvial aquifers generated them. Possibly, but less likely, the lower carbonate aquifer could have formed the spring deposits (BSC 2004, p. 8-100).

2.2.2.1.4 Indian Pass

A final location of ancient spring discharge in the vicinity of Yucca Mountain is near the toe of the northeast-facing slope of the Funeral Mountains. This site, designated the Indian Pass deposit, occurs at an elevation of 780 meters (2,560 feet) above sea level and has deposits similar to those at the Crater Flat sites, including being of the same general age.

2.2.2.1.5 Other Paleodischarge Locations

Evidence of other ancient lakes and discharge locations within the Death Valley regional groundwater flow system, some of which are mentioned in Section 2.2.2 above, is not addressed further. These other locations are too far removed from potential groundwater flow paths from Yucca Mountain to be relevant to the discussion. For example, the shallow lakes described in Section 2.2.2 that existed in the Gold Flat, Kawich, and Emigrant basins to the north and northwest of the Nevada National Security Site are well away from flow paths from Yucca Mountain. Were those lakes to reform during a future, wetter climate, they would not be affected by any contaminants migrating in groundwater away from Yucca Mountain. Similarly, there are wetland deposits in Pahrump Valley (Belcher 2004, p. 158; Belcher and Sweetkind 2010, p. 154) that suggest the area could have surface water in future climates, but that area would not receive groundwater flow from beneath Yucca Mountain.

2.2.2.2 Ancient Groundwater Flow Paths

The USGS used the regional flow system model of the time to address different climate scenarios (D’Agnese et al. 1999) with a goal of assessing the potential impacts on the flow system. The simulation of interest to the current discussion was based on climatic conditions of approximately 21,000 years ago and was intended to represent cooler and wetter conditions during the late Pleistocene under a full glacial condition. This section addresses specific findings from that simulation.

The USGS modeled the cooler and wetter climate of 21,000 years ago primarily by changing the distribution and rates of groundwater recharge over the model grid (D’Agnese et al. 1999, p. 1). Results from the climate-change simulation were evaluated by several means, one of which was the comparison of simulated discharge areas with paleodischarge sites. The model results indicated there would have been sufficient groundwater to maintain paleolake levels in the northern parts of the regional flow system and for Lake Manly in Death Valley, and that groundwater discharges occurred at most of the paleodischarge sites. A few exceptions to matching paleodischarge sites occurred along the east side of the flow system. For example, in Indian Springs Valley, there is evidence of paleodischarges and wetlands in a large area extending north from the present community of Indian Springs. The model failed to identify discharges in this area except for springs closest to the Spring Mountains near the present-day Indian Springs and Cactus Springs (D’Agnese et al. 1999, p. 22). The paleodischarge areas closest to Yucca Mountain, however, were reasonably well duplicated; in instances where paleodischarge sites were not simulated as discharging, the potentiometric surface appeared to be close to land surface. Based on discharge areas, the simulation is considered a valid representation of paleoclimatic and paleohydrologic conditions.

In conclusion, the model simulation resulted in a raised water table with a regional potentiometric surface shaped very similar to that for present conditions (D’Agnese et al. 1999, p. 1). This means the groundwater flow paths under the simulated past climate condition were basically the same as for the present day. In addition, the potentiometric surface configuration also predicted surface discharges that match well with identified paleodischarge sites, providing additional confidence in the results. The locations of the primary recharge areas (the mountains) and the regional sink (Death Valley) are the same as at present, further supporting a conclusion that flow paths were not significantly different.

For these reasons, DOE reached the following conclusions with respect to which paleodischarge sites would be in the flow path from Yucca Mountain:

- Ash Meadows. Devils Hole, the other springs within Ash Meadows, and the area of Amargosa Flat (or Peters Playa) are all east of the current flow paths from Yucca Mountain. As a result, the identified paleodischarge locations within the general area of Ash Meadows would not be potential discharge locations for groundwater from beneath Yucca Mountain. Similar to current conditions, water from the lower carbonate aquifer rising to or near the surface in this area resulted in a higher potentiometric surface, or head, in this area, which affected flow paths from Yucca Mountain by keeping the primary paths to the west, closer to the Amargosa River.

- Southern Crater Flat Area. As with the fossil spring deposits of the Ash Meadows area, the Crater Flat sites are not within the current flow paths from Yucca Mountain, and it appears they were not in the flow path in past times when groundwater levels were higher. The groundwater flow path from beneath Yucca Mountain is to the southeast, then basically beneath Fortymile Wash and southward. At its closest, Fortymile Wash is approximately 10 kilometers (6 miles) to the east of the Crater Flat sites.

- State Line Deposits. The State Line fossil spring deposits are in the area where the Amargosa River and Fortymile Wash join. This area is in the flow path of groundwater from beneath Yucca Mountain. Both the river and the wash were likely perennial streams during the last glacial period. The USGS's modeling effort characterized the area bracketed by the confluence of the two streams as a potential wetland area (D'Agnese et al. 1999, p. 18). The USGS's simulation also described the southern part of Fortymile Wash as being a gaining stream (D'Agnese et al. 1999, p. 22), meaning groundwater contributed to its flow. Based on a figure provided in the USGS's report that shows the distribution of drains and constant head cells in the past climate simulation (D'Agnese et al. 1999, p. 23), it appears that under the simulation, the gaining portion of the stream extended as far as about 20 kilometers (12 miles) upstream (to the north) from where Fortymile Wash joins Amargosa River.

- Indian Pass. The fossil spring deposits at Indian Pass are located directly southwest, across the Amargosa Desert from the Crater Flat sites. Being even further west of Fortymile Wash than the Crater Flat sites, the Indian Pass site is not within the groundwater flow path from Yucca Mountain.

As identified in the preceding statements, it appears that of the fossil springs, or paleodischarge sites, identified in the vicinity of Yucca Mountain, only the State Line site would be within the groundwater flow path from beneath Yucca Mountain. As a result, this discharge area, along with the southern reach of Fortymile Wash, would be locations where groundwater contaminants originating in a repository could surface under a future cooler and wetter climate.

2.3 Numerical Modeling of the Regional Groundwater Flow System

2.3.1 PREVIOUS WORK

Groundwater modeling efforts in the Death Valley region began more than 30 years ago and have resulted in a succession of models with increasingly more realistic representations of the groundwater flow system. DOE has supported the development of these models for use at the Nevada Test Site (now the Nevada National Security Site) and Yucca Mountain to address the complex water resource issues in the region. This section describes some of the earlier efforts and how they contributed to the most recent flow model, the *Death Valley Regional Ground-Water Flow System, Nevada and California – Hydrogeologic Framework and Transient Ground-Water Flow Model*. The primary source of information for this section is the 2004 USGS report of the same title (Belcher 2004) and its re-issue of 2010 (Belcher and Sweetkind 2010), which is described later in this section. Many of the models described in this section were also developed by USGS.

Results from a series of modeling efforts were published from 1982 to 1995. Two models were developed, one in 1982 and one in 1984, to simulate groundwater systems of the Nevada Test Site and

Amargosa Desert, respectively. In 1984, another model was constructed to address the Nevada Test Site and vicinity. All of these were two-dimensional models and each had notable shortcomings; common to each was the inability to reproduce adequate simulations of vertical flow components. In 1987, results of a more sophisticated, quasi-three-dimensional model of the Nevada Test Site regional groundwater flow system were published. This 1987 model consisted of two aquifer layers: the uppermost layer represented a shallow aquifer—for example, volcanic rocks or basin-fill deposits—and the lowermost layer represented a deep aquifer composed of carbonate and volcanic rocks. Although this model represented the Nevada Test Site flow system more accurately than the earlier models, analysis of the model indicated that small changes in recharge or discharge rates generally produced substantial changes in the simulated magnitude and direction of groundwater flow (Belcher 2004, p. 14; Belcher and Sweetkind 2010, p. 12).

Results were published from another model in 1995. In this case, the model was a regional-scale numerical model of the carbonate-rock province of the Great Basin. The conceptual model of the groundwater flow system behind this numerical model was one of relatively shallow components where groundwater moved from mountain ranges to basin-fill deposits in adjacent valleys, as well as a deeper component where groundwater moved through the carbonate rocks. This conceptual model of the groundwater flow system is the basis for subsequent numerical models of the Death Valley regional groundwater flow system.

The more recent efforts have consisted of three-dimensional groundwater flow models, which allowed for a better representation of the spatial and process complexities and heterogeneities of the hydrogeologic system. The efforts have incorporated a three-dimensional hydrogeologic framework model into the groundwater flow model. The hydrogeologic framework model is a digital, computer-based description of the geometry and composition of the hydrogeologic units that are internal to the volume encompassed by the groundwater flow model. This framework provides the basis for assigning the hydrologic properties that directly affect groundwater movement in the groundwater flow model. For example, the hydrogeologic framework model (or a specific unit within that model) provides the initial spatial bounds for a permeability parameter assigned to the model and which can later be modified or adjusted in the flow analysis and calibration. Modeling efforts in this group include a 1996 effort by IT Corporation for the Nevada Test Site and centered on the Nevada Test Site, a 1997 USGS effort for the region around Yucca Mountain, and a 2002 effort that merged elements of the other two models (Belcher 2004, p. 15; Belcher and Sweetkind 2010, p. 13). The remaining portion of this section briefly describes these three modeling efforts. Also described is a specific application of the 1997 model.

The 1996 modeling effort by IT Corporation for the Nevada Test Site was undertaken to estimate hydrologic and *radionuclide attenuation* properties of the rocks through which radionuclides related to nuclear weapons testing might migrate (Belcher 2004, p. 15; Belcher and Sweetkind 2010, p. 12). It included a geologic model with a 2,000-meter (6,560-foot) horizontal grid, with 20 vertical layers of varying thickness, and extending from land surface to 7,600 meters (25,000 feet) below sea level. Twenty hydrogeologic units were modeled. This was integrated into a three-dimensional, *steady-state* flow model. The model domain encompassed 17,700 square kilometers (6,830 square miles) that centered on the Nevada Test Site and extended west to east from Death Valley to the East Pahranagat Range, and north to south from the southern Railroad Valley to the Black Mountains. DOE also used the model for estimating the amount of water moving through the flow system and associated uncertainties, and for supplying boundary conditions for more detailed models of underground testing areas.

The 1997 modeling effort for the former Yucca Mountain Project included a geologic model with a 1,500-meter (4,920-foot) horizontal grid, with variable vertical thickness, and extending from land surface to 10,000 meters (32,800 feet) below sea level. Ten hydrogeologic units were modeled. This was integrated into a three-dimension, steady-state flow model. The model domain encompassed 70,000 square kilometers (27,000 square miles) that centered on Yucca Mountain and the Nevada Test Site and extended west to east from Death Valley to the East Pahranagat Range, and north to south from Cactus Flat to the Avawatz Mountains. The three-layer flow model supported analysis of interactions between the relatively shallow, local and subregional flow paths and the deeper, regional flow paths of the lower carbonate aquifer (Belcher 2004, p. 15; Belcher and Sweetkind 2010, p. 13).

The USGS, in cooperation with DOE, subsequently used the 1997 model to assess the potential effects of past and future climates on the regional flow system. This effort involved the simulation of flow system conditions during the full glacial climate of 21,000 years ago, as well as during future conditions under a scenario involving a doubling of atmospheric carbon dioxide (D'Agnese et al. 1999, p. 1). Section 2.2.2.2 describes this modeling effort and results from the full glacial climate simulation.

In 2002, the hydrogeological framework models from the 1996 and 1997 efforts were merged. This resulted in a single, integrated hydrogeologic framework model for use with a steady-state, prepumping flow model. The three-dimensional flow model incorporated a nonlinear least-squares regression technique to estimate aquifer-system parameters. This model was designated the Death Valley regional groundwater flow system prepumping model, and its lateral boundaries were slightly larger than those of the 1997 model. This model provided a reasonable representation of prepumping conditions for the regional flow system and was an improvement over previous models; however, important uncertainties and model errors remained (Belcher 2004, p. 17; Belcher and Sweetkind 2010, p. 15).

The current USGS model of the Death Valley regional groundwater flow system, initially published in 2004, builds upon these previous efforts.

2.3.2 DEATH VALLEY REGIONAL FLOW SYSTEM MODEL (2004 AND 2010)

In 1998, the USGS began a 5-year project to develop an improved groundwater flow model of the Death Valley regional groundwater flow system. This project was in support of both the Nevada Test Site and the former Yucca Mountain Project and was largely funded by DOE. However, because of the model's potential use in dealing with a wide range of regional water resource issues, several other agencies contributed financially to the work, including Nye County in Nevada, Inyo County in California, the National Park Service, the U.S. Fish and Wildlife Service, and the U.S. Air Force (Belcher 2004, p. iii; Belcher and Sweetkind 2010, p. iii). The initial objectives of this effort included development of the steady-state model representing prepumping conditions (see above). The goal of this project was to provide a starting point for the calibration of a transient groundwater flow model (Belcher 2004, p. 7; Belcher and Sweetkind 2010, p. 5). Ultimately, the model was intended to be used for the following (Belcher 2004, pp. 7 and 8; Belcher and Sweetkind 2010, pp. 5 and 7):

- Providing the boundary conditions for the site-scale models at Yucca Mountain and Corrective Action Units at the Nevada Test Site;
- Evaluating the impacts of natural or human-induced changes in system *flux*;
- Providing a technical basis for decisions on the quantity of water available for development on the Nevada Test Site;
- Determining the potential effects of increased offsite water use on Nevada Test Site water supplies;
- Providing a framework for determining effective groundwater quality monitoring locations; and

- Facilitating the development of a cooperative, regional Death Valley groundwater management district.

The 2004 Death Valley regional groundwater flow system model was constructed with 16 layers and a horizontal grid with cells 1,500 meters (4,920 feet) on a side. The total model domain has 194 rows and 160 columns and is essentially the same as the 2002 prepumping model described in Section 2.3.1. The hydrogeologic framework model component includes the geometries of 27 hydrogeologic units that include (from youngest to oldest) (USGS 2006, p. 2):

- Cenozoic basin-fill and playa deposits (making up local aquifers and confining units depending on the characteristics of the deposits);
- Cenozoic volcanic rocks (making up aquifers and confining units depending on their physical properties);
- Cenozoic and Mesozoic intrusive igneous rocks (making up local confining units);
- Mesozoic sedimentary and volcanic rocks (making up aquifers and confining units depending on their physical properties);
- Paleozoic carbonate rocks (main regional aquifer);
- Paleozoic to Late Proterozoic sedimentary rocks (main regional confining unit); and
- Proterozoic igneous and metamorphic rocks (regional confining unit, generally forming the bottom of the flow system).

Investigators tested and calibrated the Death Valley regional groundwater flow system model by performing and repeating simulations with adjusted input parameters until water-level and spring-flow values simulated by the model matched the corresponding measured values. The input parameters adjusted during this process included values for parameters of the hydrogeologic units, and recharge and discharge amounts and locations. The model was first calibrated for steady-state groundwater levels developed for prepumping conditions (that is, for conditions before groundwater pumping began in the region in 1913). The model was then calibrated for transient conditions using values for water level, spring flows, evapotranspiration, and pumping as they changed over time from 1913 to 1998 (USGS 2006, p. 3).

Results from the model simulations indicated that modeled groundwater flow matched well with inferred groundwater flow patterns throughout the model domain. Simulated groundwater levels generally matched measured water levels except in areas where the water levels change rapidly over a short distance. Areas with this steep hydraulic gradient condition include Indian Springs, western Yucca Flat, and the southern part of the Bullfrog Hills. Water level declines from the transient simulations generally matched those declines observed in Pahrump Valley, Amargosa Desert, and Penoyer Valley. The model also adequately simulated observed spring flow declines in Pahrump Valley during the last century. Finally, the hydrologic parameters of the hydrogeologic units that define the ability of the unit to transmit and store water, and that were adjusted during the calibration process, ended at values within the range of values measured in the field (USGS 2006, p. 5).

In 2010, the USGS re-issued its Belcher 2004 report on the Death Valley regional groundwater flow system model under the same title, *Death Valley Regional Groundwater Flow System, Nevada and California – Hydrogeologic Framework and Transient Groundwater Flow Model*, but as Professional

Paper 1711 (Belcher and Sweetkind 2010). According to its Acknowledgments section, the 2010 report “updates and finalizes” the 2004 effort and includes corrections to “a number of minor errors and inconsistencies within and between chapters” as well as improving “the clarity and accuracy of a number of figures.” With those exceptions, the 2010 report is described as remaining “essentially unchanged” from the 2004 Scientific Investigations Report. This Analysis of Postclosure Groundwater Impacts continues to reference the 2004 document in order to maintain a consistent sequence of references and events. As a primary example, License Application documents for the former Yucca Mountain Project, including site-scale groundwater modeling results described in Section 2.4, were prepared before re-issue of the USGS model and are fixed in time, so they are not being altered to reference a new document. USGS expects to publish a revision to the Death Valley regional groundwater flow system model late in 2014.

Section 2.4 of this Analysis of Postclosure Groundwater Impacts provides an overview of the extensive modeling done to evaluate the potential impacts of the analyzed repository. The discussion focuses on the movement of water through the *unsaturated zone* at Yucca Mountain (including through the horizon of a repository), into the saturated zone beneath the analyzed repository location, and away from Yucca Mountain in the hydraulically downgradient direction. DOE used site-scale models to simulate water movement in the unsaturated and saturated zones at Yucca Mountain and downgradient past the location of the *accessible environment*, as defined by regulation (Section 2.4.3.1). Because these site-scale models were developed to simulate a much smaller area than the regional models, they could be developed at much finer detail. Evaluations for this Analysis of Postclosure Groundwater Impacts required that output from the site-scale saturated zone flow model be input to the regional model to evaluate potential impacts from a repository to locations beyond the accessible environment. This involved using the site-scale saturated zone model to track a group of simulated particles from beneath a repository at Yucca Mountain to the boundary of the accessible environment. The distribution of particles from this site-scale model simulation was then input to the regional model, and the particle tracking function was again used to develop simulated flowpaths beyond the accessible environment boundary. The site-scale and regional models can support this action, but transition to the coarser level of detail inherent in the regional model has certain limitations.

DOE has high confidence in the site-scale saturated zone flow model for use in evaluating potential repository impacts. The model includes a horizontal grid with cells 250 meters (820 feet) on a side and 67 layers of varying size or depth in the vertical direction. For comparison, the most recent regional model has a 1,500-meter (4,920-foot) grid size and 16 layers (SNL 2009, p. 34). One can visualize the effect of the differences in these model construction parameters in terms of the hydrogeologic framework models. The site-scale and regional models can have the same physical information describing the positions of applicable hydrogeologic units. However, in the regional model, the hydraulic conductivity for an entire cell (defined by one grid in the horizontal plane and one model layer) is represented by a single geometric mean value calculated from whatever hydrogeologic units are within that cell. Therefore, depending on what units are present, some detail can be lost through the averaging process. In the horizontal plane, the 250-meter grid of the site-scale model offers a resolution that is 36 times finer than the regional model (DOE 2008b, p. 2.3.9-22).

In the evaluations Chapter 3 describes, the regional model was sometimes used in simulations similar to those for which the site-scale model was used. Variation in model results are recognized and expected; these differences are attributed primarily to the coarse scale of the regional model in comparison with the site-scale, but can also be attributed to the overall purposes for which both models were originally constructed. The regional model was constructed to support simulations from which regional conclusions might be drawn. In some cases, evaluations described in Chapter 3 are based on efforts to use the regional model to define characteristics of discrete flow paths within a small portion of the region. These efforts are within the general capabilities of the model, but the results need to be taken in context of the model’s intended use, the relative coarseness of the model structure, and uncertainties inherent to the modeling process.

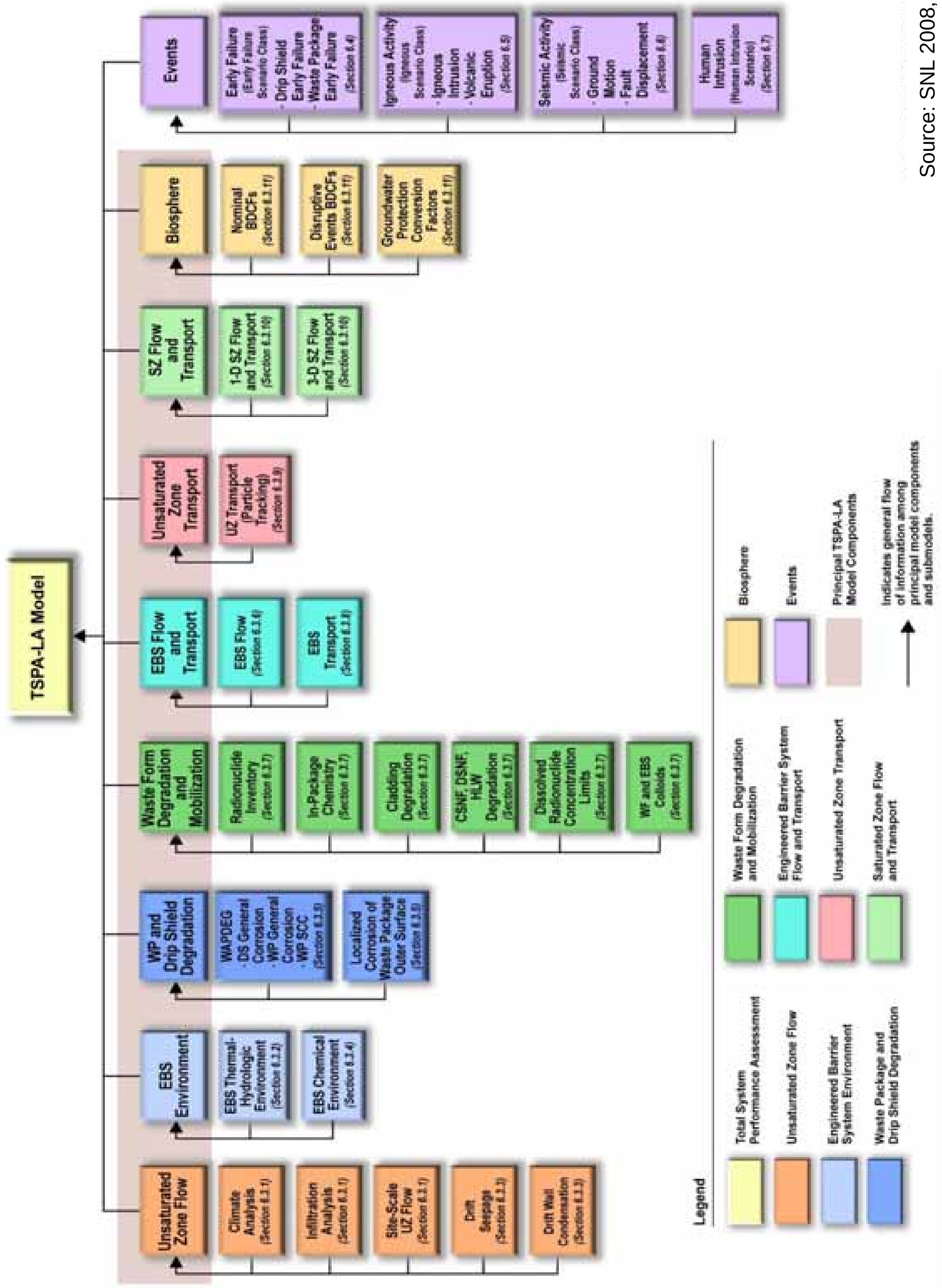
As a final note on the Death Valley regional groundwater flow system model, DOE performed simulations described in Chapter 3 and Appendices A and B using the USGS model, but with slight modifications from what is described in Belcher 2004 and Belcher and Sweetkind 2010. The USGS model described in these reports, as noted above, was calibrated for transient conditions based on groundwater records, including pumping rates, over the period 1913 to 1998. For the simulations performed to support this Analysis of Postclosure Groundwater Impacts, DOE chose to incorporate groundwater data updated to 2003 by Moreo and Justet (2008) (SNL 2009). For simulation of transient flow conditions, the model was then calibrated (or recalibrated) against the expanded dataset. The long-term pumping simulations described in other sections of this document are based on a continuation of 2003 pumping rates.

2.4 Modeling of Yucca Mountain Infiltration, Groundwater Movement, and Impacts as Described in the Repository Final SEIS

This section discusses the basis for the groundwater modeling presented in Chapter 3. The discussion is primarily in terms of the modeling associated with the Repository Final SEIS but also includes how that effort fits with the regional model the USGS developed. Chapter 3 discusses the specific ways in which the current evaluation used the existing models.

The Repository Final SEIS described results from the *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008) (TSPA-LA), which was used to assess long-term repository performance in terms of a characterization of radiological dose to humans over time. The configuration of the TSPA-LA model provided a framework for the incorporation of information from various *process models* and *abstraction model*s into an integrated representation of the important features, events, and processes that apply to the analyzed repository system, including engineered and natural *barriers*. Figure 2-6 provides an overview of the principal model components and submodels that were integrated into the TSPA-LA model.

Process models (large, complex computer models) provided information to the TSPA-LA model and included representations of such features as thermal-hydrologic conditions, degradation characteristics of the *Engineered Barrier System*, and unsaturated and saturated zone flow fields. The process models were based on fundamental laboratory and field data. Abstraction models are generally simpler than the process models, possibly consisting of nothing more than a simple function or table of numbers, but usually representing the results from a much more detailed process model. The TSPA-LA model functioned by handing off data from one subsystem to the next along the primary release path and allowing an assessment of behavior at intermediate points. The integration performed by the TSPA-LA model occurred in a Monte-Carlo simulation-based method to create multiple random combinations of the likely ranges of parameter values for the process models. In this manner, the TSPA-LA model computed the probabilistic performance of the entire waste *disposal* system, and the result reflected an appropriate range of process behaviors or parameter values, or both, of the inherently variable analyzed repository system (SNL 2008, p. ES-7). Performance was measured in terms of radiological dose to the RMEI



Source: SNL 2008, P. FES-9.

Figure 2-6. TSPA-LA principal model components and submodels.

located at a distance of approximately 18 kilometers (11 miles) south of the repository, which is the predominant direction of groundwater flow (DOE 2008a, p. F-4). The TSPA-LA model evaluated the following nine major elements of the analyzed repository (SNL 2008, pp. ES-8 and FES-9):

- Water flow from the ground surface through the unsaturated tuffs above and below the repository horizon, which would include water that dripped into the waste *emplacement drifts*;
- Thermal and chemical environments in the Engineered Barrier System, effects of disruptive events on that system, and perturbations to the surrounding natural system due to waste emplacement;
- The degradation of the engineered components that would contain the *radioactive* wastes;
- The degradation and dissolution of the waste forms and the release of radionuclides from the waste packages;
- The release of radionuclides from the Engineered Barrier System to the unsaturated zone below the repository;
- The migration of these radionuclides through the unsaturated zone below the repository to the saturated zone;
- The migration of these radionuclides from beneath the repository and downgradient through saturated rocks and alluvium to the RMEI;
- Arrival of the radionuclides at the *biosphere* and their potential uptake by humans at the RMEI location, which could lead to a radiation dose consequence; and
- Disruptive events such as igneous activity, *seismicity*, and human intrusion (drilling).

The remainder of this section briefly describes how the TSPA-LA modeled the movement of water through the various model components. This section mentions other elements of the analyzed repository system that interacted with the modeling of water, but the focus of the discussion is the water as it infiltrates, through the unsaturated zone, reaches the groundwater, and moves away from Yucca Mountain. Appendix F of the Repository Final SEIS (DOE 2008a) contains additional summary information on other elements of the analyzed repository, as well as on the water. DOE’s report on the TSPA-LA (SNL 2008) provides more detail on the model of the entire repository system.

2.4.1 INFILTRATION AT YUCCA MOUNTAIN AND MOVEMENT THROUGH THE UNSATURATED ZONE

This section discusses how the TSPA-LA model treated infiltration and the movement of infiltrating water through the unsaturated zone.

2.4.1.1 Infiltration

The initial water input into the TSPA-LA model is from the site-scale unsaturated zone flow model, which incorporates infiltration at ground surface above the analyzed repository location. The net infiltration is the precipitation that is not lost to evapotranspiration, runoff, or change in the amount held in the soil or rock, and makes it as deep percolation into the unsaturated zone flow system. Modeling of infiltration for the TSPA-LA model was much different than that used in the TSPA model as described in the Yucca Mountain FEIS. As the Repository Final SEIS, Appendix F described (DOE 2008a, pp. F-7 to F-9), the TSPA-LA model used a new infiltration model to increase confidence in the model's performance. The manner in which climate variation was addressed during the post-10,000-year period was changed significantly to meet requirements proposed by the NRC in changes to CFR 63.342(c) (70 FR 53313, September 8, 2005).

The TSPA-LA considered infiltration scenarios for three specific climates for the first 10,000 years after *closure*: present day (or interglacial), monsoon, and glacial transition (or intermediate). For each of these climates, there was a set of four infiltration rates that represented 10th-, 30th-, 50th-, and 90th-percentile values, which allowed the model to incorporate infiltration rate uncertainty. In modeling the first 10,000 years, the TSPA-LA used the present-day climate for the period from 0 to 600 years; the monsoon climate for the period from 600 to 2,000 years; and the glacial-transition climate for the period from 2,000 to 10,000 years (DOE 2008a, p. F-8).

The rate of deep percolation at the repository horizon for the post-10,000-year period was specified by the proposed changes to 10 CFR 63.342(c)(2) (70 FR 53313, September 8, 2005). The proposed rule directed that DOE represent the effects of climate change after 10,000 years by assigning percolations rates at the repository horizon that vary between 13 and 63 millimeters (0.5 and 2.5 inches) per year. DOE implemented this direction by defining the new, temporally averaged climate in the same terms as it used for the three pre-10,000-year climates.

It should be noted that since the Repository Final SEIS and license application were submitted, the EPA issued a final rule (73 FR 61256, October 15, 2008) governing the post-10,000-year period. The NRC thereafter issued a final rule (74 FR 10811, March 13, 2009) revising 10 CFR Part 63 to implement the EPA's revision. The final NRC rule revised the deep percolation rate to be used in modeling the post-10,000-year climate slightly upward from that contained in the earlier proposed rule and which was used in the license application. In particular, the NRC's proposed rule permitted DOE to represent future climate change in the performance assessment by sampling constant-in-time deep percolation rates from a log-uniform distribution with a range of 13 to 64 millimeters (0.5 and 2.5 inches) per year and an average arithmetic mean of 32 millimeters (1.3 inches) per year. By way of comparison, the NRC final rule slightly raised the average arithmetic mean for the deep percolation rate to 41 millimeters (1.6 inches) per year, while broadening the range of the lognormal distribution to between 10 and 100 millimeters (0.39 and 3.9 inches) per year.

The radionuclide mass release rates used for this Analysis of Postclosure Groundwater Impacts were the mean results obtained from the outputs of the TSPA-LA, which were developed in accordance with the NRC proposed rule. Because the NRC Final Rule increased the average arithmetic mean of the deep percolation rate distribution from 32 to 41 millimeters (1.3 to 1.6 inches) per year, one would expect the mean radionuclide mass release rate at the location of the RMEI to show only minor, if any, increase. This conclusion is reflected in the NRC's responses to comments on the proposed amended rule in the *Federal Register* notice of the Final Rule (74 FR 10811, March 13, 2009) (from page 10820): "… dry-to-wet transients in performance assessments would have less influence on the mean of the distribution of projected doses than on any single projected dose used to construct the distribution. …Performance assessment models and analyses continue to improve; however, dry-to-wet conditions appear to have a limited effect on the mean dose within the constraints of current performance assessment approaches." Therefore, it is unlikely that this slight change in the distribution of deep percolation values would have any significant effect on the mean radionuclide mass release rates used in this analysis.

Table 2-4 shows the average net infiltration rates the TSPA-LA model used. It is important to note that the rates in the first four rows of the table are the averages over the entire domain of the site-scale unsaturated zone flow model, a larger area than the footprint of the analyzed repository. Corresponding infiltration rates over the smaller area of the repository footprint would be slightly larger. As an example, the table also shows infiltration rates for the post-10,000-year period over the repository footprint. These rates are more easily recognized as those proposed by the NRC. The net infiltration rate for the post-10,000-year climate is representative of a temporal average that accounts for all four climate conditions expected to occur in the future. As Table 2-4 shows, the post-10,000-year climate is associated with higher infiltration rates than either present-day or glacial-transition climates, which when combined, would account for about 80 percent of the future climate based on paleoclimatology studies described in Section 2.2.1.2 (Table 2-3).

Table 2-4. Average net infiltration rates (millimeters per year)[a] for each of the climates considered in the TSPA-LA.

Climate	Percentile 10th	30th	50th	90th
Infiltration over the unsaturated zone flow and transport model domain[b]				
Present-day (interglacial)	3.03	7.96	12.28	26.78
Monsoon	6.74	12.89	15.37	73.26
Glacial-transition (intermediate)	11.03	20.45	25.99	46.68
Post-10,000-year	16.89	28.99	34.67	48.84
Infiltration over the repository footprint (for comparison)[c]				
Post-10,000-year	21.29	39.52	51.05	61.03

a. To convert millimeters to inches, multiply by 0.03937.
b. Source: DOE 2008a, p. F-9.
c. Source: SNL 2007b, p. 6-19.

2.4.1.2 Unsaturated Zone

The TSPA-LA model incorporated numerous process and abstraction models to represent the events that would, or could take place in the unsaturated zone; that is, the zone at Yucca Mountain lying between the surface and the water table, which would include the analyzed repository. The various system elements are interwoven as necessary to depict complete processes and often involve effects from or to water moving through the zone. For example, a model simulates a breach in a *drip shield* and in the underlying *waste package* containment, then incorporates water moving down through the unsaturated zone that could dissolve some of the waste material in the analyzed repository and carry that material to the saturated zone. DOE developed several models for the area or zone of the mountain where a repository would be located to represent how contaminants could be released. DOE also developed an unsaturated zone flow model to represent the movement of water in this zone. The unsaturated zone transport model was developed to describe the movement of radionuclides through the natural system below the level of the analyzed repository (DOE 2008a, p. F-18).

The site-scale unsaturated zone flow model of the TSPA-LA was designed to represent the rock mass of Yucca Mountain that would be the pathway of water moving down from the surface, past or through the analyzed repository, and to the underlying groundwater. Significant observations from study of the unsaturated zone included these facts (DOE 2008a, p. F-9):

- Water moves in both fractures and the rock *matrix* (the solid, but porous, portion of the rock), but generally moves faster in fractures;
- In some areas, water movement along faults can also be significant;
- Water can collect in locally saturated zones (perched water); and

- Water can be diverted in lateral directions due to differences in rock properties at rock layer interfaces or the presence of features such as perched water bodies.

The unsaturated zone flow model that was part of the TSPA-LA represented these physical features of the unsaturated zone. A primary objective of the unsaturated zone flow model was to generate values for the percolation flux at the water table, where percolation flux was defined as the total vertical liquid mass flux through both fractures (and faults) and matrix, expressed as millimeters (or inches) per year (SNL 2007b, p. 6-80). The flow model also generated percolation flux values at different locations or layers of the unsaturated zone; at those locations, the model generated estimates of the amount of water moving through fractures, the matrix, and in faults (SNL 2007b, p. 6-91 to 6-96). This feature was used to characterize the nature and quantities of water that would reach the footprint of the analyzed repository and included the ability to generate frequency distribution plots displaying the average percentage of the analyzed repository area subject to a particular percolation rate. The infiltration model described above provided the net infiltration boundary condition to the unsaturated zone model. The unsaturated zone model used temporally constant, but spatially variable, infiltration boundary conditions for each climate state and generated three-dimensional flow fields for each of the four boundary conditions represented by the 10th-, 30th-, 50th-, and 90th-percentile infiltration rates for each climate.

At the repository horizon (or repository level), the unsaturated zone flow model integrated with several other models representing processes that would affect the movement of water and transport of radionuclides in or near the unsaturated zone. Some of these other models are described as follows:

- A thermal hydrology model represented the effects that heat generated by the waste would have on water movement near the emplacement drifts. During an initial period after emplacement of the nuclear materials, water and gas in the heated rock would be driven away from the repository drifts. Over time, the thermal output of the material decreases, the rock returns to its normal temperature, and the water and gas flow back toward the analyzed repository (DOE 2008a, p. F-11).

- A seepage flow model characterized how water would move when it reached drift walls. In many areas, the capillary effect at the drift walls would have a barrier effect and cause water to be diverted around the drift. In other areas, hydrogeologic properties would focus water movement and cause a seep into the drift. As infiltration would increase with changing climates, the number and locations of seeps would tend to increase. DOE based the seepage model on measurements from tests in the Exploratory Studies Facility (DOE 2008a, p. F-10) and designed the model to include *probability distributions* for the fraction of waste packages that could encounter seepage and the seep 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 (SNL 2007c, 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 Final SEIS (DOE 2008a, 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 analyzed repository. The transport model considered both advective and diffusive transport of radionuclides from a breached waste package and included colloid-facilitated transport (SNL 2007c, p. 1-1).

There are a number of other models associated with the analyzed 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 analyzed 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 Final SEIS (DOE 2008a, 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 be 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

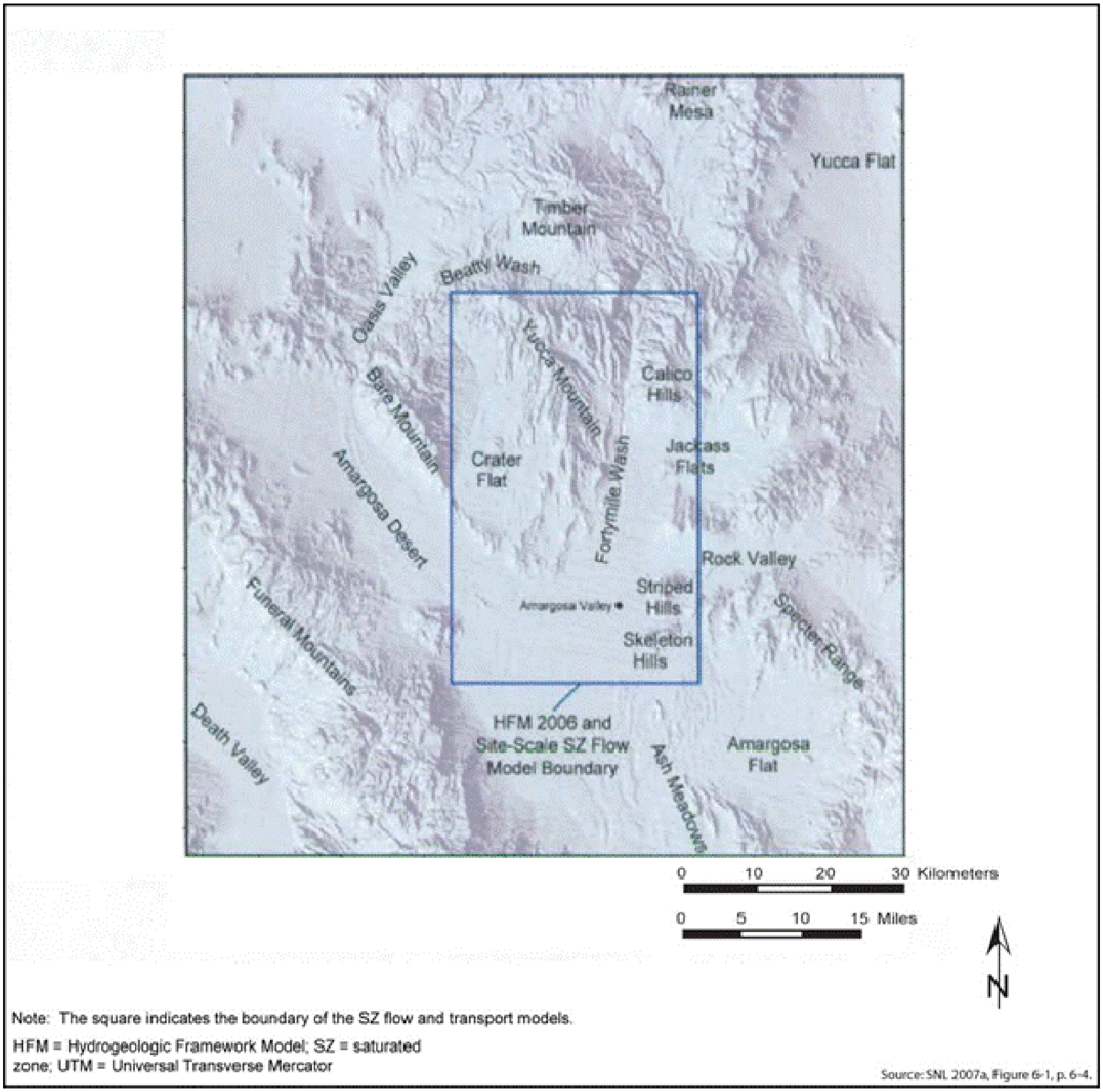
The TSPA-LA modeled the flow of groundwater and the transport of radionuclides within the saturated zone from beneath Yucca Mountain. As with the movement of water and radionuclides in the unsaturated zone, the saturated zone involved both a flow model and a transport model.

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 analyzed repository, while still being small enough to incorporate the necessary structural detail and have reasonable computational efficiency (SNL 2007a, 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 (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 release rates at the water table beneath Yucca Mountain. Output from the model was also in the form of radionuclide mass release rates, 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 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 release rates, was combined with this library of breakthrough curves to determine the radionuclide mass release rates 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 (Belcher 2004; Belcher and Sweetkind 2010) 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 a repository at Yucca Mountain and one of the ultimate objectives was to provide target boundary conditions for the site-scale saturated zone model (Belcher 2004, p. 7; Belcher and Sweetkind 2010, p. 5).



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

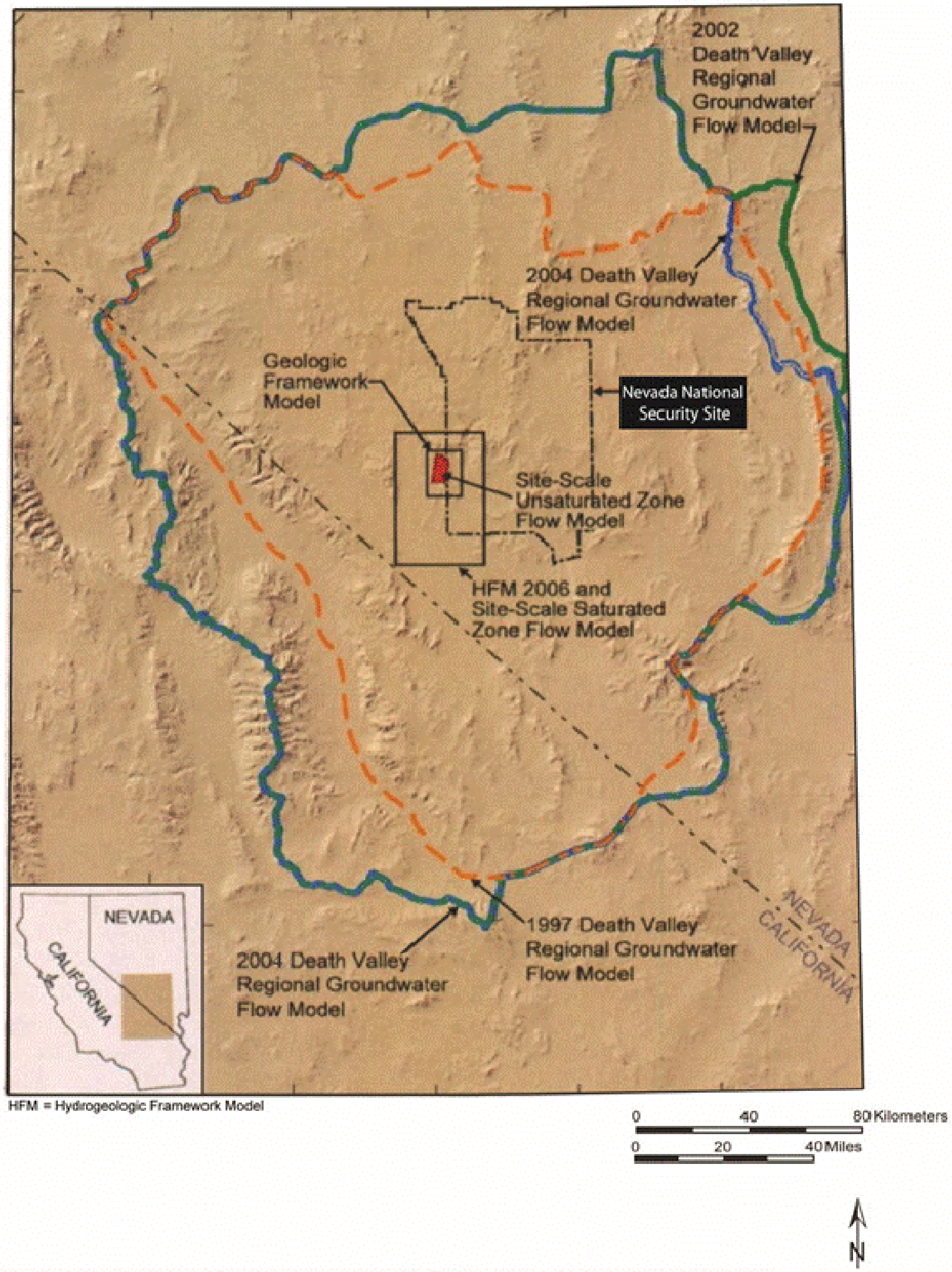
HFM = Hydrogeologic Framework Model; SZ = saturated zone; UTM = Universal Transverse Mercator

Source: SNL 2007a, Figure 6-1, p. 6-4.

Figure 2-7. Boundaries of the site-scale saturated zone flow model and nearby surface features.

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, which is integrated into the site-scale saturated zone model, 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 (SNL 2007a, p. 6-29). Examples of ways in which



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: SNL 2007d, Figure 6-1, p. 6-11.

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

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 (SNL 2007a, 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 (SNL 2007a, 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.

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 analyzed 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 chemically toxic materials with available regulatory standards (DOE 2008a, 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 a 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 197.21(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 (BSC 2005, pp. 4-1 to 4-9). DOE documented the results of the evaluations in *Characteristics of the Receptor for the Biosphere Model* (BSC 2005) 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 a repository at Yucca Mountain 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."

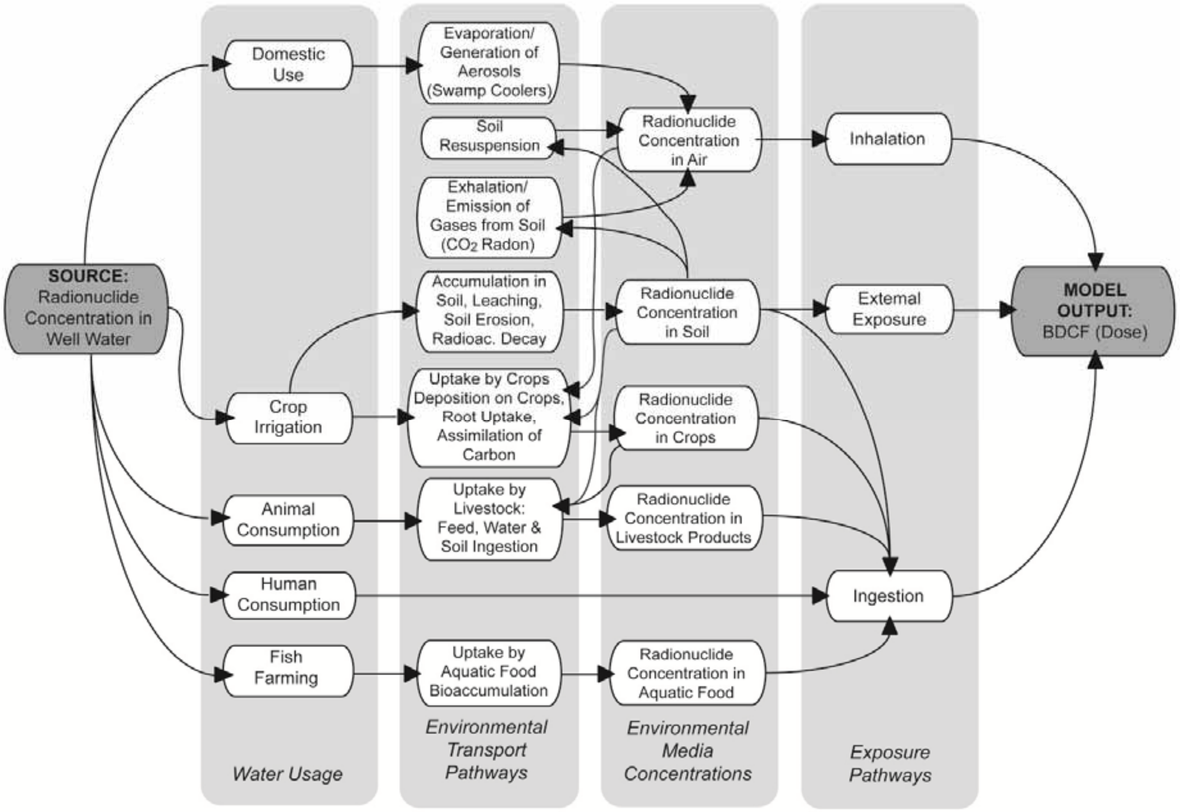
2.4.3.2 Biosphere Dose Conversion Factors

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 (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 (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.



BDCF = biosphere dose conversion factor.

Source: SNL 2007e, Figure 6.3-3, p. 6-43.

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

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 (SNL 2007e, pp. 6-13, 6-68, and 6-69).

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		Example dose factors for one radionuclide – Pu-239 [in (mrem/yr)/(pCi/L)][a,b]	
	Group	Subgroup	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		6.36×10^{-1}	
Ingestion				7.83×10^{-1}
	Ingestion dose for water		6.77×10^{-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	6.73×10^{-5}	
		Milk	2.57×10^{-6}	
		Poultry	1.01×10^{-5}	
		Eggs	1.80×10^{-4}	
	Ingestion dose for fish		3.63×10^{-2}	
	Ingestion dose for soil		3.24×10^{-2}	
All pathway dose conversion factor ($BDCF_{Pu-239}$)				2.73

Source: SNL 2007e, 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 $(3.53 \pm 1.25) \times 10^0$ (SNL 2007e, 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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Chapter 3

ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

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3 ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

This chapter describes assessments and analyses 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 non-radiological contaminants. The analyses estimate 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; DOE 2008) (Repository Final SEIS) analyzed the transport of *radionuclides* from a repository at Yucca Mountain to the *Regulatory Compliance Point* south of the analyzed repository where a hypothetical *reasonably maximally exposed individual* (RMEI) used water from a hypothetical well. The Repository Final SEIS reported results of an assessment of the radiological 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 Final SEIS radiological analysis. The Repository Final SEIS also assessed the release of *non-radiological contaminants*, transport to the Regulatory Compliance Point (the location of the RMEI), and impacts. The Repository Final SEIS analysis provided a qualitative evaluation of radiological and non-radiological impacts that might occur beyond the Regulatory Compliance Point.

REGULATORY COMPLIANCE POINT

This point is defined by the EPA and indicated by NRC at 10 CFR 63.312(a) as the point of compliance for calculating dose with respect to the postclosure individual protection, human intrusion, and groundwater protection standards, based on the definition of the controlled area in 10 CFR 63.302. The TSPA-LA calculates radiological dose to a reasonably maximally exposed individual located at a point on the Nevada National Security Site boundary (36°40’13.66661” North Latitude) that is approximately 18 kilometers south of the analyzed repository footprint in the predominant direction of groundwater flow.

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:

- Traced the release and movement of contaminants from a repository at Yucca Mountain into the *aquifer* system up to and beyond the Regulatory Compliance Point, including releases at natural discharge sites.

- Assessed the cumulative amounts entering and leaving the aquifer system and the accumulation within the system; and

CONTAMINANTS

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

- Assessed the impacts resulting from the release, movement, and accumulation of contaminants.

The analyses discussed in this chapter followed these steps:

- Used a regional groundwater flow model to define the potential paths contaminants would take after exiting the analyzed repository, transporting to the Regulatory Compliance Point, and beyond into the region. This modeling also identified natural discharge points (Belcher et al. 2004; SNL 2007a);
- 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* (SNL 2008; TSPA-LA) (see Chapter 2, Section 2.4);
- Performed the transport analyses of non-radiological 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 Final SEIS (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 human health impacts from 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.

This Analysis of Postclosure Groundwater Impacts includes minor changes in the calculations. The dose calculations for some radionuclide daughter products were changed to reflect new information about disequilibrium of certain parent-daughter pairs. These changes are detailed within this chapter and also further discussed in Appendix B.

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. The analytical methods and approaches used represent conservatively, reasonably foreseeable impacts. DOE used bounding assumptions to address incomplete or unavailable information or uncertainties to provide an assessment of environmental impacts consistent with the applicable requirements.

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 at 40 CFR Part 197, and

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

A clear understanding of future populations and future human activities is unknown, unavailable information. General guidance on predicting the evolution of society has been provided by the National Academy of Sciences. In its report, *Technical Bases for Yucca Mountain Standards* (NRC 1995), the Committee on Technical Bases for Yucca Mountain Standards concluded that there is no scientific basis for predicting future human behavior. The analyses use the two above assumptions based on guidance in the resulting 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 Determination Report), the NRC staff specifically mentioned that the requested analyses should be performed for the present and a future, wetter climate (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. It is not possible to predict with certainty what future climates will be in the affected area. The range of uncertainty can be captured by two extremes that represent a reasonably expected range. One end of this range was suggested by the NRC as present day. DOE chose the other end of the range as being reasonably represented by the wetter climate described above. In this Analysis of Postclosure Groundwater Impacts, DOE conducted the analysis for the two climate cases, with the climate constant in each case for the entire 1-million-year postclosure period.

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.* The site-scale saturated zone flow model and the Death Valley regional groundwater flow system model include particle-tracking capabilities. This allows 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 USGS (Moreo and Justet 2008) (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.

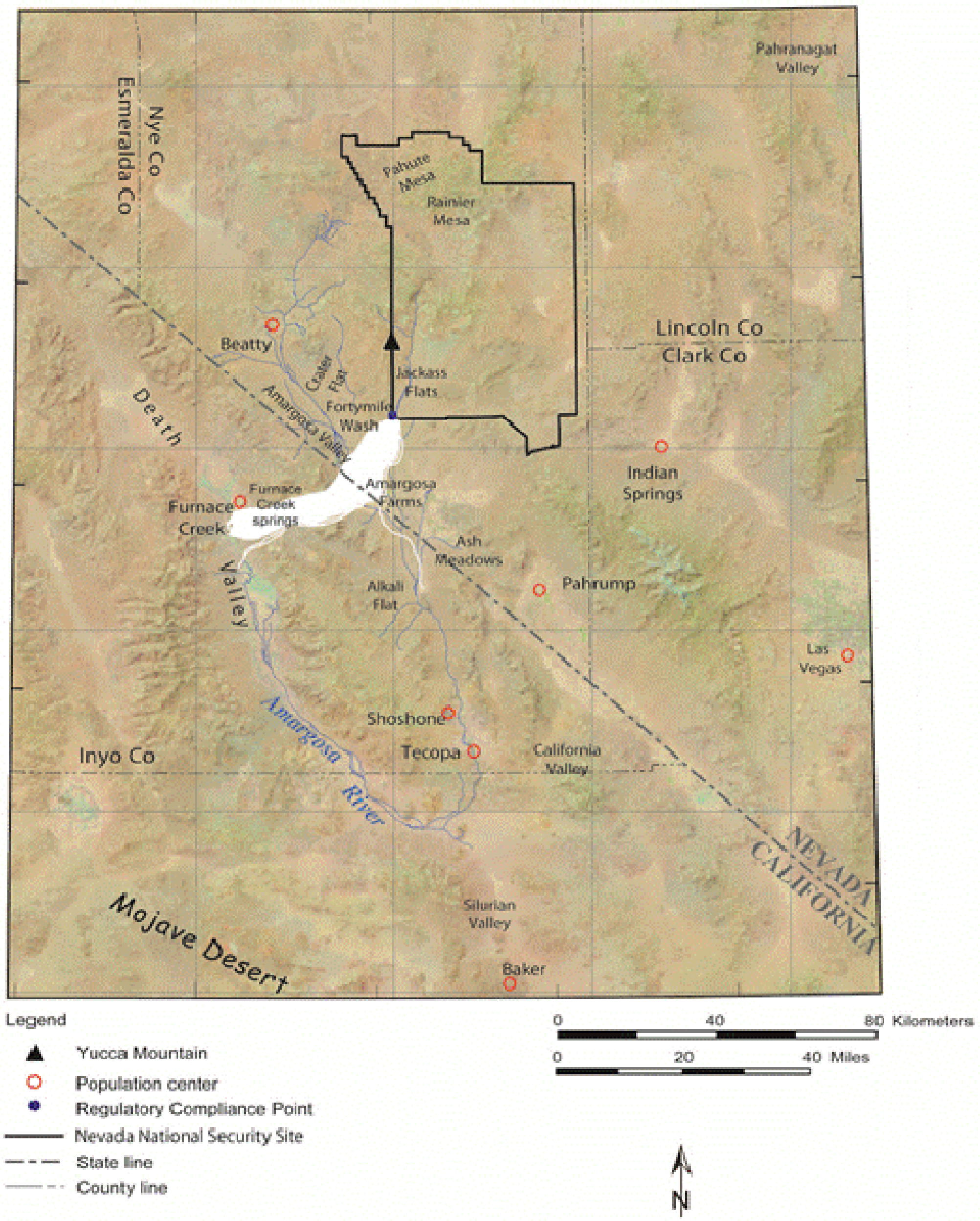
Under the no-pumping scenario (Figure 3-1), the model shows the particles initially traveling to the south from the Regulatory Compliance Point. Then essentially all of the particles flow to the west to exit the groundwater flow system at the *floor of Death Valley* in the Furnace Creek area on or near 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. These two deviations represent a small amount of water that diverts to the south in the model.

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. This means that all water is drawn into the pumping location at Amargosa Farms.

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 a 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 (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.

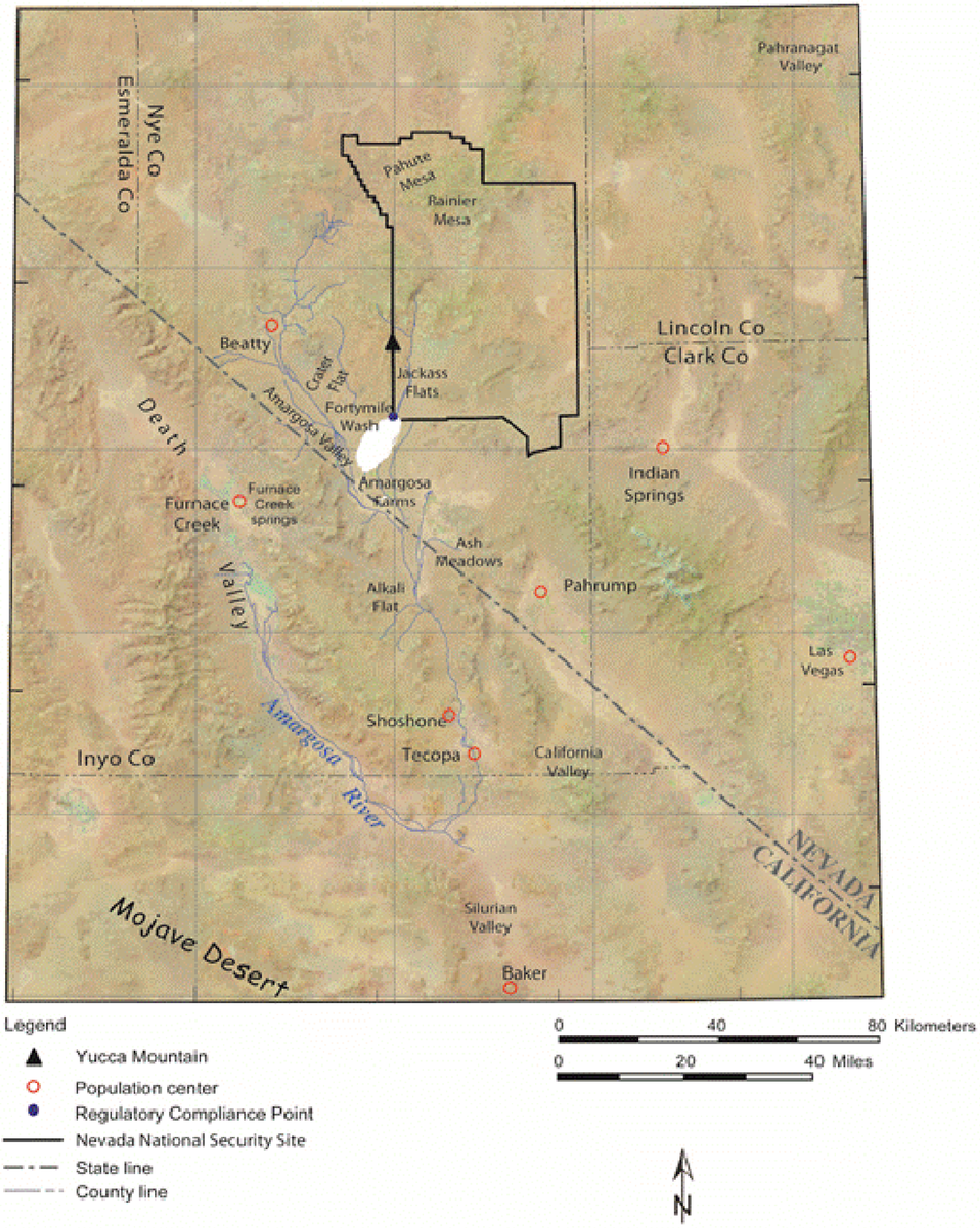
The no-pumping scenario of the analysis focused on the floor of Death Valley in the Furnace Creek area. Although the regional flow model predicts that natural discharge would exit the flow system through *evapotranspiration* from the alluvium on the floor of Death Valley at Middle Basin, DOE cannot preclude the possibility that contaminants could mix with carbonate waters and discharge at the springs in the Furnace Creek area. For this reason DOE analyzed two possibilities 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 a few particles could flow to Alkali Flat, DOE assessed the impacts from discharges at that location.



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: SNL 2009, Figure 11.

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: SNL 2009, Figure 13.

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

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. Because it is likely that future events would lie on a spectrum between the two end member scenarios, the analysis of the two scenarios 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 Final SEIS, DOE used the TSPA-LA model to analyze four 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 analyzed repository or intrusion of igneous material into the repository; and

- Seismic Scenario Class: events and processes initiated by ground motion or fault displacement.

The TSPA-LA model gave repository release results for a combined case, which was the sum of results from all of the above scenario classes. This provides a conservative result because it combines all the possible mechanisms for release as if they all occur. For this Analysis of Postclosure Groundwater Impacts, the mass release rates from the Repository Final SEIS combined case were used as the input to the transport analysis in the paths beyond the Regulatory Compliance Point. The estimated waste package failures in the combined case were used to develop the mass release rates for the non-radiological contaminants, which were then used as input to the transport analysis for those contaminants (see Section 3.2.1.3).

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 contaminants. The analytical constructs used to assess potential impacts are the following:

- 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.

The potential impacts at Alkali Flat, where only 2 of 8,024 particles were projected to be transported, relative to impacts at Middle Basin, are discussed in Section 3.3.1 below.

As mentioned above, DOE analyzed each of the six analytical constructs 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 Final SEIS for 10,000 years after *closure* at the Regulatory Compliance Point.

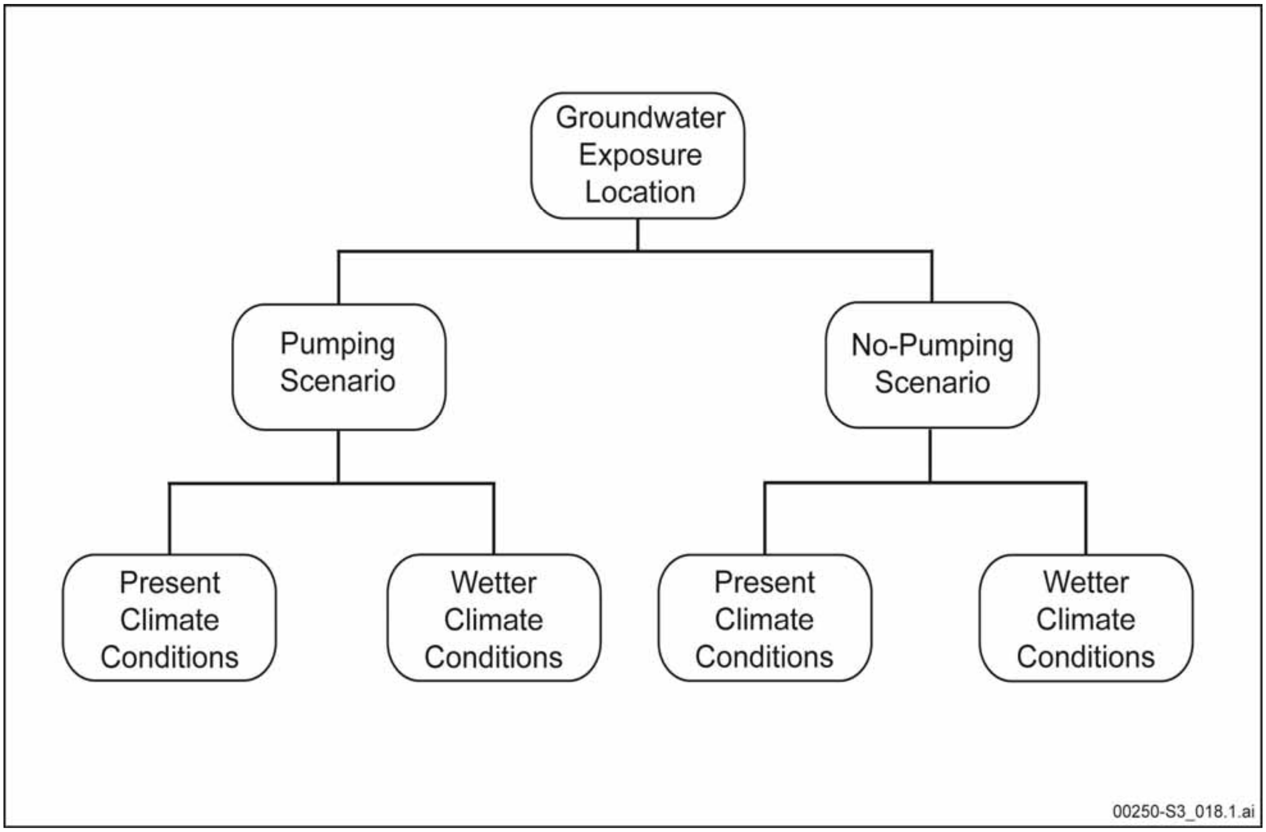


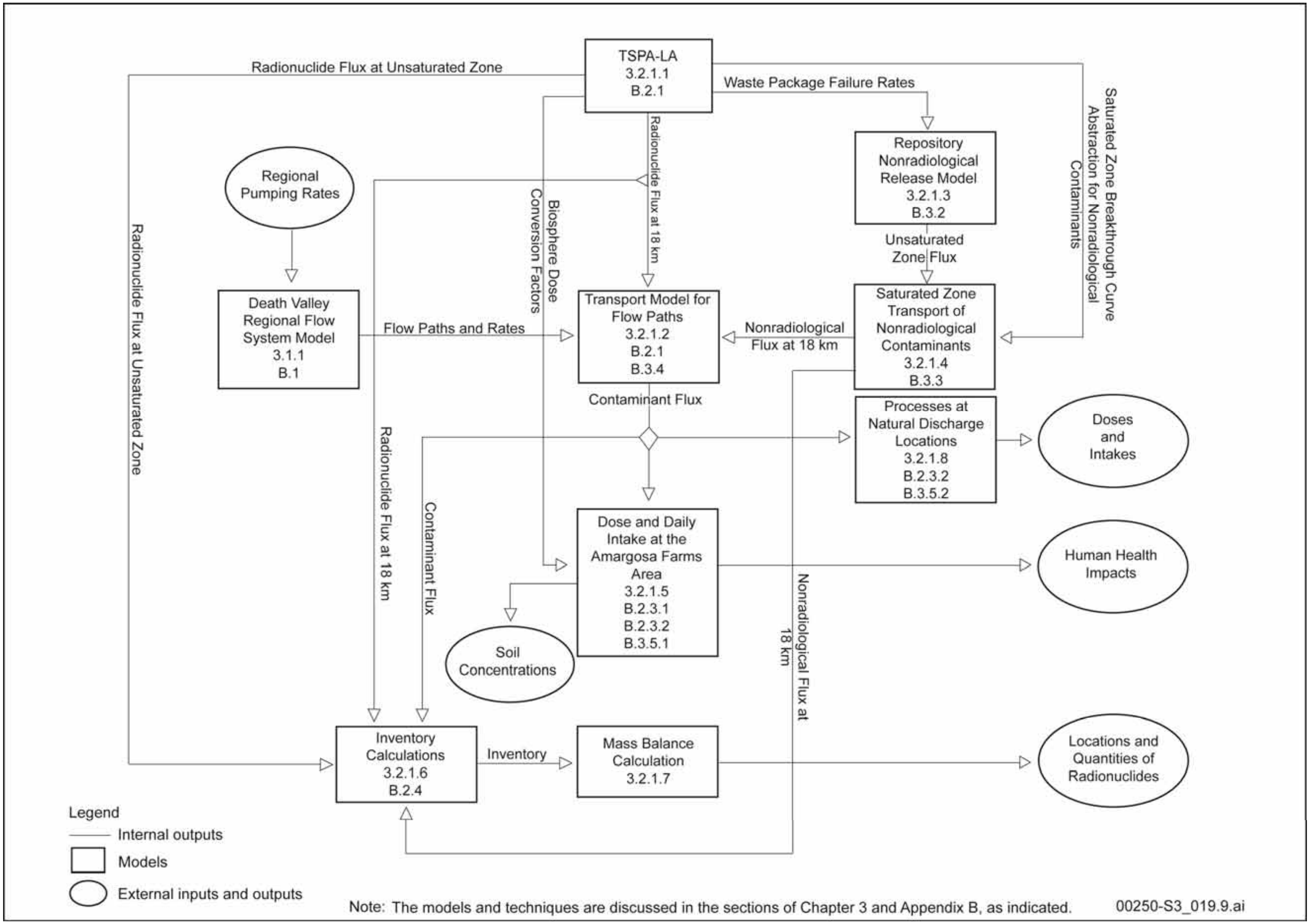
Figure 3-3. Analytical framework for each potential groundwater exposure location.

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.



Note: The models and techniques are discussed in the sections of Chapter 3 and Appendix B, as indicated.

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 Final SEIS. This Analysis of Postclosure Groundwater Impacts used five types of output from the TSPA-LA, as follows:

1. Radionuclide mass release rate at the unsaturated zone-saturated zone interface,
2. Radionuclide mass release rate 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 outputs used from the TSPA-LA were the sets of mass release rates at the unsaturated zone-saturated zone interface under the analyzed repository and at the saturated zone at the Regulatory Compliance Point. The mass release rates 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), equilibrium adsorption of dissolved contaminants on surfaces of a porous solid contained within the pipe and decay of radionuclide contaminants while in the pipe. DOE assumes the pipe contains the entire plume (that is, all of the mass release rate) 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 (SNL 2008, p. 4-13). This model took the contaminant mass release rate at the Regulatory Compliance Point as input and generated the mass release rate at the output of the pipe. For radionuclides, the TSPA-LA output provided the input mass release rate. For this deterministic analysis, all cases used the *mean value* outputs from TSPA-LA. For non-radiological contaminants, DOE developed the input mass release rate from the saturated zone transport model for non-radiological contaminants described below in Section 3.2.1.4.

3.2.1.3 Repository Non-Radiological Release Model

Since the TSPA-LA model did not analyze the mass release rate of the non-radiological contaminants molybdenum, nickel, and vanadium, DOE developed a means for estimating the mass release rates of these metals at the unsaturated zone-saturated zone interface (see Appendix B for a more detailed discussion on the choice of non-radiological contaminants for this analysis). 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 Final SEIS analysis of non-radiological contaminants (DOE 2008, Appendix F, Section F.4) was for 10,000 years (before a significant number of packages would be expected to fail) and therefore did not consider potential releases of non-radiological contaminants from the inside of waste packages. Using package failure rates from the TSPA-LA model output, DOE extended the release analysis to 1 million years accounted for materials inside the packages. The output of the non-radiological contaminant release model was the mass release rate of the non-radiological contaminants at the unsaturated zone-saturated zone interface, which became the input to the saturated zone transport model for non-radiological contaminants molybdenum, nickel, and vanadium.

3.2.1.4 Saturated Zone Transport of Non-Radiological Contaminants to the Compliance Point

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 non-radiological materials to the Regulatory Compliance Point. The mass release rates developed as output were then the input to the transport model described above in Section 3.2.1.2, which then produced the mass release rates of non-radiological contaminants at the potential exposure locations.

3.2.1.5 Dose and Daily Intake at Amargosa Farms

The radiological dose and non-radiological daily intake calculations used the mass release rates 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* (SNL 2007b, 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 release rate, 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 groundwater such as in wind erosion of the soil, or carrying away of soil with harvested crops. 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 non-radiological contaminants for a 70-kilogram person, drinking 2 liters of water per day (see Section 3.3.2 for more details). Note that intake could also include ingestion of soils. Based on a 100 mg/day rate of accidental ingestion of soil (EPA 2011, Table 5-1) preliminary calculations by DOE showed that intake from drinking water was 5 to 8 orders of magnitude higher than intake from soil ingestion so that soil ingestion was dropped from the calculations as having negligible contribution at Amargosa Farms. For non-radiological contaminants there are no dosing standards beyond the Oral Reference Dose as related to daily intakes so this approach was adopted to assess the impacts on non-radiological contaminants.

3.2.1.6 Inventory Calculations

The mass release rate of contaminants resulted in an inventory at each location analyzed in the transport analysis. This inventory was a decay- and growth-adjusted measure (as occurring during transport down the flow path) of the total amount of material arriving at the specific location as a function of time. While this information is not considered to be an impact per se, it is information suggested by NRC in the Staff’s Adoption Determination Report. DOE calculated the inventory for a contaminant from the mass release rate by integrating the release rate 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 release rate-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. While this information is not considered to be an impact per se, it is information suggested by NRC in the Staff's Adoption Determination Report. 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 to any individuals present substantially overestimates the risk to visitors to Death Valley National Park or other non-residents who might come to 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 (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 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 (Reynolds et al. 2007, p. 1812). As the evaporite mineral crystals form, they displace the rock-derived *clastic* minerals, expanding the sediments upward (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 (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 (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 non-radiological 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 non-radiological 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. Doses and intakes would be proportional to this concentration. 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.

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, the State Line Deposits, 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. Periodic flooding of the playa would reduce, if not eliminate, exposure to contaminants in the deposits. 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. Accordingly, to account for these processes and remain conservative, for the inhalation pathway, the analysis used a relatively high annual average concentration of resuspended particles associated with conducting activities outdoors while not significantly disturbing soil. A value of 10^{-7} kilogram per cubic meter (0.1 milligram per cubic meter (SNL 2007a, Table 6.6-3) was used. Inhalation exposure was eliminated, however, during the wetter climate because the playa would be covered by standing water. 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 (Reynolds et al. 2007, p. 1814). In both the wet and present day (dry) climates, radiation exposure due to gamma radiation from the playa surface was included in the dose analysis for radiological contaminants.

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 were 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).

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. The following conservatisms were inherent in the analytical framework.

- 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.

- *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 (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 would 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. This wet climate is conservative because it represents the wettest conditions over the past 1 million years.

- 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,* which are a measure of the extent of delay). 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 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* (non-uniform rock and soil structure and properties) 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 was not known, DOE selected *partition coefficients* with lower values compared with literature values (especially for the non-radiological contaminants).

The transport analysis was done in discrete steps in time so that the mass release rate would be constant for each period of time. For this Analysis of Postclosure Groundwater Impacts, DOE used a fairly large time step in the release rate-versus-time curves. When a continuous curve was broken into steps, the value at the end of the time period was assumed to occur at the beginning of the time period. This made the stepped curve higher at any particular time than the continuous release rate curve being represented. This approach maximizes both the release rate (during a period of rising release rate) and the cumulative release (release rate X time).

The release rates for the non-radiological contaminants from the analyzed 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 analyzed repository. The non-radiological 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. This is a conservative approach and the impacts are, therefore, overestimated.

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

- In the estimate of concentration of contaminants in the solids, DOE used a low end of the range of total-dissolved-solids values found in local groundwater. Higher values of total-dissolved-solids would reduce the estimated concentration because the dissolved solids co-precipitate with the contaminants thus diluting the contaminants in the precipitate. The diluted precipitate would result in lower 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 (while this value was for no major soil disturbance, it is still very high and would account for the types of soil disturbance expected by the very limited activities); and
  - The single value of breathing rate used ignores the fact that people spend about 8 hours asleep when their breathing rate would drop by at least half the assumed value. While at times a higher breathing rate might occur during activities, it is still conservative because it ignores the long period of much lower breathing rates.
- 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 (EPA 2011, Table 5-1).
- 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 because the total radioactivity would be higher for deeper contamination. Therefore, lesser depths would reduce the estimate of dose; and
  - DOE assumed that the receptor would be outdoors and exposed to contaminated evaporites year-round.

The above 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 radiological doses (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}
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}
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}

As a point of comparison, the mean peak annual dose for 10,000 years after closure reported in the Repository Final 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 (DOE 2008, p. 5-27). Note that the Repository Final 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. Therefore, the estimated dose at Amargosa Farms for the wetter climate would be slightly higher than the RMEI location. Also, the doses estimated at the Amargosa Farms area were based on recycling of contaminants back into the groundwater and this was not done for the RMEI location. A recent calculation of recycling for the RMEI location showed up to a 33-percent increase in dose when recycling was applied (SNL 2013, Table 2). 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). A more detailed discussion of these results accompanies the detailed time plots below.

Figures 3-5 to 3-8 present the estimate of doses over time for all radionuclides at the Amargosa Farms area, the Furnace Creek springs area, and the floor of Death Valley (Middle Basin). Appendix B provides plots of dose contributions by individual radionuclides.

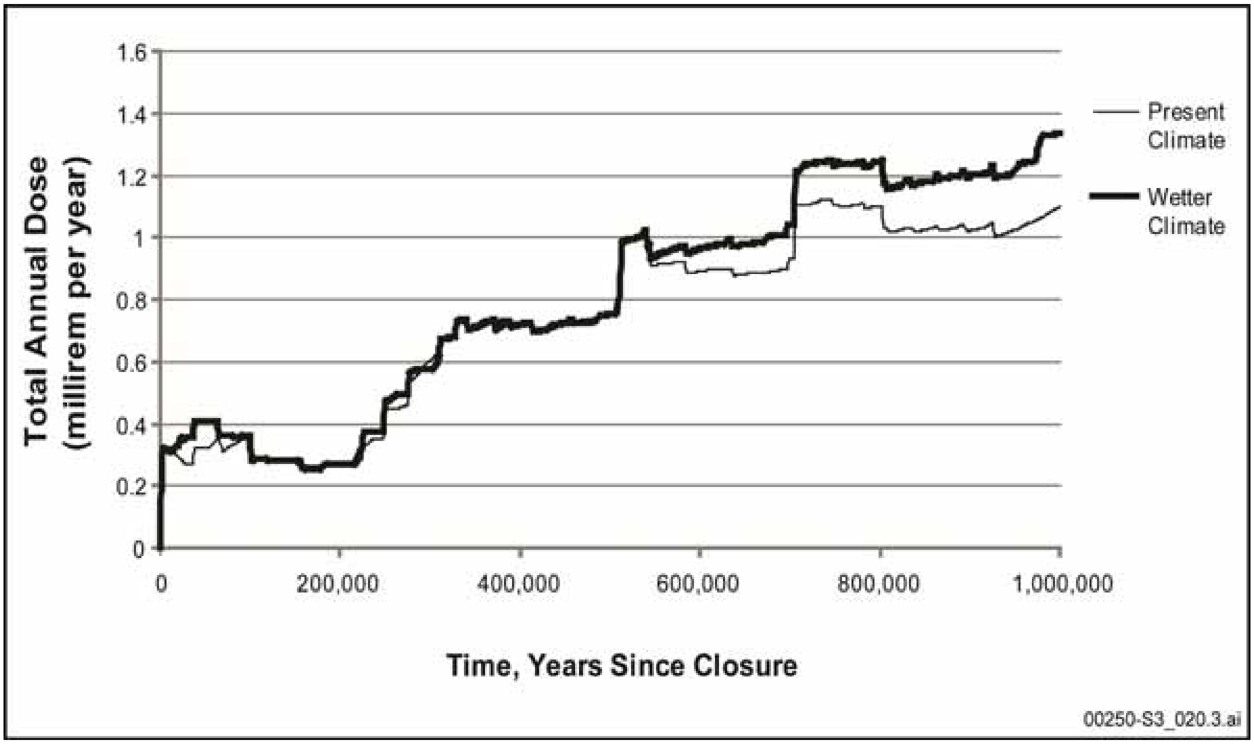


Figure 3-5. Total annual dose at the Amargosa Farms area.

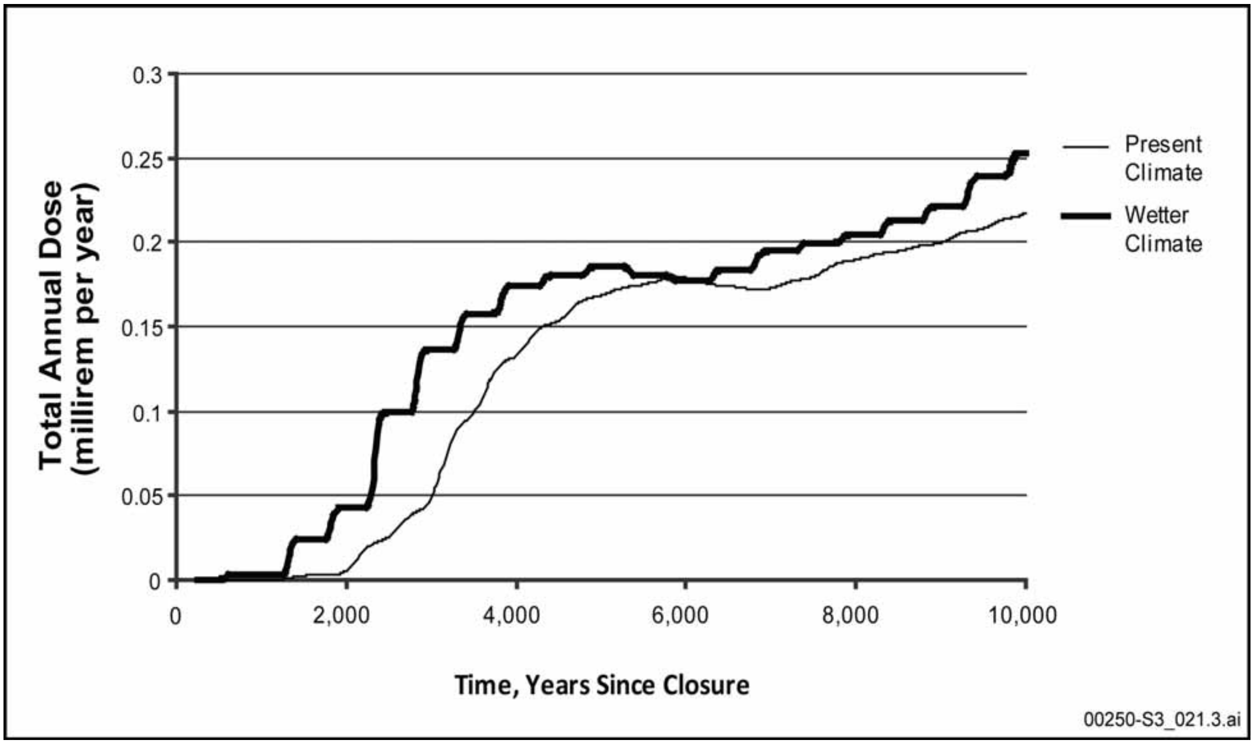


Figure 3-6. Total annual dose at the Amargosa Farms area for the first 10,000 years.

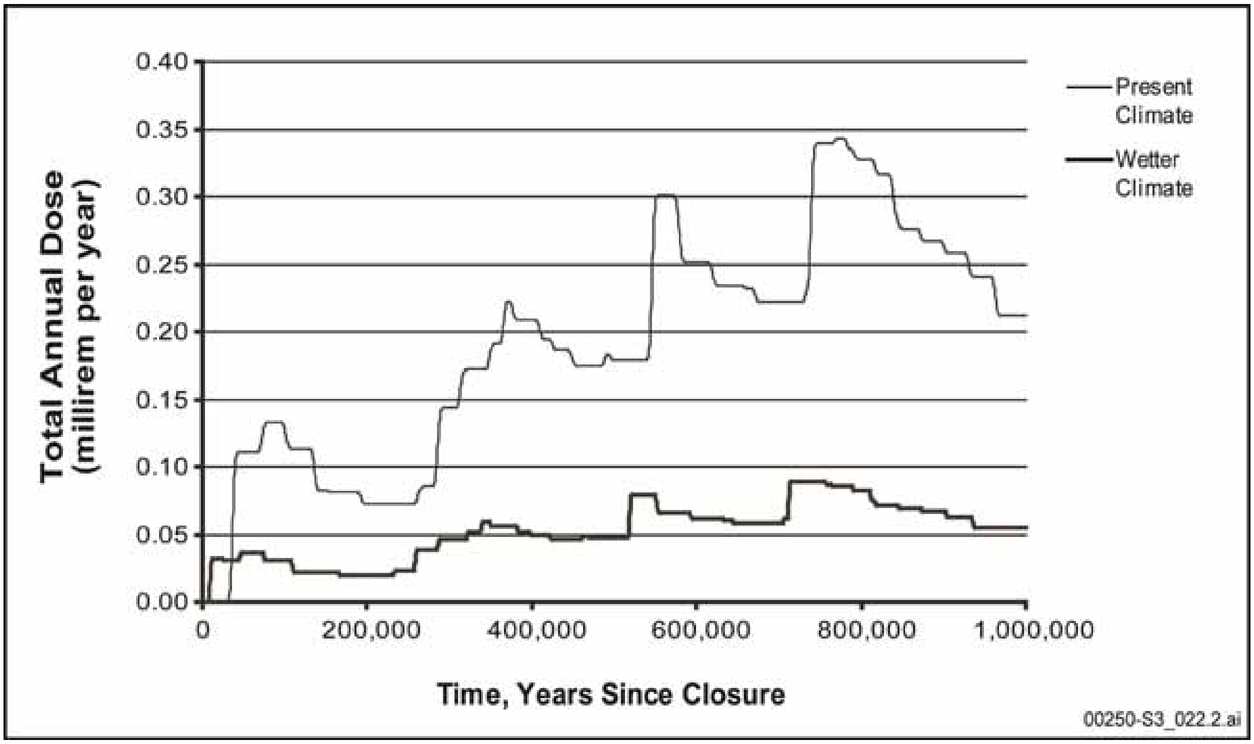


Figure 3-7. Total annual dose at the Furnace Creek springs area.

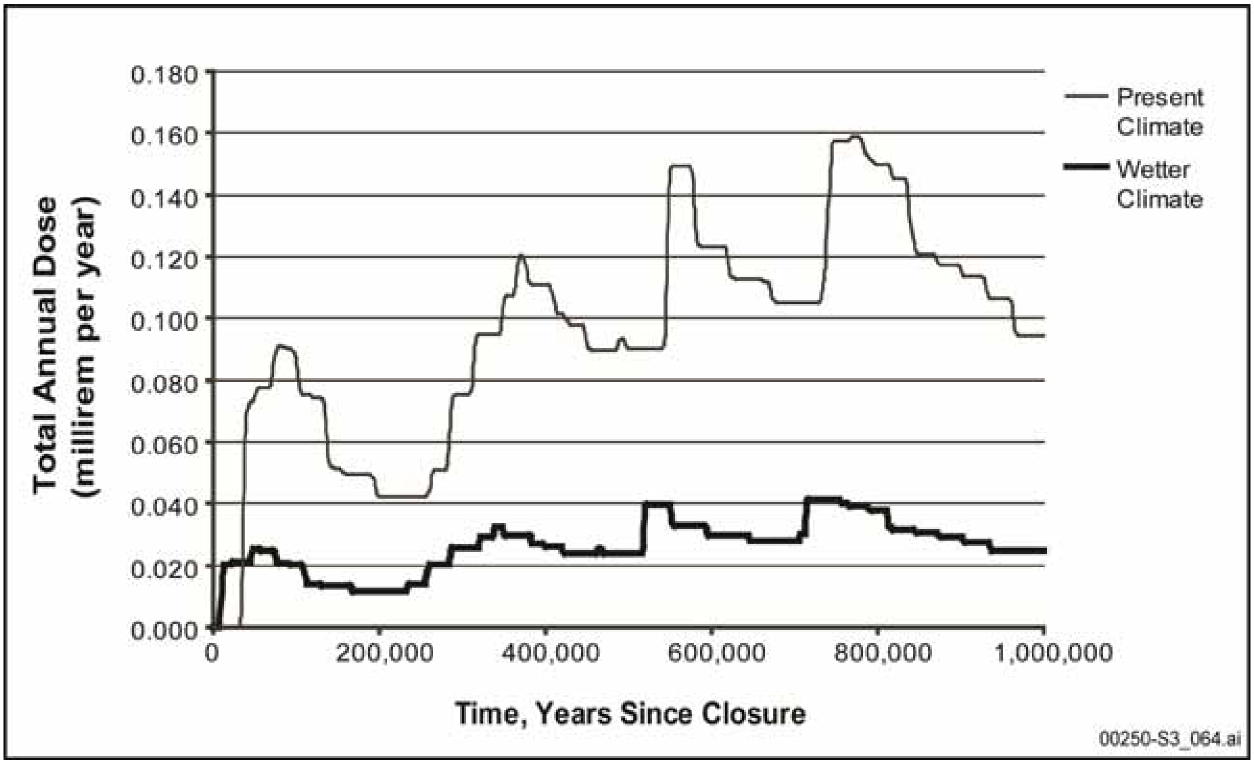


Figure 3-8. Total annual dose at the Middle Basin.

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 (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 less than 100 millirad.

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 between 300,000 and 1,000,000 years. 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.

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 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, which would just extend through the more jagged curve, but would not have significantly changed any of the results since the height of the jagged steps is not significant; accordingly this would not have changed the conclusions of the analyses.

There is uncertainty in the percentage of flow that could divert to Alkali Flat as opposed to the floor of Death Valley. The flow simulations showed 2 of the 8,024 particles reached Alkali Flat in the no-pumping scenario (none reach this area in the pumping scenario). There are no permanent residents in this area compared to Death Valley, where Native Americans reside as well as temporary park visitors. If some small fraction of flow, as indicated by the particle tracks, were to reach this area in the no-pumping scenario, then the doses and intakes would be very much smaller than those found for the Death Valley Middle Basin.

3.3.2 NON-RADIOLOGICAL CONTAMINANTS

The non-radiological contaminants considered include molybdenum, nickel, vanadium, and uranium. Uranium is included in both radiological and non-radiological 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 non-radiological materials by comparing daily intakes with EPA's *Oral Reference Dose* standard (EPA 1994, 1997, 1999a, 1999b). 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 non-radiological contaminants. The bottom row of the table shows EPA's Oral Reference Doses. Oral Reference Doses are levels below which no detectable health effects would occur.

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 non-radiological contaminants.

	Peak daily intakes (mg/kg body wt.-day) of metals during 1 million years after closure			
Scenario	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}
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
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
Oral Reference Dose (mg/kg body-wt/day)	5.00×10^{-3}	2.00×10^{-2}	9.00×10^{-3}	3.00×10^{-3}

Sources: EPA 1999a, 1999b 2002a, EPA 2002b.

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. Since several conservatisms have been used to treat uncertainties, the actual intakes likely would be much less than those reported. The zero values in the table signify when a contaminant is not expected to reach the discharge area during the 1-million years.

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

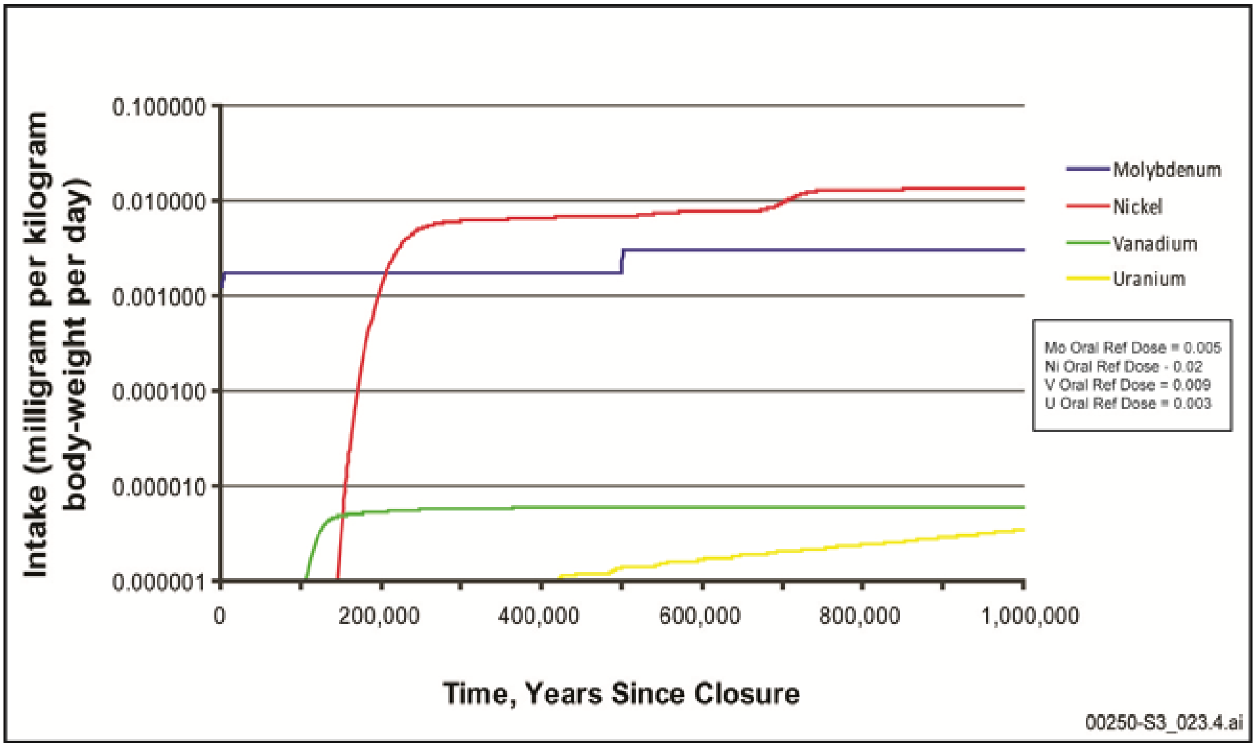


Figure 3-9. Daily intakes of non-radiological contaminants at the Amargosa Farms area, present climate.

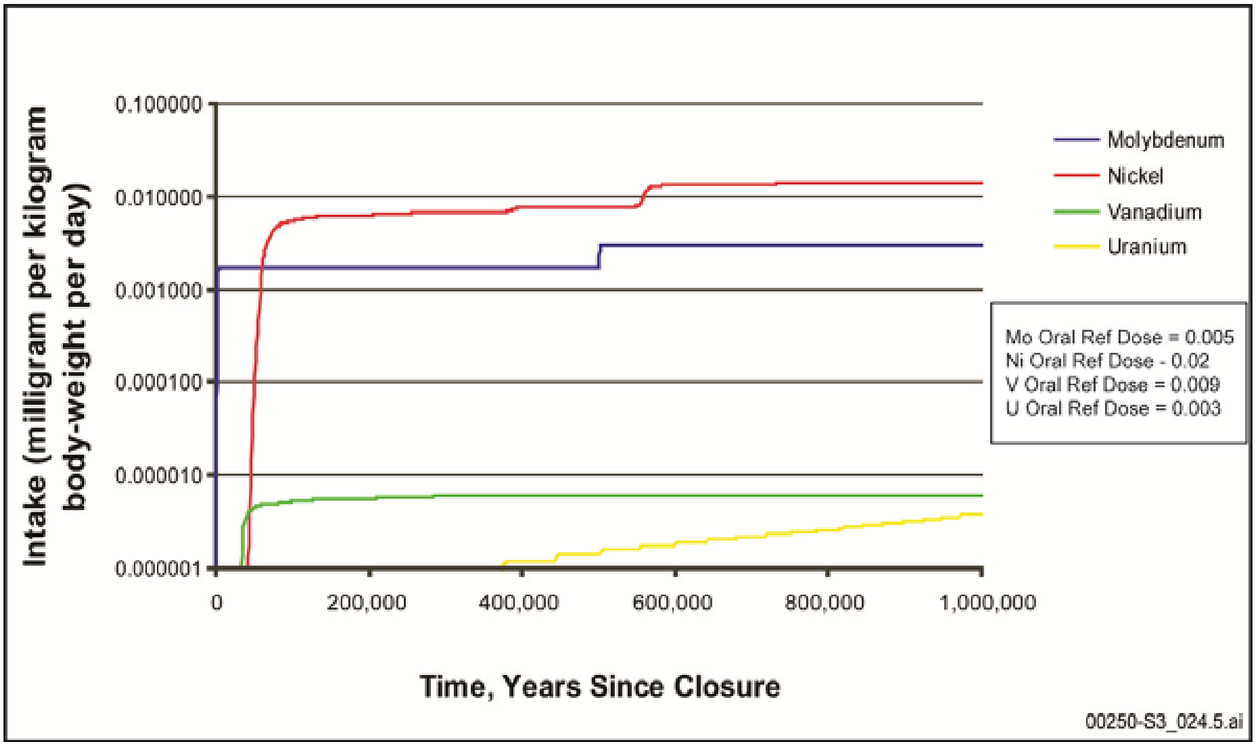


Figure 3-10. Daily intakes of non-radiological contaminants at the Amargosa Farms area, wetter climate.

Figures 3-11 and 3-12 show estimated daily intakes of molybdenum at the Furnace Creek springs area. Molybdenum is the only non-radiological contaminant that is projected to reach the Death Valley natural discharge locations during the 1-million-year period. This is because the other metals have higher partition coefficients and are held up in the soil while molybdenum is assumed to have no soil sorption (a zero partition coefficient) and moves with the same speed as the water. Figure 3-13 shows the estimated daily intakes of molybdenum at the Death Valley floor (Middle Basin).

Just as with the radionuclides, because the flow of potential contaminants to Alkali Flat was represented by 2 particles out of 8,024, the intakes at Alkali Flat would be much smaller than those reported here for Death Valley Middle Basin.

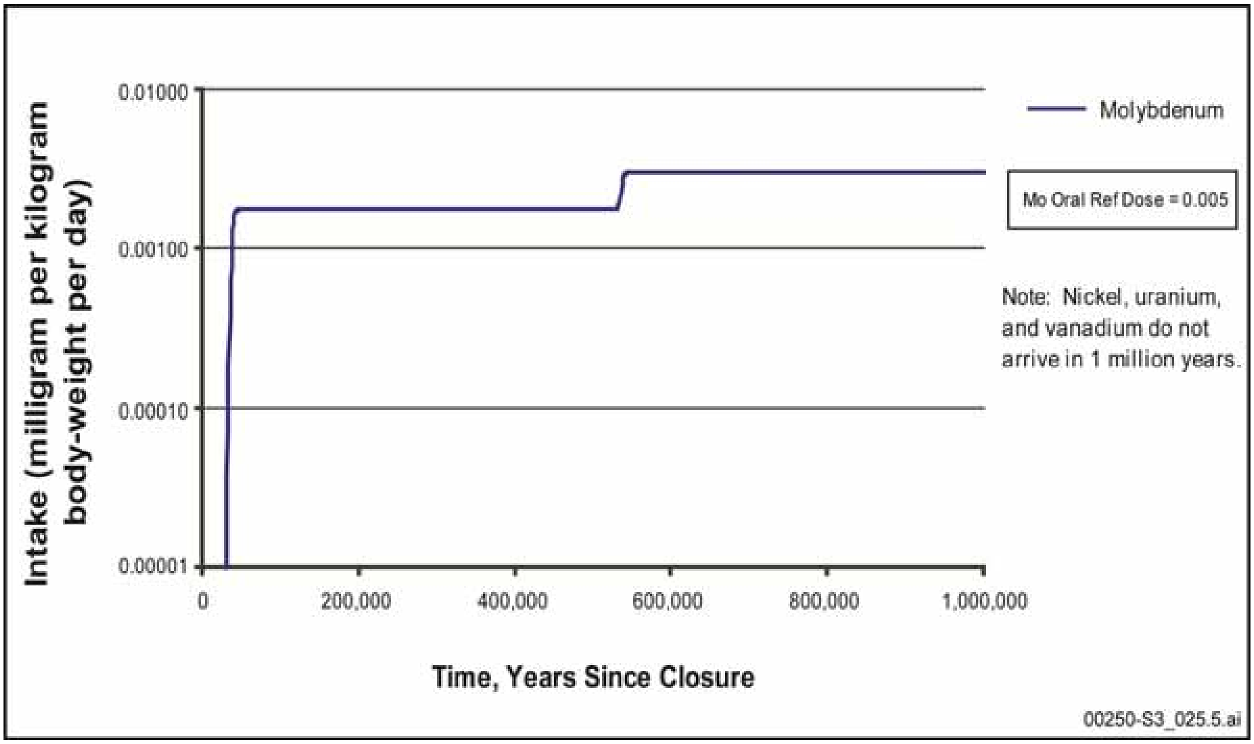


Figure 3-11. Molybdenum daily intake at the Furnace Creek springs area, no-pumping, present climate.

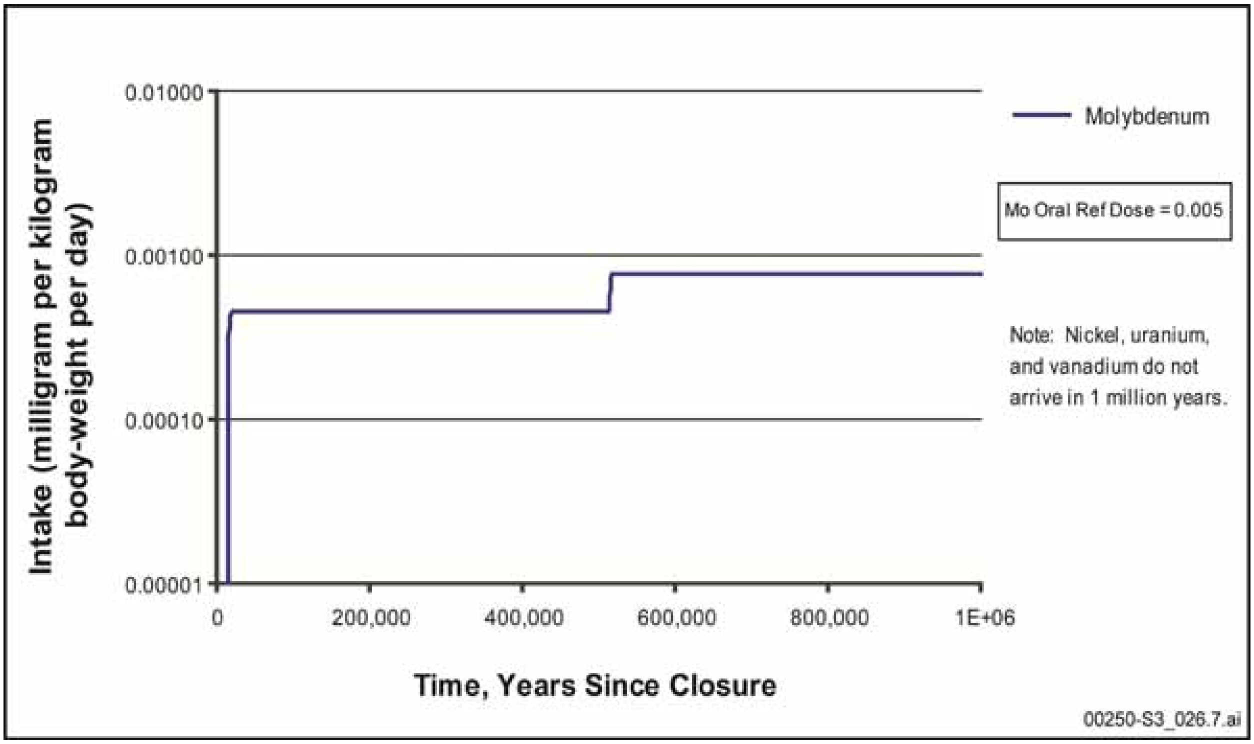


Figure 3-12. Molybdenum daily intake at the Furnace Creek springs area, no-pumping, wetter climate.

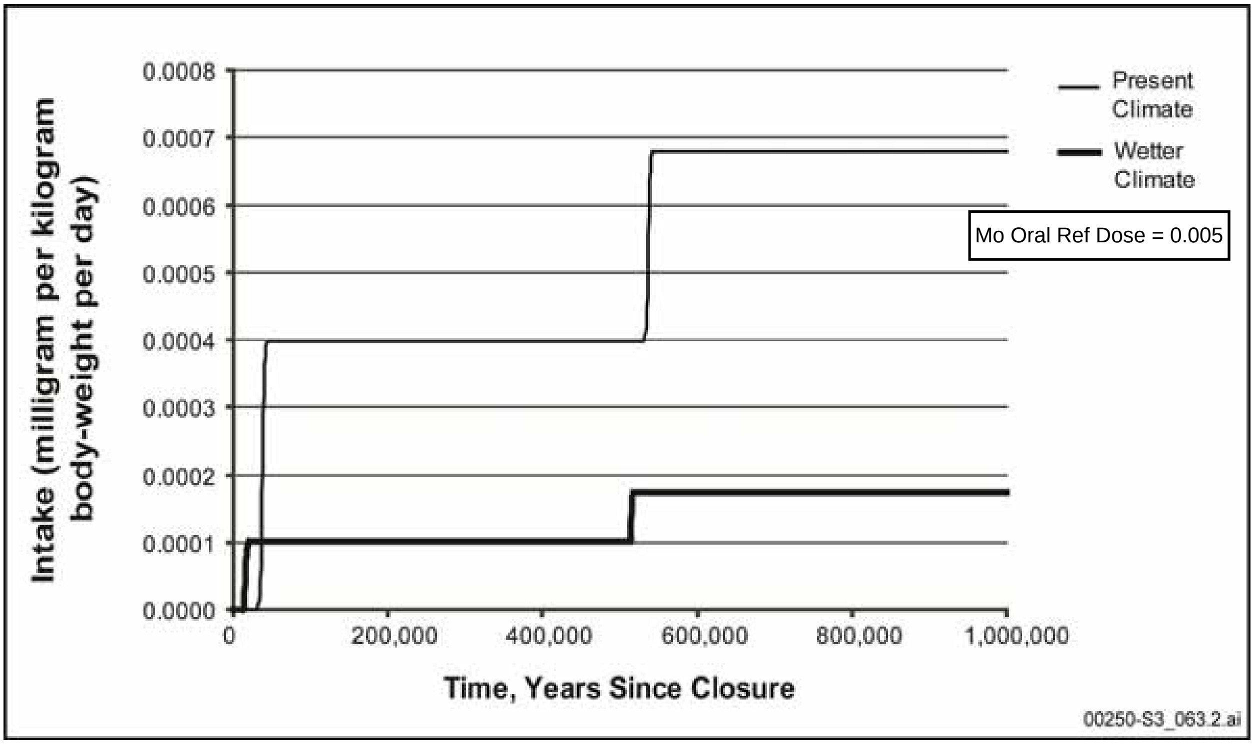


Figure 3-13. Molybdenum daily intake at Middle Basin, no-pumping.

3.3.3 MASS BALANCES

As discussed in Chapter 1, Section 1.2.1, in the NRC Staff's Adoption Determination Report (NRC 2008), NRC suggested that DOE's response could include various types of information. One type of information suggested by NRC was a complete mass balance that would show the location and quantities of contaminants in the groundwater system of the affected environment. DOE used the mass release rates 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

As discussed in Chapter 1, Section 1.2.1, in the NRC Staff's Adoption Determination Report (NRC 2008), NRC suggested that DOE's response could include the extent of soil contamination in the affected environment. 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). This area lies a few kilometers northwest of the Amargosa Farms area (D'Agnese et al. 1999, Figure 14). The USGS (D'Agnese et al. 1999, p. 22) identified this area as a discharging area during a future climate similar to the wetter climate analyzed in this Analysis of Postclosure Groundwater Impacts. Therefore, while the analysis for this report did not indicate discharge in the State Line Deposits area, there is some uncertainty whether there could be discharge there. It is not clear what discharge rate might occur at this site, but it would be all or some part of the Furnace Creek discharge rate. Estimates show Furnace Creek springs' discharge to be over 2,300 acre-feet in the present climate. Therefore, it is reasonable to assume that it might be approximately 2,300 acre-feet per year during a wetter climate. If some portion of the contaminant plume were to flow to this discharge area, then the dose and intake estimates would 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. In the pumping scenario, the water from the discharge site would 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 the Amargosa River in a generally southerly direction. Assuming this surface water might be used for farming, the doses resulting from its use would be somewhere between those estimated for the Amargosa Farms area and those estimated in the Repository Final SEIS for the Regulatory Compliance Point. The possible existence of this additional natural discharge site and possible presence of surface water could lead to less pumping, which would result in less groundwater flow, and therefore less contaminants flowing 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.

3.4 Cumulative Impacts

The Repository Final SEIS analyzed the potential environmental impacts of disposing of Inventory Modules 1 and 2 beyond that of the *Proposed Action* (70,000 *metric tons of heavy metal*) (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 Final SEIS developed scale factors for how the addition of Modules 1 and 2 to the analyzed repository inventory would affect the dose and non-radiological impacts at the Regulatory Compliance Point. DOE found that impacts of the modules would increase linearly relative to the increased number of waste packages. The scale factors were as follows: Module 1 would increase by a factor of 2 over the impacts projected for the base inventory; Module 2 would increase by an additional factor of 1.01 over Module 1 (DOE 2008, p. S-54). Since the regional impacts reported in this Analysis of Postclosure Groundwater Impacts depended directly on the mass release rates 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 Final SEIS. The scale factors for the non-radiological 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 Final 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 Final SEIS for the inventory modules. Likewise, the intakes of toxic metals would be less than or about equal to those presented in the Repository Final SEIS.

The most recent sitewide EIS for the Nevada National Security Site (DOE 2013) includes limited data on the potential long-term contribution of contaminated groundwater resulting primarily from past underground testing on the Site. Specifically, DOE (2013) states, "Because some of the groundwater beneath the [Nevada National Security Site] is thought to flow in a southwesterly direction and surface in the Amargosa Valley or in Death Valley, there is a potential for impacts to springs and seeps from radioactive contamination. Based on the most current understanding of groundwater flow rates and directions and modeling of contaminant transport, it is unlikely that any radioactive contamination from [the Nevada National Security Site] would reach Death Valley in the foreseeable future." Therefore, there is not enough detailed data to quantitatively evaluate any incremental contribution from the Nevada National Security Site on the results presented in Table 3-1.

3.5 Tribal Government 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 (DOE 2002, Section 4.1.5.2) and Repository Final SEIS (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 beginning in the late 1980s to obtain input and perspectives from Tribal Governments. 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 Tribal Governments 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 (AIWS 1998) and discussed that document in the above environmental impact statements.

Neither the Yucca Mountain FEIS nor Repository Final 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 (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 Final SEIS for the Regulatory Compliance Point (DOE 2008, Section 5.1.1.4 and Appendix F). This Analysis of Postclosure Groundwater Impacts concludes 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 Tribal Government 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 (NRC 2009, pp. 28 to 30).

To evaluate changes in groundwater quality during the postclosure period, and potential impacts to Native Americans and other residents of Death Valley, DOE estimated annual doses of radiological contaminants and daily intakes of non-radiological 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 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, in making these estimates, 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 (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 (see Table 3-1).

The only non-radiological 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 Final 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 provide opportunities for community input to the process, which includes input on potential effects and mitigation measures (Section 4.1.13 of the Repository Final SEIS includes 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 Final SEIS, DOE concluded that there would be no high or adverse impacts on members of the public, including minority and low-income communities.

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 information 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 a repository.

3.6 References

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Chapter 4

GLOSSARY

4 GLOSSARY

The U.S. Department of Energy (DOE) has provided this glossary to assist readers in the interpretation of this 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 analysis. 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 a *repository* at Yucca Mountain, 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 groundwater contamination from a repository at Yucca Mountain.
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.
advection	Mass transport in groundwater that is due simply to the flow of the water in which the mass is carried. The direction and rate of transport coincide with that of the groundwater flow.
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.

canister	An unshielded metal container used as: • A pour mold in which molten vitrified *high-level radioactive waste* could solidify and cool. • A container in which DOE and electric utilities would place intact *spent nuclear fuel*, loose rods, or nonfuel components for shipping or storage. In general, a container that provides *radionuclide* confinement. Canisters would be used in combination with specialized overpacks that provide structural support, *shielding*, or confinement for storage, transportation, and *emplacement*. Overpacks used for transportation are usually referred to as transportation casks; those used for emplacement in a *repository* are referred to as *waste packages*.
carbonate aquifer	A *permeable* unit of *carbonate rock*, such as limestone or dolomite, that also qualifies as an *aquifer*. For this analysis, it is one of the three general aquifer types described for the *Death Valley regional groundwater flow system*.
carbonate rock	The *geologic* strata found over extensive portions of the Great Basin. Within the boundaries of the *Death Valley regional groundwater flow system*, this stratum is primarily limestone or dolomite.
cladding	The metallic outer sheath of a fuel element generally made of stainless steel or a zirconium alloy. Its purpose is to isolate the fuel element from the external environment.
clastic	Of or belonging to or being a rock composed of fragments of older rocks (for example, conglomerates or sandstone).
closure (analytical period)	Includes 10 years of activities that would begin upon receipt of a license amendment to close the analyzed repository. Activities would include decommissioning and demolishing surface facilities, emplacing *drip shields*, backfilling, sealing subsurface-to-surface openings, restoring the surface to its approximate condition before repository construction, and constructing monuments to mark the site. See *repository closure*.
commercial spent nuclear fuel	Rods that have been removed from a *nuclear reactor* after use as nuclear fuel at commercial nuclear power plants. See *spent nuclear fuel* and *DOE spent nuclear fuel*.
confining unit	In *geology*, a confining unit is a rock or sediment unit of relatively low *permeability* that retards the movement of water in or out of adjacent *aquifers*.
contaminant	Foreign materials that could be released from a repository into the *accessible environment* over time. For this analysis, there are two types of contaminants: radiological and non-radiological.
corrosion	The *process* of dissolving or wearing away gradually, especially by chemical action.

Death Valley floor	See *floor of Death Valley*.
Death Valley region	The area described by the outer boundaries of the *Death Valley regional groundwater flow system model*.
Death Valley regional groundwater flow system model	A multi-agency-funded effort by the U.S. Geological Survey to develop a *steady-state groundwater* model simulating pre-pumping conditions within the Death Valley region and a transient groundwater model to simulate changes over time from pumping over the period from 1913 to 1998. The model was created to support investigations at the Nevada Test Site, licensing of the proposed *geologic repository* at Yucca Mountain, and other regional groundwater resource issues.
Death Valley subregion	One of the three areas (that is, northern, central, and southern) that make up the *Death Valley region*.
decay (radioactive)	The *process* in which a *radionuclide* spontaneously transforms into another element called a decay product. That decay product may undergo further decay.
diatomite	A soft, chalk-like sedimentary rock rich in the skeletons of diatoms.
discharge (groundwater)	The areas where *groundwater* leaves the ground. Discharge points typically occur as springs or seepage into wetlands, lakes, and streams. Discharge also occurs as *evapotranspiration*.
disposal	For this analysis, the *emplacement* in a *repository* of *high-level radioactive waste*, *spent nuclear fuel*, or other *radioactive* material with no foreseeable intent of recovery, whether or not such emplacement would permit the recovery of such waste, and the *isolation* of such waste from the *accessible environment*.
DOE spent nuclear fuel	Nuclear fuel that has been withdrawn from a *nuclear reactor*, provided the constituent elements of the fuel have not been separated by reprocessing, that DOE manages from its defense production reactors, U.S. naval reactors, and DOE test and experimental reactors, as well as from university and other research reactors, commercial reactor fuel acquired by DOE for research and development, and from foreign research reactors.
drift	From mining terminology, a horizontal underground passage. In relation to a *repository* at Yucca Mountain, this includes excavations for *emplacement* (emplacement drifts), ventilation (exhaust mains), access (access mains), and performance confirmation (observation drift).
drip shield	A corrosion-resistant *engineered barrier* that DOE would place above a *waste package* to prevent seepage water from direct contact with the waste package for thousands of years. The drip shield would also protect the waste package from rock fall.

effective-moisture	Precipitation not lost to evaporation; that is, precipitation that is available to contribute to surface waters or to *infiltration*.
emplacement	The placement and positioning of *waste packages* in a *repository*.
emplacement pallet	Structure used to support the *waste package* in the emplacement *drift*.
Engineered Barrier System	The designed or engineered components that would contribute to waste containment and isolation in the underground facility at Yucca Mountain: *waste package*, *emplacement pallet*, emplacement *drift* invert, *drip shield*, and emplacement drift.
eolian processes	Erosion, transport, and deposition of soil and other materials by the wind.
evaporite	Water soluble mineral sediments that result from the evaporation of bodies of surficial water.
evapotranspiration	The loss of water by evaporation from the soil and other surfaces, including evaporation of moisture emitted or transpired from plants.
floor of Death Valley	The topographic low area, or structural trough, running roughly northwest-to-southeast in the Death Valley National Park.
flux	The amount of fluid that flows through a unit area per unit time.
friable	Crumbly; easily broken into small fragments or reduced to powder.
fuel assembly	A number of fuel elements held together by structural materials for use in a *nuclear reactor*.
fuel rods	Sealed tubes filled with cylindrical fuel pellets made of a *radioactive* material, typically uranium oxide enriched in uranium-235, for use in a *nuclear reactor*.
geohydrology	The science that deals with the distribution and movement of *groundwater* in the soil and rocks.
geologic	Of or related to a natural *process* that acts as a dynamic physical force on Earth (such as, faulting, erosion, and mountain-building resulting in rock formations).
geologic repository	A system for disposing of *spent nuclear fuel* and *high-level radioactive waste* in excavated *geologic* media, which includes surface and *subsurface* areas of operation and the adjacent part of the geologic setting that provides *isolation* of radioactive materials in a controlled area.
geologic stability	The million years after *disposal*, per 40 CFR 197.20(a).
glacial (climate)	Glacial is one of the four basic climate types discussed in this analysis and is substantially cooler and wetter relative to today.

groundwater	Water located beneath the ground surface in soil pore spaces and in the fractures of *lithologic* formations.
high-level radioactive waste	1. The highly *radioactive* material that resulted from the reprocessing of *spent nuclear fuel*, which includes liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains *fission* products in sufficient concentrations. (Note: DOE would *vitrify* liquid high-level radioactive waste before shipping it to a *repository*.) 2. Other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent *isolation*.
hydraulic gradient (aquifer)	The rate of change of hydraulic head per unit of distance of flow at a given point and in a given direction; the measure of steepness between two or more hydraulic head measurements over the length of the flow path. For this analysis, the hydraulic gradient is used to determine the direction and rate of groundwater movement.
hydrogeologic	The subject area of *geology* that deals with the distribution and movement of *groundwater* in the soil and rocks. In the *Death Valley regional groundwater flow system model*, a hydrogeologic unit is a grouping of rocks or deposits that reaches over a considerable lateral extent and has reasonably distinct hydrologic properties because of its geologic and structural characteristics.
infiltration	For this analysis, and based on the TSPA-LA, infiltration is the precipitation that is not lost to *evapotranspiration* or runoff and makes it into the *unsaturated zone* flow system.
interglacial (climate)	Interglacial is one of the four basic climate types discussed in this analysis and is described as the relatively dry, warm climate that is at the opposite end of the spectrum from the cooler and wetter glacial climate; present day climate.
intermediate (climate)	Intermediate is one of the four basic climate types discussed in this analysis and is the general climate of transition between the *glacial* and *interglacial* periods. It is also referred to as the “glacial-transition” climate. Intermediate has cooler and wetter summers and winters relative to today.
isolation	Inhibition of the transport of *radioactive* material so the amounts and concentrations of the material that enters the *accessible environment* stay within prescribed limits.
latent cancer fatality	A death that results from cancer that exposure to ionizing radiation caused. There typically is a latent, or dormant, period between the time of the radiation exposure and the time the cancer cells become active.
lithology	The scientific study and description of rocks, especially at the macroscopic level, in terms of their color, texture, and composition.

longitudinal dispersion	Mixing of *groundwater* and *contaminants* in the direction of groundwater flow as water flows in an *aquifer*.
lower carbonate aquifer	In this analysis, this is the saturated *carbonate rock* that is extensive over the region, often at great depths, and often referred to as the regional *aquifer*. An *upper carbonate aquifer* is also present in the region, but is much less extensive and is not significant in discussions of the flow paths from Yucca Mountain.
macrofossil	A fossil large enough to be observed by direct inspection.
mass balance	The total accounting for all mass of a specific element in a system.
matrix	The solid, but porous, portion of the rock.
mean value	The average of a set of values equaling the sum of all values divided by the number of values.
metric tons of heavy metal (MTHM)	Quantities of *spent nuclear fuel* are traditionally expressed in terms of MTHM (typically uranium, but including plutonium and thorium), without the inclusion of other materials such as *cladding* and structural materials. A metric ton is 1,000 kilograms (1.1 short tons or approximately 2,200 pounds). Uranium and other metals in spent nuclear fuel are called heavy metals because they are extremely dense; that is, they have high weights per unit volume. One MTHM disposed of as spent nuclear fuel would fill a space approximately the size of the refrigerated storage area in a typical household refrigerator.
microfossil	A small fossil that typically can be studied only microscopically and that may be either a fragment of a larger organism or an entire minute organism.
mixed-oxide fuel	A mixture of uranium oxide and plutonium oxide that could be used to power commercial *nuclear reactors*.
monsoon (climate)	Monsoon is one of the four basic climate types discussed in this analysis and is characterized by hotter summers with increased summer rainfall relative to today.
non-radiological contaminants	*Contaminants* that could be released from a repository over the postclosure period that include chemically toxic metals such as molybdenum, nickel, and vanadium. These materials generally originate from construction materials of the *repository* and *waste packages*. Uranium, while a *radioactive* element, is also evaluated for its chemical toxicity as a non-radiological contaminant.
no-pumping scenario	Simulation of conditions of the *Death Valley regional groundwater flow system* before any significant *groundwater* pumping had started (or the equilibrium conditions if all pumping were to cease).
nuclear reactor	A device in which a nuclear fission chain reaction can be initiated, sustained, and controlled to generate heat or to produce useful *radiation*.

Oral Reference Dose	Established by the U.S. Environmental Protection Agency as 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. The Oral Reference Dose is expressed in units of milligrams per kilograms of body-weight per day.
orbital parameters	Three of Earth's orbital parameters vary on a cyclical basis and show a relationship with *glacial* and *interglacial* periods: eccentricity, precession, and obliquity.
paleoclimatology	Study of past climatic conditions, in timescales of hundreds of thousands of years.
paleodischarge	Prehistoric *discharge*.
paleohydrology	Study of past hydrologic conditions.
partition coefficient	The ratio of the concentration of the *contaminant adsorbed* (grams per mass of solid) to the concentration of the contaminant remaining in solution of *groundwater* (grams per unit volume) at equilibrium.
perennial (stream)	A stream or river (channel) that has continuous flow in parts of its bed all year round during years of normal rainfall.
permeable	Pervious; a permeable rock is one that is either porous or cracked and that allows water to soak into and pass through freely.
postclosure	The timeframe after *repository closure* through the 1 million years analyzed in this analysis.
potentiometric surface	A hypothetical surface representing the level to which *groundwater* would rise if not trapped in a confined *aquifer*. The potentiometric surface is equivalent to the water table in an unconfined aquifer.
primarily canistered approach	The packaging of most (a goal of 90 percent) *commercial spent nuclear fuel* at the commercial sites in multipurpose *transportation, aging, and disposal canisters*. The remaining commercial spent nuclear fuel (about 10 percent) would arrive at a *repository* as *uncanistered spent nuclear fuel* or in dual-purpose canisters.
probability	The relative frequency at which an event can occur during a defined period. Statistical probability is about what happens in the real world and is verifiable by observation or sampling. Knowledge of the exact probability of an event is usually limited by the inability to know, or compile the complete set of, all possible outcomes over time or space. Probability is measured on a scale of 0 (event will not occur) to 1 (event will occur).
probability distribution	A function that describes how the *probability* of occurrence of the value of a specific parameter varies with the value of the parameter.

process	Any phenomenon that occurs over a relatively long period, as opposed to an event, which occurs relatively instantaneously. An example of a process is general corrosion of metal.
process model	Generally a large, complex computer model developed to simulate a specific *process*.
proposed action	The activity proposed to accomplish a federal agency's purpose and need. An environmental impact statement analyzes the environmental impacts of the proposed action. A proposed action includes the project and its related support activities (preconstruction, construction, and operation, along with postoperational requirements). The Proposed Action for the Yucca Mountain FEIS and Repository Final SEIS was the *construction*, *operation* and *monitoring*, and eventual *closure* of a *geologic repository* for *spent nuclear fuel* and *high-level radioactive waste* at Yucca Mountain in Nevada.
pumping scenario	Simulation of *steady-state* conditions with *groundwater* pumping at 2003 levels was the pumping scenario used for the primary evaluations (Chapter 3 and Appendix B) of this Analysis of Postclosure Groundwater Impacts.
radioactive	Emitting *radioactivity*.
radioactivity	The property possessed by some elements (for example, uranium) of spontaneously emitting radiation in the form of alpha, beta, or gamma rays by the disintegration of atomic nuclei.
radionuclide	An unstable nuclide capable of spontaneous transformation into another nuclide by emitting photons or particles, thus changing its nuclear configuration or energy level.
reactor	See *nuclear reactor*.
reasonably maximally exposed individual	A hypothetical person who is exposed to environmental *contaminants* (in this case *radionuclides*) in such a way (that is, by a combination of factors that include location, lifestyle, and dietary habits) that this individual is representative of the exposure of the general population. DOE used this term in the license application to evaluate long-term *repository* performance against the standards in 10 CFR Part 63. The details of the regulatory definition of reasonably maximally exposed individual can be found in Section 2.4.3.1 of this analysis of Postclosure Groundwater Impacts. The reasonably maximally exposed individual is a *receptor* at a regulation-specific location.
receptor	An individual or population that are presently or will potentially be exposed to, and adversely affected by, the release or migration of environmental *contaminants*. This analysis evaluates receptors at a variety of locations (for example, Amargosa Farms area, and Furnace Creek springs area).
recharge (groundwater)	Water seeping into an *aquifer*. Recharge occurs where *permeable* soil or rock allows water to seep into the ground and reach groundwater.

Regulatory Compliance Point	The accessible environment above the highest concentration of radionuclides in the plume of contamination mentioned in 10 CFR 63.312, or the point of compliance for calculating dose with respect to the postclosure individual protection, human intrusion, and groundwater protection standards, based on the definition of the controlled area in 10 CFR 63.302. Consistent with the regulatory definition at 10 CFR 63.302, DOE has defined the southern boundary of the controlled area as extending to 36° 40’ 13.6661” North Latitude, approximately 18 kilometers from the analyzed repository footprint in the predominant direction of *groundwater* flow.
repository	A burial vault. See *Yucca Mountain Repository*.
Repository closure	The point in time when activities associated with the closure analytical period, such as decommissioning and demolishing surface facilities and backfilling subsurface-to-surface openings, have been completed. Permanent closure of the repository would be complete; postclosure timeframe would begin.
reprocessing	A chemical *process* to extract plutonium and other materials from the reactor-irradiated nuclear materials, which includes *spent nuclear fuel*.
saturated zone	The subsurface ground zone where water fills all of the openings (pores) in the soil or rock. Water that seeps deep into the ground continues downward under the force of gravity until it reaches this zone.
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
solar radiance	The light (and energy) emitted from the sun and received by the earth.
sorption	Any *process* by which one substance becomes attached to another. As used in this analysis, for example, sorption occurs when a dissolved solid is attached to or bonded with a solid that is exposed to the solution.
spent	The state of fuel in a *nuclear reactor* after a period of operation.

spent nuclear fuel	1. *Nuclear reactor* fuel that has been used to the extent that it can no longer effectively sustain a chain reaction. 2. Fuel that has been withdrawn from a nuclear reactor after irradiation, the component elements of which have not been separated by reprocessing. For this Analysis of Postclosure Groundwater Impacts, this refers to: a. Intact, nondefective *fuel assemblies*, b. Failed fuel assemblies in *canisters*, c. Fuel assemblies in canisters, d. Consolidated *fuel rods* in canisters, e. Nonfuel assembly hardware inserted in pressurized-water reactor fuel assemblies, f. Fuel channels attached to boiling-water reactor fuel assemblies, and g. Nonfuel assembly hardware and structural parts of assemblies resulting from consolidation in canisters.
steady-state	That point when all input rates to a system are balanced by all the output rates.
terrestrial changes (climate)	The manner in which the earth’s lithosphere, atmosphere, hydrosphere, and *biosphere* respond to changes in *solar radiance*.
throughflow	*Groundwater* flowing from one groundwater basin into an adjoining groundwater basin.
transportation, aging, and disposal canisters	A *canister* suitable for storage, shipping, and *disposal* of *commercial spent nuclear fuel*. Commercial spent nuclear fuel would be placed directly into the canister at the commercial *reactor*. At a *repository* at Yucca Mountain, DOE would remove the canister from the transportation cask and place it directly into a *waste package* or an aging overpack. This type of canister is one of a number of types of disposable canisters.
unsaturated zone	The region between the surface and the *water table* where water fills only some of the spaces (fractures and rock pores).
upper carbonate aquifer	One of the two *carbonate aquifers* recognized in the *Death Valley regional groundwater flow system model*.
vitrification	A waste treatment *process* that uses glass (for example, *borosilicate glass)* to encapsulate or immobilize *radioactive* wastes.
volcanic aquifer	One of three principal *aquifers* described in this analysis; found in *permeable* units of igneous rock.

waste package	A *disposal* container that consists of the *corrosion*-resistant outer container (*Alloy 22* outer cylinder) and structural inner container (stainless-steel inner cylinder), baskets, and shielding integral to the container. Waste packages would be ready for *emplacement* in a *repository* at Yucca Mountain when the inner and outer lid welds were complete and the volume of the inner container had been evacuated and filled with helium gas to achieve an inert condition.
water table	1. The upper limit of the *saturated zone* (the portion of the ground wholly saturated with water). 2. The upper surface of a zone of saturation above which the majority of pore spaces and *fractures* are less than 100 percent saturated with water most of the time (*unsaturated zone*) and below which the opposite is true (*saturated zone*).
welded tuff	A tuff deposited under conditions where the particles that make up the rock were heated sufficiently to cohere. In contrast to nonwelded tuff, welded tuff is denser, less porous, and more likely to be fractured (which increases *permeability*).
Yucca Mountain Repository	Inclusive term for all areas in the *Yucca Mountain site* where DOE evaluated a repository and facilities to support a *repository*, including roads.
Yucca Mountain site	The area inside the site boundary over which DOE would have control.

APPENDIX A

COMMENTS RECEIVED ON THE OCTOBER 24, 2008, NOTICE OF INTENT

CONTENTS

LIST OF FIGURES

A COMMENTS RECEIVED ON THE OCTOBER 24, 2008, NOTICE OF INTENT

A.1 Purpose

This appendix presents the comments received in response to the U.S. Department of Energy (DOE) Notice of Intent, “Supplement to the Environmental Impact Statements for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV” (73 FR 63463, October 24, 2008). Although this Analysis of Postclosure Groundwater Impacts is not a supplemental EIS, DOE has elected to include the comments and responses for benefit of the U.S. Nuclear Regulatory Commission (NRC).

A.2 Summary

DOE received four comment letters from the following entities. The scanned images of the letters are included at the end of this appendix.

- Inyo County Planning Director, County of Inyo, California. Requested expansion and/or refinement of the scope of the supplement as defined by the NRC staff. Specifically, the County requested that DOE evaluate perceived flaws in the model used to analyze long term performance, impacts from continued regional groundwater pumping, and impacts to endangered species in springs in Death Valley, as well as address cleanup and remediation measures.

- White Pine County Nuclear Waste Project Office, Nevada. Requested an expansion of the scope of the supplement to include additional analysis of the potential impacts of a volcanic eruption, specifically addressing how the release of volcanic tephra and radioactive gases might impact human health and the environment in areas downwind of Yucca Mountain, including White Pine County.

- Board of Commissions, Lincoln County, Nevada. Requested an expansion of the scope of the supplement to include additional analysis of the potential impacts of a volcanic eruption, specifically addressing how the release of volcanic tephra and radioactive gases might impact human health and the environment in areas downwind of Yucca Mountain, including Lincoln County.

- Joe Kennedy, Timbisha Shoshone Tribe. Requested that the supplement include analyses of several topics related to groundwater flow, potential transport of nuclear waste, and possible effects in Death Valley National Monument.

A.3 Comments and DOE’s Responses

The following subsections present the comment letters received and DOE’s responses regarding the comments in each letter.

A.3.1 INYO COUNTY

Inyo County comments pose five topics for consideration, as quoted below:

1. The SEIS should address the flaws in the Total System Performance Assessment model

2. The SEIS should describe of [sic] the full extent of the lower carbonate aquifer, particularly those parts that could become contaminated and how water (and potential contaminants) can leave the flow system

3. Impacts to the lower carbonate aquifer from regional groundwater pumping

4. Impact to Endangered Species that utilize the springs in Death Valley

5. Clean up and remediation measures.

Items 1, 2, and 3 are somewhat interrelated, in that they deal with the pumping scenarios the *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008; TSPA-LA) model evaluated, the effects pumping could have on characteristics of the lower carbonate aquifer, and the fate of contaminants should they reach the lower carbonate aquifer. As a result, items 1, 2, and 3 are addressed in the first section below. The second and third sections address impacts to endangered species (item 4 above) and remediation measures (item 5), respectively.

A.3.1.1 Comments on the Total System Performance Assessment (TSPA) and the Lower Carbonate Aquifer

The following summaries are DOE responses to the Inyo County comments. Additional detail and support for these responses can be found in the referenced documents.

Comment #1 Summary

Inyo County asserts that DOE’s TSPA-LA model is flawed because the saturated zone flow model “neglects the fact that there is groundwater development in the region, especially in the Amargosa Valley.” Inyo County’s comment continues, “the drawdown, including the predicted future drawdown that will result from a continuation of current pumping in the region, must be included in the new SEIS’s analysis of groundwater flow for the site.”

Response to Comment #1

The Repository Final SEIS used the TSPA DOE prepared for its application to the NRC for a license for construction authorization and is referred to as the TSPA-LA. Inyo County is incorrect in asserting that groundwater pumping was not considered in the TSPA-LA evaluations. Both the groundwater flow models used in the TSPA-LA [that is, the site-scale saturated zone flow model (SNL 2007) and the Death Valley regional groundwater flow system model (Belcher 2004; Belcher and Sweetkind 2010) were calibrated to groundwater elevations that resulted from historical regional pumping from 1913 to 1998, so the effects of that pumping are inherent in the application of those models. The County is correct, however, in its assertion that the TSPA-LA evaluation did not consider how groundwater levels might change in the future as a result of continued pumping. The TSPA-LA’s use of steady-state conditions for the future evaluation was appropriate and reasonable for two primary reasons:

1. United States court decisions, including that of the U.S. Supreme Court (Cappaert et al. v. United States et al. 1976), protect the water level in Devils Hole at a specific elevation. Currently, water in the pool at Devils Hole is less than 1 foot above the court-mandated level. DOE has prepared regional flow model simulations that project the protected water level could be reached in the 2016 time frame, assuming the continuation of current pumping conditions (SNL 2009, p. 25). This leads DOE to conclude that (1) current levels of pumping in the Amargosa Desert are not likely to continue at their current rate into the foreseeable future and (2) the groundwater levels simulated in the TSPA-LA model are a reasonable representation of where groundwater levels will remain based on court decisions.

2. The TSPA-LA modeling effort was required to address not just a hundred or a thousand years into the future, but hundreds of thousands of years into the future. There simply is no reasonable basis for projecting what groundwater pumping conditions will exist during that period of time. Fossil records and paleoclimatology studies of the Earth's rotational changes suggest there will be significant climate changes over that period, but there are no comparable records to support projections for human activity. As identified above, there is currently a societal set point for groundwater conditions, and DOE contends it is more reasonable to extend that point of reference into the future than any of the limitless number of other scenarios that could be envisioned.

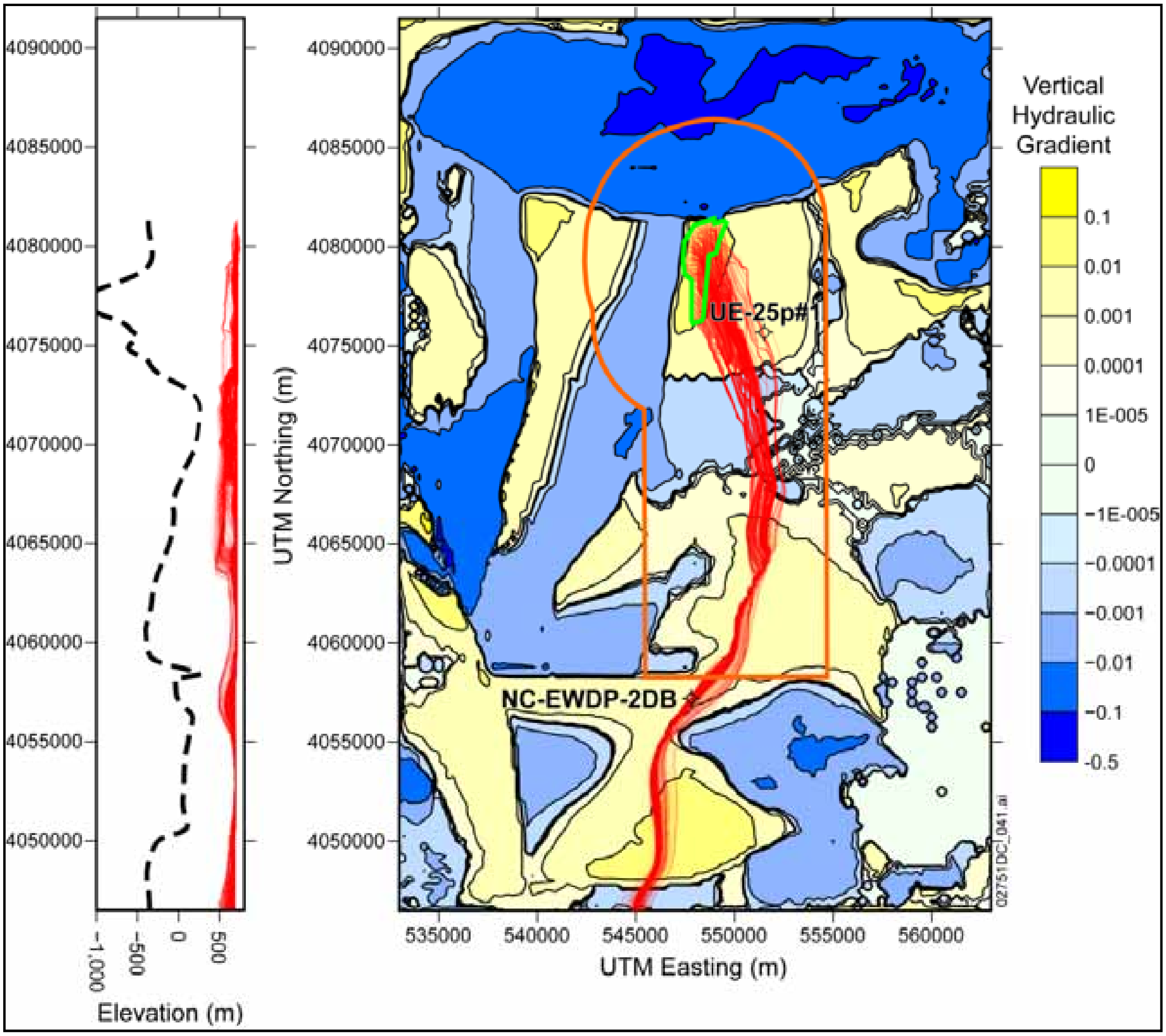
Even though DOE believes it is speculative to predict future pumping rates in the Amargosa Desert over long periods of time, DOE's evaluation in this Analysis of Postclosure Groundwater Impacts (Chapter 3 and Appendix B) includes a scenario of continued pumping (for 1 million years) to provide a reasonable range of potential impacts at natural discharge locations as well as locations of groundwater pumping.

Comment #2 Summary

Inyo County commented that DOE needs to describe the full extent of the lower carbonate aquifer, just as the NRC requested a full description of the volcanic and alluvial aquifers, and that DOE needs to identify how contaminants could reach the lower carbonate aquifer and where they would go. The County asked if the RMEI location should be moved should contamination reach the lower carbonate aquifer.

Response to Comment #2

DOE, Nye County, and Inyo County have each drilled a well into the lower carbonate aquifer along the general groundwater flow path from Yucca Mountain (see Sections 2.1.1.1.1 and 2.1.1.1.2 of this Analysis of Postclosure Groundwater Impacts). An upward hydraulic gradient exists in the lower carbonate aquifer compared with the overlying aquifers in each of these wells. DOE has not identified any reasonable scenario under which contaminants could reach the lower carbonate aquifer at or near Yucca Mountain. Based on additional model simulations (SNL 2009), DOE is confident that the upward hydraulic gradient will persist in the future (see Comment #3 and Response below) and that the thick intervening layers of low permeability strata will be present for the foreseeable future. As a result, any contaminants entering the groundwater below the analyzed repository will remain well above the lower carbonate aquifer at or near Yucca Mountain. As an example of the evaluations that support this position, NRC posed a question on how the site-scale saturated zone flow model reproduced the vertical hydraulic gradient between the lower carbonate aquifer and the overlying aquifers. In response, DOE extracted information from the model (Williams 2009) and generated Figure A-1 by comparing simulated head values in the lower carbonate aquifer with those of the water table. The left side of the figure also shows a cross section of simulated particle paths originating beneath a repository at Yucca Mountain, and the dashed black line represents the upper surface of the lower carbonate unit. To help in orienting the location of Figure A-1, the southwest corner of the large rectangular area is positioned roughly over the California-Nevada state line; the Furnace Creek area and the floor of Death Valley are about 15 miles, or 24 kilometers, farther to the southwest.



Note: The left side of the figure also shows a cross section of simulated particle paths originating beneath a repository at Yucca Mountain, and the dashed black line represents the upper surface of the lower carbonate unit. To help in orienting the location of Figure A-1, the southwest corner of the large rectangular area is positioned roughly over the California-Nevada state line; the Furnace Creek area and the floor of Death Valley are about 15 miles, or 24 kilometers, farther to the southwest.

Source: Williams 2009.

Figure A-1. Map of vertical hydraulic gradient between the water table and the top of the lower carbonate aquifer and cross section of simulated particle paths.

The model simulates an upward hydraulic gradient in the areas of the two wells (that is, UE-25p#1 and NC-EWDP-2DB shown in the figure) into the carbonate aquifer, as well as for much, but not all, of the area in between the two wells. The site-scale model also predicts a zone of slight downward gradient to the south of the analyzed repository site. This is attributed to a section of higher, thrusted carbonate rock with high permeability. The cross-section portion of the figure shows some downward movement of the simulated particles in this area, but it is relatively minor and in no areas does the model show particles entering the lower carbonate aquifer. As the figure shows, the model predicts the particles going no deeper than about 300 to 400 meters (1,000 to 1,300 feet) below the water table within its domain, and in many places along the flow path, the vertical spread is noticeably less.

For this Analysis of Postclosure Groundwater Impacts, DOE has evaluated a specific pathway by which contaminants could reach the lower carbonate aquifer (see Chapter 3), but this is in areas well south of the analyzed repository and the RMEI location (and to the southwest of the area shown in Figure A-1). The pathway evaluated is via fractures in the carbonate rock in the southern Funeral Mountains, and the evaluated areas of impact are the springs in the Furnace Creek area and the floor of Death Valley beyond. This is not consistent with the scenario envisioned in the Inyo County comments (with contaminants reaching the lower carbonate aquifer directly below the analyzed repository), but is a potential flow path identified in the Yucca Mountain FEIS and Repository Final SEIS.

Since the pathway through the Funeral Mountains is outside the site-scale saturated zone model domain, it was evaluated through use of the Death Valley regional groundwater flow system model. In the area between the RMEI location and the Funeral Mountains, the regional model predicts slightly different behavior for particles moving along the flow path from Yucca Mountain. The regional model simulation shows a small portion of the particles (9 to 10 percent) moving low enough in the Amargosa Desert to reach and enter the lower carbonate aquifer. These particles quickly come back out of the lower carbonate aquifer and resume on the path toward the Funeral Mountains (SNL 2009, Section 4.3). The regional model also predicts that the upward hydraulic gradient in the lower carbonate aquifer is not continuous along the flow path from Yucca Mountain, but in areas where the models overlap, locations where the upward gradient is lost are not the same as the site-scale model predicted. These differences between the site-scale model and the regional model may be attributed to the coarser grid of the regional model and to fundamental differences between the models (for example, numerical implementation, geologic interpretation, and vertical resolution). In any case, the differences had no significant effect on the impact evaluations presented in this analysis.

With respect to the possible need to move the RMEI location, this location is set by U.S. Environmental Protection Agency (EPA) and NRC regulations as the point in the accessible environment above the highest groundwater concentration. There is nothing in the results presented in Chapter 3 of this Analysis of Postclosure Groundwater Impacts that indicate higher groundwater concentrations would exist at locations other than what the TSPA-LA and Repository Final SEIS evaluated.

Comment #3 Summary

Inyo County commented that DOE relies on the upward hydraulic gradient in the lower carbonate aquifer to prevent radionuclide migration to that aquifer and, as a result, must evaluate the effects of regional pumping on the upward hydraulic gradient.

Response to Comment #3

DOE does not agree that it relies on the upward hydraulic gradient to prevent radionuclide migration, but this gradient is an element of the natural environment that affects how groundwater moves, just as there are other elements of the physical setting that affect groundwater movement. As noted previously, the thick sequence of low permeability strata that sits atop the lower carbonate aquifer at Yucca Mountain (DOE 2002, p. 3-52) is another of the natural features of significance.

With respect to the other portion of Inyo County’s comment, DOE has evaluated the effects of regional pumping on the upward hydraulic gradient of the lower carbonate aquifer (SNL 2009, Section 4.1). As noted in the preceding discussion and shown in Figure A-1, models of the groundwater flow system do not predict this upward gradient to be continuous over the complete groundwater pathway from Yucca Mountain to the floor of Death Valley. This is true of the site-scale saturated zone flow model (Figure A-1) (Williams 2009) and the Death Valley regional groundwater flow system model (SNL 2009, Section 4.1). Furthermore, long-term model simulations of current and proposed groundwater pumping rates predict no significant decrease in the magnitude of the upward hydraulic gradient between the lower carbonate aquifer and overlying aquifers along flow paths from Yucca Mountain. To the contrary, the model simulations predict that should heavy pumping continue from the shallow aquifers (in conflict with the potential discussed above regarding the water levels at Devils Hole), this pumping would result in an increase in the upward vertical gradient of the lower carbonate aquifer in the Amargosa Desert (SNL 2009, p. 27). DOE’s evaluation of the effects of regional pumping on the upward hydraulic gradient included use of the regional model to simulate transient groundwater conditions using 2003 pumping rates for an additional 500 years. The simulation results after 500 years of pumping indicated a drop of about 5 meters in the carbonate aquifer at Yucca Mountain. This is consistent with the Inyo County finding of a drop of 10 meters after a 1,000-year simulation with the regional model using 1998 pumping rates. DOE’s simulation results also show that the upward hydraulic gradient would be maintained after 500 years of additional pumping and that the magnitude of the upward hydraulic gradient would be within about 3 percent of the magnitude predicted for steady-state conditions with no pumping (SNL 2009, Section 4.1).

DOE ran the 500-year transient simulation described above, using 2003 groundwater pumping rates, a second time with an additional 10,600 acre-feet (13.1 million cubic meters) of annual groundwater withdrawal from the lower carbonate and alluvial aquifers east of the Nevada National Security Site, as the Southern Nevada Water Authority proposes (SNL 2009, p. 9). The specific well locations and pumping rates used in the simulations for the additional pumping were based on a Southern Nevada Water Authority May 17, 2005 application to the Nevada State Engineer's Office and a subsequent ruling on June 15, 2006 by the Nevada State Engineer (Ricci 2006). Another finding from these simulations was that the additional pumping the Southern Nevada Water Authority proposed had little additional impact on water levels in areas of the flow paths from Yucca Mountain; that is, compared with the effects on water levels in those areas without the additional pumping (SNL 2009).

A.3.1.2 Comments on Impacts to Endangered Species

Comment #4 Summary

Inyo County’s fourth comment states there is no discussion about how radionuclide migration from the analyzed repository could affect the health and well being of endangered species that rely on the springs in Death Valley and on the Devils Hole pupfish, which resides in the Devils Hole spring. These springs are fed from the lower carbonate aquifer.

Response to Comment #4

The only federally listed threatened or endangered aquatic species living within or near the potential path of water flowing beneath Yucca Mountain are the Devils Hole pupfish and other listed species in the Ash Meadows area. The Repository Final SEIS (DOE 2008a, pp. 3-31 and 3-33) described the general flow path of groundwater from beneath Yucca Mountain, including Devils Hole and the Ash Meadows area. Specifically, as groundwater in the Alkali Flat – Furnace Creek groundwater basin moves south beneath the Amargosa Desert, groundwater from the Ash Meadows area joins it. The lower carbonate aquifer feeds a line of springs, which marks a portion of the boundary between the Alkali Flat – Furnace Creek basin and the Ash Meadows basin. These springs support habitat in the Ash Meadows National Wildlife Refuge. Devils Hole, a groundwater-filled cave in a fault zone, is on the eastern side of the refuge. In the Ash Meadows area, there is a relatively sharp decrease in groundwater head, or elevation, from east to west, so it is clear that groundwater from the Ash Meadows area and Devils Hole moves into the Alkali Flat – Furnace Creek basin rather than the opposite direction.

DOE does not expect any impacts to the Devils Hole pupfish or other species in the Ash Meadows area because under all analyzed conditions (that is, pumping, no-pumping, present climate, and wetter climate), no contamination would move into the Ash Meadows area due to potentiometric head differentials. Chapter 2 of this Analysis of Postclosure Groundwater Impacts further describes the groundwater flow system in the area of Devils Hole and the Ash Meadows area.

The estimated concentrations of radionuclides at the natural discharge sites in the region, and associated human health consequences, are so low that DOE would not expect any harm to other flora and fauna, including rare or protected aquatic and terrestrial species living within or near the discharge sites.

A.3.1.3 Comments on Mitigation Measures

Comment #5 Summary

Inyo County's fifth comment regards mitigation measures; specifically, the Yucca Mountain FEIS and Repository Final SEIS did not address remediation of specific impacts to groundwater in Inyo County.

Response to Comment #5

The comment infers that DOE has deferred its obligations to analyze the appropriate mitigation and remediation measures. The Repository Final SEIS Comment-Response Document [DOE 2008a, Volume III, Comment 1.7.4 (2365)] responded to a comment of this nature, as quoted below:

> "During the active, preclosure phases of the project, DOE would be required by NRC regulations (10 CFR 63.161) to develop and be prepared to implement an emergency plan to cope with radiological accidents that may occur at the repository operations area. After sealing the repository, DOE would conduct postclosure monitoring to continue to ensure acceptable performance. DOE studies and models of postclosure performance, as described in Chapter 5 and Appendix F, indicate that impacts under even the most severe scenarios would be represented by low quantities and slow increases of radionuclides in the groundwater pathway. DOE's postclosure monitoring would provide early detection of any unusual conditions in the groundwater. As a consequence, there would be ample time to plan corrective measures to protect the public."

Nonetheless, this Analysis of Postclosure Groundwater Impacts indicates that while radionuclides will distribute into several locations and possibly discharge from springs, the estimated human health consequences would be minimal and well below the Repository Final SEIS assessments over the 1-million-year period. Therefore, there is no need to consider specific mitigation. In the event that unanticipated impacts occur, the postclosure monitoring program would detect such an occurrence and mitigation and remediation measures could be developed as appropriate in accordance with the processes described in Chapter 9 of the Repository Final SEIS.

A.3.2 WHITE PINE COUNTY

Comment Summary

White Pine County recommended that an SEIS include estimates of the public health and environmental consequences of contaminated ash from a volcanic eruption and the consequences of the transport of radionuclides in volcanic gases at locations downwind of the analyzed repository site, including White Pine County. The County also recommended that an SEIS include a discussion of various measures for mitigating the public health and environmental consequences of a volcanic eruption through the Yucca Mountain Repository.

Response

DOE considered the volcanic events in the Repository Final SEIS (DOE 2008a, pp. 3-21 and 3-22), as quoted below.

> "In 1995 and 1996, a panel of 10 recognized experts from federal agencies, national laboratories, and universities evaluated the potential for disruption of the repository by a volcanic intrusion, also known as a dike. The result of that effort was an estimate of the

> average probability of 1 chance in 7,000 that a volcanic dike could intersect or disrupt the repository during the first 10,000 years after repository-closure. As the Yucca Mountain FEIS reported, DOE increased this probability to 1 chance in 6,300 to account for a slightly larger repository footprint than the expert panel considered (DOE 2002, p. 3-27). The likelihood of an intersection increases by small amounts if the footprint size increases because the larger area presents a larger "target" for the dike to intersect, should an event occur. Since DOE completed the Yucca Mountain FEIS, the size and shape of the repository footprint has changed slightly, and so has the probability of a dike intersection. DOE based the new calculation on the work in 1995 and 1996 by the panel of experts. The estimated probability of a dike intrusion is now 1 chance in 5,900 during the first 10,000 years, with 5th- and 95th-percentile values of 1 chance in 133,000 and 1 in 1,800, respectively (BSC 2004, pp. 7-1 and 7-2, and Table 7-1)."

Presented in terms of annual frequency, the estimated value of the mean annual frequency of a volcanic dike intersecting the repository footprint is 1.7×10^{-8}. The 5th and 95th percentiles of the uncertainty distribution are 7.4×10^{-10} and 5.5×10^{-8}, respectively (DOE 2008b, p. 2.3.11-22).

The probability that such a volcanic eruption would result in radionuclides entrained in tephra and that such a volcanic eruption would release radionuclides via atmospheric transport in volcanic gases is even lower than estimated by the above distribution because two additional conditional probabilities must also be considered: (1) the conditional probability that a conduit would form within the repository footprint, and (2) the conditional probability that the conduit intersects waste packages. The combined conditional probability that a conduit forms within the repository footprint and intersects waste packages is about 0.083 (DOE 2008b, Section 2.3.11.4.2.1). Consideration of these conditional probabilities reduces by more than an order of magnitude the estimated probability that a volcanic eruption would occur at the Yucca Mountain site that would result in the release of radiologically contaminated tephra.

DOE provides the following guidance for the consideration of low-probability events in *National Environmental Policy Act* (NEPA) documents:

- Consider scenarios with frequencies of 10^{-6} to 10^{-7} per year if the consequences may be very large.
- Scenarios with frequencies less than 10^{-7} per year will rarely need examination.
- Report the probability of the accident occurring during the lifetime of the Proposed Action.

DOE guidance on NEPA document preparation, *Recommendations for Analyzing Accidents under the National Environmental Policy Act* (DOE 2002, p. 9) states that:

> "In determining which low frequency accident scenarios to analyze, document preparers should consider differences between natural phenomena and human-caused events with respect to the degree to which their consideration would inform decision making. It may not be useful to consider extremely low frequency accidents resulting from certain natural phenomena."

White Pine County's comment regards a low-frequency accident resulting from a natural phenomenon. The probability that a volcanic eruption would occur at the Yucca Mountain site and result in the release of radiologically contaminated tephra is more than 1 order of magnitude lower than the 10^{-7} threshold the DOE guidance suggests. On January 28, 2009, Peter Swift, Lead Laboratory Chief Scientist for Sandia National Laboratories, reported to the Nuclear Waste Technical Review Board that the mean annual intersection of a volcanic dike intersecting the repository footprint is estimated at 3.1×10^{-8}; an increase from 1.7 × 10^{-8}. With this increase, the release of radiologically contaminated tephra is still about 1 order of magnitude lower than the 10^{-7} threshold.

Even though below the low-probability threshold, DOE evaluated the consequences at a site 18 kilometers from the analyzed repository, the RMEI location, should a volcanic eruption occur. The results of this evaluation show the impacts at that location to be less than 1 millirem projected annual dose. These impacts are not considered "very large." DOE has not evaluated the impacts at locations 230 kilometers or 285 kilometers from the analyzed repository, as requested by White Pine County.

The Council on Environmental Quality and DOE regulations require discussion of potential mitigation measures only for reasonably foreseeable impacts. Because a volcanic eruption through the analyzed repository is not a reasonably foreseeable event, identification of potential mitigation measures for this event is not required.

A.3.3 LINCOLN COUNTY

Lincoln County also recommended that an SEIS include analysis and disclosure of the public health and environmental consequences of a volcanic eruption through the Yucca Mountain Repository upon areas located predominately downwind of the analyzed repository site, including Lincoln County. The County also recommended that the SEIS scope include a discussion of various measures for mitigating the public health and environmental consequences of a volcanic eruption through the Yucca Mountain Repository.

DOE's perspective regarding the comments from Lincoln County is the same as its perspective regarding the comments from White Pine County presented in Section A.3.2 above.

A.3.4 TIMBISHA SHOSHONE TRIBE

The following bullets are quoted from the Timbisha Shoshone Tribe comment letter; as applicable, the Repository Final SEIS (DOE 2008a) section that addresses the requested information follows each bullet. The Yucca Mountain FEIS (DOE 2002), Repository Final SEIS, and accompanying comment-response documents address all of the points the Timbisha Shoshone Tribe raised in its comment letter.

- "Information concerning the interrelation between the ground and surface water within the Amargosa Desert and Ash Meadows alluvial aquifer" – Repository Final SEIS, Sections 3.1.4.1 and 3.1.4.2.

- "Additional information concerning the possibility of water vapor contamination and water vapor routes and its potential effect on groundwater" – Repository Final SEIS, Appendix F, pp. F-11 to F-13.

- "Information on the potential for groundwater Geothermal Hot Water Upwelling" – Repository Final SEIS, Section 3.1.4.2.2, pp. 3-44 to 3-49; Volume III, comment response 1.7.4 (494).

- "The effect of oxidizing groundwater and its potential to transport radionuclides" – Repository Final SEIS, Section 5.1.2; Volume III, comment responses 1.6.5 (57) and 1.9 (4135).

- "The possibility of establishing a separate ground water standard for the YMP as opposed to using the standards promulgated by the Environmental Protection Agency" – The EPA established the groundwater standard, and DOE does not have the authority to modify this standard.

- "Information concerning the potential of groundwater infiltration into nuclear waste packages and the potential release of radionuclides due to water infiltration and potential release rates" – Repository Final SEIS, Volume III, comment responses 1.7.4 (3708) and 1.7.4 (3749).

- "Travel time estimates concerning the length of time it takes for groundwater to travel to the surface both in and near the YMP project (including release rates to the Ash Meadows aquifer, if any)" – Repository Final SEIS Section 3.1.4.2.1, p. 3-34; Volume III, comment responses 1.7.4 (89), (4189), (325), (3708), (3749) and 1.11 (495).

- "Seismic and tectonic activities potential effect on ground and surface water flows and aquifer water releases, including the effect of groundwater contamination due to a catastrophic flood of the YMP facility and impact area(s)" – The combined case results discussion in Chapter 3 of this Analysis of Postclosure Groundwater Impacts addresses potential postclosure health impacts from contaminated groundwater as a result of seismic disruptive events. Flooding hazards at the analyzed repository site were addressed in the Repository Final SEIS Section 3.1.4.1 and the Yucca Mountain FEIS Section 3.1.4.1.

- "Potential effect of release of nuclear waste, specifically heavy metals, due to corroded and structurally degraded nuclear waste containers into groundwater sources and aquifers" – Chapter 3 of this Analysis of Postclosure Groundwater Impacts and the Repository Final SEIS, Section 5.7.

- "A historical study on ground and surface water tables and water flow" – Repository Final SEIS Sections 3.1.4.2.1 and 3.1.4.2.

- "The potential effect of dramatic and catastrophic climate change upon ground and surface water flows and aquifers at or near the YMP impact area(s)"– Chapter 3 of this Analysis of Postclosure Groundwater Impacts and the Repository Final SEIS, p. 3-44 and Section 5.5.

- "Groundwater infiltration and 'fracture flow' analysis on nuclear waste containers that were designed for 300-1,000 year durations, compared to the anticipated 10,000 year nuclear waste isolation period" – Repository Final SEIS Appendix F, Section F.2.7.

- "Nuclear and hazardous waste groundwater contaminations potential effect on plant and animal life important to indigenous peoples within the YMP impact area(s)" – Chapter 3 of this Analysis of Postclosure Groundwater Impacts and the Repository Final SEIS Volume III, comment response 1.7.5 (157).

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APPENDIX B

ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

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B ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

This appendix details the analysis carried out to track radionuclides and non-radiological contaminants in the groundwater and surface water system after release from the analyzed repository during the postclosure period. The contaminants in this analysis are the radionuclides identified in the TSPA-LA as significant contributors to dose and the non-radiological contaminants identified in the Repository Final SEIS as species of concern (DOE 2008). The appendix discusses the models used and presents detailed results.

The analysis started at the point where contaminants would be released from the unsaturated zone to the saturated zone underneath the analyzed repository. For the radionuclides, DOE used results from *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008a) (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 Death Valley region. While the analysis beyond the Regulatory Compliance Point is the main subject of this Analysis of Postclosure Groundwater Impacts, this appendix also presents some aspects of the TSPA-LA results to provide sufficient background information to allow for a comparison and understanding of results. This appendix also discusses an analysis of the release of non-radiological contaminants at the unsaturated zone and subsequent transport to the Regulatory Compliance Point. DOE carried out the same analysis for the non-radiological contaminants as that performed for the radionuclides for locations beyond the Regulatory Compliance Point.

REGULATORY COMPLIANCE POINT

This point is defined by the EPA and indicated by NRC at 10 CFR 63.312(a) as the point of compliance for calculating dose with respect to the postclosure individual protection, human intrusion, and groundwater protection standards, based on the definition of the controlled area in 10 CFR 63.302. The TSPA-LA calculates radiological dose to a reasonably maximally exposed individual located at a point on the Nevada National Security Site boundary (36°40’13.66661” North Latitude) that is approximately 18 kilometers south of the analyzed repository footprint in the predominant direction of groundwater flow.

In 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; DOE 2008) (Repository Final SEIS), DOE analyzed postclosure performance using the TSPA-LA model. That analysis evaluated the transport of radionuclides to the Regulatory Compliance Point as the result of a number of scenario classes in the analyzed repository. DOE analyzed and presented results for a combined scenario case that included:

CONTAMINANTS

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

- The Nominal Scenario Class: undisturbed case where normal degradation processes, such a corrosion of waste packages, continued over time,

- 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 analyzed repository or intrusion of igneous material into the repository, and
- Seismic Scenario Class: events and processes initiated by ground motion or fault displacement.

The TSPA-LA is a probabilistic analysis that accounts for many types of uncertainties and presents statistical results in terms of mean, median, and various percentiles. In the TSPA-LA, many variables were treated as distributions; meaning that the values used for these variables (such as soil-water partition coefficients of contaminants) were analyzed as a range of values with specific probabilities of occurrence. The TSPA-LA model is a 300-realization simulation using a Monte Carlo technique; Appendix F of the Repository Final SEIS (DOE 2008, Appendix F) describes this in detail.

The TSPA-LA used a simulation of various climates occurring in fixed time periods. The model represented future climate shifts as a series of instant changes. During the first 10,000 years, there would be three changes from present-day (0 to 600 years) to monsoon (600 to 2,000 years) and then to glacial-transition climate (2,000 to 10,000 years). In its proposed changes to Title 10 of the Code of Federal Regulations (CFR) 63.342(c), the U.S. Nuclear Regulatory Commission directed DOE to represent climate change after 10,000 years (the post-10,000-year climate) with a constant value determined from a log-uniform probability distribution for deep percolation rates from 13 to 64 millimeters (0.5 to 2.5 inches) per year.

It should be noted that since the Repository Final SEIS and license application were submitted, the EPA issued a final rule (73 FR 61256, October 15, 2008) governing the post-10,000-year period. The NRC thereafter issued a final rule (74 FR 10811, March 13, 2009) revising 10 CFR Part 63 to implement the EPA's revision. The final NRC rule revised the deep percolation rate to be used in modeling the post-10,000-year climate slightly upward from that contained in the earlier proposed rule and which was used in the license application. In particular, the NRC's proposed rule permitted DOE to represent future climate change in the performance assessment by sampling constant-in-time deep percolation rates from a log-uniform distribution with a range of 13 to 64 millimeters (0.5 and 2.5 inches) per year and an average arithmetic mean of 32 millimeters (1.3 inches) per year. By way of comparison, the NRC final rule slightly raised the average arithmetic mean for the deep percolation rate to 37 millimeters (1.5 inches) per year, while broadening the range of the lognormal distribution to between 10 and 100 millimeters (0.39 and 3.9 inches) per year.

The radionuclide mass release rates used for this Analysis of Postclosure Groundwater Impacts were the mean results obtained from the outputs of the TSPA-LA, which were developed in accordance with the NRC proposed rule. Because the NRC Final Rule increased the average arithmetic mean of the deep percolation rate distribution from 32 to 37 millimeters (1.3 to 1.5 inches) per year, one would expect the mean radionuclide mass release rate at the location of the reasonably maximally exposed individual (RMEI) to show only minor, if any, increase. This conclusion is reflected in the NRC's responses to comments on the proposed amended rule in the *Federal Register* notice of the Final Rule (74 FR 10811, March 13, 2009): (from page 10820) "… dry-to-wet transients in performance assessments would have less influence on the mean of the distribution of projected doses than on any single projected dose used to construct the distribution. … Performance assessment models and analyses continue to improve; however, dry-to-wet conditions appear to have a limited effect on the mean dose within the constraints of current performance assessment approaches." Therefore, it is unlikely that this slight change in the distribution of deep percolation values would have any significant effect on the mean radionuclide mass release rates used in this analysis.

The results of the TSPA-LA analysis combined case form the starting point for the analysis in this Analysis of Postclosure Groundwater Impacts.

B.1 Analysis Cases

The purpose of the Analysis of Postclosure Groundwater Impacts is to characterize how contaminants would move from the analyzed repository to the Regulatory Compliance Point and then beyond, possibly accumulate, and discharge to the surface. The mean value results of the TSPA-LA represented the analysis up to the Regulatory Compliance Point. Beyond that point, DOE analyzed a single-value deterministic result. Because DOE did not use a probabilistic analysis, many aspects of the analysis were biased toward conservative results to ensure that the results did not underestimate impacts.

The Analysis of Postclosure Groundwater Impacts focused on a number of analytical constructs to ensure representation of any possible future conditions within these varying constructs. DOE analyzed two climate conditions and two pumping scenarios. The two climate conditions were (1) a present-day climate existing from closure until 1 million years postclosure, and (2) a wetter climate equivalent to the post-10,000-year climate in the TSPA-LA existing from closure until 1 million years postclosure. Note that this analysis uses radionuclide mass release rates derived from previous TSPA-LA model runs as input (for example, the radionuclide mass release rates at the Regulatory Compliance Point). When the TSPA-LA model produced these mass release rates, 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 analyzed 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). Therefore, this analysis used the TSPA-LA results as input to both the present and future, wetter climates for the regional analysis.

The two pumping scenarios were (1) regional flow when pumping in the Amargosa Farms area from repository closure time to 1 million years postclosure at a rate equivalent to the 2003 pumping rates (Moreo and Justet 2008, Figure 3, p. 5) (referred to as the pumping scenario) and (2) regional flow with no pumping from closure time to 1 million years postclosure (no-pumping scenario). DOE used the 2003 pumping rate because it represents the best available documented rates. Note that in this scenario, this pumping rate continues for the entire 1 million years. Such a pumping scenario would yield a drawdown in the vicinity of Devils Hole of about 78 meters (SNL 2009, p. 18), significantly below the level prescribed by the Supreme Court (Cappaert et al. v. United States et al. 1976) and later by the Nevada State Engineer in 2008 (Taylor 2008). Although this pumping rate may not be sustainable, this scenario maximizes, and thus bounds, the capture of contaminants in the Amargosa Farms area.

Sandia National Laboratories carried out a regional flow modeling effort to characterize flow directions and flow rates for contaminants in the Death Valley region beyond the Regulatory Compliance Point (SNL 2009). Both the TSPA-LA site-scale saturated zone flow model and the Death Valley regional groundwater flow system model modified with MODPATH include particle-tracking capabilities. Particle tracking allows simulation of water flow paths from one point to another. This allowed a computer simulation of adding particles at any location within the domain of the model and being able to track where they would go as they moved with the water (that is, there is no adsorption, dispersion, filtering, decay, or other mechanisms that would prohibit the particles from moving with the water). As Chapter 2 of this Analysis of Postclosure Groundwater Impacts explains, the site-scale saturated zone model only extends southward to an area in Amargosa Farms. The Death Valley regional groundwater flow system model extends further south to encompass the entire Death Valley flow region. Therefore, the particle-tracking effort required the application of both models to determine where those particles would move in the regional flow system.

For the pumping scenario, the model identified one flow path extending from the Regulatory Compliance Point directly southward to the site of the pumping (the Amargosa Farms area) (SNL 2009, Figure 13). The model predicted that in this scenario, no particles would bypass the pumping in the area.

For the no-pumping scenario, the regional flow modeling identified two flow pathways: (1) a flow path extending from the Regulatory Compliance Point to the southeast then turning more westerly, terminating at a discharge location at the floor of Death Valley (in an area referred to as Middle Basin) via evapotranspiration and (2) a minor path extending from the Regulatory Compliance Point generally southward, terminating at Alkali Flat where discharge occurs via evapotranspiration (SNL 2009, Figure 11). The modeling results indicated that the path to Alkali Flat represented only two particles in 8,024 (less than 0.03 percent) going in that direction. Within the uncertainties of the model, this could mean that no flow or some minor flow might go in this direction. Other studies indicate that the flow paths will not vary for wetter climate (D’Agnese et al. 1999).

DOE analyzed the transport of contaminants for the paths to the Amargosa Farms area and toward Death Valley discussed in the previous paragraph. The analysis consisted of calculating the resulting contaminant mass release rates (in grams per year) arriving at the Amargosa Farms area and the Death Valley floor based on the input mass release rates at the Regulatory Compliance Point. An assessment of the doses and intakes at Alkali Flat as a possible alternative location was also made. The evaluations used groundwater flow rates associated with the pumping scenario for the path to the Amargosa Farms area and the no-pumping scenario for the path to the Death Valley floor. DOE carried out all the transport analyses (described in Sections B.2 and B.3) for the present climate and a wetter climate as necessitated in order to address NRC concerns with postclosure groundwater characteristics.

For the analysis of natural discharges in Death Valley, the regional flow model predicts that the flow would discharge as evapotranspiration from the alluvial deposits forming the floor of Death Valley in Middle Basin. Because the flow path from the Amargosa Desert includes passing through carbonate rocks under the Funeral Mountains, it is possible that some of the contaminants could be transported to the Furnace Creek springs in Death Valley, which are composed primarily of waters from the lower carbonate aquifer. Because DOE cannot preclude the possibility that contaminants could reach the Furnace Creek springs, this analysis includes both cases: (1) all of the contaminants discharge into the floor of Death Valley, and (2) all of the contaminants enter the Furnace Creek springs. These two cases ensure full disclosure of the potential impacts of natural discharges into Death Valley.

DOE performed the following additional analyses:

- Converted the mass release rates of contaminants to water concentrations based on discharge rates of water at the Furnace Creek springs area and pumping rates in the Amargosa Farms area;
- Calculated annual radiological doses to individuals and daily intakes (for non-radiological contaminants) based on the water concentrations. In the case of non-radiological contaminants, DOE evaluated intakes as milligram per kilogram body-weight per day and compared with Oral Reference Dose standards (see Section B.3.5 below);
- Analyzed doses and intakes resulting from the Death Valley floor (Middle Basin). This analysis was based on an evapotranspiration scenario;

- Estimated inventories as a function of time for contaminants, adjusted for decay and growth (radionuclides only) at points in the flow system. This provided a mass balance of contaminants throughout the flow system;
- Evaluated soil concentrations at the Amargosa Farms area and the floor of Death Valley;
- Analyzed how results would compare if the contaminants were transported to Alkali Flats as a possible alternative destination; and
- Analyzed the influence of an additional natural discharge area suggested by paleoclimatological studies.

B.2 Analysis of Radionuclides

This section describes the various models used in each aspect of the analysis. DOE used Microsoft® Excel® to carry out the computations. The section describes models for transport, accumulation, dose, and soil concentration assessments.

B.2.1 TRANSPORT MODEL

This Analysis of Postclosure Groundwater Impacts models the transport of contaminants along flow paths using a model formulated as a one-dimensional “pipe” containing a porous solid with solution flowing through at constant velocity. The processes occurring in the pipe are longitudinal hydraulic dispersion, equilibrium adsorption of the dissolved species on the solid surfaces of the aquifer materials, and decay of radiological contaminants. This one-dimensional pipe approach is very suitable for the analysis because the lateral and vertical mixing in this aquifer system is extremely small (SNL 2008c, p. 4-13). To the extent that this lateral and vertical mixing is ignored, the model is conservative. The regional flow model results indicate that the particles would travel through several different water-bearing components (aquifer systems) along the flow paths. Each of these components has somewhat different transport properties [that is, specific discharge, dispersion coefficient, bulk density, porosity, and contaminant-specific partition coefficients (K_d)]. The regional flow model results indicate the fraction of the path distance that would represent the total travel through any given component. A single set of transport properties was developed for each flow path by using a distance-weighted average of the properties for the individual structures. Values of the properties were derived from distributions used by the TSPA-LA and from other literature sources. Specific discharges were averaged directly from the regional flow model. Table B-1 presents these distance-weighted averaged properties for the pumping and non-pumping flow paths.

The following example describes how the transport properties were averaged for the flow path using porosity: The flow paths for the no-pumping scenario generally pass through alluvial sediments and undifferentiated volcanic and sedimentary basin-fill unconsolidated deposits before traveling through the lower carbonate aquifer prior to discharge by either evapotranspiration through the floor of Death Valley or by spring discharge at the Furnace Creek springs. Of the approximately 60-kilometer total travel path length from the Regulatory Compliance Point to these points of natural discharge (assuming no pumping), about 40 percent of the travel distance is through the lower carbonate aquifer (generally that portion of flow beneath the Funeral Mountains) and the remainder is through the alluvial or other unconsolidated basin fill deposits (with minor amounts predicted to flow through Cenozoic lava flow units). Considering the average porosity of the lower carbonate aquifer is 0.01 and the average porosity of the alluvial and other basin fill deposits is 0.18 (Arnold 2009, Table 1), the distance-weighted average porosity along the total travel path length is $(0.4 \times 0.01) + (0.6 \times 0.18)$ or 0.11.

Table B-1. Transport properties of the flow paths.

Transport property	No-pumping flow path	Pumping flow path
Porosity (no units; fraction of solid volume occupied by voids)[a]	0.11	0.16
Bulk Density (grams per milliliter)[a]	2.32	2.00
Dispersion Coefficient (meters)[b]	100	100
Specific Discharge present climate (meters per day)[c]	0.00046	0.0061
Specific Discharge wetter climate (meters per day)[c]	0.0018	0.024
K_d for uranium (milliliters per gram)[a]	8.7	4.2
K_d for neptunium (milliliters per gram)[a]	44	6
K_d for plutonium (milliliters per gram)[a]	164	93
K_d for cesium (milliliters per gram)[d]	728	728
K_d for americium, thorium, protactinium, and actinium (milliliters per gram)[a]	3,008	4,762
K_d for strontium (milliliters per gram)[d]	210	210
K_d for radium (milliliters per gram)[d]	550	550
K_d for selenium (milliliters per gram)[d]	14	14
K_d for tin (milliliters per gram)[d]	1,916	1,916
K_d for carbon[d], technetium[d], iodine[d], chlorine[d], and molybdenum[e] (milliliters per gram)	0	0
K_d for nickel (milliliters per gram)[f]	15	15
K_d for vanadium (milliliters per gram)[g]	8	8

a. Source: Arnold 2009.
b. Source: SNL 2008, p. 4-13.
c. Source: SNL 2009, pp. 36 and 38.
d. Source: DOE 2008, Table 2.3.9-14.
e. Source: Jacobs 1993, p. 180.
f. Source: BSC 2001, p. 180.
g. Source: Mikkonen and Tummavuori 1994, p. 364.
K_d = partition coefficient.

TRANSPORT PROPERTIES

Specific discharge:
The volumetric flow of liquid through the aquifer divided by the cross-sectional area of the flow path.

Dispersion coefficient:
A measure of the influence of the structure of the solids in an aquifer on mixing in water flowing through it. When the dispersion coefficient (in length units) is multiplied by the fluid velocity (length/time) the result is the dispersivity (length^2/time) which is like a hydrodynamic diffusivity.

Bulk density:
The mass of the aquifer per unit volume.

Porosity:
The fraction of the aquifer that consists of voids.

Partition coefficient:
The ratio of the amount of contaminant adsorbed on the solid surfaces to the amount of contaminant in solution.

The above-described approach to calculating the average transport properties is essentially equivalent to assuming that the rock matrix of the fractured lower carbonate aquifer is fully available for sorption of dissolved contaminants. Access to the sorptive capacity of the carbonate rock matrix would have to be via molecular diffusion of contaminants from the groundwater in fractures. This could result in somewhat smaller effective partition coefficients than those used. However, see Section B.5 concerning relative insensitivity of results to partition coefficients.

Note that K_d for cesium, strontium, radium, selenium, and tin are not sensitive to the path. This is because DOE has assumed that the K_d for these elements are the same in all media in the flow path. The impact of this assumption is very small because the mass release rates of these radionuclides are generally very small or zero and their contribution to dose is usually negligible for the analysis performed. Further, tin has a high K_d in alluvium and volcanic rocks and would be expected to have a reasonably high K_d in just about any soil. As a result, tin is essentially immobile.

Note also the general insensitivity of the results to K_d since the zero K_d radionuclides dominate doses in most cases. The zero K_d elements are also insensitive to path because they tend to have a zero or near-zero K_d in all media.

The K_d for molybdenum, nickel, and vanadium also are path-independent. For molybdenum, the assumption is justified because it is a zero K_d element (see discussion above). Nickel and vanadium appear to have a similar K_d in a wide variety of media. As with radionuclides, even at the low end of their range, these elements tend to give the same result and are fairly insensitive over a broad range for the pumped site (Amargosa Farms). Nickel and vanadium are sensitive to K_d for the pathway to Middle Valley and Furnace Creek because they dictate the arrival times. For the K_d values used in this analysis neither nickel or vanadium arrive at this location in one million years but for much lower K_d values these would arrive during the one million period. However, sample calculations show intake values at Furnace Creek would be very low (less than one-tenth of the Oral Reference Dose) even at K_ds equal to zero.

The approach used for highly sorbing elements such as plutonium, americium, thorium, protactinium, cesium and tin does not account for the potential impact of colloid-facilitated transport. This would have a small effect on the results because:

- The TSPA-LA results, which include colloid-facilitated modeling, show only plutonium and thorium isotopes with a significant mass release rate at the Regulatory Compliance Point. Except for plutonium-242, the isotopes of these elements generally contribute an insignificant amount to dose in the results of this Analysis of Postclosure Groundwater Impacts and would not contribute a significant amount even if they were to arrive sooner at the evaluated exposure locations.

- Colloid transport involves only a fraction of any particular isotope.

- The sensitivity test in Section B.5 shows only a mild sensitivity of the results to K_d. The principle effect of colloid-facilitated transport is to lower the effective K_d.

The transport model is implemented with an analytical solution to a step function input to yield “breakthrough curves.” Generally, the input to a flow path is not a simple step function, but rather a function of time (often it is a breakthrough curve from a previous path). Breakthrough curves are commonly known as response functions, meaning they describe the response of the flow path to a step input. The TSPA-LA used response functions in abstracted models for saturated zone transport (but these are developed for a much more complex transport system). An important principal for using response functions is that if the system is linear (as in the transport model used in this Analysis of Postclosure Groundwater Impacts), then responses can be superimposed linearly. DOE applied this principle by representing the input function as a series of step functions, using the breakthrough curve to calculate a function of time that represents the response to each step, and then adding all the step function responses together to obtain the overall response to the input function. This approach is equivalent to the convolution method the TSPA-LA model used to convert an input release rate to an output release rate represented with breakthrough curves. DOE employed this method for analysis of flow paths in the Amargosa Desert. Each pipe has an input mass release rate versus time (from an upstream pipe or process) and an output mass release rate versus time.

To analyze the flow paths from the Regulatory Compliance Point, DOE used the transport model described in this section to calculate the response based on the mass release rates at the Regulatory Compliance Point supplied from the TSPA-LA for radionuclides and from additional analysis described later for non-radiological contaminants. In all cases, the analysis used the mean value of the mass release rates for the radionuclides. Where distributions of the various parameters were available, the analysis used the mean value of those parameters. Where an uncertainty distribution was not known, the analysis used conservative values of parameters. For example, no distributions were available for the partition coefficients of molybdenum, nickel, and vanadium from the TSPA-LA. DOE surveyed literature values and found some limited information that was used to develop a range of possible values. Because the data are limited, DOE chose values near the low (conservative) end of the ranges and these are presented in Table B-1.

B.2.2 RADIONUCLIDE CHAINS

Several of the radionuclides of interest in the analysis are members of decay chains. Along these chains, some of the radionuclides can increase as parent radionuclides decay. These processes must be evaluated to get a more accurate measure of the mass release rates of radionuclides. The radionuclides evaluated in this analysis are the same as those the TSPA-LA evaluated. Four decay chains were identified in the TSPA-LA radionuclide screening analysis, for the purposes of transport analysis for the saturated zone transport model (SNL 2008a, p. 6-26). These consist of the following:

1. Actinium Series:

   $$^{243}\mathrm{Am}\rightarrow{}^{239}\mathrm{Pu}\rightarrow{}^{235}\mathrm{U}\rightarrow{}^{231}\mathrm{Pa}\rightarrow{}^{227}\mathrm{Ac}$$

2. Neptunium Series:

   $$^{241}\mathrm{Am}\rightarrow{}^{237}\mathrm{Np}\rightarrow{}^{233}\mathrm{U}\rightarrow{}^{229}\mathrm{Th}$$

3. Thorium Series:

   $$^{240}\mathrm{Pu}\rightarrow{}^{236}\mathrm{U}\rightarrow{}^{232}\mathrm{Th}\rightarrow{}^{228}\mathrm{Ra}$$

4. Uranium Series:

   $$\begin{tikzcd} {}^{242}\mathrm{Pu} \arrow[r] & {}^{238}\mathrm{U} \arrow[dr] & & & & \\ & & {}^{234}\mathrm{U} \arrow[r] & {}^{230}\mathrm{Th} \arrow[r] & {}^{226}\mathrm{Ra} \arrow[r] & {}^{210}\mathrm{Pb} \\ & {}^{238}\mathrm{Pu} \arrow[ur] & & & & \end{tikzcd}$$

The radionuclide transport analysis accounted for decay and growth in these chains.

In the analysis, the following pairs where originally treated as if the parent and daughter were in secular equilibrium within the groundwater (i.e., the activity of the parent equals the activity of the daughter): $^{231}\mathrm{Pa}\rightarrow{}^{227}\mathrm{Ac}$, $^{232}\mathrm{Th}\rightarrow{}^{228}\mathrm{Ra}$, and $^{226}\mathrm{Ra}\rightarrow{}^{210}\mathrm{Pb}$. In the case of $^{232}\mathrm{Th}\rightarrow{}^{228}\mathrm{Ra}$ and $^{226}\mathrm{Ra}\rightarrow{}^{210}\mathrm{Pb}$, it has recently been found (SNL 2009, Enclosure 1; Olszewska-Wasiolek and Arnold 2011) that the large difference in K_d between parent and daughter renders the assumption of secular equilibrium invalid. In this analysis, sorption disequilibrium has been accounted for by increases in the biological dose conversion factors. Note, however, that the effect of these corrections is negligible because of the very low contribution to total dose of these radionuclides.

The sorption enhancement factor for ^{231}Pa→^{227}Ac and ^{232}Th→^{228}Ra is given by

$$SEF = \frac{R_{parent}}{R_{daughter}}$$

where:

R = retardation factor for the parent or daughter = $(1 + \frac{K_d \rho}{\epsilon})$

where:

K_d = sorption coefficient for parent or daughter
ϵ = porosity fraction
ρ = bulk soil density.

From the transport properties for the pumping path in Table B-1 the sorption enhancement factor for the Th-Ra pair is 8.7 and for the Pa-Ac pair is 1.0 (since the multiplier is 1 there is no disequilibrium effect for this pair).

The sorption enhancement factor for ^{226}Ra→^{210}Pb is complicated by dose pathways from radon-222 and its daughters and is not as simple as the relationships above. A sorption enhancement factor of 1.8 for both ^{226}Ra and ^{210}Pb is taken from Olszewska-Waliolek and Arnold (2011, p. 771).

These enhancement factors are applied in Tables B-3 and B-4 (below).

B.2.3 DOSE CALCULATIONS

The radionuclide mass release rates were converted to an annual dose at the end of each path. This was accomplished by first deriving an estimated concentration at the location and then converting the concentration to an estimated annual dose. The approach is somewhat different at the Amargosa Farms area where there is pumping compared with natural water discharge locations because of the different exposure pathways in water and soil.

The projection of radiological impacts at different potential receptor locations (Amargosa Farms area and Death Valley area) assuming different future climates (a dry climate such as exists today and a wetter climate that is based on the glacial transition climate state) has used a similar construct as employed in the TSPA-LA. The TSPA-LA model was based on the concept of taking the concentration of radionuclides (with units of curies per liter) in the annual water demand of the RMEI and multiplying this concentration by a radionuclide-specific biosphere dose conversion factor (with units of millirem per year per curies per liter) to generate a radionuclide-specific projected annual dose (in units of millirem per year) to the RMEI. The biosphere dose conversion factor provides the sum of the effective dose equivalent for external exposures and the effective dose equivalent for internal exposures. Compliance with the numerical requirements of 10 CFR 63.321 is based on the mean of the distribution of projected doses from DOE's performance assessment, where the distribution of projected doses accounts for aleatory and epistemic uncertainty. In the TSPA-LA analysis, four different scenario classes (early failure, igneous, nominal, and seismic) are analyzed separately, and the resulting projected mean annual doses are summed to provide a total mean annual dose for comparison with the numerical requirements of 10 CFR 63.321.

In this Analysis of Postclosure Groundwater Impacts, the total annual dose was estimated using radionuclide-specific concentrations and biosphere dose conversion factors for the pumping scenario and for discharge locations at springs in the Furnace Creek area. The concentrations were based on the mean value of the concentration at each receptor location and the mean value of the radionuclide-specific biosphere dose conversion factors. The upgradient source term input to the analysis of concentrations at each receptor location is the sum of the mean annual mass (or activity) release rate of each radionuclide at the Regulatory Compliance Point for all the analyzed scenario classes from the results of the TSPA-LA model. As a result, this source term includes the effects of the aleatory and epistemic uncertainty included in the TSPA-LA model used as the basis for the Repository Final SEIS.

The epistemic and aleatory uncertainty is not explicitly analyzed in this Analysis of Postclosure Groundwater Impacts, as was done in the TSPA-LA for the estimates of potential impacts to other receptors downgradient from the Regulatory Compliance Point. Instead, the mean values of the input parameters were employed to provide an estimate of the potential expected mean value of the radiological dose impact. The mean values used in the analysis are described in Section B.2.1 for the transport of radionuclides from the Regulatory Compliance Point to the other potential receptor locations and Sections B.2.3.1 and B.2.3.2 for the biosphere dose conversion factors at the different receptor locations. These sections present the potential radiological dose impacts as radionuclide-specific annual doses and a total annual dose, which is the sum of the dose from all individual radionuclides contributing to the dose.

B.2.3.1 Dose at the Amargosa Farms Area

The activities and lifestyle of people in the Amargosa Farms area were important inputs to the development of the biosphere dose conversion factors. The TSPA-LA and Repository Final SEIS used this hypothetical individual to present dose results. It is reasonable to assume that the RMEI dose pathways would apply to people in the Amargosa Farms area because the lifestyles and activities at that location are the same as those for the Regulatory Compliance Point. Table B-2 shows these pathways.

Table B-2. Biosphere dose pathways considered in the TSPA-LA for the reasonably maximally exposed individual.

	Dose contributing parameters	
Exposure pathway	Group	Subgroup
External		
	Environment-specific exposure time (hours/day)	Active outdoors Inactive outdoors Active indoors Asleep indoors Away
Inhalation		
	Inhalation dose, soil particles (including Ra-226) Inhalation dose, evaporative cooler	
Ingestion		
	Ingestion dose for water	
	Ingestion dose for crops	Leafy vegetables Other vegetables Fruit Grain
	Ingestion dose for animal products	Meat Milk Poultry Eggs
	Ingestion dose for fish	
	Ingestion dose for soil	

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

Thus, after deriving a well-water concentration, with three exceptions, DOE calculated the dose using the same biosphere dose conversion factors as those used in the RMEI analysis for the TSPA-LA. As discussed above in Section B.2.2, the dose factors for ^{228}Ra, ^{226}Ra, and ^{210}Pb were increased by factors of 8.7, 1.8, and 1.8, respectively. Note that biosphere dose conversion factors are, in part, a function of climate; that is, the distribution of the radionuclides in the biosphere is different for wetter climates than for dry climates. The biosphere dose conversion factors are higher for the present climate in part because humans would tend to use more groundwater during the drier climate conditions. Just as with TSPA-LA, the analysis in this Analysis of Postclosure Groundwater Impacts ignored this variation. The dose conversion factors this analysis used are based on the dry (present) climate; therefore, the results in this analysis are conservative for the wetter climate. Table B-3 lists the biosphere dose conversion factors this analysis used for the Amargosa Farms area.

Table B-3. Biosphere dose conversion factors for the Amargosa Farms area.[a]

Radionuclide	Biosphere dose conversion factor
C-14	7.03×10^{-6}
Cl-36	3.00×10^{-5}
Se-79	8.88×10^{-5}
Sr-90	1.26×10^{-4}
Tc-99	4.07×10^{-6}
Sn-126	1.59×10^{-3}
I-129	4.81×10^{-4}
Cs-135	5.55×10^{-5}
Cs-137	4.81×10^{-4}
Pb-210[b]	1.79×10^{-2}
Ra-226[b]	2.55×10^{-2}
Ra-228[c]	2.87×10^{-2}
Ac-227	4.81×10^{-3}
Th-228	1.15×10^{-3}
Th-229	9.62×10^{-3}
Th-230	4.07×10^{-3}
Th-232	7.03×10^{-3}
Pa-231	8.88×10^{-3}
U-232	2.22×10^{-3}
U-233	3.33×10^{-4}
U-234	3.03×10^{-4}
U-235	3.48×10^{-4}
U-236	2.85×10^{-4}
U-238	2.92×10^{-4}
Np-237	9.99×10^{-4}
Pu-238	2.81×10^{-3}
Pu-239	3.52×10^{-3}
Pu-240	3.52×10^{-3}
Pu-242	3.37×10^{-3}

Table B-3. Biosphere dose conversion factors for the Amargosa Farms area (continued).[a]

Radionuclide	Biosphere dose conversion factor
Am-241	3.07×10^{-3}
Am-243	3.29×10^{-3}

Source: DOE 2008b, Table 2.3.10-12

a. In rem per year per picocurie per liter.
b. Increased by a factor of 1.8 relative to the value in the sourcd document to account for disequilibrium (see Section B.2.2).
c. Increased by a factor of 8.7 relative to the value in the source document to account for disequilibrium (see Section B.2.2).

The key differences between the pumping location at the Amargosa Farms area and the Regulatory Compliance Point (or RMEI location that was evaluated in the TSPA-LA) are the larger, current pumping withdrawal rates (approximately 17,000 acre-feet per year) and spatial distribution of wells (Moreo and Justet 2008, Figure 3, p. 5). These differences are such that all of the radionuclides in the water pumped onto fields for irrigation would be recaptured into the system of wells. It is important to note that the effects of recycling were explicitly included in this Analysis of Postclosure Groundwater Impacts due to the large recapture and recycling fractions in the Amargosa Farms pumping scenario from the larger area affected by the larger withdrawals.

DOE used an analytical expression to calculate well water concentration. The concentration is a function of pumping rates from the wells, fraction of well water used for irrigation, well capture fraction, and release rate of radionuclides (SNL 2007, p. 7-1). The amount of contaminants that are recycled depends essentially on the product of the recycling fraction (the fraction of contaminants that realistically could infiltrate back to the water table after initial groundwater withdrawal) and the recapture fraction (the percentage of contaminants that, once back in the water table, get recaptured and pumped back to the surface). To ensure that this analysis did not underestimate potential impacts of accumulation at the pumping location and did not allow contaminants to travel to natural discharge locations in the pumping scenario, DOE set the recapture rate to 100 percent.

The *Irrigation Recycle Model* (SNL 2007) evaluates the potential recapture fraction for 3,000 acre-feet of pumping to have a mean value of approximately 0.12. Even with the higher pumping rates evaluated as part of the pumping scenario (approximately 17,000 acre-feet), it would not be expected that 100 percent of the contaminants could be recaptured, therefore, this is a very conservative assumption.

The recycle fraction depends on the specific uses identified for the withdrawn water. For the TSPA-LA analyses, 85 percent was used for irrigation of alfalfa; 3 percent for commercial/industrial; 4 percent for individual/municipal; and 8 percent residual uncertainty. The average distribution of annual water withdrawals for purposes of irrigation over the 7-year period from 1997 to 2003 is about 86 percent (Moreo and Justet 2008, Figure 3, p. 5).

The Irrigation Recycle Model identifies that residential or commercial water use that is classified as "indoor water use" could also contribute to recycling because it could be a constant water flow path (that is, via a septic leach field). Any outdoor water use that is not a constant overwatering, such as irrigation, would not have the motive force to carry the contaminants back to the water table and therefore is not included in the recycle fraction. The combination of recycle and recapture fractions for the recycle report equates to about 0.11 (0.96 × 0.12) with an annual withdrawal rate of 3,000 acre-feet.

Since DOE used a recapture fraction of 1.0, this Analysis of Postclosure Groundwater Impacts used a recycle fraction of 0.86. This reflects the fraction of water used in irrigation. Although some of the commercial/ residential/industrial water use could contribute to recycling via leaching through septic fields (unlikely because the leach fields are shallow and water is lost by evaporation), this contribution is more than offset by the higher-than-expected recapture fraction. Also note that some radionuclides will be lost to soil erosion as well as via uptake in crops that are hauled away, in exported milk, and various other loss paths. These factors result in a combination of recycle and recapture fractions of 0.86 (compared with the 0.11 identified as the mean in the *Irrigation Recycle Model*; SNL 2007, p. 6-39). Use of this bounding case overestimates the effects of recycle, making this approach very conservative.

B.2.3.2 Dose at Discharge Locations

At natural discharge locations, DOE calculated the dose differently from the evaluation at the Amargosa Farms area. At the discharge locations, there is no pumping and therefore no recycle. Instead, water is either discharged as a liquid or lost by evapotranspiration. In the present-day climate, the springs at Furnace Creek are flowing and so would likely continue flowing during a wetter climate. At the Death Valley floor and at Alkali Flat, water currently reaches the surface at a few locations but most is lost by evapotranspiration. In a wetter climate or wet episode of a dry climate, the evapotranspiration discharge areas could have additional temporary springs or bodies of surface water.

B.2.3.2.1 Furnace Creek Springs Area

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, as well as 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.

Since there is no large-scale irrigation of agricultural fields in the Furnace Creek springs area, the irrigation recycle model was not used to calculate radionuclide concentrations in the soil. The concentration of radionuclides in the water (grams per unit volume) was estimated as the mass release rate of radionuclides (grams per year) divided by the total discharge rate from the springs (volume per year).

To calculate the annual dose resulting from the radionuclide concentration in the water at the Furnace Creek area, DOE also used the biosphere dose conversion factors developed for the TSPA-LA. However, the biosphere dose conversion factors were modified because the dose pathways are different than those at the Amargosa Farms area. There is little agricultural production or other local production of foodstuffs in the Furnace Creek area, so DOE did not include food ingestion pathways. 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. Table B-4 presents the reduction percentages and resulting reduced biosphere dose conversion factors used in this analysis.

Since 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 Valley DOE also performed an analysis for use of water from springs in the Furnace Creek area using the full biosphere dose conversion factors given in Section B.2.3.1. This information was provided to compare the degree to which dose might be increased if local populations carried out a lifestyle that included gardening or other activities that would lead to ingestion of contaminated foodstuffs.

Table B-4. Biosphere dose conversion factors for the Furnace Creek springs area.[a]

Radionuclide	Percent of biosphere dose conversion factor that includes external exposure, inhalation, and soil ingestion[b]	Biosphere dose conversion factor
C-14	22.6	1.59×10^{-6}
Cl-36	9.5	2.80×10^{-6}
Se-79	9.1	8.08×10^{-6}
Sr-90	67.2	8.45×10^{-5}
Tc-99	44.1	1.79×10^{-6}
Sn-126	94.5	1.50×10^{-3}
I-129	60.5	2.91×10^{-4}
Cs-135	11.3	6.27×10^{-6}
Cs-137	43.5	2.09×10^{-4}
Pb-210[c]	57.9	6.36×10^{-3}
Ra-226[c]	94.7	2.39×10^{-2}
Ra-228[d]	85.7	2.48×10^{-2}
Ac-227	95.9	4.61×10^{-3}
Th-228	89.5	1.03×10^{-3}
Th-229	93.9	9.03×10^{-3}
Th-230	94.5	3.85×10^{-3}
Th-232	94.2	6.62×10^{-3}
Pa-231	97.7	8.68×10^{-3}
U-232	91.1	2.02×10^{-3}
U-233	90.2	3.00×10^{-4}
U-234	89.7	2.72×10^{-4}
U-235	91.3	3.18×10^{-4}
U-236	89.6	2.55×10^{-4}
U-238	89.6	2.62×10^{-4}
Np-237	96.0	9.32×10^{-4}
Pu-238	94.6	2.66×10^{-3}
Pu-239	95.1	3.34×10^{-3}
Pu-240	95.2	3.35×10^{-3}
Pu-242	95.2	3.21×10^{-3}
Am-241	96.4	2.96×10^{-3}
Am-243	96.6	3.18×10^{-3}

a. In rem per year per picocurie per liter.

b. Source: DOE 2008, Tables 2.3.10-11 and -12

c. Increased by a factor of 1.8 relative to the value in the source document to account for disequilibrium (see Section B.2.2).

d. Increased by a factor of 8.7 relative to the value in the source document to account for disequilibrium (see Section B.2.2).

B.2.3.2.2 Death Valley Floor and Alkali Flat

The primary destination for radionuclides and non-radiological contaminants indentified by the particle tracking flow modeling was a location on the Death Valley floor designated in the modeling domain as a unit called OBS-DV-MIDDL (Belcher et al. 2004, Table F-4, Figure 4-7; Belcher and Sweetkind 2010). This unit coincides with an area to the southwest of the springs at Furnace Creek called Middle Basin, which typifies the many playas in the region. Playas in this region of Nevada and California have been classified as wet playas and dry playas (Reynolds et al. 2007, p. 1811). Wet playas are characterized as having groundwater less than 5 meters below the surface. The basins in this part of Death Valley 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 typically is rich in minerals such as calcium carbonate, hydrated calcium sulfate, sodium chloride (common salt), and sodium sulfate. The deposits originate from the 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 (Reynolds et al. 2007, p. 1812). As the evaporite mineral crystals form, they displace the rock-derived clastic minerals, expanding the sediments upward (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 (Reynolds et al. 2007, p. 1823). It has been observed that changes occur in evaporite sediments due to wind erosion, rainfall events, and water table fluctuations (Reynolds et al. 2007, p. 1816). Thus, the deposits may take on many forms; some very susceptible to resuspension and some not. Over the course of an extended time there may be widely varying air concentration of these materials.

Occasional flooding of the playa would reduce, if not eliminate, the doses and intakes from the deposits. Any standing water or runoff water would be extremely brackish and non-potable so ingestion of water would not be expected.

The same receptor as was used in the analysis at the Furnace Creek springs area (a full-time resident of Death Valley) was considered in the analysis of health impacts from the deposition of contaminated evaporites on the soil surface at Middle Basin. Three exposure pathways, (1) external exposure to evaporite minerals, (2) inhalation of resuspended evaporites, and (3) ingestion of evaporites, were evaluated to estimate the annual dose that would occur if all radionuclides in the groundwater were to travel to the floor of Death Valley and rise to the surface soil via evapotranspiration of groundwater. Ingestion of water and other uses of contaminated water were not included in this analysis 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. The consequences of ingesting water from springs, and using that water for other purposes (for example, evaporative cooling), were included in the calculation of the annual dose from use of water from the springs in the Furnace Creek area.

As surface evaporite minerals form, they would precipitate any trace contaminants (such as radionuclides or other non-radiological contaminants) along with them. There is no mechanism for preferential precipitation by evaporation so the ratio of trace contaminants to evaporites is reflective of the ratio or concentration of trace contaminants to concentration of total-dissolved-solid minerals in the water that is evaporating. Thus, the concentration of a radionuclide in the evaporite minerals was calculated as the concentration of the radionuclide in the water divided by the total-dissolved-solids in the water.

The total-dissolved-solids in the groundwater will increase the farther the water flows in the ground. To be conservative, DOE used the total-dissolved-solids of water from well J-13, which is close to Yucca Mountain. The total-dissolved-solids of groundwater flowing past that well would be lower than it would be after traveling south toward Death Valley (larger total-dissolved-solids values will reduce the concentration of the contaminant in the evaporites and therefore the estimate of dose or intake). The total-dissolved-solids for J-13 well water is 257 milligrams per liter (BSC 2004, Table 7-44).

The observed evapotranspiration rate of unit OBS-DV-MIDDL (Middle Basin) is 6,625 cubic meters per day during the present climate (Belcher et al. 2004, Table F-4; Belcher and Sweetkind 2010). DOE estimated that during the wetter climate this value would increase by a factor of 3.9 (SNL 2008b, Table 6-4a), resulting in an evapotranspiration rate of 25,837 cubic meters per day. The concentration of the contaminant in the water was calculated as the mass release rate of contaminant in grams per year divided by the inflow of water (evapotranspiration rate).

The annual dose resulting from evapotranspiration was calculated using the concentrations of radionuclides in evaporite minerals that would result from evaporation of near-surface groundwater. The methods for calculating doses in the TSPA-LA biosphere model (SNL 2007, Section 6.4), were adapted to calculate the dose for each of the three pathways considered. Unless otherwise specified, the representative fixed values for input parameters to the TSPA-LA biosphere model (SNL 2007, Table 6.6-3) were used for this calculation.

To calculate external exposure and inhalation exposure of contaminated evaporites, DOE assumed that the receptor would always be in the inactive outdoor environment, as described in the *Biosphere Model Report* (SNL 2007, Section 6.4.2.1). This environment is representative of conditions that occur when a person is outdoors in areas where radionuclides may be present and engaged in activities that would not resuspend soil (that is, not operating heavy machinery, plowing, or driving large vehicles on dirt surface). It was also assumed that all particulates inhaled and inadvertently ingested would be contaminated evaporites. The dose calculation does not account for time spent indoors, where concentrations of resuspended particles would be lower and the receptor would be shielded from some radiation. Nor does it account for inhalation of particulates from soil-disturbing activities (when concentrations would be higher). Furthermore, the calculation does not account for time the receptor would spend outside of the limited area that would be contaminated by evapotranspiration of groundwater. In other words, it is assumed that the receptor is outdoors, exposed to and breathing contaminated evaporite minerals year-round. The maximum value of the distribution of mass loading for the inactive outdoor environment (0.1 milligram per cubic meter; SNL 2007, Table 6.6-3) was used in the calculation of inhalation exposure to account for high levels of resuspended particulates that may occur temporarily on or near the playa during high winds. Although much higher concentrations of resuspended particulates may occur during dust storms, such high values do not represent the average annual value of mass loading required for this calculation.

The total dose from radionuclides in evaporite minerals is the sum of doses from direct exposure, inhalation, and ingestion. Using dose coefficients and appropriate parameters from the TSPA-LA biosphere model, DOE estimated these individual dose components and the total dose from each radionuclide in the release rate of contaminants estimated to arrive at Death Valley.

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

- In the estimate of concentration of contaminants in the solids, DOE used a low end of the range of total-dissolved-solids found in local groundwater. Higher values of total-dissolved-solids would reduce the estimated concentration because the dissolved solids co-precipitate with the contaminants thus diluting the contaminants in the precipitate. The diluted precipitate would result in lower 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 (while this value was for no major soil disturbance it is still very high and would account for the types of soil disturbance expected by the very limited activities); 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. While at times a higher breathing rate might occur during activities it is still conservative because it ignores the long period of much lower breathing rates.
- 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 (EPA 2011, Table 5-1).
- For external exposure to radionuclides in soil:
  - DOE used dose coefficients (as a function of concentration) 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 because the total radioactivity would be higher for deeper contamination. Therefore, lesser depths would reduce the estimate of dose; and
  - DOE assumed that the receptor would be outdoors and exposed to contaminated evaporites year-round.

B.2.4 RADIONUCLIDE INVENTORY CALCULATIONS

At various locations, the dose calculation used the mass release rate to develop an inventory. This inventory is a decay- and growth-adjusted measure of the total amount of material that arrived at the specific location as a function of time. Note that for some radionuclides, this cumulative total could decrease after long times due to decay. The inventory included assessments for the following regions:

- Inventory released to the saturated zone at the analyzed repository,
- Inventory released beyond the Regulatory Compliance Point (RMEI location),
- Inventory accumulated at the Amargosa Farms area, and
- Inventory released into Death Valley.

DOE analyzed inventory for each radionuclide over time to provide a measure of how much material exists in a specific region at any time during the 1-million-year period.

DOE then constructed mass balances by 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 was the difference between the inventory released beyond the Regulatory Compliance Point and the inventory accumulated at the Amargosa Farms area. The mass balances provided an overall accounting of where radionuclides might travel to and where they might accumulate.

B.2.5 SOIL CONCENTRATIONS OF RADIONUCLIDES AT THE AMARGOSA FARMS AREA

In the Amargosa Farms area where irrigated farming takes place, water is pumped out of wells. If this well water contained radionuclides, these radionuclides could land on the surface soil during irrigation. Some fraction of the radionuclides would decay, some fraction would leach back into the aquifer, and some fraction would escape by soil erosion. In the formulation of the TSPA-LA biosphere model, DOE developed many modeling concepts that are useful for obtaining estimates of the fate of contaminants in an irrigated region. After some period of time at a constant release rate, the processes of soil erosion, leaching, and decay would balance the influx of radionuclides, thus achieving a steady-state wherein the soil concentration became constant in time. That is, the soil concentration is a function of three rate constants (radioactive decay, erosion, and leaching) and the rate of influx of radionuclides. The erosion and leaching rate constants can be calculated from soil erosion rates, watering rates, and properties such as soil moisture content, porosity, and K_d. The time to steady-state can be hundreds or even thousands of years, but the mass release rates vary slowly so that an assumption of constant steady-state is a reasonable approximation.

B.3 Analysis of Non-Radiological Contaminants

Chemically toxic materials that could present a human health risk when released to the groundwater would be present in materials disposed of in a repository. These materials, referred to herein as non-radiological contaminants, would come from materials used in the construction of a repository and waste packages and from the disposal materials within the waste packages.

B.3.1 MATERIALS OF CONCERN

During the preparation of the Yucca Mountain FEIS and Repository Final SEIS, DOE conducted various screening studies to determine which materials would be of sufficient concern to warrant further analysis of the postclosure transport of these materials and possible resulting impacts. During the development of the FEIS, DOE surveyed all of the materials and analyzed their potential hazard. It was found that the materials of concern were chromium, molybdenum, nickel, and vanadium. The analysis of the toxic materials in the FEIS was limited to 10,000 years postclosure. Because only a few percent of the packages would fail by 10,000 years, DOE assumed in the FEIS that the contribution from inside the packages was negligible. Thus, the FEIS contained a simple bounding analysis of chromium, molybdenum, nickel, and vanadium released as the products of corrosion of repository and waste package construction materials outside of the waste package; that is, of stainless steel and Alloy 22.

During development of the Repository Final SEIS, DOE conducted further screening studies. Significant additional volumes of stainless-steel material had been added to the repository design at this point. Since completion of the Yucca Mountain FEIS, new data showed that the corrosion of chromium-bearing materials would not likely result in the very soluble (and toxic) valence (+6) of chromium, but rather that the chromium would be in the insoluble (and non-toxic) valence (+3). Based on this, DOE removed chromium from the list of materials of concern (DOE 2008a, p. F-38).

This Analysis of Postclosure Groundwater Impacts addresses the entire 1-million-year postclosure period. Since some fraction of waste packages would be likely to fail over this extended time, exposing the internal materials to corrosion, materials inside of waste packages are revisited. DOE conducted additional screening studies that showed there were no new materials of concern; therefore, materials of concern for this analysis still include molybdenum, nickel, and vanadium. However, there is a fairly large quantity of materials bearing some of these elements within the waste package so that the quantities of these materials would increase over the 1-million-year period due to package failures. Uranium is retained as a non-radiological contaminant as well as a radiological contaminant because uranium has a high toxicity as a heavy metal. Note that previous screening studies had not rejected uranium but rather had ignored uranium as a toxic material because only a few percent of the packages would fail in the first 10,000 years after closure. Therefore, the contaminants of concern analyzed for the extended-time analysis in this analysis are molybdenum, nickel, vanadium, and uranium.

B.3.2 DEVELOPMENT OF MASS RELEASE RATES AT THE UNSATURATED ZONE-SATURATED ZONE INTERFACE

This Analysis of Postclosure Groundwater Impacts analyzes non-radiological contaminants during the 1-million-year postclosure period in a manner consistent with the radiological contaminant analysis.

The bounding analysis in the Repository Final SEIS took no credit for any attenuating processes once the corrosion of the construction materials and waste packages released the non-radiological contaminants nickel, molybdenum, and vanadium. The mass release rate of metal arriving at the hypothetical well at the Regulatory Compliance Point was the rate of release by corrosion. Thus, the mass release rate was equal to the mobilization rate of the alloy times the fraction of alloy represented by the particular element. The mobilization rate was simply the area of exposed alloy times the thickness loss (that is, from corrosion) times the density. The concentration of metal in a hypothetical well was then the mass release rate divided by the volumetric pumping rate of the well, assuming full capture of the metals by the well. This approach was extremely conservative. It did not allow for delays due to sorption processes or other possible attenuating processes. It also assumed that all of the available surface area of alloy was constantly exposed to water and corroding.

To develop a mass release rate of metals from a repository to the unsaturated zone for this Analysis of Postclosure Groundwater Impacts, DOE used a similar analysis to that used in the Repository Final SEIS, but with the added effects of corrosion of materials inside the waste package.

The approach DOE used includes:

- Assessing the number of waste package failures for the combined scenario case at 100,000 years and 1 million years.
- Calculating mobilization rates based on exposed area (external plus internal for failed packages) for the combined scenario case at 100,000 and 1 million years.
- Characterizing the mass release rate from the unsaturated zone to the saturated zone as a combination of step functions as follows: The mass release rate is represented by a step function at postclosure time equal to 0 with magnitudes represented by the total external materials and the internal materials equal to that contained in the fraction of waste packages failed at 100,000 years. Another step function occurring at 500,000 years is then added. The magnitude of this step

relates to the amount of external material plus internal material released from the fraction of waste packages failed at 1 million years. This is a conservative result because the values at time of closure really do not occur until 100,000 years and the values applied at 500,000 years do not occur until 1 million years.

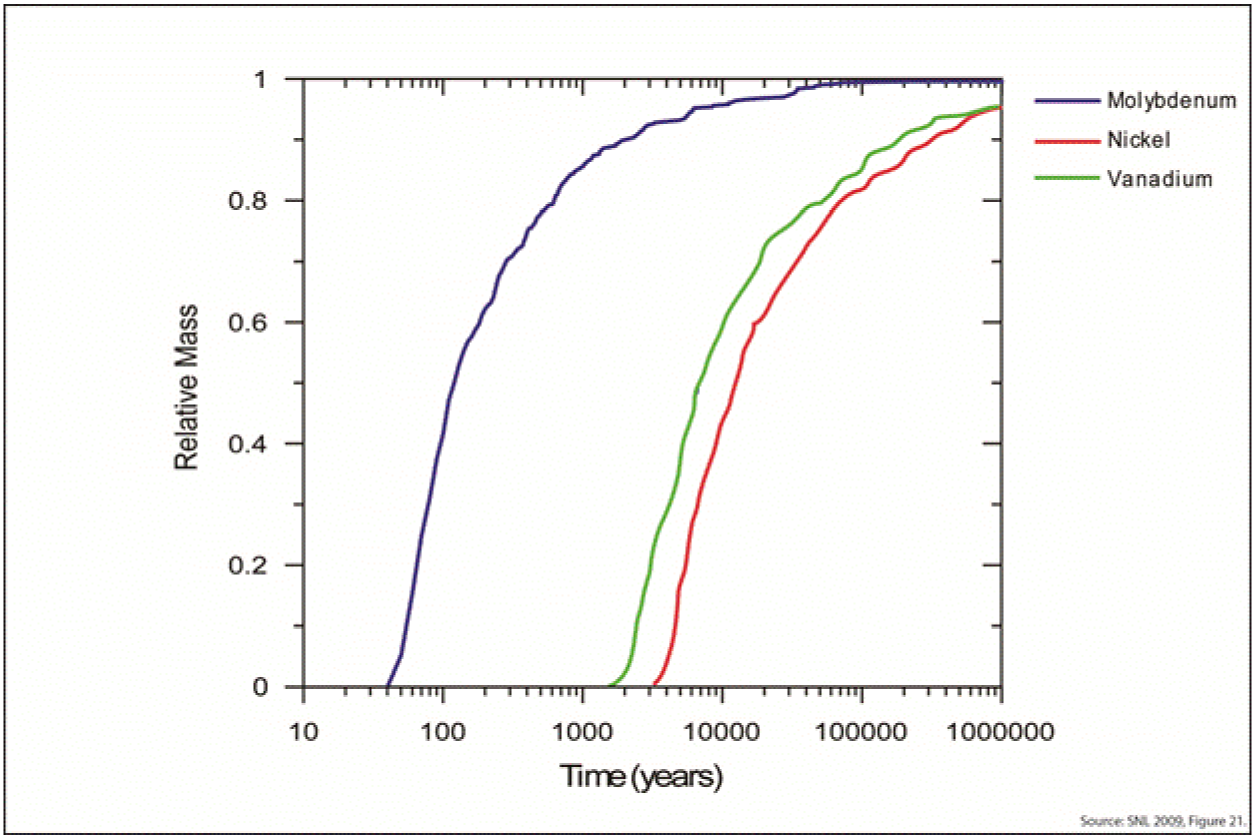
B.3.3 MASS RELEASE RATE AT THE REGULATORY COMPLIANCE POINT

This section addresses the transport of molybdenum, nickel, and vanadium from the point where they would enter the saturated zone under the analyzed repository to the Regulatory Compliance Point. (Note that the mass release rate of uranium is already calculated in the radionuclide calculations; see Section B.2.) The starting point for this analysis is the release of the materials into the saturated zone during the 1-million-year postclosure period. Section B.3.2 describes how the release rates at the beginning of the saturated zone under the repository were calculated. The metals mass release rates developed from those calculations are the input to the calculations in this section.

The variable having the greatest influence on transport is the sorption partition coefficient of each contaminant. The K_d is a measure of the partitioning between the contaminant in solution and the contaminant adsorbed on to the solid medium. Because little is known about interactions of the nonnuclear contaminants with colloids, this analysis neglects any effects of colloids. Colloid transport could result in a different transport speed of the metal than its retardation factor would indicate. In the case of molybdenum, which has an assumed K_d of zero, colloid transport might slow down its transport. Because the metals have no decay and dispersion has a minimal effect, the change in transport rate only changes the time of arrival, so there is little effect on the ultimate impacts.

All of the transport processes in the saturated zone that affect radionuclides could affect how the non-radiological contaminants move. Processes that can be accounted for are based on available data and the state of knowledge concerning nickel, molybdenum, and vanadium. The TSPA-LA showed some radionuclides that transport (travel) only as solutes (no colloidal processes). The parameters governing transport of these radionuclides are the K_d for adsorption on the solid, the specific discharge, and structure of the aquifer system (for example, fractures and matrix porosity). The TSPA-LA provided a set of standardized breakthrough curves developed from detailed modeling of the saturated zone. The transport of the metals can be simulated using standard breakthrough curves for radionuclides that transport in the solute mode (that is, no colloidal transport) with a matching K_d.

DOE used the TSPA-LA saturated zone transport model to generate breakthrough curves as a response to unit step functions. This was done by running the saturated zone transport model with all saturated zone parameters set to their mean values and the K_d set to a value corresponding to the values developed from a literature study (SNL 2009, Section 4.6). Figure B-1 shows the resulting breakthrough curves for groundwater flow with glacial-transition climate conditions. The breakthrough curves in Figure B-1 were multiplied by the magnitude of the unsaturated zone step functions (Section B.3.2) with the appropriate delay (one step at repository closure and the next step at 500,000 years). The summation curve of the result represents the mass release rate history of the metal at 18 kilometers.



Source: SNL 2009, Figure 21.

Figure B-1. Simulated breakthrough curves in the saturated zone for molybdenum, vanadium, and nickel.

B.3.4 MASS RELEASE RATE OF NON-RADIOLOGICAL CONTAMINANTS BEYOND THE REGULATORY COMPLIANCE POINT

The analysis used for molybdenum, nickel, and vanadium beyond the Regulatory Compliance Point is the same as that used for radionuclides. The same flow paths and termination points were analyzed. Rather than radiological dose, however, the non-radiological analysis assessed the impact of the contaminants on humans by comparing calculated daily intakes with the Oral Reference Dose (see Section B.3.5 below).

The mass release rates developed for the Regulatory Compliance Point are the starting point for the transport analysis, just as with the radionuclides.

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.

B.3.5 DAILY INTAKES

Daily intakes were evaluated at the Amargosa Farms area, the springs at Furnace Creek, and the Death Valley floor (Middle Basin) using the mass release rates developed for the non-radiological contaminants. The following sections describe daily intakes and how they were estimated.

B.3.5.1 Amargosa Farms Area and the Springs at Furnace Creek

Mass release rates of non-radiological contaminants into the Amargosa Farms area and the springs at Furnace Creek provide water concentrations of molybdenum, nickel, and vanadium in the same manner as for radionuclides (see Section B.2.3.1). DOE developed the water concentration of uranium by adding all the isotopes of uranium together from the radionuclide analysis. DOE based daily intakes on a 70-kilogram person drinking 2 liters of water per day. The daily intake is therefore equal to the water concentration (milligrams per liter) times 2 (liters) divided by 70 (kilograms) and expressed as milligrams per kilogram of body-weight per day. Oral Reference Doses are daily intake guidelines set by the U.S. Environmental Protection Agency (EPA 1994, 1997b, 1999a, 1999b).

B.3.5.2 Death Valley Floor (Middle Basin)

Section B.2.3.2.2 discusses the processes at the Death Valley floor (Middle Basin). The method for estimating the concentration of non-radiological contaminants in the evaporite minerals is the same as that for the radionuclides. Daily intakes to receptors at this site can occur from inhalation and inadvertent ingestion. Inhalation exposure occurs by breathing respirable contaminant particles in the air. DOE estimated the concentration of respirable contaminant particles from the concentration of contaminants in the evaporite minerals and an air burden (concentration of resuspended particles in the air), the latter of which was calculated using the methods from the TSPA-LA biosphere model. DOE used the high end of the statistical range for the air burden concentration (SNL 2007, Table 6.6-3). The analysis estimated the ingestion of contaminants using the same inadvertent soil ingestion rate as that used for the radionuclide dose estimates. Thus, from inhalation and ingestion exposures, DOE estimated an intake rate in milligrams per day. That rate was divided by the 70-kilogram body-weight to calculate daily intake in milligrams per kilogram of body-weight per day. These intakes were then compared with the same Oral Reference Dose values as was done for the analysis of intake at the Amargosa Farms area and the springs at Furnace Creek.

B.3.6 SOIL CONCENTRATIONS AT THE AMARGOSA FARMS AREA

Section B.2.5 discusses the calculation of radionuclide soil concentrations at the Amargosa Farms area. The same approach was used to calculate the soil concentrations for molybdenum, nickel, and vanadium. The uranium soil concentrations were calculated as individual radionuclides. The total uranium concentration was obtained by adding the concentrations of all the uranium isotopes. The uranium totals are reported along with the other non-radiological contaminants.

B.4 Results and Discussion

The following sections provide detailed results obtained through the use of the models described in this appendix.

B.4.1 DOSES AND INTAKES

DOE evaluated radiological dose and daily intakes of non-radiological contaminants at three locations where the regional flow model projects discharge of contaminants: the Amargosa Farms area, the Furnace

Creek springs area, and the Death Valley floor (Middle Basin). DOE also estimated doses and intakes that might occur if, under the no-pumping scenario, all flow went to Alkali Flat.

B.4.1.1 Amargosa Farms Area

As described above, the doses and intakes at the Amargosa Farms area are a function of the pumping rates and the fraction of pumped water used to irrigate fields. Based on data from 1994 to 2003, DOE established an average pumping rate of 16,828 acre-feet per year (Moreo and Justet 2008, Figure 3, p. 5). DOE used 0.86 for the fraction of radionuclides recycled to the well in analyses of the irrigation recycling process at the Amargosa Farms area (see Section B.2.3.1).

Figures B-2 through B-9 are plots of the total dose and dose by radionuclide for the two climate conditions at the Amargosa Farms area. These plots all represent the pumping scenario.

The TSPA-LA model estimated that some radionuclides would release much earlier in the analyzed repository than might be expected from normal degradation processes. This is due to the probabilistic contribution of seismic events that the model postulated to damage the packages and repository. Figures B-2 through B-5 demonstrate this phenomenon. An example of an early released radionuclide is neptunium-237. Note that iodine-129 and technetium-99 are important radionuclides throughout the dose history.

CONTAINMANTS NOT SHOWN ON PLOTS

Generally, all of the contaminants studied do not appear on the detailed plots of radionuclides and non-radiological contaminants. This is because a particular contaminant may sometimes not reach that location within 1 million years or is estimated to contribute an extremely small amount to the total dose. In such cases, the contaminant does not appear on the plot.

Figures B-6 through B-9 show the results for the 10,000-year analysis for the Amargosa Farms area. This analysis was carried out because the 1-million-year analysis used a fairly coarse time step, which introduced considerable uncertainty in the value at 10,000 years. There was interest in the peak dose at 10,000 years, especially at the Amargosa Farms area due to the similarities with the RMEI location evaluated in the Repository Final SEIS. Therefore, DOE carried out an analysis with a finer time step over 10,000 years to more accurately estimate the radiological dose at the Amargosa Farms area for the first 10,000 years.

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 for this:

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 this analysis. Using a shorter time step would have resulted in smoother curves, but would not have significantly changed any of the results or conclusions of the analyses.

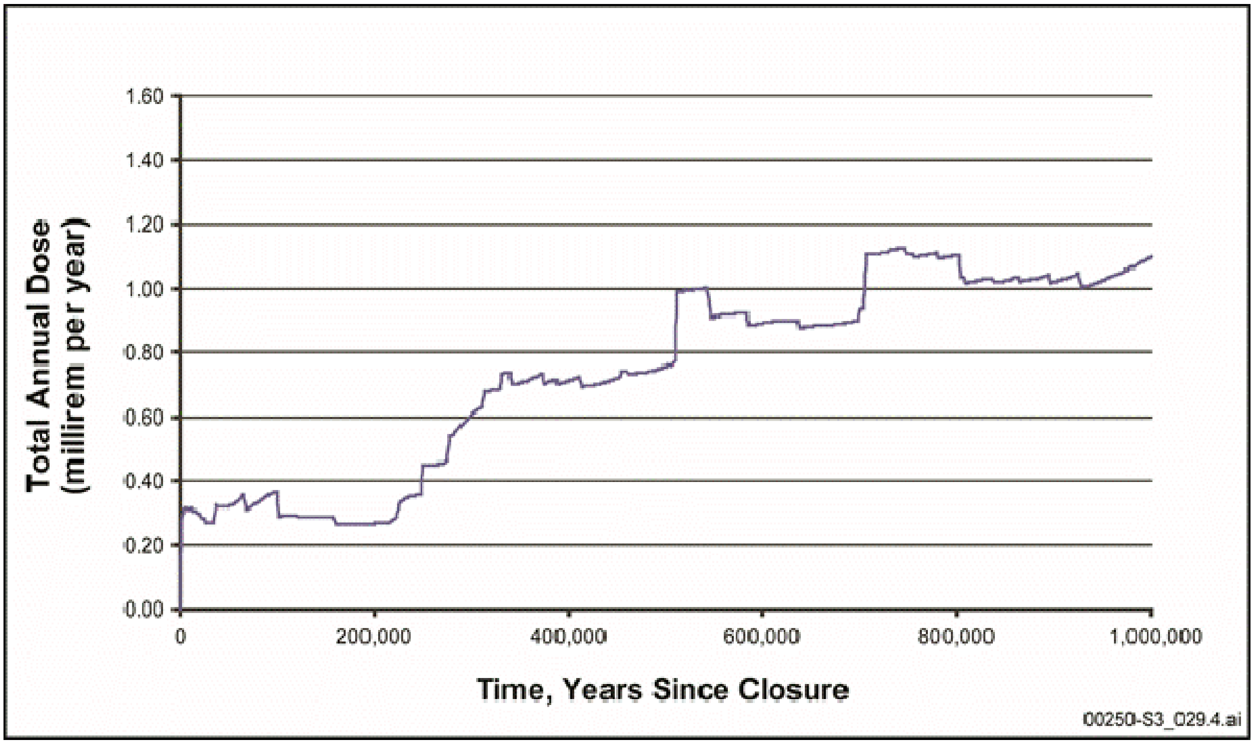


Figure B-2. Total dose at the Amargosa Farms area for present climate.

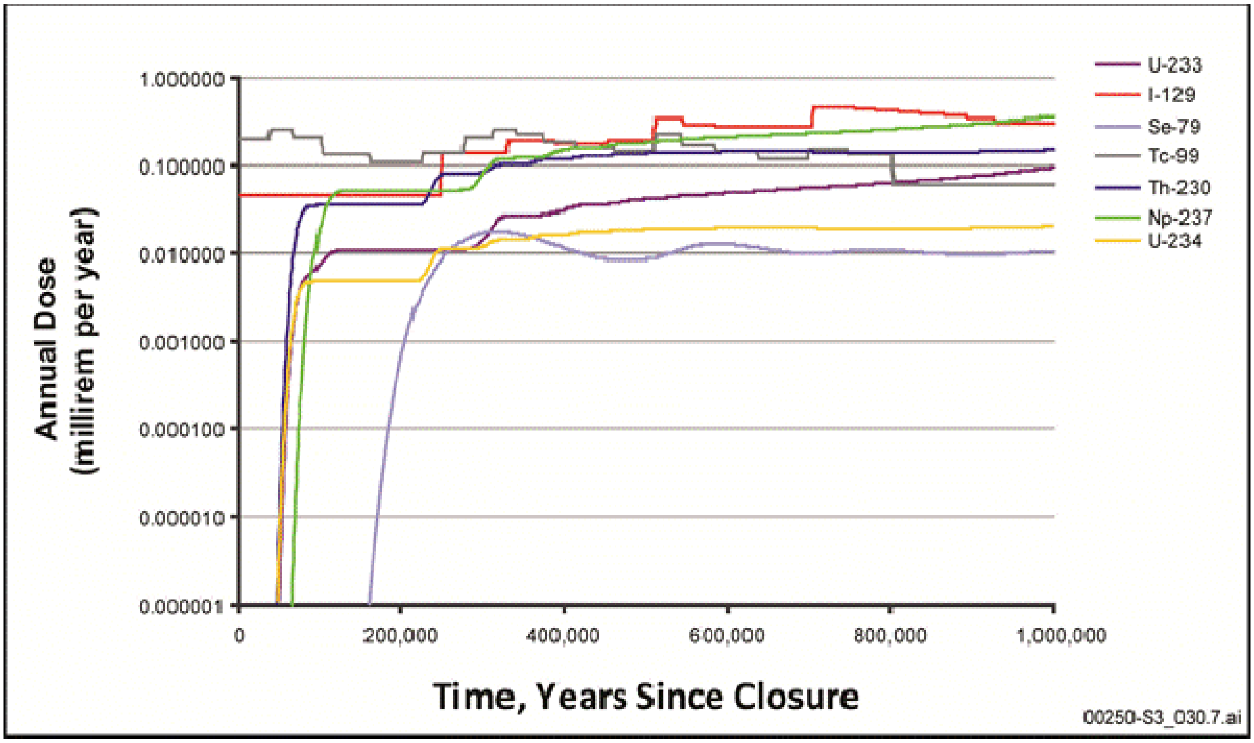


Figure B-3. Dose by radionuclide at the Amargosa Farms area for present climate.

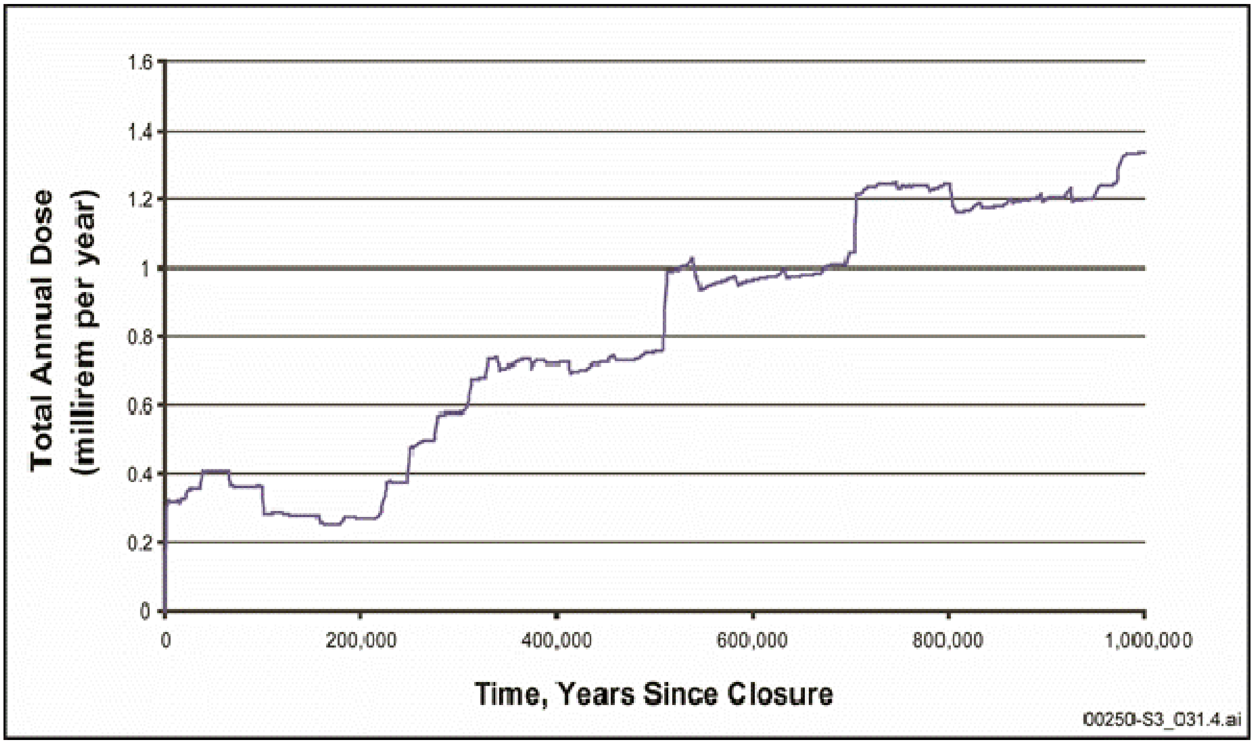


Figure B-4. Total dose at the Amargosa Farms area for wetter climate.

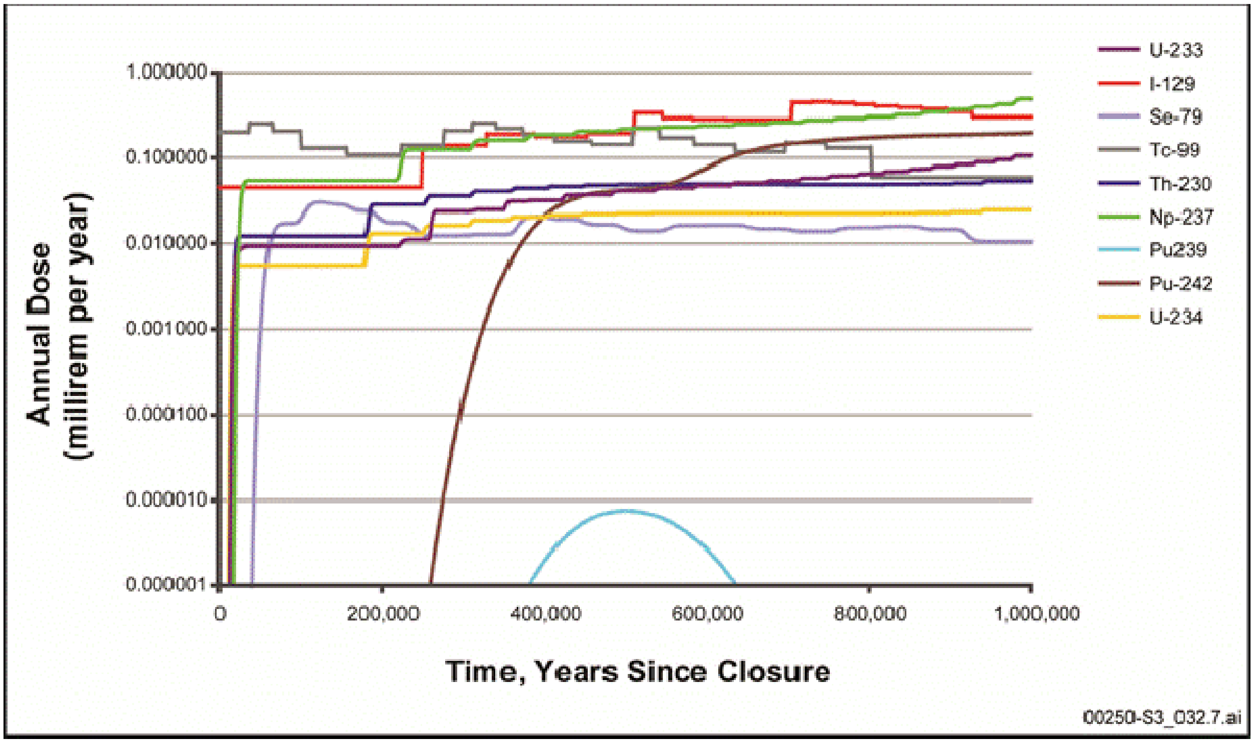


Figure B-5. Dose by radionuclide at the Amargosa Farms area for wetter climate.

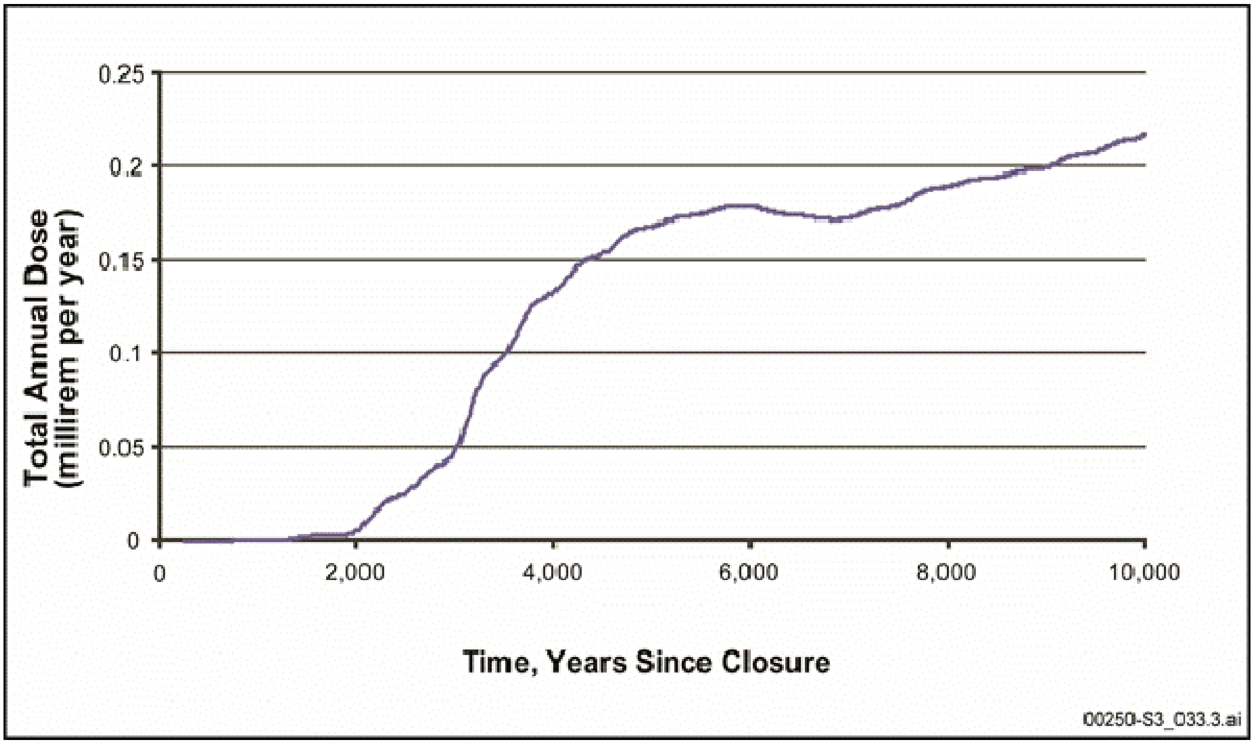


Figure B-6. Total dose at the Amargosa Farms area, present climate, 10,000-year case.

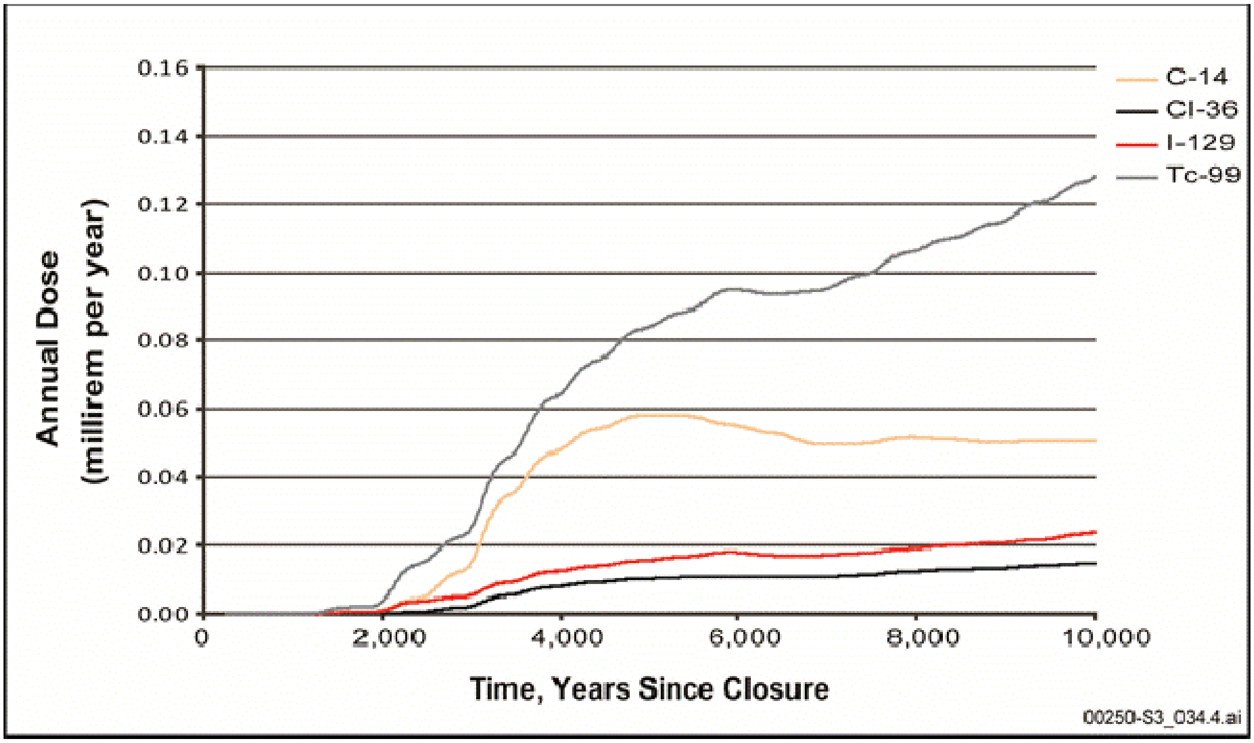


Figure B-7. Dose by radionuclide at the Amargosa Farms area, present climate, 10,000-year case.

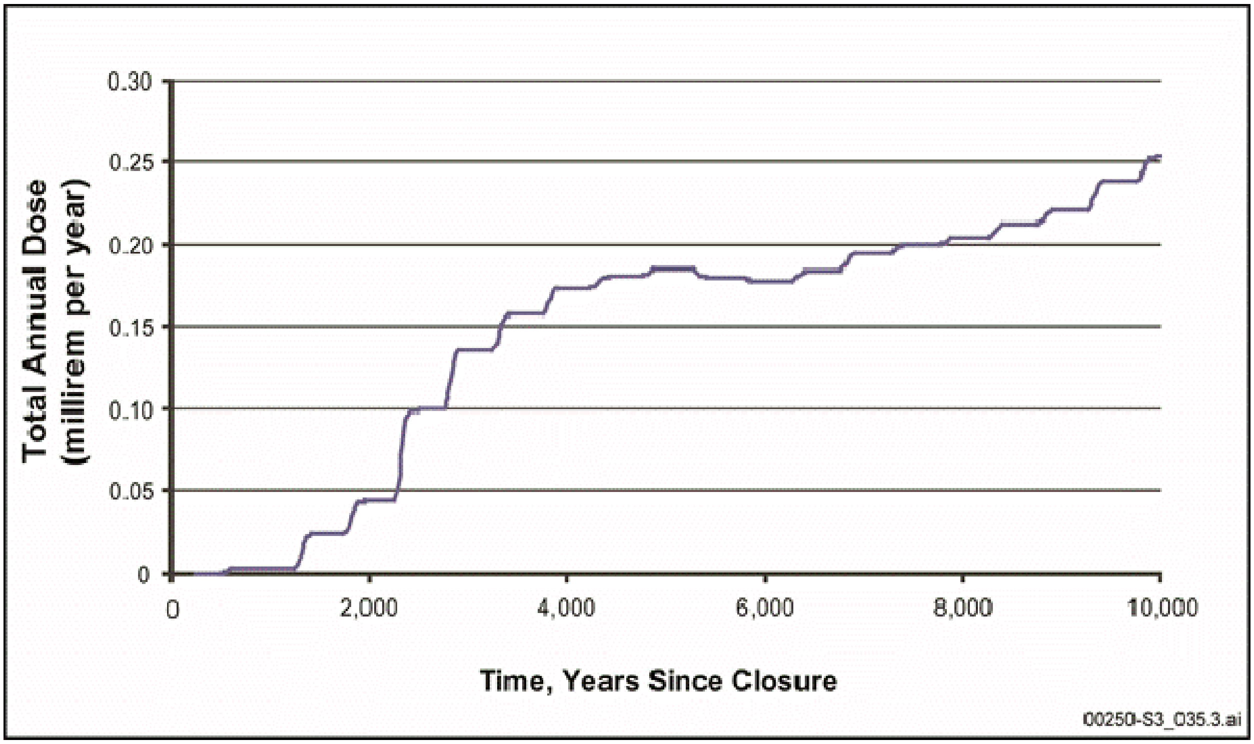


Figure B-8. Total dose at the Amargosa Farms area, wetter climate, 10,000-year case.

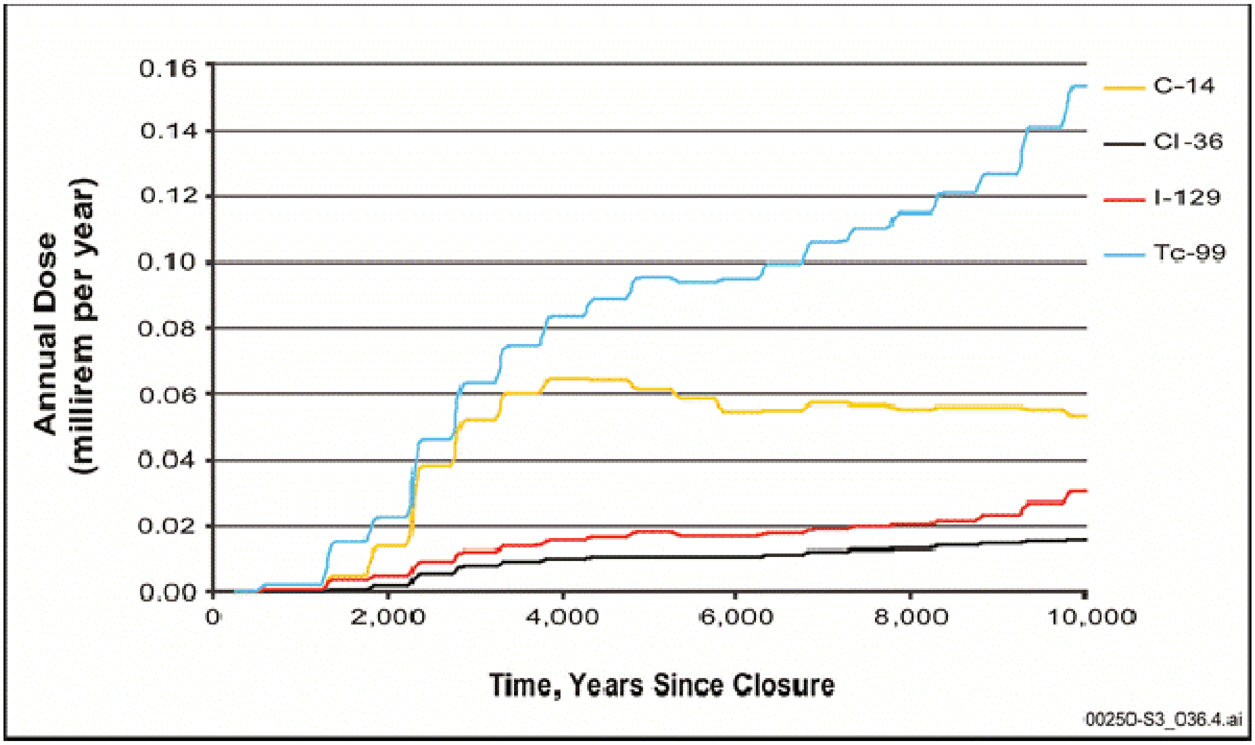


Figure B-9. Dose by radionuclide at the Amargosa Farms area, wetter climate, 10,000-year case.

Figures B-10 and B-11 show the daily intakes for non-radiological contaminants and compare these intakes with the Oral Reference Doses (EPA 1994, 1997b, 1999a, 1999b). All the estimated daily intakes are below the Oral Reference Dose.

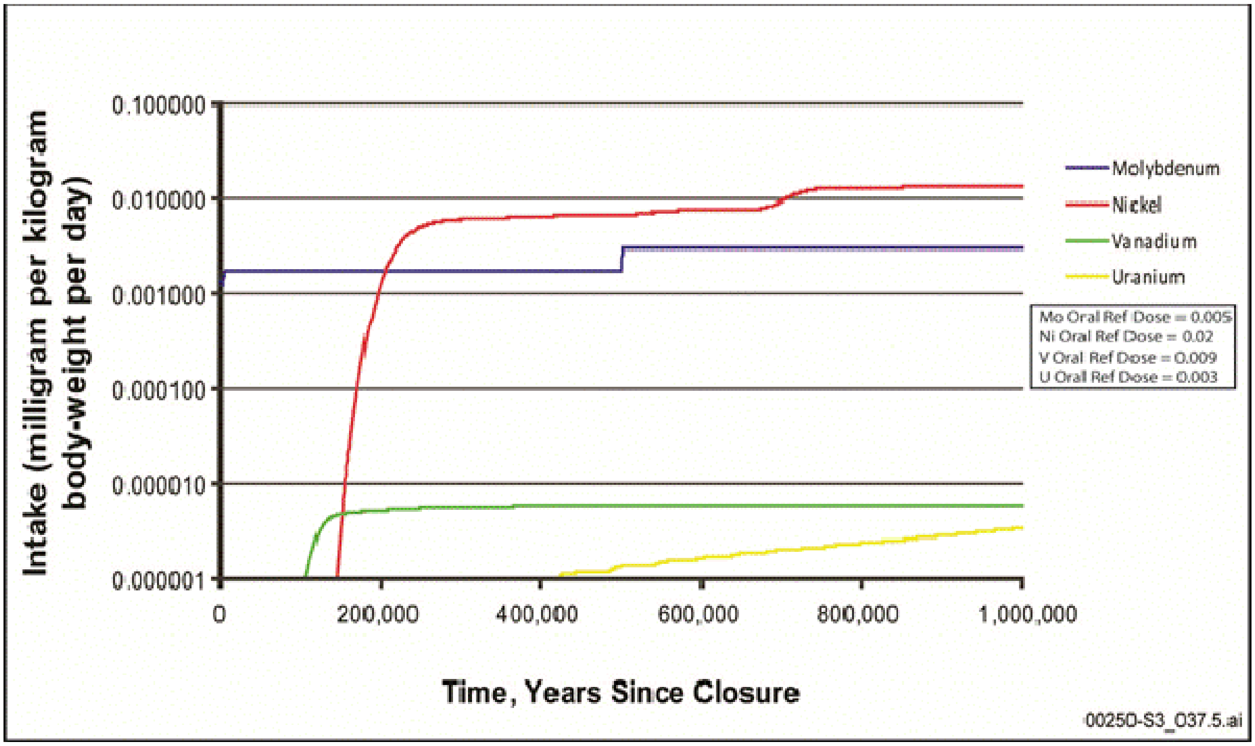


Figure B-10. Intakes of non-radiological contaminants at the Amargosa Farms area, present climate.

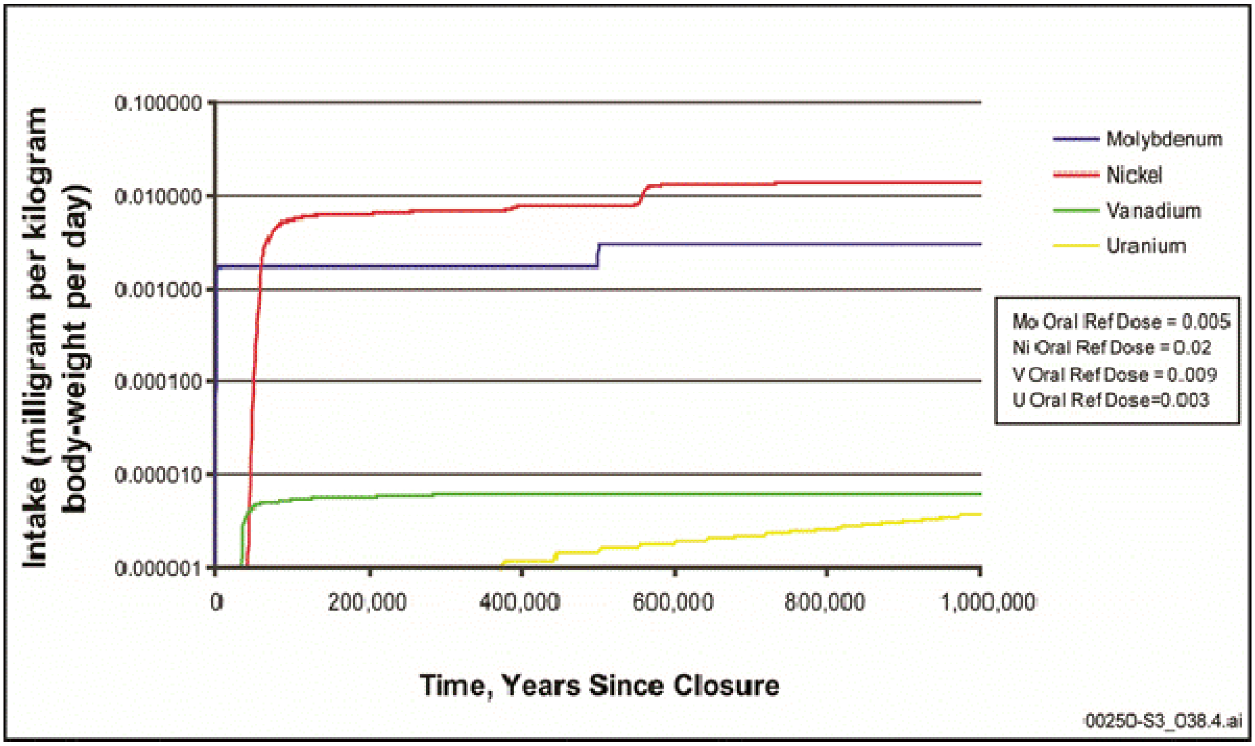


Figure B-11. Intakes of non-radiological contaminants at the Amargosa Farms area, wetter climate.

B.4.1.2 Death Valley

The regional flow modeling indicates that essentially all of the contaminants will flow to Death Valley and that the most likely termination point is the valley floor (see Section B.1). However, it is possible that the contaminants could flow to the Furnace Creek springs area very close to where the particles terminate at the floor of Death Valley. This section presents two types of doses and daily intakes associated with contaminants reaching Death Valley. The first set represents doses and intakes that individuals might receive when exposed to contaminated soils at the Death Valley floor where there is no liquid water present and to contaminated water when it is present. The second set of doses and daily intakes represents those received by individuals using contaminated water if it arrived at the Furnace Creek springs area. In the case of radiological doses from contaminated water in the Furnace Creek springs area, the dose factors have been adjusted to reflect the exposure scenarios (see Section B.2.3.2.1).

B.4.1.2.1 Death Valley Floor (Middle Basin)

The particle tracks strongly indicate that the contaminants would flow to the Death Valley floor at Middle Basin instead of the Furnace Creek springs area. The Death Valley floor in this area is normally an evapotranspiration area with no water emerging as liquid on the surface. DOE estimated doses and intakes at this location using the methods described in Sections B.2.3.2.2 and B.3.5.2.

Figures B-12 through B-15 show the results for radionuclide doses. In all cases the estimated doses are very low when compared with doses at any of the other locations. During the 1-million-year analysis period, the only non-radiological contaminant reaching the Death Valley floor would be molybdenum. Figures B-16 and B-17 present daily intakes for molybdenum. In all cases the molybdenum intake is well below the EPA guidelines for Oral Reference Dose.

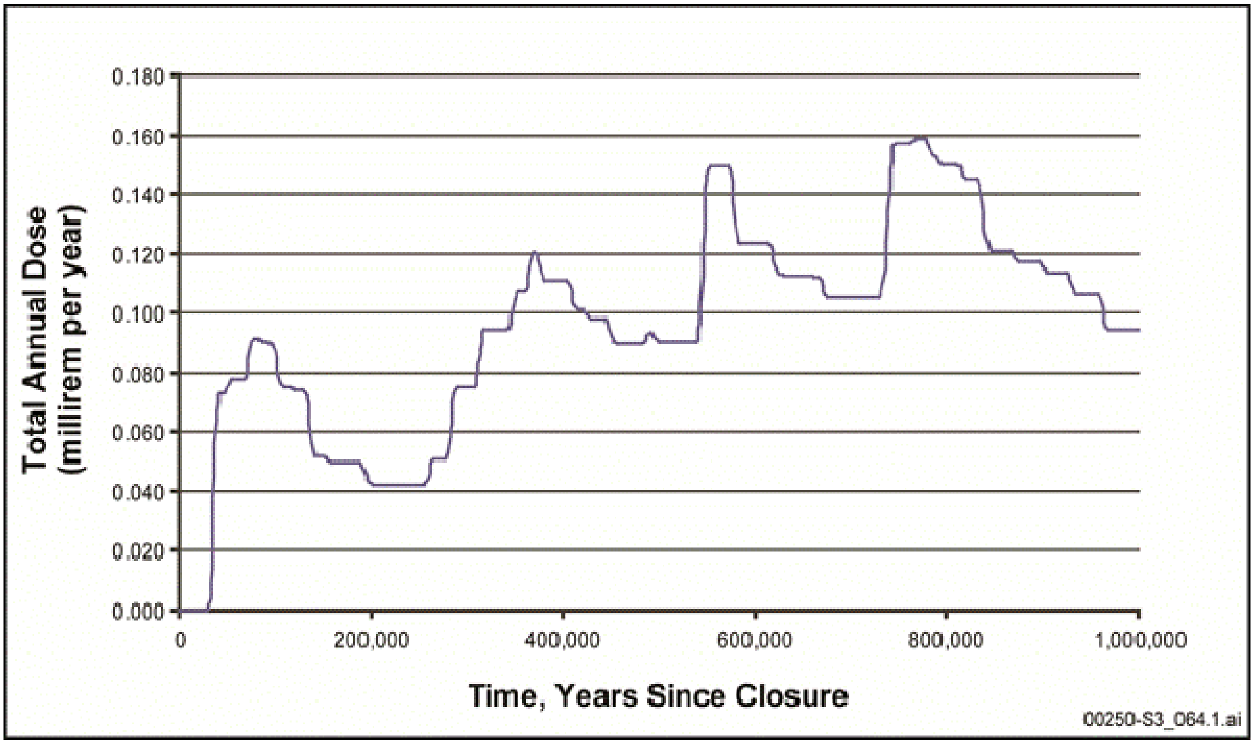


Figure B-12. Total dose at Middle Basin, present climate.

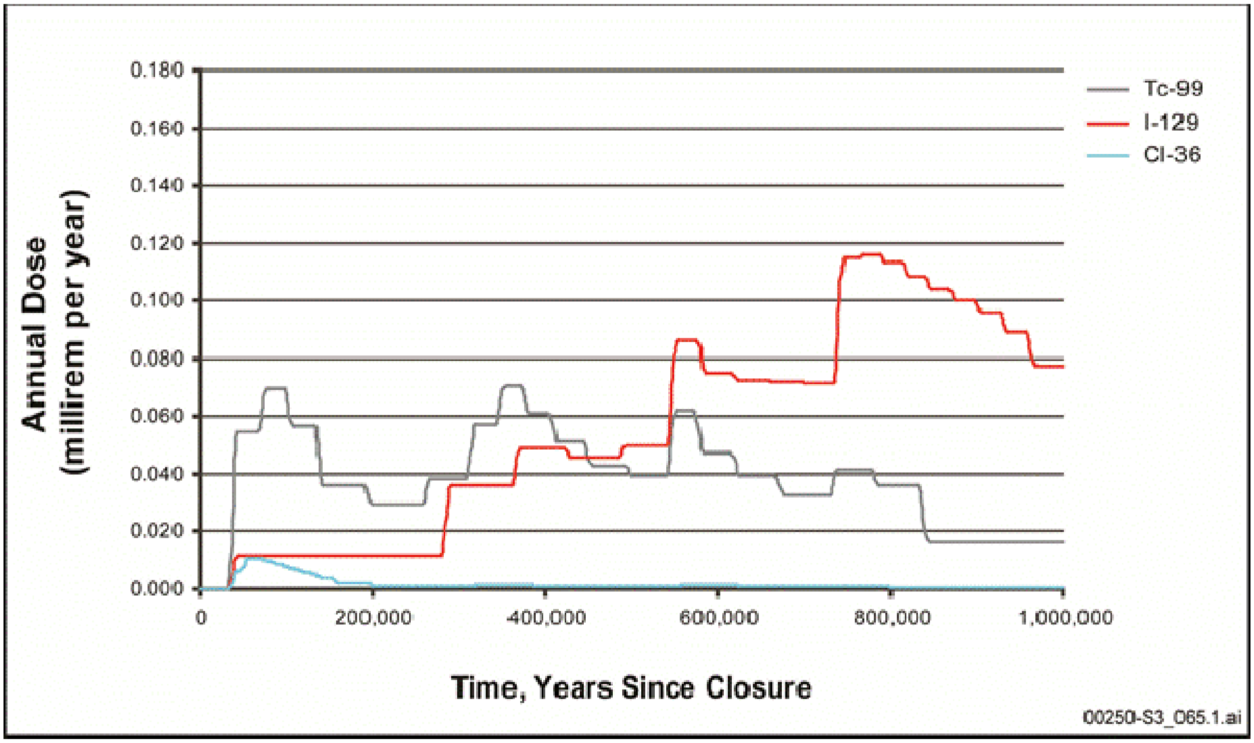


Figure B-13. Dose by radionuclide at Middle Basin, present climate.

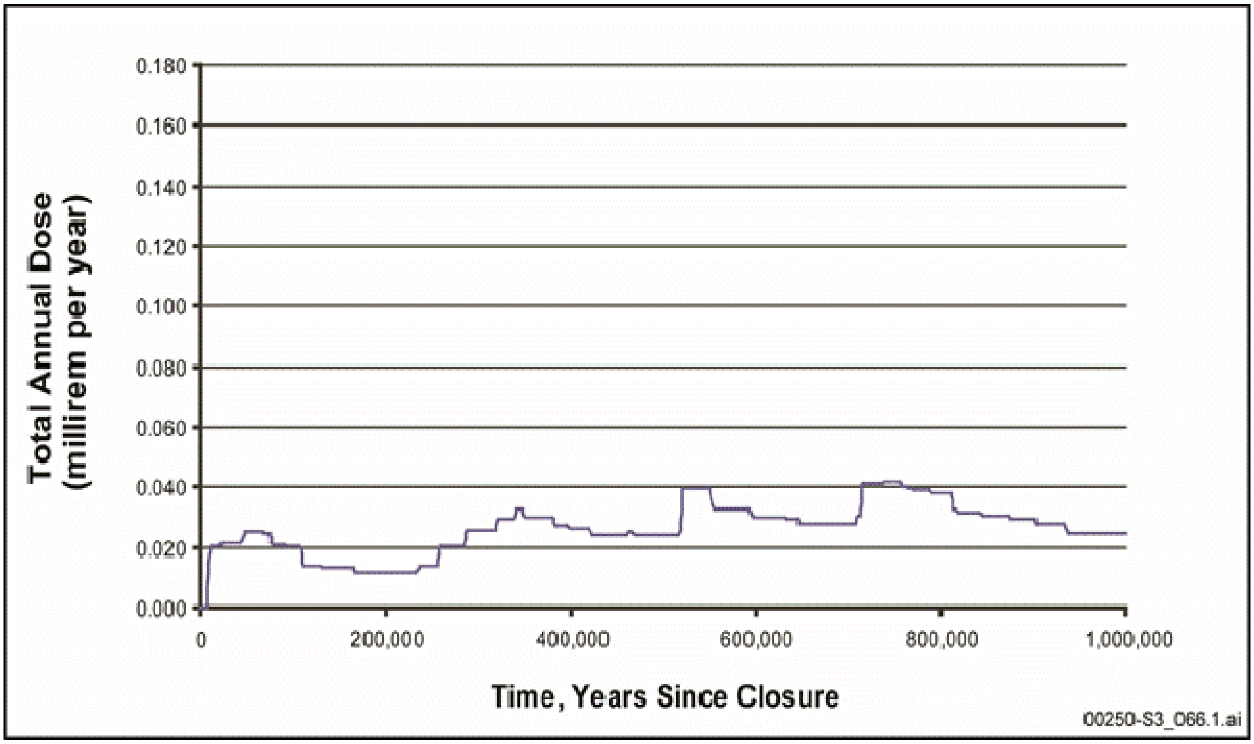


Figure B-14. Total dose at Middle Basin, wetter climate.

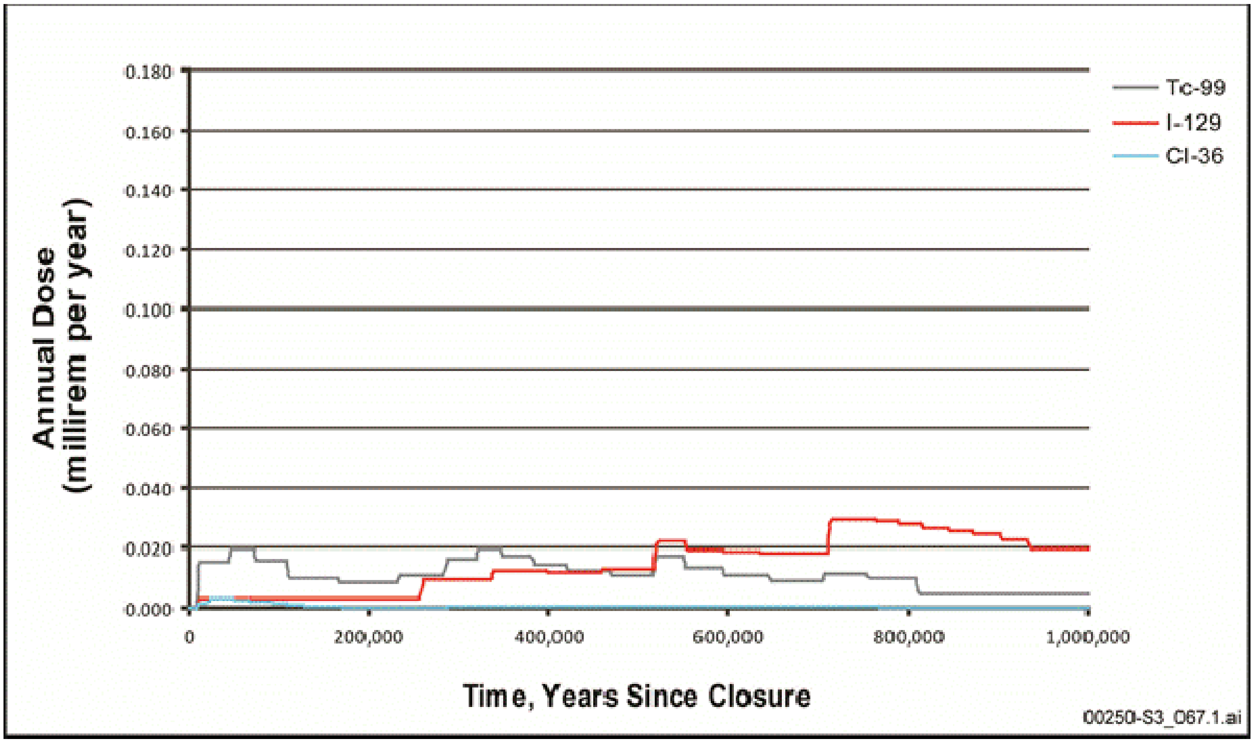


Figure B-15. Dose by radionuclide at Middle Basin, wetter climate.

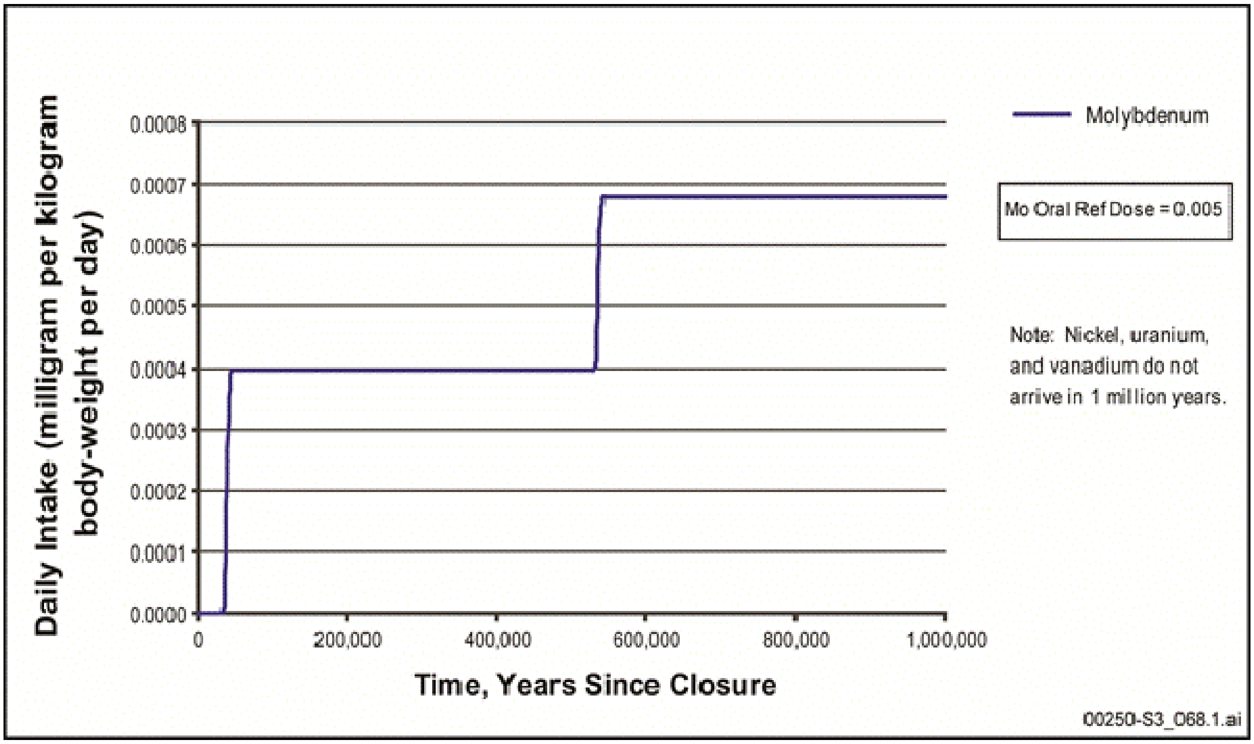


Figure B-16. Molybdenum Intake at Middle Basin, present climate.

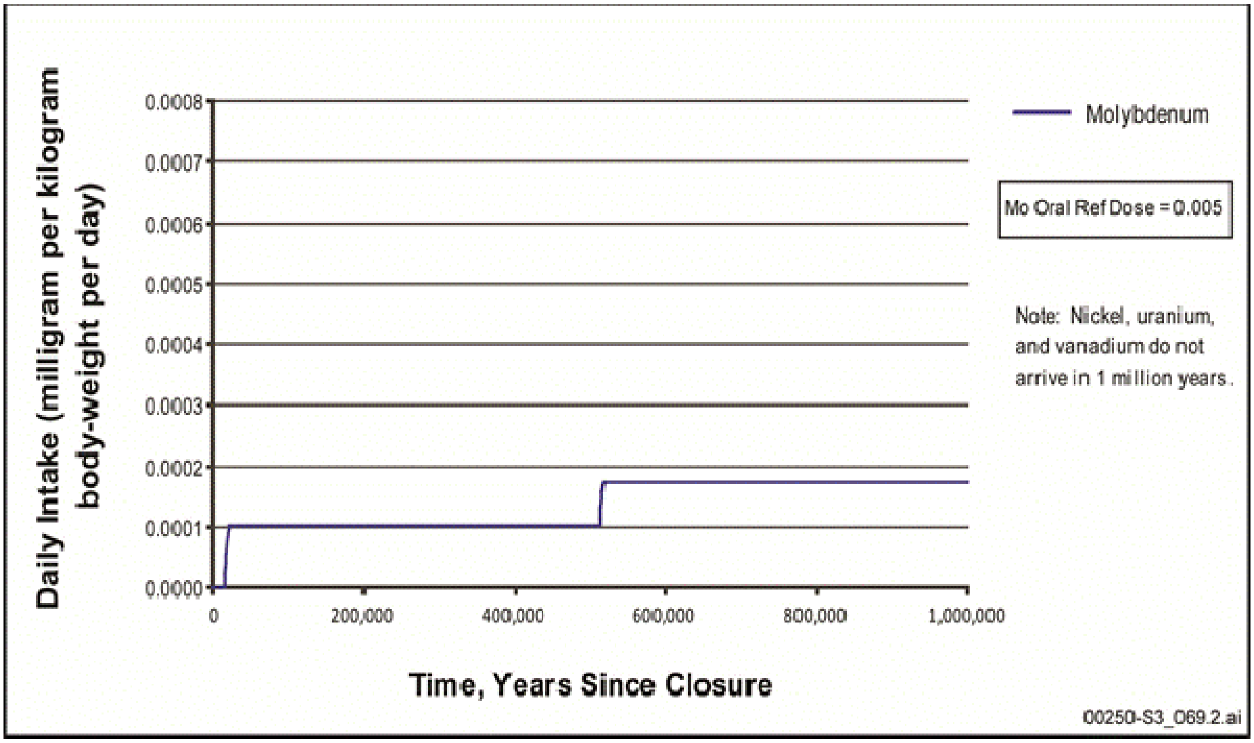


Figure B-17. Molybdenum Intake at Middle Basin, wetter climate.

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 be precipitated along with the same or similar mass of dissolved solids. Evaporite minerals deposited on the surface of wet playas in this region often are 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 in 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 could be redeposited would be less than that estimated for Middle Basin on the floor of Death Valley.

The above doses and intakes are based on the scenario that the wet playa continues to exist for the entire analysis period. Occasional dust storms, rain storms, or runoff may alter the evaporite deposits causing erosion, silt coverage, compaction, and consolidation. These alterations may change the concentration of resuspended particles, but a high concentration for the environment considered was used in the analysis. In fact, compaction and consolidation tend to reduce air emissions. Occasional flooding of the playa would reduce, if not eliminate, exposure to the evaporite minerals because the flood waters would likely deposit soil particles on the surface of evaporite deposits. Any standing water or runoff water would be extremely brackish and non-potable (even to animals) so ingestion of water would not be expected. At the Franklin Lake Playa (Alkali Flat), stagnant water has a total-dissolved-solids content 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 (Reynolds et al. 2007, p. 1814). With the exception of the dose from external exposure, which would be no greater than the dose from the dry surface materials, doses and intakes during the wetter climate would be greatly reduced or eliminated because of permanent standing non-potable water (especially since the analysis assumed infinite depth).

B.4.1.2.2 Furnace Creek Springs Area

Figures B-18 and B-19 show the estimated radiological dose for the Furnace Creek springs area for the present-day climate. Figures B-20 and B-21 show the estimated radiological doses for the Furnace Creek springs area for the wetter climate. These results are based on the annual flow to the valley with the annual release of radionuclides totally captured within that flow.

In both the present and wetter climates, only radionuclides with a zero partition coefficient make it to the valley during the 1-million-year analysis period. Of these, the major contributors are technetium-99, iodine-129, and chlorine-36.

Of all the non-radiological contaminants, only molybdenum arrives in any significant amount at the Furnace Creek springs area during the 1-million-year analysis period. Figures B-22 and B-23 show the daily intakes of molybdenum at the Furnace Creek area from exposure to annual flows. The daily intakes for this case are below the Oral Reference Dose.

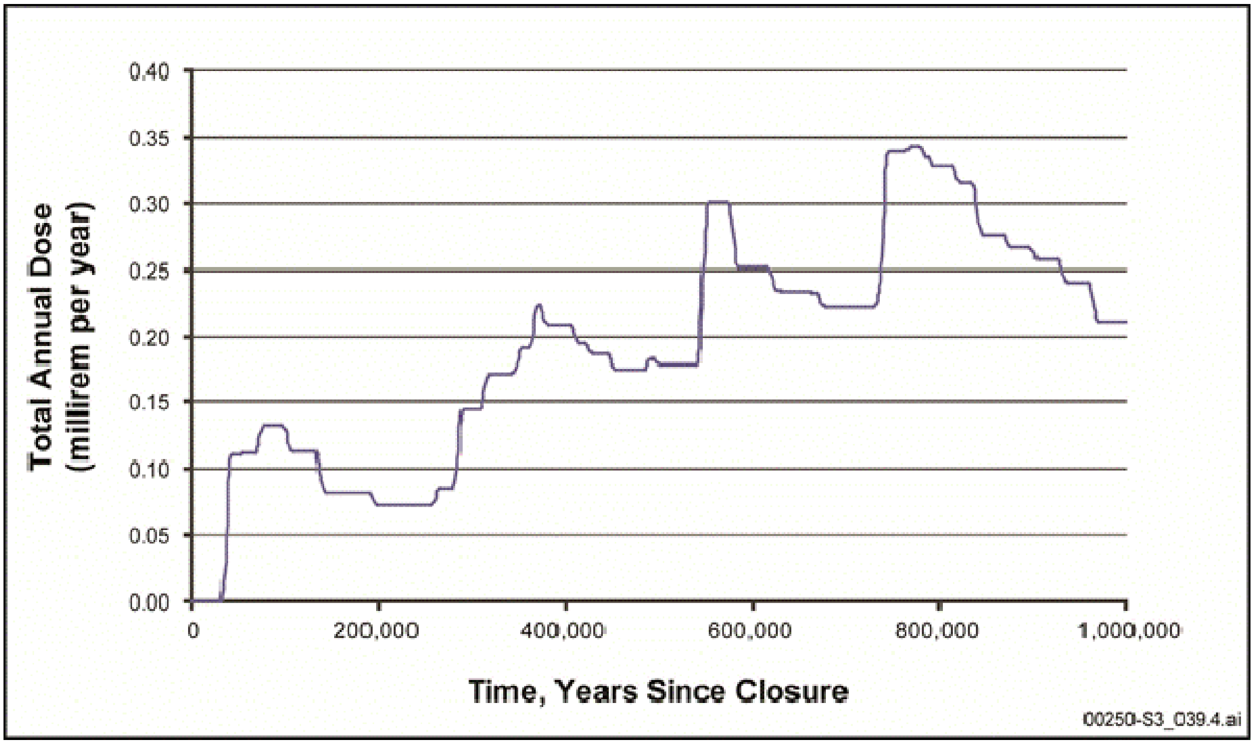


Figure B-18. Total dose at the Furnace Creek springs area, no-pumping, present climate.

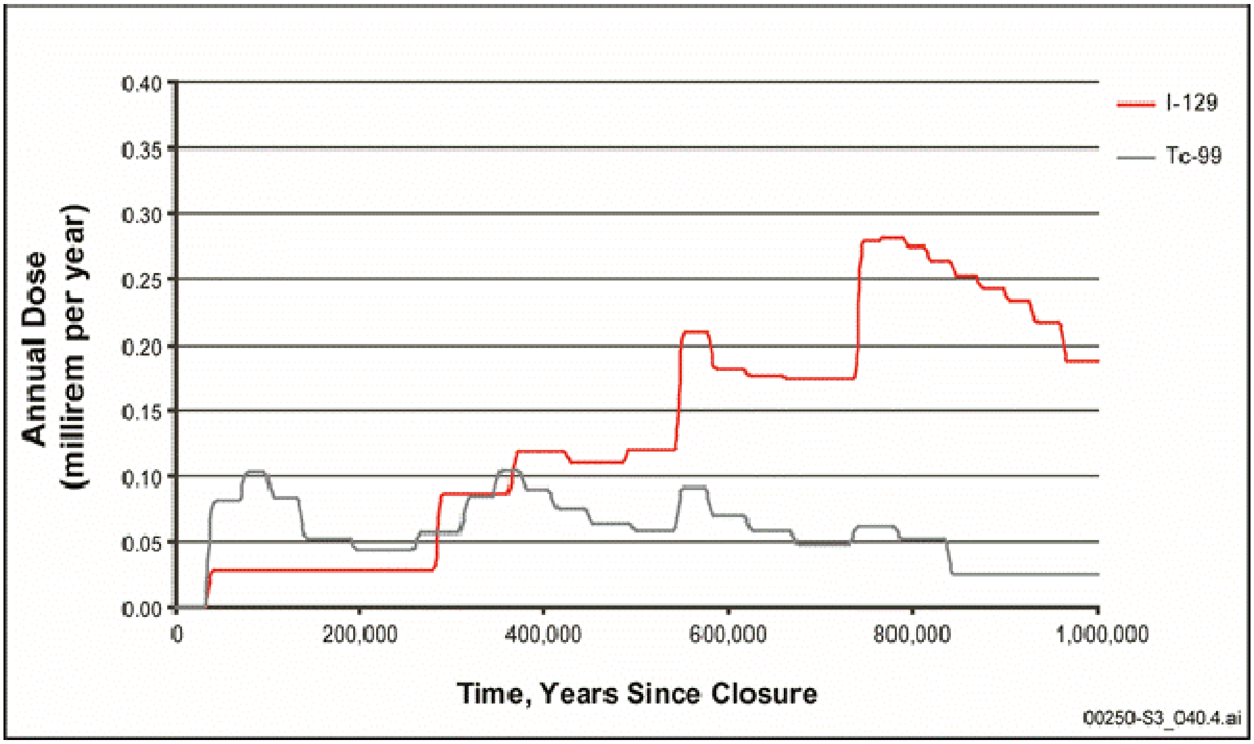


Figure B-19. Dose by radionuclide at the Furnace Creek springs area, no-pumping, present climate.

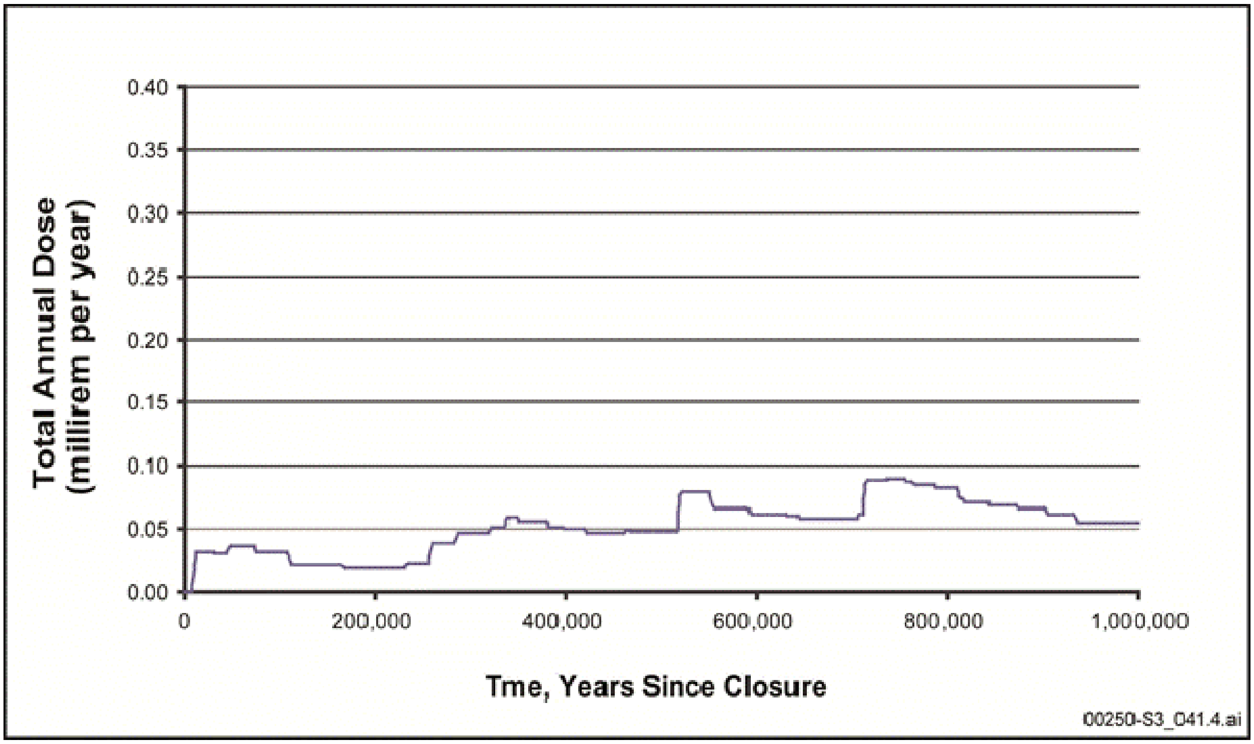


Figure B-20. Total dose at the Furnace Creek springs area, no-pumping, wetter climate.

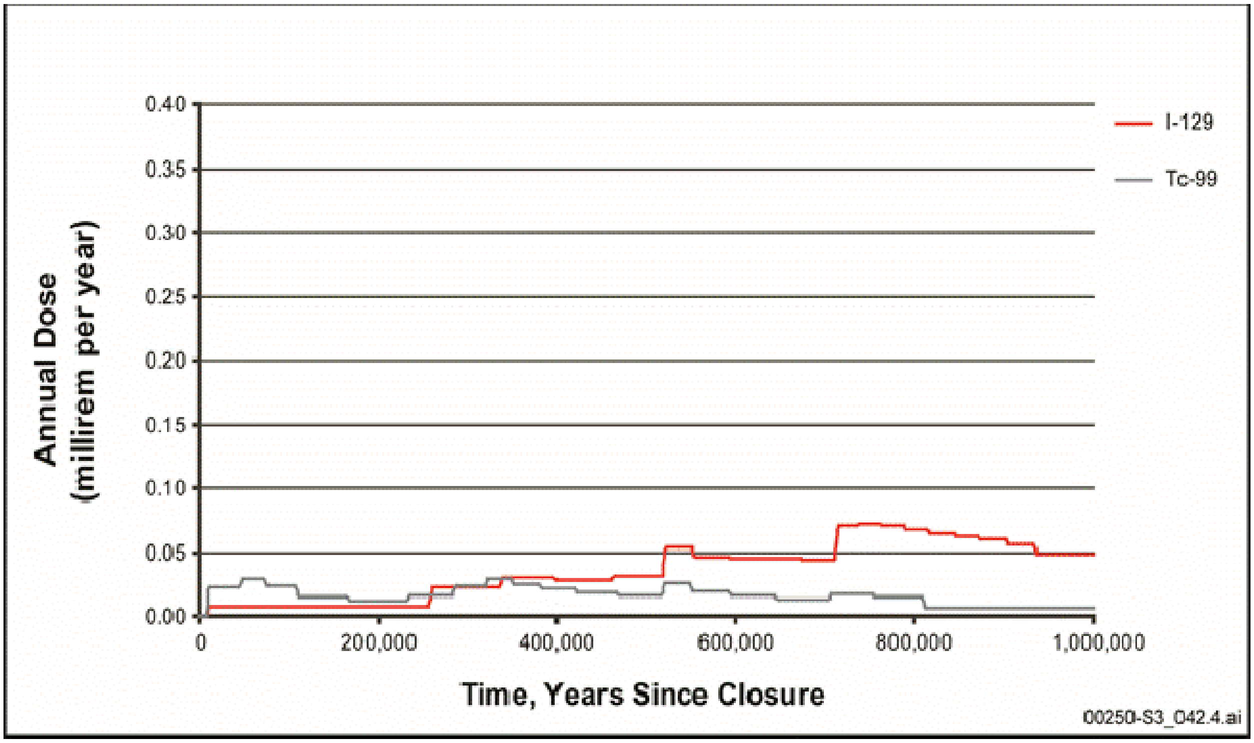


Figure B-21. Dose by radionuclide at the Furnace Creek springs area, no-pumping, wetter climate.

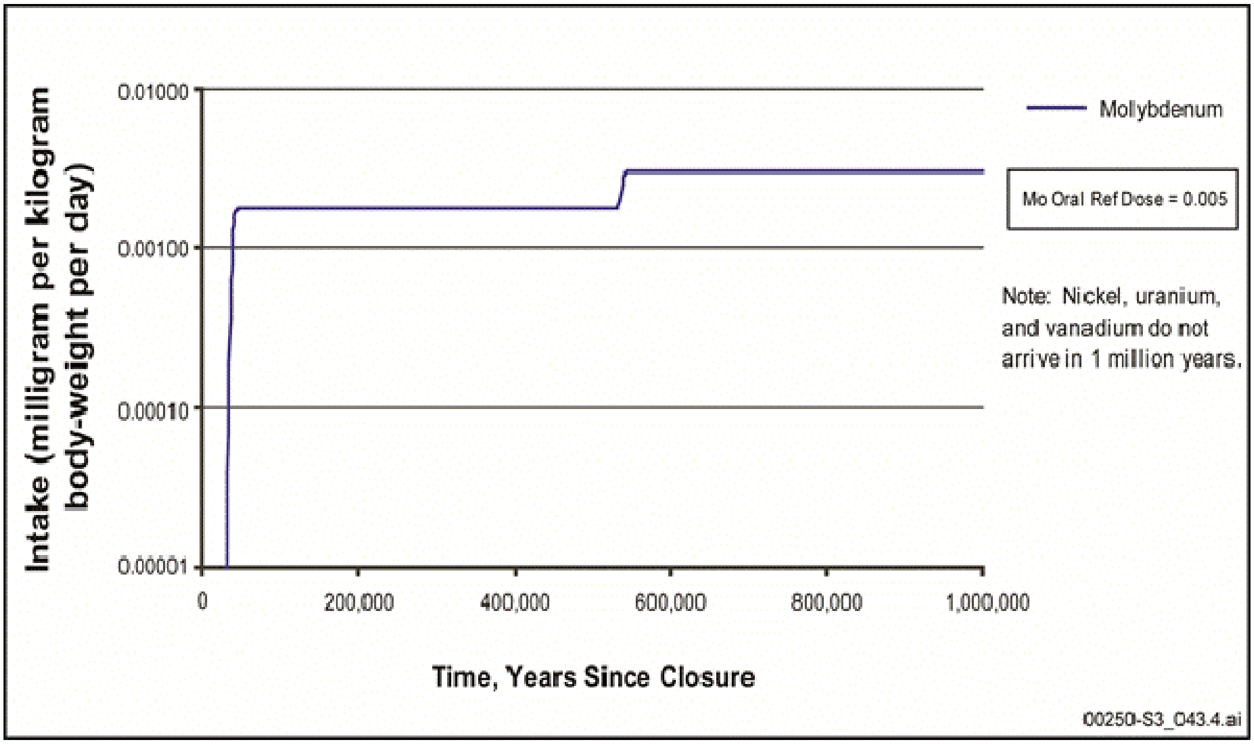


Figure B-22. Daily intakes of molybdenum at the Furnace Creek springs area, no-pumping, present climate.

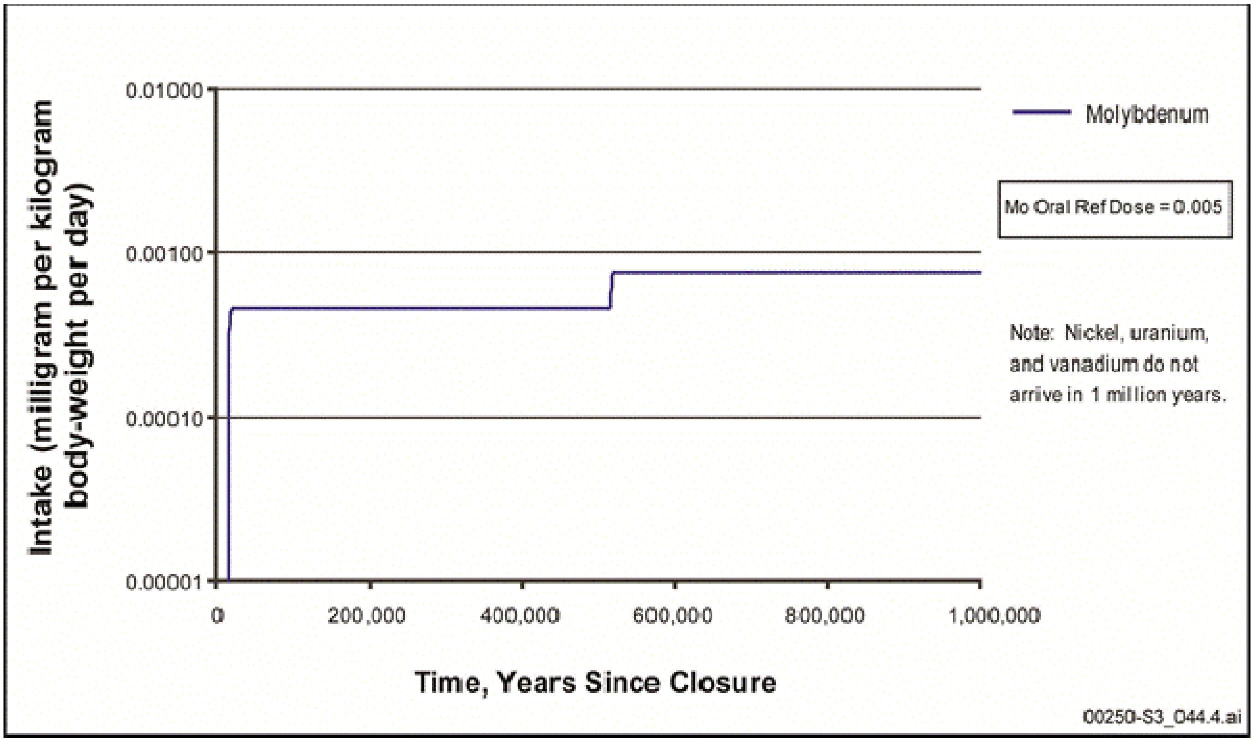


Figure B-23. Daily intakes of molybdenum at the Furnace Creek springs area, no-pumping, wetter climate.

B.4.2 MASS BALANCES

Using the decay- and growth-adjusted inventories (see Section B.2.4), DOE estimated mass balances for radionuclides and non-radiological contaminants that have significant inventories. These balances provide some insight concerning where material would be located as a function of time for the scenarios evaluated.

B.4.2.1 Radionuclides

It is important to note that at all times radionuclides are decaying, and in some cases radionuclides of interest are increasing in mass, as the result of decay of parent radionuclides. The inventories that make up these mass balances are adjusted for this decay and growth. This means that the term *release to the saturated zone* means the cumulative release adjusted for growth and decay and thus means it is possible for this amount to actually decrease with time or increase with time at a rate that looks faster than the mass release rate. The adjustment is made to allow calculation of a true inventory in between release points by the difference in inflow and outflow. This Analysis of Postclosure Groundwater Impacts presents these mass balances to provide a picture of trends and relative location of radionuclides.

Tables B-5 through B-8 present the mass balances for radionuclides important to dose for the 4 scenarios in the analysis (pumping, present climate; pumping, wetter climate; no-pumping, present climate; and no-pumping, wetter climate). The total mass arriving at the Furnace Creek springs area or the Death Valley floor would be the same and is designated in the tables as “released at Death Valley.” The total amounts released at Alkali Flat would be similar if all flow was diverted in that direction. Note that in some of the tables, some radionuclides have zero inventories further down the flow path. This indicates that after 1 million years, some slower-moving radionuclides had not traveled the full length of the path and had not reached a discharge location. Generally speaking, there are significant inventories of radionuclides distributed throughout the flow paths. These accumulated materials do not have an impact because they have no path by which to reach the biosphere.

An important note about the “accumulated” mass in the Amargosa Farms area:

In the case of the pumping scenario, 14 percent of the mass is actually not accumulated, but is assumed to be transported out of the Amargosa Farms area (water released to septic tanks or swamp coolers or used for other industrial purposes); that is, that fraction of mass and activity is assumed to be removed. All other activity (that does not decay) is assumed to be recycled even though some fraction of that activity would be removed via plant (notably alfalfa) uptake and used for fodder and the milk and meat products leaving the area (however this is conservatively not included in the analysis). Other portions of the mass and activity would be removed by soil erosion and dispersed across southern Nevada and California (again this loss is conservatively not included in the analysis).

Table B-5. Mass balance (grams), pumping, present climate.

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 km and the Amargosa Farms area	Accumulated at the Amargosa Farms area
Uranium-235					
1.00×10^{4}	7.66×10^{3}	1.26×10^{3}	6.40×10^{3}	6.40×10^{3}	0.0
5.00×10^{4}	4.31×10^{4}	7.78×10^{3}	3.54×10^{4}	3.54×10^{4}	3.23×10^{-1}
1.00×10^{5}	8.90×10^{4}	1.70×10^{4}	7.20×10^{4}	5.24×10^{4}	1.96×10^{4}
3.00×10^{5}	3.47×10^{5}	7.09×10^{4}	2.76×10^{5}	1.12×10^{5}	1.64×10^{5}
5.00×10^{5}	9.41×10^{5}	1.48×10^{5}	7.94×10^{5}	2.23×10^{5}	5.71×10^{5}
8.00×10^{5}	2.42×10^{6}	2.91×10^{5}	2.12×10^{6}	3.92×10^{5}	1.73×10^{6}
1.00×10^{6}	4.00×10^{6}	4.26×10^{5}	3.58×10^{6}	6.05×10^{5}	2.97×10^{6}
Neptunium-237					
1.00×10^{4}	2.43×10^{3}	3.92×10^{2}	2.04×10^{3}	2.04×10^{3}	0.0
5.00×10^{4}	1.33×10^{4}	2.15×10^{3}	1.11×10^{4}	1.11×10^{4}	1.23×10^{-9}
1.00×10^{5}	2.67×10^{4}	4.31×10^{3}	2.24×10^{4}	2.17×10^{4}	6.33×10^{2}
3.00×10^{5}	1.17×10^{5}	2.00×10^{4}	9.69×10^{4}	5.50×10^{4}	4.19×10^{4}
5.00×10^{5}	2.84×10^{5}	3.75×10^{4}	2.47×10^{5}	9.32×10^{4}	1.53×10^{5}
8.00×10^{5}	6.02×10^{5}	6.56×10^{4}	5.37×10^{5}	1.36×10^{5}	4.00×10^{5}
1.00×10^{6}	9.21×10^{5}	9.63×10^{4}	8.25×10^{5}	2.09×10^{5}	6.15×10^{5}
Uranium-233					
1.00×10^{4}	9.00×10^{1}	1.48×10^{1}	7.52×10^{1}	7.52×10^{1}	0.0
5.00×10^{4}	6.25×10^{2}	1.02×10^{2}	5.23×10^{2}	5.23×10^{2}	2.05×10^{-3}
1.00×10^{5}	1.56×10^{3}	2.54×10^{2}	1.30×10^{3}	1.16×10^{3}	1.43×10^{2}
3.00×10^{5}	1.07×10^{4}	1.84×10^{3}	8.83×10^{3}	4.60×10^{3}	4.24×10^{3}
5.00×10^{5}	3.28×10^{4}	4.39×10^{3}	2.84×10^{4}	1.01×10^{4}	1.83×10^{4}
8.00×10^{5}	8.12×10^{4}	9.05×10^{3}	7.21×10^{4}	1.79×10^{4}	5.43×10^{4}
1.00×10^{6}	1.28×10^{5}	1.37×10^{4}	1.15×10^{5}	2.86×10^{4}	8.60×10^{4}
Thorium-229					
1.00×10^{4}	4.78	4.29	4.96×10^{-1}	4.96×10^{-1}	0.0
5.00×10^{4}	2.54×10^{1}	1.41×10^{1}	1.13×10^{1}	1.13×10^{1}	1.99×10^{-6}
1.00×10^{5}	5.49×10^{1}	2.03×10^{1}	3.47×10^{1}	3.22×10^{1}	2.52
3.00×10^{5}	2.96×10^{2}	8.05×10^{1}	2.16×10^{2}	1.03×10^{2}	1.13×10^{2}
5.00×10^{5}	9.30×10^{2}	1.88×10^{2}	7.41×10^{2}	2.64×10^{2}	4.78×10^{2}
8.00×10^{5}	2.57×10^{3}	3.89×10^{2}	2.18×10^{3}	5.31×10^{2}	1.65×10^{3}
1.00×10^{6}	4.26×10^{3}	6.11×10^{2}	3.64×10^{3}	8.15×10^{2}	2.83×10^{3}
Uranium-236					
1.00×10^{4}	2.75×10^{3}	6.78×10^{2}	2.07×10^{3}	2.07×10^{3}	0.0
5.00×10^{4}	1.51×10^{4}	3.70×10^{3}	1.14×10^{4}	1.14×10^{4}	1.05×10^{-1}
1.00×10^{5}	3.06×10^{4}	7.53×10^{3}	2.30×10^{4}	1.67×10^{4}	6.34×10^{3}
3.00×10^{5}	1.19×10^{5}	3.49×10^{4}	8.40×10^{4}	3.13×10^{4}	5.28×10^{4}
5.00×10^{5}	3.54×10^{5}	8.70×10^{4}	2.67×10^{5}	8.06×10^{4}	1.86×10^{5}
8.00×10^{5}	9.46×10^{5}	1.96×10^{5}	7.50×10^{5}	1.40×10^{5}	6.10×10^{5}
1.00×10^{6}	1.54×10^{6}	2.97×10^{5}	1.24×10^{6}	2.00×10^{5}	1.04×10^{6}
Thorium-232					
1.00×10^{4}	1.58×10^{3}	1.40×10^{3}	1.78×10^{2}	1.78×10^{2}	0.0
5.00×10^{4}	8.70×10^{3}	7.71×10^{3}	9.91×10^{2}	9.91×10^{2}	1.55×10^{-4}
1.00×10^{5}	1.76×10^{4}	1.56×10^{4}	2.04×10^{3}	2.02×10^{3}	1.88×10^{1}
3.00×10^{5}	6.06×10^{4}	5.39×10^{4}	6.70×10^{3}	6.24×10^{3}	4.68×10^{2}
5.00×10^{5}	1.69×10^{5}	1.46×10^{5}	2.35×10^{4}	2.07×10^{4}	2.75×10^{3}
8.00×10^{5}	5.07×10^{5}	4.28×10^{5}	7.91×10^{4}	6.47×10^{4}	1.44×10^{4}
1.00×10^{6}	1.02×10^{6}	8.67×10^{5}	1.57×10^{5}	1.27×10^{5}	3.05×10^{4}

Table B-5. Mass balance (grams), pumping, present climate (continued).

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 km and the Amargosa Farms area	Accumulated at the Amargosa Farms area
Uranium-234					
1.00×10^{4}	8.69×10^{1}	7.99×10^{1}	7.99×10^{1}	7.99×10^{1}	0.0
5.00×10^{4}	4.53×10^{2}	4.16×10^{2}	4.16×10^{2}	4.16×10^{2}	3.32×10^{-3}
1.00×10^{5}	8.56×10^{2}	7.87×10^{2}	7.87×10^{2}	5.92×10^{2}	1.94×10^{2}
3.00×10^{5}	3.76×10^{3}	3.55×10^{3}	3.55×10^{3}	1.74×10^{3}	1.81×10^{3}
5.00×10^{5}	6.92×10^{3}	7.27×10^{3}	7.27×10^{3}	2.36×10^{3}	4.91×10^{3}
8.00×10^{5}	9.73×10^{3}	1.06×10^{4}	1.06×10^{4}	2.39×10^{3}	8.17×10^{3}
1.00×10^{6}	1.15×10^{4}	1.19×10^{4}	1.19×10^{4}	2.61×10^{3}	9.30×10^{3}
Thorium-230					
1.00×10^{4}	7.45×10^{1}	7.99×10^{1}	3.56	3.56	0.0
5.00×10^{4}	3.26×10^{2}	4.16×10^{2}	5.19×10^{1}	5.19×10^{1}	6.90×10^{-4}
1.00×10^{5}	5.05×10^{2}	7.87×10^{2}	1.48×10^{2}	1.03×10^{2}	4.48×10^{1}
3.00×10^{5}	1.12×10^{3}	3.55×10^{3}	7.69×10^{2}	3.74×10^{2}	3.96×10^{2}
5.00×10^{5}	1.27×10^{3}	7.27×10^{3}	1.19×10^{3}	4.30×10^{2}	7.65×10^{2}
8.00×10^{5}	9.90×10^{2}	1.06×10^{4}	1.04×10^{3}	2.89×10^{2}	7.49×10^{2}
1.00×10^{6}	7.65×10^{2}	1.19×10^{4}	7.95×10^{2}	2.08×10^{2}	5.87×10^{2}
Uranium-238					
1.00×10^{4}	3.54×10^{5}	8.93×10^{4}	2.65×10^{5}	2.65×10^{5}	0.0
5.00×10^{4}	1.95×10^{6}	4.92×10^{5}	1.46×10^{6}	1.46×10^{6}	1.34×10^{1}
1.00×10^{5}	3.94×10^{6}	9.94×10^{5}	2.95×10^{6}	2.14×10^{6}	8.12×10^{5}
3.00×10^{5}	1.53×10^{7}	4.52×10^{6}	1.07×10^{7}	3.96×10^{6}	6.78×10^{6}
5.00×10^{5}	4.48×10^{7}	1.10×10^{7}	3.38×10^{7}	1.00×10^{7}	2.37×10^{7}
8.00×10^{5}	1.20×10^{8}	2.51×10^{7}	9.51×10^{7}	1.78×10^{7}	7.73×10^{7}
1.00×10^{6}	1.98×10^{8}	3.91×10^{7}	1.59×10^{8}	2.61×10^{7}	1.33×10^{8}
Iodine-129					
1.00×10^{4}	1.44×10^{4}	5.30×10^{2}	1.39×10^{4}	2.38×10^{1}	1.38×10^{4}
5.00×10^{4}	7.92×10^{4}	2.92×10^{3}	7.63×10^{4}	2.75×10^{1}	7.63×10^{4}
1.00×10^{5}	1.60×10^{5}	5.90×10^{3}	1.54×10^{5}	3.21×10^{1}	1.54×10^{5}
3.00×10^{5}	6.64×10^{5}	3.47×10^{4}	6.29×10^{5}	1.10×10^{3}	6.28×10^{5}
5.00×10^{5}	1.92×10^{6}	6.77×10^{4}	1.85×10^{6}	4.45×10^{3}	1.85×10^{6}
8.00×10^{5}	5.43×10^{6}	1.74×10^{5}	5.26×10^{6}	3.95×10^{3}	5.25×10^{6}
1.00×10^{6}	7.80×10^{6}	1.91×10^{5}	7.61×10^{6}	1.31×10^{3}	7.61×10^{6}
Selenium-79					
1.00×10^{4}	7.38×10^{2}	3.68×10^{2}	3.70×10^{2}	3.70×10^{2}	0.0
5.00×10^{4}	4.53×10^{3}	2.48×10^{3}	2.04×10^{3}	2.04×10^{3}	0.0
1.00×10^{5}	8.98×10^{3}	3.78×10^{3}	5.20×10^{3}	5.20×10^{3}	2.65×10^{-15}
3.00×10^{5}	1.34×10^{4}	4.36×10^{3}	9.08×10^{3}	7.40×10^{3}	1.68×10^{3}
5.00×10^{5}	1.69×10^{4}	4.75×10^{3}	1.21×10^{4}	7.18×10^{3}	4.97×10^{3}
8.00×10^{5}	1.87×10^{4}	4.77×10^{3}	1.39×10^{4}	6.67×10^{3}	7.25×10^{3}
1.00×10^{6}	1.68×10^{4}	3.67×10^{3}	1.31×10^{4}	5.31×10^{3}	7.78×10^{3}
Technetium-99					
1.00×10^{4}	8.28×10^{4}	8.58×10^{3}	7.42×10^{4}	4.46×10^{2}	7.38×10^{4}
5.00×10^{4}	4.52×10^{5}	3.96×10^{4}	4.12×10^{5}	2.61×10^{3}	4.10×10^{5}
1.00×10^{5}	8.23×10^{5}	4.18×10^{4}	7.81×10^{5}	3.56×10^{3}	7.77×10^{5}
3.00×10^{5}	1.33×10^{6}	5.67×10^{4}	1.27×10^{6}	3.56×10^{3}	1.27×10^{6}
5.00×10^{5}	1.86×10^{6}	6.09×10^{4}	1.79×10^{6}	6.04×10^{3}	1.79×10^{6}
8.00×10^{5}	1.91×10^{6}	6.02×10^{4}	1.85×10^{6}	8.67×10^{3}	1.84×10^{6}
1.00×10^{6}	1.38×10^{6}	3.16×10^{4}	1.34×10^{6}	6.18×10^{3}	1.34×10^{6}

Table B-6. Mass balance (grams), pumping, wetter climate.

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released Beyond 18 kilometers	Held in path between 18 km and the Amargosa Farms area	Accumulated at the Amargosa Farms area
Uranium-235					
1.00×10^{4}	7.66×10^{3}	1.26×10^{3}	6.40×10^{3}	6.40×10^{3}	7.14×10^{-7}
5.00×10^{4}	4.31×10^{4}	7.78×10^{3}	3.54×10^{4}	1.29×10^{4}	2.24×10^{4}
1.00×10^{5}	8.90×10^{4}	1.70×10^{4}	7.20×10^{4}	1.36×10^{4}	5.84×10^{4}
3.00×10^{5}	3.47×10^{5}	7.09×10^{4}	2.76×10^{5}	3.48×10^{4}	2.41×10^{5}
5.00×10^{5}	9.41×10^{5}	1.48×10^{5}	7.94×10^{5}	6.13×10^{4}	7.33×10^{5}
8.00×10^{5}	2.42×10^{6}	2.91×10^{5}	2.12×10^{6}	1.04×10^{5}	2.02×10^{6}
1.00×10^{6}	4.00×10^{6}	4.26×10^{5}	3.58×10^{6}	1.61×10^{5}	3.42×10^{6}
Neptunium-237					
1.00×10^{4}	2.43×10^{3}	3.92×10^{2}	2.04×10^{3}	2.04×10^{3}	0.0
5.00×10^{4}	1.33×10^{4}	2.15×10^{3}	1.11×10^{4}	5.89×10^{3}	5.25×10^{3}
1.00×10^{5}	2.67×10^{4}	4.31×10^{3}	2.24×10^{4}	5.99×10^{3}	1.64×10^{4}
3.00×10^{5}	1.17×10^{5}	2.00×10^{4}	9.69×10^{4}	1.64×10^{4}	8.06×10^{4}
5.00×10^{5}	2.84×10^{5}	3.75×10^{4}	2.47×10^{5}	2.58×10^{4}	2.21×10^{5}
8.00×10^{5}	6.02×10^{5}	6.56×10^{4}	5.37×10^{5}	3.75×10^{4}	4.99×10^{5}
1.00×10^{6}	9.21×10^{5}	9.63×10^{4}	8.25×10^{5}	6.02×10^{4}	7.64×10^{5}
Uranium-233					
1.00×10^{4}	9.00×10^{1}	1.48×10^{1}	7.52×10^{1}	7.52×10^{1}	6.84×10^{-9}
5.00×10^{4}	6.25×10^{2}	1.02×10^{2}	5.23×10^{2}	2.14×10^{2}	3.08×10^{2}
1.00×10^{5}	1.56×10^{3}	2.54×10^{2}	1.30×10^{3}	2.71×10^{2}	1.03×10^{3}
3.00×10^{5}	1.07×10^{4}	1.84×10^{3}	8.83×10^{3}	1.31×10^{3}	7.52×10^{3}
5.00×10^{5}	3.28×10^{4}	4.39×10^{3}	2.84×10^{4}	2.75×10^{3}	2.56×10^{4}
8.00×10^{5}	8.12×10^{4}	9.05×10^{3}	7.21×10^{4}	4.92×10^{3}	6.72×10^{4}
1.00×10^{6}	1.28×10^{5}	1.37×10^{4}	1.15×10^{5}	8.20×10^{3}	1.06×10^{5}
Thorium-229					
1.00×10^{4}	4.78	4.29	4.96×10^{-1}	4.96×10^{-1}	1.48×10^{-14}
5.00×10^{4}	2.54×10^{1}	1.41×10^{1}	1.13×10^{1}	6.51	4.76
1.00×10^{5}	5.49×10^{1}	2.03×10^{1}	3.47×10^{1}	1.00×10^{1}	2.47×10^{1}
3.00×10^{5}	2.96×10^{2}	8.05×10^{1}	2.16×10^{2}	3.21×10^{1}	1.84×10^{2}
5.00×10^{5}	9.30×10^{2}	1.88×10^{2}	7.41×10^{2}	7.41×10^{1}	6.67×10^{2}
8.00×10^{5}	2.57×10^{3}	3.89×10^{2}	2.18×10^{3}	1.49×10^{2}	2.03×10^{3}
1.00×10^{6}	4.26×10^{3}	6.11×10^{2}	3.64×10^{3}	2.33×10^{2}	3.41×10^{3}
Uranium-236					
1.00×10^{4}	2.75×10^{3}	6.78×10^{2}	2.07×10^{3}	2.07×10^{3}	2.31×10^{-7}
5.00×10^{4}	1.51×10^{4}	3.70×10^{3}	1.14×10^{4}	4.13×10^{3}	7.27×10^{3}
1.00×10^{5}	3.06×10^{4}	7.53×10^{3}	2.30×10^{4}	4.13×10^{3}	1.89×10^{4}
3.00×10^{5}	1.19×10^{5}	3.49×10^{4}	8.40×10^{4}	1.21×10^{4}	7.19×10^{4}
5.00×10^{5}	3.54×10^{5}	8.70×10^{4}	2.67×10^{5}	2.22×10^{4}	2.45×10^{5}
8.00×10^{5}	9.46×10^{5}	1.96×10^{5}	7.50×10^{5}	3.67×10^{4}	7.13×10^{5}
1.00×10^{6}	1.54×10^{6}	2.97×10^{5}	1.24×10^{6}	5.26×10^{4}	1.19×10^{6}
Thorium 232					
1.00×10^{4}	1.58×10^{3}	1.40×10^{3}	1.78×10^{2}	1.78×10^{2}	6.85×10^{-11}
5.00×10^{4}	8.70×10^{3}	7.71×10^{3}	9.91×10^{2}	9.81×10^{2}	1.08×10^{1}
1.00×10^{5}	1.76×10^{4}	1.56×10^{4}	2.04×10^{3}	1.98×10^{3}	5.60×10^{1}
3.00×10^{5}	6.06×10^{4}	5.39×10^{4}	6.70×10^{3}	6.07×10^{3}	6.38×10^{2}
5.00×10^{5}	1.69×10^{5}	1.46×10^{5}	2.35×10^{4}	1.98×10^{4}	3.61×10^{3}
8.00×10^{5}	5.07×10^{5}	4.28×10^{5}	7.91×10^{4}	6.23×10^{4}	1.68×10^{4}
1.00×10^{6}	1.02×10^{6}	8.67×10^{5}	1.57×10^{5}	1.22×10^{5}	3.49×10^{4}

Table B-6. Mass balance (grams), pumping, wetter climate (continued).

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released Beyond 18 kilometers	Held in path between 18 km and the Amargosa Farms area	Accumulated at the Amargosa Farms area
Uranium-234					
1.00×10^{4}	8.69×10^{1}	7.99×10^{1}	7.99×10^{1}	7.99×10^{1}	8.55×10^{-9}
5.00×10^{4}	4.53×10^{2}	4.16×10^{2}	4.16×10^{2}	1.58×10^{2}	2.58×10^{2}
1.00×10^{5}	8.56×10^{2}	7.87×10^{2}	7.87×10^{2}	1.59×10^{2}	6.28×10^{2}
3.00×10^{5}	3.76×10^{3}	3.55×10^{3}	3.55×10^{3}	5.09×10^{2}	3.04×10^{3}
5.00×10^{5}	6.92×10^{3}	7.27×10^{3}	7.27×10^{3}	6.59×10^{2}	6.61×10^{3}
8.00×10^{5}	9.73×10^{3}	1.06×10^{4}	1.06×10^{4}	6.60×10^{2}	9.91×10^{3}
1.00×10^{6}	1.15×10^{4}	1.19×10^{4}	1.19×10^{4}	7.22×10^{2}	1.12×10^{4}
Thorium-230					
1.00×10^{4}	7.45×10^{1}	7.99×10^{1}	3.56	3.56	6.10×10^{-10}
5.00×10^{4}	3.26×10^{2}	4.16×10^{2}	5.19×10^{1}	1.54×10^{1}	3.65×10^{1}
1.00×10^{5}	5.05×10^{2}	7.87×10^{2}	1.48×10^{2}	2.44×10^{1}	1.24×10^{2}
3.00×10^{5}	1.12×10^{3}	3.55×10^{3}	7.69×10^{2}	1.11×10^{2}	6.58×10^{2}
5.00×10^{5}	1.27×10^{3}	7.27×10^{3}	1.19×10^{3}	1.24×10^{2}	1.07×10^{3}
8.00×10^{5}	9.90×10^{2}	1.06×10^{4}	1.04×10^{3}	8.18×10^{1}	9.57×10^{2}
1.00×10^{6}	7.65×10^{2}	1.19×10^{4}	7.95×10^{2}	5.87×10^{1}	7.36×10^{2}
Uranium-238					
1.00×10^{4}	3.54×10^{5}	8.93×10^{4}	2.65×10^{5}	2.65×10^{5}	2.96×10^{-5}
5.00×10^{4}	1.95×10^{6}	4.92×10^{5}	1.46×10^{6}	5.28×10^{5}	9.29×10^{5}
1.00×10^{5}	3.94×10^{6}	9.94×10^{5}	2.95×10^{6}	5.28×10^{5}	2.42×10^{6}
3.00×10^{5}	1.53×10^{7}	4.52×10^{6}	1.07×10^{7}	1.50×10^{6}	9.24×10^{6}
5.00×10^{5}	4.48×10^{7}	1.10×10^{7}	3.38×10^{7}	2.71×10^{6}	3.11×10^{7}
8.00×10^{5}	1.20×10^{8}	2.51×10^{7}	9.51×10^{7}	4.63×10^{6}	9.05×10^{7}
1.00×10^{6}	1.98×10^{8}	3.91×10^{7}	1.59×10^{8}	6.82×10^{6}	1.52×10^{8}
Iodine-129					
1.00×10^{4}	1.44×10^{4}	5.30×10^{2}	1.39×10^{4}	2.11×10^{-1}	1.39×10^{4}
5.00×10^{4}	7.92×10^{4}	2.92×10^{3}	7.63×10^{4}	1.16	7.63×10^{4}
1.00×10^{5}	1.60×10^{5}	5.90×10^{3}	1.54×10^{5}	2.35	1.54×10^{5}
3.00×10^{5}	6.64×10^{5}	3.47×10^{4}	6.29×10^{5}	9.59	6.29×10^{5}
5.00×10^{5}	1.92×10^{6}	6.77×10^{4}	1.85×10^{6}	2.82×10^{1}	1.85×10^{6}
8.00×10^{5}	5.43×10^{6}	1.74×10^{5}	5.26×10^{6}	8.03×10^{1}	5.26×10^{6}
1.00×10^{6}	7.80×10^{6}	1.91×10^{5}	7.61×10^{6}	1.16×10^{2}	7.61×10^{6}
Selenium-79					
1.00×10^{4}	7.38×10^{2}	3.68×10^{2}	3.70×10^{2}	3.70×10^{2}	0.0
5.00×10^{4}	4.53×10^{3}	2.48×10^{3}	2.04×10^{3}	2.04×10^{3}	2.49
1.00×10^{5}	8.98×10^{3}	3.78×10^{3}	5.20×10^{3}	3.84×10^{3}	1.35×10^{3}
3.00×10^{5}	1.34×10^{4}	4.36×10^{3}	9.08×10^{3}	1.71×10^{3}	7.37×10^{3}
5.00×10^{5}	1.69×10^{4}	4.75×10^{3}	1.21×10^{4}	1.96×10^{3}	1.02×10^{4}
8.00×10^{5}	1.87×10^{4}	4.77×10^{3}	1.39×10^{4}	2.16×10^{3}	1.18×10^{4}
1.00×10^{6}	1.68×10^{4}	3.67×10^{3}	1.31×10^{4}	1.44×10^{3}	1.17×10^{4}
Technetium-99					
1.00×10^{4}	8.28×10^{4}	8.58×10^{3}	7.42×10^{4}	8.34×10^{1}	7.41×10^{4}
5.00×10^{4}	4.52×10^{5}	3.96×10^{4}	4.12×10^{5}	4.63×10^{2}	4.12×10^{5}
1.00×10^{5}	8.23×10^{5}	4.18×10^{4}	7.81×10^{5}	8.76×10^{2}	7.80×10^{5}
3.00×10^{5}	1.33×10^{6}	5.67×10^{4}	1.27×10^{6}	1.43×10^{3}	1.27×10^{6}
5.00×10^{5}	1.86×10^{6}	6.09×10^{4}	1.79×10^{6}	2.02×10^{3}	1.79×10^{6}
8.00×10^{5}	1.91×10^{6}	6.02×10^{4}	1.85×10^{6}	2.08×10^{3}	1.85×10^{6}
1.00×10^{6}	1.38×10^{6}	3.16×10^{4}	1.34×10^{6}	1.51×10^{3}	1.34×10^{6}

Table B-7. Mass balance (grams), no-pumping, present climate.

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Death Valley	Released at Death Valley
Uranium-235					
1.00×10^{4}	7.66×10^{3}	1.26×10^{3}	6.40×10^{3}	6.40×10^{3}	0.0
5.00×10^{4}	4.31×10^{4}	7.78×10^{3}	3.54×10^{4}	3.54×10^{4}	0.0
1.00×10^{5}	8.90×10^{4}	1.70×10^{4}	7.20×10^{4}	7.20×10^{4}	0.0
3.00×10^{5}	3.47×10^{5}	7.09×10^{4}	2.76×10^{5}	2.76×10^{5}	0.0
5.00×10^{5}	9.41×10^{5}	1.48×10^{5}	7.94×10^{5}	7.94×10^{5}	0.0
8.00×10^{5}	2.42×10^{6}	2.91×10^{5}	2.12×10^{6}	2.12×10^{6}	0.0
1.00×10^{6}	4.00×10^{6}	4.26×10^{5}	3.58×10^{6}	3.58×10^{6}	0.0
Neptunium-237					
1.00×10^{4}	2.43×10^{3}	3.92×10^{2}	2.04×10^{3}	2.04×10^{3}	0.0
5.00×10^{4}	1.33×10^{4}	2.15×10^{3}	1.11×10^{4}	1.11×10^{4}	0.0
1.00×10^{5}	2.67×10^{4}	4.31×10^{3}	2.24×10^{4}	2.24×10^{4}	0.0
3.00×10^{5}	1.17×10^{5}	2.00×10^{4}	9.69×10^{4}	9.69×10^{4}	0.0
5.00×10^{5}	2.84×10^{5}	3.75×10^{4}	2.47×10^{5}	2.47×10^{5}	0.0
8.00×10^{5}	6.02×10^{5}	6.56×10^{4}	5.37×10^{5}	5.37×10^{5}	0.0
1.00×10^{6}	9.21×10^{5}	9.63×10^{4}	8.25×10^{5}	8.25×10^{5}	0.0
Uranium-233					
1.00×10^{4}	9.00×10^{1}	1.48×10^{1}	7.52×10^{1}	7.52×10^{1}	0.0
5.00×10^{4}	6.25×10^{2}	1.02×10^{2}	5.23×10^{2}	5.23×10^{2}	0.0
1.00×10^{5}	1.56×10^{3}	2.54×10^{2}	1.30×10^{3}	1.30×10^{3}	0.0
3.00×10^{5}	1.07×10^{4}	1.84×10^{3}	8.83×10^{3}	8.83×10^{3}	0.0
5.00×10^{5}	3.28×10^{4}	4.39×10^{3}	2.84×10^{4}	2.84×10^{4}	0.0
8.00×10^{5}	8.12×10^{4}	9.05×10^{3}	7.21×10^{4}	7.21×10^{4}	0.0
1.00×10^{6}	1.28×10^{5}	1.37×10^{4}	1.15×10^{5}	1.15×10^{5}	0.0
Thorium-229					
1.00×10^{4}	4.78	4.29	4.96×10^{-1}	4.96×10^{-1}	0.0
5.00×10^{4}	2.54×10^{1}	1.41×10^{1}	1.13×10^{1}	1.13×10^{1}	0.0
1.00×10^{5}	5.49×10^{1}	2.03×10^{1}	3.47×10^{1}	3.47×10^{1}	0.0
3.00×10^{5}	2.96×10^{2}	8.05×10^{1}	2.16×10^{2}	2.16×10^{2}	0.0
5.00×10^{5}	9.30×10^{2}	1.88×10^{2}	7.41×10^{2}	7.41×10^{2}	0.0
8.00×10^{5}	2.57×10^{3}	3.89×10^{2}	2.18×10^{3}	2.18×10^{3}	0.0
1.00×10^{6}	4.26×10^{3}	6.11×10^{2}	3.64×10^{3}	3.64×10^{3}	0.0
Uranium-236					
1.00×10^{4}	2.75×10^{3}	6.78×10^{2}	2.07×10^{3}	2.07×10^{3}	0.0
5.00×10^{4}	1.51×10^{4}	3.70×10^{3}	1.14×10^{4}	1.14×10^{4}	0.0
1.00×10^{5}	3.06×10^{4}	7.53×10^{3}	2.30×10^{4}	2.30×10^{4}	0.0
3.00×10^{5}	1.19×10^{5}	3.49×10^{4}	8.40×10^{4}	8.40×10^{4}	0.0
5.00×10^{5}	3.54×10^{5}	8.70×10^{4}	2.67×10^{5}	2.67×10^{5}	0.0
8.00×10^{5}	9.46×10^{5}	1.96×10^{5}	7.50×10^{5}	7.50×10^{5}	0.0
1.00×10^{6}	1.54×10^{6}	2.97×10^{5}	1.24×10^{6}	1.24×10^{6}	0.0
Thorium-232					
1.00×10^{4}	1.58×10^{3}	1.40×10^{3}	1.78×10^{2}	1.78×10^{2}	0.0
5.00×10^{4}	8.70×10^{3}	7.71×10^{3}	9.91×10^{2}	9.91×10^{2}	0.0
1.00×10^{5}	1.76×10^{4}	1.56×10^{4}	2.04×10^{3}	2.04×10^{3}	0.0
3.00×10^{5}	6.06×10^{4}	5.39×10^{4}	6.70×10^{3}	6.70×10^{3}	0.0
5.00×10^{5}	1.69×10^{5}	1.46×10^{5}	2.35×10^{4}	2.35×10^{4}	0.0
8.00×10^{5}	5.07×10^{5}	4.28×10^{5}	7.91×10^{4}	7.91×10^{4}	0.0
1.00×10^{6}	1.02×10^{6}	8.67×10^{5}	1.57×10^{5}	1.57×10^{5}	0.0

Table B-7. Mass balance (grams), no-pumping, present climate (continued).

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Death Valley	Released at Death Valley
Uranium-234					
1.00×10^4	8.69×10^1	7.04	7.99×10^1	7.99×10^1	0.0
5.00×10^4	4.53×10^2	3.67×10^1	4.16×10^2	4.16×10^2	0.0
1.00×10^5	8.56×10^2	6.93×10^1	7.87×10^2	7.87×10^2	0.0
3.00×10^5	3.76×10^3	2.12×10^2	3.55×10^3	3.55×10^3	0.0
5.00×10^5	6.92×10^3	0.0	7.27×10^3	7.27×10^3	0.0
8.00×10^5	9.73×10^3	0.0	1.06×10^4	1.06×10^4	0.0
1.00×10^6	1.15×10^4	0.0	1.19×10^4	1.19×10^4	0.0
Thorium-230					
1.00×10^4	7.45×10^1	7.09×10^1	3.56	3.56	0.0
5.00×10^4	3.26×10^2	2.74×10^2	5.19×10^1	5.19×10^1	0.0
1.00×10^5	5.05×10^2	3.57×10^2	1.48×10^2	1.48×10^2	0.0
3.00×10^5	1.12×10^3	3.50×10^2	7.69×10^2	7.69×10^2	0.0
5.00×10^5	1.27×10^3	7.86×10^1	1.19×10^3	1.19×10^3	0.0
8.00×10^5	9.90×10^2	0.0	1.04×10^3	1.04×10^3	0.0
1.00×10^6	7.65×10^2	0.0	7.95×10^2	7.95×10^2	0.0
Uranium-238					
1.00×10^4	3.54×10^5	8.93×10^4	2.65×10^5	2.65×10^5	0.0
5.00×10^4	1.95×10^6	4.92×10^5	1.46×10^6	1.46×10^6	0.0
1.00×10^5	3.94×10^6	9.94×10^5	2.95×10^6	2.95×10^6	0.0
3.00×10^5	1.53×10^7	4.52×10^6	1.07×10^7	1.07×10^7	0.0
5.00×10^5	4.48×10^7	1.10×10^7	3.38×10^7	3.38×10^7	0.0
8.00×10^5	1.20×10^8	2.51×10^7	9.51×10^7	9.51×10^7	0.0
1.00×10^6	1.98×10^8	3.91×10^7	1.59×10^8	1.59×10^8	0.0
Iodine-129					
1.00×10^4	1.44×10^4	5.30×10^2	1.39×10^4	1.39×10^4	0.0
5.00×10^4	7.92×10^4	2.92×10^3	7.63×10^4	5.59×10^4	2.04×10^4
1.00×10^5	1.60×10^5	5.90×10^3	1.54×10^5	5.59×10^4	9.83×10^4
3.00×10^5	6.64×10^5	3.47×10^4	6.29×10^5	1.73×10^5	4.56×10^5
5.00×10^5	1.92×10^6	6.77×10^4	1.85×10^6	2.39×10^5	1.61×10^6
8.00×10^5	5.43×10^6	1.74×10^5	5.26×10^6	5.30×10^5	4.73×10^6
1.00×10^6	7.80×10^6	1.91×10^5	7.61×10^6	3.68×10^5	7.24×10^6
Selenium-79					
1.00×10^4	7.38×10^2	3.68×10^2	3.70×10^2	3.70×10^2	0.0
5.00×10^4	4.53×10^3	2.48×10^3	2.04×10^3	2.04×10^3	0.0
1.00×10^5	8.98×10^3	3.78×10^3	5.20×10^3	5.20×10^3	0.0
3.00×10^5	1.34×10^4	4.36×10^3	9.08×10^3	9.08×10^3	0.0
5.00×10^5	1.69×10^4	4.75×10^3	1.21×10^4	1.21×10^4	0.0
8.00×10^5	1.87×10^4	4.77×10^3	1.39×10^4	1.39×10^4	0.0
1.00×10^6	1.68×10^4	3.67×10^3	1.31×10^4	1.31×10^4	0.0
Technetium-99					
1.00×10^4	8.28×10^4	8.58×10^3	7.42×10^4	7.42×10^4	0.0
5.00×10^4	4.52×10^5	3.96×10^4	4.12×10^5	3.16×10^5	9.63×10^4
1.00×10^5	8.23×10^5	4.18×10^4	7.81×10^5	3.00×10^5	4.81×10^5
3.00×10^5	1.33×10^6	5.67×10^4	1.27×10^6	2.66×10^5	1.00×10^6
5.00×10^5	1.86×10^6	6.09×10^4	1.79×10^6	2.11×10^5	1.58×10^6
8.00×10^5	1.91×10^6	6.02×10^4	1.85×10^6	1.92×10^5	1.66×10^6
1.00×10^6	1.38×10^6	3.16×10^4	1.34×10^6	8.95×10^4	1.25×10^6

Table B-8. Mass balance (grams), no-pumping, wetter climate.

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Furnace Creek	Released at Death Valley
Uranium-235					
1.00×10^{4}	7.66×10^{3}	1.26×10^{3}	6.40×10^{3}	6.40×10^{3}	0.0
5.00×10^{4}	4.31×10^{4}	7.78×10^{3}	3.54×10^{4}	3.54×10^{4}	0.0
1.00×10^{5}	8.90×10^{4}	1.70×10^{4}	7.20×10^{4}	7.20×10^{4}	0.0
3.00×10^{5}	3.47×10^{5}	7.09×10^{4}	2.76×10^{5}	2.76×10^{5}	0.0
5.00×10^{5}	9.41×10^{5}	1.48×10^{5}	7.94×10^{5}	7.94×10^{5}	0.0
8.00×10^{5}	2.42×10^{6}	2.91×10^{5}	2.12×10^{6}	2.12×10^{6}	0.0
1.00×10^{6}	4.00×10^{6}	4.26×10^{5}	3.58×10^{6}	3.58×10^{6}	0.0
Neptunium-237					
1.00×10^{4}	2.43×10^{3}	3.92×10^{2}	2.04×10^{3}	2.04×10^{3}	0.0
5.00×10^{4}	1.33×10^{4}	2.15×10^{3}	1.11×10^{4}	1.11×10^{4}	0.0
1.00×10^{5}	2.67×10^{4}	4.31×10^{3}	2.24×10^{4}	2.24×10^{4}	0.0
3.00×10^{5}	1.17×10^{5}	2.00×10^{4}	9.69×10^{4}	9.69×10^{4}	0.0
5.00×10^{5}	2.84×10^{5}	3.75×10^{4}	2.47×10^{5}	2.47×10^{5}	0.0
8.00×10^{5}	6.02×10^{5}	6.56×10^{4}	5.37×10^{5}	5.37×10^{5}	0.0
1.00×10^{6}	9.21×10^{5}	9.63×10^{4}	8.25×10^{5}	8.25×10^{5}	0.0
Uranium-233					
1.00×10^{4}	9.00×10^{1}	1.48×10^{1}	7.52×10^{1}	7.52×10^{1}	0.0
5.00×10^{4}	6.25×10^{2}	1.02×10^{2}	5.23×10^{2}	5.23×10^{2}	0.0
1.00×10^{5}	1.56×10^{3}	2.54×10^{2}	1.30×10^{3}	1.30×10^{3}	0.0
3.00×10^{5}	1.07×10^{4}	1.84×10^{3}	8.83×10^{3}	8.83×10^{3}	0.0
5.00×10^{5}	3.28×10^{4}	4.39×10^{3}	2.84×10^{4}	2.84×10^{4}	0.0
8.00×10^{5}	8.12×10^{4}	9.05×10^{3}	7.21×10^{4}	7.21×10^{4}	0.0
1.00×10^{6}	1.28×10^{5}	1.37×10^{4}	1.15×10^{5}	1.15×10^{5}	0.0
Thorium-229					
1.00×10^{4}	4.78	4.29	4.96×10^{-1}	4.96×10^{-1}	0.0
5.00×10^{4}	2.54×10^{1}	1.41×10^{1}	1.13×10^{1}	1.13×10^{1}	0.0
1.00×10^{5}	5.49×10^{1}	2.03×10^{1}	3.47×10^{1}	3.47×10^{1}	0.0
3.00×10^{5}	2.96×10^{2}	8.05×10^{1}	2.16×10^{2}	2.16×10^{2}	0.0
5.00×10^{5}	9.30×10^{2}	1.88×10^{2}	7.41×10^{2}	7.41×10^{2}	0.0
8.00×10^{5}	2.57×10^{3}	3.89×10^{2}	2.18×10^{3}	2.18×10^{3}	0.0
1.00×10^{6}	4.26×10^{3}	6.11×10^{2}	3.64×10^{3}	3.64×10^{3}	0.0
Uranium-236					
1.00×10^{4}	2.75×10^{3}	6.78×10^{2}	2.07×10^{3}	2.07×10^{3}	0.0
5.00×10^{4}	1.51×10^{4}	3.70×10^{3}	1.14×10^{4}	1.14×10^{4}	0.0
1.00×10^{5}	3.06×10^{4}	7.53×10^{3}	2.30×10^{4}	2.30×10^{4}	0.0
3.00×10^{5}	1.19×10^{5}	3.49×10^{4}	8.40×10^{4}	8.40×10^{4}	0.0
5.00×10^{5}	3.54×10^{5}	8.70×10^{4}	2.67×10^{5}	2.67×10^{5}	0.0
8.00×10^{5}	9.46×10^{5}	1.96×10^{5}	7.50×10^{5}	7.50×10^{5}	0.0
1.00×10^{6}	1.54×10^{6}	2.97×10^{5}	1.24×10^{6}	1.24×10^{6}	0.0
Thorium 232					
1.00×10^{4}	1.58×10^{3}	1.40×10^{3}	1.78×10^{2}	1.78×10^{2}	0.0
5.00×10^{4}	8.70×10^{3}	7.71×10^{3}	9.91×10^{2}	9.91×10^{2}	0.0
1.00×10^{5}	1.76×10^{4}	1.56×10^{4}	2.04×10^{3}	2.04×10^{3}	0.0
3.00×10^{5}	6.06×10^{4}	5.39×10^{4}	6.70×10^{3}	6.70×10^{3}	0.0
5.00×10^{5}	1.69×10^{5}	1.46×10^{5}	2.35×10^{4}	2.35×10^{4}	0.0
8.00×10^{5}	5.07×10^{5}	4.28×10^{5}	7.91×10^{4}	7.91×10^{4}	0.0
1.00×10^{6}	1.02×10^{6}	8.67×10^{5}	1.57×10^{5}	1.57×10^{5}	0.0

Table B-8. Mass balance (grams), no-pumping, wetter climate (continued).

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Furnace Creek	Released at Death Valley
Uranium-234					
1.00×10^4	8.69×10^1	7.04	7.99×10^1	7.99×10^1	0.0
5.00×10^4	4.53×10^2	3.67×10^1	4.16×10^2	4.16×10^2	0.0
1.00×10^5	8.56×10^2	6.93×10^1	7.87×10^2	7.87×10^2	0.0
3.00×10^5	3.76×10^3	2.12×10^2	3.55×10^3	3.55×10^3	0.0
5.00×10^5	6.92×10^3	0.0	7.27×10^3	7.27×10^3	0.0
8.00×10^5	9.73×10^3	0.0	1.06×10^4	1.06×10^4	0.0
1.00×10^6	1.15×10^4	0.0	1.19×10^4	1.19×10^4	0.0
Thorium-230					
1.00×10^4	7.45×10^1	7.09×10^1	3.56	3.56	0.0
5.00×10^4	3.26×10^2	2.74×10^2	5.19×10^1	5.19×10^1	0.0
1.00×10^5	5.05×10^2	3.57×10^2	1.48×10^2	1.48×10^2	0.0
3.00×10^5	1.12×10^3	3.50×10^2	7.69×10^2	7.69×10^2	0.0
5.00×10^5	1.27×10^3	7.86×10^1	1.19×10^3	1.19×10^3	0.0
8.00×10^5	9.90×10^2	0.0	1.04×10^3	1.04×10^3	0.0
1.00×10^6	7.65×10^2	0.0	7.95×10^2	7.95×10^2	0.0
Uranium-238					
1.00×10^4	3.54×10^5	8.93×10^4	2.65×10^5	2.65×10^5	0.0
5.00×10^4	1.95×10^6	4.92×10^5	1.46×10^6	1.46×10^6	0.0
1.00×10^5	3.94×10^6	9.94×10^5	2.95×10^6	2.95×10^6	0.0
3.00×10^5	1.53×10^7	4.52×10^6	1.07×10^7	1.07×10^7	0.0
5.00×10^5	4.48×10^7	1.10×10^7	3.38×10^7	3.38×10^7	0.0
8.00×10^5	1.20×10^8	2.51×10^7	9.51×10^7	9.51×10^7	0.0
1.00×10^6	1.98×10^8	3.91×10^7	1.59×10^8	1.59×10^8	0.0
Iodine-129					
1.00×10^4	1.44×10^4	5.30×10^2	1.39×10^4	1.27×10^4	1.15×10^3
5.00×10^4	7.92×10^4	2.92×10^3	7.63×10^4	1.31×10^4	6.32×10^4
1.00×10^5	1.60×10^5	5.90×10^3	1.54×10^5	1.31×10^4	1.41×10^5
3.00×10^5	6.64×10^5	3.47×10^4	6.29×10^5	4.18×10^4	5.87×10^5
5.00×10^5	1.92×10^6	6.77×10^4	1.85×10^6	5.88×10^4	1.79×10^6
8.00×10^5	5.43×10^6	1.74×10^5	5.26×10^6	1.24×10^5	5.14×10^6
1.00×10^6	7.80×10^6	1.91×10^5	7.61×10^6	8.67×10^4	7.52×10^6
Selenium-79					
1.00×10^4	7.38×10^2	3.68×10^2	3.70×10^2	3.70×10^2	0.0
5.00×10^4	4.53×10^3	2.48×10^3	2.04×10^3	2.04×10^3	0.0
1.00×10^5	8.98×10^3	3.78×10^3	5.20×10^3	5.20×10^3	0.0
3.00×10^5	1.34×10^4	4.36×10^3	9.08×10^3	9.08×10^3	0.0
5.00×10^5	1.69×10^4	4.75×10^3	1.21×10^4	1.21×10^4	0.0
8.00×10^5	1.87×10^4	4.77×10^3	1.39×10^4	1.39×10^4	0.0
1.00×10^6	1.68×10^4	3.67×10^3	1.31×10^4	1.31×10^4	0.0
Technetium-99					
1.00×10^4	8.28×10^4	8.58×10^3	7.42×10^4	6.82×10^4	6.06×10^3
5.00×10^4	4.52×10^5	3.96×10^4	4.12×10^5	9.10×10^4	3.21×10^5
1.00×10^5	8.23×10^5	4.18×10^4	7.81×10^5	7.30×10^4	7.08×10^5
3.00×10^5	1.33×10^6	5.67×10^4	1.27×10^6	7.64×10^4	1.19×10^6
5.00×10^5	1.86×10^6	6.09×10^4	1.79×10^6	5.60×10^4	1.74×10^6
8.00×10^5	1.91×10^6	6.02×10^4	1.85×10^6	5.19×10^4	1.80×10^6
1.00×10^6	1.38×10^6	3.16×10^4	1.34×10^6	2.56×10^4	1.32×10^6

B.4.2.2 Non-Radiological Contaminants

This section presents mass balances for nickel, vanadium, and molybdenum (Tables B-9 through B-12). Unlike the radionuclides, these non-radiological contaminants do not decay so there is no decay or growth adjustment. The major uranium isotopes were included in the radionuclide mass balances. Uranium-238 represents nearly all the uranium.

Table B-9. Mass balance (grams), pumping, present climate.

Time (year)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Amargosa Farms	Accumulated at Amargosa Farms
Molybdenum					
1.00×10^{4}	1.74×10^{9}	1.94×10^{8}	1.55×10^{9}	1.19×10^{8}	1.43×10^{9}
5.00×10^{4}	8.89×10^{9}	4.22×10^{8}	8.46×10^{9}	1.19×10^{8}	8.34×10^{9}
1.00×10^{5}	1.78×10^{10}	7.07×10^{8}	1.71×10^{10}	1.19×10^{8}	1.70×10^{10}
3.00×10^{5}	5.35×10^{10}	1.85×10^{9}	5.17×10^{10}	1.19×10^{8}	5.16×10^{10}
5.00×10^{5}	8.94×10^{10}	3.13×10^{9}	8.63×10^{10}	1.19×10^{8}	8.62×10^{10}
8.00×10^{5}	1.87×10^{11}	1.18×10^{10}	1.75×10^{11}	1.19×10^{8}	1.75×10^{11}
1.00×10^{6}	2.52×10^{11}	1.75×10^{10}	2.34×10^{11}	1.19×10^{8}	2.34×10^{11}
Nickel					
1.00×10^{4}	8.12×10^{9}	6.95×10^{9}	1.17×10^{9}	1.17×10^{9}	0.0
5.00×10^{4}	4.14×10^{10}	2.10×10^{10}	2.04×10^{10}	2.04×10^{10}	0.0
1.00×10^{5}	8.30×10^{10}	3.31×10^{10}	4.99×10^{10}	4.99×10^{10}	7.21×10^{-6}
3.00×10^{5}	2.50×10^{11}	6.99×10^{10}	1.80×10^{11}	1.40×10^{11}	4.01×10^{10}
5.00×10^{5}	4.17×10^{11}	8.87×10^{10}	3.28×10^{11}	1.60×10^{11}	1.68×10^{11}
8.00×10^{5}	8.77×10^{11}	1.55×10^{11}	7.22×10^{11}	2.89×10^{11}	4.33×10^{11}
1.00×10^{6}	1.18×10^{12}	1.90×10^{11}	9.93×10^{11}	2.94×10^{11}	6.99×10^{11}
Vanadium					
1.00×10^{4}	6.83×10^{6}	5.02×10^{6}	1.80×10^{6}	1.80×10^{6}	0.0
5.00×10^{4}	3.48×10^{7}	1.47×10^{7}	2.01×10^{7}	2.01×10^{7}	1.13×10^{-11}
1.00×10^{5}	6.98×10^{7}	2.39×10^{7}	4.59×10^{7}	4.58×10^{7}	7.16×10^{4}
3.00×10^{5}	2.10×10^{8}	5.06×10^{7}	1.59×10^{8}	6.69×10^{7}	9.23×10^{7}
5.00×10^{5}	3.50×10^{8}	7.35×10^{7}	2.76×10^{8}	6.80×10^{7}	2.08×10^{8}
8.00×10^{5}	5.60×10^{8}	1.05×10^{8}	4.55×10^{8}	6.93×10^{7}	3.86×10^{8}
1.00×10^{6}	7.00×10^{8}	1.25×10^{8}	5.74×10^{8}	6.93×10^{7}	5.05×10^{8}

Table B-10. Mass balance (grams), pumping, wetter climate.

Time (year)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometers and Amargosa Farms	Accumulated at Amargosa Farms
Molybdenum					
1.00×10^{4}	1.74×10^{9}	1.94×10^{8}	1.55×10^{9}	8.63×10^{7}	1.46×10^{9}
5.00×10^{4}	8.89×10^{9}	4.22×10^{8}	8.46×10^{9}	8.63×10^{7}	8.38×10^{9}
1.00×10^{5}	1.78×10^{10}	7.07×10^{8}	1.71×10^{10}	8.63×10^{7}	1.70×10^{10}
3.00×10^{5}	5.35×10^{10}	1.85×10^{9}	5.17×10^{10}	8.63×10^{7}	5.16×10^{10}
5.00×10^{5}	8.94×10^{10}	3.13×10^{9}	8.63×10^{10}	8.63×10^{7}	8.62×10^{10}
8.00×10^{5}	1.87×10^{11}	1.18×10^{10}	1.75×10^{11}	8.63×10^{7}	1.75×10^{11}
1.00×10^{6}	2.52×10^{11}	1.75×10^{10}	2.34×10^{11}	8.63×10^{7}	2.34×10^{11}
Nickel					
1.00×10^{4}	8.12×10^{9}	6.95×10^{9}	1.17×10^{9}	1.17×10^{9}	0.0
5.00×10^{4}	4.14×10^{10}	2.10×10^{10}	2.04×10^{10}	2.04×10^{10}	1.40×10^{7}
1.00×10^{5}	8.30×10^{10}	3.31×10^{10}	4.99×10^{10}	3.25×10^{10}	1.75×10^{10}
3.00×10^{5}	2.50×10^{11}	6.99×10^{10}	1.80×10^{11}	3.69×10^{10}	1.43×10^{11}
5.00×10^{5}	4.17×10^{11}	8.87×10^{10}	3.28×10^{11}	4.20×10^{10}	2.86×10^{11}
8.00×10^{5}	8.77×10^{11}	1.55×10^{11}	7.22×10^{11}	7.51×10^{10}	6.47×10^{11}
1.00×10^{6}	1.18×10^{12}	1.90×10^{11}	9.93×10^{11}	7.51×10^{10}	9.18×10^{11}
Vanadium					
1.00×10^{4}	6.83×10^{6}	5.02×10^{6}	1.80×10^{6}	1.80×10^{6}	0.0
5.00×10^{4}	3.48×10^{7}	1.47×10^{7}	2.01×10^{7}	1.40×10^{7}	6.09×10^{6}
1.00×10^{5}	6.98×10^{7}	2.39×10^{7}	4.59×10^{7}	1.55×10^{7}	3.04×10^{7}
3.00×10^{5}	2.10×10^{8}	5.06×10^{7}	1.59×10^{8}	1.74×10^{7}	1.42×10^{8}
5.00×10^{5}	3.50×10^{8}	7.35×10^{7}	2.76×10^{8}	1.74×10^{7}	2.59×10^{8}
8.00×10^{5}	5.60×10^{8}	1.05×10^{8}	4.55×10^{8}	1.77×10^{7}	4.38×10^{8}
1.00×10^{6}	7.00×10^{8}	1.25×10^{8}	5.74×10^{8}	1.77×10^{7}	5.57×10^{8}

Table B-11. Mass balance (grams), no-pumping, present climate.

Time (years)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometers	Held in path between 18 kilometer and Death Valley	Released into Death Valley
Molybdenum					
1.00×10^4	1.74×10^9	1.94×10^8	1.55×10^9	1.55×10^9	0.0
5.00×10^4	8.89×10^9	4.22×10^8	8.46×10^9	6.30×10^9	2.17×10^9
1.00×10^5	1.78×10^{10}	7.07×10^8	1.71×10^{10}	6.30×10^9	1.08×10^{10}
3.00×10^5	5.35×10^{10}	1.85×10^9	5.17×10^{10}	6.30×10^9	4.54×10^{10}
5.00×10^5	8.94×10^{10}	3.13×10^9	8.63×10^{10}	6.30×10^9	8.00×10^{10}
8.00×10^5	1.87×10^{11}	1.18×10^{10}	1.75×10^{11}	1.07×10^{10}	1.64×10^{11}
1.00×10^6	2.52×10^{11}	1.75×10^{10}	2.34×10^{11}	1.07×10^{10}	2.23×10^{11}
Nickel					
1.00×10^4	8.12×10^9	6.95×10^9	1.17×10^9	1.17×10^9	0.0
5.00×10^4	4.14×10^{10}	2.10×10^{10}	2.04×10^{10}	2.04×10^{10}	0.0
1.00×10^5	8.30×10^{10}	3.31×10^{10}	4.99×10^{10}	4.99×10^{10}	0.0
3.00×10^5	2.50×10^{11}	6.99×10^{10}	1.80×10^{11}	1.80×10^{11}	0.0
5.00×10^5	4.17×10^{11}	8.87×10^{10}	3.28×10^{11}	3.28×10^{11}	0.0
8.00×10^5	8.77×10^{11}	1.55×10^{11}	7.22×10^{11}	7.22×10^{11}	0.0
1.00×10^6	1.18×10^{12}	1.90×10^{11}	9.93×10^{11}	9.93×10^{11}	0.0
Vanadium					
1.00×10^4	6.83×10^6	5.02×10^6	1.80×10^6	1.80×10^6	0.0
5.00×10^4	3.48×10^7	1.47×10^7	2.01×10^7	2.01×10^7	0.0
1.00×10^5	6.98×10^7	2.39×10^7	4.59×10^7	4.59×10^7	0.0
3.00×10^5	2.10×10^8	5.06×10^7	1.59×10^8	1.59×10^8	0.0
5.00×10^5	3.50×10^8	7.35×10^7	2.76×10^8	2.76×10^8	0.0
8.00×10^5	5.60×10^8	1.05×10^8	4.55×10^8	4.55×10^8	0.0
1.00×10^6	7.00×10^8	1.25×10^8	5.74×10^8	5.74×10^8	0.0

Table B-12. Mass balance (grams), no-pumping, wetter climate.

Time (year)	Released from the unsaturated zone to the saturated zone	Held in path between the unsaturated zone and 18 kilometers	Released beyond 18 kilometer	Held in path between 18 kilometers and Death Valley	Released into Death Valley
Molybdenum					
1.00×10^{4}	1.74×10^{9}	1.94×10^{8}	1.55×10^{9}	1.55×10^{9}	6.50×10^{-6}
5.00×10^{4}	8.89×10^{9}	4.22×10^{8}	8.46×10^{9}	2.62×10^{9}	5.85×10^{9}
1.00×10^{5}	1.78×10^{10}	7.07×10^{8}	1.71×10^{10}	2.62×10^{9}	1.45×10^{10}
3.00×10^{5}	5.35×10^{10}	1.85×10^{9}	5.17×10^{10}	2.62×10^{9}	4.91×10^{10}
5.00×10^{5}	8.94×10^{10}	3.13×10^{9}	8.63×10^{10}	2.62×10^{9}	8.37×10^{10}
8.00×10^{5}	1.87×10^{11}	1.18×10^{10}	1.75×10^{11}	4.39×10^{9}	1.71×10^{11}
1.00×10^{6}	2.52×10^{11}	1.75×10^{10}	2.34×10^{11}	4.39×10^{9}	2.30×10^{11}
Nickel					
1.00×10^{4}	8.12×10^{9}	6.95×10^{9}	1.17×10^{9}	1.17×10^{9}	0.0
5.00×10^{4}	4.14×10^{10}	2.10×10^{10}	2.04×10^{10}	2.04×10^{10}	0.0
1.00×10^{5}	8.30×10^{10}	3.31×10^{10}	4.99×10^{10}	4.99×10^{10}	0.0
3.00×10^{5}	2.50×10^{11}	6.99×10^{10}	1.80×10^{11}	1.80×10^{11}	0.0
5.00×10^{5}	4.17×10^{11}	8.87×10^{10}	3.28×10^{11}	3.28×10^{11}	0.0
8.00×10^{5}	8.77×10^{11}	1.55×10^{11}	7.22×10^{11}	7.22×10^{11}	0.0
1.00×10^{6}	1.18×10^{12}	1.90×10^{11}	9.93×10^{11}	9.93×10^{11}	0.0
Vanadium					
1.00×10^{4}	6.83×10^{6}	5.02×10^{6}	1.80×10^{6}	1.80×10^{6}	0.0
5.00×10^{4}	3.48×10^{7}	1.47×10^{7}	2.01×10^{7}	2.01×10^{7}	0.0
1.00×10^{5}	6.98×10^{7}	2.39×10^{7}	4.59×10^{7}	4.59×10^{7}	0.0
3.00×10^{5}	2.10×10^{8}	5.06×10^{7}	1.59×10^{8}	1.59×10^{8}	0.0
5.00×10^{5}	3.50×10^{8}	7.35×10^{7}	2.76×10^{8}	2.76×10^{8}	0.0
8.00×10^{5}	5.60×10^{8}	1.05×10^{8}	4.55×10^{8}	4.55×10^{8}	0.0
1.00×10^{6}	7.00×10^{8}	1.25×10^{8}	5.74×10^{8}	5.74×10^{8}	8.13

B.4.3 SOIL CONCENTRATIONS AT THE AMARGOSA FARMS AREA

Soil concentrations at the Amargosa Farms area refer to concentrations of contaminants contained in a surface soil layer. This surface layer contains some of the contaminants. The balance of the contaminants remains in the entire soil column of the unsaturated zone or migrate to the saturated zone, where some are recycled. Note that according to the assumptions in the analysis for this Analysis of Postclosure Groundwater Impacts, some fraction of contaminants (about 14 percent) are removed because the water is not used for irrigation. This percentage could be in homes, swamp cooler filters, septic systems—any place other than irrigation.

Note that to obtain these concentrations as grams-per-cubic-meter values, divide by the thickness of the soil surface layer (0.25 meter). Note also that grams-per-cubic-meter is equivalent to milligrams per liter.

Table B-13 lists soil concentrations of radionuclides which have significant soil adsorption and are the most important to dose at certain times. Table B-14 lists soil concentrations of non-radiological contaminants.

Table B-13. Soil concentrations of radionuclides at the Amargosa Farms area.

	Soil concentration (grams per square meter)					
Time (year)	Np-237	Pu-242	U-235	Th-230	U-238	U-233
Present Climate						
10,000	0.0	0.0	0.0	0.0	0.0	0.0
100,000	3.18×10^{-6}	0.0	3.41×10^{-5}	6.23×10^{-7}	1.41×10^{-3}	3.30×10^{-7}
500,000	2.72×10^{-5}	0.0	1.38×10^{-4}	2.41×10^{-6}	5.92×10^{-3}	1.75×10^{-6}
1,000,000	5.48×10^{-5}	7.23×10^{-12}	3.60×10^{-4}	2.70×10^{-6}	1.58×10^{-2}	4.03×10^{-6}
Wetter Climate						
10,000	0.0	0.0	1.78×10^{-14}	1.18×10^{-16}	7.38×10^{-13}	1.74×10^{-16}
100,000	4.36×10^{-6}	0.0	1.80×10^{-5}	1.19×10^{-7}	7.45×10^{-4}	2.09×10^{-7}
500,000	1.75×10^{-5}	2.25×10^{-6}	8.34×10^{-5}	4.78×10^{-7}	3.43×10^{-3}	9.33×10^{-7}
1,000,000	3.90×10^{-5}	1.04×10^{-5}	2.18×10^{-4}	5.23×10^{-7}	9.45×10^{-3}	2.43×10^{-6}

Table B-14. Soil concentrations of non-radiological contaminants at the Amargosa Farms area.

	Soil concentration (grams per square meter)			
Time (year)	Molybdenum	Nickel	Vanadium	Uranium
Present climate				
10,000	3.06×10^{-3}	0.0	0.0	0.0
100,000	3.06×10^{-3}	1.80×10^{-14}	1.76×10^{-5}	1.16×10^{-3}
500,000	3.06×10^{-3}	2.48	6.20×10^{-4}	5.27×10^{-3}
1,000,000	5.24×10^{-3}	5.05	6.32×10^{-4}	1.33×10^{-2}
Wetter climate				
10,000	3.06×10^{-3}	0.0	0.0	5.26×10^{-9}
100,000	3.06×10^{-3}	2.01	5.45×10^{-4}	6.13×10^{-4}
500,000	3.06×10^{-3}	2.81	6.20×10^{-4}	2.84×10^{-3}
1,000,000	5.24×10^{-3}	5.05	6.32×10^{-4}	7.77×10^{-3}

B.4.4 SOIL CONCENTRATIONS AT MIDDLE BASIN

At Middle Basin on the floor of Death Valley, concentrations of radiological and non-radiological contaminants were developed as an input to dose and daily intake estimates. Table B-15 presents these concentrations in terms of mass of contaminant per mass of evaporite, and they are reported as "soil concentrations." Note that the actual soil concentrations would be smaller because the evaporites would be mixed with clastic rock soils; however, the actual concentration cannot be readily determined. Because these soil concentrations were used to estimate dose and daily intake, the results shown in Section B.4.1.2.1 are conservatively high. The contaminants included in Table B-15 represent the radionuclides that contribute to dose and the only non-radiological contaminant that appears at Middle Basin during the 1-million-year period after closure of the analyzed repository.

The concentrations in Table B-15 are reported as grams of contaminant per gram of solid rather than grams per square meter as in Tables B-13 and B-14 in the previous section. The grams-per-square-meter values at Middle Basin are indeterminate because the characteristic depth is not known. To compare the values in Tables B-13 and B-14 with those given in Table B-15, divide the values in Tables B-13 and B-14 by 0.25 meter and then by the estimated bulk density of the soil (1.5×10^6 grams per cubic meter). As an example, the molybdenum concentration at the Amargosa Farms area for the present climate scenario (Table B-14) at 1 million years is 5.24×10^{-3} grams per cubic meter, which converts to

1.39×10^{-3} gram per gram of soil compared with a value of 4.76×10^{-4} gram per gram of soil in Table B-15.

Table B-15. Soil concentrations of selected contaminants at Middle Basin.

	Soil concentration (grams per gram of soil)			
Time (year)	Clorine-36	Iodine-129	Technetium-99	Molybdenum
Present Climate				
10,000	0.0	0.0	0.0	0.0
100,000	7.21×10^{-11}	2.51×10^{-9}	1.48×10^{-8}	2.78×10^{-4}
500,000	9.06×10^{-12}	1.06×10^{-8}	8.72×10^{-9}	2.78×10^{-4}
1,000,000	5.42×10^{-12}	1.65×10^{-8}	3.62×10^{-9}	4.76×10^{-4}
Wetter Climate				
10,000	1.15×10^{-11}	4.75×10^{-10}	2.50×10^{-9}	4.00×10^{-5}
100,000	1.40×10^{-11}	6.44×10^{-10}	3.50×10^{-9}	7.13×10^{-5}
500,000	2.47×10^{-12}	2.73×10^{-9}	2.44×10^{-9}	7.13×10^{-5}
1,000,000	1.48×10^{-12}	4.25×10^{-9}	1.01×10^{-9}	1.22×10^{-4}

B.4.5 INFLUENCE OF AN ADDITIONAL DISCHARGE AREA

The regional flow modeling discussed in Section B.1 did not identify additional discharge areas during the wetter climate. This is due to the restrictions/simplifications of this modeling. The U.S. Geological Survey identified drains and discharge areas in the Death Valley regional groundwater flow system for a future wetter climate (D’Agnese et al. 1999). Chapter 2 of this Analysis of Postclosure Groundwater Impacts discusses these potential discharge areas along or north of the State Line Deposits. The remainder of this section discusses impacts resulting from one important discharge point that could be in the flow paths identified in the regional flow modeling.

In addition to the Death Valley floor, the Furnace Creek springs area, and Alkali Flat, there is another discharge area that radionuclides might reach during the wetter climate. This area lies a few kilometers northwest of the Amargosa Farms area near the Nevada-California state line (D’Agnese et al. 1999, Figure 14) and would be an area of groundwater discharge during a future climate, similar to the wetter climate analyzed in this document. It is not clear what discharge rate might occur at such a spring, but it is reasonable to assume that it might be a few thousand acre-feet per year during a wetter climate (the Furnace Creek springs currently discharge about 2,300 acre-feet annually). Nor is it clear what portion of the contaminants would discharge at this potential location; however, if some portion of the plume were to discharge at the surface in this area, estimates have the resultant doses somewhere between those presented for the Amargosa Farms area (pumping scenario with recycle) and those the Repository Final SEIS estimated for the Regulatory Compliance Point (assuming full discharge of all contaminants). Discharge of a portion of the plume in this area would reduce the doses somewhat at the Amargosa Farms area in the pumping scenario and Death Valley in the no-pumping scenario because the discharge would alter the original mass balance prepared for this analysis. In the pumping scenario, the water from the discharge site would contain concentrations of radionuclides less than those at the Regulatory Compliance Point and somewhat higher than those at the Amargosa Farms area and would flow down the Amargosa River in a generally southerly direction. Assuming this surface water might be used for subsistence farming, the doses resulting from its use would be estimated to fall somewhere between those estimated for the Amargosa Farms area and those estimated in the Repository Final SEIS for the Regulatory Compliance Point. In the no-pumping scenario, this water discharging from the additional site would result in doses somewhere between those for the Regulatory Compliance Point and those calculated for the Furnace Creek springs area.

B.5 Sensitivity Test

As mentioned earlier in this appendix, there is some uncertainty in the flow paths of the contaminants and in the transport properties of the water-bearing structures through which the contaminants may or may not pass. The transport properties are the key properties in the analysis of how the contaminants could move in the environment beyond the Regulatory Compliance Point. Since this Analysis of Postclosure Groundwater Impacts is a deterministic, single-point analysis, it not only is appropriate to characterize uncertainties, it is necessary to understand their importance. To this end, DOE has conducted a sensitivity analysis.

In this sensitivity analysis, DOE considered the transport to Amargosa Farms in the no-pumping, wetter climate scenario. The bulk density and porosity were set at the mean values for alluvium. The partition coefficients were set at their 0 percentile or lower limit values (DOE 2008, Table 2.3.9-14) Table B-16 shows a comparison of the parameters used to the base case. Figure B-24 shows the results. As can be seen, the results only show a 15-percent difference. This indicates a relatively mild sensitivity of the results to the key transport parameter. Thus, it is not critical to pinpoint exact transport parameters to give an adequate result.

Table B-16. Comparison of sensitivity case and base case parameters.

Transport property	Sensitivity case[a]	Base case[b]
Porosity (no units; fraction of solid volume occupied by voids)	0.16	0.16
Bulk Density (grams per milliliter)	2.00	2.00
Dispersion Coefficient (meters)	100	100
Specific Discharge wetter climate (meters per day)	0.024	0.024
K_d for uranium (milliliters per gram)	1.7	4.2
K_d for neptunium (milliliters per gram)	1.8	6
K_d for plutonium (milliliters per gram)	50	93
K_d for cesium (milliliters per gram)	100	728
K_d for americium, thorium, protactinium, and actinium (milliliters per gram)	1000	4762
K_d for strontium (milliliters per gram)	20	210
K_d for radium (milliliters per gram)	100	550
K_d for selenium (milliliters per gram)	1	14
K_d for tin (milliliters per gram)	100	1,916
K_d for carbon, technetium, iodine, and chlorine (milliliters per gram)	0	0

a. Source: DOE 2008, Table 2.3.9-14.

b. Source: Table B-1, Pumping flow path column, from this appendix.

K_d = partition coefficient.

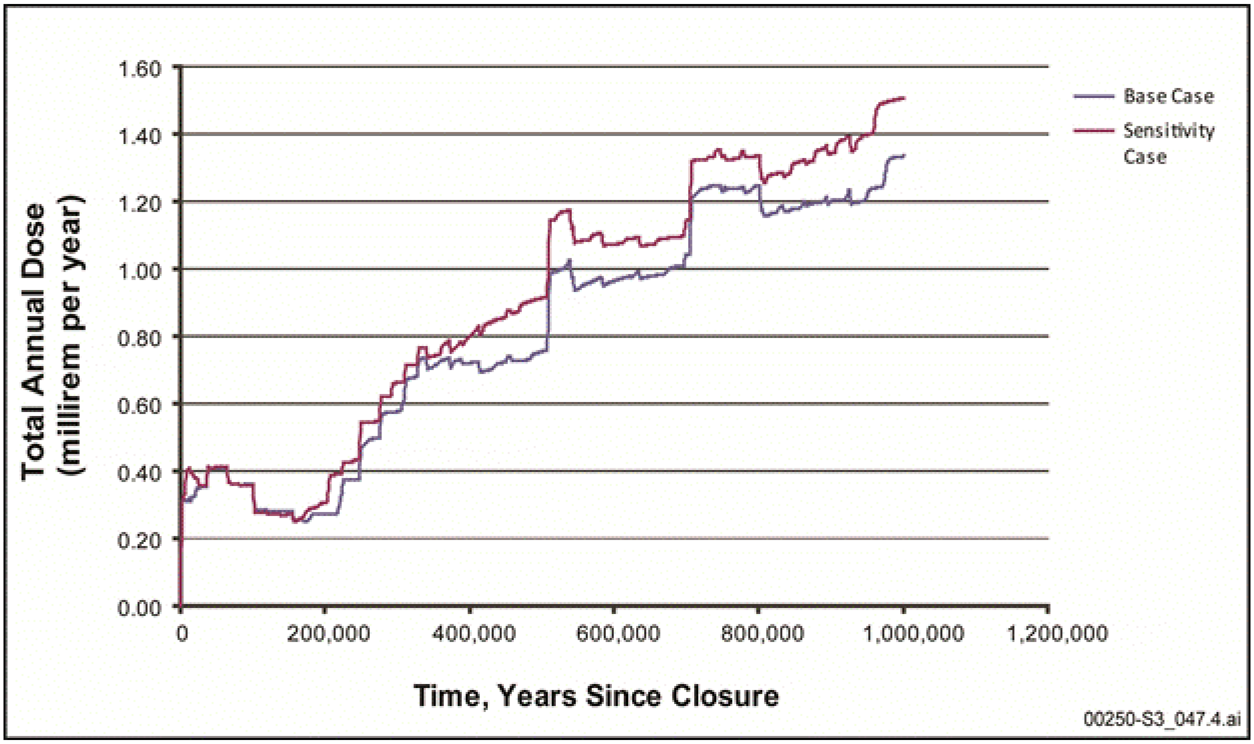


Figure B-24. Sensitivity case for the Amargosa Farms area, pumping, wetter climate.

B.6 New Science Considered for this Analysis

DOE considered new information to determine if it warranted changes in the analysis. This information arose from new publications and dialog in the early part of the Yucca Mountain licensing process. Some new information led to some minor changes in the analysis. These changes are presented in updates to the report text in various places. It should be noted that after the changes in the analysis described throughout the appendix there were no significant changes in any of the results. Other new information is discussed in the following subsections.

B.6.1 NEW INFORMATION ON SOIL PARTITION COEFFICIENTS FOR THE NON-RADIOLOGICAL CONTAMINANTS

DOE examined recent work on adsorption of metals. A weakness with the most recent work is that it is concentrated on agricultural soils rather than rock and alluvial materials such as found in the flow paths studied in this analysis. However, the results of the recent work give some insights into whether the values previously used in the 2009 Analysis are still reasonable and conservative. In each case identified below, partition coefficients derived from Langmuir isotherms are examined.

B.6.1.1 Nickel

Two journal articles on nickel adsorption were found to be the most relevant to this analysis. The first article (Ghasemi-Fasaei et al. 2012) provides results from which partition coefficients can be deduced. The results were given for four cases: (1) acidic soils when nickel competes with cadmium, (2) acidic soils with no competition, (3) basic soils with competition, and (4) basic soils with no competition. The overall range was about 75 to 400 milliliters per gram (Ghasemi-Fasaei et. al. 2012, Figure 2). These values are much higher than those used in the Yucca Mountain analysis, but these soils contained considerable amounts of organic material, which tend to boost the partition coefficient.

The second article (Adhami et al. 2008) gives values ranging from 15 to 68 milliliters per gram, with an average of 48 milliliters per gram (Adhami et. al. 2008, Table 5). These results are for a wide variety of soils. The low value in this range was used in this analysis.

B.6.1.2 Vanadium

DOE found one reasonably relevant article on vanadium adsorption (Gäbler et al. 2009), which examined vanadium adsorption on a variety of German soils. For sandy soils, the partition coefficient averaged about 200 milliliters per gram, while subsoils with pH higher than 5.5 exhibited partition coefficients of up to 1,000 milliliters per gram (Gäbler et al. 2009, Figure 5). Note that the soils exhibiting very high partition coefficients contained high amounts of organic material, which tends to increase adsorption. The soils and rocks in the paths relevant to this Analysis of Postclosure Groundwater Impacts do not contain much, if any, organic material.

B.6.1.3 Molybdenum

DOE examined several similar articles on molybdenum adsorption. All tended to have similar results that showed low values of partition coefficients, especially at neutral or higher pH. One example showed very low retardation factors (Mohammad and Moheman 2010, Figure 3) but this article did not give the porosity and density of the soils. If one assumed a density of 2 grams per milliliter and a porosity of 0.2 (fairly typical values), the resulting partition coefficient values would range from 0.05 to 1 milliliters per gram. This would indicate that DOE’s assumption that the partition coefficient equals zero was appropriate.

B.6.1.4 Conclusions

In reflecting on appropriate partition coefficient values for this analysis, it is important to make some observations:

- The ultimate concentrations at a discharge location are insensitive to the partition coefficient value picked. This is because these metals do not decay like the radionuclides. So the only effect of soil delay is to allow some dispersion to occur, which has a very weak effect on peak dose.

- The time of arrival is very sensitive to partition coefficient, and the path lengths to the discharge locations are large enough that a value very much larger than zero tends to delay the metal long enough that it never appears at the discharge location during the 1-million-year analysis period of this analysis. With the currently used values, only molybdenum arrives at the Furnace Creek or Death Valley floor during the 1 million years. Any significant increase in vanadium or nickel partition coefficient values would cause the materials to disappear completely from any impacts at Amargosa Farms.

DOE concludes that the new information does not warrant any changes in the partition coefficient values for nickel, vanadium, or molybdenum. The uranium values were taken from TSPA work that has not been updated. Uranium only appears at the Amargosa Farms location with very low concentrations. In consideration of all of the above, this updated analysis did not make any changes in the partition coefficients for the non-radiological contaminants. The new information could have justified increases in partition coefficients for all of these contaminants. This would have resulted in even longer travel times to Amargosa Farms but would have virtually no effect on the ultimate peak intakes there. The effects at

Furnace Creek and the Death Valley Floor are detailed in the second bullet above and show that not changing the partition coefficient leads to a conservative effect.

B.6.2 DEVELOPMENT OF A NEW IRRIGATION RECYCLE MODEL

The analysis in this report uses a limiting case of the irrigation recycle model to assess the effect of radionuclides percolating back into the soil from crop irrigation and then being taken up again by well capture. This would tend to increase the effective concentration of radionuclides in the well water used by the population at Amargosa Farms. This recycling was discussed in Section B.2.3.1.

Since the initial issuance of the 2009 Analysis of Postclosure Groundwater Impacts, a more advanced model of irrigation recycle was developed (Kalinina and Arnold 2013). This new version of the model incorporated the following features:

- Capability to specify a source of solute mass applied to an irrigated field based on the solute mass removed from the pumping well; and
- Erosional removal of sorbing contaminants from the top soil during the periods of time when irrigation takes place.

The existence of this new model has no bearing on this analysis because DOE used a very conservative, simplified, limiting condition model that created a much higher dose than the more rigorous 2007 model. This limiting case is still relevant to the 2013 Kalinina and Arnold model, hence the existence of the new model does not warrant any changes in the analysis.

B.6.3 INTAKE FROM SOIL INGESTION AT AMARGOSA FARMS

This update evaluates the consideration of whether soil ingestion should be included in the calculation of intakes of the non-radiological contaminants at Amargosa Farms. Intakes from soil ingestion were the only mechanisms considered in the dry discharge sites where there was either no water or unusable water. It would seem that both water sources and soil sources should be considered at the pumped location since the non-radiological contaminants accumulate in the soil.

A sample calculation was performed for the Amargosa Farms area. This calculation was performed by taking the soil concentrations already available from the transport analysis and calculating the intake from ingestion. It was found that for a 100-milligram ingestion per day (the same value used at the dry discharge sites), the contribution to intake was several orders of magnitude smaller than the intake from water ingestion. It was therefore concluded that inclusion of soil ingestion at Amargosa Farms was unnecessary because it has no significant effect on the results.

B.6.4 SUPPORT FROM SANDIA NATIONAL LABORATORIES

The 2009 Analysis of Postclosure Groundwater Impacts relied, in part, on support work done by Sandia National Laboratories (SNL 2009). This support was in large part the hydrological modeling necessary to define the flow paths and flow parameters for the analysis of the transport of contaminants. Some other miscellaneous support work was also done by SNL, including application of the Biosphere Model for determining doses from radiological contaminants. As support to this update, Sandia staff reviewed their previous report (SNL 2009), documenting their support work, and determined that with the exception of the change to the biosphere model to account for parent-daughter disequilibrium described in Section B.2.2, no further updates to the analyses were warranted (Bryan et al. 2014).

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