

canister	<p>An unshielded metal container used as:</p> <ul style="list-style-type: none">• A pour mold in which molten vitrified <i>high-level radioactive waste</i> could solidify and cool.• A container in which DOE and electric utilities would place intact <i>spent nuclear fuel</i>, loose rods, or nonfuel components for shipping or storage. <p>In general, a container that provides <i>radionuclide</i> confinement. Canisters would be used in combination with specialized overpacks that provide structural support, <i>shielding</i>, or confinement for storage, transportation, and <i>emplacement</i>. Overpacks used for transportation are usually referred to as transportation casks; those used for emplacement in a <i>repository</i> are referred to as <i>waste packages</i>.</p>
carbonate aquifer	<p>A <i>permeable</i> unit of <i>carbonate rock</i>, such as limestone or dolomite, that also qualifies as an <i>aquifer</i>. For this analysis, it is one of the three general aquifer types described for the <i>Death Valley regional groundwater flow system</i>.</p>
carbonate rock	<p>The <i>geologic</i> strata found over extensive portions of the Great Basin. Within the boundaries of the <i>Death Valley regional groundwater flow system</i>, this stratum is primarily limestone or dolomite.</p>
cladding	<p>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 <i>accessible environment</i>.</p>
clastic	<p>Of or belonging to or being a rock composed of fragments of older rocks (for example, conglomerates or sandstone).</p>
closure (analytical period)	<p>Includes 10 years of activities that would begin upon receipt of a license amendment to close the repository. Activities would include decommissioning and demolishing surface facilities, emplacing <i>drip shields</i>, backfilling, sealing subsurface-to-surface openings, restoring the surface to its approximate condition before repository construction, and constructing monuments to mark the site. See <i>repository closure</i>.</p>
commercial spent nuclear fuel	<p>Rods that have been removed from a <i>nuclear reactor</i> after use as nuclear fuel at commercial nuclear power plants. See <i>spent nuclear fuel</i> and <i>DOE spent nuclear fuel</i>.</p>
confining unit	<p>In <i>geology</i>, a confining unit is a rock or sediment unit of relatively low <i>permeability</i> that retards the movement of water in or out of adjacent <i>aquifers</i>.</p>

contaminant	Foreign materials that could be released from the repository into the <i>accessible environment</i> over time. For this Analysis of Postclosure Groundwater Impacts, there are two types of contaminants: radiological and nonradiological.
corrosion	The <i>process</i> of dissolving or wearing away gradually, especially by chemical action.
Death Valley floor	See <i>floor of Death Valley</i> .
Death Valley region	The area described by the outer boundaries of the <i>Death Valley regional groundwater flow system model</i> .
Death Valley regional groundwater flow system model	A multi-agency-funded effort by the U.S. Geological Survey to develop a <i>steady-state groundwater</i> 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 <i>geologic repository</i> 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 <i>Death Valley region</i> .
decay (radioactive)	The <i>process</i> in which a <i>radionuclide</i> 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 <i>groundwater</i> leaves the ground. Discharge points typically occur as springs or seepage into wetlands, lakes, and streams. Discharge also occurs as <i>evapotranspiration</i> .
disposal	For this analysis, the <i>emplacement</i> in a <i>repository</i> of <i>high-level radioactive waste</i> , <i>spent nuclear fuel</i> , or other <i>radioactive material</i> with no foreseeable intent of recovery, whether or not such emplacement would permit the recovery of such waste, and the <i>isolation</i> of such waste from the <i>accessible environment</i> .
DOE spent nuclear fuel	Nuclear fuel that has been withdrawn from a <i>nuclear reactor</i> , 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 the proposed <i>repository</i> , this includes excavations for <i>emplacement</i> (emplacement drifts), ventilation (exhaust mains), access (access mains), and performance confirmation (observation drift).
drip shield	A corrosion-resistant <i>engineered barrier</i> that DOE would place above a <i>waste package</i> 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 <i>infiltration</i> .
emplacement	The placement and positioning of <i>waste packages</i> in the proposed <i>repository</i> .
emplacement pallet	Structure used to support the <i>waste package</i> in the emplacement <i>drift</i> .
Engineered Barrier System	The designed or engineered components that would contribute to waste containment and isolation in the underground facility at Yucca Mountain: <i>waste package</i> , <i>emplacement pallet</i> , emplacement <i>drift</i> invert, <i>drip shield</i> , and emplacement drift.
colian 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 <i>nuclear reactor</i> .
fuel rods	Sealed tubes filled with cylindrical fuel pellets made of a <i>radioactive</i> material, typically uranium oxide enriched in uranium-235, for use in a <i>nuclear reactor</i> .

geohydrology	The science that deals with the distribution and movement of <i>groundwater</i> in the soil and rocks.
geologic	Of or related to a natural <i>process</i> 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 <i>spent nuclear fuel</i> and <i>high-level radioactive waste</i> in excavated <i>geologic</i> media, which includes surface and <i>subsurface</i> areas of operation and the adjacent part of the geologic setting that provides <i>isolation</i> of radioactive materials in a controlled area.
geologic stability	The million years after <i>disposal</i> , 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 <i>lithologic</i> formations.
high-level radioactive waste	<ol style="list-style-type: none">1. The highly <i>radioactive</i> material that resulted from the reprocessing of <i>spent nuclear fuel</i>, which includes liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains <i>fission</i> products in sufficient concentrations. (Note: DOE would <i>vitrify</i> liquid high-level radioactive waste before shipping it to the proposed <i>repository</i>.)2. Other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent <i>isolation</i>.
hydraulic gradient (aquifer)	<p>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.</p> <p>For this analysis, the hydraulic gradient is used to determine the quantity of the <i>groundwater discharge</i>.</p>
hydrogeologic	The subject area of <i>geology</i> that deals with the distribution and movement of <i>groundwater</i> in the soil and rocks. In the <i>Death Valley regional groundwater flow system model</i> , 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 of Postclosure Groundwater Impacts, and based on the TSPA-LA, infiltration is the precipitation that is not lost to <i>evapotranspiration</i> or runoff and makes it into the <i>unsaturated zone</i> 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 <i>glacial</i> and <i>interglacial</i> 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 <i>radioactive</i> material so the amounts and concentrations of the material that enters the <i>accessible environment</i> 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 <i>groundwater</i> and <i>contaminants</i> along the flowpath (in both directions) as water flows in an <i>aquifer</i> .
lower carbonate aquifer	In this Analysis of Postclosure Groundwater Impacts, this is the saturated <i>carbonate rock</i> that is extensive over the region, often at great depths, and often referred to as the regional <i>aquifer</i> . An <i>upper carbonate aquifer</i> 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 <i>spent nuclear fuel</i> are traditionally expressed in terms of MTHM (typically uranium, but including plutonium and thorium), without the inclusion of other materials such as <i>cladding</i> 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 <i>nuclear reactors</i> .
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.
nonradiological contaminants	<i>Contaminants</i> that could be released from the 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 <i>repository</i> and <i>waste packages</i> . Uranium, while a <i>radioactive</i> element, is also evaluated for its chemical toxicity as a nonradiological contaminant.
no-pumping scenario	Simulation of conditions of the <i>Death Valley regional groundwater flow system</i> before any significant <i>groundwater</i> 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 <i>radiation</i> .
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 <i>glacial</i> and <i>interglacial</i> periods: eccentricity, precession, and obliquity.

paleoclimatology	Study of past climatic conditions, in timescales of hundreds of thousands of years
paleodischarge	Prehistoric <i>discharge</i> .
paleohydrology	Study of past hydrologic conditions.
partition coefficient	The ratio of the concentration of the <i>contaminant adsorbed</i> (grams per mass of solid) to the concentration of the contaminant remaining in solution of <i>groundwater</i> (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 analytical timeframe after <i>repository closure</i> through the 1 million years.
potentiometric surface	A hypothetical surface representing the level to which <i>groundwater</i> would rise if not trapped in a confined <i>aquifer</i> . 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) <i>commercial spent nuclear fuel</i> at the commercial sites in multipurpose <i>TAD canisters</i> . The remaining commercial spent nuclear fuel (about 10 percent) would arrive at the <i>repository</i> as <i>uncanistered spent nuclear fuel</i> 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 <i>probability</i> 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 <i>process</i> .

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 SEIS is the <i>construction, operation, monitoring</i> , and eventual <i>closure</i> of a <i>geologic repository</i> for <i>spent nuclear fuel</i> and <i>high-level radioactive waste</i> at Yucca Mountain in Nevada.
pumping scenario	Simulation of <i>steady-state</i> conditions with <i>groundwater</i> pumping at 2003 levels.
radioactive	Emitting <i>radioactivity</i> .
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 <i>nuclear reactor</i> .
reasonably maximally exposed individual	A hypothetical person who is exposed to environmental <i>contaminants</i> (in this case <i>radionuclides</i>) 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 <i>repository</i> 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 <i>receptor</i> at a regulation-specific location.
receptor	A hypothetical person who is exposed to environmental <i>contaminants</i> in such a way (that is, by a combination of factors including location, lifestyle and dietary habits) that this individual is representative of the exposure of the general population. 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 <i>aquifer</i> . Recharge occurs where <i>permeable</i> soil or rock allows water to readily seep into the ground.

Regulatory Compliance Point	The point over the highest concentration of <i>contaminants</i> in a hypothetical plume located at a point on the Nevada Test Site boundary (36°40'13.66661" North Latitude) that is approximately 18 kilometers along the <i>groundwater</i> flow path (south) from the repository.
repository	A burial vault. See <i>Yucca Mountain Repository</i> .
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 <i>process</i> to extract plutonium and other materials from the reactor-irradiated nuclear materials, which includes <i>spent nuclear fuel</i> .
saturated zone	Water that seeps into the ground and continues downward under the force of gravity until it reaches a depth where water fills all of the openings (pores) in the soil or rock.
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 <i>process</i> by which a dissolved solid is attached to or bonded with a solid that is exposed to the solution.
spent	The state of fuel in a <i>nuclear reactor</i> after a period of operation.

spent nuclear fuel	<ol style="list-style-type: none">1. <i>Nuclear reactor</i> 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:<ol style="list-style-type: none">a. Intact, nondefective <i>fuel assemblies</i>,b. Failed fuel assemblies in <i>canisters</i>,c. Fuel assemblies in canisters,d. Consolidated <i>fuel rods</i> in canisters,e. Nonfuel assembly hardware inserted in pressurized-water reactor fuel assemblies,f. Fuel channels attached to boiling-water reactor fuel assemblies, andg. 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 <i>biosphere</i> respond to changes in <i>solar radiance</i> .
throughflow	<i>Groundwater</i> flowing from one groundwater basin into an adjoining groundwater basin.
transportation, aging, and disposal (TAD) canisters	A <i>canister</i> suitable for storage, shipping, and <i>disposal</i> of <i>commercial spent nuclear fuel</i> . Commercial spent nuclear fuel would be placed directly into a TAD canister at the commercial <i>reactor</i> . At the <i>repository</i> , DOE would remove the TAD canister from the transportation cask and place it directly into a <i>waste package</i> or an aging overpack. The TAD canister is one of a number of types of disposable canisters.
unsaturated zone	The region between the surface and the <i>water table</i> where water fills only some of the spaces (fractures and rock pores).
upper carbonate aquifer	One of the two <i>carbonate aquifers</i> recognized in the <i>Death Valley regional groundwater flow system model</i> .

vitriification	A waste treatment <i>process</i> that uses glass (for example, <i>borosilicate glass</i>) to encapsulate or immobilize <i>radioactive</i> wastes.
volcanic aquifer	One of three principal <i>aquifers</i> described in this analysis; found in <i>permeable</i> units of igneous rock.
waste package	A <i>disposal</i> container that consists of the <i>corrosion</i> -resistant outer container (<i>Alloy 22</i> outer cylinder) and structural inner container (stainless-steel inner cylinder), baskets, and shielding integral to the container. Waste packages would be ready for <i>emplacement</i> in the <i>repository</i> 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	<ol style="list-style-type: none">1. The upper limit of the <i>saturated zone</i> (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 <i>fractures</i> are less than 100 percent saturated with water most of the time (<i>unsaturated zone</i>) and below which the opposite is true (<i>saturated zone</i>).
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 <i>permeability</i>).
Yucca Mountain Repository	Inclusive term for all areas in the <i>Yucca Mountain site</i> where DOE would construct the proposed facilities to support the proposed <i>repository</i> , including roads.
Yucca Mountain site	The area inside the site boundary over which DOE would have control.

APPENDICES

A. COMMENTS RECEIVED ON OCTOBER 24, 2008 NOTICE OF INTENT TO PREPARE THE POSTCLOSURE GROUNDWATER SEIS

A.1 Purpose

This appendix presents the comments received in response to the U.S. Department of Energy (DOE or Department) 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, the Department has elected to include the comments and responses for the 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* (DIRS 183478-SNL 2008, all; 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 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 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 (DIRS 177391-SNL 2007, all) and the Death Valley regional groundwater flow system model (DIRS 173179-Belcher 2004, all)] were calibrated to groundwater elevations that resulted from historical regional pumping from 1913 to 1998, so the effects of that pumping is 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 (DIRS 148102-Cappaert et al. v. United States et al. 1976, all), 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 by the time the repository opened, assuming the continuation of current pumping conditions (DIRS

186186-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 (DIRS 186186-SNL 2009, all), 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 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 (DIRS 186215-Williams 2009, all) and generated Figure A-1 by comparing simulated head values in the lower carbonate aquifer with those of the water table. The figure also shows a cross section of simulated particle paths originating beneath the proposed repository at Yucca Mountain.

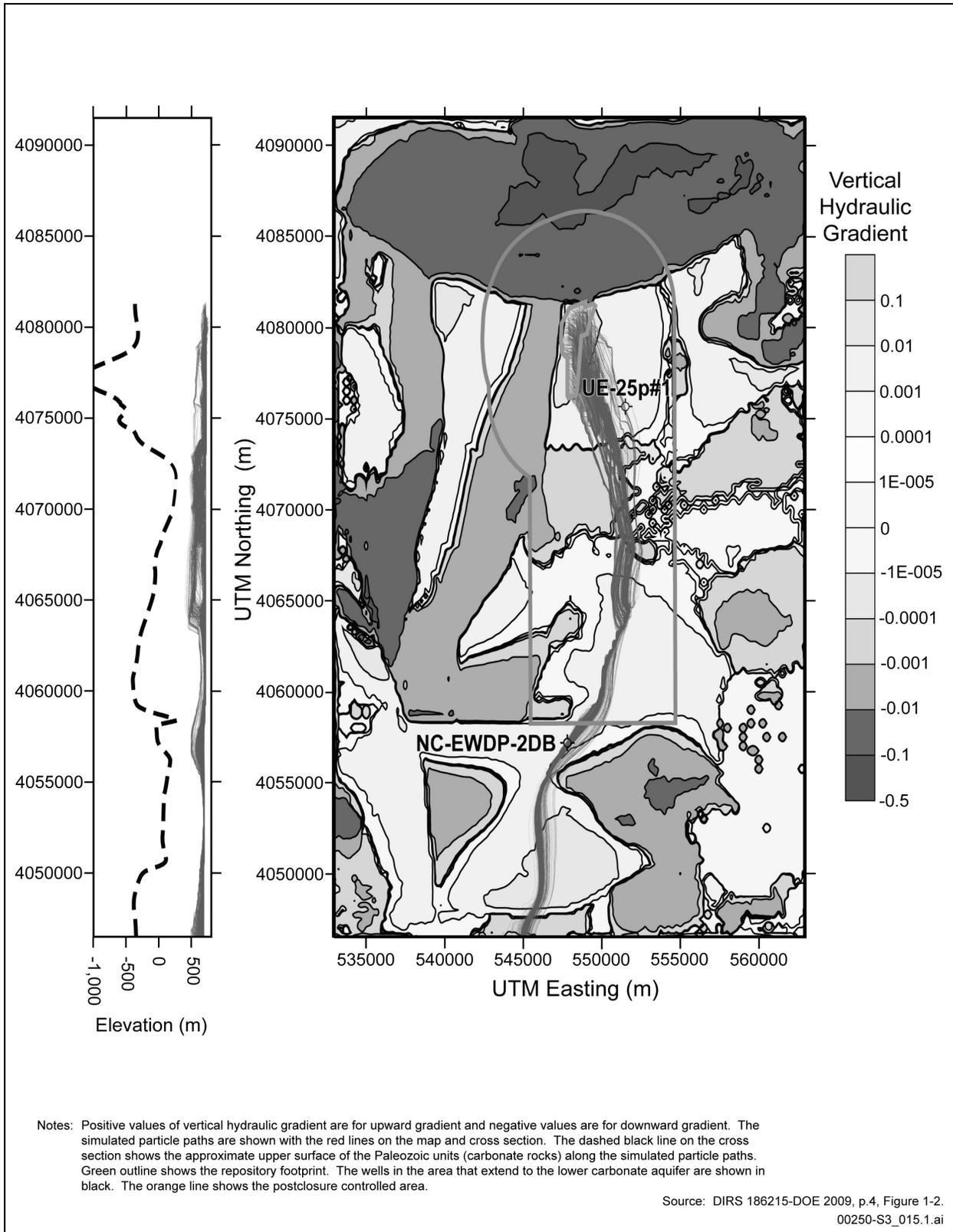


Figure A-1. Map of vertical hydraulic gradient between the water table and the top of the lower carbonate aquifer and cross section of simulated particle paths.

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 repository site. This is attributed to a section of higher, thrustured 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 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 repository), but is a potential flow path identified in the Yucca Mountain FEIS and Repository 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 (DIRS 186186-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 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 (DIRS 155970-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 (DIRS 186186-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) (DIRS 186215-Williams 2009, all) and the Death Valley regional groundwater flow system model (DIRS 186186-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 (DIRS 186186-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 (DIRS 186186-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 Test Site, as the Southern Nevada Water Authority proposes (DIRS 186186-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 (DIRS 186217-Ricci 2006, all). 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 (DIRS 186186-SNL 2009, all).

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 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 SEIS (DIRS 180751-DOE 2008, 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 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 SEIS Comment-Response Document [DIRS 180751-DOE 2008, 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, the 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 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 SEIS.

A.3.2 WHITE PINE COUNTY

Comment Summary

White Pine County recommended that a Postclosure Groundwater 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 repository site, including White Pine County. The County also recommended that a 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 SEIS (DIRS 180751-DOE 2008, 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 (DIRS 155970-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 (DIRS 169989-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 (DIRS 185814-DOE 2008, 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 (DIRS 185814-DOE 2008, 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* (DIRS 172283-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 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 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 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 a 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 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.1.2 above.

A.3.4 TIMBISHA SHOSHONE TRIBE

The following bullets are quoted from the Timbisha Shoshone Tribe comment letter; the Repository SEIS section that addresses the requested information follows each bullet. The Yucca Mountain FEIS, Repository 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” – See Repository SEIS, Sections 3.1.4.1 and 3.1.4.2 (DIRS 180751-DOE 2008, 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” – See Repository SEIS, Appendix F, pp. F-11 to F-13 (DIRS 180751-DOE 2008, Appendix F, pp. F-11 to F-13).
- “Information on the potential for groundwater Geothermal Hot Water Upwelling” – See Repository SEIS, Section 3.1.4.2.2, pp. 3-44 to 3-49; Volume III, comment response 1.7.4 (494) [DIRS 180751-DOE 2008, Section 3.1.4.2.2, pp. 3-44 to 3-49; DIRS 180751-DOE 2008, Volume III, comment response 1.7.4 (494)].
- “The effect of oxidizing groundwater and its potential to transport radionuclides” – See Repository SEIS, Section 5.1.2; Volume III, comment responses 1.6.5 (57) and 1.9 (4135) [DIRS 180751-DOE 2008, Section 5.1.2; DIRS 180751-DOE 2008, 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 the 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” – See Repository SEIS, Volume III, comment responses 1.7.4 (3708) and 1.7.4 (3749) [DIRS 180751-DOE 2008, 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)” – See

Repository 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) [DIRS 180751-DOE 2008, Section 3.1.4.2.1, p. 3-34; DIRS 180751-DOE 2008, 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 ground water as a result of seismic disruptive events. Flooding hazards at the repository site were addressed in the Repository SEIS Section 3.1.4.1 and the Yucca Mountain FEIS Section 3.1.4.1 (DIRS 180751-DOE 2008, Section 3.1.4.1; DIRS 155970-DOE 2002, 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” – See Chapter 3 of this Analysis of Postclosure Groundwater Impacts; Repository SEIS Section 5.7 (DIRS 180751-DOE 2008, Section 5.7).
- “A historical study on ground and surface water tables and water flow” – See Repository SEIS Sections 3.1.4.2.1 and 3.1.4.2 (DIRS 180751-DOE 2008, 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)” – See Chapter 3 of this Analysis of Postclosure Groundwater Impacts; Repository SEIS p. 3-44 and Section 5.5 (DIRS 180751-DOE 2008, p. 3-44; DIRS 180751-DOE 2008, 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” – See Repository SEIS Appendix F, Section F.2.7 (DIRS 180751-DOE 2008, 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)” – See Chapter 3 of this Analysis of Postclosure Groundwater Impacts; Repository SEIS Volume III, comment response 1.7.5 (157) [DIRS 180751-DOE 2008, Volume III, comment response 1.7.5 (157)].

REFERENCES

- 173179 Belcher 2004 Belcher, W.R. 2004. *Death Valley Regional Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model*. Scientific Investigations Report 2004-5205. Reston, Virginia: U.S. Geological Survey. ACC: MOL.20050323.0070.

- 169989 BSC 2004 BSC (Bechtel SAIC Company) 2004. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*. ANL-MGR-GS-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041015.0002; DOC.20050718.0007; LLR.20080311.0079.
- 148102 Cappaert et al. v. United States et al. 1976 *Cappaert et al. v. United States et al.*, 426 U.S. 128; 96 S. Ct. 2026. Decided June 7, 1976. ACC: MOL.20010730.0380.
- 155970 DOE 2002 DOE (U.S. Department of Energy) 2002. *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-0250. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020524.0314; MOL.20020524.0315; MOL.20020524.0316; MOL.20020524.0317; MOL.20020524.0318; MOL.20020524.0319; MOL.20020524.0320.
- 172283 DOE 2002 DOE (U.S. Department of Energy) 2002. *Recommendations for Analyzing Accidents under the National Environmental Policy Act*. Washington, D.C.: U.S. Department of Energy, Office of NEPA Policy and Compliance. ACC: MOL.20041122.0199.
- 180751 DOE 2008 DOE (U.S. Department of Energy) 2008. *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. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20080606.0001.
- 185814 DOE 2008 DOE (U.S. Department of Energy) 2008. *Yucca Mountain Repository License Application*. DOE/RW-0573, Update No. 1. Docket No. 63-001. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20081023.0041.

- 186217 Ricci 2006 Ricci, H. 2006. "Ruling #5621, In the Matter of Protested Applications 72787, 72788, 72789, 72790, 72791, 72792, 72793, 72794, 72795, 72796 and 72797 Filed to Change the Point of Diversion and Place of Use of Underground Water Previously Appropriated Under Permit 53950, Permit 53951, Permit 54060, Permit 54062, Permit 54066, Permit 54068 and Permit 54069 Within the Three Lakes Valley-Southern Part, Hydrographic Basin (211), Clark County, Nevada." Carson City, Nevada: State of Nevada, Office of the State Engineer. ACC: MOL.20090324.0117.
- 177391 SNL 2007 SNL (Sandia National Laboratories) 2007. *Saturated Zone Site-Scale Flow Model*. MDL-NBS-HS-000011 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070626.0004; DOC.20071001.0013; LLR.20080408.0261; LLR.20080512.0162; DOC.20080623.0001; DOC.20090227.0001.
- 183478 SNL 2008 SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application*. MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001.
- 186186 SNL 2009 SNL (Sandia National Laboratories) 2009. *Inputs to Jason Associates Corporation in Support of the Postclosure Repository Supplemental Environmental Impact Statement (SEIS-3)*. LSA-AR-037. Las Vegas, Nevada: Sandia National Laboratories.
- 186215 Williams 2009 Williams, J.R. 2009. "Yucca Mountain - Request for Additional Information Re: License Application (Safety Analysis Report Sections 2.3.9.2.2 and 2.3.9.2.3), Safety Evaluation Report Volume 3 - Postclosure Chapter 2.2.1.3.8 - Flow Path in the Saturated Zone, Set 1." Letter from J.R. Williams (DOE) to J.H. Sulima (NRC), January 30, 2009, OTM: CJM-0395, Docket Number 63-001, with enclosures ACC: MOL.20090202.0001.

B. ENVIRONMENTAL IMPACTS OF POSTCLOSURE REPOSITORY PERFORMANCE

This appendix details the analysis carried out to track radionuclides and nonradiological contaminants in the groundwater and surface water system after release from the repository during the postclosure period. 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 repository. For the radionuclides, DOE used results from *Total System Performance Assessment Model/Analysis for the License Application* (DIRS 183478-SNL 2008, all; 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 nonradiological contaminants at the unsaturated zone and subsequent transport to the Regulatory Compliance Point. DOE carried out the same analysis for the nonradiological contaminants as that performed for the radionuclides for locations beyond the Regulatory Compliance Point.

REGULATORY COMPLIANCE POINT

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

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; DIRS 180751-DOE 2008, all) (Repository 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 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 nonradiological contaminants (such as toxic metals with a nonradiological toxicity). When the word "contaminants" is used by itself, then the reference is to both types of contaminants.

- The 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 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 SEIS (DIRS 180751-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 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 fluxes 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 flux 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 fluxes 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 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 fluxes derived from previous TSPA-LA model runs as input (for example, the radionuclide fluxes at the Regulatory Compliance Point). When the TSPA-LA model produced these fluxes, it was run with four climate changes occurring during the 1-million-year period. The climate changes in the TSPA-LA are primarily drivers to the infiltration into the repository rather than regional transport. Reprogramming and rerunning the TSPA-LA twice with a fixed climate for 1 million years solely to match each of the climate assumptions in this document would be unnecessary for the following reasons: (1) it would input conservative results for the present climate scenario and (2) it would input essentially the same results for the wetter climate (the TSPA-LA maintained the present climate for only 600 years and then the climate became progressively wetter). 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 (DIRS 185968-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 (DIRS 186186-SNL 2009, p. 18), significantly below the level prescribed by the Supreme Court (DIRS 148102-Cappaert et al. v. United States et al. 1976, all) and later by the Nevada State Engineer in 2008 (DIRS 186145-Taylor 2008, all). 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 (DIRS 186186-SNL 2009, all). 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) (DIRS 186186-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 (DIRS 186186-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 (DIRS120425-D'Agnese et al. 1999, all).

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 fluxes (in grams per year) arriving at the Amargosa Farms area and the Death Valley floor based on the input fluxes 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 for the present climate and a wetter climate.

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 fluxes 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 nonradiological contaminants) based on the water concentrations. In the case of nonradiological 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 and equilibrium adsorption of the dissolved species on the solid surfaces of the aquifer materials. This one-dimensional pipe approach is very suitable for the analysis because the lateral and vertical mixing in this aquifer system is extremely small (DIRS 184806-SNL 2008, 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.

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 ^c (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: DIRS 186221-Arnold 2009, all.

b. Source: DIRS 184806-SNL 2008, p. 4-13.

c. Source: DIRS 186186-SNL 2009, pp. 36 and 38.

d. Source: DIRS 185814-DOE 2008, Table 2.3.9-14.

e. Source: DIRS 186114-Jacobs 1993, p. 180.

f. Source: DIRS 160828-BSC 2001, p. 180.

g. Source: DIRS 186118-Mikkonen and Tummavuori 1994, p. 364.

K_d = partition coefficient.

An example of how the porosity is developed is as follows: 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, 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.

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 (length²/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.

This 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 do not appear to be 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 fluxes 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 appear to be 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.

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 flux 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 .

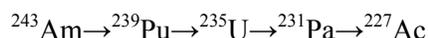
The transport model is implemented with an analytical solution to a step function input to yield “breakthrough curves.” Generally, the input to a flow path is not a simple step function, but rather a function of time (often it is a breakthrough curve from a previous path). Breakthrough curves are commonly 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 principle 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 flux to an output flux represented with breakthrough curves. DOE employed this method for analysis of flow paths in the Amargosa Desert. Each pipe has an input flux versus time (from an upstream pipe or process) and an output flux versus time.

To analyze the flow paths from the Regulatory Compliance Point, DOE used this transport model to calculate the response based on the fluxes at the Regulatory Compliance Point supplied from the TSPA-LA for radionuclides and from additional analysis described later for nonradiological contaminants. In all cases, the analysis used the mean value of the fluxes 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.

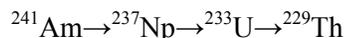
B.2.2 RADIONUCLIDE CHAINS

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 fluxes of radionuclides. The radionuclides evaluated in this analysis are the same as those the TSPA-LA evaluated. Some of the radionuclides are members of decay chains. Four decay chains were identified for the purposes of transport analysis for the saturated zone transport model (DIRS 183750-SNL 2005, p. 6-26). These consist of the following:

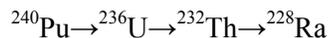
1. Actinium Series:



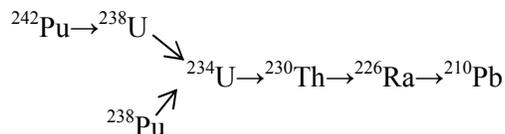
2. Neptunium Series:



3. Thorium Series:



4. Uranium Series:



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

B.2.3 DOSE CALCULATIONS

The radionuclide fluxes 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) flux 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 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 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 for the RMEI.

Exposure pathway	Dose contributing parameters	
	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 Ingestion dose for animal products Ingestion dose for fish Ingestion dose for soil	Leafy vegetables Other vegetables Fruit Grain Meat Milk Poultry Eggs

Source: DIRS 177399-SNL 2007, pp. 6-261 to 6-264, Table 6.10-1.
RMEI = reasonably maximally exposed individual.

Thus, after deriving a well-water concentration, DOE calculated the dose using the same biosphere dose conversion factors as those used in the RMEI analysis for the TSPA-LA. 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 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.

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 (DIRS 185968-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 flux of radionuclides (DIRS 182130-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* (DIRS 182130-SNL 2007, all) 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 (DIRS 185968-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.

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	9.99×10^{-3}
Ra-226	1.41×10^{-2}
Ra-228	3.33×10^{-3}
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}
Am-241	3.07×10^{-3}
Am-243	3.29×10^{-3}

Source: DIRS 185814-DOE 2008, Table 2.3.10-12

a. In rem per year per picocurie per liter.

Because 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. This results 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*; DIRS 182130-SNL 2007, p. 6-39).

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 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.

Because 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 flux 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.

Because the biosphere dose conversion factors were developed based on year-round exposure to soil and groundwater by residents, the calculated dose substantially overestimates the risk to visitors to Death Valley National Park or other non-residents in the Valley. Table B-4 presents the reduction percentages and resulting reduced biosphere dose conversion factors used in the analysis.

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	57.9	5.78×10^{-3}
Ra-226	94.7	1.33×10^{-2}
Ra-228	85.7	2.85×10^{-3}
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: DIRS 185814-DOE 2008, Tables 2.3.10-11 and -12

B.2.3.2.2 Death Valley Floor and Alkali Flat

The primary destination for radionuclides and nonradiological contaminants identified 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-MIDDLE (DIRS 173179-Belcher et al. 2004, Table F-4, Figure 4-7). 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 (DIRS 186240-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 (DIRS 186240-Reynolds et al. 2007, p. 1812). As the evaporite mineral crystals form, they displace the rock-derived clastic minerals, expanding the sediments upward (DIRS 186240-Reynolds et al. 2007, p. 1812). Sometimes a more compact, but still friable, material forms, which contains a lower fraction of evaporites. These deposits are associated with lower rates of evaporation or lower salinity in the groundwater.

At times, durable, wind-resistant crusts of evaporite minerals can form a protective layer about 1 centimeter thick on top of unconsolidated and dry fine-grained sediment that might be as much as 10 centimeters thick. Breaking this crust can release material that is easily carried by the wind (DIRS 186240-Reynolds et al. 2007, p. 1823). It has been observed that changes occur in evaporite sediments due to wind erosion, rainfall events, and water table fluctuations (DIRS 186240-Reynolds et al. 2007, p. 1816). Thus, the deposits may take on many forms; some very susceptible to resuspension and some not. 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 nonradiological 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 (DIRS 169734-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 (DIRS 173179-Belcher et al. 2004, Table F-4). DOE estimates that during the wetter climate this value would increase by a factor of 3.9, resulting in an evapotranspiration rate of 25,837 cubic meters per day. The concentration of the contaminant in the water was calculated as the flux 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 (DIRS 177399-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 (DIRS 177399-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* (DIRS 177399-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; DIRS 177399-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 flux of contaminants estimated to arrive at Death Valley.

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

- In the estimate of concentration of contaminants in the solids, DOE used a low level of total-dissolved-solids found in local groundwater. Higher values of total-dissolved-solids would reduce the estimated concentration and therefore dose and intakes.
- In the calculation of exposure from inhalation of airborne particulates:
 - DOE assumed that all resuspended particulates that the receptor breathes in are evaporite minerals. Inclusion of rock-based clastic soils would reduce the estimated concentration and therefore doses and intakes;
 - DOE used the maximum value for the concentration of resuspended particles for the environment considered in the analysis;
 - DOE assumed that the receptor would inhale air containing the estimated concentration of contaminants for the entire year; and
 - The single value of breathing rate used ignores the fact that people spend 8 or so hours asleep when their breathing rate would drop by at least half the assumed value.
- For ingestion of contaminated soil:
 - DOE assumed that all material that is inadvertently ingested consists of evaporite minerals, and
 - The daily ingestion rate is relatively high at 100 milligram per day (for example, the EPA recommends 50 milligrams per day for adults and 100 milligrams per day for children (DIRS 152549-EPA 1997, Table 4-23).
- For external exposure to radionuclides in soil:
 - DOE used dose coefficients developed for soil contaminated to an infinite depth, although most evaporites would be on or near the soil surface. Dose coefficients for a lesser depth would be lower and would reduce the estimate of dose; and
 - DOE assumed that the receptor would be outdoors and exposed to contaminated evaporites year-round.

B.2.4 RADIONUCLIDE INVENTORY CALCULATIONS

At various locations, the dose calculation used the mass flux 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 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 flux, 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 fluxes vary slowly so that an assumption of constant steady-state is a reasonable approximation.

B.3 Analysis of Nonradiological Contaminants

Chemically toxic materials that could present a human health risk when released to the groundwater would be present in materials disposed of in the repository. These materials, referred to herein as nonradiological contaminants, would come from construction materials of the 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 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 from the repository 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 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 (DIRS 180751-DOE 2008, p. F-38).

This Analysis of Postclosure Groundwater Impacts addresses the entire 1-million-year postclosure period and, as such, revisits materials inside of waste packages. DOE conducted additional screening studies that showed there were no new materials of concern; therefore, materials of concern for this analysis are still 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.

B.3.2 DEVELOPMENT OF FLUX AT THE UNSATURATED ZONE-SATURATED ZONE INTERFACE

This Analysis of Postclosure Groundwater Impacts analyzes nonradiological contaminants during the 1-million-year postclosure period in a manner consistent with the radiological contaminant analysis. This analysis includes quantities of materials from inside the waste packages, as some fraction of waste packages would be likely to fail over time, exposing the internal materials to corrosion. Uranium is retained as a nonradiological 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. In this Analysis of Postclosure Groundwater Impacts, package failures, and thus materials within the package, are accounted for. Therefore, the contaminants of concern analyzed for the extended-time analysis in this document are molybdenum, nickel, vanadium, and uranium.

The bounding analysis in the Repository SEIS took no credit for any attenuating processes once the corrosion of the construction materials and waste packages released the nonradiological contaminants nickel, molybdenum, and vanadium. The flux of metal arriving at the hypothetical well at the Regulatory Compliance Point was the rate of release by corrosion. Thus, the flux 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 flux 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 flux of metals from the repository to the unsaturated zone for this Analysis of Postclosure Groundwater Impacts, DOE used a similar analysis to that used in the Repository SEIS. However, because this analysis considers the 1-million-year period, it took into account the 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 flux from the unsaturated zone to the saturated zone as a combination of step functions as follows: The flux 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 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 FLUX 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 repository to the Regulatory Compliance Point. (Note that the flux 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 fluxes 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 nonradiological 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 (DIRS 186186-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 flux history of the metal at 18 kilometers.

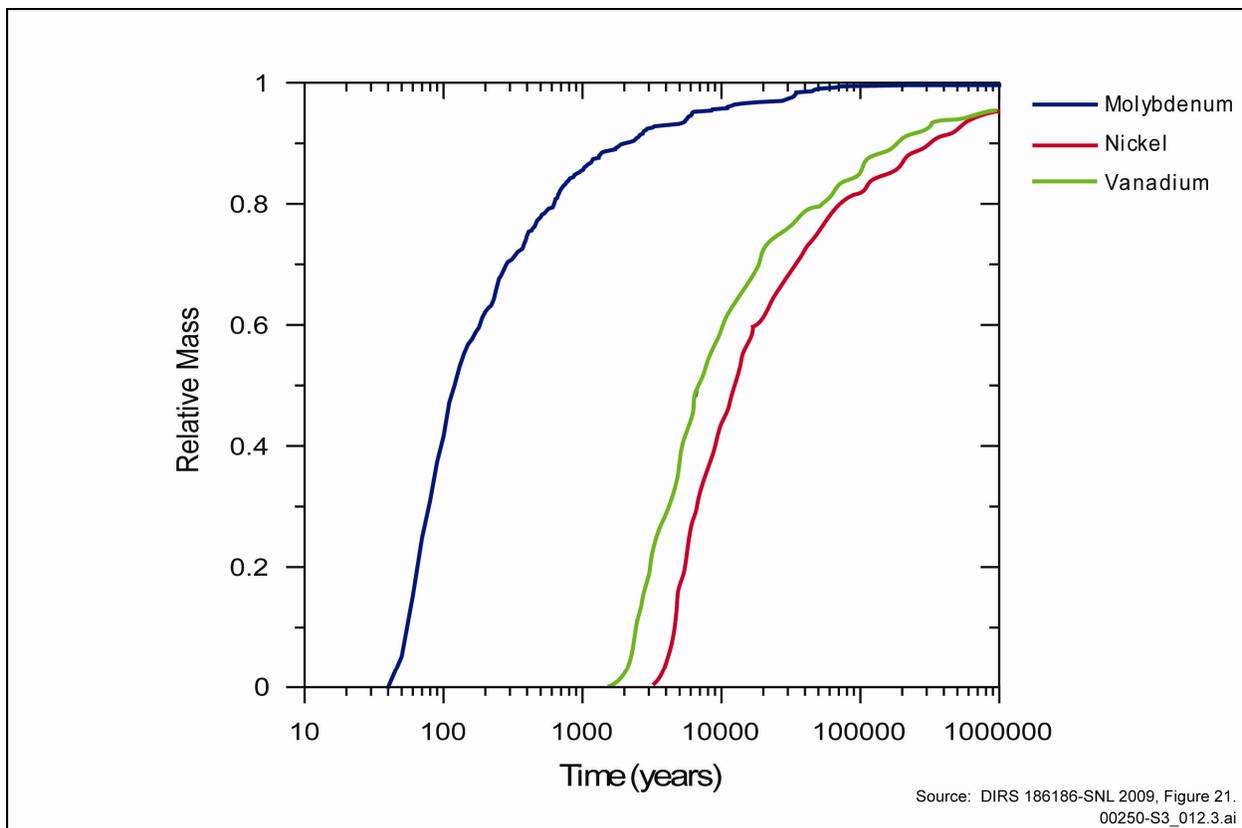


Figure B-1. Simulated breakthrough curves in the saturated zone for molybdenum, vanadium, and nickel.

B.3.4 FLUX OF NONRADIOLOGICAL 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 radiologic dose, however, the nonradiological 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 fluxes developed for release at 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 fluxes developed for the nonradiological 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

Fluxes of nonradiological 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 (DIRS 148228-EPA 1999, all; DIRS 148229-EPA 1999, all; DIRS 103705-EPA 1997, all; DIRS 102173-EPA 1994, all).

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 nonradiological 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 (DIRS 177399-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 nonradiological 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 nonradiological 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 (DIRS 185968-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 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 the 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.

CONTAMINANTS NOT SHOWN ON PLOTS

Generally, all of the contaminants studied do not appear on the detailed plots of radionuclides and nonradiological 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 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 changed any of the results or conclusions of the analyses.

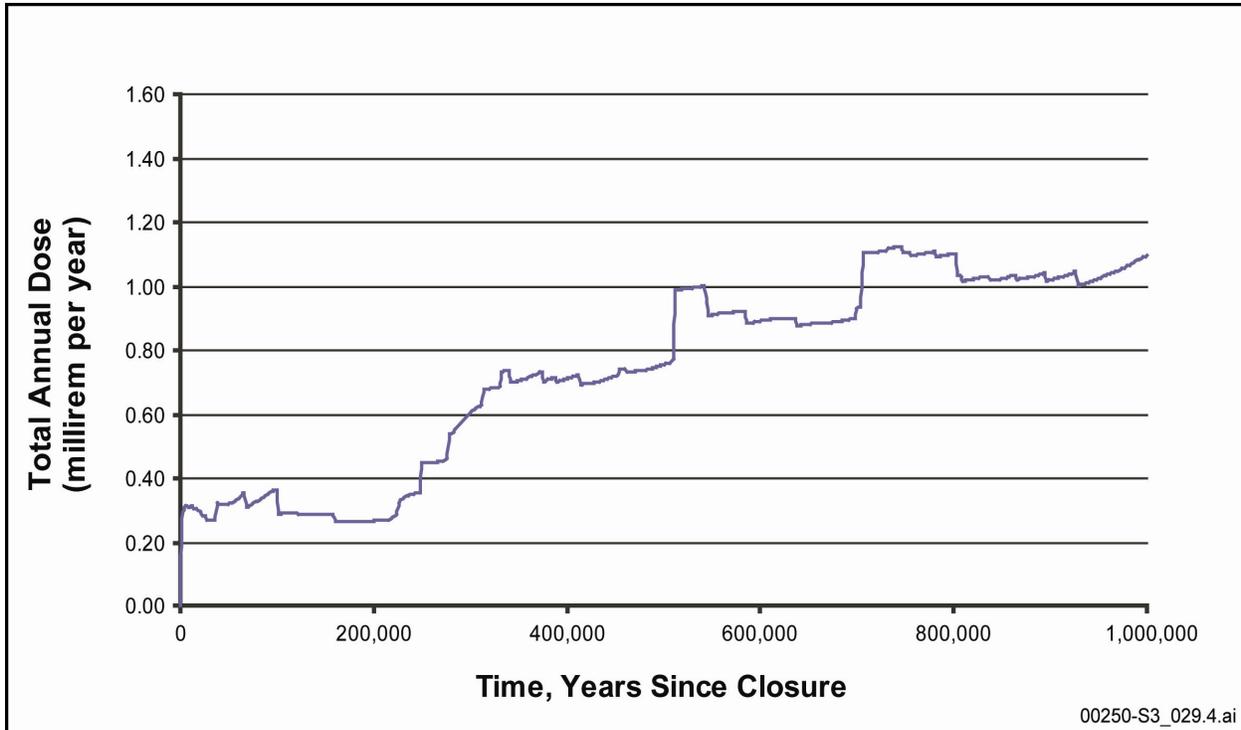


Figure B-2. Total dose at the Amargosa Farms area for present climate.

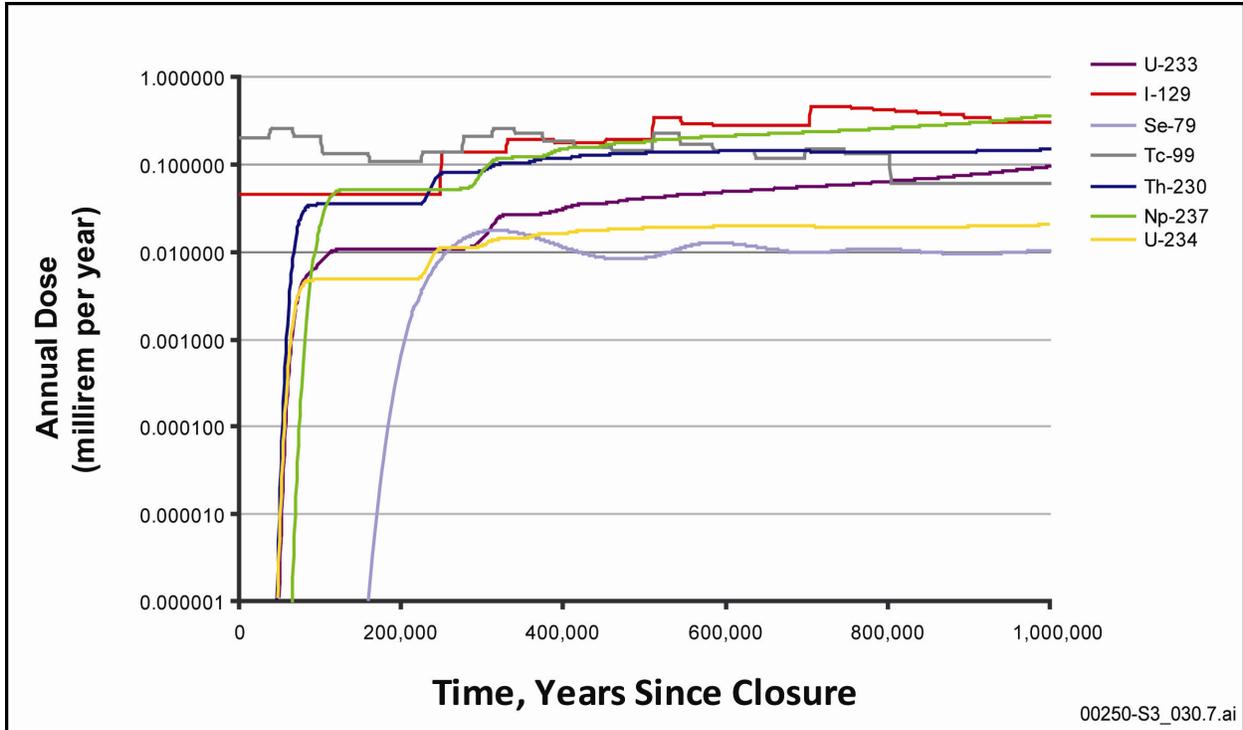


Figure B-3. Dose by radionuclide at the Amargosa Farms area for present climate.

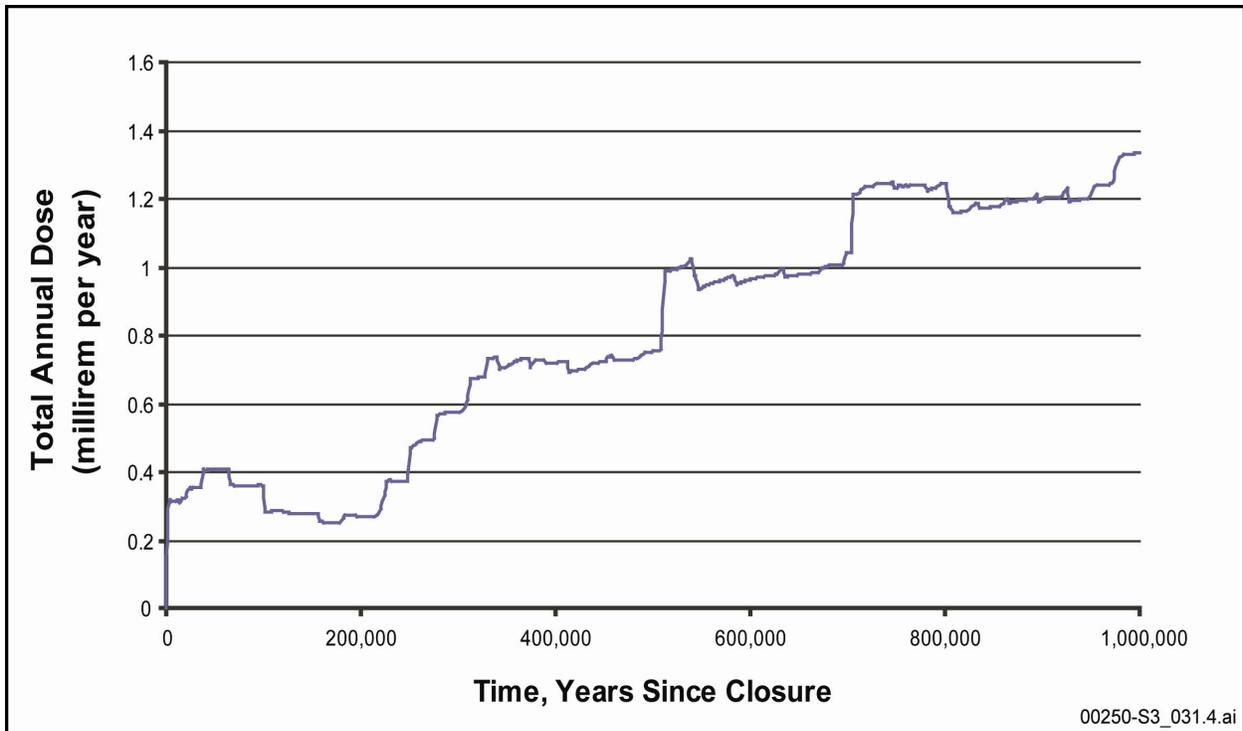


Figure B-4. Total dose at the Amargosa Farms area for wetter climate.

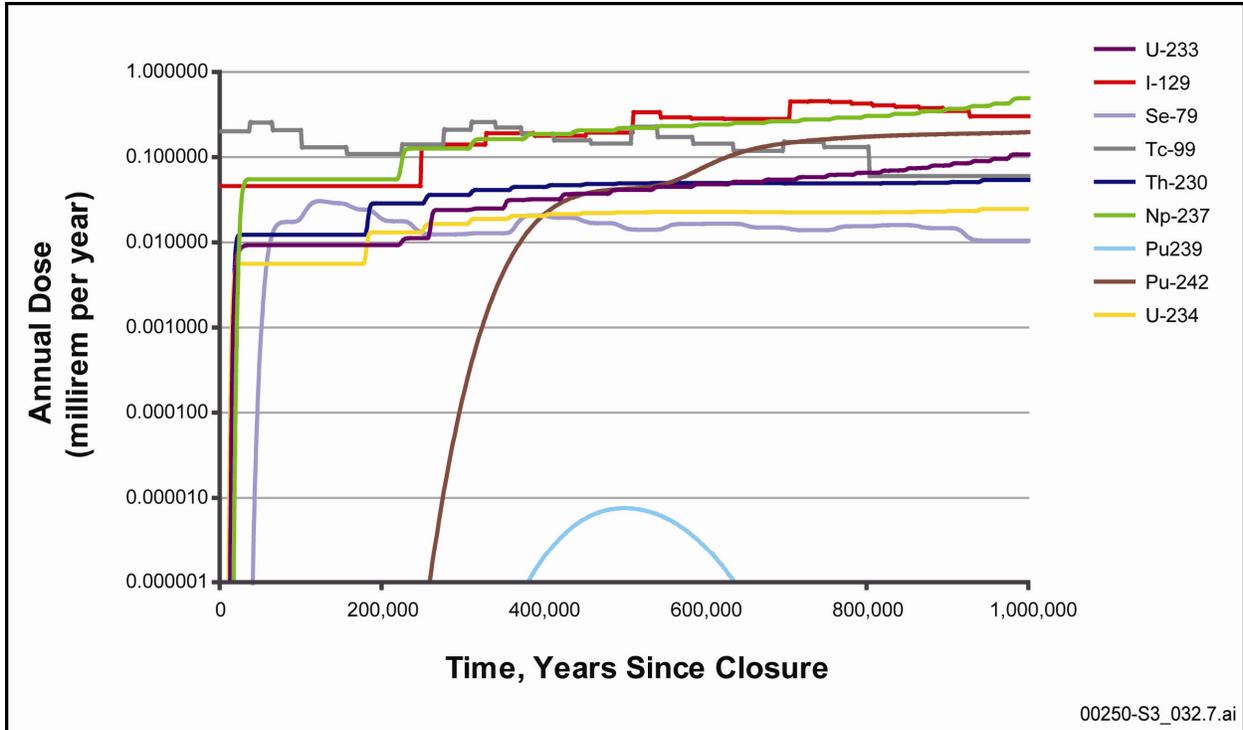


Figure B-5. Dose by radionuclide at the Amargosa Farms area for wetter climate.

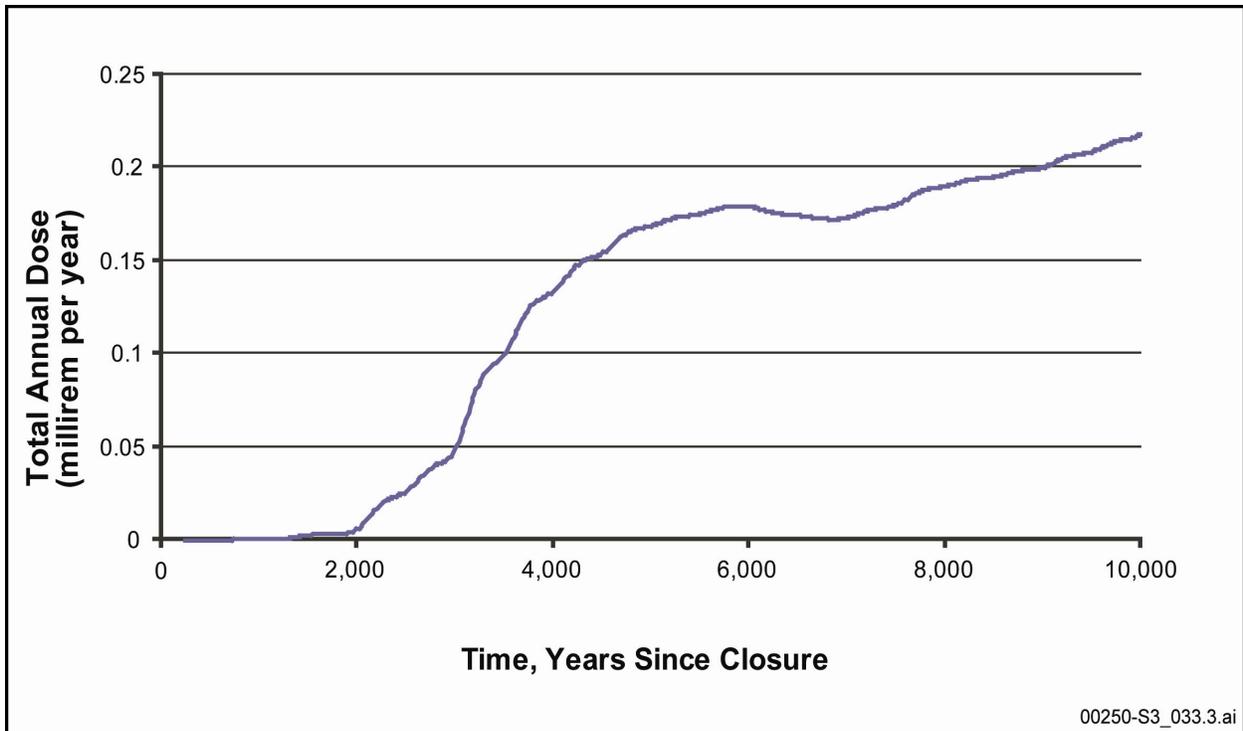


Figure B-6. Total dose at the Amargosa Farms area, present climate, 10,000-year case.

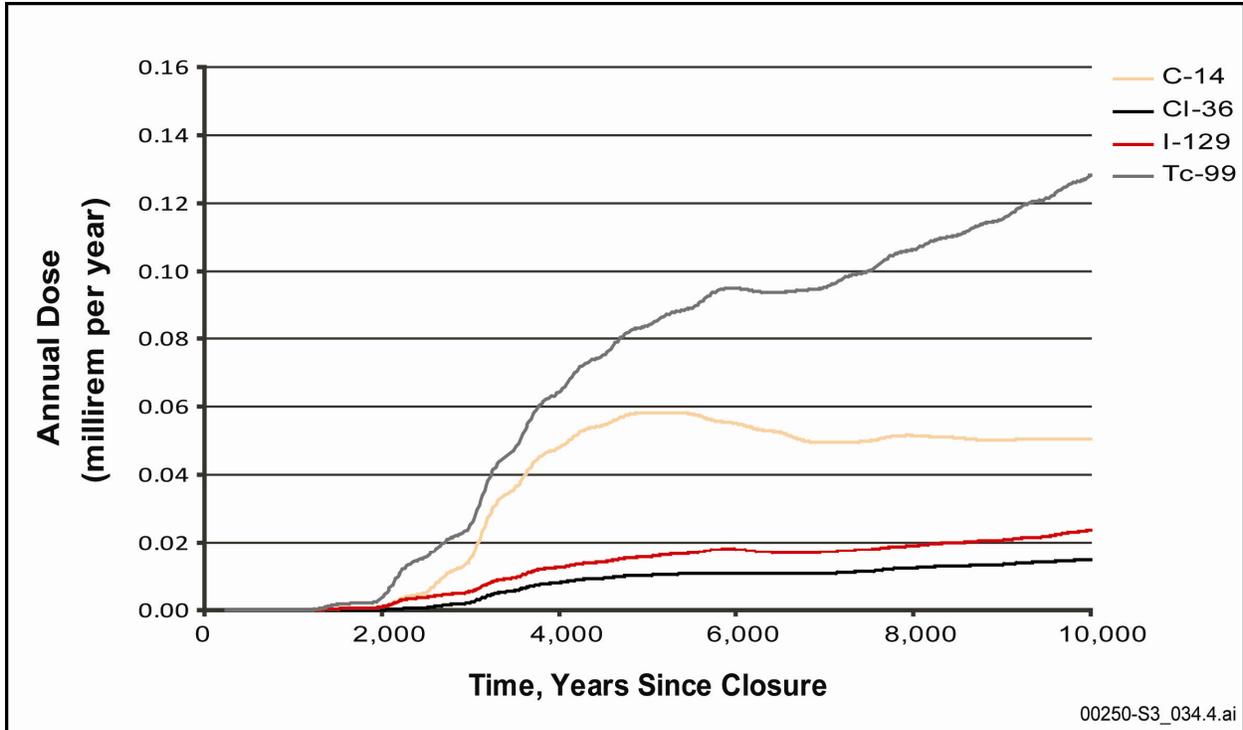


Figure B-7. Dose by radionuclide at the Amargosa Farms area, present climate, 10,000-year case.

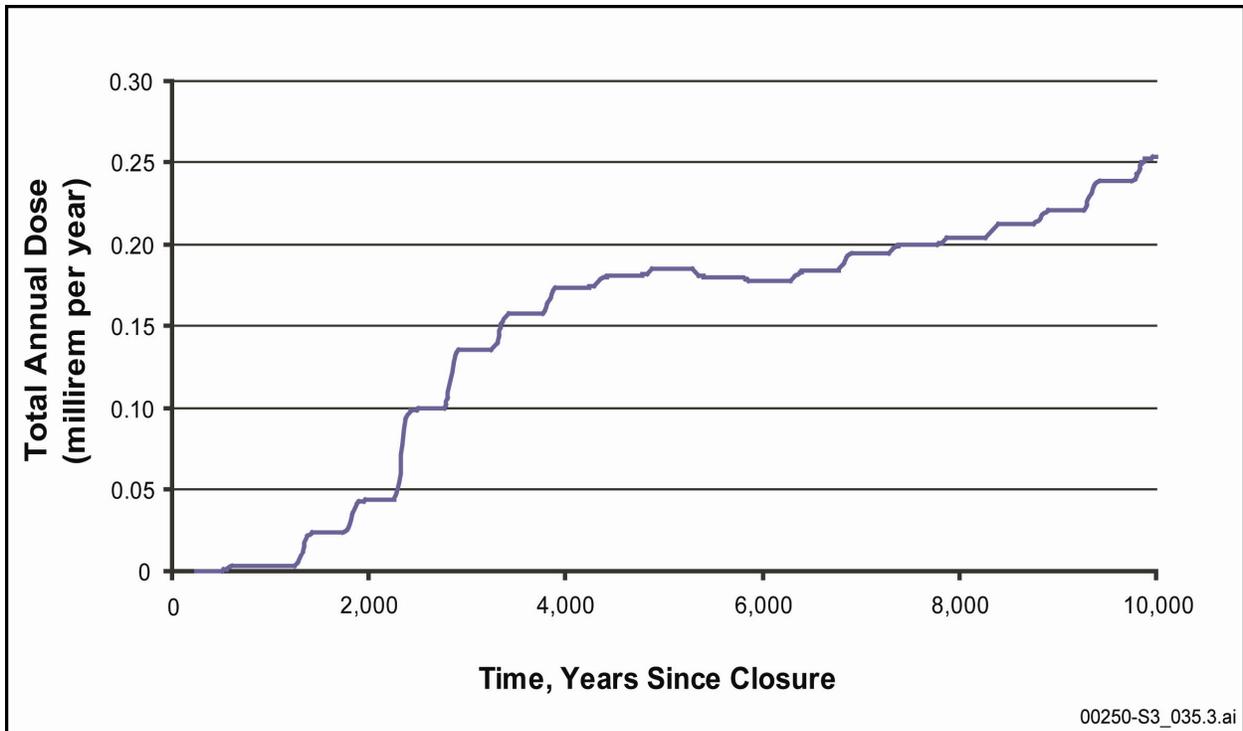


Figure B-8. Total dose at the Amargosa Farms area, wetter climate, 10,000-year case.

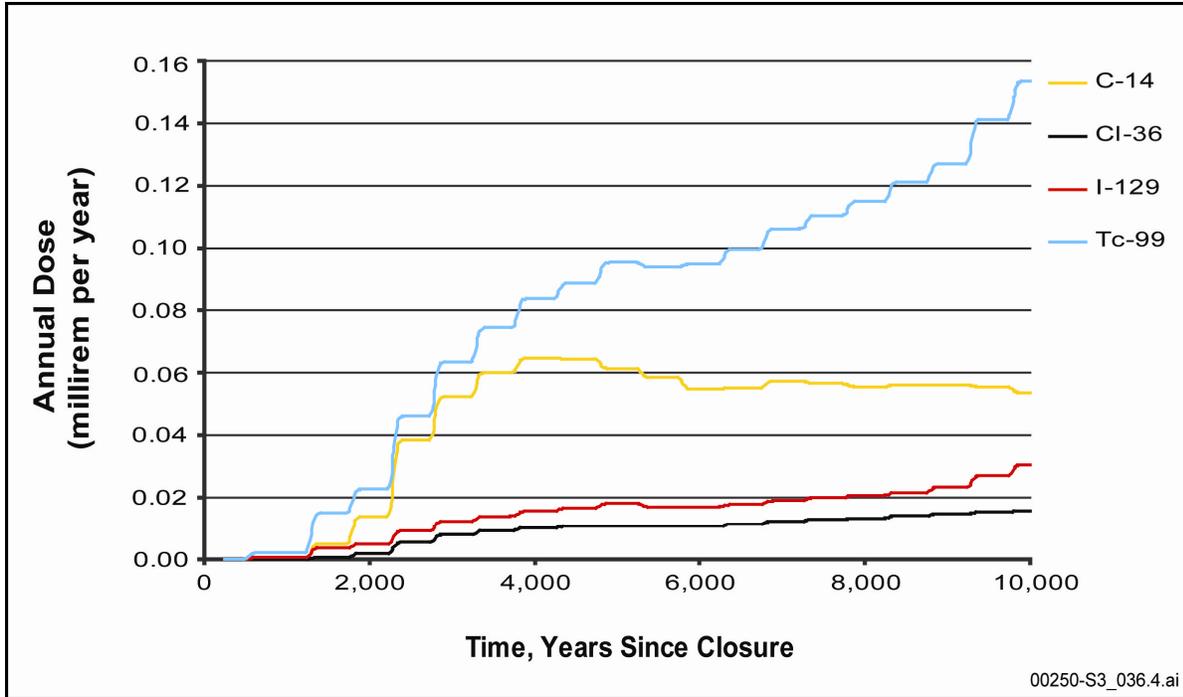


Figure B-9. Dose by radionuclide at the Amargosa Farms area, wetter climate, 10,000-year case.

Figures B-10 and B-11 show the daily intakes for nonradiological contaminants and compare these intakes with the Oral Reference Doses (DIRS 148228-EPA 1999, all; DIRS 148229-EPA 1999, all; DIRS 103705-EPA 1997, all; DIRS 102173-EPA 1994, all). All the estimated daily intakes are below the Oral Reference Dose.

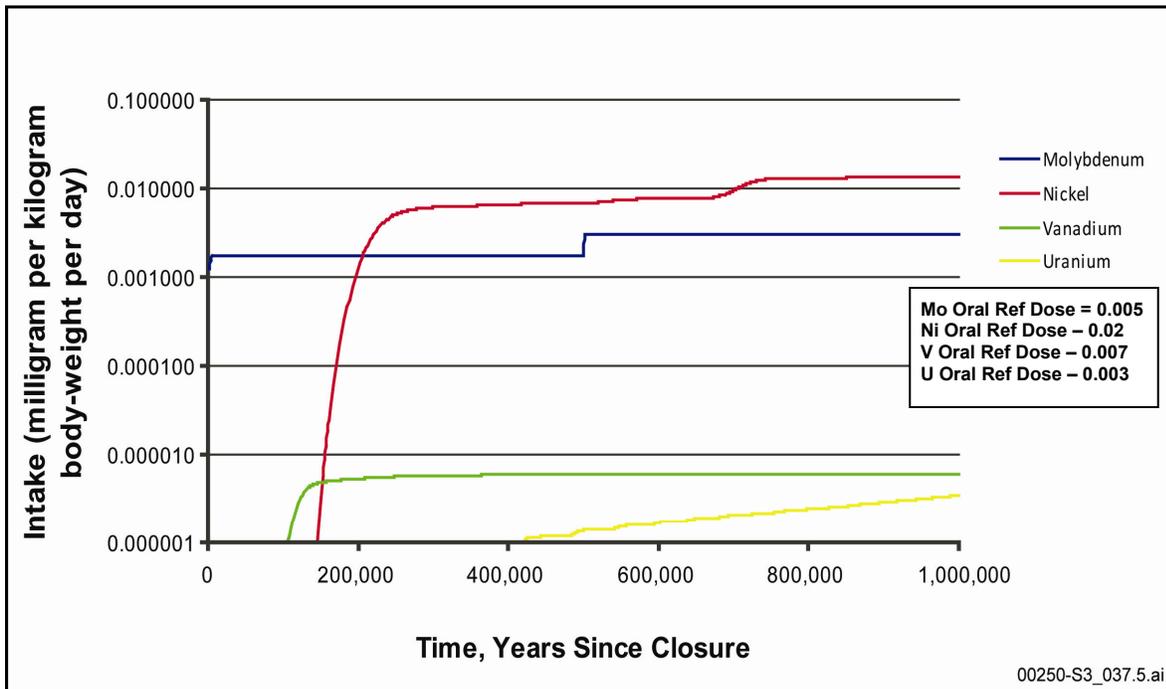


Figure B-10. Intakes of nonradiological contaminants at the Amargosa Farms area, present climate.

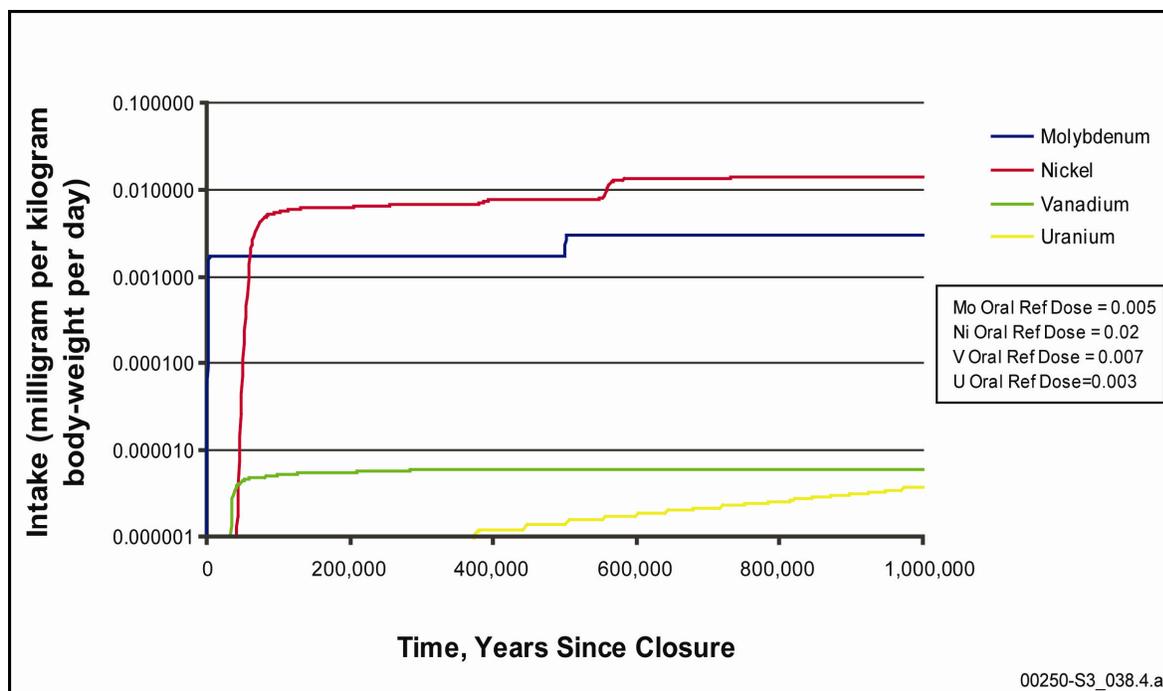


Figure B-11. Intakes of nonradiological contaminants at the Amargosa Farms area, wetter climate.

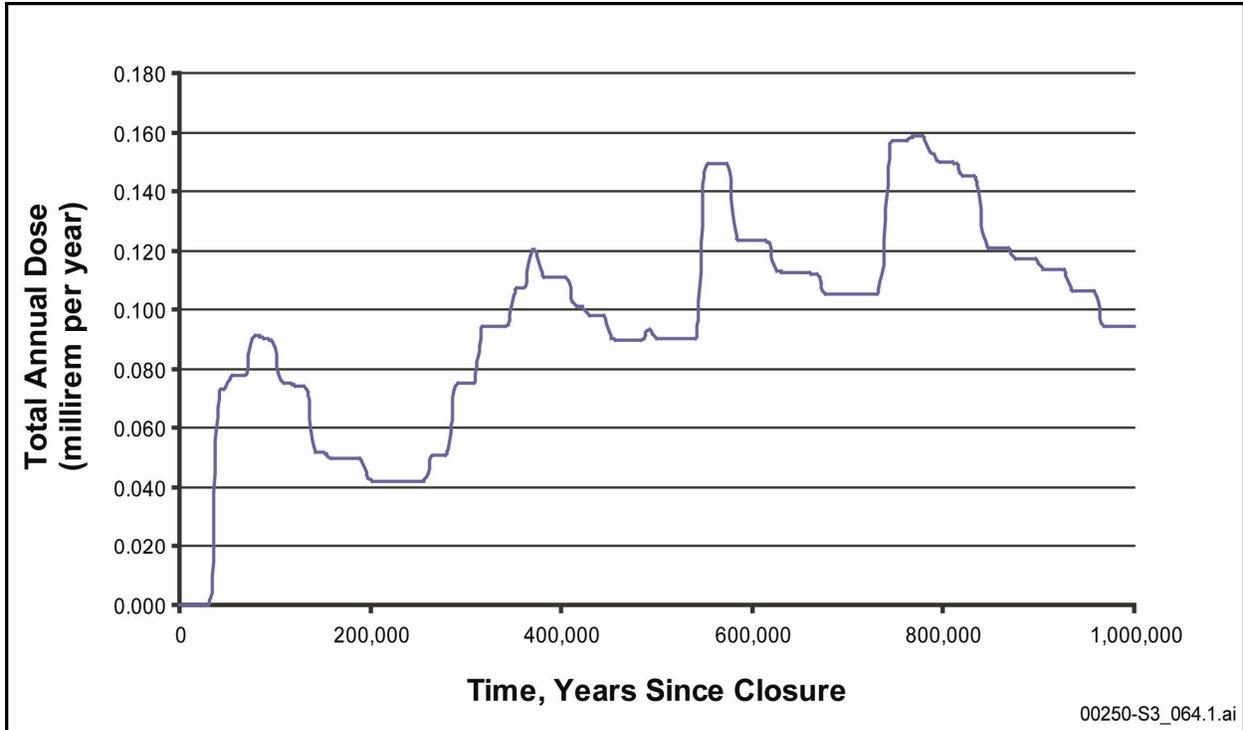
B.4.1.2 Death Valley

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 of doses and daily intakes represents those received by individuals using contaminated water if it arrived at the Furnace Creek springs area. The second 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. 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)

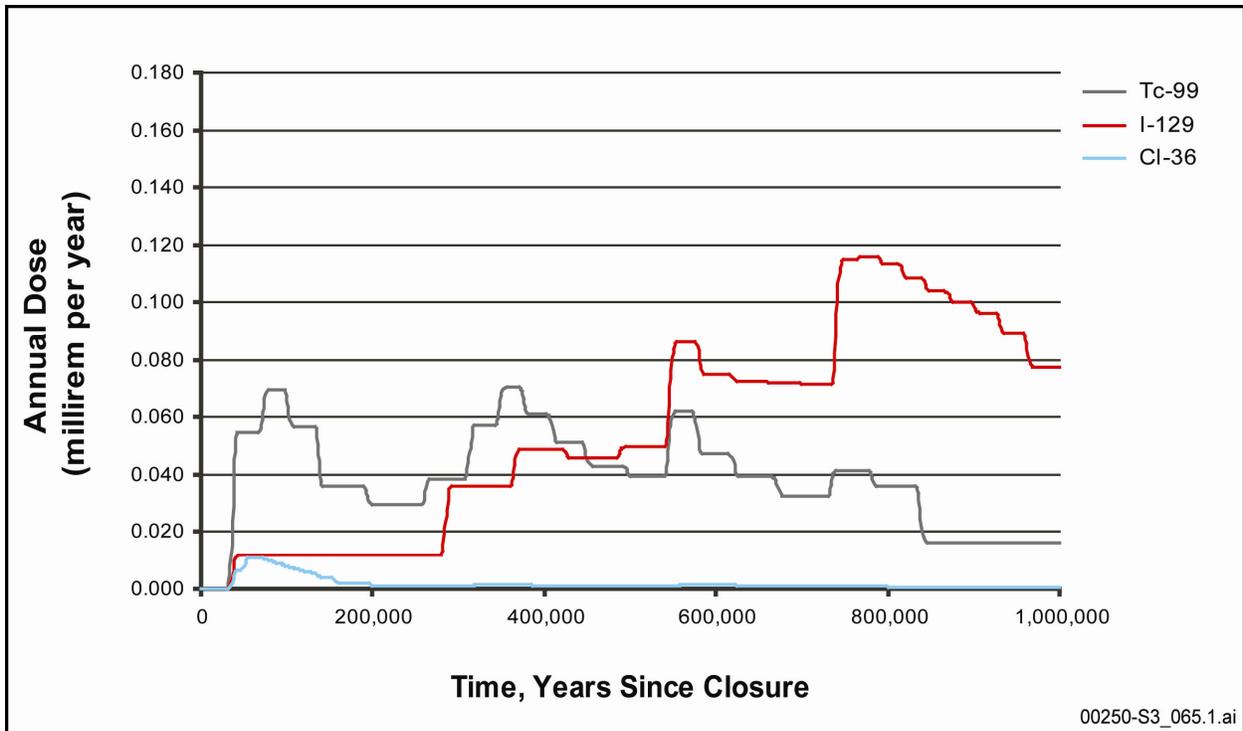
The particle tracks strongly indicate that the contaminants would flow to the Death Valley floor at Middle Basin instead of the Furnace Creek springs area. The Death Valley floor in this area is normally an evapotranspiration area with no water emerging as liquid on the surface. DOE estimated doses and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



00250-S3_064.1.ai

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



00250-S3_065.1.ai

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

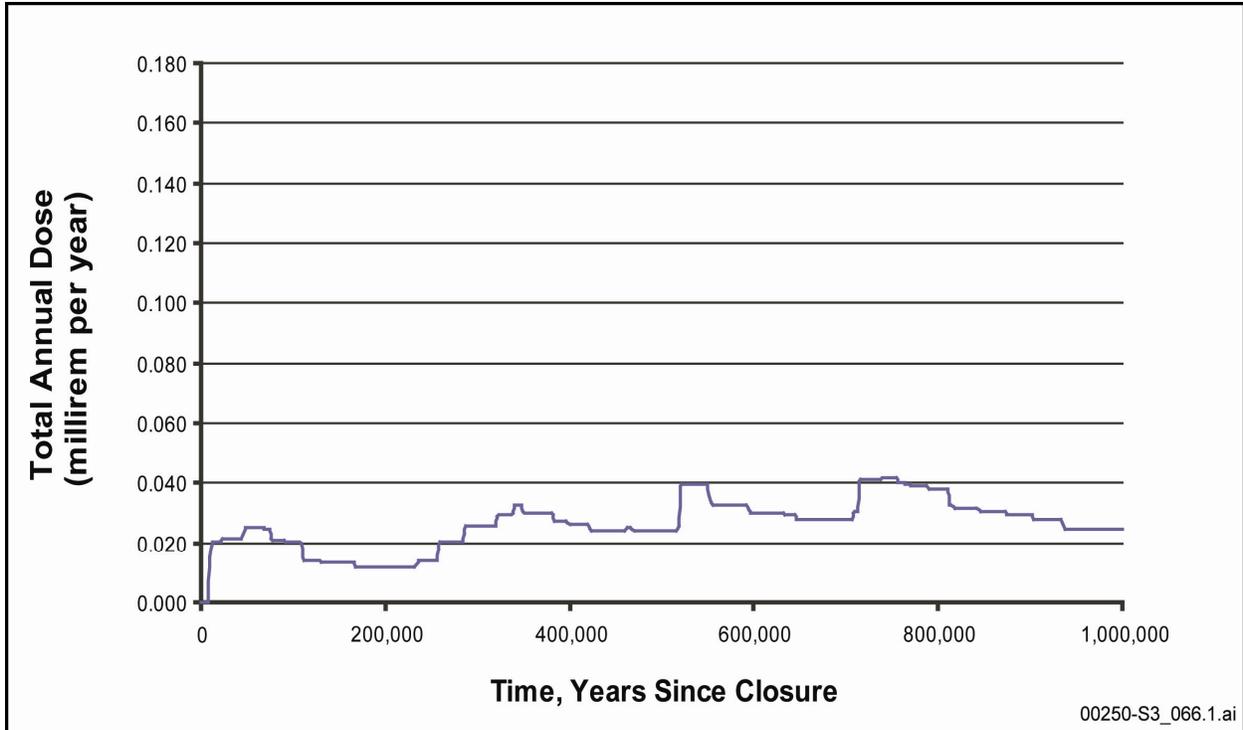


Figure B-14. Total dose at Middle Basin, wetter climate.

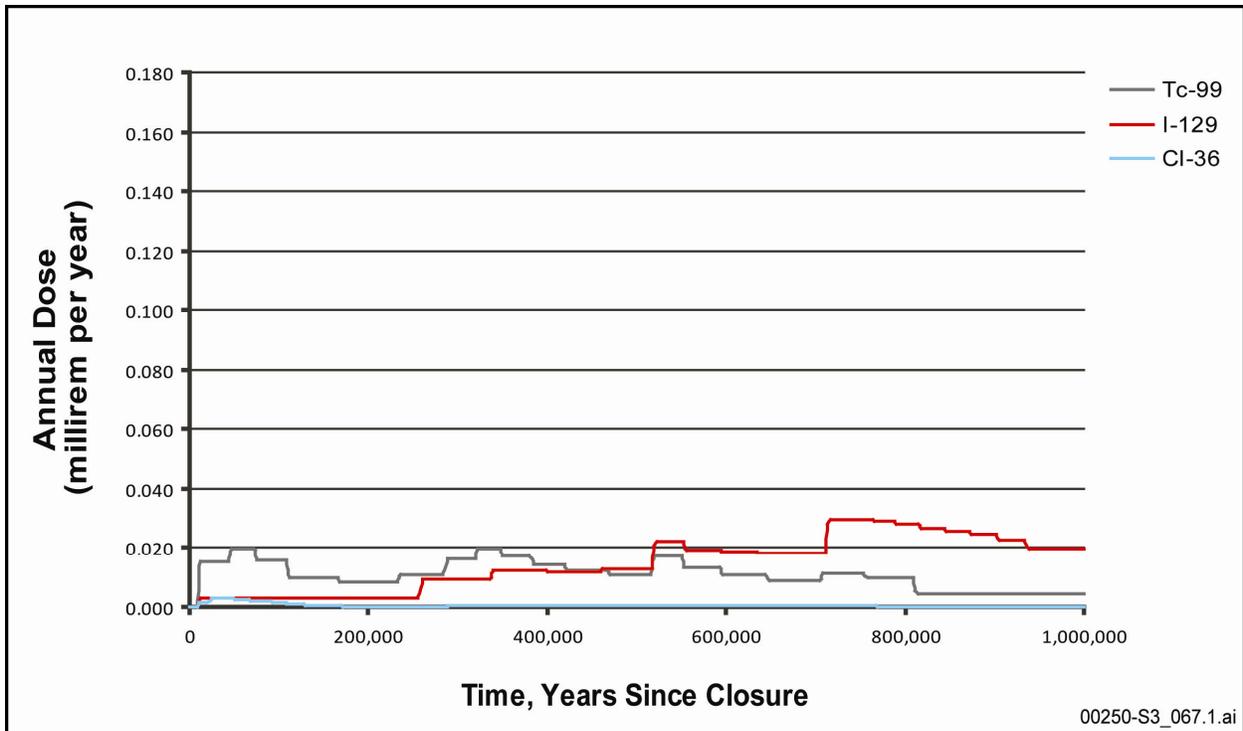


Figure B-15. Dose by radionuclide at Middle Basin, wetter climate.

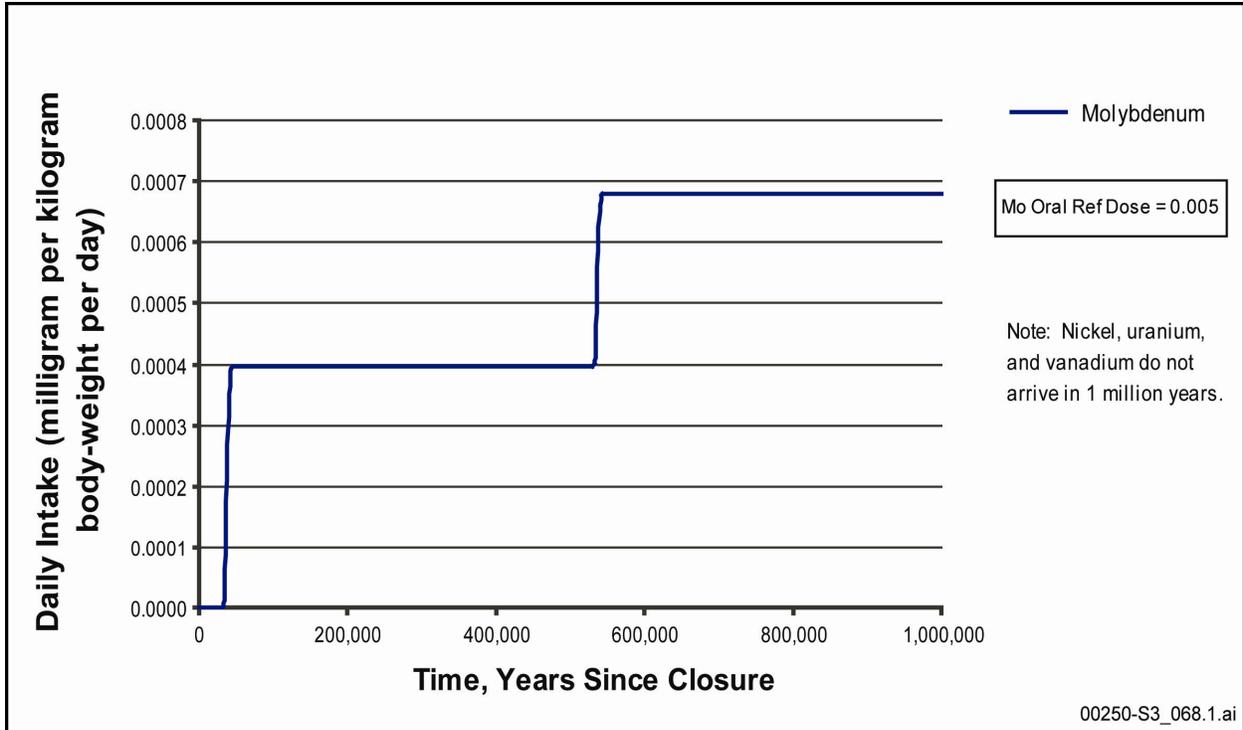


Figure B-16. Molybdenum Intake at Middle Basin, present climate.

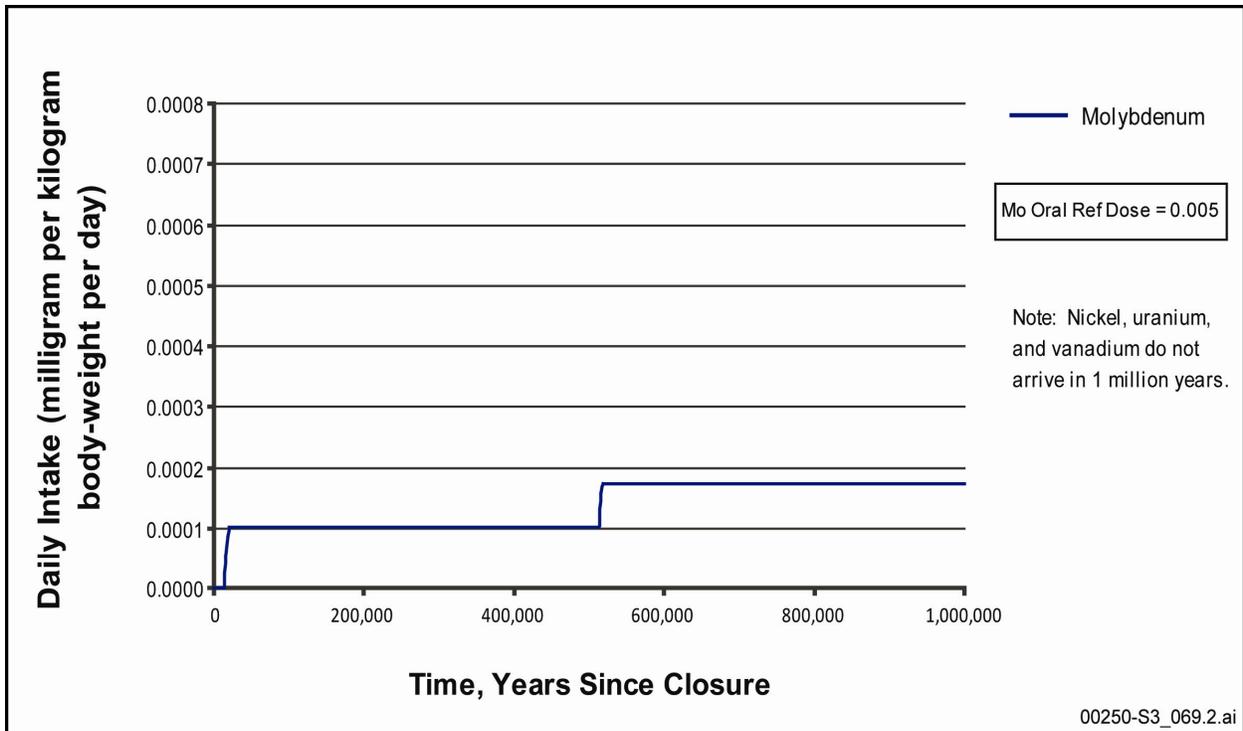


Figure B-17. Molybdenum Intake at Middle Basin, wetter climate.

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 (DIRS 186240-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 flux 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 nonradiological 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.

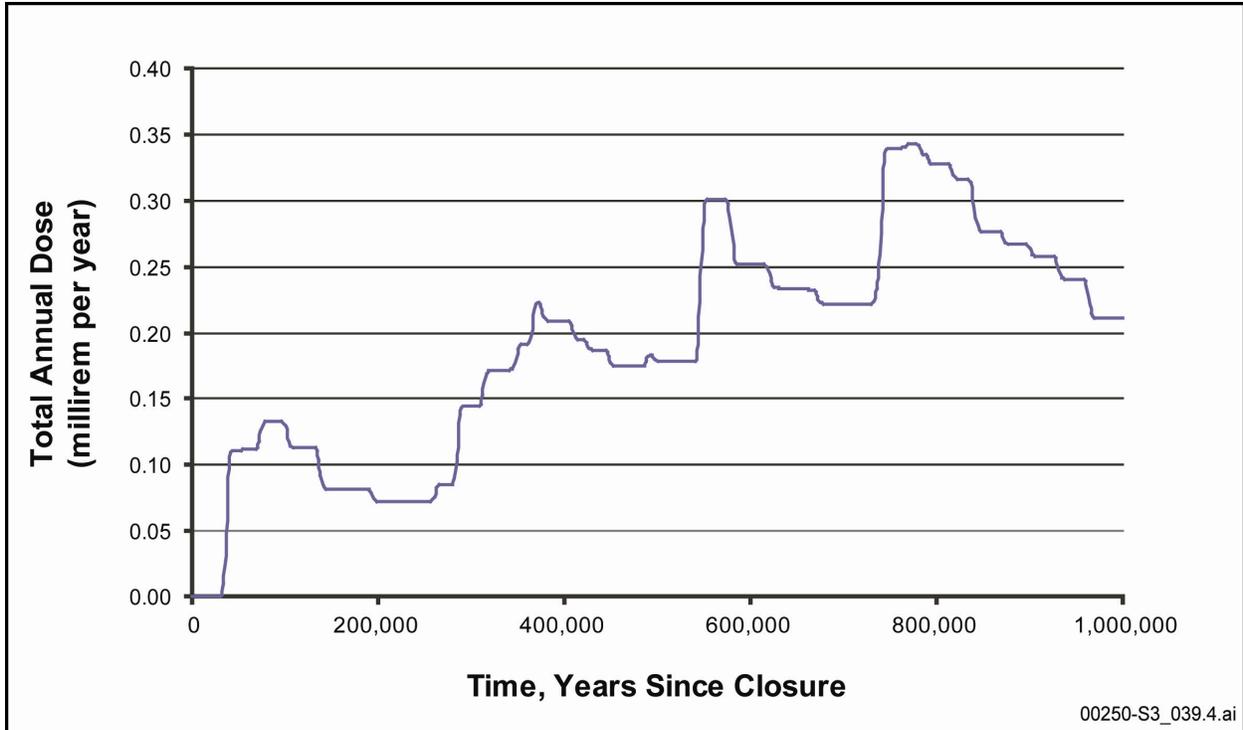


Figure B-18. Total dose at the Furnace Creek springs area, no-pumping, present climate.

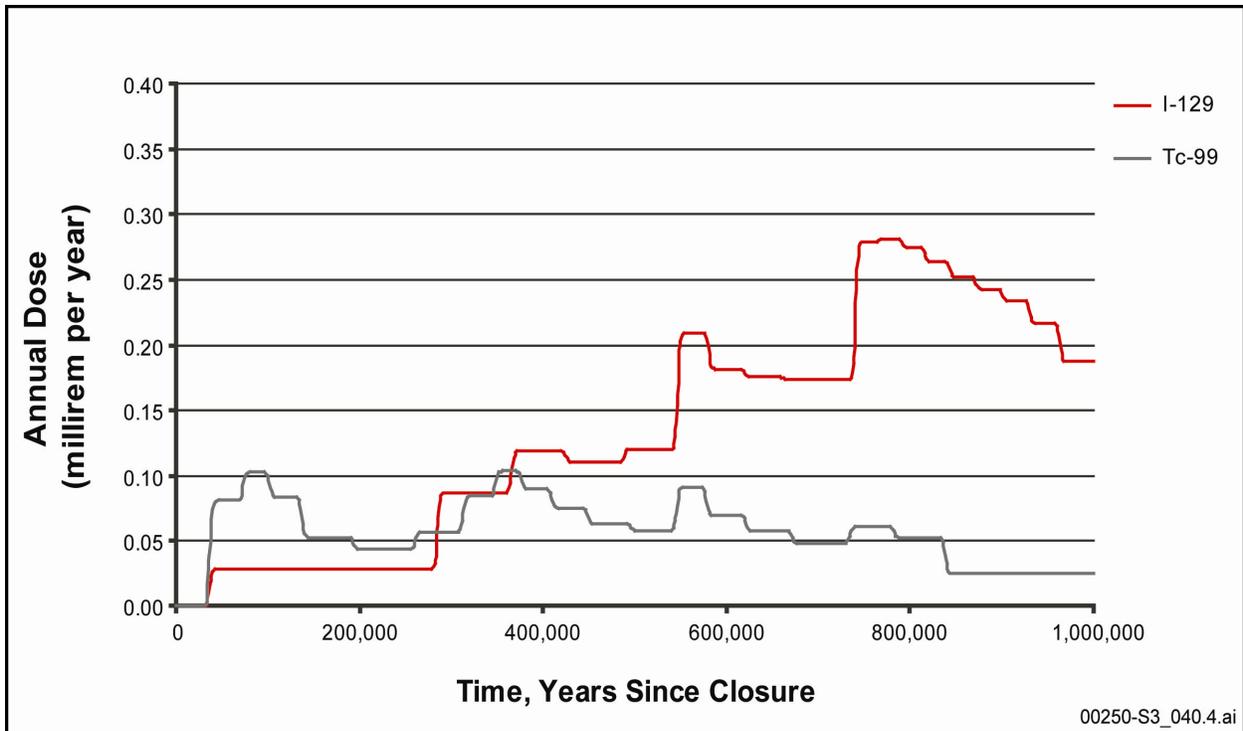


Figure B-19. Dose by radionuclide at the Furnace Creek springs area, no-pumping, present climate.

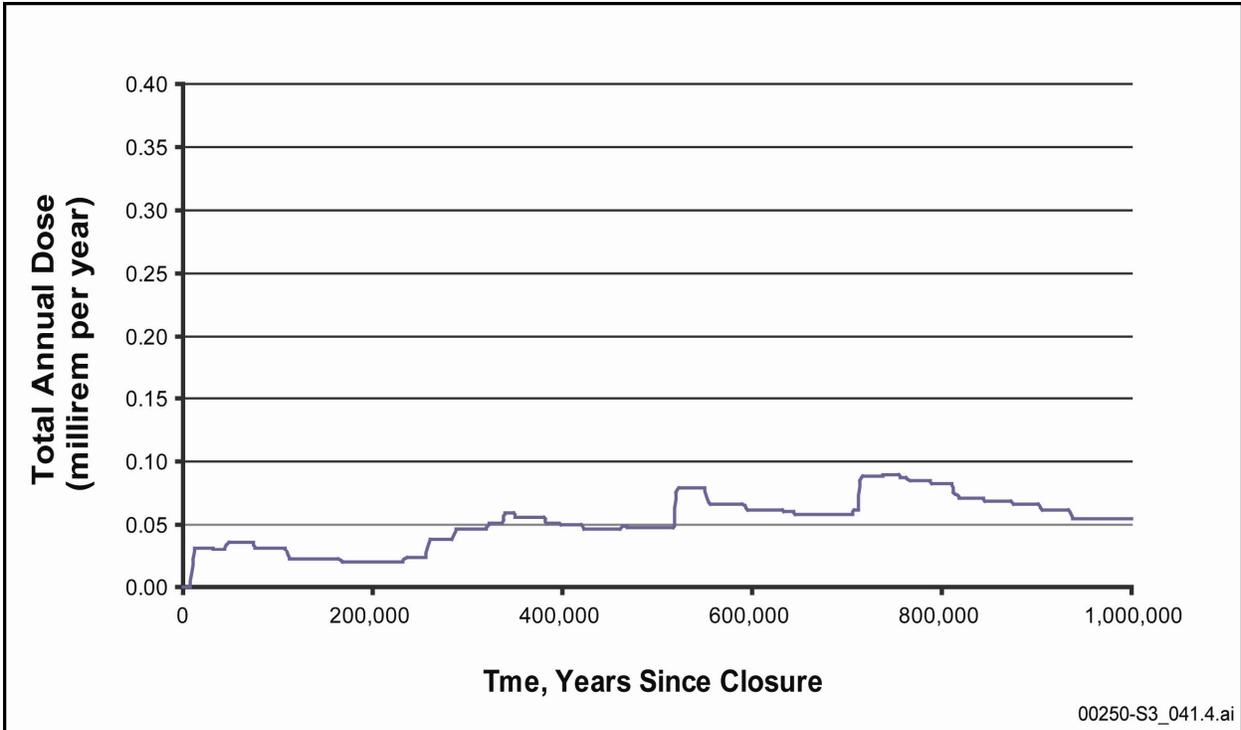


Figure B-20. Total dose at the Furnace Creek springs area, no-pumping, wetter climate.

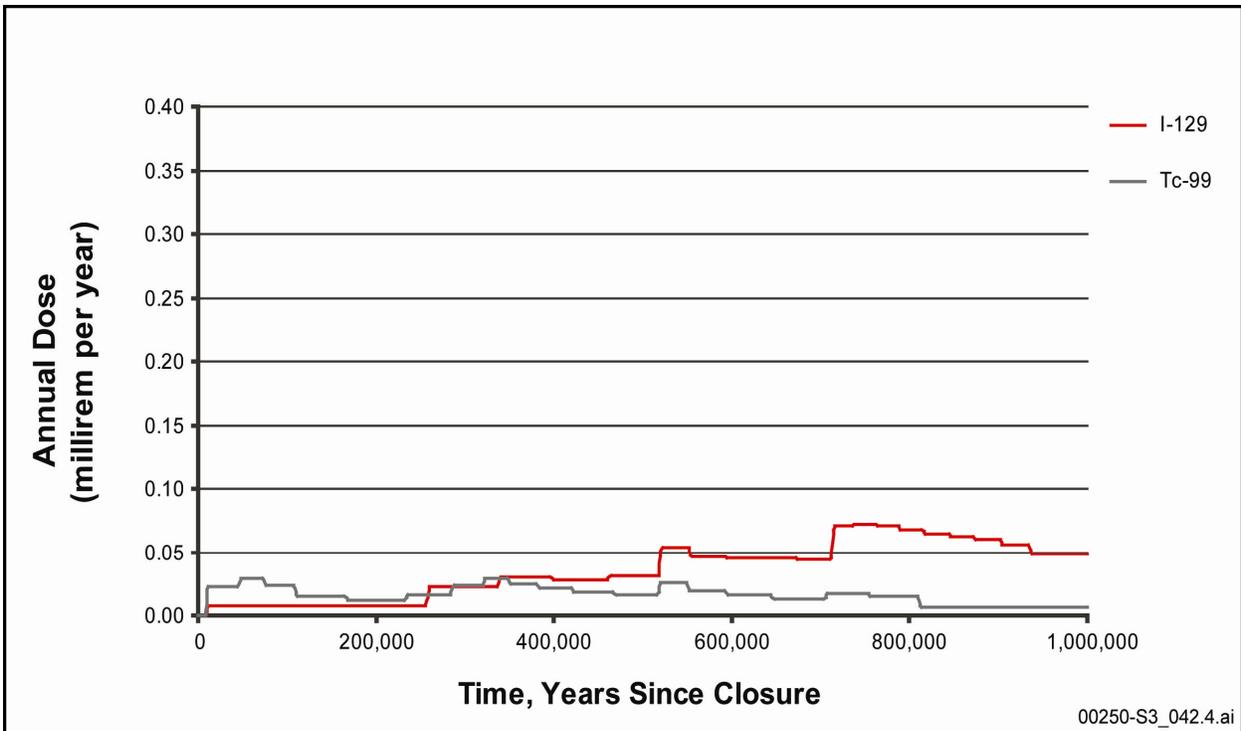


Figure B-21. Dose by radionuclide at the Furnace Creek springs area, no-pumping, wetter climate.

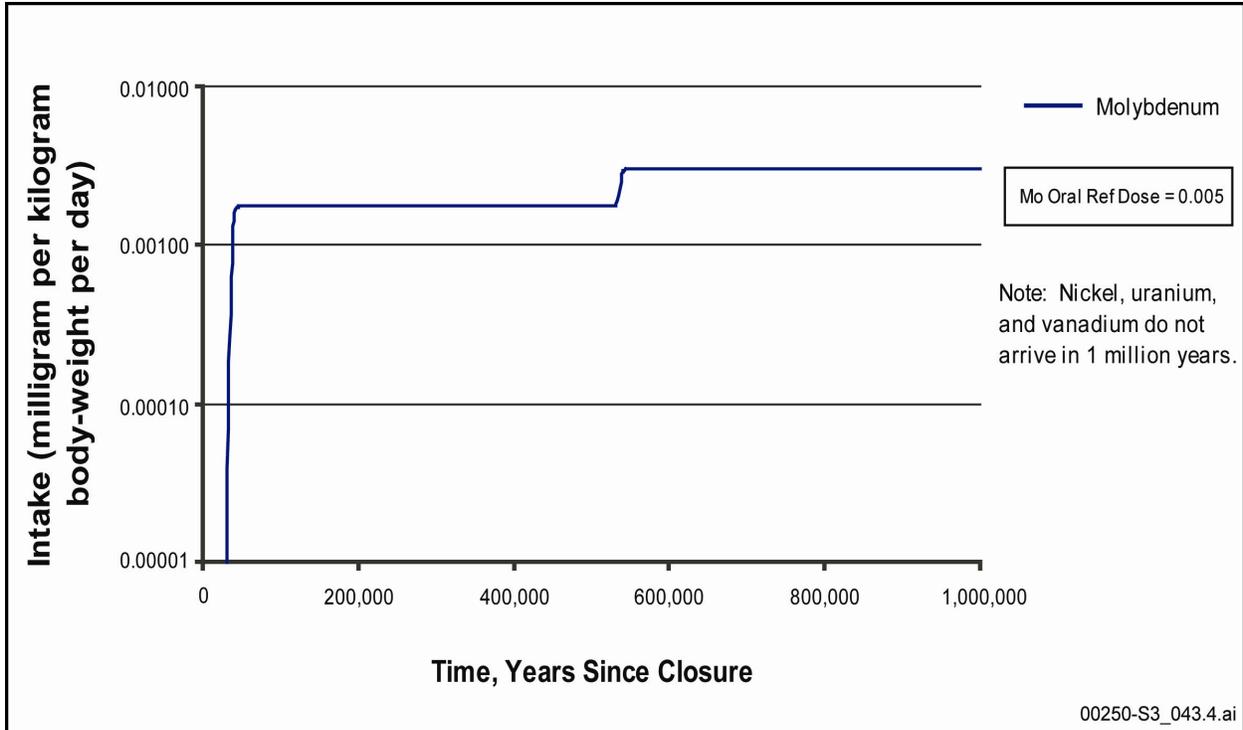


Figure B-22. Daily intakes of molybdenum at the Furnace Creek springs area, no-pumping, present climate.

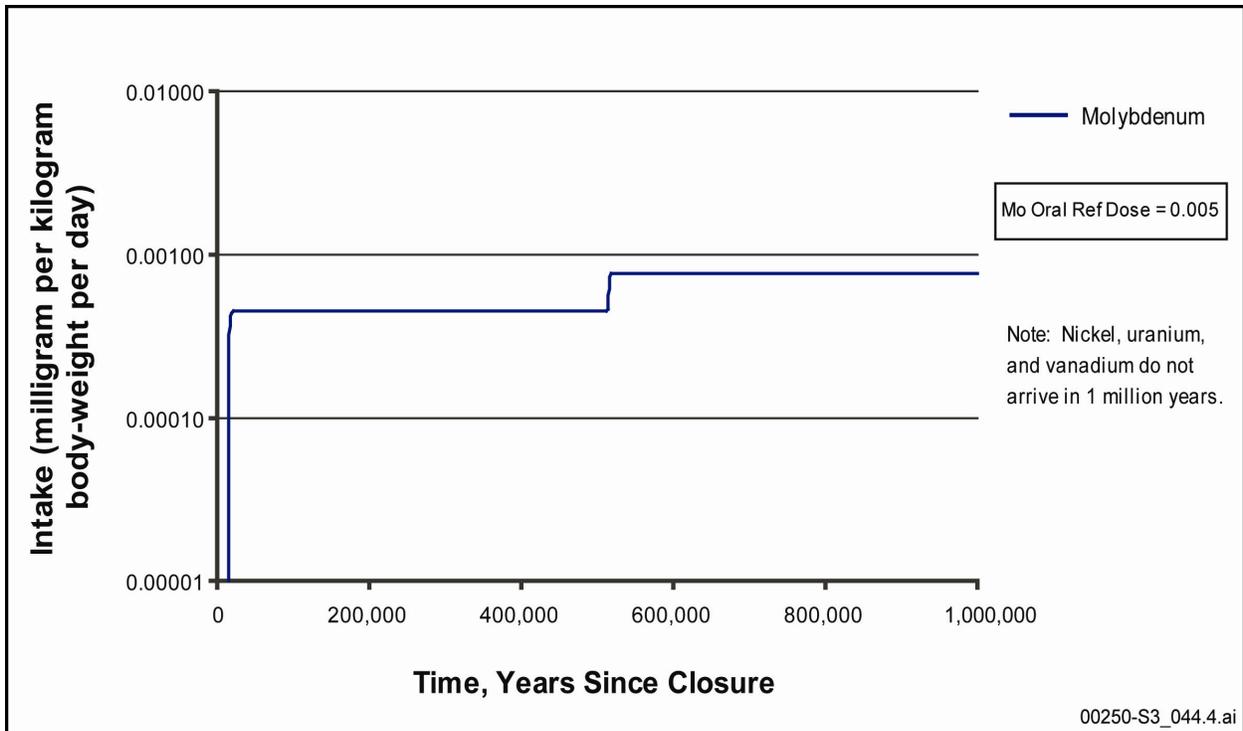


Figure B-23. Daily intakes of molybdenum at the Furnace Creek springs area, no-pumping, wetter climate.

B.4.1.3 Alkali Flat

According to the regional flow model, a small fraction of the contaminant plume from the Regulatory Compliance Point would follow a path toward Alkali Flat for the no-pumping case. Two particles out of the 8,024 were shown going to Alkali Flat from the Regulatory Compliance Point. Therefore, it would be expected that only small amounts of radiological or nonradiological contaminants would arrive at Alkali Flat during the 1-million-year postclosure period. The Franklin Lake Playa at Alkali Flat is a wet playa similar to the location on the Death Valley floor analyzed above. Even though the contaminant fluxes would be about the same, the amount of evapotranspiration at Franklin Lake Playa is currently about one-half that of Middle Basin in Death Valley. Because the doses and intakes are inversely proportional to the evapotranspiration rate, if all the contaminants went to Alkali Flat instead of Death Valley, then the doses and intakes would be about twice the values estimated for Death Valley.

This estimated result applies a very conservative assumption, in that if all of the contaminants were to divert to Alkali Flat, the evapotranspiration rate at that location would not increase from its current measured value. It would be very likely that any diversion of contaminants would be the result of increased groundwater flow in the direction of Alkali Flat and that there would be increases in the evapotranspiration rate at the playa. Since these parameters are not known, DOE made this conservative, qualitative estimate.

B.4.2 MASS BALANCES

Using the decay- and growth-adjusted inventories (see Section B.2.4), DOE estimated mass balances for radionuclides and nonradiological contaminants with 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 flux. 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

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-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
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					

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
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 Nonradiological Contaminants

This section presents mass balances for nickel, vanadium, and molybdenum (Tables B-9 through B-12). Unlike the radionuclides, these nonradiological 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 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 nonradiological contaminants.

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

Time (year)	Soil concentration (grams per square meter)					
	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 nonradiological contaminants at the Amargosa Farms area.

Time (year)	Soil concentration (grams per square meter)			
	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 nonradiological 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 nonradiological contaminant that appears at Middle Basin during the 1-million-year period after closure of the 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.

Time (year)	Soil concentration (grams per gram of soil)			
	Chlorine-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 (DIRS 120425-D'Agnes et al. 1999, all). 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 (DIRS 120425-D'Agnes 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 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 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. Because the 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 (DIRS 185814-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: DIRS 185814-DOE 2008, Table 2.3.9-14.

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

K_d = partition coefficient.

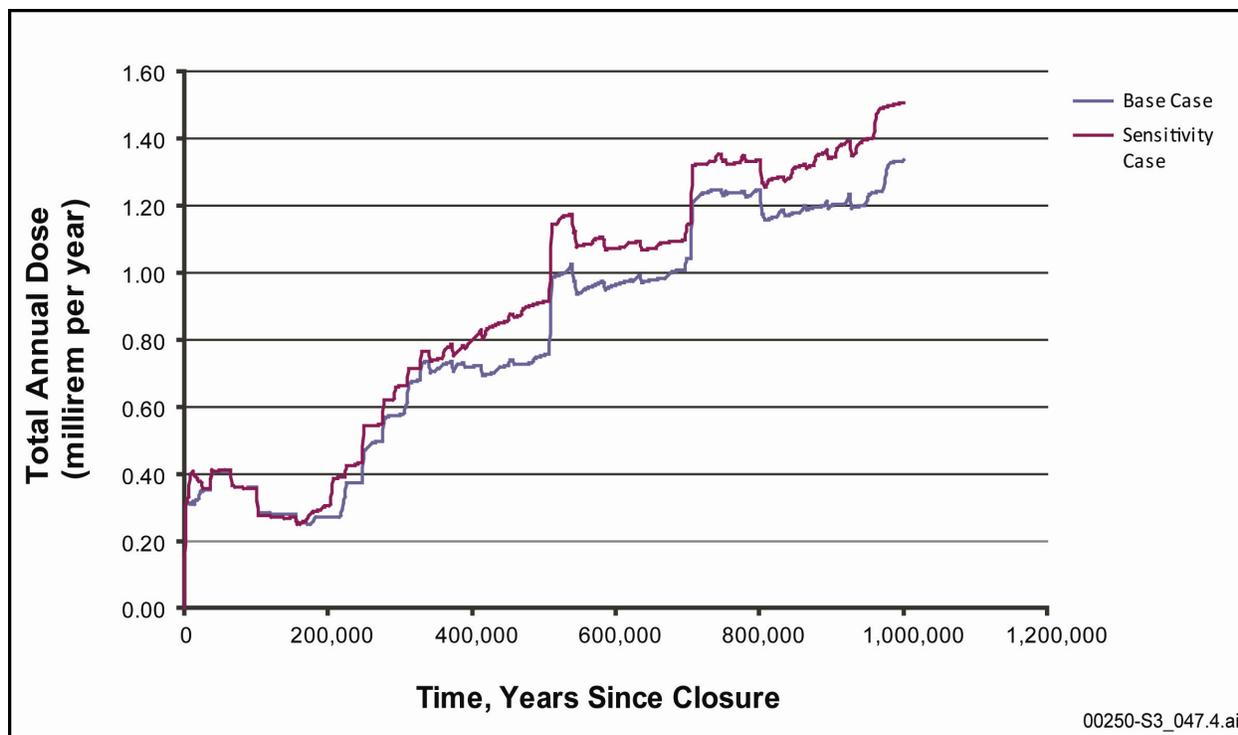


Figure B-24. Sensitivity case for the Amargosa Farms area, pumping, wetter climate.

REFERENCES

- | | | |
|--------|---|--|
| 186221 | Arnold 2009 | Arnold, B.W. 2009. "Summary of Additional Information on Flow Paths, Hydrogeologic Units, and Transport Parameters for the SEIS Analysis." Email from B.W. Arnold to J. Rivers and D. Lester, March 31, 2009, with attachment. ACC: MOL.20090422.0060. |
| 160828 | BSC 2001 | BSC (Bechtel SAIC Company) 2001. <i>Unsaturated Zone and Saturated Zone Transport Properties (U0100)</i> . ANL-NBS-HS-000019 REV 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020311.0017. |
| 169734 | BSC 2004 | BSC (Bechtel SAIC Company) 2004. <i>Yucca Mountain Site Description</i> . TDR-CRW-GS-000001 REV 02 ICN 01. Two volumes. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040504.0008; LLR.20080423.0019; DOC.20080707.0002. |
| 148102 | Cappaert et al. v. United States et al., 1976 | <i>Cappaert et al. v. United States et al.</i> , 426 U.S. 128; 96 S. Ct. 2026. Decided June 7, 1976. ACC: MOL.20010730.0380. |

- 120425 D'Agnese et al. 1999 D'Agnese, F.A.; O'Brien, G.M.; Faunt, C.C.; and San Juan, C.A. 1999. *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California*. Water-Resources Investigations Report 98-4041. Denver, Colorado: U.S. Geological Survey. TIC: 243555.
- 180751 DOE 2008 DOE (U.S. Department of Energy) 2008. *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. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20080606.0001.
- 185814 DOE 2008 DOE (U.S. Department of Energy) 2008. *Yucca Mountain Repository License Application*. DOE/RW-0573, Update No. 1. Docket No. 63-001. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20081023.0041.
- 102173 EPA 1994 EPA (U.S. Environmental Protection Agency) 1994. *Health Effects Assessment Summary Tables, FY-1994 Annual*. EPA 540-R-94-020. Washington, D.C.: U.S. Environmental Protection Agency. ACC: MOL.20010724.0297.
- 103705 EPA 1997 EPA (U.S. Environmental Protection Agency) 1997. *Health Effects Assessment, Summary Tables, FY-1997 Update*. EPA 540/R-97-036. Washington, D.C.: U.S. Environmental Protection Agency. ACC: MOL.20010724.0301.
- 152549 EPA 1997 EPA 1997. *Food Ingestion Factors*. Volume II of *Exposure Factors Handbook*. EPA/600/P-95/002F. Washington, D.C.: U.S. Environmental Protection Agency. TIC: 241061.
- 148228 EPA 1999 EPA (U.S. Environmental Protection Agency) 1999. "Molybdenum; CASRN 7439-98-7." IRIS (Integrated Risk Information System). Washington, D.C.: U.S. Environmental Protection Agency. Accessed June 10, 1999. ACC: MOL.20010719.0363. URL: <http://www.epa.gov/iris/subst/0425.htm>
- 148229 EPA 1999 EPA (U.S. Environmental Protection Agency) 1999. "Nickel, Soluble Salts; CASRN Various." IRIS (Integrated Risk Information System). Washington, D.C.: U.S. Environmental Protection Agency. Accessed June 10, 1999. ACC: MOL.20010719.0364. URL: <http://www.epa.gov/iris/subst/0271.htm>

- 186114 Jacobs 1993 Jacobs Engineering Group 1993. *Adsorption Isotherm Special Study*. DOE/AL/62350-17F. Albuquerque, New Mexico: U.S. Department of Energy, UMTRA Project Office. ACC: MOL.20090210.0020.
- 186118 Mikkonen and Tummavuori 1994 Mikkonen, A. and Tummavuori, J. 1994. "Retention of Vanadium (V) by Three Finnish Mineral Soils." *European Journal of Soil Science*, 45, 361-368. Oxford, England: Blackwell Scientific and British Society of Soil Science. TIC: 260225.
- 185968 Moreo and Justet Moreo, M.T. and Justet, L. 2008. *Update to the Ground-Water Withdrawals Database for the Death Valley Regional Ground-Water Flow System, Nevada and California, 1913 – 2003*. Data Series 340. Reston, Virginia: U.S. Geological Survey. ACC: LLR.20090106.0183.
- 186239 Reheis 2006 Reheis, M.C. 2006. "Owens (Dry) Lake, California: A Human-Induced Dust Problem." *Impact of Climate Change and Land Use in the Southwestern United States*. Denver, Colorado: U.S. Geological Survey. Accessed April 21, 2009. ACC: MOL.20090504.0040. URL: <http://geochange.er.usgs.gov/sw/impacts/geology/owens/>
- 186240 Reynolds et al. 2007 Reynolds, R.L.; Yount, J.C.; Reheis, M.; Goldstein, H.; Chavez, P., Jr.; Fulton, R.; Whitney, J.; Fuller, C.; and Forester, R.M. 2007. "Dust Emission from Wet and Dry Playas in the Mojave Desert, USA." *Earth Surface Processes and Landforms*, 32, 1811-1827. New York, New York: John Wiley & Sons. ACC: MOL.20090504.0041.
- 177399 SNL 2007 SNL (Sandia National Laboratories) 2007. *Biosphere Model Report*. MDL-MGR-MD-000001 REV 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070830.0007; LLR.20080328.0002.
- 182130 SNL 2007 SNL (Sandia National Laboratory) 2007. *Irrigation Recycling Model*. MDL-MGR-HS-000001 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071105.0005; DOC.20080117.0001; LLR.20080414.0002.

- 183478 SNL 2008 SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application*. MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001.
- 183750 SNL 2008 SNL (Sandia National Laboratories) 2008. *Saturated Zone Flow and Transport Model Abstraction*. MDL-NBS-HS-000021 REV 03 AD 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080107.0006; LLR.20080408.0256.
- 184806 SNL 2008 SNL (Sandia National Laboratories) 2008. *Site-Scale Saturated Zone Transport*. MDL-NBS-HS-000010 REV 03 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080121.0003; DOC.20080117.0002; DOC.20090115.0001.
- 186186 SNL 2009 SNL (Sandia National Laboratories) 2009. *Inputs to Jason Associates Corporation in Support of the Postclosure Repository Supplemental Environmental Impact Statement (SEIS-3)*. LSA-AR-037. Las Vegas, Nevada: Sandia National Laboratories.
- 186145 Taylor 2008 Taylor, T. 2008. "State of Nevada Order 1197, Applications to Appropriate Additional Underground Water and any Application to Change the Point of Diversion of an Existing Ground-Water Right to Point of Diversion Closer to Devils Hole." Carson City, Nevada: State of Nevada, Office of the State Engineer. ACC: MOL.20090324.0118.