ANL/EVS/R-10/8

Post-Closure Performance Analysis of the Conceptual Disposal Facility Designs at the Sites Considered for the Greater-Than-Class C Environmental Impact Statement

Environmental Science Division

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by
Environmental Science Division, Argonne National Laboratory

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NOTATION

The following is a list of acronyms, abbreviations, and units of measure used in this report. Most of these are used in the text, while others may only be used in tables.

GENERAL ACRONYMS AND ABBREVIATIONS

AMC	activated metal canister
CFR	*Code of Federal Regulations*
CH	contact handled
DCF	dose conversion factor
DOE	U.S. Department of Energy
EIS	environmental impact statement
EM	Office of Environmental Management (DOE)
EPA	U.S. Environmental Protection Agency
GTCC	greater-than-Class C
INL	Idaho National Laboratory
K_d	distribution coefficient
LANL	Los Alamos National Laboratory
LLRW	low-level radioactive waste
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act of 1985
NDA	NRC-licensed disposal area
NNSS	Nevada National Security Site (formerly Nevada Test Site [NTS])
NOI	Notice of Intent
NRC	U.S. Nuclear Regulatory Commission
RH	remote handled
ROD	Record of Decision
SDA	state-licensed disposal area
SRS	Savannah River Site
SWB	standard waste box
SZ	saturated zone
TRU	transuranic
UZ	unsaturated zone
WIPP	Waste Isolation Pilot Plant

UNITS OF MEASURE

Ci	curie(s)
cm	centimeter(s)
cm^3	cubic centimeter(s)
d	day(s)
g	gram(s)
gal	gallon(s)
h	hour(s)
kg	kilogram(s)
L	liter(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mrem	millirem(s)
pCi	picocurie(s)
rem	roentgen equivalent man
yr	year(s)

POST-CLOSURE PERFORMANCE ANALYSIS OF THE CONCEPTUAL DISPOSAL FACILITY DESIGNS AT THE SITES CONSIDERED FOR THE GREATER-THAN-CLASS C ENVIRONMENTAL IMPACT STATEMENT

by

Environmental Science Division
Argonne National Laboratory

1 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Environmental Management (EM) is preparing the environmental impact statement (EIS) for developing disposal capability for greater-than-Class C (GTCC) low-level radioactive waste (LLRW) and GTCC-like waste. A number of disposal sites and disposal methods are being evaluated in the EIS. Some of these alternatives involve the disposal of waste in land disposal facilities. A major component involved in determining the effectiveness of these land disposal methods is their long-term performance; specifically, the potential impacts on nearby future receptors following closure of the facilities at the various sites under consideration need to be determined. This report presents the evaluation that was performed to assess the post-closure effectiveness of such facilities at the sites evaluated in the GTCC EIS.

1.1 BACKGROUND

GTCC LLRW is defined by the U.S. Nuclear Regulatory Commission (NRC) as LLRW that has radionuclide concentrations exceeding the limits for Class C LLRW given in Title 10, Part 61, of the *Code of Federal Regulations* (10 CFR Part 61: "Licensing Requirements for Land Disposal of Radioactive Waste"). Class C LLRW has the highest radionuclide concentration limits as specified in 10 CFR 61.55. GTCC LLRW is generated by activities licensed by the NRC or Agreement States and cannot be disposed of in currently licensed commercial LLRW disposal facilities. Section 3(b)(1)(D) of the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) assigned the responsibility for the disposal of GTCC LLRW to the federal government. The LLRWPAA specifies that GTCC LLRW is to be disposed of in a facility licensed and determined to be adequate by the NRC. DOE is the federal agency responsible for the disposal of GTCC LLRW.

Section 631 of the Energy Policy Act of 2005 requires the Secretary of Energy to (1) provide Congress with notification of the DOE office with responsibility for completing activities needed to provide for safe disposal of GTCC LLRW; (2) submit a report to Congress containing an estimate of the cost and schedule to complete an EIS and record of decision (ROD) for a permanent disposal facility for GTCC LLRW; and (3) prior to issuing the ROD, submit to Congress a report that describes all alternatives considered in the EIS. In response to these requirements, DOE designated EM as the lead organization having responsibility to develop GTCC LLRW disposal capability, and EM submitted a report to Congress in July 2006 on the estimated cost and projected schedule to complete the EIS. Activities on the EIS began in September 2007 following the public comment period on the NOI.

In addition, DOE owns and generates LLRW and transuranic (TRU) waste with characteristics similar to GTCC LLRW and that may not have a path to disposal. DOE has decided to include this waste

in the scope of the EIS as described in the NOI. This waste is referred to as GTCC-like waste. The use of this term does not have the effect of creating a new classification of DOE radioactive waste.

NRC regulations state that GTCC LLRW is generally not acceptable for near-surface disposal but should be disposed of in a geologic repository. However, 10 CFR 61.7(b)(5) states that there may be instances where GTCC LLRW would be acceptable for near-surface disposal with special processing or design. For completeness of analysis, the EIS is considering both geologic repositories and near-surface land disposal facilities for this waste. This report addresses post-closure impacts and is limited to land disposal facilities.

1.2 PURPOSE

The purpose of this report is to summarize the evaluation of the post-closure impacts on human health from the land disposal facilities being considered in the GTCC EIS. Direct intrusion into the wastes is not considered a likely event, because a number of markers and barriers will be placed on, in, and near such a facility to warn individuals of the hazardous nature of the buried wastes, as described in a report issued by Sandia National Laboratories (Sandia 2007). As such, potential human health impacts from direct human intrusion into the closed disposal facility are not considered here.

The two mechanisms by which off-site members of the general public could be impacted by disposal of these wastes in land-based facilities in the long term are (1) leaching of radionuclides to groundwater, with subsequent migration to an accessible location such as a groundwater well, or (2) airborne emissions following erosion of the disposal facility cover. Measures would be taken in designing and constructing land-based disposal facilities to minimize the likelihood of such events and their impacts.

Of these two mechanisms, the radionuclide migration to groundwater pathway is considered more critical than the airborne emission pathway, because the dilution associated with the airborne pathway is much greater than that associated with the groundwater pathway. In addition, the airborne emission rate would be reduced because any material removed from the facility surface cover by erosion or weathering would be replenished by nearby soil similarly removed. Hence, potential impacts from the groundwater pathway are the main focus of analysis in this report.

The disposal facility would be sited in a location consistent with the requirements specified in 10 CFR 61.50(a)(10) for LLRW disposal facilities; i.e., in an area that is not subject to "surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering (that) occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives."

The potential impacts associated with radionuclide releases to the surrounding environment are given in this report in terms of the potential radiation doses to an individual (a) from using contaminated groundwater at the point at which it is accessible to the general public and (b) from inhaling the gaseous radionuclides being blown off site at this point.

1.3 SCOPE

The scope of this assessment includes the post-closure impacts from disposal of the GTCC LLRW and GTCC-like waste at six DOE sites and four generic commercial sites considered in the EIS. In addition, to provide better perspective for the disposal alternatives, potential human health impacts

resulting from leaving the wastes in their respective containers on the ground surface (i.e., the No Action Alternative) were also evaluated. These potential impacts were evaluated for the same four generic commercial sites that were developed for the disposal alternatives, assuming the GTCC LLRW and GTCC-like waste would be consolidated within each of the NRC regions and stored temporarily at the generic commercial site located in that region.

Information on the waste inventory was obtained from the supplement report (Argonne 2010a) that updates the estimates of waste volume and radionuclide activities. Two disposal technologies were identified in the NOI for analysis in the EIS: enhanced near-surface disposal and intermediate-depth borehole disposal. Two variations of the near-surface disposal concept are considered here. In the first approach, waste disposal is completely above grade in vaults. This approach accommodates conditions at sites having very shallow depths to groundwater. The second approach involves placement of the wastes in enhanced near-surface trenches.

This evaluation addresses the GTCC LLRW and GTCC-like waste currently in storage and those to be generated in the foreseeable future. This inventory is described in more detail in the next section.

2 SUMMARY OF GTCC LLRW AND GTCC-LIKE WASTE

A summary of the GTCC LLRW and GTCC-like waste addressed in the EIS is given in this chapter. Preliminary GTCC waste inventories were provided in the NOI to prepare the EIS, and the bases of these estimates are described in Sandia (2007). Additional details on this inventory are provided in a subsequent report prepared by Sandia (2008). Since issuance of the NOI and these two reports, additional wastes have been identified for inclusion in the EIS, and updated estimates have been developed for certain wastes.

To facilitate presentation of the GTCC waste information addressed in the EIS, a supplemental inventory report (Argonne 2010a) was prepared to present updated estimates of the volumes and radionuclide activities of the GTCC LLRW and GTCC-like wastes used in the EIS analyses. This supplemental inventory report summarizes the key information from several references, including the two reports prepared by Sandia, so that a single concise source of GTCC waste information is available. This GTCC waste inventory is summarized here in a format allowing for evaluation of the impacts associated with releases to air and groundwater. For use in the EIS analyses, the waste inventory was divided into two groups. Group 1 waste consists of waste already in storage or expected to be generated from facilities already in operation. Group 2 waste consists mostly of wastes from potential future activities and is therefore considered to be projected waste.

2.1 DESCRIPTION OF WASTES

For purposes of analysis in the EIS, GTCC LLRW and GTCC-like waste are considered to be in one of three waste types: activated metals, sealed sources, and Other Waste, and they include wastes that were already generated and in storage as well as those to be generated in the future. As noted above, Group 1 GTCC wastes are those that were already generated and are in storage or are projected to be generated by facilities currently in operation. All stored GTCC LLRW and GTCC-like wastes are included in Group 1. Group 2 wastes include wastes that might be generated from several DOE projects, molybdenum-99 (Mo-99) production activities, and new nuclear power plants that have not yet been licensed by the NRC or constructed. Group 2 GTCC wastes also include those associated with proposed alternatives for decommissioning two large radioactive waste disposal areas at the West Valley Site in New York.

Group 1 includes both stored and projected wastes. The projected wastes are those that are expected to be generated in the future by current activities or facilities in operation. The future inventories are projected to 2035 for Other Waste, 2062 for activated metals, and 2083 for sealed sources. The time period used for activated metals accounts for the decommissioning of all currently NRC-licensed commercial nuclear power plants. Many nuclear utilities are currently seeking and being granted extensions to their operating licenses from NRC. These extensions are generally for about 20 years. Assuming that all commercial nuclear power reactors receive 20-year license extensions, the last currently operating nuclear power plant will cease operation in 2055. A six-year cooling period is assumed before decommissioning operations commence and these wastes become available for disposal. Allowing one year for disposal, all such waste will be disposed of by 2062.

The time period for the Group 1 Other Waste reflects a reasonable amount of time for addressing the indicated wastes. Many of the wastes in this category are associated with the West Valley Site, and activities that could generate Group 1 wastes at this site are expected to be completed before 2035. The waste volumes and activities for the Other Waste generated by other sources are comparatively small and

well defined. The time period for Group 1 sealed sources is consistent with the assumption used to address the future decommissioning of Group 2 commercial nuclear power reactors.

All of the wastes from Group 2 will be generated in the future. Some of these facilities may or may not be constructed and operated as currently envisioned, so these projections have a high degree of uncertainty associated with them. The same approach as that used for estimating the activated metal wastes from commercial nuclear reactors for Group 1 was used for estimating comparable Group 2 wastes from proposed new reactors. All other GTCC wastes in Group 2 are expected to be disposed of shortly after generation.

The activated metal wastes consist of steel, stainless steel, and a number of specialty alloys used in nuclear reactors. Portions of the reactor assembly and other components near the nuclear fuel are activated by high fluxes of neutrons during reactor operations for long periods of time, and high concentrations of some radionuclides result. Many of these have very short half-lives and decay rapidly, while others have longer half-lives and remain radioactive for an extended period of time. Most of the activated metal wastes will be generated in the future from the decommissioning of commercial nuclear power reactors. For purposes of analysis in the EIS, all of this waste is assumed to be remote-handled (RH) waste and will need shielding to reduce the levels of radiation to acceptable levels and/or will have to be handled remotely. RH waste is waste having contact dose rates greater than 200 mrem/h. The physical form of this waste is solid metal, which is both physically and chemically inert.

Sealed sources are generally small and consist of concentrated radioactive materials enclosed in metal containers. These sources are commonly used to sterilize medical products, detect flaws and failures in pipelines and metal welds, determine moisture content in soil and other materials, and diagnose and treat illnesses such as cancer. It is assumed that these sealed sources will be packaged in 55-gal drums by radionuclide based on packaging factor limits developed by the DOE Global Threat Reduction Initiative/Off-Site Source Recovery Project at Los Alamos National Laboratory. In addition to these small sealed sources, there are 1,435 large commercial cesium-137 sources in the GTCC waste inventory. These sources cannot be packaged in 55-gal drums but are assumed to be disposed of individually in their original shielded devices.

Sealed sources can encompass several physical forms including ceramic oxides, salts, or metal. For purposes of analysis in the EIS, the cesium-137 sources are assumed to be present as cesium chloride salt, and the other sealed sources are assumed to be in the form of oxides. For the EIS, all of this waste is assumed to be contact-handled (CH) waste, i.e., the contact dose rates on the surface of the package are less than 200 mrem/h. Even though a few packaged sources may be RH waste, this assumption is considered reasonable for purposes of analysis in the EIS. Should RH sealed source waste be generated, appropriate precautions would be taken in waste handling and disposal operations to protect workers.

Other Waste includes a wide variety of materials such as contaminated equipment, debris, scrap metals, filters, resins, soil, solidified sludges, and other materials. The waste can come in a number of physical forms, and a range of radionuclides may be present. For purposes of analysis, it is assumed that this waste would be stabilized by grout or another matrix prior to shipment for disposal.

The radionuclides present in GTCC LLRW and GTCC-like waste can generally be categorized as neutron activation products, fission products, and actinides (i.e., radionuclides higher than actinium in the Chart of the Nuclides). The radionuclides in activated metals are mainly neutron activation products, while fission products and actinides are expected to be present in sealed sources and Other Waste and also to be present in low concentrations in activated metals.

The inventory estimates summarized here and provided in more detail in Argonne (2010a) were obtained by using the results of data calls, information provided in databases, review of documents prepared by DOE and the NRC on GTCC LLRW and TRU waste, and discussions with DOE Field Office representatives. The list of documents reviewed in developing these estimates is given in the references of Argonne (2010a). The inventory estimates address the volumes and activities (in curies) in these wastes. Separate estimates are given for GTCC LLRW and GTCC-like waste, and they consider wastes currently in storage as well as those to be produced in the future. These estimates are briefly described here. A more complete description of these inventories and the procedures used to develop them is given in Argonne (2010a).

2.2 VOLUME

The estimated volumes of GTCC LLRW and GTCC-like waste currently in storage and projected to be generated in the future are summarized in Table 2-1. As noted previously, the activated metals are assumed to be RH waste, and the sealed sources are assumed to be CH waste (with a few containers possibly being RH waste). Separate estimates of RH and CH waste volumes are given for the Other Waste category.

The total packaged volume of GTCC LLRW in Groups 1 and 2 addressed in the EIS is estimated to be about 8,800 m^3, and the total volume of GTCC-like wastes in these two groups is estimated to be about 2,800 m^3. The combined total volume of wastes in these two groups is about 12,000 m^3 (Table 2-1). Of this total, about 1,100 m^3 has already been generated and is in storage and 11,000 m^3 is projected to be generated in the future. Most of the stored waste is GTCC-like waste, and much of this waste is being stored at the West Valley Site. About 82% of the projected waste volume is GTCC LLRW, and 18% is GTCC-like waste. About 17% of the total waste volume is activated metals, 25% is sealed sources, and 58% is Other Waste. The post closure performance assessment presented in this report considers the disposal of both Group 1 and Group 2 GTCC LLRW and GTCC-like wastes.

2.3 RADIOLOGICAL INVENTORY

Estimates of the radionuclide inventories (in curies) in the various GTCC LLRW and GTCC-like wastes are also provided in Argonne (2010a). The estimates of radionuclide inventory were based on Sandia (2007 and 2008) and a review of information contained in other references. The analysis in Sandia (2007 and 2008) focused on obtaining estimates for those radionuclides most prevalent in the various wastes; however, some additional radionuclides that might be present in lower concentrations could present a long-term management concern because of their greater radiotoxicity and mobility in the environment. These radionuclides were added to the list presented in Sandia (2007 and 2008) to ensure completeness of analysis in the EIS.

Radionuclide profiles were used to develop estimates of the total curies of each radionuclide that would be present in the various waste streams, and then the individual waste streams were summed to obtain an estimate of the total radionuclide activity for the wastes that made up a category. The total radionuclide inventory for Group 1 GTCC LLRW and GTCC-like waste in the three waste types are given in Tables 2-2, 2-3, and 2-4. Table 2-2 contains the total (stored and projected) inventories for GTCC LLRW and GTCC-like waste, which are divided into the stored inventories (Table 2-3) and projected inventories (Table 2-4). Most of the activity is associated with the neutron activation products in commercial nuclear reactors (i.e., the activated metal category under GTCC LLRW). The sealed sources contribute a relatively small amount to the total radionuclide inventory, with the exception of cesium-137

(which has a half-life of 30 years). While the total radionuclide inventory in the Other Waste type is much less than it is in the activated metal waste, the Other Waste contains a number of TRU radionuclides that might present a long-term management concern.

The total radionuclide inventory for Group 2 GTCC LLRW and GTCC-like waste is given in Table 2-5. The approach used to estimate these activities was generally the same as that described above for Group 1 wastes. However, there is greater uncertainty associated with these estimates than with those for Group 1.

TABLE 2-1 Packaged Waste Volumes (m^3) of GTCC LLRW and GTCC-Like Waste Estimated for EIS Analysis[a]

	GTCC LLRW				GTCC-Like Waste				
Waste Group	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Total
Group 1 stored	59	0.0	42	33	6.2	0.21	430	520	1,100
Group 1 projected	820	2,800	0.0	1.0	6.6	0.62	310	200	4,200
Group 2 projected	1,100	23	1,600	2,300	0.0	0.0	490	870	6,400
Total	2,000	2,900	1,600	2,400	13	0.83	1,200	1,600	12,000

[a] All values are given to two significant figures.

TABLE 2-2 Total Radionuclide Activity (in Curies) of Group 1 GTCC LLRW and GTCC-Like Waste[a]

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Hydrogen-3	6.8×10^{3}	–	–	–	–	2.3×10^{5}	–	–	1.7×10^{-1}	1.6×10^{1}
Carbon-14	2.3×10^{4}	–	–	–	5.8×10^{-3}	6.8×10^{2}	–	–	1.3×10^{1}	1.0×10^{2}
Manganese-54	4.9×10^{4}	–	–	–	9.6×10^{-3}	2.8×10^{-5}	–	–	4.7×10^{-3}	4.8×10^{1}
Iron-55	4.0×10^{7}	–	–	–	6.3×10^{-4}	1.7×10^{2}	–	–	5.7	8.2
Nickel-59	1.3×10^{5}	–	–	–	1.1×10^{-1}	3.1	–	–	7.6×10^{-2}	1.6×10^{2}
Cobalt-60	5.0×10^{7}	–	–	–	8.7	4.7×10^{3}	–	–	4.1×10^{-3}	1.2×10^{3}
Nickel-63	1.8×10^{7}	–	–	–	5.3	8.0×10^{2}	–	–	2.5×10^{-2}	9.4×10^{3}
Strontium-90	1.2×10^{4}	–	–	–	1.5×10^{3}	–	–	–	6.6×10^{1}	3.6×10^{4}
Molybdenum-93	1.1×10^{2}	–	–	–	–	–	–	–	–	–
Niobium-94	6.0×10^{2}	–	–	–	–	1.3×10^{-2}	–	–	5.2×10^{-5}	9.8×10^{-2}
Technetium-99	4.5×10^{3}	–	–	–	7.6×10^{-1}	–	–	–	3.2×10^{-1}	1.7×10^{2}
Iodine-129	1.9	–	–	–	–	–	–	–	9.7×10^{-5}	2.7
Cesium-137	1.3×10^{4}	–	1.7×10^{6}	5.7	2.0×10^{3}	–	–	–	6.5×10^{1}	3.9×10^{4}
Promethium-147	–	–	–	–	–	–	–	–	1.4×10^{-3}	5.6
Samarium-151	–	–	–	–	–	–	–	–	2.9×10^{-3}	1.7×10^{-1}
Europium-152	–	–	–	–	–	6.6×10^{2}	–	–	3.1×10^{-3}	6.8×10^{2}
Europium-154	–	–	–	–	–	6.0	–	–	1.9×10^{-1}	2.2×10^{2}
Europium-155	–	–	–	–	–	7.1×10^{-1}	–	–	3.1×10^{-4}	9.2×10^{1}
Lead-210	–	–	–	–	5.1×10^{-9}	–	–	–	3.6×10^{-6}	2.3×10^{-9}
Radium-226	–	–	–	–	–	–	–	–	4.3	–
Actinium-227	–	–	–	–	–	–	–	–	3.3×10^{-2}	1.6×10^{-9}
Radium-228	–	–	–	–	–	–	–	–	2.3×10^{-1}	–
Thorium-229	–	–	–	–	8.8×10^{-4}	–	–	–	2.2	7.4×10^{-2}
Thorium-230	–	–	–	–	8.9×10^{-6}	–	–	–	4.1×10^{-1}	2.7×10^{-2}
Protactinium-231	–	–	–	–	–	–	–	–	1.1×10^{-5}	1.3×10^{-8}
Thorium-232	–	–	–	–	–	–	–	–	2.8×10^{-1}	6.8×10^{-1}
Uranium-232	–	–	–	–	–	–	–	–	2.3×10^{1}	1.9
Uranium-233	–	–	–	–	6.0×10^{-1}	–	–	–	9.4	7.9×10^{2}
Uranium-234	–	–	–	–	–	–	–	–	4.4×10^{1}	1.6
Uranium-235	–	–	–	–	5.2×10^{-3}	–	–	–	1.6×10^{-1}	3.5×10^{-1}
Uranium-236	–	–	–	–	–	–	–	–	5.4×10^{-2}	7.9×10^{-1}
Neptunium-237	–	–	–	–	3.2×10^{-3}	–	–	–	1.1	1.5

TABLE 2-2 (Cont.)

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Uranium-238	–	–	–	–	–	–	–	–	9.1×10^{-2}	1.1×10^{1}
Plutonium-238	8.8×10^{-1}	1.2×10^{5}	–	–	1.8×10^{1}	–	–	–	1.3×10^{3}	1.5×10^{3}
Plutonium-239	4.5×10^{3}	8.4×10^{3}	–	–	2.5×10^{1}	–	–	–	9.0×10^{2}	2.9×10^{3}
Plutonium-240	–	–	–	–	7.5	–	2.2×10^{1}	–	7.1×10^{2}	1.8×10^{3}
Plutonium-241	2.5×10^{1}	–	–	–	6.2×10^{2}	–	–	–	1.4×10^{4}	1.7×10^{4}
Americium-241	6.4×10^{1}	1.5×10^{5}	–	5.0	6.6×10^{1}	–	–	–	4.4×10^{3}	5.3×10^{3}
Plutonium-242	–	–	–	–	2.3×10^{-3}	–	–	–	4.5	3.9
Americium-243	–	–	–	–	4.7×10^{-3}	–	3.5×10^{-1}	–	3.4×10^{1}	8.6×10^{1}
Curium-243	–	–	–	–	–	–	–	–	7.6×10^{-2}	2.2
Curium-244	–	2.2×10^{1}	–	–	5.2	–	5.4×10^{1}	–	1.8	1.1×10^{3}
Curium-245	–	–	–	–	–	–	–	–	2.0×10^{-9}	3.4×10^{2}
Curium-246	–	–	–	–	–	–	–	–	1.9×10^{-11}	5.4×10^{1}

[a] The activities represent values at the time the wastes are projected to be available for disposal and are given to two significant figures. Separate estimates were developed for GTCC LLRW and GTCC-like waste. A dash means there is no value for that entry. CH = contact-handled (waste), RH = remote-handled (waste).

[b] All of the activated metal wastes are expected to be RH waste.

[c] All of the sealed source wastes are expected to be CH waste, with the possible exception of two americium-241/beryllium sources.

TABLE 2-3 Radionuclide Activity (in Curies) of Stored Group 1 GTCC LLRW and GTCC-Like Waste[a]

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Hydrogen-3	1.6×10^{2}	–	–	–	–	2.3×10^{5}	–	–	1.1×10^{-1}	1.6×10^{1}
Carbon-14	1.4×10^{3}	–	–	–	5.6×10^{-3}	2.0×10^{2}	–	–	1.0×10^{1}	1.0×10^{2}
Manganese-54	9.2×10^{-3}	–	–	–	9.4×10^{-3}	2.8×10^{-5}	–	–	2.3×10^{-6}	4.2×10^{-3}
Iron-55	3.4×10^{4}	–	–	–	6.1×10^{-4}	1.7×10^{2}	–	–	9.9×10^{-1}	8.2
Nickel-59	7.8×10^{3}	–	–	–	1.1×10^{-1}	6.0×10^{-1}	–	–	5.9×10^{-2}	1.6×10^{2}
Cobalt-60	3.5×10^{5}	–	–	–	8.4	8.5×10^{2}	–	–	4.0×10^{-3}	3.1×10^{2}
Nickel-63	9.6×10^{5}	–	–	–	5.2	1.9×10^{2}	–	–	2.5×10^{-2}	9.4×10^{3}
Strontium-90	4.7×10^{2}	–	–	–	1.5×10^{3}	–	–	–	8.6	2.9×10^{4}
Molybdenum-93	7.4	–	–	–	–	–	–	–	–	–
Niobium-94	4.1×10^{1}	–	–	–	–	1.8×10^{-3}	–	–	5.2×10^{-5}	9.8×10^{-2}
Technetium-99	2.8×10^{2}	–	–	–	7.3×10^{-1}	–	–	–	2.4×10^{-1}	1.7×10^{2}
Iodine-129	1.2×10^{-1}	–	–	–	–	–	–	–	4.9×10^{-5}	2.7
Cesium-137	5.5×10^{2}	–	–	5.7	2.0×10^{3}	–	–	–	5.0	3.0×10^{4}
Promethium-147	–	–	–	–	–	–	–	–	1.4×10^{-3}	5.6
Samarium-151	–	–	–	–	–	–	–	–	2.9×10^{-3}	1.7×10^{-1}
Europium-152	–	–	–	–	–	6.6×10^{2}	–	–	3.1×10^{-3}	6.0×10^{-4}
Europium-154	–	–	–	–	–	6.0	–	–	1.1×10^{-1}	1.7×10^{1}
Europium-155	–	–	–	–	–	7.1×10^{-1}	–	–	3.1×10^{-4}	7.9×10^{-1}
Lead-210	–	–	–	–	4.9×10^{-9}	–	–	–	3.6×10^{-6}	2.2×10^{-9}
Radium-226	–	–	–	–	–	–	–	–	3.4	–
Actinium-227	–	–	–	–	–	–	–	–	2.4×10^{-2}	1.6×10^{-9}
Radium-228	–	–	–	–	–	–	–	–	1.1×10^{-1}	–
Thorium-229	–	–	–	–	8.5×10^{-4}	–	–	–	1.7	7.4×10^{-2}
Thorium-230	–	–	–	–	8.6×10^{-6}	–	–	–	3.2×10^{-1}	2.7×10^{-2}
Protactinium-231	–	–	–	–	–	–	–	–	1.1×10^{-5}	1.3×10^{-8}
Thorium-232	–	–	–	–	–	–	–	–	2.2×10^{-1}	6.8×10^{-1}
Uranium-232	–	–	–	–	–	–	–	–	1.8×10^{1}	1.9
Uranium-233	–	–	–	–	5.8×10^{-1}	–	–	–	7.3	1.7×10^{1}
Uranium-234	–	–	–	–	–	–	–	–	3.4×10^{1}	1.6
Uranium-235	–	–	–	–	5.0×10^{-3}	–	–	–	1.5×10^{-1}	3.5×10^{-1}
Uranium-236	–	–	–	–	–	–	–	–	4.2×10^{-2}	7.9×10^{-1}

TABLE 2-3 (Cont.)

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Neptunium-237	–	–	–	–	3.1×10^{-3}	–	–	–	1.0	1.5
Uranium-238	–	–	–	–	–	–	–	–	7.0×10^{-2}	1.8
Plutonium-238	4.7×10^{-2}	–	–	–	1.8×10^{1}	–	–	–	1.0×10^{3}	7.5×10^{2}
Plutonium-239	2.8×10^{2}	–	–	–	2.4×10^{1}	–	–	–	7.0×10^{2}	2.7×10^{3}
Plutonium-240	–	–	–	–	7.3	–	–	–	5.6×10^{2}	1.7×10^{3}
Plutonium-241	6.4×10^{-1}	–	–	–	6.0×10^{2}	–	–	–	9.6×10^{3}	1.6×10^{4}
Americium-241	3.8	–	–	5.0	6.4×10^{1}	–	–	–	3.6×10^{3}	5.3×10^{3}
Plutonium-242	–	–	–	–	2.2×10^{-3}	–	–	–	3.5	3.9
Americium-243	–	–	–	–	4.6×10^{-3}	–	–	–	2.7×10^{1}	8.6×10^{1}
Curium-243	–	–	–	–	–	–	–	–	5.3×10^{-2}	1.8
Curium-244	–	–	–	–	5.0	–	6.0	–	1.2	3.8×10^{1}
Curium-245	–	–	–	–	–	–	–	–	2.0×10^{-9}	3.4×10^{2}
Curium-246	–	–	–	–	–	–	–	–	1.9×10^{-11}	5.4×10^{1}

[a] The activities represent values at the time the wastes are projected to be available for disposal and are given to two significant figures. Separate estimates were developed for GTCC LLRW and GTCC-like waste. A dash means there are no values for that entry. CH = contact-handled (waste), RH = remote-handled (waste).

[b] All of the activated metal wastes are expected to be RH waste.

[c] All of the sealed source wastes are expected to be CH waste, with the possible exception of two americium-241/beryllium sources.

TABLE 2-4 Radionuclide Activity (in Curies) of Projected Group 1 GTCC LLRW and GTCC-Like Waste[a]

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Hydrogen-3	6.7×10^{3}	–	–	–	–	–	–	–	5.7×10^{-2}	–
Carbon-14	2.1×10^{4}	–	–	–	1.7×10^{-4}	4.9×10^{2}	–	–	3.0	1.4×10^{-2}
Manganese-54	4.9×10^{4}	–	–	–	2.9×10^{-4}	–	–	–	4.7×10^{-3}	4.8×10^{1}
Iron-55	4.0×10^{7}	–	–	–	1.9×10^{-5}	–	–	–	4.7	1.1×10^{-5}
Nickel-59	1.2×10^{5}	–	–	–	3.3×10^{-3}	2.5	–	–	1.7×10^{-2}	2.0×10^{-3}
Cobalt-60	5.0×10^{7}	–	–	–	2.6×10^{-1}	3.8×10^{3}	–	–	9.8×10^{-5}	8.8×10^{2}
Nickel-63	1.7×10^{7}	–	–	–	1.6×10^{-1}	6.1×10^{2}	–	–	–	9.5×10^{-2}
Strontium-90	1.1×10^{4}	–	–	–	4.6×10^{1}	–	–	–	5.7×10^{1}	7.3×10^{3}
Molybdenum-93	1.0×10^{2}	–	–	–	–	–	–	–	–	–
Niobium-94	5.5×10^{2}	–	–	–	–	1.1×10^{-2}	–	–	–	–
Technetium-99	4.2×10^{3}	–	–	–	2.3×10^{-2}	–	–	–	8.7×10^{-2}	2.1
Iodine-129	1.8	–	–	–	–	–	–	–	4.8×10^{-5}	6.6×10^{-5}
Cesium-137	1.3×10^{4}	–	1.7×10^{6}	–	6.0×10^{1}	–	–	–	6.0×10^{1}	9.5×10^{3}
Promethium-147	–	–	–	–	–	–	–	–	–	–
Samarium-151	–	–	–	–	–	–	–	–	–	–
Europium-152	–	–	–	–	–	–	–	–	–	6.8×10^{2}
Europium-154	–	–	–	–	–	–	–	–	7.5×10^{-2}	2.0×10^{2}
Europium-155	–	–	–	–	–	–	–	–	–	9.1×10^{1}
Lead-210	–	–	–	–	1.5×10^{-10}	–	–	–	–	9.1×10^{-11}
Radium-226	–	–	–	–	–	–	–	–	9.5×10^{-1}	–
Actinium-227	–	–	–	–	–	–	–	–	9.5×10^{-3}	–
Radium-228	–	–	–	–	–	–	–	–	1.2×10^{-1}	–
Thorium-229	–	–	–	–	2.6×10^{-5}	–	–	–	4.9×10^{-1}	1.6×10^{-5}
Thorium-230	–	–	–	–	2.7×10^{-7}	–	–	–	8.8×10^{-2}	1.6×10^{-7}
Protactinium-231	–	–	–	–	–	–	–	–	–	–
Thorium-232	–	–	–	–	–	–	–	–	6.2×10^{-2}	–
Uranium-232	–	–	–	–	–	–	–	–	5.5	5.6×10^{-3}
Uranium-233	–	–	–	–	1.8×10^{-2}	–	–	–	2.1	7.8×10^{2}
Uranium-234	–	–	–	–	–	–	–	–	9.6	2.4×10^{-3}
Uranium-235	–	–	–	–	1.5×10^{-4}	–	–	–	4.1×10^{-3}	3.1×10^{-4}
Uranium-236	–	–	–	–	–	–	–	–	1.2×10^{-2}	–

TABLE 2-4 (Cont.)

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[c]		Other Waste			Sealed Sources[c]		Other Waste	
Radionuclide	Activated Metals[b]	Actinides	Nonactinides	CH	RH	Activated Metals[b]	Actinides	Nonactinides	CH	RH
Neptunium-237	–	–	–	–	9.5×10^{-5}	–	–	–	1.1×10^{-2}	3.1×10^{-2}
Uranium-238	–	–	–	–	–	–	–	–	2.2×10^{-2}	8.8
Plutonium-238	8.3×10^{-1}	1.2×10^{5}	–	–	5.4×10^{-1}	–	–	–	2.9×10^{2}	7.5×10^{2}
Plutonium-239	4.2×10^{3}	8.4×10^{3}	–	–	7.4×10^{-1}	–	–	–	2.0×10^{2}	2.0×10^{2}
Plutonium-240	–	–	–	–	2.2×10^{-1}	–	2.2×10^{1}	–	1.6×10^{2}	3.4×10^{1}
Plutonium-241	2.4×10^{1}	–	–	–	1.8×10^{1}	–	–	–	4.6×10^{3}	1.0×10^{2}
Americium-241	6.0×10^{1}	1.5×10^{5}	–	–	2.0	–	–	–	7.1×10^{2}	6.0×10^{1}
Plutonium-242	–	–	–	–	6.8×10^{-5}	–	–	–	9.8×10^{-1}	4.1×10^{-5}
Americium-243	–	–	–	–	1.4×10^{-4}	–	3.5×10^{-1}	–	7.5	8.4×10^{-5}
Curium-243	–	–	–	–	–	–	–	–	2.3×10^{-2}	3.4×10^{-1}
Curium-244	–	2.2×10^{1}	–	–	1.5×10^{-1}	–	4.8×10^{1}	–	5.9×10^{-1}	1.1×10^{3}
Curium-245	–	–	–	–	–	–	–	–	–	–
Curium-246	–	–	–	–	–	–	–	–	–	–

[a] The activities represent values at the time the wastes are projected to be available for disposal and are given to two significant figures. Separate estimates were developed for GTCC LLRW and GTCC-like waste. A dash means there are not values for that entry. CH = contact-handled (waste), RH = remote-handled (waste).

[b] All of the activated metal wastes are expected to be RH waste.

[c] All of the sealed source wastes are expected to be CH waste, with the possible exception of two americium-241/beryllium sources.

TABLE 2-5 Total Radionuclide Activity (in Curies) of Group 2 GTCC LLRW and GTCC-Like Waste[a]

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[b]		Other Waste			Sealed Sources		Other Waste	
Radionuclide	Activated Metals[c]	Actinides	Nonactinides	CH	RH	Activated Metals[c]	Actinides	Nonactinides	CH	RH
Hydrogen-3	3.6×10^{3}	–	–	2.0×10^{2}	1.9×10^{2}	–	–	–	1.1×10^{-1}	1.7×10^{-1}
Carbon-14	1.0×10^{4}	–	–	4.4	1.5×10^{2}	–	–	–	5.9	9.0
Manganese-54	2.3×10^{4}	–	–	–	1.8×10^{-7}	–	–	–	9.4×10^{-3}	1.4×10^{-2}
Iron-55	1.8×10^{7}	–	–	3.9×10^{-1}	3.1	–	–	–	9.4	1.4×10^{1}
Nickel-59	5.4×10^{4}	–	–	3.3×10^{-2}	2.1	–	–	–	3.3×10^{-2}	5.1×10^{-2}
Cobalt-60	2.3×10^{7}	–	–	6.5	4.8×10^{1}	–	–	–	2.0×10^{-4}	3.0×10^{-4}
Nickel-63	7.5×10^{6}	–	–	3.7	1.8×10^{2}	–	–	–	–	–
Strontium-90	1.3×10^{4}	–	–	2.8	1.0×10^{5}	–	–	–	6.1	5.1×10^{4}
Molybdenum-93	4.7×10^{1}	–	–	–	5.5×10^{-5}	–	–	–	–	–
Niobium-94	2.7×10^{2}	–	–	1.0×10^{-3}	2.8×10^{-2}	–	–	–	–	–
Technetium-99	1.9×10^{3}	–	–	1.0×10^{-3}	1.7×10^{1}	–	–	–	1.3×10^{-1}	3.2
Iodine-129	2.1	–	–	2.9×10^{-3}	5.4×10^{-2}	–	–	–	–	3.8×10^{-3}
Cesium-137	2.3×10^{4}	–	–	2.2×10^{1}	1.1×10^{5}	–	–	–	3.3	3.4×10^{5}
Promethium-147	1.1×10^{-1}	–	–	–	1.7×10^{5}	–	–	–	–	4.4×10^{3}
Samarium-151	1.7×10^{2}	–	–	–	2.4×10^{3}	–	–	–	–	–
Europium-152	3.3×10^{-1}	–	–	–	1.1	–	–	–	–	–
Europium-154	1.8×10^{1}	–	–	–	5.9×10^{1}	–	–	–	1.5×10^{-1}	2.3×10^{-1}
Europium-155	7.0×10^{-1}	–	–	–	2.0×10^{3}	–	–	–	–	–
Lead-210	3.3×10^{-7}	–	–	–	5.1×10^{-7}	–	–	–	–	–
Radium-226	1.5×10^{-6}	–	–	–	2.5×10^{-6}	–	–	–	1.9	2.9
Actinium-227	1.1×10^{-2}	–	–	–	1.8×10^{-2}	–	–	–	1.9×10^{-2}	2.9×10^{-2}
Radium-228	3.2×10^{-4}	–	–	–	5.6×10^{-4}	–	–	–	2.4×10^{-1}	3.6×10^{-1}
Thorium-229	1.2×10^{-2}	–	–	–	2.2×10^{-2}	–	–	–	9.8×10^{-1}	1.5
Thorium-230	1.3×10^{-4}	–	–	–	2.4×10^{-4}	–	–	–	1.8×10^{-1}	2.7×10^{-1}
Protactinium-231	3.0×10^{-2}	–	–	–	5.2×10^{-2}	–	–	–	–	–
Thorium-232	3.2×10^{-3}	–	–	–	5.6×10^{-3}	–	–	–	1.2×10^{-1}	1.9×10^{-1}
Uranium-232	1.4	–	–	–	2.9	–	–	–	1.1×10^{1}	1.7×10^{1}
Uranium-233	3.8	–	–	–	7.4	–	–	–	4.1	6.4
Uranium-234	2.0×10^{-1}	–	–	9.7×10^{-3}	3.9×10^{-1}	–	–	–	1.9×10^{1}	2.9×10^{1}
Uranium-235	7.2×10^{-2}	–	–	4.8×10^{-4}	3.7	–	–	–	8.0×10^{-3}	1.4×10^{-2}
Uranium-236	1.1×10^{-1}	–	–	–	4.4×10^{-1}	–	–	–	2.4×10^{-2}	3.6×10^{-2}

TABLE 2-5 (Cont.)

	GTCC LLRW					GTCC-Like Waste				
		Sealed Sources[b]		Other Waste			Sealed Sources		Other Waste	
Radionuclide	Activated Metals[c]	Actinides	Nonactinides	CH[d]	RH[d]	Activated Metals[c]	Actinides	Nonactinides	CH	RH
Neptunium-237	6.7×10^{-2}	–	–	3.4×10^{-9}	9.9×10^{-2}	–	–	–	2.2×10^{-2}	2.3
Uranium-238	8.4×10^{-1}	–	–	1.0×10^{-2}	3.1	–	–	–	3.9×10^{-2}	7.3×10^{-2}
Plutonium-238	1.3×10^{2}	–	–	2.1×10^{4}	2.1×10^{2}	–	–	–	5.7×10^{2}	1.9×10^{3}
Plutonium-239	2.1×10^{3}	–	–	4.9×10^{1}	4.5×10^{2}	–	–	–	4.0×10^{2}	6.4×10^{2}
Plutonium-240	1.6×10^{2}	–	–	4.5×10^{1}	2.4×10^{2}	–	–	–	3.2×10^{2}	5.1×10^{2}
Plutonium-241	2.5×10^{3}	–	–	2.7×10^{3}	3.9×10^{3}	–	–	–	9.3×10^{3}	1.5×10^{4}
Americium-241	7.2×10^{2}	–	–	1.2×10^{-2}	1.0×10^{3}	–	–	–	1.4×10^{3}	2.6×10^{3}
Plutonium-242	1.4×10^{-1}	–	–	4.4×10^{-2}	2.0×10^{-1}	–	–	–	2.0	3.0
Americium-243	1.1	–	–	6.8×10^{-4}	6.8×10^{-1}	–	–	–	1.5×10^{1}	2.3×10^{1}
Curium-243	1.4×10^{-1}	–	–	7.4×10^{-6}	2.4×10^{-1}	–	–	–	3.9×10^{-2}	3.9
Curium-244	8.0	–	–	4.9×10^{-3}	5.3	–	–	–	1.0	9.1×10^{1}
Curium-245	8.0×10^{-4}	–	–	–	1.3×10^{-3}	–	–	–	–	–
Curium-246	6.4×10^{-5}	–	–	–	1.1×10^{-4}	–	–	–	–	–

[a] There is a large degree of uncertainty in the schedules and plans for the projects that will generate these wastes. The activities represent values at the time the wastes are projected to be available for disposal and are given to two significant figures. Separate estimates were developed for GTCC LLRW and GTCC-like waste. All of these wastes will be generated in the future, and there are no Group 2 GTCC-like activated metal and sealed source wastes. A dash means there is no value for that entry. CH = contact-handled (waste), RH = remote-handled (waste).

[b] The radionuclide activities for the small volume of sealed sources in the SDA are included with the activities reported for the GTCC LLRW Other Waste - RH category.

[c] All of the activated metal wastes are expected to be RH waste.

3 METHODOLOGY

The approach used in this report to address the post-closure radiological impacts from the disposal alternatives on a nearby individual was to conceptually place the entire waste inventory summarized in Section 2 into each of the three land disposal facilities at the sites under consideration and to then model the movement of the radionuclides from the disposal facility to the individual. The same approach was used for the No Action Alternative, except that rather than considering the impact from the entire waste inventory, the waste inventory was distributed among four geographic regions, and one generic storage facility was assumed in each region. The impact results are reported for the total inventory and separately for the different types of waste under the stored and projected categories (see Section 4). Calculations were performed until the time of peak dose or for 100,000 years, whichever occurred first.

The hypothetical receptor is assumed to be located 100 m from the edge of the disposal facility in the direction that maximizes the radiation dose from the air and groundwater pathway, respectively. This distance was chosen to be consistent with the performance assessment requirements identified for DOE LLRW disposal facilities in Section P(2)(b) of Chapter IV of the DOE *Radioactive Waste Management Manual* (DOE 2001). This section states: "The point of compliance shall correspond to the point of highest projected dose or concentration beyond a 100 meter buffer zone surrounding the disposed wastes. A larger or smaller buffer zone may be used if adequate justification is provided." Given the conceptual nature of these designs, this 100-m distance was assumed to be from the edge of the disposal facility, with no additional buffer zone. To be consistent with the assumption for the disposal alternatives, the hypothetical receptor for the No Action Alternative was also assumed to be located 100 m from the edge of the storage facility in the direction of groundwater flow that would maximize the potential radiation dose to the receptor.

Waste containers can remain intact from a few years to more than 100 years, depending on the materials used to construct the containers. A typical 55-gal drum would be expected to maintain its integrity for several decades; more robust containers would last somewhat longer. In addition to waste containers, the various layers of engineered materials covering and lining the disposal area can also prevent and reduce the infiltration of water into the disposal area. For this analysis, it is assumed that the waste containers and engineered materials would remain intact for 500 years and then gradually degrade, allowing water to come in contact with the waste materials. That is, the radionuclides would remain confined within the waste packages in the maintained disposal unit (aboveground cell, trench, or borehole) during the first 500 years following facility closure. The radionuclides would decay during this time period, and some would no longer present a long-term concern. However, additional radionuclides would be added to the inventory from ingrowth, especially with regard to the actinides.

For the No Action Alternative, the waste containers were assumed to be stacked on the ground surface, exposed directly to weathering without the protection from any cover or engineered materials. As a result, degradation of the containers would start earlier, allowing precipitation to enter the containers. For the long-term impact analysis, it is assumed that the degradation would start 100 years after all the waste containers were placed into storage. Because the decay of radionuclides in the waste materials is less extensive for the No Action Alternative than for the disposal alternatives when the leaching process begins, the amount of radioactivity available for leaching would be greater for the No Action Alternative than for the disposal alternatives.

To illustrate the significance of radionuclide decay and ingrowth, the radionuclide inventory in the waste at the end of 30, 100, 500, and 1,000 years is shown in Table 3-1. As can be seen in this table, some radionuclides decay away quite quickly and are at very low concentrations at 500 years. However, the inventory does not change significantly between 500 and 1,000 years post-closure; that is, the

TABLE 3-1 Radionuclide Inventory of GTCC LLRW and GTCC-Like Waste at Future Times[a,b]

Radionuclide	Half-Life (yr)	Time of Disposal	Radioactivity (Ci) 30 Years	100 Years	500 Years	1,000 Years
Hydrogen-3	1.24×10^{1}	2.42E+05	4.49E+04	8.83E+02	1.57E-07	1.02E-19
Carbon-14	5.73×10^{3}	3.38E+04	3.37E+04	3.34E+04	3.18E+04	2.99E+04
Manganese-54	8.56×10^{-1}	7.20E+04	2.00E-06	0.00E+00	0.00E+00	0.00E+00
Iron-55	2.70	5.73E+07	2.59E+04	4.06E-04	0.00E+00	0.00E+00
Nickel-59	7.50×10^{4}	1.81E+05	1.81E+05	1.81E+05	1.80E+05	1.80E+05
Cobalt-60	5.27	7.35E+07	1.42E+06	1.43E+02	2.05E-21	0.00E+00
Nickel-63	9.60×10^{1}	2.52E+07	2.03E+07	1.22E+07	6.81E+05	1.84E+04
Strontium-90	2.91×10^{1}	2.14E+05	1.05E+05	1.98E+04	1.45E+00	9.85E-06
Molybdenum-93	3.50×10^{3}	1.58E+02	1.57E+02	1.55E+02	1.43E+02	1.30E+02
Niobium-93m	1.36×10^{3}	0.00E+00	1.23E+02	1.54E+02	1.44E+02	1.30E+02
Niobium-94	2.03×10^{4}	8.66E+02	8.66E+02	8.63E+02	8.52E+02	8.37E+02
Technetium-99	2.13×10^{5}	6.55E+03	6.55E+03	6.54E+03	6.54E+03	6.52E+03
Iodine-129	1.57×10^{7}	6.77E+00	6.77E+00	6.77E+00	6.77E+00	6.77E+00
Cesium-137	3.00×10^{1}	2.26E+06	1.13E+06	2.24E+05	2.17E+01	2.09E-04
Samarium-151	90	2.55E+03	2.02E+03	1.18E+03	5.42E+01	1.15E+00
Europium-152	13.33	6.81E+02	1.43E+02	3.76E+00	3.48E-09	1.78E-20
Europium-154	8.8	2.98E+02	2.80E+01	1.13E-01	2.34E-15	0.00E+00
Europium-155	4.96	2.09E+03	3.16E+01	1.80E-03	0.00E+00	0.00E+00
Lead-210	2.23×10^{1}	4.42E-06	5.48E+00	8.45E+00	7.64E+00	6.50E+00
Polonium-210	3.79×10^{-1}	2.78E-27	5.42E+00	8.45E+00	7.64E+00	6.50E+00
Radium-226	1.60×10^{3}	9.10E+00	8.99E+00	8.75E+00	7.55E+00	6.44E+00
Radium-228	5.75	8.22E-01	1.27E+00	1.28E+00	1.28E+00	1.28E+00
Thorium-228	1.91	1.32E+01	4.52E+01	1.28E+00	1.76E+00	1.28E+00
Actinium-227	21.77	1.10E-01	4.24E-02	4.57E-03	1.35E-08	1.65E-15
Thorium-229	7.34×10^{3}	4.81E+00	4.79E+00	4.76E+00	4.59E+00	4.37E+00
Thorium-230	7.70×10^{4}	8.77E-01	9.04E-01	9.76E-01	1.48E+00	2.13E+00
Protactinium-231	3.28×10^{4}	8.27E-02	8.54E-02	9.16E-02	1.27E-01	1.71E-01
Thorium-232	1.41×10^{10}	1.28E+00	1.28E+00	1.28E+00	1.28E+00	1.28E+00
Uranium-232	72	5.71E+01	4.28E+01	0.00E+00	4.64E-01	3.76E-03
Uranium-233	1.59×10^{5}	8.24E+02	8.24E+02	8.24E+02	8.22E+02	8.20E+02
Uranium-234	2.45×10^{5}	9.44E+01	1.06E+02	1.24E+02	1.47E+02	1.47E+02
Uranium-235	7.04×10^{8}	4.29E+00	4.29E+00	4.29E+00	4.30E+00	4.31E+00
Uranium-236	2.34×10^{7}	1.46E+00	1.46E+00	1.47E+00	1.51E+00	1.56E+00
Neptunium-237	2.14×10^{6}	5.09E+00	6.71E+00	1.02E+01	2.42E+01	3.28E+01
Uranium-238	4.47×10^{9}	1.48E+01	1.48E+01	1.48E+01	1.48E+01	1.48E+01
Plutonium-238	8.77×10^{1}	1.49E+05	1.17E+05	6.75E+04	2.86E+03	5.51E+01
Plutonium-239	2.41×10^{4}	2.03E+04	2.03E+04	2.03E+04	2.01E+04	1.98E+04
Plutonium-240	6.54×10^{3}	3.79E+03	3.78E+03	3.76E+03	3.60E+03	3.42E+03
Plutonium-241	1.44×10^{1}	6.49E+04	1.56E+04	8.58E+02	3.23E+02	3.10E+02
Americium-241	4.32×10^{2}	1.69E+05	1.63E+05	1.46E+05	7.71E+04	3.47E+04
Plutonium-242	3.76×10^{5}	1.36E+01	1.36E+01	1.36E+01	1.37E+01	1.37E+01
Americium-243	7.38×10^{3}	1.60E+02	1.60E+02	1.59E+02	1.53E+02	1.46E+02
Curium-243	28.5	6.51E+00	3.14E+00	5.72E-01	3.40E-05	1.78E-10
Curium-244	1.81×10^{1}	1.33E+03	4.23E+02	2.90E+01	6.52E-06	3.18E-14
Curium-245	8.5×10^{3}	3.36E+02	3.35E+02	3.33E+02	3.23E+02	3.10E+02
Curium-246	4.73×10^{3}	5.42E+01	5.39E+01	5.34E+01	5.04E+01	4.68E+01

[a] The activities at 30, 100, 500, and 1,000 years include the contribution from ingrowth and decay. Radionuclides given in italics are produced by ingrowth and not present in the initial inventory.

[b] Values of less than 1×10^{-10} Ci are reported as zero.

radionuclides that will decay away within a relatively short time period do so within the first few hundred years. This information can be useful in determining the appropriate length of time for an institutional control period.

In general, the maximum annual doses from groundwater ingestion would be lower if the leaching of radionuclides began at a later time. However, the impact is generally minor because most of the radioactive decay occurs as the radionuclides are migrating from the failed waste containers to groundwater. A sensitivity analysis was conducted to evaluate the impact of the assumed time period before leaching; it can be found in Appendix D.

A brief description of the three conceptual facility designs for the disposal facilities is given in Section 3.1. More details can be obtained by reviewing the cited references.

3.1 LAND DISPOSAL METHODS

Three land disposal methods are addressed in the EIS: intermediate-depth borehole, enhanced near-surface trench, and above-grade vault disposal. Conceptual designs for these methods were developed to allow for an assessment of environmental impacts in the GTCC EIS. Additional detailed engineering is required before any of these could be used for disposal of GTCC LLRW and GTCC-like waste.

The land disposal facilities described here were based on the following considerations as identified in a report recently issued by Argonne National Laboratory (Argonne 2010b). The facility design must:

- Enhance the natural ability of the site to meet the identified performance objectives;
- Minimize the potential for the wastes to come into contact with water during and after operations;
- Allow the monitoring and collection of any water that may accumulate in the disposal facility during operations and closure, and during the institutional control period;
- Minimize voids between the waste packages in the disposal facility in order to minimize the likelihood of future subsidence;
- Function properly without active maintenance after the disposal facility is closed and the active institutional control period has ended;
- Permit the use of conventional construction and operating equipment, methods, and procedures; and
- Promote safety during construction activities and disposal operations.

The land disposal methods technologies are summarized in the following subsections. Additional information on these concepts is provided in the references cited in Argonne (2010b).

3.1.1 Above-Grade Vault Disposal

In the above-grade vault disposal concept, the GTCC LLRW and GTCC-like wastes would be placed in a facility constructed above grade. The wastes would be placed in reinforced concrete vaults constructed near grade level, with the footings and floors of the vault situated in a slight excavation. The above-grade vault design described here is based on previous conceptual designs proposed for disposal of GTCC LLRW in Henry (1993) and is similar to the vault LLRW disposal options previously investigated by the U.S. Army Corps of Engineers (Denson et al. 1987). A similar concrete vault structure is currently in use (although mostly below grade) for disposal of higher-activity LLRW at the Savannah River Site (MMES et al. 1994). These previous studies are identified in the references cited in Argonne (2010b).

The above-grade vault disposal facility would consist of a number of vaults. Each vault would be divided into 11 individual cells in the linear dimension. The approximate dimensions of each vault would be 11-m wide, 94-m long, and 7.9-m tall. The interior dimensions of each individual disposal cell within the vault would be about 8.2-m wide, 7.5-m long, and 5.5-m high. A total of 12 vaults would be necessary to accommodate the current and projected volume of GTCC LLRW and GTCC-LLRW-like waste given in Table 2-1. This design has flexibility in terms of waste disposal capacity in that the number of vaults could be increased or decreased, as appropriate, to accommodate the total volume of waste. Additional details on this design concept are provided in Argonne (2010b), and a schematic cross section of a vault is given in Figure 3-1.

The packing arrangement of 55-gal CH waste drums in a cell assumes placement of 7-drum packs as received at the facility in a TRUPACT-II Type B transportation package. Twenty standard waste boxes (SWBs) could be arranged in one layer, with five layers (for 100 SWBs) in one vault cell. In addition, about 300 Cs-137 irradiators (three layers in a 10-by-10 array) are assumed to fit in one cell. SWBs, 7-drum packs, and 4-packs of irradiators would be taken off an on-site transport truck and loaded into the cell by an overhead crane.

For disposal of RH waste, AMCs, 55-gal drums, or canisters would be emplaced from a bottom-loading transfer cask into vertical concrete cylinders with thick concrete shield plugs within each cell. A cylinder would hold three AMCs, four 55-gal drums, or one RH canister.

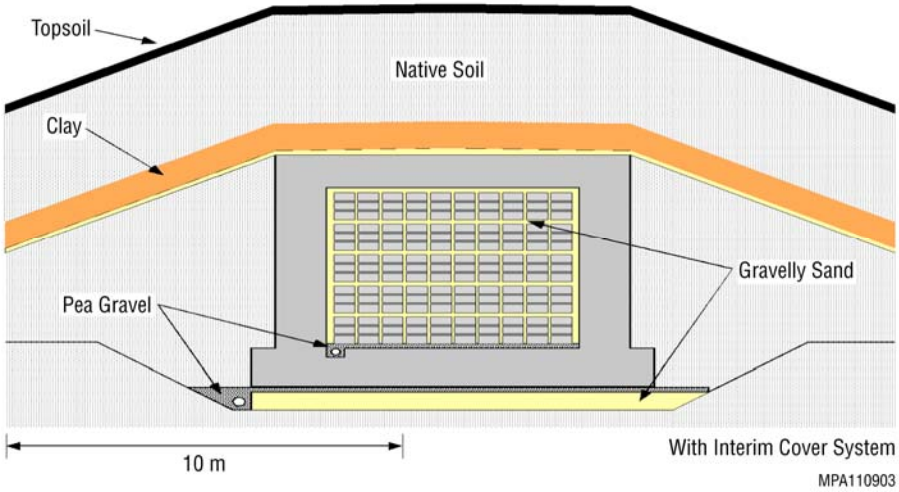

FIGURE 3-1 Cross Section of the Conceptual Design for a Vault Cell

Each disposal cell would have a 15-cm layer of pea gravel on the floor to assist in the drainage of any water that might infiltrate into the cell. Cell floors would have a slope of approximately 1% to one side, with a drain pipe to collect water into a common area for removal from the vault. For those wastes packaged in 55-gal drums, a layer of drums would be put in place with sandy gravel used as backfill. A layer of sandy gravel about 0.3-m high would be used to separate layers of waste packages. This design can accommodate four layers of drums in a cell, with a final layer of 0.76 m of sandy gravel backfill on top. Other waste containers, such as AMCs and shielded cesium-137 sealed sources, would be placed in the disposal cell in an appropriate manner, consistent with surrounding waste packages.

The vault facility would be designed by using standard engineering concepts and constructed by using standard engineering equipment. The vaults and cells would be constructed as needed, and filled cells could be incrementally closed to reduce the gamma exposure rate in the area. After the disposal facility was filled, the internal water collection system would be filled with grout, and an engineered cover would be placed on top of the vaults to further aid in isolating the wastes from the environment over the long term. This cover would reduce the gamma exposure rate from the disposed wastes in addition to the reduction provided by the vault and its internal backfill. This design would allow surface water to be directed away from the waste and would help deter intrusion by humans, plants, and animals. Minimum and maximum slope requirements would be incorporated to assure adequate drainage, reduce erosion, and maintain slope stability.

Two engineered cover systems would be used for the vaults. The first would be an interim cover that would be put in place after a vault was filled with waste and permanently closed; alternatively, it could be implemented incrementally as the cells within a vault were filled. This incremental closure could be done to reduce the gamma exposure rate in the area, especially for the disposal of high-exposure-rate wastes, such as the AMCs. The second cover would be the final cover, and it would be put in place prior to final closure of the disposal facility. Both covers would have a minimum depth of 5 m. The interim cover would consist of layers of gravelly sand, clay, native soil, and topsoil. The final cover would consist of layers of native soil, geotextile material, gravel, pea gravel, sand, and topsoil.

3.1.2 Enhanced Near-Surface Trench Disposal

Enhanced near-surface or trench disposal involves the disposal of LLRW in the uppermost portion of the earth, with the wastes buried less than 30-m deep. This approach is currently used for disposal of LLRW at NRC-licensed disposal sites and at a number of DOE sites. Use of this concept for disposal of GTCC LLRW and GTCC-like waste would require that this technology be enhanced over that used for other LLRW.

` The enhancements considered here include a deeper depth of burial and the use of a subsurface deflection shield. For the enhanced near-surface trench disposal concept, the wastes would be placed at depths greater than 5 m below the ground surface. Disposal at such depths would remove the wastes from most normal human activities, such as constructing basements, installing and repairing underground utility trenches and lines, etc. In addition, use of a deflection shield made of concrete and steel with a 30 degree angle from the vertical would deflect a drill bit from someone who was unknowingly attempting to drill into the disposal trench following closure. This shield would serve additional purposes, including preventing animal and root intrusion into the waste zone, deflecting surface water infiltration, and serving as a warning or barrier to inadvertent human intrusion. These enhancements, along with institutional controls, historical knowledge, markers, and waste recognition, would work together to greatly reduce the chance that an individual would inadvertently access the buried wastes.

The conceptual design for such a trench facility consists of a series of narrow trenches, each one being 3-m wide, 10-m deep, and 100-m long. Narrow trenches such as these are commonly referred to as slit trenches and are used at LLRW disposal sites for disposing of high-exposure-rate wastes. The narrow width of the trench allows the soil to provide shielding from the gamma rays being emitted by the wastes already placed in the open trench. A width of 3 m was selected to take advantage of this soil shielding while still allowing for optimal waste disposal capacity. The trench depth of 10 m is a reasonable depth consistent with the constraints of commercially available excavation and shoring equipment. While there is no limit on the length of the trench, a length of 100 m was considered to be reasonable on the basis of current LLRW disposal site operations. A conceptual drawing of this trench design is given in Figure 3-2.

The side walls of the trench would be vertical (with no side slope), and a well-compacted material would be placed on top of the native material in the bottom of the trench. A layer of sand 0.3-m thick would be placed on top of the compacted material. The floor of the trench would be constructed so that it is permeable, so standing water would not form in the trench bottom. Depending on the site characteristics, a bottom liner and leachate collection system might be installed to remove any water that would accumulate in the trench. The accessible portions of the leachate collection system would be filled with grout at the end of the institutional control period as part of site closure. The trench would be constructed with temporary metal shoring that would be removed when the trench was closed, unless the sidewalls were in competent rock. Metal shoring would not be required if the trench was constructed in rock.

The waste packages would be placed into the trench, and sand or another fine-grained, cohesionless fill material would be used to backfill around the waste containers to fill voids. After the trench was filled with waste packages and backfill, a subsurface deflection shield would be placed over the filled trench. This deflection shield would be modular and in the shape of a wedge, 3-m wide by 5-m long. Twenty shield modules would be needed for each trench. It is anticipated that the clean fill from the construction of the trenches would be used to backfill the trench above the subsurface deflection shield. The backfill would be screened to remove large-diameter rock and vegetative materials,

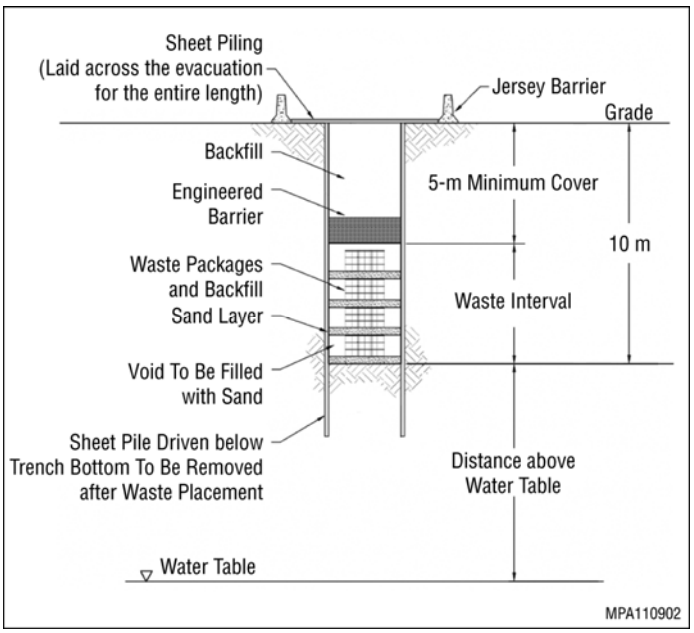

FIGURE 3-2 Cross Section of the Conceptual Design for a Trench

placed in lifts, and compacted to prevent future subsidence and ensure long-term site stability. The fill material would provide a minimum of 5 m of final cover.

The dimensions of the trench would allow it to be covered with sheet piling during construction and waste placement. This temporary cover would prevent animals and precipitation from entering the trench during placement of waste containers. Additional features would be necessary for the trenches in which RH waste would be emplaced in order to provide shielding for the workers once the waste was in place. The RH waste packages (including the AMCs, 55-gal drums, and RH canisters) would be disposed of in vertical cylinders with concrete shield plugs on the top of each cylinder. A mating flange would enable coupling of the bottom-loading transfer cask to a given cylinder for transfer of the waste package into the disposal unit. The transfer cask would be moved off an on-site transport truck and moved into position by an overhead crane. Each cylinder would be capable of holding up to three AMCs, four individual 55-gal drums, or one RH canister.

This trench design would have a disposal zone about 5-m thick. A total of 29 trenches would be needed to dispose of the 12,000 m^3 of GTCC LLRW and GTCC-like waste identified in Table 2-1. Trenches would not be constructed until needed, and partially filled trenches could be temporarily closed to reduce the gamma radiation levels in the area, as is currently done at existing LLRW disposal facilities.

3.1.3 Intermediate-Depth Borehole Disposal

Intermediate-depth borehole disposal involves the emplacement of LLRW into boreholes at depths greater than 30 m but less than 300 m. Boreholes can vary in diameter from 0.3 to 3 m, and the proximity of one borehole to another can vary depending on site characteristics and the design of the facility. The technology for drilling larger-diameter boreholes is relatively simple, and the necessary equipment is readily available. While the borehole concept has not been widely used to dispose of LLRW in the United States, it was used for disposal of wastes with characteristics similar to GTCC LLRW as part of the DOE greater confinement disposal project at the Nevada Test Site from 1984 to 1989. Most LLRW is disposed of by shallow land burial in trenches in the United States.

As was the case for the trench concept, borehole disposal includes the enhancements of a deeper burial depth and the use of a subsurface deflection shield. In the borehole approach, the depth of waste disposal is greater than 30 m, which is much deeper than the depth for the trench concept. Hence, the borehole concept has all of the benefits of the trench concept associated with burial depth. In addition, use of a deflection shield made of concrete and steel with a 30 degree angle from vertical would deflect a drill bit from someone attempting to drill into the borehole following closure. This shield would also serve as a warning or barrier to inadvertent human intrusion. The smaller cross-sectional area of the disposed-of waste and deeper burial depth would reduce the likelihood of anyone attempting to drill into the borehole facility in comparison to the trench facility. As they would for the trench facility, these enhancements, along with institutional controls, historical knowledge, markers, and waste recognition, would work together to greatly reduce the chance that an individual would inadvertently access the wastes disposed of in a borehole.

The conceptual design for a borehole facility consists of a series of boreholes, each borehole being 2.4 m in diameter and 40-m deep, with a spacing of 30 m between boreholes. The borehole diameter was selected to optimize the waste disposal capacity for the expected waste packages, and it is comparable to (but slightly smaller than) the width of the trench. The borehole depth was selected on the basis of the subsurface geological characteristics of the DOE sites under consideration and the availability of commercial drilling equipment. A conceptual drawing of the borehole design is given in Figure 3-3.

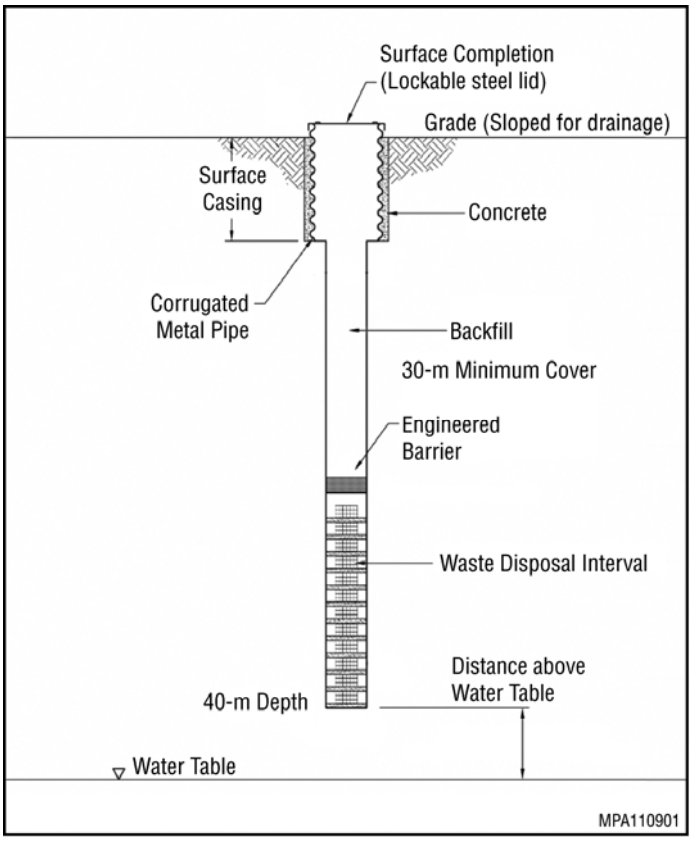

FIGURE 3-3 Cross Section of the Conceptual Design for an Intermediate-Depth Borehole

After drilling the borehole, a surface completion about 6 m in diameter and 1.5-m deep would be placed around the borehole. The first 0.75 m of the surface completion would include a concrete collar around corrugated metal pipe. The metal pipe would be secured by using bentonite grout below the concrete collar. The surface completion would also include a lockable steel lid. Depending on site conditions, a smooth casing could be advanced to the depth of the borehole during drilling and construction for stability. The upper 30 m of the casing would be removed prior to backfilling the borehole.

A layer of sand or gravel 0.3-m thick would be placed into the bottom of the borehole to provide a smooth foundation to place the initial layer of waste containers. Once the initial waste containers were placed in a borehole, sand would be placed around the waste packages to fill void spaces. An additional 0.3 m of sand would be placed over the waste packages prior to the placement of the next layer of waste packages. This process would continue until the wastes were about 30 m from the surface. A final layer of sand would then be placed on top of the waste packages prior to installation of the subsurface cone-shaped deflection shield.

It is anticipated that the clean fill from the construction of the borehole would be used to backfill the opening above the subsurface deflection shield. The backfill would be screened to remove large-diameter rock and vegetative materials, placed in lifts, and compacted to prevent future subsidence and to ensure long-term site stability. The fill material would provide a minimum of 30 m of final cover.

Waste packages could be bundled together prior to placement in the borehole to ensure maximum disposal capacity and increased stability of the facility upon closure. The packages would be lowered into the borehole by using a crane and placed into position. Temporary shielding would be used as necessary to reduce the gamma exposure rate in the area. The steel lid on the borehole would be used as a safety device to keep animals or workers from inadvertently falling into the borehole. The borehole would be opened only during waste disposal operations. This lid would also keep precipitation from entering the borehole when not in use.

This borehole design would have a 10-m thick disposal zone. For a borehole, the packing arrangements assumed for CH waste are eight intervals (levels) of 55-gal drum 7-packs, five intervals of Cesium-137 irradiator 4-packs, or eight intervals of one SWB. For RH waste, three intervals of two 3-packs of RH canisters or six intervals of two 3-packs of AMCs are assumed. A total of 927 boreholes would be needed to dispose of the 12,000 m^3 of GTCC LLRW and GTCC-like waste identified in Table 2-1. As are the vault and trench concepts, the borehole concept is modular, and the number of disposal units (boreholes) could easily be adjusted to accommodate the requisite disposal capacity. Boreholes would not be constructed until they were needed, and extra shielding could be placed on top of the closed lid of the partially filled boreholes to reduce the gamma radiation levels in the area.

3.2 SITES EVALUATED

Six DOE sites were analyzed in the EIS as candidate locations for land-based disposal facilities for GTCC LLRW and GTCC-like wastes. These six sites are Idaho National Laboratory (INL) in Idaho, Los Alamos National Laboratory (LANL) and the Waste Isolation Pilot Plant (WIPP) Vicinity in New Mexico, Nevada National Security Site (NNSS) in Nevada, Savannah River Site (SRS) in South Carolina, and Hanford Site in Washington. While the vault and trench technology would be implemented at all six of these sites, the depth to groundwater and/or subsurface geological conditions at SRS limit the suitability of the borehole disposal facility. Table 3-2 is a matrix illustrating which technologies were evaluated at these six sites. The rationale for this selection is provided in more detail in the EIS.

The NOI indicates that the EIS would also evaluate disposal at generic commercial facilities. Four generic commercial facilities located in different geographic areas were considered. The generic facilities were assumed to be located in each of the four NRC regions with generic site characteristics available in the literature. Considering the depth to groundwater table, it was assumed that a vault facility would be applicable in each of the four regions, while trenches were addressed in only two of the regions (NRC Regions II and IV), and boreholes were considered in only one (NRC Region IV). In addition to being used for analyzing the impacts associated with the disposal alternatives, the four generic sites were also used for evaluating the long-term impacts associated with the No Action Alternative.

To evaluate the No Action Alternative, it was assumed that the activated metals and Other Waste would be continuously stored in the same region where the facilities that generate them are located. The inventory of sealed sources was assumed to be divided among the four NRC regions in proportion to the number of licenses in each region. Therefore, at the same generic site, the waste inventory evaluated for the No Action Alternative is always less than the waste inventory evaluated for the disposal alternatives.

3.3 GENERAL APPROACH

The same approach was used to analyze the long-term impacts associated with the No Action Alternative and the disposal alternatives. It was assumed that for a period of time following closure of the storage or disposal facility, the waste containers would remain intact, with minimal water infiltrating into

TABLE 3-2 Summary of Technologies Being Evaluated for Land Disposal Sites

	Land Disposal Technology		
Site	Above-Grade Vault	Near-Surface Trench	Intermediate-Depth Borehole
Hanford Site	X	X	X
Idaho National Laboratory	X	X	X
Los Alamos National Laboratory	X	X	X
Nevada National Security Site	X	X	X
Savannah River Site	X	X	NA[a]
WIPP Vicinity	X	X	X
Commercial facility in Region I	X	NA	NA
Commercial facility in Region II	X	X	NA
Commercial facility in Region III	X	NA	NA
Commercial facility in Region IV	X	X	X

[a] NA means not analyzed because the technology is considered not applicable at the site because of the shallow groundwater there. For the borehole technology, the 40-m conceptual design was analyzed in this report.

the containers. However, after this time period, cracks or other defects would form, allowing water to infiltrate the containers, contact the waste materials, and leach out radionuclides contained in the waste. The leached radionuclides would move downward with this water and eventually reach the subsurface groundwater system.

The rates at which radionuclides move through soils underneath the storage or disposal area (i.e., the vadose zone) depend on a number of parameters. The two most important are the amount of water and the distribution coefficient (K_d). The amount of water carrying radionuclides through the vadose zone could be different than the amount of water infiltrating into the waste containers. Contact of water with the waste materials results in the dissolution of radionuclides in the water. A higher water infiltration rate results in a greater potential for leaching. Similarly, when more water is available, the transport speed of radionuclides through the vadose zone is also faster.

For the groundwater analysis, failure of the disposal unit and waste packages is assumed to begin at the same time, 500 years following facility closure. This failure would allow water to enter the waste disposal zone and contact the wastes. This assumption is clearly conservative, because many of the waste packages would be expected to retain their integrity for some time even after the disposal facility began to fail. Nevertheless, this assumption was made to provide a consistent basis for evaluating the potential groundwater contamination at the various land disposal sites. A step function was assumed for the water infiltration rate in the analysis. Prior to failure of the disposal unit (500 years post closure), the water infiltration was taken to be zero. After this time period, the infiltration rate to the waste containers was assumed to be 20% of the natural infiltration rate for soils in the nearby area; that is, the natural infiltration rate was reduced by a factor of 5 in this analysis to account for the designs incorporated into the disposal facility, specifically the engineered cell cover and subsurface deflection shield. This assumption was made on the basis of a study at the SRS that indicated that after 10,000 years, the closure cap at the F-area would still shed about 80% of the cumulative precipitation falling on it, with a higher degree of effectiveness occurring before 10,000 years (Phifer et al. 2007). The cover effectiveness would

continue to decrease very slowly after 10,000 years. The 20% natural infiltration rate assumption is used for the disposal area in the analysis.

For the No Action Alternative, failure of the waste packages is assumed to begin 100 years following closure of the storage facility. A shorter time period is used for the No Action Alternative than for the disposal alternatives because there would be no protection of waste containers against weathering. A step function was also assumed for the water infiltration rate, which is equivalent to the average precipitation rate at the storage site. The precipitation would enter the waste containers through cracks or holes, contact the waste materials, and flow out from the cracks or holes at the bottom of the containers. Equilibrium is assumed between the amount of water getting in and getting out, with negligible loss of water through evaporation; therefore, no accumulation of water is considered inside the containers.

Once the radionuclides were released from the waste containers, they could move with the percolating water downward toward the groundwater table. Because of the adsorption of radionuclides to the soil particles, the speed at which the radionuclides would travel toward the groundwater table could be much slower than the percolating water and would depend on the K_d of the radionuclides. This coefficient is defined as the equilibrium concentration ratio of the adsorbed radionuclide in a solid matrix (such as soil) to the desorbed radionuclide in the accompanying water. This parameter can have a wide range of values, from zero to more than 10,000 cm^3/g. A K_d of zero means that the radionuclide is not absorbed into the soil at all, as would occur for tritiated water. A very high K_d means that the radionuclide is tightly bound to the soil, with very little potential to dissolve in water. The lower the value of K_d, the higher the concentration of the radionuclide in water. The K_d depends strongly on the soil properties, and its values for the same radionuclide can vary widely at different sites.

For this analysis, the contaminated waste that is either stored on the ground surface or placed in the disposal facility was modeled as a single medium, with radionuclides uniformly distributed throughout its volume. Release of radionuclides from the waste materials is analyzed on the basis of the following considerations. For activated metals, dissolution of radionuclides in water will not occur unless the metal is corroded. The release fraction of radionuclides resulting from corrosion is assumed to be 1.19×10^{-5}/yr, on the basis of experimental data collected at INL (INL 2006; Adler Flitton et al. 2004).

The release rates of radionuclides in sealed sources were simulated on the basis of the assumption that radionuclides would partition between water and the sealed source matrix when coming in contact with water. The partitioning can be represented by a partitioning factor. It is assumed that the partitioning factor of each radionuclide with the sealed sources is the same as the K_d value of that radionuclide with the surface soil at the various sites. Because there would be backfill soil surrounding the waste containers in the case of disposal alternatives, radionuclides released from the sealed sources would have to travel through the surrounding soils before leaving the disposal area. By using the soil K_d values to calculate the radionuclide release rates, the binding of radionuclides to the sealed source matrix is assumed to be the same as that in the surrounding soil. This approach is conservative, because it tends to overestimate the release rates of radionuclides from sealed sources.

While activated metals and sealed sources are structurally sound and generally resistant to leaching with water, many of the wastes categorized as Other Waste are not. In the analysis for disposal alternatives, it is assumed that Other Waste would be solidified by grouting with cement before being placed in the disposal units. This assumption is reasonable and consistent with current disposal practices for such wastes, which include a wide variety of materials that could compact or quickly degrade without such measures.

The solidification provided by mixing the Other Waste with cement would also reduce the leaching of radionuclides. The dissolution rate of a radionuclide in water can be determined by the K_d value of that radionuclide with the cement system. However, the reduction in leaching might not last over a long period of time, when the nature of the stabilizing agent would change in the environment or the integrity of the stabilizing agent would deteriorate. In the analysis, the effectiveness of solidification in terms of leaching reduction is assumed to last for 500 years following closure of the disposal facility; after 500 years, the retention of radionuclides by cement is no different than their retention by the backfill soil.

In the analysis for No Action Alternative, the solidification assumption is not applied to Other Waste (i.e., Other Waste is not assumed to be solidified for storage). Therefore, rather than the cement K_d, the soil K_d was used to calculate the radionuclide release rate, based on the same consideration for sealed sources.

The radionuclide release rates with activated metals and with grouted Other Waste during the effective solidification period calculated on the basis of the above assumptions were checked before being used in the groundwater modeling for the disposal alternatives. After the radionuclides would be released from the waste material and dissolve in water, they would be carried by the water through the backfill soils surrounding the waste material prior to leaving the disposal area. During the passage through the backfill soils, radionuclides could become adsorbed to soil particles. Therefore, the final release rate of a radionuclide from the waste disposal area is determined by comparing the release rate of that radionuclide from the metal matrix or the grout matrix with the release rate of that radionuclide from a soil matrix. The smaller release rate is used for groundwater modeling.

After leaving the disposal/storage area, the radionuclides that would dissolve in the water would be transported vertically through the underlying soil to the groundwater table. Once in groundwater, the radionuclides would travel horizontally with the water toward a well assumed to be located 100 m downgradient from the edge of the disposal/storage facility. The highest-exposed individual is assumed to use water from this well as his sole source of potable water. This individual is assumed to ingest the contaminated groundwater and to use the groundwater for household activities and to feed livestock and irrigate agricultural fields where crops are grown and livestock are raised.

In addition to leaching, which was assumed to start 500 years after the closure of the disposal facility, gaseous radionuclides formed in the waste disposal area could diffuse upward through cracks of the containers and covering materials and eventually reach the open atmosphere. Here they would be blown to downwind locations and inhaled by the off-site highest-exposed individual receptor. The gaseous radionuclides formed over time in the waste disposal area could include radon, tritium-3 (assumed to be in the form of HTO), and carbon-14 (assumed to be in the form of carbon dioxide [CO_2]). For C-14 and H-3, the conversion to gaseous form is considered in addition to their dissolution in water with subsequent traveling to the groundwater table. Such dual consideration ensures the calculation of more conservative human radiation exposures. The potential impact on human health from the air dispersion pathway is expected to be much less than that from the groundwater pathways, because of the greater dilution in the atmosphere than in the groundwater aquifer.

For the No Action Alternative, the release of radionuclides was evaluated only for the groundwater pathway. Potential release through the airborne pathway was not evaluated. The airborne release pathway would be a viable pathway for human exposure and could result in significant radiation exposure if the waste containers were left on the ground surface for a long period of time to degrade extensively and if the receptor was located nearby. However, in reality, the No Action Alternative that was assumed in the EIS would not be implemented for a long time (i.e., it is not a long-term management

solution for the GTCC LLRW and GTCC-like waste). Eventually, the waste would need to be stored or disposed of with some protective measures against environmental weathering.

The long-term impacts for the No Action Alternative were calculated to provide a comparison with those for the disposal alternatives. Because the long-term impacts for the disposal alternatives result mainly from the groundwater pathway, the analysis of the No Action Alternative focused on the groundwater pathway too. In addition to radiation exposure resulting from the drinking water pathway, it is considered that the use of contaminated groundwater for irrigation would result in exposures through the external radiation and inhalation pathways. The peak dose from the groundwater release might occur later than that from the airborne release; however, because there would be less dilution in the groundwater aquifer than in the atmosphere, for the off-site general public, the peak dose from groundwater release would be greater than the peak dose from airborne release. In the analysis, the potential loss of radionuclides through airborne release was not accounted for, so the dose results obtained for the groundwater release pathways would be greater than the actual exposures.

The RESRAD-OFFSITE computer code was used to perform both air dispersion and groundwater transport simulations. This code is one of the RESRAD family of computer codes developed by Argonne National Laboratory (Yu et al. 2007) for DOE and the NRC. Site-specific input parameters were used for this modeling effort to the extent that such information was available. When site-specific values were not available, generic values for the same soil type or default RESRAD-OFFSITE input parameters were used. The results of the RESRAD-OFFSITE evaluation are given in Section 4 for the groundwater-related pathways and in Section 5 for the air dispersion pathway.

4 GROUNDWATER EVALUATIONS

As noted in Section 1.2, the most significant post-closure impacts from disposal of GTCC LLRW and GTCC-like wastes in the land disposal facilities would be associated with the leaching of radionuclides from the disposed-of wastes and their subsequent migration to groundwater, where they could be unknowingly ingested and used by a future hypothetical nearby resident. Potential groundwater contamination following the closure of the disposal facilities was analyzed with the RESRAD-OFFSITE computer code (Yu et al. 2007). The code was designed for evaluating both on-site and off-site radiation exposures resulting from soil contamination through various exposure pathways. It incorporates a groundwater transport model that simulates the movement of radionuclides through up to five unsaturated zones and in the underlying groundwater aquifer.

A rate-controlled release is used to model the quantity of contaminants that can be removed by leaching from the wastes as water flows down through the primary zone of contamination. The release rate can be specified to vary as a function of time and is used by RESRAD-OFFSITE to simulate the entry of radionuclides into the percolating water with subsequent transport in the unsaturated zone(s) and groundwater aquifer. This is a very useful feature for use in the EIS analyses, because it allows the source term (GTCC waste) to have any physical or chemical form. What needs to be specified is the release rate of the radionuclides from the source.

The RESRAD-OFFSITE code addresses contaminant transport by convection and dispersion in the liquid phase. In addition, the groundwater transport model in RESRAD-OFFSITE considers the decay of the parent radionuclide, the ingrowth of progeny radionuclide(s), and their respective retardation due to sorption and desorption in the solid phase. Numerical methods are employed to evaluate the analytical solutions to the differential equations that characterize the behavior of radionuclide transport in the unsaturated and saturated zones. This section presents the approach and assumptions used for the groundwater analysis, the development of input parameters, and the radiation doses associated with using this groundwater in the future by a hypothetical adult receptor. In general, the approach and assumptions applied to evaluate the disposal alternatives are also applied to evaluate the No Action Alternative, unless differences are specifically pointed out in the following sections.

4.1 DESCRIPTION OF APPROACH

The analysis presented here addresses the eight individual waste categories of GTCC LLRW and GTCC-like wastes, using the radiological inventories presented in Tables 2-2 through 2-4. The potential groundwater concentrations and resultant annual doses were analyzed separately for each of the eight waste categories to facilitate future decisions on how to manage these wastes. This approach allows for the consideration of disposing of different types of waste at different locations using different technologies. Various combinations of disposal sites and technologies may be appropriate for managing the wastes, and organizing the analysis in this manner should support such an evaluation. The total groundwater impacts associated with disposing of more than one type of waste at the same location can be determined by adding the impacts associated with each individual type of waste at that location.

While the waste inventories considered for the disposal alternatives are the same regardless of the location of the disposal facility and disposal method, the waste inventories considered for the No Action Alternative are different for different NRC regions. For the disposal alternatives, the waste inventory is the sum of different sources generated across different geographic regions. For the No Action Alternative, the waste inventory of activated metals and Other Waste, respectively, considered for a specific region is the sum of wastes generated within that region. For sealed sources, the total inventory is distributed

among the four NRC regions in proportion to the number of licenses in each region. Therefore, the waste inventory evaluated for the No Action Alternative at any of the four generic storage facilities is always smaller than that evaluated for the disposal alternatives at any of the disposal facilities. Table 4-1 lists the packaged waste volume and total radioactivity considered in the analysis for the No Action Alternative with different storage locations.

For modeling purposes, wastes of the same category were consolidated to form a single source of contamination at the center of the disposal facility. The area of the contamination source was determined to be the sum of the areas of the disposal units needed for that waste category, and it does not include the area between individual disposal units. The length of the contamination source in the direction of groundwater flow, which is part of the transport path of radionuclides in the groundwater aquifer, was assumed to be the square root of the contamination area. The entire area of the disposal facility depends on the disposal technology implemented and includes areas occupied by support buildings and structures that are needed for container handling and waste disposal activities. An off-site well located 100 m from the edge of the disposal facility was assumed to provide water for use by the highest-exposed individual. Therefore, the total distance traveled by radionuclides in the groundwater aquifer can be determined as the distance from the edge of the contamination area to the location of the off-site well, which is a function of the area of the contamination source and the area of the disposal facility. Table 4-2 shows the dimensions assumed for the contamination sources representing different waste categories that are disposed of with different technologies.

In reality, wastes of the same category may be separated and not placed in adjacent disposal units; however, the exact locations can not be determined at this time. The use of the consolidation concept described above provides the same basis for evaluating the impacts associated with the disposal of a specific waste category with different disposal technologies at different locations. Total impacts from different waste categories can be also obtained by adding the impacts from individual waste categories.

Table 4-3 shows the dimensions assumed for the contamination sources representing different waste categories that would be stored at different storage sites under the No Action Alternative. Except for activated metals, the same method was used to calculate the effective area of the contamination source for different waste categories. The waste packages were assumed to be stacked to the same height as they were with the vault disposal method (i.e., 5.5 m for sealed sources and Other Waste - CH and 4.3 m for Other Waste - RH. Then a source area (assuming the waste packages were tightly packed and stacked, with no space among them) was calculated by dividing the total packaged waste volume by the assumed stack height. This calculated source area was then multiplied by a factor of 2 to obtain the effective area used in the modeling to account for a randomly and less-tightly-stacked condition. For activated metals, because of the potentially high gamma radiation, the waste containers were assumed to be placed inside dry storage canisters for storage. The numbers of dry storage canisters were determined for each region; these were used to determine the contamination source area needed in the RESRAD-OFFSITE analysis. The height of the dry storage canisters was assumed to be 4.6 m. The footprint of the generic storage facility was assumed to be 300 m in both width and length.

Potential long-term impacts to the highest-exposed individual from groundwater pathways were obtained with a three-step calculation procedure. The first step involved the calculation of the potential dose from the drinking water pathway associated with each individual radionuclide in the waste material. The radiation dose from the drinking water pathway are then scaled to obtain the radiation dose that would result from all the groundwater-related pathways in the second step. In the last step, the radiation doses from all groundwater-related pathways from individual radionuclides were added together to give the total impact associated with the specific waste material under consideration. The scaling factors used to scale the dose from the drinking water pathway to obtain the dose from all groundwater-related pathways were radionuclide-specific. Their derivation is discussed in detail in Appendix C. In addition to

Table 4-1 Inventories of the GTCC LLRW and GTCC-Like Waste in the Four NRC Regions for the No Action Alternative[a]

	GTCC LLRW Volume (m^3)				GTCC-Like Waste Volume (m^3)				
NRC Region	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	All Waste Types
I	960	520	1,600	2,000	0	0	930	1,300	7,300
II	420	740	0	390	2.9	0	270	270	2,100
III	220	420	0	0	0	0	0	0	640
IV	390	1200	42	33	9.9	0.83	31	19	1,700

	GTCC LLRW Activity (Ci)				GTCC-Like Waste Activity (Ci)				
NRC Region	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	All Waste Types
I	3.3E+07	3.7E+05	2.4E+04	3.1E+04	0.0	0.0	3.3E+04	4.9E+05	3.4E+07
II	5.2E+07	5.3E+05	0.0	9.8E+04	2.3E+05	0.0	2.4E+02	4.2E+04	5.3E+07
III	2.4E+07	3.0E+05	0.0	0.0	0.0	0.0	0.0	0.0	2.4E+07
IV	4.7E+07	8.2E+05	1.1E+01	9.5E+04	5.2+03	7.7E+01	1.3E+03	2.0E+02	4.8E+07

[a] All values are given to two significant figures.

TABLE 4-2 Assumed Source Areas (m^2) for Different Waste Categories Used in the RESRAD-OFFSITE Analysis for the Land Disposal Alternatives

		Area for GTCC LLRW (m^2)				Area for GTCC-Like Waste (m^2)			
Waste Group	Disposal Method	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
Group 1 stored	Borehole[a]	26	–[d]	22	18	3	0.13	180	270
	Trench[b]	50	–	27	38	5	0.13	150	600
	Vault[c]	45	–	20	34	5	0.10	150	530
Group 1 projected	Borehole[a]	370	1300	–	0.53	3.0	0.32	120	100
	Trench[b]	710	1700	–	1.2	5.7	0.39	99	220
	Vault[c]	640	1100	–	1.0	5.1	0.29	100	200
Group 2 projected	Borehole[a]	500	12	630	1,200	–	–	190	470
	Trench[b]	960	15	510	2,600	–	–	150	1000
	Vault[c]	860	11	520	2,400	–	–	160	900

[a] Thickness of the contamination source was assumed to be 10 m for the borehole disposal method.
[b] Thickness of the contamination source was assumed to be 5.6 m for the trench disposal method.
[c] Thickness of the contamination source was assumed to be 5.5 m for the vault disposal method, except for the Other Waste - RH, for which a thickness of 4.3 m was assumed.
[d] A dash indicates the waste volume is 0 m^3.

TABLE 4-3 Assumed Source Areas (m^2) for Different Waste Categories Used in the RESRAD-OFFSITE Analysis for the No Action Alternative

	Area for GTCC LLRW (m^2)				Area for GTCC-Like Waste (m^2)			
NRC Region	Activated Metals[a]	Sealed Sources[b]	Other Waste - CH[b]	Other Waste - RH[c]	Activated Metals[a]	Sealed Sources[b]	Other Waste - CH[b]	Other Waste - RH[c]
I	980	420	1,000	4,100	–[d]	–	610	2,700
II	430	520	–	800	2.1	–	180	550
III	220	410	–	–	–	–	–	–
IV	400	880	40	67	6.3	0.78	29	40

[a] Thickness of the contamination source was assumed to be 4.6 m for the activated metal waste.
[b] Thickness of the contamination source was assumed to be 5.5 m for the sealed sources waste and Other Waste - CH.
[c] Thickness of the contamination source was assumed to be 4.3 m for the Other Waste - RH.
[d] A dash indicates the waste volume is 0 m^3.

the drinking water pathway, the exposure pathways included external radiation; inhalation; and ingestion of soil, plant food, meat, and milk. All these other pathways result from the use of contaminated groundwater for irrigation. Figure 4-1 illustrates the links between the various exposure pathways to the use of contaminated groundwater.

Separate RESRAD-OFFSITE input files were developed for each of the eight waste categories, 10 disposal sites (6 DOE sites plus 4 commercial sites), and three conceptual facility designs. Likewise, for the No Action Alternative, separate RESRAD-OFFSITE input files were developed for each of the eight waste categories and the four generic storage facilities in different geographic regions. The RESRAD-OFFSITE evaluations were conducted for 10,000 years following closure of the storage or disposal facility to obtain the drinking water dose from each radionuclide at a distance of 100 m from the edge of the storage or disposal facility. In situations where the peak drinking water dose was not observed within 10,000 years, the RESRAD-OFFSITE simulations were extended to 100,000 years. In some cases, the peak drinking water dose did not occur within 100,000 years. No attempt was made to identify the time of peak dose beyond 100,000 years, because this is the maximum time accepted by RESRAD-OFFSITE.

The annual radiation doses associated with the use of the contaminated groundwater were calculated by using the dose conversion factors (DCFs) published in ICRP-72 (ICRP 1996) for the inhalation and ingestion pathways. For the external exposure pathway (groundshine), radiation doses were calculated by using the DCFs in the RESRAD-OFFSITE database, which were developed on the basis of Federal Guidance Report No. 12 (Eckerman and Ryman 1993). These DCF values are included in the RESRAD-OFFSITE computer code.

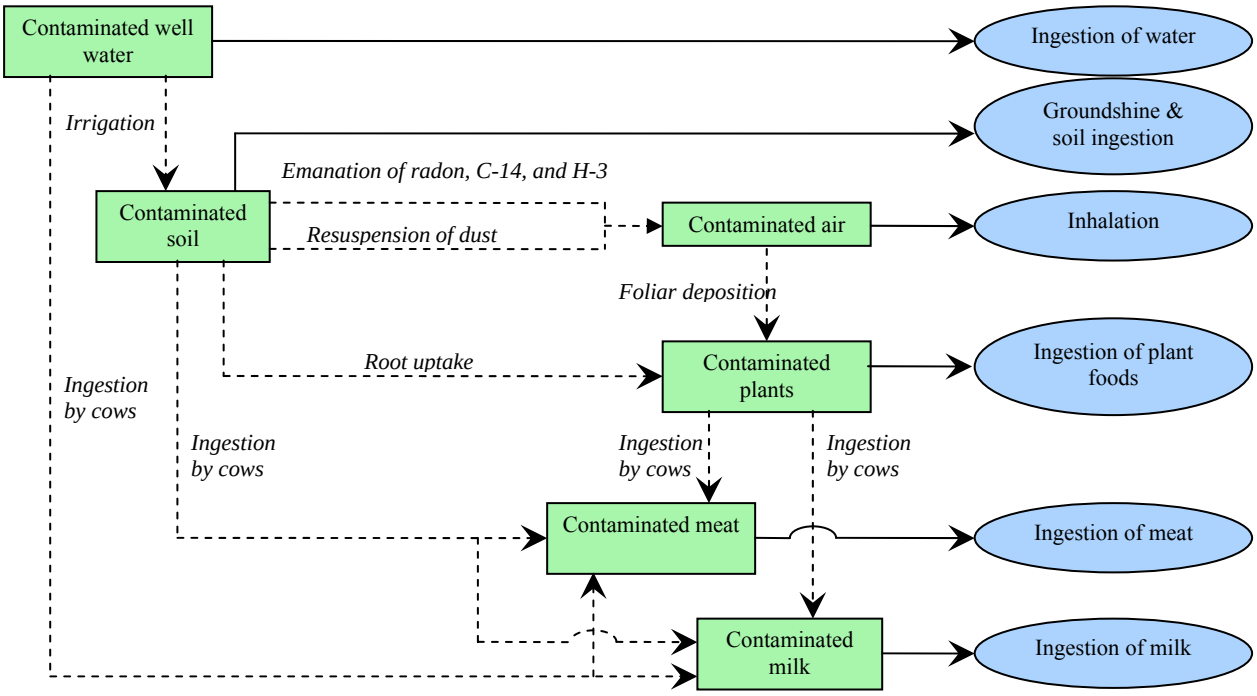

FIGURE 4-1 Exposure Pathways Associated with the Use of Contaminated Groundwater

4.2 ASSUMPTIONS

To analyze potential groundwater impacts associated with the storage or disposal of GTCC LLRW and GTCC-like waste, the release of radionuclides from the contamination source over time has to be estimated. For the disposal alternatives, the release of radionuclides would not occur until the integrity of the engineered covers and waste containers started to fail, allowing water to contact the waste material. However, with the preliminary nature of facility design and limited data on the deterioration of engineered barriers and containers over a long period of time, estimating a realistic radionuclide release rate is very difficult. As such, several prudent and conservative assumptions were made to simplify the task. They are discussed in the following paragraphs.

Breaching in the engineered covers and waste containers was assumed to occur 500 years following the institutional control period; at that time it was assumed that water would begin infiltrating into the waste containers and release radionuclides that would move from the degraded waste packages into the soils surrounding the waste containers, then travel downward to soils beneath the disposal unit, and eventually reach the groundwater table. The initial activity of each radionuclide at the time of disposal was adjusted to account for the radiological ingrowth and decay during this 500-year time period, and the adjusted activity was used to calculate the concentration in the contamination source used for RESRAD-OFFSITE modeling.

It was assumed that after 500 years, water would infiltrate into the waste containers at a rate that is equivalent to 20% of the natural background level. This reduced water infiltration rate (from the natural rate for the area) would be limited to the waste disposal area; outside the disposal area, the natural background infiltration rate is used in the RESRAD-OFFSITE analyses. This assumed effectiveness of the engineered measures can be a critical factor for distinguishing between facility performance at a humid site and at an arid site. A sensitivity analysis was conducted to examine the potential change in off-site doses by using various water infiltration rates in the simulations. The results of this sensitivity analysis are given in Appendix D.

RESRAD-OFFSITE accepts specifications of annual release fractions of radionuclides from the contamination source through leaching and uses them to calculate release rates of individual radionuclides. The annual release fraction of a radionuclide is defined as the fraction of the total activity of that radionuclide in the source that is leached out annually from the disposal area. To develop radionuclide release fractions from activated metals, it is considered that the release of radionuclides would not occur unless the metal was corroded, setting free the radionuclides imbedded in the metal. However, because the waste packages are surrounded by backfill soil in the disposal unit, radionuclides released from the metal could be adsorbed to the surrounding soil when they would be carried outside the waste containers. Therefore, for groundwater modeling with the disposal alternatives, the release fraction of a radionuclide was selected to be the smaller value between the value corresponding to the corrosion rate of metal, 1.19×10^{-5}/yr (INL 2006; Adler Flitton et al. 2004) and the value determined with the K_d value of that radionuclide in the surrounding soil. Tables 4-4 through 4-6 list the release fractions of radionuclides assumed in the groundwater modeling, considering disposal of GTCC LLRW and GTCC-like activated metals at different sites with the three different designs of disposal facilities. For the No Action Alternative, because there is no backfill soil surrounding the waste containers, the radionuclide release fraction is set to 1.19×10^{-5}/yr for all radionuclides at all of the storage locations.

For GTCC LLRW and GTCC-like sealed source waste, radionuclides are assumed to partition between the matrix and the liquid phase when water contacts the waste materials. The partitioning factor of a radionuclide is assumed to be the same as the K_d value of that radionuclide in the surface soil. The

TABLE 4-4 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Activated Metal Waste by Using the Borehole Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS[b]	WIPP Vicinity	Region I[b]	Region II[b]	Region III[b]	Region IV
Ac	1.97E-06	1.30E-07	4.27E-07	4.76E-11	–[c]	4.94E-08	–	–	–	4.87E-08
Am	1.97E-06	2.05E-08	2.31E-08	4.76E-11	–	1.54E-08	–	–	–	1.35E-07
C	1.19E-05	9.46E-06	1.19E-05	4.30E-06	–	4.35E-06	–	–	–	1.19E-05
Cm	1.11E-07	1.30E-07	1.11E-06	8.33E-11	–	5.56E-09	–	–	–	1.35E-07
Co	1.19E-05	1.94E-08	1.19E-05	5.55E-09	–	3.70E-07	–	–	–	5.29E-06
Cs	8.89E-07	4.85E-07	7.30E-06	1.19E-09	–	7.93E-08	–	–	–	2.17E-07
Fe	2.02E-06	1.77E-07	2.66E-07	1.59E-09	–	1.06E-07	–	–	–	5.31E-08
Gd	1.85E-06	4.71E-08	1.11E-06	4.04E-10	–	2.69E-08	–	–	–	2.22E-07
H	1.19E-05	1.19E-05	1.19E-05	4.30E-06	–	1.19E-05	–	–	–	1.19E-05
I	1.19E-05	1.19E-05	1.19E-05	4.30E-06	–	1.19E-05	–	–	–	1.19E-05
Mn	8.87E-06	7.76E-07	3.51E-07	6.66E-09	–	4.44E-07	–	–	–	2.22E-07
Mo	1.19E-05	3.85E-06	1.19E-05	3.31E-08	–	2.20E-06	–	–	–	2.71E-06
Nb	8.89E-07	1.30E-07	5.55E-07	4.76E-11	–	1.39E-07	–	–	–	2.22E-07
Ni	4.44E-06	9.72E-08	1.11E-06	3.33E-09	–	5.55E-08	–	–	–	9.18E-07
Np	1.19E-05	1.19E-05	1.19E-05	6.56E-08	–	4.35E-06	–	–	–	3.58E-06
Pa	1.19E-05	1.19E-05	1.01E-08	6.56E-08	–	5.85E-08	–	–	–	1.19E-05
Pb	1.65E-06	4.85E-07	2.21E-06	1.11E-09	–	8.23E-08	–	–	–	4.75E-08
Po	2.96E-06	2.59E-07	5.49E-06	1.11E-09	–	1.48E-07	–	–	–	4.75E-08
Pu	1.78E-07	2.59E-07	1.19E-05	4.40E-08	–	4.04E-08	–	–	–	1.10E-06
Ra	7.73E-07	3.85E-06	1.11E-07	1.80E-09	–	4.44E-08	–	–	–	4.61E-07
Sm	1.78E-07	1.30E-07	1.11E-06	1.36E-09	–	9.07E-08	–	–	–	4.87E-08
Sr	1.19E-05	3.85E-06	1.38E-06	7.94E-10	–	1.47E-06	–	–	–	4.61E-07
Tc	1.19E-05	1.19E-05	1.19E-05	4.30E-06	–	1.19E-05	–	–	–	3.58E-06
Th	8.89E-07	1.22E-08	1.11E-08	4.76E-11	–	6.94E-09	–	–	–	1.11E-07
U	1.19E-05	1.19E-05	1.19E-05	3.80E-07	–	6.33E-07	–	–	–	1.19E-05

[a] Radioisotopes of the same element are assumed to have the same release fraction.

[b] Disposal with the borehole method is not considered for SRS or the generic sites in Region I, II, or III.

[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-5 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Activated Metal Waste by Using the Trench Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I[b]	Region II	Region III[b]	Region IV
Ac	3.53E-06	2.31E-07	7.62E-07	8.50E-11	8.78E-07	8.82E-08	–[c]	6.64E-06	–	8.70E-08
Am	3.53E-06	3.65E-08	4.13E-08	8.50E-11	8.78E-07	2.75E-08	–	1.19E-05	–	2.42E-07
C	1.19E-05	1.19E-05	1.19E-05	7.68E-06	1.19E-05	7.77E-06	–	1.19E-05	–	1.19E-05
Cm	1.98E-07	2.31E-07	1.98E-06	1.49E-10	8.78E-07	9.92E-09	–	1.19E-05	–	2.42E-07
Co	1.19E-05	3.47E-08	1.19E-05	9.91E-09	1.19E-05	6.60E-07	–	1.19E-05	–	9.45E-06
Cs	1.59E-06	8.67E-07	1.19E-05	2.13E-09	1.19E-05	1.42E-07	–	1.19E-05	–	3.88E-07
Fe	3.61E-06	3.15E-07	4.74E-07	2.85E-09	1.19E-05	1.90E-07	–	1.19E-05	–	9.49E-08
Gd	3.31E-06	8.42E-08	1.98E-06	7.21E-10	8.78E-07	4.81E-08	–	1.19E-05	–	3.96E-07
H	1.19E-05	1.19E-05	1.19E-05	7.68E-06	1.19E-05	1.19E-05	–	1.19E-05	–	1.19E-05
I	1.19E-05	1.19E-05	1.19E-05	7.68E-06	1.19E-05	1.19E-05	–	1.19E-05	–	1.19E-05
Mn	1.19E-05	1.39E-06	6.27E-07	1.19E-08	1.19E-05	7.92E-07	–	1.19E-05	–	3.96E-07
Mo	1.19E-05	6.87E-06	1.19E-05	5.91E-08	1.19E-05	3.93E-06	–	1.19E-05	–	4.84E-06
Nb	1.59E-06	2.31E-07	9.91E-07	8.50E-11	1.19E-05	2.48E-07	–	1.19E-05	–	3.96E-07
Ni	7.93E-06	1.74E-07	1.98E-06	5.95E-09	1.19E-05	9.92E-08	–	1.19E-05	–	1.64E-06
Np	1.19E-05	1.19E-05	1.19E-05	1.17E-07	1.19E-05	7.77E-06	–	1.19E-05	–	6.40E-06
Pa	1.19E-05	1.19E-05	1.80E-08	1.17E-07	1.19E-05	1.04E-07	–	1.19E-05	–	1.19E-05
Pb	2.94E-06	8.67E-07	3.95E-06	1.98E-09	1.49E-06	1.47E-07	–	5.98E-06	–	8.48E-08
Po	5.29E-06	4.63E-07	9.81E-06	1.98E-09	1.49E-06	2.64E-07	–	5.98E-06	–	8.48E-08
Pu	3.17E-07	4.63E-07	1.19E-05	7.86E-08	1.26E-06	7.21E-08	–	1.19E-05	–	1.96E-06
Ra	1.38E-06	6.87E-06	1.98E-07	3.22E-09	1.19E-05	7.93E-08	–	1.19E-05	–	8.23E-07
Sm	3.17E-07	2.31E-07	1.98E-06	2.43E-09	8.78E-07	1.62E-07	–	6.64E-06	–	8.70E-08
Sr	1.19E-05	6.87E-06	2.47E-06	1.42E-09	1.19E-05	2.63E-06	–	1.19E-05	–	8.23E-07
Tc	1.19E-05	1.19E-05	1.19E-05	7.68E-06	1.19E-05	1.19E-05	–	1.19E-05	–	6.40E-06
Th	1.59E-06	2.17E-08	1.98E-08	8.50E-11	3.73E-06	1.24E-08	–	7.14E-06	–	1.98E-07
U	1.19E-05	1.19E-05	1.19E-05	6.78E-07	1.19E-05	1.13E-06	–	1.19E-05	–	1.19E-05

[a] Radioisotopes of the same element are assumed to have the same release fraction.
[b] Disposal with the trench method is not considered for the generic sites in Region I or III.
[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-6 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Activated Metal Waste by Using the Vault Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I	Region II	Region III	Region IV
Ac	3.60E-06	2.36E-07	7.78E-07	8.67E-11	8.95E-07	8.99E-08	6.56E-06	6.77E-06	1.88E-06	8.87E-08
Am	3.60E-06	3.73E-08	4.22E-08	8.67E-11	8.95E-07	2.80E-08	1.19E-05	1.19E-05	5.06E-06	2.47E-07
C	1.19E-05	1.19E-05	1.19E-05	7.83E-06	1.19E-05	7.93E-06	1.19E-05	1.19E-05	1.19E-05	1.19E-05
Cm	2.02E-07	2.36E-07	2.02E-06	1.52E-10	8.95E-07	1.01E-08	1.19E-05	1.19E-05	5.06E-06	2.47E-07
Co	1.19E-05	3.54E-08	1.19E-05	1.01E-08	1.19E-05	6.73E-07	1.19E-05	1.19E-05	1.19E-05	9.64E-06
Cs	1.62E-06	8.84E-07	1.19E-05	2.17E-09	1.19E-05	1.45E-07	1.19E-05	1.19E-05	4.06E-06	3.96E-07
Fe	3.68E-06	3.22E-07	4.84E-07	2.90E-09	1.19E-05	1.94E-07	7.16E-06	1.19E-05	4.84E-06	9.68E-08
Gd	3.37E-06	8.59E-08	2.02E-06	7.36E-10	8.95E-07	4.91E-08	1.19E-05	1.19E-05	1.19E-05	4.04E-07
H	1.19E-05	1.19E-05	1.19E-05	7.83E-06	1.19E-05	1.19E-05	1.19E-05	1.19E-05	1.19E-05	1.19E-05
I	1.19E-05	1.19E-05	1.19E-05	7.83E-06	1.19E-05	1.19E-05	1.19E-05	1.19E-05	1.19E-05	1.19E-05
Mn	1.19E-05	1.41E-06	6.40E-07	1.21E-08	1.19E-05	8.08E-07	1.19E-05	1.19E-05	1.19E-05	4.04E-07
Mo	1.19E-05	7.01E-06	1.19E-05	6.02E-08	1.19E-05	4.01E-06	1.19E-05	1.19E-05	1.19E-05	4.94E-06
Nb	1.62E-06	2.36E-07	1.01E-06	8.67E-11	1.19E-05	2.53E-07	1.19E-05	1.19E-05	1.01E-05	4.04E-07
Ni	8.08E-06	1.77E-07	2.02E-06	6.07E-09	1.19E-05	1.01E-07	1.19E-05	1.19E-05	1.19E-05	1.67E-06
Np	1.19E-05	1.19E-05	1.19E-05	1.20E-07	1.19E-05	7.93E-06	1.19E-05	1.19E-05	1.19E-05	6.53E-06
Pa	1.19E-05	1.19E-05	1.84E-08	1.20E-07	1.19E-05	1.06E-07	1.19E-05	1.19E-05	1.19E-05	1.19E-05
Pb	3.00E-06	8.84E-07	4.03E-06	2.02E-09	1.52E-06	1.50E-07	6.40E-06	6.10E-06	1.69E-06	8.65E-08
Po	5.39E-06	4.72E-07	1.00E-05	2.02E-09	1.52E-06	2.70E-07	6.40E-06	6.10E-06	1.69E-06	8.65E-08
Pu	3.24E-07	4.72E-07	1.19E-05	8.01E-08	1.29E-06	7.36E-08	1.19E-05	1.19E-05	1.01E-05	2.00E-06
Ra	1.41E-06	7.01E-06	2.02E-07	3.28E-09	1.19E-05	8.09E-08	1.19E-05	1.19E-05	1.01E-05	8.40E-07
Sm	3.24E-07	2.36E-07	2.02E-06	2.48E-09	8.95E-07	1.65E-07	6.56E-06	6.77E-06	1.88E-06	8.87E-08
Sr	1.19E-05	7.01E-06	2.52E-06	1.45E-09	1.19E-05	2.68E-06	1.19E-05	1.19E-05	1.01E-05	8.40E-07
Tc	1.19E-05	1.19E-05	1.19E-05	7.83E-06	1.19E-05	1.19E-05	1.19E-05	1.19E-05	1.19E-05	6.53E-06
Th	1.62E-06	2.21E-08	2.02E-08	8.67E-11	3.80E-06	1.26E-08	1.19E-05	7.28E-06	2.02E-06	2.02E-07
U	1.19E-05	1.19E-05	1.19E-05	6.92E-07	1.19E-05	1.15E-06	1.19E-05	1.19E-05	1.19E-05	1.19E-05

[a] Radioisotopes of the same element are assumed to have the same release fraction.

release fractions used for groundwater modeling for the sealed source waste are listed in Tables 4-7 through 4-9.

GTCC LLRW and GTCC-like waste that are categorized as Other Waste are considered to be grouted with cement for stabilization before being shipped for land disposal. While the stabilization is effective, the release fractions of radionuclides from the disposal area were determined by taking into account their partitionings in the cement system as well as their partitionings in the surrounding soil system. Two release fractions, one calculated with the K_d value for the cement system and the other calculated with the K_d value for the surrounding soil system, were compared, and the smaller one was selected for use in groundwater modeling. When the effectiveness of stabilization was compromised over time (assumed to be 500 years after the closure of the disposal facility), the release of radionuclides was assumed to be determined primarily by the radionuclides partitioning in the soil system. Then the release fractions would be the same as those listed in Tables 4-7 through 4-9 for the sealed source waste with the three different disposal methods.

Discussions on the radionuclide K_d values for the cement system are provided in Appendix C. K_d values for the surrounding soil were assumed to be the same as those for the uppermost unsaturated zone at each land disposal site, when one considers the unsaturated soil dug up during the construction of the disposal facility would be used as backfill material. K_d values for the unsaturated zones at the six DOE sites are compared in Table 4-17. Table 4-18 compares the unsaturated zone K_d values at the four generic commercial sites. Tables 4-10 through 4-13 list the radionuclide release fractions used for groundwater modeling for the GTCC LLRW and GTCC-like Other Waste during the effective stabilization period. Because the dimensions of the waste containers and the stacking of containers in the vault disposal cells are different, the thickness of the contamination source assumed for Other Waste - RH (4.27 m) is different from that assumed for Other Waste - CH (5.49 m). As a result, the calculated release fractions for Other Waste - RH and Other Waste - CH are different. The release fractions for Other Waste - CH disposed of in a vault facility are listed in Table 4-12. Those for Other Waste - RH disposed of in a vault facility are listed in Table 4-13.

While the RESRAD-OFFSITE groundwater transport model considers dispersion in both the unsaturated and saturated zones, the value of dispersivity is difficult to measure, and site-specific data are limited. Therefore, in the groundwater modeling analysis, a commonly used approach was adopted and applied to all the land disposal sites under consideration. The longitudinal dispersivity for the vadose zone was set to 0 m, while the longitudinal dispersivity, horizontal lateral dispersivity, and vertical lateral dispersivity for the saturated zone were set to 1/10, 1/100, and 1/1,000, respectively, of the distance traveled by the radionuclides in the groundwater aquifer.

As depicted in Figure 4-1, multiple exposure pathways linked to the use of contaminated groundwater were considered in the calculation of the radiation dose incurred by the highest-exposed individual after the closure of the storage or disposal facility. The highest-exposed individual was assumed to be a resident farmer who uses groundwater from a well located 100 m from the edge of the storage or disposal facility for drinking, household activities, raising livestock, and irrigation. The ingestion rates were assumed to be 730 L/yr (EPA 2000) for the farmer and each of the three other family members, 50 L/d for each beef cattle (two were raised by the farmer), and 160 L/d for each milk cow (two were raised by the farmer). The farmer was assumed to use the groundwater to irrigate a fruit, grain, and nonleafy vegetable field of 500 m^2, a leafy vegetable field of 500 m^2, a pasture and silage field of 10,000 m^2, and a livestock feed grain field of 10,000 m^2. An irrigation rate of 0.2 m/yr was assumed for the first two vegetable fields, if they were located in a dry area (INL, Hanford, LANL, NTS, WIPP Vicinity, Region III, and Region IV); otherwise, an irrigation rate of 0.1 m/yr was assumed (for SRS, Region I, and Region II). An irrigation rate of 0.1 m/yr was assumed for the pasture/silage and grain fields. In addition

TABLE 4-7 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Sealed Source Waste by Using the Borehole Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I[b]	Region II[b]	Region III[b]	Region IV
Ac	1.97E-06	1.30E-07	4.27E-07	4.76E-11	–[c]	4.94E-08	–	–	–	4.87E-08
Am	1.97E-06	2.05E-08	2.31E-08	4.76E-11	–	1.54E-08	–	–	–	1.35E-07
C	8.36E-04	9.46E-06	4.92E-04	4.30E-06	–	4.35E-06	–	–	–	1.11E-04
Cm	1.11E-07	1.30E-07	1.11E-06	8.33E-11	–	5.56E-09	–	–	–	1.35E-07
Co	4.39E-05	1.94E-08	9.87E-05	5.55E-09	–	3.70E-07	–	–	–	5.29E-06
Cs	8.89E-07	4.85E-07	7.30E-06	1.19E-09	–	7.93E-08	–	–	–	2.17E-07
Fe	2.02E-06	1.77E-07	2.66E-07	1.59E-09	–	1.06E-07	–	–	–	5.31E-08
Gd	1.85E-06	4.71E-08	1.11E-06	4.04E-10	–	2.69E-08	–	–	–	2.22E-07
H	3.38E-03	3.54E-04	4.92E-04	4.30E-06	–	1.34E-04	–	–	–	1.11E-04
I	3.38E-03	3.54E-04	4.92E-04	4.30E-06	–	2.01E-05	–	–	–	1.11E-04
Mn	8.87E-06	7.76E-07	3.51E-07	6.66E-09	–	4.44E-07	–	–	–	2.22E-07
Mo	4.39E-05	3.85E-06	1.35E-05	3.31E-08	–	2.20E-06	–	–	–	2.71E-06
Nb	8.89E-07	1.30E-07	5.55E-07	4.76E-11	–	1.39E-07	–	–	–	2.22E-07
Ni	4.44E-06	9.72E-08	1.11E-06	3.33E-09	–	5.55E-08	–	–	–	9.18E-07
Np	1.92E-05	1.49E-05	2.40E-05	6.56E-08	–	4.35E-06	–	–	–	3.58E-06
Pa	5.47E-05	1.49E-05	1.01E-08	6.56E-08	–	5.85E-08	–	–	–	1.11E-04
Pb	1.65E-06	4.85E-07	2.21E-06	1.11E-09	–	8.23E-08	–	–	–	4.75E-08
Po	2.96E-06	2.59E-07	5.49E-06	1.11E-09	–	1.48E-07	–	–	–	4.75E-08
Pu	1.78E-07	2.59E-07	1.32E-05	4.40E-08	–	4.04E-08	–	–	–	1.10E-06
Ra	7.73E-07	3.85E-06	1.11E-07	1.80E-09	–	4.44E-08	–	–	–	4.61E-07
Sm	1.78E-07	1.30E-07	1.11E-06	1.36E-09	–	9.07E-08	–	–	–	4.87E-08
Sr	3.66E-05	3.85E-06	1.38E-06	7.94E-10	–	1.47E-06	–	–	–	4.61E-07
Tc	3.38E-03	3.54E-04	4.92E-04	4.30E-06	–	1.08E-04	–	–	–	3.58E-06
Th	8.89E-07	1.22E-08	1.11E-08	4.76E-11	–	6.94E-09	–	–	–	1.11E-07
U	2.86E-05	5.48E-05	2.21E-05	3.80E-07	–	6.33E-07	–	–	–	1.11E-04

[a] Radioisotopes of the same element are assumed to have the same release fraction.

[b] Disposal with the borehole method is not considered for SRS or the generic sites in Region I, II, or III.

[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-8 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Sealed Source Waste by Using the Trench Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I[b]	Region II	Region III[b]	Region IV
Ac	3.53E-06	2.31E-07	7.62E-07	8.50E-11	8.78E-07	8.82E-08	–	6.64E-06	–	8.70E-08
Am	3.53E-06	3.65E-08	4.13E-08	8.50E-11	8.78E-07	2.75E-08	–	1.78E-05	–	2.42E-07
C	1.49E-03	1.69E-05	8.79E-04	7.68E-06	4.81E-02	7.77E-06	–	2.43E-02	–	1.98E-04
Cm	1.98E-07	2.31E-07	1.98E-06	1.49E-10	8.78E-07	9.92E-09	–	1.78E-05	–	2.42E-07
Co	7.83E-05	3.47E-08	1.76E-04	9.91E-09	2.47E-04	6.60E-07	–	3.90E-04	–	9.45E-06
Cs	1.59E-06	8.67E-07	1.30E-05	2.13E-09	2.98E-05	1.42E-07	–	1.43E-05	–	3.88E-07
Fe	3.61E-06	3.15E-07	4.74E-07	2.85E-09	1.86E-05	1.90E-07	–	1.71E-05	–	9.49E-08
Gd	3.31E-06	8.42E-08	1.98E-06	7.21E-10	8.78E-07	4.81E-08	–	7.12E-05	–	3.96E-07
H	6.03E-03	6.31E-04	8.79E-04	7.68E-06	4.81E-02	2.40E-04	–	2.43E-02	–	1.98E-04
I	6.03E-03	6.31E-04	8.79E-04	7.68E-06	9.88E-03	3.59E-05	–	2.43E-02	–	1.98E-04
Mn	1.58E-05	1.39E-06	6.27E-07	1.19E-08	3.73E-05	7.92E-07	–	7.12E-05	–	3.96E-07
Mo	7.83E-05	6.87E-06	2.41E-05	5.91E-08	6.21E-05	3.93E-06	–	8.61E-04	–	4.84E-06
Nb	1.59E-06	2.31E-07	9.91E-07	8.50E-11	4.81E-02	2.48E-07	–	3.57E-05	–	3.96E-07
Ni	7.93E-06	1.74E-07	1.98E-06	5.95E-09	2.47E-04	9.92E-08	–	6.04E-05	–	1.64E-06
Np	3.43E-05	2.66E-05	4.29E-05	1.17E-07	2.12E-04	7.77E-06	–	1.13E-03	–	6.40E-06
Pa	9.76E-05	2.66E-05	1.80E-08	1.17E-07	2.12E-04	1.04E-07	–	7.12E-05	–	1.98E-04
Pb	2.94E-06	8.67E-07	3.95E-06	1.98E-09	1.49E-06	1.47E-07	–	5.98E-06	–	8.48E-08
Po	5.29E-06	4.63E-07	9.81E-06	1.98E-09	1.49E-06	2.64E-07	–	5.98E-06	–	8.48E-08
Pu	3.17E-07	4.63E-07	2.35E-05	7.86E-08	1.26E-06	7.21E-08	–	3.57E-05	–	1.96E-06
Ra	1.38E-06	6.87E-06	1.98E-07	3.22E-09	4.35E-04	7.93E-08	–	3.57E-05	–	8.23E-07
Sm	3.17E-07	2.31E-07	1.98E-06	2.43E-09	8.78E-07	1.62E-07	–	6.64E-06	–	8.70E-08
Sr	6.54E-05	6.87E-06	2.47E-06	1.42E-09	4.35E-04	2.63E-06	–	3.57E-05	–	8.23E-07
Tc	6.03E-03	6.31E-04	8.79E-04	7.68E-06	2.10E-02	1.93E-04	–	1.77E-04	–	6.40E-06
Th	1.59E-06	2.17E-08	1.98E-08	8.50E-11	3.73E-06	1.24E-08	–	7.14E-06	–	1.98E-07
U	5.11E-05	9.78E-05	3.95E-05	6.78E-07	2.49E-05	1.13E-06	–	7.12E-05	–	1.98E-04

[a] Radioisotopes of the same element are assumed to have the same release fraction.

[b] Disposal with the trench method is not considered for the generic sites in Region I or III.

[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-9 Release Fractions Assumed for Groundwater Modeling Considering Disposal of the Sealed Source Waste by Using the Vault Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I	Region II	Region III	Region IV
Ac	3.60E-06	2.36E-07	7.78E-07	8.67E-11	8.95E-07	8.99E-08	6.56E-06	6.77E-06	1.88E-06	8.87E-08
Am	3.60E-06	3.73E-08	4.22E-08	8.67E-11	8.95E-07	2.80E-08	1.82E-05	1.82E-05	5.06E-06	2.47E-07
C	1.52E-03	1.72E-05	8.96E-04	7.83E-06	4.91E-02	7.93E-06	1.09E-02	2.48E-02	7.57E-03	2.02E-04
Cm	2.02E-07	2.36E-07	2.02E-06	1.52E-10	8.95E-07	1.01E-08	1.82E-05	1.82E-05	5.06E-06	2.47E-07
Co	7.99E-05	3.54E-08	1.80E-04	1.01E-08	2.52E-04	6.73E-07	7.01E-04	3.98E-04	1.11E-04	9.64E-06
Cs	1.62E-06	8.84E-07	1.33E-05	2.17E-09	3.04E-05	1.45E-07	2.93E-05	1.46E-05	4.06E-06	3.96E-07
Fe	3.68E-06	3.22E-07	4.84E-07	2.90E-09	1.90E-05	1.94E-07	7.16E-06	1.74E-05	4.84E-06	9.68E-08
Gd	3.37E-06	8.59E-08	2.02E-06	7.36E-10	8.95E-07	4.91E-08	2.99E-05	7.26E-05	2.02E-05	4.04E-07
H	6.15E-03	6.44E-04	8.96E-04	7.83E-06	4.91E-02	2.45E-04	1.09E-02	2.48E-02	7.57E-03	2.02E-04
I	6.15E-03	6.44E-04	8.96E-04	7.83E-06	1.01E-02	3.66E-05	1.09E-02	2.48E-02	7.57E-03	2.02E-04
Mn	1.61E-05	1.41E-06	6.40E-07	1.21E-08	3.80E-05	8.08E-07	2.99E-05	7.26E-05	2.02E-05	4.04E-07
Mo	7.99E-05	7.01E-06	2.46E-05	6.02E-08	6.33E-05	4.01E-06	3.62E-04	8.78E-04	2.45E-04	4.94E-06
Nb	1.62E-06	2.36E-07	1.01E-06	8.67E-11	4.91E-02	2.53E-07	2.99E-05	3.64E-05	1.01E-05	4.04E-07
Ni	8.08E-06	1.77E-07	2.02E-06	6.07E-09	2.52E-04	1.01E-07	1.23E-04	6.16E-05	1.71E-05	1.67E-06
Np	3.50E-05	2.71E-05	4.38E-05	1.20E-07	2.16E-04	7.93E-06	4.77E-04	1.16E-03	3.23E-04	6.53E-06
Pa	9.96E-05	2.71E-05	1.84E-08	1.20E-07	2.16E-04	1.06E-07	1.09E-02	7.26E-05	2.02E-05	2.02E-04
Pb	3.00E-06	8.84E-07	4.03E-06	2.02E-09	1.52E-06	1.50E-07	6.40E-06	6.10E-06	1.69E-06	8.65E-08
Po	5.39E-06	4.72E-07	1.00E-05	2.02E-09	1.52E-06	2.70E-07	6.40E-06	6.10E-06	1.69E-06	8.65E-08
Pu	3.24E-07	4.72E-07	2.40E-05	8.01E-08	1.29E-06	7.36E-08	1.48E-04	3.64E-05	1.01E-05	2.00E-06
Ra	1.41E-06	7.01E-06	2.02E-07	3.28E-09	4.44E-04	8.09E-08	6.20E-05	3.64E-05	1.01E-05	8.40E-07
Sm	3.24E-07	2.36E-07	2.02E-06	2.48E-09	8.95E-07	1.65E-07	6.56E-06	6.77E-06	1.88E-06	8.87E-08
Sr	6.67E-05	7.01E-06	2.52E-06	1.45E-09	4.44E-04	2.68E-06	6.20E-05	3.64E-05	1.01E-05	8.40E-07
Tc	6.15E-03	6.44E-04	8.96E-04	7.83E-06	2.14E-02	1.97E-04	4.77E-04	1.81E-04	5.03E-05	6.53E-06
Th	1.62E-06	2.21E-08	2.02E-08	8.67E-11	3.80E-06	1.26E-08	1.50E-05	7.28E-06	2.02E-06	2.02E-07
U	5.21E-05	9.98E-05	4.03E-05	6.92E-07	2.54E-05	1.15E-06	1.09E-02	7.26E-05	2.02E-05	2.02E-04

[a] Radioisotopes of the same element are assumed to have the same release fraction.

TABLE 4-10 Release Fractions Assumed for Groundwater Modeling Considering Disposal of Other Waste by Using the Borehole Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I[b]	Region II[b]	Region III[b]	Region IV
Ac	1.97E-06	2.92E-08	4.17E-08	4.76E-11	–[c]	1.67E-08	–	–	–	8.33E-09
Am	3.33E-07	2.05E-08	2.31E-08	4.76E-11	–	1.54E-08	–	–	–	8.33E-09
C	3.32E-05	2.90E-06	4.15E-06	2.49E-08	–	1.66E-06	–	–	–	8.30E-07
Cm	1.11E-07	2.92E-08	4.17E-08	8.33E-11	–	5.56E-09	–	–	–	8.33E-09
Co	3.33E-06	1.94E-08	4.16E-07	2.50E-09	–	1.67E-07	–	–	–	8.33E-08
Cs	8.89E-07	4.85E-07	7.30E-06	1.19E-09	–	7.93E-08	–	–	–	2.17E-07
Fe	2.02E-06	1.77E-07	2.66E-07	1.59E-09	–	1.06E-07	–	–	–	5.31E-08
Gd	3.33E-07	2.92E-08	4.17E-08	2.50E-10	–	1.67E-08	–	–	–	8.33E-09
H	3.38E-03	3.54E-04	4.92E-04	4.30E-06	–	1.34E-04	–	–	–	1.11E-04
I	1.66E-05	1.46E-06	2.08E-06	1.25E-08	–	8.32E-07	–	–	–	4.16E-07
Mn	3.33E-06	2.92E-07	3.51E-07	2.50E-09	–	1.67E-07	–	–	–	8.33E-08
Mo	4.39E-05	3.85E-06	1.35E-05	3.31E-08	–	2.20E-06	–	–	–	2.71E-06
Nb	3.33E-07	2.92E-08	4.17E-08	4.76E-11	–	1.67E-08	–	–	–	8.33E-09
Ni	3.33E-06	9.72E-08	4.16E-07	2.50E-09	–	5.55E-08	–	–	–	8.33E-08
Np	1.11E-06	9.72E-08	1.39E-07	8.33E-10	–	5.55E-08	–	–	–	2.78E-08
Pa	1.67E-07	1.46E-08	1.01E-08	1.25E-10	–	8.33E-09	–	–	–	4.17E-09
Pb	6.67E-07	5.83E-08	8.33E-08	5.00E-10	–	3.33E-08	–	–	–	1.67E-08
Po	6.67E-07	5.83E-08	8.33E-08	5.00E-10	–	3.33E-08	–	–	–	1.67E-08
Pu	6.67E-08	5.83E-09	8.33E-09	5.00E-11	–	3.33E-09	–	–	–	1.67E-09
Ra	7.73E-07	2.92E-07	1.11E-07	1.80E-09	–	4.44E-08	–	–	–	8.33E-08
Sm	1.78E-07	2.92E-08	4.17E-08	2.50E-10	–	1.67E-08	–	–	–	8.33E-09
Sr	3.66E-05	3.85E-06	1.38E-06	7.94E-10	–	1.47E-06	–	–	–	4.61E-07
Tc	3.33E-07	2.92E-08	4.17E-08	2.50E-10	–	1.67E-08	–	–	–	8.33E-09
Th	6.67E-08	5.83E-09	8.33E-09	4.76E-11	–	3.33E-09	–	–	–	1.67E-09
U	6.67E-08	5.83E-09	8.33E-09	5.00E-11	–	3.33E-09	–	–	–	1.67E-09

[a] Radioisotopes of the same element are assumed to have the same release fraction.
[b] Disposal with the borehole method is not considered for SRS or the generic sites in Region I, II, or III.
[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-11 Release Fractions Assumed for Groundwater Modeling Considering Disposal of Other Waste by Using the Trench Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I[b]	Region II	Region III[b]	Region IV
Ac	5.95E-07	5.21E-08	7.44E-08	8.50E-11	8.78E-07	2.98E-08	–[c]	2.68E-06	–	1.49E-08
Am	5.95E-07	3.65E-08	4.13E-08	8.50E-11	8.78E-07	2.75E-08	–	2.68E-06	–	1.49E-08
C	5.93E-05	5.19E-06	7.41E-06	4.45E-08	5.57E-04	2.96E-06	–	2.67E-04	–	1.48E-06
Cm	1.98E-07	5.21E-08	7.44E-08	1.49E-10	8.78E-07	9.92E-09	–	2.68E-06	–	1.49E-08
Co	5.95E-06	3.47E-08	7.44E-07	4.46E-09	5.59E-05	2.97E-07	–	2.68E-05	–	1.49E-07
Cs	1.59E-06	8.67E-07	1.30E-05	2.13E-09	2.98E-05	1.42E-07	–	1.43E-05	–	3.88E-07
Fe	3.61E-06	3.15E-07	4.74E-07	2.85E-09	1.86E-05	1.90E-07	–	1.71E-05	–	9.49E-08
Gd	5.95E-07	5.21E-08	7.44E-08	4.46E-10	8.78E-07	2.98E-08	–	2.68E-06	–	1.49E-08
H	6.03E-03	6.31E-04	8.79E-04	7.68E-06	4.81E-02	2.40E-04	–	2.43E-02	–	1.98E-04
I	2.97E-05	2.60E-06	3.71E-06	2.23E-08	2.79E-04	1.49E-06	–	1.34E-04	–	7.43E-07
Mn	5.95E-06	5.21E-07	6.27E-07	4.46E-09	3.73E-05	2.97E-07	–	2.68E-05	–	1.49E-07
Mo	7.83E-05	6.87E-06	2.41E-05	5.91E-08	6.21E-05	3.93E-06	–	8.61E-04	–	4.84E-06
Nb	5.95E-07	5.21E-08	7.44E-08	8.50E-11	5.60E-06	2.98E-08	–	2.68E-06	–	1.49E-08
Ni	5.95E-06	1.74E-07	7.44E-07	4.46E-09	5.59E-05	9.92E-08	–	2.68E-05	–	1.49E-07
Np	1.98E-06	1.74E-07	2.48E-07	1.49E-09	1.86E-05	9.92E-08	–	8.93E-06	–	4.96E-08
Pa	2.98E-07	2.60E-08	1.80E-08	2.23E-10	2.80E-06	1.49E-08	–	1.34E-06	–	7.44E-09
Pb	1.19E-06	1.04E-07	1.49E-07	8.93E-10	1.49E-06	5.95E-08	–	5.36E-06	–	2.98E-08
Po	1.19E-06	1.04E-07	1.49E-07	8.93E-10	1.49E-06	5.95E-08	–	5.36E-06	–	2.98E-08
Pu	1.19E-07	1.04E-08	1.49E-08	8.93E-11	1.12E-06	5.95E-09	–	5.36E-07	–	2.98E-09
Ra	1.38E-06	5.21E-07	1.98E-07	3.22E-09	5.59E-05	7.93E-08	–	2.68E-05	–	1.49E-07
Sm	3.17E-07	5.21E-08	7.44E-08	4.46E-10	8.78E-07	2.98E-08	–	2.68E-06	–	1.49E-08
Sr	6.54E-05	6.87E-06	2.47E-06	1.42E-09	4.35E-04	2.63E-06	–	3.57E-05	–	8.23E-07
Tc	5.95E-07	5.21E-08	7.44E-08	4.46E-10	5.60E-06	2.98E-08	–	2.68E-06	–	1.49E-08
Th	1.19E-07	1.04E-08	1.49E-08	8.50E-11	1.12E-06	5.95E-09	–	5.36E-07	–	2.98E-09
U	1.19E-07	1.04E-08	1.49E-08	8.93E-11	1.12E-06	5.95E-09	–	5.36E-07	–	2.98E-09

[a] Radioisotopes of the same element are assumed to have the same release fraction.
[b] Disposal with the trench method is not considered for the generic sites in Region I or III.
[c] A dash indicates the waste volume is 0 m^3.

TABLE 4-12 Release Fractions Assumed for Groundwater Modeling Considering Disposal of Other Waste - CH by Using the Vault Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I	Region II	Region III	Region IV
Ac	6.07E-07	5.31E-08	7.59E-08	8.67E-11	8.95E-07	3.04E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
Am	6.07E-07	3.73E-08	4.22E-08	8.67E-11	8.95E-07	2.80E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
C	6.05E-05	5.29E-06	7.56E-06	4.53E-08	5.68E-04	3.02E-06	1.12E-04	2.72E-04	7.56E-05	1.51E-06
Cm	2.02E-07	5.31E-08	7.59E-08	1.52E-10	8.95E-07	1.01E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
Co	6.07E-06	3.54E-08	7.59E-07	4.55E-09	5.70E-05	3.03E-07	1.12E-05	2.73E-05	7.59E-06	1.52E-07
Cs	1.62E-06	8.84E-07	1.33E-05	2.17E-09	3.04E-05	1.45E-07	2.93E-05	1.46E-05	4.06E-06	3.96E-07
Fe	3.68E-06	3.22E-07	4.84E-07	2.90E-09	1.90E-05	1.94E-07	7.16E-06	1.74E-05	4.84E-06	9.68E-08
Gd	6.07E-07	5.31E-08	7.59E-08	4.55E-10	8.95E-07	3.04E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
H	6.15E-03	6.44E-04	8.96E-04	7.83E-06	4.91E-02	2.45E-04	1.09E-02	2.48E-02	7.57E-03	2.02E-04
I	3.03E-05	2.65E-06	3.79E-06	2.27E-08	2.85E-04	1.51E-06	5.60E-05	1.36E-04	3.79E-05	7.57E-07
Mn	6.07E-06	5.31E-07	6.40E-07	4.55E-09	3.80E-05	3.03E-07	1.12E-05	2.73E-05	7.59E-06	1.52E-07
Mo	7.99E-05	7.01E-06	2.46E-05	6.02E-08	6.33E-05	4.01E-06	3.62E-04	8.78E-04	2.45E-04	4.94E-06
Nb	6.07E-07	5.31E-08	7.59E-08	8.67E-11	5.71E-06	3.04E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
Ni	6.07E-06	1.77E-07	7.59E-07	4.55E-09	5.70E-05	1.01E-07	1.12E-05	2.73E-05	7.59E-06	1.52E-07
Np	2.02E-06	1.77E-07	2.53E-07	1.52E-09	1.90E-05	1.01E-07	3.74E-06	9.11E-06	2.53E-06	5.06E-08
Pa	3.04E-07	2.66E-08	1.84E-08	2.28E-10	2.85E-06	1.52E-08	5.62E-07	1.37E-06	3.79E-07	7.59E-09
Pb	1.21E-06	1.06E-07	1.52E-07	9.11E-10	1.52E-06	6.07E-08	2.25E-06	5.46E-06	1.52E-06	3.04E-08
Po	1.21E-06	1.06E-07	1.52E-07	9.11E-10	1.52E-06	6.07E-08	2.25E-06	5.46E-06	1.52E-06	3.04E-08
Pu	1.21E-07	1.06E-08	1.52E-08	9.11E-11	1.14E-06	6.07E-09	2.25E-07	5.46E-07	1.52E-07	3.04E-09
Ra	1.41E-06	5.31E-07	2.02E-07	3.28E-09	5.70E-05	8.09E-08	1.12E-05	2.73E-05	7.59E-06	1.52E-07
Sm	3.24E-07	5.31E-08	7.59E-08	4.55E-10	8.95E-07	3.04E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
Sr	6.67E-05	7.01E-06	2.52E-06	1.45E-09	4.44E-04	2.68E-06	6.20E-05	3.64E-05	1.01E-05	8.40E-07
Tc	6.07E-07	5.31E-08	7.59E-08	4.55E-10	5.71E-06	3.04E-08	1.12E-06	2.73E-06	7.59E-07	1.52E-08
Th	1.21E-07	1.06E-08	1.52E-08	8.67E-11	1.14E-06	6.07E-09	2.25E-07	5.46E-07	1.52E-07	3.04E-09
U	1.21E-07	1.06E-08	1.52E-08	9.11E-11	1.14E-06	6.07E-09	2.25E-07	5.46E-07	1.52E-07	3.04E-09

[a] Radioisotopes of the same element are assumed to have the same release fraction.

TABLE 4-13 Release Fractions Assumed for Groundwater Modeling Considering Disposal of Other Waste - RH by Using the Vault Method at the Various Sites Evaluated

	Release Fraction (1/yr) from the Contamination Source									
Element[a]	INL	Hanford	LANL	NNSS	SRS	WIPP Vicinity	Region I	Region II	Region III	Region IV
Ac	7.81E-07	6.83E-08	9.76E-08	1.12E-10	1.15E-06	3.90E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
Am	7.81E-07	4.79E-08	5.42E-08	1.12E-10	1.15E-06	3.60E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
C	7.77E-05	6.80E-06	9.72E-06	5.83E-08	7.31E-04	3.89E-06	1.44E-04	3.50E-04	9.72E-05	1.94E-06
Cm	2.60E-07	6.83E-08	9.76E-08	1.95E-10	1.15E-06	1.30E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
Co	7.80E-06	4.55E-08	9.75E-07	5.85E-09	7.33E-05	3.90E-07	1.44E-05	3.51E-05	9.75E-06	1.95E-07
Cs	2.08E-06	1.14E-06	1.71E-05	2.79E-09	3.91E-05	1.86E-07	3.77E-05	1.88E-05	5.22E-06	5.09E-07
Fe	4.73E-06	4.14E-07	6.22E-07	3.73E-09	2.45E-05	2.49E-07	9.21E-06	2.24E-05	6.22E-06	1.24E-07
Gd	7.81E-07	6.83E-08	9.76E-08	5.85E-10	1.15E-06	3.90E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
H	7.91E-03	8.28E-04	1.15E-03	1.01E-05	6.31E-02	3.14E-04	1.40E-02	3.19E-02	9.73E-03	2.59E-04
I	3.90E-05	3.41E-06	4.87E-06	2.92E-08	3.66E-04	1.95E-06	7.21E-05	1.75E-04	4.87E-05	9.74E-07
Mn	7.80E-06	6.83E-07	8.23E-07	5.85E-09	4.89E-05	3.90E-07	1.44E-05	3.51E-05	9.75E-06	1.95E-07
Mo	1.03E-04	9.01E-06	3.16E-05	7.75E-08	8.14E-05	5.15E-06	4.65E-04	1.13E-03	3.15E-04	6.35E-06
Nb	7.81E-07	6.83E-08	9.76E-08	1.12E-10	7.34E-06	3.90E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
Ni	7.80E-06	2.28E-07	9.75E-07	5.85E-09	7.33E-05	1.30E-07	1.44E-05	3.51E-05	9.75E-06	1.95E-07
Np	2.60E-06	2.28E-07	3.25E-07	1.95E-09	2.45E-05	1.30E-07	4.81E-06	1.17E-05	3.25E-06	6.50E-08
Pa	3.90E-07	3.42E-08	2.37E-08	2.93E-10	3.67E-06	1.95E-08	7.22E-07	1.76E-06	4.88E-07	9.76E-09
Pb	1.56E-06	1.37E-07	1.95E-07	1.17E-09	1.96E-06	7.81E-08	2.89E-06	7.03E-06	1.95E-06	3.90E-08
Po	1.56E-06	1.37E-07	1.95E-07	1.17E-09	1.96E-06	7.81E-08	2.89E-06	7.03E-06	1.95E-06	3.90E-08
Pu	1.56E-07	1.37E-08	1.95E-08	1.17E-10	1.47E-06	7.81E-09	2.89E-07	7.03E-07	1.95E-07	3.90E-09
Ra	1.81E-06	6.83E-07	2.60E-07	4.22E-09	7.33E-05	1.04E-07	1.44E-05	3.51E-05	9.75E-06	1.95E-07
Sm	4.16E-07	6.83E-08	9.76E-08	5.85E-10	1.15E-06	3.90E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
Sr	8.58E-05	9.01E-06	3.24E-06	1.86E-09	5.70E-04	3.45E-06	7.98E-05	4.68E-05	1.30E-05	1.08E-06
Tc	7.81E-07	6.83E-08	9.76E-08	5.85E-10	7.34E-06	3.90E-08	1.44E-06	3.51E-06	9.76E-07	1.95E-08
Th	1.56E-07	1.37E-08	1.95E-08	1.12E-10	1.47E-06	7.81E-09	2.89E-07	7.03E-07	1.95E-07	3.90E-09
U	1.56E-07	1.37E-08	1.95E-08	1.17E-10	1.47E-06	7.81E-09	2.89E-07	7.03E-07	1.95E-07	3.90E-09

[a] Radioisotopes of the same element are assumed to have the same release fraction.

TABLE 4-14 Water Rates (m/yr) Used in the RESRAD-OFFSITE Analyses for the Six DOE Sites

Rate	Hanford	INL	LANL	NNSS	SRS	WIPP Vicinity
Precipitation	0.17	0.22	0.356	0.13	1.2	0.3
Irrigation[a]	0	0	0	0	0	0
Water infiltration[b]	0.0035	0.04	0.005	0.00003	0.376	0.002

[a] No agricultural activity was assumed above the disposal area.

[b] 20% of the water infiltration rate was assumed to enter the disposal area and contact the GTCC LLRW and GTCC-like waste.

to water for drinking and irrigation the well also provided water for household activities, with a usage rate of 225 L/d per household member.

The highest-exposed individual was assumed to live at the same location for 30 years, during which he continuously irrigated the agricultural fields with the groundwater. The radionuclides deposited in the agricultural fields were subjected to radiological ingrowth and decay as well as leaching, just like the radionuclides in the contamination source of the storage or disposal facility. The farming activities were assumed to produce 50% of the plant foods, meat, and milk consumed by the farmer and his family. The RESRAD-OFFSITE default values for consumption parameters were used in the dose calculations, as were the yield, growth, and transfer factors related to the plant, meat, and milk pathways.

4.3 DEVELOPMENT OF SITE-SPECIFIC INPUT PARAMETERS

The transport of leached radionuclides in the unsaturated and saturated zones was simulated at each of the six potential DOE sites and each of the generic commercial sites in different regions. For the DOE sites, site-specific input parameter values reported in previous performance analysis reports evaluating waste disposal facilities were used in the RESRAD-OFFSITE analysis when they were available; otherwise, they were derived by using site-specific monitoring data. When site-specific data were not available, values reported in the literature for the same soil type were used. If the soil at a specific site was best characterized as a mixture of different soil types, the average value of the different types of soil or the RESRAD-OFFSITE default value was used. In some cases, site-specific data were reported as a range with minimum and maximum values; then the average or geometric mean value, depending on the generic distribution of that parameter, was calculated and used as parameter value. If the most likely value was reported, it was used directly. The site-specific parameter values developed were reviewed and commented on by site personnel familiar with the specific conditions at the site who had experience conducting risk assessments for the site. Their comments or suggested parameter values were accepted and used in the groundwater modeling, unless they were judged to be inconsistent with the modeling assumptions.

The RESRAD-OFFSITE input parameters describing the settings for the four generic commercial sites in different regions were developed from those used in similar analyses. Soil properties and hydrogeological characteristics of the vadose zone and saturated zone were assumed to be the same as those used in the Yucca Mountain EIS for the No Action Alternative (Tables K-5 and K-10 in DOE 2002; Toblin 1998, 1999). Because NRC Regions IV and V have since been combined as Region IV, the

TABLE 4-15 Unsaturated Zone Characteristics Used as Input Parameters in the RESRAD-OFFSITE Analyses for the Six DOE Sites[a]

Zone and Parameter	Hanford	INL	LANL	NNSS	SRS	WIPP Vicinity
Unsaturated Zone 1						
Thickness (m)	58	9.14	13	246	6.1	153
Density (g/cm^3)	1.65	1.64	1.4	1.65	1.65	1.47
Total porosity	0.37	0.5	0.41	0.36	0.39	0.445
Effective porosity	0.37	0.5	0.41	0.36	0.39	0.404
Field capacity	0.03	0.1	0.02	0.3	0.3	0.3
Hydraulic conductivity (m/yr)	710	29,200	61.81	0.00003	2.7	107.31
Soil b parameter	4.05	4.34	0.175	5.3	6.62	1.76
Unsaturated Zone 2						
Thickness (m)	30	94.6	26	–[b]	16.9	–
Density (g/cm^3)	1.93	2.0	1.2	–	1.62	–
Total porosity	0.27	0.05	0.47	–	0.39	–
Effective porosity	0.27	0.05	0.47	–	0.39	–
Field capacity	0.024	0.001	0.02	–	0.3	–
Hydraulic conductivity (m/yr)	148	3,650	46.36	–	29	–
Soil b parameter	7.12	0.76	1.339	–	4.1	–
Unsaturated Zone 3						
Thickness (m)	–	7.47	16	–	–	–
Density (g/cm^3)	–	1.46	1.2	–	–	–
Total porosity	–	0.57	0.44	–	–	–
Effective porosity	–	0.57	0.44	–	–	–
Field capacity	–	0.3	0.04	–	–	–
Hydraulic conductivity (m/yr)	–	1.29	71.08	–	–	–
Soil b parameter	–	3.6	2.152	–	–	–
Unsaturated Zone 4						
Thickness (m)	–	15.39	3	–	–	–
Density (g/cm^3)	–	1.64	0.8	–	–	–
Total porosity	–	0.5	0.67	–	–	–
Effective porosity	–	0.5	0.67	–	–	–
Field capacity	–	0.3	0.00001	–	–	–
Hydraulic conductivity (m/yr)	–	29,200	46.36	–	–	–
Soil b parameter	–	10.4	1.891	–	–	–
Unsaturated Zone 5						
Thickness (m)	–	10.52	211	–	–	–
Density (g/cm^3)	–	2.0	2.7	–	–	–
Total porosity	–	0.05	0.001	–	–	–
Effective porosity	–	0.05	0.001	–	–	–
Field capacity	–	0.001	0.00001	–	–	–
Hydraulic conductivity (m/yr)	–	365,000	309.05	–	–	–
Soil b parameter	–	1.67	2.71	–	–	–

[a] The values given here were used in the RESRAD-OFFSITE evaluations for post-closure performance of the vault method. A smaller value for thickness (of the effective unsaturated zone) was used as the input value for evaluating post-closure performance of the trench and borehole methods to simulate placement of the waste in the unsaturated zone for these two methods.

[b] A dash means not applicable.

TABLE 4-16 Saturated Zone Characteristics Used as Input Parameters in the RESRAD-OFFSITE Analyses for the Six DOE Sites

Parameter	Hanford	INL	LANL	NNSS	SRS	WIPP Vicinity
Thickness (m)	45	495	37.5	220	27.85	5.1
Density of saturated zone (g/cm^3)	1.98	2.0	2.7	1.6	1.39	1.47
Total porosity	0.25	0.05	0.05	0.36	0.38	0.445
Effective porosity	0.25	0.05	0.05	0.36	0.25	0.404
Hydraulic conductivity (m/yr)	12,775	1979	309.1	439	1265	107.31
Hydraulic gradient to well	0.00124	0.00075	0.013	0.000097	0.0079	0.017
Depth of aquifer contributing to well (m)	10	10	10	10	10	5.1

parameters used for Region V in the Yucca Mountain EIS were used in the analysis for a generic commercial facility located in Region IV in this analysis.

The Yucca Mountain EIS provides data on the precipitation rates in the various NRC regions but not on the water infiltration rates to deeper soils. The infiltration to deeper soils would be expected to be much lower than the precipitation rates because of surface runoff and evapotranspiration. To facilitate the analysis of the impacts from GTCC waste disposal at generic commercial facilities in the EIS, the natural water infiltration rates were taken to be those assumed in the draft EIS on 10 CFR Part 61 (NUREG-0782, Vol. 4, Appendix J, Table J.5, NRC 1981). These values are 0.074 m/yr for Region I, 0.18 m/yr for Region II, 0.05 m/yr for Region III, and 0.001 m/yr for Region IV.

The site-specific input parameters used in the EIS for the six DOE sites are provided in Tables 4-14 through 4-17 and are discussed in more detail in Appendix A. The water infiltration rates used for this analysis are listed in Table 4-14. The infiltration rates are site-specific and were obtained or derived by using site-specific data, except for NNSS. Because the evapotranspiration rate at NNSS is about 12 to 14 times higher than the mean annual precipitation rate, the average infiltration rate should be zero. However, for this analysis, the infiltration rate was set to the hydraulic conductivity of the vadose zone, 0.00003 m/yr (Shott et al. 1998). For groundwater analysis pertaining to the disposal alternatives, it is assumed that 20% of the infiltration water would enter the disposal area and contact the GTCC LLRW and GTCC-like waste disposed of there.

The parameters used to define the unsaturated zones at the six DOE sites are given in Table 4-15. This table provides the values for the thickness, density, total porosity, effective porosity, field capacity, hydraulic conductivity, soil b parameter, and longitudinal dispersivity. For some sites, the number of geological units beneath the disposal area and above the groundwater table are more than the maximum number (5) of unsaturated zones allowed for modeling by RESRAD-OFFSITE. To approximate site conditions, similar hydrological units at different depths were combined to form a single unsaturated zone with representative properties. In this case, the thickness of the unsaturated zone was set to the combined thickness contributed by the individual geological units. An example for combining different unsaturated zones is provided in the following paragraph on the Hanford Site.

TABLE 4-17 Soil/Water Distribution Coefficient (K_d) Values (cm^3/g) for Different Radionuclides Used in RESRAD-OFFSITE Analyses for the Six DOE Sites[a]

Element[b]	Soil Layer[c]	Hanford	INL	LANL[d]	NNSS	SRS	WIPP Vicinity
Actinium	UZ	300,30	225, 0, 225, 225, 0	130	7000	8500, 1100	450
	SZ	300	9	130	7000	1100	450
Americium	UZ	1900,190	225, 0, 225, 225, 0	2400	7000	8500, 1100	1445
	SZ	1900	9	2400	7000	1100	1445
Carbon	UZ	4, 0.4	0.4, 0, 0.4, 0.4, 0	0	0	0,0	5
	SZ	4	0.016	0	0	0	5
Curium	UZ	300, 30	4000, 0, 4000, 4000, 0	50	4000	8500, 1100	4000
	SZ	300	160	50	4000	1100	4000
Cobalt	UZ	2000, 200	10, 0, 10, 10, 0	0.45	60	30, 7	60
	SZ	2000	0.4	0.45	60	7	60
Cesium	UZ	80, 8	500, 0, 500, 500, 0	7.5	280	250, 50	280
	SZ	80	20	7.5	280	50	280
Iron	UZ	220, 22	220, 0, 220, 220, 0	209	209	400, 200	209
	SZ	220	8.8	209	209	200	209
Gadolinium	UZ	825, 82.5	240, 0, 240, 240, 0	50	825	8500, 1100	825
	SZ	825	9.6	50	825	8500	825
Hydrogen	UZ	0, 0	0, 0, 0, 0, 0	0	0	0	0.06
	SZ	0	0	0	0	0	0.06
Iodine	UZ	0.2, 0.02	0, 0, 0, 0, 0	0	0	0.6, 0	1
	SZ	0.2	0	0	0	0	1
Manganese	UZ	50, 5	50, 0, 50, 50, 0	158	50	200, 15	50
	SZ	50	50	158	50	15	50
Molybdenum	UZ	10, 1	10, 0, 10, 10, 0	4	10	0, 0	10
	SZ	10	0.4	4	10	0	10
Niobium	UZ	300, 30	500, 0, 500, 500, 0	100	7000	0, 0	160
	SZ	300	20	100	7000	0	160
Nickel	UZ	400, 40	100, 0, 100, 100, 0	50	100	30, 7	400
	SZ	400	4	50	100	7	400
Neptunium	UZ	2.5, 0.25	23, 0, 23, 23, 0	2.2	5	35, 0.60	5
	SZ	2.5	0.92	2.2	5	0.6	5
Protactinium	UZ	2.5, 0.25	8, 0, 8, 8, 0	5500	5	35, 0.6	380
	SZ	2.5	0.32	5500	5	0.6	380
Lead	UZ	80, 8	270, 0, 270, 270, 0	25	300	5000, 2000	270
	SZ	80	10.8	25	300	2000	270

TABLE 4-17 (Cont.)

Element[b]	Soil Layer[c]	Hanford	INL	LANL[d]	NNSS	SRS	WIPP Vicinity
Polonium	UZ	150, 15	150, 0, 150, 150, 0	10	300	5000, 2000	150
	SZ	150	6	10	300	2000	150
Plutonium	UZ	150, 15	2500, 0, 2500, 2500, 0	4.1	7.5	5900, 270	550
	SZ	150	100	4.1	7.5	270	550
Radium	UZ	10, 1	575, 0, 575, 575, 0	500	185	17, 5	500
	SZ	10	23	500	185	5	500
Samarium	UZ	300, 30	2500, 0, 2500, 2500, 0	50	245	8500, 1100	245
	SZ	300	100	50	245	1100	245
Strontium	UZ	10, 1	12, 0, 12, 12, 0	40	420	17, 5	15
	SZ	10	0.48	40	420	5	15
Technetium	UZ	0, 0	0, 0, 0, 0, 0	0	0	0.2, 0.1	0.1
	SZ	0	0	0	0	0.1	0.1
Thorium	UZ	3200, 320	500, 0, 500, 500, 0	5000	7000	2000, 900	3200
	SZ	3200	20	5000	7000	900	3200
Uranium	UZ	0.6, 0.06	15.4, 0, 15.4, 15.4, 0	2.4	0.8	300, 200	35
	SZ	0.6	0.616	2.4	0.8	200	35

[a] The K_d values were obtained from site reports and other site sources, as identified in Tables A-2, A-4, A-6, A-8, A-10, and A-12 in Appendix A.

[b] The K_d values for different isotopes of the same element were assumed to be the same in the analysis.

[c] For purposes of this analysis, the transport of radionuclides leached from the disposal area is assumed to occur in vadose zones and the saturated zone at the six DOE sites. The physical properties of these zones are site dependent. The notation for vadose zones (which are unsaturated) is UZ for unsaturated zone and is SZ for saturated zone. Release rates of radionuclides from the contaminated zone were determined by the leach rate constants, whose values are listed in Tables 4-4 through 4-13.

[d] For the LANL site, all the vadose zones are assumed to have the same K_d value.

The two focuses of the transport analysis related to the unsaturated zones are (1) the overall transport time of radionuclides and (2) the radionuclide concentrations in water emerging from the bottom layer of these unsaturated zones before the radionuclides enter the groundwater table. For the Hanford Site, two unsaturated zones were developed for use in the groundwater analysis. The first unsaturated zone was developed by combining the fine-sand-dominated layer and coarse-sand-dominated layer in the Hanford Formation. The layers were combined due to the similarity in geological and hydrogeological properties as presented in Last et al. (2006). The second unsaturated zone was developed by combining the gravel-dominated layers in the Hanford Formation and the Ringold Unit E. The rationale for this combination was the same as that for the first unsaturated zone. Most of the values for the unsaturated zone parameters were site-specific, except for a few soil b values, which were selected on the basis of soil type. Additional information on the literature sources and rationale for the selection of the parameter values is provided in Appendix A.

The parameters used to define the saturated zones at the six DOE sites are given in Table 4-16. The uppermost groundwater aquifer underlying the waste disposal area at each site was used in the groundwater modeling to obtain conservative estimates of the groundwater concentrations. The thickness, density, porosity, hydraulic conductivity, and hydraulic gradient are all site-specific values obtained from published literature. The depth of the aquifer contribution to a well was set at 10 m, unless the thickness of groundwater aquifer was less than 10 m, in which case the thickness of groundwater aquifer was used.

The K_d values for the various elements at the potential disposal sites used in the analysis are given in Table 4-17. As identified in Section 3.3, the K_d is a very important parameter in this analysis. Its values can range over several orders of magnitude, and this value has a great influence on the transport speed of radionuclides and the partitioning of radionuclides between soil and water. Site-specific data were used to the extent they were available; if unavailable, representative values for the same or a similar soil type at the site or the RESRAD-OFFSITE default value, whichever was smaller (more conservative), was used. Additional information on the literature sources and rationale for the K_d values is given in Appendix A.

Tables 4-18 and 4-19 compare the RESRAD-OFFSITE input parameters used for the four generic commercial sites. Table 4-18 provides the values for all input parameters except the K_d values, and Table 4-19 provides the K_d values. These same values were also used for the No Action Alternative analysis.

4.4 RESULTS

The following sections provide the RESRAD-OFFSITE calculation results from groundwater modeling. They are summarized for the No Action Alternative and disposal alternatives separately in Section 4.4.1, then discussed in more detail for the storage or disposal facilities located at different sites in Section 4.4.2.

TABLE 4-18 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for Generic Commercial Sites in the Four Regions

Parameter Name	Region I	Region II	Region III	Region IV
Site properties				
Precipitation (m/yr)[a]	0.074	0.18	0.05	0.001
Primary contamination area properties[b]				
Irrigation (m/yr)	0	0	0	0
Evapotranspiration coefficient	0	0	0	0
Runoff coefficient[c]	0	0	0	0
Rainfall and runoff[c]	160	160	160	160
Slope-length-steepness factor	0.4	0.4	0.4	0.4
Cover and management factor	0.03	0.03	0.03	0.03
Support practice factor	1	1	1	1
Contaminated zone[b]				
Total porosity	0.4	0.4	0.4	0.4
Erosion rate (m/yr)	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Dry bulk density (g/cm^3)	1.8	1.8	1.8	1.8
Soil erodibility factor	0.42	0.42	0.42	0.42
Field capacity	0.3	0.3	0.3	0.3
b-parameter	5.3	5.3	5.3	5.3
Hydraulic conductivity (m/yr)	10	10	10	10
Cover layer[b]				
Total porosity	0.4	0.4	0.4	0.4
Erosion rate (m/yr)	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Dry bulk density (g/cm^3)	1.5	1.5	1.5	1.5
Soil erodibility factor	0.35	0.35	0.35	0.35
Unsaturated zone 1[d]				
Thickness (m)	3.353	13.41	2.16	54.86
Density (g/cm^3)	1.6	1.5	1.5	1.6
Total porosity	0.38	0.42	0.44	0.41
Effective porosity	0.38	0.42	0.44	0.41
Field capacity	0.093	0.15	0.23	0.12
Hydraulic conductivity (m/yr)	1981	201	518	1798
b parameter[b]	5.3	5.3	5.3	5.3
Longitudinal dispersivity (m)[b]	0	0	0	0
Saturated zone hydrology[d]				
Thickness (m)	13.72	15.24	11.28	64
Density of saturated zone (g/cm^3)	1.6	1.8	1.6	1.7
Total porosity	0.38	0.4	0.38	0.3
Effective porosity	0.22	0.23	0.22	0.17
Hydraulic conductivity (m/yr)[e]	103.6	18.9	21.03	91
Hydraulic gradient to well[e]	1	1	1	1
Depth of aquifer contributing to well (m), below water table	10	10	10	10
Longitudinal dispersivity (m)	10% of distance traveled	10% of distance traveled	10% of distance traveled	10% of distance traveled

TABLE 4-18 (Cont.)

Parameter Name	Region I	Region II	Region III	Region IV
Horizontal lateral dispersivity (m)	10% of longitudinal dispersivity	10% of longitudinal dispersivity	10% of longitudinal dispersivity	10% of longitudinal dispersivity
Disperse vertically (yes/no)	Yes	Yes	Yes	Yes
Vertical lateral dispersivity (m)	10% of horizontal lateral dispersivity	10% of horizontal lateral dispersivity	10% of horizontal lateral dispersivity	10% of horizontal lateral dispersivity

[a] The input value for the precipitation rate was set to match the infiltration rate used in NUREG-0782, Vol. 4 (NRC 1981). In order to obtain the same rate of infiltration to the vadose zone as that used in NUREG-0782, the irrigation rate, evapotranspiration rate, and runoff coefficient were all set to 0.

[b] Input parameters for the primary contamination area, contaminated zone, and cover layers were kept the same as those used for the DOE alternate sites, unless specifically noted.

[c] The evapotranspiration rate and runoff coefficient were set to zero in order to obtain the desired water infiltration rate. See also note footnote a.

[d] Input parameters for the unsaturated and saturated zones were obtained from Toblin (1998, 1999), and Poe (1998), unless specifically noted.

[e] To obtain the same Darcy's velocity as used in Toblin (1999), the hydraulic conductivity was set to the Darcy velocity value, while the hydraulic gradient was set to 1.

TABLE 4-19 Soil/Water Distribution Coefficient (K_d) Values (cm^3/g) for Different Radionuclides[a] Used for Commercial Facilities in the Four Regions

	Region I		Region II		Region III		Region IV	
Element	Unsaturated Zone	Saturated Zone	Unsaturated Zone	Saturated Zone	Unsaturated Zone	Saturated Zone	Unsaturated Zone	Saturated Zone
Ac	228	228	538	228	538	228	228	228
Am	82	82	200	82	200	82	82	82
C	0	0	0	0	0	0	0	0
Cm	82	82	200	82	200	82	82	82
Co	2	2	9	2	9	2	2	2
Cs	51	51	249	51	249	51	51	51
Fe[b]	209	209	209	209	209	209	209	209
Gd[b]	50	50	50	50	50	50	50	50
H	0	0	0	0	0	0	0	0
I	0	0	0	0	0	0	0	0
Mn[b]	50	50	50	50	50	50	50	50
Mo[b]	4	4	4	4	4	4	4	4
Nb	50	50	100	50	100	50	50	50
Ni	12	12	59	12	59	12	12	12
Np	3	3	3	3	3	3	3	3
Pa	0	0	50	0	50	0	0	0
Pb	234	234	597	234	597	234	234	234
Po[c]	234	234	597	234	597	234	234	234
Pu	10	10	100	10	100	10	10	10
Ra	24	24	100	24	100	24	24	24
Sm	228	228	538	228	538	228	228	228
Sr	24	24	100	24	100	24	24	24
Tc	3	3	3	3	3	3	3	3
Th	100	100	100	100	100	100	100	100
U	0	0	50	0	50	0	0	0

[a] K_d values were obtained from Toblin (1999) unless specifically noted.

[b] Selected K_d values for Fe, Gd, Mn, and Mo were the smallest values among those used for the six federal sites.

[c] The value of the K_d for Po was set to be same as that for Pb.

4.4.1 Summary

The results of the RESRAD-OFFSITE simulations for the No Action Alternative are summarized in Table 4-20. This table presents the estimated peak annual doses when consideration is given to the storage of each individual waste type at each generic site in different regions. As indicated by the results, storage of the GTCC LLRW and GTCC-like wastes in Region I would result in very high radiation exposure to a hypothetical farmer residing 100 m from the edge of the storage facility. The peak annual dose could reach 270,000 mrem/yr for the GTCC-like Other Waste - RH in this region. The peak annual dose for Region II during the first 10,000 years would be much lower, with a maximum value of about 850 mrem/yr for GTCC LLRW Other Waste - RH. However, after 10,000 years, the peak annual dose would increase and could reach as high as 16,000 mrem/yr for GTCC LLRW sealed sources.

TABLE 4-20 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater for the No Action Alternative[a]

		Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
		GTCC LLRW				GTCC-like Waste			
NRC Region	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
I	10,000	130	73,000	3,800	26,000	–-	–	97,000	270,000
	100,000	130	73,000	3,800	26,000	–	–	97,000	270,000
II	10,000	10	210	–	850	0.14	–	0.14	0
	100,000	170	16,000	–	3,200	0.14	–	180	14,000
III	10,000	6.2	120	–	–	–	–	–	–
	100,000	190	13,000	–	–	–	–	–	–
IV	10,000	0	0	0	0	0	0	0	0
	100,000	0	9.3	0	0.023	0	0	0.89	9.8

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the storage facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the peak annual doses from each waste type. Because of the different radionuclide mixes and activities contained in the different waste types, the peak annual doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses from the entire GTCC waste inventory are given in Table 4-25.

A similar tendency was found with the estimated annual doses for Region III. The lowest impacts would occur in Region IV. Within 100,000 years, the peak annual dose was estimated to be less than 10 mrem/yr. While the estimated results can largely be explained on the basis of the precipitation and infiltration rates as well as the depth to groundwater table assumed for the storage site at each region, they are also in part due to the different waste inventories assumed to be stored in the different regions.

The results for the disposal alternatives are summarized in Tables 4-21 through 4-24. Table 4-21 presents the estimated peak annual doses to the hypothetical resident farmer from each individual waste type in the Group 1 stored inventory, and Table 4-22 presents the results from each individual waste type in the Group 1 projected inventory. These results are based on the dose conversion factors for an adult in ICRP 72 (ICRP 1996). The peak annual doses from each individual waste type in the entire Group 1 waste inventory are given in Table 4-23. Table 4-24 gives the peak annual doses for the Group 2 inventory (all of which is projected waste). These two groups of wastes are defined in Section 2 of this report. The dose calculations were performed over two time periods — 10,000 years and 100,000 years — following closure of the disposal facility.

The results are provided separately for GTCC LLRW and GTCC-like wastes and address the three separate types of waste materials (activated metals, sealed sources, and Other Waste). The estimated peak annual doses are associated with the disposal of each type of waste material, respectively; therefore, they may occur at different times in the future. The results are provided in this format to allow for an evaluation of the post-closure human health impacts associated with disposing of certain types of wastes at specific locations with specific disposal approaches. For example, it is possible to compare the peak annual projected doses for the stored activated metal GTCC LLRW that could result from using the three disposal methods at the different alternate sites by looking at the appropriate column in Table 4-21. It is important to remember that these results are intended to be viewed in a comparative manner given the uncertainties associated with the assumptions made for the performance of the engineered materials and waste containers.

The results given in Tables 4-21 through 4-24 differ from those given in the following sections that provide more detailed discussions on the results for individual sites. The values given in these four tables are the peak annual doses associated with the disposal of each individual waste type in the Group 1 stored inventory (Table 4-21), Group 1 projected inventory (Table 4-22), Group 1 total inventory (Table 4-23), and Group 2 total inventory (Table 4-24). The values given in the following subsections represent the peak annual doses to the hypothetical resident farmer at the time of peak annual dose for the entire GTCC waste inventory. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The results given in the following subsections could be used to support the decision-making process when disposal of the entire inventory at a single separate location is considered, while those in Tables 4-21 through 4-24 would support decision-making for the disposal of individual waste types.

The peak annual doses range from zero (meaning that the radioactive contaminants from that particular waste type do not reach the off-site receptor) up to 2,300 mrem/yr in 10,000 years. All annual doses calculated as being less than 0.001 mrem/yr are reported as being "<0.001 mrem/yr," since these doses are much too low to be measured or detected. The highest doses calculated for the federal sites are those from disposing of wastes at INL, with doses of SRS being slightly lower. For SRS, the high doses are largely due to the humid nature of the environment in the area (that is, the abundant precipitation and the generally shallow groundwater tables at this location). For the INL site, the high doses are due to the low K_d values for several radionuclides, particularly for I-129 and uranium isotopes (a value of 0 cm^3/g was used for I-129, and for uranium isotopes, a value of 0 cm^3/g was used for part of the basalt layers and

TABLE 4-21 Estimated Peak Annual Doses (in mrem/yr) from the Use of Contaminated Groundwater at the Various Sites for the Stored Group 1 Inventory[a,b]

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
Hanford	Vault	10,000	0.26	–[d]	0	0.044	0	0	0.012	40
		100,000	0.26	–	< 0.001	0.36	0	< 0.001	20	40
	Trench	10,000	0.33	–	0	0.042	0	0	0.014	39
		100,000	0.33	–	< 0.001	0.35	0	< 0.001	24	39
	Borehole	10,000	0.17	–	0	0.013	0	0	< 0.0042	0.11
		100,000	0.17	–	0	0.11	< 0.001	< 0.001	7.5	0.63
INL	Vault	10,000	7.7	–	0	2.3	0.86	0	5.5	2,200
		100,000	7.7	–	0.0029	2.3	0.86	0	70	2,200
	Trench	10,000	8.9	–	0	2.0	0.99	0	6.4	1,900
		100,000	8.9	–	0	2.0	0.99	0	78	1,900
	Borehole	10,000	6.2	–	0	0.79	0.68	0	48	750
		100,000	6.2	–	0	0.79	0.68	0	53	750
LANL	Vault	10,000	60	–	0	0.22	0.45	0	1.8	230
		100,000	60	–	0	0.22	0.45	0	1.8	230
	Trench	10,000	5.2	–	0	0.21	0.55	0	2.2	210
		100,000	5.2	–	0	0.21	0.55	0	2.2	210
	Borehole	10,000	3.0	–	0	0.065	0.33	0	0.74	67
		100,000	3.0	–	0	0.065	0.33	0	0.74	67
NNSS	Vault	10,000	0	–	0	0	0	0	0	0
		100,000	0	–	0	0	0	0	0	0
	Trench	10,000	0	–	0	0	0	0	0	0
		100,000	0	–	0	0	0	0	0	0
	Borehole	10,000	0	–	0	0	0	0	0	0
		100,000	0	–	0	0	0	0	0	0
SRS[c]	Vault	10,000	2.9	–	0.0051	1.3	0.21	< 0.001	40	1,000
		100,000	2.9	–	0.0051	1.3	0.21	< 0.001	120	1,000
	Trench	10,000	4.0	–	0.0059	1.4	0.27	< 0.001	62	1,100
		100,000	8.0	–	0.0059	1.4	0.27	< 0.001	130	1,100

TABLE 4-21 (Cont.)

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
WIPP Vicinity	Vault	10,000	0	–	0	0	0	0	0	0
		100,000	2.9	–	0	0.16	0	0	0.039	36
	Trench	10,000	0	–	0	0	0	0	0	0
		100,000	2.9	–	0	0.12	0	0	0.039	28
	Borehole	10,000	0	–	0	0	0	0	0	0
		100,000	2.9	–	0	0.068	0	0	0.022	16
Region I[c]	Vault	10,000	14	–	0	24	0.027	0.0075	700	3,200
		100,000	14	–	0	24	0.027	0.0075	700	3,200
Region II[c]	Vault	10,000	0.98	–	0.013	0.056	0.13	0	18	940
		100,000	16	–	0.013	5.4	0.13	0	130	940
	Trench	10,000	1.7	–	0	0.25	0.16	0	20	950
		100,000	62	–	0	18	0.16	0	590	2,100
Region III[c]	Vault	10,000	1.1	–	0	0.077	0.16	0	6.3	410
		100,000	32	–	0	3.7	0.16	0	90	410
Region IV	Vault	10,000	0	–	0	0	0	0	0	0
		100,000	0.0041	–	0	0.11	0	0	5.8	5.7
	Trench	10,000	0	–	0	0	0	0	0	0
		100,000	0.0072	–	0	0.10	0	0	7.1	5.4
	Borehole	10,000	0	–	0	0	0	0	0	0
		100,000	0.028	–	0	0.034	0.0039	0	2.3	1.7

Footnotes appear on next page.

TABLE 4-21 (Cont.)

[a] CH = contact-handled, GTCC = greater-than-Class C, INL = Idaho National Laboratory, LANL = Los Alamos National Laboratory, NNSS = Nevada National Security Site; RH = remote-handled, SRS = Savannah River Site, WIPP = Waste Isolation Pilot Plant, Region I–IV = a generic commercial site located within each of the four major regions of the country.

[b] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. Annual doses of less than 0.001 mrem/yr are reported as <0.001. The values given in this table represent the peak annual doses from each waste type. Because of the different radionuclide mixes and activities contained in the different waste types, the peak annual doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses from the entire GTCC waste inventory are given in the following site-specific sections.

[c] The above-grade vault is the only method evaluated for Region I and Region III because of the shallow groundwater depth. The borehole method is not considered suitable for SRS and Regions I, II, and III.

TABLE 4-22 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater at the Various Sites for the Projected Group 1 Inventory[a,b]

			Peak Annual Dose (in mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
Hanford	Vault	10,000	4.0	0	–	0.0013	0	0	0.0045	0.12
		100,000	4.0	21	–	0.011	0	0.0012	5.6	480
	Trench	10,000	5.0	0	–	0.0013	0	0	0.0055	0.12
		100,000	5.0	25	–	0.011	0	0.0015	6.9	460
	Borehole	10,000	2.6	0	–	< 0.001	0	0	0.0016	0.036
		100,000	2.6	11	–	0.0033	< 0.001	< 0.001	2.1	140
INL	Vault	10,000	120	0.028	–	0.069	2.1	0	1.6	6.4
		100,000	120	150	–	0.069	2.1	0.0058	19	1,700
	Trench	10,000	140	0	–	0	2.5	0	1.8	5.7
		100,000	140	170	–	0	2.5	0	22	1,500
	Borehole	10,000	93	32	–	0.024	1.7	0	8.4	580
		100,000	93	74	–	0.024	1.7	0	8.6	580
LANL	Vault	10,000	64	0	–	0	1.1	0	0.52	0.62
		100,000	64	0	–	0	1.1	0	0.52	0.62
	Trench	10,000	78	0	–	0	1.4	0	0.63	0.58
		100,000	78	0	–	0	1.4	0	0.63	0.58
	Borehole	10,000	46	0	–	0	0.81	0	0.21	0.18
		100,000	46	0	–	0	0.81	0	0.21	0.18
NNSS	Vault	10,000	0	0	–	0	0	0	0	0
		100,000	0	0	–	0	0	0	0	0
	Trench	10,000	0	0	–	0	0	0	0	0
		100,000	0	0	–	0	0	0	0	0
	Borehole	10,000	0	0	–	0	0	0	0	0
		100,000	0	0	–	0	0	0	0	0

TABLE 4-22 (Cont.)

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
SRS[c]	Vault	10,000	45	150	–	0.039	0.53	< 0.001	10	3.6
		100,000	45	150	–	0.039	0.53	< 0.001	33	400
	Trench	10,000	60	170	–	0.043	0.66	< 0.001	16	3.9
		100,000	120	330	–	0.043	0.66	0.073	38	430
WIPP Vicinity	Vault	10,000	0	0	–	0	0	0	0	0
		100,000	44	0	–	0.0047	0	0	0.014	0.44
	Trench	10,000	0	0	–	0	0	0	0	0
		100,000	44	0	–	0.0037	0	0	0.014	0.34
	Borehole	10,000	0	0	–	0	0	0	0	0
		100,000	44	0	–	0.0021	0	0	< 0.001	0.19
Region I[c]	Vault	10,000	220	5,300	–	0.73	0.067	10	200	9,700
		100,000	220	5,300	–	0.73	0.067	10	200	9,700
Region II[c]	Vault	10,000	15	220	–	0.0059	0.33	0	3.2	0.55
		100,000	250	1,400	–	0.16	0.33	0.049	37	330
	Trench	10,000	26	250	–	0	0.39	0	4.7	320
		100,000	940	5,400	–	0.54	0.39	4.6	170	430
Region III[c]	Vault	10,000	18	95	–	0	0.40	0	1.4	0.2
		100,000	490	940	–	0.11	0.40	0.19	26	170
Region IV	Vault	10,000	0	0	–	0	0	0	0	0
		100,000	0.062	5.7	–	0.0032	0	0	1.6	130
	Trench	10,000	0	0	–	0	0	0	0	0
		100,000	0.11	6.9	–	0.0031	0.0013	0	1.9	130
	Borehole	10,000	0	0	–	0	0	0	0	0
		100,000	0.45	2.3	–	< 0.001	< 0.001	0	0.64	44

Footnotes appear on next page.

TABLE 4-22 (Cont.)

[a] CH = contact-handled, GTCC = greater-than-Class C, INL = Idaho National Laboratory, LANL = Los Alamos National Laboratory, NNSS = Nevada National Security Site, RH = remote-handled, SRS = Savannah River Site, WIPP = Waste Isolation Pilot Plant, Region I–IV = a generic commercial site located within each of the four major regions of the country.

[b] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. Annual doses of less than 0.001 mrem/yr are reported as <0.001. The values given in this table represent the peak annual doses from each waste type. Because of the different radionuclide mixes and activities contained in the different waste types, the peak annual doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses from the entire GTCC waste inventory are given in the following site-specific sections.

[c] The above-grade vault is the only method evaluated for Region I and Region III because of the shallow groundwater depth. The borehole method is not considered suitable for SRS and Regions I, II, and III.

TABLE 4-23 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater at the Various Sites for the Total Group 1 Inventory[a,b]

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
Hanford	Vault	10,000	4.2	0	0	0.045	0	0	0.016	41
		100,000	4.2	21	< 0.001	0.38	0	0.0012	26	490
	Trench	10,000	5.3	0	0	0.043	0	0	0.02	39
		100,000	5.3	25	< 0.001	0.36	0	0.0015	31	480
	Borehole	10,000	2.8	0	0	0.013	0	0	0.0058	0.14
		100,000	2.8	11	0	0.11	< 0.001	< 0.001	9.6	140
INL	Vault	10,000	130	0.028	0	2.3	3.0	0	7.1	2,200
		100,000	130	150	0.0029	2.3	3.0	0.0058	89	2,200
	Trench	10,000	150	0	0	2.0	3.4	0	8.2	1,900
		100,000	150	170	0	2.0	3.4	0	100	1,900
	Borehole	10,000	99	32	0	0.81	2.4	0	56	750
		100,000	99	74	0	0.81	2.4	0	61	750
LANL	Vault	10,000	120	0	0	0.22	1.6	0	2.3	230
		100,000	120	0	0	0.22	1.6	0	2.3	230
	Trench	10,000	84	0	0	0.21	1.9	0	2.8	210
		100,000	84	0	0	0.21	1.9	0	2.8	210
	Borehole	10,000	49	0	0	0.065	1.1	0	0.95	67
		100,000	49	0	0	0.065	1.1	0	0.95	67
NNSS	Vault	10,000	0	0	0	0	0	0	0	0
		100,000	0	0	0	0	0	0	0	0
	Trench	10,000	0	0	0	0	0	0	0	0
		100,000	0	0	0	0	0	0	0	0
	Borehole	10,000	0	0	0	0	0	0	0	0
		100,000	0	0	0	0	0	0	0	0
SRS[c]	Vault	10,000	48	150	0.0051	1.3	0.74	< 0.001	50	1,000
		100,000	48	150	0.0051	1.3	0.74	< 0.001	150	1,000
	Trench	10,000	64	170	0.0059	1.4	0.93	< 0.001	79	1,100
		100,000	130	330	0.0059	1.4	0.93	0.073	170	1,100

TABLE 4-23 (Cont.)

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
WIPP Vicinity	Vault	10,000	0	0	0	0	0	0	0	0
		100,000	47	0	0	0.16	0	0	0.054	36
	Trench	10,000	0	0	0	0	0	0	0	0
		100,000	47	0	0	0.13	0	0	0.053	28
	Borehole	10,000	0	0	0	0	0	0	0	0
		100,000	47	0	0	0.070	0	0	0.030	16
Region I[c]	Vault	10,000	230	5,300	0	25	0.093	10	900	10,000
		100,000	230	5,300	0	25	0.093	10	900	10,000
Region II[c]	Vault	10,000	16	220	0.013	0.060	0.46	0	19	940
		100,000	260	1,400	0.013	5.5	0.46	0.049	170	940
	Trench	10,000	27	250	0	0.25	0.55	0	22	950
		100,000	1,000	5,400	0	18	0.55	4.6	760	2,600
Region III[c]	Vault	10,000	19	95	0	0.077	0.55	0	6.8	410
		100,000	520	940	0	3.8	0.55	0.19	120	580
Region IV	Vault	10,000	0	0	0	0	0	0	0	0
		100,000	0.066	5.7	0	0.11	0	0	7.3	140
	Trench	10,000	0	0	0	0	0	0	0	0
		100,000	0.12	6.9	0	0.11	0.0013	0	9	130
	Borehole	10,000	0	0	0	0	0	0	0	0
		100,000	0.48	2.3	0	0.035	0.013	0	3	45

Footnotes appear on next page.

TABLE 4-23 (Cont.)

[a] CH = contact-handled, GTCC = greater-than-Class C, INL = Idaho National Laboratory, LANL = Los Alamos National Laboratory, NNSS = Nevada National Security Site, RH = remote-handled, SRS = Savannah River Site, WIPP = Waste Isolation Pilot Plant, Region I– IV = a generic commercial site located within each of the four major regions of the country.

[b] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures. Annual doses of less than 0.001 mrem/yr are reported as <0.001. The values given in this table represent the peak annual doses from each waste type. Because of the different radionuclide mixes and activities contained in the different waste types, the peak annual doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses from the entire GTCC waste inventory are given in the following site-specific sections.

[c] The above-grade vault is the only method evaluated for Region I and Region III because of the shallow groundwater depth. The borehole method is not considered suitable for SRS and Regions I, II, and III.

TABLE 4-24 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater at the Various Sites for the Total Group 2 Inventory[a,b]

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
Hanford	Vault	10,000	2.0	0	0.025	1.6	–	–	0.0062	0.23
		100,000	2.0	0	3.7	9.4	–	–	11	22
	Trench	10,000	2.5	0	0.031	1.5	–	–	0.0076	0.22
		100,000	2.5	0	4.5	8.9	–	–	14	21
	Borehole	10,000	1.3	0	0.0091	0.47	–	–	0.0023	0.066
		100,000	1.3	0	1.4	2.8	–	–	4.2	6.5
INL	Vault	10,000	57	0	2.4	100	–	–	3.1	12
		100,000	57	0	13	100	–	–	38	76
	Trench	10,000	65	0	2.9	100	–	–	3.6	11
		100,000	65	0	14	100	–	–	43	69
	Borehole	10,000	45	0	5.6	50	–	–	17	26
		100,000	45	0	5.9	50	–	–	18	30
LANL	Vault	10,000	30	0	0.87	40	–	–	1.0	3.1
		100,000	30	0	0.87	40	–	–	1.0	3.1
	Trench	10,000	37	0	1.0	38	–	–	1.2	2.9
		100,000	37	0	1.0	38	–	–	1.2	2.9
	Borehole	10,000	22	0	0.35	13	–	–	0.42	0.96
		100,000	22	0	0.35	13	–	–	0.42	0.96
NNSS	Vault	10,000	0	0	0	0	–	–	0	0
		100,000	0	0	0	0	–	–	0	0
	Trench	10,000	0	0	0	0	–	–	0	0
		100,000	0	0	0	0	–	–	0	0
	Borehole	10,000	0	0	0	0	–	–	0	0
		100,000	0	0	0	0	–	–	0	0
SRS[c]	Vault	10,000	21	0	10	390	–	–	20	50
		100,000	21	0	26	390	–	–	66	110
	Trench	10,000	28	0	13	460	–	–	32	59
		100,000	62	0	27	460	–	–	76	59

TABLE 4-24 (Cont.)

			Peak Annual Dose (mrem/yr) within 10,000 and 100,000 Years							
			GTCC LLRW				GTCC-Like Waste			
Site	Method	Time Period of Analysis (yr)	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH
WIPP Vicinity	Vault	10,000	0	0	0	0	–	–	0	0
		100,000	20	0	0.017	3.6	–	–	0.022	0.67
	Trench	10,000	0	0	0	0	–	–	0	0
		100,000	20	0	0.016	2.8	–	–	0.022	0.52
	Borehole	10,000	0	0	0	0	–	–	0	0
		100,000	19	0	0.0091	1.6	–	–	0.012	0.29
Region I[c]	Vault	10,000	110	0	71	490	–	–	410	820
		100,000	110	0	71	490	–	–	410	820
Region II[c]	Vault	10,000	7.1	0	5.4	210	–	–	6.3	39
		100,000	120	0	10	210	–	–	76	150
	Trench	10,000	12	0	6.6	210	–	–	9.5	35
		100,000	480	0	43	330	–	–	340	530
Region III[c]	Vault	10,000	7.8	0	2.1	83	–	–	2.5	15
		100,000	240	0	7.1	74	–	–	56	110
Region IV	Vault	10,000	0	0	0	0	–	–	0	0
		100,000	0.11	0	1.0	8.4	–	–	3.1	6.2
	Trench	10,000	0	0	0	0	–	–	0	0
		100,000	0.14	0	1.2	6.9	–	–	3.9	5.8
	Borehole	10,000	0	0	0	0	–	–	0	0
		100,000	0.26	0	0.41	1.5	–	–	1.3	2.0

Footnotes appear on next page.

TABLE 4-24 (Cont.)

[a] CH = contact-handled, GTCC = greater-than-Class C, INL = Idaho National Laboratory, LANL = Los Alamos National Laboratory, NNSS = Nevada National Security Site, RH = remote-handled, SRS = Savannah River Site, WIPP = Waste Isolation Pilot Plant, Region I–IV = a generic commercial site located within each of the four major regions of the country.

[b] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. Annual doses of less than 0.001 mrem/yr are reported as <0.001. The values given in this table represent the peak annual doses from each waste type. Because of the different radionuclide mixes and activities contained in the different waste types, the peak annual doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses from the entire GTCC waste inventory are given in the following site-specific sections.

[c] The above-grade vault is the only method evaluated for Region I and Region III because of the shallow groundwater depth. The borehole method is not considered suitable for SRS and Regions I, II, and III.

a value of 0.66 cm^3/g was used for the saturated zone in the groundwater analysis). A low K_d indicates that the radionuclide has a high potential for partitioning to the liquid phase while moving through soil.

The highest dose for the generic commercial facilities located in the four regions ranges from zero up to 10,000 mrem/yr in 10,000 years. It is estimated that there would be no groundwater dose within 10,000 years for a generic commercial facility located in Region IV because the radioactive contamination is not modeled to reach the groundwater table in 10,000 years because of the arid conditions at this location. The highest dose estimated is for a commercial facility located in Region I because of the higher water infiltration rate there, in combination with a shallow depth to groundwater table and low K_d values for C-14 and I-129 (a value of 0 cm^3/g was used in the analysis).

The sites with the lowest estimated annual doses are those located in the arid regions of the country. The analyses indicate that the radionuclides are not expected to reach groundwater for any waste type and disposal method at NNSS in 100,000 years, and generally lower doses are projected to occur at the other sites located in the Western United States (except for INL). No radionuclides are expected to reach groundwater at the WIPP Vicinity in 10,000 years, and the maximum annual doses in 100,000 years at this site are low.

Doses in arid sites are lower because of the lower water infiltration rates there (due to lower precipitation) and the longer distance to the groundwater table. Of these two factors, the water infiltration rate appears to be more significant than the depth to the groundwater table. The time period of the groundwater analysis is very long (longer than 10,000 years), and many of the radionuclides have very long half-lives. Radionuclides released from the disposed-of wastes would eventually reach the groundwater table within this time period, even if the depth to the groundwater table was increased. Reducing the water infiltration rate would not only reduce the radionuclide release rate but would also increase the transport time to reach the hypothetical exposure location.

4.4.2 Detailed Results

4.4.2.1 No Action Alternative

For the No Action Alternative, it is assumed that the waste containers would degrade 100 years after they were placed in the storage yard, allowing precipitation to enter the containers and contact the waste materials. For this analysis, it is assumed that the activated metals and Other Waste would stay within the NRC region in which the facility that generated the wastes was located, and the sealed sources would be divided in the four NRC regions in proportion to the number of NRC-licensed facilities within each region. It needs to be emphasized that the waste inventory to be stored in each region would be less than that assumed for the disposal alternatives in which the entire GTCC LLRW and GTCC-like waste inventory is assumed to be disposed of at each site by using one of the disposal methods.

For purposes of the analysis of long-term impacts, the storage facility is assumed to have a footprint of 300 × 300 m, and the receptor is assumed to be located 100 m from the edge of this footprint. It is recognized that these simplifying assumptions do not represent the current situation, and GTCC wastes are currently stored throughout the region at a number of locations. However, this approach is thought to be reasonable for estimating the potential radiation doses in order to address the long-term impacts associated with the No Action Alternative.

Potential radiation doses for the first 10,000 years following the assumed 100-year institutional control period are presented in Table 4-25. Figures 4-2 through 4-8 illustrate the results for a time period extending to 100,000 years. The tables provide the peak radiation dose considering the storage of different types of waste in each of the four NRC regions, and the contribution to this peak dose from each waste type at the time of the peak dose. The figures illustrate the radionuclides expected to be the significant dose contributors. In some figures, the time and dose scales are linear, and in others, they are logarithmic, in order to better illustrate the results.

The highest radiation doses for the four regions evaluated are associated with NRC Region I. This region has the largest portion of the GTCC waste inventory assumed (due to the presence of the waste from the West Valley Site). The West Valley Site accounts for about 56% of the entire GTCC waste inventory, and much of this waste meets the DOE definition of TRU waste. The total estimated volume of GTCC LLRW at the West Valley Site is about 4,300 m^3, and the volume of GTCC-like waste is estimated to be about 2,200 m^3.

Another reason for the higher doses in NRC Region I is that the storage facility would likely be in a generally humid environment with a relatively short distance to the groundwater table. These properties would probably result in higher radiation doses, especially when compared with the more arid sites expected in NRC Region IV.

The peak annual dose in NRC Region I within 10,000 years would be 470,000 mrem/yr, and this dose would occur about 3,700 years after termination of the institutional control period (assumed to be 100 years). It is assumed that this dose would result if an exposure pathway to the contaminated groundwater was possible and if the resident farmer scenario realistically represents this exposure. This dose would be largely attributable to plutonium isotopes and Am-243 (which decays to Pu-239) and would result from the long-term storage of GTCC LLRW sealed sources containing plutonium and Am-243 and from the Other Waste. The Other Waste would contribute about 84% to this peak annual dose and be associated with GTCC wastes from the West Valley Site. In addition to this peak annual dose at 3,700 years in the future, there would be a high dose (about 14,000 mrem/yr) in the very near term from C-14, I-129, Pu-238, and uranium isotopes, because it is assumed in this analysis that C-14, I-129, and uranium would dissolve completely in water. It was calculated that this dose would occur about 50 years following the assumed 100-year institutional control period.

The peak annual doses in NRC Regions II and III would be lower than the dose for Region I, but they would exceed 100 mrem/yr. The peak annual dose within 10,000 years in NRC Region II was calculated to be 860 mrem/yr and to occur about 98 years following the assumed institutional control period. This peak dose would be largely attributable to C-14 and I-129, with GTCC LLRW Other Waste - RH being the main contributor. The peak annual dose within 10,000 years in NRC Region III was calculated to be 120 mrem/yr and to occur about 1,100 years in the future. This dose would be largely attributable to Np-237 and Am-241 (which decays to Np-237), with GTCC LLRW sealed sources being the main contributor to this dose. Much larger doses were calculated to occur in these two NRC regions in the very long term (see Figures 4-6 and 4-7), largely because of uranium and plutonium isotopes. There is a very large degree of uncertainty in estimates that range this far into the future.

It was calculated that radionuclides would not reach the groundwater table in NRC Region IV within 10,000 years, so the results presented in Table 4-25 have zeroes for this region for all waste types. Radionuclides were calculated to reach the groundwater table and a well located 100 m downgradient at about 40,000 years in NRC Region IV (see Figure 4-8). The peak annual dose in this region was determined to be about 19 mrem/yr, largely due to uranium and plutonium isotopes and their radioactive decay products.

TABLE 4-25 Estimated Peak Annual Doses (in mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years for the No Action Alternative[a,b]

	GTCC LLRW				GTCC-Like Waste				
Region[c]	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Peak Annual Dose
I	120	73,000	3,800	26,000	0.0	0.0	97,000	270,000	470,000
II	7.5	0.0	0.0	850	0.052	0.0	0.0	0.0	860
III	5.4	120	0.0	0.0	0.0	0.0	0.0	0.0	120
IV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[a] These doses are associated with the use of contaminated groundwater by a resident farmer located 100 m from the edge of the storage facility. All values are given to two significant figures. The times for the peak annual doses for NRC Regions I, II, and III were calculated to be about 3,700, 98, and 1,100 years, respectively, after an assumed institutional control period of 100 years. No doses from the groundwater pathway were calculated to occur within 10,000 years in Region IV for the No Action Alternative. The primary contributors to the dose are GTCC LLRW sealed sources, GTCC LLRW Other Waste - RH, and GTCC-like Other Waste - RH. The primary radionuclides contributing to the dose are C-14, I-129, Np-237, and isotopes of uranium, plutonium, and americium.

[b] The values given in this table represent the maximum or peak annual dose to the hypothetical resident farmer when the assumed entire GTCC waste inventory for a particular region is considered. The values in the waste-type-specific columns provide the doses associated with each waste type at the time of the maximum or peak annual dose for the entire inventory. These contributions do not necessarily represent the maximum or peak dose that could result from each of these waste types separately. Because of the different radionuclide mixes and activities for each of the waste types, the maximum or peak annual dose that could result from each waste type individually could occur at a different time.

[c] Region I includes the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Washington, D.C. Region II includes the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. Region III includes the states of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Region IV includes Alaska, Arizona, Arkansas, California, Colorado, Hawaii, Idaho, Kansas, Louisiana, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

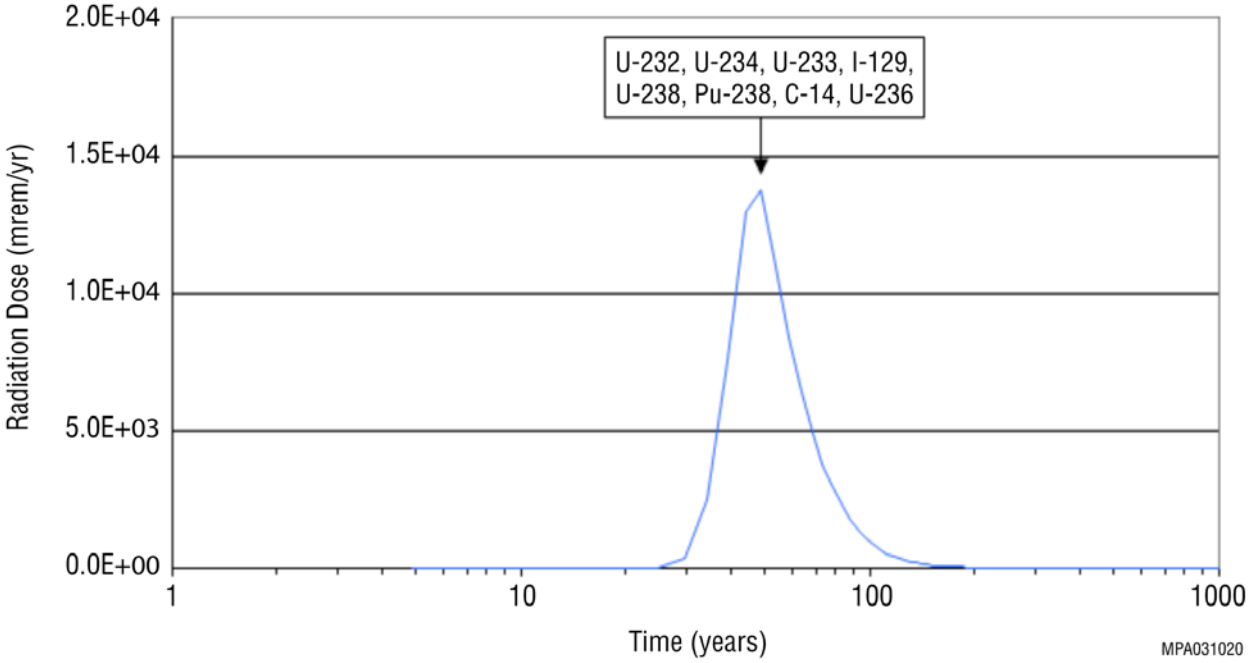

FIGURE 4-2 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 1,000 Years in NRC Region I for the No Action Alternative

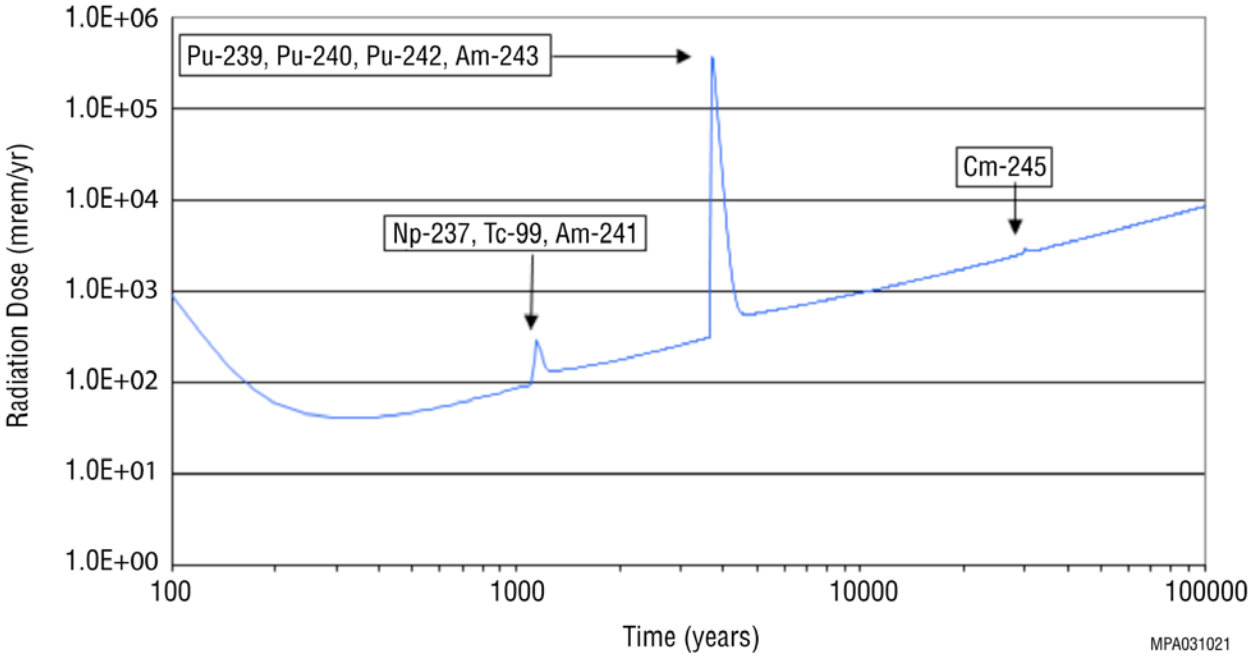

FIGURE 4-3 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years NRC Region I for the No Action Alternative

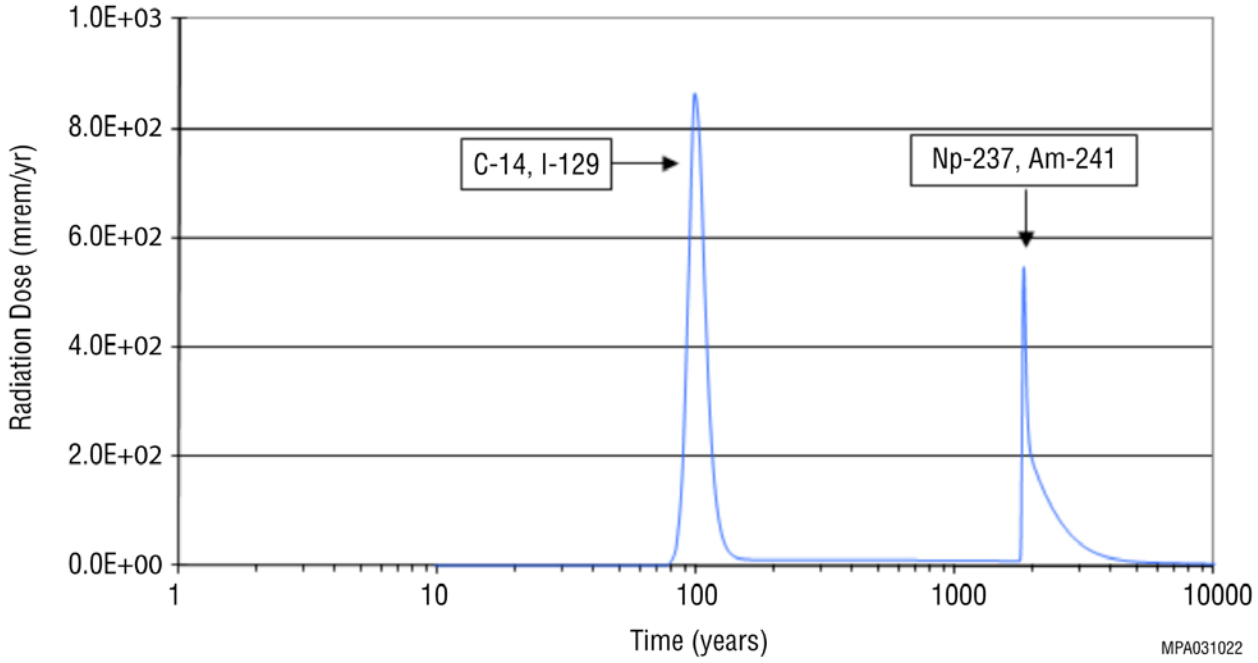

FIGURE 4-4 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater in NRC Region II for the No Action Alternative

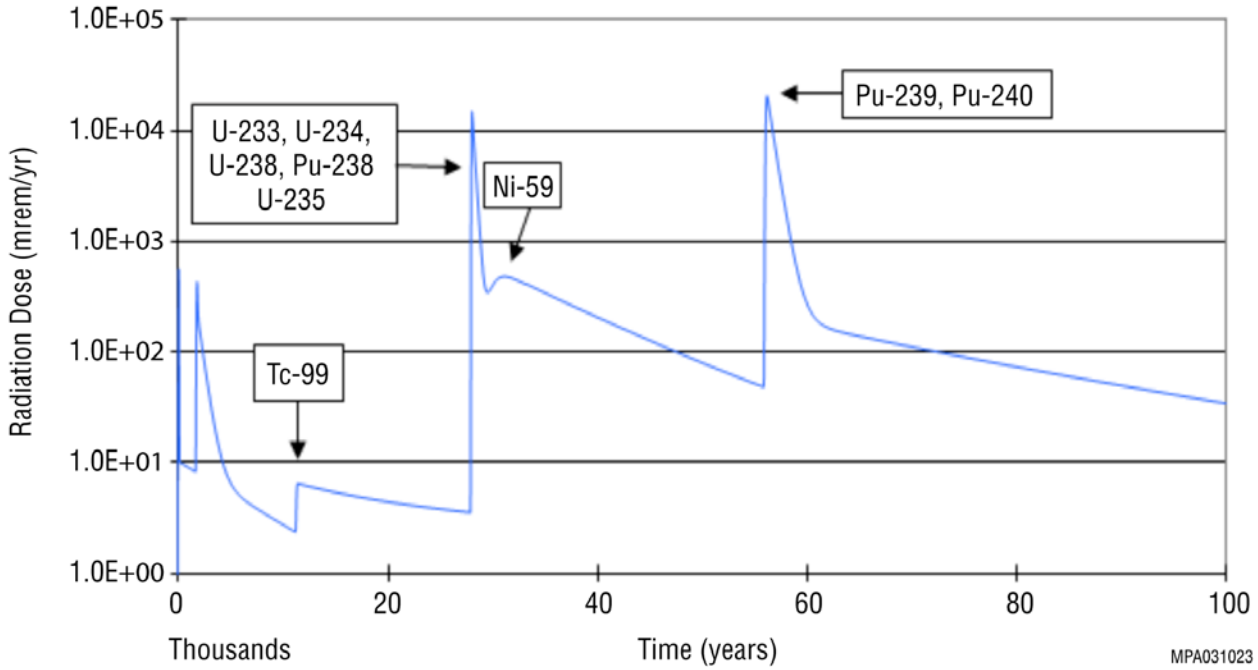

FIGURE 4-5 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years in NRC Region II for the No Action Alternative

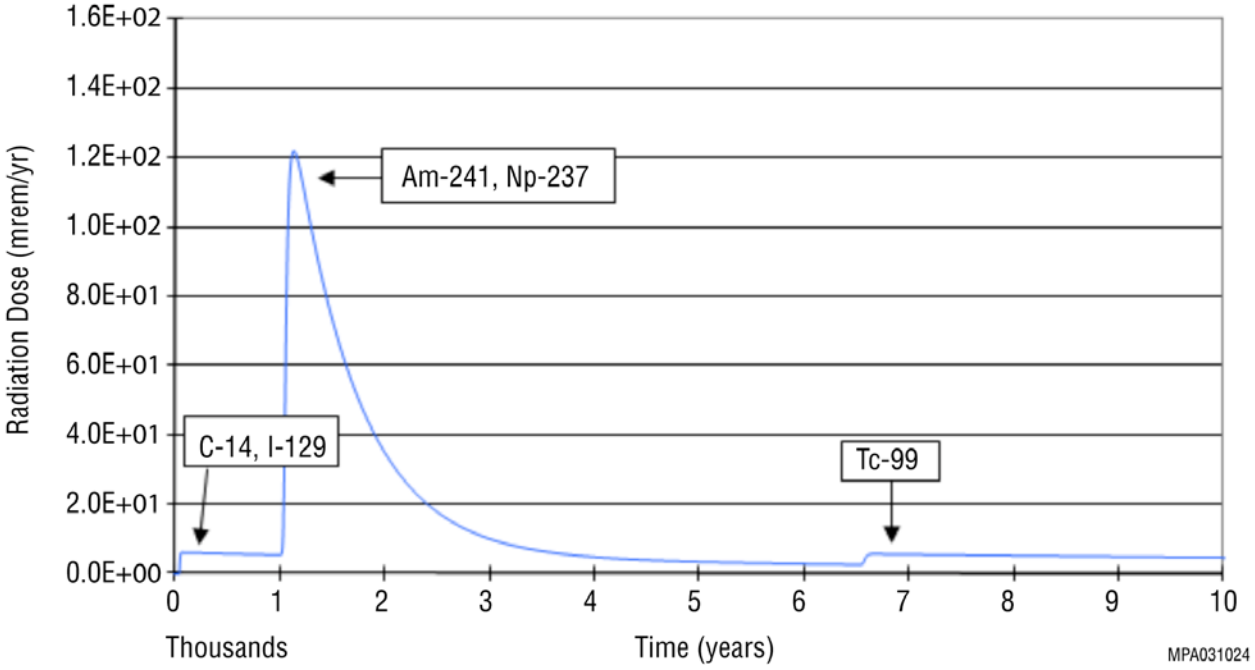

FIGURE 4-6 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years in NRC Region III for the No Action Alternative

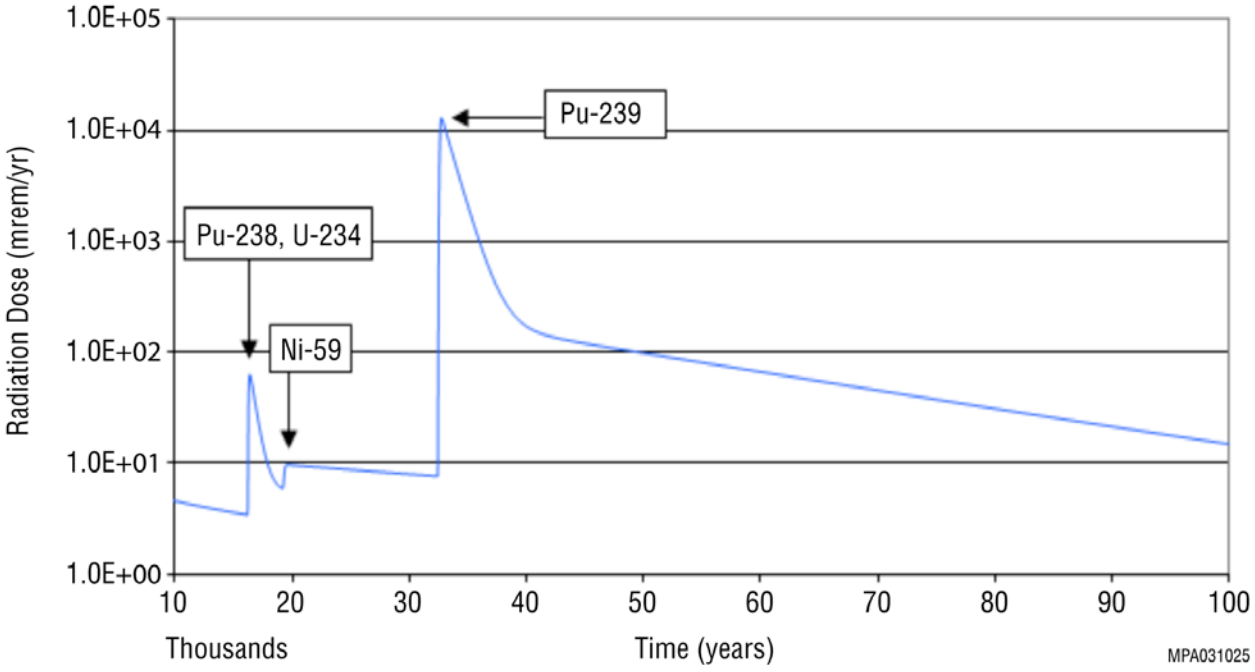

FIGURE 4-7 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years in NRC Region III for the No Action Alternative

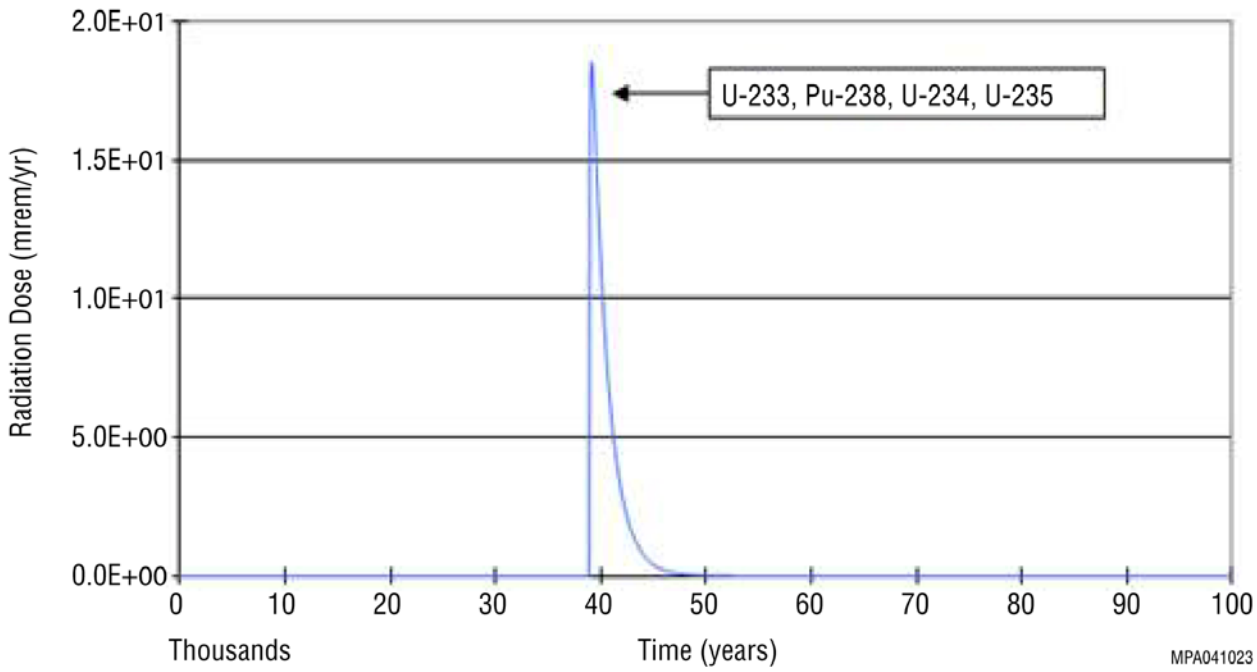

FIGURE 4-8 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years in NRC Region IV for the No Action Alternative

4.4.2.2 Land Disposal Alternatives

Tables 4-26 and 4-27 compare the calculated maximum radiation doses for 10,000 years for the disposal alternatives. Table 4-26 compares the maximum radiation doses for the six DOE sites, and Table 4-27 compares the maximum radiation doses for the four generic sites in different regions. These results were obtained by considering the disposal of the entire GTCC LLRW and GTCC-like waste inventory at the various sites with the three different disposal methods described in Chapter 3. Detailed discussions on the contributions from different waste types to these maximum doses are provided in the following sections.

Results for the Hanford Site

Because the distance to the groundwater table would be closer from boreholes than from trenches or vaults, radionuclides that leached out from wastes in the boreholes would reach the groundwater table in a shorter time than radionuclides that leached out from the trenches or vaults. Within 10,000 years, Tc-99 and I-129 could reach the groundwater table and a well installed by a hypothetical resident farmer located a distance of 100 m from the downgradient edge of the disposal facility. Both of these radionuclides are highly soluble in water, a quality that could lead to potentially significant groundwater doses to the hypothetical resident farmer. The peak annual dose associated with the use of contaminated groundwater from disposal of the entire GTCC waste inventory at the Hanford Site was calculated to be 4.8 mrem/yr for the borehole method, 49 mrem/yr for the vault method, and 48 mrem/yr for the trench method. These two radionuclides would contribute essentially all of the dose to the hypothetical resident farmer within the first 10,000 years after closure of the disposal facility. The exposure pathways considered in this analysis include the ingestion of contaminated groundwater, soil, plants, meat, and milk; external radiation; and the inhalation of radon gas and its short-lived progeny.

TABLE 4-26 Comparison of Maximal Doses (mrem/yr) within 10,000 Years for the Resident Farmer Scenario Associated with the Use of Contaminated Groundwater at the Six DOE Sites Evaluated for the Land Disposal Methods[a]

Disposal Facility	Hanford	INL	LANL	NNSS	SRS	WIPP Vicinity
Borehole	4.8	820	160	0	NA[b]	0
Trench	48	2,100	380	0	1,700	0
Vault	49	2,300	430	0	1,300	0

[a] All values are given to two significant figures. The values are based on the entire inventory of GTCC LLRW and GTCC-like waste being disposed of in a borehole, trench, or vault facility at each site. These results do not address combinations of disposal methods, which could result in lower doses, depending on the waste types being disposed of.

[b] NA = not applicable.

TABLE 4-27 Comparison of Maximal Doses (mrem/yr) within 10,000 Years for the Resident Farmer Scenario Associated with the Use of Contaminated Groundwater at the Four Generic Sites Evaluated for the Land Disposal Methods[a]

Disposal Facility	Region I	Region II	Region III	Region IV
Borehole	NA[b]	NA	NA	0
Trench	NA	1,200	NA	0
Vault	12,000	1,200	530	0

[a] All values are given to two significant figures. The values are based on the entire inventory of GTCC LLRW and GTCC-like waste being disposed of in a borehole, trench, or vault facility at each site. These results do not address combinations of disposal methods, which could result in lower doses, depending on the waste types being disposed of.

[b] NA = not applicable.

Table 4-28 presents the peak doses to the hypothetical resident farmer (from the use of potentially contaminated groundwater within the first 10,000 years after closure of the disposal facility) when disposal of the entire GTCC waste inventory by using the land disposal methods evaluated is considered. In this table, the doses contributed by each waste type (i.e., the dose for each waste type at the time or year when the peak dose for the entire inventory is observed) to the peak dose reported are also tabulated. The doses presented from the various waste types do not necessarily represent the peak dose of the waste type itself when considered on its own.

For borehole disposal, it is estimated that the peak dose would occur at about 1,800 years, with GTCC LLRW activated metal waste being the primary dose contributor. The peak doses were calculated to occur at about 3,300 years and 2,900 years after disposal for vault and trench disposal, respectively. These times represent the time after failure of the engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The major dose contributor for these two disposal

TABLE 4-28 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal at the GTCC Reference Location at the Hanford Site[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Borehole									4.8[b]
Group 1 stored	0.17	–	0.0	0.013	0.0	0.0	0.0042	0.11	–
Group 1 projected	2.6	0.0	–	0.00038	0.0	0.0	0.0016	0.036	–
Group 2 projected	1.3	0.0	0.0091	0.47	–	–	0.0023	0.066	–
Vault									49[b]
Group 1 stored	0.26	–	0.0	0.044	0.0	0.0	0.012	40	–
Group 1 projected	4.0	0.0	–	0.0013	0.0	0.0	0.0045	0.12	–
Group 2 projected	2.0	0.0	0.025	1.6	–	–	0.0062	0.23	–
Trench									48[b]
Group 1 stored	0.33	–	0.0	0.042	0.0	0.0	0.014	39	–
Group 1 projected	5.0	0.0	–	0.0013	0.0	0.0	0.0055	0.12	–
Group 2 projected	2.5	0.0	0.031	1.5	–	–	0.0076	0.22	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24.

[b] The times for the peak annual doses of 4.8 mrem/yr for boreholes, 49 mrem/yr for vaults, and 48 mrem/yr for trenches were calculated to be about 1,800 years, 3,300 years, and 2,900 years, respectively, for disposal of the entire GTCC waste inventory. These times represent the time after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses from the specific waste types at the time of these peak doses. For borehole disposal, the primary contributor to the dose is GTCC LLRW activated metals; for trench and vault disposal, the primary contributor to the dose is GTCC-like Other Waste - RH. Tc-99 and I-129 would be the primary radionuclides causing this dose.

methods would be GTCC-like Other Waste - RH, with GTCC LLRW contributing about 15% of the total dose.

Tables 4-21 through 4-24 in Section 4.4 present peak doses for each waste type when considered on its own. Because these peak doses generally occur at different times, the results should not be summed to obtain total doses for comparison with those presented in Table 4-28 (although for some cases, these sums might be close to those presented in the site-specific sections).

Figure 4-9 is a temporal plot of the radiation doses associated with the use of contaminated groundwater for a period extending to 10,000 years, and Figure 4-10 shows these results to 100,000 years for the three land disposal methods. Note that the time scale in Figure 4-9 is logarithmic, while the time scale in Figure 4-10 is linear. A logarithmic time scale was used in the first figure to better illustrate the projected radiation doses to a hypothetical resident farmer in the first 10,000 years following closure of the disposal facility.

Although Tc-99 and I-129 would result in measureable radiation doses for the first 10,000 years, the inventory in the disposal areas would be depleted rather quickly, and the doses would gradually decrease with time after about 5,000 years. After the depletion of these two radionuclides, no other radionuclides would reach the groundwater table within 10,000 years. In the very long term, however, various isotopes of uranium and Np-237 that were originally contained in the waste streams or generated from radioactive decay could reach the groundwater table and result in doses to this hypothetical resident farmer. The maximum annual doses would exceed 100 mrem/yr for all three disposal methods and would occur within the first 25,000 years following closure of the disposal facility. There is a high degree of uncertainty associated with estimates that project this far into the future.

The results given here are assumed to be conservative because the location selected for the residential exposure is 100 m from the edge of the disposal facility. Use of a longer distance, which might be more realistic for the sites being evaluated, would significantly lower the estimated doses (i.e., by as much as 70%). A sensitivity analysis performed to determine the effect of a distance longer than 100 m is presented in Appendix D.

These analyses assume that engineering controls would be effective for 500 years following closure of the disposal facility. This means that essentially no infiltrating water would reach the wastes from the top of the disposal units. It is assumed that after 500 years, the engineered barriers would begin to degrade, allowing infiltrating water to come in contact with the disposed-of wastes. For purposes of analysis in the EIS, it is assumed that the amount of infiltrating water that would contact the wastes would be 20% of the site-specific natural infiltration rate for the area, and that the water infiltration rate around and beneath the disposal facilities would be 100% of the natural rate for the area. These are conservative assumptions because it is expected that the engineered systems (including the disposal facility cover) would last longer than 500 years, even in the absence of active maintenance measures.

It is assumed that the Other Waste would be stabilized with grout or other material and that this stabilizing agent would be effective for 500 years. Consistent with the assumptions used for engineering controls, no credit was taken in this analysis for the effectiveness of this stabilizing agent after 500 years. Therefore, any water that would contact the wastes after 500 years would be able to leach much more of the radioactive constituents from the disposed-of materials. These radionuclides could then move with the percolating groundwater to the underlying groundwater system. This scenario is assumed to be conservative because it is expected that the use of grout or other stabilizing materials would enable them to retain their integrity for longer than 500 years, especially under the protection of engineered materials.

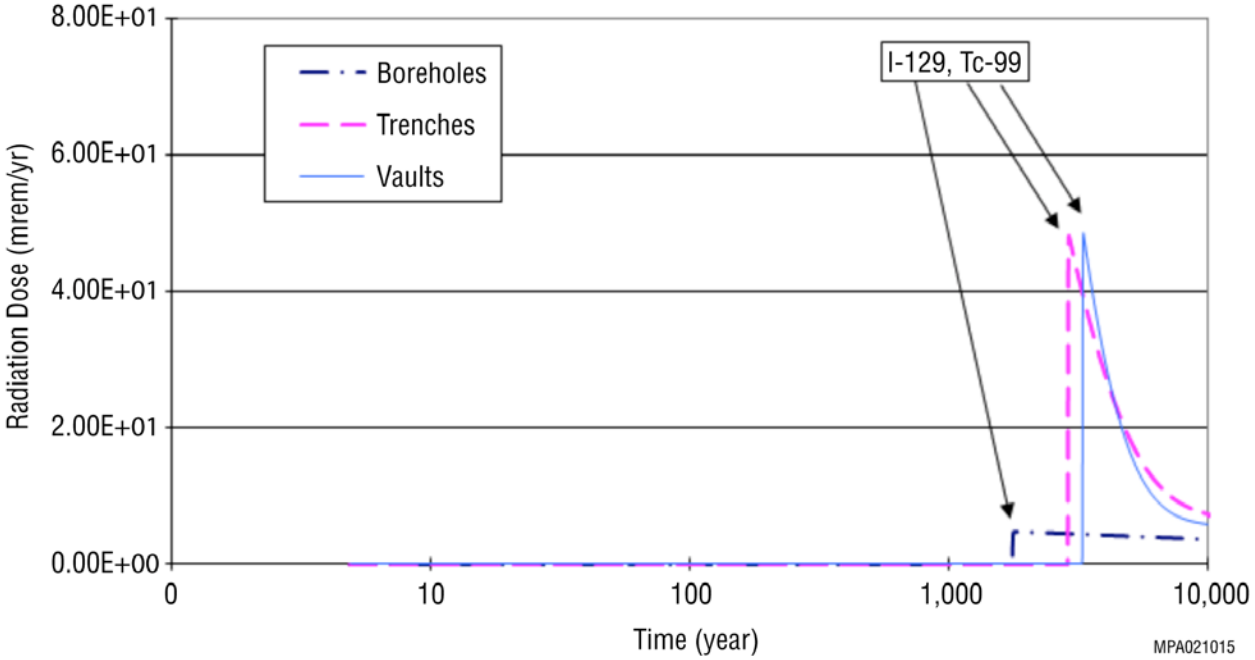

FIGURE 4-9 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal for the Three Land Disposal Methods at the Hanford Site

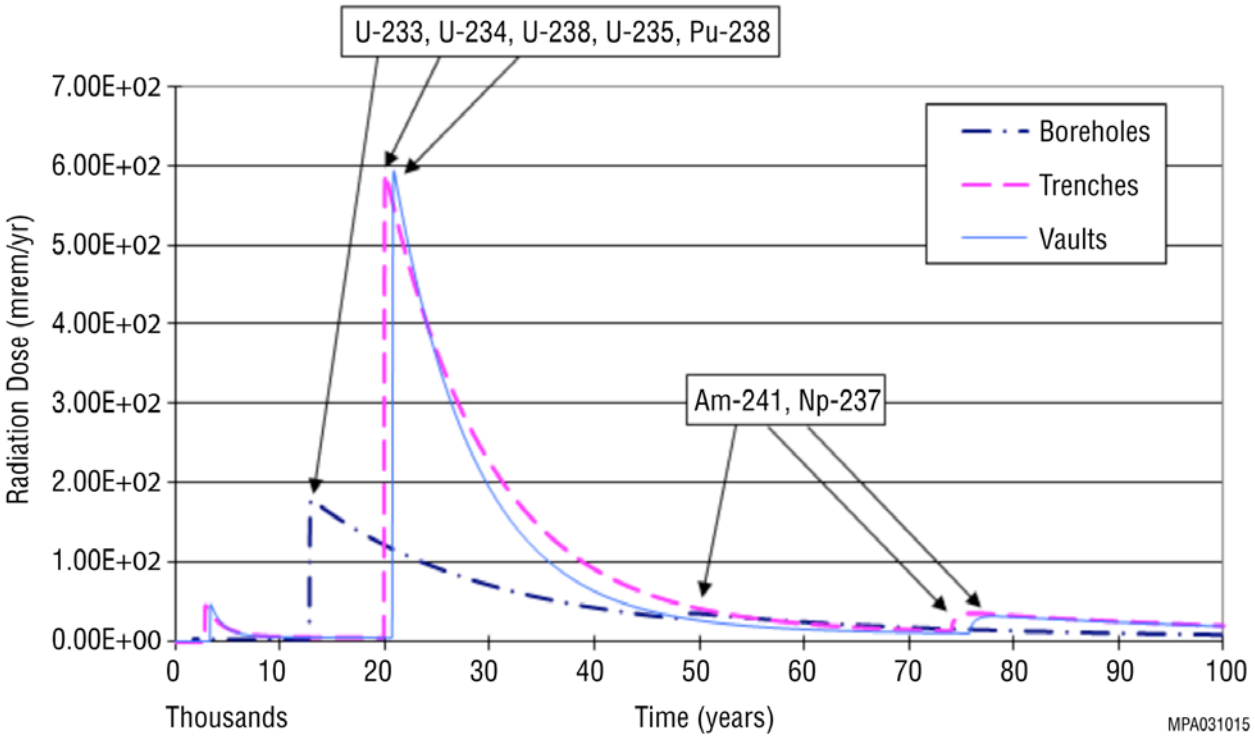

FIGURE 4-10 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal for the Three Land Disposal Methods at the Hanford Site

Sensitivity analyses performed relative to these assumptions indicate that if a higher infiltration rate to the top of the disposal facilities was assumed, the doses would increase in a linear manner from those presented. Conversely, the doses would decrease in a linear manner with lower infiltration rates. This finding indicates the need to ensure that there is a good cover over the closed disposal units. Also, the doses would be lower if it was assumed that the grout would last for a longer time. Because of the long-lived nature of the radionuclides associated with some of the GTCC LLRW and GTCC-like waste, any stabilization effort (such as grouting) would have to be effective for longer than 5,000 years in order to substantially reduce doses that could result from potential future leaching of the disposed-of waste.

It is important to note that the radiation doses presented in this report are intended to be used for comparing the performance of each of the land disposal methods at each site evaluated. The sensitivity analysis results indicate that the use of robust engineering designs and redundant measures to contain the radionuclides in the disposal facility could delay the potential release of radionuclides and could reduce the release to very low levels, thereby minimizing the potential groundwater contamination and associated human health impacts in the future.

Results for INL

Within 10,000 years, C-14, Tc-99, and I-129 could reach the groundwater table and a well installed by a hypothetical resident farmer located at a distance of 100 m (330 ft) from the downgradient edge of the disposal facility. All three of these radionuclides are highly soluble in water, a quality that could lead to potentially significant groundwater concentrations and subsequently to a measurable radiation dose to the resident farmer. The peak annual dose associated with the use of contaminated groundwater from disposal of the entire GTCC waste inventory at INL was calculated to be 820 mrem/yr for the borehole method, 2,300 mrem/yr for the vault method, and 2,100 mrem/yr for the trench method.

Although radionuclides would reach the groundwater table sooner under the borehole method, the peak annual dose within 10,000 years would occur later than it would under the other two disposal methods because of the uranium isotopes from the disposal facility that would reach the groundwater table near the end of the 10,000-year time frame. The uranium isotopes would produce a radiation dose to the hypothetical resident farmer that would be slightly higher than the dose resulting from the C-14, Tc-99, and I-129 that would reach the groundwater table sooner under the borehole disposal method. Calculations indicate that the uranium isotopes would not reach the groundwater table within 10,000 years under the trench and vault disposal methods.

Table 4-29 presents the peak annual doses to the hypothetical resident farmer (from use of potentially contaminated groundwater within the first 10,000 years after closure of the disposal facility) when the disposal of the entire GTCC waste inventory by the land disposal methods evaluated is considered. In this table, the doses contributed by each waste type (i.e., dose for each waste type at the time or year when the peak dose for the entire inventory is observed) to the peak dose reported are also tabulated. The doses from the various waste types that are presented do not necessarily represent the peak dose of the waste type itself when it is considered on its own.

For borehole disposal, it is estimated that the peak annual dose would occur about 9,200 years after disposal, and calculations indicate that the peak annual dose would occur 220 years after disposal for the vault method and 190 years after disposal for the trench method. These times represent the time after failure of the engineered barriers (including the cover), which is assumed to begin 500 years after closure of the disposal facility. The GTCC-like Other Waste - RH would be the primary contributor to the dose in all cases. Tc-99 and I-129 would be the primary radionuclides of concern within a time frame of

TABLE 4-29 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal at INL[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Borehole									820[b]
Group 1 stored	2.6	0.0	0.0	0.45	0.21	0.0	48	17	–
Group 1 projected	39	32	0.0	0.013	0.52	0.0	8.4	580	–
Group 2 projected	21	0.0	5.6	24	0.0	0.0	17	26	–
Vault									2,300[b]
Group 1 stored	1.5	0.0	0.0	2.9	0.0	0.0	0.59	2,800	–
Group 1 projected	24	0.0	0.0	0.089	0.0	0.0	0.22	8.2	–
Group 2 projected	12	0.0	1.4	110	0.0	0.0	0.33	160	–
Trench									2,100[b]
Group 1 stored	1.7	0.0	0.0	2.0	0.0	0.0	0.65	1,900	–
Group 1 projected	28	0.0	0.0	0.0	0.0	0.0	0.24	5.7	–
Group 2 projected	14	0.0	1.5	77	0.0	0.0	0.37	11	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24.

[b] The times for the peak annual doses of 820 mrem/yr for boreholes, 2,300 mrem/yr for vaults, and 2,100 mrem/yr for trenches were calculated to be about 9,200 years, 220 years, and 190 years, respectively, for disposal of the entire GTCC waste inventory. These times represent the time after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses for the specific waste types at the time of these peak doses. The primary contributor to the dose in all cases is GTCC-like Other Waste - RH. For borehole disposal, the primary radionuclides causing the dose would be uranium isotopes; and C-14, Tc-99, and I-129 would be the primary radionuclides causing this dose for the vault and trench disposal methods.

10,000 years after closure of the disposal facility for all the three disposal methods. As noted above, under the borehole method, uranium isotopes would also reach the groundwater table within 10,000 years and contribute to the maximum dose at 9,200 years. These radionuclides contribute more than 90% of the total dose.

Tables 4-21 through 4-24 in Section 4.4 present peak doses for each waste type when considered on its own. Because these peak doses generally occur at different times, the results should not be summed to obtain total doses for comparison with those presented in Table 4-29 (although for some cases, these sums might be close to those presented in the site-specific sections).

Figure 4-11 is a temporal plot of the radiation doses associated with the use of contaminated groundwater for a period extending to 10,000 years, and Figure 4-12 shows these results to 100,000 years for the three land disposal methods. Note that the time scale is logarithmic in Figure 4-11 and linear in Figure 4-12. A logarithmic time scale was used in the first figure to better illustrate the projected radiation doses to a hypothetical resident farmer in the first 1,000 years.

Although C-14, Tc-99, and I-129 would result in measurable radiation doses in the first 10,000 years, the inventory of these radionuclides in the disposal areas would be depleted rather quickly. Under the three land disposal options, various isotopes of uranium as well as Np-237 and Am-241 would reach the groundwater table after about 9,000 to 16,000 years and contribute to radiation exposures. At that time, the radiation doses from these radionuclides could greatly exceed those from C-14, Tc-99, and I-129, and the magnitude of the calculated annual doses to the hypothetical resident farmer would be comparable to those that are predicted to occur in the first 10,000 years. However, there is a high degree of uncertainty associated with results like these, which are for such a long time of analysis.

The assumptions for exposure distance, effective period of engineered materials, water infiltration rate, and effective period of grouting used for calculating the potential radiation doses presented in this report are considered to be conservative; therefore, it is expected that the actual dose associated with the disposal of the GTCC LLRW and GTCC-like waste would be much lower than those presented in this section. Sensitivity analyses were conducted to evaluate the influence of these assumptions on the dose results and are presented in Appendix D.

It is important to remember that the radiation doses presented in this report are intended to be used for comparing the performance of each of the land disposal methods at each site evaluated. The sensitivity analysis results indicate that the use of robust engineering designs and redundant measures to contain the radionuclides in the disposal facility could delay the potential release of radionuclides and could reduce the release to very low levels, thereby minimizing the potential groundwater contamination and associated human health impacts in the future.

Results for LANL

Within 10,000 years, C-14, Tc-99, and I-129 could reach the groundwater table and a well installed by a hypothetical farmer at a distance of 100 m from the downgradient edge of the disposal facility. All three of these radionuclides are highly soluble in water, a quality that could lead to potentially significant groundwater concentrations and subsequently a measurable radiation dose to the resident farmer. The peak annual dose associated with the use of contaminated groundwater from disposal of the entire GTCC inventory at LANL was calculated to be 160 mrem/yr for the borehole method, 430 mrem/yr for the vault method, and 380 mrem/yr for the trench method. Exposure pathways related to the use of contaminated groundwater include ingestion of water, soil, plants, meat, and milk; external radiation; and inhalation of radon gas and its short-lived progeny. Except for the water ingestion pathway, all the pathways that contribute significantly to the dose to this hypothetical resident farmer are associated

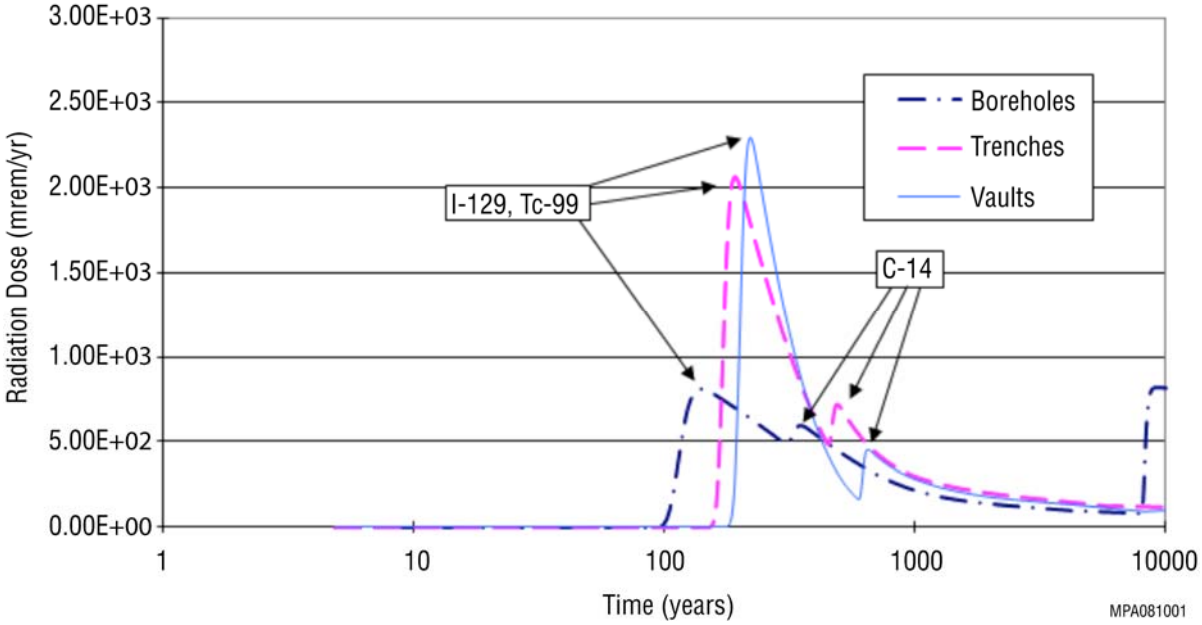

FIGURE 4-11 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal for the Three Land Disposal Methods at INL

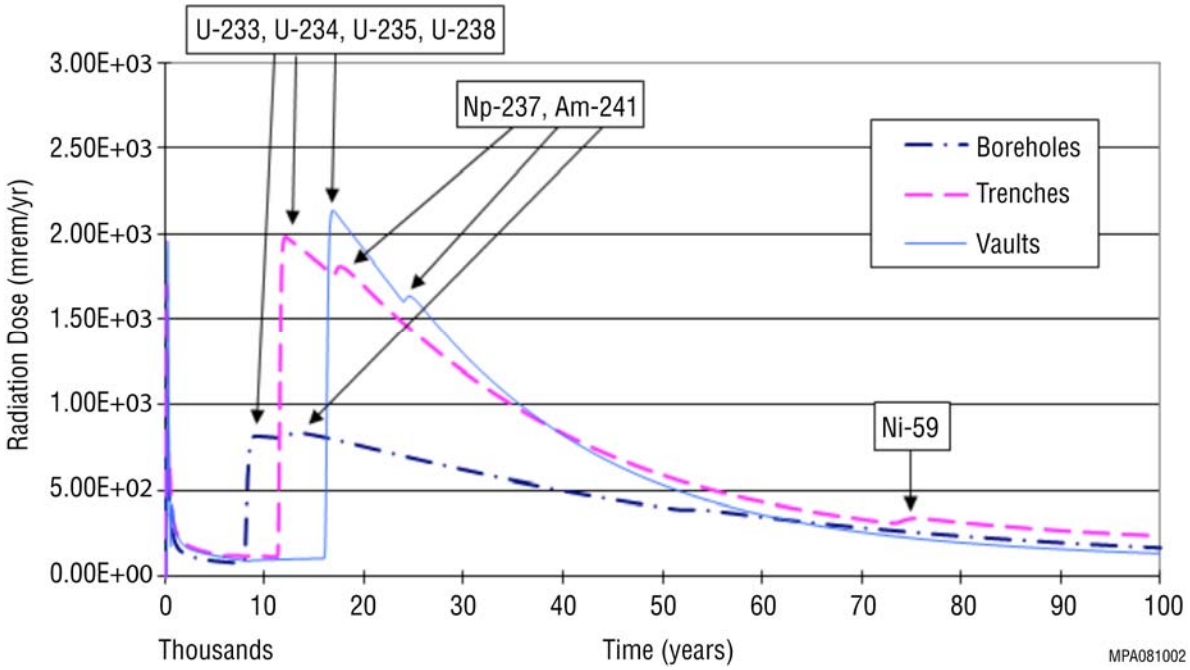

FIGURE 4-12 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal for the Three Land Disposal Methods at INL

with the accumulation of radionuclides in agricultural fields as a result of the use of contaminated groundwater for irrigation.

Table 4-30 presents the peak annual doses to the hypothetical resident farmer (from use of potentially contaminated groundwater within the first 10,000 years after closure of the disposal facility) associated with the disposal of the entire GTCC waste inventory by using the land disposal methods evaluated. In this table, the annual doses contributed by each waste type (i.e., dose and risk for each waste type at the time or year when the peak dose or risk for the entire inventory is observed) to the peak dose are also tabulated. The doses presented for the various waste types do not necessarily represent the peak dose of the waste type itself when it is considered on its own, which are presented in Tables 4-21 through 4-24.

For borehole disposal, it is estimated that the peak annual dose would occur at about 500 years, and calculations indicate that the peak annual doses would occur at about 1,100 years after disposal for vaults and at about 1,000 years for trenches. These times represent the time after failure of the engineered barriers (including the cover), which is assumed to begin 500 years after closure of the disposal facility. The GTCC LLRW activated metals and GTCC-like Other Waste - RH would be the primary contributors to the doses in all cases. The doses from C-14 and Tc-99 would be largely attributable to the GTCC LLRW activated metal wastes, and the doses from I-129 and Tc-99 would be largely attributable to GTCC-like Other Waste - RH.

Figure 4-13 is a temporal plot of the radiation doses associated with the use of contaminated groundwater for a time period extending to 10,000 years, and Figure 4-14 shows these results to 100,000 years for the three land disposal methods. Note that the time scale is logarithmic in Figure 4-13 and linear in Figure 4-14. A logarithmic time scale was used in the first figure to better illustrate the projected radiation doses to a hypothetical resident farmer in the first 1,000 years after closure of the disposal facility.

Although C-14, Tc-99, and I-129 would result in measureable radiation doses for the first 10,000 years, the inventory in the disposal areas would be depleted rather quickly, and the doses would gradually decrease with time after about 2,000 years. After the depletion of these three radionuclides, there would be no other radionuclides reaching the groundwater table within 100,000 years. The lack of groundwater contamination from other radionuclides at the LANL site between 10,000 and 100,000 years would be attributable to a low water infiltration rate of 0.5 cm/yr (0.2 in./yr) and the relatively long distance to the groundwater table (about 270 m [890 ft]).

The assumptions for exposure distance, effective period of engineered materials, water infiltration rate, and effective period of grouting used for calculating the potential radiation doses presented in this report are considered to be conservative; therefore, it is expected that the actual doses associated with the disposal of the GTCC LLRW and GTCC-like waste would be much lower than those presented in this section. Sensitivity analyses were conducted to evaluate the influence of these assumptions on the dose results and are presented in Appendix D.

It is important to remember that the radiation doses presented in this report are intended to be used for comparing the performance of each of the land disposal methods at each site evaluated. The sensitivity analysis results indicate that the use of robust engineering designs and redundant measures to contain the radionuclides in the disposal facility could delay the potential release of radionuclides and could reduce the release to very low levels, thereby minimizing the potential groundwater contamination and associated human health impacts in the future.

TABLE 4-30 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal at LANL[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Borehole									160[b]
Group 1 stored	3.0	0.0	0.0	0.065	0.33	0.0	0.74	67	–
Group 1 projected	46	0.0	0.0	0.0	0.81	0.0	0.21	0.18	–
Group 2 projected	22	0.0	0.35	13	0.0	0.0	0.42	0.96	–
Vault									430[b]
Group 1 stored	60	0.0	0.0	0.28	0.45	0.0	1.8	290	–
Group 1 projected	64	0.0	0.0	0.0	1.1	0.0	0.52	0.79	–
Group 2 projected	30	0.0	0.87	52	0.0	0.0	1.0	4.0	–
Trench									380[b]
Group 1 stored	5.2	0.0	0.0	0.21	0.55	0.0	2.2	210	–
Group 1 projected	78	0.0	0.0	0.0	1.4	0.0	0.63	0.58	–
Group 2 projected	37	0.0	1.1	38	0.0	0.0	1.2	2.9	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24.

[b] The time for the peak annual dose of 160 mrem/yr for boreholes, 430 mrem/yr for vaults, and 380 mrem/yr for trenches were calculated to be about 500 years, 1,100 years, and 1,000 years, respectively, for disposal of the entire GTCC waste inventory. This times represent the time after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses for the specific waste types at the time of the peak doses. The primary contributors to the dose in all cases are GTCC LLRW activated metals and GTCC-like Other Waste - RH. The primary radionuclides causing this dose would be C-14, Tc-99, and I-129.

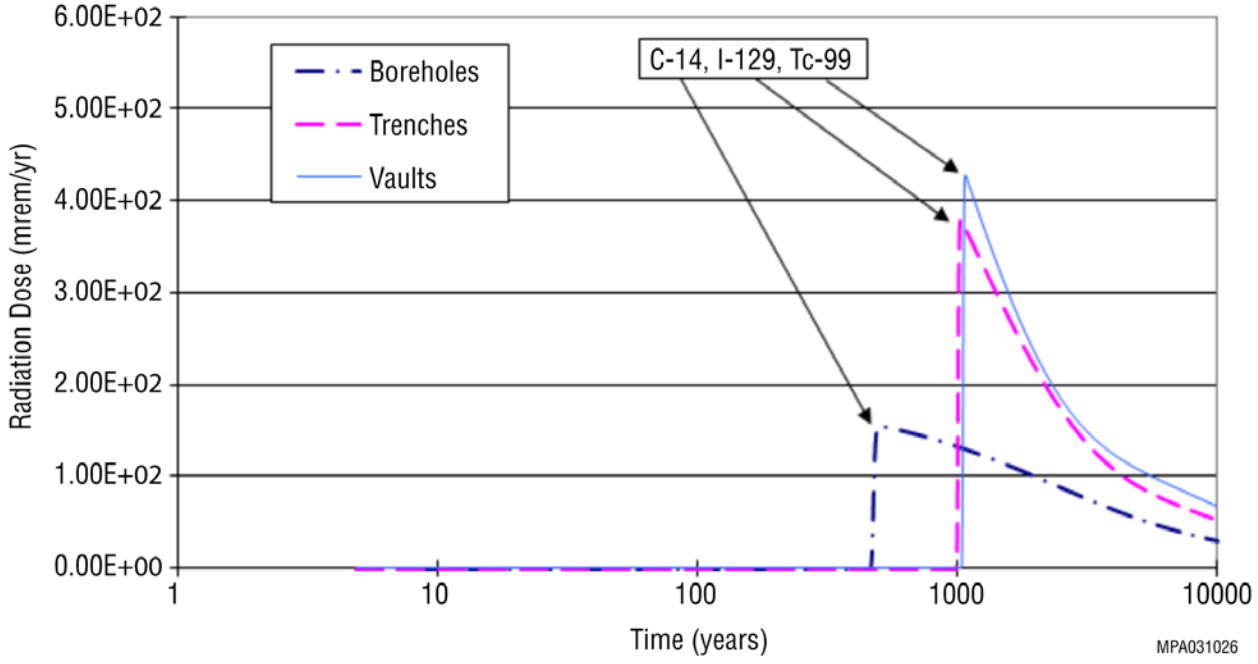

FIGURE 4-13 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal for the Three Land Disposal Methods at LANL

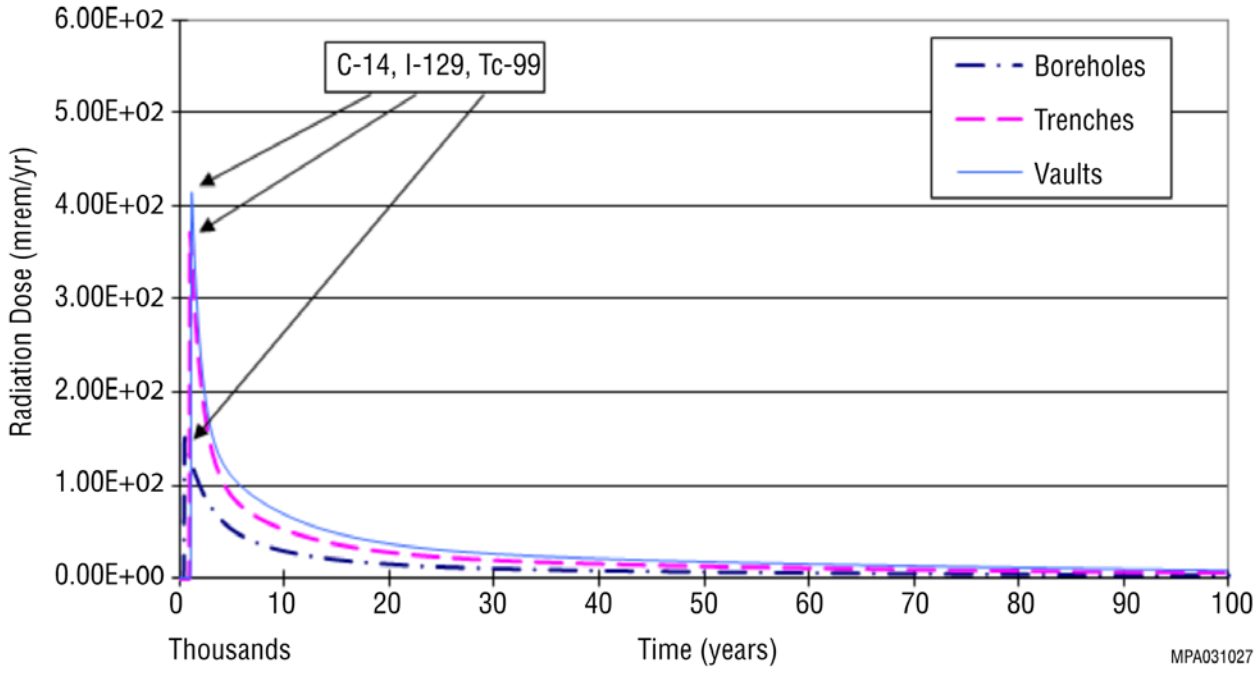

FIGURE 4-14 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal for the Three Land Disposal Methods at LANL

Results for NNSS

Because of the extremely arid climate, the precipitation rate at NTS averages only about 12 cm/yr. However, the annual evapotranspiration was estimated to be about 1.68 m/yr, or about 14 times the average precipitation rate (Bechtel Nevada 2001). As a result, water infiltration to the disposal area would be nearly zero (1.0×10^{-6} m/yr was used in the RESRAD-OFFSITE analyses). With an insufficient driving force for leaching, radionuclides are not expected to reach the groundwater table within 100,000 years. Therefore, no radiation exposure to a hypothetical resident farmer living 100 m from the GTCC waste disposal facility is indicated by the calculations performed.

Results for SRS

At SRS, the climate is generally humid, with an average annual precipitation rate of about 1.2 m/yr. The natural water infiltration rate to deeper soils is estimated to be about 0.38 m/yr, which is much larger than the natural infiltration rate estimated for other sites considered in this report. As a result, more radionuclides would be carried to the groundwater table in a shorter period of time. It is estimated that within 10,000 years, the peak annual radiation dose associated with the use of contaminated groundwater from disposal of the entire GTCC waste inventory at SRS by a hypothetical resident farmer living 100 m from the disposal facility would be 1,300 mrem/yr for the vault method and 1,700 mrem/yr for the trench method (see Table 4-31).

The peak annual doses are calculated to occur quite quickly for SRS because the water infiltration rate is so high there. The maximum annual dose would occur about 54 years (for the vault method) and 29 years (for the trench method) after failure of the engineered cover and barriers, which is assumed to begin 500 years after closure of the disposal facility. The exposure pathways related to the use of contaminated groundwater considered in this analysis include the ingestion of contaminated groundwater, soil, plants, meat, and milk; external radiation; and the inhalation of radon gas and its short-lived progeny

The peak annual doses given in Table 4-31 to the hypothetical resident farmer (from use of potentially contaminated groundwater within the first 10,000 years after closure of the disposal facility) are those associated with the disposal of the entire GTCC waste inventory by using the vault and trench disposal methods. In these tables, the annual doses contributed by each waste type (i.e., dose and risk for each waste type at the time or year when the peak dose for the entire inventory is observed) to the peak dose are also tabulated. The doses presented for the various waste types do not necessarily represent the peak dose of the waste type itself when it is considered on its own, which is reported in Tables 4-21 through 4-24.

The radiation doses are largely associated with the GTCC-like Other Waste - RH; GTCC LLRW Other Waste - RH contributes about one-fourth of the peak annual dose. Activated metals also contribute a measurable amount to the peak for each disposal method.

It is calculated that within 100 years after breach of the engineered barriers (including cover), C-14, Tc-99, I-129, and Np-237 would reach the groundwater table and a well installed by the hypothetical resident farmer. These radionuclides are highly soluble in water, a characteristic that could lead to potentially significant groundwater concentrations and subsequently high doses to this hypothetical receptor. Additional radionuclides that would contribute to the groundwater dose within 10,000 years include Ni-59, Ni-63, Ra-226, Am-241, and Th-230. Of these five radionuclides, Ni-59, Ni-63, and Ra-226 would reach the groundwater table and a well located 100 m downgradient of the disposal facility. The radiation doses attributable to Am-241 and Th-230 would largely be those associated with the decay products of these two radionuclides (Np-237 and Ra-226).

TABLE 4-31 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal at the GTCC Reference Location at SRS[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Vault									1,300[b]
Group 1 stored	2.0	0.0	0.0	1.3	0.21	0.0	15	1,000	–
Group 1 projected	30	0.0	0.0	0.039	0.53	0.0	4.2	3.6	–
Group 2 projected	14	0.0	6.5	230	0.0	0.0	8.3	18	–
Trench									1,700[b]
Group 1 stored	2.2	0.0	0.0	1.0	0.24	0.0	31	1,100	–
Group 1 projected	33	0.0	0.0	0.031	0.60	0.0	8.7	2.9	–
Group 2 projected	16	0.0	13	460	0.0	0.0	17	31	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24.

[b] The times for the peak annual doses of 1,300 mrem/yr for vaults and 1,700 mrem/yr for trenches were calculated to be about 54 years and 29 years, respectively, for disposal of the entire GTCC waste inventory. These times represent the time after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses from the specific waste types at the time of these peak doses. The primary contributors to the dose are GTCC LLRW Other Waste - RH and GTCC-like Other Waste - RH. The primary radionuclides causing this dose would be C-14, Tc-99, I-129, and Np-237

Figure 4-15 is a temporal plot of the doses associated with the use of contaminated groundwater for the vault and trench disposal methods for a period extending to 10,000 years, and Figure 4-18 shows these results to 100,000 years. Note that the time scale in Figure 4-17 is logarithmic, while the time scale in Figure 4-18 is linear. A logarithmic time scale was used in the first figure to better illustrate the projected radiation doses to a hypothetical resident farmer in the first 1,000 years.

As shown in Figure 4-16, a number of additional actinides (mainly isotopes of uranium, plutonium, and thorium) would contribute to the groundwater dose thousands of years after closure of the disposal facility and would last over a very long duration. The peak annual doses from these radionuclides would occur about 30,000 years following closure of the trench disposal facility and about 40,000 years following closure of the vault facility. These maximum doses are lower than those that are predicted to occur within the first 10,000 years by the RESRAD-OFFSITE computer code.

The assumptions for exposure distance, effective period of engineered materials, water infiltration rate, and effective period of grouting used for calculating the potential radiation doses presented in this report are considered to be conservative; therefore, it is expected that the actual doses associated with the disposal of the GTCC LLRW and GTCC-like waste would be much lower than those presented in this section. Sensitivity analyses were conducted to evaluate the influence of these assumptions on the dose results and are presented in Appendix D.

It is important to remember that the radiation doses presented in this report are intended to be used for comparing the performance of each of the land disposal methods at each site evaluated. The sensitivity analysis results indicate that the use of robust engineering designs and redundant measures to contain the radionuclides in the disposal facility could delay the potential release of radionuclides and could reduce the release to very low levels, thereby minimizing the potential groundwater contamination and associated human health impacts in the future.

Results for the WIPP Vicinity

On the basis of the RESRAD-OFFSITE calculation results, within 10,000 years, no radiation exposure would be incurred by a hypothetical resident farmer living 100 m from the disposal facility as a result of using groundwater. Potential exposure could occur after 10,000 years and would be caused mainly by I-129 and Tc-99 that reached the groundwater table. Transport times needed by other radionuclides to reach the groundwater table would be longer than 100,000 years as a result of their greater retardation in the soil.

Figure 4-17 shows the temporal plot of the radiation doses associated with the use of contaminated groundwater for a time frame extended to 100,000 years under the three land disposal methods. The late occurrence of radiation exposure associated with the use of contaminated groundwater is attributed to a small natural water infiltration rate (0.2 cm/yr or 0.08 in./yr) and a deep groundwater table of about 150 m. The peak annual doses are calculated to be 84 mrem/yr for use of boreholes, 99 mrem/yr for use of trenches, and 110 mrem/yr for use of the vault disposal method. These peak annual doses are estimated to occur in about 11,000 years, 14,000 years, and 15,000 years for the borehole, trench, and vault methods, respectively. Most of this dose would be from Tc-99 and associated with the GTCC LLRW activated metal waste and GTCC-like Other Waste - RH. There is a high degree of uncertainty associated with results like these, which are for such a long time of analysis.

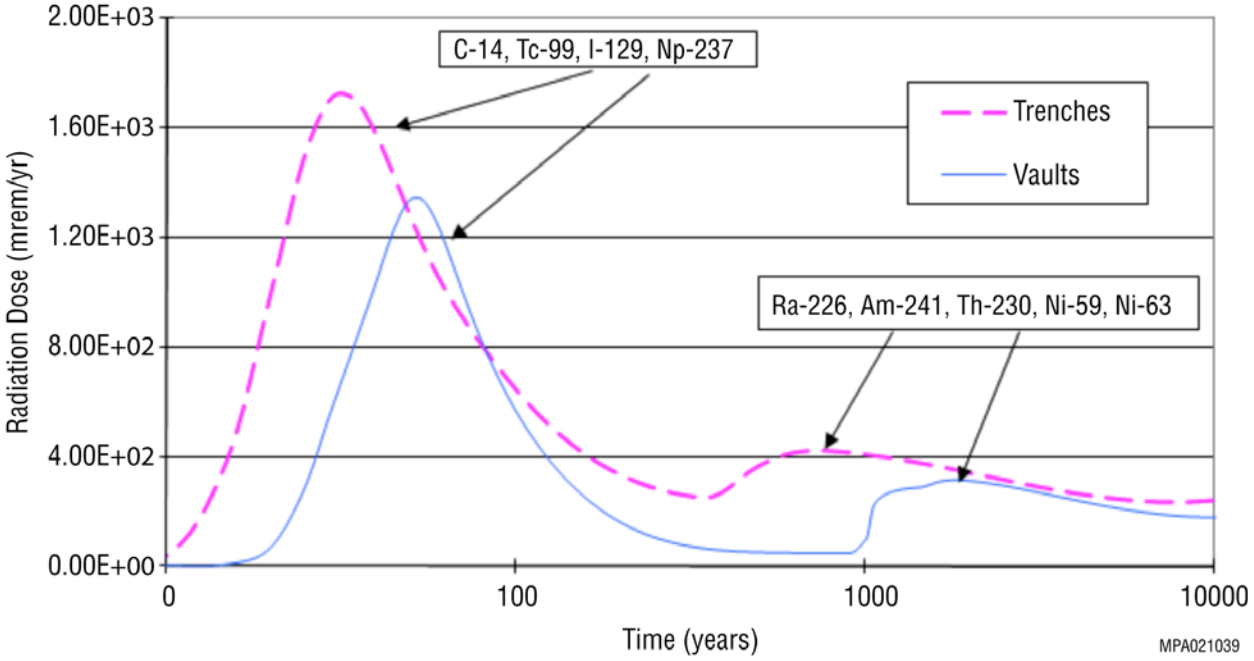

FIGURE 4-15 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal for the Trench and Vault Disposal Methods at SRS

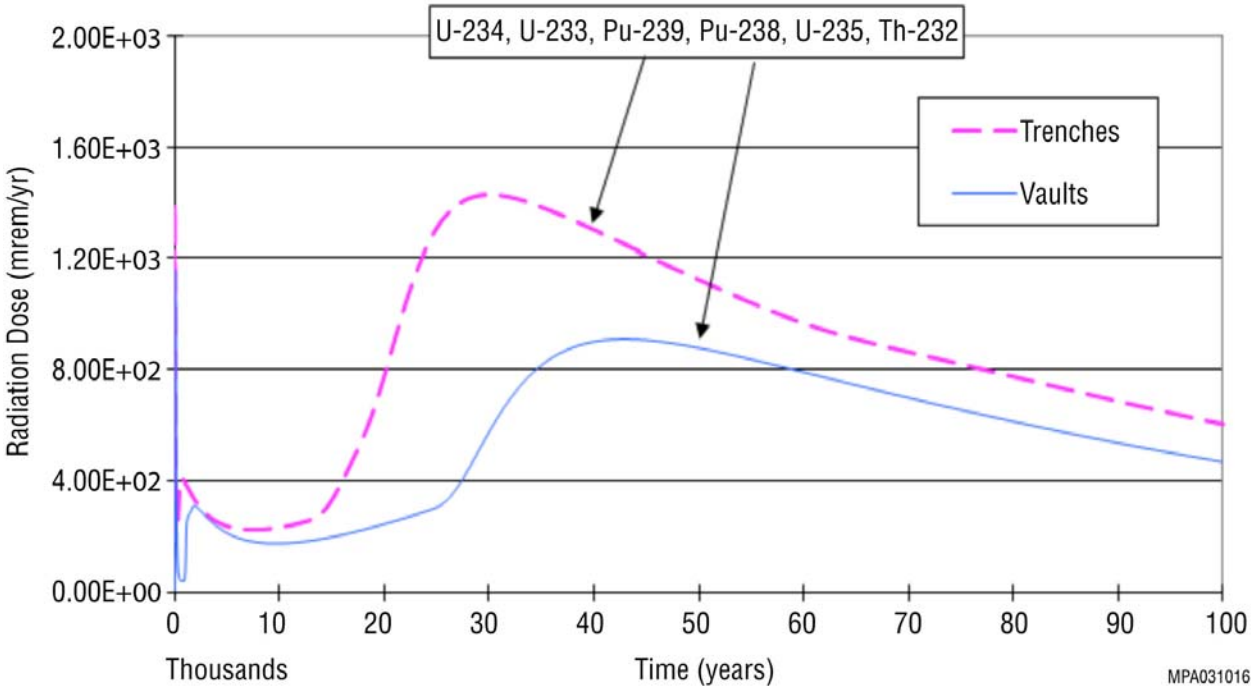

FIGURE 4-16 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal for the Trench and Vault Disposal Methods at SRS

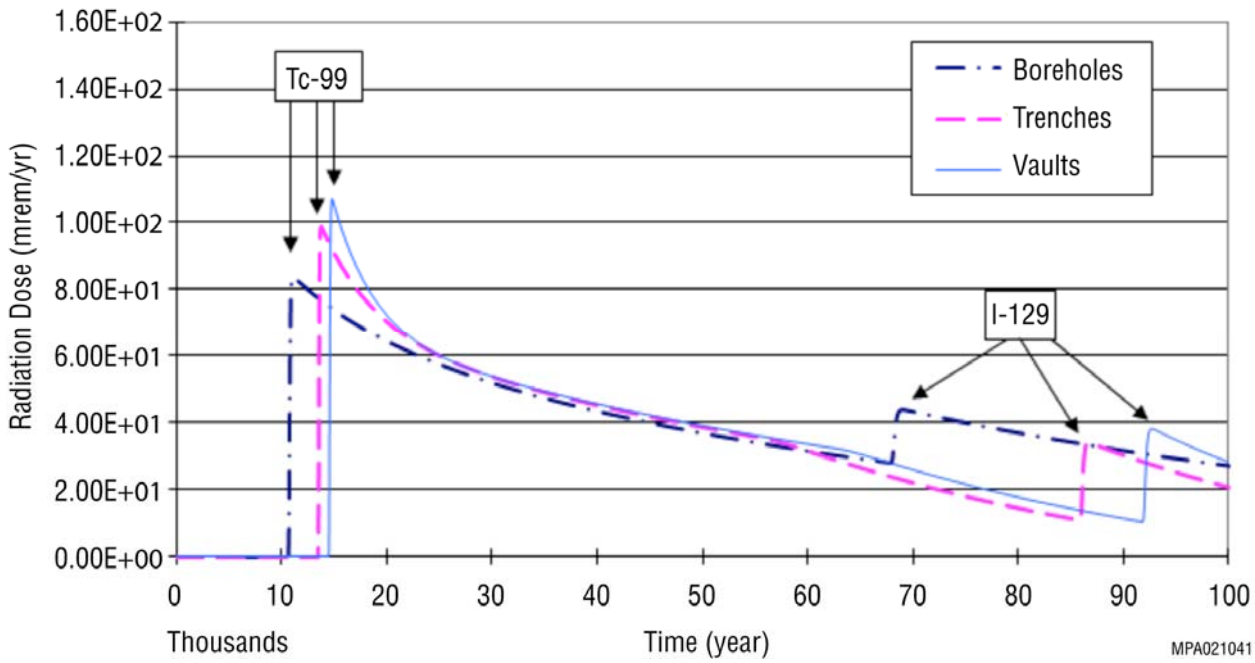

FIGURE 4-17 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal for the Three Land Disposal Methods at the WIPP Vicinity

Results for the Generic Sites

For this assessment, the entire GTCC waste inventory is assumed to be disposed of at a single commercial facility in each of the four NRC regions. Representative parameters were chosen for each location so that the RESRAD-OFFSITE computer code could be used to address the movement of radioactive contaminants from these GTCC wastes to the nearby environment. The pathway of most concern in the long term is leaching to groundwater and subsequent movement in groundwater to a nearby receptor location. The use of the vault method was assumed applicable for all four regions, and trenches were assumed applicable to Regions II and IV. The borehole method was limited to Region IV, given the generally greater distance to groundwater in the Western States.

The analysis for use of a commercial facility to dispose of GTCC wastes was done in a manner consistent with the analysis performed for the DOE sites addressed in previous sections. It was assumed that engineering controls (such as use of stabilizing agents in certain wastes and maintenance of the disposal facility cover) would minimize water infiltration into the wastes for the first 500 years following closure of the disposal facility. This would allow time for the short-lived radionuclides to decay to innocuous levels. No credit is taken for these engineering controls after 500 years. It is further assumed that after the first 500 years, the facility covers would still be effective in reducing water infiltration to the top of the facility (i.e., 80% reduction is assumed).

Calculations indicate that within 10,000 years, radionuclides would reach the groundwater table and a well installed by a hypothetical resident farmer located a distance of 100 m from the downgradient edge of a disposal facility in Regions I, II, and III. Radionuclides are not predicted to reach this hypothetical well within 10,000 years in Region IV for any of the three disposal methods. This assumption reflects the more arid climate and greater depth to groundwater in the Western United States.

However, calculations indicate that radionuclides would reach the groundwater table and this hypothetical well after 10,000 years, and these results are discussed here.

The results of these modeling calculations are given in Tables 4-32 through 4-34 and Figures 4-18 through 4-24. The tables provide the peak annual doses associated with use of contaminated groundwater resulting from the disposal of the entire GTCC waste inventory at a commercial disposal facility in Regions I, II, and III. The tables show the contributions from the different waste types to the peak annual doses at the time of peak impact, and the figures illustrate the radionuclides that provide most of the annual dose. Since the calculations indicate that the GTCC LLRW and GTCC-like waste in a borehole, trench, or vault facility in Region IV would not reach the groundwater table in 10,000 years, a table summarizing the peak annual doses is not provided for this region. However, the radiation doses out to 100,000 years for these three disposal methods in Region IV are shown in Figure 4-24. The major dose contributor in all four regions is GTCC-like Other Waste - RH. The primary radionuclides causing this dose are generally C-14, I-129, and isotopes of uranium and plutonium.

Because the radionuclide mixes are different for each waste type (i.e., activated metals, sealed sources, and Other Waste), the peak annual doses do not necessarily occur at the same time for each waste type. In addition, the peak annual doses for the entire GTCC waste inventory considered as a whole could be different from those for the individual waste types. Therefore, the dose results presented in Tables 4-32 through 4-34 may not match those listed in Tables 4-21 through 4-24, which present the peak annual doses for each waste type when it is considered to be disposed of on its own.

Figures 4-18, 4-20, and 4-22 are temporal plots of the annual doses associated with the use of contaminated groundwater for a time period that extends to 10,000 years in Regions I, II, and III, respectively. Figures 4-19, 4-21, 4-23, and 4-24 show these results for a period that extends to 100,000 years in all four geographic regions. Note that the time scale is logarithmic in the figures illustrating the results to 10,000 years and linear in the figures illustrating the results to 100,000 years. A logarithmic time scale was used in the figures that extend the results to 10,000 years to better show the projected radiation doses to a hypothetical resident farmer shortly after closure of the disposal facility.

The highest estimated annual doses associated with the use of a commercial disposal facility for GTCC wastes were calculated to occur in Region I. The peak annual dose within 10,000 years from the use of a vault disposal facility in this region was calculated to be 12,000 mrem/yr, and this dose would occur about 49 years after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). This dose would be largely due to C-14, I-129, and uranium isotopes (see Figure 4-18). A comparable annual dose was calculated to occur at about 3,800 years from plutonium isotopes.

C-14, I-129, and uranium are relatively soluble in water. (All are assumed to have a K_d value of 0 cm^3/g; K_d measures the partitioning of radionuclides to the soil particles relative to the liquid in soil columns.) This solubility could lead to potentially significant groundwater doses to the resident farmer. The exposure pathways considered in this analysis include the ingestion of contaminated groundwater, soil, plants, meat, and milk; external radiation; and the inhalation of radon gas and its short-lived progeny. Except for the ingestion of contaminated groundwater, all pathways result from using the contaminated groundwater for irrigation and feeding livestock. The doses in Region I are the highest of the doses in the four regions, largely because of (1) the more humid environment there, (2) the generally shorter distance to groundwater there than in the other three regions, and (3) the assumed low K_ds for several important radionuclides.

TABLE 4-32 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Commercial Vault Disposal Facility in Region I[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Vault									12,000[b]
Group 1 stored	0.0	0.0	0.0	7.2	0.026	0.0	400	370	–
Group 1 projected	2.8	400	0.0	0.22	0.065	0.0	110	9,700	–
Group 2 projected	1.3	0.0	71	210	0.0	0.0	230	440	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24. Region I is composed of the Northeastern states, including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Washington, D.C.

[b] The time for the peak annual dose of 12,000 mrem/yr for disposal of the entire GTCC waste inventory was calculated to be about 49 years after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses from the specific waste types at the time of the peak annual dose; i.e., at 49 years following failure of the cover and engineered barriers. The primary contributor to the dose is GTCC-like Other Waste - RH, and the primary radionuclides causing this dose are C-14, I-129, and uranium and plutonium isotopes.

TABLE 4-33 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Commercial Vault or Trench Disposal Facility in Region II[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Vault									1,200[b]
Group 1 stored	0.86	0.0	0.0	0.0	0.12	0.0	11	940	–
Group 1 projected	13	0.0	0.0	0.0	0.29	0.0	3.1	0.0	–
Group 2 projected	6.2	0.0	5.3	210	0.0	0.0	6.2	13	–
Trench									1,200[b]
Group 1 stored	1.1	0.0	0.0	0.0	0.15	0.0	14	950	–
Group 1 projected	17	0.0	0.0	0.0	0.38	0.0	0.39	0.0	–
Group 2 projected	8.1	0.0	6.6	210	0.0	0.0	7.8	12	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24. Region II is composed of the Southeastern states, including Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

[b] The times for the peak annual doses of 1,200 mrem/yr for disposal of the entire GTCC waste inventory using the vault and trench methods were calculated to be about 100 and 34 years, respectively, after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported from the other entries in this table represent the annual doses for the specific waste types at the time of the peak annual dose; i.e., at 100 and 34 years following failure of the cover and engineered barriers for the vault and trench methods, respectively. For both cases, the primary contributor to the dose is GTCC-like Other Waste - RH, and the primary radionuclides causing this dose are C-14 and I-129.

TABLE 4-34 Estimated Peak Annual Doses (mrem/yr) from the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Vault Disposal Facility in Region IV[a]

Disposal Technology/ Waste Tier	GTCC LLRW				GTCC-Like Waste				Peak Annual Dose from Entire Inventory
	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	Activated Metals	Sealed Sources	Other Waste - CH	Other Waste - RH	
Borehole									530[b]
Group 1 stored	11	0.0	0.0	0.0	0.16	0.0	4.7	410	–
Group 1 projected	18	0.0	0.0	0.0	0.39	0.0	1.4	0.017	–
Group 2 projected	7.8	0.0	2.1	83	0.0	0.0	2.5	5.2	–

[a] These annual doses are associated with the use of contaminated groundwater by a hypothetical resident farmer located 100 m from the edge of the disposal facility. All values are given to two significant figures, and a dash means there is no inventory for that waste type. The values given in this table represent the annual doses to the hypothetical resident farmer at the time of the peak annual dose from the entire GTCC waste inventory. These contributions do not represent the maximum doses that could result from each of these waste types separately. Because of the different radionuclide mixes and activities contained in the different waste types, the maximum doses that could result from each waste type individually generally occur at different times than the peak annual dose from the entire inventory. The peak annual doses that could result from each of the waste types are presented in Tables 4-21 through 4-24. Region IV is composed of the Midwestern states, including Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin.

[b] The time for the peak annual dose of 530 mrem/yr for disposal of the entire GTCC waste inventory was calculated to be about 69 years after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). The values reported for the other entries in this table represent the annual doses from the specific waste types at the time of the peak annual dose; i.e., at 69 years following failure of the cover and engineered barriers. The primary contributor to the dose is GTCC-like Other Waste - RH, and the primary radionuclides causing this dose are C-14 and I-129.

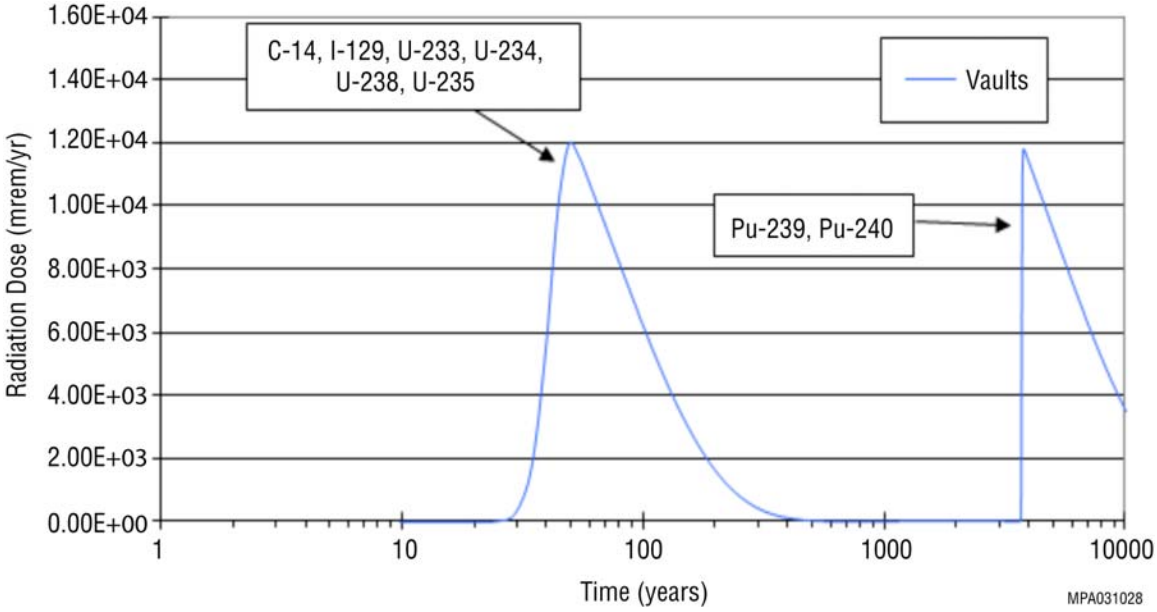

FIGURE 4-18 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Commercial Vault Disposal Facility in Region I

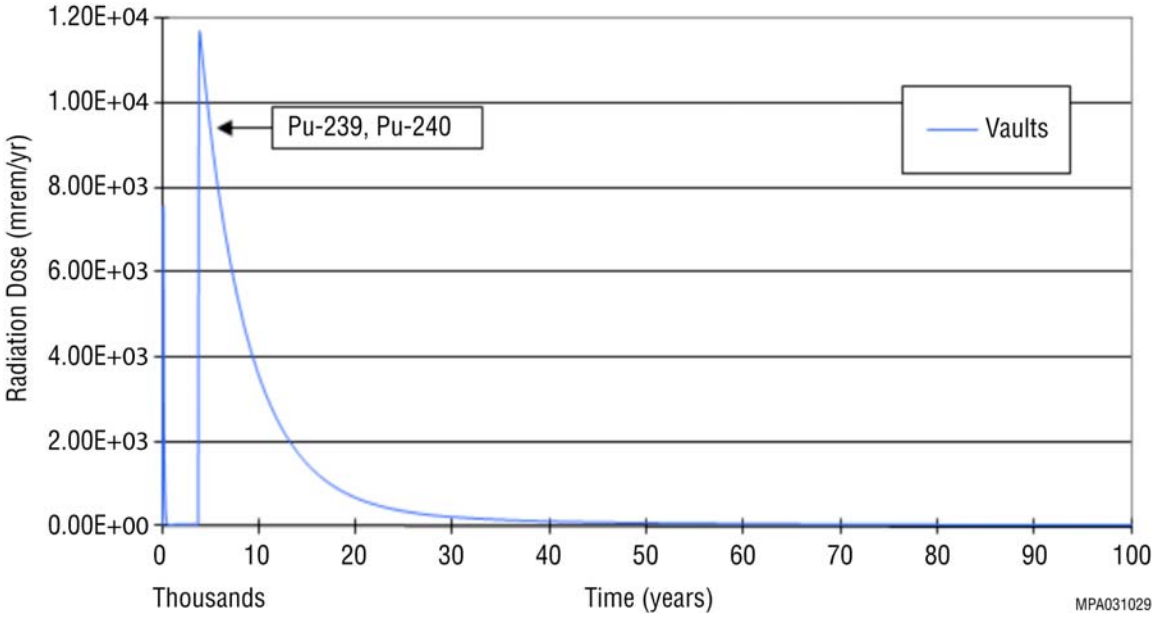

FIGURE 4-19 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal in a Commercial Vault Disposal Facility in Region I

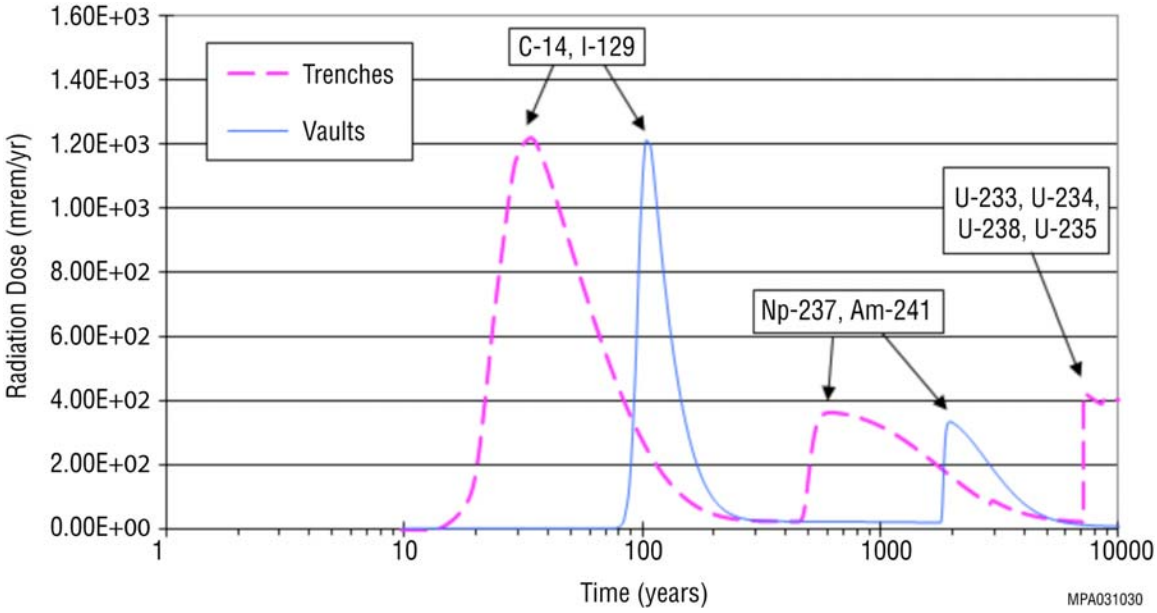

FIGURE 4 20 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Commercial Vault or Trench Disposal Facility in Region II

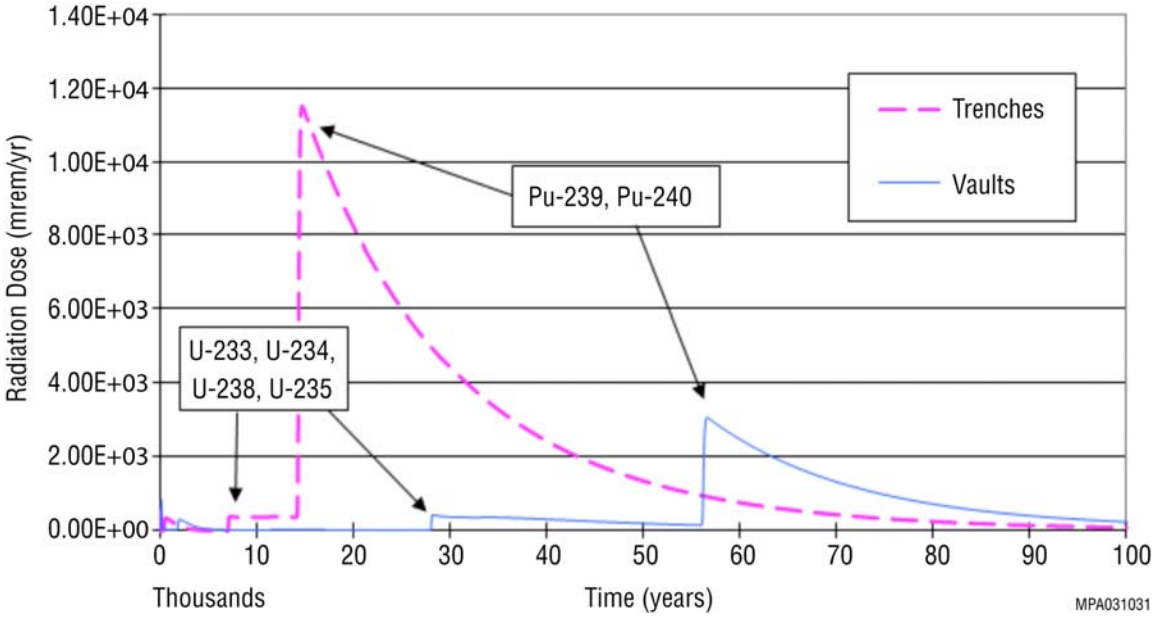

FIGURE 4-21 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal in a Commercial Vault or Trench Disposal in Region II

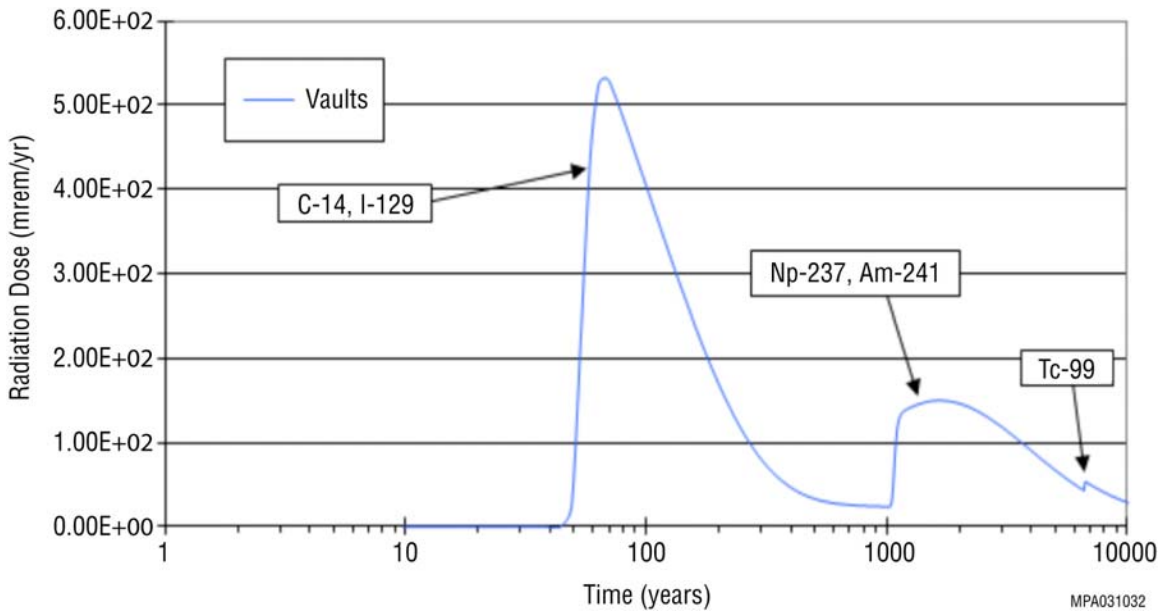

FIGURE 4-22 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 10,000 Years of Disposal in a Commercial Vault Disposal Facility in Region III

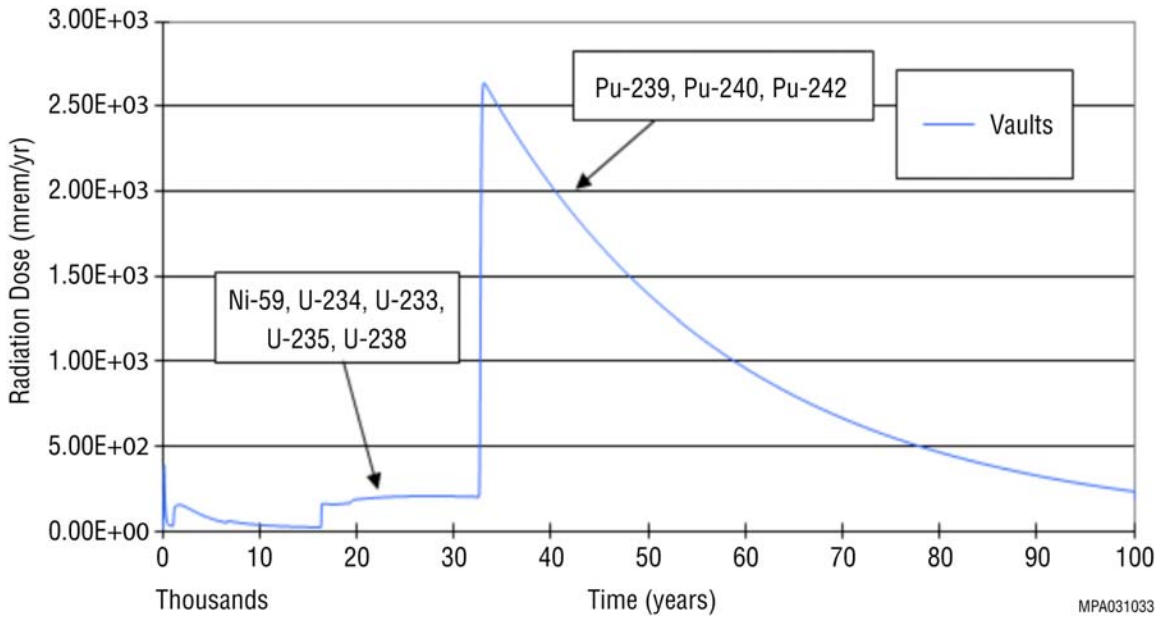

FIGURE 4-23 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal in a Commercial Vault Disposal Facility in Region III

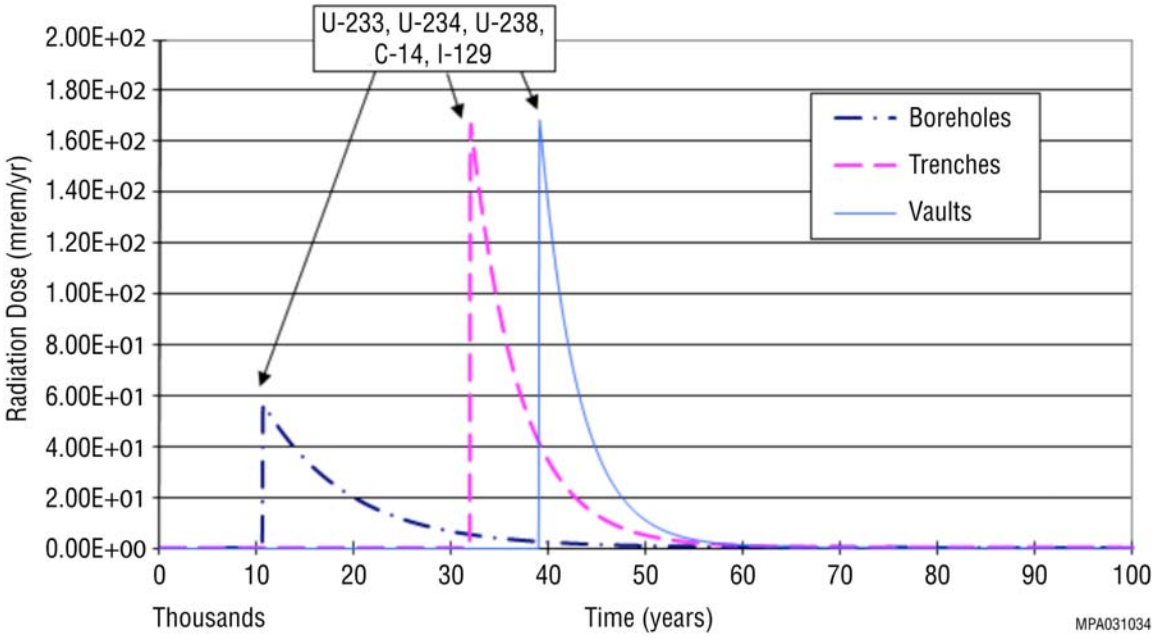

FIGURE 4-24 Temporal Plot of Radiation Doses Associated with the Use of Contaminated Groundwater within 100,000 Years of Disposal in a Commercial Borehole, Trench, or Vault Disposal Facility in Region IV

Two disposal methods (vault and trench) are evaluated for Region II. The peak annual dose within 10,000 years from the use of either of these two methods to dispose of the entire GTCC waste inventory was calculated to be 1,200 mrem/yr. This dose would occur at about 100 years for the vault method and 34 years for the trench method after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). These doses would be largely due to C-14 and I-129 (see Figure 4-20). A larger annual dose was calculated to occur after 10,000 years from plutonium isotopes. This dose was calculated to be 12,000 mrem/yr at 15,000 years in the future for trenches, and 3,000 mrem/yr at 57,000 years for vaults (see Figure 4-21).

The peak annual doses in Region III from vault disposal of the entire GTCC waste inventory are lower than those in Regions I and II. The peak annual dose within 10,000 years was calculated to be 530 mrem/yr, and this dose occurs about 69 years after failure of the cover and engineered barriers (which is assumed to begin 500 years after closure of the disposal facility). This dose would also be largely due to C-14 and I-129 (see Figure 4-22). A larger annual dose was calculated to occur in Region III after 10,000 years from plutonium isotopes. This dose was calculated to be 2,600 mrem/yr and to occur about 33,000 years in the future (see Figure 4-23).

The peak annual doses are lowest in Region IV. It is predicted that radionuclides would not reach the groundwater table and the well of a hypothetical resident farmer within the first 10,000 years following disposal because of the much lower water infiltration rate assumed for this region than for the other three regions. However, it was calculated that radionuclides would reach the groundwater table after 10,000 years. The peak annual doses were calculated to be 170 mrem/yr for use of vaults or trenches and 57 mrem/yr for use of boreholes. These peak doses are estimated to occur at about 39,000, 32,000, and 11,000 years in the future for these three disposal methods, respectively. These doses would mainly result from uranium isotopes, C-14, and I-129 (see Figure 4-24). These results illustrate that as the distance to

the groundwater table increases (from boreholes to trenches to vaults), the length of time it takes for the radionuclides to reach the groundwater table also increases.

As can be seen by these results, the maximum radiation doses are relatively high for all regions except Region IV. This result is expected because the use of an arid site would likely result in lower doses from the groundwater pathway than would the use of a more humid site. The modeling approach used here is assumed to be conservative; the use of a longer distance to a hypothetical receptor might be more realistic and would be evaluated as part of the NRC licensing process.

The highest radiation doses occur in Region I. A disposal facility in this region is expected to be in a generally humid environment, and the distance to the groundwater table is expected to be relatively short. These properties of a humid site are expected to result in radiation doses that would be higher and would occur earlier than those at more arid sites, such as those expected in Region IV.

The assumptions for exposure distance, effective period of engineered materials, water infiltration rate, and effective period of grouting used for calculating the potential radiation doses presented in this report are considered to be conservative; therefore, it is expected that the actual doses associated with the disposal of the GTCC LLRW and GTCC-like waste would be much lower than those presented in this section. Sensitivity analyses were conducted to evaluate the influence of these assumptions on the dose results and are presented in Appendix D.

It is important to remember that the radiation doses presented in this report are intended to be used for comparing the performance of each of the land disposal methods at each site evaluated. The sensitivity analysis results indicate that the use of robust engineering designs and redundant measures to contain the radionuclides in the disposal facility could delay the potential release of radionuclides and could reduce the release to very low levels, thereby minimizing the potential groundwater contamination and associated human health impacts in the future.

5 AIRBORNE RELEASE EVALUATIONS

The analyses of long-term impacts conducted to evaluate the performance of GTCC LLRW and GTCC-like waste disposal facilities include analyses of contamination in both groundwater and air. Because dilution is much greater in the open air than in the groundwater aquifer, the potential radiation exposure associated with the release of radionuclides to the air is expected to be much lower than that associated with the release of radionuclides to the groundwater aquifer.

For the evaluation of airborne release of radionuclides, the receptor chosen was the same one who was used for the groundwater impact analysis. The selected receptor was considered to represent the highest-exposed individual of the general public, because of his close proximity to the disposal facility. This individual (a resident farmer) was assumed to set up living at a distance of 100 m from the edge of the disposal facility. The potential radiation exposure incurred by the farmer would result from inhalation of radon and gaseous radionuclides (C-14 in the form of CO_2 and H-3 in the form of HTO) that diffuse out directly from the disposal area and are blown off site to the location of the farm. The RESRAD-OFFSITE computer code (Yu et al. 2007) that incorporates a Gaussian air dispersion model was used for the airborne release evaluation.

5.1 ASSUMPTIONS

The integrity of the disposal facility was assumed to fail 500 years after closure. The failure not only allows water to infiltrate to the waste disposal area but also allows the gaseous radionuclides formed within the disposal area to diffuse to the open air. The radionuclide inventory in the disposal area was adjusted for radiological ingrowth and decay during this 500-year period and used as the initial inventory for the air transport modeling.

The gaseous radionuclides considered in the analysis are radon, H-3, and C-14. The radon gas would be formed from the decay of Ra-226 and Ra-228. HTO would result from conversion of H-3, and CO_2 would result from conversion of C-14 upon contact with the outside environment. To model the airborne release rates, the disposal cells were consolidated as a single contamination source — the same as that assumed in groundwater modeling — and the contamination source was treated as a continuous porous medium in which radionuclides were homogeneously distributed. Although in reality, the enclosed waste disposal area consists of various components that are not homogeneously mixed and some components (e.g., the waste containers) that are rigid rather than porous, the treatment of the entire disposal area as a continuous porous medium enables the diffusion rates through the open pore space to be calculated. The diffusion rate thus estimated would be greater than the rate for the actual situation and would result in more conservative predictions of radiation exposures (i.e., higher exposure rates). A density of 1.8 g/cm^3 and a total porosity of 0.4 were assumed for the contamination source.

Backfill soils and layers of engineered covers would be placed on top of the contamination source to shield and contain the waste material. In the modeling, a single porous medium that had a typical soil density of 1.5 g/cm^3 and a total porosity of 0.4 was assumed. In reality, clay or other dense materials are usually used as covers; therefore, the assumption of soil properties would facilitate gas diffusion and result in the prediction of greater diffusion fluxes. For the borehole method, the cover thickness was assumed to be 30 m; the cover thicknesses were assumed to be 6.2 m and 5 m for vaults and trenches, respectively. To keep consistency with the groundwater modeling, the erosion rate of the cover material was assumed to be 1×10^{-5} m/yr.

A water infiltration rate that was 20% of the background level was used in the airborne release modeling, consistent with the groundwater evaluation. The smaller infiltration rate would result in a lower moisture content in the contamination source, so that more pore space would be available for gas diffusion. The other parameters used for calculating diffusion fluxes at the ground surface were set to the RESRAD-OFFSITE default values, including the diffusion and emanation coefficients for radon; the thickness of the evasion layer and the evasion flux rate for C-14 modeling; and the humidity in air for H-3 modeling.

After emerging from the ground surface, the gaseous radionuclides would be blown by wind to the downwind location where the resident farmer is assumed to live. The joint frequency data from the weather station that is closest to the site under consideration were used for air dispersion modeling to determine the air concentration at the receptor location. The resident farmer was assumed to spend 75% of the time near home (50% indoors and 25% outdoors) and 25% of the time away from home. An average inhalation rate of 8,400 m^3/yr was assumed for the farmer.

5.2 RESULTS

According to the RESRAD-OFFSITE calculation results, the potential inhalation dose that could be incurred by the highest-exposed individual from the airborne release is small. There would be no measurable exposure with the borehole method. The potential inhalation dose at a distance of 100 m from the disposal facility is estimated to be less than 1.8 mrem/yr for the trench method and 0.52 mrem/yr for the vault method. The radiation exposures would be caused mainly by inhalation of Rn-222 and its short-lived progeny.

The borehole method would provide better protection against potential exposures from airborne releases of radionuclides because of the greater depth of the cover material. The boreholes would be 30 m below the ground surface, and this depth of overlying soil would inhibit the diffusion of radon gas, CO_2 gas (containing C-14), and tritium (H-3) water vapor to the atmosphere above the disposal area. However, because the distance to the groundwater table would be closer from boreholes than from trenches or vaults, radionuclides that leached out from wastes in the boreholes would reach the groundwater table in a shorter period of time than radionuclides that leached out from the trenches or vaults. Potential radiation exposures resulting from groundwater releases are discussed in Section 4.

6 SUMMARY AND CONCLUSIONS

An assessment was performed of the post-closure impacts on human health under the No Action Alternative and land disposal alternatives being considered in the EIS for GTCC LLRW and GTCC-like waste. This assessment covers impacts from the airborne releases of gaseous radionuclides formed through radiological decay and chemical conversion upon contact with the surrounding environment for the disposal alternatives, and waterborne releases of radionuclides resulting from leaching by the infiltration water into the waste containers for both the No Action Alternative and the disposal alternatives. Both impacts were assessed in terms of the estimated annual radiation dose to an individual (an adult) assumed to be located 100 m downgradient from the edge of the specific facility. The dose calculations covered two time periods: 10,000 years and 100,000 years following closure of the storage or disposal facilities.

The hypothetically impacted individual was assumed to be a resident farmer who consumed 730 L of potentially contaminated groundwater per year. In addition to ingestion of water, other exposure pathways considered for the groundwater impact analysis included the ingestion of plant food, meat, and milk; external radiation; and inhalation of dust particles and radon. All these exposure pathways are linked to the use of contaminated groundwater for irrigation, household activities, and feeding livestock. The same farmer was also assumed to inhale radon, C-14, and H-3 that were released from the waste disposal area to the atmosphere and were blown to the downwind location. An inhalation rate of 8,400 m^3/yr was assumed. The potential impact was reported as the annual radiation dose that would be incurred by the resident farmer. The dose estimates were provided separately for each of the individual waste types, with each of the three land disposal methods being considered for GTCC LLRW and GTCC-like wastes at the six DOE sites and four generic locations.

Potential impacts associated with the airborne release of radionuclides directly from the waste containers were not assessed for the No Action Alternative; however, they are expected to be much lower than those associated with the release to the groundwater at the location where the resident farmer is assumed to reside. The lower impacts would be due to the much greater dilution in the air than in the groundwater aquifer. In reality, the No Action Alternative assumed in the EIS is not a feasible long-term management alternative for the GTCC LLRW and GTCC-like wastes; therefore, the long-term impacts assessed for the No Action Alternative would likely never occur; they were calculated for comparison purposes with the disposal alternatives.

The RESRAD-OFFSITE computer code was used for the evaluations of both the airborne and groundwater releases, and site-specific parameters were used to the extent that such information was available. Where site-specific data were not available, default values or estimates based on representative information for the vicinity of the site were used. The parameter values that were determined were reviewed and commented on by people familiar with the conditions at the site. The suggestions of the reviewers were accepted unless they were inconsistent with the assumptions used in the modeling.

For the groundwater impact analysis, the water infiltration rate into the disposal unit was assumed to be 20% of the natural infiltration rate for the area. A reduced infiltration rate was used to account for the design characteristics of the disposal facilities, specifically those features meant to minimize water infiltration into the waste zone. Outside the disposal units, the water infiltration rate was assumed to be the same as the background level. Release rates of radionuclides from the disposal area to the soils underneath it were estimated by considering the adsorption of radionuclides in the backfill soils and the dissolution of radionuclides in water when water contacted the waste material. The dissolution of radionuclides in activated metals was assumed to be controlled by corrosion, with a corresponding dissolution rate of 1.19×10^{-5}/yr. Some radionuclides in sealed sources were assumed to partition to

water instantaneously upon contact with water, similar to the partitioning in a soil system. Other Waste was assumed to be stabilized by cement through grouting. The dissolution of radionuclides upon contact with water was determined by the K_d values in the cement system. The stabilization was assumed to be effective and reduce the radionuclide release rate for 500 years. The final release rate of radionuclides to deeper soils beneath the disposal area was selected to be the smaller value between the dissolution rate from the waste material and the desorption rate from the backfill soils.

The approach used to analyze groundwater impacts associated with the No Action Alternative was the same as that used to analyze the disposal alternatives, except that the water infiltration rate to the waste containers was set to the annual precipitation rate, because there would not be any protection for the containers against weathering, and because no backfill soil would surround the waste containers, so the radionuclide release rates were determined by the dissolution rate from the waste material. Unlike the disposal alternatives, for the No Action Alternative, it was assumed that Other Waste would be sent to the storage yard without solidification.

According to the modeling results, potential human health impacts from airborne releases would be much lower than those from waterborne releases because of the much greater dilution in the atmosphere than in the groundwater aquifer. For the disposal alternatives with the borehole method, radiation exposure resulting from airborne releases would not occur within the time frame of analysis. Radiation exposure would be less than 1.8 mrem/yr for the trench disposal method and less than 0.52 mrem/yr for the vault disposal method.

For the disposal alternatives considered for the DOE sites, groundwater modeling estimated that radiation doses would be high for disposal at SRS (1,300 mrem/yr for the vault method and 1,700 mrem/yr for the trench method) because of the humid environment and relatively shallow groundwater table there. It was estimated that disposal at the sites located in arid regions of the country would result in lower radiation doses. The analyses indicate that the radionuclides would not be expected to reach groundwater for any waste types and disposal methods at NNSS within the time frame of the analysis (100,000 years) and at the WIPP Vicinity within the first 10,000 years. Except for INL, all the annual radiation doses projected for the arid sites would be less than 430 mrem/yr. The exception for INL was caused by the low K_d values for some of the critical radionuclides and by the fractured basalt units, which provide little retardation to the transport of radionuclides. It should be noted that the dose results were obtained by applying the same assumption to all the potential sites, in order to consider the protection provided by the engineered materials and designs. In reality, use of more robust designs at the humid locations could offset the benefit gained by placing the disposal facilities in arid locations.

Groundwater modeling results for the disposal alternatives considered for generic facilities in different regions show the same tendency as that observed for the various DOE sites. In general, potential impacts from disposal facilities located in arid regions (Regions III and IV) of the country are lower than those from facilities located in humid regions (Regions I and II).

The majority of the projected doses were contributed by the GTCC-like Other Waste - RH, especially those from the stored Group 1 inventory. GTCC activated metal waste would be a concern at LANL, INL, and SRS. GTCC Other Waste - RH would be a concern at INL. GTCC-like Other Waste - CH would be a concern at SRS. Although Other Waste was assumed to be grouted with cement for solidification, the effectiveness was assumed to last for only 500 years. Sensitivity analyses (presented in Appendix C) indicate that to minimize the groundwater contamination associated with Other Waste, the effectiveness of grouting should last for at least 5,000 years, which is needed to reduce the radioactivity of some critical long-lived radionuclides contained in the waste material.

The trench and vault methods place wastes at disposal units that are farther from the groundwater table than are those associated with the borehole method (use of 40-m boreholes). This location should provide for additional groundwater protection by increasing the length of time for radionuclides to reach the groundwater table. However, the calculated maximum annual doses from the borehole method are generally smaller than those from the trench and vault methods. Since the boreholes have a greater vertical height, the cross-sectional area they use would be smaller than the areas of the other two methods. Less water would thus infiltrate the disposal area, and a slower rate of dissolution of radionuclides would result. These two factors (distance to groundwater table and cross-sectional area) tend to offset each other for the trench and vault methods, resulting in comparable doses being calculated for these two disposal methods.

Without any protection against environmental weathering for the waste containers, GTCC LLRW and GTCC-like waste stacked randomly in a storage yard could have much greater groundwater impacts than if they were disposed of by any of the three disposal methods considered in the EIS. This result is especially true for the waste inventory generated within Region I, as indicated by the calculated groundwater dose results for the No Action Alternative.

Finally, it should be emphasized that assessing the dose is only one component in determining an acceptable means for disposing of GTCC LLRW and GTCC-like waste. Moreover, this analysis is being done primarily for the purpose of comparing the likely long-term performance of the disposal concepts at the various sites. After a decision is made on a management alternative for the GTCC LLRW and GTCC-like wastes, a more detailed, site-specific analysis that more realistically simulates the performance of various engineered designs incorporated in the disposal facility will be conducted. This site-specific analysis will provide more precise estimates of the potential human health impacts associated with the decision.

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APPENDIX A:

SITE-SPECIFIC INPUT PARAMETER VALUES

This appendix documents the site-specific input parameter values developed for use in the groundwater modeling for the six DOE sites with the RESRAD-OFFSITE computer code. The site-specific parameter values were developed by reviewing numerous reports documenting the soil, surface water, and groundwater environment; environmental surveillance and monitoring activities; risk assessments for waste management practices; and performance of waste disposal facilities at the potential sites considered for GTCC LLRW and GTCC-like waste disposal. The developed parameter values were reviewed and commented on by site staff who were familiar with the conditions at the site and involved in conducting human health risk assessment associated with the disposal of hazardous wastes at the site. The values that they suggested were accepted and used in groundwater modeling if they were judged to be consistent with the approach and assumptions adopted for the modeling.

Information on the site-specific parameters is presented in two tables for each potential land disposal site. The first table contains parameters defining the infiltration rate to subsurface soils as well as the properties of various soil layers, including the contaminated zone, unsaturated zone(s), and saturated zone. The second table contains information on the K_d parameter, which defines the ratio of radionuclide concentrations between the solid phase and liquid phase in soil under equilibrium. In addition to the values, the rationales for selecting the values and the sources of the values are also listed in the tables.

Tables A-1 and A-2 contain information for the Hanford Site. Tables A-3 and A-4 contain information for INL. Tables A-5 and A-6 are for LANL, and Tables A-7 and A-8 are for NNSS. Information on SRS is contained in Tables A-9 and A-10. The last two tables, Tables A-11 and A-12, are for the WIPP Vicinity.

TABLE A-1 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for the Hanford Site

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	3.4	Site-specific data at Hanford Meteorology Station (HMS), 50 m above ground.	DOE 2004
Precipitation (m/yr)	0.17	Site-specific data (54.39 in./yr), based on HMS measurements. Consistent with values reported by the Western Regional Climate Center (1948–2005).	DOE 2004, p. 4.16
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities.	Yu et al. 2007
Evapotranspiration coefficient	0.97878	In DOE 2005, the infiltration rate suggested for the post-design life for the sitewide surface barrier is 3.5 mm/yr; the post-design life for the Integrated Disposal Facility (IDF) surface barrier is 0.9 mm/yr. However, for the IDF surface barrier, a sensitivity analysis needs to be conducted for an infiltration rate of 5.0 mm/yr as well. Considering the recharge rate at the 200 E Area, which ranges from 1.5 to 4 mm/yr with shrub covering, and to be consistent with the other sites that use a natural infiltration rate for the GTCC analysis, an infiltration rate of 3.5 mm/yr was chosen for the groundwater analysis. To obtain an infiltration rate of 0.0035 m/yr (3.5 mm/yr), the evapotranspiration coefficient was calculated to be 0.97878.	DOE 2005
Runoff coefficient	0.03	Runoff is about 3% of the total precipitation, most of the remaining precipitation is lost through evapotranspiration.	Duncan et al. 2007
Rainfall and runoff	160	To obtain the desired erosion rates for the cover and contamination zone.	Yu et al. 2007 (applies to sum of all four parameters at left)
Slope-length-steepness factor	0.4		
Cover and management factor	0.003		
Support practice factor	1		

TABLE A-1 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the contaminated zone would not be eroded away. Will yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste streams, based on preliminary GTCC waste inventory data.	Sandia 2008
Soil erodibility factor	0.42	To obtain the desired erosion rate.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the buried waste would remain covered within the time frame considered (i.e., would yield more conservative groundwater results because there would be no losses through surface runoff and erosion).	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.35	To obtain the desired erosion rate.	Yu et al. 2007
Unsaturated Zone 1		Fine sand plus coarse sand-dominated layers in the Hanford Formation. They were considered together because of their similar geological and hydrogeological properties.	
Thickness (m)	58	Average value calculated with the stratigraphic columns data for 200 E area.	Last et al. 2006
Density (g/cm^3)	1.65	For fine sand and coarse sand layers in Hanford Formation.	Last et al. 2006
Total porosity	0.37	Set to the same as effective porosity	Last et al. 2006
Effective porosity	0.37	For fine sand and coarse sand layers in Hanford Formation.	Last et al. 2006
Field capacity	0.03	Residual moisture content.	Last et al. 2006
Hydraulic conductivity (m/yr)	710	Corresponding to 2.25E-3 cm/s. Selected based on the information presented in Last et al. 2006 for fine and coarse sands in Hanford Formation.	Last et al. 2006
b-parameter	4.05	Value for sand soil.	Yu et al. 2001
Longitudinal dispersivity (m)	0	No dispersion.	Assumption used for all sites

TABLE A-1 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Unsaturated Zone 2		Gravel-dominated layers in the Hanford Formation plus Ringold Unit E. They were considered together because of their similar geological and hydrogeological properties.	
Thickness (m)	30	Average value calculated with the stratigraphic columns data for 200 E area.	Data presented in Last et al. 2006, Appendix A.
Density (g/cm^3)	1.93	For gravel dominated layers in Hanford Formation and Ringold Unit E.	Last et al. 2006
Total porosity	0.27	Value for Hanford and Ringold gravel.	DOE 2009
Effective porosity	0.27	Set to the same as total porosity.	DOE 2009
Field capacity	0.024	Residual moisture content.	Last et al. 2006
Hydraulic conductivity (m/yr)	148	Corresponding to 4.68E-4 cm/s. Selected on the basis of information presented in Last et al. 2006 for gravel-dominated layers in Hanford Formation and Ringold Unit E.	Last et al. 2006
b-parameter	7.12	Value for sandy clay loam soil.	Yu et al. 2001, Table E-2
Longitudinal dispersivity (m)	0	No dispersion.	Assumption used for all sites.
Saturated zone hydrology		Consider the combination of the Hanford Formation and Ringold Unit E.	
Thickness (m)	45	Entire aquifer is 45 to 71.7 m thick. Use the lower value.	Horton 2007
Density of saturated zone (g/cm^3)	1.98	Calculated on the basis of a soil particle density of 2.65 g/cm^3 and a total porosity of 0.25.	
Total porosity	0.25	Used for unconfined aquifer.	Page O-91, DOE 2009
Effective porosity	0.25	Set to the same as total porosity.	Page O-91, DOE 2009
Hydraulic conductivity (m/yr)	12,775	Slug tests at five monitoring wells in the IDF location (Reidel 2004) indicate a high-permeability condition, ranging from >25 to >45 m/d. These estimates for the hydraulic conductivity beneath the IDF site are consistent with the unconfined aquifer flow through the gravel-dominated facies of the lower Hanford Formation. Use the average of 35 m/day, which converts to 12,775 m/yr.	Reidel 2004
Hydraulic gradient to well	0.00124	Geometric mean of the range from 0.00073 to 0.00209.	Horton 2007
Depth of aquifer contributing to well (m), below water table	10		RESRAD-OFFSITE default

TABLE A-1 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Longitudinal dispersivity (m)	10% of distance traveled	Assumptions used for all sites. Common practices for groundwater transport modeling.	
Horizontal lateral dispersivity (m)	10% of longitudinal dispersivity		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	10% of horizontal lateral dispersivity	Assumptions used for all sites.	

TABLE A-2 Soil/Water Distribution Coefficients (K_d Values)[a] for Different Radionuclides for the Hanford Site

Source	K_d Value (cm^3/g) Unsaturated Zone 1	Unsaturated Zone 2	Saturated Zone	Value Selection Rationale for Unsaturated Zone 1 and Saturated Zone	Source	Value Selection Rationale for Unsaturated Zone 2	Source
Ac	300	30	300	Best K_d value for far field in sand sequence with natural recharge (no impact from wastes).	Krupka et al. 2004, Table 5.6	Use 10% of the value for sand-dominated soil, an approach used in the groundwater data package.	Thorne et al. 2006
Am	1900	190	1900	To be consistent with values used in DOE 2009.	DOE 2009; Beyeler et al. 1999	Same as above.	Thorne et al. 2006
C	4	0.4	4	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Cm	300	30	300	Best K_d value for far field in sand sequence with natural recharge (no impact from wastes).	Table 5.6, Krupka et al. 2004	Same as above.	Thorne et al. 2006
Co	2,000	200	2,000	Best K_d value for far field in sand sequence with natural recharge (no impact from wastes).	Table 5.6, Krupka et al. 2004	Same as above.	Thorne et al. 2006
Cs	80	8	80	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006

TABLE A-2 (Cont.)

Source	K_d Value (cm^3/g) Unsaturated Zone 1	Unsaturated Zone 2	Saturated Zone	Value Selection Rationale for Unsaturated Zone 1 and Saturated Zone	Source	Value Selection Rationale for Unsaturated Zone 2	Source
Fe	220	22	220	Generic value for sand soil.	Site-specific value preferred. Sheppard and Thibault 1990; Yu et al. 2000	Same as above.	Thorne et al. 2006
Gd	825	82.5	825	Generic value for soil.	Yu et al. 2000	Same as above.	Thorne et al. 2006
H	0	0	0	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
I	0	0	0	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Mn	50	5	50	To be consistent with the values used DOE 2009.	Sheppard and Thibault 1990; Yu et al. 2000	Same as above.	Thorne et al. 2006
Mo	10	1	10	To be consistent with the values used DOE 2009.	Sheppard and Thibault 1990; Yu et al. 2000	Same as above.	Thorne et al. 2006
Nb	300	30	300	Best K_d value for far field in sand sequence with natural recharge (no impact from wastes).	Krupka et al. 2004, Table 5.6	Same as above.	Thorne et al. 2006
Ni	400	40	400	To be consistent with the values used in DOE 2009.	DOE 2009; Beyeler et al. 1999	Same as above.	Thorne et al. 2006

TABLE A-2 (Cont.)

Source	K_d Value (cm^3/g) Unsaturated Zone 1	Unsaturated Zone 2	Saturated Zone	Value Selection Rationale for Unsaturated Zone 1 and Saturated Zone	Source	Value Selection Rationale for Unsaturated Zone 2	Source
Np	2.5	0.25	2.5	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Pa	2.5	0.25	2.5	Set to the same values as Np.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Pb	80	8	80	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Po	150	15	150	Generic value for sand soil.	Sheppard and Thibault 1990; Yu et al. 2000	Same as above.	Thorne et al. 2006
Pu	150	15	150	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Ra	10	1	10	Same as Sr.	DOE 2005	Same as above.	Thorne et al. 2006
Sm	300	30	300	Same as Ac.	Krupka et al. 2004, Table 5.6	Same as above.	Thorne et al. 2006
Sr	10	1	10	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Tc	0	0	0	To be consistent with the values used in DOE 2009.	DOE 2005, 2009	Same as above.	Thorne et al. 2006
Th	3,200	320	3,200	To be consistent with the values used in DOE 2009.	DOE 2009; Beyeler et al. 1999	Same as above.	Thorne et al. 2006

TABLE A-2 (Cont.)

Source	K_d Value (cm^3/g) Unsaturated Zone 1	Unsaturated Zone 2	Saturated Zone	Value Selection Rationale for Unsaturated Zone 1 and Saturated Zone	Source	Value Selection Rationale for Unsaturated Zone 2	Source
U	0.6	0.06	0.6	To be consistent with the values used in DOE 2009.	DOE 2009; Beyeler et al. 1999	Same as above.	Thorne et al. 2006

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and the site-specific soil K_d values and cementitious system K_d values for Other Waste.

TABLE A-3 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for INL

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	3.4	Site-specific data.	WRCC 2007
Precipitation (m/yr)	0.22	Site-specific data.	WRCC 2007
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities.	Yu et al. 2007
Evapotranspiration coefficient	0.52	To obtain an infiltration rate of 4 cm/yr, which is close to the value used for the base-case scenario (4.1 cm/yr) in the performance assessment (PA) for the Tank Farm facility.	DOE 2003
Runoff coefficient	0.6212		
Rainfall and runoff	160	To obtain an erosion rate of 1E-5 m/yr for the cover and contamination zone (i.e., would yield more conservative results).	Yu et al. 2007 (applies to the sum of all four parameters at left)
Slope-length-steepness factor	10		
Cover and management factor	0.045		
Support practice factor	1		
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the contaminated zone would not be eroded away (i.e., would yield more conservative results).	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste types, based on GTCC inventory data.	Sandia 2008
Soil erodibility factor	0.00112	To obtain an erosion rate of 1E-5 m/yr.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the buried waste would remain covered within the time frame considered (i.e., would yield more conservative groundwater results because there would be no losses through surface runoff and erosion).	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.00093	To obtain an erosion rate of 1E-5 m/yr.	Yu et al. 2007
Unsaturated Zone 1		Alluvium (surficial sediment, a coarse-grain unit consisting of predominantly sand and gravel).	
Thickness (m)	9.14	Based on Well USGS-51 strata information.	DOE 2003, p. 2-46
Density (g/cm^3)	1.643	Density for sandy clay/clay.	Yu et al. 2000, Table 3.1-1
Total porosity	0.5		DOE 2003

TABLE A-3 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Effective porosity	0.5	Set to the same value as total porosity.	DOE 2003
Field capacity	0.1	Coarse grain retains less water.	
Hydraulic conductivity (m/yr)	29,200	Corresponds to 80 m/d used in the PA for the Tank Farm facility.	DOE 2003, p. 3-42
b-parameter	4.339	This b-parameter value, along with the hydraulic conductivity and infiltration rate, gives a moisture content of 0.16.	
Longitudinal dispersivity (m)	0	No dispersivity is assumed for all the sites.	
Unsaturated Zone 2		Thick-flow basalt units.	
Thickness (m)	94.64	Sum of thicknesses of thick-flow basalt layers. According to Well USGS-51 strata profile, thick-flow basalt constitutes roughly 90% of the total thickness of all basalt layers above the groundwater table.	
Density (g/cm^3)	2	Density for basalt.	DOE 2007
Total porosity	0.05	Value assumed for the basalt unit.	DOE 2003
Effective porosity	0.05	Set to the same as total porosity.	DOE 2003
Field capacity	0.001	Set to a value less than moisture content.	
Hydraulic conductivity (m/yr)	3,650	Corresponds to 10 m/d.	DOE 2003, p. 3-43
b-parameter	0.76	Selected to give a moisture content of 0.004, which is provided in INL's comments on RESRAD-OFFSITE input parameters.	Willcox 2008
Longitudinal dispersivity (m)	0	No dispersivity is assumed for all sites.	
Unsaturated Zone 3		Upper interbed sequence with a low permeability.	
Thickness (m)	7.47	Sum of thicknesses of upper interbeds.	
Density (g/cm^3)	1.46	Value for silt loam.	NUREG/CR-6697 (Yu et al. 2000)
Total porosity	0.57	Porosity used for the C-D interbed in the Radioactive Waste Management Complex (RWMC) PA.	DOE 2006a
Effective porosity	0.57	Set to the same as total porosity.	DOE 2006a
Field capacity	0.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	1.29	Corresponds to 0.0035 m/d, the geometric mean of 0.005 m/d and 0.0025 m/d assumed for the C-CD and D-DE2 interbeds in the Tank Farm facility PA.	DOE 2003

TABLE A-3 (Cont.)

Parameter	Value	Value Selection Rationale	Source
b-parameter	3.6	Calculated mean for silt loam soil. Distribution is log normal (1.28, 0.334). The b-parameter, along with the assumed infiltration rate and hydraulic conductivity, results in a moisture content of 0.414.	NUREG/CR-6697 (Yu et al. 2000)
Longitudinal dispersivity (m)	0	No dispersivity is assumed for all sites.	
Unsaturated Zone 4		Lower sedimentary interbeds.	
Thickness (m)	15.39	The difference between total thickness of the interbeds (estimated to be about 23.35 m according to the Well USGS-51 profile) and the thickness of the upper interbeds, 7.47 m.	
Density (g/cm^3)	1.643	Set to the value for alluvium sediment since they were assumed to have similar hydraulic characteristics in the Tank Farm facility PA.	DOE 2003
Total porosity	0.5		
Effective porosity	0.5	Set to the same as total porosity.	
Field capacity	0.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	29,200	Set to the same value as for alluvium.	DOE 2003
b-parameter	10.4	Value for silty clay. This b-parameter value, along with the infiltration rate and hydraulic conductivity, results in a moisture content of 0.286.	
Longitudinal dispersivity (m)	0	No dispersivity is assumed for all sites.	
Unsaturated Zone 5		Thin-flow basalt units.	
Thickness (m)	10.52	Sum of thicknesses of thin-flow basalt layers. According to Well USGS-51 strata profile, thin flows basalt constitutes roughly 10% of the total thickness of all basalt layers above the groundwater table.	
Density (g/cm^3)	2	Density for basalt.	DOE 2007
Total porosity	0.05	Value assumed for the basalt unit.	DOE 2003
Effective porosity	0.05	Set to the same as total porosity.	DOE 2003
Field capacity	0.001	Set to a value less than moisture content.	
Hydraulic conductivity (m/yr)	365,000	Corresponds to 1,000 m/d.	DOE 2003, p. 3-43
b-parameter	1.67	Selected to give a moisture content of 0.004, which is provided in INL's comments on RESRAD-OFFSITE input parameters.	Willcox 2008

TABLE A-3 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Longitudinal dispersivity (m)	0	No dispersivity is assumed for all sites.	
Saturated zone hydrology			
Thickness (m)	495	Site-specific average (76–914 m).	Anderson and Lewis 1989
Density of saturated zone (g/cm^3)	2	Density for basalt.	DOE 2007
Total porosity	0.05	Value assumed for basalt.	DOE 2003
Effective porosity	0.05	Set to the same as total porosity.	DOE 2003
Hydraulic conductivity (m/yr)	1,979	Corresponds to 5.42 m/d (the geometric mean of the range from 3.0E-3 to 9.8E+3 m/d, reported as the effective hydraulic conductivity of the basalt and interbedded sediments that compose the Snake River Plain Aquifer at and near INL).	DOE 2003
Hydraulic gradient to well	0.00075	Average for the site (0.00019 to 0.0028), close to the average slope of the water table (4 ft/mi) reported in the Tank Farm Facility PA.	McCarthy and McElroy 1995; Anderson and Lewis 1989; DOE 2003
Depth of aquifer contributing to well (m), below the water table	10		RESRAD-OFFSITE default
Longitudinal dispersivity (m)	10% of distance traveled	Assumption used for all sites, which is commonly used for groundwater transport modeling.	
Horizontal lateral dispersivity (m)	10% of longitudinal dispersivity		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	10% of the horizontal lateral dispersivity	Assumption used for all sites.	

TABLE A-4 Soil/Water Distribution Coefficients (K_d Values)[a] for Different Radionuclides for INL

Element	K_d Value (cm^3/g) Unsaturated Zone 1 (alluvium, surficial sediment)	Unsaturated Zone 2 (thick flows basalt units)	Unsaturated Zone 3 (upper interbed sequence with a low permeability)	Unsaturated Zone 4 (lower sedimentary interbeds)	Unsaturated Zone 5 (thin flows basalt units)	Saturated Zone	Value Selection Rationale[b]	Source
Ac	225	0	225	225	0	9	Based on comments from INL, the same K_d value was used for alluvium and interbeds. The basalt K_d was set to 0, and the K_d for the saturated zone was set to 1/25 that of alluvium and interbeds.	DOE 2007
Am	225	0	225	225	0	9	Same as for Ac.	DOE 2007
C	0.4	0	0.4	0.4	0	0.016	Same as for Ac.	DOE 2007
Cm	4,000	0	4,000	4,000	0	160	Same as for Ac.	DOE 2007
Co	10	0	10	10	0	0.40	Same as for Ac.	Jenkins 2001
Cs	500	0	500	500	0	20	Same as for Ac.	Jenkins 2001
Fe	220	0	220	220	0	8.8	Same as for Ac.	Jenkins 2001
Gd	240	0	240	240	0	9.6	Same as for Ac.	Jenkins 2001
H	0	0	0	0	0	0	Same as for Ac.	DOE 2007
I	0	0	0	0	0	0	Same as for Ac.	DOE 2007
Mn	50	0	50	50	0	2	Same as for Ac.	Jenkins 2001
Mo	10	0	10	10	0	0.4	Same as for Ac.	DOE 2007
Nb	500	0	500	500	0	20	Same as for Ac.	DOE 2007
Ni	100	0	100	100	0	4	Same as for Ac.	Jenkins 2001
Np	23	0	23	23	0	0.92	Same as for Ac.	DOE 2007
Pa	8	0	8	8	0	0.32	Same as for Ac.	DOE 2007
Pb	270	0	270	270	0	10.80	Same as for Ac.	DOE 2007
Po	150	0	150	150	0	6	Same as for Ac.	Jenkins 2001
Pu	2,500	0	2,500	2,500	0	100	Same as for Ac.	DOE 2007

TABLE A-4 (Cont.)

Element	K_d Value (cm^3/g) Unsaturated Zone 1 (alluvium, surficial sediment)	Unsaturated Zone 2 (thick flows basalt units)	Unsaturated Zone 3 (upper interbed sequence with a low permeability)	Unsaturated Zone 4 (lower sedimentary interbeds)	Unsaturated Zone 5 (thin flows basalt units)	Saturated Zone	Value Selection Rationale[b]	Source
Ra	575	0	575	575	0	23	Same as for Ac.	DOE 2007
Sm	2,500	0	2,500	2,500	0	100	Same as for Ac.	DOE 2007
Sr	12	0	12	12	0	0.48	Same as for Ac.	Jenkins 2001
Tc	0	0	0	0	0	0	Same as for Ac.	DOE 2007
Th	500	0	500	500	0	20	Same as for Ac.	DOE 2007
U	15.4	0	15.4	15.4	0	0.616	Same as for Ac.	DOE 2007

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and site-specific soil K_d values and cementitious system K_d values for Other Waste.

[b] For INL's review comments on the RESRAD-OFFSITE input parameters, see Willcox (2008).

TABLE A-5 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for LANL

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	2.65	Geometric mean of the distribution log normal (2.65, 1.35)	Distribution information from Henckel 2008. The distribution function is based on wind speed data collected at the meteorological tower at Ta-54 from January 1992 through April 2005 (http://weather.lanl.gov)
Precipitation (m/yr)	0.356	Site-specific data.	Bowen 1990
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities.	Yu et al. 2007
Evapotranspiration coefficient	0.9	To obtain an infiltration rate of 5 mm/yr, which was determined for use in the analysis based on the histogram shown on p. 23 of Stauffer et al. 2005.	Stauffer et al. 2005
Runoff coefficient	0.8596		
Rainfall and runoff	160	To obtain the erosion rates used as the input values for the cover and contamination zone.	Yu et al. 2007 (refers to the sum of all four parameters at left)
Slope-length-steepness factor	10		
Cover and management factor	0.045		
Support practice factor	1		
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the contaminated zone would not be eroded away. Will yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste streams, based on preliminary GTCC inventory data.	Sandia 2008
Soil erodibility factor	0.00112	To obtain the erosion rate used for the input value.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the cover material would not be eroded away completely within the time frame considered.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.00093	To obtain the erosion rate used for the input value.	Yu et al. 2007

TABLE A-5 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Unsaturated Zone 1		Tshirege Member Unit 2.	
Thickness (m)	13	Determined based on as-drilled data for Well R-22.	Stauffer et al. 2005, Table 2
Density (g/cm^3)	1.4	Value for Tshirege Member Unit 2.	Stauffer et al. 2005, Table 4
Total porosity	0.41	Value for Tshirege Member Unit 2.	Stauffer et al. 2005, Table 4
Effective porosity	0.41	Set to the same value as total porosity.	
Field capacity	0.02	Set to a smaller value than 0.024, the moisture content for a saturation of 0.06.	
Hydraulic conductivity (m/yr)	61.81	Corresponds to a permeability of 2.0E-13 m^2 for the Tshirege Member Unit 2.	Stauffer et al. 2005, Table 4
b-parameter	0.175	Selected to give a saturation of 0.06, an approximated value based on the range of site data for Unit 2 presented in Figure 2.1-2 of Birdsell et al. 1999.	Birdsell et al. 1999
Longitudinal dispersivity (m)	0	No dispersion for vadose zone, an assumption applied to all sites.	
Unsaturated Zone 2		Tshirege Units 1v, 1g, and Cerro Toledo Interval.	
Thickness (m)	26	Determined based on as-drilled data for Well R-22.	Stauffer et al. 2005, Table 2
Density (g/cm^3)	1.2	Value for Tshirege Member Unit 2.	Stauffer et al. 2005, Table 4
Total porosity	0.47	Average value for Tshirege Units 1f, 1g, and Cerro Toledo interval.	Stauffer et al. 2005, Table 4
Effective porosity	0.47	Set to the same value as total porosity.	
Field capacity	0.02	Set to a smaller value than 0.094, the moisture content for a saturation of 0.2.	
Hydraulic conductivity (m/yr)	46.36	Corresponds to a permeability of 1.5E-13 m^2, the average for Tshirege Member Units 1v, 1g, and Terro Toledo interval.	Stauffer et al. 2005, Table 4
b-parameter	1.339	Selected to give a saturation of 0.2, an approximated value based on the range of site data for Unit 2 presented in Figure 2.1-2 of Birdsell et al. 1999.	Birdsell et al. 1999
Longitudinal dispersivity (m)	0	No dispersion for vadose zone, an assumption applied to all sites.	

TABLE A-5 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Unsaturated Zone 3		Otowi Member above Guaje Pumice.	
Thickness (m)	16	Determined based on as-drilled data for Well R-22.	Stauffer et al. 2005, Table 2
Density (g/cm^3)	1.2	Value for Otowi Member above Guaje Pumice.	Stauffer et al. 2005, Table 4
Total porosity	0.44	Value for Otowi Member above Guaje Pumice.	Stauffer et al. 2005, Table 4
Effective porosity	0.44	Set to the same value as total porosity.	
Field capacity	0.04	Set to a smaller value than 0.12, the moisture content corresponds to a saturation of 0.27.	
Hydraulic conductivity (m/yr)	71.08	Corresponds to a permeability of 2.3E-13 m^2 for Otowi Member above Guaje Pumice.	Stauffer et al. 2005, Table 4
b-parameter	2.152	Selected to give a saturation of 0.27, an approximated value based on a range of site data in Figure 2.1-2 of Birdsell et al. 1999.	Birdsell et al. 1999
Longitudinal dispersivity (m)	0	No dispersion for vadose zone, an assumption applied to all sites.	
Unsaturated Zone 4		Otowi Member Guaje Pumice.	
Thickness (m)	3	Determined based on as-drilled data for Well R-22.	Stauffer et al. 2005, Table 2
Density (g/cm^3)	0.8	Value for Otowi Member Guaje Pumice.	Stauffer et al. 2005, Table 4
Total porosity	0.67	Value for Otowi Member Guaje Pumice.	Stauffer et al. 2005, Table 4
Effective porosity	0.67	Set to the same value as total porosity.	
Field capacity	0.00001	Set to a small value so that it is not used to reset the saturation ratio calculated.	
Hydraulic conductivity (m/yr)	46.36	Corresponds to a permeability of 1.5E-13 m^2 for the Otowi Member Guaje Pumice.	Stauffer et al. 2005, Table 4
b-parameter	1.891	Selected to give a saturation of 0.26, an approximated value based on a range of site data presented in Figure 2.1-2 of Birdsell et al. 1999.	Birdsell et al. 1999
Longitudinal dispersivity (m)	0	No dispersion for vadose zone, an assumption applied to all sites.	
Unsaturated Zone 5		Cerros del Rio basalts vadose zone.	
Thickness (m)	211	Determined based on as-drilled data for Well R-22.	Stauffer et al. 2005, Table 2
Density (g/cm^3)	2.7	Value for the basalts.	Stauffer et al. 2005, Table 4
Total porosity	0.001	Value for basalts vadose zone	Stauffer et al. 2005, Table 4

TABLE A-5 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Effective porosity	0.001	Set to the same value as total porosity.	
Field capacity	0.00001	Set to a small value so that it is not used to reset the saturation ratio calculated.	
Hydraulic conductivity (m/yr)	309.05	Corresponds to a permeability of 1.0E-12 m^2 for the basalts vadose zone.	Stauffer et al. 2005, Table 4
b-parameter	2.713	Selected to give a saturation of 0.27, an approximated value based on the range of site data presented in Figure 2.1-2 of Birdsell et al. 1999.	Birdsell et al. 1999
Longitudinal dispersivity (m)	0	No dispersion for vadose zone, an assumption applied to all sites.	
Saturated zone hydrology		Cerro del Rio basalts saturated zone.	
Thickness (m)	37.5	Used for groundwater modeling.	Stauffer et al. 2005
Density of saturated zone (g/cm^3)	2.7	Value for the basalts.	Stauffer et al. 2005, Table 4
Total porosity	0.05	Value for basalts saturated zone.	Stauffer et al. 2005, Table 4
Effective porosity	0.05	Set to the same value as total porosity.	
Hydraulic conductivity (m/yr)	309.05	Corresponds to a permeability of 1.0E-12 m^2 for the basalts vadose zone.	Stauffer et al. 2005, Table 4
Hydraulic gradient to well	0.013		Stauffer et al. 2005, Section 3.1.4.3
Depth of aquifer contributing to well (m), below water table	10		RESRAD-OFFSITE default
Longitudinal dispersivity (m)	10% of distance traveled	Assumption applied to all sites considered. A common practice used in groundwater modeling.	
Horizontal lateral dispersivity (m)	10% of the longitudinal dispersivity		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	10% of the horizontal lateral dispersivity	Assumption applied to all sites considered.	

TABLE A-6 Soil/Water Distribution Coefficients (K_d Values)[a] for Different Radionuclides for LANL

Element	K_d Value (cm^3/g) Unsaturated Zone	Saturated Zone	Value Selection Rationale	Source
Ac	130	130	Value suggested by French of LANL for use in RESRAD-OFFSITE modeling to develop a GTCC disposal facility.	French 2008; Wolsberg 1980
Am	2,400	2,400	Most likely value based on the distribution, T(2.0E+02, 2.4E+3, 2.7E+04).	French 2008; Longmire et al. 1996
C	0	0	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984; French 2008
Cm	50	50	For devitrified volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984; French 2008
Co	0.45	0.45	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984; French 2008
Cs	7.5	7.5	Mean of distribution, U(1.0E+0, 1.5E+01; 7.5E+0).	French 2008; Bechtel/SAIC 2004
Fe	209	209	Value for generic soil.	Yu et al. 2000
Gd	50	50	Value for generic soil.	Krier et al. 1997
H	0	0	Assumed no adsorption.	Krier et al. 1997
I	0	0	For volcanic tuff.	Birdsell et al. 1999, Krier et al. 1997
Mn	158	158	Value for generic soil.	Yu et al. 2000
Mo	4	4	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984
Nb	100	100	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984
Ni	50	50	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins 1984
Np	2.2	2.2	Most likely value based on the distribution, T(1.7E-01, 2.2E+0, 3.1E+0).	French 2008; Longmire et al. 1996
Pa	5,500	5,500	Mean of the distribution, TN(5.5E+03, 1.5E+03, 1.0E+03, 1.0E+04).	French 2008; Bechtel/SAIC 2004
Pb	25	25	For volcanic tuff.	Birdsell et al. 1999; Krier et al. 1997; Brookins, 1984
Po	10	10	Value for generic soil.	Yu et al. 2000
Pu	4.10	4.10	Geometric mean for volcanic tuff (4.1-110).	Birdsell et al. 1999, Krier et al. 1997
Ra	500	500	Mean of the distribution, U(1.0E+2, 1.0E+03, 5.0E+02).	French 2008; Bechtel/SAIC 2004
Sm	50	50	Set to the same value as Gd.	Krier et al. 1997; Baes et al. 1984
Sr	40	40	Mean of the distribution, U(1.0E+0, 7.0E+01, 4.0E+01).	French 2008; Bechtel/SAIC 2004
Tc	0	0	Assumed no adsorption.	Birdsell et al. 1999; Krier et al. 1997; French 2008; Longmire et al. 1996
Th	5,000	5,000	Mean of the distribution, U(1.0E+3, 1.0E+04, 5.0E+03).	French 2008; Bechtel/SAIC 2004
U	2.4	2.4	Most likely value based on the distribution, T(1.4E+0, 2.4E+0, 3.5E+0).	French 2008; Longmire et al. 1996

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and site-specific soil K_d values and cementitious system K_d values for other wastes.

TABLE A-7 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for NNSS

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	2.6	Site-specific data.	Bechtel Nevada 2006
Precipitation (m/yr)	0.13	Site-specific data.	National Security Technologies, LLC 2008
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities.	Yu et al. 2007
Evapotranspiration coefficient	0.99	Selected to give an infiltration rate of 0.00003 m/yr, which is the site-specific hydraulic conductivity for the vadose zone.	Shott et al. 1998
Runoff coefficient	0.977		
Rainfall and runoff	160	To obtain the erosion rates used as the input values for the cover and contamination zone.	Yu et al. 2007 (refers to sum of all four parameters at left)
Slope-length-steepness factor	0.4		
Cover and management factor	0.003		
Support practice factor	1		
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Choose a small value so that the contaminated zone would not be eroded away. Will yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste streams, based on preliminary GTCC inventory data.	Sandia 2008
Soil erodibility factor	0.42	To obtain the erosion rate used as the input value.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Choose a small value so that the cover material would not be eroded away completely within the time frame considered. Would yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.35	To obtain the erosion rate used as the input value.	Yu et al. 2007
Unsaturated Zone 1			
Thickness (m)	246	Average of the range from 235.3 to 256.6 m.	Bechtel Nevada 2001, 2002
Density (g/cm^3)	1.65	Site-specific data.	Shott et al. 1998
Total porosity	0.36	Site-specific data.	Shott et al. 1998

TABLE A-7 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Effective porosity	0.36	Site-specific data.	Shott et al. 1998
Field capacity	0.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	0.00003	Site-specific data.	Shott et al. 1998
b-parameter	5.3		RESRAD-OFFSITE default
Longitudinal dispersivity (m)	0	No dispersivity was assumed for the unsaturated zone.	Assumption used for all sites
Saturated zone hydrology			
Thickness (m)	220	Average value from well monitoring data.	Reynolds Electrical & Engineering Company, Inc. 1994
Density of saturated zone (g/cm^3)	1.6	Site-specific data.	Shott et al. 1998
Total porosity	0.36	Site-specific data.	Shott et al. 1998
Effective porosity	0.36	Site-specific data.	Shott et al. 1998
Hydraulic conductivity (m/yr)	439	Site-specific data.	Shott et al. 1998
Hydraulic gradient to well	9.70E-05	Site-specific data.	National Security Technologies, LLC 2008
Depth of aquifer contributing to well (m), below water table	10		RESRAD-OFFSITE default
Longitudinal dispersivity (m)	10% of the distance traveled		Assumption used for all sites Common practices for groundwater modeling.
Horizontal lateral dispersivity (m)	10% of the longitudinal dispersivity		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	10% of the horizontal lateral dispersivity		Assumption used for all sites

TABLE A-8 Soil/Water Distribution Coefficients for Different Radionuclides for NNSS[a]

Element	K_d Value (cm^3/g) Unsaturated Zone	Saturated Zone	Value Selection Rationale	Source
Ac	7,000	7,000	Mean value of the distribution used in the Area 5 Radioactive Waste Management Site (RWMS) performance assessment (PA) model.	Bechtel Nevada 2006
Am	7,000	7,000	Same as Ac.	Bechtel Nevada 2006
C	0	0	Same as Ac.	Bechtel Nevada 2006
Cm	4,000	4,000	Suggested value for sandy soil.	Yu et al. 2000
Co	60	60	Suggested value for sandy soil.	Yu et al. 2000
Cs	280	280	Suggested value for sandy soil.	Yu et al. 2000
Fe	209	209	Suggested value for generic soil.	Yu et al. 2000
Gd	825	825	Suggested value for generic soil.	Yu et al. 2000
H	0	0	Value used in the Area 5 RWMS PA model.	Bechtel Nevada 2006
I	0	0	Value used in the Area 5 RWMS PA model.	Bechtel Nevada 2006
Mn	50	50	Suggested value for sandy soil.	Yu et al. 2000
Mo	10	10	Suggested value for sandy soil.	Yu et al. 2000
Nb	7,000	7,000	Mean value of the distribution used in the Area 5 RWMS PA model.	Bechtel Nevada 2006
Ni	100	100	Same as Nb.	Bechtel Nevada 2006
Np	5	5	Same as Nb.	Bechtel Nevada 2006
Pa	5	5	Same as Nb.	Bechtel Nevada 2006
Pb	300	300	Same as Nb.	Bechtel Nevada 2006
Po	300	300	Set to the same value as Pb.	Bechtel Nevada 2006
Pu	7.5	7.5	Same as Nb.	Bechtel Nevada 2006
Ra	185	185	Same as Nb.	Bechtel Nevada 2006
Sm	245	245	Set to the same value as Eu used in the Area 5 RWMS PA model.	Bechtel Nevada 2006
Sr	420	420	Same as Nb.	Bechtel Nevada 2006
Tc	0	0	Same as Nb.	Bechtel Nevada 2006
Th	7,000	7,000	Same as Nb.	Bechtel Nevada 2006
U	0.8	0.8	Same as Nb.	Bechtel Nevada 2006

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and site-specific soil K_d values and cementitious system K_d values for other wastes.

TABLE A-9 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for SRS

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	3	Site-specific data.	SRCC 2007a
Precipitation (m/yr)	1.2	Site-specific data.	SRCC 2007b; Cook et al. 2004
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities	Yu et al. 2007
Evapotranspiration coefficient	0.598	Along with an evapotranspiration coefficient of 0.598, would give an infiltration rate of 0.376 m/yr (14.8 in./yr). The Flach et al. 2005 estimate for trenches covered with a 4-ft operational soil cover and topsoil is 14.8 in./yr. The Young and Pohlmann 2003 study shows an infiltration rate ranging from 9 to 16 in./yr with a median value of 14.8 in./yr, or 1/3 of the yearly rainfall of approximately 48 in. The above information is cited in WSRC 2008, Part C, pp. 68 and 69.	WSRC 2008 (applies to both parameters at left)
Runoff coefficient	0.221		
Rainfall and runoff	160	To obtain the desired erosion rates for the cover and contamination zone.	Yu et al. 2007 (applies to sum of all four parameters at left)
Slope-length-steepness factor	10		
Cover and management factor	0.045		
Support practice factor	1		
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.01E-05	Chose a small value so that the contaminated zone would not be eroded away. Will yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste streams, based on preliminary GTCC inventory data.	Sandia 2008
Soil erodibility factor	0.00112	To obtain the desired erosion rate.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Chose a small value so that the cover material would not be eroded away completely within the time frame considered.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.00093	To obtain the desired erosion rate.	Yu et al. 2007

TABLE A-9 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Unsaturated Zone 1			
Thickness (m)	6.1	According to Part B, Figure 1-6, of WSRC 2008, the thickness of the upper vadose zone can be calculated as the sum of those of the soil fill (4 ft), upper waste zone (2.5 ft), and lower waste zone (13.5 ft). The total is 20 ft, (i.e., 6.1 m).	WSRC 2008, Figure 1-6
Density (g/cm^3)	1.65	Calculated with a soil particle density of 2.70 g/cm^3 and an effective porosity of 0.39.	WSRC 2008, Part B, Table 1-14
Total porosity	0.39		WSRC 2008, Part B, Table 1-14, p. 1-55
Effective porosity	0.39	Set to the same value as total porosity.	
Field capacity	0.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	2.7	For upper vadose zone.	WSRC 2008, Part B, Table 1-14, Appendix G, Table G-2
b-parameter	6.62	Mean of distribution, log normal (LN) (1.89, 0.260) for sandy clay soil	Yu et al. 2000 (NUREG/CR-6697)
Longitudinal dispersivity (m)	0		WSRC 2008, p. 2-43
Unsaturated Zone 2			
Thickness (m)	16.9	The water table in the E- and Z-Areas is approximately 20 to 25 m below the ground surface.	Kaplan 2006
Density (g/cm^3)	1.62	Calculated with a soil particle density of 2.66 g/cm^3 and an effective porosity of 0.39.	WSRC 2008, Table 1-14
Total porosity	0.39	Used for PORFLOW transport analysis for lower vadose zone.	WSRC 2008, p. 2043
Effective porosity	0.39	For lower vadose zone.	WSRC 2008, Table 1-14
Field capacity	0.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	29	For lower vadose zone.	WSRC 2008, Tables 1-14, G-2
b-parameter	4.1	Mean of distribution, LN (1.41, 0.275), for sandy clay loam.	Yu et al. 2000 (NUREG/CR-6697)
Longitudinal dispersivity (m)	0		WSRC 2008, p. 2-43
Saturated zone hydrology			
Thickness (m)	27.85	Mean of the range of site-specific data (15.5–40.2 m), including thicknesses from the upper and lower aquifer zones and the tan clay confining zone.	For E Area, Cook et al. 2004
Density of saturated zone (g/cm^3)	1.39	Considering the distribution of local clayey sediments throughout the sandy aquifer.	WSRC 2008, p. 1-67
Total porosity	0.38	For sandy material associated with aquifers.	WSRC 2008, p. 1-57

TABLE A-9 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Effective porosity	0.25	Considering the distribution of local clayey sediments throughout the sandy aquifer.	WSRC 2008, p. 1-67
Hydraulic conductivity (m/yr)	1,265	Geometric mean of the values for Upper Three Runs aquifer and Lower Three Runs aquifers.	WSRC 2008, p. 1-57 and Table G-1
Hydraulic gradient to well	0.0079	Geometric mean of the site-specific range for Aquifer Unit IIB, 0.0035–0.018.	MMES et al. 1994
Depth of aquifer contributing to well (m), below water table	10		RESRAD-OFFSITE default
Longitudinal dispersivity (m)	10% of the distance traveled		Assumptions used for all sites. Common practices for groundwater modeling.
Horizontal lateral dispersivity (m)	1% of distance traveled		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	0.1% of distance traveled		Assumption used for all sites.

TABLE A-10 Soil/Water Distribution Coefficients for Different Radionuclides for SRS[a]

Element	K_d Value (cm^3/g) Unsaturated Zone 1	Unsaturated Zone 2	Saturated Zone	Value Selection Rationale	Source
Ac	8,500	1,100	1,100	Clay/sand material best estimated K_d. Clay material K_d for unsaturated Zone 1. Sand material K_d for unsaturated Zone 2 and saturated zone.	WSRC 2008, Table 2-33; Kaplan 2006
Am	8,500	1,100	1,100	Same as above.	Same as above.
C	0	0	0	Same as above.	Same as above.
Cm	8,500	1,100	1,100	Same as above.	Same as above.
Co	30	7	7	Best value for clayey/sandy sediment.	Kaplan 2006, Table 10
Cs	250	50	50	Best value for sandy/clayey sediment.	Kaplan 2006, Table 10
Fe	400	200	200	Best value for clayey/sandy soil.	Kaplan 2007
Gd	8,500	1,100	1,100	Best value for clayey/sandy sediment.	Kaplan 2006, Table 10
H	0	0	0	Clay/sand material best estimated K_d. Clay material K_d for unsaturated Zone 1. Sand material K_d for unsaturated Zone 2 and saturated zone.	WSRC 2008, Table 2-33; the values listed were obtained from Kaplan 2006
I	0.6	0	0	Same as above.	Same as above.
Mn	200	15	15	Best value for clayey/sandy soil.	Kaplan 2007
Mo	120	6	6	Best value for clayey/sandy soil.	Kaplan 2007
Nb	0	0	0	Same as above.	WSRC 2008, Table 2-33; the values listed were obtained from Kaplan 2006
Ni	30	7	7	Same as above.	Same as above.
Np	35	0.6	0.6	Same as above.	Same as above.
Pa	35	0.6	0.6	Same as above.	Same as above.
Pb	5,000	2,000	2,000	Same as above.	Same as above.
Po	5,000	2,000	2,000	Best value for clayey/sandy soil.	Kaplan 2006
Pu	5,900	270	270	Clay/sand material best estimated K_d. Clay material K_d for unsaturated Zone 1. Sand material K_d for unsaturated Zone 2 and saturated zone.	WSRC 2008, Table 2-33; the values listed were obtained from Kaplan 2006
Ra	17	5	5	Same as above.	Same as above.
Sr	17	5	5	Same as above.	Same as above.
Sm	8,500	1,100	1,100	Same as above.	Same as above.
Tc	0.2	0.1	0.1	Same as above.	Same as above.
Th	2,000	900	900	Same as above.	Best value for sandy soil, Kaplan 2006
U	300	200	200	Same as above.	Same as above.

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and site-specific soil K_d values and cementitious system K_d values for other wastes.

TABLE A-11 RESRAD-OFFSITE Input Parameter Values for Groundwater Analysis for WIPP Vicinity

Parameter	Value	Value Selection Rationale	Source
Site properties			
Wind speed (m/s)	3.71	Site-specific data, low end of the most prevalent range.	DOE 2006b
Precipitation (m/yr)	0.3048	Site-specific data (about 12 in.).	DOE 2006b
Primary contamination area properties			
Irrigation (m/yr)	0	No agricultural activities.	Yu et al. 2007
Evapotranspiration coefficient	0.9934	To obtain an infiltration rate of 0.002 m/yr, which is suggested by WIPP staff.	Campbell et al. 1996
Runoff coefficient	0.0125	Because of the flat ground surface, the annual runoff is typically 0.1 to 0.2 in. The average value of 0.15 in. converts to a runoff coefficient of 0.0125.	For annual runoff — DOE 2006b
Rainfall and runoff	160	To obtain the erosion rates used as input values for the cover and contamination zone.	Yu et al. 2007 (applies to sum of all four parameters at left)
Slope-length-steepness factor	0.4		
Cover and management factor	0.003		
Support practice factor	1		
Contaminated zone			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Choose a small value so that the contaminated zone would not be eroded away. Will yield more conservative results.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.8	Estimated average for different waste streams, based on preliminary GTCC inventory data.	Sandia 2008
Soil erodibility factor	0.42	To obtain the erosion rate used as the input value.	Yu et al. 2007
Field capacity	0.3		RESRAD-OFFSITE default
b-parameter	5.3		RESRAD-OFFSITE default
Hydraulic conductivity (m/yr)	10		RESRAD-OFFSITE default
Cover layer			
Total porosity	0.4		RESRAD-OFFSITE default
Erosion rate (m/yr)	1.00E-05	Choose a small value so that the cover material would not be eroded away completely within the time frame considered.	Yu et al. 2007
Dry bulk density (g/cm^3)	1.5		RESRAD-OFFSITE default
Soil erodibility factor	0.35	To obtain the erosion rate used as the input value.	Yu et al. 2007

TABLE A-11 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Unsaturated Zone 1		The perched aquifer located in the Dewey Lake Formation was selected as the groundwater of concern in the modeling. Among the subsurface and deep groundwater aquifers, it has the best water quality and was classified as a U.S. Environmental Protection Agency (EPA) Class II aquifer. Although in general, the perched aquifer is not the water supply to wells, about 1 mi south of the WIPP site, it is the water source for domestic and supply wells. The depth to the groundwater table (153 m) specified in Table 4.4-1 of Sandia 2007 (Task 3.4 report) also corresponds to this aquifer in Dewey Lake Formation.	
Thickness (m)	153	Comparable to the groundwater level measurement data.	DOE 2006b; Sandia 2007
Density (g/cm^3)	1.47	Average of sandy and silty soils. According to the description in DOE 2006, the Dewey Lake Redbeds Formation consists of alternating thin beds of siltstone and fine-grained sandstone.	Yu et al. 2000
Total porosity	0.445	Average of silty and sandy soil.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Effective porosity	0.404	Average of silty and sandy soil.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Field capacity	0.1	Use a smaller value because the moisture content is expected to be low because of the small infiltration rate.	
Hydraulic conductivity (m/yr)	107.31	Geometric mean for sandy and silty soils. Gemetric mean for sandy soil was calculated as 803.5 m/yr. Geometric mean for silty soil was calculated as 14.33 m/yr.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
b-parameter	1.76	Geometric mean for sandy and silty soils. Geometric mean for sandy soil was calculated as 0.975. Geometric mean for silty soil was calculated as 3.1899.	Distribution information for sand and silt soils from NUREG-6697 (Yu et al. 2000)
Longitudinal dispersivity (m)	0	No dispersivity was assumed for the unsaturated zone.	Assumption used for all sites.

TABLE A-11 (Cont.)

Parameter	Value	Value Selection Rationale	Source
Saturated zone hydrology		The perched aquifer located in the Dewey Lake Formation was selected as the groundwater of concern.	
Thickness (m)	5.1	Saturated thickness for the natural water table identified in middle Dewey Lake.	DOE 2006b
Density of saturated zone (g/cm^3)	1.47	Average of sandy and silty soils.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Total porosity	0.445	Average of silt and sand soil.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Effective porosity	0.404	Average of silt and sand soil.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Hydraulic conductivity (m/yr)	107.31	Geometric mean for sandy and silty soils. Gemetric mean for sandy soil was calculated as 803.5 m/yr. Geometric mean for silty soil was calculated as 14.33 m/yr.	Distribution information for silt and sand soils from NUREG-6697 (Yu et al. 2000)
Hydraulic gradient to well	0.017	The gradient in Dewey Lake is 20–40 ft/mi in the east. It is up to 150 ft/mi to the west. Average is 90 ft/mi.	Powers 1978
Depth of aquifer contributing to well (m), below water table	5.1	Set to the depth of aquifer.	Yu et al. 2007
Longitudinal dispersivity (m)	10% of the distance traveled		Assumption used for all sites. Common practices for groundwater modeling.
Horizontal lateral dispersivity (m)	10% of the longitudinal dispersivity		
Disperse vertically (yes/no)	Yes	To consider dispersion.	Yu et al. 2007
Vertical lateral dispersivity (m)	10% of the horizontal lateral dispersivity		Assumption used for all sites.

TABLE A-12 Soil/Water Distribution Coefficients for Different Radionuclides for WIPP Vicinity[a]

Element	K_d Value (cm^3/g) Unsaturated Zone	Saturated Zone	Value Selection Rationale[b]	Source
Ac	450	450	Value for sandy soil	Sheppard and Thibault 1990
Am	1,445	1,445	Value for generic soil	NUREG/CR-6697 (Yu et al. 2000)
C	5	5	Value for sandy soil	Sheppard and Thibault 1990
Cm	4,000	4,000	Value for sandy soil	Sheppard and Thibault 1990
Co	60	60	Value for sandy soil	Sheppard and Thibault 1990
Cs	280	280	Value for sandy soil	Sheppard and Thibault 1990
Fe	209	209	Value for generic soil	NUREG/CR-6697 (Yu et al. 2000)
Gd	825	825	Value for generic soil	NUREG/CR-6697 (Yu et al. 2000)
H	0.06	0.06	Value for generic soil	NUREG/CR-6697 (Yu et al. 2000)
I	1	1	Value for sandy soil	Sheppard and Thibault 1990
Mn	50	50	Value for sandy soil	Sheppard and Thibault 1990
Mo	10	10	Value for sandy soil	Sheppard and Thibault 1990
Nb	160	160	Value for sandy soil	Sheppard and Thibault 1990
Ni	400	400	Value for sandy soil	Sheppard and Thibault 1990
Np	5	5	Value for sandy soil	Sheppard and Thibault 1990
Pa	380	380	Value for generic soil	NUREG/CR-6697 (Yu et al. 2000)
Pb	270	270	Value for sandy soil	Sheppard and Thibault 1990
Po	150	150	Value for sandy soil	Sheppard and Thibault 1990
Pu	550	550	Value for sandy soil	Sheppard and Thibault 1990
Ra	500	500	Value for sandy soil	Sheppard and Thibault 1990
Sr	15	15	Value for sandy soil	Sheppard and Thibault 1990
Sm	245	245	Value of sandy soil	Sheppard and Thibault 1990
Tc	0.1	0.1	Value for sandy soil	Sheppard and Thibault 1990
Th	3,200	3,200	Value for sandy soil	Sheppard and Thibault 1990
U	35	35	Value for sandy soil	Sheppard and Thibault 1990

[a] K_d values are listed for the unsaturated zones and the saturated zone. For the contaminated zone, the release fraction of radionuclides is correlated with the metal corrosion rate for the activated metal wastes, the site-specific soil K_d values for sealed sources, and site-specific soil K_d values and cementitious system K_d values for other wastes.

[b] The K_d value selected was the smaller one of either the value for sandy soil given in Sheppard and Thibault (1990) or the value for generic soil recommended in NUREG/CR-6697 (Yu et al. 2000).

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APPENDIX B:

VALUES OF DISTRIBUTION COEFFICIENTS FOR RADIONUCLIDES IN CEMENTITIOUS SYSTEMS

In evaluating long-term impacts on groundwater resulting from the disposal of the GTCC LLRW and GTCC-like wastes at the six DOE sites and four different geographic regions, it was assumed that Other Waste, including both remote-handled (RH) and contact-handled (CH) wastes, would be solidified during waste packaging. The solidification was assumed to use cement as the grouting agent. To estimate the radionuclide release rates from the grouting system, the distribution coefficient (K_d) values of radionuclides in this system had to be determined first. This appendix documents the selection of appropriate K_d values for the cementitous system.

According to data in the literature, slag-containing cement that has a low reduction potential would effectively reduce the leaching of Ni, Tc, and U more than cement that does not contain slag and that does have an oxidizing potential. Because Tc and U are major radionuclides of concern with regard to the Other Waste - RH and Other Waste - CH, it was assumed that slag-containing cement would be used to solidify the GTCC and GTCC-like wastes. Table B-1 presents the K_d values obtained from different literature sources. For comparison, the reported K_d values for both types of cementitious systems are included.

In the Pacific Northwest National Laboratory (PNNL) report (Krupka et al. 2004), only one set of K_ds (listed in the second column of Table B-1) was available that was judged to correspond to oxidizing cementitious systems (i.e., without slag material). Because Kaplan was one of the authors of both the PNNL and Westinghouse Savannah River Company or WSRC report (Kaplan 2006), and because the WSRC report was published later (in 2006) than the PNNL report (in 2004), it was reasoned that the WSRC report contains additional information that was not available when the PNNL report was published. Therefore, during the K_d-value selection process, data from the WSRC report were compared with data from the Savannah River National Laboratory (SRNL) report (Kaplan 2007) and Battelle report (Mattigod et al. 2002). The last two columns of Table B-1 list the selected K_d values for the oxidizing and reducing cementitous systems, respectively. K_ds for the reducing cementitious system were used in the groundwater evaluation. These values are generally the lowest (or most conservative in that they allow for the most potential leaching into the groundwater) of the reported values, unless multiple sources provided the same higher value. In addition to the reported values, chemical similarity was also considered in determining the values to be used in the groundwater analysis. The use of the smallest K_d values would result in more conservative (higher) dose estimates.

As shown in Table B-1, the final K_d values for the oxidizing cementitious system are the same as those for the reducing cementitious system, except for Ni, Tc, and U; for these, the K_d values for the reducing cementitous system are greater than those for the oxidizing cementitious system. Therefore, the reducing cementitous system (cement with slags) is a better choice for grouting in terms of reducing the leaching of Ni, Tc, and U isotopes from the GTCC and GTCC-like wastes.

TABLE B-1 Distribution Coefficients for Cementitious Systems (moderately aged concrete)[a]

Element	PNNL-13037 Rev. 2 (Krupka et al. 2004)	WSRC-TR-2006-0004 Rev. 0 (Kaplan 2006)		SRNL-RPA-2007-00006 (Kaplan 2007)		Battelle (Mattigod et al. 2002)[b]		Battelle (Mattigod et al. 2002)	Selected Value for Use in the EIS Analyses	
		Oxidizing	Reducing	Oxidizing	Reducing	Oxidizing	Reducing	Haddam Neck Samples	Oxidizing	Reducing
Ac	5,000	5,000	5,000	–	–	–	–	–	1,000	1,000
Am	5,000	5,000	5,000	–	–	1,000–5,000	1,000–5,000	>230 – >1,750	1,000	1,000
C	10	10	10	–	–	100	100	–	10	10
Cm	5,000	5,000	5,000	–	–	1,000	1,000	–	1,000	1,000
Co	100	1,000	1,000	–	–	100	100	3,400–32,500, 180–380	100	100
Cs	30	4	4	–	–	20	20	14,800–26,800, 34–240	4	4
Fe	–	–	–	5,000	1,000	100	100	7–18	12	12
Gd	–	5,000	5,000	–	–	–	–	–	1,000	1,000
H	0	0	0	–	–	0	0	–	0	0
I	8	20	20	–	–	–	–	–	20	20
Mn	–	–	–	100	100	–	–	–	100	100
Mo	–	–	–	0.1	0.1	–	–	–	0.1	0.1
Nb	40	1,000	1,000	–	–	1,000	1,000	–	1,000	1,000
Ni	100	1,000	1,000	–	–	100	100	10-61	10	100
Np	2,000	2,000	2,000	–	–	2,000–5,000	5,000	>300 – >510	300	300
Pa	2,000	2,000	2,000	–	–	–	–	–	2,000	2,000
Pb	5,000	500	500	–	–	–	–	–	500	500
Po		500	500	–	–	–	–	–	500	500
Pu	5,000	5,000	5,000	–	–	5,000	5,000	>1,300 – >5,600	5,000	5,000
Ra	100	100	100	–	–	–	–	–	100	100
Sm	–	5,000	5,000	–	–	–	–	–	1,000	1,000
Sr	–	1	1	–	–	1–3	1–3	10–11	1	1
Tc	0	0	5,000	–	–	0-1	1,000	6–21	0	1,000
Th	5,000	5,000	5,000	–	–	5,000	5,000	–	5,000	5,000
U	1,000	1,000	5,000	–	–	–	–	–	1,000	5,000

[a] Sources for the K_d values for cementitious systems are Krupka et al. (2004), Kaplan (2006, 2007), and Mattigod et al. (2002).

[b] Values obtained from Table 5 of Mattigod et al. (2002) for Environment II, which considers moderately aged cement that may last from 100–10,000 years to 1,000–100,000 years. The original sources cited by Mattigod et al. (2002) for the K_d values are Krupka and Serne (1998) and Bradbury and Van Loon (1998).

[c] A dash means no information was available.

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APPENDIX C:

CALCULATION OF THE FACTORS USED TO SCALE DOSES FROM THE DRINKING WATER PATHWAY TO OBTAIN DOSES FROM ALL GROUNDWATER-RELATED PATHWAYS

Estimates of potential radiation exposures that could result from using contaminated groundwater after the closure of the disposal facility were obtained by following a three-step procedure, as discussed in Section 4.1. The first step of the procedure was to calculate the radiation dose from the drinking water pathway for individual radionuclides contained in the waste materials. In the second step, the radiation dose associated with the drinking water pathway was scaled to obtain the radiation dose associated with all the groundwater-related pathways. The all-pathway dose summed across all radionuclides contained in the waste material yielded the final dose results reported in Chapter 4 of this report. This appendix describes the derivation of the scaling factors used in Step 2 of the dose calculation procedure.

The scaling factor is the ratio of radiation dose associated with all groundwater-related pathways to the radiation dose associated with only the drinking water pathway. Different radionuclides have different scaling factors. For the resident farmer scenario considered in the groundwater modeling, the potential uses of groundwater include ingestion, household activities, irrigation of agricultural fields, and feeding livestock. Radionuclides could accumulate in the agricultural fields, since the irrigation was assumed to continue for 30 years. This accumulation would give rise to the potential radiation exposure through external radiation, inhalation, and possibly soil ingestion. Relationships between the various exposure pathways to the contaminated groundwater are illustrated in Figure 4-1. RESRAD-OFFSITE was used to develop the values for the scaling factors, because it accounts for the accumulation of radionuclides at off-site locations and tracks the loss in this accumulation over time through radiological ingrowth and decay, erosion, diffusion, resuspension, and leaching.

To develop scaling factors, a contamination source (in soil) with a concentration of 1,000,000 pCi/g for each radionuclide of concern was assumed. The distribution coefficient (K_d) value for each radionuclide in the source was assumed to be 100 cm^3/g. The precipitation rate was set to 1.4 m/yr, and it was assumed that the contaminated area would not be irrigated. RESRAD-OFFSITE default values (0.2 and 0.5) were used for the runoff and evapotranspiration coefficients. With the above settings, the average water infiltration rate to the contamination source was 0.56 m/yr. Radionuclides in the contamination source would leach out with water; however, because of the significant adsorption to soil particles, the leaching would proceed slowly but stably over time. In other words, the leach rate would be maintained at a constant level for an extended period of time.

To observe groundwater contamination soon after initiation of leaching from the contaminated zone, a thickness of 0.3 m was assumed for the unsaturated zone, with a K_d value of 1 cm^3/g. The well that provides water for daily use was assumed to be at the downgradient edge of the contaminated area so that travel time of radionuclides in the groundwater aquifer was reduced to a minimum. Except for dispersivities, which were set to 0, the other parameters for the saturated zone were set to the RESRAD-OFFSITE default values. By assuming a well water pumping rate of 2,500 m^3/yr, the groundwater concentration would reach 4.10 pCi/L in 5 years and stay around that level for the next 100 years. The well water pumping rate of 2,500 m^3/yr was obtained by assuming a water ingestion rate of 730 L/yr per person for a family of four; a water use of 225 L/d per person for household activities; an ingestion rate of 50 L/d for each of two beef cattle; an ingestion rate of 160 L/d for each of two milk cows; an irrigation rate of 0.2 m/yr (for Hanford, INL, LANL, the WIPP Vicinity, Region III, and Region IV) or 0.1 m/yr (for SRS, Region I, and Region II) for a fruit, grain, and nonleafy vegetable field of 500 m^2; the same

irrigation rate for a leafy vegetable field of 500 m^2; and an irrigation rate of 0.1 m/yr for a pasture, silage, and livestock feed grain field of about 20,000 m^2.

To obtain radiation doses resulting from the use of contaminated groundwater, all the RESRAD-OFFSITE exposure pathways were activated except for the aquatic food pathway. The activated exposure pathways include external radiation; inhalation of dust particles; ingestion of soil, plant, meat, milk, and water; and inhalation of radon. To avoid the inclusion of a non-water-related dose, a thick cover layer was placed on top of the contamination source to inhibit source erosion. Furthermore, the receptor was assumed to spend no time at the primary contaminated area. The receptor was assumed to spend 50% of the time indoors at the off-site dwelling area and 5% outdoors at the dwelling area and each of agricultural fields and livestock feed areas, which together made up 25% of the time.

For the agricultural fields and livestock feed areas, site-specific soil K_d values were used. In addition to soil K_d values, the evapotranspiration coefficient was also assigned a site-specific value if one was available; otherwise, an assumed value of 0.75 was used. The evapotranspiration coefficient determines the fraction of irrigation water infiltrating to deeper soils. The value of the runoff coefficient was then derived so that the infiltration rate from precipitation (fixed at 1.4 m) would equal the background infiltration rate at each site.

Half of the plant food, meat, and milk ingested by the resident farmer was assumed to be produced with the use of contaminated groundwater. The ingestion rates were set to the RESRAD-OFFSITE default values; it was assumed that the farmer would ingest 160 kg/yr of fruit, grain, and nonleafy vegetables; 14 kg/yr of leafy vegetables; 63 kg/yr of meat; and 92 L/yr of milk. In addition to food, the farmer was also assumed to ingest 36.5 g/yr of surface soil.

Annual radiation doses for 35 years were retrieved after RESRAD-OFFSITE finished the calculations. The selection of 35 years was made to consider the accumulation of radionuclides in soil due to irrigation for 30 years, which is the assumed exposure duration for the resident farmer. As discussed previously, the groundwater concentration reached 4.1 pCi/L within 5 years and stayed at that level for more than 100 years. For each radionuclide, the ratio of the annual radiation dose from all exposure pathways to that from the drinking water pathway was calculated over 35 years, and the maximum ratio was selected as the scaling factor for that radionuclide. Depending on the leachability of each radionuclide in the agricultural fields, the ratio could vary over time, although in most cases, it was about the same. The use of the maximum ratio as the scaling factor for each radionuclide would result in more conservative all-pathway doses being calculated.

Table C-1 lists the scaling factors developed for five of the DOE sites (Hanford, INL, LANL, SRS, and WIPP Vicinity) and the four geographic regions considered for the disposal of GTCC LLRW and GTCC-like waste. Scaling factors were not derived for NNSS because there would be no groundwater contamination within the time frame (100,000 years) considered for this analysis.

TABLE C.1 Scaling Factors Developed for the Various Sites Considered for the Disposal of GTCC LLRW and GTCC-Like Waste

Nuclide	INL	LANL	SRS	WIPP	Hanford	Region I	Region II	Region III	Region IV
Am-241	1.07E+00	1.07E+00	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Am-243	-[a]	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
C-14	1.17E+00	1.15E+00	1.11E+00	2.25E+00	2.10E+00	1.12E+00	1.11E+00	1.12E+00	1.15E+00
Cm-245	–	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Cm-246	–	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
I-129	1.28E+00	1.29E+00	1.25E+00	1.29E+00	1.29E+00	1.25E+00	1.25E+00	1.25E+00	1.38E+00
Nb-94	–	–	1.04E+00	2.81E+00	2.83E+00	2.07E+00	2.06E+00	2.16E+00	3.28E+00
Ni-59	1.51E+00	1.51E+00	1.44E+00	1.51E+00	1.51E+00	1.44E+00	1.45E+00	1.45E+00	1.68E+00
Ni-63	–	–	1.44E+00	1.51E+00	1.51E+00	1.44E+00	1.45E+00	1.45E+00	1.68E+00
Np-237	1.09E+00	1.08E+00	1.05E+00	1.09E+00	1.08E+00	1.04E+00	1.04E+00	1.04E+00	1.09E+00
Pu-238	1.07E+00	1.07E+00	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Pu-239	1.07E+00	1.07E+00	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Pu-240	–	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Pu-241	–	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Pu-242	–	–	1.04E+00	1.07E+00	1.07E+00	1.04E+00	1.04E+00	1.04E+00	1.07E+00
Ra-226	–	–	1.17E+00	1.20E+00	1.20E+00	1.15E+00	1.15E+00	1.15E+00	1.19E+00
Tc-99	1.15E+00	1.19E+00	1.07E+00	1.25E+00	1.20E+00	1.51E+00	2.14E+00	2.67E+00	2.72E+00
Th-228	–	–	–	–	1.09E+00	1.05E+00	1.05E+00	1.05E+00	1.10E+00
Th-232	–	–	–	–	1.11E+00	1.06E+00	1.06E+00	1.06E+00	1.12E+00
U-233	1.08E+00	1.08E+00	1.05E+00	1.09E+00	1.08E+00	1.05E+00	1.05E+00	1.05E+00	1.09E+00
U-234	1.09E+00	1.08E+00	1.05E+00	1.09E+00	1.08E+00	1.05E+00	1.05E+00	1.05E+00	1.09E+00
U-235	1.09E+00	1.09E+00	1.05E+00	1.09E+00	1.08E+00	1.05E+00	1.05E+00	1.05E+00	1.09E+00
U-236	1.09E+00	1.08E+00	1.05E+00	1.09E+00	1.08E+00	1.05E+00	1.05E+00	1.05E+00	1.09E+00
U-238	1.09E+00	1.09E+00	1.05E+00	1.09E+00	1.08E+00	1.05E+00	1.05E+00	1.05E+00	1.09E+00
Pa-231	1.09E+00	1.09E+00	1.05E+00	1.09E+00	–	–	–	–	–
Mo-93	–	–	1.11E+00	–	–	–	–	–	–
Th-230	–	–	1.04E+00	–	–	–	–	–	–

[a] A dash indicates that a scaling factor was not calculated. The radionuclide would not appear in groundwater for the specific site.

APPENDIX D:

SENSITIVITY ANALYSIS

The peak annual doses to a hypothetical resident farmer located 100 m downgradient of the edge of a disposal facility from using contaminated groundwater are presented in Section 4 of this report. The following assumptions were made to perform this evaluation:

1. The engineering barriers incorporated in the disposal facility would keep percolating water out of the waste units for 500 years following closure of the disposal facility.

2. After 500 years, the integrity of the barriers and waste containers would begin to degrade, allowing for water infiltration into the top of the disposal units at 20% of the natural infiltration rate for the area.

3. The water infiltration rate around and beneath the disposal facility would remain at 100% of the natural rate for the area at all times.

4. Once water would begin to affect the disposed-of wastes, radionuclides would be leached out at a rate that would depend on the waste type.

5. A stabilizing agent (grout) would be used to solidify the Other Waste type, and this grout would maintain its effectiveness for 500 years.

6. After 500 years, the effectiveness of the grout would be compromised, allowing for more leaching to occur.

7. The activated metal and sealed source wastes would be disposed of without the use of any additional stabilizing material.

These assumptions were applied across various alternate sites so that the peak annual doses for the different sites could be compared on a uniform basis.

The parameters used in these analyses were generally selected to provide conservative estimates (i.e., to overestimate the peak annual doses that would likely occur in the future should one of these alternatives be implemented). Uncertainties are inherent with these types of analyses, especially given the long periods analyzed in the environmental impact statement (EIS) (10,000 years and longer to obtain peak annual doses). To evaluate the uncertainties associated with the key assumptions used to analyze long-term human health impacts, a sensitivity analysis was performed to provide information on the effects that key assumptions have on the results. In this sensitivity analysis, the RESRAD-OFFSITE calculations were repeated while the value of only one parameter was varied and the values of the other parameters were kept at their base values. This approach excluded the influence of the other parameters and provided results that could be analyzed to determine which assumptions have the most impact on these estimates.

Two sites were considered in this sensitivity analysis: Savannah River Site (SRS) and Waste Isolation Pilot Plant (WIPP) Vicinity. The first site is representative of sites in the Eastern United States (a humid site), and the second site is representative of sites in the Western United States (an arid site). The analysis was limited to trench disposal of the GTCC-like stored Group 1 Other Waste - CH, and it covered a time period of 10,000 years (GTCC is greater-than-Class C; CH is contact handled). It was

assumed that this waste would be stabilized with grout and that this waste type has a radionuclide mix that is representative of many of the GTCC wastes. The results of the sensitivity analysis for this waste type and disposal method at these two sites can be used to infer conclusions about different waste streams disposed of at other alternate sites by using the three land disposal methods. This analysis also gives some indication of the level of conservatism in the results, which is useful information for the decision-making process.

Three parameters were addressed in this sensitivity analysis: (1) the water infiltration rate through the disposal facility cover after 500 years following closure of the facility, (2) the effectiveness of the stabilizing agent (grout) used for Other Waste, and (3) the distance to the assumed hypothetical receptor. These three parameters address issues related to disposal facility design, waste form stability, and site selection.

To address the influence of the water infiltration rate on the estimated radiation doses to the hypothetical future farmer, two additional infiltration rates (corresponding to 50% and 100% of the natural infiltration rate for the area) were considered along with the base value of 20%.

The effective period for the stabilizing agent (grout) used for Other Waste was assumed to be 500 years in the analysis. This assumption is considered to be reasonable, but it is likely that the grout would be effective for a longer period of time. To address the significance of this time period assumed for grout, two additional effective periods were addressed for both SRS and the WIPP Vicinity: 2,000 years and 5,000 years.

The exposure distance to the resident farmer is assumed to be 100 m from the edge of the disposal facility. This distance was based on the minimum buffer zone identified for U.S. Department of Energy (DOE) low-level radioactive waste (LLRW) disposal facilities. This distance would likely be much longer, especially for the DOE sites considered in the EIS. To address the significance of the distance to a future hypothetical receptor (which may have a bearing on site selection and development of a buffer zone), this distance was increased to 300 m and 500 m.

In addition to the base case, two additional values were considered for each of the three parameters at the two sites as discussed above. A total of 10 additional cases were constructed and analyzed by using RESRAD-OFFSITE at SRS and the WIPP Vicinity. Table D-1 lists the different cases and the parameter values assumed for those cases.

Tables D-2 and D-3 provide the peak annual doses and the times at which they would occur for the base case and the 10 sensitivity analysis cases analyzed for the WIPP Vicinity and SRS, respectively. A time period of 10,000 years was used to perform these analyses with the RESRAD-OFFSITE computer code.

For the WIPP Vicinity, groundwater contamination would not occur within 10,000 years for any of the three water infiltration rates used in this analysis (20%, 50%, or 100% of the natural background rate for this area) after failure of the engineering barriers (including the cover) and waste containers. A higher rate than is naturally present at that site is needed for groundwater contamination to occur. A higher infiltration rate to the disposal units would result in higher release rates of radionuclides, yielding higher peak doses. However, the transport time required for radionuclides to move to the groundwater table after leaving the disposal units would be the same, regardless of the water infiltration rate to the disposal units. This is because in the analysis, it is assumed that the water infiltration rate to areas outside the waste disposal units would be equivalent to the natural background rate. (This assumption was selected to provide more conservative estimates of the potential doses.) Since groundwater contamination

TABLE D-1 Sensitivity Analysis Cases Addressed in the EIS

Parameter	Base Case	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
Effective period of grout (yr)	500	500	500	2,000	2,000	2,000	5,000	5,000	5,000	500	500
Percentage of natural infiltration rate into the waste units after 500 years (%)	20	50	100	20	50	100	20	50	100	20	20
Distance to the hypothetical receptor (m)	100	100	100	100	100	100	100	100	100	300	500

TABLE D-2 Maximum Annual Radiation Doses within 10,000 Years and the Occurrence Times at the WIPP Vicinity for the Different Sensitivity Analysis Cases

Result	Base Case	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
Maximum annual dose (mrem/yr)	0	0	0	0	0	0	0	0	0	0	0
Time (yr)	0	0	0	0	0	0	0	0	0	0	0

TABLE D-3 Maximum Annual Radiation Doses within 10,000 Years and the Occurrence Times at SRS for the Different Sensitivity Analysis Cases

Result	Base Case	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
Maximum annual dose (mrem/yr)	62	140	250	36	76	110	38	74	100	23	13
Time (yr)	610	580	550	10,000	2,600	2,500	5,600	5,600	5,600	780	940

would not occur within 10,000 years in the base case, the contamination would not be observed in Cases I or II either.

For Cases III to VIII, the effectiveness of grouting was extended from 500 years to either 2,000 years or 5,000 years, which would cause the leaching of radionuclides to be reduced for a longer time when compared with the time for the Base Case. Consequently, at the WIPP Vicinity, no groundwater contamination was observed within 10,000 years for these cases. Increasing the exposure distance of the receptor from 100 m to 300 m in Case IX and to 500 m in Case X would postpone the onset of radiation exposure. In addition, because of the extra dilution by clean water coming down from the ground surface, the potential radiation dose would also be lower than that in the base case. The maximum dose of 0 mrem/yr within 10,000 years as calculated for Cases IX and X at the WIPP Vicinity is consistent with this expectation.

The results for the base case and Cases I and II as calculated for SRS (Table D-3) demonstrate the influence of the water infiltration rate on the GTCC wastes in the disposal unit. The results provide information on the influence that the performance of the disposal facility cover has on long-term radiation doses through the groundwater pathway. The peak annual dose would increase as the water infiltration rate increased, because when more water would enter the waste packages, more radionuclides would be leached and released from the disposal area. The increase in the peak annual dose would be roughly proportional to the increase in the water infiltration rate. Similar conclusions can be drawn about the results for Cases III, IV, and V and Cases VI, VII, and VIII. Figure D-1 compares the radiation doses as a function of time among the base case, Case I, and Case II. Figure D-2 compares the radiation doses among Cases III, IV, and V. Figure D-3 compares the radiation doses among Cases VI, VII, and VIII.

In Figure D-1, for all three cases (base case, Case I, and Case II), the sharp peak that occurs close to time 0 is caused by C-14, which was assumed to be highly soluble in water (a distribution coefficient [K_d] value of 0 cm^3/g was used in the analyses). After C-14, Np-237 and then Ra-226 would reach the groundwater table. The main contributor to the radiation dose between 100 and 350 years is Np-237. After 350 years, Ra-226 plays a dominant role in determining the radiation dose. Because there is more adsorption to the soil particles during transport to the receptor location, the peaks created by Np-237 and Ra-226 are not as sharp as the peak created by C-14. In addition to being in the initial inventory in the Group 1 GTCC-like stored Other Waste - CH, Np-237 could be generated by the decay of Am-241, while Ra-226 could be generated by the decay of U-234 and Th-230. The ingrowth of Np-237 and Ra-226 explains the gradual rise of the radiation dose, which continues all the way to 10,000 years after the peak at around 500–600 years. Note that for the RESRAD-OFFSITE analyses, time 0 corresponds to the onset of leaching of radionuclides, which is assumed to occur 500 years after the closure of the disposal facility when the integrity of the barrier materials and waste containers begins to degrade. Therefore, if the reported time is 600 years, that time means 1,100 years after the closure of the disposal facility.

The influence of the effectiveness of the stabilizing agent (grout) on the potential radiation doses is demonstrated by comparing the results of the base case and Cases III and VI (see Figure D-4). During the effective period, the release rates of radionuclides from the waste disposal area would be reduced, thereby reducing the radiation dose associated with groundwater contamination for the corresponding period. The retention of more radionuclides in the waste containers would allow more radioactive decay to occur before the release. Hence, the peak annual dose after the effective period would be lower than it would be when there was no waste stabilizing or when the effective period of the stabilizing agent was shorter. The longer the effective period, the more evident the delay and reduction of the peak dose (compare the dose results for Cases I, IV, and VII in Figure D-5 or the results for Cases II, V, and VIII in Figure D-6).

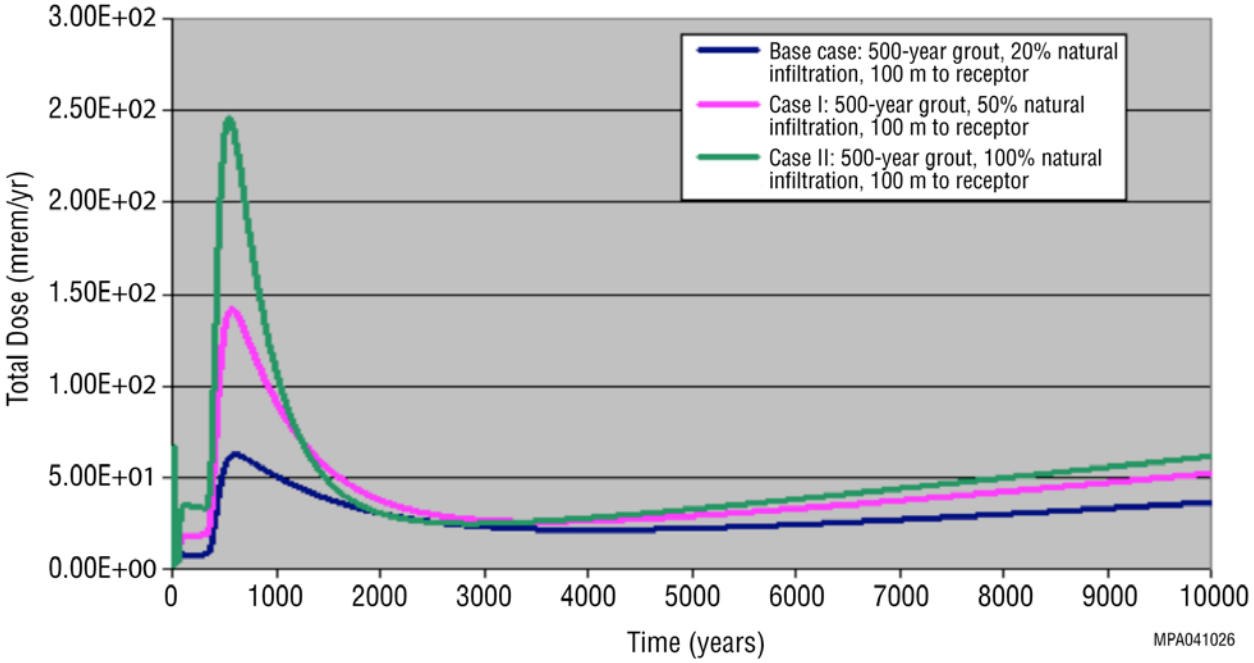

FIGURE D-1 Comparison of Annual Doses for the Base Case and Cases I and II for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

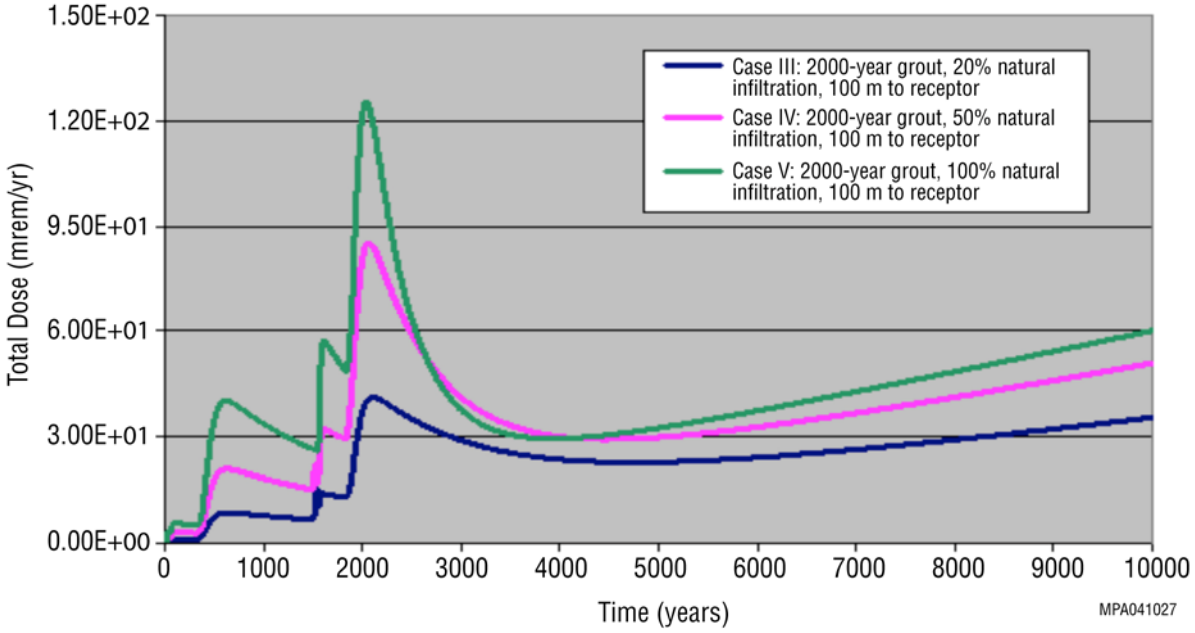

FIGURE D-2 Comparison of Annual Doses for Cases III, IV, and V for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

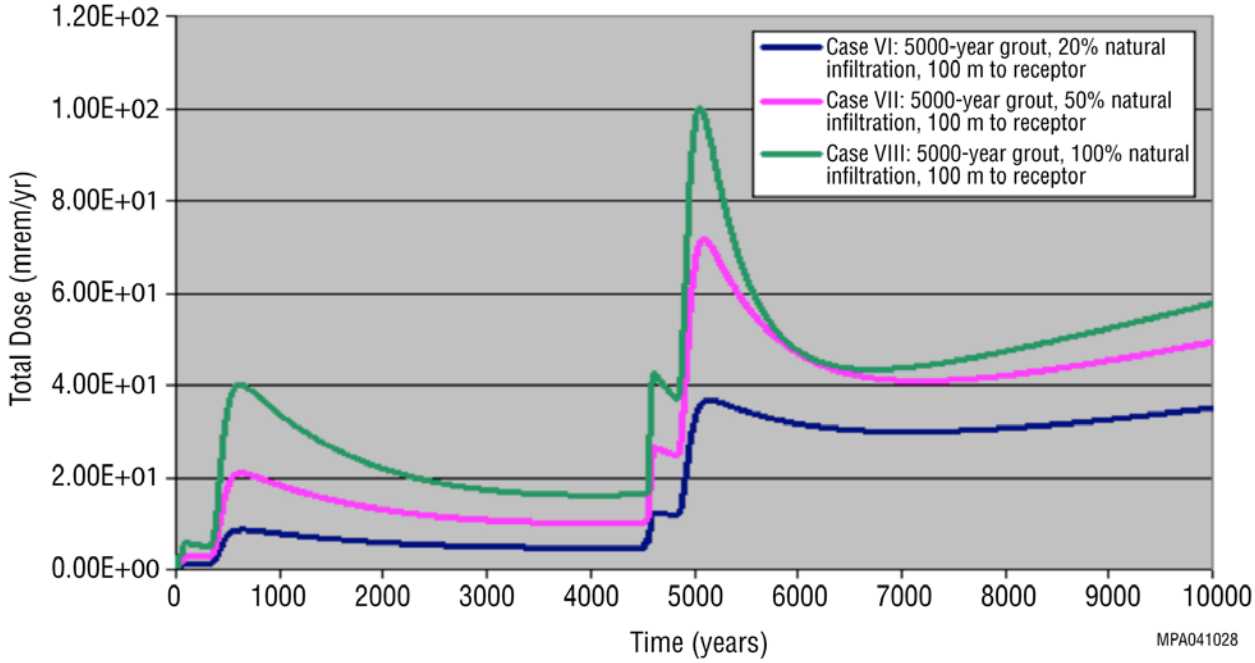

FIGURE D-3 Comparison of Annual Doses for Cases VI, VII, and VIII for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

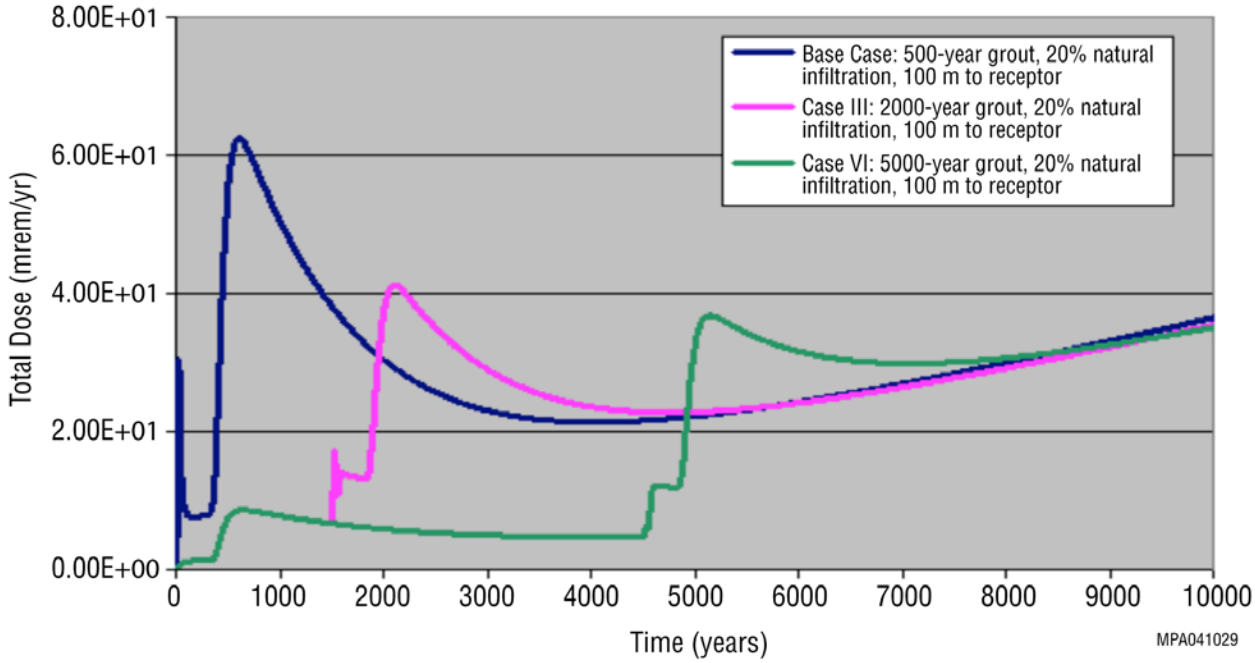

FIGURE D-4 Comparison of Annual Doses for the Base Case and Cases III and VI for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

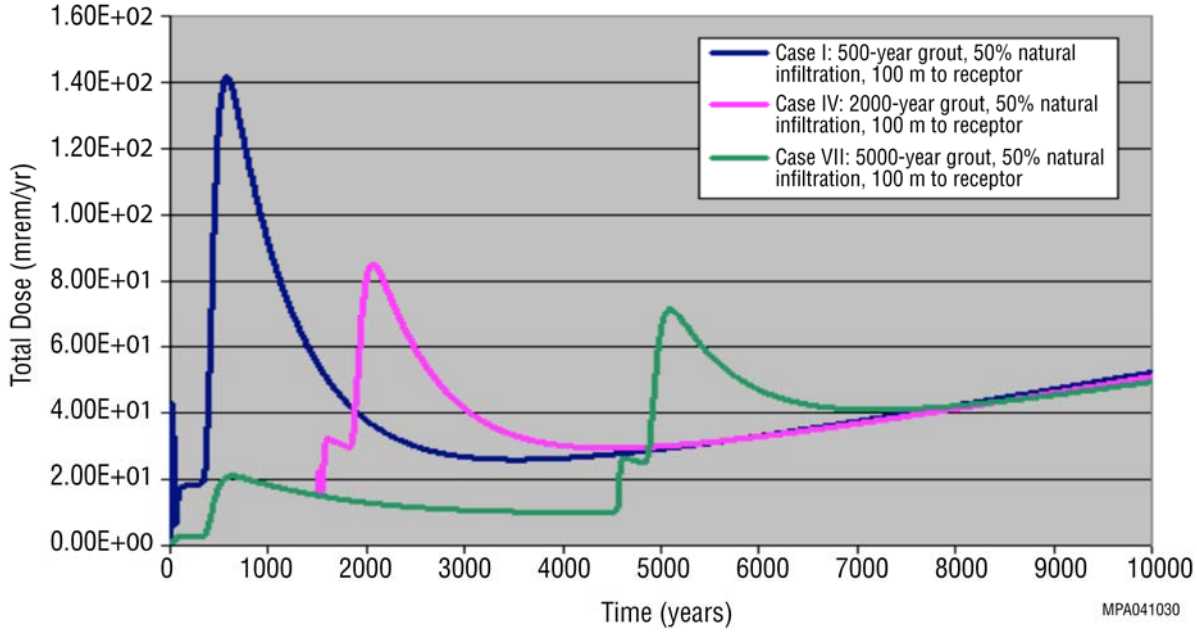

FIGURE D-5 Comparison of Annual Doses for Cases I, IV, and VII for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

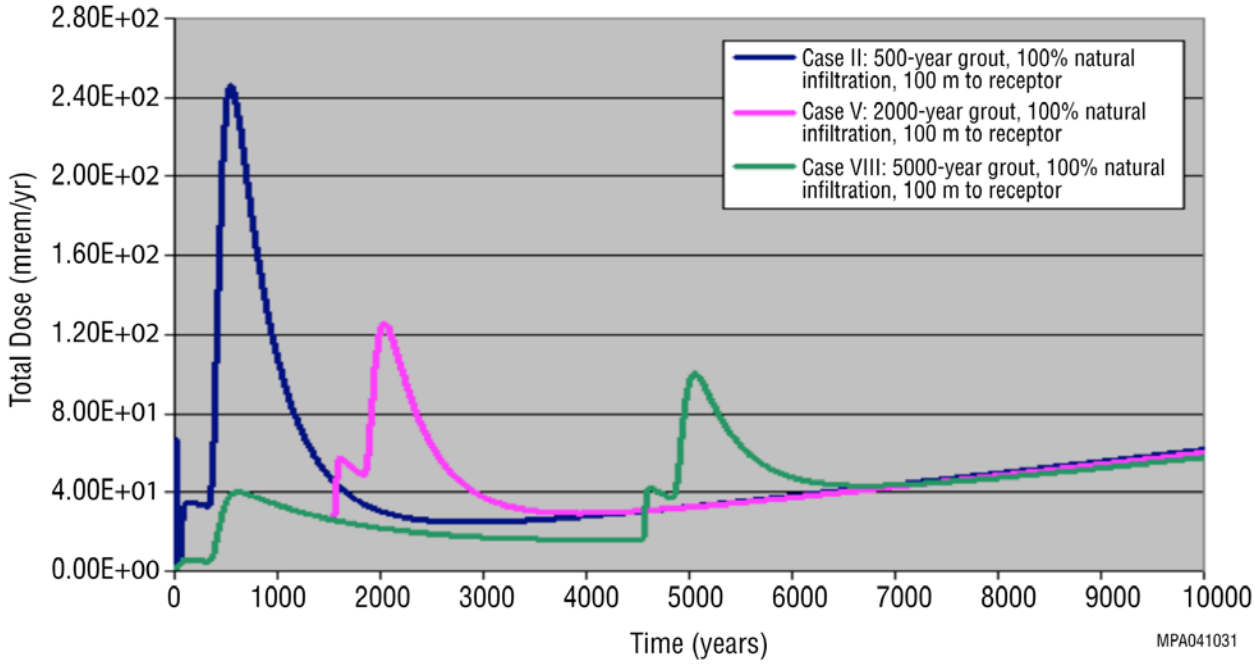

FIGURE D-6 Comparison of Annual Doses for Cases II, V, and VIII for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

For Case III in Figure D-4 (the first part of the curve overlaps with the curve for Case VI), the dose results were obtained by assuming that the grouting would be effective for 2,000 years (i.e., the grouting would be effective for 1,500 years after water started to infiltrate into the waste containers). The grouting would reduce the releases of radionuclides and allow more radioactive decay to take place in the containers. By the time the grout was no longer effective, the partitioning of radionuclides to the water phase would increase simultaneously, resulting in a sudden increase in the release rates, and the corresponding increase in the radiation dose would be observed at a later time, depending on the travel time required for the radionuclides to reach the receptor location. Because the grouting has a greater influence on Np-237 than on Ra-226 (K_ds used for Np-237 and Ra-226 were 300 and 100 cm^3/g, respectively, in the analyses), the largest contributor to the radiation dose within the effective period (the first 1,500 years in the RESRAD-OFFSITE analyses) would be Ra-226. After the effective period, the release rates of both Np-237 and Ra-226 would increase. However, because Np-237 (with a K_d of 0.6 cm^3/g) would travel faster than Ra-226 (with a K_d of 5 cm^3/g) in the soil column and groundwater aquifer, its influence on the radiation dose would be observed earlier (the first peak after 1,500 years in the dose profile) than the influence from Ra-226 (the second peak after 1,500 years in the dose profile). The grouting would also reduce the release rate of C-14 (a K_d of 10 cm^3/g was assumed for the grouting system); therefore, a sharp peak before 1,500 years would no longer be observed. The sharp peak (close to 1,500 years in the dose profiles) could occur after the effective period of the grout; however, the radioactivity of C-14 would have decayed to some extent by then, so the sharp peak would become less obvious.

For Case VI in Figure D-4, the dose results were obtained by assuming that the effectiveness of grouting would last for 5,000 years. The dose profiles are similar to the profiles for Case III and would occur for the same reasons discussed in the previous paragraph, except that more decay and ingrowth of radioactivity would occur in the waste containers before the loss of grout effectiveness. The increased radioactive decay explains why the magnitudes of the peaks after 4,500 years for Case VI are smaller than magnitudes of the peaks after 1,500 years for Case III. The increased ingrowth of progeny radionuclides explains why the difference in the maximum dose between Cases III and VI is less than the difference in the maximum dose between the base case and Case III.

The radiation dose incurred by the hypothetical resident farmer considered for post-closure impact analyses would decrease with increasing exposure distance, as demonstrated by the results for the base case and Cases IX and X (see also Figure D-7). As mentioned before, this result would occur because the radionuclide concentrations in groundwater would become more diluted as a result of the additional transport distance to the location of the off-site well. It was calculated that as the distance increased from 100 m to 500 m, the maximum annual radiation dose decreased by more than 70%.

Although the sensitivity analysis was not conducted for the entire inventory of GTCC LLRW and GTCC-like waste, the results in this appendix provide a good indication of the reduction in dose that would occur for the entire inventory under more favorable conditions than those assumed for the base case (i.e., a lower water infiltration rate with better engineering of the cover, a longer effective time for the stabilizing agent [grout], and a longer distance to a hypothetical receptor). It is expected that with more robust engineering barrier designs and waste containment procedures, the actual human health impacts would be much lower than those presented in Chapter 4 of this report.

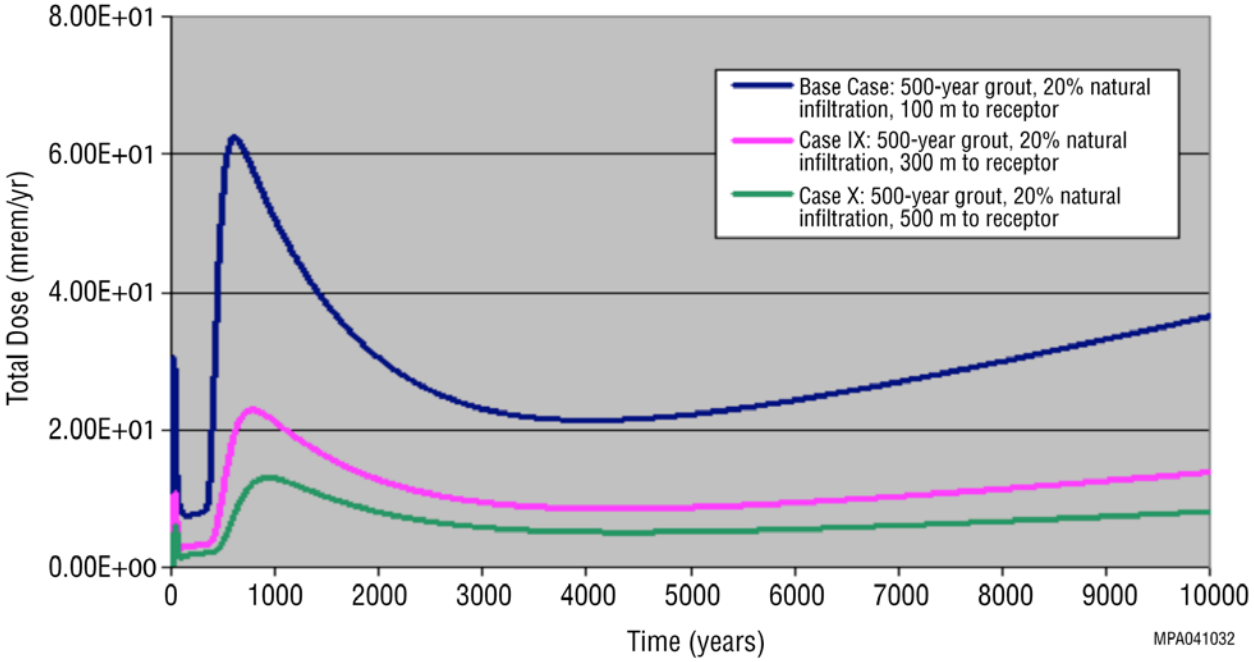

FIGURE D-7 Comparison of Annual Doses for the Base Case and Cases IX and X for Trench Disposal of Stored Group 1 GTCC-Like Other Waste - CH at SRS

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