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Explanation of Significant Differences Between Models Used to Assess Groundwater Impacts for the Disposal of Greater-Than-Class C Low-Level Radioactive Waste and Greater-Than-Class C-Like Waste Environmental Impact Statement (DOE/EIS-0375-D) and the Environmental Assessment for the INL Remote-Handled Low-Level Waste Disposal Project (INL/EXT-10-19168)

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August 2011

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ABSTRACT

Models have been used to assess the groundwater impacts to support the *Draft Environmental Impact Statement for the Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste (DOE-EIS 2011)* for a facility sited at the Idaho National Laboratory and the *Environmental Assessment for the INL Remote-Handled Low-Level Waste Disposal Project (INL 2011)*. Groundwater impacts are primarily a function of (1) location determining the geologic and hydrologic setting, (2) disposal facility configuration, and (3) radionuclide source, including waste form and release from the waste form. In reviewing the assumptions made between the model parameters for the two different groundwater impacts assessments, significant differences were identified. This report presents the two sets of model assumptions and discusses their origins and implications for resulting dose predictions. Given more similar model parameters, predicted doses would be commensurate.

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ACRONYMS

ATR	Advanced Test Reactor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
EA	environmental assessment
EIS	environmental impact statement
GTCC	greater than Class C
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
K_d	distribution coefficient
LLW	low-level waste
RH	remote-handled

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1. PURPOSE

The purpose of this document is to assess differences in groundwater impacts at the Idaho National Laboratory (INL) as predicted in the *Draft Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste Environmental Impact Statement* (DOE-EIS 2011) and the *INL Remote-Handled (RH) Low-Level Waste (LLW) Environmental Assessment* (DOE-EA 2011; INL 2011). It includes an evaluation of radionuclide inventory, disposal facility configuration, and transport from the facility to a hypothetical receptor via the groundwater pathway. The first of these assessments (DOE-EIS 2011) evaluated several options for disposal of GTCC and GTCC-like waste from across the Department of Energy (DOE) complex. One of these options is disposal at INL using one of three land disposal configurations. The second and separate assessment (DOE-EA 2011) also evaluated onsite land disposal at INL. The representative INL site chosen for evaluation of disposal of GTCC LLW and GTCC-like waste (DOE-EIS 2011) corresponds to one of the locations evaluated for disposal of RH-LLW at INL (DOE-EA 2011, INL 2011). This site is located southwest of the Advanced Test Reactor (ATR) Complex at INL (see Figure 1).

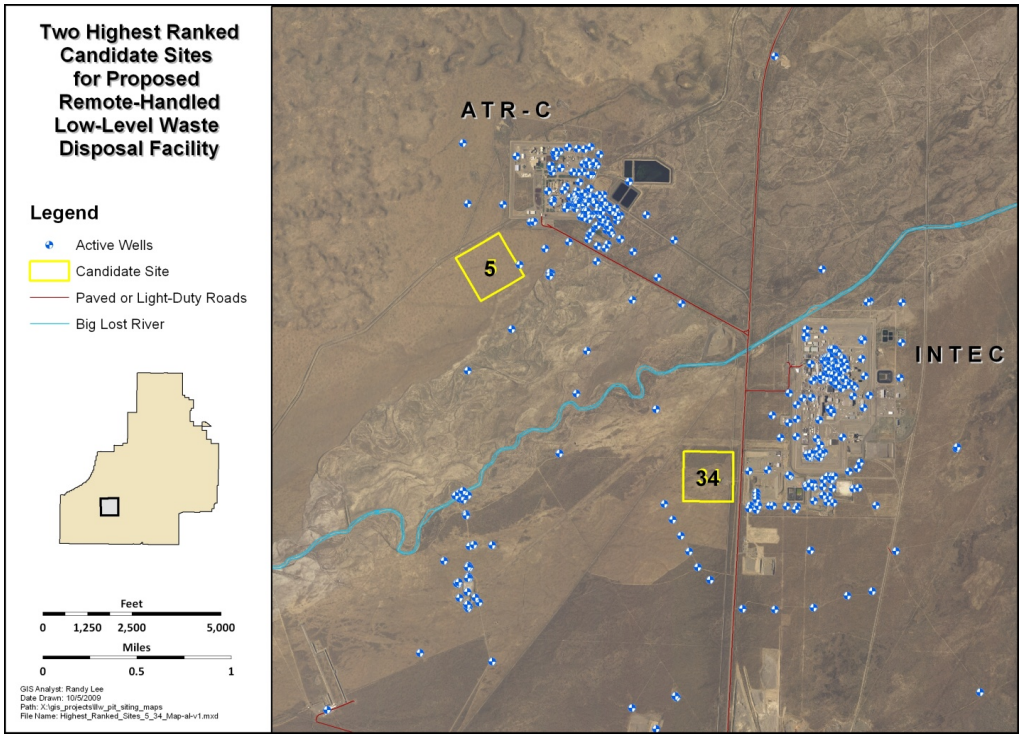

Figure 1. Sites evaluated in the INL RH-LLW EA. Site 5 was the representative location at INL evaluated in the GTCC draft EIS.

2. BACKGROUND

A location southwest of the ATR Complex has been evaluated for use in disposing of radioactive waste at INL under two different proposed actions by DOE. The first proposed action is documented in the DOE-EIS 2011. The second proposed action is documented in DOE-EA 2011. In both of these assessments, potential groundwater impacts were evaluated. The evaluations considered the respective inventories of the individual proposed actions, release of the inventories to the disposal facility environment, and subsequent transport through the vadose zone into the aquifer to potential downgradient receptors. Results of both analyses indicate that C-14, I-129, Tc-99, and U-238 pose the greatest threat to groundwater quality. However, because of significant differences in inventory, disposal facility configuration, and assumed vadose zone and aquifer transport properties, predicted doses cannot be easily reconciled between the two different assessments. The purpose of this analysis is to clarify and explain the origin of the model differences and to show that predicted doses in both models are conservative.

Inventory and waste form comprise the source release term used in groundwater models. Inventories for the two different proposed actions differ in specific radionuclides, radionuclide activity, and distribution across different waste forms. These differences are discussed in the following sections.

Disposal facility configuration determines the areal extent and geologic media remaining between the source and aquifer. The areal extent and placement of the source within the disposal area controls total dilution in the aquifer and the distance to downgradient receptors. The vertical location of the source determines the amount of material excavated from the near-surface soils and the amount remaining beneath the facility. Remaining surficial soils differentially adsorb transported radionuclides.

Once released from the near surface, radionuclides are transported through the vadose zone by infiltrating water. Total infiltration is a function of precipitation, evapotranspiration, soil disturbance, and the engineered cover that will be placed over the disposal facility. Transport rates and concentrations are buffered in the vadose zone by sorption onto native materials. More sorption results in lower concentrations, slower transport rates, and lower fluxes from the vadose zone into the aquifer. Vadose zone pore water concentrations are reduced upon reaching the aquifer in proportion to the differences between vadose zone infiltration rates and aquifer flow velocity. Low infiltration rates and high aquifer flow velocities allow for more dilution to occur, resulting in lower concentrations and drinking water dose.

Different models were developed and parameterized for the GTCC EIS and the INL RH-LLW EA. The conceptual models in both analyses were similar; however, model parameters were different. In the EIS, the model parameters were selected based on very conservative values used in previous performance assessments conducted for INL facilities or thought to be representative based on data collected across INL. In the *Evaluation of Groundwater Impacts to Support the National Environmental Policy Act Environmental Assessment for the INL Remote-Handled Low-Level Waste Disposal Projec*t (INL 2011), model parameters were selected based on site-specific data collected at the ATR Complex or at the nearby Idaho Nuclear Technology and Engineering Center (INTEC). Model parameters for the two different assessments are presented in Section 3.

An assessment of the differences between inventory, source release, disposal facility configuration, and transport models is provided in Section 4. Section 4 shows that the model supporting the GTCC EIS (DOE-EIS 2011) is more conservative than that used to support the INL RH-LLW disposal facility.

2.1 Summary of Predicted Doses for the Greater Than Class C Environmental Impact Statement and Idaho National Laboratory Remote-Handled Low-Level Waste Disposal Facility

Significantly different groundwater all-pathways effective dose equivalents (dose) were determined for the GTCC-EIS and INL RH-LLW disposal facilities. Results for these two analyses are summarized in terms of key radionuclides in the following subsections.

2.1.1 All-Pathways Effective Dose Equivalent Predicted by the Greater Than Class C Environmental Impact Statement Groundwater Assessment

Three different disposal configurations were evaluated by the GTCC EIS. These disposal configurations included boreholes, trenches, and vaults at land surface. Borehole disposal entails emplacement of waste in boreholes at depths deeper than 30 m (100 ft), but above 300 m (1,000 ft) below ground surface. A trench facility would consist of several individual trenches, extending from land surface to a depth of 11 m. In the conceptual design for vault disposal of GTCC low-level radioactive waste and GTCC-like waste, a reinforced concrete vault would be constructed near grade level, with the footings and floors of the vault situated in a slight excavation just below grade.

Within 10,000 years, C-14, Tc-99, and I-129 could reach the aquifer 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/year for the borehole method, 2,300 mrem/year for the vault method, and 2,100 mrem/year for the trench method.

Although radionuclides would reach the aquifer 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 uranium isotopes from the disposal facility would reach the aquifer near the end of the 10,000-year timeframe. 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 aquifer sooner under the borehole disposal method. Calculations indicate that the uranium isotopes would not reach the aquifer within 10,000 years under the trench and vault disposal methods.

Table 1 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 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., 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 also are tabulated.

For borehole disposal, it is estimated that the peak annual dose occurs 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 RH other waste is the primary contributor to the peak dose in all cases. C-14, Tc-99, and I-129 are the primary radionuclides of concern within a time frame of 10,000 years after closure of the disposal facility for all the three disposal methods. Under the borehole method, uranium isotopes would reach the aquifer within 10,000 years and contribute to the maximum dose at 9,200 years. These radionuclides contribute more than 90% of the total dose. 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

and Np-237 and Am-241 would reach the aquifer 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 predicted to occur in the first 10,000 years. These results are summarized in Figures 2 and 3.

Table 1. Summary of estimated peak annual doses (mrem/year) from use of contaminated groundwater at the INL as determined in the GTCC EIS.

Disposal Configuration/ Waste Group	GTCC Low-Level Radioactive Waste				GTCC-Like Waste				Peak Annual Dose for Entire Inventory[a] (mrem/year)
	Activated Metals (mrem/year)	Sealed Sources	Other Waste (CH) (mrem/year)	Other Waste (RH) (mrem/year)	Activated Metals (mrem/year)	Sealed Sources (mrem/year)	Other Waste (CH) (mrem/year)	Other Waste (RH) (mrem/year)	
Borehole									
Group 1 stored	2.6	–	0.0	0.45	0.21	0.0	48	17	820
Group 2 projected	39	32	–	0.013	0.52	0.0	8.4	580	
Group 3 projected	21	0.0	5.6	24	0	0	17	26	
Vault									
Group 1 stored	1.5	–	0.0	2.3	0.0	0.0	0.49	2,200	2,300
Group 2 projected	24	0.0	–	0.069	0.0	0.0	0.22	6.4	
Group 3 projected	12	0.0	1.4	86	0	0	0.33	12	
Trench									
Group 1 stored	1.7	–	0.0	2.0	0.0	0.0	0.65	1,900	2,100
Group 2 projected	28	0.0	–	0.0	0.0	0.0	0.24	5.7	
Group 3 projected	14	0.0	1.5	77	–	–	0.37	11	

a. The times for the peak annual doses of 820 mrem/year for boreholes, 2,300 mrem/year for vaults, and 2,100 mrem/year for trenches were calculated to be about 9,200 years, 220 years, and 190 years, respectively. These times represent the time after failure of the cover and engineered barriers (which is assumed to begin 500 years after facility closure). 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; C-14, Tc-99, and I-129 would be the primary radionuclides causing this dose for the vault and trench disposal methods.

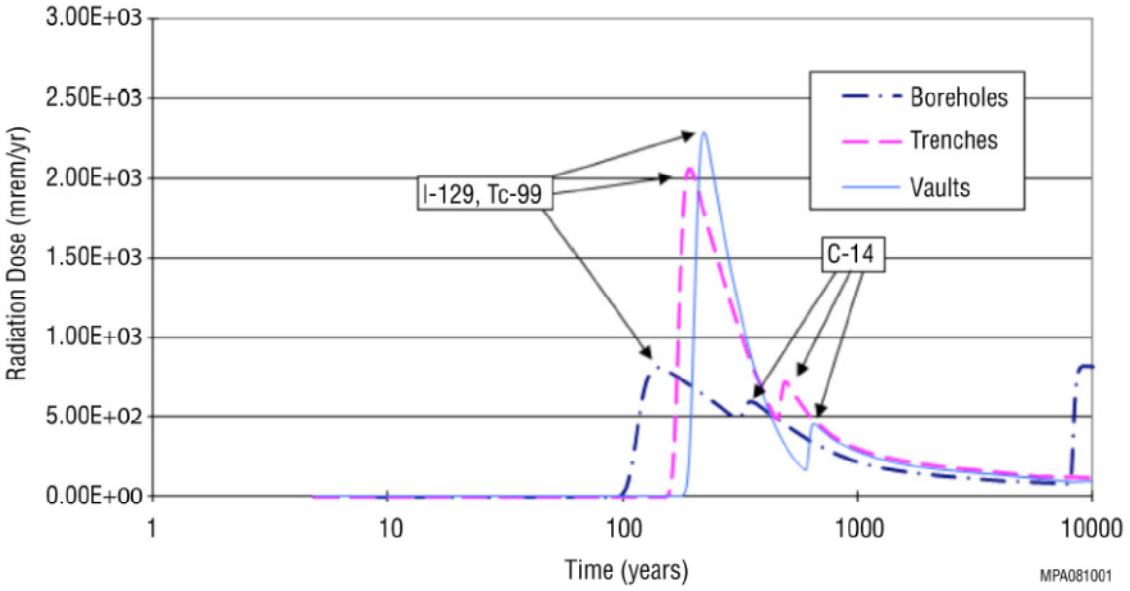

Figure 2. All-pathways effective dose equivalent predicted for the entire inventory evaluated in the GTCC EIS for time periods up to 10,000 years following facility closure. All three disposal configurations are shown. The time is shown on a logarithmic axis.

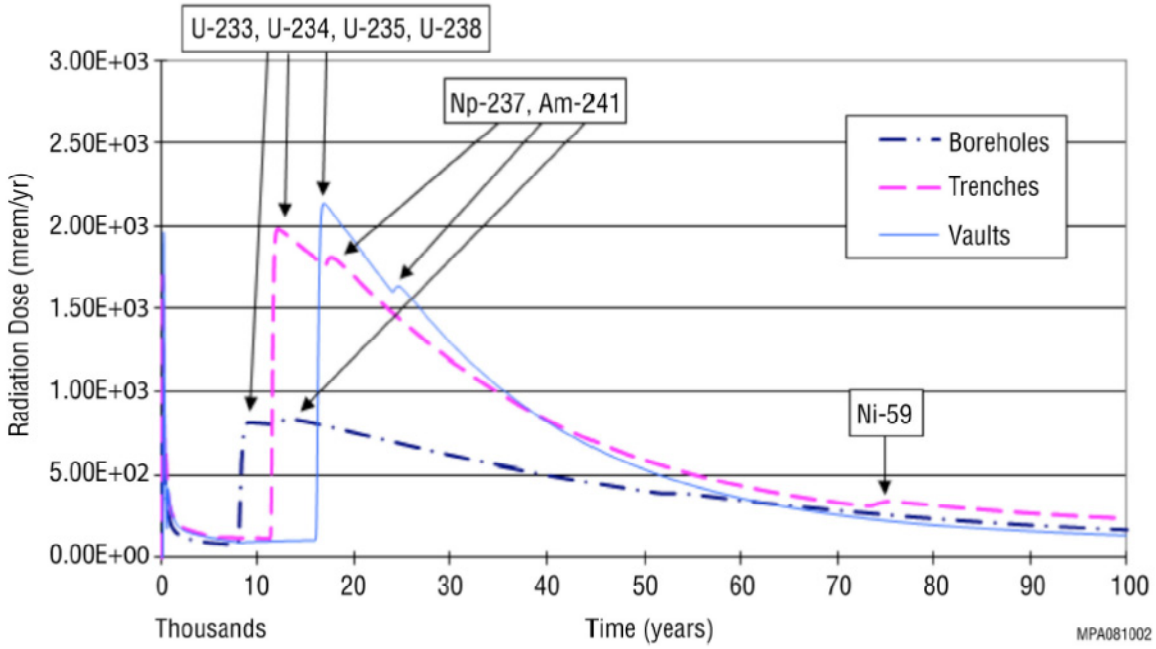

Figure 3. All-pathways effective dose equivalent predicted for the entire inventory evaluated in the GTCC EIS for time periods up to 100,000 years following facility closure. All three disposal configurations are shown. Time is not logarithmic. The combined doses shown in Figure 2 appear during the first 10,000 years.

2.1.2 All-Pathways Effective Dose Equivalent Predicted by the INL RH-LLW Disposal Facility EA Groundwater Assessment

The disposal facility configuration for the proposed RH-LLW disposal facility is a below-grade vault. The vault system will be comprised of concrete base sections (0.4 m), vertical risers (6 m), and top plugs (1.5 m) underlain by a sand/gravel base layer. Sand/gravel will be used to infill between the vault risers. The total height of the vaults is about 8 m and they will extend from land-surface downward into the alluvium. The array of vaults will be 240 m long and 10 m wide, oriented perpendicular to groundwater flow.

The peak total dose during the 1,000-year time of compliance is 0.62 mrem/year for the proposed site located southwest of the ATR Complex. This peak (which occurs 1,000 years after closure) represents the cumulative dose from all radionuclides in the groundwater 100 m from the downgradient facility boundary. Primary contributors to the peak dose during the 1,000-year time of compliance are Tc-99 (0.60 mrem/year) and C-14 (0.015 mrem/year). The peak dose over all time is 0.88 mrem/year and occurs 3,500 years after closure. This dose primarily is due to C-14 (0.85 mrem/year), with small contributions from I-129 (0.013 mrem/year), Cl-36 (0.012 mrem/year), and Tc-99 (0.004 mrem/year). After several thousands of years, isotopes of uranium (predominantly U-238) arrive in groundwater with minor contributions from Mo-93, Nb-94, Ni-59, and isotopes of Np-237. The primary dose from uranium originates with U-238, which has primary daughters U-234, Th-230, Ra-226, and Pb-210 as it radioactively decays. A significant percentage of the dose associated with this chain is produced by Pb-210, which has a 100-fold higher dose coefficient than the other daughters. Pb-210 has a very small initial inventory; however, due to the long residence times of parent nuclides in the vadose zone, it is produced in sufficient quantity to account for the majority of the U-238 total dose (Figure 4).

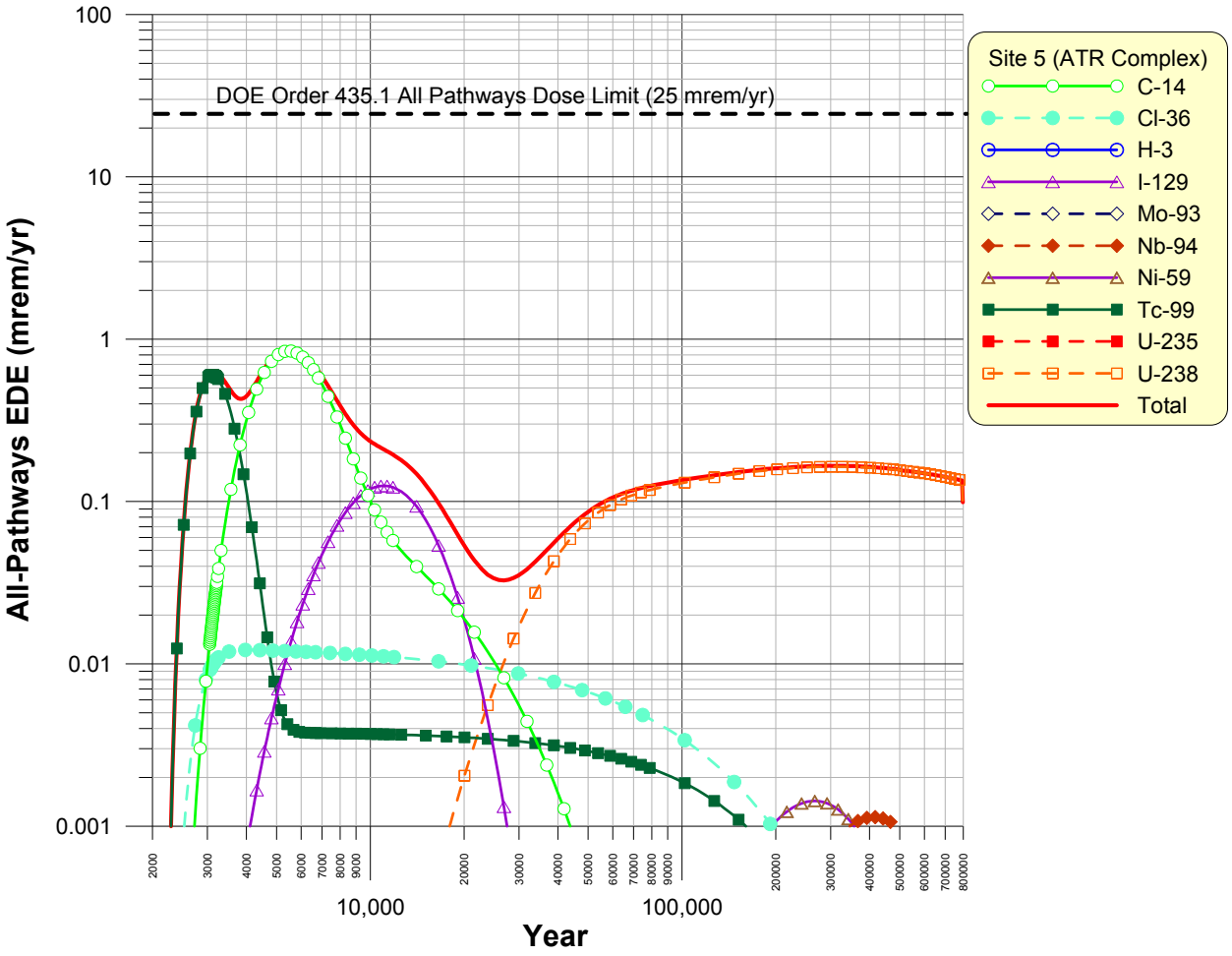

Figure 4. All-pathways effective dose equivalent as a function of calendar year for the INL RH-LLW disposal facility site southwest of the ATR Complex. Pu-239, Pu-240, and Np-237 are not shown because their doses are less than 0.001 mrem/year. The dashed line is the 25 mrem/year limit imposed by DOE Order 435.1.

3. INVENTORIES AND SOURCE RELEASE MODELS

The predicted groundwater all-pathway doses for the GTCC EIS and INL RH-LLW EA are largely determined by the radionuclide inventory, waste form, and release model assumed. The following subsections contain an overview of the inventories by waste form and source release model assumptions used in the two different analyses. Following the overview, a direct comparison of key radionuclide inventories is presented.

3.1 Greater Than Class C Environmental Impact Statement Inventory and Source Release Assumptions

Appendix B of DOE-EIS (2011) contains detailed information on the inventories (volumes and radionuclide activities) of the waste addressed in the EIS for disposal of GTCC low-level radioactive waste and for GTCC-like waste. In the GTCC EIS, the waste was categorized into one of two groups. Group 1 consisted of waste that was already generated and in storage or projected to be generated by existing facilities such as commercial nuclear power plants. Group 2 consisted of waste that might be generated from proposed future activities, including several DOE projects, two planned Mo-99 production

projects, and new nuclear power plants that have not yet been licensed by the U.S. Nuclear Regulatory Commission or constructed.

The estimated waste volumes and total radionuclide activities for the waste in Groups 1 and 2 are shown in Tables B-4 and B-7 of DOE-EIS (2011) and are reproduced in Table 2. The total waste volume is11,700 m^3 and contains a total of 159 megacuries of radionuclide activity, mainly from decommissioning of commercial nuclear power reactors currently in operation.

Table 2. Radionuclide inventory evaluated in the GTCC EIS (modified from Table B-4 and B-7 of DOE-EIS 2011).

Radionuclide	Activated Metals (Ci)	Sealed Sources (Ci)	Other Waste (Ci)	Total (Ci)	Radionuclide	Activated Metals (Ci)	Sealed Sources (Ci)	Other Waste (Ci)	Total (Ci)
Hydrogen-3	2.40E+05	0.00E+00	4.06E+02	2.41E+05	Thorium-229	1.20E-02	0.00E+00	4.78E+00	4.79E+00
Carbon-14	3.37E+04	0.00E+00	2.82E+02	3.40E+04	Thorium-230	1.30E-04	0.00E+00	8.87E-01	8.87E-01
Magnesium-54	7.20E+04	0.00E+00	4.80E+01	7.20E+04	Protactinium-231	3.00E-02	0.00E+00	5.20E-02	8.20E-02
Iron-55	5.80E+07	0.00E+00	4.08E+01	5.80E+07	Thorium-232	3.20E-03	0.00E+00	1.28E+00	1.28E+00
Nickle-59	1.84E+05	0.00E+00	1.62E+02	1.84E+05	Uranium-232	1.40E+00	0.00E+00	5.58E+01	5.72E+01
Cobalt-60	7.30E+07	0.00E+00	1.26E+03	7.30E+07	Uranium-233	3.80E+00	0.00E+00	8.18E+02	8.22E+02
Nickel-63	2.55E+07	0.00E+00	9.59E+03	2.55E+07	Uranium-234	2.00E-01	0.00E+00	9.40E+01	9.42E+01
Strontium-90	2.50E+04	0.00E+00	1.89E+05	2.14E+05	Uranium-235	7.20E-02	0.00E+00	4.24E+00	4.31E+00
Molybdenum-93	1.57E+02	0.00E+00	5.50E-05	1.57E+02	Uranium-236	1.10E-01	0.00E+00	1.34E+00	1.45E+00
Niobium-94	8.70E+02	0.00E+00	1.27E-01	8.70E+02	Neptunium-237	6.70E-02	0.00E+00	5.02E+00	5.09E+00
Technetium-99	6.40E+03	0.00E+00	1.91E+02	6.59E+03	Uranium-238	8.40E-01	0.00E+00	1.43E+01	1.52E+01
Iodine-129	4.00E+00	0.00E+00	2.76E+00	6.76E+00	Plutonium-238	1.31E+02	1.20E+05	2.65E+04	1.47E+05
Cesium-137	3.60E+04	1.70E+06	4.91E+05	2.23E+06	Plutonium-239	6.60E+03	8.40E+03	5.36E+03	2.04E+04
Promethium-147	1.10E-01	0.00E+00	1.74E+05	1.74E+05	Plutonium-240	1.60E+02	2.20E+01	3.63E+03	3.81E+03
Samarium-151	1.70E+02	0.00E+00	2.40E+03	2.57E+03	Plutonium-241	2.53E+03	0.00E+00	6.25E+04	6.50E+04
Europium-152	6.60E+02	0.00E+00	6.81E+02	1.34E+03	Americium-241	7.84E+02	1.50E+05	1.48E+04	1.66E+05
Europium-154	2.40E+01	0.00E+00	2.80E+02	3.04E+02	Plutonium-242	1.40E-01	0.00E+00	1.36E+01	1.38E+01
Europium-155	1.40E+00	0.00E+00	2.09E+03	2.09E+03	Americium-243	1.10E+00	3.50E-01	1.78E+02	1.79E+02
Lead-210	3.30E-07	0.00E+00	4.12E-06	4.45E-06	Curium-243	1.40E-01	0.00E+00	6.49E+00	6.63E+00
Radium-226	1.50E-06	0.00E+00	9.10E+00	9.10E+00	Curium-244	8.00E+00	7.60E+01	1.02E+04	1.03E+04
Actinium-227	1.10E-02	0.00E+00	9.90E-02	1.10E-01	Curium-245	8.00E-04	0.00E+00	3.40E+02	3.40E+02
Radium-228	3.20E-04	0.00E+00	8.31E-01	8.31E-01	Curium-246	6.40E-05	0.00E+00	5.40E+01	5.40E+01

In the GTCC EIS, waste was considered to be in one of three waste types: (1) activated metals, (2) sealed sources, or (3) other waste as indicated in Table 2. The waste type determines the rate of release into the environment once contacted by infiltrating water. Assumptions used in the GTCC EIS by waste type are as follows:

- **Activated metal waste** was assumed to be released as the metals corrode. The radionuclide release fraction for activated metals was taken to be 1.19×10^{-5}/year in this analysis. This value was attributed to INL (DOE-ID 2007, Adler-Flitton et al. 2004).
- **Radionuclides in sealed sources** were assumed to partition between water and the sealed source matrix. The partition coefficient (K_d) for the sealed source matrix was assumed to be equal to the K_d for the surface soil.
- **Radionuclides in other waste were assumed to be stabilized in a cementitious grout.** Grout was assumed to be effective for the first 500 years following facility closure, after which, the K_d of the grout was assumed be the same as the surrounding surface soils. K_ds were taken from the smallest reported data in Kaplan (2006), considering the effects of oxidizing and reducing conditions and selecting the lower of the reported values.

3.2 Remote-Handled Low-Level Waste Environmental Assessment Inventory and Source Release Assumptions

The proposed INL disposal facility will accept three primary types of RH-LLW: (1) activated metals, (2) ion-exchange resins, and (3) miscellaneous contaminated debris. The activated metals are generated at INL by ATR Complex operations, Naval Reactors Facility operations, and from processing waste stored in the Radioactive Scrap and Waste Facility at the Materials and Fuels Complex. The activated metals are typically reactor core components replaced during core internal changeouts and are made from stainless steel, inconel, zircaloy, or aluminum. The ion-exchange resins are beads used to purify reactor cooling water as part of routine operations at the Naval Reactors Facility and the ATR Complex. The design life of the proposed RH-LLW disposal facility is 50 years. Disposal inventories for a 50-year period were projected by each of the waste generators; the combined inventory from all generators, in terms of activity, is shown in Table 3.

Table 3. Inventory of radionuclides with half-lives greater than 5 years used in the INL RH-LLW EA groundwater impacts analysis.

Radionuclide	Activated Metals (Ci)	Resins (Ci)	Other (Debris and Surface Contamination) (Ci)	Radionuclide	Activated Metals (Ci)	Resins (Ci)	Other (Debris and Surface Contamination) (Ci)
Ac-227	1.849E-06			Ni-59	3.085E+03	3.034E+01	1.262E+02
Ag-108m	2.917E-05			Ni-63	3.789E+05	3.674E+03	9.621E+03
Am-241	3.059E-01	3.467E-02	4.999E-02	Np-237	8.460E-06	2.667E-04	2.721E-03
Am-242m	2.486E-03	7.906E-06	2.695E-04	Os-194	4.051E-09		
Am-243	7.660E-04	2.728E-05	2.394E-04	Pa-231	8.806E-06		
Ba-133	1.830E-03			Pb-205	8.319E-07		
Be-10	1.804E-04			Pd-107	4.005E-05		2.762E-04
Bi-210m	1.094E-06			Pm-145	1.616E-10		
C-14	3.744E+02	2.638E+00	5.518E+01	Pm-146	8.440E-08		
Ca-41	1.345E-02			Pt-193	9.080E-04		
Cd-113m	5.637E-02			Pu-238	2.488E-01	3.981E-01	5.830E-02
Cf-249	1.408E-12		8.813E-12	Pu-239	3.048E-01	7.226E-02	1.177E-01
Cf-250	1.470E-10			Pu-240	2.399E-01	5.050E-03	2.885E-03
Cf-251	3.334E-15		3.217E-13	Pu-241	2.596E+01	1.135E-01	1.029E+00
Cl-36	1.533E-01			Pu-242	3.161E-04	4.118E-06	6.898E-05
Cm-243	1.564E-03	2.248E-05	3.129E-04	Ra-226	7.999E-11		
Cm-244	3.526E-02	2.495E-02	1.674E-02	Ra-228	2.961E-07		
Cm-245	7.190E-07		7.778E-07	Rb-87	1.277E-06		
Cm-246	5.487E-07		5.150E-07	Re-187	2.142E-05	8.940E-01	
Cm-247	5.023E-15		4.828E-13	Se-79	3.376E-03	9.272E-05	4.968E-03
Co-60	1.325E+06	4.712E+03	1.572E+06	Si-32	6.452E-07	1.960E-08	
Cs-135	2.433E-04		1.522E-02	Sm-147	4.379E-10		
Cs-137	1.901E+01	3.614E+01	6.218E+03	Sm-151	3.300E-01	4.222E-02	4.827E+01
Eu-152	1.893E-01	1.020E+01		Sn-121m	1.377E+02		
Eu-154	6.881E-01	3.008E+01	2.143E+02	Sn-126	1.811E-04		1.677E-05
H-3	3.908E+03	9.834E+00	3.159E-04	Sr-90	9.407E+00	6.165E+01	6.111E+03
Hf-178m	4.012E-08			Tc-99	8.708E+00	5.072E+00	2.946E+00
Hf-182	1.151E-04			Th-229	6.385E-08		

Table 3. (continued).

Radionuclide	Activated Metals (Ci)	Resins (Ci)	Other (Debris and Surface Contamination) (Ci)	Radionuclide	Activated Metals (Ci)	Resins (Ci)	Other (Debris and Surface Contamination) (Ci)
Ho-166m	5.571E-08			Th-230	6.821E-08		
I-129	1.335E-05	1.330E-01	3.714E-04	Th-232	1.562E-07		1.559E-07
Ir-192m	1.112E-05			U-232	1.246E-04		2.344E-04
K-40	1.107E-06	1.260E-03		U-233	1.145E-04		3.439E-06
La-137	2.376E-06			U-234	2.628E-04	9.244E-04	1.261E-05
Lu-176	1.504E-08			U-235	8.190E-06	2.061E-05	5.143E-03
Mo-93	1.993E+00		2.710E+01	U-236	2.272E-05	1.064E-04	1.647E-07
Nb-93m	5.938E+02	2.161E-04	1.038E+02	U-238	2.891E-04	4.305E-08	1.619E+01
Nb-94	1.020E+02	2.120E+00	6.575E+00	Zr-93	4.362E+01	4.649E-02	5.149E-02

In the groundwater impacts analysis (INL 2011) for the INL RH-LLW disposal facility, the differential release from the different waste forms was considered. Assumptions used in the RH-LLW EA by waste type are as follows:

- **Radionuclides in resins** were assumed to be sorbed to the resins. Once contacted by infiltrating water, the radionuclides would partition into the infiltrating water and be transported into the vault environment. The vault environment was assumed to contain sand and cement. For conservatism, partitioning of radionuclides to the resins, sand, and cement within the vault environment was neglected.
- **Radionuclides on debris** were assumed to be released into the vault environment once contacted by infiltrating water. As with the resin waste form, sorption was neglected in the vault environment.
- **Radionuclides in activated metals** were assumed to be released as the activated metals corrode. The most conservative corrosion rates at INL were determined for immersion tests conducted at INTEC (1,312 to 1,968 years/mm), where Type 304 stainless steel coupons were subjected to a magnesium chloride solution at a 6-m burial depth temperature and oxygen content. The magnesium chloride solution was used in the studies at INTEC to represent the long-term use of a dust suppressant at the Radioactive Waste Management Complex. A value similar in magnitude was recommended for use at the Subsurface Disposal Area by Nagata and Banaee (1996). This value (4,500 years/mm or 2.22E-05 cm/year) comes from corrosion of sensitized Type 304 stainless steel buried in soils near Toppenish, Washington. These two rates are both greater than the rates measured by Adler-Flitton et al. (2011) for activated metal types expected to be deposited in the proposed RH-LLW facility. Based on direct testing of coupons buried 1.22 m (4 ft) and 3.05 m (10 ft) below ground surface near the Radioactive Waste Management Complex, Adler Flitton et al. (2011) measured corrosion rates for aluminum, zircaloy, inconel, and various types of stainless steel (304, 316L, and 316L welded) after 1 year, 3 years, 6 years, and 12 years of burial. Corrosion rates decreased with burial depth and with time of burial for all reported results.

  In addition to corrosion data, a geometric shape factor (surface-area-to-volume ratio) is required to calculate the fractional release of radionuclides from activated metal components. Based on a study of power reactors (Oztunali and Roles 1986), a surface-area-to-volume ratio of 0.535 cm^{-1} was used for typical INL-type reactor components. Combining the Nagata and Banaee (1996) corrosion rate (2.22E-05 cm/year) and the Oztunali and Roles (1986) geometry factor (0.535 cm^{-1}) results in a fractional release rate from stainless steel of 1.19E-05/year. In comparison, fractional release rates using average 12-year corrosion rates from Adler-Flitton et al. (2011) for different metal types (see Table 4), are lower by one to three orders of magnitude. For conservatism, a 1.19E-05/year fractional

release rate was used in the groundwater impacts analysis for the INL RH-LLW disposal facility. This is the same value used in the GTCC EIS.

Table 4. Corrosion rates and fractional release rates for buried metals in INL soils.

Metal	Corrosion Rate[a]		Fractional Release Rate[b]
	mils/year	cm/year	year^{-1}
Aluminum	7.86E-04	2.00E-06	1.07E-06
Stainless steel: 304L, 316L, 316L welded	5.17E-05a	1.31E-07	7.01E-08
Inconel and Zircaloy	4.75E-05a	1.21E-07	6.47E-08

a. Average corrosion rates for stainless steel and inconel and zircaloy samples were calculated from Adler-Flitton et al. (2011) data by replacing the corrosion rates of samples with no measurable (zero) corrosion, with the minimum measured rate of all samples. After 12 years of burial, 10 of 23 stainless steel samples, and 13 of 16 inconel and zircaloy samples had no measurable corrosion.
b. Based on a surface-area-to-volume ratio of 0.535 cm^{-1} (Oztunali and Roles 1986).

The resultant activity flux from the source zone of the key dose contributors (C-14, I-129, Tc-99, and U-238) are shown in Figure 5 assuming an infiltration rate of 0.1 cm/year. The high peak in radionuclide flux (release) from the facility is a result of radionuclides released from surface contaminated materials and resins. The relatively constant releases of C-14, I-129, and Tc-99 after the initial peak occur as the activated metals corrode, releasing radionuclides. Throughout the simulations, the total release of U-238 is limited by solubility, reducing its flux from the waste zone compared to the other radionuclides. Figure 5 shows that the relative contribution from activated metals is several orders of magnitude lower than contributions from surface contaminated debris and resins when it is assumed radionuclides do not sorb to resins.

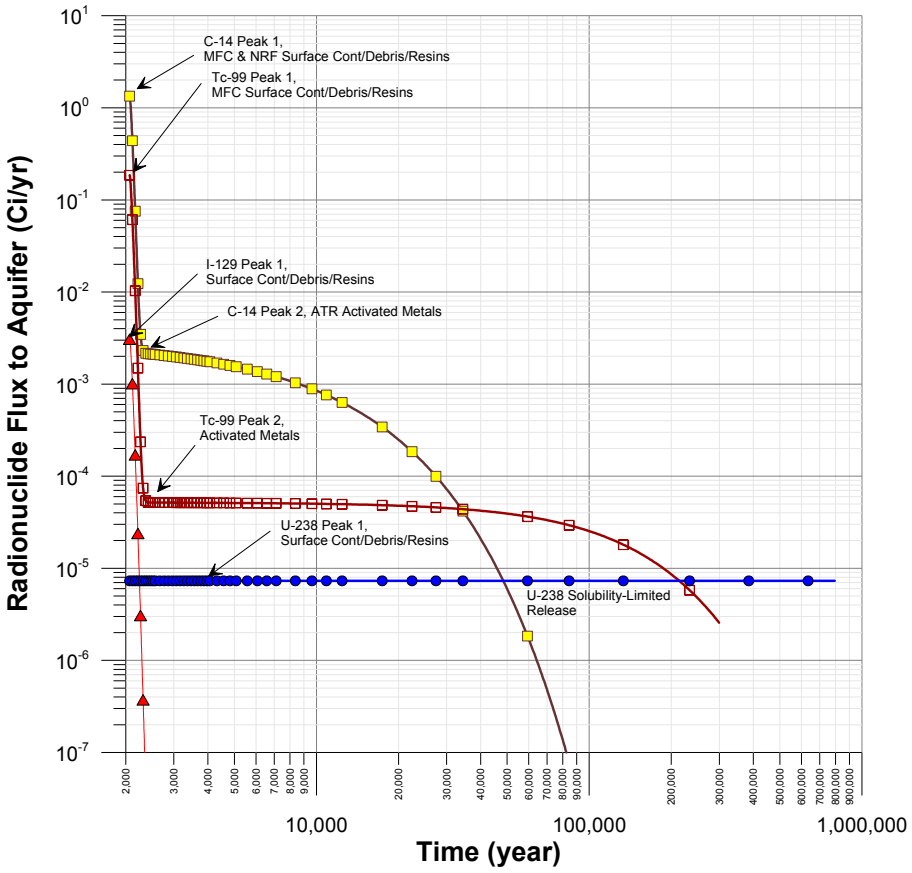

Figure 5. Activity flux of C-14, I-129, Tc-99, and U-238 from the source zone as calculated by the performance assessment model showing significant contributions by radionuclide and generator.

3.3 Comparison of the Inventories and Source Release Assumptions for the Greater Than Class C Environmental Impact Statement and Remote-Handled Low-Level Waste Environmental Assessment

Table 5 contains a summary of the key radionuclide inventories used in the GTCC EIS and RH-LLW EA groundwater impacts analysis by waste form. Columns 2 and 3 present the total activity contained in the GTCC EIS inventory, including the GTCC low-level radioactive waste and GTCC-like waste for both Groups 1 and 2. The activated metal inventory is separated from the total contained in sealed and other sources because of the differences in release mechanism. Assumptions used to model the sealed sources and other waste result in similar release rates for those two waste forms. The arrival of activity contained in nonactivated metal waste will occur earlier in time (Figure 5), while the arrival of activity contained in activated metals will be relatively constant and a function of the infiltration rate as the engineered cover is assumed to fail. Columns 4 and 5 contain the inventory estimated to be disposed of in the INL RH-LLW disposal facility during 50 years of operations as evaluated for the EA. As with the GTCC EIS inventory, the INL RH-LLW inventory has been separated into activated metals and nonactivated metals. Columns 6 and 7 present the RH-LLW disposal facility inventory as a percentage of the GTCC EIS inventory by waste form.

The estimated inventory of activated metals that will be disposed of at the RH-LLW disposal facility is less than 1% of the total activated metal inventory associated with the GTCC EIS. Nonactivated metal inventories for the key radionuclides are about 5% for I-129 and Tc-99, and slightly more at 20.5% for C-14. Similar inventories of U-238 are proposed for disposal at both facilities.

Table 5. Summary of key radionuclide inventories for the GTCC EIS and INL RH-LLW disposal facility groundwater impacts analyses.

	GTCC EIS		RH-LLW Disposal Facility EA		RH-LLW Disposal Facility Inventory as a % of the GTCC EIS Inventory	
Radionuclide	Total Curies in Activated Metals	Total Curies not in Activated Metals	Total Curies in Activated Metals	Total Curies not in Activated Metals	Activated Metals	Nonactivated Metals
C-14	3.37E+04	2.82E+02	3.74E+02	5.78E+01	1.1	20.5
I-129	4.00E+00	2.76E+00	1.34E-05	1.33E-01	0.00035	4.8
Tc-99	6.40E+03	1.91E+02	8.71E+00	8.02E+00	0.014	4.2
Np-237	6.70E-02	5.02E+00	8.46E-06	0.003	0.0126	0.0598
Am-241	7.84E+02	1.65E+05	0.306	0.0847	0.039	5.13E-5
Cl-36	-	-	0.153		N/A	N/A
Mo-93	1.57E+02	5.50E-05	1.99	27.1	1.27	4.93E+07
Ni-59	1.84E+05	1.62E+02	3085	157	1.68	96.9
Nb-94	8.70E+02	1.27E-01	102	8.7	11.7	6,850
U-232	1.40E+00	5.58E+01	1.25E-04	2.34E-04	0.00893	0.00042
U-233	3.80E+00	8.18E+02	1.15E-04	3.44E-06	0.003	4.21E-07
U-235	7.20E-02	4.24E+00	8.19E-06	5.16E-03	0.0114	0.122
U-236	1.10E-01	1.34E+00	2.27E-05	1.07E-04	0.0206	0.00799
U-238	8.40E-01	1.43E+01	2.89E-04	1.62E+01	0.003	113
U-234	2.00E-01	9.40E+01	2.63E-04	9.37E-04	0.13	0.00099
Th-230	1.3E-04	8.87E-01	6.82E-08		0.052	
Ra-226	1.5E-06	9.1E+00	7.99E-11		0.00532	
Pb-210	3.30E-07	4.12E-06				

As shown in Figure 5, early releases from both facilities are associated with C-14, Tc-99, and I-129, with the arrival of the uranium isotopes occurring well after the 1,000-year time of compliance for the RH-LLW disposal facility and well after the 10,000-year timeframe considered in the GTCC EIS. This release behavior is reflected in both the GTCC EIS and in the RH-LLW disposal facility groundwater impacts analysis because of similarities in assumed release parameters.

Both the GTCC EIS and the INL RH-LLW EA treated the release of radionuclides from activated metals using the same corrosion rate. Nonactivated metals were assumed to be sorbed to vault material. For the GTCC EIS, the vault material was assumed to have a K_d for each of the radionuclides equal to 20% of the alluvium sorptive capacity. In the case of the RH-LLW EA, no sorption in the vault was accounted for. As shown in the following sections, this results in similar release functions for this waste type for all but C-14 and isotopes of uranium because of the zero K_d applied by the GTCC EIS for I-129 and Tc-99 at INL.

In addition to inventory and release mechanism (sorption or corrosion), radionuclides are released from the disposal facility (vault, borehole, or trench) in infiltrating water. The infiltration rate controls the net rate of release, while transport of the radionuclides is controlled by a combination of sorption and infiltration rate in the vadose zone. The final concentration in the aquifer is dictated largely by the ratio of water flux from the vadose zone and water fluxes (velocities) in the aquifer. Concentration determines the final dose to potential downgradient groundwater users.

4. VADOSE ZONE TRANSPORT MODELS AND PARAMETERS

In the groundwater impact analyses conducted in support of the GTCC EIS and RH LLW EA, contaminants released from near land surface were assumed to be transported downward through the stratigraphic layers comprising the vadose zone and into the aquifer. The general groundwater pathway from the disposal facility to the aquifer used in both models is illustrated in Figure 6. Radiologic doses via the groundwater pathway are governed by the release of radionuclides from the waste zone to the vadose zone, radioactive decay and hydrodynamic dispersion during transit in the vadose zone en route to the aquifer, and dilution in the aquifer. Residence time in the vadose zone is controlled by the infiltration rate, vadose zone sediment thickness, and sorption. The residence time in the vadose zone allows for decay of the parent radionuclide and ingrowth and decay of progeny. The decay rate also is radionuclide specific and is determined by the half-life of each radionuclide. Sorption serves to retard the rate of downward migration and is dependent on water chemistry and solid surfaces in addition to being radionuclide specific. Dilution in the aquifer is controlled by the flux of radionuclides into the aquifer, the Darcy velocity in the aquifer underlying the disposal facility, and hydrodynamic dispersion. The aquifer velocity is spatially variable underlying INL and is site specific.

4.1 Parameters used in the Greater Than Class C Environmental Impact Statement

In the conceptual model adopted for the GTCC EIS groundwater impacts analysis, the important parameters and characteristics are (1) disposal facility configuration, (2) infiltration rate (3) relative sediment abundance, (4) soil characteristics of the alluvium and interbeds, and (5) the velocity of water in the aquifer.

The disposal facility configuration ultimately determines the volume of material containing the waste and its position in the vadose zone. The areal extent determines the extent of dilution in the aquifer and facility depth, or depth of disposal, determines the remaining material for sorption in the vadose zone. The infiltration rate through the source zone fixes the hydraulic conductivity to be equal to the infiltration rate under steady-state, unit-gradient conditions in the vadose zone. Total sediment thickness in the vadose zone determines the net sorption occurring along the transport path because it was assumed that no sorption occurs in the basalt and that transit time through the basalt is instantaneous. Sediment characteristics include the K_d, bulk density, and moisture content at a given hydraulic conductivity. The

moisture content, K_d, and bulk density determine contaminant retardation. Net aquifer concentrations are largely determined by radionuclide flux from the vadose zone compared to influx of clean water moving with the aquifer velocity.

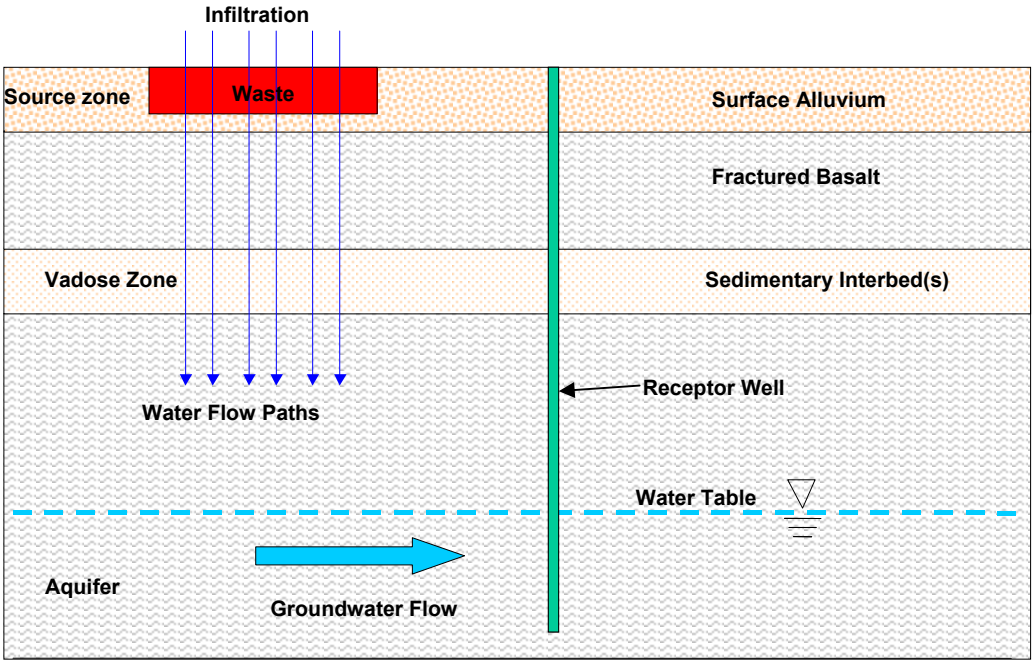

Figure 6. Simplified conceptual model of the groundwater pathway (from INL 2011).

- **Disposal facility configurations** evaluated by the GTCC EIS include boreholes, trenches, and vaults at land surface. About 44 ha (110 acres) of land would be required to accommodate the approximately 930 boreholes needed to dispose of the waste packages containing the 12,000 m^3 (420,000 ft^3) of GTCC low-level radioactive waste and GTCC-like waste. Borehole disposal entails emplacement of waste in boreholes at depths deeper than 30 m (100 ft) but above 300 m (1,000 ft) below ground surface.

  A trench facility for disposal of the entire 12,000 m^3 of GTCC low-level radioactive waste and GTCC-like waste would require include 29 trenches occupying a footprint of about 20 ha (50 acres). Each trench would be approximately 3-m (10-ft) wide, 11-m (36-ft) deep, and 100-m (330-ft) long.

  In the conceptual design for vault disposal of GTCC low-level radioactive waste and GTCC-like waste, a reinforced concrete vault would be constructed near grade level, with the footings and floors of the vault situated in a slight excavation just below grade. The vault disposal facility would occupy a footprint of about 24 ha (60 acres) to accommodate the 12 vaults required to dispose of the entire 12,000 m^3 of GTCC low-level radioactive waste and GTCC-like waste. Each vault (excluding the interim and final cover) would be about 11-m wide, 94-m long, and 7.9-m tall, with 11 disposal cells situated in a linear array. Interior cell dimensions would be about 8.2-m wide, 7.5-m long, and 5.5-m high, with an internal volume of 340 m^3 per cell. These dimensions are summarized in Table 6.

Table 6. Depth and area affected by disposal options considered in the GTCC EIS.

Dimension	Borehole	Trench	Vault
Depth affected by disposal option	30 m < depth < 300 m	0<depth<10 m	0 m
Areal footprint	4.45E05 m^2	2.02E05 m^2	2.43E5 m^2

- **Infiltration rates** in the GTCC EIS included the effects of an engineered cover. The engineered cover was assumed to be completely effective during the first 500 years following facility closure. During this early time period, no infiltration was assumed to pass through the waste zone. After 500 years, infiltration through the waste was assumed to achieve 20% of the background infiltration rate. Outside the waste zone, an infiltration rate equal to the background infiltration rate was assigned. For the GTCC EIS, the background infiltration rate was assigned a value of 4 cm/year, approximating the infiltration rate assumed to apply for the INL Tank Farm Facility Performance Assessment (DOE-ID 2003a).

  A wide range in the rate of infiltration rates at the INL site have been reported in the literature and in site-specific studies. These values range from a low of 0.16 in./year (0.41 cm/year) to a high of 4.9 in./year (12 cm/year) in data collected prior to preparation of the INL Tank Farm Facility Performance Assessment (DOE-ID 2003a). Most of the early reported values in the literature are estimates based on the amount of precipitation and best guess estimates of the evapotranspiration rates for the area. One of the few actual field measurements conducted at the site is reported by Cecil et al. (1992). By measuring tritium and Cl-36 profiles in the soil, test results yielded a range of 0.16 to 4.3 in./year (0.4 to 1.1 cm/year) infiltration.

  A detailed investigation of water infiltration rates was conducted at the Central Facilities Area Landfill by Miller, Hammel, and Hall (1990), where it was determined that infiltration rates from 1.0 to 1.6 in./year (2.5 to 4.1 cm/year) through the Central Facilities Area Landfill II occur. The Central Facilities Area Landfill II is a low-risk site, covered by an earthen-based material from the surrounding area with minimal intent to control evapotranspiration. The cover materials consist of an upper layer of sand and gravel approximately 1-ft thick, overlying a lower layer of gravel and sand. The total cover thickness ranges from 0.33 to 3.17 ft, with a mean of 1.5 ft and standard deviation of 0.69 ft.

  Based on measurements of infiltration through the two-layer soil Central Facilities Area Landfill II cover, the analysis of contaminant migration from the Tank Farm Facility Performance Assessment was modeled using the value of 1.6 in./year (4.1 cm/year) reported by Miller, Hammel and Hall (1990). More recent investigations (DOE-ID 2006d) show that infiltration through the Central Facilities Area Landfill II cover is enhanced above the background infiltration rate through undisturbed soils between Central Facilities Area Landfills I, II, and III (DOE-ID 2006d). This suggests that a value of 4.1 cm/year is likely overly conservative.

- **Relative sediment abundance** was included in the GTCC EIS groundwater impacts model. The model included the alluvium, basalt, and interbeds. The total thicknesses of each unit are shown in Column 3 of Table 7 and are taken from Well USGS-051, which is located south of INTEC. The Well USGS 051 is about 4.5 miles south and 4.5 miles east of the proposed facility location.

  Based on information contained in the GTCC EIS, it is clear that each configuration would place the waste at different depths in the vadose zone at INL (Table 6). These depths were not provided in the GTCC EIS. However, based on the depth range affected, the borehole and trench disposal configurations would penetrate the entire alluvium, while the vault disposal configuration would not penetrate any of the alluvium.

- **Soil characteristics** of the materials comprising the vadose zone are shown in Tables 7 and 8. The general and hydraulic conductivity values shown were taken from previous analyses across INL as indicated. Radionuclide sorption properties assigned to each unit are shown in Table 8 for the key radionuclides. As indicated, vadose zone basalt was not assumed to adsorb radionuclides while aquifer basalt was assigned a small distribution coefficient. C-14 and uranium isotopes were assumed to sorb to surface alluvium and sedimentary interbed material, while I-129 and Tc-99 were not.

Sorption to sediment results in lower aqueous phase concentrations, slower transport, and lower aquifer concentrations.

Table 7. RESRAD-Offsite Model Parameters Used for the Proposed INL Site.

Unit	Description	Thickness (m)	Porosity	Dry Bulk Density (g/cm^3)	Field Capacity	b-Parameter (Moisture Content)	Hydraulic Conductivity (m/year)
Contaminated Zone	Source	Varies for each disposal method	0.4 (RESRAD-offsite default)	1.8 (RESRAD-offsite default)	0.3 (RESRAD-offsite default)	5.3 (RESRAD-offsite default)	10 (RESRAD-offsite default)
UZ1	Alluvium	9.14 (USGS-051)	0.5 (Tank Farm Facility Performance Assessment; DOE-ID 2003a)	1.643 (sandy-clay/clay Yu et al. 2000)	0.1	4.339 (0.16)	29,200 (80 m/day Tank Farm Facility Performance Assessment; DOE-ID 2003a)
UZ2	Basalt	94.64 (USGS-051)	0.05 (Tank Farm Facility Performance Assessment; DOE-ID 2003a)	2.0 (Radioactive Waste Management Complex Performance Assessment; DOE 2007)	0.001	0.76 (0.004 Wilcox 2008)	3,650 (10 m/day Tank Farm Facility Performance Assessment; DOE-ID 2003a)
UZ3	Upper interbed	7.47 (USGS-051)	0.57 (C-D interbed at the Radioactive Waste Management Complex; DOE 2006a	1.46 (silt-loam Yu et al. 2000)	0.3	3.6 (0.414)	1.29 (geometric mean of 0.005m/d and 0.0025 m/d assumed for the C-CD and D-DE2 interbeds in the Tank Farm Facility Performance Assessment; DOE-ID 2003a)
UZ4	Lower interbed	15.88 (USGS-051)	0.5 (alluvium value in Tank Farm Facility Performance Assessment; DOE-ID 2003a)	1.643 (alluvium value)	0.3	10.4 (0.286 moisture content for silty clay)	29,200 (alluvium value)
UZ5	Basalt	15.4 (USGS-051)	0.05 (Tank Farm Facility Performance Assessment; DOE-ID 2003a)	2.0 (Radioactive Waste Management Complex Performance Assessment; DOE 2007)	0.001	1.67 (0.004)	365,00 (1,000 m/day from Tank Farm Facility Performance Assessment; DOE-ID 2003a)
Total vadose zone sediment thickness		143 (470 ft)					

Table 8. Distribution coefficients assigned to the model units in the GTCC EIS model.

Radionuclide	UZ1 (alluvium) K_d (ml/g)	UZ3 and UZ4 (interbed) K_d (ml/g)	UZ2 and UZ5 (basalt) K_d (ml/g)	Aquifer Basalt K_d (ml/g)
C-14	0.4	0.4	0.0	0.016
I-129	0	0	0	0
Tc-99	0	0	0	0
Uranium isotopes	15.4	15.4	0	0.62

- **Aquifer velocity** was effectively a Darcy velocity of 1.48 m/year. For the GTTC EIS, the velocity resulted from applying an INL sitewide geometric mean hydraulic conductivity and a geometric mean hydraulic gradient. The range of hydraulic conductivities was taken from the Tank Farm Facility Performance Assessment (DOE-ID 2003a). As discussed in the Tank Farm Facility Performance Assessment, the effective hydraulic conductivity of the basalt and interbedded sediment that compose the Snake River Plain Aquifer at and near INL ranges from 1.0E−02 to 3.2E+04 ft/d (3.0E−03 to 9.8E+03 m/d). Detailed analyses of the geologic control related to hydraulic conductivity, along with hydraulic testing results for the regional aquifer, are presented in reports by Walker (1960), Ackerman (1991), and Anderson, Kuntz, and Davis (1999). The six-order-of-magnitude range provided in the Tank Farm Facility Performance Assessment was estimated from single-well aquifer tests in 114 wells and was mainly attributed to the physical characteristics and distribution of basalt flows and dikes (Anderson, Kuntz, and Davis 1999).

  Similarly, the hydraulic gradient applied in the GTCC EIS was derived from the Tank Farm Facility Performance Assessment discussion. Based on the Tank Farm Facility Performance Assessment, the general direction of regional groundwater movement underlying INL is to the south and southwest. The average slope of the water table is about 4 ft/mi. In the northern part of INL, near Birch Creek Valley, the water-table gradient is relatively low, sloping southward about 1 ft/mi (0.2 m/km) (Barraclough et al. 1967).

  The hydraulic conductivity used in the GTCC EIS model was 1,979 m/year, corresponding to a geometric mean of the range 3.0E-03 m/year and 9.8E+03 m/year. Applying a geometric mean to determine the hydraulic conductivity as a spatial mean assumes uncorrelated distributions of basalt flows or the extent of the basalt flows are much shorter than the transport distance. The mean hydraulic gradient applied in the GTCC EIS model was equal to 0.00075 m/m (4 ft/mi) representative of the northern part of INL as opposed to the south-central portion nearer the proposed facility location.

4.2 Parameters used in the Groundwater Impacts Analysis Supporting the Remote-Handled Low-Level Waste Environmental Assessment

- **Disposal facility configuration** for the proposed RH-LLW disposal facility is a below-grade vault. The vault system will be comprised of concrete base sections (0.4 m thick), vertical risers (6 m high) and top plugs (1.5 m thick) underlain by a sand/gravel base layer. Sand/gravel will be used to infill between the vault risers. The total height of the vaults is about 8 m and will extend from land-surface downward into the alluvium. The array of vaults will be 240 m long and 10 m wide, oriented perpendicular to groundwater flow (INL 2010a).
- **Infiltration rates** in the RH-LLW disposal facility groundwater impacts analysis were assumed to be 1 cm/year throughout the duration of the simulations. After facility closure, an infiltration-reducing engineered barrier (cover) will be placed over the facility. The cover will conform to design specifications determined by the facility performance assessment and, in keeping with similar barriers

emplaced at INL, is expected to initially limit infiltration to less than 1 mm/year. During the next 1,000 years, the infiltration rate is expected to increase as the performance of the cover degrades, with the infiltration rate reverting back to conditions representative of INL undisturbed sediment (i.e., 1 cm/year). However, for conservatism, in the groundwater impacts analysis for the INL RH-LLW disposal facility, it was assumed that background infiltration rate of 1 cm/year would occur throughout the duration of simulation.

To put this into perspective, the total precipitation at INL is on the order of 20 cm/year. Background infiltration rates outside the Subsurface Disposal Area at the Radioactive Waste Management Complex in undisturbed sediment have been estimated to be on the order of 1.0 cm/year (Cecil et al. 1992) or as low as 0.1 cm/year based on Mattson et al. (2004). Site-specific estimates under disturbed conditions inside facilities have been determined using inverse modeling of meteorological time histories and measured soil moisture profiles obtained with neutron logging for monitoring locations around the Subsurface Disposal Area (Martian and Magnuson 1994; Martian 1995). These inverse modeling estimates were used in combination with surface topography to assign a distribution of three infiltration rates across the Subsurface Disposal Area (Martian 1995). The three rates applied are 1 cm/year (0.4 in./year), which is the same as the background infiltration rate traditionally assumed for undisturbed soil outside the Subsurface Disposal Area; 3.7 cm/year (1.5 in./year), representing a medium value; and 10.0 cm/year (4 in./year), representing infiltration obtained near drainage ditches where water and snow are intentionally diverted (DOE-ID 2006c).

Similarly, inverse modeling at INTEC was performed for the Operable Unit 3-14 tank farm soil and groundwater remedial investigation and feasibility study (DOE-ID 2006b) to determine infiltration rates. This study indicated net infiltration across disturbed INTEC soils was 18 cm/year. This value is representative of highly disturbed gravels in the tank farm where infiltration is enhanced by leaks through a temporary cover and evapotranspiration is eliminated by the cover. As with the Subsurface Disposal Area model, disturbed conditions were accounted for explicitly. In the INTEC model, infiltration through undisturbed areas at INTEC was assigned a value of 1 cm/year and disturbed areas were assigned the higher rate of 18 cm/year (DOE-ID 2006c).

For moderate to highly sorbing radionuclides of interest to the RH-LLW disposal facility, the vadose zone transit time will be on the order of 10,000s to 100,000s of years. Over these long time periods, natural compaction and weathering processes would return the contaminated soil source zones to undisturbed conditions. Therefore, assuming 1-cm/year infiltration representative of undisturbed conditions throughout the lifetime of the facility is appropriate.

- **Relative sediment abundance** was determined for the RH-LLW disposal facility groundwater impacts analysis based on existing data. Primary sedimentary interbeds have been identified and extensively characterized through activities supporting Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions at the ATR Complex and at INTEC (DOE-ID 1997a; DOE-ID 1997b; DOE-ID 2006b; and Helm-Clark et al. 2005). The lateral continuity and variability in sediment thickness at INTEC was evaluated in DOE-ID (2006b) as part of the CERCLA investigation and at the ATR Complex (INL 2010b).

  Based on these previous investigations and the facility design, the groundwater impacts analysis for the RH-LLW disposal facility incorporated a source zone, base layer, near-surface alluvium, and unsaturated lithology below the first basalt contact extending to the top of the Snake River Plain Aquifer. The 150-m thick vadose zone lithology was based on the geostatistical analysis and the data from nearby wells (Site-19, USGS-79, TRA-5, USGS-63, TRA-5A, TRA-07, TRA-08, Middle-1823, ICPP-SCI-V-213, and ICP-SCI-V-214). The total alluvial thickness in the region of the RH-LLW disposal facility, based on the eight closest wells and supported by the geostatistical analysis, is on the order of 14 m. The surface alluvium thickness estimated by a closely spaced seismic survey suggests

a total alluvial thickness at the RH-LLW disposal facility location near ATR Complex of 8 to 18 m (INL 2010d).

The most important underlying sediment units near the proposed facility are Sediment Units 2, 3, 4, 5, and 6. Average thicknesses for these five units, based on the closest wells are 1.7, 4.2, 3.6, 4.8, and 4.2 m, respectively. Based on the geostatistical analysis and on observations of Unit 7 thickness in wells TRA-06, TRA-06A, and USGS-065, the average thickness of Unit 7 could be as high as 1.6 m (5.3 ft). The total average thickness of Sediment Units 1 through 7 is 20 m (66 ft). The discontinuous occurrences of clays and sands were not included in the groundwater impacts model for the INL RH-LLW disposal facility.

- **Soil characteristics** were assigned to the RH-LLW disposal facility groundwater impacts model also based on existing data. Sediment texture and hydraulic conductivity were characterized as part of the INTEC and ATR Complex CERCLA investigations (DOE-ID 1997a, DOE-ID 1997b, DOE-ID 2006a, EGG-WM-10002). Sediment comprising the interbeds near the ATR Complex is predominantly silty clays and clays, containing very little gravel. The percentages of clay, silt, sand, and gravel at this site are 22.9, 38.6, 37.7, and 0.8%, respectively (Doornbos et al. 1991).

  Hydraulic conductivity properties were assigned to the interbeds based on the texture description and using the data obtained by the U.S. Geological Survey for nearby well ICPP-SCI-V-214. Alluvium conductivity was assumed to be equal to the high permeability observed at INTEC. High-permeability values were used to represent the degraded cement and sand vaults, the sand and gravel base layer, and the remaining surface alluvium. In general, higher hydraulic conductivity will result in faster water and radionuclide transit times in the unsaturated zone compared to low-conductivity units. The values used in the model are given in Table 9. The resultant moisture content of the high-permeability alluvium is 0.099 cm^3/cm^3.

Table 9. Hydraulic parameters used to represent flow at Site 5.

Lithology	Saturated Hydraulic Conductivity (m/year)	Total Porosity	Residual Moisture Content	Van Genuchten Fitting Parameter *n*	Van Genuchten Fitting Parameter α (1/m)	Van Genuchten Fitting Parameter *m*	Mualem (1976) Fitting Parameter *L*	Bulk Density (g/cm^3)	Reference
High-permeability alluvium and waste	8,798	0.32	0.0002	1.4	100	0.29	0.5	1.82	DOE-ID (2006b)
Interbed	1.258	0.459	0.165	1.4	0.052	0.83	9.25	1.5	Based on best fit of hydraulic data from well ICPP-SCI-V-213 (38 ft) (DOE-ID 2003b, DOE-ID 2004), bulk density (DOE-ID 1994)
Unsaturated fractured basalt	91[a] (300 mDarcy)	0.05[a]	0.001[a]	10[b]	2.5[b]	0.90[b]	0.5[b]	2	See footnotes, bulk density assumed

a. From Magnuson (1995), who originally used a residual moisture content of 0.0, but subsequently increased it to 0.01 in the Operable Unit 7-13/14 remedial investigation and baseline risk assessment (DOE-ID 2006c).
b. Parameters determined for the Van Genuchten (1980) model to mimic the behavior of the Magnuson (1995) hydraulic relationships for fractured basalt at low saturation.

- **Distribution coefficients** for radionuclides evaluated in the groundwater impacts analysis for the INL RH-LLW disposal facility were taken from INL (2010c) and are presented in Table 10. Sorption was assumed to occur in the compacted sand/gravel base layer, the surface alluvium below the base layer (above the basalt), and the sedimentary interbeds. Sorption was conservatively neglected for the waste zone, vadose zone basalt, and aquifer. Recommended values for natural alluvium (INL 2010c) were used for sedimentary interbeds. It was assumed that the downward migration of cement-affected

water would impact both the compacted sand/gravel base layer and the surface alluvium, and the recommended cement impacted alluvium values from INL 2010c were used for both.

Table 10. Distribution coefficients used in the groundwater impacts analysis for the INL RH-LLW disposal facility (all values from INL 2010c).

Element	Waste Zone K_d (mL/g)	Base Layer K_d (mL/g)	Alluvium below Base Layer K_d (mL/g)	Interbed K_d (mL/g)	Basalt K_d (mL/g)
Ac	0	360	360	300	0
C	0	2	2	0.5	0
Cl	0	0	0	0	0
H	0	0	0	0	0
I	0	0.3	0.3	3	0
Mo	0	14	14	10	0
Nb	0	224	224	160	0
Ni	0	30	30	100	0
Np	0	17.5	17.5	17.5	0
Pa	0	825	825	550	0
Pb	0	54	54	270	0
Pu	0	1,480	1,480	1,140	0
Ra	0	250	250	500	0
Tc	0	0.01	0.01	0.1	0
Th	0	150	150	500	0
U	0	10	10	10	0

- **Aquifer velocities** across INL are spatially variable. An INL sitewide CERCLA investigation of groundwater developed a calibrated flow model that encompassed the INTEC and ATR Complex areas (DOE-ID 2008). The model was calibrated to over 50 years of radionuclide transport, including H-3 and I-129 from both facilities. In this parameterized model, the Darcy velocities downgradient of the ATR Complex have a Darcy velocity of 21.0 m/year. This value was used in the RH-LLW disposal facility groundwater impacts analysis.
- **Other model parameters** included dispersivity and distance to the receptor. Dispersivity used in the groundwater impacts analysis for the INL RH-LLW disposal facility was taken from the Idaho CERCLA Disposal Facility performance assessment (DOE-ID 2010). The vertical dispersivity in the vadose zone was 1.44 m based on the implicit dispersion in the MCM model. Three-dimensional dispersivity in the aquifer was assigned values of 3.31 m, 0.662 m, and 0.00384 m in the longitudinal, transverse, and vertical directions, respectively. The receptor was assumed to reside 100 m downgradient of the proposed RH-LLW facility boundary.

4.3 Comparison of the Model Parameters used for the Greater Than Class C Environmental Impact Statement and Remote-Handled Low-Level Waste Environmental Assessment

- **Disposal facility configuration** for the proposed RH-LLW disposal facility is a below-grade vault with a length 240 m perpendicular to flow, 10 m parallel to flow, and a depth of 6 m for a total areal extent of 2,400 m^2. It was assumed that the waste was distributed uniformly within the upper 6 m of alluvium. The areal extent of the GTCC EIS disposal facility configurations ranged from 4.45E5 m^2, 2.02E05 m^2, and 2.43E5 m^2 for the borehole, trench, and vault arrays, respectively. Boreholes were assumed to extend from 30 m below grade to a maximum depth of 300 m. The trench depth of 10 m is similar to the configuration of the RH-LLW disposal facility, while the vault system was entirely

above grade. With the exception of the vault configuration for the GTCC EIS, more sedimentary material would remain at the RH-LLW disposal facility after the RH-LLW disposal vaults were installed. Increased sediment (alluvium) thickness would provide more opportunity for sorption to occur along the infiltration path and would allow more time for radioactive decay.

- **Infiltration rates** in the RH-LLW disposal facility groundwater impacts analysis were assumed to be 1 cm/year throughout the duration of the simulations. In contrast, a time-varying infiltration rate was assumed to control leaching from the waste, and a constant infiltration rate was assumed to control transport through the vadose zone in the GTCC EIS. For the GTCC EIS leaching calculations, no infiltration was assumed to penetrate the waste during the first 500 years. After 500 years, the infiltration rate through the waste was assigned a value of 20% of the background infiltration rate. The background infiltration rate through the vadose zone infiltration rate was assigned a value of 4 cm/year, making the leaching infiltration rate 0.8 cm/year.

  For the first 500 years, no radionuclide transport would occur in the GTCC EIS because of the assumed effectiveness of the engineered cover. This would delay radionuclide arrival in the aquifer compared to the more conservative immediate leaching assumed to occur in the INL RH-LLW disposal facility groundwater impacts analysis. However, the overall leaching rate after the first 500 years is very similar. Once released from the waste, the GTCC EIS modeled infiltration rate of 4.1 cm/year would transport contaminants much faster to the aquifer compared to the 1 cm/year assumed to apply in the INL RH-LLW disposal facility groundwater impacts model.

- **Relative sediment abundance** was determined for the RH-LLW disposal facility groundwater impacts analysis based on existing data. A total sediment thickness of 20 m (66 ft) was applied with 14 m used to represent the alluvium. Similar total sediment thicknesses were used in the GTCC EIS, which applied an alluvium thickness of 9 m and cumulative sedimentary interbed thickness of 23.3 m for a total of 32.5 m of sedimentary material. It is unclear from the information provided in the GTCC EIS whether or not the model used for each disposal facility configuration adjusted the total sediment thickness based on disposal depth. However, overall, the sediment thickness used in the GTCC EIS model is larger than applied in the RH-LLW disposal facility model. Thicker sediment units allow more sorption to occur along the flow path through the basalt-sediment sequence at INL.

- **Soil hydraulic properties** were assigned to the RH-LLW disposal facility groundwater impacts model based on data from wells nearby the ATR Complex that were collected from previous analyses. Properties applied to the GTCC EIS model were taken from the Radioactive Waste Management Complex Performance Assessment and from the INTEC Tank Farm Facilities Performance Assessment. The hydraulic properties in both models are similar, yielding comparable moisture content and hydraulic conductivity high enough to prevent excessive accumulation of moisture in the vadose zone at the applied infiltration rates.

- **Distribution coefficients** for radionuclides evaluated in the groundwater impacts analysis for the INL RH-LLW disposal facility were taken from INL (2010c). This report presented an exhaustive review of site-specific sorption data interpreted in the context of water chemistry expected to exist in the near-vault environment impacted by cementitious materials and in unimpacted sedimentary interbeds. Sorption values applied in the GTCC EIS are largely equivalent to the conservative Track 2 values used in previous INL evaluations of low-impact CERCLA sites. The K_ds for key radionuclides are particularly important. These include C-14, I-129, Tc-99, and uranium isotopes. A comparison of values used is given in Table 11. Values used in the RH-LLW disposal facility groundwater impacts analysis are significantly higher for C-14, I-129, and Tc-99 than those assumed in the GTCC EIS model. In contrast, K_d values applied for uranium isotopes in the GTCC EIS are about 50% higher than the value used in the RH-LLW disposal facility model.

  Not accounting for sorption in the alluvium and sedimentary interbeds increases groundwater concentrations in proportion to the K_d difference and increases transport rates in proportion to the

retardation coefficient. The fraction of contaminant mass (fw) present in the dissolved phase is defined mathematically in terms of the concentration in either the water or solid phase $[A]_w$ and $[A]_s$ and the volume of water (Vw) and solid (Vs):

$$fw = \frac{[A]_w Vw}{[A]_w Vw + [A]_s Vs} = \frac{Vw}{Vw + k_D Vs} = \frac{1}{1 + k_D \frac{1-\phi}{\phi Sw}}$$

Given a sediment porosity of 20%, water saturation of 30%, and K_d = 5, the water contains about 15% of the contaminant mass. Relative to a K_d of zero that implies a 1/15% or approximately a 7-fold reduction in concentration. The retardation coefficient

$$R = 1 + \frac{\rho_B k_D}{\phi Sw}\text{e}$$

reduces the Darcy velocity to transport velocity. For C-14, the retardation coefficient for sediment is about 31 in the RH-LLW disposal facility, while it is about 3 in the GTCC EIS. Given the relatively short half-life of 5,740 years, this difference is significant. For I-129, the sedimentary interbed retardation factor in the RH-LLW disposal facility is about 46 and it is 2.5 for Tc-99. In both cases, the K_d is significant enough to affect the fraction of mass in solution (i.e., concentrations) while the retardation factor relative to the half-life would not. For uranium, the larger difference in predicted concentrations would be associated with the K_d as opposed to the potential for radioactive decay.

The lower K_ds used in the GTCC EIS groundwater impacts analysis would result in concentrations approximately seven times higher than predicted for the RH-LLW disposal facility given the same initial inventory.

Table 11. Comparison of K_ds of key radionuclides used in the groundwater impacts analysis for the INL RH-LLW disposal facility EA and GTCC EIS.

	RH-LLW Disposal Facility			GTCC EIS		
Element	Base Layer K_d (mL/g)	Alluvium Below Base Layer K_d (mL/g)	Interbed K_d (mL/g)	Alluvium K_d (mL/g)	Interbed K_d (mL/g)	Aquifer Basalt
C	2	2	0.5	0.4	0.4	0.016
I	0.3	0.3	3	0	0	0
Tc	0.01	0.01	0.1	0	0	0
U	10	10	10	15.4	15.4	0.62

- **Aquifer velocity** was assigned a value of 21 m/year in the groundwater impacts analysis conducted for the RH-LLW disposal facility. At the same location, the GTCC EIS model applied a value of 1.5 m/year.

  To provide a more direct comparison to the values used in the GTCC EIS, the transmissivity and aquifer penetration thickness determined by Ackerman (1991) is provided in Table 12 for wells in the near vicinity of the ATR Complex. Well USGS 76 (i.e., Well 76 in Figure 7) is closest to the proposed location south of the ATR Complex. Ackerman (1991) provided the transmissivity values and penetration values. The penetration distance corresponds to the distance penetrated by the well below the water table and is recommended by Ackerman (1991) for use in determining an approximate hydraulic conductivity. Computed hydraulic conductivities are given using the values supplied by Ackerman (1991) in units of m/year for comparison to the value of 1,979 m/year used in the GTCC EIS. With the exception of Well TRA-02, the hydraulic conductivity values of the wells are 45 to 3,000 times greater than the GTCC EIS value.

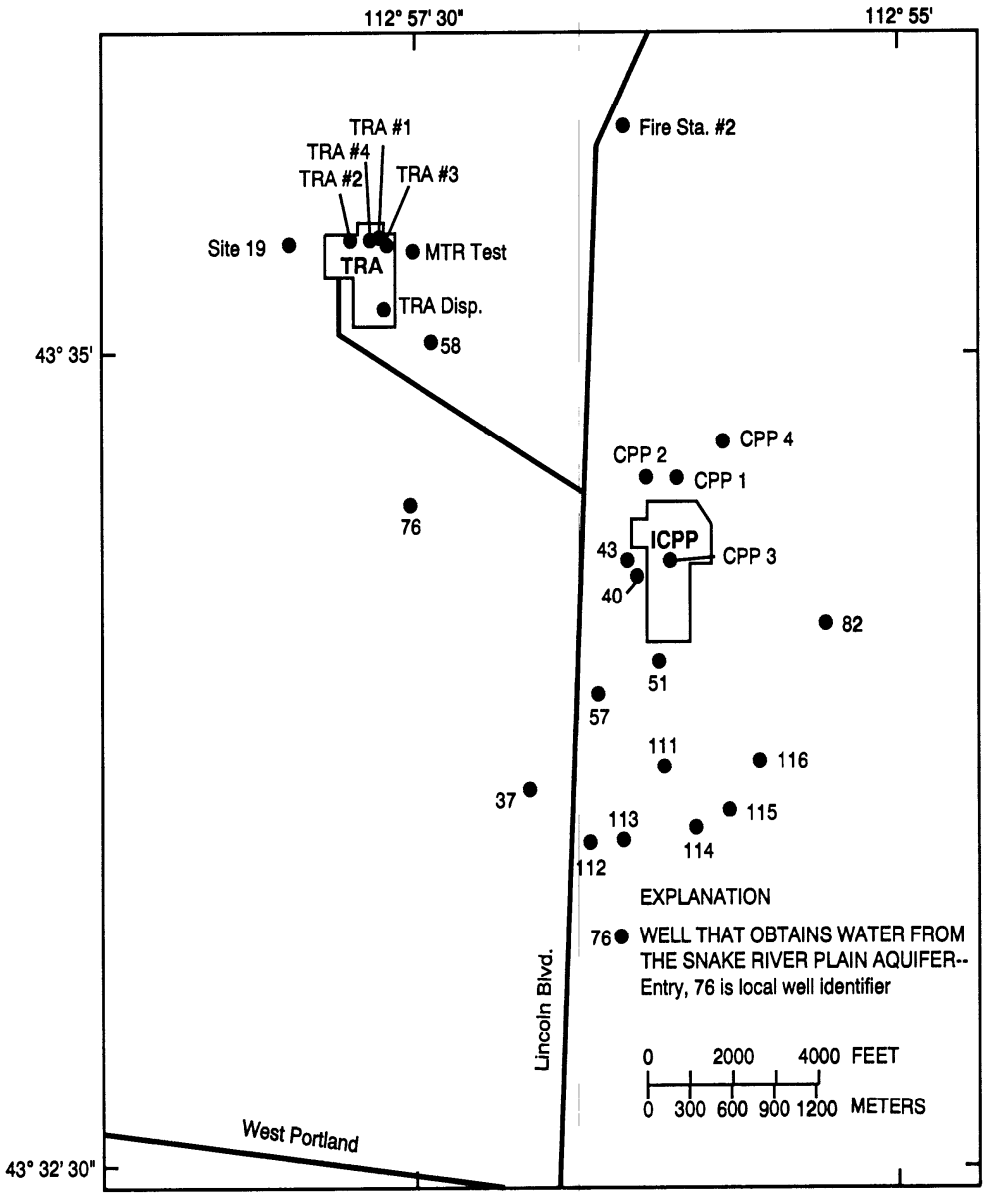

Figure 7. Well identifiers and locations used to determine transmissivity near the ATR Complex (from Ackerman 1991).

The hydraulic gradient near the ATR Complex is very small, and on the order of 5E-5 (m/m), based on hydraulic head measurements in Wells TRA-07 and TRA-08 (separated by about 6,000 ft) and data shown in Figure 8 (Figure 11 of DOE-ID 2003c). This value is smaller than the gradient (0.00075 m/m) adopted in the GTCC EIS. Using a head gradient of 1E-4 (m/m) and hydraulic conductivity of the nearest well (Well USGS-76), the computed Darcy velocity is on the order of 45 m/year, which is higher than the value determined from the calibrated sitewide aquifer model, and about a factor of 30 higher than the aquifer velocity used in the GTCC EIS.

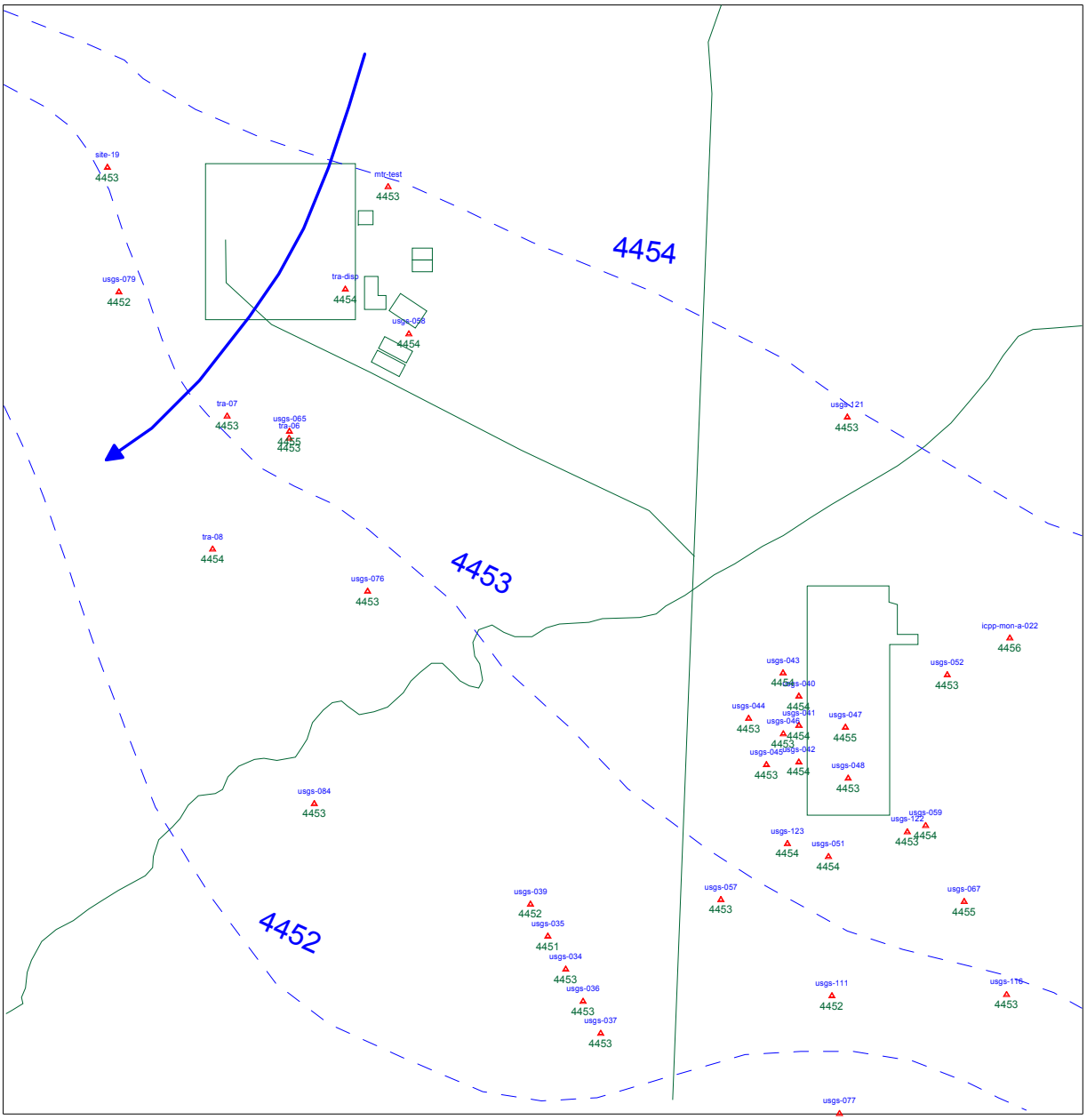

Figure 8. Aquifer water table configuration for October 2002 (from DOE-ID 2003c). Distance between Wells TRA-07 and TRA-08 is about 6,000 ft.

A mass balance calculation shows that in 1 year, the total flux into a cell of dimensions of 1 m x 1 m x 1 m would be 21.01 m^3 with 21 m^3 coming from the aquifer and 0.01 m^3 coming from the vadose zone in the INL RH-LLW disposal facility model, resulting in a net dilution of 2,101 times. The higher infiltration rate of 4 cm/year and lower aquifer velocity of 1.5 m/year used in the GTCC EIS results in a total influx volume of 1.541 m^3 for a net dilution of 37.5 times. This means that for a unit activity flux, the RH-LLW disposal facility model would yield a concentration 57 times smaller than the GTCC EIS model.

Table 12. Transmissivity, well penetration length, and hydraulic conductivity for wells near the ATR Complex (modified from Ackerman 1991).

Well Identifier	Transmissivity (ft^2/day)	Penetration (ft)	Hydraulic Conductivity (m/year)	Well Identifier	Transmissivity (ft^2/day)	Penetration (ft)	Hydraulic Conductivity (m/year)
TRA-01	7.3E5	144	6.07E+06	Site 19	3.1E4	398	9.33E+04
TRA-02	7.9E2	315	3.01E+03	MTR Test	2E5	137	1.75E+06
TRA-03	1.0E5	141	8.50E+05	USGS-58	3.7E4	50	8.87E+05
TRA-04	8.7E4	517	2.02E+05	USGS-76	1.9E5	252	9.04E+05
TRA Disp	6.2E4	815	9.12E+04	USGS-37	1.6E4	106	1.81E+05

- **Dispersivity** used in the groundwater impacts analysis for the INL RH-LLW disposal facility vadose zone model was 1.44 m in the vertical direction. Three-dimensional dispersivity in the aquifer was assigned values of 3.31 m, 0.662 m, and 0.00384 m in the longitudinal, transverse, and vertical directions, respectively. Values used for the RH-LLW disposal facility were determined through transport calibration to direct aquifer injection, 50 years of transport, and to vadose zone transport at INTEC (DOE-ID 2006b). These parameters account for laterally distributing transport through the fractured basalt and aquifer when used in one-dimensional flow models. Values applied in the GTCC EIS model were assumed to be zero in the vadose zone. For a transport distance to a receptor of 100 m, the longitudinal dispersivity would equate to about 10 m, the horizontal transverse dispersivity to 1 m, and the vertical transverse dispersivity to 0.1 m. Using smaller dispersivity neglects the influence of heterogeneity in the basalt and sediment.
- **Receptor distance –** in the groundwater impacts model for the RH-LLW disposal facility, the receptor was assumed to reside 100 m downgradient of the proposed RH-LLW facility boundary. This distance fixes the total dilution path length. In the GTCC EIS, the distance varied because of the placement of the waste with respect to the facility boundary location for each of the disposal configurations. For the assessment of the vault and trench configurations, the waste is relatively uniformly distributed within the waste area and a distance was applied from the facility perimeter. For the borehole installation, an effective borehole area was determined based on the total of all boreholes and it was placed in the center of the facility area. This effectively increases the distance from the waste to the facility perimeter, increasing the distance to the downgradient receptor. In theory, because the K_ds used for I-129 and Tc-99 were zero in the GTCC EIS and because they have long half-lives compared to the transport time to the aquifer, the GTCC EIS predicted doses for each facility configuration should be scalable by the facility cross-sectional area. However, in the GTCC EIS, the borehole configuration results in much lower doses compared to the surface vault and near-surface trench installations. Intuitively, the borehole configuration should have resulted in higher doses because of nearer proximity to the aquifer and shorter transport path through sorptive alluvial sediment. However, the K_ds were assigned very low or zero values for all sediment and the receptor distance for the borehole disposal configuration was about twice as far as for the other configurations considered. Therefore, the difference in receptor distance accounts for the apparently non-scalable results in the GTCC EIS based on other facility dimensions.

5. SUMMARY

In the GTCC EIS, the predicted peak all-pathways dose ranges between 800 and 2,300 mrem/year, depending on the disposal method. The peak all-pathways dose predicted by the groundwater impacts model for the INL RH-LLW disposal facility was less than 1 mrem/year. In both cases, the peak all-pathways effective dose equivalent is dominated by C-14, I-129, and Tc-99 during the first 10,000 years, and by uranium isotopes afterward. In both models, the slow release of radionuclides from activated metals allows the early dose to be dominated by miscellaneous other contaminated materials. The total inventory of nonactivated metal radionuclides in the GTCC EIS, excluding uranium isotopes is

476 Ci and is 66 Ci in the RH-LLW disposal facility. The total inventory difference is about a factor of 7. However, during the 100,000-year timeframe, the dose is dominated by isotopes of uranium. The initial inventories of U-238 are similar in the inventory of GTCC and INL RH-LLW waste. However, the inventory of U-234 is about 5E6 times larger in the GTCC inventory. Daughters of U-234 will be retained near the disposal facility because of a relatively large distribution coefficient in both assessments, allowing the production of Pb-210, which has a much larger dose-to-concentration conversion. The initially large GTCC EIS inventory of U-234 will lead to a much higher groundwater dose than predicted in the RH-LLW disposal facility groundwater assessment, with the peak dose occurring after 100,000 years following facility closure.

Peak all-pathways doses determined by the GTCC EIS and RH-LLW disposal facility groundwater impacts analyses cannot be directly compared because of conservatisms introduced through the groundwater models. The groundwater models used in the two analyses adopted similar conceptualizations of the vadose zone flow path and for the release mechanisms of the individual waste forms. By separating the inventories for the respective analyses into an activated metal and nonactivated metal component, if the groundwater model parameterizations had been closer, the predicted doses from both models could be reconciled.

The remaining difference between the predicted all-pathways effective dose equivalent can be attributed to significantly different sorption coefficients, infiltration rates, and – most importantly – aquifer velocities used in the two models. Model parameters used in the GTCC EIS were derived largely from INL sitewide geometric average values reported in the literature. Parameters used in the groundwater impacts analysis for the INL RH-LLW disposal facility were tailored to the environment near the ATR Complex. It is estimated that by not applying site-specific sorption parameters, the GTCC EIS doses are higher by at least an order of magnitude. In applying a higher infiltration rate, doses were over predicted by another factor of 5. Underestimating dilution in the very high aquifer velocities near the ATR Complex by a factor of 30 increases the level of conservatism by that factor. Overall, concentrations predicted by the GTCC EIS groundwater models are likely over predicted by several orders of magnitude.

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