INL/MIS-23-73457-Revision-0

Assessment of Potential Dose and Environmental Impacts from Proposed Testing at the INL Radiological Response Training Range

July 2023

A Jeffrey Sondrup

Changing the World's Energy Future

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9. Objective / Purpose

This assessment uses screening-level models to calculate potential environmental impacts from proposed tests at the Idaho National Laboratory (INL) Radiological Response Training Range (RRTR) site. Proposed tests could be conducted using 11 different radioactive material types that include K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m. The tests could potentially release radioactive material to the atmosphere and radionuclides and other contaminants to the soil, which could leach into the unsaturated zone and migrate to the aquifer. Atmospheric transport of radionuclides to potential human receptors and time-integrated air concentrations were calculated with a Gaussian plume model and three years of hourly meteorological data. Potential surface-soil impacts were calculated with the computer program mixing-cell model (MCM). Groundwater impacts were calculated with the computer programs MCM and GWSCREEN.

Radiological doses from potential atmospheric releases were calculated for public receptors off the INL Site and for workers at nearby INL facilities. Results were compared to regulatory dose limits. Maximum potential groundwater concentrations were estimated in the aquifer below the NSTR site and compared to drinking water standards or risk-based screening levels for resident tap water. Soil concentrations were calculated and compared to risk-based screening levels for workers and potential future residents. All impacts were estimated assuming 12 tests are conducted annually using all 11 material types for a period of 15 years.

This document provides the resources to enable a subject matter expert in the field of environmental assessments to replicate the modeling and calculations. The methodology and parameters are presented in the text. All electronic files, including computer-code input, output, executable files, batch files, scripts, and spreadsheet files are contained in a zip file that can be accessed by selecting "Additional Information" (select Native File) in the INL Electronic Document Management System (EDMS).

10. If revision, please state the reason and list sections and/or page being affected.

Revision 2 (Sondrup 2019a) includes evaluation of three additional material types (Cu, Zr, and F) combined with the original three material types (K_2O, $LaBr_3$, and KBr) which were evaluated in

Revision 1. These changes impact both the atmospheric and groundwater pathway results. A surface-soil impacts assessment was added as well as a discussion on testing frequency.

This revision (Revision 3) includes an evaluation of five additional material types (Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m) combined with the six material types evaluated in Revision 2. In addition, dose coefficients and lung-absorption types for radionuclides were updated with the most recent values, and regional screening levels for nonradionuclides and preliminary remediation goals (PRGs) for radionuclides were also updated to the most recent values.

11. Conclusion / Recommendations

It is highly unlikely the test scenarios evaluated in this ECAR will adversely impact human health based on comparisons of calculated dose and concentration against regulatory standards and risk-based screening levels. Conservative estimates of dose to workers and the public from atmospheric transport of possible radionuclide releases are far below federal radiation protection standards. Conservative estimates of potential contaminant concentrations in groundwater are less than federal drinking water standards or screening levels. Predicted radionuclide concentrations in surface soils are below risk-based screening levels, except for Ge-68 (material Ga-68) for the worker. The Ge-68 soil concentration can be made less than the worker PRG, if the number of annual tests using Ga-68 is reduced from 12 to 6. However, the sum of ratios still exceeds one because of the high K-40 ratio. If the EF of the worker (number of days the worker is in the contaminated testing area) is reduced from 225 days/yr (default value for full time worker) to 112 days/yr, the Ge-68 ratio is less than one and the sum of ratios is less than one.

Actual radiation doses and groundwater and surface-soil concentrations are likely to be much less than those calculated because of the conservative assumptions and parameters employed in the modeling. For example, atmospheric-transport calculations assume the entire inventory of each material type is readily released to the atmosphere and no plume deposition, depletion, or radioactive decay occurs during transport. The calculations also assume the same meteorological conditions (e.g., wind velocity, wind direction, stability class) that produce the maximum 95^{th} percentile concentration (i.e., concentration representing the 95^{th} percentile of a distribution of concentrations derived from 3 years of hourly meteorological data) at each receptor location are the same for all 12 tests during the year, and each receptor is assumed to be present during all 12 tests.

The surface-soil assessment assumes the entire inventory of each test is deposited in the top 5 cm of soil. No atmospheric dispersal is assumed, and the radionuclides are subject only to leaching and radioactive decay. The groundwater-pathway modeling is conservative in that it is one-dimensional in the unsaturated zone (no lateral spreading/dilution) and assumes the entire inventory of contaminants infiltrates into the ground at the same location for every test. This is especially conservative for particulate radionuclides because they would have to dissolve or corrode first and some would be dispersed into the atmosphere. The groundwater receptor is also assumed to consume water directly from a hypothetical well positioned in the location of maximum concentration. In addition, conservative degradation rates were used, and volatilization was not considered for the nonradioactive chemicals modeled. And finally, the calculations assume all 12 tests will be performed at the same place at both locations, and all 11 radioactive material types will be used for each test. This is conservative because it is anticipated that no more than two material types will be used per test.

CONTENTS

1.0 PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
Performer	Jeffrey Sondrup	BEA (H530)	All
Checker[a]	Arthur S. Rood	KSpar Inc.	All
Independent Reviewer[b]	Kristopher Murray	BEA (H550)	All
CUI Reviewer[c]	TBD	BEA (XXXX)	All
Manager[d]	Scott D. Lee	BEA (H530)	All
Requestor[e]	L. Trent Armstrong	BEA (D130)	All
Nuclear Safety[e]	NA		
Document Owner[e]	A. Jeffrey Sondrup	BEA (H530)	

Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
b. Concurrence of method or approach. See definition LWP-10106.
c. Concurrence with the document's markings in accordance with LWP-11202.
d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
e. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

NOTE: *Delete or mark "NA" for project roles not engaged. Include ALL personnel and their roles listed above in the eCR system. The list of the roles above is not all inclusive. If needed, the list can be extended or reduced.*

2.0 SCOPE AND BRIEF DESCRIPTION

Containment and explosive-disablement (CED) test activities described in the Final Environmental Assessment for Expanding Capabilities at the National Security Test Range (NSTR) and Radiological Response Training Range (RRTR) at Idaho National Laboratory (INL) (DOE/EA 2019) have been conducted since 2017 at RRTR. The first radiological test at NSTR is scheduled to begin in fiscal year 2024. The activities use projectile devices and explosives to disable radiological dispersal devices (RDDs). CED tests are either open-air detonations, or conducted inside a 16-ft diameter or 30-ft diameter fabric dome tent filled with containment foam designed to minimize dispersal of radioactive materials and projectiles. The foam is a mixture of water, air, and the product BlastGuard AFC-380, which was developed for this express purpose.

The previous revision of this ECAR (Revision 2, Sondrup 2019a) evaluated six different material types that could be used in testing. It has been proposed that five additional radiological materials be considered for testing for a total of 11 types:

Original materials

- Potassium oxide (K_2O)
- Lanthanum bromide ($LaBr_3$)
- Potassium bromide (KBr)
- Copper metal (Cu)
- Zirconium metal (Zr)
- Fluorine (Fl)

Proposed new materials

- Gallium metal (Ga)
- Gallium oxide (Ga_2O_3)
- Sodium nitrite ($NaNO_2$)
- Ga-68
- Tc-99m.

This assessment calculates potential atmospheric dose, and soil and groundwater impacts from proposed CED tests using all 11 radiological material types at the RRTR site. A companion document (ECAR-3565) contains a similar evaluation for NSTR, which is also at the INL Site.

Atmospheric transport of potential airborne radionuclides to potential human receptors was calculated with a straight-line Gaussian plume model and three years of hourly meteorological data. The model is described in Rood and Sondrup (2015), and a summary is included in Appendix A of this ECAR for completeness. The modeling conservatively assumes the entire inventory of radionuclides is dispersed (i.e., there is no containment) into the atmosphere. Radiological doses were calculated for public receptors off the INL Site and for workers at nearby INL facilities.

Potential groundwater impacts were evaluated by calculating maximum groundwater concentrations using computer programs MCM (Rood 2010) and GWSCREEN (Rood 2003). The modeling conservatively assumes the entire inventory of radionuclides and nonradioactive contaminants in the foam infiltrates the soil and migrates toward the aquifer. Maximum concentrations were estimated in the aquifer below each test location and compared to drinking water standards or risk-based screening levels for resident tap water.

Surface-soil impacts were evaluated by calculating maximum radionuclide concentrations in surface soil from repeated testing. Calculations were performed with the MCM computer program (Rood 2010), and soil concentrations were compared to U.S. Environmental Protection Agency (EPA) preliminary remediation goals (PRGs) for soil. PRGs are risk-based screening levels that would not likely result in adverse health impacts under reasonable maximum exposure conditions for long-term or chronic exposures.

This document provides the resources to enable a subject matter expert in the field of environmental assessments to replicate the modeling and calculations. This ECAR presents the methodology, equations, and model results. All electronic files, including code input, output, executable files, batch files, scripts, and spreadsheet files, are contained in a zip file that can be accessed by selecting "Additional Information" (select Native File) in the INL Electronic Document Management System (EDMS).

3.0 DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

All design or technical parameter inputs are included in the Discussion/Analysis section.

4.0 RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

Background information is presented in the Discussion/Analysis section and included in the references.

5.0 ASSUMPTIONS

All major assumptions are presented and discussed in the Discussion/Analysis section. Important assumptions are summarized in the Conclusion section at the end of each pathway subsection.

6.0 COMPUTER CODE VALIDATION

All computer code modeling and calculations were performed on a Dell Precision 7820 computer (Intel Xeon Silver 4110 CPU @ 2.10 GHz) running Microsoft Windows 10 Enterprise or on a Mac Pro computer with two Quad-Core Intel Xeon Processors (2.93 GHz) running Mac OS X 10.7.5 (11G63), Kernel Version Darwin 11.4.2. All electronic files, including computer code input, output, executable files, batch files, scripts, and spreadsheet files are contained in a zip file that can be accessed by selecting "Additional Information" (select Native File) in the INL EDMS.

Atmospheric transport was simulated with a straight-line Gaussian plume model, which is a set of equations coded into a Perl script for generation of time-integrated concentrations. The Gaussian plume model is used in standard EPA-approved models (e.g., CAP88, SCREEN3) and is a widely used approach for obtaining quick, reliable estimates of the mean ground-level concentrations of nondepositing and nonreactive air pollutants from point sources diffusing over flat terrain. The model was used for this assessment because it is appropriate for the distances and conditions considered and could be conveniently adapted to run with the 3-year set of 1-hour meteorological data. The model methodology is described in Appendix A. Time-integrated concentrations were copied and pasted from script output into a spreadsheet, and a visual verification was performed to ensure accuracy. Doses were calculated in the spreadsheet from the time-integrated concentrations using dose coefficients and other parameters as necessary, depending on the exposure route.

Surface-soil concentrations were calculated with the one-dimensional MCM computer code, Version 072210f_072710t (Rood 2010). Groundwater-pathway calculations were performed with the same MCM computer code and the GWSCREEN code, Version 2.5a (Rood 2003). Both MCM and GWSCREEN were developed at INL and have been used in numerous INL subsurface assessments. The MCM code simulates vadose zone water flow and contaminant transport and is composed of two codes: (1) MCMF, which computes water flow and saturation calculations and produces a file of water fluxes that can vary as a function of time and space, and (2) MCMT, which reads the water-flux file produced by MCMF and calculates contaminant transport. The version date of the MCMF and MCMT codes are July 22, 2010, and July 27, 2010, respectively. The MCM software theory, verification and validation, test plan, and configuration management plan are documented in Rood (2010).

The GWSCREEN computer code was used to model contaminant transport in the aquifer. It reads time-dependent contaminant-flux information output by MCMT and calculates transport in the aquifer assuming steady-state conditions. Installation and validation of the software is documented in “Software Verification and Validation Plan for the GWSCREEN Code” (Rood 1993) and “GWSCREEN Configuration Management, Validation Test Plan, and Validation Test Report” (EDF-7372 2006). The version date of the GWSCREEN code is January 23, 2007.

Microsoft Excel for Office 365 MSO (16.0.11231.20164) 32-bit, which is part of Microsoft Office 365 ProPlus, was used to support calculations and creating graphs of results. To validate the calculations performed with Excel, the calculation cell formulas were checked for accuracy, and a sample of the calculations were checked by hand.

7.0 DISCUSSION/ANALYSIS

This assessment calculates potential dose and environmental impacts from proposed CED tests at the RRTR site. Impacts were determined for tests performed at both the Northern Test Range (NTR), located north of the Specific Manufacturing Capability (SMC) facility, and the Southern Test Range (STR), located south of the Radioactive Waste Management Complex (RWMC) (see Figure 1). Radiological doses from potential atmospheric releases were calculated for public receptors off the INL Site and for workers at nearby INL facilities. Groundwater impacts were determined by estimating maximum groundwater concentrations below the NTR and STR sites and comparing them to drinking water standards or risk-based screening levels for resident tap water. Maximum potential soil concentrations were calculated and compared to risk-based screening levels for workers and potential future residents.

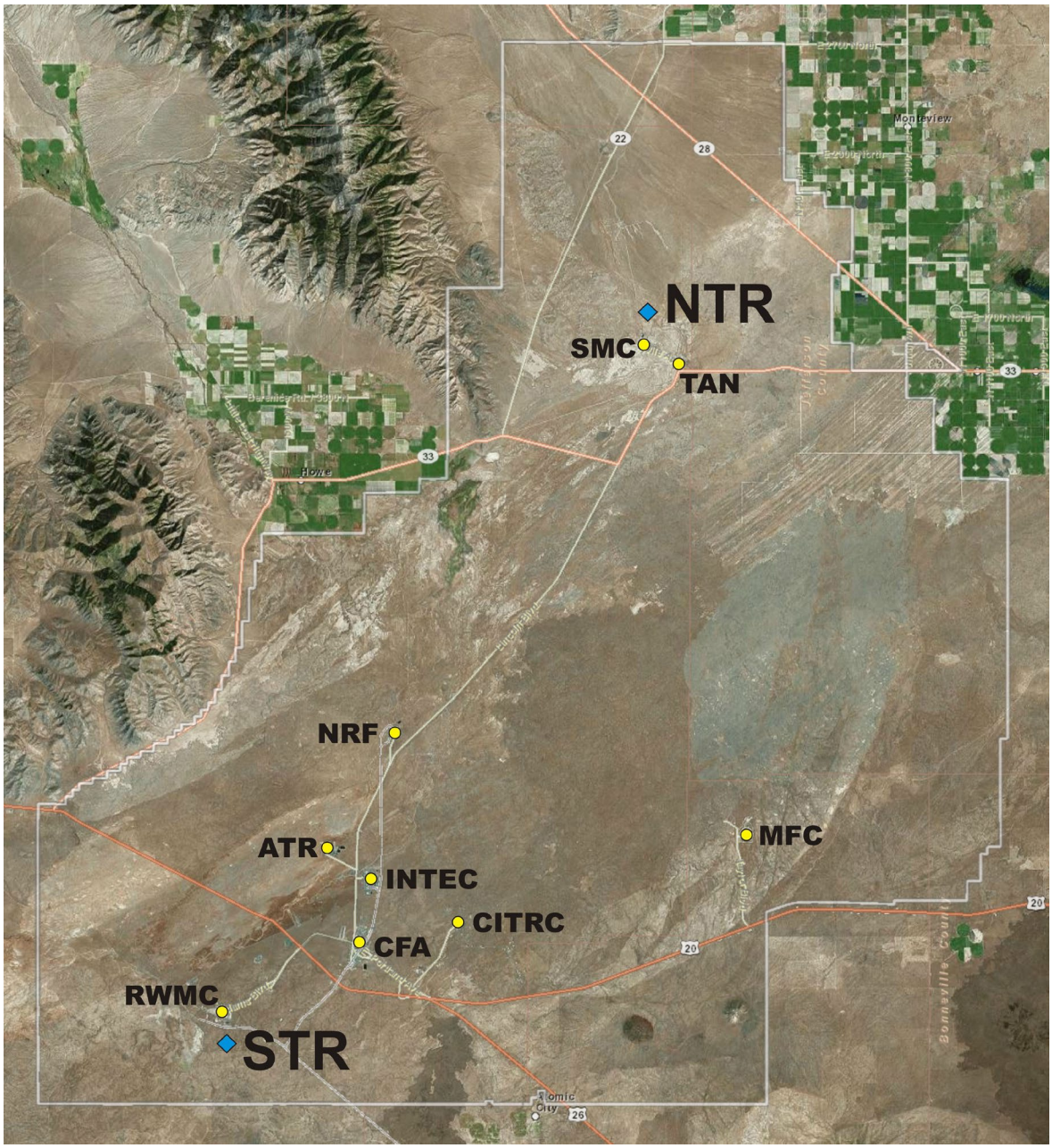

Figure 1. Map showing the locations of NTR, STR, and major INL facilities.

All calculations are based on the radiological source term presented in Table 1. The radionuclide and activity information for the original six material types (K_2O, $LaBr_3$, KBr, Cu, Zr, and F) was based on calculations by Sterbentz (2019) and documented in INL (2019). The source term for the Ga, Ga_2O_3, and $NaNO_2$ was provided by Nick Mann[1] based on 1 Ci of Ga-72 in both Ga and Ga_2O_3, and 1 Ci Na-24 in $NaNO_2$. Impurities were determined by gamma spectroscopy during post-irradiation analysis. The source term for 40 mCi Ga-68 is based on TEV-3580 (2021), and the 1 mCi Tc-99m source term is based on calculations provided by Jake Reynolds.[2]

[1] Nick Mann email to Jeff Sondrup, March, 13, 2023.

[2] Jake Reynolds email to Trent Armstrong, March 16, 2023.

The atmospheric-pathway assessment assumes all radionuclides are released into the atmosphere during each test. The surface soil and groundwater-pathway analyses only considered radionuclides that would persist long enough to cause soil or groundwater impacts. The groundwater analysis also considered the impact of nonradiological contaminants in the BlastGuard AFC-380 used to make the containment foam. The assessment assumes 12 tests will be performed per year at the same location at each test area (NTR and STR), and all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m) will be used for each test.

7.1 ATMOSPHERIC-PATHWAY ASSESSMENT

7.1.1 Atmospheric-Pathway Assessment Methodology

Atmospheric-transport modeling was performed using a straight-line Gaussian plume model, as described in Appendix A. Source data, meteorological data, dose coefficients, and receptor information are described below.

7.1.2 Atmospheric-Pathway Source Term

Estimated radionuclide release rates, half-life information, and dose coefficients are presented in Table 1 and are grouped by material type. This assessment assumes 12 tests will be performed annually at each test area (NTR and STR), and all 11 radioactive material types (K2O, LaBr3, KBr, Cu, Zr, F, Ga, Ga2O3, NaNO2, Ga-68 and Tc-99m) will be used for each test. This is conservative because it is anticipated that no more than two material types will be used per test. The total activity per test is conservatively assumed to be released to the atmosphere and to be readily transported. This is especially conservative for radionuclides that are metal particulates. Even for unconfined testing, dispersal of these radionuclides would likely be limited to the immediate test area. For this analysis, materials in liquid form are assumed to be transported as particulates and respirable.

7.1.3 Gaussian Plume Model and Dose Calculations

A Gaussian plume model was coupled with three years of hourly meteorological data (2006–2008). Data used for NTR came from the nearby tower at Test Area North (TAN), and data for STR came from the nearby tower at RWMC. Both towers are part of the National Oceanic and Atmospheric Administration (NOAA)/INL meteorological monitoring network. The model computes *X/Q* at each worker and public receptor location. *X/Q* is the atmospheric concentration of a radioactive material at a downwind location, normalized by the release rate of the material from the source. The model conservatively assumes no deposition or depletion of the plume and no radioactive decay during transport.

The U.S. Nuclear Regulatory Commission Regulatory Guide 1.145 (NRC 1983) recommends the 95th percentile of the dose distribution for consequence analysis of reactor accidents. The 95th percentile *X/Q* means that there is only a 5% chance that the dose from a release will be exceeded. Because tests will be performed during daytime work hours, the 95th percentile *X/Q* was calculated using meteorological data from 9:00 a.m. to 4:00 p.m. The 95th percentile *X/Q* is calculated by determining the *X/Q* for each daytime hour of the three-year meteorological data set and calculating the percentile value using the percentile function in Microsoft Excel. For the dose calculations, the 95th percentile *X/Q* was multiplied by the total annual release (see Table 1), resulting in a time-integrated concentration at the receptor location. The product of the time-integrated concentration and the inhalation rate provides an intake rate, which, when multiplied by a dose coefficient, yields an annual inhalation dose. For submersion doses, the time-integrated concentration multiplied by the submersion dose coefficient

yields the annual dose from submersion. The total dose is the sum of the inhalation and submersion doses. The inhalation and submersion dose equations are shown in *Equation (1)* and *Equation (2)*.

$$D_{inh} = X/Q \times Q_{total} \times IH \times DC_{inh}$$
$$D_{sub} = X/Q \times Q_{total} \times DC_{sub} \quad \text{(1) and (2)}$$

where

D_{inh} = inhalation effective dose (rem)

D_{sub} = submersion effective dose (rem)

X/Q = dispersion factor (hr/m^3)

Q_{total} = total annual release (Ci)

IH = inhalation rate (m^3/hr)

DC_{inh} = inhalation effective dose coefficient (rem/Ci)

DC_{sub} = submersion effective dose coefficient (rem-m^3/Ci-hr).

The inhalation rate used in the calculations (0.917 m^3/hr) is the default value for the CAP88-PC computer model (EPA 2013). The dose coefficients (see Table 1) were taken from DOE-STD-1196 (DOE 2022). For the worker, the committed, effective inhalation and effective submersion dose coefficients for an adult were used. For the public, the committed, effective per capita inhalation and effective submersion dose coefficients were used. Each per capita dose coefficient for a radionuclide and exposure mode is a weighted sum of age-specific effective dose coefficients, where the weight considers the fraction of each subgroup in the U.S. population, represented by an age-specific effective dose coefficient and the level of exposure to the radionuclide for that age group. They are used in demonstrations of compliance with public dose limits without having to assess doses to individual age-specific categories.

7.1.4 Atmospheric-Pathway Receptors and X/Q Results

X/Q values were calculated at potential public- receptor and worker locations. Figure 2 shows potentially habitable public receptor locations (orange squares), as reported in Rood and Sondrup (2015). These 27 locations are a subset of the 98 potential residences within approximately 5 miles of the INL Site boundary, which were identified by a survey conducted in 2013 by the U.S. Department of Energy (DOE) Idaho Environmental Surveillance, Education, and Research (ESER) program (DOE-ID 2014). *X/Q* values were calculated for the nearest public receptors to both sources (STR and NTR) and receptors on either side of it. The public receptor nearest to STR is Location 3 (Frenchman's cabin), and the nearest to NTR is Location 19. Comparison of the 95th percentile *X/Q* values for Locations 2, 3, and 4, which are nearest to STR, confirmed Location 3 would produce the highest value. Comparison of 95th percentile *X/Q* values for Locations 16–20 nearest NTR indicate the maximum was not at Location 19, but at Location 20. Location 3 is 6,036 m (3.75 mi) SSW of STR. Location 20 is 14,775 m (9.18 mi) NE of NTR.

X/Q values were calculated for workers located at INL facilities nearest to NTR and STR. The nearest worker-occupied area to NTR is the NW corner of the SMC facility, which is approximately 1,640 m (1.02 mi) SSW of NTR (see Figure 1). The nearest point of exposure for STR is the Advanced Mixed Waste Treatment Project (AMWTP) parking lot (SE corner of RWMC) located 1,500 m (0.93 mi) NNE of STR (see Figure 1). Given the close proximity of SMC and AMWTP to NTR and STR respectively, no other facilities were considered for workers.

Table 2 shows the distance, direction, and 95th percentile *X/Q* results for each worker and public receptor location analyzed. The same public and worker receptors were assumed to be present during each of the 12 tests during the year.

Table 1. Radionuclide release rates and dose coefficients (grouped by material type).

Isotope	Half-Life	Release per Test (Ci)	Total Annual Release[a] (Ci)	Lung-Absorption Type[b]	Inhalation Dose Coefficient Adult[c] (rem/Ci)	Inhalation Dose Coefficient per Capita[d] (rem/Ci)	Submersion Dose Coefficient Adult[c] (rem-m^3/Ci-hr)	Submersion Dose Coefficient per Capita[d] (rem-m^3/Ci-hr)
Material: Potassium Oxide (K_2O)								
Be-10	1.51E+06 yr	2.87E-20	3.44E-19	M	4.11E+04	4.40E+04	7.42E+00	7.59E+00
C-14	5.7E+03 yr	2.13E-09	2.56E-08	M	3.61E+03	3.92E+03	5.14E-01	5.29E-01
Cl-36	3.01E+05 yr	6.78E-08	8.14E-07	F	1.60E+03	1.95E+03	8.58E+00	8.78E+00
Ar-39	269 yr	1.43E-04	1.72E-03	NA	0	0	6.21E+00	6.35E+00
Ar-41	1.83 hr	2.17E-09	2.61E-08	NA	0	0	8.26E+02	8.48E+02
Ar-42	32.9 yr	2.15E-15	2.58E-14	NA	0	0	6.77E+00	6.93E+00
K-40	1.25E+09 yr	3.43E-06	4.11E-05	M	4.03E+04	4.33E+04	1.20E+02	1.24E+02
K-42	12.4 hr	7.00E+00	84	M	1.29E+03	1.48E+03	2.54E+02	2.61E+02
Material: Lanthanum Bromide ($LaBr_3$)								
As-76	1.09 d	1.22E-06	1.46E-05	M	1.81E+03	2.04E+03	3.01E+02	3.10E+02
Se-79	3.26E+05 yr	1.45E-11	1.74E-10	M	5.14E+03	5.92E+03	5.75E-01	5.91E-01
Se-81m	57.3 m	1.48E-24	1.77E-23	M	1.34E+02	1.52E+02	7.11E+00	7.42E+00
Br-80	17.68 m	1.71E-03	2.06E-02	F	3.17E+01	3.70E+01	7.58E+01	7.81E+01
Br-80m	4.42 hr	1.60E-03	1.92E-02	F	1.45E+02	1.83E+02	2.45E+00	2.73E+00
Br-82	35.3 hr	4.88E-01	5.86E+00	F	7.73E+02	8.81E+02	1.61E+03	1.67E+03
Kr-79	35.0 hr	1.68E-12	2.02E-11	NA	0	0	1.45E+02	1.51E+02
Kr-81	2.29E+05 yr	5.00E-15	6.00E-14	NA	0	0	4.92E-01	5.21E-01
Kr-83m	1.83 hr	7.19E-16	8.63E-15	NA	0	0	1.23E-02	1.73E-02
Cs-135	2.3E+06 yr	2.71E-19	3.25E-18	M	6.88E+03	7.44E+03	1.59E+00	1.63E+00
Cs-136	13.04 d	3.59E-09	4.30E-08	M	6.11E+03	6.55E+03	1.29E+03	1.33E+03
Cs-137	30.08 yr	1.85E-19	2.22E-18	M	3.10E+04	3.23E+04	5.18E+00	5.30E+00
Ba-136m	0.308 s	5.91E-10	7.09E-09	NA	0	0	0	0
Ba-139	83.06 m	3.73E-17	4.47E-16	M	1.71E+02	2.00E+02	6.50E+01	6.69E+01
Ba-140	12.75 d	4.19E-17	5.03E-16	M	1.08E+04	1.18E+04	1.13E+02	1.16E+02
La-137	6.00E+04 yr	1.15E-14	1.38E-13	M	1.74E+04	1.75E+04	3.10E+00	3.46E+00
La-138	1.02E+11 yr	9.48E-11	1.14E-09	M	4.03E+05	4.03E+05	7.69E+02	7.91E+02

Isotope	Half-Life	Release per Test (Ci)	Total Annual Release[a] (Ci)	Lung-Absorption Type[b]	Inhalation Dose Coefficient Adult[c] (rem/Ci)	Inhalation Dose Coefficient per Capita[d] (rem/Ci)	Submersion Dose Coefficient Adult[c] (rem-m^3/Ci-hr)	Submersion Dose Coefficient per Capita[d] (rem-m^3/Ci-hr)
La-140	1.679 d	5.08E-01	6.10E+00	M	2.33E+03	2.58E+03	1.48E+03	1.52E+03
La-141	3.92 hr	1.89E-10	2.27E-09	M	4.11E+02	4.77E+02	6.26E+01	6.42E+01
Ce-139	137.6 d	4.44E-26	5.33E-25	M	4.22E+03	4.51E+03	7.66E+01	7.97E+01
Ce-141	32.51 d	4.83E-09	5.80E-08	M	4.22E+03	4.63E+03	4.32E+01	4.48E+01
Material: Potassium Bromide (KBr)								
Cl-36	3.01E+05 yr	7.73E-10	9.27E-09	F	1.60E+03	1.95E+03	8.58E+00	8.78E+00
Ar-39	269 yr	1.63E-06	1.95E-05	NA	0	0	6.21E+00	6.35E+00
Ar-41	1.83 hr	2.48E-11	2.97E-10	NA	0	0	8.26E+02	8.48E+02
Ar-42	32.9 yr	2.44E-17	2.93E-16	NA	0	0	6.77E+00	6.93E+00
K-40	1.25E+09 yr	3.90E-08	4.69E-07	M	4.03E+04	4.33E+04	1.20E+02	1.24E+02
K-42	12.4 hr	7.98E-02	9.57E-01	M	1.29E+03	1.48E+03	2.54E+02	2.61E+02
Ni-63	101.2 yr	2.06E-14	2.47E-13	M	1.02E+03	1.12E+03	6.15E-02	6.34E-02
Ni-65	2.52 hr	4.16E-16	5.00E-15	M	2.22E+02	2.55E+02	3.78E+02	3.89E+02
Cu-64	12.7 hr	3.97E-09	4.76E-08	M	2.21E+02	2.45E+02	1.12E+02	1.15E+02
Cu-67	61.83 hr	1.57E-11	1.89E-10	M	8.84E+02	9.73E+02	6.55E+01	6.79E+01
Zn-65	243.9 d	1.22E-08	1.46E-07	M	7.96E+03	8.40E+03	3.58E+02	3.69E+02
Zn-69	56.4 m	1.38E-20	1.66E-19	M	7.14E+01	8.07E+01	1.06E+01	1.08E+01
Ga-72	14.1 hr	1.08E-21	1.30E-20	M	1.12E+03	1.25E+03	1.74E+03	1.80E+03
As-76	1.09 d	1.22E-05	1.46E-04	M	1.81E+03	2.04E+03	3.01E+02	3.10E+02
Se-79	3.26E+05 yr	1.45E-10	1.74E-09	M	5.14E+03	5.92E+03	5.75E-01	5.91E-01
Se-81m	57.3 m	1.48E-23	1.78E-22	M	1.34E+02	1.52E+02	7.11E+00	7.42E+00
Br-80	17.68 m	1.71E-02	2.06E-01	F	3.17E+01	3.70E+01	7.58E+01	7.81E+01
Br-80m	4.42 hr	1.60E-02	1.92E-01	F	1.45E+02	1.83E+02	2.45E+00	2.73E+00
Br-82	35.3 hr	4.89E+00	5.86E+01	F	7.73E+02	8.81E+02	1.61E+03	1.67E+03
Kr-79	35.0 hr	1.68E-11	2.02E-10	NA	0	0	1.45E+02	1.51E+02
Kr-81	2.29E+05 yr	5.01E-14	6.01E-13	NA	0	0	4.92E-01	5.21E-01
Kr-83m	1.83 hr	7.20E-15	8.64E-14	NA	0	0	1.23E-02	1.73E-02
Kr-85	10.78 yr	2.48E-12	2.98E-11	NA	0	0	8.88E+00	9.11E+00
Kr-87	1.27 h	4.95E-21	5.94E-20	NA	0	0	5.77E+02	5.91E+02
Rb-86	18.64 d	3.57E-06	4.28E-05	M	9.14E+03	9.99E+03	8.52E+01	8.76E+01
Rb-87	4.97E+10 yr	5.28E-11	6.34E-10	M	8.29E+03	8.99E+03	2.32E+00	2.37E+00
Rh-105	35.36 hr	2.46E-23	2.95E-22	M	5.37E+02	5.92E+02	4.80E+01	4.96E+01
Pd-107	6.5E+06 yr	3.26E-21	3.91E-20	M	3.42E+02	3.81E+02	1.01E-02	1.04E-02
Pd-109	13.7 hr	1.10E-13	1.32E-12	M	6.88E+02	7.70E+02	1.45E+01	1.49E+01
Ag-106	24.0 hr	1.83E-12	2.20E-11	M	4.03E+01	4.66E+01	4.28E+02	4.42E+02
Ag-109m	39.6 s	1.13E-13	1.35E-12	NA	0	0	1.76E+00	1.90E+00
Ag-110	24.6 s	2.24E-11	2.69E-10	NA	0	0	7.57E+01	7.77E+01

Isotope	Half-Life	Release per Test (Ci)	Total Annual Release[a] (Ci)	Lung-Absorption Type[b]	Inhalation Dose Coefficient Adult[c] (rem/Ci)	Inhalation Dose Coefficient per Capita[d] (rem/Ci)	Submersion Dose Coefficient Adult[c] (rem-m^3/Ci-hr)	Submersion Dose Coefficient per Capita[d] (rem-m^3/Ci-hr)
Ag-110m	249.8 d	1.69E-09	2.02E-08	M	3.33E+04	3.47E+04	1.69E+03	1.74E+03
Ag-111	7.45 d	2.93E-14	3.52E-13	M	2.53E+03	2.79E+03	2.72E+01	2.80E+01
Cd-109	461.4 d	3.67E-17	4.41E-16	M	1.24E+04	1.34E+04	2.40E+00	2.65E+00
Ir-192	73.83 d	9.27E-10	1.11E-08	M	1.21E+04	1.30E+04	4.74E+02	4.90E+02
Ir-194	19.28 hr	3.65E-09	4.39E-08	M	1.08E+03	1.23E+03	8.90E+01	9.16E+01
Material: Copper Metal (Cu)								
Cu-64	12.7 hr	3	36	M	2.21E+02	2.45E+02	1.12E+02	1.15E+02
Material: Zirconium Metal (Zr)								
Zr-97	16.744 hr	10	120	M	1.81E+03	2.04E+03	5.59E+02	5.77E+02
Material: Fluorine (Fl)								
F-18	109.8 m	5	60	F	7.25E+01	8.29E+01	5.86E+02	6.06E+02
Material: Gallium Metal (Ga)								
Ga-72	14.1 h	1.00E+00	12	M	1.12E+03	1.25E+03	1.74E+03	1.80E+03
Zn-65	244.06 d	3.44E-09	4.13E-08	M	7.96E+03	8.40E+03	3.58E+02	3.69E+02
Material: Gallium Oxide (Ga_2O_3)								
Ga-72	14.1 h	1.00E+00	12	M	1.12E+03	1.25E+03	1.74E+03	1.80E+03
Zn-65	244.06 d	4.99E-14	5.99E-13	M	7.96E+03	8.40E+03	3.58E+02	3.69E+02
Hf-181	42.39 d	2.15E-12	2.58E-11	M	8.14E+03	8.84E+03	3.04E+02	3.14E+02
Ta-182	114.43 d	2.11E-16	2.53E-15	M	1.78E+04	1.91E+04	7.85E+02	8.09E+02
Material: Sodium Nitrite ($NaNO_2$)								
Na-24	14.959 h	1.00E+00	12	M	1.37E+03	1.52E+03	2.77E+03	2.84E+03
Sc-46	83.79 d	4.83E-11	5.80E-10	M	1.83E+04	1.98E+04	1.24E+03	1.27E+03
Zn-65	244.06 d	1.01E-10	1.21E-09	M	7.96E+03	8.40E+03	3.58E+02	3.69E+02
Material: Ga-68								
Ga-68	67.71 m	4.00E-02	4.80E-01	M	1.39E+02	1.62E+02	5.89E+02	6.09E+02
Ge-68	270.95 d	2.00E-06	2.40E-05	M	4.77E+04	5.07E+04	1.02E-03	1.68E-03
Material: Tc-99m								
Tc-99m	6.015 h	1.00E-03	1.20E-02	M	3.66E+01	4.00E+01	6.85E+01	7.10E+01
Tc-99	2.11E+05 y	3.21E-12	3.85E-11	M	6.96E+03	7.55E+03	1.94E+00	2.00E+00

a. The assessment assumes all 11 radioactive material types are used for each of the 12 tests per year.
b. Lung-absorption type: F = Fast, M = Medium, S = Slow. Type is the recommended type from DOE-STD-1196 (DOE 2022) Table 5. Values do not apply to non-particulates (e.g., gases).
c. Adult inhalation and submersion dose coefficients used for workers.
d. Per capita inhalation and submersion dose coefficients used for public receptors.

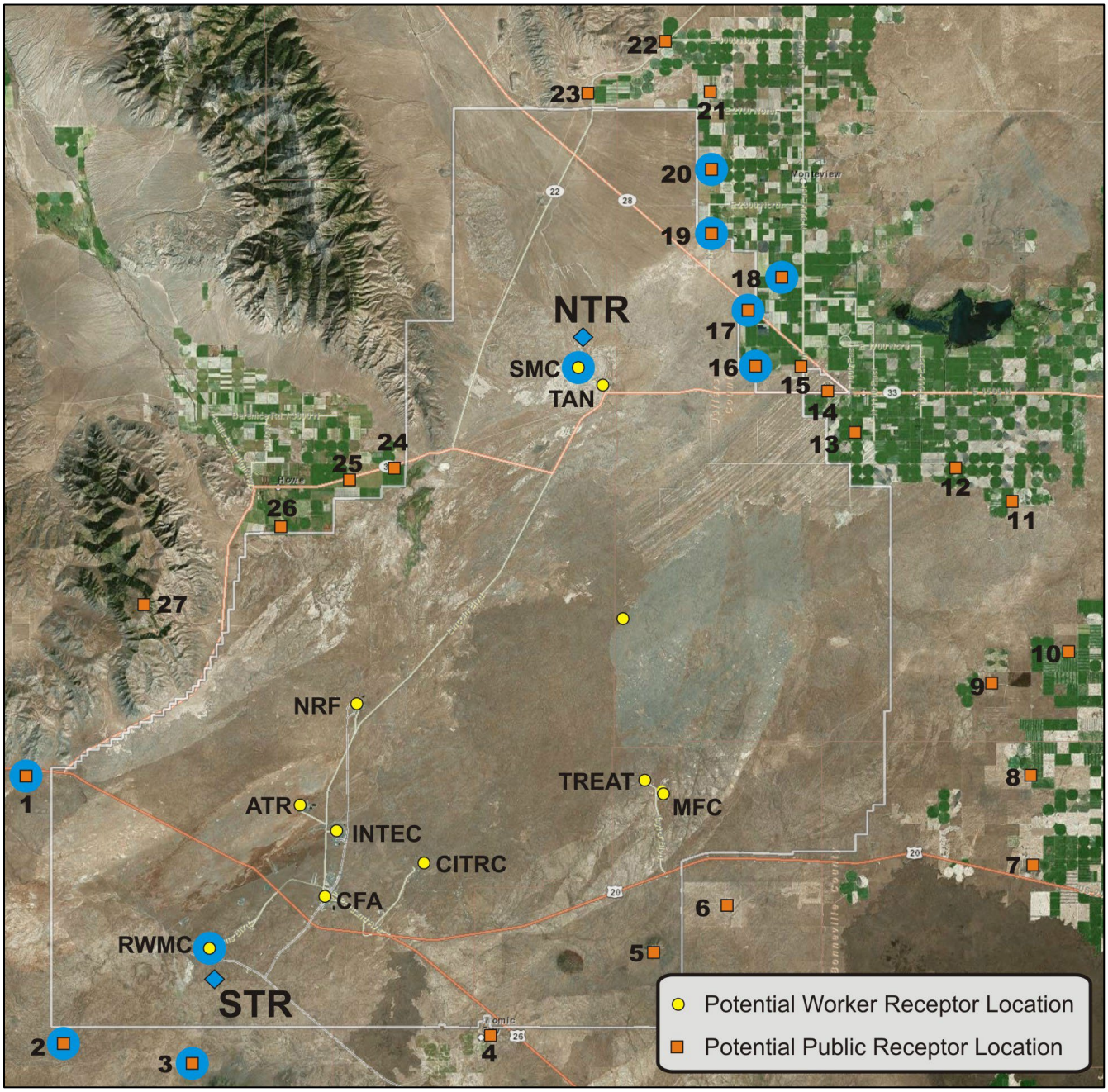

Figure 2. INL map showing potential public and worker receptor locations. Analyzed receptors are circled in blue.

Table 2. Receptor distance, azimuth, and 95th percentile *X/Q* results for NTR and STR receptors.

	Worker Receptors				Public Receptors			
Training Range	Location	Distance (m)	Azimuth (degree)	95th Percentile *X/Q* (hr/m³)	Location	Distance (m)	Azimuth (degree)	95th Percentile *X/Q* (hr/m³)
NTR	SMC	1,640	195	6.79E-10	Location 20	14,775	39	4.78E-11
STR	RWMC	1,500	9.1	6.66E-10	Location 3	6,036	195.7	3.40E-13

7.1.5 Atmospheric-Pathway Dose Results

Table 3 shows the annual effective dose results by radionuclide for both NTR and STR at the worker and public receptor locations with the maximum 95th percentile *X/Q*. The table shows the total dose by material type and the total dose assuming all 11 radioactive material types are used for each test.

Table 4 shows the total dose if the maximum total doses from both NTR and STR are combined. This is not a realistic dose because the receptor locations are different. Nevertheless, it shows that even the combined dose is less than the regulatory limit. Figure 3 shows the percent contribution to the total dose by material type for each receptor. The graphs are the same for both NTR and STR and show that for worker and public receptors, most of the dose comes from Zr-97. The Ga-68 and Tc-99m contributions are insignificant (~ 0.05%).

Table 3. Maximum 95th percentile annual effective dose results for both test locations.

	NTR		STR	
Radionuclide	Worker Dose (SMC)[a] (mrem/yr)	Public Dose (Location 20)[a] (mrem/yr)	Worker Dose (RWMC)[a] (mrem/yr)	Public Dose (Location 3)[a] (mrem/yr)
Material: Potassium Oxide (K_2O)				
Be-10	8.80E-21	6.64E-22	8.63E-21	4.72E-24
C-14	5.74E-11	4.39E-12	5.63E-11	3.12E-14
Cl-36	8.15E-10	6.97E-11	8.00E-10	4.96E-13
Ar-39	7.23E-09	5.21E-10	7.10E-09	3.70E-12
Ar-41	1.46E-11	1.06E-12	1.44E-11	7.52E-15
Ar-42	1.18E-19	8.52E-21	1.16E-19	6.06E-23
K-40	1.04E-06	7.82E-08	1.02E-06	5.56E-10
K-42	8.19E-02	6.49E-03	8.03E-02	4.62E-05
Total Dose K_2O	**8.19E-02**	**6.49E-03**	**8.03E-02**	**4.62E-05**
Material: Lanthanum Bromide ($LaBr_3$)				
As-76	1.94E-08	1.52E-09	1.91E-08	1.08E-11
Se-79	5.58E-13	4.52E-14	5.48E-13	3.21E-16
Se-81m	1.57E-27	1.24E-28	1.54E-27	8.85E-31
Br-80	1.46E-06	1.10E-07	1.44E-06	7.82E-10
Br-80m	1.77E-06	1.57E-07	1.73E-06	1.11E-09
Br-82	9.23E-03	6.92E-04	9.06E-03	4.92E-06

	NTR		STR	
Radionuclide	Worker Dose (SMC)[a] (mrem/yr)	Public Dose (Location 20)[a] (mrem/yr)	Worker Dose (RWMC)[a] (mrem/yr)	Public Dose (Location 3)[a] (mrem/yr)
Kr-79	1.99E-15	1.45E-16	1.95E-15	1.03E-18
Kr-81	2.00E-20	1.49E-21	1.97E-20	1.06E-23
Kr-83m	7.18E-23	7.14E-24	7.05E-23	5.08E-26
Cs-135	1.39E-20	1.06E-21	1.37E-20	7.53E-24
Cs-136	2.01E-10	1.51E-11	1.98E-10	1.07E-13
Cs-137	4.29E-20	3.14E-21	4.21E-20	2.23E-23
Ba-136m	0	0	0	0
Ba-139	6.73E-20	5.34E-21	6.61E-20	3.80E-23
Ba-140	3.44E-18	2.62E-19	3.37E-18	1.86E-21
La-137	1.49E-15	1.06E-16	1.47E-15	7.51E-19
La-138	2.86E-10	2.01E-11	2.81E-10	1.43E-13
La-140	1.50E-02	1.13E-03	1.47E-02	8.04E-06
La-141	6.77E-13	5.44E-14	6.64E-13	3.87E-16
Ce-139	1.43E-27	1.08E-28	1.40E-27	7.64E-31
Ce-141	1.54E-10	1.19E-11	1.51E-10	8.44E-14
Total Dose $LaBr_3$	**2.42E-02**	**1.82E-03**	**2.38E-02**	**1.30E-05**
Material: Potassium Bromide (KBr)				
Cl-36	9.28E-12	7.95E-13	9.11E-12	5.65E-15
Ar-39	8.24E-11	5.93E-12	8.08E-11	4.22E-14
Ar-41	1.67E-13	1.20E-14	1.63E-13	8.56E-17
Ar-42	1.35E-21	9.71E-23	1.32E-21	6.90E-25
K-40	1.18E-08	8.92E-10	1.16E-08	6.34E-12
K-42	9.33E-04	7.40E-05	9.15E-04	5.26E-07
Ni-63	1.57E-16	1.21E-17	1.54E-16	8.61E-20
Ni-65	1.97E-18	1.49E-19	1.94E-18	1.06E-21
Cu-64	1.01E-11	7.74E-13	9.95E-12	5.50E-15
Cu-67	1.12E-13	8.66E-15	1.10E-13	6.15E-17
Zn-65	7.59E-10	5.64E-11	7.45E-10	4.01E-13
Zn-69	8.57E-24	6.72E-25	8.41E-24	4.78E-27
Ga-72	2.44E-23	1.82E-24	2.39E-23	1.30E-26
As-76	1.94E-07	1.52E-08	1.91E-07	1.08E-10
Se-79	5.58E-12	4.52E-13	5.48E-12	3.22E-15
Se-81m	1.57E-26	1.25E-27	1.54E-26	8.86E-30
Br-80	1.46E-05	1.10E-06	1.44E-05	7.83E-09
Br-80m	1.77E-05	1.57E-06	1.73E-05	1.11E-08
Br-82	9.24E-02	6.93E-03	9.07E-02	4.93E-05
Kr-79	1.99E-14	1.45E-15	1.95E-14	1.03E-17

	NTR		STR	
Radionuclide	Worker Dose (SMC)[a] (mrem/yr)	Public Dose (Location 20)[a] (mrem/yr)	Worker Dose (RWMC)[a] (mrem/yr)	Public Dose (Location 3)[a] (mrem/yr)
Kr-81	2.00E-19	1.50E-20	1.97E-19	1.06E-22
Kr-83m	7.19E-22	7.15E-23	7.05E-22	5.08E-25
Kr-85	1.80E-16	1.30E-17	1.76E-16	9.21E-20
Kr-87	2.32E-23	1.68E-24	2.28E-23	1.19E-26
Rb-86	2.46E-07	1.89E-08	2.41E-07	1.34E-10
Rb-87	3.27E-12	2.50E-13	3.21E-12	1.78E-15
Rh-105	1.08E-25	8.35E-27	1.06E-25	5.94E-29
Pd-107	8.32E-24	6.53E-25	8.16E-24	4.65E-27
Pd-109	5.79E-16	4.55E-17	5.68E-16	3.24E-19
Ag-106	6.93E-15	5.09E-16	6.80E-15	3.62E-18
Ag-109m	1.62E-18	1.23E-19	1.59E-18	8.75E-22
Ag-110	1.38E-14	9.99E-16	1.36E-14	7.10E-18
Ag-110m	4.44E-10	3.24E-11	4.35E-10	2.31E-13
Ag-111	5.61E-16	4.34E-17	5.50E-16	3.09E-19
Cd-109	3.41E-18	2.59E-19	3.35E-18	1.84E-21
Ir-192	8.74E-11	6.59E-12	8.58E-11	4.69E-14
Ir-194	3.22E-11	2.55E-12	3.15E-11	1.81E-14
Total Dose KBr	**9.34E-02**	**7.00E-03**	**9.16E-02**	**4.98E-05**
Material: Copper Metal (Cu)				
Cu-64	7.67E-03	5.85E-04	7.53E-03	4.16E-06
Total Dose Cu-64	**7.67E-03**	**5.85E-04**	**7.53E-03**	**4.16E-06**
Material: Zirconium Metal (Zr)				
Zr-97	1.81E-01	1.40E-02	1.77E-01	9.97E-05
Total Dose Zr-97	**1.81E-01**	**1.40E-02**	**1.77E-01**	**9.97E-05**
Material: Fluorine (Fl)				
F-18	2.66E-02	1.96E-03	2.61E-02	1.39E-05
Total Dose F-18	**2.66E-02**	**1.96E-03**	**2.61E-02**	**1.39E-05**
Material: Gallium Metal (Ga)				
Ga-72	2.26E-02	1.69E-03	2.22E-02	1.20E-05
Zn-65	2.15E-10	1.59E-11	2.10E-10	1.13E-13
Total Dose Ga	**2.26E-02**	**1.69E-03**	**2.22E-02**	**1.20E-05**
Material: Gallium Oxide (Ga_2O_3)				
Ga-72	2.26E-02	1.69E-03	2.22E-02	1.20E-05
Zn-65	3.11E-15	2.31E-16	3.05E-15	1.64E-18
Hf-181	1.36E-13	1.04E-14	1.34E-13	7.38E-17
Ta-182	2.95E-17	2.21E-18	2.89E-17	1.57E-20

	NTR		STR	
Radionuclide	Worker Dose (SMC)[a] (mrem/yr)	Public Dose (Location 20)[a] (mrem/yr)	Worker Dose (RWMC)[a] (mrem/yr)	Public Dose (Location 3)[a] (mrem/yr)
Total Dose Ga_2O_3	**2.26E-02**	**1.69E-03**	**2.22E-02**	**1.20E-05**
Material: Sodium Nitrite ($NaNO_2$)				
Na-24	3.28E-02	2.39E-03	3.22E-02	1.70E-05
Sc-46	7.08E-12	5.37E-13	6.95E-12	3.82E-15
Zn-65	6.30E-12	4.67E-13	6.18E-12	3.32E-15
Total Dose $NaNO_2$	**3.28E-02**	**2.39E-03**	**3.22E-02**	**1.70E-05**
Material: Ga-68				
Ga-68	2.34E-04	1.74E-05	2.29E-04	1.23E-07
Ge-68	7.13E-07	5.33E-08	7.00E-07	3.79E-10
Total Dose Ga-68	**2.34E-04**	**1.74E-05**	**2.30E-04**	**1.24E-07**
Material: Tc-99m				
Tc-99m	8.32E-07	6.17E-08	8.16E-07	4.39E-10
Tc-99	1.67E-13	1.27E-14	1.64E-13	9.05E-17
Total Dose Tc-99m	**8.32E-07**	**6.17E-08**	**8.16E-07**	**4.39E-10**
Total Dose All Materials	**4.93E-01**	**3.77E-02**	**4.83E-01**	**2.68E-04**

a. See Figure 2 for locations.

Table 4. Overall maximum 95th percentile annual effective dose results for both NTR and STR combined.

Test Location	Worker Dose (mrem/yr)	Public Dose (mrem/yr)
NTR	4.93E-01 (SMC)	3.77E-02 (Location 20)
STR	4.83E-01 (RWMC)	2.68E-04 (Location 3)
Total	**9.76E-01**[a]	**3.79E-02**[a]

a. These values are mathematical summations and do not represent realistic doses since each dose calculation used a different location. Results are summed only for comparison to regulatory limits.

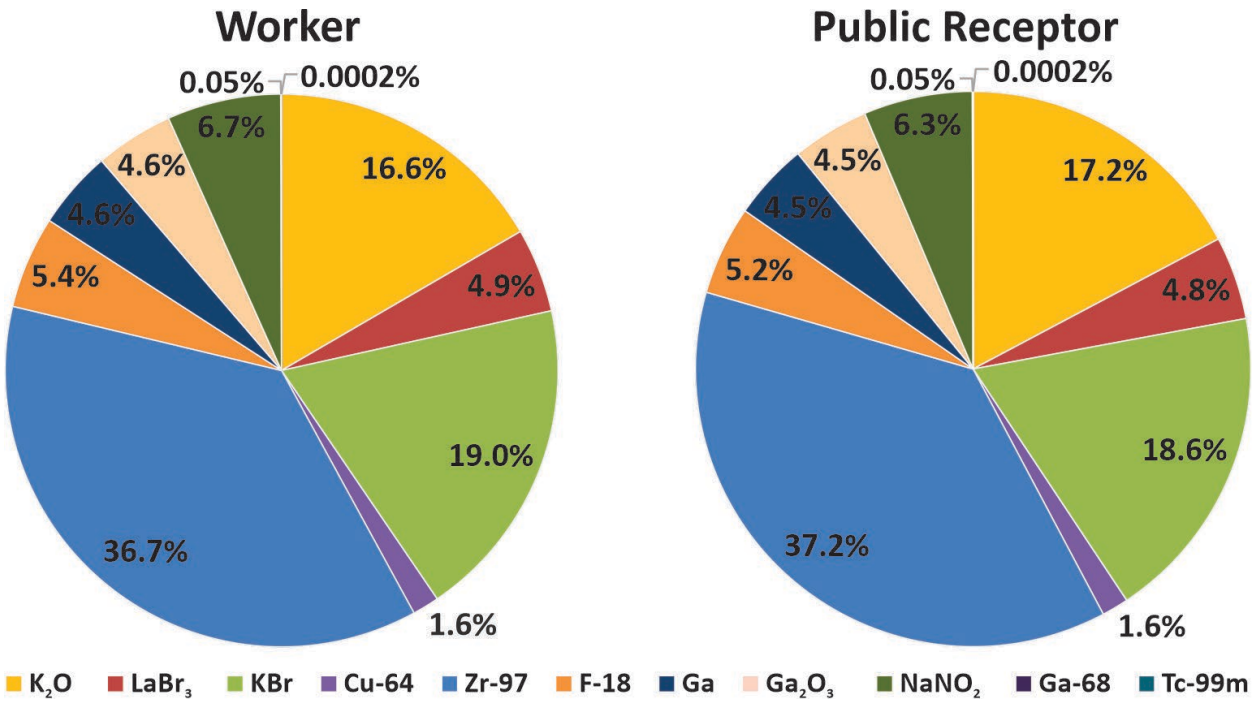

Figure 2. Percent contribution to total dose by material type for both workers and public receptors. The graphs are the same for both NTR and STR.

7.1.6 Atmospheric-Pathway Regulatory Dose Limits

The DOE Occupational Radiation Protection (10 CFR 835) establishes radiation protection standards, limits, and program requirements for protecting employees and the public from ionizing radiation resulting from the conduct of DOE activities. The dose limit from DOE sources to employees is 5000 mrem/yr effective dose. 10 CFR 835 also establishes a dose limit for the public entering a controlled area at 100 mrem/yr effective dose. DOE Order 458.1, “Radiation Protection of the Public and the Environment,” also establishes a total effective dose limit of 100 mrem/yr for the public located off DOE sites and on DOE sites outside of controlled areas. 40 CFR 61, Subpart H, has established the public dose limit for radionuclide emissions to ambient air from all DOE facilities as 10 mrem/yr effective dose. This applies at any offsite location where there is a residence, school, business, or office. A residence is defined as any home, house, apartment building, or other place of dwelling, which is occupied during any portion of the year.

7.1.7 Atmospheric-Pathway Conclusions

The calculated maximum 95th percentile annual effective doses for workers and public receptors are considerably less than regulatory limits. The maximum 95th percentile dose for a public receptor is 0.0377 mrem/yr, which is more than 250 times less than the regulatory limit of 10 mrem/yr for all INL emission sources. This dose is for a receptor 14.8 km NE of NTR (see Figure 2, Location 20). The maximum 95th percentile public dose for STR is 3.43E-04 mrem/yr at Location 3 (see Figure 2), which is negligible compared to 10 mrem/yr. The maximum 95th percentile doses for workers are about the same for NTR (0.493 mrem/yr) and STR (0.483 mrem/yr). These doses are more than 10,000 times less than the federal limit of 5,000 mrem/yr.

Actual doses are likely to be much less than those presented in Table 3 because of the conservative assumptions and parameters employed in the modeling. For example, the calculations assume the

entire inventory of each material type is readily released to the atmosphere and that no plume deposition, depletion, or radioactive decay occurs during transport. The calculations also assume the same meteorological conditions (e.g., wind velocity, wind direction, stability class) that produce the 95th percentile *X/Q* are the same for all 12 tests during the year, and each receptor is assumed to be present during all 12 tests. Although this is very unlikely, it should be mentioned that since the same meteorological conditions are assumed to exist for each test, it does not matter if the total annual release values noted in Table 1 (Column 4) are released in more or less than 12 tests; the dose estimates will be the same. It is extremely unlikely that the same conditions would exist for every test, but this assumption becomes less conservative if the annual release is combined into fewer tests. The results also assume all 12 tests will be performed annually at both locations, and all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68 and Tc-99m) will be used for each test. This is conservative because it is anticipated that no more than two material types will be used in a given test.

Given the results and the conservative assumptions employed in the atmospheric-pathway modeling, actual doses are expected to be far less than regulatory dose limits.

7.2 GROUNDWATER-PATHWAY ASSESSMENT

The groundwater-pathway assessment considered the same radionuclides evaluated for the atmospheric pathway and nonradionuclide contaminants in the containment foam.

7.2.1 Groundwater-Pathway Assessment Methodology

Groundwater flow and transport of contaminants from the test (source) areas at land surface through the unsaturated zone was simulated using the one-dimensional computer code MCM (Rood 2010), and transport through the underlying aquifer was simulated using the two-dimensional computer code GWSCREEN (Rood 2003). Model parameters and assumptions are generally consistent with those used to perform Track 2 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) assessments for low-probability hazard sites at INL (DOE-ID 1994).

Figure 4 shows the conceptual model for flow and transport from the source area to a hypothetical receptor well. The model accounts for (1) transient water influx from the infiltration area, (2) transport through the unsaturated zone, and (3) dilution and mixing in the aquifer. The transport calculations account for advection, dispersion, and sorption in the unsaturated zone along this pathway and advection and dispersion in the underlying aquifer. Sorption was assumed to occur on alluvium and sedimentary interbed materials but not on basalt. The calculations account for radioactive decay for radionuclides and degradation for nonradionuclides, but volatilization was not considered. This is discussed in the Groundwater Model Parameters Section.

The models were used to calculate maximum contaminant concentrations in the aquifer that were compared to EPA-imposed maximum contaminant levels (MCLs) or EPA-derived screening levels for resident tap water. Two source-area sizes were simulated based on the 16-ft and a 30-ft diameter dome tents. In this assessment, the receptor well (see Figure 4) is presumed to exist at the immediate downgradient edge of the source area, which is the location of maximum concentration. Since MCM and GWSCREEN use rectangular source areas, the 16-ft and 30-ft diameter source areas were converted to square sources of equivalent area. It is assumed that a receptor directly ingests the water at the downgradient edge of the source, which is the location of maximum concentration.

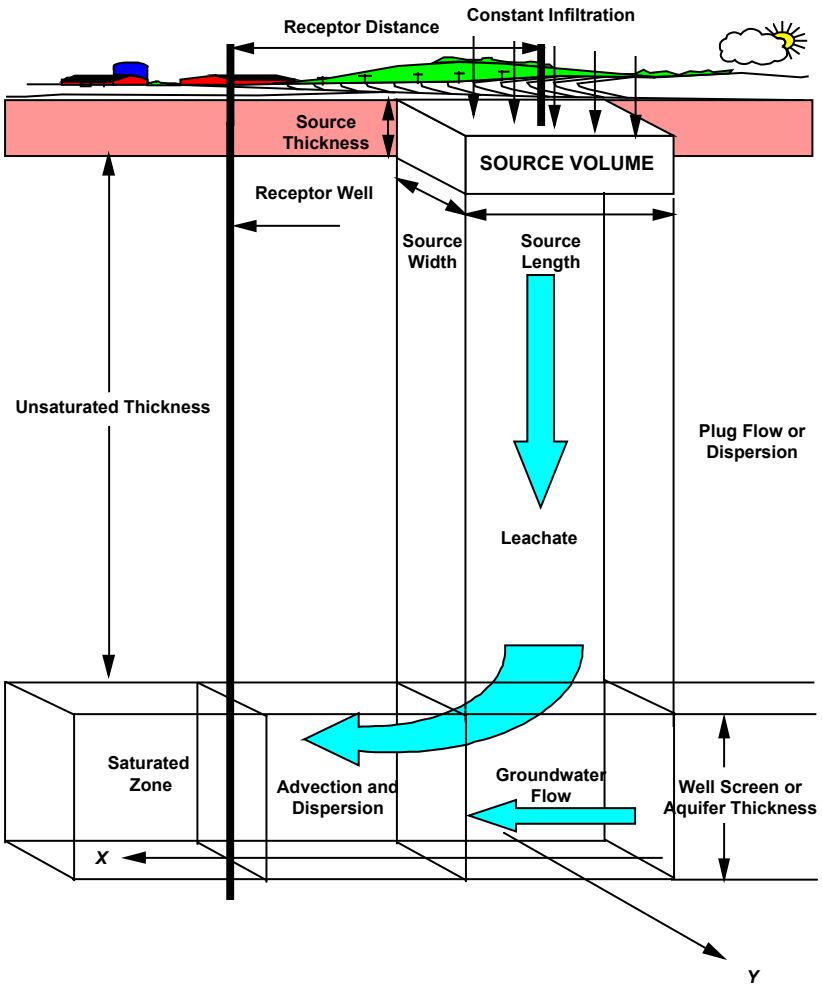

Figure 3. Conceptual model of flow and transport for the groundwater pathway. The receptor well location for this assessment is the immediate downgradient edge of the source (different from figure).

7.2.2 Groundwater-Pathway Source Term

7.2.2.1 Nonradionuclides

Groundwater-pathway modeling was performed to determine the impact from 12 tests performed annually for 15 years. Each test was assumed to occur at the same locations at both NTR and STR. A single test for a 16-ft diameter dome is estimated to require 150 gallons of water and 10 gallons of BlastGuard AFC-380 foam concentrate, for a total liquid volume of 160 gallons (0.606 m^3). A single test for a 30-ft diameter dome requires approximately 900 gallons of water and 65 gallons of BlastGuard AFC-380 foam concentrate, for a total liquid volume of 965 gallons (3.65 m^3). According to the material safety data sheet (MSDS), BlastGuard AFC-380 includes hazardous constituents diethylene glycol monobutyl ether (DGBE), 1-dodecanol, and isobutanol. Table 5 shows the mass fractions, volumes, and masses of each contaminant for the two dome sizes. After each test, it takes approximately 3–4 days for the foam to fully collapse to an aqueous mixture and infiltrate the soil. The modeling assumes the entire volume of liquid and assumes the contaminants from each test soak into the ground.

Table 5. Contaminant properties and mass released per test for both dome sizes.

				16-ft Dome		30-ft Dome	
Contaminant	CAS #	Volume Fraction	Component Density (kg/L)	Volume in 10 Gallons[a] (L)	Mass Released per Test (kg)	Volume in 65 Gallons[a] (L)	Mass Released per Test (kg)
DGBE	112-34-5	0.1	0.995	3.79	3.77	24.6	24.5
1-dodecanol	112-53-8	0.01	0.833	0.379	0.315	2.46	2.05
Isobutanol	78-83-1	0.5	0.803	1.89	1.52	12.3	9.88

a. Gallons of BlastGuard AFC-380.

7.2.2.2 Radionuclides

The source term for radionuclides assumes the same release quantities used for the atmospheric-pathway assessment (see Table 1). This is very conservative, but it simplifies the analysis by not having to partition releases between the atmospheric and groundwater pathways. The source term assumes 12 tests will be performed per year at both NETA and RTP, and assumes all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68 and Tc-99m) will be used for each test. This assumption is conservative because it is anticipated that a maximum of two material types will be used per test. It is also assumed the radionuclides are readily soluble and transported as an aqueous phase. This is also very conservative because many of the radionuclides are particulates and would have to corrode or dissolve before being transported.

Not all radionuclides considered for the atmospheric pathway were modeled for the groundwater pathway because many would decay to inconsequential levels before reaching the aquifer. Only non-gaseous radionuclides with half-lives greater than 74 days were modeled. This is a short time relative to the time it would take for water to travel from land surface to the aquifer, which is approximately 2 years based on enhanced infiltration rates from testing (see Groundwater Model Parameters Section for infiltration rates). It is even shorter compared to the approximate 11 years it would take for a non-sorbing contaminant to transit the vadose zone and reach a steady-state flux to the aquifer. The activity of a radionuclide with a 74-day half-life would be approximately 1/1,000 its original activity after 2 years and approximately 1E-17 its original activity after 11 years. Table 6 provides the release quantities of radionuclides modeled for the groundwater pathway. Included in the analysis were K-40, even though it is not regulated (EPA 2000a), and La-138, which is essentially stable.

Table 6. Releases for radionuclides considered for the groundwater-pathway analysis.

Radionuclide	Half-Life (yrs)	Release per Test (Ci)	Total Annual Release[d] (Ci)
Ag-110m	6.84E-01	1.69E-09	2.02E-08
Be-10	1.51E+06	2.87E-20	3.44E-19
C-14	5.70E+03	2.13E-09	2.56E-08
Cd-109	1.26E+00	3.67E-17	4.41E-16
Cl-36	3.01E+05	6.86E-08[a]	8.23E-07
Cs-135	2.30E+06	2.71E-19	3.25E-18
Cs-137	3.02E+01	1.85E-19	2.22E-18
Ge-68	7.42E-01	2.00E-06	2.40E-05
K-40	1.25E+09	3.46E-06[a]	4.16E-05
La-137	6.00E+04	1.15E-14	1.38E-13
La-138	1.02E+11	9.48E-11	1.14E-09
Ni-63	1.00E+02	2.06E-14	2.47E-13
Pd-107	6.50E+06	3.26E-21	3.91E-20
Rb-87	4.92E+10	5.28E-11	6.34E-10
Sc-46	2.29E-01	4.83E-11	5.80E-10
Se-79	2.95E+05	1.60E-10[b]	1.92E-09
Ta-182	3.13E-01	2.11E-16	2.53E-15
Tc-99	2.11E+05	3.21E-12	3.85E-11
Zn-65	6.68E-01	1.57E-08[c]	1.89E-07

a. Includes Cl-36 and K-40 from both K_2O and KBr materials (see Table 1).
b. Includes Se-79 from both KBr and $LaBr_3$ materials (see Table 1).
c. Includes Zn-65 from KBr, Ga, Ga_2O_3, and $NaNO_2$ materials (see Table 1).
d. Assumes 12 tests per year.

7.2.3 Groundwater-Pathway Screening Levels

7.2.3.1 Nonradionuclides

There are no enforceable federal or State of Idaho drinking water standards for the nonradionuclide contaminants in Table 5. Therefore, EPA regional screening levels for tap water were used for comparison to the maximum estimated groundwater concentrations (see Table 7). The contaminants are not carcinogens, so the non-cancer screening levels for children from the Hazard Index (HI) = 1 table were used (see https://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search). Screening levels are not enforceable standards but serve as technical guidance for water-quality officials or managers of contaminated sites. They are risk-based concentrations derived from standardized equations, combining conservative exposure information assumptions with EPA toxicity data. In this case, they are concentrations in tap water that are protective of human exposures (including sensitive subpopulations) over a lifetime. For this assessment, groundwater was considered tap water. The contaminant 1-dodecanol was not modeled because there is no MCL or screening level. This is likely because it is practically non-toxic and is an allowed food-additive (TOXNET 2015).

Table 7. Regional screening values for nonradionuclide contaminants in tap water.

Contaminant	CAS #	Non-Cancer Screening Level for Child (HI=1) (µg/L)
DGBE	112-34-5	597
1-dodecanol	112-53-8	None available
Isobutanol	78-83-1	731

7.2.3.2 Radionuclides

Table 8 lists the limiting aquifer concentrations for radionuclides. MCLs from EPA (2000b) are provided if a value exists. For radionuclides that do not have a published MCL, the EPA PRG for resident tap water ingestion is listed. These values are based on a risk level of 1E-06 and, using the "Calculator" option, can be found at https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search.

Table 8. Limiting concentration standards for radionuclides.

Radionuclide	Limiting Concentration (pCi/L)	Standard Type
Ag-110m	90	MCL
Be-10	7.43	EPA PRG[a]
C-14	2,000	MCL
Cd-109	600	MCL
Cl-36	700	MCL
Cs-135	900	MCL
Cs-137	200	MCL
Ge-68	7.22	EPA PRG[a]
K-40	2.12	EPA PRG[a]
La-137	148	EPA PRG[a]
La-138	14.7	EPA PRG[a]
Ni-63	50	MCL
Pd-107	202	EPA PRG[a]
Rb-87	300	MCL

Radionuclide	Limiting Concentration (pCi/L)	Standard Type
Sc-46	100	MCL
Se-79	7.55	EPA PRG[a]
Ta-182	100	MCL
Tc-99	900	MCL
Zn-65	300	MCL

a. PRG based on water ingestion.

7.2.4 Groundwater Model Parameters

The most important groundwater-pathway model parameters and characteristics are infiltration rate, unsaturated zone hydrostratigraphy, hydraulic conductivity and moisture content relationships, texture of the sedimentary interbeds, sorptive properties for each contaminant, and the velocity of water in the aquifer. Parameters were generally obtained from guidance documents, previous INL studies of flow and transport, or regional studies of groundwater flow and transport.

Each test is assumed to occur in a dome; thus, the infiltration rate is higher due to the additional liquid from the foam. The infiltration rate during the time it takes the foam to collapse (assumed 1/100 yr or 3.65 days) is the volume of liquid required by the test (see Table 5) divided by the area of the test. The total infiltration rate also includes the 0.1 m/yr background infiltration rate assumed for disturbed, unvegetated soils at INL (DOE-ID 1994). Between tests, when the foam is not collapsing and infiltrating the soil, the background infiltration rate is assigned. The calculation and resulting infiltration rate for a 16-ft diameter dome is shown in Equation (3). This is based on 160 gallons (0.606 m^3) of liquid (150 gallons water plus 10 gallons BlastGuard AFC-380). The infiltration rate for a 30-ft diameter dome tent (65.7 m^2) is 5.66 m/yr based on 965 gallons (3.65 m^3) of liquid (900 gallons water plus 65 gallons BlastGuard AFC-380).

$$Infiltration\ Rate\left(\frac{m}{yr}\right) = \frac{\frac{0.606\ m^3}{3.65\ d}365\frac{d}{yr}}{18.7\ m^2} + 0.1\frac{m}{yr} = 3.34\ \frac{m}{yr} \quad (3)$$

The unsaturated zone hydrostratigraphy for both NTR and STR sites is presented in Table 9. NTR hydrostratigraphy is based on data from the nearby well ANP-04. STR hydrostratigraphy is based on the nearby well USGS-132. The hydraulic properties assigned to the hydrostratigraphic units is presented in

Table 10. Alluvium and sedimentary interbed materials were assumed sandy-clay-loam properties from the MCM manual (Rood 2010). This may be conservative for NTR, where well logs indicate the materials were mostly clay. The sediment materials in well USGS-132 were described as a mixture of sands, clays, and silts, so the sandy-clay-loam assumption is appropriate. Basalt layers were assigned properties from Magnuson (1995).

Table 11 contains chemical-specific parameters used in the assessment. Sorption coefficients for nonradionuclides were calculated for alluvium and interbed materials as the product of the soil organic carbon-water partition coefficient (Koc) and the fraction of organic carbon content (foc), according to Equation (4).

$$Kd\ \left(\frac{ml}{g}\right) = Koc\left(\frac{ml}{g}\right) foc \quad (4)$$

The *foc* value used (0.0005) was conservatively chosen as the minimum value for interbed samples from the RWMC at the INL Site (Colwell 1988), where the values ranged from 0.0005 to 0.0017. No sorption was assumed for basalt materials. Because the aquifer is assumed to comprise basalt entirely, no sorption is assumed for the aquifer. Sorption coefficients for radionuclides were taken as default values from DOE-ID (1994) and Jenkins (2001). These values are generally the smaller values from several sources, which are the more conservative values for the groundwater pathway.

Table 9. Estimated hydrostratigraphy for NTR and STR locations.

Site	Well Name[a]	Depth to Water (m)	Top Depth (m)	Bottom Depth (m)	Thickness (m)	Material Description from Well Report[a]	Assigned Material Description[b]
NTR	ANP-04	64	0	12	12	Clay	Alluvium
			12	58	46	Basalt	Basalt
			58	61	3	Clay	Interbed
			61	64	3	Basalt	Basalt
STR	USGS-132	186	0	3	3	Surficial material	Alluvium
			3	9	6	Basalt	Basalt
			9	10	1	Unknown	Interbed
			10	40	30	Basalt	Basalt
			40	57	17	Sand/gravel/clay/silt	Interbed
			57	79	22	Basalt	Basalt
			79	81	2	Silt/clay	Interbed
			81	131	50	Basalt	Basalt
			131	132	1	Silt/clay	Interbed
			132	165	33	Basalt	Basalt
			165	168	3	Clay	Interbed
			168	187	19	Basalt	Basalt

a. Nearby well from which hydrostratigraphy was obtained. Material depths and description taken from INL Environmental Data Warehouse. Depths rounded to the nearest meter.

b. Alluvium and Interbed materials were assigned sandy-clay-loam properties from the MCM Manual (Rood 2010).

Table 10. Hydraulic properties assigned to hydrostratigraphic units.

Material	Saturated Hydraulic Conductivity (m/yr)	Total Porosity	Residual Moisture Content	Van Genuchten Fitting Parameter, α (1/m)	Van Genuchten Fitting Parameter, n	Bulk Density (g/cm^3)
Alluvium[a]	114.8	0.39	0.1	5.9	1.48	1.5
Basalt[b]	91	0.05	0.001	2.5	10	1.9

a. Alluvium assigned dandy-clay-loam properties from Rood (2010).
b. b. From Magnuson (1995).

Table 11. Contaminant properties and sorption coefficients for alluvium and interbed materials.

Contaminant	Molecular Weight (g/mol)	Solubility (mg/L)	Organic Carbon-Water Partition Coefficient, *Koc* (ml/gm)	Sorption Coefficient, *Kd* (ml/gm)	Degradation or Decay Half-Life (yrs)
DGBE	162.2	1.00E+06[a]	10[a]	0.005	1[b]
Isobutanol	74.12	8.50E+04[a]	3[a]	0.002	1[c]
Be-10	10	1E+09[d]	NA	250[e]	1.51E+06
C-14	14	1E+09[d]	NA	0[e]	5.73E+03
Cl-36	36	1E+09[d]	NA	0[f]	3.01E+05
K-40	40	1E+09[d]	NA	15[e]	1.25E+09
Ni-63	63	1E+09[d]	NA	100[e]	1.01E+02
Zn-65	65	1E+09[d]	NA	16[e]	6.68E-01
Se-79	79	1E+09[d]	NA	4[e]	3.27E+05
Rb-87	87	1E+09[d]	NA	55[f]	4.97E+10
Pd-107	107	1E+09[d]	NA	55[f]	6.50E+06
Cd-109	109	1E+09[d]	NA	6[e]	1.26E+00
Ag-110m	110	1E+09[d]	NA	90[e]	6.84E-01
Cs-135	135	1E+09[d]	NA	500[e]	2.30E+06
Cs-137	137	1E+09[d]	NA	500[e]	3.01E+01
La-137	137	1E+09[d]	NA	1200[f]	6.00E+04
La-138	138	1E+09[d]	NA	1200[f]	1.02E+11

a. OakRidge National Laboratory Risk Assessment Information System, https://rais.ornl.gov/.
b. Field experiment at INL RRTR North Training Range estimated DGBE degradation half-life to be 10 hours or less (Sondrup 2019). To be very conservative, model simulations were performed using a half-life of 1 year.
c. Isobutanol assigned same half-life as DGBE based on DOW (2014a, 2014b).
d. Although not likely to be solubility limited, solubility for radionuclides assigned high value to be sure.
e. Suggested Track 1 value from DOE-ID (1994), Table F-1.
f. Jenkins (2001).

Table 12 contains the remainder of the parameters used in the groundwater-pathway modeling. Site-specific Darcy velocity values for the aquifer at NTR and STR were estimated from information in DOE-ID (2008). Figure 5 shows a map of average linear groundwater flow velocities and vectors calculated for the INL sitewide groundwater model (DOE-ID 2008). From Figure 5, the velocities near NTR and

STR are estimated to be 0.5 and 1.5 m/day respectively. To obtain Darcy velocities for input to the model, the average linear velocities were multiplied by the aquifer porosity of 0.06 (see Table 12) and converted from m/day to m/yr.

Table 12. Miscellaneous groundwater-pathway model parameter values.

Variable	Parameter Description	Value	Model(s)	Comments
L,W	Length and width of source for 16-ft dome	4.3 m	MCMT, GWSCREEN	Side length of square with area equivalent to 16-ft diameter circle
XREC	Receptor distance from center of source for 16-ft dome	2.2 m	GWSCREEN	Length of source assumed parallel to flow direction. Receptor located at downgradient edge of source (L/2)
L,W	Length and width of source for 30-ft dome	8.1 m	MCMT, GWSCREEN	Side length of square with area equivalent to 30-ft diameter circle
XREC	Receptor distance from center of source for 30-ft dome	4.1 m	GWSCREEN	Length of source assumed parallel to flow direction. Receptor located at downgradient edge of source (L/2)
PERC	Background Percolation rate	0.1 m/yr	MCMF, GWSCREEN	DOE-ID (1994), MCMF value assigned in infiltration input file MCMF.PTT
DEPTH	Depth from source to aquifer	0.001 m	GWSCREEN	Very thin since mass flux from unsaturated zone comes from MCMT model output
THETAU	Moisture content in unsaturated zone	0.3	GWSCREEN	DOE-ID (1994), Value is unimportant given the small value for DEPTH
AX	Longitudinal dispersivity in aquifer	9 m	GWSCREEN	DOE-ID (1994)
AY	Transverse dispersivity in aquifer	4 m	GWSCREEN	DOE-ID (1994)
B	Aquifer thickness	15 m	GWSCREEN	Given the receptor is at the downgradient edge of the source (very near the source), the value is unimportant yet conservative
Z	Well screen thickness	15 m	GWSCREEN	DOE-ID (1994) – Two-dimensional aquifer model used
U	Darcy velocity in aquifer	32.9 m/yr 10.9 m/yr	GWSCREEN	NTR site-specific value from DOE-ID (2008) STR site-specific value from DOE-ID (2008)
PHI	Porosity in aquifer	0.06	GWSCREEN	DOE-ID (2008)
RHOA	Bulk density in aquifer	1.9 g/cm^3	GWSCREEN	DOE-ID (1994), Same as unsaturated zone basalt (see Table 10)

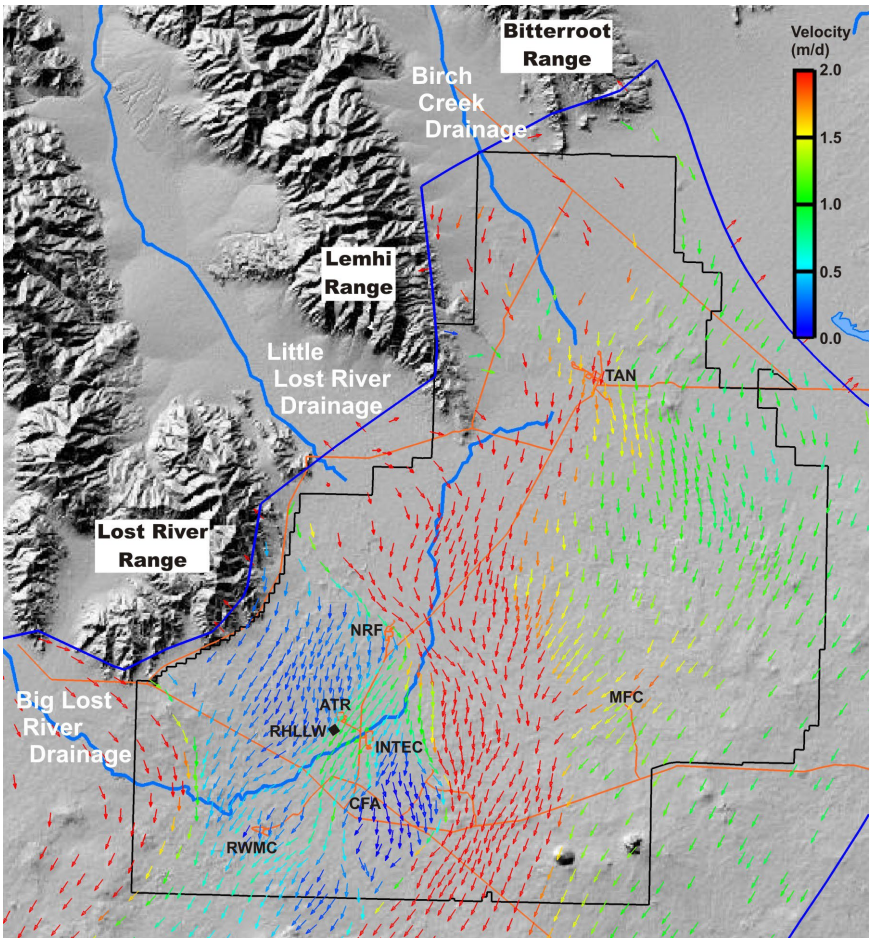

Figure 4. Model-predicted average linear-flow velocity vectors in the Snake River Plain Aquifer below the INL (from DOE-ID 2008).

7.2.5 Nonradionuclide Degradation

Preliminary modeling indicated that maximum DGBE groundwater concentrations could exceed the HI = 1 child-screening level of 597 mg/L if degradation is not considered. Although DGBE will tend to remain in water due to high solubility and low volatility, DOW (2014a) indicates that it is “readily biodegradable” and “degrades rapidly in water.” Therefore, a field experiment was conducted to determine a site-specific degradation rate that could be applied in the modeling (see Appendix B).

In the experiment, a 4 ft by 4 ft by 4 ft bottomless box was placed on the soil and filled with foam. The foam was made from approximately 60 gallons of liquid and contained 428 grams of glycol ether. The foam was allowed to turn aqueous and infiltrate the soil. A soil sample was collected in the area where the foam was applied prior to foam application to obtain a baseline concentration of total glycols in the soil. After a period of 3 days, the foam had dissipated into the soil, and another sample was collected to determine the concentration of glycol in the soil. Thereafter, samples were collected every week for three weeks for a total of five sampling events. The samples were analyzed for total glycol concentrations, including diethylene glycol, ethylene glycol, propylene glycol, and triethylene glycol. None of the glycols were detected in any of the samples. The practical quantitation limits (PQL) for the sample analyses ranged from 10 to 54 mg/kg.

The experiment was simulated using the MCM model developed for this assessment (with finer vertical discretization) to determine the degradation rate that would match the results of the experiment. Model simulations were performed using DGBE half-lives of 1, 10, 100, and1000 hours, and infinite (i.e., with no decay). Figure 6 contains concentration vs. time results for each simulation. The results indicate that DGBE would have to degrade very rapidly (half-life of 10 hours or less) for the total concentration (aqueous and sorbed) in the top 5 cm of soil to be less than the maximum PQL of 54 mg/kg after collapse and infiltration of the foam. To be very conservative, model simulations were performed using a DGBE half-life of 1 year. Although isobutanol was not included in the field test, the same degradation rate was applied based on similar evidence from DOW (2014a, 2014b). To be conservative, volatilization was not considered for either contaminant.

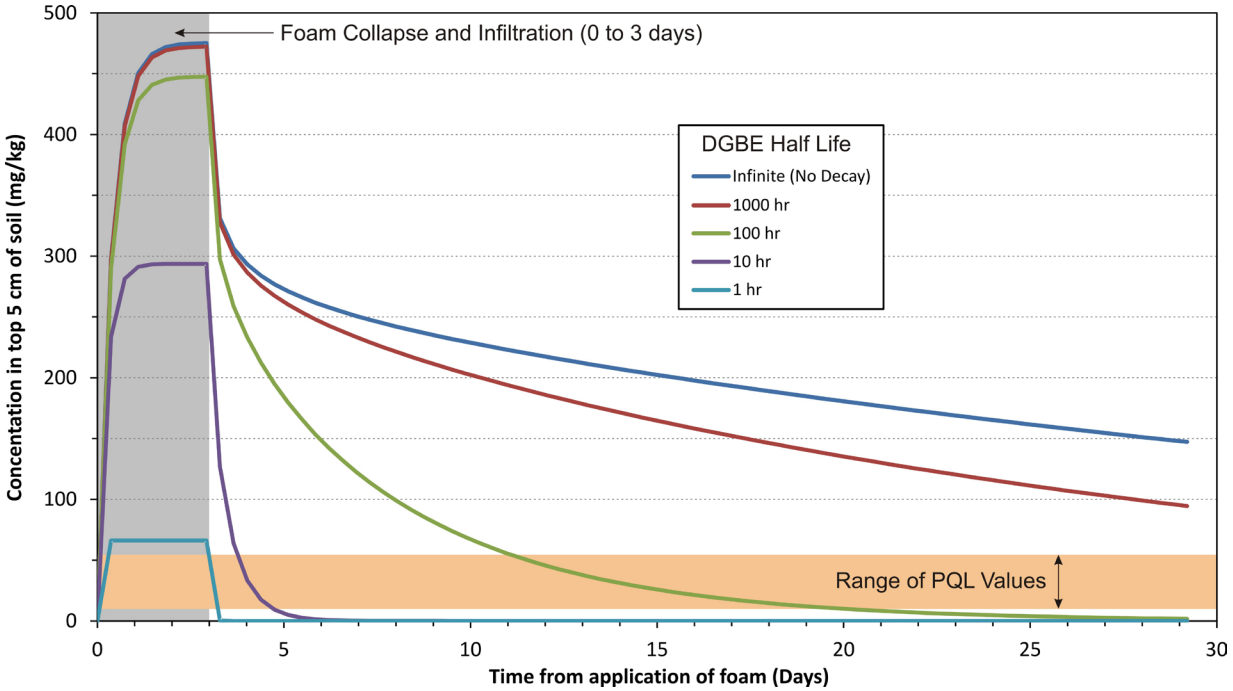

Figure 5. Simulation results used to determine appropriate DGBE half-life.

7.2.6 Groundwater-Pathway Results

7.2.6.1 Nonradionuclides

Predicted peak nonradionuclide groundwater concentrations as a function of time for the 16-ft and 30-ft diameter domes at both NTR and STR are presented in Figure 7 through Figure 10, assuming 12 tests/year for 15 years. The maximum concentrations occur at the downgradient edge of the source zone (see Figure 4). Maximum concentrations are higher for the 30-ft dome because of the larger contaminant mass per area and higher infiltration rate. Contaminants are predicted to arrive later in the aquifer at STR and are lower due to the thicker vadose zone and larger abundance of sedimentary interbeds.

Table 13 contains the overall maximum concentrations compared to non-cancer screening levels from Table 7. It is clear from the results that both DGBE and isobutanol are not likely to exceed the screening levels. It does appear that continued testing beyond 15 years would not increase maximum concentrations at NTR but could increase the peak concentration slightly at STR.

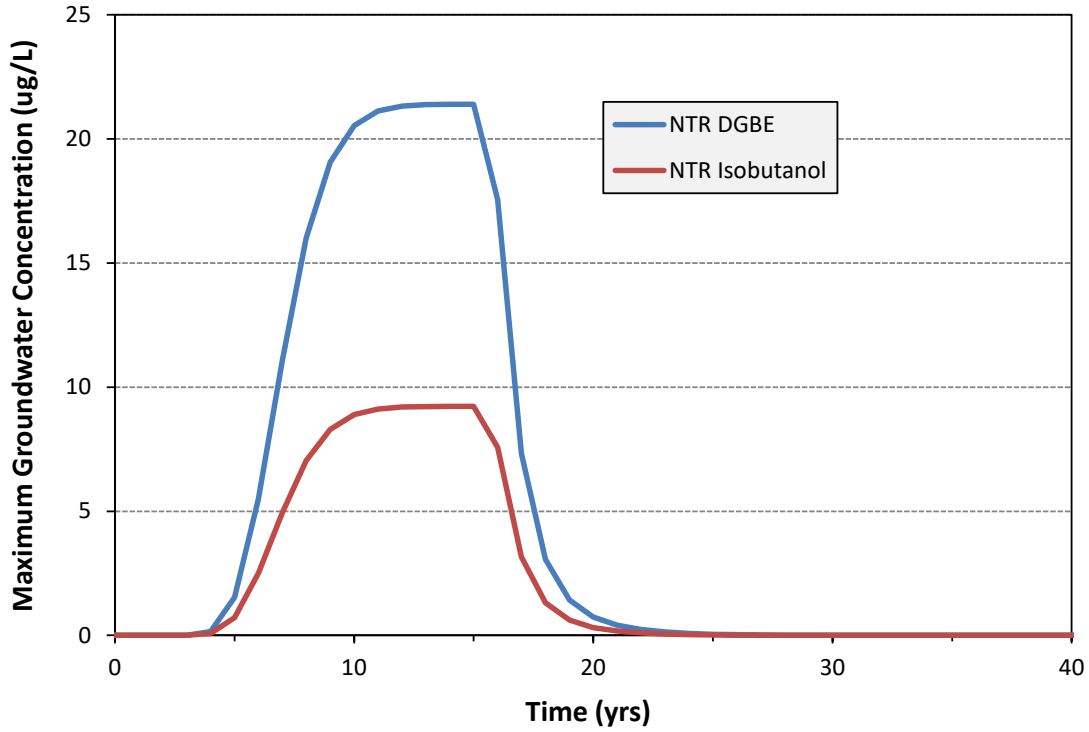

Figure 6. Predicted maximum groundwater concentrations for 16-ft dome at NTR (12 tests/yr for 15 yr).

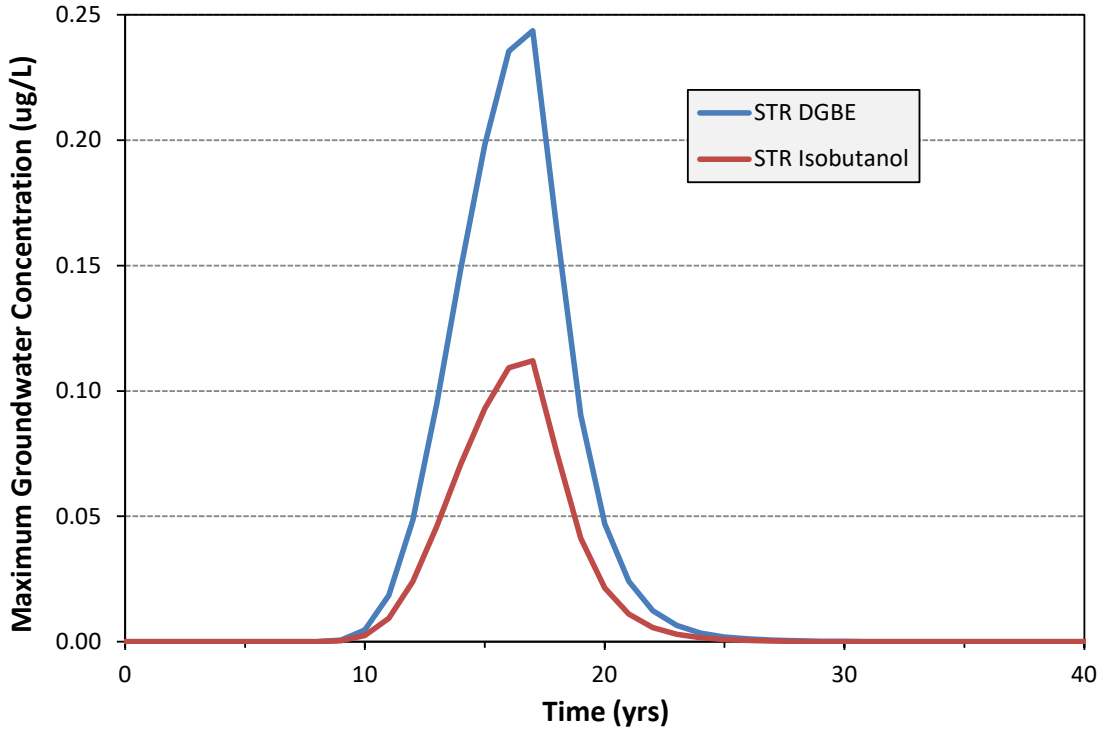

Figure 7. Predicted maximum groundwater concentrations for 16-ft dome at STR (12 tests/yr for 15 yr).

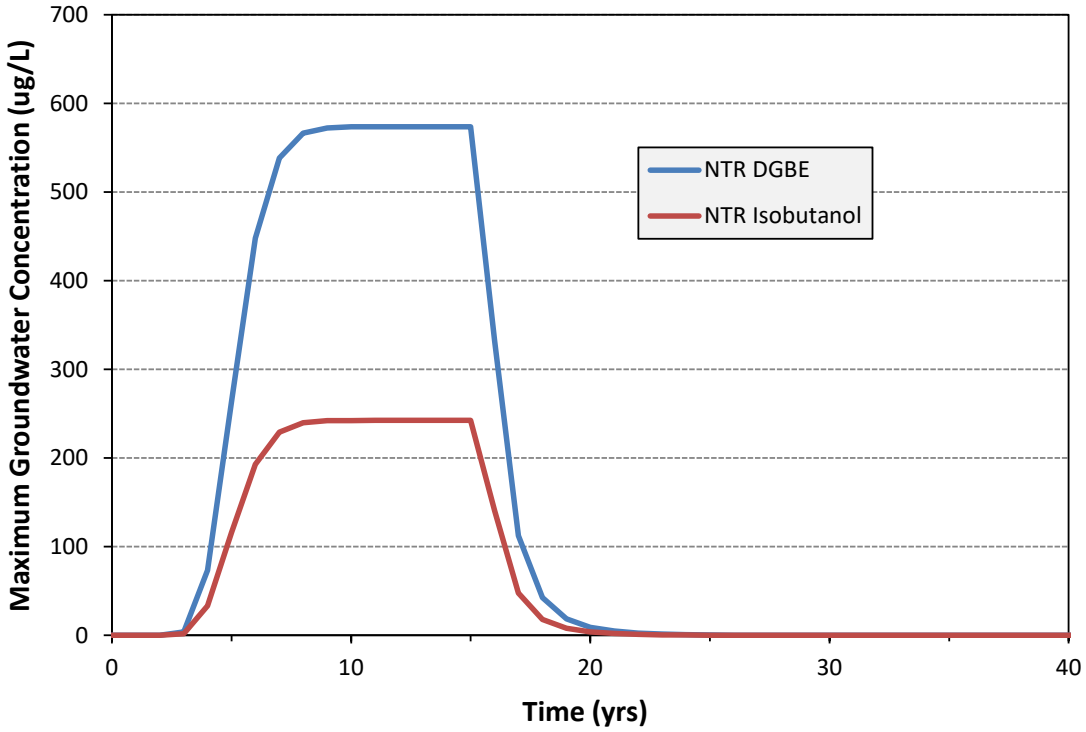

Figure 8. Predicted maximum groundwater concentrations for 30-ft dome at NTR (12 tests/yr for 15 yr).

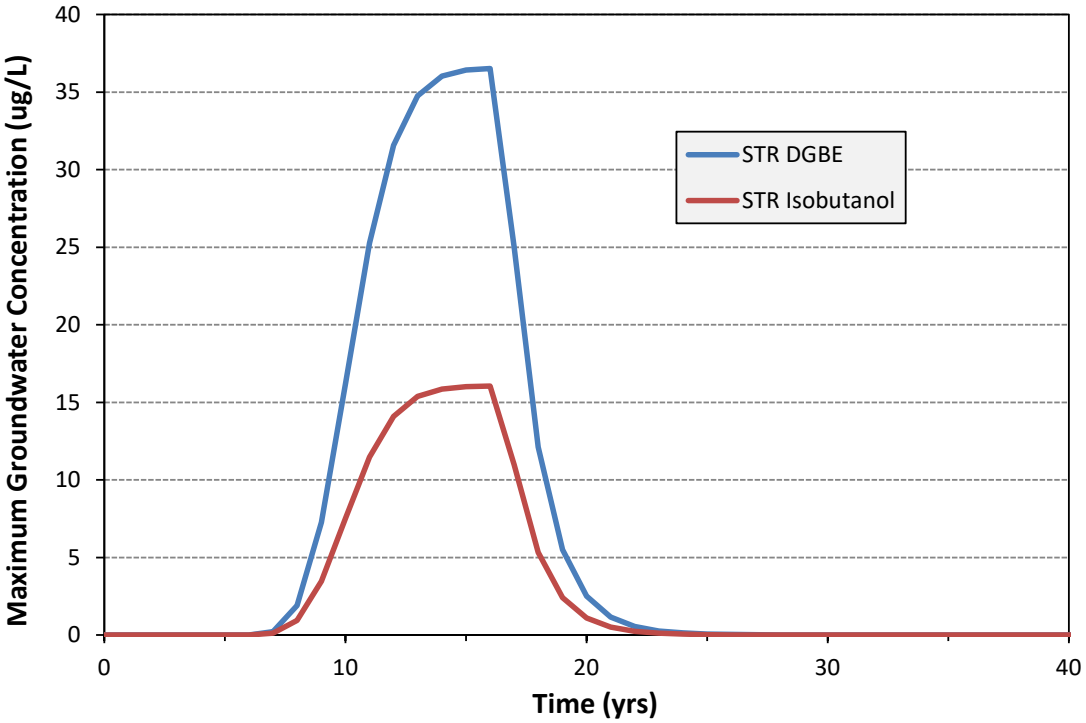

Figure 9. Predicted maximum groundwater concentrations for 30-ft dome at STR (12 tests/yr for 15 yr).

Table 13. Predicted overall maximum groundwater concentrations for nonradionuclides.

Contaminant	HI=1 Non-Cancer Screening Level for Child (µg/L)	Maximum Concentration 16-ft Diameter Dome (12 tests/yr for 15 yr)	Maximum Concentration 30-ft Diameter Dome (12 tests/yr for 15 yr)

		NTR (µg/L)	STR (µg/L)	NTR (µg/L)	STR (µg/L)
DGBE	597	21.4	0.24	574	36.5
Isobutanol	731	9.23	0.11	243	16.1

7.2.6.2 Radionuclides

Given the rather large sorption coefficients and long half-lives for some radionuclides, simulations were run for a period of 100,000 years from the start of testing. In addition, radionuclides were only simulated for the 30-ft dome because it is the limiting case based on the nonradionuclide simulation results.

Table 14 contains the overall maximum concentrations of radionuclides compared to limiting concentrations from Table 8. Peak radionuclide concentrations in the aquifer are less than MCLs (where available) and less than PRGs (if MCLs are not available). Concentrations of Sc-46 and Ta-182 are reported as zero because they are less than 1E-100 pCi/L due to strong sorption and short half-lives. Concentrations of Ag-110m, C-14, Cd-109, Cl-36, Ge-68, Tc-99, and Zn-65 peak near the end of the testing period due to low sorption or short half-lives. Most other radionuclide concentrations peak beyond 1,000 years due to strong sorption and long half-lives. Cs-135, La-137, and La-138 concentrations had not peaked by the end of the 100,000-year simulation time, but the concentrations at 100,000 years are very low (<1E-17 pCi/L) and will not exceed the limiting values beyond 100,000 years. Potassium-40 concentrations were the highest percentage of the respective limiting concentration (1.5%), but K-40 occurs naturally and is not regulated in food or drinking water.

Concentrations of C-14, Cl-36, Zn-65, Cd-109, and Ag-110m peak near the end of the testing period due to low sorption and/or short half-lives. Most other radionuclide concentrations peak beyond 1,000 years due to larger sorption coefficients and long half-lives. Cs-135, La-137, and La-138 concentrations had not peaked by the end of the 100,000-year simulation time, but the concentrations at 100,000 years are very low (<1E-11 pCi/L) and will not exceed the limiting values beyond 100,000 years. Potassium-40 concentrations were the highest percentage of the respective limiting concentration (~ 3%), but K-40 occurs naturally and is not regulated in food or drinking water.

It is clear from the results that radionuclide concentrations are not likely to exceed the limiting concentrations as long as the rate of testing is not more than 12 tests per year. The results indicate that continued testing after 15 years is not likely to result in an exceedance of limiting concentrations. In addition, dividing the total annual release (see Table 6) into less than 12 tests per year is likely to result in lower concentrations because fewer tests would add less water from the foam, which would increase the travel time to the aquifer and result in more decay before radionuclides reach the aquifer (see Comments on Testing Frequency Section).

Table 14. Comparison of limiting concentrations and predicted maximum groundwater concentrations for radionuclides.

Radionuclide	Limiting Concentration (pCi/L)	Time of Maximum Concentration (years after tests begin)	Maximum Concentration for 30-ft Dome (12 tests/year for 15 years) (pCi/L)	Ratio of Maximum Modeled Concentration to Limiting Concentration
Northern Test Range				
Ag-110m	90	17	2.51E-38	2.79E-40
Be-10	7.43[a]	52000	1.37E-17	1.85E-18
C-14	2000	13	2.47E-03	1.23E-06
Cd-109	600	15	1.17E-25	1.95E-28
Cl-36	700	13	7.96E-02	1.14E-04
Cs-135	900	>100,000[b]	6.31E-17	7.01E-20
Cs-137	200	550	1.41E-47	7.04E-50
Ge-68	7.22[a]	16	2.88E-28	3.99E-29
K-40	2.12[a]	3100	2.82E-02	1.33E-02
La-137	148[a]	>100,000[b]	3.88E-15	2.62E-17
La-138	14.7[a]	>100,000[b]	1.01E-10	6.84E-12
Ni-63	50	1800	8.80E-26	1.76E-27
Pd-107	202[a]	11000	7.18E-18	3.56E-20
Rb-87	300	11000	1.17E-07	3.88E-10
Sc-46	100	18	3.34E-62	3.34E-64
Se-79	7.55[a]	800	4.75E-06	6.29E-07
Ta-182	100	19	2.39E-59	2.39E-61
Tc-99	900	14	3.72E-06	4.13E-09
Zn-65	300	15	8.31E-26	2.77E-28
			Sum of Ratios →	0.0134[c]
Southern Test Range				
Ag-110m	90	19	5.91E-68	6.57E-70
Be-10	7.43a	97000	2.99E-17	4.03E-18
C-14	2000	16	7.22E-03	3.61E-06
Cd-109	600	18	1.05E-40	1.75E-43
Cl-36	700	16	2.33E-01	3.33E-04
Cs-135	900	>100,000[b]	1.17E-18	1.30E-21
Cs-137	200	0	0.00E+00	0.00E+00
Ge-68	7.22[a]	18	7.18E-53	9.94E-54
K-40	2.12[a]	5800	6.26E-02	2.95E-02
La-137	148[a]	>100,000[b]	1.97E-21	1.33E-23
La-138	14.7[a]	>100,000[b]	5.09E-17	3.46E-18
Ni-63	50	3300	3.83E-38	7.67E-40

Pd-107	202[a]	21000	1.60E-17	7.94E-20
Rb-87	300	21000	2.61E-07	8.68E-10
Sc-46	100	NA[c]	0	0
Se-79	7.55[a]	1600	1.04E-05	1.38E-06
Ta-182	100	NA[c]	0	0
Tc-99	900	16	1.09E-05	1.21E-08
Zn-65	300	17	1.44E-46	4.80E-49
			Sum of Ratios →	0.0298[d]

a. MCL not available for this radionuclide. Limiting concentration based on PRG for tap water ingestion.
b. Concentration increasing slightly at 100,000 years due to strong sorption and long half-life.
c. Maximum concentration of Sc-46 and Ta-182 for STR is less than 1E-100 pCi/L and reported as zero. Therefore, the time of maximum concentration is not applicable.
d. Sum of ratios conservatively presented as if all maximum concentrations occurred at the same time, which they do not.

7.2.7 Groundwater-Pathway Conclusions

Predicted maximum groundwater concentrations from proposed CED testing at NTR and STR sites are less than regulatory or other relevant limits for all nonradionuclide and radionuclide contaminants simulated. The groundwater-pathway modeling is conservative in that it is one-dimensional in the unsaturated zone (i.e., no lateral spreading/dilution) and assumes the entire inventory of contaminants infiltrates into the ground at the same location for every test. This is especially conservative for particulate radionuclides, which would have to first dissolve or corrode, and, in some cases, would be dispersed into the atmosphere. The receptor is also assumed to consume water directly from a well positioned in the location of maximum concentration. In addition, the degradation rate for DGBE is significantly greater than indicated by field testing. This same rate is likely conservative for isobutanol, which is described in DOW (2014b) as “readily biodegradable.” Even though isobutanol has a higher tendency to evaporate than DGBE, volatilization was not considered for either contaminant. This assessment also conservatively assumes all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m) will be used for each test when it is anticipated that a maximum of two material types will be used per test.

Given the results and the conservative assumptions employed in the groundwater-pathway modeling, it is highly unlikely that contamination from CED testing will adversely impact water quality in the aquifer.

7.3 SURFACE SOIL ASSESSMENT

This section calculates concentrations of radionuclides in the soil due to buildup from continued testing and compares them to EPA PRGs for workers and potential future residents. The surface soil assessment considered the same radionuclides and release rates evaluated for the groundwater pathway (see Table 6). PRGs were calculated using the “Calculator” option at https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search. Default values were used for all parameters in the PRG calculations, except the contaminated area was changed from “infinite” (default) to a site-specific 20 m^2, which is slightly greater than the test area based on a 16-ft diameter dome (18.7 m^2).

The analysis assumed 12 tests are performed annually for 15 years at the same test area using all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m). Soil concentration calculations were performed with the same MCM computer program (Rood 2010) used for the groundwater-pathway assessment. One set of calculations was performed for NTR and STR as soil and infiltration conditions were assumed to be similar for both ranges.

Calculations assume the entire radionuclide inventory is deposited onto the soil and is subject to leaching and radioactive decay. No atmospheric dispersal or volatilization is assumed. During the 15-year testing period, a background infiltration rate of 0.1 m/yr is assigned in addition to transient water from the use of foam. After testing, the infiltration rate is assumed to be a constant 0.1 m/yr for 10 years, and 0.01 m/yr thereafter. An infiltration rate of 0.1 m/yr is a typical background rate for disturbed unvegetated soils at the INL Site; 0.01 m/yr is reflective of undisturbed vegetated soils. The test area is based on a 16-ft diameter dome. This is more conservative than the 30-ft diameter dome because the amount of water used for testing in a 16-ft diameter dome is less, which results in less leaching and higher soil concentrations. Predicted concentrations are the average concentration in the top 5 cm of soil. Table 15 shows the model parameter values.

Table 15. Parameter values for surface soil concentration calculations.

Parameter	Value	Source/Comment
Operational period	15 yrs	Assumed value.
Infiltration rate during 3.65-day period of foam collapse	3.34 m/yr	Volume of liquid used in testing infiltrated over a 3.65-day period plus 0.1 m/yr background infiltration rate (see Equation [3]).
Infiltration rate between tests and for 10 years after testing	0.10 m/yr	Typical background infiltration rate for disturbed, unvegetated INL soils.
Infiltration rate beyond 10 years after testing ends	0.01 m/yr	Typical background infiltration rate for undisturbed, vegetated INL soils.
Soil thickness	5 cm	Typical value for surface exposure assessments.
Soil hydraulic parameters	various	Same values used for groundwater assessment (see Table 10).
Soil bulk density	1.5 g/cm^3	INL surface soil value from DOE-ID (1994).
Radionuclide solubility	1E+09 mg/L	Same value for all radionuclides.
Radionuclide sorption coefficients	various (mL/g)	Kd values are the same values used for the groundwater-pathway assessment (see Table 11) except for C-14 (2.4 mL/g), Ni-63 (400 mL/g) and Tc-99 (0 mL/g). These are the “alluvium most likely maximum” values from Table 18 of INL (2011). For conservatism, the larger values (larger than the groundwater assessment values in Table 11) were used for the surface soil assessment because it conservatively results in less leaching and higher soil concentrations. Kd values for other radionuclides are not available in INL (2011) and were not changed.

7.3.1 Surface-Soil Assessment Results

Table 16 presents PRGs for both an outdoor worker and a potential future resident. For the potential future resident, PRG exposure parameters were taken from EDF-11483 (IEC 2023) which describes the standard protocol for calculating PRG values at the INL Site for CERCLA risk assessments. Worker PRGs and resident PRGs are based on a target risk level of 1E-04.

The PRGs for the worker are calculated using the secular equilibrium option and a 25-year exposure time. This option essentially eliminates decay from the PRG equation. This PRG is evaluated against the 25-year average soil concentration that includes both leaching and radioactive decay. For the resident, the predicted concentration in 2095 (the end of the 100-year institutional control period measured from 1995) is evaluated against a PRG that includes radioactive decay and ingrowth during the receptors 26-year exposure period.

Calculated 25-year average soil concentrations for the worker are less than PRGs except for Ge-68 (material Ga-68). For K-40 (materials KO and KBr), the soil-to-PRG ratio is 0.814 and the predicted 25-year average K-40 concentration (34.7 pCi/g), is slightly greater than the average background concentration of K-40 in surface soil at the INL (24 pCi/g, Rood et al. 1996). For the resident, all predicted concentrations in the year 2095 are less than resident PRGs for a target risk level of 1E-04.

Table 16. Predicted soil concentrations compared to PRGs for workers and potential future residents.

	Worker			Future Resident		
Radionuclide	25-Year Average Soil Concentration (pCi/g)	Worker PRG (pCi/g)	Ratio 25-Year Average Soil Concentration to Worker PRG	Soil Concentration in Year 2095 (pCi/g)	Resident PRG (pCi/g)	Ratio Soil Concentration in Year 2095 to Resident PRG
Ag-110m	7.76E-03	2.64E+00	2.94E-03	8.64E-28	4.12E+01	2.10E-29
Be-10	1.97E-12	1.95E+04	1.01E-16	2.55E-12	3.49E+03	7.31E-16
C-14	2.98E-03	1.23E+05	2.42E-08	8.13E-07	9.13E+03	8.90E-11
Cd-109	9.15E-11	3.04E+03	3.01E-14	1.05E-25	4.84E+03	2.16E-29
Cl-36	9.55E-03	1.17E+04	8.16E-07	0.00E+00[b]	1.59E+01	0.00E+00
Cs-135	2.11E-11	2.62E+04	8.04E-16	2.88E-11	5.07E+03	5.69E-15
Cs-137	1.18E-11	1.45E+01	8.15E-13	4.55E-12	1.14E+01	3.99E-13
Ge-68	8.56E+00	7.74E+00	**1.11E+00[a]**	5.93E-23	1.11E+02	5.34E-25
K-40	3.47E+01	4.26E+01	8.14E-01	1.10E+01	2.00E+01	5.49E-01
La-137	9.67E-07	5.49E+03	1.76E-10	1.36E-06	3.18E+03	4.29E-10
La-138	7.97E-03	5.64E+00	1.41E-03	1.13E-02	3.35E+00	3.36E-03
Ni-63	1.46E-06	4.98E+05	2.94E-12	1.35E-06	3.72E+04	3.62E-11
Pd-107	1.09E-13	1.69E+06	6.46E-20	9.83E-14	4.38E+04	2.25E-18
Rb-87	1.77E-03	4.05E+04	4.37E-08	1.59E-03	3.67E+02	4.34E-06
Sc-46	8.71E-05	3.38E+00	2.58E-05	1.66E-79	1.58E+02	1.05E-81
Se-79	3.81E-04	3.48E+04	1.09E-08	2.99E-06	2.67E+02	1.12E-08
Ta-182	5.01E-10	5.60E+00	8.94E-11	1.19E-64	1.91E+02	6.23E-67
Tc-99	2.60E-06	1.04E+05	2.50E-11	2.17E-12	4.73E+02	4.59E-15
Zn-65	5.02E-02	1.16E+01	4.33E-03	4.58E-28	1.72E+02	2.66E-30
		Sum of Ratios	**1.93[a]**		Sum of Ratios	0.55
	Sum of Ratios (excluding K-40)		**1.11[a]**	Sum of Ratios (excluding K-40)		0.0034

a. Ratio greater than 1 indicates the predicted concentration exceeds the PRG.
b. Concentrations reported as 0 are calculated to be less than 1E-90.

In order to reduce the ratio of 25-year average soil concentration to PRG for the worker, two parameters were investigated:

- The number of tests using Ga-68 (which contains the Ge-68) was reduced from 12 tests per year to 6 tests per year. This reduced the 25-year average soil concentration of Ge-68 from 8.56 to 4.28 pCi/g.

- The EF (number of days a worker is in the contaminated testing area) was reduced to 112 days per year, which is one-half the default value of 225 days per year. This raised the PRG for Ge-68 and for all other radionuclides by a factor of 2.

Table 17 shows the impact of changing these two parameters on the results. When the number of annual tests using Ga-68 is reduced from 12 to 6; the 25-year average Ge-68 concentration is less than the PRG. The Ge-68 soil-to-PRG ratio is 0.525, but the sum of ratios is still greater than one (1.35) due to the large K-40 ratio. If the K-40 ratio is not included, the sum of ratios is 0.53. Reducing the EF frequency from 225 days/yr to 112 days/yr essentially doubles the PRG values. In this case, all ratios are less than one and the sum of ratios is less than one (0.96).

Table 17. Predicted soil concentrations compared to PRGs for workers when number of tests using Ga-68 are reduced and worker EF is reduced.

	Ga-68 Tests Reduced to 6/yr[a]			EF Reduced to 112 days/yr[b]		
Radionuclide	25-Year Average Soil Concentration (pCi/g)	Worker PRG (pCi/g)	Ratio 25-Year Average Soil Concentration to Worker PRG	25-Year Average Soil Concentration (pCi/g)	Worker PRG (pCi/g)	Ratio 25-Year Average Soil Concentration to Worker PRG
Ag-110m	7.76E-03	2.64E+00	2.94E-03	7.76E-03	5.30E+00	1.46E-03
Be-10	1.97E-12	1.95E+04	1.01E-16	1.97E-12	3.91E+04	5.03E-17
C-14	2.98E-03	1.23E+05	2.42E-08	2.98E-03	2.47E+05	1.21E-08
Cd-109	9.15E-11	3.04E+03	3.01E-14	9.15E-11	6.10E+03	1.50E-14
Cl-36	9.55E-03	1.17E+04	8.16E-07	9.55E-03	2.35E+04	4.06E-07
Cs-135	2.11E-11	2.62E+04	8.04E-16	2.11E-11	5.27E+04	4.00E-16
Cs-137	1.18E-11	1.45E+01	8.15E-13	1.18E-11	2.92E+01	4.05E-13
Ge-68	4.06E+00	7.74E+00	5.25E-01	8.56E+00	1.55E+01	5.52E-01
K-40	3.47E+01	4.26E+01	8.14E-01	3.47E+01	8.55E+01	4.06E-01
La-137	9.67E-07	5.49E+03	1.76E-10	9.67E-07	1.10E+04	8.79E-11
La-138	7.97E-03	5.64E+00	1.41E-03	7.97E-03	1.13E+01	7.06E-04
Ni-63	1.46E-06	4.98E+05	2.94E-12	1.46E-06	1.00E+06	1.46E-12
Pd-107	1.09E-13	1.69E+06	6.46E-20	1.09E-13	3.39E+06	3.22E-20
Rb-87	1.77E-03	4.05E+04	4.37E-08	1.77E-03	8.13E+04	2.18E-08
Sc-46	8.71E-05	3.38E+00	2.58E-05	8.71E-05	6.79E+00	1.28E-05
Se-79	3.81E-04	3.48E+04	1.09E-08	3.81E-04	6.99E+04	5.45E-09
Ta-182	5.01E-10	5.60E+00	8.94E-11	5.01E-10	1.12E+01	4.47E-11
Tc-99	2.60E-06	1.04E+05	2.50E-11	2.60E-06	2.09E+05	1.25E-11
Zn-65	5.02E-02	1.16E+01	4.33E-03	5.02E-02	2.32E+01	2.16E-03
		Sum of Ratios	**1.35[c]**		Sum of Ratios	0.96
	Sum of Ratios (excluding K-40)		0.53	Sum of Ratios (excluding K-40)		0.56

a. **Reduced the number of Ga-68 tests from 12 to 6 per year. This reduced the 25-year average Ge-68 soil concentration from 8.56 to 4.06 pCi/g. The average concentration of other radionuclides did not change.**
b. **Reduced the EF of the worker from 225 to 112 days per year. This increased the PRG of all radionuclides.**
c. Ratio greater than 1 indicates the predicted concentration exceeds the PRG.

7.3.2 Surface-Soil Assessment Conclusions

Maximum radionuclide soil concentrations are less than EPA PRGs for a potential future resident. For a worker, the 25-year average soil concentrations are less than PRGs, except for Ge-68. The Ge-68 soil concentration can be made less than the worker PRG, if the number of annual tests using Ga-68 is reduced from 12 to 6. However, the sum of ratios still exceeds one because of the high K-40 ratio. If the EF of the worker (number of days the worker is in the contaminated testing area) is reduced from 225 days/yr (default value for full time worker) to 112 days/yr, the Ge-68 ratio is less than one and the sum of ratios is less than one.

For a worker, the calculated maximum soil concentrations are less than PRGs, except for Ge-68 and K-40. When K-40 is appropriately excluded from consideration given the high background concentration, the sum of ratios for the worker is still greater than one due to Ge-68 (Ratio = 1.90). The maximum calculated Ge-68 soil concentration can be made less than the worker PRG and the sum of ratios less than one, if the number of annual tests using Ga-68 is reduced from 12 to 6 or if the EF of the worker (number of days the worker is in the contaminated testing area) is reduced from 225 days/yr (default value for full time worker) to 112 days/yr. If both the number of Ga-68 tests is reduced and the EF is reduced, the sum of ratios is less than one, even when K-40 is included. Nevertheless, it is advisable that the soil at the testing site be sampled and monitored periodically to confirm this.

7.4 Comments on Testing Frequency and Location

This evaluation assumes 12 tests are performed annually at each test range, and all 11 radioactive material types (K_2O, $LaBr_3$, KBr, Cu, Zr, F, Ga, Ga_2O_3, $NaNO_2$, Ga-68, and Tc-99m) are used for each test. It is possible that testing could occur more or less frequently than 12 times per year. The atmospheric-pathway assessment assumes the meteorological conditions that produce the 95th percentile annual effective dose results are the same for all 12 tests during the year, and each receptor is assumed to be present during all 12 tests. Given the similar conditions assumed for each test, the predicted dose will be the same if fewer or more than 12 tests are performed so long as the total annual release quantities (Table 1, Column 4) remain the same. If total annual releases are less, the predicted dose will be less regardless of the number of tests. Similarly, if the total annual releases are greater, the predicted dose will be higher regardless of the number of tests.

Groundwater and surface-soil pathway assessments are a little more complicated because transport rates are impacted by the amount of water used for making the foam. The amount of water depends on the number of tests performed. The amount of water impacts the infiltration rate, which is the driving force for transporting the contaminants to the aquifer or leaching contaminants from the soil. For the groundwater pathway, fewer tests mean less water, which means less infiltration and longer travel times through the vadose zone to the aquifer. This is a positive impact because it allows more time for radioactive decay or degradation. This results in lower concentrations in the aquifer assuming the total annual release quantities (see Table 6, Column 4) remain the same. Conversely, more tests mean additional water and shorter travel times through the vadose zone to the aquifer, resulting in less decay/degradation. If the total annual release quantity remains the same, this would result in higher concentrations than predicted (a negative impact). The impact on the surface-soil pathway is opposite from the groundwater pathway in that more tests means more water and higher leach rates of contaminants from the surface soil (a positive impact). Fewer tests mean less water and less leaching of contaminants (a negative impact). Again, this is only true if the total annual release quantities (see Table 6, Column 4) remain unchanged.

For nonradionuclides, more frequent testing is problematic for both the groundwater and surface-soil pathway because more testing means more contaminants from the BlastGuard foam. However, degradation rates used in the assessment were conservative by a factor of 10 to 100 when compared to the rates predicted by testing and sampling (see Sondrup 2019, Appendix B), indicating more frequent testing is likely not a concern for nonradionuclide impacts on soil or groundwater. Less frequent testing is obviously not a concern because it would mean fewer contaminants.

This evaluation assumes all 12 tests will be performed at the same place at both locations, and all 11 radioactive material types will be used for each test. If half of the tests are performed at one location and the other half at another nearby location, it would have minimal impact on the atmospheric-pathway dose calculations, but it would impact the groundwater and surface-soil pathway calculations. The maximum predicted groundwater and soil concentrations would be half of those presented in this report. The surface-soil pathway assessment evaluated the impact of reducing the number of tests using Ga-68 from 12 to 6 per year. This is analogous to performing 12 tests in two different locations. Thus, the number of Ga-68 tests would not need to be reduced, but the tests could be done at two different locations.

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Appendix A

Gaussian Plume Model Description

(from Rood and Sondrup 2015)

This appendix contains a description of the Gaussian plume model and its implementation in a Perl script for generating time-integrated concentrations (TICs).

A-1. GAUSSIAN PLUME FORMULATION

The Gaussian plume model for a conservative tracer with no deposition or depletion is given in Equation (A-1) (Turner 1994):

$$\chi(x,y,z,u,H,Q) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] G(z)$$

$$G(z) = \sum_{n=-\infty}^{\infty} \left\{ \exp\left[-\frac{1}{2}\left(\frac{2nH - z_h - z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nH + z_h - z}{\sigma_z}\right)^2\right] \right\} \quad \text{(A-1)}$$

where

χ = tracer concentration in air at downwind location x, y, and z (Ci/m3)

x = downwind distance (m)

y = crosswind distance (m)

z = height above ground (m)

u = wind speed (m/s)

zh = plume height (stack height plus plume rise) (m)

H = mixing height (m)

σy, σz = diffusion coefficients in the y and z direction, respectively

Q = continuous release rate (Ci/s).

For a release of finite duration, the TIC is found by integrating Equation (A-1). Because there are no time terms in Equation (A-1), the TIC is simply χ multiplied by the integration of time. Assuming transport time from source to receptor is short relative to release time, the TIC is simply Equation *(A-1)*, replacing the release rate (*Q*) with the quantity released over the integration time (*q*, in Ci).

A-1.1 Release Height

The release height is the physical height of the release plus plume rise due to momentum or buoyant rise. Both momentum and buoyant rise are calculated, and the higher of the two is used in the calculations.

Buoyancy flux (*F*) is given by Equation (A-2) in Turner (1994):

$$F = \frac{g\, v\, d^2\, \Delta T}{4 T_s} \tag{A-2}$$

where

g = acceleration due to gravity (9.8 m/s2)

v = stack gas exit velocity (m/s)

d = inside stack diameter at top of stack (m)

ΔT = stack gas temperature minus ambient temperature (K)

Ts = stack gas exit temperature (K).

For unstable or neutral conditions, the buoyant rise is found using Equation (A-3).

$$\Delta H = \frac{21.425 F^{3/4}}{u_h}, \quad F < 55$$
$$\Delta H = \frac{38.71 F^{3/5}}{u_h}, \quad F \geq 55 \tag{A-3}$$

where

u_h = the wind speed at the top of the stack (m/s).

For unstable or neutral conditions, the momentum rise is found using Equation (A-4).

$$\Delta H = \frac{3\, d\, v}{u_h} \tag{A-4}$$

For stable conditions, the buoyant rise is a function of the stability parameter (*s*), as shown in Equation (A-5).

$$s = \frac{g\left(\frac{d\theta}{dz}\right)}{T}$$
$$\frac{d\theta}{dz} = \frac{dT}{dz} + \Gamma \tag{A-5}$$

where

Γ is the adiabatic lapse rate (0.0098 K/m).

The final buoyant rise is given by Equation (A-6) where the lower of the two values is used:

$$\Delta H = 2.6\left[\frac{F}{u_h s}\right]^{1/3}$$
$$\Delta H = 4F^{1/4}s^{-3/8} \quad \text{(A-6)}$$

Momentum rise for stable conditions is found using Equation (A-7).

$$\Delta H = 1.5\left[\frac{v^2 d^2 T}{4T_s u_h}\right]^{1/3} s^{-1/6} \quad \text{(A-7)}$$

Momentum rise for stable conditions is also calculated using Equation (A-4), and the lower of the two values is used.

A-1.2 Diffusion Coefficients

The diffusion coefficients used in this assessment were the Briggs Urban coefficients described in Turner (1994). Both the Pasquill-Gifford and Briggs dispersion coefficients were run in the model and compared with results from CALPUFF. The Briggs dispersion coefficients produced doses much closer to those of CALPUFF when compared to the Pasquill-Gifford dispersion coefficients (Table A-1). For these reasons, the Briggs dispersion coefficients were used.

Table A-1. Am-241 inhalation dose and TIC for a release of 6.907E+07 pCi from CPP-1774 with a 1-hour release time.

Sampler	Distance	Bearing	Gaussian Plume Dose (mrem)	CALPUFF Dose (mrem)	Gaussian Plume TIC (pCi-hour/m^3)	CALPUFF TIC (pCi-hour/m^3)
Briggs Dispersion Coefficients						
BEA-TRA	3,040	304	0.182	0.165	0.661	0.5993
BEA-CPP	343	290	3.945	2.511	14.3	9.124
BEA-INTEC	1,050	18	0.736	0.5738	2.67	2.09
BEA-RTC	3,161	318	0.1417	0.184	0.515	0.669
Pasquill-Gifford Dispersion Coefficients						
BEA-TRA	3,040	304	0.409	0.165	1.49	0.5993
BEA-CPP	343	290	6.25	2.511	22.7	9.124
BEA-INTEC	1,050	18	6.47	0.5738	23.5	2.09
BEA-RTC	3,161	318	0.6129	184	2.23	0.669

A-1.3 Stability Class

Stability class was determined using the solar radiation-delta-temperature method described in EPA (2000).

A-1.4 Coordinate Transformations

The coordinates of each of the receptors (x_{rec}, y_{rec}) located at distance r and azimuth ϕ from the source were calculated using Equation (A-8):

$$x_{rec} = \sin(\phi) r + x_{source}$$
$$y_{rec} = \cos(\phi) r + y_{source} \quad \text{(A-8)}$$

where

x_{source} and y_{source} are the Cartesian coordinates of the source. In most cases, the wind does not blow at the same azimuth direction as the receptor is from the source.

The downwind distance x and crosswind distance y of the receptor located at azimuth ϕ and a wind vector ψ is given by using Equation *(*A-9*)* (see Figure A-1)

$$x = r - abs(x_{rec} - x_{wind})$$
$$y = r \sin(\phi - \psi)$$
$$x_{wind} = \sin(\psi) r + x_{source} \quad \text{(A-9)}$$

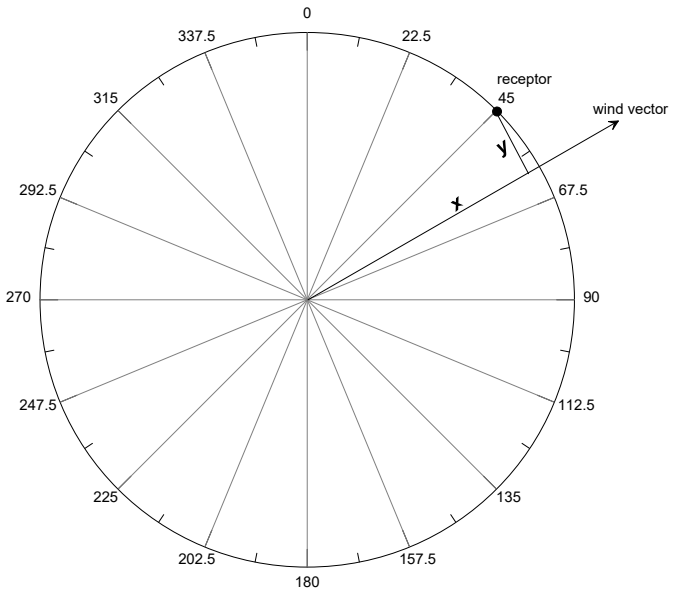

Figure A-1. Diagram showing downwind distance and crosswind distance for a receptor located at azimuth 45 degrees and wind vector azimuth of 58 degrees.

A-1.5 References

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Appendix B

Results Summary for Foam Glycol Sampling at Radiological Response Training Range

An experiment on the effects of a foam that is used in containment and explosive-disablement (CED) training was performed at the Radiological Response Training Range (RRTR) at Idaho National Laboratory (INL). The foam is a mixture of water, air, and the product BlastGuard AFC-380. It is similar to common fire-fighting foams. The foam is used to minimize the dispersal of radioactive materials and projectiles during disablement activities. Over time, the foam collapses into an aqueous mixture and soaks into the ground. A GWSCREEN model of soil contamination indicated that the diethylene glycol monobutyl ether in AFC-380 has the potential to exceed the concentration, which would result in a hazard quotient (HQ) of 1. If the HQ is greater than 1, an investigation under the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA) may be required. The experiment was conducted to determine if use of the foam over time necessitates a CERCLA investigation.

The experiment was conducted in an area free of radiation. A 4 ft by 4 ft bottomless box was place on the soil to contain the foam. The box was filled with foam, and then the foam was allowed to turn aqueous and sink into the soil. A soil sample was collected in the area where the foam was applied prior to the foam application to obtain a baseline concentration of total glycols in the soil. After the foam was applied and all of it dissipated into the soil, another sample was collected to determine the concentration of glycol in the soil immediately after the foam was in the soil (Time 0). Total glycol concentrations were measured every week for three weeks thereafter for a total of five sampling events. One sample was collected for each of the sampling events, with the exception of the first sampling event after foam application. Two samples were collected at Time 0 to obtain a crude measure of variability. Table B-1 shows the dates of the sampling events.

Table B-1. Time of sampling events for foam sampling at RRTR.

Sampling Event	Date	Description
Baseline	4/8/2016	Single soil sample prior to foam application
Time 0	4/18/2016	Two soil samples immediately after foam soaked into soil
Time 1	4/27/2016	Single soil sample approximately 1 week after foam soaked in
Time 2	5/5/2016	Single soil sample approximately 2 weeks after foam soaked in
Time 2	5/12/2016	Single soil sample approximately 3 weeks after foam soaked in

The chemicals diethylene glycol, ethylene glycol, propylene glycol, and triethylene glycol were measured in each sample. None of the glycols were detected in any of the samples. The detection limit was the same for each glycol in each sample so only one method detection limit (MDL) and one practical quantitation limit (PQL) are shown for each sample. The MDLs and PQLs for each sample are shown in Figure B-1 and in Table B-2. The detection limits are much larger for Time 1–3 than they are for the baseline and for Time 0. This is not because the concentrations increased but because the samples were run separately at the laboratory, and variation occurs in the detection limits from one run to the next. There were no quality issues at the laboratory that would cause one to question the validity of the detection limits. It can be concluded that the concentration of glycols in the soils is very small.

Table B-2. Detection limits for the glycols in the soils for the RRTR foam test. Detection limits are reported because glycol was not detected in any of the samples.

Time	Date	MDL	PQL	Units
Baseline	4/8/2016	3.34	10.1	mg/kg
Time 0	4/18/2016	3.48	10.6	mg/kg
Time 0	4/18/2016	3.47	10.5	mg/kg
Time 1	4/27/2016	17.7	53.6	mg/kg
Time 2	5/5/2016	17.1	51.8	mg/kg
Time 3	5/12/2016	17.4	52.7	mg/kg

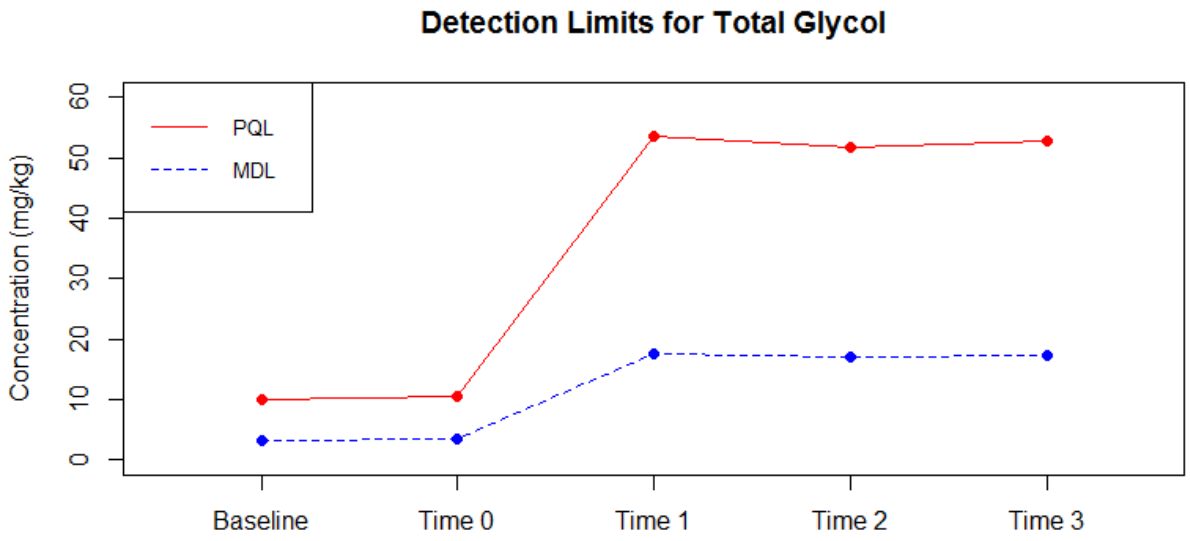

Figure B-1. Detection limits for each sampling event for each measured glycol.