Chapter 8: Dose to the Public and Biota

CHAPTER 8

Airborne emissions from Idaho National Laboratory (INL) Site operations were used to determine potential radiological dose to members of the public using the Clean Air Act Assessment Package 88-PC computer program. The annual dose to the maximally exposed individual in 2022, as determined using Clean Air Act Assessment Package 88-PC, was 0.018 mrem (0.18 µSv), which was well below the applicable standard of 10 mrem (100 µSv) per year. A maximum potential dose from ingestion of game animals was also estimated using the highest radionuclide concentrations in the edible tissue of waterfowl collected at Advanced Test Reactor ponds in 2022. The maximum potential dose to an individual who consumes waterfowl was calculated to be 0.0009 mrem (0.009 µSv). It was determined there is no dose associated with the consumption of big game animals. Therefore, the total dose (from air emissions and ingestion of the waterfowl) to the maximally exposed individual during 2022 was estimated to be 0.019 mrem (0.19 µSv). This dose is also well below the public dose limit of 100 mrem (1 mSv) established by the U.S. Department of Energy (DOE) for a member of the public.

The maximum potential population dose to the approximately 353,435 people residing within an 80 km (50 mi) radius of any INL Site facility was also evaluated. The population dose was calculated using reported releases, an air dispersion model (HYSPLIT) used by the National Oceanic and Atmospheric Administration Special Operations and Research Division, and a dose calculation model. For 2022, the estimated potential population dose was 1.91×10^{-2} person-rem (1.91×10^{-4} person-Sv). This is approximately 0.00001 percent of the expected dose from exposure to natural background radiation of 134,109 person-rem (1,341 person-Sv).

The potential doses to aquatic and terrestrial biota from contaminated soil and water were evaluated using a graded approach. Initially, the potential doses were screened using maximum concentrations of radionuclides detected in soil and effluents at the INL Site. Results of the screening calculations indicate that contaminants released from INL Site activities do not have an adverse impact on plants or animal populations. Additionally, maximum concentrations of radionuclides measured in waterfowl accessing INL Site ponds and in bats, which were collected at or near INL facilities, were used to estimate internal doses to the waterfowl and bats. These calculations indicate the potential doses to waterfowl and bats do not exceed the DOE limits for biota.

No reportable unplanned radiological effluent or emission releases occurred from the INL Site in 2022; therefore, no doses or impacts were manifested.

8. DOSE TO THE PUBLIC AND BIOTA

DOE O 458.1, "Radiation Protection of the Public and the Environment," contains requirements for protecting the public and the environment against undue risk from radiation associated with radiological activities conducted under DOE control. In addition to requiring environmental monitoring to ensure compliance with the order, DOE O 458.1 establishes a public dose limit. DOE sites must perform dose evaluations using mathematical models that represent various environmental pathways to demonstrate compliance with the public dose limit and to assess collective (population) doses. In the interest of protecting the environment against ionizing radiation, DOE also developed the technical standard DOE-STD-1153-2019, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE 2019). The standard provides a graded approach for evaluating radiation doses to aquatic and terrestrial biota.

Title 40 CFR Part 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities," establishes federal radiation dose limits for the maximally exposed member of the public from all airborne emissions and pathways. It requires that doses to members of the public from airborne releases are calculated using U.S. Environmental Protection Agency (EPA)-approved sampling procedures, computer models, or other procedures.

This chapter describes the estimated potential dose to members of the public and biota from operations at the INL Site, based on 2022 environmental monitoring measurements or calculated emissions.

8.1 Possible Exposure Pathways to the Public

Air, soil, groundwater, agricultural products, and biota are routinely sampled to document the amount of radioactivity in these media and to determine if radioactive materials have been transported off the INL Site. The air pathway is the primary way people living beyond the INL Site boundary could be exposed to releases from INL Site operations, as shown in Figure 4-1.

Airborne radioactive materials are carried from the source and dispersed by winds. The concentrations from routine releases are too small to measure at locations around the INL Site, so atmospheric dispersion models were used to estimate the downwind concentration of air pollutants and the potential doses from these projected offsite concentrations. Conservative doses were also calculated from the ingestion of meat from wild game animals that access the INL Site. Ingestion doses were calculated from the concentrations of radionuclides measured in game animals killed by vehicles on INL Site roads and waterfowl harvested from INL Site wastewater ponds that had detectable levels of human-made radionuclides. External exposure to radiation in the environment—primarily from naturally-occurring radionuclides—was measured directly using thermoluminescent dosimeters and optically-stimulated luminescence dosimeters.

Water pathways were not considered major contributors to dose, because no surface water flows off the INL Site and radionuclides associated with INL Site releases have not been measured in public drinking water wells.

8.2 Dose to the Public from INL Site Air Emissions

The potential doses from INL Site air emissions were estimated using the amounts reported to be released or could be released by the facilities. The 2022 INL National Emission Standards for Hazardous Air Pollutants (NESHAP) evaluation (DOE-ID 2023) reported potential radionuclide releases from 67 source locations at the INL Site. However, many of the sources resulted in doses that were insignificant, and many sources are located relatively close together, such that the sampling network response from a release would be the same for all nearby sources. Therefore, insignificant sources were not explicitly modeled, and some sources were consolidated with nearby sources. Emissions from four large operating stacks were modeled explicitly and included the Advanced Test Reactor (ATR) main stack (TRA-770), the Idaho Nuclear Technology and Engineering Center (INTEC) main stack (CPP-708), the Experimental Breeder Reactor-II main stack (MFC-764), and the Transient Reactor Test Facility (TREAT) stack. All other releases within a facility were assigned as near ground-level releases from a single location within the facility. These other releases include other non-fugitive releases from stacks, ducts, and vents, and also include fugitive releases from ponds, soil, or other sources. Figure 8-1 shows the location of all sources modeled in the dose assessment. Emissions from the Safety and Tritium Applied Research facility (TRA-666) at the ATR Complex are typically routed to and out of the Material Test Reactor stack. During calendar year 2022, TRA-666 began a building ventilation system modification project, and emissions were routed to a much shorter temporary stack for most of the year. Therefore, all TRA-666 emissions for calendar year 2022 were conservatively reported as a ground-level release and no emissions were reported for the Material Test Reactor stack.

The radionuclides and source terms used in the dose calculations were presented previously in Table 4-2 of Chapter 4 and are summarized in Table 8-1. The category of noble gases comprised the largest emission quantity but only contributed slightly to the dose. Radionuclides that were categorized as noble gases tend to have short half-lives and are not typically incorporated into the food supply. Radionuclides that contributed most to the overall estimated dose to the maximally exposed individual (MEI) were uranium-238 (^{238}U), chlorine-36 (^{36}Cl), uranium-234 (^{234}U), americium-241 (^{241}Am), strontium-90 (^{90}Sr), cesium-137 (^{137}Cs), and tritium (^{3}H). These radionuclides are a very small fraction of the total amount of radionuclides reported.

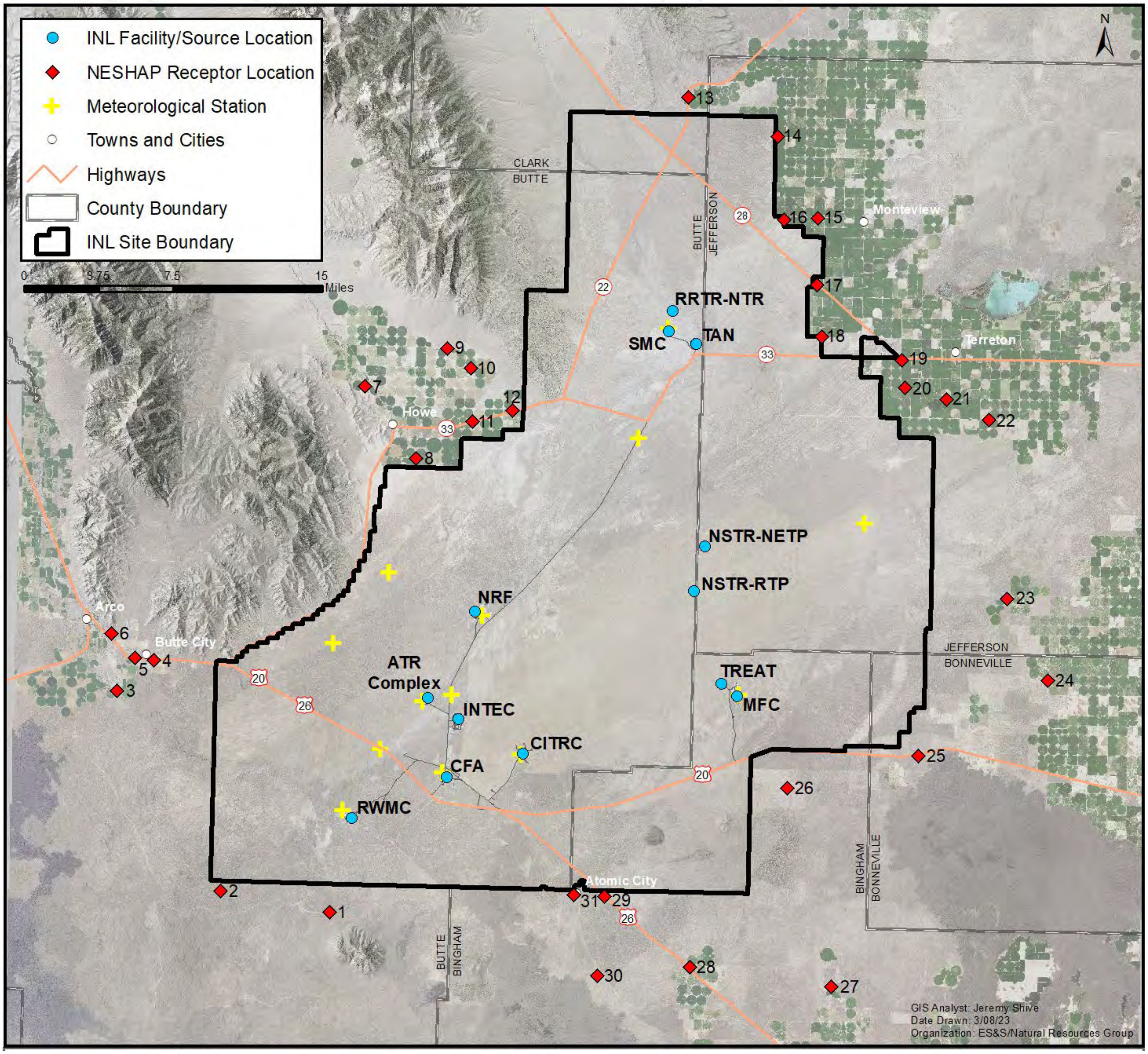

Figure 8-1. INL Site major facility airborne source locations. *TRA-770, CPP-708, TREAT, and MFC-764 were modeled as stack releases. The remaining sources were modeled as ground-level releases. Newer facilities including the Radiological Response Training Range - New Explosive Test Pad (RRTR-NTR), National Security Test Range - Radiological Training Pad (NSTR-RTP), and National Security Test Range - New Explosive Test Pad (NSTR-NETP) reported no releases in the calendar year 2022; therefore were not included in the analysis. Thirty-one specific receptor locations are also shown, including the MEI (location 26), modeled by Clean Air Act Assessment Package-1988 personal computer (CAP88-PC).*

Table 8-1. Summary of radionuclide composition of INL Site airborne effluents (2022).

FACILITY[b]	TOTAL CURIES[a] RELEASED										
	TRITIUM	NOBLE GASES[c] (*T1/2* > 40 DAYS)	NOBLE GASES[d] (*T1/2* < 40 DAYS)	FISSION AND ACTIVATION PRODUCTS[e] (*T1/2* < 3 HOURS)	FISSION AND ACTIVATION PRODUCTS[f] (*T1/2* > 3 HOURS)	TOTAL RADIOIODINE[g]	TOTAL RADIOSTRONTIUM[h]	TOTAL URANIUM[i]	PLUTONIUM[j]	OTHER ACTINIDES[k]	OTHER[l]
ATR Complex	9.88E+00	1.48E-19	2.92E-04	1.04E-05	1.24E-02	4.33E-06	2.75E-02	2.07E-09	8.46E-06	2.21E-05	3.06E-10
CFA	5.39E-01	6.68E-06	1.77E-01	1.90E-03	9.40E-07	8.47E-11	3.32E-11	2.47E-10	9.10E-1212	3.05E-11	4.41E-15
CITRC	0.00E+00	0.00E+00	0.00E+00	4.40E-08	0.00E+00	0.00E+00	0.00E+00	8.82E-10	0.00E+00	0.00E+00	0.00E+00
INTEC	2.33E-01	1.09E+00	0.00E+00	0.00E+00	4.50E-04	7.93E-05	2.99E-03	4.77E-07	4.34E-04	5.79E-04	0.00E+00
MFC	3.82E-01	7.97E-02	2.26E+02	3.62E+01	6.57E-02	8.94E-02	8.31E-03	1.05E-01	3.05E-07	2.16E-03	0.00E+00
NRF	1.10E-02	4.20E-03	0.00E+00	0.00E+00	3.20E-01	1.44E-05	5.50E-05	0.00E+00	2.70E-06	0.00E+00	0.00E+00
RRTR	0.00E+00	3.35E-06	8.53E-11	5.02E-11	3.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RWMC	4.81E+01	0.00E+00	0.00E+00	0.00E+00	2.22E-02	0.00E+00	4.31E-08	1.67E-08	4.78E-05	1.03E-04	0.00E+00
TAN	1.45E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.01E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SMC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-07	0.00E+00	0.00E+00	0.00E+00
Total	5.92E+01	1.17E+00	2.26E+02	3.62E+01	3.36E+01	8.94E-02	3.88E-02	1.05E-01	4.94E-04	2.86E-03	3.06E-10

a. One curie (Ci) = 3.7 × 10^{10} becquerels (Bq).

b. ATR Complex = Advanced Test Reactor Complex; CFA = Central Facilities Area; CITRC = Critical Infrastructure Test Range Complex; INTEC = Idaho Nuclear Technology and Engineering Center; MFC = Materials and Fuels Complex; NRF = Naval Reactors Facility; RRTR = Radiological Response Training Range-Northern Test Range; RWMC = Radioactive Waste Management Complex (including Advanced Mixed Waste Treatment Project); TAN = Test Area North; and SMC = Specific Manufacturing Capability.

c. Noble gases ($T_{1/2}$ > 40 days) released in 2022 = ^{39}Ar, ^{42}Ar, ^{81}Kr, and ^{85}Kr (^{39}Ar, ^{42}Ar and ^{81}Kr release is negligible).

d. Noble gases ($T_{1/2}$ < 40 days) released in 2022 = ^{41}Ar, ^{79}Kr, ^{83m}Kr, ^{85m}Kr, ^{87}Kr, ^{88}Kr, ^{89}Kr, ^{90}Kr, ^{91}Kr, ^{92}Kr ^{219}Rn, ^{220}Rn, ^{127}Xe, ^{131m}Xe, ^{133}Xe, ^{133m}Xe, ^{135}Xe, ^{135m}Xe, ^{137}Xe, ^{138}Xe, ^{139}Xe, and ^{140}Xe.

e. Fission products and activation products ($T_{1/2}$ < 3 hours) released in 2021 = ^{106}Ag, ^{109m}Ag, ^{110}Ag, ^{78}As, ^{137m}Ba, ^{139}Ba, ^{141}Ba, ^{211}Bi, ^{80}Br, ^{83}Br, ^{84}Br, ^{117}Cd, ^{60m}Co, ^{138}Cs, ^{139}Cs, ^{140}Cs, ^{165}Dy, ^{158}Eu, ^{68}Ga, ^{70}Ga, ^{75}Ge, ^{78}Ge, ^{114}In, ^{117}In, ^{142}La, ^{56}Mn, ^{97}Nb, ^{149}Nd, ^{65}Ni, ^{150}Pm, ^{144}Pr, ^{144m}Pr, ^{88}Rb, ^{89}Rb, ^{90}Rb, ^{103m}Rh, ^{106}Rh, ^{106m}Rh, ^{126m}Sb, ^{128m}Sb, ^{130}Sb, ^{81}Se, ^{81m}Se, ^{127}Sn, ^{128}Sn, ^{129}Te, ^{131}Te, ^{133}Te, ^{134}Te, ^{208}Tl, ^{89m}Y, ^{91m}Y, and ^{69}Zn.

f. Fission products and activation products ($T_{1/2}$ > 3 hours) released in 2022 = ^{108m}Ag, ^{110m}Ag, ^{111}Ag, ^{112}Ag, ^{73}As, ^{76}As, ^{77}As, ^{133}Ba, ^{140}Ba, ^{10}Be, ^{207}Bi, ^{210}Bi, ^{210m}Bi, ^{82}Br, ^{14}C, ^{45}Ca, ^{109}Cd, ^{113m}Cd, ^{115}Cd, ^{115m}Cd, ^{139}Ce, ^{141}Ce, ^{143}Ce, ^{144}Ce, ^{36}Cl, ^{57}Co, ^{58}Co, ^{58m}Co, ^{60}Co, ^{51}Cr, ^{134}Cs, ^{135}Cs, ^{136}Cs, ^{137}Cs, ^{64}Cu, ^{67}Cu, ^{159}Dy, ^{166}Dy, ^{169}Er, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{156}Eu, ^{157}Eu, ^{55}Fe, ^{59}Fe, ^{60}Fe, ^{72}Ga, ^{73}Ga, ^{153}Gd, ^{159}Gd, ^{68}Ge, ^{71}Ge, ^{77}Ge, ^{175}Hf, ^{178m}Hf, ^{179m}Hf, ^{180m}Hf, ^{181}Hf, ^{182}Hf, ^{203}Hg, ^{166}Ho, ^{166m}Ho, ^{114m}In, ^{115m}In, ^{190}Ir, ^{192}Ir, ^{194}Ir, ^{40}K, ^{42}K, ^{140}La, ^{141}La, ^{177}Lu, ^{177m}Lu, ^{52}Mn, ^{53}Mn, ^{54}Mn, ^{93}Mo, ^{99}Mo, ^{22}Na, ^{24}Na, ^{92m}Nb, ^{93m}Nb, ^{94}Nb, ^{95}Nb, ^{95m}Nb, ^{96}Nb, ^{147}Nd, ^{57}Ni, ^{59}Ni, ^{63}Ni, ^{66}Ni, ^{185}Os, ^{189m}Os, ^{191}Os, ^{191m}Os, ^{193}Os, ^{32}P, ^{33}P, ^{205}Pb, ^{210}Pb, ^{107}Pd, ^{109}Pd, ^{146}Pm, ^{147}Pm, ^{148}Pm, ^{148m}Pm, ^{149}Pm, ^{151}Pm, ^{210}Po, ^{143}Pr, ^{145}Pr, ^{189}Pt, ^{191}Pt, ^{193}Pt, ^{193m}Pt, ^{195m}Pt, ^{197}Pt, ^{83}Rb, ^{84}Rb, ^{86}Rb, ^{87}Rb, ^{184}Re, ^{184m}Re, ^{186}Re, ^{186m}Re, ^{187}Re, ^{188}Re, ^{102}Rh, ^{102m}Rh, ^{105}Rh, ^{103}Ru, ^{105}Ru, ^{106}Ru, ^{35}S, ^{122}Sb, ^{124}Sb, ^{125}Sb, ^{126}Sb, ^{127}Sb, ^{128}Sb, ^{129}Sb, ^{46}Sc, ^{47}Sc, ^{48}Sc, ^{79}Se, ^{32}Si, ^{151}Sm, ^{153}Sm, ^{156}Sm, ^{113}Sn, ^{117m}Sn, ^{119m}Sn, ^{121}Sn, ^{121m}Sn, ^{123}Sn, ^{125}Sn, ^{126}Sn, ^{179}Ta, ^{180}Ta, ^{182}Ta, ^{183}Ta, ^{184}Ta, ^{157}Tb, ^{158}Tb, ^{160}Tb, ^{161}Tb, ^{97m}Tc, ^{99}Tc, ^{99m}Tc, ^{123m}Te, ^{125m}Te, ^{127}Te, ^{127m}Te, ^{129m}Te, ^{131m}Te, ^{132}Te, ^{204}Tl, ^{168}Tm, ^{170}Tm, ^{171}Tm, ^{48}V, ^{49}V, ^{181}W, ^{185}W, ^{187}W, ^{188}W, ^{88}Y, ^{90}Y, ^{91}Y, ^{92}Y, ^{93}Y, ^{65}Zn, ^{69m}Zn, ^{71m}Zn, ^{72}Zn, ^{93}Zr, ^{95}Zr, and ^{97}Zr.

g. Radioiodine released in 2022 = ^{125}I, ^{126}I, ^{128}I, ^{129}I, ^{130}I, ^{131}I, ^{132}I, ^{133}I, ^{134}I, and ^{135}I.

h. Radiostrontium released in 2022 = ^{80}Sr, ^{85}Sr, ^{89}Sr, ^{90}Sr, ^{91}Sr, and ^{92}Sr.

i. Uranium isotopes released in 2022 = ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{237}U, and ^{238}U.

j. Plutonium isotopes released in 2022 = ^{236}Pu, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{244}Pu.

k. Other actinides released in 2022 = ^{227}Ac, ^{241}Am, ^{243}Am, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{252}Cm, ^{237}Np, ^{239}Np, ^{231}Pa, ^{233}Pa, ^{234}Pa, ^{234m}Pa, ^{227}Th, ^{228}Th, ^{229}Th, ^{230}Th, ^{231}Th, ^{232}Th, and ^{234}Th.

l. Other = radioisotopes of elements that are not noble gases, activation or fission products, radioiodine, radiostrontium, or actinides released in 2022. These are typically heavy elements that are decay chain members of actinides. They include ^{212}Bi, ^{214}Bi, ^{211}Pb, ^{212}Pb, ^{214}Pb, ^{212}Po, ^{215}Po, ^{216}Po, ^{223}Ra, ^{224}Ra, ^{226}Ra, and ^{207}Tl.

The following two kinds of dose estimates were made using the release data:

- ***The effective dose to the hypothetical MEI, as defined by the NESHAP regulations.*** The CAP88-PC model Version 4.1 (EPA 2020) was used to predict the maximum concentration and dose at offsite receptor locations. The receptor location with the highest estimated dose is the MEI location.
- ***The collective effective dose (population dose) for the population within 80 km (50 mi) of any INL Site facility.*** For this calculation, the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Stein et al. 2015) was used to model atmospheric transport, dispersion, and deposition of radionuclides released to the air from the INL Site. The population dose was estimated using the Dose Multi-Media (DOSEMM) model (Rood 2019) using dispersion and deposition factors calculated by HYSPLIT to comply with DOE O 458.1.

The dose estimates considered the air immersion dose from gamma-emitting radionuclides, internal dose from inhalation of airborne radionuclides, internal dose from ingestion of radionuclides in plants and animals, and external dose from gamma-emitting radionuclides deposited on soil (previously shown in Figure 4-1). The CAP88-PC computer model uses dose and risk tables developed by the EPA. Population dose calculations were made using (1) DOE effective dose coefficients for inhaled radionuclides (DOE 2021), (2) EPA dose conversion factors for ingested radionuclides (EPA 2002), and (3) EPA dose conversion factors for external exposure to radionuclides in the air and deposited on the ground surface (EPA 2002).

8.2.1 Maximally Exposed Individual Dose

The EPA NESHAP regulation requires demonstrating that radionuclides other than radon released to the air from any DOE nuclear facility do not result in a dose to the public of greater than 10 mrem/yr (0.1 mSv/yr) (40 CFR 61, Subpart H). EPA requires the use of an approved computer model such as CAP88-PC, to demonstrate compliance with 40 CFR 61, Subpart H. CAP88-PC uses a modified Gaussian plume model to estimate the average dispersion of radionuclides released from up to six sources. It uses average annual wind files based on data collected at multiple locations on the INL Site by the National Oceanic and Atmospheric Administration (NOAA).

In calendar year 2022, NESHAP receptor locations were revised to ensure the currently selected locations are still occupied by the public and to capture new residences, schools, or offices that were constructed since the last receptor location evaluation. Receptor locations were last updated in 1995 when 62 locations were identified during a helicopter fly-over inspection of the INL Site boundary (Ritter 1997). This updated analysis employed high-resolution aerial imagery to identify suitable receptor locations quickly and easily. The use of aerial imagery instead of in-person helicopter surveys ensures this process can be completed at a reasonably frequent interval and at minimum cost. Additionally, a defensible strategy for identifying receptor locations was established to eliminate selecting redundant receptor locations. The analysis resulted in a total of 31 NESHAP receptor locations. The calendar year 2022 MEI remains at the same location as previous years; however, it is now identified as Receptor 26 rather than Receptor 54. References to the MEI prior to 2019 (Receptor 1) continue to be referred to as Receptor 1 in the new arrangement (INL 2023).

The dose to the MEI from INL Site airborne releases of radionuclides was calculated to demonstrate compliance with NESHAP and is published in the *National Emissions Standards for Hazardous Air Pollutants – Calendar Year 2022 INL Report for Radionuclides* (DOE-ID 2023). To identify the MEI, the doses at 31 offsite locations shown in Figure 8-1, were calculated and then screened for the maximum potential dose to an individual who might live at one of these locations. The highest potential dose location was determined to be location 26, a farmhouse and cattle operation located 3.1 km south of Highway 20 and 3 km from INL Site's east entrance. This is the same MEI location as the previous year, but it is different from the MEI location prior to 2019 which was location 1 (i.e., Frenchmans Cabin). Location 1 is located 2.3 km south of the INL boundary, south of RWMC. An effective annual dose of 0.018 mrem (0.18 µSv) was calculated for a hypothetical person living at location 26 during 2022. The 2022 dose at the former MEI (location 1) was 0.0097 mrem/yr and it was the fourth highest receptor location in terms of dose.

Figure 8-2 compares the MEI doses calculated for years 2013–2022. All the doses are well below the whole-body dose limit of 10 mrem/yr (0.1 mSv/yr) for airborne releases of radionuclides established by 40 CFR 61, Subpart H. The highest dose estimated during the past ten years was in 2021.

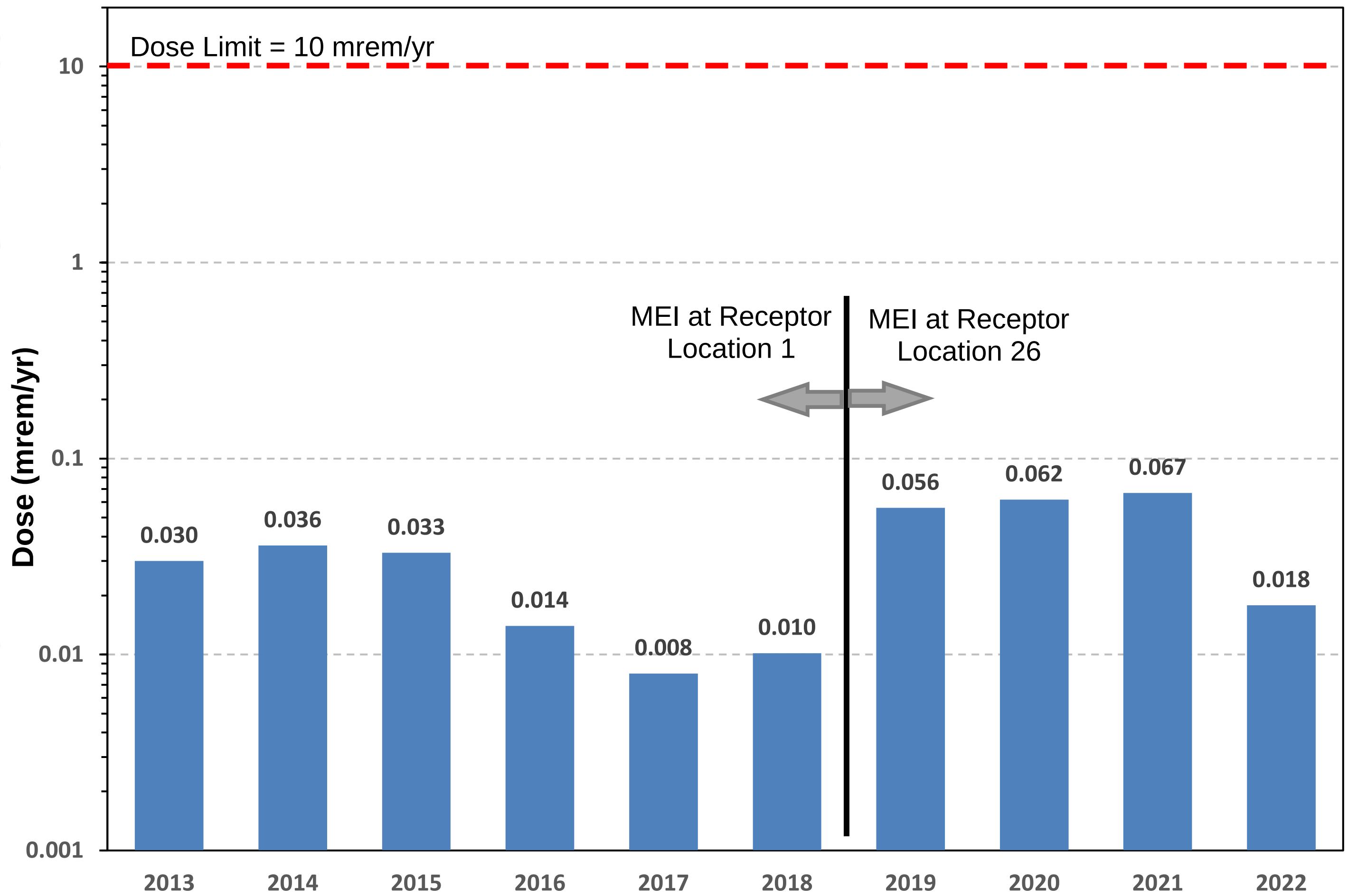

Figure 8-2. MEI dose from INL Site airborne releases estimated for 2013–2022. *See Figure 8-1 for INL Site receptor locations.*

Although noble gases were the radionuclides that were released in the largest quantities in 2022, they accounted for less than 3.5% of the cumulative MEI dose from all pathways largely because of their relatively short half-lives and because they only affect the immersion dose (i.e., they are excluded from the food supply). For example, about 26% of the total INL activity released was argon-41 (^{41}Ar) as shown in Table 4-2 of Chapter 4, yet ^{41}Ar accounted for less than 2% of the estimated MEI dose. In contrast, radionuclides typically associated with airborne particulates, such as ^{241}Am, ^{238}U, ^{234}U, and ^{36}Cl, comprised only a small fraction (e.g., less than 0.04%) of the total amount of radionuclides reported to be released in Table 4-2 of Chapter 4, yet the radionuclides resulted in approximately 82.11% of the estimated MEI dose, as shown in Figure 8-3. Uranium-234 and ^{238}U are isotopes of natural uranium with half-lives of 245,500 years and 4.5 billion years, respectively. During decay, both isotopes emit alpha particles which are less penetrating than other forms of radiation, and ^{238}U emits a weak gamma ray. As long as it remains outside the body, uranium poses a small health hazard, mostly from gamma-rays. If inhaled or ingested, the radioactivity poses increased risks of cancer due to alpha particle emissions. Chlorine-36 also has a very long half-life that decays by emitting a relatively low-energy beta particle and a small amount of gamma radiation that poses a hazard only if ingested. Americium-241 has a half-life of 432.2 years and is a strong alpha emitter; ingestion and inhalation of ^{241}Am being the pathways of greatest concern.

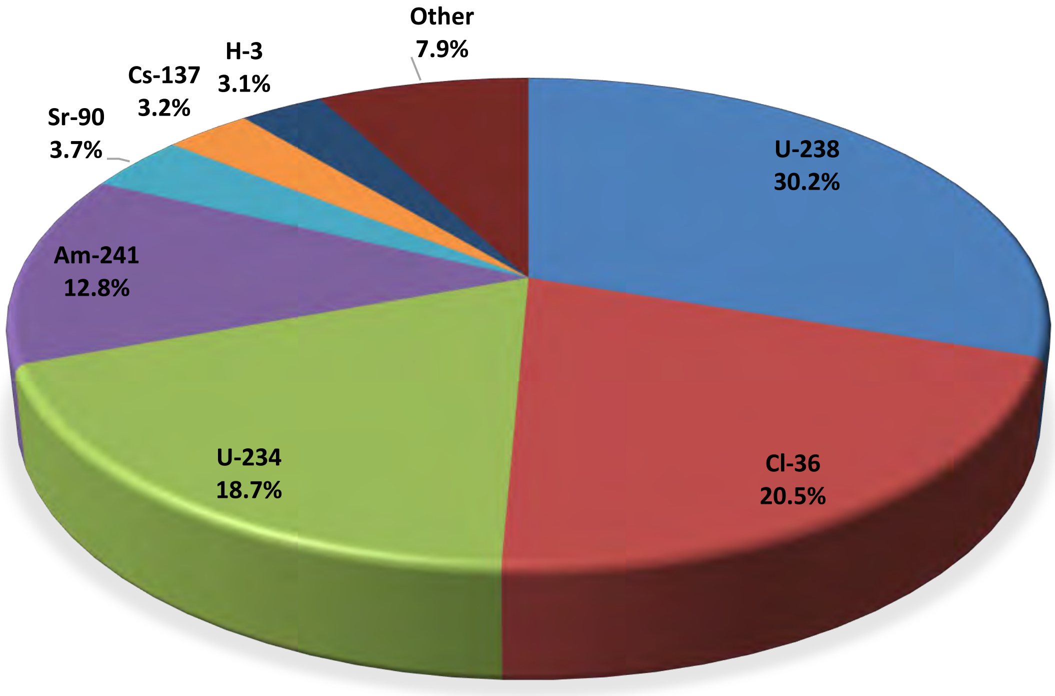

Figure 8-3. Radionuclides contributing to dose to MEI from INL Site airborne effluents as calculated using the CAP88-PC Model (2022).

Primary sources of the major radionuclides used to estimate the dose to the MEI, identified in Figure 8-3 were identified during the preparation of the annual NESHAP report (DOE-ID 2023) as follows:

- ^{238}U and ^{234}U account for 30.2% and 18.7% of the MEI dose, respectively; the majority of which came from the Electron Microscopy Laboratory (MFC-774) at MFC.
- The second largest dose contribution was from ^{36}Cl (20.5%), most of which originated at the Electron Microscopy Laboratory (MFC-774) at MFC.
- ^{241}Am contributed 12.8% to the MEI dose, which primarily came from MFC's Experimental Fuels Facility-West (MFC-794-002).
- Tritium accounts for 3.1% of the MEI dose with 96.1% coming from the RWMC Beryllium Blocks, 1.3% coming from the Warm Waste Evaporation Pond, 0.5% from the ATR stack, and the rest from other sources.
- ^{90}Sr and ^{137}Cs contributed 3.7% and 3.2%, respectively. The remaining 7.9% came from other radionuclides.

The largest contribution by facility to the MEI dose overwhelmingly came from MFC at 70.37%, followed by the RWMC at 15.23%, and the ATR Complex at 3.14% as shown in Figure 8-4. This is expected for location 26 given the proximity to MFC. Additionally, primary wind directions at the INL Site are from the southwest and northeast; thus, emissions from Test Area North, the Naval Reactors Facility, INTEC, ATR Complex, and RWMC are off axis from a receptor near MFC.

The dose to the MEI is lower than in 2021 at 0.018 mrem/year, which is far below the regulatory standard of 10 mrem/yr (0.1 mSv/yr) (40 CFR 61, Subpart H).

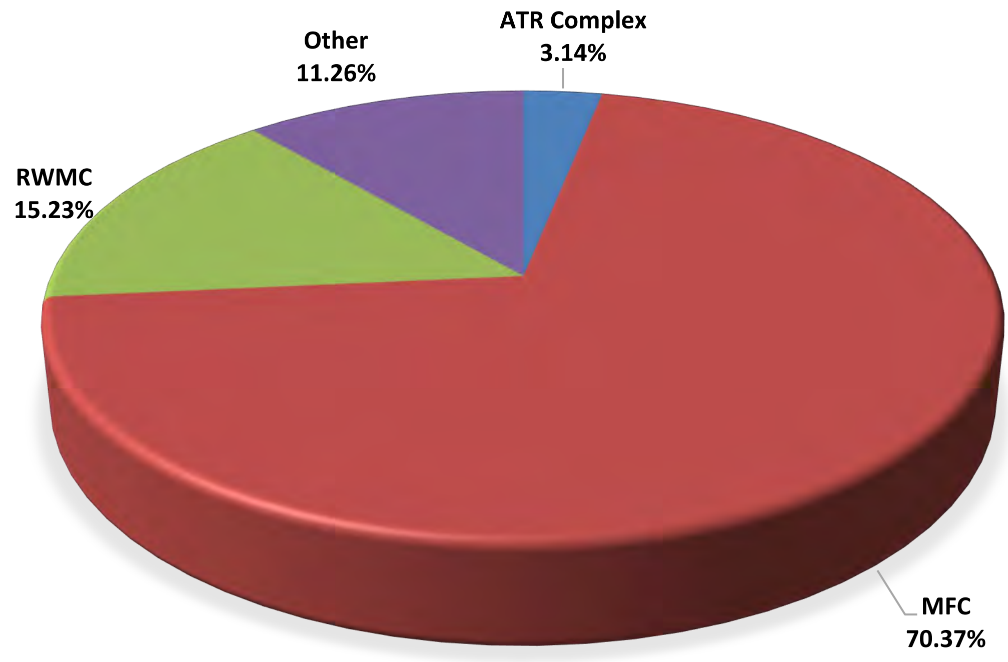

Figure 8-4. Percent contributions, by facility, to MEI dose from the INL Site airborne effluents as calculated using the CAP88-PC Model (2022).

8.2.2 Eighty Kilometer (50 Mile) Population Dose

The total effective population dose from airborne releases was calculated using air dispersion modeling performed by the NOAA Air Research Laboratory Special Operations and Research Division using their HYSPLIT model (Stein et al. 2015; Draxler et al. 2013), and the DOSEMM v 190926 (Rood 2019) dose assessment model. The HYSPLIT model and its capabilities are described on the NOAA Air Resources Laboratory website (see https://www.arl.noaa.gov/hysplit/).

The objective of these calculations was to provide a grid of total effective dose across a model domain that encompasses an 80-km (50-mi) radius from any INL Site source, as observed in Figure 8-5. In addition to INL Site sources, releases from the Idaho Falls facilities located at the INL Research Center (IRC) within Idaho Falls city limits were also included. These data were then used with geographical information system software to compute population dose.

The radionuclide source term for facilities that contributed significantly to the annual dose were the same as those used by the CAP88-PC (EPA 2020) modeling performed for the annual NESHAP report (DOE-ID 2022). These sources and radionuclides were included in the HYSPLIT/DOSEMM modeling. Radionuclides and facilities that yielded greater than 0.01% of the total dose at the location of the INL Site MEI were selected to be modeled, as observed in Tables 8-2 and 8-3. For Idaho Falls facilities, radionuclides that result in a dose greater than 0.1% of the total dose at the MEI in Idaho Falls, Idaho, were included. The radionuclide source term used for the Idaho Falls facilities modeling is shown in Table 8-4.

During 2022, the NOAA Air Resources Laboratory Special Operations and Research Division continuously gathered meteorological data at 34 meteorological stations on and around the INL Site (see *Meteorological Monitoring*, a supplement to this Annual Site Environmental Report). The transport and dispersion of contaminants by winds and deposition onto the ground was projected by the HYSPLIT model using hourly averaged observations from the meteorological stations throughout 2022 together with regional topography. The model predicted dispersion and deposition resulting from releases from each facility at each of 17,877 grid points projected on and around the INL Site.

The Cartesian grid was designed to encompass the region within 80 km (50 mi) of INL Site facilities, as shown in Figure 8-5. In addition, 27 boundary receptor locations, representing actual residences around the INL Site, were included in the modeling. These 27 receptor locations are a subset of the 62 receptor locations used for the NESHAP evaluation.

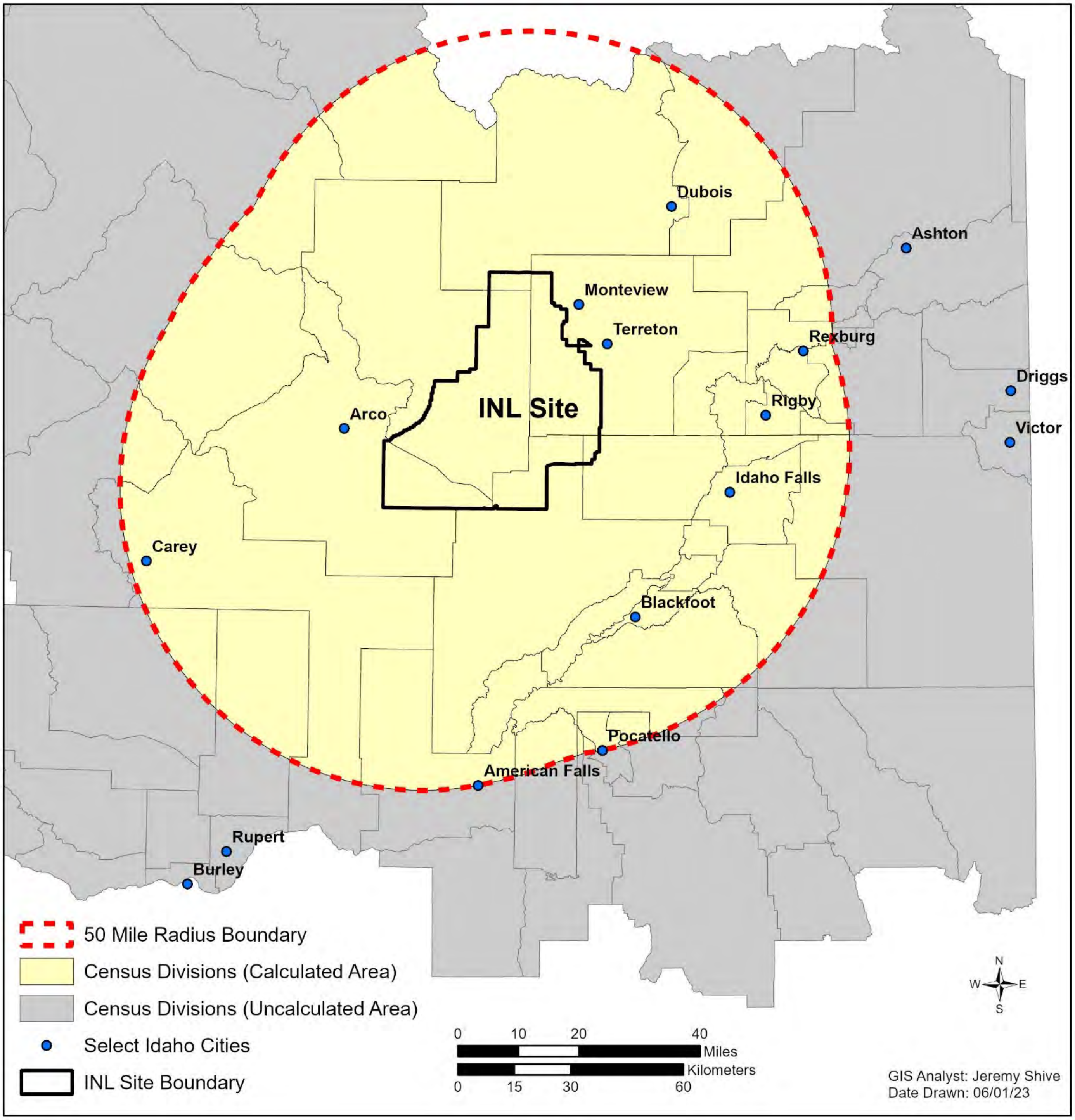

Figure 8-5. Region within 80 km (50 miles) of INL Site facilities. *Census divisions used in the 50-mile population dose calculation are shown.*

Table 8-2. Particulate radionuclide source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.01% of the total dose for INL Site facilities at the MEI location (2023).

RADIONCULIDE	ATRC[a]	ATRC-ATR[a]	ATRC-MTR[a]	CFA[a]	INTEC[a]	INTEC-MS[a]	MFC[a]	MFC-MS[a]	MFC-TREAT[a]	NRF[a]	RRTR[a]	RWMC[a]	SMC[a]	TAN[a]	TOTAL (Ci yr^{-1})[b]
Americium-241	2.19E-05	—[c]	—	—	—	5.79E-04	—	2.11E-03	—	—	—	—	1.03E-04	—	2.81E-03
Bromine-82	—	—	—	—	—	—	—	—	—	—	—	6.02E+00	—	—	6.02E+00
Cadmium-109	—	—	—	—	—	—	—	5.28E-03	—	—	—	—	—	—	5.28E-03
Californium-252	—	—	—	—	—	—	—	5.00E-05	—	—	—	—	—	—	5.00E-05
Cesium-134	—	—	—	—	—	—	—	6.31E-05	—	—	—	—	—	—	6.31E-05
Cesium-137	5.35E-03	—	—	—	—	3.39E-04	—	3.55E-03	—	—	—	—	—	—	9.24E-03
Chlorine-36	—	—	—	—	—	—	—	7.17E-03	—	—	—	—	—	—	7.17E-03
Cobalt-60	6.31E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	6.31E-03
Copper-64	—	—	—	—	—	—	—	—	—	—	—	2.70E+01	—	—	2.70E+01
Plutonium-239	—	—	—	—	—	2.14E-04	—	—	—	—	—	—	3.75E-05	—	2.52E-04
Plutonium-240	—	—	—	—	—	2.14E-04	—	—	—	—	—	—	8.61E-06	—	2.23E-04
Stronium-90	2.75E-02	—	—	—	—	2.99E-03	—	1.97E-03	—	—	—	—	—	—	3.24E-02
Tellurium-129	—	—	—	—	—	—	—	2.71E+01	—	—	—	—	—	—	2.71E+01
Tellurium-129m	—	—	—	—	—	—	—	3.93E-02	—	—	—	—	—	—	3.93E-02
Uranium-234	—	—	—	—	—	—	—	4.32E-02	—	—	—	—	—	—	4.32E-02
Uranium-235	—	—	—	—	—	—	—	2.44E-03	—	—	—	—	—	—	2.44E-03
Uranium-238	—	—	—	—	—	—	—	5.98E-02	—	—	—	—	—	—	5.98E-02

a. ATRC = Advanced Test Reactor Complex, ATRC-ATR = Advanced Test Reactor Complex-Advanced Test Reactor, ATRC-MTR = Advanced Test Reactor Complex-Material Test Reactor, CFA = Central Facilities Area, INTEC = Idaho Nuclear Technology and Engineering Center, INTEC-MS = Idaho Nuclear Technology and Engineering Center-Main Stack, MFC = Materials and Fuels Complex, MFC-MS = Materials and Fuels Complex-Main Stack, MFC-TREAT = Materials and Fuels Complex-Transient Reactor Test Facility, NRF = Naval Reactors Facility, RRTR = Radiological Response Test Range, RWMC = Radioactive Waste Management Complex (including Advanced Mixed Waste Treatment Project), SMC = Specific Manufacturing Capability, TAN = Test Area North (including Technical Support Facility).

b. Total curies may be less than the originally reported amounts due to changes in total activity associated with conversion from short-lived radionuclides into progeny with half-lives long enough to be modeled and for dose to be calculated.

c. A long dash signifies no emissions reported in 2022.

Table 8-3. Noble gases, iodine, tritium and carbon-14 source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.01% of the total dose for INL Site facilities at the MEI location (2023).

RADIONUCLIDE	ATRC[a]	ATRC-ATR[a]	ATRC-MTR[a]	CFA[a]	INTEC[a]	INTEC-MS[a]	MFC[a]	MFC-TREAT[a]	NRF[a]	RWMC[a]	SMC[a]	TAN[a]	TOTAL (Ci yr^{-1})[b]
Argon-41	—[c]	—	—	—	—	—	—	—	—	8.19E+01	—	—	8.19E+01
Carbon-14	—	—	—	—	—	—	—	—	—	—	3.20E-01	—	3.42E-01
Hydrogen-3	3.14E+00	6.74E+00	—	5.39E-01	—	—	—	3.82E-01	—	—	—	—	5.92E+01
Krypton-85m	—	—	—	—	—	—	—	—	—	1.01E+01	—	—	1.01E+01
Krypton-87	—	—	—	—	—	—	—	—	—	1.06E+01	—	—	1.06E+01
Krypton-88	—	—	—	—	—	—	—	—	—	9.63E+00	—	—	9.64E+00
Krypton-89	—	—	—	—	—	—	—	—	—	3.47E+01	—	—	3.47E+01
Iodine-129	—	—	—	—	—	—	—	4.94E-05	—	—	—	—	1.38E-04
Iodine-131	—	—	—	—	—	—	—	8.93E-02	—	—	—	—	8.93E-02
Xenon-135	—	—	—	—	—	—	—	—	—	2.65E+00	—	—	2.80E+00
Xenon-138	—	—	—	—	—	—	—	—	—	1.64E+01	—	—	1.64E+01

a. ATRC = Advanced Test Reactor Complex, ATRC-ATR = Advanced Test Reactor Complex-Advanced Test Reactor, ATRC-MTR = Advanced Test Reactor Complex-Material Test Reactor, CFA = Central Facilities Area, INTEC = Idaho Nuclear Technology and Engineering Center, INTEC-MS = Idaho Nuclear Technology and Engineering Center-Main Stack, MFC = Materials and Fuels Complex, MFC-TREAT = Materials and Fuels Complex-Transient Reactor Test Facility, NRF = Naval Reactors Facility, RRTR = Radiological Response Training Range, RWMC = Radioactive Waste Management Complex (including Advanced Mixed Waste Treatment Project), SMC = Specific Manufacturing Capability, TAN = Test Area North (including Technical Support Facility).

b. Total curies may be less than the originally reported amounts due to changes in total activity associated with conversion from short-lived radionuclides into progeny with half-lives long enough to be modeled and for dose to be calculated.

c. A long dash signifies no emissions reported in 2022.

Table 8-4. Radionuclide source term (Ci yr^{-1}) for radionuclides that contributed greater than 0.1% of the total dose for INL in-town facilities (2022).

RADIONUCLIDE	IF-603[a]	IF-683 (RESL)[a]	ANNUAL RELEASE (Ci yr^{-1})
Actinium-227	—[b]	5.23E-12	5.23E-12
Americium-241	—	1.04E-10	1.04E-10
Americium-243	—	2.09E-12	2.09E-12
Barium-133	—	3.36E-10	3.36E-10
Cobalt-60	3.90E-13	3.92E-11	3.96E-11
Cesium-134	—	1.76E-11	1.76E-11
Cesium-137	—	7.54E-11	7.54E-11
Europium-152	—	4.26E-11	4.26E-11
Europium-154	—	1.73E-10	1.73E-10
Lead-210	—	2.24E-11	2.24E-11
Neptunium-237	—	6.48E-12	6.48E-12
Protactinium-231	—	1.15E-12	1.15E-12
Plutonium-238	—	7.77E-11	7.77E-11
Plutonium-239	—	1.32E-10	1.32E-10
Radium-226	—	7.52E-11	7.52E-11
Sodium-22	—	9.14E-11	9.14E-11
Strontium-90	—	6.87E-11	6.87E-11
Uranium-232	—	3.15E-11	3.15E-11
Uranium-233	—	1.64E-10	1.64E-10
Xenon-133	6.57E-01	—	6.57E-01

a. IF-683 = Radiological and Environmental Sciences Laboratory (RESL) and IF-603 = INL Research Complex Laboratory (IRC-L).
b. A long dash signifies no emissions reported in 2022.

Outputs from the NOAA HYSPLIT model were radionuclide air concentrations and deposition amounts for a unit release (1 Ci/s) for each significant INL Site source calculated at 17,877 grid nodes across the model domain. These values were converted to dispersion and deposition factors for use in DOSEMM (Rood 2019).

The dispersion factor, often referred to as the X/Q value (concentration divided by source), was calculated by dividing the concentration in the air (Ci/m^3) by the unit release rate (1 Ci/s) resulting in dispersion factor units of s/m^3. The deposition factor was calculated by dividing the total deposition (Ci/m^2) by the release time (seconds), then dividing that total by the unit release rate (1 Ci/s) to yield deposition factors in units in 1/m^2. Dispersion and deposition factors were calculated for each month of the year and were read into DOSEMM along with the annual radionuclide release rates from each source. Although annual release quantities were provided, monthly release quantities could have been used if available to account for seasonal variations in atmospheric dispersion.

Using DOSEMM, the actual estimated radionuclide emission rate (Ci/s) for each radionuclide and each facility was multiplied by the air dispersion and deposition factors that were calculated by HYSPLIT to yield an air concentration (Ci/m^3) and deposition (Ci/m^2) at each of the grid points over the time of interest (in this case, one year). The products were then used to calculate the effective dose (mrem) via inhalation, ingestion, and external exposure pathways at each grid point and at each boundary receptor location using the methodology described in Rood (2019).

Figure 8-6 displays the summation of the doses calculated from the modeling of all releases from the facilities (including INL in-town facilities) as isopleths, ranging in value from 0.0008 to 0.8 mrem (0.008 to 8 µSv). The highest dose to an INL Site boundary receptor was estimated to be 0.00349 mrem (0.0349 µSv) at a farmhouse and cattle operation (Receptor location 26, which is the same Receptor location in Figure 8-1). The farmhouse and cattle operation are also the location of the MEI used for the NESHAP dose assessment in 2022, which reported an estimated dose of 0.018 mrem (0.18 µSv) to the MEI (see Section 8.2.1). The lower dose of the HYSPLIT/DOSEMM model are attributed to the generally lower HYSPLIT dispersion factors when compared to those from CAP88-PC and to the one-year buildup time in soil in DOSEMM for external exposure compared to 100-year buildup time in CAP88-PC (Rood 2022). The HYSPLIT dispersion factors reflect differences in plume trajectory, turbulent diffusion, terrain complexities, plume depletion, and sector averaging between the HYSPLIT and CAP88-PC models.

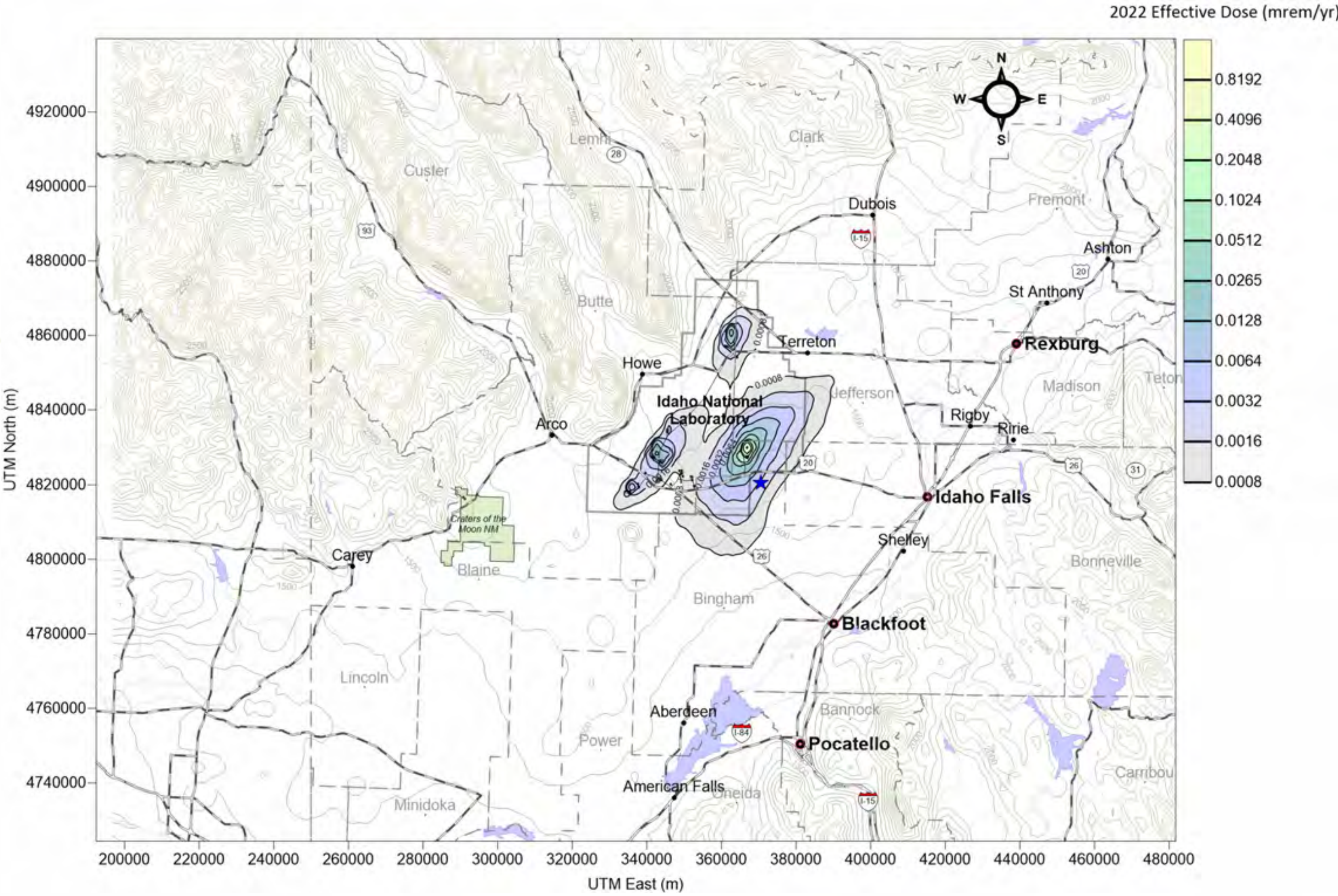

Figure 8-6. Effective dose (mrem) isopleth map with boundary receptor locations displayed (2022). *The maximum receptor dose is projected at Receptor 6, which is a farmhouse and cattle operation, as depicted as a blue star east of the INL east entrance. This is the same location as Receptor 54 in Figure 8-1.*

To calculate the 80 km (50 mi) population dose, the number of people living in each census division was first estimated with data from the 2020 census and extrapolated to 2022. The extrapolation of the population for each census division was performed by calculating the change in the population during the last ten-year period between censuses (i.e., 2010–2020), then the result was divided by ten to yield the rate of change per year. The rate of change per year was adjusted for the 2022 time period and applied to the 2020 population to estimate the number of people living in each census division. The next step involved the use of the geographic information system. The grid and dose values from DOSEMM were imported into the geographic information system. The doses within each census division were averaged and multiplied by the population within each of the divisions or division portions within the 80 km (50 mi) area defined in Figure 8-5. These doses were then summed over all census divisions to obtain the 80 km (50 mi) population dose. The estimated potential population dose was 1.91 $\times 10^{-2}$ person-rem (1.91 $\times 10^{-4}$ person-Sv) to a population of approximately 349,242. When compared with the approximate population dose of 134,109 person-rem (e.g., 1,341 person-Sv) estimated to be received from natural background radiation, as observed in Table 8-5, this represents an increase of about 0.00001 percent.

The estimated population dose for 2022 is lower than that calculated for 2021 (2.85 x 10^{-2} person-rem).

Table 8-5. Contribution to estimated annual dose from INL Site facilities by pathway (2022).

PATHWAY	ANNUAL DOSE TO MEI		PERCENT OF DOE 100 mrem/yr LIMIT[a]	ESTIMATED POPULATION DOSE		POPULATION WITHIN 80 km	ESTIMATED BACKGROUND RADIATION POPULATION DOSE (PERSON-rem)[b]
	(mrem)	(µSv)		(PERSON-rem)	(PERSON-Sv)		
Air	0.018	0.18	0.018	0.019	0.00019	349,242	134,109
Waterfowl	0.0009	0.009	0.0009	NA[c]	NA	NA	NA
Big Game Animals	0.000	0.00	NA	NA	NA	NA	NA
TOTAL, ALL PATHWAYS	**0.019**	**0.19**	**0.019**	**0.019**	**0.00019**	**NA**	**NA**

a. The DOE public dose limit from all sources of ionizing radiation and exposure pathways that could contribute significantly to the total dose is 100 mrem/yr (1 mSv/yr) total effective dose equivalent. It does not include dose from background radiation.

b. The individual background dose was estimated to be 384 mrem or 0.384 rem in 2022, as shown previously in Table 7-8. The background population dose is calculated by multiplying the individual background dose by the population within 80 km (50 mi) of the INL Site.

c. NA = Not applicable.

8.3 Dose to the Public from Ingestion of Wild Game from the INL Site

The potential dose that an individual may receive from occasionally ingesting meat from game animals continues to be studied at the INL Site. These studies estimate the potential dose to individuals who may eat waterfowl that may briefly reside at wastewater disposal ponds at the ATR Complex and MFC and game animals that may reside on or migrate through the INL Site.

8.3.1 Waterfowl

The maximum potential dose of 0.0009 mrem (0.009 µSv) calculated for an individual consuming contaminated waterfowl based on 2022 sample results is lower than the dose estimated for 2021 (0.002 mrem [0.02 µSv]). As in the past, the 2022 samples were not collected directly from the warm wastewater evaporation ponds at the ATR Complex but from sewage lagoons adjacent to them. The dose calculation assumes the waterfowl resided at all the ponds while they were in the area.

8.3.2 Big Game Animals

A study on the INL Site from 1972–1976 conservatively estimated the potential whole-body dose that could be received from an individual eating the entire muscle (27,000 g [952 oz]) and liver mass (500 g [17.6 oz]) of an antelope with the highest levels of radioactivity found in these animals. This dose was 2.7 mrem (27 µSv) (Markham et al. 1982). Game animals collected at the INL Site during the past few years have generally shown much lower concentrations of radionuclides. In 2022, none of the game samples collected (e.g., four elk and one pronghorn) had a detectable concentration of ^{137}Cs or other human-made radionuclides. Therefore, no dose from human-made radionuclides would be associated with the consumption of these animals.

The contribution of game animal consumption to the population dose is calculated because only a limited percentage of the population hunts game, few animals killed have spent time on the INL Site, and most of the animals that migrate from the INL Site would have reduced concentrations of radionuclides in their tissues by the time they were harvested (Halford, Markham, and White 1983). The total population dose contribution from these pathways would realistically be less than the sum of the population doses from the inhalation of air, submersion in air, ingestion of vegetables, and deposition on soil.

8.4 Dose to the Public from Drinking Groundwater from the INL Site

Tritium has previously been detected in three U.S. Geological Survey monitoring wells located on the INL Site along the southern boundary (Mann and Cecil 1990; Bartholomay, Hopkins, and Maimer 2015; Twining et al. 2021). These wells, located in an uninhabited area, have shown a historical downward trend in tritium detections. The maximum concentration from all the wells on the INL Site (3,970 ± 130 pCi/L) in 2022 is considerably less than the maximum contaminant level established by EPA for drinking water (20,000 pCi/L). An individual drinking water from a well with the maximum concentration would hypothetically receive a dose of 0.184 mrem (0.00184 mSv) in one year. Because these wells are not used for drinking water, this is an unrealistic scenario, and the groundwater ingestion pathway is not included in the total dose estimate to the MEI.

8.5 Dose to the Public from Direct Radiation Exposure along INL Site Borders

The direct radiation exposure pathway from gamma radiation to the public is monitored annually using thermoluminescent dosimeters and optically stimulated luminescent dosimeters, as previously shown in Figure 7-4.

In 2022, the external radiation measured along the INL Site boundary was statistically equivalent to that of background radiation and, therefore, does not represent a dose resulting from INL Site operations.

8.6 Dose to the Public from All Pathways

DOE O 458.1 establishes a radiation dose limit to a member of the general public from all possible pathways as a result of DOE facility operations. This limit is 100 mrem/yr (1 mSv/yr) above the dose from background radiation and includes the air transport, ingestion, and direct exposure pathways (Figure 8-7). For 2022, the only probable pathways from INL Site activities to a realistic MEI include the air transport pathway and ingestion of game animals.

The hypothetical individual, assumed to live at a farmhouse and cattle operation located 3.1 km south of Highway 20, and 3 km from INL Site's east entrance presented in Figures 8-1 and Figure 8-6, would receive a calculated dose from INL Site airborne releases reported for 2022 (Section 8.2.1) and from consuming a duck contaminated by the ATR Complex wastewater ponds (Section 8.3.1). No dose was calculated from eating big game animals in 2022 (Section 8.3.2).

The dose estimate for an offsite MEI is presented in Table 8-5. The total all-pathways dose was conservatively estimated to be 0.019 mrem (0.19 μSv) for 2022. This represents about 0.005 percent of the annual dose expected to be received from background radiation (384 mrem [3.8 mSv], as shown in Table 7-7) and is well below the 100 mrem/yr (1 mSv/yr) public dose limit above the background radiation dose established by DOE. As discussed in the Helpful Information section of this report, the 100 mrem/yr limit is far below the exposure levels expected to result in acute health effects.

The dose received by the entire population within 80 km (50 mi) of INL Site facilities was calculated to be 1.91×10^{-2} person-rem (1.91×10^{-4} person-Sv), as identified in Table 8-5. This is approximately 0.00001 percent of the dose (134,109 person-rem, [1,341 person-Sv], Table 8-5) expected from exposure to natural background radiation in the region.

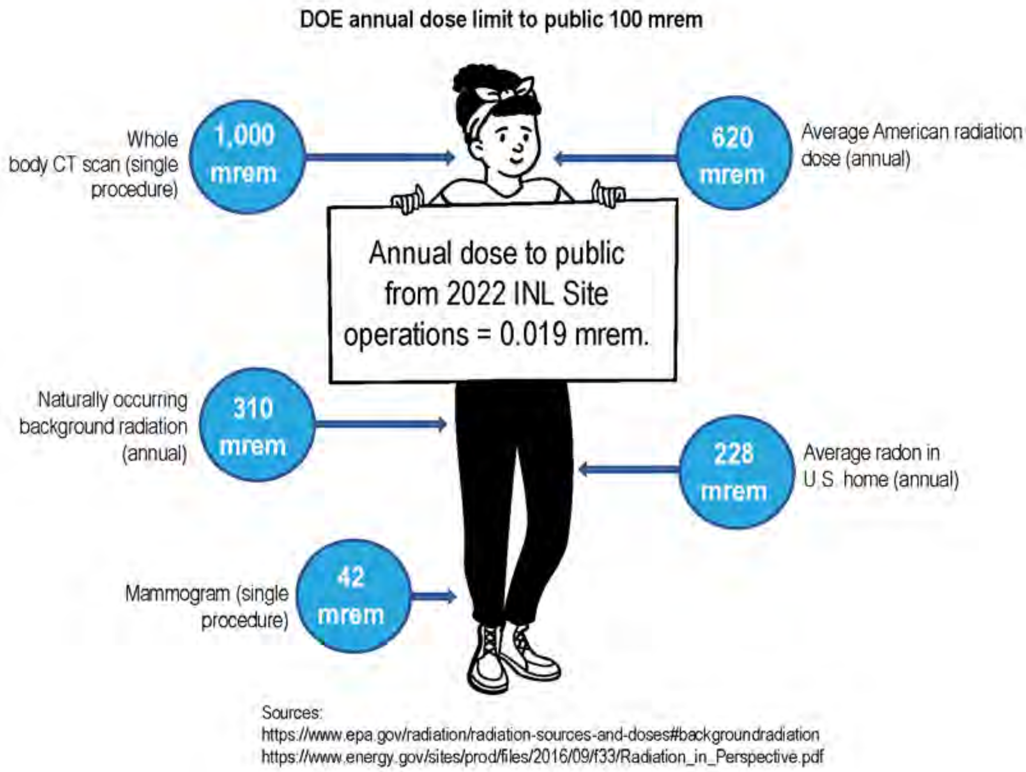

Figure 8-7. Radiation doses associated with some common sources.

8.7 Dose to the Public from Operations on the INL Research and Education Campus

Facilities in Idaho Falls that reported potential radionuclide emissions for inclusion in the 2022 NESHAP report include the IRC Laboratory (IF-603), DOE Radiological and Environmental Sciences Laboratory (RESL, IF-683), and the National Security Laboratory (IF-611). However, due to software limitations, releases from IF-603 and IF-611 were modeled as collocated releases from IF-603. These facilities are located contiguously at the IRC, which is part of the Research and Education Campus on the north side of the city of Idaho Falls. Though programs and operations at the IRC are affiliated with INL, the IRC is located within the city limits of Idaho Falls and is not contiguous with the INL Site. The nearest boundary of the INL Site is approximately 35 km (22 mi) west of Idaho Falls. For this reason, the 2022 INL NESHAP evaluation (DOE-ID 2023) includes a dose calculation to a member of the public that is separate from the INL Site MEI. (Note: The Research and Education Campus source term was, however, included in the population dose calculation reported in Section 8.2.2.) The IRC MEI for calendar year 2022 is approximately 323 meters north of IF-683. The effective dose equivalent to the MEI was conservatively calculated, using CAP88-PC, to be 0.004 mrem/yr (0.040 μSv/yr), which is less than 0.1 percent of the 10-mrem/yr federal standard.

8.8 Dose to Biota

8.8.1 Introduction

The impact of environmental radioactivity at the INL Site on nonhuman biota was assessed using *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2019) and the associated software, RESRAD-Biota 1.8 (DOE 2019). The graded approach includes a screening method and three more detailed levels of analysis for demonstrating compliance with standards for the protection of biota. The threshold of protection is assumed at the following absorbed doses: 1 rad/d (10 mGy/d) for aquatic animals, 0.1 rad/d (1 mGy/d) for terrestrial animals, and 1 rad/d (10 mGy/d) for terrestrial plants.

The first step in the graded approach uses conservative default assumptions and maximum values for all currently available data. This general screening level (Level 1 in RESRAD-Biota) provides generic limiting concentrations of radionuclides in environmental media, termed “Biota Concentration Guides.” Each biota concentration guide is the environmental concentration of a given radionuclide in soil or water that, under the assumptions of the model, would result in a dose rate of less than 1 rad/d (10 mGy/d) to aquatic animals or terrestrial plants or of 0.1 rad/d (1 mGy/d) to terrestrial animals. If the sum of the measured maximum environmental concentrations divided by the biota concentration guides (i.e., the combined sum of fractions) is less than one, no negative impact to plant or animal populations is expected. Doses are not calculated unless the screening process indicates a more detailed analysis is necessary. Failure at this initial screening step does not necessarily imply harm to organism populations. Instead, it is an indication that more realistic model assumptions may be necessary.

If the screening process indicates the need for a more site-specific analysis, an analysis is performed using site-representative parameters (e.g., distribution coefficients, bioconcentration factors) instead of the more conservative default parameters. This is Level 2 in RESRAD-Biota.

The next step in the graded approach methodology involves a site-specific analysis employing a kinetic modeling tool provided in RESRAD-Biota (Level 3). Multiple parameters that represent contributions to the organism internal dose (e.g., body mass, consumption rate of food/soil, inhalation rate, lifespan, biological elimination rates) can be modified to represent site- and organism-specific characteristics. The kinetic model employs equations relating body mass to internal dose parameters. At Level 3, bioaccumulation (the process by which biota concentrate contaminants from the surrounding environment) can be modeled to estimate the dose to a plant or animal. Alternatively, concentrations of radionuclides measured in the tissue of an organism can be input into RESRAD-Biota to estimate the dose to the organism.

The final step in the graded approach involves an actual site-specific biota dose assessment. This would include a problem formulation, analysis, and risk characterization protocol similar to that recommended by the EPA (1998). RESRAD-Biota cannot perform these calculations.

8.8.2 Terrestrial Evaluation

The division of the INL Site into evaluation areas based on potential soil contamination and habitat types is of particular importance for the terrestrial evaluation portion of the 2022 biota dose assessment. For the INL Site, it is appropriate to consider specific areas that have been historically contaminated above background levels. Most of these areas have been monitored for radionuclides in soil since the early 1970s (Jessmore, Lopez, and Haney 1994). In some of these areas, structures have been removed and areas cleaned to a prescribed, safe contamination level, but the soil may still have residual, measurable concentrations of radionuclides. These areas are associated with the facilities shown in Figure 1-4 and include the following:

- Auxiliary Reactor Area
- ATR Complex
- Critical Infrastructure Test Range Complex
- INTEC
- Large Grid, a 24-mile radius around INTEC
- MFC
- Naval Reactors Facility
- RWMC
- Test Area North.

For the initial terrestrial evaluation, the most recently measured maximum concentrations of radionuclides in INL Site soil were used, as discussed in Table 8-6. The table includes laboratory analyses of soil samples collected in 2005, 2006, 2012, 2015, 2022 (soil samples were not collected on the INL Site in 2016, 2018, 2019, 2020, or 2021).

Using the maximum radionuclide concentrations for all locations in Table 8-6, a screening level analysis was made of the potential terrestrial biota dose. The soil concentrations are conservative because background concentrations were not subtracted. The analysis also assumed that animals have access to water in facility effluents and ponds. The maximum radionuclide concentrations reported in ponds at the INL Site were for the MFC Industrial Waste Pond presented in Table A-17. The results for uranium-233/234 ($^{233/234}U$) and ^{238}U in Table A-17 (in Appendix A), 0.273 pCi/L and 0.241 pCi/ respectively, were used to represent surface water concentrations. When $^{233/234}U$ was reported, it was assumed that the radionuclide present was ^{233}U since doses due to ingestion and inhalation are more conservative for ^{233}U than for ^{234}U (EPA 2002).

The combined sum of fractions was less than one for both terrestrial animals (0.21) and plants (0.002) and passed the general screening test, as pointed out in Table 8-7. Based on the results of the graded approach, there is no evidence that INL Site-related radioactivity in soil is harming terrestrial plant or animal populations.

Tissue data from bats collected at or near INL facilities were also available and were previously presented in Table 7-4 (in Chapter 7). Concentrations of radionuclides in tissue were input into the RESRAD-Biota computer model at the Level 3 step to calculate the internal dose to bats. The results of the dose evaluation to bats using radionuclide concentrations measured in their tissue are shown in Table 8-8. The maximum dose received by bats at the INL Site was estimated to be 0.0006 rad/d (0.006 mGy/d) in 2022. The calculated doses are well below the threshold of 1 rad/d (10 mGy/d). Based on these results, members of the bat population at the INL Site receive an absorbed dose that is within the DOE standard established for the protection of terrestrial animals.

8.8.3 Aquatic Evaluation

Maximum radionuclide concentrations reported in Table A-17 of Appendix A (results for the MFC Industrial Waste Pond) were also used for aquatic evaluation. Potassium-40 reported in ponds was assumed to be of natural origin and was not included in the 2022 calculations. The results shown in Table 8-9 indicate that INL Site-related radioactivity in ponds and liquid effluents is not harming aquatic biota. The combined sum of fractions was less than one for both aquatic animals (0.002) and riparian animals (0.0007).

Table 8-6. Concentrations of radionuclides in INL Site soils, by area.

LOCATION[a]	RADIONUCLIDE	DETECTED CONCENTRATION (pCi/g)[b]	
		MINIMUM	MAXIMUM
ARA/CITRC	Cesium-134	4.0E-02	6.0E-02
	Cesium-137	1.3E-01	3.0
	Strontium-90	2.1E-01	3.7E-01
	Plutonium-238	—[c]	3.9E-03
	Plutonium-239/240	1.3E-02	1.8E-02
	Americium-241	5.5E-03	8.5E-03
ATR Complex	Cesium-137	2.0E-1	6.1E-01
	Strontium-90	—	5.8E-02
	Plutonium-238	5.9E-03	4.3E-02
	Plutonium-239/240	1.7E-02	2.2E-02
EFS	Cesium-137	1.7E-01	6.2E-01
	Strontium-90	—	2.1E-01
	Plutonium-239/240	—	1.9E-02
INTEC	Cesium-134	—	8.0E-02
	Cesium-137	3.0E-02	3.5
	Strontium-90	4.9E-01	7.1E-01
	Plutonium-238	2.5E-02	4.3E-02
	Plutonium-239/240	1.1E-02	2.9E-02
	Americium-241	6.1E-03	8.1E-03
MFC	Cesium-134	4.0E-02	6.0E-02
	Cesium-137	1.3E-01	4.9E-01
	Cobalt-60	—	5.0E-02
	Plutonium-239/240	1.5E-02	2.9E-02
	Americium-241	4.3E-03	1.2E-02
NRF	Cesium-134	—	6.0E-02
	Cesium-137	—	3.3E-01
	Plutonium-239/240	5.7E-03	1.6E-02
	Americium-241	4.3E-03	9.7E-03
Rest Area	Cesium-137	2.3E-01	3.3E-01
	Strontium-90	—	1.1E-01
	Plutonium-239/240	—	2.0E-02
	Americium-241	—	1.3E-02
RWMC	Cesium-137	8.0E-02	6.2E-01
	Strontium-90	5.6E-02	2.3E-01
	Plutonium 238	9.9E-03	2.4E-02

Table 8-6. continued.

LOCATION[a]	RADIONUCLIDE	DETECTED CONCENTRATION (pCi/g)[b]	
		MINIMUM	MAXIMUM
	Cesium-134	—	6.0E-02
	Cesium-137	—	3.3E-01
	Plutonium-239/240	1.6E-02	1.6E+00
	Americium-241	1.4E-02	1.2E+00
TAN/SMC	Cesium-134	4.0E-02	6.0E-02
	Cesium-137	1.1E-01	3.1
	Plutonium-239/240	1.3E-02	1.7E-02
	Americium-241	3.2E-03	5.7E-03
All	Cesium-134	3.0E-02	9.0E-02
	Cesium-137	1.4E-02	3.5
	Cobalt-60	—	5.0E-02
	Strontium-90	1.0E-02	7.1E-01
	Plutonium-238	2.2E-03	4.3E-02
	Plutonium-239/240	5.7E-03	9.5E-01
	Americium-241[d]	3.2E-03	6.2E-01

a. ATR Complex = Advanced Test Reactor Complex, ARA/CITRC = Auxiliary Reactor Area/Critical Infrastructure Test Range Complex, EFS = Experimental Field Station, MFC = Materials and Fuels Complex, INTEC = Idaho Nuclear Technology and Engineering Center, RWMC = Radioactive Waste Management Complex, TAN/SMC = Test Area North/Specific Manufacturing Capability. See Figure 1-4.

b. Legend:

a.	Results measured in 2013–2014 using in situ gamma spectroscopy.
b.	Results measured by laboratory analyses of soil samples collected in 2005.
c.	Results measured by laboratory analyses of soil samples collected in 2006.
d.	Results measured by laboratory analyses of soil samples collected in 2012.
e.	Results measured by laboratory analyses of soil samples collected in 2015.
f.	Results measured by laboratory analyses of soil samples collected in 2022.

c. — indicates that only one measurement was taken and is reported as the maximum result.

d. The data were the results of laboratory analysis for Americium-241 in soil samples.

Table 8-7. RESRAD Biota assessment (screening level) of terrestrial ecosystems on the INL Site (2022).

TERRESTRIAL ANIMAL						
	WATER			SOIL		
NUCLIDE	CONCENTRATION (pCi/l)	BCG[a] (pCi/l)	RATIO	CONCENTRATION (pCi/g)	BCG (pCi/g)	RATIO
Americium-241	—	2.02E+05	—	1.2	3.89E+03	3.08E-04
Cobalt-60	—	1.19E+06	—	0.05	6.92E+02	7.23E-05
Cesium-134	—	3.26E+05	—	0.09	1.13E+01	7.97E-03
Cesium-137	—	5.99E+05	—	3.5	2.08E+01	1.69E-01
Plutonium-238	—	1.89E+05	—	0.043	5.27E+03	8.16E-06
Plutonium-239	—	2.00E+05	—	1.6	6.11E+03	2.62E-04
Strontium-90	—	5.45E+04	—	0.71	2.25E+01	3.16E-02
Uranium-233	0.27	4.01E+05	6.81E-07	—	4.83E+03	—
Uranium-238	0.24	4.06E+05	5.94E-07	—	1.58E+03	—
SUMMED	**—**	**—**	**1.27E-06**	**—**	**—**	**2.09E-01**
TERRESTRIAL PLANT						
	WATER			SOIL		
NUCLIDE	CONCENTRATION (pCi/l)	BCG (pCi/l)	RATIO	CONCENTRATION (pCi/g)	BCG (pCi/g)	RATIO
Americium-241	—	7.04E+08	—	1.2	2.15E+04	5.57E-05
Cobalt-60	—	1.49E+07	—	0.05	6.13E+03	8.16E-06
Cesium-134	—	2.28E+07	—	0.09	1.09E+03	8.28E-05
Cesium-137	—	4.93E+07	—	3.5	2.21E+03	1.59E-03
Plutonium-238	—	3.95E+09	—	0.043	1.75E+04	2.46E-06
Plutonium-239	—	7.04E+09	—	1.6	1.27E+04	1.26E-04
Strontium-90	—	3.52E+07	—	0.71	3.58E+03	1.98E-04
Uranium-233	0.27	1.06E+10	2.58E-11	—	5.23E+04	—
Uranium-238	0.24	4.28E+07	5.62E-09	—	1.57E+04	—
SUMMED	**—**	**—**	**5.65E-09**	**—**	**—**	**2.06E-03**

a. BCG = Biota Concentration Guide. Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium, which would not result in recommended dose standards for biota to be exceeded.

Table 8-8. RESRAD Biota assessment (Level 3 analysis) of terrestrial ecosystems on the INL Site using measured bat tissue data (2022).

BAT DOSE (rad/d)					
NUCLIDE	WATER	SOIL	SEDIMENT	TISSUE[a]	SUMMED
Americium-241	—	2.87E-05	—	2.72E-05	2.87E-05
Cobalt-60	—	—	—	4.78E-05	4.78E-05
Cesium-134	—	1.05E-04	—	9.77E-05	1.05E-04
Cesium-137	—	9.91E-05	—	3.77E-05	1.37E-04
Plutonium-238	—	7.99E-07	—	7.98E-07	7.99E-07
Plutonium-239/240	—	2.57E-05	—	2.57E-05	2.57E-05
Strontium-90	—	4.27E-06	—	4.75E-04	4.80E-04
Uranium-233/234	6.80E-08	—	—	6.80E-08	6.80E-08
Uranium-238	5.35E-08	—	—	5.28E-08	5.35E-08
TOTAL	**1.21E-07**	**2.63E-04**	**—**	**7.12E-04**	**8.24E-04**

a. Calculated using maximum concentrations measured in bat tissues.

Table 8-9. RESRAD Biota assessment (screening level) of aquatic ecosystems on the INL Site (2022).

AQUATIC ANIMAL						
	WATER			SEDIMENT		
NUCLIDE	CONCENTRATION (pCi/l)	BCG[a] (pCi/l)	RATIO	CONCENTRATION (pCi/g)	BCG (pCi/g)	RATIO
Uranium-233	0.27	2.00E+02	1.37E-03	0.014	1.06E+07	1.29E-09
Uranium-238	0.24	2.23E+02	1.08E-03	0.012	4.28E+04	2.81E-07
Summed	**—**	**—**	**2.45E-03**	**—**	**—**	**2.83E-07**
RIPARIAN ANIMAL						
	WATER			SEDIMENT		
NUCLIDE	CONCENTRATION (pCi/l)	BCG (pCi/l)	RATIO	CONCENTRATION (pCi/g)	BCG (pCi/g)	RATIO
Uranium-233	0.27	6.76E+02	4.04E-04	0.014	5.28E+03	2.59E-06
Uranium-238	0.24	7.56E+02	3.19E-04	0.012	2.49E+03	4.84E-06
SUMMED	**—**	**—**	**7.23E-04**	**—**	**—**	**7.43E-06**

a. BCG = Biota Concentration Guide. Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium which would not result in recommended dose standards for biota to be exceeded.

Tissue data from waterfowl collected on the ATR Complex wastewater ponds in 2022 were also available, as shown previously in Table 7-3 of Chapter 7. Concentrations of radionuclides in tissue can be input into the RESRAD-Biota code at the Level 3 step to calculate the internal dose to biota. To confirm that doses to waterfowl from exposure to radionuclides in the vicinity of the ATR Complex are not harmful, a Level 3 analysis was performed using the maximum tissue concentrations from Table 7-3. The waterfowl were assumed in the model to be riparian animals, accessing both aquatic and terrestrial environments in the area. External dose was calculated using the maximum radionuclide concentrations measured in soils around the ATR Complex and uranium concentrations in water. The concentrations of uranium in sediment were estimated by the RESRAD-Biota code from the concentrations in water.

Results of the dose evaluation to waterfowl using radionuclide concentrations measured in tissue are shown in Table 8-10. The estimated dose to waterfowl was calculated by RESRAD-Biota to be 1.72×10^{-4} rad/d (1.72×10^{-2} mGy/d). This dose is significantly less than the standard of 1 rad/d (10 mGy/d). Based on these results, there is no evidence that water held in ponds at the INL Site is harming aquatic biota.

Table 8-10. RESRAD Biota assessment (Level 3 analysis) of aquatic ecosystems on the INL Site using measured waterfowl tissue data (2022).

WATERFOWL DOSE (rad/d)					
NUCLIDE	WATER[a]	SOIL[b]	SEDIMENT	TISSUE[c]	SUMMED
Americium-241	—	8.45E-07	—	—	8.45E-07
Cobalt-60	—	4.97E-06	—	6.20E-07	1.12E-05
Cesium-134	—	5.37E-06	—	—	5.37E-06
Cesium-137	—	7.58E-05	—	—	7.58E-05
Plutonium-238	—	1.76E-10	—	—	1.76E-10
Plutonium-239	—	3.27E-09	—	—	3.27E-09
Strontium-90	—	5.14E-07	—	6.44E-06	6.95E-06
Uranium-233	4.03E-05	NA	2.57E-07	4.06E-05	4.06E-05
Uranium-238	3.13E-05	NA	2.09E-07	3.15E-05	3.15E-05
Zinc-65	—	—	—	3.13E-08	3.13E-08
TOTAL	**7.16E-05**	**8.75E-05**	**4.66E-07**	**8.48E-05**	**1.72E-04**

a. Only uranium isotopes were measured in the Material and Fuels Complex Industrial Waste Pond. Hence, doses were not calculated for other radionuclides in water and sediment.

b. External doses to waterfowl were calculated using soil concentrations. Maximum concentrations of radionuclides measured in soil at the INL Site were used (Table 8-7). Note: NA = uranium isotopes were not analyzed in soil.

c. Internal doses to waterfowl were calculated using maximum concentrations in edible tissue shown in Table 7-3. Note: NA=uranium isotopes were not analyzed for in tissue samples.

8.9 Unplanned Releases

In 2022, the INL Site did not have any events that resulted in emissions exceeding reporting thresholds. All radiological emissions were accounted for in the dose received by the MEI.

8.10 References

40 CFR 61, Subpart H, 2023, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-61/subpart-H.

Bartholomay, R. C., C. B. Hopkins, and N. V. Maimer, 2015, “Chemical Constituents in Groundwater from Multiple Zones in the Eastern Snake River Plain Aquifer, Idaho National Laboratory, Idaho, 2009–13, Scientific Investigations Report 2-15-5002, DOE/ID-22232, U.S. Geological Survey, 120 p., https://pubs.usgs.gov/sir/2015/5002/pdf/sir2015-5002.pdf.

DOE, 2019, “A Graded Approach for Evaluating Doses to Aquatic and Terrestrial Biota,” DOE-STD-1153-2019, U.S. Department of Energy, https://resrad.evs.anl.gov/docs/technicalStandard.pdf.

DOE, 2021, “Derived Concentration Technical Standard,” DOE-STD-1196-202`, U.S. Department of Energy.

DOE O 458.1, 2011, “Radiation Protection of the Public and the Environment,” U.S. Department of Energy.

DOE-ID, 2023, “National Emissions Standards for Hazardous Air Pollutants – Calendar Year 2022 INL Report for Radionuclides,” DOE/ID-11441, U.S. Department of Energy Idaho Operations Office.

Draxler, R. R., B. Stunder, G. Rolph, A. Stein, and A. Taylor, 2013, “HYSPLIT4 User’s Guide,” Version 4 revision, National Oceanic and Atmospheric Administration, College Park, MD, http://ready.arl.noaa.gov/HYSPLIT.php.

EPA, 1998, “Guidelines for Ecological Risk Assessment,” EPA/630/R-95/002F, U.S. Environmental Protection Agency, Risk Assessment Forum, EPA, Washington, D.C.

EPA, 2002, “Cancer Risk Coefficients for Environmental Exposure to Radionuclides,” Federal Guidance Report 13, EPA-402-R-99-001, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 2020, “Clean Air Act Assessment Package-1988, PC Version (CAP88-PC),” Version 4.1, U.S. Environmental Protection Agency, Washington, D.C.

Halford, D. K., O. D. Markham, and G. C. White, 1983, “Biological Elimination of Radioisotopes by Mallards Contaminated at a Liquid Radioactive Waste Disposal Area,” *Health Physics*, 45:745–756.

INL, 2023, “Update of Receptor Locations for INL National Emissions Standard for Hazardous Air Pollutants (NESHAP) Assessment,” INL/RPT-23-72759, Revision 0, Idaho National Laboratory, Idaho Falls, Idaho.

Jessmore, P. J., L. A. Lopez, and T. J. Haney, 1994, “Compilation and Evaluation of the Idaho National Engineering Laboratory Radiological and Environmental Sciences Laboratory Surface Soil Sample Data for Use in Operable Unit 10-06 Baseline Risk Assessment,” EGG-ER-11227, EG&G Idaho, Scoville, ID.

Mann, L. J. and L. D. Cecil, 1990, “Tritium in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations 90-4090,” DOE/ID-22090, U.S. Department of Energy, https://doi.org/10.3133/wri904090.

Markham, O. D., D. K. Halford, R. E. Autenrieth, and R. L. Dickson, 1982, “Radionuclides in Pronghorn Resulting from Nuclear Fuel Reprocessing and Worldwide Fallout,” Journal of Wildlife Management, 46(1):30–42.

Ritter, P. D., 1997. “Source-to-Receptor Range and Bearing to Potential Maximally Exposed Individuals for Use in Determining Compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAP), Based on the 1995 INEL Boundary Inspection Flight,” Engineering Design File NES-95-004.2, Lockheed Martin Idaho Technologies Company.

Rood, A. S., 2019, “DOSEMM: A Model for Assessment of Airborne Releases, Terrestrial Transport and Dose Assessment,” RAC Report No. 01-2017-FINAL, Risk Assessment Corporation.

Rood, A. S., 2022, “Total Effective Dose from Radiologic Emissions from INL Facilities for Calculation of Population Dose for the INL 2021 CY Annual Site Environmental Report,” Risk Assessment Corporation.

Stein, A. F., R. R. Draxler, G. D. Rolph, B. J. B. Stunder, M. D. Cohen, and F. Ngan, 2015, “NOAA’s HYSPLIT Atmospheric Transport and Dispersion Modeling System,” Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-14-00110.1.

Twining, B. V., R. C. Bartholomay, J. C. Fisher, and C. Anderson, 2021, “Multilevel groundwater monitoring of hydraulic head, water temperature, and chemical constituents in the eastern Snake River Plain Aquifer, Idaho National Laboratory, Idaho, 2014–18: U.S. Geological Survey Scientific Investigations Report 2021–5002,” https://doi.org/10.3133/sir20215002.