Total Effective Dose from Radiologic Emissions from INL Facilities for Calculation of Population Dose for the INL 2023 Annual Site Environmental Report

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July 11, 2024

INTRODUCTION

Total effective radiation dose from airborne releases was calculated using air dispersion modeling performed by the National Oceanic and Atmospheric Administration (NOAA) Idaho Falls Office using their HYSPLIT computer model (Stein et al. 2015; Draxler et al. 2013), and the Dose Multi-Media (DOSEMM) dose assessment model version 230612 (Rood 2019)[1]. The objective of these calculations was to provide a grid of total effective dose across a model domain that encompasses a 50-mile (80-km) radius from any Idaho National Laboratory (INL) Site source. In addition to INL Site sources, releases from the Radiological and Environmental Sciences Laboratory (RESL) (Bldg IF-683), Bldg-611 and Bldg IF-603 located at the INL Research Center (IRC) within the Idaho Falls city limits were also included. The dose results will be combined with GIS software to compute a total population dose for the calendar year (CY) 2023 INL Annual Site Environmental Report (ASER). This report does not cover the population dose calculation and only documents generation of the gridded dose file.

MODEL DOMAIN AND HYSPLIT PROCESSING

The HYSPLIT model was used to calculate dispersion and deposition factors. Dispersion factors are defined as the monthly-average air concentration (g m^{-3}) divided by the release rate (g s^{-1}) and have units of s m^{-3}. Deposition factors are defined as the monthly-average deposition rate (g m^{-2} s^{-1}) divided by the release rate (g s^{-1}) and have units of m^{-2}. HYSPLIT model results were received from Jason Rich of the NOAA Idaho Falls office in NetCDF format. The modeling domain parameters are presented in Table 1. The 0.02-degree grid spacing equates to approximately 2 km. The files were first processed through the utility ncdump via the Perl script *runncdumpl.pl* that produced ASCII files of the gridded concentrations and deposition data (Appendix A) for each facility modeled.

[1] The DOSEMM documentation (Rood 2019) is for version 190429. The difference is version 230612 has the option to use age-specific external dose coefficients from Federal Guidance Report 15 (EPA 2019) and to neglect deposition and inhalation and ingestion doses for noble gas radionuclides. These options were used for the calculations in this report; however, the receptor is an adult so results between the two versions would be identical provided the non-age-specific dose coefficients represented an adult.

Table 1. HYSPLIT modeling domain parameters

Parameter	Value
Model domain SW corner latitude (degrees)[a]	42.6
Model domain SW corner longitude (degrees)[a]	-114.76
Number of East-West nodes	177
Number of North-South nodes	101
Grid spacing (degrees)	0.02
Datum	WGS84
Grid center latitude (degrees)	43.6
Grid center longitude (degrees)	-113.0
Top of ground-level cell	50 m above ground level

a. These coordinates represent the SW corner of the grid cell in the SW corner of the model domain. The center of the SW cell is at 42.61 and -114.75 degrees.

Separate NetCDF files were produced for each INL Site facility (e.g., INTEC, INTEC-MS, CFA, etc.) and IRC facilities (Table 2). Within each file, concentration data for three species were provided. Average monthly ground-level concentration output (in units of g m^{-3}) was provided in the variables con1, con2, and con3. The variable con1 was for concentration of a tracer (i.e., non-decaying non-depositing) gas. The variable con2 was for the concentration of a particulate with a dry deposition velocity of 0.0018 m s^{-1}, and the variable con3 was for the concentration of a reactive gas with a deposition velocity of 0.035 m s^{-1}. Monthly deposition output (in units of g m^2) was provided in the variable dep2 and dep3 corresponding to species 2 and 3. There was no deposition output for species 1 as it is a gas. All concentration and deposition values were based on a constant source release rate of 1 g s^{-1}.

Table 2. Facilities modeled with HYSPLIT and release parameters. Only those facilities that had an appreciable dose were considered.

Facility	File Designation	Latitude and Longitude (degrees)	Release parameters
Advanced Test Reactor (ATR) Complex ATR stack[a]	ATR_stack	43.589, -112.9671	Ht: 76.2 m, Stack dia: 1.524 m, Exit vel: 10.03 m/s, Temp: 293 K
ATR Complex, surface release	ATR_surface	43.5878, -112.9643	Ht: 0 m
Central Facilities Area (CFA)	CFA_surface	43.529, -112.9441	Ht: 0 m
Critical Infrastructure Test Range Complex (CITRC)[b]	CITRC_surface	43.5504, -112.8593	Ht: 0 m
Idaho Nuclear Technology and Engineering Center (INTEC), main stack[c] (MS)	INTEC_stack	43.572, -112.9336	Ht: 76.2 m, Stack dia: 1.83 m, Exit vel: 10.65 m/s, Temp: 293 K
Idaho Nuclear Technology and Engineering Center surface release	INTEC_surface	43.572, -112.9336	Ht: 0 m
Materials and Fuels Complex (MFC) surface release	MFC_surface	43.5951, -112.6567	Ht: 0 m
MFC, main stack and Transient Reactor Test Facility (TREAT) stack[d]	MFC_stack	43.5951, -112.6567	Ht: 60 m, Stack dia: 1.52 m, Exit vel: 9.081 m/s, Temp: 293 K
Naval Reactors Facility	NRF_surface	43.6489, -112.9162	Ht: 0 m
Radioactive Waste Management Complex (RWMC)	RWMC_surface	43.4999, -113.0407	Ht: 0 m
Radioactive Release Test Range (RRTR), Test Area North Technical Support Facility (TAN-TSF), and Specific Manufacturing Capability (SMC)	RRTR_surface	43.8734, -112.725	Ht: 0 m

Facility	File Designation	Latitude and Longitude (degrees)	Release parameters
Radiological and Environmental Sciences Laboratory (RESL), Buildings IF-683, IF-611, and IF-603[e]	RESL_surface	43.5159, -112.0348	Ht: 10 m, Exit Vel 0 m/s (no plume rise)

a. The RTC-ATR stack exit velocity is based on 2013-2015 records. For 2023 the RTC-ATR stack had an exit velocity of 9.70 m/s. The small difference in exit velocity will have a minimal impact on the results.
b. Releases from CITRC resulted in CAP88 doses that were about 5 orders of magnitude less than all the other facilities at the MEI. For this reason, CITRC was not included in the dose calculations.
c. The INTEC main stack exit velocity is based on 2013-2015 records. For 2023 the INTEC main stack had an exit velocity of 8.34 m/s. The small difference in exit velocity will have a minimal impact on the results.
d. Releases from the TREAT stack were modeled using the dispersion and deposition values from the MFC main stack. The stack exit velocity for the MFC main stack is based on 2013-2015 records. For 2023 the MFC main stack had an exit velocity of 8.72 m/s. The small difference in exit velocity will have a minimal impact on the results.
e. All three sources are located at the INL Research Center and were assumed to be released from the RESL stack location.

SOURCE TERM

The radionuclide source term for facilities that contributed significantly to the annual dose was determined using CAP88 version 4.1 (EPA 2019) modeling performed for the annual INL NESHAPs[2] report for radionuclides (INL 2024). These sources and radionuclides were included in the HYSPLIT/DOSEMM modeling. Radionuclides that yielded a dose greater than 0.005% of the total dose at the location of the maximally exposed individual (MEI) for the INL Site were selected (Table 3, Table 4, and Table 5). The 0.005% value was a factor of 2 less than previous years which used a cutoff of 0.01%. Using 0.005% resulted in the addition of Pu-242 and I-129 to the source term. These nuclides were identified as important in previous ASERs and therefore were included in this assessment. However, a cutoff of 0.1% would probably be sufficient for identifying important radionuclides. The INL Site MEI for 2023 was Receptor 26 near the INL east entrance.

For the IRC sources in Idaho Falls, radionuclides that result in a dose greater than 0.1% of the total dose at the MEI location in Idaho Falls were included (Table 6). The in-town MEI receptor (Receptor 1) is located south of the IRC. Output from the CAP88 post-processing databases was used for this task.

[2] The National Emission Standards for Hazardous Air Pollutants (NESHAPs) report for radionuclides is produced annually for all U.S. Department of Energy facilities that emit any radionuclides other than radon-222 and radon-220 into the air according to 40 CFR part 61, Subpart H.

Table 3. Particulate radionuclide source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.005% of the total dose for INL Site facilities at the MEI location.

Source	Am-241	Br-82	Cl-36	Co-60	Cs-134	Cs-137	Np-237
CFA	7.75E-12	1.80E-06	1.25E-08	5.41E-13	2.04E-09	4.16E-06	5.20E-12
CITRC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
INTEC	1.30E-05	0.00E+00	1.75E-07	1.34E-15	0.00E+00	3.78E-04	9.18E-17
INTEC-MS	2.66E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-12	0.00E+00
MFC	2.31E-11	6.90E-09	7.17E-03	0.00E+00	8.59E-04	7.64E-03	1.42E-05
MFC-MS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFC-TREAT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E-08	0.00E+00
NRF	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.04E-05	0.00E+00
RRTR	0.00E+00	6.29E+00	1.66E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RTC[a]	2.18E-05	0.00E+00	0.00E+00	5.90E-03	1.21E-06	5.23E-03	2.60E-10
RTC-ATR[a]	3.67E-07	0.00E+00	0.00E+00	4.25E-06	0.00E+00	6.22E-05	0.00E+00
RTC-MTR[a]	0.00E+00	0.00E+00	0.00E+00	1.32E-09	5.51E-13	9.67E-11	0.00E+00
RWMC	5.49E-05	0.00E+00	0.00E+00	7.18E-18	0.00E+00	1.13E-18	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
TAN-TSF	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	9.01E-05	6.29E+00	7.17E-03	5.90E-03	8.60E-04	1.34E-02	1.42E-05

Source	Pu-239	Pu-240	Pu-242	Sr-90	U-234	U-235	U-238
CFA	1.96E-12	1.51E-13	2.21E-13	5.97E-13	2.29E-14	2.20E-13	3.18E-13
CITRC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
INTEC	4.93E-06	4.78E-06	3.07E-16	3.00E-04	1.71E-07	1.78E-07	1.32E-07
INTEC-MS	9.80E-14	8.83E-14	0.00E+00	5.49E-10	0.00E+00	0.00E+00	0.00E+00
MFC	4.95E-06	2.00E-08	1.26E-06	1.22E-03	7.66E-02	3.49E-03	1.45E-01
MFC-MS	4.78E-08	0.00E+00	0.00E+00	8.54E-07	0.00E+00	0.00E+00	0.00E+00
MFC-TREAT	4.23E-12	0.00E+00	0.00E+00	8.51E-11	0.00E+00	5.19E-12	5.75E-14
NRF	2.70E-06	0.00E+00	0.00E+00	5.60E-05	0.00E+00	0.00E+00	0.00E+00
RRTR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RTC[a]	8.46E-06	1.43E-14	1.40E-13	2.82E-02	2.95E-13	3.32E-10	8.90E-10
RTC-ATR[a]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RTC-MTR[a]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E-10	1.13E-11	8.59E-10
RWMC	2.57E-05	5.89E-06	0.00E+00	2.00E-08	0.00E+00	4.39E-12	2.75E-10
SMC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.03E-13	1.10E-14	8.83E-13
TAN-TSF	0.00E+00	0.00E+00	0.00E+00	3.01E-05	0.00E+00	0.00E+00	0.00E+00
Total	4.68E-05	1.07E-05	1.26E-06	2.98E-02	7.66E-02	3.49E-03	1.45E-01

a. The Advanced Test Reactor (ATR) Complex was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 4. Noble gases source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.005% of the total dose for INL Site facilities at the MEI location.

Source	Ar-41	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-133	Xe-135	Xe-138
CFA	2.00E-05	1.14E-02	8.90E-04	1.92E-02	0.00E+00	1.55E-02	2.29E-01	0.00E+00
CITRC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
INTEC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
INTEC-MS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.09E-03	0.00E+00	0.00E+00
MFC-MS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFC-TREAT	7.46E+01	9.21E+00	9.65E+00	8.77E+00	3.16E+01	1.93E-01	2.41E+00	1.49E+01
NRF	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RRTR	5.33E-11	0.00E+00	1.06E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RTC[a]	5.40E-05	9.60E-06	3.40E-05	1.18E-03	0.00E+00	4.20E-08	3.20E-05	1.18E-04
RTC-ATR[a]	1.97E+03	2.04E+00	6.81E+00	3.82E+00	0.00E+00	3.44E+02	1.83E+01	1.67E+01
RTC-MTR[a]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RWMC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	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	0.00E+00
TAN-TSF	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	2.04E+03	1.13E+01	1.65E+01	1.26E+01	3.16E+01	3.44E+02	2.09E+01	3.16E+01

a. The Advanced Test Reactor (ATR) Complex was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 5. Iodine, C-14, and H-3 source term (Ci yr^{-1}) for radionuclide-facility combinations that contributed greater than 0.005% of the total dose for INL Site facilities at the MEI location.

Source	I-131	I-129	H-3	C-14
CFA	1.41E-02	4.68E-12	3.62E-01	2.00E-09
CITRC	0.00E+00	0.00E+00	2.20E-01	0.00E+00
INTEC	0.00E+00	1.39E-04	3.44E-02	2.43E-03
INTEC-MS	0.00E+00	3.92E-06	4.72E-10	0.00E+00
MFC	2.90E-06	0.00E+00	2.17E+02	0.00E+00
MFC-MS	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFC-TREAT	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRF	4.60E-06	9.60E-06	1.10E-02	2.10E-01
RRTR	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RTC[a]	3.02E-08	2.69E-14	1.76E+01	4.75E-10
RTC-ATR[a]	4.01E-07	0.00E+00	5.05E+02	0.00E+00
RTC-MTR[a]	0.00E+00	0.00E+00	6.50E+00	1.50E-14
RWMC	0.00E+00	0.00E+00	4.29E+01	2.22E-02
SMC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TAN-TSF	0.00E+00	0.00E+00	1.45E-02	0.00E+00
Total	1.41E-02	1.52E-04	7.90E+02	2.35E-01

a. The Advanced Test Reactor (ATR) Complex was formerly known as the Test Reactor Area (TRA) and Reactor Technology Complex (RTC). Acronyms based on former names may still be used to describe facility buildings, meteorological stations, etc.

Table 6. Radionuclide source term (Ci yr^{-1}) for radionuclides that contributed greater than 0.1% of the total dose for INL facilities in Idaho Falls.

Radionuclide	IF-603	IF-611	IF-683 (RESL)	Total
Ac-227	0.00E+00	0.00E+00	5.06E-09	5.06E-09
Am-241	0.00E+00	0.00E+00	1.04E-07	1.04E-07
Am-243	0.00E+00	0.00E+00	2.09E-09	2.09E-09
Ba-133	8.17E-11	0.00E+00	3.15E-07	3.15E-07
Co-60	4.98E-13	0.00E+00	3.51E-08	3.51E-08
Cs-134	3.12E-07	0.00E+00	1.26E-08	3.25E-07
Cs-137	2.67E-08	0.00E+00	7.38E-08	1.00E-07
Eu-152	2.03E-17	0.00E+00	4.04E-08	4.04E-08
Eu-154	1.11E-12	0.00E+00	1.60E-07	1.60E-07
H-3	0.00E+00	0.00E+00	1.35E-04	1.35E-04
I-125	0.00E+00	0.00E+00	7.22E-08	7.22E-08
I-131	0.00E+00	0.00E+00	2.12E-07	2.12E-07
Na-22	0.00E+00	0.00E+00	7.01E-08	7.01E-08
Np-237	0.00E+00	0.00E+00	6.48E-09	6.48E-09
Pa-231	0.00E+00	0.00E+00	1.15E-09	1.15E-09
Pb-210	0.00E+00	0.00E+00	4.26E-08	4.26E-08
Pu-238	0.00E+00	0.00E+00	7.71E-08	7.71E-08
Pu-239	0.00E+00	0.00E+00	1.32E-07	1.32E-07
Ra-226	0.00E+00	0.00E+00	7.52E-08	7.52E-08
Sr-90	0.00E+00	0.00E+00	6.71E-08	6.71E-08
U-232	0.00E+00	0.00E+00	3.12E-08	3.12E-08
U-233	0.00E+00	0.00E+00	1.64E-07	1.64E-07
Xe-133	0.00E+00	4.50E-01	0.00E+00	4.50E-01

DOSEMM MODELING AND MODEL PARAMETERS

The DOSEMM model version 230612 (Rood 2019) was used to calculate total effective dose across the model domain for a fixed receptor scenario. DOSEMM reads the dispersion and deposition factors produced by HYSPLIT and the source term summarized in Table 3, Table 4, Table 5, and Table 6. The dispersion and deposition factors and source term are used in combination with a food-chain and exposure model in DOSEMM to calculate radionuclide concentrations in air, soil, vegetables, meat, and milk, and calculate the associated doses from inhalation, ingestion, and external exposure. Nuclide independent parameters were taken from previous ASER spreadsheet calculations for assessment years 2015 and earlier[3] (Table 7). DOSEMM uses a food-chain model similar to the ASER spreadsheet calculations which is based on the CAP88 model (EPA 2013). Appendix B in Rood (2019) contains a benchmark comparison of the DOSEMM output and the

[3] For assessment years 2015 and earlier, the ASER population dose was calculated in a spreadsheet and used the earlier NOAA model MDIFF to calculate dispersion and deposition factors.

ASER spreadsheet. Nuclide-independent parameters included the media intake rates and agriculture parameters.

Element-specific parameters include the linear sorption coefficient (K_d), plant and forage concentration ratios, and milk and meat transfer coefficients (Table 8). Carbon-14 and tritium are modeled using a specific-activity model and model parameters for these nuclides are presented in Table 9. Radionuclide-specific parameters (Table 10) include half-lives and dose coefficients for ingestion, inhalation, ground surface (ground plane) and volume external exposure (ground volume), and submersion in air. Exposure scenario parameters were taken from CAP88 version 4.1 and include inhalation and ingestion rates (Table 11). The NESHAP dose was computed using CAP88 version 4.1. The half-lives (not reported) were taken from the ICRP-107 (ICRP 2008) tabulation.

Table 7. Radionuclide independent parameters for DOSEMM modeling.

Variable	Value	Units	Description
V_d	0.0018	$m\ s^{-1}$	Deposition velocity for particulates
V_d	0.035	$m\ s^{-1}$	Deposition velocity for molecular iodine
DD1	0.50	---	Fraction of radioactivity retained on leafy vegetables and produce after washing.
FSUBG	1.00	---	Fraction of produce grown in garden of interest
FSUBL	1.00	---	Fraction of leafy vegetables grown in garden of interest
FSUBP	0.40	---	Fraction of year animals graze on pasture
FSUBS	0.43	---	Fraction of daily feed that is pasture grass when animal grazes on pasture
LAMW	0.0029	hr^{-1}	Removal rate for weathering from plants
P	215.00	$kg\ m^{-2}$	Effective surface density of soil. This value assumes a 15-cm soil depth with a bulk density of 1.43 g/cm^3
QSUBF	15.60	$kg\ day^{-1}$	Consumption rate of contaminated feed or forage by an animal (dry wt)
R_1	0.57		Fallout interception fraction (pasture)
R_2	0.2		Fallout interception fraction (vegetables)
TH_1	0.00	hr	Time delay-ingestion of pasture grass by animals
TH_2	2,160	hr	Time delay-ingestion of stored feed by animals
TH_3	336	hr	Time delay-ingestion of leafy vegetables by man
TH_4	336	hr	Time delay-ingestion of produce by man
TSUBB	876,000	hr	Buildup time in soil (hr) for food chain (100 yrs)
$TSUBE_1$	720	hr	Period of exposure (grassy pasture)
$TSUBE_2$	1,440	hr	Period of exposure (crops/leafy vegetables)
TSUBF	2.0	day	Transport time: animal feed-milk-man
TSUBS	20	day	Average time from slaughter of meat animal to consumption
VSUBM	11.0	$liter\ day^{-1}$	Milk production of cow
$YSUBV_1$	0.28	$kg\ m^{-2}$	Productivity: agriculture (grass-cow-milk-man pathway)
$YSUBV_2$	0.716	$kg\ m^{-2}$	Productivity: produce and vegetables (wet)

Table 8. Element-specific parameters for DOSEMM modeling (default values for RESRAD v7.2 Kamboj et al., 2018 except as noted).

Element	K_d (mL g^{-1})	Concentration Ratio vegetables	Concentration Ratio forage	Transfer Coefficient milk (L d^{-1})	Transfer Coefficient meat (kg d^{-1})
Ac	2.00E+01	2.50E-03	1.00E-01	2.00E-05	2.00E-05
Am	2.00E+01	1.00E-03	1.00E-03	2.00E-06	5.00E-05
Ar	(a)	(a)	(a)	(a)	(a)
Ba	0.00E+00	5.00E-03	5.00E-03	5.00E-04	2.00E-04
Bi	0.00E+00	1.00E-01	1.00E-01	5.00E-04	2.00E-03
Br	1.00E-01	2.00E-02	2.00E-02	1.00E-02	7.00E-03
C	(b)	(b)	(b)	(b)	(b)
Cd	0.00E+00	3.00E-01	3.00E-01	1.00E-03	4.00E-04
Cl	0.00E+00	2.00E+01	2.00E+01	8.00E-02	6.00E-02
Co	1.00E+03	8.00E-02	8.00E-02	2.00E-03	2.00E-02
Cs	4.60E+03	4.00E-02	4.00E-02	8.00E-03	3.00E-02
Cf	2.00E+03[c]	1.00E-03	1.00E-03	8.00E-03	3.00E-03
Cu	3.50E+01[c]	1.30E-01	1.30E-01	2.00E-03	1.00E-01
H	(b)	(b)	(b)	(b)	(b)
I	1.00E-01	2.00E-02	2.00E-02	1.00E-02	7.00E-03
Kr	(a)	(a)	(a)	(a)	(a)
Na	1.00E+02	5.00E-02	5.00E-02	4.00E-02	8.00E-02
Np	8.00E+00[c]	2.00E-02	2.00E-02	5.00E-06	1.00E-03
Pa	5.00E+01	2.50E-03	1.00E-01	5.00E-06	5.00E-03
Pb	1.00E+02	1.00E-02	1.00E-02	3.00E-04	8.00E-04
Po	1.00E+01	9.00E-03	1.00E-01	3.00E-04	5.00E-03
Pu	2.00E+03	1.00E-03	1.00E-03	1.00E-06	1.00E-04
Ra	7.00E+01	4.00E-02	4.00E-02	1.00E-03	1.00E-03
Rn	(a)	(a)	(a)	(a)	(a)
Sr	3.00E+01	3.00E-01	3.00E-01	2.00E-03	8.00E-03
Te	0.00E+00	6.00E-01	6.00E-01	5.00E-04	7.00E-03
Th	6.00E+04	1.00E-03	1.00E-03	5.00E-04	7.00E-03
U	5.00E+01	2.50E-03	2.50E-03	5.00E-04	7.00E-03
Y	0.00E+00	2.50E-03	2.50E-03	2.00E-05	2.00E-03
Xe	(a)	(a)	(a)	(a)	(a)
Zn	0.00E+00	4.00E-01	4.00E-01	1.00E-02	1.00E-01

a. Noble gases do not deposit and are not incorporated into food products.
b. C-14 and H-3 are modeled using a specific activity model.
c. The K_d value for Np was the INL default value for INTEC modeling (Jenkins 2001) because RESRAD does not have a default value. Cf was assumed to be the same as Pu and Cu was taken from Baes et al. (1984)

Table 9. Tritium and carbon-14 model parameters used for DOSEMM modeling.

Parameter	Value	Reference
Absolute humidity (g m^{-3})	4.90	Till (1983)
Atmospheric concentration of carbon (g m^{-3})	0.18	Till (1983)
Fraction of vegetation that is water	0.824	Moore et al. (1979)
Fraction of vegetation that is carbon	0.339	Moore et al. (1979)
Fraction of beef that is water	0.623	Moore et al. (1979)
Fraction of milk that is water	1.0	NCRP (1996)
Fraction of beef that is carbon	0.23	NCRP (1996)
Fraction of milk that is carbon	0.169	Moore et al. (1979)

Table 10. Radionuclide dose coefficients (DCs) used for DOSEMM modeling (DOE 2022 and EPA 2019).

Nuclide	Solubility Class[a]	Inhalation (Sv/Bq)[c]	Ingestion (Sv/Bq)[c]	Submersion (Sv-m^3/Bq-s)[c]	Ground Plane (Sv-m^2/Bq-s)[d]	Ground Volume (Sv-m^3/Bq-s)[d]
Ac-227	M	4.60E-05	1.73E-07	4.22E-18	6.10E-20	2.17E-21
Ac-228	M	6.17E-09	1.60E-10	4.04E-14	5.80E-16	2.39E-17
Am-241	M	1.54E-05	5.91E-08	5.00E-16	9.90E-18	2.20E-19
Am-243	M	1.52E-05	5.84E-08	1.48E-15	2.81E-17	7.47E-19
Ar-41	n/a	e	e	6.20E-14	8.48E-16	3.62E-17
Ba-133	M	2.91E-09	1.00E-09	1.56E-14	2.26E-16	9.06E-18
Ba-137m	n/a	e	e	2.66E-14	3.90E-16	1.60E-17
Bi-210	M	5.05E-08	2.14E-09	1.03E-15	4.73E-17	5.90E-19
Bi-211	n/a	e	e	2.01E-15	2.89E-17	1.19E-18
Bi-214	M	1.09E-08	4.77E-11	7.21E-14	1.00E-15	4.19E-17
Br-82	F	2.09E-10	4.91E-10	1.21E-13	1.67E-15	7.18E-17
C-14	M	9.75E-10	1.59E-10	3.86E-17	6.12E-19	2.70E-20
Cd-115m	M	4.39E-09	9.95E-10	3.34E-15	1.13E-16	1.97E-18
Cf-252	M	7.85E-06	2.08E-08	2.28E-14	3.08E-16	1.30E-17
Cl-36	F	4.32E-10	9.92E-10	6.44E-16	1.87E-17	3.62E-19
Co-60	M	1.13E-08	3.25E-09	1.18E-13	1.54E-15	6.93E-17
Cs-134	M	8.86E-09	1.39E-08	7.02E-14	9.98E-16	4.21E-17
Cs-137	M	8.38E-09	1.36E-08	3.89E-16	7.85E-18	2.20E-19
Cs-138	M	3.31E-11	1.29E-10	1.18E-13	1.62E-15	6.79E-17
Cu-64	M	5.96E-11	5.71E-11	8.38E-15	1.24E-16	5.03E-18
Eu-152	M	3.73E-08	6.55E-10	5.33E-14	7.22E-16	3.12E-17
Eu-154	M	3.84E-08	7.16E-10	5.76E-14	7.88E-16	3.39E-17
H-3	W[b]	1.97E-11	1.95E-11	3.80E-20	6.65E-22	2.93E-23
I-125	F	5.35E-09	1.26E-08	2.78E-16	4.64E-18	5.35E-20
I-129	F	4.00E-08	9.39E-08	2.54E-16	4.41E-18	7.41E-20
I-131	F	6.87E-09	1.63E-08	1.69E-14	2.44E-16	1.01E-17
Kr-85	n/a	e	e	6.67E-16	1.67E-17	3.79E-19

Table 10. Radionuclide dose coefficients (DCs) used for DOSEMM modeling (DOE 2022 and EPA 2019).

Nuclide	Solubility Class[a]	Inhalation (Sv/Bq)[c]	Ingestion (Sv/Bq)[c]	Submersion (Sv-m^3/Bq-s)[c]	Ground Plane (Sv-m^2/Bq-s)[d]	Ground Volume (Sv-m^3/Bq-s)[d]
Kr-85m	n/a	e	e	7.09E-15	1.09E-16	3.92E-18
Kr-87	n/a	e	e	4.33E-14	6.65E-16	2.48E-17
Kr-88	n/a	e	e	9.73E-14	1.18E-15	5.46E-17
Kr-89	n/a	e	e	9.89E-14	1.34E-15	5.62E-17
Na-22	M	9.35e-09	3.49e-09	1.01e-13	1.37e-15	5.96e-17
Np-237	M	8.17E-06	3.00E-08	7.70E-16	1.17E-17	3.71E-19
Np-239	M	4.04E-10	8.53E-11	7.26E-15	1.00E-16	3.89E-18
Pa-231	S	9.08E-05	1.82E-07	1.40E-15	1.96E-17	8.05E-19
Pa-234m	S	e	e	3.42E-15	1.38E-16	2.05E-18
Pb-210	F	5.54E-07	3.55E-07	3.75E-17	6.80E-19	1.25E-20
Pb-211	F	1.65E-08	1.01E-10	4.12E-15	1.02E-16	2.44E-18
Pb-214	F	1.33E-08	7.70E-11	1.11E-14	1.64E-16	6.51E-18
Po-210 (inorganic)	M	1.87E-06	2.42E-07	4.40E-19	6.16E-21	2.64E-22
Po-214	M	e	e	3.75E-18	5.26E-20	2.25E-21
Po-218	M	e	e	1.65E-20	2.35E-22	1.04E-23
Pu-238	M	2.49E-05	1.10E-07	2.55E-18	2.11E-20	5.27E-22
Pu-239	M	2.71E-05	1.21E-07	3.30E-18	4.18E-20	1.41E-21
Pu-240	M	2.71E-05	1.21E-07	2.52E-18	2.17E-20	5.41E-22
Pu-241	M	2.51E-07	1.13E-09	1.10E-19	1.73E-21	6.85E-23
Pu-242	M	2.58E-05	1.15E-07	5.87E-18	6.90E-20	2.60E-21
Ra-226	M	2.32E-06	1.27E-07	3.00E-16	4.09E-18	1.67E-19
Ra-228	M	2.01E-06	3.41E-07	2.71E-18	1.57E-20	6.72E-22
Rn-222	n/a	e	e	1.71E-17	2.51E-19	1.03E-20
Sb-125	M	3.56E-09	5.46E-10	1.88E-14	2.73E-16	1.12E-17
Sr-90	M	3.21E-08	2.39E-08	4.03E-16	6.52E-18	2.26E-19
Te-125m	M	1.09E-09	1.91E-10	2.52E-16	4.06E-18	5.07E-20
Te-129m	M	3.41E-09	8.90E-10	2.01E-15	5.14E-17	1.18E-18
Te-129	M	2.87E-11	6.07E-11	4.07E-15	1.13E-16	2.40E-18
Th-227	S	3.64E-06	1.34E-09	5.01E-15	7.00E-17	2.87E-18
Th-228	S	3.70E-05	3.11E-08	7.49E-17	1.11E-18	3.92E-20
Th-230	S	2.69E-05	5.99E-08	1.25E-17	2.05E-19	6.15E-21
Th-231	S	1.89E-10	1.71E-11	4.79E-16	7.36E-18	2.40E-19
Th-232	S	1.08E-04	7.05E-08	6.19E-18	1.04E-19	2.73E-21
Th-234	S	5.24E-09	5.93E-10	3.11E-16	5.06E-18	1.56E-19
Tl-207	n/a	e	e	1.52E-15	7.19E-17	8.84E-19
Tl-208	n/a	e	e	1.68E-13	2.04E-15	9.32E-17
U-232	M	5.24E-06	1.77E-07	9.20E-18	1.27E-19	3.92E-21
U-233	M	2.44E-06	3.54E-08	9.70E-18	1.33E-19	4.78E-21

Table 10. Radionuclide dose coefficients (DCs) used for DOSEMM modeling (DOE 2022 and EPA 2019).

Nuclide	Solubility Class[a]	Inhalation (Sv/Bq)[c]	Ingestion (Sv/Bq)[c]	Submersion ($Sv\text{-}m^3/Bq\text{-}s$)[c]	Ground Plane ($Sv\text{-}m^2/Bq\text{-}s$)[d]	Ground Volume ($Sv\text{-}m^3/Bq\text{-}s$)[d]
U-234	M	2.40E-06	3.47E-08	5.15E-18	6.42E-20	1.87E-21
U-235	M	2.21E-06	3.18E-08	6.67E-15	9.07E-17	3.69E-18
U-238	M	2.09E-06	3.07E-08	2.65E-18	2.94E-20	8.66E-22
Xe-131m	n/a	e	e	3.08E-16	4.14E-18	9.98E-20
Xe-133	n/a	e	e	1.22E-15	2.09E-17	5.91E-19
Xe-135	n/a	e	e	1.13E-14	1.72E-16	6.58E-18
Xe-135m	n/a	e	e	1.86E-14	2.82E-16	1.12E-17
Xe-138	n/a	e	e	5.58E-14	7.60E-16	3.19E-17
Y-90	M	7.90E-10	5.63E-10	3.18E-15	1.47E-16	1.93E-18
Zn-65	M	2.15E-09	4.30E-09	2.69E-14	3.58E-16	1.59E-17

a. Solubility Types: S=slow, M=medium, F=fast, W=tritiated water, n/a= not applicable because inhalation DCs are zero. Solubility types were the default values in Table 5 of DOE-Std-1196-2022.
b. The default solubility type for H-3 is M as a particulate, however H-3 was assumed to be in the form of tritiated water.
c. Adult values from DOE-Std-1196-2022 (DOE-2022).
d. FGR-15 (EPA 2019). Ground volume represents a depth from the surface of 15 cm.
e. No ingestion or inhalation dose coefficient because it is either a noble gas or has a short half-life.

Table 11. Media intake rates used for CAP88 version 4.1.

Parameter	CAP88 version 4.1
Inhalation rate ($m^3\ yr^{-1}$)	5256
Leafy vegetable ingestion ($kg\ yr^{-1}$)	7.79
Other vegetable ingestion ($kg\ yr^{-1}$)	76.2
Meat ingestion ($kg\ yr^{-1}$)	84
Milk ingestion ($L\ yr^{-1}$)	53

Dose Coefficients

Population dose calculations in ASERs prior to 2023 were calculated with dose coefficients from DOE-Std-1196-2011 (DOE 2011) and FGR-13 (EPA 1999). For ASER population dose calculations from 2023 onwards, the most up-to-date dose coefficients were used as represented by DOE-Std-1196-2022 (DOE 2022) and Federal Guidance Report 15 (EPA 2019).

Radioactive Decay and Ingrowth

DOSEMM allows for decay and ingrowth of radioactive progeny that deposit on soil. For the 1-year time frame considered none of the radionuclides in the source term have progeny that would have significant activity, except those that are short-lived and assumed to be in secular equilibrium with their parent. Dose coefficients for radionuclides that are assumed to be in secular equilibrium with their parent are included if the progeny half-life is less than a cutoff value. For inhalation and ingestion, radionuclide decay and ingrowth are already accounted for in the dose coefficient. The half-life cutoff for submersion is 24 hours and for ground exposure is 30 days. That is, radioactive progeny that have half-lives less than these values are assumed to be in secular equilibrium with their parent and the dose coefficients are added. The dose coefficients for the radionuclides and progeny that were added together are presented in Table 12.

Table 12. Radioactive progeny that are assumed to be in secular equilibrium with the parent radionuclide. For these radionuclides the dose coefficients for the progeny are added to the parent.

Parent	Progeny	Pathway(s)
Ac-227	Th-227	ground exposure and submersion
Am-243	Np-239	ground exposure
Cs-137	Ba-137m	ground exposure
I-131	Xe-131m	ground exposure
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214	ground exposure
Sr-90	Y-90	ground exposure and submersion
Te-129	Te-129m	ground exposure and submersion
U-238	Pa-234m, Th-234	ground exposure and submersion
Xe-138	Cs-138	ground exposure and submersion

RESULTS

Results consist of doses at the MEI for the INL Site and INL in-town facilities. In general, doses at the INL Site and INL in-town MEIs calculated with HYSPLIT/DOSEMM were lower than those calculated by CAP88. Differences between the two dose models are explained in a subsequent section.

INL Site MEI Doses

The HYSPLIT/DOSEMM model was used to compute the effective dose at the MEI location and then calculate the dose at every grid node in the model domain for the MEI exposure scenario. Prior to 2019, the MEI was at what is known as Frenchman's Cabin (located south of the INL at coordinates longitude -113.05666 and latitude 43.42690, UTM Zone 12 coordinates 333528E 4810276N, see Figure 1 receptor 1 location), Since 2019, the MEI has been at the receptor 26 location (see Figure 1) south-southeast of the MFC facility (-112.602013 longitude, 43.526498 latitude, UTM Zone 12 370542E 4820531N).

The DOSEMM calculated dose at the MEI was 6.01E-03 mrem yr^{-1} for 2023 which was higher than the 2022 dose of 3.49E-03 mrem yr^{-1}. The dose by pathway for INL Site sources (Table 13) was highest for the direct inhalation pathways followed by ingestion of other vegetables and beef. Particulate radionuclides had the highest contribution to the total dose. Dose by radionuclide at the INL Site MEI location (Table 14) were highest for Cl-36, U-238, U-235, U-234, Ar-41, and H-3. For comparison, the CAP88 version 4.1 doses at the MEI location are also shown in Table 14. The CAP88 total dose was about a factor of 4.8 greater than the HYSPLIT/DOSEMM dose. This difference is investigated and explained in a subsequent section.

Table 13. Dose by pathway and radionuclide type at the INL Site MEI location for the HYSPLIT/DOSEMM model simulation for the 2023 ASER.

Pathway	Particulates (mrem yr^{-1})	Iodine (mrem yr^{-1})	Noble gas (mrem yr^{-1})	C-14, H-3 (mrem yr^{-1})	Total (mrem yr^{-1})
Inhalation, direct	3.37E-03	4.93E-09	0.00E+00	3.59E-05	3.41E-03
Inhalation, resuspension	3.26E-04	2.84E-09	0.00E+00	0.00E+00	3.26E-04
Ingestion, Leafy Veg	6.07E-05	2.43E-08	0.00E+00	8.84E-06	6.96E-05
Ingestion, Other Veg	6.44E-04	2.75E-07	0.00E+00	8.65E-05	7.31E-04
Ingestion Beef	6.86E-04	1.09E-07	0.00E+00	7.22E-05	7.59E-04
Ingestion Milk	3.17E-04	1.64E-07	0.00E+00	7.30E-05	3.90E-04
External, ground	5.98E-05	3.34E-08	0.00E+00	0.00E+00	5.99E-05
Submersion in air	1.09E-06	6.56E-11	2.64E-04	4.26E-10	2.65E-04
All Pathway	5.47E-03	6.14E-07	2.64E-04	2.76E-04	6.01E-03

Table 14. Dose by radionuclide at the INL Site MEI location for the HYSPLIT/DOSEMM and CAP88 version 4.1 model simulations for the 2023 ASER.

Radionuclide	DOSEMM Dose (mrem yr^{-1})	DOSEMM Fraction of Total	CAP88 Dose (mrem yr^{-1})	CAP88 Fraction of Total
U-238	2.74E-03	45.61%	1.30E-02	44.81%
U-234	1.55E-03	25.74%	5.90E-03	20.34%
Cl-36	1.03E-03	17.17%	3.58E-03	12.34%
H-3	2.76E-04	4.59%	3.53E-03	12.17%
Ar-41	1.90E-04	3.16%	4.63E-04	1.60%
U-235	7.17E-05	1.19%	3.49E-04	1.20%
Kr-88	4.60E-05	0.77%	8.64E-05	0.30%
Cs-137	4.04E-05	0.67%	1.09E-03	3.76%
Sr-90	1.80E-05	0.30%	5.23E-04	1.80%
Kr-87	1.26E-05	0.21%	1.95E-05	0.067%
Xe-138	1.21E-05	0.20%	2.70E-05	0.093%
Br-82	1.02E-05	0.17%	2.01E-04	0.693%
Cs-134	4.44E-06	0.074%	4.98E-05	0.172%
Kr-85m	2.03E-06	0.034%	5.30E-06	0.018%
Pu-239	1.29E-06	0.022%	2.30E-05	0.079%
Xe-135	1.27E-06	0.021%	3.54E-06	0.012%
Np-237	9.62E-07	0.016%	8.82E-06	0.030%
C-14	5.09E-07	0.008%	3.47E-05	0.120%
Co-60	4.40E-07	0.007%	6.49E-05	0.224%
Xe-133	3.77E-07	0.006%	3.13E-06	0.011%
I-129	3.50E-07	0.006%	1.48E-06	0.005%
I-131	2.64E-07	0.004%	3.11E-06	0.011%
Pu-242	2.63E-07	0.004%	1.52E-06	0.005%
Am-241	2.45E-07	0.004%	3.08E-05	0.106%
Pu-240	6.25E-08	0.001%	4.23E-06	0.015%
Kr-89	1.23E-08	0.000%	6.32E-06	0.022%
Total	6.01E-03	100%	2.91E-02	100%

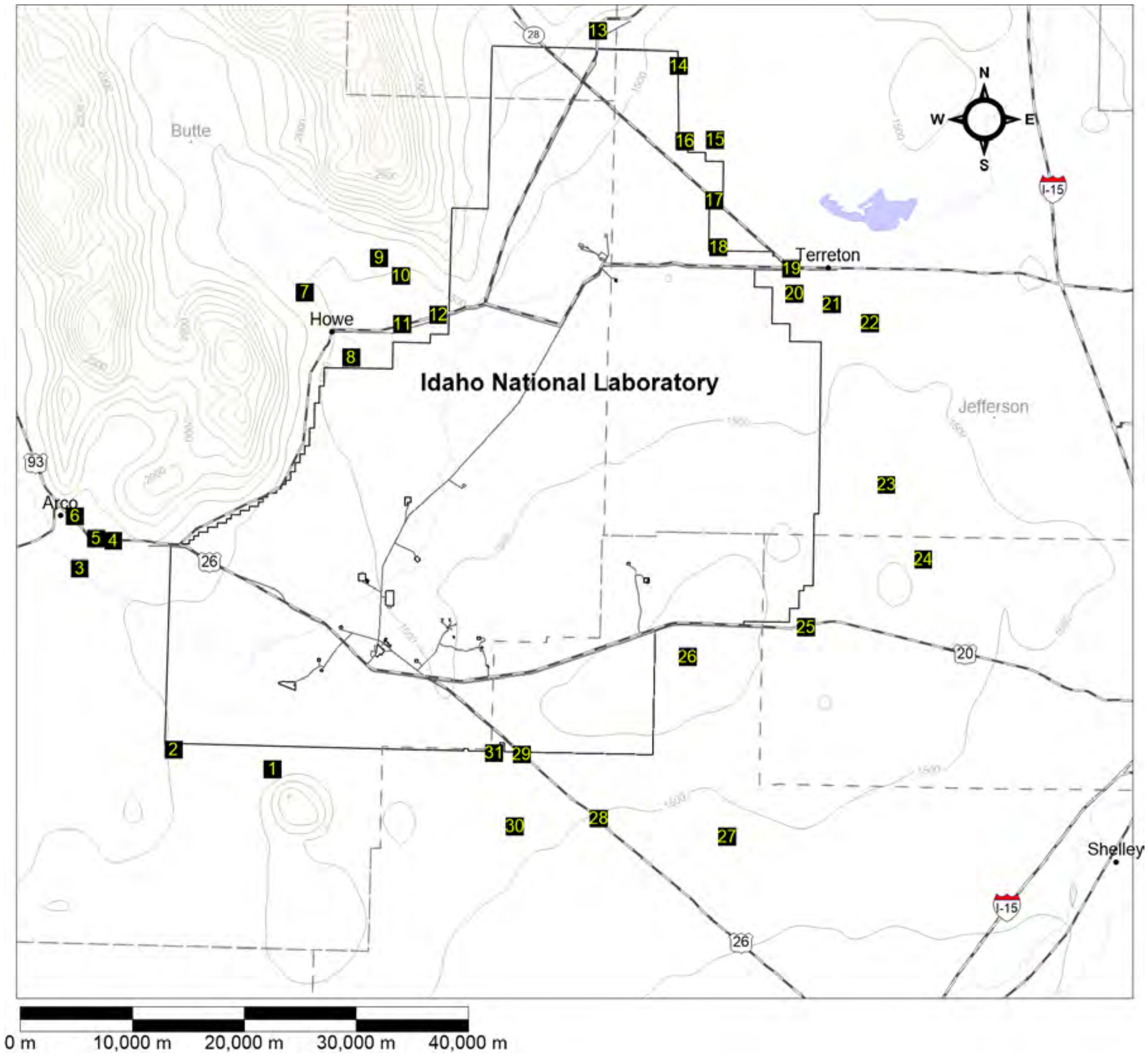

Figure 1. Maximally exposed individual locations surrounding the INL Site. The 31 locations (black squares) used in the CAP88 modeling are from Overin et al., (2023).

INL In-Town MEI Doses

The highest dose from INL in-town sources (includes the Idaho Research Center [IRC] and RESL) was calculated at the nearest HYSPLIT model node northeast of the IRC (1,139 m, azimuth bearing 2.07 degrees) of the RESL/IRC facility (longitude -112.03412, latitude 43.51462 HYSPLIT node number 8279) (Table 15). This location represents the HYSPLIT node nearest to the intown receptor number 19 (952 m azimuth 4.03 degrees from building IF-603). The HYSPLIT grid resolution (about 2 km) was such that close in receptors could not be represented. All 30 of the potential MEI in-town receptors were run and DOSEMM assigns the closest grid node to each receptor.

The total dose was 9.37E-06 mrem/yr (Table 15 and Table 16) which about three orders of magnitude lower than the dose for INL Site sources at the INL Site MEI location. Important radionuclides from the DOSEMM modeling for INL in-town facilities were Pu-239 (37.76%), Pu-238 (20.26%), Am-241 (16.88%), U-233 (4.86%), Ra-226 (4.13%), and Ac-227 (2.45%).

The CAP88 dose for INL in-town facilities was 4.79E-03 mrem yr^{-1} which is a factor of 500 greater than that calculated by HYSPLIT/DOSEMM, but this value was calculated 147m south of IF-683. The HYSPLIT grid did not resolve these close in receptors. Important radionuclides in the CAP88 simulation were Pu-239 (33.10%), Am-241 (21.8%), Pu-238 (17.7%), Ra-226 (7.54%), and U-233 (2.60%). The differences between the CAP88 and HYSPLIT/DOSEMM results are explained in the next section.

Table 15. Dose by pathway and radionuclide type at the INL in-town MEI location for the HYSPLIT/DOSEMM model simulation for the 2023 ASER. Noble gas isotopes were not significant radionuclides but were nonetheless included in the simulation.

Pathway	Particulates (mrem yr^{-1})	Iodine (mrem yr^{-1})	Noble gas (mrem yr^{-1})	C-14, H-3 (mrem yr^{-1})	Total (mrem yr^{-1})
Inhalation, direct	7.27E-06	1.33E-09	0.00E+00	2.35E-09	7.27E-06
Inhalation, resuspension	7.67E-07	9.98E-10	0.00E+00	0.00E+00	7.68E-07
Ingestion, Leafy Veg	5.11E-08	6.66E-09	0.00E+00	5.79E-10	5.83E-08
Ingestion, Other Veg	5.72E-07	8.18E-08	0.00E+00	5.67E-09	6.60E-07
Ingestion Beef	2.65E-07	3.21E-08	0.00E+00	4.73E-09	3.02E-07
Ingestion Milk	4.34E-08	5.16E-08	0.00E+00	4.79E-09	9.98E-08
External, ground	2.03E-07	7.24E-09	0.00E+00	0.00E+00	2.11E-07
Submersion in air	2.67E-10	1.49E-11	3.50E-09	2.72E-14	3.78E-09
All Pathway	9.17E-06	1.82E-07	3.50E-09	1.81E-08	9.37E-06

Table 16. Dose by radionuclide at the INL in-town MEI location for the HYSPLIT/DOSEMM and CAP88 version 4.1 model simulations for the 2023 ASER.

Radionuclide	DOSEMM Dose (mrem yr^{-1})	DOSEMM Fraction of Total	CAP88 Dose (mrem yr^{-1})	CAP88 Fraction of Total
Pu-239	3.55E-06	37.76%	1.58E-03	33.10%
Pu-238	1.90E-06	20.26%	8.48E-04	17.70%
Am-241	1.59E-06	16.88%	1.04E-03	21.80%
U-233	4.57E-07	4.86%	1.25E-04	2.60%
Ra-226	3.89E-07	4.13%	3.61E-04	7.54%
Ac-227	2.31E-07	2.45%	9.11E-05	1.90%
Cs-134	2.26E-07	2.40%	2.96E-05	0.62%
U-232	2.23E-07	2.37%	1.22E-04	2.54%
Pb-210	1.28E-07	1.36%	5.97E-05	1.25%
I-125	1.16E-07	1.23%	2.60E-05	0.54%
Pa-231	1.04E-07	1.10%	2.75E-05	0.58%
Sr-90	9.80E-08	1.04%	5.77E-05	1.21%
Cs-137	6.90E-08	0.735%	8.54E-05	1.78%
I-131	6.61E-08	0.703%	1.02E-05	0.21%
Np-237	5.40E-08	0.574%	3.82E-05	0.80%
Na-22	4.61E-08	0.490%	2.66E-05	0.56%
Eu-154	4.10E-08	0.436%	7.99E-05	1.67%
Am-243	3.15E-08	0.335%	2.09E-05	0.44%

Radionuclide	DOSEMM Dose (mrem yr^{-1})	DOSEMM Fraction of Total	CAP88 Dose (mrem yr^{-1})	CAP88 Fraction of Total
H-3	1.81E-08	0.193%	8.76E-06	0.18%
Co-60	1.76E-08	0.188%	2.42E-05	0.51%
Eu-152	9.70E-09	0.103%	2.63E-05	0.55%
Ba-133	6.93E-09	0.074%	5.66E-05	1.18%
Xe-133	3.50E-09	0.037%	1.85E-05	0.39%
Total	9.37E-06		4.79E-03	

Comparison with CAP88 Effective Dose at the INL Site and Town MEI Location

CAP88 version 4.1 effective doses were calculated at receptor locations surrounding the INL Site that represent potential locations where a person might reside (Figure 1). The maximum effective dose for the INL Site MEI was calculated at receptor 26 in Figure 1. The CAP88 version 4.1 MEI dose at receptor 26 was 2.91×10^{-2} mrem yr^{-1} whereas DOSEMM calculated a dose of 6.01×10^{-3} mrem yr^{-1} at this location, which represents a factor of 4.84 difference.

The lower doses of the HYSPLIT/DOSEMM model are attributed to 1) lower HYSPLIT dispersion factors compared to those from CAP88, 2) different dose coefficients between DOSEMM and CAP88, and 3) build-up in soil for external exposure. Dispersion factors reflect differences in plume trajectory, turbulent diffusion, terrain complexities, plume depletion, and sector averaging between the HYSPLIT and CAP88 models. Releases from MFC accounted for most of the dose at the MEI. The average particulate X/Q calculated with HYSPLIT for releases at MFC was 1.16E-08 s m^{-3}. Based on CAP88 modeling performed for year 2023, the X/Q at the MEI from MFC was 4.04E-08 s m^{-3}. This represents a factor of 3.5 difference in airborne concentration and deposition between CAP88 and HYSPLIT/DOSEMM.

The second difference between CAP88 and HYSPLIT/DOSEMM doses resides with the dose coefficients. CAP88 doses are based on dose coefficients derived in Federal Guidance Report 13 whereas the DOSEMM simulation used the most recent compilation of dose coefficients in DOE (2022) for internal dosimetry and FGR-15 (EPA 2019) for external dosimetry. The ingestion and inhalation dose coefficients in DOE (2022) implement a physiological-based biokinetic model that differs from the simple retention-based models used previously. For U-238, ingestion and inhalation dose coefficients are a factor of 1.07 and 1.45 respectively higher in CAP88 compared to DOE (2022). For Cl-36, ingestion dose coefficients are about the same between DOE (2022) and CAP88. Inhalation was a minor pathway for Cl-36.

The remainder of the difference is attributed to the CAP88 100-year buildup time in soil for external dose calculations. A 100-year buildup time is used in DOSEMM for accumulation of activity in vegetables, milk, and meat but not soil for external dose calculations. In DOSEMM the buildup in soil only occurs for the source input time (i.e., 1-year) and deposition is mixed in a 3-cm surface layer with a radionuclide-specific removal rate constant. In CAP88, the deposition is mixed in a 15-cm surface layer with a removal rate constant of 0.02 y^{-1} for all radionuclides. The surface removal rate constant can be found in the CAP88 ".GEN" file listed under radionuclide-dependent parameters and surface decay constant. Radionuclide buildup in surface soil for DOSEMM and CAP88 is given by

$$C(t) = \frac{\psi}{k}\left(1 - e^{-kt}\right) \tag{1}$$

where

$C(t)$ = surface soil concentration as a function of time, t (Ci m^{-2}),

ψ = surface deposition rate (Ci m^{-2} s^{-1}),

k = effective removal rate constant, leaching plus radioactive decay (s^{-1}),
t = deposition time (1 year for DOSEMM, 100 years for CAP88).

The effective removal rate constant includes radioactive decay and leaching. In DOSEMM, leaching is accounted for using a first-order leach rate constant calculated by

$$k_L = \frac{I}{\theta\, T\left(1+\frac{K_d\,\rho_b}{\theta}\right)} \quad (2)$$

where
k_L = leach rate constant (y^{-1}),
I = infiltration rate (10 cm/yr, default value in DOE-ID, 1994)
θ = moisture content (0.3 m^3/m^3, default value in DOE-ID 1994),
T = layer thickness (0.03 m for surface layer),
K_d = soil-water partitioning coefficient (mL g^{-1}),
ρ_b = bulk soil density (1.5 g m^{-3}, default value in DOE-ID, 1994).

Radionuclides with significant gamma exposure from deposition in the surface soil are Cs-137 and U-238 for INL Site facilities and Cs-137 and Ra-226 for in-town facilities. There were also some differences in the dose coefficients between CAP88 and DOSEMM. Differences in buildup and dose coefficients are summarized in Table 17.

Table 17. Parameters and dose coefficients for important gamma-emitting radionuclides for the surface soil external exposure dose pathway for CAP88 and DOSEMM.

Parameter	Cs-137	U-238	Ra-226
Important progeny	Ba-137m	Th-234, Pa-234m	Pb-214, Bi-214
CAP88 Removal rate constant (y^{-1})	0.02	0.02	0.02
DOSEMM Removal rate constant (y^{-1})	4.83E-4	4.47E-2	3.17E-2
Decay rate constant (y^{-1})	2.30E-02	1.55E-10	4.33E-04
CAP88 Dose coefficients (rem-m^2/Ci-s)[a,b]	2.14E-03	4.46E-04	6.14E-03
DOSEMM Dose coefficients (rem-m^2/Ci-s)[b]	1.39E-03	5.04E-4	4.32E-03
CAP88/DOSEMM factor for soil buildup	23.2	44.2	43.3
CAP88/DOSEMM factor for dose coefficients	1.54	0.841	1.42
Total CAP88/DOSEMM factor[c]	35.9	37.2	12.9

a. Converted from mrem-cm^2/µC-y to rem-m^2/Ci-y using conversion factor 1/3.1536E+08.
b. Includes contributions from all important progeny.
c. Product of CAPP8/DOSEMM ratio for soil buildup and dose coefficients. This factor is multiplied by the DOSEMM external dose to adjust it to an equivalent CAP88 dose.

Adjusting for the X/Q difference (3.5), inhalation and ingestion dose coefficient difference for uranium isotopes, and 100-year buildup for external exposure from Cs-137 and U-238 accounts for almost all the difference between the CAP88 dose and the HYSPLIT/DOSEMM dose at the INL

Site MEI. The corrected DOSEMM total annual effective dose was 0.0276 mrem whereas the CAP88 total annual effective dose was 0.0291 mrem.

The difference between the MEI dose for the in-town receptor was mostly attributed to the X/Q differences, differences in dose coefficients, and buildup in soil for Cs-137 and Ra-226. The HYSPLIT X/Q at the in-town MEI was 1.42E-06 s m^{-3} whereas the CAP88 X/Q was 3.94E-04 s m^{-3} at the MEI (a factor of 278) for releases from Building 683. The CAP88/DOSEMM ratio of inhalation dose coefficients were 1.79, 2.60, and 1.79 for Pu-239, Am-241, and Pu-238 respectively. Combined with the correction factors for the external exposure pathway (see Table 17) the DOSEMM total annual effective dose was 4.70E-3 mrem whereas the CAP88 dose was 4.77E-03 mrem. In all these comparisons, the dose from resuspension calculated in DOSEMM was omitted from the total because CAP88 does not include the resuspension pathway.

TOTAL EFFECTIVE DOSE ISOPLETH MAP

An isopleth map of total effective dose across the model domain based on the MEI receptor scenario is shown in Figure 2. The INL Site MEI location (receptor 26) is indicated by the blue star near the southern INL boundary and south of the MFC facility. The isopleths reflect the southwest to northeast prevailing winds at the INL and terrain features. An ASCII text file containing the effective dose by exposure pathway at each of the model grid nodes is provided in the file *EffectiveTotal.dat*. As expected, doses from the Idaho Falls facilities were not discernable in the dose contours.

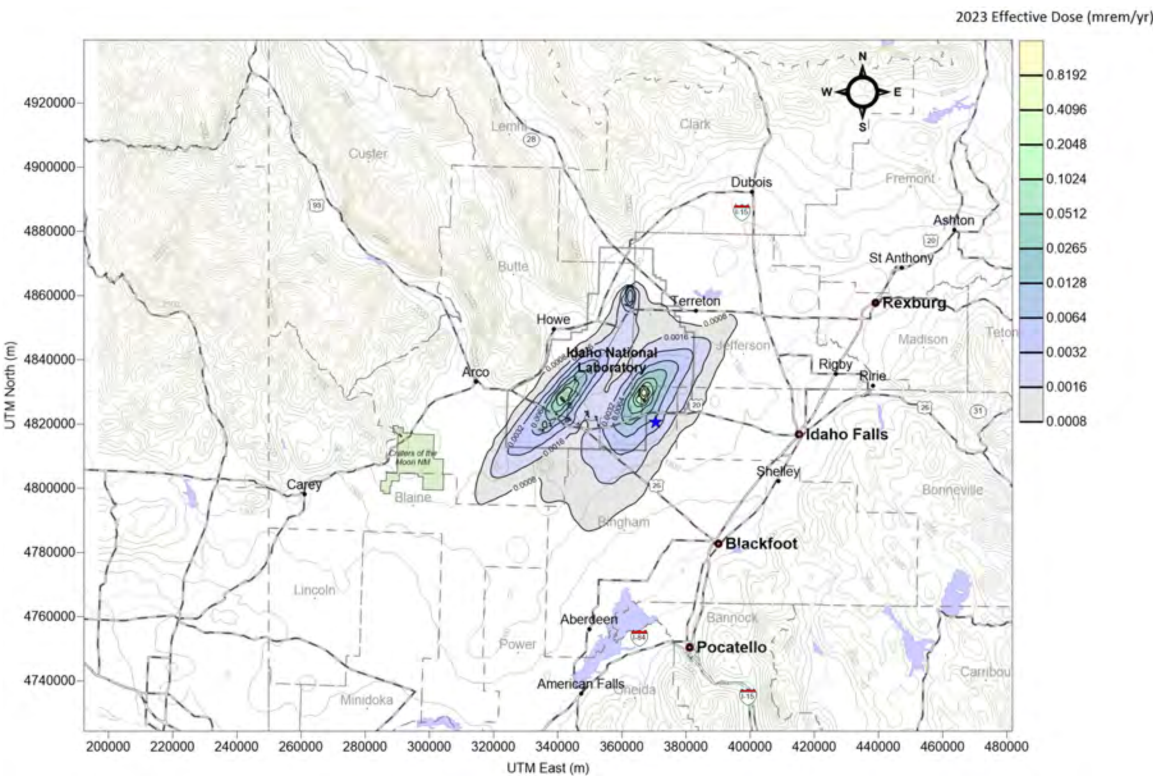

Figure 2. Isopleth map to total effective dose based on the MEI exposure scenario. The INL Site MEI at receptor 26 location is depicted as a blue star south of the INL southern boundary and near the MFC facility.

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APPENDIX A: PERL SCRIPT FOR EXTRACTING NETCDF FILES AND PROCESSING

The NetCDF files obtained from NOAA were received in a separate zip file for each facility. Each zip file was opened and in the process, created a new directory for each facility. For each facility there were 12 separate NetCDF files representing results for each month of the year. After extracting all the zip files in a directory, the runncdump.pl Perl script was run. The output files from ncdump are ASCII files that are then processed through ppnetcdf.f95 Fortran utility program. A separate parameter definition file is needed for each source. A sample parameter definition file is shown following the Perl script. The ppnetcdf input file references a file named latlon.asc. This file is produced from ncdump by

ncdump –v lat,lon [ncdumpfile] > latlon.asc

The latlon file is the same for all sources, and all years of assessment because the grid spacing and origins do not change. A sample latlon file is shown following the sample ppnetcdf input file.

```
# runncdump.pl
# This script runs ncdump and extracts concentration and deposition varaibles for each
month and each facility
# Written by A.S. Rood, 06/19/17 for Wastren Inc

# -------------------------- User Input ---------------------------------------
#@dirlst = ("ATR_surface_2016","CFA_surface_2016");

# enter the directory name for each source
@dirlst =
("ATR_stack_2016","INTEC_stack_2016","INTEC_surface_2016","MFC_stack_2016","NRF_surface_2
016","RWMC_surface_2016");

# ------------------------- End of User Input ---------------------------------

$ndir=$#dirlst;

for $i (0..$ndir)
{
   print "$dirlst[$i]\n";
   $cline=$dirlst[$i] . "/*.nc >junk";
   system "ls $cline";
   open(LST,"<junk");
   while ($line=<LST>)
   {
     chomp $line;
     $ofile=$line;
     $ofile =~ s/nc/asc/;
     $cline="ncdump -v con1,con2,con3,dep2,dep3 ".$line." >$ofile";
     print "$cline\n";
     system "$cline";
   }

}
```

Sample Input File for ppnetcdf.f95

```
INTEC_stack   5                                [srcname] [nvar]
con1,con2,con3,dep2,dep3             [varnames]
tracerxq,partxq,iodinexq,partpq,iodinepq      [specielist]
1  1  1  2  2                         [vtypeindx]
'../latlon.asc'                             [flatlon]
-1 -1 -1 -1                          [iminx][iminy[imaxx][imaxy]
```

```
12                                    [zone]
12                                    [nnetcdf]
Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sep,Oct,Nov,Dec       [ncdfnames]
INTEC_stack_2018_01.asc                               [dfile]
INTEC_stack_2018_02.asc                               [dfile]
INTEC_stack_2018_03.asc                               [dfile]
INTEC_stack_2018_04.asc                               [dfile]
INTEC_stack_2018_05.asc                               [dfile]
INTEC_stack_2018_06.asc                               [dfile]
INTEC_stack_2018_07.asc                               [dfile]
INTEC_stack_2018_08.asc                               [dfile]
INTEC_stack_2018_09.asc                               [dfile]
INTEC_stack_2018_10.asc                               [dfile]
INTEC_stack_2018_11.asc                               [dfile]
INTEC_stack_2018_12.asc                               [dfile]
```

Sample latlon file produced by ncdump

```
netcdf ATR_stack_2018_01 {
dimensions:
        x = 177 ;
        y = 101 ;
variables:
        float lat(y) ;
                string lat:long_name = "Latitude of grid points" ;
                string lat:units = "deg N" ;
        float lon(x) ;
                string lon:long_name = "Longitude of grid points" ;
                string lon:units = "deg W" ;
        double xutm(x, y) ;
                string xutm:long_name = "UTM easting" ;
                string xutm:units = "m" ;
                xutm:zone = 12 ;
                string xutm:datum = "WGS84" ;
        double yutm(x, y) ;
                string yutm:long_name = "UTM northing" ;
                string yutm:units = "m" ;
                yutm:zone = 12 ;
                string yutm:datum = "WGS84" ;
        float con1(x, y) ;
                string con1:long_name = "Monthly average concentration species 1" ;
                string con1:units = "g m-3" ;
                con1:layer_bottom_m_agl = 0.f ;
                con1:layer_top_m_agl = 50.f ;
                string con1:deposition_vel = "0.0000 m/s" ;
                string con1:release_rate = "1.0 g/s" ;
        float con2(x, y) ;
                string con2:long_name = "Monthly average concentration species 2" ;
                string con2:units = "g m-3" ;
                con2:layer_bottom_m_agl = 0.f ;
                con2:layer_top_m_agl = 50.f ;
                string con2:deposition_vel = "0.0018 m/s" ;
                string con2:release_rate = "1.0 g/s" ;
        float con3(x, y) ;
                string con3:long_name = "Monthly average concentration species 3" ;
                string con3:units = "g m-3" ;
                con3:layer_bottom_m_agl = 0.f ;
                con3:layer_top_m_agl = 50.f ;
                string con3:deposition_vel = "0.0350 m/s" ;
                string con3:release_rate = "1.0 g/s" ;
        float dep2(x, y) ;
                string dep2:long_name = "Monthly average dry deposition species 2" ;
                string dep2:units = "g m-2" ;
                string dep2:deposition_vel = "0.0018 m/s" ;
                string dep2:release_rate = "1.0 g/s" ;
        float dep3(x, y) ;
```

```
                string dep3:long_name = "Monthly average dry deposition species 3" ;
                string dep3:units = "g m-2" ;
                string dep3:deposition_vel = "0.0350 m/s" ;
                string dep3:release_rate = "1.0 g/s" ;

// global attributes:
                string :description = "HYSPLIT monthly average concentration and
depositon" ;
                string :facility = "ATR" ;
                string :release_type = "stack" ;
                :source_lat = 43.589f ;
                :source_lon = -112.9671f ;
                :source_hgt_m_agl = 76.2f ;
                :model_top_m_msl = 6500. ;
                :grid_center_lat = 43.6f ;
                :grid_center_lon = -113.f ;
                :grid_spacing_lat = 0.02f ;
                :grid_spacing_lon = 0.02f ;
                string :release_start = "2016-12-31 0000 MST" ;
                string :release_end = "2017-02-01 0000 MST" ;
                string :averaging_start = "2017-01-01 0000 MST" ;
                string :averaging_end = "2017-02-01 0000 MST" ;
                :setup_cfg_rev = 6 ;
                :stack_dia_m = 1.524f ;
                :stack_exit_vel_ms = 10.03f ;
                :stack_exit_temp_K = 293.f ;
                string :contact = "Richard Eckman" ;
                string :email = "richard.eckman@noaa.gov" ;
                string :data_version = "1.0" ;
data:

 lat = 42.6, 42.62, 42.64, 42.66, 42.68, 42.7, 42.72, 42.74, 42.76, 42.78,
    42.8, 42.82, 42.84, 42.86, 42.88, 42.9, 42.92, 42.94, 42.96, 42.98, 43,
    43.02, 43.04, 43.06, 43.08, 43.1, 43.12, 43.14, 43.16, 43.18, 43.2,
    43.22, 43.24, 43.26, 43.28, 43.3, 43.32, 43.34, 43.36, 43.38, 43.4,
    43.42, 43.44, 43.46, 43.48, 43.5, 43.52, 43.54, 43.56, 43.58, 43.6,
    43.62, 43.64, 43.66, 43.68, 43.7, 43.72, 43.74, 43.76, 43.78, 43.8,
    43.82, 43.84, 43.86, 43.88, 43.9, 43.92, 43.94, 43.96, 43.98, 44, 44.02,
    44.04, 44.06, 44.08, 44.1, 44.12, 44.14, 44.16, 44.18, 44.2, 44.22,
    44.24, 44.26, 44.28, 44.3, 44.32, 44.34, 44.36, 44.38, 44.4, 44.42,
    44.44, 44.46, 44.48, 44.5, 44.52, 44.54, 44.56, 44.58, 44.6 ;

 lon = -114.76, -114.74, -114.72, -114.7, -114.68, -114.66, -114.64, -114.62,
    -114.6, -114.58, -114.56, -114.54, -114.52, -114.5, -114.48, -114.46,
    -114.44, -114.42, -114.4, -114.38, -114.36, -114.34, -114.32, -114.3,
    -114.28, -114.26, -114.24, -114.22, -114.2, -114.18, -114.16, -114.14,
    -114.12, -114.1, -114.08, -114.06, -114.04, -114.02, -114, -113.98,
    -113.96, -113.94, -113.92, -113.9, -113.88, -113.86, -113.84, -113.82,
    -113.8, -113.78, -113.76, -113.74, -113.72, -113.7, -113.68, -113.66,
    -113.64, -113.62, -113.6, -113.58, -113.56, -113.54, -113.52, -113.5,
    -113.48, -113.46, -113.44, -113.42, -113.4, -113.38, -113.36, -113.34,
    -113.32, -113.3, -113.28, -113.26, -113.24, -113.22, -113.2, -113.18,
    -113.16, -113.14, -113.12, -113.1, -113.08, -113.06, -113.04, -113.02,
    -113, -112.98, -112.96, -112.94, -112.92, -112.9, -112.88, -112.86,
    -112.84, -112.82, -112.8, -112.78, -112.76, -112.74, -112.72, -112.7,
    -112.68, -112.66, -112.64, -112.62, -112.6, -112.58, -112.56, -112.54,
    -112.52, -112.5, -112.48, -112.46, -112.44, -112.42, -112.4, -112.38,
    -112.36, -112.34, -112.32, -112.3, -112.28, -112.26, -112.24, -112.22,
    -112.2, -112.18, -112.16, -112.14, -112.12, -112.1, -112.08, -112.06,
    -112.04, -112.02, -112, -111.98, -111.96, -111.94, -111.92, -111.9,
    -111.88, -111.86, -111.84, -111.82, -111.8, -111.78, -111.76, -111.74,
    -111.72, -111.7, -111.68, -111.66, -111.64, -111.62, -111.6, -111.58,
    -111.56, -111.54, -111.52, -111.5, -111.48, -111.46, -111.44, -111.42,
    -111.4, -111.38, -111.36, -111.34, -111.32, -111.3, -111.28, -111.26,
    -111.24 ;
}
```