INL/MIS-18-51849-Revision-1

Evaluation of Impacts from Radiological Air Emissions for the HALEU Environmental Assessment

A Jeffrey Sondrup

December 2018

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

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Prepared for the
U.S. Department of Energy

Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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ECAR No.: 4321 Rev. No.: 1 Project No.: N/A Date: 12/20/2018

1. Does this ECAR involve a Safety SSC?	N/A	**Professional Engineer's Stamp** N/A PE Stamp Not Required per LWP-10010.
2. Safety SSC Determination Document ID	N/A	
3. Engineering Job (EJ) No.	N/A	
4. SSC ID	N/A	
5. Building	N/A	
6. Site Area	MFC/INTEC	

7. Objective/Purpose:

This report contains an evaluation of radiological impacts to members of the public and collocated workers from potential air emissions resulting from production of high-assay low-enriched uranium (HALEU) fuel at Idaho National Laboratory (INL). This work considers impacts from presumed normal operations for the two alternatives outlined in *Environmental Assessment for Use of DOE-Owned HALEU Stored at INL* (DOE-EA 2018).

8. If revision, please state the reason and list sections and/or pages being affected:

Revision 1 includes an assessment of potential impacts to groundwater from deposition of radionuclide air emissions. A new section (Groundwater Pathway Dose Assessment) was added and the Summary and Conclusions section was updated to include the groundwater results.

9. Conclusions/Recommendations

Conservative estimates of dose to workers and the public from atmospheric transport of potential radionuclide emissions are substantially less than applicable standards for both alternatives considered. Maximum estimated soil concentrations from the emissions were also determined to be less than conservative EPA risk-based screening levels. Potential contamination of groundwater from air emissions depositing on soil and migrating to the aquifer was also considered, and resulting doses were well below regulatory limits. Because all impacts are based on maximum, unabated/unmitigated potential emissions and other conservative or bounding assumptions, it is highly unlikely the alternatives evaluated in this ECAR will adversely impact human health.

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PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
Performer	A. Jeffrey Sondrup	B360	eCR 665338
Checker[a]	Tim A. Solle	H510	eCR 665338
Independent Reviewer[b]	Mark A. Verdoorn	H530	eCR 665338
CUI Reviewer[c]	Jennifer L. Churchill	M310	STI INL/MIS-18-51849
Manager[d]	Brady J. Orchard	B360	eCR 665338
Requestor[e]	John S. Irving	J211	eCR 665338
Nuclear Safety[e]	N/A	N/A	
Document Owner[e]	A. Jeffrey Sondrup	B360	eCR 665338

Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.

b. Concurrence of method or approach. See definition, LWP-10106.

c. Concurrence with the document's markings in accordance with LWP-11202.

d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.

e. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

SCOPE AND BRIEF DESCRIPTION

The U. S. Department of Energy (DOE) proposes to expand the fuel fabrication capability at Idaho National Laboratory (INL) to produce needed quantities of high-assay low-enriched uranium (HALEU) fuel from HALEU material (feedstock) stored at INL. The expansion of the fuel fabrication capability would include the purchase of new equipment and proposed use of existing facilities at INL's Materials and Fuels Complex (MFC) and Idaho Nuclear Technology and Engineering Center (INTEC). This report contains an evaluation of radiological impacts to members of the public and collocated workers from potential air emissions resulting from HALEU fuel production at INL. This work considers impacts from presumed normal operations and supports the *Environmental Assessment for Use of DOE-Owned HALEU Stored at Idaho National Laboratory* (DOE-EA 2018).

The Environmental Assessment (EA) (DOE-EA 2018) proposes to process up to 5,000 kg of HALEU feedstock annually at INL. Alternative 1a of the EA proposes 2,500 kg be processed annually at each of two facilities at MFC, and Alternative 1b proposes 2,500 kg be processed annually at an MFC facility and 2,500 kg processed annually at an INTEC facility.

Atmospheric dispersion and dose calculations for public and collocated worker receptors were performed in accordance with the requirements of Code of Federal Regulations (CFR), Title 40, "Protection of the Environment," Part 61, "National Emission Standards for Hazardous Air Pollutants (NESHAPs)," Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (40 CFR 61, Subpart H 2010). Emission potentials were calculated based on the methodology in 40 CFR 61, Appendix D and additional guidance/approval by EPA Region 10 (see letter from Donald Dossett [EPA Region 10] to Tim Safford [DOE-ID], Oct 19, 2017 [CCN 241475]) for solid materials that undergo heating. Estimates of total effective dose are based on low-level chronic exposure.

Additional impacts not considered by the CAP88-PC modeling—namely, incidental ingestion of contaminated soil and inhalation of fugitive dust (particulate matter)—were assessed by calculating conservative soil concentrations due to build-up of particulate deposition during operations, and comparing the concentrations to EPA preliminary remediation goals (PRGs). PRGs are risk-based screening levels that would not likely result in adverse health impacts under reasonable maximum exposure conditions for long-term/chronic exposures.

DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

The following are sources for the primary data used in the assessment:

1. A representative radionuclide source term (radionuclide content of the HALEU feedstock material) was derived through a combination of measured values obtained by analysis and calculated values obtained by process modeling (see TEV-3537).

2. Melting points and boiling points of the radionuclides for determining emission potential were taken from the *CRC Handbook of Chemistry and Physics* http://hbcponline.com/faces/contents/InteractiveTable.xhtml?tableId=15.

3. Meteorological data from the MFC and GRID3 MESONET stations at INL were provided by the Idaho Falls National Ocean Atmospheric Administration (NOAA) Air Resources Laboratory.

Other data sources and references are provided in the Discussion/Analysis section.

RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

See Discussion/Analysis Section and References Section.

ASSUMPTIONS

See Discussion/Analysis Section.

COMPUTER CODE VALIDATION

All computer code modeling and calculations were performed on a Dell Optiplex 7020 computer (Intel Core i7-4790 CPU @ 3.60 GHz, property tag 604112) running Microsoft Windows 7 Enterprise, Service Pack 1. Atmospheric transport modeling of radionuclide emissions was performed using the CAP88-PC Version 4 (EPA 2013a) computer model. CAP88-PC is a set of computer programs, databases, and associated utility programs for estimation of dose and risk from radionuclide emissions to the air. CAP88-PC is both a mature and the EPA-recommended model for demonstration of compliance with the applicable performance objective (40 CFR 61, Subpart H). Testing and validation of CAP88-PC is performed by EPA and documented in EPA (2013b). Verification of proper installation and operation of CAP88-PC is performed annually at INL by simulating the example problem (Modtest) provided in the CAP88-PC download zip file. Additional information about CAP88-PC can be found at http://www.epa.gov/radiation/assessment/CAP88/aboutcap88.html.

Groundwater pathway calculations were performed with the GWSCREEN computer code, Version 2.5a (Rood 2003). GWSCREEN was developed at INL and has been used in numerous groundwater investigations at INL. Installation and validation is documented in *Software Verification and Validation Plan for the GWSCREEN Code* (Rood 1993) and the *GWSCREEN Configuration Management, Validation Test Plan, and Validation Test Report* (EDF-7372 2006). The version date of the GWSCREEN code is January 23, 2007.

Microsoft Excel 2013 (15.0.5041.1000) MSO (15.0.5031.1000) 32 bit, part of Microsoft Office Professional Plus 2013, was used for supporting calculations and creating graphs of results. Cell formulas were checked for accuracy, and a sample of the calculations were checked by hand. All formula cells have been locked for editing and password protected.

All electronic files, including computer input, output, and spreadsheet files are contained in a zip file that can be accessed by selecting “Additional Information” (select Native File) in the INL Electronic Document Management System.

DISCUSSION/ANALYSIS

Air Pathway Dose Assessment

Source Term and Emissions Potential

This evaluation assumes a maximum annual production rate of 2,500 kg per facility which equates to 50 batches of 50 kg each HALEU feedstock material. Table 1 contains the radionuclide activity in 2,500 kg of HALEU feedstock material. This was determined using the radionuclide composition in HALEU feedstock material from TEV-3537 (column 2), to determine the mass in 2,500 kg of HALEU material (column 3), that was converted to activity (column 5) using radionuclide specific-activity values (column 4). The inventory in Table 1 includes all major nuclides whose concentrations were measured by analysis or determined by modeling; other nuclides, including radioactive decay products, may be present at very low concentrations but it is highly unlikely they would contribute to the estimated dose.

Table 1. Composition of HALEU feedstock material.

Radionuclide	Composition	Mass in 2,500 kg Feedstock (g)	Radionuclide Specific Activity (Ci/g)[e]	Activity in 2,500 kg Feedstock (Ci)
Mn-54	3.04E-06 ppm[a]	7.60E-06	7.75E+03	5.89E-02
Co-60	2.78E-05 ppm[a]	6.95E-05	1.13E+03	7.86E-02
Sr-90	1.58E-02 ppm[a]	3.94E-02	1.37E+02	5.40E+00
Tc-99	1.50E-01 ppm[a]	3.75E-01	1.71E-02	6.41E-03
Sb-125	1.03E-04 ppm[a]	2.56E-04	1.04E+03	2.67E-01
Cs-134	2.50E-05 ppm[a]	6.25E-05	1.29E+03	8.06E-02
Cs-135	2.67E+00 ppm[a]	6.68E+00	1.15E-03	7.68E-03
Cs-137	8.00E-03 ppm[a]	2.00E-02	8.68E+01	1.74E+00
Ce-144	6.71E-05 ppm[a]	1.68E-04	3.18E+03	5.34E-01
Eu-154	2.20E-04 ppm[a]	5.50E-04	2.70E+02	1.49E-01
Eu-155	2.20E-04 ppm[a]	5.50E-04	4.85E+02	2.67E-01
Np-237	1.71E+01 ppm[a]	4.28E+01	7.05E-04	3.02E-02
Pu-239	8.36E+01 ppm[a]	2.09E+02	6.21E-02	1.30E+01
Pu-240	2.24E+00 ppm[a]	5.60E+00	2.27E-01	1.27E+00
Am-241	6.12E-02 ppm[a]	1.53E-01	3.43E+00	5.25E-01
U-234	1.60E-03 wt%U[a,b]	3.99E+03	6.21E-03	2.48E+01
U-235	1.93E-01 wt%U[a,b]	4.80E+05	2.16E-06	1.04E+00
U-236	5.20E-03 wt%U[a,b]	1.30E+04	6.47E-05	8.38E-01
U-238	7.98E-01 wt%U[a,b]	1.99E+06	3.36E-07	6.68E-01
U-232	5.04E-03 ppmU[c]	1.26E-02[d]	2.20E+01	2.77E-01
U-233	3.18E-01 ppmU[c]	7.96E-01[d]	9.64E-03	7.67E-03
U-237	2.20E-07 ppmU[c]	5.50E-07[d]	8.16E+04	4.49E-02

a. Average composition determined from elemental analysis of HALEU feedstock material (TEV-3537, Appendix C).
b. Based on average total weight percent uranium of 99.67% (TEV-3537, Appendix C).
c. Maximum value determined from process modeling (TEV-3537, Appendix B). Maximum values were used to account for uncertainty in the modeling.
d. Based on maximum total weight percent uranium of 99.97% (TEV-3537, Appendix B).
e. Specific activity for pure radionuclide calculated as $\lambda \times N_A$ / (Isotopic Weight × 3.7E+10) where $\lambda = \ln(2)$ / half-life (sec), and N_A is Avogadro's constant 6.02214E+23 atoms/mole. Half-lives taken from NNDC (2018).

To determine the emission potential from each facility, radionuclide activities in Table 1 were multiplied by appropriate emission factors based on the physical state of the HALEU feedstock material during processing. Because the material could undergo heating, an alternative to the method in 40 CFR 61 Appendix D, approved for use at INL by EPA Region 10 (see letter from Donald Dossett [EPA Region

10] to Tim Safford [DOE-ID] Oct 19, 2017 [CCN 241475]) was used to determine the emission factors for radioactive solid materials with high melting and boiling points. These emission factors are:

- 1 for radioactive solid materials heated to temperatures greater than or equal to 90% of the boiling or subliming point.
- 10^{-3} for radioactive solid materials heated to temperatures greater than or equal to their melting point but less than 90% of their boiling or subliming point.
- 10^{-6} for radioactive solid materials heated to temperatures above ambient temperature but less than their melting point.

During processing, the HALEU feedstock material will be heated to an approximate maximum temperature of 1500°C (sintering) or 2000°C (arc melting) depending on the process selected. For this analysis, the higher maximum temperature was used to determine the emission factor for each radionuclide. Table 2 presents the melting point and 90% of boiling point for each radionuclide, the emission factor, and the annual emission potential. The emission potential is the product of the activity inventory and the emission factor and represents the amount that could potentially be released from the facility annually.

Table 2. Unabated annual radionuclide potential to emit for 2,500 kg HALEU feedstock material.

Radionuclide	Activity in 2,500 kg (Ci)[a]	Melting Point (C)[b]	90% Boiling Point (C)[b]	Emission Factor[c]	Emission Potential (Ci/yr)
Mn-54	5.89E-02	1.25E+03	1.85E+03	1	5.89E-02
Co-60	7.86E-02	1.50E+03	2.63E+03	0.001	7.86E-05
Sr-90	5.40E+00	7.77E+02	1.24E+03	1	5.40E+00
Tc-99	6.41E-03	2.16E+03	3.84E+03	0.000001	6.41E-09
Sb-125	2.67E-01	6.31E+02	1.43E+03	1	2.67E-01
Cs-134	8.06E-02	2.85E+01	6.04E+02	1	8.06E-02
Cs-135	7.68E-03	2.85E+01	6.04E+02	1	7.68E-03
Cs-137	1.74E+00	2.85E+01	6.04E+02	1	1.74E+00
Ce-144	5.34E-01	7.99E+02	3.10E+03	0.001	5.34E-04
Eu-154	1.49E-01	8.22E+02	1.38E+03	1	1.49E-01
Eu-155	2.67E-01	8.22E+02	1.38E+03	1	2.67E-01
Np-237	3.02E-02	6.44E+02	3.51E+03	0.001	3.02E-05
Pu-239	1.30E+01	6.40E+02	2.91E+03	0.001	1.30E-02
Pu-240	1.27E+00	6.40E+02	2.91E+03	0.001	1.27E-03
Am-241	5.25E-01	1.18E+03	1.81E+03	1	5.25E-01
U-234	2.48E+01	1.14E+03	3.72E+03	0.001	2.48E-02
U-235	1.04E+00	1.14E+03	3.72E+03	0.001	1.04E-03
U-236	8.38E-01	1.14E+03	3.72E+03	0.001	8.38E-04
U-238	6.68E-01	1.14E+03	3.72E+03	0.001	6.68E-04
U-232	2.77E-01	1.14E+03	3.72E+03	0.001	2.77E-04
U-233	7.67E-03	1.14E+03	3.72E+03	0.001	7.67E-06
U-237	4.49E-02	1.14E+03	3.72E+03	0.001	4.49E-05

a. From Table 1.
b. From *CRC Handbook of Chemistry and Physics*, 99th Edition (2018).
c. Based on maximum processing temperature of 2000°C and EPA approved emission factors (CCN 241475).

For this analysis, doses were calculated for unmitigated emissions. No credit was taken for filtration even though processing will likely take place in a double high-efficiency particulate air (HEPA) filtered facility. Each stage of HEPA filtration removes 99.97% of airborne particulate material. It is likely that much of the radionuclide inventory that could become gaseous during processing would cool, solidify and be captured by the HEPA filters before emission. Nevertheless, the analysis does not credit the HEPA filtration.

Atmospheric Dispersion Modeling

Atmospheric-dispersion modeling of radionuclide emissions was conducted according to guidance for performing environmental compliance-driven air modeling of emissions from INL facilities (Staley et al. 2004). Emissions were modeled from a stack similar to the Irradiated Materials Characterization Laboratory (IMCL) stack at MFC. This stack is approximately 15 m tall, with an exit diameter of 0.6 m and an exit velocity of 13 m/s. Each facility is likely to have a stack similar to this.

Doses were calculated at the following locations for each alternative:

- INL Site boundary nearest MFC: Located 400 m north of INL East entrance on Highway 20. This location is accessible to the public, but there are no permanent residents or public receptors. Regulatory dose limits do not apply at this location. Doses are presented only for reference.

- INL Site boundary nearest INTEC: Located approximately 14 km directly south of the INTEC entrance and 10 km east of Atomic City. The distance to INL's Site boundary northwest of INTEC is approximately the same distance, but the dose at the south receptor is higher. This location is accessible to the public, but there are no permanent residents or public receptors. Regulatory dose limits do not apply at this location. Doses are presented only for reference.

- Residence nearest MFC: This is a farmhouse located 3.1 km south of Highway 20, 3 km from INL's East entrance. Regulatory dose limits apply at this location.

- Atomic City: This town of population 29 (2010 census) is located approximately 2 km east of INL's South entrance on Highway 26. The residence nearest INTEC is located in Atomic City. Atomic City is approximately 21 km SW of MFC and 17 km SE of INTEC. Regulatory dose limits apply at this location.

- Frenchman's Cabin: This location is approximately 2 km south of the southern INL Site boundary near Big Southern Butte. This location is used to show INL Site compliance with 40 CFR 61, Subpart H – National Emissions Standards for Hazardous Air Pollutants (NESHAPs) Other Than Radon From Department of Energy Facilities, and is the location of the INL Site maximally exposed individual (MEI). The site may be inhabited during portions of the year, but there are no permanent residents. Regulatory dose limits do apply to this location because of the potential for occupation during a portion of the year.

The above locations are shown in Figure 1 along with the distance from the sources rounded to the nearest km.

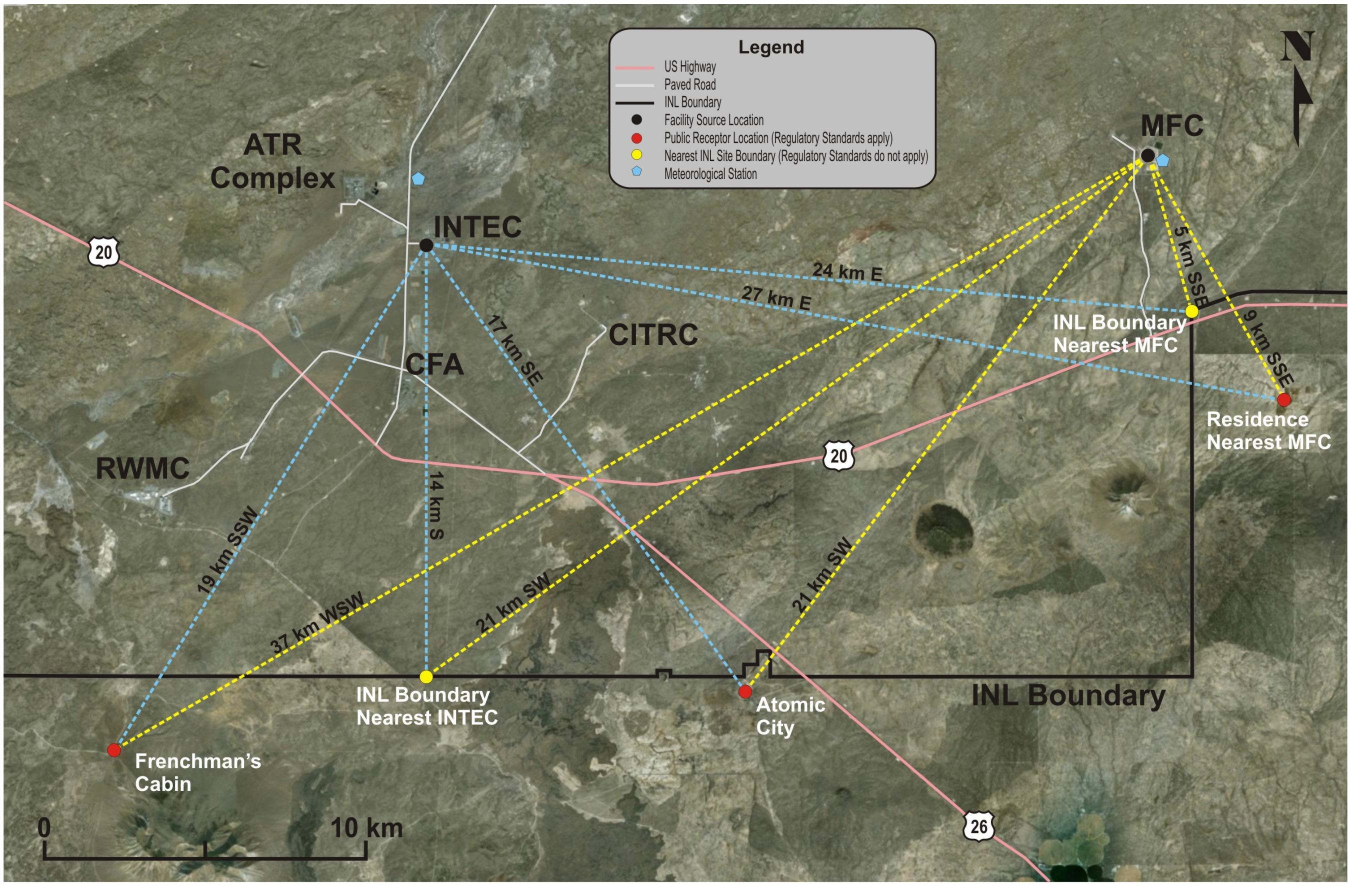


Figure 1. Public receptor locations for the air pathway analysis showing distance and direction from MFC and INTEC. Regulatory dose limits do not apply at the nearest boundary locations.

Collocated worker doses were calculated at 100 m from each source in the direction of maximum dose. For Alternative 1a, the public doses and worker doses were calculated assuming the two facilities at MFC are collocated. This is done by doubling the dose from processing 2,500 kg HALEU feedstock material. This is appropriate for the public dose since the nearest receptors are several km away and any difference in the locations is likely to be small compared to the distance to the receptor. It is conservative and bounding for the collocated worker with respect to where the facilities will be located.

Both public and worker doses were calculated using adult dose coefficients. Public receptor doses were calculated using the "local" food-production option in CAP88-PC to simulate a subsistence-farming scenario where all food products are grown at the receptor location. The CAP88-PC Version 4.0 default parameters for this exposure scenario are shown in Table 3. The collocated worker doses were calculated using the "imported" food-production option. In this case, there is no ingestion dose because the worker does not consume contaminated food products from the receptor location or assessment area. The inhalation, air-immersion and direct-ground-radiation doses for workers output from CAP88-PC were scaled to account for reduced time onsite. The scale factor is 0.228 = 2000 (annual work hours onsite) ÷ 8766 (hours in 1 year).

Table 3. CAP88-PC Version 4.0 radionuclide-independent parameters for the public receptor scenario.

Parameter Description	Value	Units
Inhalation rate	5.263E+03	m^3/year
Effective surface density of soil, dry weight (assumes 15 cm plow depth)	215	kg/m^2
Build-up time for radionuclides in soil	100[a]	year
Build-up time radionuclides deposited on ground/water	3.65E+04	day
Delay time, ingestion of pasture grass by animals	0	hr
Delay time, ingestion of stored feed by animals	2160	hr
Delay time, ingestion of leafy vegetables by man	336	hr
Delay time, ingestion of produce by man	336	hr
Delay time, transport time from animal feed-milk-man	2	day
Delay time, time from animal slaughter to consumption	20	day
Removal rate constant for physical loss by weathering	2.90E-03	1/hr
Crop exposure duration, pasture grass	720	hr
Crop exposure duration, crops or leafy vegetables	1440	hr
Agricultural productivity, grass-cow-milk-man pathway	0.28	kg/m^2
Agricultural productivity, produce/leafy vegetables for human consumption	0.716	kg/m^2
Fallout interception fraction, vegetables	0.2	---
Fallout interception fraction, pasture	0.57	---
Fraction of year animals graze on pasture	0.4	---
Fraction of daily feed that is pasture grass (when animal on pasture)	0.43	---
Animal consumption rate of contaminated feed/forage (dry weight)	15.6	kg/day
Milk production of cow	11	L/day
Muscle mass of animal at slaughter	200	kg
Fraction of animal herd slaughtered per day	3.81E-03	---
Fraction of radioactivity retained after washing (leafy veg & produce)	0.5	---
Fraction of produce ingested grown in garden of interest	1	---
Fraction of leafy vegetables ingested grown in garden of interest	1	---
Human produce ingestion rate	76.2	kg/year
Human milk ingestion rate	53	L/year
Human meat ingestion rate	84	kg/year
Human leafy vegetable ingestion rate	7.79	kg/year
Fraction of time spent swimming	0	---
Depth of water for dilution for water immersion doses	1	cm
Fraction vegetables home produced	1[b]	---
Fraction milk home produced	1[b]	---
Fraction meat home produced	1[b]	---
Fraction vegetables from assessment area	0[b]	---
Fraction meat from assessment area	0[b]	---
Fraction meat from assessment area	0[b]	---
Minimum ingestion fractions from outside area, vegetables	0	---
Minimum ingestion fractions from outside area, meat	0	---
Minimum ingestion fractions from outside area, milk	0	---
Default beef cattle density	7.19E-02[c]	#/ha
Milk cattle density	8.56E-03[c]	#/ha
Land fraction cultivated for vegetables	7.15E-02[c]	---

a. 100-year buildup time is required for NESHAP compliance demonstration. The buildup time is the length of time that isotopes accumulate in the soil based upon continuous deposition, decay, and removal. The isotopic profile in the soil at the end of the buildup period is the one used as input to the dose and risk calculations. This is a conservative assumption for this assessment because the facility is expected to operate only a few years.

b. Value for a local food-source option. Options are urban, rural, local, regional, or imported. Local assumes all food products are grown at the receptor location (i.e., home produced).

c. Values specific to the State of Idaho.

Meteorological Data

Meteorological data files were provided by the Idaho Falls Office of the National Oceanic and Atmospheric Administration (NOAA). Meteorological monitoring stations are located near each of the major INL facilities. Data from the MFC station located immediately east of MFC was used for MFC simulations, and data from the GRID3 station located 1.5 km north of INTEC was used for INTEC simulations (see Figure 1). Data from the lower measurement height (10 m) of each station was used. Stability array (*.str) files provided by NOAA were converted to wind (*.wnd) files using the computer program WINDGET and read directly by CAP88-PC. The wind files are presented in Appendix A. Other meteorological data used in the modeling is provided in Table 4.

Table 4. Other meteorological parameters used for the CAP88-PC modeling.

Variable	Value[a]	Units
Lid height	800	meters
Mean temperature	280.2	Kelvin
Annual Precipitation	20.8	cm/year
Absolute humidity	3.54	g/m^3

a. Values represent a 10-year average at the INL (Clawson et al. 1989).

Radionuclide Data

Each of the radionuclides was modeled using the default chemical form, absorption type, and particle size. In this case, all were modeled as particulate of size 1 micron per FGR13 model data. The CAP88-PC default absorption type for each radionuclide is M (medium) with the exception of the cesium radionuclides which are F (fast).

Air Pathway Dose Results

Annual dose results for low-level chronic exposure to emissions from presumed normal operations of proposed HALEU processing facilities are shown in Tables 5 through 7. Tables 5 and 6 contain the public dose estimates for Alternative 1a and 1b respectively. Table 7 contains collocated worker doses for both alternatives.

Table 5. Public dose estimates for Alternative 1a (5,000 kg processed at MFC).

Potential Receptor Location	Receptor Distance and Direction from Source[a]	Potential Dose (mrem/yr)
INL Site Boundary Nearest MFC[b]	5 km SSE	5.4[b]
Residence Nearest MFC	9 km SSE[c]	2.4[e]
Atomic City	21 km SW[d]	1.9
INL MEI (Frenchman's Cabin)	37 km WSW	0.74

a. Rounded to the nearest kilometer from INTEC entrance.
b. Regulatory dose limits do not apply to this location. Dose results are presented only for reference.
c. Farmhouse located 3.1 km south of Highway 20, 3 km east of INL entrance.
d. Distance to nearest Atomic City residence.
e. Highest potential dose at an offsite location with a residence, school, business or office.

Table 6. Public dose estimates for Alternative 1b (2,500 kg processed at both MFC and INTEC).

Potential Receptor Location	Receptor Distance and Direction from Source[a]	Potential Dose Contribution from INTEC (mrem/yr)	Potential Dose Contribution from MFC (mrem/yr)	Total Potential Dose (mrem/yr)
INL Site Boundary Nearest INTEC[b]	14 km S[c]	1.6[b]	0.59[b]	2.2[b]
Atomic City (Residence Nearest INTEC)[d]	17 km SE	0.55	0.93	1.5
INL MEI (Frenchman's Cabin)	19 km SSW	1.2	0.37	1.6[e]
INL Site Boundary Nearest MFC[b]	24 km E	0.40[b]	2.7[b]	3.1[b]
Residence Nearest MFC	27 km E	0.33	1.2	1.5

a. Rounded to the nearest kilometer from Fuel Conditioning Facility at MFC (MFC-765).
b. Regulatory limits do not apply to this location. Dose results are presented for reference only.
c. The INL Site boundary northwest of INTEC is the same distance as the nearest southern boundary, yet the dose at nearest southern boundary is higher.
d. Atomic City is the location nearest INTEC with a residence. Distance is to nearest residence in Atomic City.
e. Highest potential dose at a location with a residence, school, business or office.

Table 7. Collocated worker dose estimates for Alternatives 1a and 1b.

Alternative	INTEC Worker Dose (mrem/yr)a	MFC Worker Dose (mrem/yr)
1a (5,000 kg processed at MFC)	NA	48
1b (2,500 kg processed at both MFC and INTEC)	33	24

Dose Results Compared to Regulatory Limits

40 CR 61, Subpart H has established the public dose limit for radionuclide emissions to ambient air from all DOE facilities as 10 mrem/yr effective dose equivalent. This applies at any offsite location where there is a residence, school, business, or office. A residence is defined as any home, house, apartment building, or other place of dwelling which is occupied during any portion of the year. For workers, the DOE Occupational Radiation Protection (10 CFR 835) specifies the dose limit for general employees from DOE sources as 5,000 mrem/yr total effective dose.

The results in Tables 5 and 6 show the estimated potential public doses associated with HALEU fuel fabrication are less than the 10 mrem/yr regulatory standard. The largest potential dose from Alternative 1a is 2.4 mrem/yr at residence nearest to MFC, the farmhouse located south of Highway 20 near the INL entrance. The largest potential dose from Alternative 1b is 1.6 mrem/yr at Frenchman's cabin, the INL MEI location. Potential cumulative-dose impacts to the public associated with HALEU fuel fabrication and other INL activities are assessed in the Environmental Assessment (DOE-EA 2018). The estimated collocated-worker potential doses in Table 7 are significantly less than the 5,000 mrem/yr regulatory dose standard for both alternatives. The largest dose is from Alternative 1a at 48 mrem/yr. It is not surprising the largest dose comes from Alternative 1a given that both processing facilities were assumed to be collocated at MFC.

Surface Soil Exposure Assessment

Estimated potential doses to public receptors (Tables 5 and 6) and collocated workers (Table 7) from atmospheric emissions include doses due to air immersion, inhalation of contaminated air, ingestion of contaminated food products, and direct radiation from ground deposition. Additional impacts not considered in those calculations (incidental ingestion of contaminated soil and inhalation of fugitive dust) were assessed using a screening-level analysis. These additional pathways are less significant during the operational phase and become important typically after operations have ceased. Direct radiation and ingestion of food products are also important after operations, but doses after operations are bounded by the doses calculated during operations in Tables 5 and 6.

Concentrations of radionuclides in soil due to buildup of particulate deposition were calculated and compared to pathway-specific EPA preliminary remediation goals (PRGs). PRGs are risk-based soil concentrations derived from standardized equations combining exposure-information assumptions with EPA toxicity data. They are soil concentrations that would not likely result in adverse health impacts under reasonable maximum exposure conditions for long-term/chronic exposures. For this assessment, PRGs are based on a target lifetime cancer risk of 1E-06, meaning that a person exposed to the contamination has a one-in-one-million chance of developing cancer. The EPA PRG database is based on EPAs Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals [RAGS] Part B) (EPA 1991). PRG values were downloaded from the EPA website https://epa-prgs.ornl.gov/radionuclides/download.html.

The maximum soil concentrations anywhere were used for the comparison, even though they would be significantly greater than concentrations at any public receptor location. This was done because the soil-ingestion and dust-inhalation exposure pathways are generally less significant than the exposure pathways included in CAP88-PC dose calculations (especially while the source is active), and the maximum soil concentrations could be used to bound the impacts.

Maximum soil concentrations were calculated from maximum ground-deposition rates provided in the CAP88-PC model output. For both MFC and INTEC, maximum deposition was found to occur 200 m from the stack in the NE direction. This was determined by plotting dose as a function of distance from the source for each of the 16 sectors. Total dose was used as a surrogate for ground-deposition rates because, for this investigation, the dose is dominated by the direct ground-surface radiation pathway. In addition, the 200 m distance would likely be the shortest distance from a production facility to a location outside the MFC or INTEC fence.

Soil concentrations were calculated using a first-order kinetic expression from Whicker and Rood (2008) that includes leaching, but was modified to also account for radioactive decay:

$$C_s = \frac{R}{k_r + k_l}\left[1 - e^{(k_r + k_l)t}\right]$$

where C_s = concentration in soil surface at time t (pCi/cm^2)
R = ground deposition rate (pCi/cm^2/yr)
k_r = radioactive decay rate constant (yr^{-1})
k_l = leach rate constant (yr^{-1})
t = operational period (yr).

The radioactive decay rate constant is defined as

$$k_r = \frac{ln(2)}{t_{½}}$$

Where $t_{1/2}$ = radionuclide half-life (yr).

Leach rate constants were calculated with the following expression from Rood (2003).

$$k_l = \frac{I}{T\theta R_d}$$

where I = Infiltration rate (cm/yr)
T = thickness of contaminated layer (cm)
θ = soil moisture content (dimensionless)
R_d = retardation coefficient (dimensionless).

The retardation coefficient R_d is given by the expression:

$$R_d = 1 + \frac{\rho K_d}{\theta}$$

where ρ = soil bulk density (g/cm^3)
K_d = soil sorption coefficient (cm^3/g)

Inputs to the above expressions are provided in Tables 8 and 9. Maximum ground deposition rates and soil concentrations are provided in Table 10. Decay products are not included because the PRG values for most radionuclides (Cs-137, Sr-90, Np-237, Pu-239, U-235, and U-238) include the impact of decay products. This is typically the case for radionuclides with decay products that are in secular equilibrium with the parent radionuclide in the environment. For the remaining radionuclides (Pu-240, U-234, U-236, U-232, U-233 and U-237), PRG values do not include the impact of decay products because the primary decay products are sufficiently long-lived that they are likely not in activity equilibrium with the parent radionuclide.

Table 8. Parameter values for surface soil concentration calculations.

Parameter	Value	Source
Operational period (*t*)	2 yrs	Minimum time required to process 10 metric tons of HALEU feedstock material at a rate of 5,000 kg/yr[a].
Infiltration rate (*I*)	1 cm/yr	Typical infiltration rate at INL for undisturbed soils (Cecil et al. 1992). Annual precipitation rate is approximately 22 cm/yr.
Soil thickness (*T*)	5 cm	Assumed value
Soil moisture content (θ)	0.3	INL surface soil value from DOE-ID (1994)
Soil bulk density (ρ)	1.5 g/cm^3	INL surface soil value from DOE-ID (1994)

a. 10 metric tons is the estimated stockpile of HALEU material at INL expected to be processed into fuel. The highest processing rate and shortest operation period will produce the highest soil concentration rates.

Table 9. Radionuclide-specific parameters for surface soil concentration calculations.

Radionuclide	Half-life (yr)	Decay Rate Constant k_r (yr^{-1})	Sorption Coefficient K_d (cm^3/g)[a]	Retardation Coefficient R_d	Leach Rate Constant k_l (yr^{-1})
Mn-54	8.55E-01	8.11E-01	50	251	2.66E-03
Co-60	5.27E+00	1.31E-01	10	51	1.31E-02
Sr-90	2.89E+01	2.40E-02	24	121	5.51E-03
Tc-99	2.11E+05	3.28E-06	0.2	2	3.33E-01
Sb-125	2.76E+00	2.51E-01	50	251	2.66E-03
Cs-134	2.07E+00	3.36E-01	500	2501	2.67E-04
Cs-135	2.30E+06	3.01E-07	500	2501	2.67E-04
Cs-137	3.01E+01	2.30E-02	500	2501	2.67E-04
Ce-144	7.80E-01	8.89E-01	500	2501	2.67E-04
Eu-154	8.60E+00	8.06E-02	340	1701	3.92E-04
Eu-155	4.75E+00	1.46E-01	340	1701	3.92E-04
Np-237	2.14E+06	3.24E-07	18	91	7.33E-03
Pu-239	2.41E+04	2.87E-05	1480	7401	9.01E-05
Pu-240	6.56E+03	1.06E-04	1480	7401	9.01E-05
Am-241	4.33E+02	1.60E-03	340	1701	3.92E-04
U-234	2.46E+05	2.82E-06	10	51	1.31E-02
U-235	7.04E+08	9.85E-10	10	51	1.31E-02
U-236	2.34E+07	2.96E-08	10	51	1.31E-02
U-238	4.47E+09	1.55E-10	10	51	1.31E-02
U-232	6.89E+01	1.01E-02	10	51	1.31E-02
U-233	1.59E+05	4.35E-06	10	51	1.31E-02
U-237	1.85E-02	3.75E+01	10	51	1.31E-02

a. Maximum value for alluvium from Jenkins (2001), DOE-ID (1994), and DOE-ID (2018).

Table 10. Comparison of radionuclide soil concentrations to EPA PRGs.

Nuclide	Max Soil Deposition Rate outside MFC ($pCi/cm^2/yr$)[a]	Max Soil Deposition Rate INTEC ($pCi/cm^2/yr$)[b]	Max Soil Concentration outside MFC (pCi/g)[a]	Max Soil Concentration outside INTEC (pCi/g)[b]	EPA PRG for Soil Ingestion and Inhalation[c]	Ratio of MFC Max Soil Concentration to EPA PRG	Ratio of INTEC Max Soil Concentration to EPA PRG
Mn-54	1.64E-01	1.13E-01	2.16E-02	1.49E-02	3.8E+03	5.69E-06	3.92E-06
Co-60	2.18E-04	1.51E-04	5.06E-05	3.49E-05	8.3E+01	6.09E-07	4.20E-07
Sr-90	1.50E+01	1.04E+01	3.89E+00	2.68E+00	8.9E+00	4.37E-01	3.01E-01
Tc-99	1.78E-08	1.23E-08	3.46E-09	2.39E-09	1.2E+02	2.89E-11	1.99E-11
Sb-125	7.45E-01	5.11E-01	1.56E-01	1.07E-01	5.4E+02	2.88E-04	1.98E-04
Cs-134	2.24E-01	1.54E-01	4.35E-02	3.00E-02	1.4E+02	3.11E-04	2.14E-04
Cs-135	2.13E-02	1.47E-02	5.69E-03	3.92E-03	9.6E+01	5.93E-05	4.09E-05
Cs-137	4.84E+00	3.35E+00	1.26E+00	8.72E-01	2.8E+01	4.51E-02	3.11E-02
Ce-144	1.48E-03	1.02E-03	1.85E-04	1.27E-04	2.2E+02	8.41E-07	5.79E-07
Eu-154	4.14E-01	2.86E-01	1.02E-01	7.03E-02	8.4E+01	1.21E-03	8.38E-04
Eu-155	7.45E-01	5.11E-01	1.72E-01	1.18E-01	6.7E+02	2.57E-04	1.76E-04
Np-237	8.39E-05	5.78E-05	2.22E-05	1.53E-05	6.2E+00	3.60E-06	2.48E-06
Pu-239	3.62E-02	2.49E-02	9.64E-03	6.64E-03	3.8E+00	2.54E-03	1.75E-03
Pu-240	3.53E-03	2.43E-03	9.42E-04	6.49E-04	3.8E+00	2.48E-04	1.71E-04
Am-241	1.46E+00	1.01E+00	3.88E-01	2.68E-01	4.8E+00	8.09E-02	5.58E-02
U-234	6.88E-02	4.77E-02	1.81E-02	1.25E-02	5.9E+00	3.08E-03	2.13E-03
U-235	2.89E-03	1.99E-03	7.61E-04	5.24E-04	5.7E+00	1.33E-04	9.19E-05
U-236	2.33E-03	1.61E-03	6.13E-04	4.23E-04	6.3E+00	9.77E-05	6.74E-05
U-238	1.86E-03	1.28E-03	4.88E-04	3.37E-04	4.4E+00	1.10E-04	7.59E-05
U-232	7.70E-04	5.30E-04	2.01E-04	1.38E-04	1.9E+00	1.08E-04	7.41E-05
U-233	2.13E-05	1.47E-05	5.62E-06	3.87E-06	5.8E+00	9.70E-07	6.69E-07
U-237	1.25E+00	8.62E-01	4.44E-07	3.06E-07	6.5E+04	6.83E-12	4.71E-12
					Sum-of-Ratios[d]	**0.57**	**0.39**

a. MFC soil deposition and concentration based on annual emission of 5,000 kg (2,500 kg per facility). Facilities are assumed collocated.
b. INTEC soil deposition and concentration based on annual emission rate of 2,500 kg.
c. PRGs are based on a target cancer risk of 1E-06. PRG is the total PRG for the soil ingestion and inhalation of fugitive dust pathways. The total PRG is dominated by the ingestion PRG.
d. Sum-of-ratios less than 1 indicates concentrations will likely not result in adverse human health impacts.

The results in Table 10 indicate that all maximum radionuclide soil concentrations are less than EPA PRGs, and the sum-of-ratios less than one indicates the risk of developing cancer from the contaminated soils is less than one in one million.

Groundwater Pathway Dose Assessment

Potential impacts to groundwater in the Snake River Plain Aquifer were evaluated by calculating the potential effective dose to receptors from groundwater ingestion using the model GWSCREEN (Rood 2003). The calculations assume all emissions for the 2-year operating period are deposited uniformly over a 400 m × 400 m area surrounding the facility. This is a conservative assumption as the emissions would be spread over a much larger area as indicated by the air pathway assessment. The radionuclides are assumed leach from the soil and migrate through the unsaturated zone to the underlying aquifer, where they are transported to a downgradient receptor well.

The groundwater pathway conceptual model is illustrated in Figure 2. The model accounts for leaching, advection, dispersion, and radioactive-chain decay and ingrowth using conservative assumptions and parameters for the source, unsaturated zone, and aquifer. In the model, radionuclides in surficial soils are transported downward through the unsaturated zone and into the aquifer by natural precipitation and infiltration. In the unsaturated zone, radionuclides can undergo advection, longitudinal dispersion, sorption, and radioactive-chain decay and ingrowth. Once in the aquifer, similar transport and decay processes occur as contaminants move with the regional groundwater flow, but both longitudinal and transverse dispersion are allowed in the aquifer.

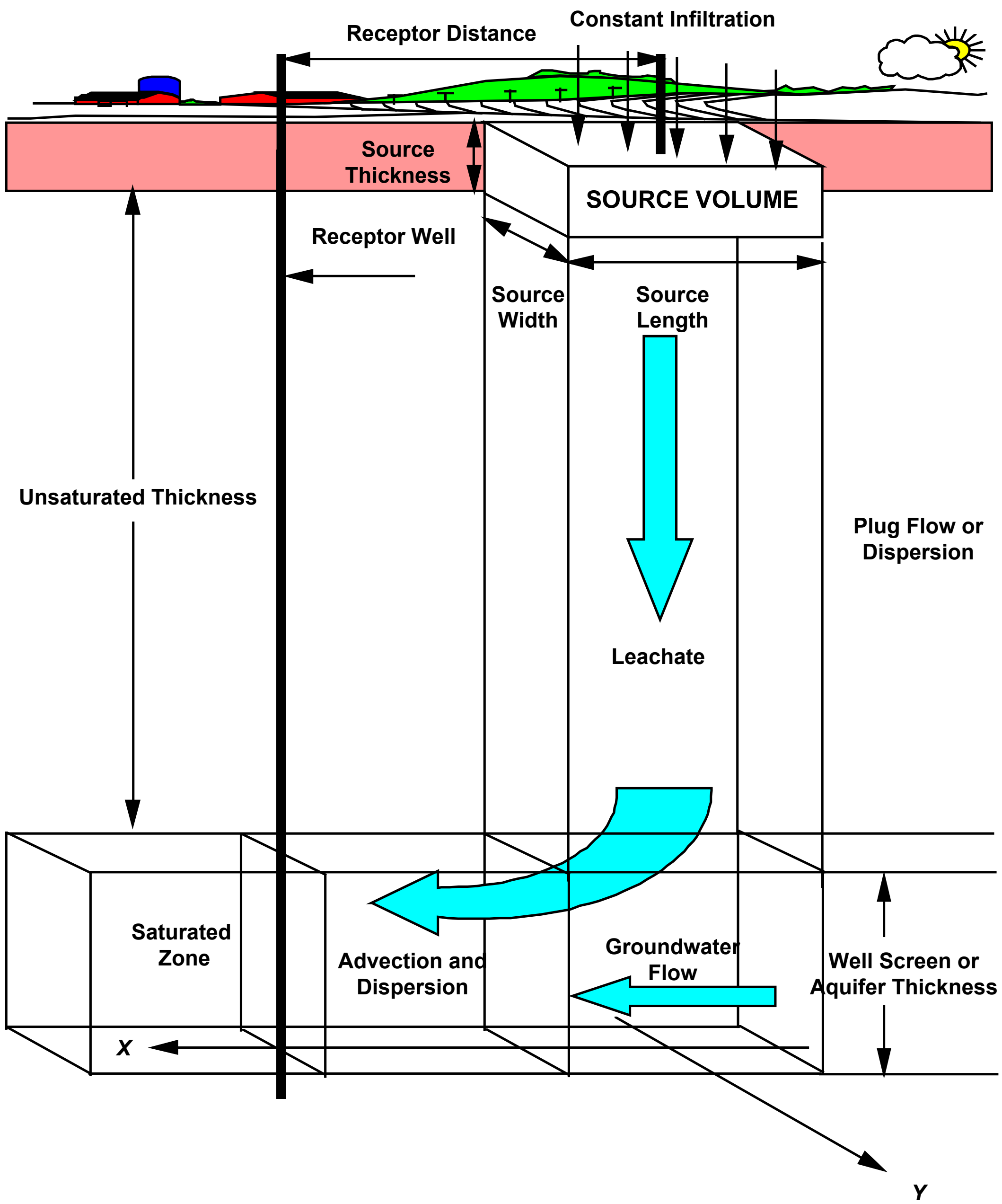


Figure 2. Conceptual model of flow and transport for the groundwater pathway. The receptor well location for this assessment is the immediate downgradient edge of the source (different from figure).

The GWSCREEN model provides concentrations in the aquifer and effective dose from groundwater ingestion at a user-defined receptor location in the aquifer. In this case, the receptor is assumed to be located at the downgradient edge of the 400 m x 400 m source zone, the location of maximum concentration. The effective dose from human consumption of drinking water is calculated using the expression:

$$D_w = C_w \times WI \times EF \times DC_w$$

where D_w = effective dose from groundwater ingestion (rem/yr)
C_w = radionuclide concentration in groundwater (Ci/L)
WI = water intake rate (L/day)
EF = exposure frequency (day/yr)
DC_w = effective dose coefficient for water ingestion (rem/Ci).

Other model parameters and assumptions are generally consistent with those used to perform Track 2 CERCLA assessments for low-probability hazard sites at INL (DOE-ID 1994). Table 11 shows the radionuclide-independent model parameters used in the assessment.

Impacts to the aquifer were bounded by only considering Alternative 1a, where all 10,000 kg of HALEU will be processed at MFC. This comes from 2,500 kg processed annually at two facilities over a two-year period. Table 12 shows the total emissions (source inventory) by radionuclide and radionuclide-specific properties (half-life, sorption coefficient, ingestion-dose coefficients) of all radionuclides modeled. Radionuclides with half-lives less than 1 year (Mn-54, Ce-144 and U-237) were not modeled because they would decay to insignificant levels before reaching the aquifer.

To evaluate the movement of radioactive progeny, the model makes the simplifying assumption that radioactive progeny travel at the same rate as the parent. This assumption has been shown to be conservative (Codell et al. 1982) and greatly simplifies the calculations. Furthermore, a zero K_d in the aquifer for all radionuclides makes this assumption accurate. Significant long-lived progeny are included explicitly in the model and assumed to be generated as parent radionuclides decay. Short-lived radionuclide progeny are not modeled explicitly, but are assumed to be in secular equilibrium with the parent. Where progeny are not explicitly modeled, the effective dose coefficients include the contribution from progeny.

Table 11. Radionuclide-independent groundwater pathway model parameter values[AJS1].

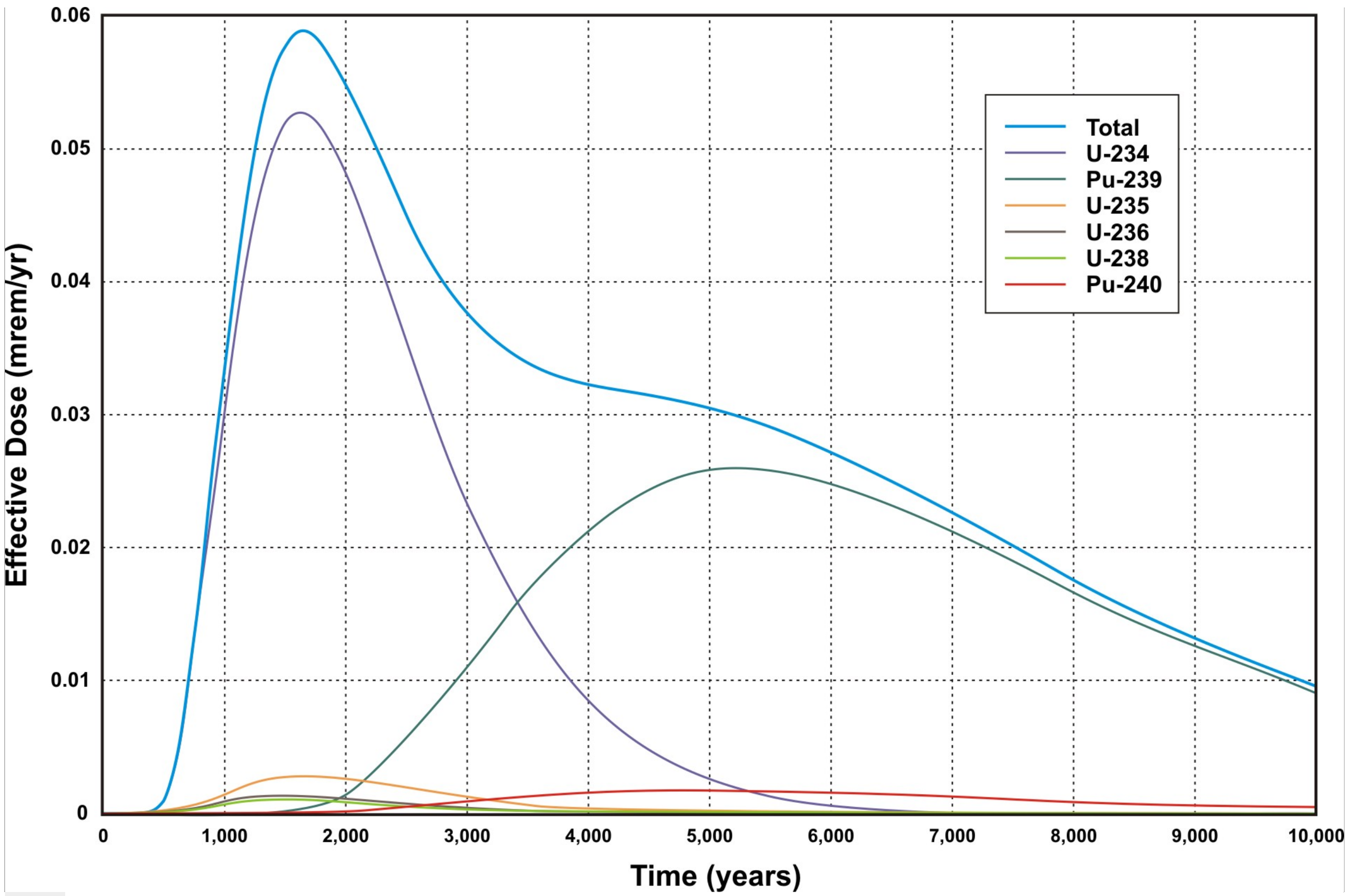
Variable	Parameter description	Value	Source/Comments
L,W	Length and width of source	400 m, 400 m	All emissions assumed deposited within 200 m of source
XREC, YREC	Receptor distance from center of source	200 m, 0 m	Receptor located at downgradient edge of source (L/2). This is the location of maximum concentration and effective dose.
PERC	Background percolation rate	0.1 m/yr	DOE-ID (1994), conservative value representing infiltration in disturbed, unvegetated soil
THICKS	Source thickness	0.05 m	Site-specific value/assumption
RHOS	Source density	1.5 g/cm^3	DOE-ID (1994)
THETAS	Moisture content in source	0.3	DOE-ID (1994)
DEPTH	Depth from source to aquifer	20 m	Cumulative interbed thickness at MFC from Operable Unit 9-04 Remedial Investigation/Feasibility Study (INEEL 1997)
RHOU	Unsaturated zone density	1.5 g/cm^3	DOE-ID (1994)
AUX	Longitudinal dispersivity in unsaturated zone	2 m	Conservatively approximated as 10% of unsaturated zone thickness
THETAU	Moisture content in unsaturated zone	0.3	DOE-ID (1994)
AX	Longitudinal dispersivity in aquifer	9 m	DOE-ID (1994)
AY	Transverse dispersivity in aquifer	4 m	DOE-ID (1994)
AZ	Vertical dispersivity in aquifer	0.1 m	DOE-ID (1994)
B	Aquifer thickness	15 m	Conservative value given the size of the source. DOE-ID (1994) has
Z	Well screen thickness	15 m	DOE-ID (1994), typical of residential well screen
U	Darcy velocity in aquifer	33 m/yr	MFC site-specific value from DOE-ID (2008) based on Darcy velocity of 2.5 m/d and porosity of 0.06
PHI	Porosity in aquifer	0.06	DOE-ID (2008)
RHOA	Bulk density in aquifer	1.9 g/cm^3	DOE-ID (1994), Value is typical density of basalt
WI	Water intake rate	2 L/d	EPA (1989)
EF	Exposure frequency	365 d/yr	Assumes no other water source for consumption

Table 12. Emission potential and radionuclide-specific properties for groundwater pathway.[AJS2]

Radionuclide[a]	Source Activity (Ci)[b]	Half-life (yrs)	Sorption Coefficient, Kd (mL/g)[c]	Water Ingestion Effective Dose Coefficient (rem/Ci)[d]
Co-60	3.14E-04	5.27E+00	10	20313
Sr-90	2.16E+01	2.89E+01	11	133200
Tc-99	2.57E-08	2.11E+05	0	3330
Sb-125	1.07E+00	2.76E+00	50	5439
Cs-134	3.22E-01	2.07E+00	500	69190
Cs-135	3.07E-02	2.30E+06	500	9768
Cs-137	6.94E+00	3.01E+01	500	49210
Eu-154	5.94E-01	8.60E+00	340	9657
Eu-155	1.07E+00	4.75E+00	340	1672.4
Np-237	1.21E-04	2.14E+06	8	462500
U-233	-----	1.59E+05	8	222740
Th-229	-----	7.34E+03	8	3328401.6 (+D)
Pu-239	5.19E-02	2.41E+04	22	1065600
U-235	-----	7.04E+08	22	203130
Pa-231	-----	3.28E+04	22	2068300
Ac-227	-----	2.18E+01	22	2320610.4 (+D)
Pu-240	5.08E-03	6.56E+03	22	1065600
U-236	-----	2.34E+07	22	202390
Th-232	-----	1.41E+10	22	1028600
Ra-228	-----	5.76E+00	22	5921901.8 (+D)
Th-228	-----	1.92E+00	22	934812.4 (+D)
Am-241 (Np-237)[e]	2.10E+00	4.33E+02	8	462500
U-233	-----	1.59E+05	8	222740
Th-229	-----	7.34E+03	8	3328401.6 (+D)
U-234	9.90E-02	2.46E+05	6	214970
Th-230	-----	7.70E+04	6	936100
Ra-226	-----	1.60E+04	6	1677387.6 (+D)
Pb-210	-----	2.23E+01	6	10255660 (+D)
U-235	4.15E-03	7.04E+08	6	203130
Pa-231	-----	3.28E+04	6	2068300
Ac-227	-----	2.18E+01	6	2320610.4 (+D)
U-236	3.35E-03	2.34E+07	6	202390
Th-232	-----	1.41E+10	6	1028600
Ra-228	-----	5.76E+00	6	5921901.8 (+D)
Th-228	-----	1.92E+00	6	934812.4 (+D)
U-238	2.67E-03	4.47E+09	6	213253.2 (+D)
U-234	-----	2.46E+05	6	214970
Th-230	-----	7.70E+04	6	936100
Ra-226	-----	1.60E+04	6	1677387.6 (+D)
Pb-210	-----	2.23E+01	6	10255660 (+D)
U-232	1.11E-03	6.89E+01	6	2429612.4 (+D)
U-233	3.07E-05	1.59E+05	6	222740
Th-229	-----	7.34E+03	6	3328401.6 (+D)

a. Parent radionuclides are shown in bold font. Progeny explicitly modeled shown in regular font and indented.
b. Based on a total of 10,000 kg material processed at MFC (2,500 kg/facility/yr x 2 facilities x 2 years). This is the annual emission potential in Table 2 (last column) multiplied by 4. In the groundwater model, this amount of activity is spread over a 400m x 400m area.
c. Minimum value for alluvium from Jenkins (2001), DOE-ID (1994), and DOE-ID (2018). Progeny are assumed to travel with the parent radionuclide, therefore the Kd for the progeny is the same as the parent.
d. Dose coefficients from DOE-STD-1196-2011 converted from Sv/Bq to rem/Ci. The coefficients are the reference person values that are age and gender weighted. Values with “+D” include the contribution for all progeny (daughters) not explicitly modeled.
e. Am-241 modeled as first-long lived progeny (Np-237).

Figure 3 shows the maximum groundwater ingestion effective dose as a function of time. The total effective dose is dominated by the contribution of U-234 for the first 3,000 years and by Pu-239 after about 4,000 years. The contribution from other radionuclides is insignificant. The maximum total effective dose is 0.059 mrem/yr and occurs approximately 1,600 years after operations. This is less than 0.1% of the regulatory limit of 100 mrem/yr (DOE O 458.1).



[AJS3]

Figure 3. Total groundwater ingestion effective dose as a function of time (t=0 occurs at the end of the production period) and contribution from individual parent radionuclides. Contribution from radionuclides not shown is negligible. The dose for parent radionuclides includes the contribution from progeny.

The total effective groundwater ingestion dose of 0.059 mrem/yr is a conservative estimate of the groundwater impact for Alternative 1a. The impact for Alternative 1b would be approximately one half the effective dose of Alternative 1a (0.03 mrem/yr) and would occur at both INTEC and MFC. There would be slight differences in the results based on differences between the two sites in terms of cumulative interbed thickness in the unsaturated zone and groundwater velocity in the aquifer, but the dose at each facility would not be greater than the 0.059 mrem/yr dose for Alternative 1a.

SUMMARY AND CONCLUSIONS

Potential radionuclide emissions from operations at proposed HALEU fuel production facilities and subsequent doses from low-level chronic exposure were estimated using methodologies and assumptions consistent with regulatory standards and approved guidance. Impacts from exposure to contaminated soils after completion of processing were evaluated by calculating maximum soil concentrations due to deposition and buildup and comparing the results to EPA risk-based screening levels. Groundwater impacts were evaluated by calculating dose from ingestion of groundwater contaminated by radionuclides deposited on soils from air emissions and transported to the aquifer.

Table 13 provides a summary of all impacts and comparisons to selected performance standards, which include enforceable regulatory limits and screening levels. The results indicate that impacts from proposed production of HALEU fuel using Alternative 1a or Alternative 1b are less than applicable standards. Alternative 1a impacts are slightly greater than Alternative 1b because all processing for Alternative 1a is performed at MFC, and the 2 facilities were conservatively assumed to be collocated for purposes of determining impacts.

Impacts are based on maximum, unabated/unmitigated potential emissions and conservative or bounding assumptions. Therefore, the impacts are assumed to represent screening or bounding-level estimates.

Table 13. Impacts summary for HALEU fuel production.

Performance Measure	Alternative 1a Potential Impact	Alternative 1b Potential Impact	Performance Standard
Maximum potential dose from air emissions at nearest INL Site boundary	**5.4 mrem/yr effective dose** (5 km SSE of MFC)	**3.1 mrem/yr effective dose** (5 km SSE of MFC)	Regulatory standards do not apply. Results presented for reference only.
Maximum potential dose from air emissions at a public residence	**2.4 mrem/yr** (Farmhouse 9 km SSE of MFC)	**1.6 mrem/yr effective dose** (Frenchman's cabin)[a]	10 mrem/yr effective dose from all emission sources (40 CFR 61, Subpart H)[b]
Maximum potential dose from air emissions at INL MEI (Frenchman's cabin)[a]	**0.74 mrem/yr effective dose**	**1.6 mrem/yr effective dose**	10 mrem/yr effective dose from all emission sources (40 CFR 61, Subpart H)[b]
Maximum potential dose from air emissions to collocated worker	**48 mrem/yr effective dose** (100 m from MFC facilities)	**33 mrem/yr effective dose** (100 m from INTEC facility)	5,000 mrem/yr total effective dose (10 CFR 835)
Maximum soil concentrations compared to EPA PRGs[c]	**Sum-of-Ratios = 0.57**	**Sum-of-Ratios = 0.39**	Sum-of-Ratios < 1.0 for cancer risk less than 1 in 1 million
Maximum potential dose from ingestion of groundwater	**0.059 mrem/yr** (200 m from MFC facilities)	**0.03 mrem/yr** (200 m from INTEC and MFC facilities)[d]	100 mrem/yr total effective dose from all sources of ionizing radiation and exposure pathways

a. Frenchman's cabin may be inhabited during portions of the year, but there are no permanent residents.
b. Potential cumulative impacts associated with HALEU fuel fabrication and other INL activities are presented in the Environmental Assessment (DOE-EA 2018).
c. Soil concentrations predicted at location considered to be just outside the MFC or INTEC fence line (200 m from source).
d. Estimated as ½ the dose calculated for Alternative 1a.

REFERENCES

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Appendix A

CAP88-PC Windfiles

Windfile: EBRL6-15.WND

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     .0732     .0570     .0984     .4754     .1794     .1166     .0000
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     .2236     .0845     .1013     .3690     .0595     .1622     .0000
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Title: Evaluation of Impacts from Radiological Air Emissions for the HALEU Environmental Assessment

ECAR No.: 4321 Rev. No.: 1 Project No.: N/A Date: 12/20/2018

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