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Engineering Design File

Project No. 23415

Streamlined Risk Assessment for Decontaminating and Dismantling of the Materials Test Reactor Facility

Idaho Cleanup Project

CH2M•WG Idaho, LLC is the Idaho Cleanup Project contractor for the U.S. Department of Energy

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EDF-7405
Revision 1
Page 1 of 37

EDF No.: 7405 EDF Rev. No.: 1 Project No.: 23415

1. Title: Streamlined Risk Assessment for Decontaminating and Dismantling of the Materials Test Reactor Facility

2. Index Codes:
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*5. (a) Affects Safety Basis: ☐ Yes ☒ No (b) Affects a SNF Facility: ☐ Yes ☒ No

6. Summary:

Problem Statement: CH2M-WG Idaho, LLC is decontaminating and dismantling the Materials Test Reactor at the Reactor Technologies Complex (formerly the Test Reactor Area) at the Idaho National Laboratory Site. This Engineering Design File provides streamlined human risk assessments for contaminants remaining in the surface soil after completion of the project.

Conclusions: For the No Action alternative and Alternative 2, radiological carcinogenic risks to a residential intruder would exceed the 1E-04 Environmental Protection Agency (EPA) significance threshold. The risk for Alternative 3 would be 3E-06, well below the EPA threshold.

For the No Action alternative and Alternative 2, the nonradiological carcinogenic risks exceed the EPA criterion of 1E-04, and the noncarcinogenic Hazard Indices exceed the EPA criterion of 1. Alternative 3 would present no significant nonradiological risks.

7. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

	R/A	Typed Name/Organization	Signature	Date
Performer/Author	N/A	C. S. Staley/CWI Environmental Services	C. S. Staley for MF	7/16/07
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*Design Authority (if applicable)	A			
*Nuclear Safety (only if 5(a) is Yes)	R			
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Requestor (if applicable)	Ac	S. L. Reno/D&D Program	For Written for S. Reno per Telecon	7/18/07
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*** Not required for commercial level calculations**

CONTENTS

TABLES

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Streamlined Risk Assessment for Decontaminating and Dismantling of the Materials Test Reactor Facility

1. INTRODUCTION

CH2M-WG Idaho, LLC (CWI) is decontaminating and dismantling (D&D) the Materials Test Reactor (MTR) at the Reactor Technologies Complex (RTC, formerly the Test Reactor Area [TRA]) at the Idaho National Laboratory (INL) Site. This engineering design file (EDF) provides a streamlined human risk assessment for contaminants that will remain in the surface soil after completion of the project. The risk assessment supports three D&D alternative scenarios: (1) No Action, which involves leaving the entire MTR facility in place; (2) remove the above-grade portions of TRA-603 and grout the reactor vessel in place; and (3) remove the MTR vessel, leaving the below-grade portions of the reactor building in place. This risk assessment does not cover contaminated soil or contaminated underground piping outside the reactor building, and does not include risk from the groundwater pathway, which will be addressed in a separate EDF. Risks from contaminated soil and underground piping are planned to be addressed in a separate risk assessment and must be considered in the cumulative risk for closure activities at RTC.

2. METHODS/ASSUMPTIONS

2.1 Radiological Source Term

Radiological contaminant inventories associated with MTR are documented in EDF-6381, "Materials Test Reactor (MTR) Complex Activity vs. Depth." Table 1 provides the radionuclide inventory initially considered for the surface soil risk assessment. The respective radiological inventories were assumed to be mixed uniformly in a block of soil beneath the TRA-603 footprint. Soil mass was calculated given the following:

- MTR (TRA-603) footprint = 1,570 m^2 (16,900 ft^2)
- Soil block thickness = 3 m (10 ft)
- Soil density = 1,500 kg/m^3.

2.1.1 Radionuclide Screening

Radionuclides were screened using the Environmental Protection Agency's (EPA's) *Soil Screening Guidance for Radionuclides* (EPA 2000). Soil screening levels (SSLs) in pCi/g—based on a 1E-06 cancer risk—were calculated using equations in the guidance for (1) soil ingestion, (2) ingestion of produce grown in contaminated soil, (3) inhalation of windblown dust, and (4) external exposure. The lowest SSL for each radionuclide was compared to soil concentrations calculated using the inventories presented in Table 1 and the above calculated soil volume. Any radionuclide exceeding its SSL for one alternative was retained for the risk assessment of all alternatives. Results of the screening are presented in Table 2.

Radionuclides retained after screening were then decayed 90 years to the year 2095, and the resultant soil concentrations (Table 3) were input to the risk assessment.

Table 1. 2005 radionuclide inventory (Ci) for MTR D&D alternatives.[a]

Nuclide	No Action Alternative	Alternative 2	Alternative 3
Ac-227	4.77E-07	4.77E-07	0.00E+00
Ag-108m	1.61E-01	1.61E-01	0.00E+00
Ag-110m	4.80E-15	4.80E-15	0.00E+00
Am-241	7.53E-02	7.47E-02	0.00E+00
Am-243	6.61E-05	6.61E-05	0.00E+00
Be-10	5.59E-02	5.59E-02	0.00E+00
C-14	3.31E+00	3.30E+00	1.84E-03
Ce-144	1.67E-13	1.67E-13	0.00E+00
Cl-36	3.20E-02	3.20E-02	0.00E+00
CM-243	4.64E-05	4.64E-05	0.00E+00
CM-244	1.23E-03	1.23E-03	0.00E+00
CM-245	1.77E-07	1.77E-07	0.00E+00
CM-246	3.10E-08	3.10E-08	0.00E+00
CM-247	4.00E-14	4.00E-14	0.00E+00
CM-248	4.81E-14	4.81E-14	0.00E+00
Co-60	6.05E+01	6.04E+01	2.10E-02
Cs-134	1.21E-03	1.21E-03	0.00E+00
Cs-137	5.08E-01	4.77E-01	6.30E-03
Eu-152	5.65E+00	5.65E+00	0.00E+00
Eu-154	1.02E+00	1.02E+00	0.00E+00
H-3	2.22E+02	2.22E+02	0.00E+00
I-129	2.30E-04	1.91E-05	1.55E-05
Mn-54	2.07E-10	2.07E-10	0.00E+00
Nb-94	5.31E-02	5.31E-02	0.00E+00
Ni-59	4.53E+00	4.53E+00	0.00E+00
Ni-63	4.69E+02	4.69E+02	2.39E-03
Np-237	1.03E-06	1.03E-06	0.00E+00
Pa-231	6.43E-07	6.43E-07	0.00E+00
Pb-210	1.90E-10	1.90E-10	0.00E+00
Pu-238	1.74E-02	1.74E-02	0.00E+00
Pu-239	3.81E-02	3.81E-02	0.00E+00
Pu240	1.41E-02	1.41E-02	0.00E+00
Pu-241	4.12E-01	4.12E-01	0.00E+00
Pu-242	2.08E-05	2.08E-05	0.00E+00
Pu-244	3.77E-13	3.77E-13	0.00E+00
Ra-226	5.12E-10	5.12E-10	0.00E+00
Ru-106	9.57E-11	9.57E-11	0.00E+00

Table 1. (continued.)

Nuclide	No Action Alternative	Alternative 2	Alternative 3
Sb-125	3.19E-04	3.19E-04	0.00E+00
Sr-90	2.00E-01	1.97E-01	5.07E-04
Tc-99	3.61E-03	3.61E-03	0.00E+00
Th-228	4.55E-05	4.55E-05	0.00E+00
Th-229	7.19E-07	7.19E-07	0.00E+00
Th-230	4.74E-08	4.74E-08	0.00E+00
Th-232	3.31E-05	3.31E-05	0.00E+00
U-232	1.22E-05	1.22E-05	0.00E+00
U-233	1.76E-04	1.76E-04	0.00E+00
U-234	1.08E-04	1.08E-04	0.00E+00
U-235	4.59E-06	4.59E-06	0.00E+00
U-236	9.79E-07	9.79E-07	0.00E+00
U-238	1.04E-04	1.04E-04	0.00E+00
Zn-65	3.51E-14	3.51E-14	0.00E+00

a. Source: Tables 1 and 3 of EDF-6381, "Materials Test Reactor (MTR) Complex Activity vs. Depth."

Table 2. Results of radionuclide screening (2005 inventories) against soil screening levels.

	Does soil concentration exceed soil screening level?[a]		
Nuclide	No Action Alternative	Alternative 2	Alternative 3
Ag-108m	Yes	Yes	No
Am-241	Yes	Yes	No
C-14	Yes	Yes	Yes
Cl-36	Yes	Yes	No
Co-60	Yes	Yes	Yes
Cs-134	Yes	Yes	No
Cs-137	Yes	Yes	Yes
Eu-152	Yes	Yes	No
Eu-154	Yes	Yes	No
H-3	Yes	Yes	No
Nb-94	Yes	Yes	No
Ni-59	Yes	Yes	No
Ni-63	Yes	Yes	No
Pu-239	Yes	Yes	No
Sr-90	Yes	Yes	Yes
Tc-99	Yes	Yes	No

a. Radionuclides not shown screened out for all alternatives.

Table 3. 2095 soil concentrations (pCi/g) for MTR D&D alternatives.

Nuclide	No Action Alternative	Alternative 2	Alternative 3
Ag-108m	1.41E+01	1.41E+01	0.00E+00
Am-241	9.24E+00	9.17E+00	0.00E+00
C-14	4.64E+02	4.63E+02	2.58E-01
Cl-36	4.53E+00	4.53E+00	0.00E+00
Co-60	6.22E-02	6.21E-02	2.16E-05
Cs-134	1.31E-14	1.31E-14	0.00E+00
Cs-137	9.11E+00	8.56E+00	1.13E-01
Eu-152	7.83E+00	7.83E+00	0.00E+00
Eu-154	1.02E-01	1.02E-01	0.00E+00
H-3	1.97E+02	1.97E+02	0.00E+00
Nb-94	7.50E+00	7.50E+00	0.00E+00
Ni-59	6.41E+02	6.41E+02	0.00E+00
Ni-63	3.56E+04	3.56E+04	1.81E-01
Pu-239	5.39E+00	5.39E+00	0.00E+00
Sr-90	3.33E+00	3.27E+00	8.42E-03
Tc-99	5.11E-01	5.11E-01	0.00E+00

2.2 Nonradiological Source Term

The nonradiological contaminant inventory associated with MTR is documented in EDF-6244, "MTR Complex Chemical Constituent Source Term." For the No Action alternative, the entire nonradiological inventory from EDF-6244, which includes inventory in buildings other than TRA-603, is used in this risk assessment. For Alternatives 2 and 3, the inventory from EDF-6244 is modified, as documented in Appendix A. Table 4 provides the nonradiological source term prior to screening. Soil concentrations were calculated given the MTR Complex soil volume of 4,710 m^3.

Nonradiological Contaminant Screening. Nonradiological contaminants were screened (Appendix B) using EPA's *Soil Screening Guidance: User's Guide* (EPA 1996). Only the soil ingestion and inhalation pathways, for both carcinogens and noncarcinogens, were considered in this screening. Results are presented in Table 5. Based on this screening, only barium and beryllium were evaluated for human risk.

Table 4. Mass (kg) of nonradioactive contaminants associated with MTR, used in screening and risk calculations.

	No Action Alternative	Alternative 2	Alternative 3
Organics			
PCBs (Aroclor 1254 & 1260)	4.10E-03	3.40E-3	3.40E-03
Inorganics			
Aluminum	1.26E+04	1.26E+04	1.00E+00
Antimony & comp.	6.00E-01	6.00E-01	6.00E-01
Barium & comp.	1.45E+06	1.45E+06	1.00E+00
Beryllium & comp.	2.15E+03	2.15E+03	1.00E+00
Boron	1.40E+02	1.40E+02	1.00E+00
Chromium	1.59E+04	1.59E+04	5.75E+03
Copper & comp.	2.93E+04	2.93E+04	1.47E+04
Lead	1.22E+04	1.22E+04	3.00E+01
Manganese & comp.	5.61E+03	5.61E+03	2.40E+03
Nickel (soluble salts)	9.79E+03	9.79E+03	3.98E+03
Silver & comp.	3.00E+01	1.00E+00	1.00E+00
Tin (inorganic)	6.00E+01	6.00E+01	6.00E+01
Zinc	1.80E+02	1.80E+02	1.80E+02

Table 5. Results of screening nonradiological contaminants.

	Does soil concentration exceed soil screening level?		
	No Action Alternative	Alternative 2	Alternative 3
Organics			
PCBs (Aroclor 1254 & 1260)	No	No	No
Inorganics			
Aluminum	No	No	No
Antimony & comp.	No	No	No
Barium & comp.	Yes	Yes	No
Beryllium & comp.	Yes	Yes	No
Boron	No	No	No
Chromium	No	No	No
Copper & comp.	No	No	No
Lead	No	No	No
Manganese & comp.	No	No	No
Nickel (soluble salts)	No	No	No
Silver & comp.	No	No	No
Tin (inorganic)	No	No	No
Zinc	No	No	No

2.3 Approach to Risk Assessment

Risks from contamination that might be left in place after the removal action were evaluated by considering a worst-case contaminant source term and exposure scenario. The risk scenario assumes any contamination remaining after D&D and radioactive decay is mixed uniformly in the top 10 ft (3.05 m) of soil and is available to an intruder in the year 2095 (90 years from present). The exposure scenario used for Alternative 2 assessments (reactor vessel left in place) assumes the remaining contamination will be grouted in place for 90 years and that the contamination will be released from the grout at the end of this period. The scenario also assumes someone will build a house at the site of the removal action as soon as the grout fails, contaminated material will be excavated to a 10-foot depth while building a basement, and the material will be spread across the surface of the housing site. Finally, the scenario assumes a person will live at the site for 30 years, including six years of childhood, while being exposed to external radiation and to contamination through soil ingestion, fugitive dust inhalation, and ingestion of contaminated fruits and vegetables grown around the house. Risks were evaluated for three alternative removal actions:

- No Action—The TRA-603 building and reactor vessel are left in place with full contaminant inventory used in the risk assessment.

- Alternative 2—The reactor vessel is assumed to be left in place and the reactor building is removed to ground level. The contaminant inventories in the entire vessel and in the reactor building below grade, to a depth of 10 ft, are used in the risk assessment.

- Alternative 3—The reactor vessel, and therefore the vessel's contaminant inventory, is removed and disposed of elsewhere, and the reactor building (TRA-603) is removed to ground level.

Standard EPA risk assessment equations are used to calculate the risks from radiological and nonradiological contaminants (see Appendices B and C). For radionuclides, these equations cover intakes via ingestion of homegrown produce, inhalation of resuspended soil, and external exposure to ionizing radiation. Exposures are then combined with risk factors (toxicity data) to assess overall risk. This streamlined assessment does not consider exposure through consumption of meat from farm animals grown onsite or exposure via ingestion of groundwater. For nonradionuclides, only the soil ingestion and inhalation pathways are evaluated. Complete analyses of groundwater risks are being evaluated separately from this risk assessment.

2.4 Uncertainty

Factors that contribute to the uncertainty of risks provided in this assessment include uncertainty in:

- Estimates of radionuclide and nonradioactive contaminant inventories.

- Estimates of soil concentrations. Most, if not all, of the radionuclide and metals inventory is bound in materials that would not be expected to leach or corrode to an appreciable degree.

- Risk assessment methodology. Uncertainties in uptake factors, slope factors, and other toxicity data that go into a risk assessment, together with the conservative assumptions regarding receptor exposures, result in a high degree of uncertainty in the final risk numbers.

With respect to these sources of uncertainty, efforts are made to err on the conservative side so that risks are over-estimated and bound any actual risk that might result from the removal actions.

3. RESULTS

Risk from Radionuclide Inventories. Risks by radionuclide and pathway, calculated for the screened inventories, are presented in Tables 6 through 8 for the three alternatives. The No Action alternative and Alternative 2 result in risks of 4E-03, exceeding the EPA criterion of 1E-04, considered by the National Oil and Hazardous Substances Pollution Contingency Plan as within the acceptable carcinogenic risk range. The risk for Alternative 3 is 3E-06, well below the 1E-04 criterion.

Risk from Nonradionuclide Inventories. Risks posed by the screened inventories of nonradionuclide contaminants are presented in Tables 9 and 10. For the No Action alternative and Alternative 2, the nonradiological carcinogenic risks exceed the EPA criterion of 1E-04, and the noncarcinogenic hazard indices exceed the EPA criterion of 1. Alternative 3 would present no significant nonradiological risks.

Tables 11 and 12 summarize quantitative and qualitative results, respectively, of this risk assessment.

Table 6. Risk by radionuclide and pathway for the No Action alternative.

Radionuclide	Soil Ingestion	Inhalation	External Exposure	Food Ingestion	SUM
Ag-108m	3E-07	3E-11	9E-04	5E-06	9E-04
Am-241	3E-06	2E-08	2E-06	2E-07	5E-06
C-14	2E-06	3E-10	3E-08	0E+00	2E-06
Cl-36	4E-08	1E-11	7E-08	0E+00	1E-07
Co-60	3E-09	2E-13	7E-06	2E-08	7E-06
Cs-134	1E-21	2E-26	8E-19	5E-21	8E-19
Cs-137+d	5E-07	1E-11	2E-04	3E-06	2E-04
Eu-152	2E-07	7E-11	4E-04	3E-08	4E-04
Eu-154	4E-09	1E-12	5E-06	8E-10	5E-06
H-3	5E-08	4E-12	0E+00	3E-05	3E-05
Nb-94	2E-07	3E-11	5E-04	2E-07	5E-04
Ni-59	6E-07	3E-11	0E+00	2E-06	3E-06
Ni-63	8E-05	5E-09	0E+00	3E-04	4E-04
Pu-239	2E-06	2E-08	1E-08	2E-07	2E-06
Sr-90+d	6E-07	3E-11	6E-07	2E-05	2E-05
Tc-99	5E-09	7E-13	4E-10	1E-03	1E-03
					4E-03

Table 7. Risk by radionuclide and pathway for Alternative 2, vessel left in place.

Radionuclide	Soil Ingestion	Inhalation	External Exposure	Food Ingestion	SUM
Ag-108m	3E-07	3E-11	9E-04	5E-06	9E-04
Am-241	3E-06	2E-08	2E-06	2E-07	5E-06
C-14	2E-06	3E-10	3E-08	0E+00	2E-06
Cl-36	4E-08	1E-11	7E-08	0E+00	1E-07
Co-60	3E-09	2E-13	7E-06	2E-08	7E-06
Cs-134	1E-21	2E-26	8E-19	5E-21	8E-19
Cs-137+d	5E-07	9E-12	2E-04	3E-06	2E-04
Eu-152	2E-07	7E-11	4E-04	3E-08	4E-04
Eu-154	4E-09	1E-12	5E-06	8E-10	5E-06
H-3	5E-08	4E-12	0E+00	3E-05	3E-05
Nb-94	2E-07	3E-11	5E-04	2E-07	5E-04
Ni-59	6E-07	3E-11	0E+00	2E-06	3E-06
Ni-63	8E-05	5E-09	0E+00	3E-04	4E-04
Pu-239	2E-06	2E-08	1E-08	2E-07	2E-06
Sr-90+D	6E-07	3E-11	6E-07	2E-05	2E-05
Tc-99	5E-09	7E-13	4E-10	1E-03	1E-03
					4E-03

Table 8. Risk by radionuclide and pathway for Alternative 3, vessel removed.

Radionuclide	Soil Ingestion	Inhalation	External Exposure	Food Ingestion	SUM
Ag-108m	0E+00	0E+00	0E+00	0E+00	0E+00
Am-241	0E+00	0E+00	0E+00	0E+00	0E+00
C-14	9E-10	2E-13	2E-11	0E+00	9E-10
Cl-36	0E+00	0E+00	0E+00	0E+00	0E+00
Co-60	1E-12	7E-17	2E-09	8E-12	2E-09
Cs-134	0E+00	0E+00	0E+00	0E+00	0E+00
Cs-137+d	6E-09	1E-13	3E-06	3E-08	3E-06
Eu-152	0E+00	0E+00	0E+00	0E+00	0E+00
Eu-154	0E+00	0E+00	0E+00	0E+00	0E+00
H-3	0E+00	0E+00	0E+00	0E+00	0E+00
Nb-94	0E+00	0E+00	0E+00	0E+00	0E+00
Ni-59	0E+00	0E+00	0E+00	0E+00	0E+00
Ni-63	4E-10	3E-14	0E+00	2E-09	2E-09
Pu-239	0E+00	0E+00	0E+00	0E+00	0E+00
Sr-90+d	2E-09	9E-14	1E-09	5E-08	5E-08
Tc-99	0E+00	0E+00	0E+00	0E+00	0E+00
					3E-06

Table 9. Nonradiological cancer risks[a] from beryllium for MTR D&D alternatives.

	Soil Concentration (mg/kg)	Soil Ingestion Risk	Inhalation Risk	Total Cancer Risk
No Action	3.05E+02	2.1E-03	1.0E-06	2E-03
Alternative 2 - Vessel in Place	3.05E+02	2.1E-03	1.0E-06	2E-03
Alternative 3 - Vessel Removed	1.42E-01	9.5E-07	4.8E-10	1E-06

a. To be compared with EPA cancer risk criterion of 1E-04.

Table 10. Nonradiological, noncancer risks from metals[a] for MTR D&D alternatives.

	No Action	Alternative 2 - Vessel in Place	Alternative 3 - Vessel Removed
Barium	3.8	3.8	0.0
Beryllium	0.6	0.6	0.0
Sum (HI)[b]	4	4	0

a. All other nonradiological contaminants screened out.

b. HI=Hazard index, to be compared with EPA hazard index criterion of 1.

Table 11. Quantitative summary of radiological and nonradiological risk

	Radiological Cancer Risk	Nonradiological Cancer Risk	Nonradiological Hazard Index
No Action	4E-03	2E-03	4
Alternative 2	4E-03	2E-03	4
Alternative 3	3E-06	1E-06	0

Table 12. Qualitative summary of radiological and nonradiological risk.

	Exceeds Radiological Cancer Risk Criterion?	Exceeds Nonradiological Cancer Risk Criterion?	Exceeds Noncancer Risk Criterion?
No Action	Yes	Yes	Yes
Alternative 2	Yes	Yes	Yes
Alternative 3	No	No	No

4. REFERENCES

EDF-6244, 2006, "Materials Test Reactor Complex Chemical Constituent Source Term," Rev. 1, Idaho Cleanup Project, January 30, 2006.

EDF-6381, 2007, "Materials Test Reactor (MTR) Complex Activity vs. Depth," Rev. 1, Idaho Cleanup Project, June 20, 2007.

EPA, 1996, *Soil Screening Guidance: User's Guide*, Second Edition, Environmental Protection Agency, EPA/540/R-96/018, July 1996.

EPA, 2000, *Soil Screening Guidance for Radionuclides: User's Guide*, Environmental Protection Agency, EPA/540-R-00-007, October 2000.

Appendix A

Notes Documenting Changes to Nonradiological Source Term

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Appendix A

Notes Documenting Changes to Nonradiological Source Term

The attached table updates nonradiological contaminant inventory information found in EDF-6244, "MTR Complex Chemical Constituent Source Term." The table was developed by B. T. Richards, CWI Environmental Project Support, and was transmitted electronically to C. S. Staley (author of this EDF) in a January 15, 2007, note.

Chemical Constituent	Quantity				
	MTR Reactor Vessels	MTR Bldg. +10 to -10 ft elevation	No Action Alternative	Alternative 2 Remove/Dispose Bldg.	Alternative 3/4 Remove/Dispose Bldg. & Vessel
Organic Compounds					
PCBs (Aroclor 1254 & 1260)		Re-calc @ 0.7 g & 3.4 g incl. Floor & ceiling	Re-calc @ 0.7 g & 3.4 g incl. Floor & ceiling	3.4 g	3.4 g
Inorganic Compounds					
Aluminum	12,556 kg		12,560 kg	12,560 kg	< 1 kg [e]
Antimony		0.6 kg	0.6 kg	0.6 kg	0.6 kg
Barium & compounds		1,452,920 kg (Bio-shield)[a.]	1,452,920 kg	1,452,920 kg	< 1 kg [e]
Beryllium & compounds	2,150 kg		2,150 kg	2,150 kg	< 1 kg [e]
Boron	1.8 kg (thermopiles) 140 kg (Boron curtain)		140 kg	140 kg	< 1 kg [e.]
Chromium	10,120 kg	29.4 kg (HB-2 cubicle)	15,870 kg	15,870 kg	5,750 kg
Copper & compounds		27,216 kg (copper wire)	29,340 kg	29,340 kg	14,670 kg [b]
Lead	12,170 kg (Pb Shielding in vessel)	0.2 g (paint) 35 kg (total)	12,200 kg	12,170 kg	30[c.]
Manganese & compounds	3,200 kg (as alloy in steel)	240 kg (as alloy in steel)	5,610 kg	5,610 kg	2,400 kg
Nickel	5,810 kg (as alloy in steel)	966 kg (as alloy in steel)	9,790 kg	9,790 kg	3,980 kg
Silver & compounds		30 kg	30 kg	< 1 kg [d.]	< 1 kg [d]
Tin		60 kg	60 kg	60 kg	60 kg
Zinc		180 kg	180 kg	180 kg	180 kg

a. To be removed with vessels?
b. Assumed 50% removed
c. Assumes remaining lead is below RCRA Regulatory Levels
d. Assumed to be removed by D&D/VCO
e. Assumes that most, but not all, is removed with the vessel

Appendix B

Nonradiological Soil Screening and Risk Assessment

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B.1 Nonradionuclide Soil Screening and Risk Assessment

Nonradionuclide screening followed the Environmental Protection Agency's (EPA's) *Soil Screening Guidance: User's Guide* (EPA 1996). Soil screening levels (SSLs), in mg/kg, were calculated for all contaminants in the initial inventory, for which risk data were available. The lowest SSL for a given contaminant was used for comparison to soil levels calculated for that contaminant. The equations for screening pathways are:

Ingestion of soil—carcinogens:

$$SSL = (TR \times AT_c \times 365d/yr) \div (SF_o \times 1E-6\,kg/mg \times EF \times IF_{soil/adj})$$

Ingestion of soil—noncarcinogens:

$$SSL = (THQ \times BW \times AT_{si} \times 365\,d/yr) \div (1/RfD_o \times 1E-6kg/mg \times EF \times ED \times IR)$$

Inhalation of dust—carcinogens:

$$SSL = (TR \times AT_c \times 365d/yr) \div (URF \times 1000ug/mg \times EF \times ED \times 1/PEF)$$

Inhalation of dust—noncarcinogens:

$$SSL = (THQ \times AT_{ncinh} \times 365d/yr) \div (EF \times ED \times [1/RfC \times 1/PEF])$$

Input parameters for these equations are described in Table B-1. Contaminant-specific risk factors and resultant SSLs are presented in Table B-2. Table B-3 compares soil concentrations with SSLs.

Table B-1. Parameters used in nonradiological soil screening equations.

Parameter	Description	Units	Default Value
TR	Target cancer risk		1.00E-06
AT_c	Averaging time - cancer	yr	70
SF_o	Oral Slope Factor	$(mg/kg-d)^{-1}$	chem-spec
EF	Exposure Frequency	d/yr	350
$IF_{soil/adj}$	Age-adjusted soil ingestion factor	mg-yr/kg-d	114
THQ	Target Hazard Quotient		1
BW	Body weight (child)	kg	15
AT_{si}	Noncarcinogen averaging time - soil ingestion	yr	6
RfD_o	oral reference dose	mg/kg-d	chem-spec
ED_{ing}	Noncarcinogen exposure duration- soil ingestion	yr	6
IR	Soil ingestion rate	mg/d	200
URF	Inhalation unit risk factor	$(ug/m^3)^{-1}$	chem-spec
ED_{inh}	Exposure duration - inhalation	yr	30
PEF	Particulate emission factor	m^3/kg	7.14E+08[b]
AT_{ncinh}	Averaging time-noncarcinogenic inhalation	yr	30
RfC	Inhalation reference concentration	mg/m^3	chem-spec

a. PEF calculated using Equation 3 from EPA 2000 and Q/C value of 69.41, which is based on 0.5-acre site and Boise climatic zone (Exhibit 11 of EPA 2000).

Table B-2. Contaminant–specific risk factors and resulting soil screening levels.

	Ingestion—Noncarcinogen		Ingestion—Carcinogen		Inhalation—Carcinogens		Inhalation—Noncarcinogens		
		Soil Screening Level		Soil Screening Level		Soil Screening Level		Soil Screening Level	**Minimum Soil Screening Level**
Organics	RfDo	mg/kg	SFo	mg/kg	URF	mg/kg	RfC	mg/kg	**mg/kg**
PCBs (Aroclor 1254)	2.00E-05	1.56E+00							1.56E+00
Inorganics									
Aluminum									NA[a]
Antimony & comp.	4.00E-04	3.13E+01							3.13E+01
Barium & comp.	2.00E-01	1.56E+04							1.56E+04
Beryllium & comp.	2.00E-03	1.56E+02	4.3	1.49E-01	2.40E-03	7.24E+02	2.00E-05	1.49E+04	1.49E-01
Boron	2.00E-01	1.56E+04							1.56E+04
Chromium	1.00E+00	7.82E+04							7.82E+04
Copper & comp.									NA
Lead									NA
Manganese & comp.	1.40E-01	1.10E+04							1.10E+04
Nickel (soluble salts)	2.00E-02	1.56E+03			2.40E-04	7.24E+03			1.56E+03
Silver & comp.	5.00E-03	3.91E+02							3.91E+02
Tin (inorganic)									NA
Zinc	3.00E-01	2.35E+04							2.35E+04

a. NA – There are no risk factors available for these metals; however, for lead, EPA has established an action level for lead contamination in bare soil of 400 ppm (mg/kg).

Table B-3. Soil concentrations (mg/kg) for alternatives compared to minimum soil screening level.

	No Action	Alternative 2	Alternative 3	Soil Screening Level
Organics				
PCBs (Aroclor 1254)	2.83E-03	4.82E-04	4.82E-04	1.56E+00
Inorganics				
Aluminum	1.78E+03	1.78E+03	1.42E-01	NA[a]
Antimony & comp.	8.50E-02	8.50E-02	8.50E-02	3.13E+01
Barium & comp.	2.07E+05	2.06E+05	1.42E-01	1.56E+04
Beryllium & comp.	3.05E+02	3.05E+02	1.42E-01	1.49E-01
Boron	1.98E+01	1.98E+01	1.42E-01	1.56E+04
Chromium	2.66E+03	2.25E+03	8.15E+02	7.82E+04
Copper & comp.	5.54E+03	4.16E+03	2.08E+03	NA
Lead	1.73E+03	1.72E+03	4.25E+00	NA
Manganese & comp.	1.06E+03	7.95E+02	3.40E+02	1.10E+04
Nickel (soluble salts)	1.58E+03	1.39E+03	5.64E+02	1.56E+03
Silver & comp.	5.67E+00	1.42E-01	1.42E-01	3.91E+02
Tin (inorganic)	1.13E+01	8.50E+00	8.50E+00	
Zinc	6.52E+01	2.55E+01	2.55E+01	2.35E+04

NA – There are no risk factors available for these metals; however, for lead, EPA has established an action level for lead contamination in bare soil of 400 ppm (mg/kg).

B.2 Nonradiological Risk Assessment

Risk is the product of exposure and effects per unit of exposure. In the case of nonradionuclides, risk from contaminants known to be carcinogenic is expressed as the incremental lifetime risk of an individual developing cancer. Risks less than 1E-04 are considered by EPA, under the National Oil and Hazardous Substances Pollution Contingency Plan, as within the acceptable carcinogenic risk range. The risks posed by ingestion of contaminated soil are particularly dependent on the age-dependent soil ingestion rate and body weight of an individual. The general equation for carcinogenic risk from soil ingestion in a residential scenario is as follows:

$$\text{Risk} = \text{Conc} \times 1\text{E-}06 \times \left(\left[\frac{(\text{CRc} \times \text{EFDc})}{\text{BWc} \times \text{ATc}} \right] + \left[\frac{(\text{CRa} \times \text{EFDa})}{\text{BWa} \times \text{ATc}} \right] \right) \times \text{SF}$$

The equation for hazardous (noncarcinogenic) risk from soil ingestion in a residential scenario is as follows:

$$\text{HQ} = \text{Conc} \times 1\text{E-}06 \times \left(\left[\frac{(\text{CRc} \times \text{EFDc})}{\text{Wc} \times \text{ATn}} \right] + \left[\frac{(\text{CRa} \times \text{EFDa})}{\text{BWa} \times \text{ATn}} \right] \right) / \text{RfD}$$

where:

Conc = Soil concentration of contaminant in mg/kg

CRc = Contact rate (intake) for child = 200 mg/day

CRa = Contact rate (intake) for adult = 100 mg/day

EFDc = Exposure frequency and duration for child = 350 days/yr × 6 yrs

EFDa = Exposure frequency and duration for adult = 350 days/yr × 24 yrs

BWc = Body weight of child = 15 kg

BWa = Body weight of adult = 70 kg

ATc = Averaging time (carcinogenic) in days = 365 days/yr × 70 years

ATn = Averaging time (noncarcinogenic) in days = 365 days/yr × 30 years

RfD = Reference dose (chem. specific) in mg/kg/day

RfC = Reference concentration (chem. specific) in mg/m^3

SF = Slope factor (chem. specific) in mg/kg/day.

Risk to humans from inhalation of nonradionuclide carcinogens is calculated using the Unit Risk[a] Factor (URF), which is derived assuming a 70-year chronic exposure. The risk from inhalation of soil particles for a residential scenario is calculated as follows:

$$Risk = Conc_s \times (1/PEF) \times 1000\ (\mu g/mg) \times URF$$

where:

$Conc_s$ = Soil concentration of contaminant in mg/kg

URF = Unit Inhalation Risk Factor (chem. specific) in $(\mu g/m^3\ /day)^{-1}$

PEF = Particulate Emission Factor = 7.14E+08 m^3/kg.

Risk to humans posed by inhalation of hazardous particulate materials (noncarcinogens) is expressed as a Hazard Quotient (HQ). The HQ is calculated using the Reference Concentration[b] as follows:

$$HQ = Conc_s \times (1/PEF) \times (1/R_fC)$$

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a. Unit Risk: The upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/L in water or 1 µg/m3 in air. The interpretation of unit risk would be as follows: if unit risk = 2 × 10-6 per µg/L, 2 excess cancer cases (upper-bound estimate) are expected to develop per 1,000,000 people if exposed daily for a lifetime to 1 µg of the chemical in 1 liter of drinking water (EPA 2005).

b. Reference Concentration (RfC): An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments. Durations include acute, short-term, subchronic, and chronic and are defined individually (EPA 2005).

where:

$Conc_s$ = Soil concentration of contaminant in mg/kg

RfC = Reference concentration (chem. specific) in mg/m^3

PEF = Particulate Emission Factor = 7.14E+08 m^3/kg.

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Appendix C

Radiological Soil Screening and Risk Assessment

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Appendix C

Radiological Soil Screening and Risk Assessment

C.1 Radionuclide Screening for Soils

Radionuclide screening followed EPA's *Soil Screening Guidance for Radionuclides: User's Guide* (EPA 2000). Soil screening levels (SSLs), in pCi/g, were calculated for all radionuclides in the initial inventory. The lowest SSL for a given radionuclide was used for comparison to soil levels calculated for that radionuclide. The equations for screening pathways are:

Ingestion of radionuclides in soil:

$$SSL_{soiling} = TR \div (SF \times IR_s \times 1E-03 \times EF \times ED)$$

Inhalation of radioactive fugitive dusts:

$$SSL_{dust} = TR \div (SF_i \times IR_i \times (1/PEF) \times 1E+03 \times EF \times ED_{inh} \times [ET_O + (ET_i \times DF_i)])$$

External exposure to radionuclides in soil:

$$SSL_{EXT} = TR \div (SF_e \times (EF/365) \times ED \times ACF \times [ET_o + (ET_i \times GSF)])$$

Ingestion of radionuclides in homegrown produce:

$$SSL_{pro} = TR \div (SF_p \times (IR_{vf} + IR_{lv}) \times 1E+03 \times CPF \times TF_p \times ED)$$

where:

SSL = soil screening level, in pCi/g

SFs = radionuclide-specific slope factors for pathways.

Other parameters definitions and values are provided in Table C-1. Table C-2 presents slope factors and SSLs for all radionuclides and pathways, and Table C-3 compares all soil concentrations to the lowest SSLs.

Table C-1. Other parameters definitions and values.

Parameter	Parameter Definition	Units	Value
TR	Target Risk		1.00E-06
IR_s	Soil Ingestion Rate (age-averaged)	mg/d	120
EF	Exposure Frequency	day/yr	350
ED	Exposure Duration	yr	30
IR_i	Inhalation Rate	M^3/d	20
PEF	Particulate Emission Factor	m^3/kg	7.14E+08
ETo	Exposure time fraction outdoor		0.073
ET_i	Exposure time fraction indoor		0.683
DF_i	Dilution factor - indoor inhalation		0.4
ACF	Area Correction Factor		0.9
GSF	Gamma Shielding Factor		0.4
IR_{vf}	Veg./fruit ingestion rate	Kg/yr	42.7
IRl_v	Leafy vegetable ingestion rate	Kg/yr	4.66
CPF	Contaminated plant fraction		0.5
TF_p	Soil to plant transfer factor	Radionuclide-specific	

Table C-2. Slope factors and soil screening levels (pCi/g) for total MTR radionuclide inventory.

	Soil Ingestion		Inhalation		External Exposure		Ingestion of Produce			
Nuclide	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	TFp	SSL	**Lowest SSL** (pCi/g)
Ac-227	3.81E-10	2.08E+00	1.49E-07	5.12E+01	3.48E-10	3.21E+02	2.45E-10	0.0025	2.30E+00	2.08E+00
Ag-108m	1.92E-11	4.13E+01	2.67E-11	2.86E+05	7.18E-06	1.55E-02	1.12E-11	0.150	8.38E-01	1.55E-02
Ag-110m	2.37E-11	3.35E+01	2.83E-11	2.70E+05	1.30E-05	8.58E-03	1.37E-11	0.150	6.85E-01	8.58E-03
Am-241	2.17E-10	3.66E+00	2.81E-08	2.72E+02	2.76E-08	4.04E+00	1.34E-10	0.001	1.05E+01	3.66E+00
Am-243	2.17E-10	3.66E+00	2.70E-08	2.83E+02	9.47E-08	1.18E+00	1.34E-10	0.001	1.05E+01	1.18E+00
Be-10	2.02E-11	3.93E+01	9.40E-11	8.12E+04	7.43E-10	1.50E+02	1.02E-11	0.004	3.45E+01	3.45E+01
C-14	2.79E-12	2.84E+02	7.07E-12	1.08E+06	7.83E-12	1.42E+04	2.00E-12	5.500	1.28E-01	1.28E-01
Ce-144	1.02E-10	7.78E+00	1.10E-10	6.94E+04	5.02E-08	2.22E+00	5.18E-11	0.002	1.36E+01	2.22E+00
Cf-252					8.66E-11	1.29E+03				1.29E+03
Cl-36	7.66E-12	1.04E+02	2.50E-11	3.05E+05	1.74E-09	6.41E+01	4.44E-12	20.000	1.59E-02	1.59E-02
Cm-242	1.05E-10	7.56E+00	1.51E-08	5.06E+02	7.73E-11	1.44E+03	5.48E-11	0.001	1.98E+01	7.56E+00
Cm-243	2.05E-10	3.87E+00	2.69E-08	2.84E+02	4.19E-07	2.66E-01	1.23E-10	0.001	1.14E+01	2.66E-01
Cm-244	1.81E-10	4.38E+00	2.53E-08	3.02E+02	4.85E-11	2.30E+03	1.08E-10	0.001	1.30E+01	4.38E+00
Cm-245	2.18E-10	3.64E+00	2.77E-08	2.76E+02	2.38E-07	4.69E-01	1.35E-10	0.001	1.04E+01	4.69E-01
Cm-246	2.12E-10	3.74E+00	2.77E-08	2.76E+02	4.57E-11	2.44E+03	1.31E-10	0.001	1.07E+01	3.74E+00
Cm-247	2.11E-10	3.76E+00	2.50E-08	3.05E+02	1.31E-06	8.52E-02	1.30E-10	0.001	1.08E+01	8.52E-02
Cm-248					3.42E-11	3.26E+03		0.001		3.26E+03
Co-60	4.03E-11	1.97E+01	3.58E-11	2.13E+05	1.24E-05	9.00E-03	2.23E-11	0.080	7.89E-01	9.00E-03
Cs-134	5.81E-11	1.37E+01	1.65E-11	4.63E+05	7.10E-06	1.57E-02	5.14E-11	0.040	6.85E-01	1.57E-02
Cs-137	4.33E-11	1.83E+01	1.19E-11	6.42E+05	2.55E-06	4.38E-02	3.74E-11	0.040	9.41E-01	4.38E-02
Eu-152	1.62E-11	4.90E+01	9.10E-11	8.39E+04	5.30E-06	2.11E-02	8.70E-12	0.003	6.47E+01	2.11E-02
Eu-154	2.85E-11	2.78E+01	1.15E-10	6.64E+04	5.83E-06	1.91E-02	1.49E-11	0.003	3.78E+01	1.91E-02
Eu-155	5.40E-12	1.47E+02	1.48E-11	5.16E+05	1.24E-07	9.00E-01	2.77E-12	0.003	2.03E+02	9.00E-01
Fe-55	2.09E-12	3.80E+02	7.99E-13	9.55E+06			1.16E-12	0.001	1.21E+03	3.80E+02
H-3	9.25E-14	8.58E+03	5.62E-14	1.36E+08			6.51E-14	4.800	4.50E+00	4.50E+00
I-129	2.71E-10	2.93E+00	6.07E-11	1.26E+05	6.10E-09	1.83E+01	3.22E-10	0.020	2.19E-01	2.19E-01

Table C-2. (continued).

	Soil Ingestion		Inhalation		External Exposure		Ingestion of Produce			
Nuclide	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	TFp	SSL	**Lowest SSL** (pCi/g)
Mn-54	5.14E-12	1.54E+02	5.88E-12	1.30E+06	3.89E-06	2.87E-02	3.11E-12	0.300	1.51E+00	2.87E-02
Nb-94	2.05E-11	3.87E+01	3.77E-11	2.02E+05	7.29E-06	1.53E-02	1.11E-11	0.010	1.27E+01	1.53E-02
Nb-95	6.36E-12	1.25E+02	5.44E-12	1.40E+06	3.53E-06	3.16E-02	3.50E-12	0.010	4.02E+01	3.16E-02
Ni-59	7.33E-13	1.08E+03	4.66E-13	1.64E+07			3.89E-13	0.050	7.24E+01	7.24E+01
Ni-63	1.79E-12	4.43E+02	1.64E-12	4.65E+06			9.51E-13	0.050	2.96E+01	2.96E+01
Np-237	1.46E-10	5.44E+00	1.77E-08	4.31E+02	5.36E-08	2.08E+00	8.29E-11	0.020	8.49E-01	8.49E-01
Pa-231	3.74E-10	2.12E+00	4.55E-08	1.68E+02	1.39E-07	8.03E-01	2.26E-10	0.010	6.23E-01	6.23E-01
Pb-210	1.84E-09	4.31E-01	2.77E-09	2.76E+03	1.41E-09	7.91E+01	1.18E-09	0.010	1.19E-01	1.19E-01
Pu-238	2.72E-10	2.92E+00	3.36E-08	2.27E+02	7.22E-11	1.55E+03	1.69E-10	0.001	8.33E+00	2.92E+00
Pu-239	2.76E-10	2.88E+00	3.33E-08	2.29E+02	2.00E-10	5.58E+02	1.74E-10	0.001	8.09E+00	2.88E+00
Pu240	2.77E-10	2.87E+00	3.33E-08	2.29E+02	6.98E-11	1.60E+03	1.74E-10	0.001	8.09E+00	2.87E+00
Pu-241	3.29E-12	2.41E+02	3.34E-10	2.29E+04	4.11E-12	2.71E+04	2.28E-12	0.001	6.17E+02	2.41E+02
Pu-242	2.63E-10	3.02E+00	3.13E-08	2.44E+02	6.25E-11	1.79E+03	1.65E-10	0.001	8.53E+00	3.02E+00
Pu-244	2.94E-10	2.70E+00	2.93E-08	2.61E+02	3.01E-11	3.71E+03	1.80E-10	0.001	7.82E+00	2.70E+00
Ra-226	7.29E-10	1.09E+00	1.15E-08	6.64E+02	2.29E-08	4.87E+00	5.14E-10	0.040	6.85E-02	6.85E-02
Ru-106	1.19E-10	6.67E+00	1.02E-10	7.48E+04	9.66E-07	1.15E-01	6.11E-11	0.030	7.68E-01	1.15E-01
Sb-125	1.32E-11	6.01E+01	1.93E-11	3.96E+05	1.81E-06	6.16E-02	7.21E-12	0.010	1.95E+01	6.16E-02
Sr-90	1.44E-10	5.51E+00	1.13E-10	6.76E+04	1.96E-08	5.69E+00	9.53E-11	0.300	4.92E-02	4.92E-02
Tc-99	7.66E-12	1.04E+02	1.41E-11	5.41E+05	8.14E-11	1.37E+03	4.00E-12	5.000	7.04E-02	7.04E-02
Th-228	2.89E-10	2.75E+00	1.32E-07	5.78E+01	5.59E-09	2.00E+01	1.48E-10	0.001	9.51E+00	2.75E+00
Th-229	4.96E-10	2.74E+00	1.75E-07	4.36E+01	2.25E-07	4.96E-01	2.90E-10	0.001	4.85E+00	4.96E-01
Th-230	2.02E-10	6.67E+00	2.85E-08	2.68E+02	8.19E-10	1.36E+02	1.19E-10	0.001	1.18E+01	6.67E+00
Th-232	2.31E-10	5.97E+00	4.33E-08	1.76E+02	3.42E-10	3.26E+02	1.33E-10	0.001	1.06E+01	5.97E+00
U-232	5.74E-10	2.06E+00	1.95E-08	3.91E+02	5.98E-10	1.87E+02	3.85E-10	0.003	1.46E+00	1.46E+00
U-233	1.60E-10	8.19E+00	1.16E-08	6.58E+02	9.82E-10	1.14E+02	9.69E-11	0.003	5.81E+00	5.81E+00
U-234	1.58E-10	5.02E+00	1.14E-08	6.70E+02	2.52E-10	4.43E+02	9.55E-11	0.003	5.90E+00	5.02E+00

Table C-2. (continued).

	Soil Ingestion		Inhalation		External Exposure		Ingestion of Produce			
Nuclide	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	TFp	SSL	**Lowest SSL** (pCi/g)
U-235	1.57E-10	5.06E+00	1.01E-08	7.56E+02	5.18E-07	2.15E-01	9.44E-11	0.003	5.96E+00	2.15E-01
U-236	1.49E-10	5.33E+00	1.05E-08	7.27E+02	1.25E-10	8.93E+02	9.03E-11	0.003	6.24E+00	5.33E+00
U-238	1.13E-10	7.02E+00	9.32E-09	8.19E+02	4.99E-11	2.24E+03	8.66E-11	0.003	6.50E+00	6.50E+00
Zn-65	2.45E-11	3.24E+01	5.81E-12	1.31E+06	2.81E-06	3.97E-02	1.54E-11	0.400	2.29E-01	3.97E-02

Table C-3. Soil concentrations (pCi/g) of radionuclides compared to SSLs.

Nuclide	No Action	Alternative 2	Alternative 3	Lowest SSL
Ac-227	6.76E-05	6.76E-05	0.00E+00	2.08E+00
Ag-108m	2.28E+01	2.28E+01	0.00E+00	1.55E-02
Ag-110m	6.80E-13	6.80E-13	0.00E+00	8.58E-03
Am-241	1.07E+01	1.06E+01	0.00E+00	3.66E+00
Am-243	9.37E-03	9.37E-03	0.00E+00	1.18E+00
Be-10	7.93E+00	7.93E+00	0.00E+00	3.45E+01
C-14	4.70E+02	4.68E+02	2.61E-01	1.28E-01
Ce-144	2.37E-11	2.37E-11	0.00E+00	2.22E+00
Cf-252	0.00E+00	0.00E+00	0.00E+00	1.29E+03
Cl-36	4.53E+00	4.53E+00	0.00E+00	1.59E-02
Cm-242	0.00E+00	0.00E+00	0.00E+00	7.56E+00
CM-243	6.58E-03	6.58E-03	0.00E+00	2.66E-01
CM-244	1.74E-01	1.74E-01	0.00E+00	4.38E+00
CM-245	2.51E-05	2.51E-05	0.00E+00	4.69E-01
CM-246	4.39E-06	4.39E-06	0.00E+00	3.74E+00
CM-247	5.66E-12	5.66E-12	0.00E+00	8.52E-02
CM-248	6.82E-12	6.82E-12	0.00E+00	3.26E+03
Co-60	8.58E+03	8.56E+03	2.97E+00	9.00E-03
Cs-134	1.71E-01	1.71E-01	0.00E+00	1.57E-02
Cs-137	7.20E+01	6.77E+01	8.93E-01	4.38E-02
Eu-152	8.01E+02	8.01E+02	0.00E+00	2.11E-02
Eu-154	1.45E+02	1.45E+02	0.00E+00	1.91E-02
Eu-155	0.00E+00	0.00E+00	0.00E+00	9.00E-01
Fe-55	0.00E+00	0.00E+00	0.00E+00	3.80E+02
H-3	3.15E+04	3.15E+04	0.00E+00	4.50E+00
I-129	3.26E-02	2.71E-03	2.19E-03	2.19E-01
Mn-54	2.93E-08	2.93E-08	0.00E+00	2.87E-02
Nb-94	7.52E+00	7.52E+00	0.00E+00	1.53E-02
Nb-95	0.00E+00	0.00E+00	0.00E+00	3.16E-02
Ni-59	6.42E+02	6.42E+02	0.00E+00	7.24E+01
Ni-63	6.65E+04	6.65E+04	3.38E-01	2.96E+01
Np-237	1.46E-04	1.46E-04	0.00E+00	8.49E-01
Pa-231	9.11E-05	9.11E-05	0.00E+00	6.23E-01
Pb-210	2.69E-08	2.69E-08	0.00E+00	1.19E-01
Pu-238	2.46E+00	2.46E+00	0.00E+00	2.92E+00
Pu-239	5.40E+00	5.40E+00	0.00E+00	2.88E+00
Pu240	1.99E+00	1.99E+00	0.00E+00	2.87E+00
Pu-241	5.84E+01	5.84E+01	0.00E+00	2.41E+02

Table C-3. (continued).

Nuclide	No Action	Alternative 2	Alternative 3	Lowest SSL
Pu-242	2.95E-03	2.95E-03	0.00E+00	3.02E+00
Pu-244	5.34E-11	5.34E-11	0.00E+00	2.70E+00
Ra-226	7.26E-08	7.26E-08	0.00E+00	6.85E-02
Ru-106	1.36E-08	1.36E-08	0.00E+00	1.15E-01
Sb-125	4.52E-02	4.52E-02	0.00E+00	6.16E-02
Sr-90	2.84E+01	2.79E+01	7.18E-02	4.92E-02
Tc-99	5.12E-01	5.12E-01	0.00E+00	7.04E-02
Th-228	6.45E-03	6.45E-03	0.00E+00	2.75E+00
Th-229	1.02E-04	1.02E-04	0.00E+00	4.96E-01
Th-230	6.72E-06	6.72E-06	0.00E+00	6.67E+00
Th-232	4.69E-03	4.69E-03	0.00E+00	5.97E+00
U-232	1.73E-03	1.73E-03	0.00E+00	1.46E+00
U-233	2.49E-02	2.49E-02	0.00E+00	5.81E+00
U-234	1.53E-02	1.53E-02	0.00E+00	5.02E+00
U-235	6.50E-04	6.50E-04	0.00E+00	2.15E-01
U-236	1.39E-04	1.39E-04	0.00E+00	5.33E+00
U-238	1.47E-02	1.47E-02	0.00E+00	6.50E+00
Zn-65	4.97E-12	4.97E-12	0.00E+00	3.97E-02

C.2 Radiological Risk Assessment

Risk is the product of exposure and effects per unit of exposure. In the case of radionuclides, risk is expressed as the incremental lifetime risk of an individual developing cancer. A risk less than 1E-04 is considered by the National Oil and Hazardous Substances Pollution Contingency Plan as within the acceptable carcinogenic risk range. For the streamlined risk assessment in this EDF, the overall equation for calculating risk to humans from radionuclide-contaminated soil in a residential scenario is:

$$\text{Risk} = (\text{Soil Concentration} \times \text{ED}_{\text{Res}} \times (e^{-\lambda \times \text{ED}_{\text{Res}}})) \times (\text{Soil Ingestion} + \text{Inhalation} + \text{External Exposure} + \text{Food Ingestion})$$

Risk per unit soil concentration per year is calculated for the four pathways using the following equations:

$$\text{Soil Ingestion} = (\text{SF}_{\text{soil}}) \times (\text{IR}_{\text{soil}}) \times (\text{EF}_{\text{Res}}) \times (0.001 \frac{\text{kg}}{\text{g}})$$

$$\text{Inhalation} = ((\text{SF}_{\text{Inh}}) \times (\text{Inh}) \times (\text{EF}_{\text{Inh}}) \times \left(\frac{1000 \frac{\text{g}}{\text{kg}}}{\text{PEF}} \right) \times (\text{ET}_{\text{out}} + (\text{ET}_{\text{in}} \times \text{DF}_{\text{i}})))$$

$$\text{External Exposure} = (\,(SF_{Ext})\ x\ (ACF)\ x\ \left(\frac{EF_{Res}}{365\ \frac{d}{yr}}\right)\ x\ (ET_{out} + (ET_{in}\ x\ GSF))\,)$$

$$\text{Food Ingestion} = (SF_{food})\ x\ (CR_f + CR_v)\ x\ (TF_{soil\ to\ plant})\ x\ (CPF)\ x\ (1000\ \frac{g}{kg})$$

where:

$$IR_{soil} = \frac{ED_{Res\ -\ Ch}\ x\ IR_{Soil\ -\ Ch} + ED_{Res\ -\ Ad}\ x\ IR_{Soil\ -\ Ad}}{ED_{Res}}$$

$$CRf = \frac{ED_{Res\ -\ Ch}\ x\ CR_{Fruit\ -\ Ch} + ED_{Res\ -\ Ad}\ x\ CR_{Fruit\ -\ Ad}}{ED_{Res}}$$

$$Inh = \frac{ED_{Res\ -\ Ch}\ x\ Inh_{Ch} + ED_{Res\ -\ Ad}\ x\ Inh_{Ad}}{ED_{Res}}$$

$$CR_v = \frac{ED_{Res\ -\ Ch}\ x\ CR_{Veg\ -\ Ch} + ED_{Res\ -\ Ad}\ x\ CR_{Veg\ -\ Ad}}{ED_{Res}}$$

General input variable definitions and values are as provided in Table C-4 and radionuclide-specific values (toxicities and transfer factors) are presented in Table C-5.

Table C-4. Variables and values used in risk equations.

Particulate Emission Factor (m^3/kg)	PEF	7.14E+08[a]
Time until beginning of scenario (yr)	T_{scen}	0
Exposure Duration-Residential (yr)	ED_{Res}	30
Exposure Frequency-Residential (day/yr)	EF_{Res}	350
Exposure Time Fraction-Residential-Outdoor (unitless)	ET_{Out}	0.073
Exposure Time Fraction-Residential-Indoor (unitless)	ET_{In}	0.683
Indoor Dilution Factor (unitless)	Df_i	0.4
Area Correction Factor (unitless)	ACF	0.9
Gamma Shielding Factor (unitless)	GSF	0.4
Contaminated Plant Fraction (unitless)	CPF	0.25
Exposure Duration-Residential-Child (yr)	$ED_{Res\text{-}Ch}$	6
Exposure Duration-Residential-Adult (yr)	$ED_{Res\text{-}Ad}$	24
Ingestion Rate-Soil-Child (mg/day)	$IR_{Soil\text{-}Ch}$	200
Ingestion Rate-Soil-Adult (mg/day)	$IR_{Soil\text{-}Ad}$	100
Inhalation Rate-Child (m^3/day)	Inh_{Ch}	10
Inhalation Rate-Adult (m^3/day)	Inh_{Ad}	20

Table C-4. (continued).

Particulate Emission Factor (m^3/kg)	PEF	7.14E+08[a]
Consumption Rate-Fruit-Child (kg/yr)	$CR_{Fruit-Ch}$	5.4
Consumption Rate-Fruit-Adult (kg/yr)	$CR_{Fruit-Ad}$	20.5
Consumption Rate-Vegetable-Child (kg/yr)	CR_{Veg-Ch}	3.8
Consumption Rate-Vegetable-Adult (kg/yr)	CR_{Veg-Ad}	10.4
Fraction Organic Content (unitless)	Foc	0.0025
a. PEF for long-term averaged emissions, calculated from Q/C value of 69.41 (g m^{-2} s^{-1} per kg m^{-3}), assuming 0.5 acre site and Boise climatic zone (Exhibit 10 of *Soil Screening Guidance for Radionuclides* [EPA 2000]).		

Table C-5. Radionuclide-specific values[a] used in risk assessment.

	Toxicity[a]					
	Soil Ingestion Slope Factor-Adult (risk/pCi)	Food Ingestion Slope Factor (risk/pCi)	Inhalation Slope Factor (risk/pCi)	External Exposure Slope Factor (risk/y per pCi/g)	Half Life (yr)	Soil to Plant Transfer Factor (unitless)
Isotope	SF-Soil	SF-Food	SF-Inh	SF-Ext	$t_{1/2}$	$TF_{Soil\ to\ Plant}$
Ag-108m	1.92E-11	1.12E-11	2.67E-11	7.18E-06	1.30E+02	90
Am-241	2.17E-10	1.34E-10	2.81E-08	2.76E-08	4.33E+02	340
C-14	2.79E-12	2.00E-12	7.07E-12	7.83E-12	5.73E+03	0
Cl-36	7.66E-12	4.44E-12	2.50E-11	1.74E-09	3.00E+05	0
Co-60	4.03E-11	2.23E-11	3.58E-11	1.24E-05	5.27E+00	10
Cs-134	5.81E-11	5.14E-11	1.65E-11	7.10E-06	2.07E+00	500
Cs-137+D	4.33E-11	3.74E-11	1.19E-11	2.55E-06	3.02E+01	500
Eu-152	1.62E-11	8.70E-12	9.10E-11	5.30E-06	1.35E+01	500
Eu-154	2.85E-11	1.49E-11	1.15E-10	5.83E-06	8.59E+00	500
H-3	2.20E-13	1.44E-13	1.99E-13	0.00E+00	1.23E+01	0
Nb-94	2.05E-11	1.11E-11	3.77E-11	7.29E-06	2.00E+04	350
Ni-59	7.33E-13	3.89E-13	4.66E-13	0.00E+00	7.50E+04	100
Ni-63	1.79E-12	9.51E-13	1.64E-12	0.00E+00	1.00E+02	100
Pu-238	2.72E-10	1.69E-10	3.36E-08	7.22E-11	8.77E+01	22
Pu-239	2.76E-10	1.74E-10	3.33E-08	2.00E-10	2.41E+04	22
Pu-240	2.77E-10	1.74E-10	3.33E-08	6.98E-11	6.54E+03	22
Sr-90+D	1.44E-10	9.53E-11	1.13E-10	1.96E-08	2.91E+01	24
Tc-99	7.66E-12	4.00E-12	1.41E-11	8.14E-11	2.13E+05	0.1

a. Values taken from EPA Radionuclide PRG web site (http://epa-prgs.ornl.gov/radionuclides).