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Project No. 23417

Streamlined Risk Assessment for D&D of the PBF Reactor Facility

Idaho Cleanup Project

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

ENGINEERING DESIGN FILE

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Problem Statement: CH2M-WG Idaho, LLC is decommissioning the Power Burst Facility at the Idaho National Laboratory (INL) Site. This Engineering Design File provides a streamlined human risk and ecological risk assessment for contaminants remaining in the surface soil after completion of the project.

Conclusions: For the No Action alternative, radiological carcinogenic risks to a residential intruder from Cs-137 would exceed the 1E-04 U.S. Environmental Protection Agency significance threshold. In order to reduce the Cs-137 risk to 1E-04, the present Cs-137 inventory would require reduction by approximately 53 times, from the existing 10.5 Ci to approximately 0.2 Ci in the 0- to 10-ft below ground surface interval. No other radionuclides in the existing (No Action) inventory would present an unacceptable risk. For the No Action alternative, both carcinogenic and noncarcinogenic risks for nonradionuclides would be below the respective criteria of 1E-04 and the hazard index (HI) threshold of 1 for human health.

No radionuclides exceeded initial screening criteria for ecological receptors. However, boron, lead, manganese, chromium III, and zinc exceeded screening levels and required further evaluation. Further evaluation indicates that the calculated concentrations of nonradionuclides result in HIs greater than 10 for small mammals such as the pygmy rabbit and the deer mouse, as well as plants. At the INL, it is accepted that, if the total HI exceeds 10, then the contaminant levels are considered a risk to ecological receptors at the population level.

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

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Streamlined Risk Assessment for D&D of the PBF Reactor Facility

1. INTRODUCTION

CH2M-WG Idaho, LLC is decommissioning the Power Burst Facility (PBF) at the Idaho National Laboratory Site. This Engineering Design File (EDF) provides a streamlined human risk and ecological risk assessment for radiological and nonradiological contaminants present in the facility. Risk is provided for the No Action alternative, which involves leaving the PBF reactor and reactor building in place. Additionally, for those radionuclides posing a significant risk (i.e., >1E-04) for the No Action alternative, back calculations were executed to provide cleanup goals that would bring the risk below 1E-04. This risk assessment does not include risk from the groundwater pathway, which is addressed in EDF-4869, "Groundwater Pathway Risk Assessment for the PBF Closure," and EDF-7618, "Groundwater Pathway Risk Assessment for the PBF Closure—2007 Update."

2. BACKGROUND

The PBF was built to test the operational behavior of nuclear reactors and to study the safety of light-water moderated, enriched fuel systems. The tests, called the Special Power Excursion Reactor Tests, began in the late 1950s. Construction of the PBF reactor building (PER-620) began in 1965 and was completed in 1970. Nuclear criticality was achieved on September 22, 1972. The PBF was designed to test fuels under simulated accident conditions. Test clusters of reactor fuel were subjected to transient and steady-state neutron fluxes to simulate a variety of postulated accident conditions, such as loss-of-coolant accidents or power-coolant mismatch accidents. From 1973 to 1985, the Nuclear Regulatory Commission sponsored over 40 fuel tests as part of the Light Water Reactor Safety Research Program. The reactor last went critical in February 1985 and was soon thereafter placed into operational standby.

The nuclear fuel that powered the PBF reactor was removed from the facility in 2003. The Phase 1 Non-Time Critical Removal Action took the PBF Complex to a "cold, dark, and dry" configuration and was completed in April 2005. Preliminary decommissioning activities commenced at PBF in the fall of 2006. This risk assessment assumes that radionuclides and nonradionuclides in place at the completion of Phase 1 are in place for the No Action alternative (Alternative 1).

3. RADIOLOGICAL SOURCE TERM

Radiological contaminant inventories associated with PBF are documented in EDF-7000, "Power Burst Facility (PBF) Below and Above Grade Source Terms." Table A-1 in Appendix A of this EDF shows the complete radionuclide inventory for the PBF reactor and building, organized by above and below grade categories to a 10-ft depth, and by major components. For the No Action alternative, the entire source term in Table A-1 is included.

Table 1 provides the radionuclide inventory initially considered for the surface soil risk assessment. The inventory was based on the assumption that the above-ground portions of the reactor building and components have collapsed and become mixed with the top 10 ft of soil. The inventory was assumed to be mixed uniformly in a block of soil with a cross-sectional area corresponding to the PBF Reactor building footprint.[a] Soil mass was calculated given the following:

- PBF footprint = 622 m^2 (6,695 ft^2)
- Soil block = 3 m (10 ft) deep
- Soil density = 1,500 kg/m^3.

Table 1. Radionuclide inventory (Ci) for Power Burst Facility decontamination and decommissioning No Action alternative for 2005.

Nuclide	Ci	Nuclide	Ci
Ac-227	7.47E-09	Np-237	4.37E-08
Ag-108m	4.63E-11	Pa-231	7.17E-09
Ag-110m	2.21E-09	Pb-210	9.59E-10
Am-241	3.54E-03	Pu-238	2.80E-05
Am-243	1.60E-07	Pu-239	1.40E-04
Be-10	2.97E-11	Pu-240	4.07E-05
C-14	2.50E-09	Pu-241	5.37E-04
Ce-144	1.26E-11	Pu-242	3.13E-09
Cl-36	1.44E-13	Pu-244	6.81E-18
CM-243	8.66E-08	Ra-226	9.74E-10
CM-244	4.63E-07	Ru-106	1.18E-09
CM-245	1.82E-11	Sb-125	3.34E-04
CM-246	3.48E-13	Sr-90	4.59E-01
CM-247	9.88E-20	Tc-99	9.61E-06
CM-248	2.18E-20	Th-228	1.24E-09
Co-60	1.87E-08	Th-229	5.37E-14
Cs-134	9.30E-05	Th-230	5.59E-08
Cs-137	1.05E+01	Th-232	3.17E-16
Eu-152	1.87E-04	U-232	1.77E-09
Eu-154	2.52E-03	U-233	2.38E-11
I-129	1.32E-06	U-234	3.00E-04
Mn-54	6.15E-14	U-235	1.35E-05
Nb-94	1.19E-11	U-236	2.88E-07
Ni-59	4.86E-11	U-238	3.92E-06
Ni-63	1.37E-06	Zn-65	2.55E-11

a. Footprint is for reactor building main floor, excluding wings and annexes. This information provided in the following memo: Culp, Bruce, Idaho Cleanup Project, to Chris Staley, CH2M-WG Idaho, LLC, October 5, 2006.

3.1 Radionuclide Screening for Human Health

As discussed in Appendix B, radionuclides were screened using the U.S. Environmental Protection Agency's (EPA's) *Soil Screening Guidance for Radionuclides: User's Guide* (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 homegrown 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 inventory presented in Table 1 and the PBF soil volume. The screening is presented in Appendix B and the results are presented in Table 2.

Radionuclides retained for human health after screening (Table 2) were then decayed 90 years to the year 2095, and the resultant soil concentrations (Table 3) were input to the risk assessment presented in Section 5.

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

Nuclide	Soil Concentration Exceeds SSL?
Cs-134	YES
Cs-137+D	YES
Eu-152	YES
Eu-154	YES
Sb-125+D	YES
Sr-90+D	YES

a. Radionuclides not shown were screened out.

Table 3. Year 2095 soil concentrations for PBF No Action alternative.

Nuclide	Soil Concentration (pCi/g)
Cs-134	2.53E-15
Cs-137+D	4.75E+02
Eu-152	6.50E-04
Eu-154	6.31E-04
Sb-125+D	1.80E-11
Sr-90+D	1.92E+01

4. NONRADIOLOGICAL SOURCE TERM

The nonradiological contaminant inventory associated with PBF is listed in Table 4. The inventory was developed from Table 3-2 in *Engineering Evaluation/Cost Analysis for Power Burst Facility (PER-620) Final End State and PBF Vessel Disposal* (DOE 2007). The greatest quantities of materials are those used in the construction of equipment and components for nuclear operations (primarily stainless steel), including the PBF vessel and components, piping, valves, and tanks; and materials required to provide necessary radiation shielding for nuclear operations. Thus, most of the mass accounted for in this inventory consists of chromium and nickel, which are the principal alloys (for hardening and corrosion resistance) in stainless steel. Soil concentrations were calculated given the PBF soil volume.

Table 4. Mass (kg) of nonradiological contaminants associated with PBF No Action alternative, used in screening and risk calculations.

	Mass (kg)
Aluminum	2.04E+03
Boron	1.64E+02
Chromium, Cr-III	2.18E+04
Lead	5.00E+01
Manganese & comp.	2.17E+03
Nickel (soluble salts)	1.11E+04
Selenium	3.00E-02
Uranium metal	1.11E+00
Zinc	4.54E+02

4.1 Nonradiological Contaminant Screening for Human Health

Nonradiological contaminants were screened for human health (Appendix C) 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; the results are presented in Table 5. Based on this screening, only nickel is evaluated further for human risk.

Table 5. Results of screening nonradiological contaminants.

	Soil Concentration Exceeds SSL?
Aluminum	NA[a]
Boron	No
Chromium, Cr-III	No
Lead	No[b]
Manganese & comp.	No
Nickel (soluble salts)	YES
Selenium	No
Uranium metal	No
Zinc	No

a. NA—There are no SSLs or EPA action levels for aluminum.
b. Soil lead concentrations would be below the 400 mg/kg EPA action level.

5. HUMAN HEALTH RISK ASSESSMENT

Risks from contamination that might be left in place were evaluated by considering worst case contaminant source terms and exposure scenarios. The risk scenarios for the No Action alternative assume any contamination remaining after decontamination and decommissioning (D&D) and after radioactive decay, is mixed uniformly in the top 10 ft (3.05 m) of soil over an area the size of PBF and will be available to a resident beginning in the year 2095 (90 years from present).

Consistent with the risk assumptions and methodologies presented in the *Record of Decision for the Power Burst Facility and Auxiliary Reactor Area* (DOE-ID 2000), it is assumed a person builds a house adjacent to the reactor building and is exposed to the contaminated soil in the same manner as if the house were built on the contaminated soil. The 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 near the house. Standard EPA risk assessment equations were used to calculate the risks from radiological and nonradiological contaminants (see Appendixes B and C). For radionuclides, these equations cover intakes via ingestion of soil (small children) and 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 on-Site, or exposure via ingestion of groundwater. For nonradionuclides, only the soil ingestion and inhalation pathways are evaluated.

5.1 Human Health Risk from Radionuclide Inventories

Appendix B presents the evaluation of risks by radionuclide and pathway for the screened inventory of the No Action alternative. The results are presented in Table 6. Only Cs-137 (risk = 6E-03) would present a risk exceeding the EPA criterion of 1E-04.[b] In order to reduce the Cs-137 risk to 1E-04, the present Cs-137 inventory would require reduction by approximately 53 times, from the existing 10.5 Ci to approximately 0.2 Ci. No other radionuclides in the existing (No Action) inventory would present an unacceptable risk.

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

Radionuclides	Soil Ingestion	Inhalation	External Exposure	Food Ingestion	SUM
Cs-134	8.E-27	2.E-31	7.E-24	4.E-26	7.E-24
Cs-137+D	1.E-05	3.E-10	5.E-03	7.E-05	6.E-03
Eu-152	3.E-12	1.E-15	7.E-09	6.E-13	7.E-09
Eu-154	2.E-12	6.E-16	3.E-09	4.E-13	3.E-09
Sb-125+D	2.E-22	2.E-26	2.E-19	8.E-24	2.E-19
Sr-90+D	2.E-06	1.E-10	2.E-06	5.E-05	6.E-05
					6.E-03

b. A risk <1E-04 is considered by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) as within the acceptable carcinogenic risk range.

5.2 Human Health Risk from Nonradionuclide Inventories

Nickel was the only nonradionuclide that exceeded screening criteria. Both carcinogenic risk and noncarcinogenic risk calculated for nickel would be below the respective criteria of 1E-04 and the hazard index (HI) threshold of 1 (Table 7). Therefore, the risks from existing (No Action) inventories of nonradioactive, hazardous materials at PBF would be at acceptable levels for the residential intruder.

Table 7. Risk results for the metal nickel, for the Power Burst Facility No Action alternative.

Carcinogenic Risk[a] (Fugitive Dust Inhalation)	1E-06
Noncarcinogenic Risk[b] —Hazard Quotient (Soil Ingestion)	0.7
a. To be compared with EPA cancer risk criterion of 1E-04. b. To be compared with EPA hazard index criterion of 1.	

6. ECOLOGICAL RISK ASSESSMENT

The streamlined ecological risk assessment is presented in Appendix D. To assess risk to ecological receptors, the streamlined soil screening initially compares concentrations calculated to ecologically based screening levels (EBSLs) or other ecological benchmarks. Details for EBSL development and EBSL values are presented in Appendix D. Tables D-1 and D-2 present the comparison of EBSLs to the maximum concentration calculated to be present in the soil. No radionuclide exceeded an EBSL. Therefore, radionuclides are eliminated as a concern for ecological receptors.

In the initial screen, the nonradionuclides boron, chromium III, lead, manganese, and zinc exceed the EBSLs. However, the inclusion of these constituents in the overall soil concentration is a highly conservative assumption. As discussed in Section 4, all of the concentrations of these metals in this environment were calculated from a debris mass estimated to remain in the area, including reactor components, control rods, wiring, pipes, and pumps. In the environment at this site, this debris will not degrade to a bioavailable form uniformly throughout this soil, as was modeled. The concentrations of contaminants of potential concern will be highly localized and will not be in a bioavailable form. It is unreasonable to assume they would pose an unacceptable exposure to ecological receptors. Therefore, the nonradiological materials associated with this debris are eliminated as an ecological concern.

7. UNCERTAINTY

Numerous factors contribute to the uncertainty of risks provided in this assessment. These factors include the following:

- Uncertainty in estimates of radioactive and nonradioactive contaminant inventories
- Uncertainty in 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
- Uncertainty in 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.

8. SUMMARY AND CONCLUSIONS

Streamlined human and ecological risk assessments were performed to support the No Action alternative for the D&D of the PBF Reactor Facility. For ecological health, the nonradionuclides boron, lead, manganese, chromium III, and zinc exceeded screening levels and required further evaluation. However, the inclusion of these metals at these concentrations in soil is a highly conservative assumption. As discussed in Section 4, all of the metals in this environment were estimated from a mass assumed to remain in debris left in the area, including reactor components, control rods, wiring, pipes, and pumps. These metals will be highly localized and will not be in a bioavailable form. It is unreasonable to assume they would pose an unacceptable exposure to ecological receptors. Therefore, the nonradiological materials associated with this debris were eliminated as an ecological concern.

For human health, nickel was the only nonradionuclide that exceeded screening criteria. Both carcinogenic risk and noncarcinogenic risk calculated for nickel would be below the respective criteria of 1E-04 and the HI threshold of 1. Therefore, the risks from existing (No Action) inventories of nonradioactive, hazardous materials at PBF would be at acceptable levels for the residential intruder.

The ecological risk assessment found that no radionuclide exceeded an EBSL. Therefore, radionuclides are eliminated as a concern for ecological receptors. The human health assessment found that only Cs-137 (risk = 6E-03) would present a risk exceeding the EPA criterion of 1E-04.[c] In order to reduce the Cs-137 risk to 1E-04, the present Cs-137 inventory would require reduction by approximately 53 times, from the existing 10.5 Ci to approximately 0.2 Ci. No other radionuclides in the existing (No Action) inventory would present an unacceptable risk.

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c. A risk < 1E-04 is considered by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) as within the acceptable carcinogenic risk range.

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Appendix A

Radiological Source Term for Power Burst Facility

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Appendix A

Radiological Source Term for Power Burst Facility

Table A-1. Radionuclide inventory of PBF Reactor Facility[a].

	Above-Grade Inventory						Below-Grade Inventory to 10 Feet								
Nuclide	Above-Grade Reactor Internal Contamination (Ci)	Above-Grade Reactor External Contamination (Ci)	Main Floor Surface Contamination (Ci)	Annulus Surface Contamination (Ci)	Above-Grade Piping and Components (Ci)	**Total Above Grade**	Reactor Internal Contamination (Ci)	Reactor External Contamination (Ci)	Cubicle 10 Resin Beds (Ci)	Cubicle 10 Hot Spots, Surface, Piping, and Components (Ci)	Cubicle 13 Surfaces, Piping, and Components (Ci)	First Basement Piping	First Basement Misc. Surfaces	Reactor Annulus Surfaces	**Total Below Grade**
Ac-227	5.53E-12					5.53E-12	2.57E-11		7.44E-09						7.46E-09
Ag-108m	1.77E-19					1.77E-19	8.22E-19		4.63E-11						4.63E-11
Ag-110m	3.92E-10					3.92E-10	1.82E-09		5.44E-14						1.82E-09
Am-241	5.73E-11					5.73E-11	2.67E-10		3.54E-03						3.54E-03
Am-243	3.62E-25					3.62E-25	1.69E-24		1.60E-07						1.60E-07
Be-10	2.89E-16					2.89E-16	1.34E-15		2.97E-11						2.97E-11
C-14	1.41E-12					1.41E-12	6.55E-12		2.49E-09						2.50E-09
Ce-144	1.21E-13					1.21E-13	5.65E-13		1.19E-11						1.25E-11
Cl-36	2.56E-14					2.56E-14	1.19E-13								1.19E-13
CM-243						0.00E+00	1.69E-24		8.66E-08						8.66E-08
CM-244	2.75E-28					2.75E-28	1.28E-27		4.63E-07						4.63E-07
CM-245						0.00E+00	0.00E+00		1.82E-11						1.82E-11
CM-246						0.00E+00	0.00E+00		3.48E-13						3.48E-13
CM-247						0.00E+00	0.00E+00		9.88E-20						9.88E-20
CM-248						0.00E+00	0.00E+00		2.18E-20						2.18E-20
Co-60	3.30E-09					3.30E-09	1.54E-08								1.54E-08
Cs-134	2.16E-08					2.16E-08	1.00E-07		9.29E-05						9.30E-05
Cs-137	5.94E-06	1.49E-04	4.98E+00	1.28E-04	1.36E-01	5.11E+00	2.76E-05	5.59E-04	2.64E+00	1.67E+00	9.84E-01	1.37E-01	8.78E-03	7.15E-04	5.44E+00
Eu-152	4.72E-09					4.72E-09	2.20E-08		1.86E-04						1.87E-04
Eu-154	5.06E-10					5.06E-10	2.35E-09		2.52E-03						2.52E-03
I-129	1.88E-08					1.88E-08	8.77E-08		1.21E-06						1.30E-06
Mn-54	1.09E-14					1.09E-14	5.06E-14								5.06E-14
Nb-94	2.19E-15					2.19E-15	1.02E-14		1.19E-11						1.19E-11
Ni-59	8.61E-12					8.61E-12	4.00E-11								4.00E-11

Table A-1. (continued).

	Above-Grade Inventory						Below-Grade Inventory to 10 Feet								
Nuclide	Above-Grade Reactor Internal Contamination (Ci)	Above-Grade Reactor External Contamination (Ci)	Main Floor Surface Contamination (Ci)	Annulus Surface Contamination (Ci)	Above-Grade Piping and Components (Ci)	**Total Above Grade**	Reactor Internal Contamination (Ci)	Reactor External Contamination (Ci)	Cubicle 10 Resin Beds (Ci)	Cubicle 10 Hot Spots, Surface, Piping, and Components (Ci)	Cubicle 13 Surfaces, Piping, and Components (Ci)	First Basement Piping	First Basement Misc. Surfaces	Reactor Annulus Surfaces	**Total Below Grade**
Ni-63	2.43E-07					2.43E-07	1.13E-06								1.13E-06
Np-237	4.54E-13					4.54E-13	2.11E-12		4.37E-08						4.37E-08
Pa-231	1.81E-11					1.81E-11	8.41E-11		7.07E-09						7.15E-09
Pb-210	1.90E-13					1.90E-13	8.86E-13		9.58E-10						9.59E-10
Pu-238	4.04E-11					4.04E-11	1.88E-10		2.80E-05						2.80E-05
Pu-239	1.86E-10					1.86E-10	8.63E-10		1.40E-04						1.40E-04
Pu-240	1.86E-10					1.86E-10	8.63E-10		4.07E-05						4.07E-05
Pu-241	4.98E-14					4.98E-14	2.32E-13		5.37E-04						5.37E-04
Pu-242	2.55E-22					2.55E-22	1.18E-21		3.13E-09						3.13E-09
Pu-244	2.48E-38					2.48E-38	1.15E-37		6.81E-18						6.81E-18
Ra-226	9.00E-13					9.00E-13	4.18E-12		9.69E-10						9.74E-10
Ru-106	1.06E-12					1.06E-12	4.93E-12		1.18E-09						1.18E-09
Sb-125	1.68E-09					1.68E-09	7.82E-09		3.34E-04						3.34E-04
Sr-90	5.60E-08					5.60E-08	2.60E-07		4.59E-01						4.59E-01
Tc-99	1.55E-07					1.55E-07	7.23E-07		8.73E-06						9.46E-06
Th-228	1.30E-13					1.30E-13	6.06E-13		1.24E-09						1.24E-09
Th-229	7.27E-18					7.27E-18	3.38E-17		5.37E-14						5.37E-14
Th-230	1.21E-12					1.21E-12	5.65E-12		5.59E-08						5.59E-08
Th-232	5.91E-20					5.91E-20	2.75E-19		3.17E-16						3.17E-16
U-232	1.27E-13					1.27E-13	5.92E-13		1.77E-09						1.77E-09
U-233	3.17E-15					3.17E-15	1.47E-14		2.38E-11						2.38E-11
U-234	5.19E-11					5.19E-11	2.41E-10		3.00E-04						3.00E-04
U-235	9.44E-12					9.44E-12	4.39E-11		1.35E-05						1.35E-05
U-236	4.89E-11					4.89E-11	2.27E-10		2.87E-07						2.88E-07
U-238	2.77E-10					2.77E-10	1.29E-09		3.92E-06						3.92E-06
Zn-65	4.52E-12					4.52E-12	2.10E-11								2.10E-11

a. Source: EDF-7000.

Appendix B

Human Health Radiological Soil Screening and Risk Assessment

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Appendix B

Human Health Radiological Soil Screening and Risk Assessment

B-1. HUMAN HEALTH 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

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

Inhalation of radioactive fugitive dusts

$$SSL_{dust} = TR \div (SF_i \times IR_i \times (1/PEF) \times 1E+03 \times EF \times ED_{inh} \times [ET_O + (ET_i \times DF_i)]) \quad \text{(B-2)}$$

External exposure to radionuclides in soil

$$SSL_{EXT} = TR \div (SF_e \times (EF/365) \times ED \times ACF \times [ET_o + (ET_i \times GSF)]) \quad \text{(B-3)}$$

Ingestion of radionuclides in homegrown produce

$$SSL_{pro} = TR \div (SF_p \times (IR_{vf} + IR_{lv}) \times 1E+03 \times CPF \times TF_p \times ED) \quad \text{(B-4)}$$

where

SSL = soil screening level, in pCi/g

SF = radionuclide-specific slope factors for pathways—see Table B-1.

The definitions and values of other parameters are provided in Table B-2.

Table B-2 presents slope factors and SSLs for all radionuclides and pathways, and Table B-3 compares all soil concentrations to the lowest SSLs.

Table B-1. Slope factors and calculated soil screening levels (SSLs - pCi/g) for total PBF radionuclide inventory.

	Soil Ingestion		Inhalation		External Exposure		Ingestion of Produce			**Lowest SSL (pCi/g)**
Nuclide	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	TFp	SSL	
Ac-227	3.81E-10	2.08E+00	1.49E-07	6.59E+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	3.68E+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	3.47E+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	3.50E+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	3.64E+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	1.05E+05	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	1.39E+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	8.93E+04	5.02E-08	2.22E+00	5.18E-11	0.002	1.36E+01	2.22E+00
Cl-36	7.66E-12	1.04E+02	2.50E-11	3.93E+05	1.74E-09	6.41E+01	4.44E-12	20.000	1.59E-02	1.59E-02
CM-243	2.05E-10	3.87E+00	2.69E-08	3.65E+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	3.88E+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	3.55E+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	3.55E+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	3.93E+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	2.74E+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	5.95E+05	7.10E-06	1.57E-02	5.14E-11	0.040	6.85E-01	1.57E-02
Cs-137+D	4.33E-11	1.83E+01	1.19E-11	8.26E+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	1.08E+05	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	8.54E+04	5.83E-06	1.91E-02	1.49E-11	0.003	3.78E+01	1.91E-02
Fe-55	2.09E-12	3.80E+02	7.99E-13	1.23E+07	—	—	1.16E-12	0.001	1.21E+03	3.80E+02
Mn-54	5.14E-12	1.54E+02	5.88E-12	1.67E+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	2.61E+05	7.29E-06	1.53E-02	1.11E-11	0.010	1.27E+01	1.53E-02
Ni-59	7.33E-13	1.08E+03	4.66E-13	2.11E+07	—	—	3.89E-13	0.050	7.24E+01	7.24E+01
Ni-63	1.79E-12	4.43E+02	1.64E-12	5.99E+06	—	—	9.51E-13	0.050	2.96E+01	2.96E+01
Np-237	1.46E-10	5.44E+00	1.77E-08	5.55E+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	2.16E+02	1.39E-07	8.03E-01	2.26E-10	0.010	6.23E-01	6.23E-01

Table B-1. (continued).

	Soil Ingestion		Inhalation		External Exposure		Ingestion of Produce			**Lowest SSL (pCi/g)**
Nuclide	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	SSL	Slope Factor	TFp	SSL	
Pb-210	1.84E-09	4.31E-01	2.77E-09	3.55E+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	2.92E+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	2.95E+02	2.00E-10	5.58E+02	1.74E-10	0.001	8.09E+00	2.88E+00
Pu-240	2.77E-10	2.87E+00	3.33E-08	2.95E+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	2.94E+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	3.14E+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	3.35E+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	8.54E+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	9.63E+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	5.09E+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	8.69E+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	6.97E+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	7.44E+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	5.61E+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	3.45E+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	2.27E+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	5.04E+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	8.47E+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	8.62E+02	2.52E-10	4.43E+02	9.55E-11	0.003	5.90E+00	5.02E+00
U-235	1.57E-10	5.06E+00	1.01E-08	9.73E+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	9.36E+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	1.05E+03	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	1.69E+06	2.81E-06	3.97E-02	1.54E-11	0.400	2.29E-01	3.97E-02

SSL = soil screening level

Table B-2. Additional parameter definitions and values.

Parameter	Parameter Definition	Units	Value
TR	Target risk	Unitless	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	Unitless	0.073
ET_i	Exposure time fraction indoor	Unitless	0.683
DF_i	Dilution factor—indoor inhalation	Unitless	0.4
ACF	Area correction factor	Unitless	0.9
GSF	Gamma shielding factor	Unitless	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	Unitless	0.5
TF_p	Soil-to-plant transfer factor	Radionuclide-specific	

Table B-3. Soil concentrations (No Action, 2005 inventory) compared to soil screening levels.

	Total (Ci)	Soil Concentration (pCi/g)	Lowest SSL	Exceeds SSL?
Ac-227	7.47E-09	2.62E-06	2.08E+00	No
Ag-108m	4.63E-11	1.62E-08	1.55E-02	No
Ag-110m	2.21E-09	7.75E-07	8.58E-03	No
Am-241	3.54E-03	1.24E+00	3.66E+00	No
Am-243	1.60E-07	5.60E-05	1.18E+00	No
Be-10	2.97E-11	1.04E-08	3.45E+01	No
C-14	2.50E-09	8.76E-07	1.28E-01	No
Ce-144	1.26E-11	4.41E-09	2.22E+00	No
Cl-36	1.44E-13	5.06E-11	1.59E-02	No
CM-243	8.66E-08	3.03E-05	2.66E-01	No
CM-244	4.63E-07	1.62E-04	4.38E+00	No
CM-245	1.82E-11	6.38E-09	4.69E-01	No
CM-246	3.48E-13	1.22E-10	3.74E+00	No
CM-247	9.88E-20	3.46E-17	8.52E-02	No
CM-248	2.18E-20	7.63E-18	3.26E+03	No
Co-60	1.87E-08	6.54E-06	9.00E-03	No
Cs-134	9.30E-05	3.26E-02	1.57E-02	Yes

Table B-3. (continued).

	Total (Ci)	Soil Concentration (pCi/g)	Lowest SSL	Exceeds SSL?
Cs-137+D	1.05E+01	3.69E+03	4.38E-02	Yes
Eu-152	1.87E-04	6.53E-02	2.11E-02	Yes
Eu-154	2.52E-03	8.84E-01	1.91E-02	Yes
I-129	1.32E-06	4.62E-04	2.19E-01	No
Mn-54	6.15E-14	2.15E-11	2.87E-02	No
Nb-94	1.19E-11	4.16E-09	1.53E-02	No
Ni-59	4.86E-11	1.70E-08	7.24E+01	No
Ni-63	1.37E-06	4.81E-04	2.96E+01	No
Np-237	4.37E-08	1.53E-05	8.49E-01	No
Pa-231	7.17E-09	2.51E-06	6.23E-01	No
Pb-210	9.59E-10	3.36E-07	1.19E-01	No
Pu-238	2.80E-05	9.82E-03	2.92E+00	No
Pu-239	1.40E-04	4.91E-02	2.88E+00	No
Pu-240	4.07E-05	1.43E-02	2.87E+00	No
Pu-241	5.37E-04	1.88E-01	2.41E+02	No
Pu-242	3.13E-09	1.10E-06	3.02E+00	No
Pu-244	6.81E-18	2.38E-15	2.70E+00	No
Ra-226	9.74E-10	3.41E-07	6.85E-02	No
Ru-106	1.18E-09	4.14E-07	1.15E-01	No
Sb-125	3.34E-04	1.17E-01	6.16E-02	Yes
Sr-90	4.59E-01	1.61E+02	4.92E-02	Yes
Tc-99	9.61E-06	3.37E-03	7.04E-02	No
Th-228	1.24E-09	4.36E-07	2.75E+00	No
Th-229	5.37E-14	1.88E-11	4.96E-01	No
Th-230	5.59E-08	1.96E-05	6.67E+00	No
Th-232	3.17E-16	1.11E-13	5.97E+00	No
U-232	1.77E-09	6.20E-07	1.46E+00	No
U-233	2.38E-11	8.34E-09	5.81E+00	No
U-234	3.00E-04	1.05E-01	5.02E+00	No
U-235	1.35E-05	4.74E-03	2.15E-01	No
U-236	2.88E-07	1.01E-04	5.33E+00	No
U-238	3.92E-06	1.37E-03	6.50E+00	No
Zn-65	2.55E-11	8.94E-09	3.97E-02	No
SSL = soil screening level				

B-2. HUMAN HEALTH 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 (NCP) (40 CFR 300) 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 as follows:

$$\text{Risk} = (\text{Soil Concentration x } ED_{Res} \text{ x } (e^{-\lambda \text{ x } ED_{Res}})) \text{ x } (\text{Soil Ingestion} + \text{Inhalation} + \text{External Exposure} + \text{Food Ingestion}) \quad \text{(B-5)}$$

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

$$\text{Soil Ingestion} = (SF_{soil}) \text{ x } (IR_{soil}) \text{ x } (EF_{Res}) \text{ x } (0.001 \frac{kg}{g}) \quad \text{(B-6)}$$

$$\text{Inhalation} = ((SF_{Inh}) \text{ x } (Inh) \text{ x } (EF_{Inh}) \text{ x } \left(\frac{1000 \frac{g}{kg}}{PEF}\right) \text{ x } (ET_{out} + (ET_{in} \text{ x } DF_i))) \quad \text{(B-7)}$$

$$\text{External Exposure} = ((SF_{Ext}) \text{ x } (ACF) \text{ x } \left(\frac{EF_{Res}}{365 \frac{d}{yr}}\right) \text{ x } (ET_{out} + (ET_{in} \text{ x } GSF))) \quad \text{(B-8)}$$

$$\text{Food Ingestion} = (SF_{food}) \text{ x } (CR_f + CR_v) \text{ x } (TF_{soil\ to\ plant}) \text{ x } (CPF) \text{ x } (1000 \frac{g}{kg}) \quad \text{(B-9)}$$

where

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

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

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

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

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

Table B-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
Consumption Rate-Fruit-Child (kg/yr)	$CR_{Fruit\text{-}Ch}$	5.4
Consumption Rate-Fruit-Adult (kg/yr)	$CR_{Fruit\text{-}Ad}$	20.5
Consumption Rate-Vegetable-Child (kg/yr)	$CR_{Veg\text{-}Ch}$	3.8
Consumption Rate-Vegetable-Adult (kg/yr)	$CR_{Veg\text{-}Ad}$	10.4
Fraction Organic Content (unitless)	Foc	0.0025

a. Particulate emission factor (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: User's Guide* [EPA 2000]).

Table B-5. Radionuclide-specific values used in risk assessment.

	Toxicity[a]					
	Soil Ingestion Slope Factor (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	1.50E-01
Am-241	2.17E-10	1.34E-10	2.81E-08	2.76E-08	4.33E+02	1.00E-03
C-14	2.79E-12	2.00E-12	7.07E-12	7.83E-12	5.73E+03	—
Cl-36	7.66E-12	4.44E-12	2.50E-11	1.74E-09	3.00E+05	—
Cm-244	1.81E-10	1.08E-10	2.53E-08	4.85E-11	1.81E+01	1.10E-03
Co-60	4.03E-11	2.23E-11	3.58E-11	1.24E-05	5.27E+00	8.00E-02
Cs-134	4.48E-11	5.14E-11	1.65E-11	7.10E-06	2.07E+00	4.00E+02
Cs-137+D	4.33E-11	3.74E-11	1.19E-11	2.55E-06	3.02E+01	4.00E-02
Eu-152	1.62E-11	8.70E-12	9.10E-11	5.30E-06	1.35E+01	2.50E-03
Eu-154	2.85E-11	1.49E-11	1.15E-10	5.83E-06	8.59E+00	2.50E-03
H-3	2.20E-13	1.44E-13	1.99E-13	0.00E+00	1.23E+01	4.80E+00
Nb-94	2.05E-11	1.11E-11	3.77E-11	7.29E-06	2.00E+04	1.00E-02
Ni-59	7.33E-13	3.89E-13	4.66E-13	0.00E+00	7.50E+04	5.00E-02
Ni-63	1.79E-12	9.51E-13	1.64E-12	0.00E+00	1.00E+02	5.00E-02
Pu-238	2.72E-10	1.69E-10	3.36E-08	7.22E-11	8.77E+01	1.00E-03
Pu-239	1.21E-10	1.74E-10	3.33E-08	2.00E-10	2.41E+04	1.00E-03
Sb-125+D	2.38E-12	7.21E-12	1.93E-11	1.81E-06	2.76E+00	5.60E-04
Sr-90+D	1.44E-10	9.53E-11	1.13E-10	1.96E-08	2.91E+01	3.00E-01
Tc-99	7.66E-12	4.00E-12	1.41E-11	8.14E-11	2.13E+05	2.6E+03

a. Values obtained from EPA Radionuclide preliminary remediation goal (PRG) website (EPA 2007a) (http://epa-prgs.ornl.gov/radionuclides).

Appendix C

Human Health Nonradiological Soil Screening and Risk Assessment

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Appendix C

Human Health Nonradiological Soil Screening and Risk Assessment

C-1. HUMAN HEALTH NONRADIONUCLIDE SCREENING FOR SOILS

Nonradionuclide screening followed 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

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

Ingestion of soil—noncarcinogens

$$SSL = (THQ \times BW \times AT_{si} \times 365\ d / yr) \div (1 / RfD_o \times 1E-6 kg / mg \times EF \times ED \times IR) \quad \text{(C-2)}$$

Inhalation of dust—carcinogens:

$$SSL = (TR \times AT_c \times 365d / yr) \div (URF \times 1000ug / mg \times EF \times ED \times 1 / PEF) \quad \text{(C-3)}$$

Inhalation of dust—noncarcinogens:

$$SSL = (THQ \times AT_{ncinh} \times 365d / yr) \div (EF \times ED \times [1 / RfC \times 1 / PEF]) \quad \text{(C-4)}$$

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

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

Parameter	Description	Units	Default Value
TR	Target cancer risk	unitless	1.00E-06
AT_c	Averaging time—cancer	Yr	70
SF_o	Oral slope factor	$(mg/kg\text{-}d)^{-1}$	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	unitless	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[a]
AT_{ncinh}	Averaging time—noncarcinogenic inhalation	Yr	30
RfC	Inhalation reference concentration	mg/m^3	chem-spec.

a. Particulate emission factor (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 C-2. Contaminant-specific risk factors and resulting soil screening levels.

	Ingestion—Noncarcinogens		Ingestion—Carcinogens		Inhalation—Carcinogens		Inhalation—Noncarcinogens		
	RfDo	SSL (mg/kg)	SFo	SSL (mg/kg)	URF	SSL (mg/kg)	RfC	SSL (mg/kg)	**Minimum SSL (mg/kg)**
Aluminum	ND	—	ND	—	ND	—	ND	—	NA[a]
Boron	2.00E-01	1.56E+04	ND	—	ND	—	ND	—	1.56E+04
Chromium, Cr-III	1.00E+00	7.82E+04	ND	—	ND	—	ND	—	7.82E+04
Lead	ND	—	ND	—	ND	—	ND	—	NA[a]
Manganese & comp.	1.40E-01	1.10E+04	ND	—	ND	—	ND	—	1.10E+04
Nickel (soluble salts)	2.00E-02	1.56E+03	ND	—	2.40E-04	7.24E+03	ND	—	1.56E+03
Selenium	5.00E-03	3.91E+02	ND	—	ND	—	ND	—	3.91E+02
Uranium metal	3.00E-03	2.35E+02	ND	—	ND	—	ND	—	2.35E+02
Zinc	3.00E-01	2.35E+04	ND	—	ND	—	ND	—	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).

ND = no data available
SSL = soil screening level

Table C-3. Soil concentrations compared to minimum soil screening level.

	Soil Concentration (mg/kg)	SSL (mg/kg)
Aluminum	7.27E+02	NA[a]
Boron	5.84E+01	1.56E+04
Chromium, Cr-III	7.75E+03	7.82E+04
Lead	1.78E+01	NA[a]
Manganese & comp.	7.74E+02	1.10E+04
Nickel (soluble salts)	3.94E+03	1.56E+03
Selenium	1.07E-02	3.91E+02
Uranium metal	3.95E-01	2.35E+02
Zinc	1.62E+02	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).

SSL = soil screening level

C-2. HUMAN HEALTH 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 (NCP), 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:

$$\text{Risk} = \text{Conc} * 1\text{E}-06 * \left[\frac{[(\text{CRc} * \text{EFDc})]}{\text{BWc} * \text{ATc}} + \frac{[(\text{CRa} * \text{EFDa})]}{\text{BWa} * \text{ATc}} \right] * \text{SF} \qquad \text{(C-5)}$$

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

$$\text{HQ} = \text{Conc} * 1\text{E}-06 * \left[\frac{[(\text{CRc} * \text{EFDc})]}{\text{BWc} * \text{ATn}} + \frac{[(\text{CRa} * \text{EFDa})]}{\text{BWa} * \text{ATn}} \right] / \text{RfD} \qquad \text{(C-5)}$$

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 (chemical specific) in mg/kg/day

RfC = reference concentration (chemical specific) in mg/m^3

SF = slope factor (chemical 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:

$$\text{Risk} = \text{Conc}_s \times (1/\text{PEF}) \times 1000\ (\mu g/mg) \times \text{URF} \qquad \text{(C-6)}$$

where

Conc_s = soil concentration of contaminant in mg/kg

URF = unit inhalation risk factor (chemical 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:

$$\text{HQ} = \text{Conc}_s \times (1/\text{PEF}) \times (1/\text{RfC}) \qquad \text{(C-7)}$$

where

Conc_s = soil concentration of contaminant in mg/kg

RfC = reference concentration (chemical specific) in mg/m^3

PEF = particulate emission factor = 7.14E+08 m^3/kg.

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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 $\mu g/m^3$ in air. The interpretation of unit risk would be as follows: if unit risk = 2×10^{-6} per µg/L, then two 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 2007b).

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 no observed adverse effect level (NOAEL), lowest observed adverse effect level (LOAEL), or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. RfCs are generally used in EPA's non-cancer health assessments. (Durations include acute, short-term, subchronic, and chronic and are defined individually) (EPA 2007b).

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Appendix D

Ecological Risk Assessment

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Appendix D

Ecological Risk Assessment

D-1. RISK APPROACH

The screening ecological risk assessment followed the approach presented in the *Guidance Manual for Conducting Screening Level Ecological Risk Assessments at the INEL* (Van Horn, Hampton, and Morris 1995) and was documented in the *Comprehensive Remedial Investigation/Feasibility Study for Waste Area Groups 6 and 10 Operable Unit 10-04* (DOE-ID 2001) and the *Risk-Based Screening and Assessment Report for Waste Area Group 1 Soils* (Van Horn and Stacey 2004). Contaminants of potential concern (COPCs) that exceeded screening were evaluated further. The initial screening process is discussed in the following subsections.

D-1.1 Essential Nutrient Identification

Part of the ecological screening process is an essential nutrient analysis. Site chemicals that are considered essential nutrients are not evaluated further unless the concentration is greatly in excess of the background value (10 times). The six metals routinely eliminated by this screening step are aluminum, calcium, iron, magnesium, potassium, and sodium (Cirone 1991).

D-1.2 Comparison of Maximum Concentration to Ecologically Based Screening Level

For the remaining chemicals, the next step in the ecological chemical screening process is to compare potential contaminants associated with the site with EBSLs or EPA Region 4 ecological soil screening levels, as noted. If the maximum concentration for a given chemical is greater than or equal to the most conservative EBSL, then the chemical is retained for further evaluation. The EBSLs used for the screening are consistent with the INL-wide screening levels. Details for EBSL development and EBSL values are documented in Appendix D2 of the *Work Plan for Waste Area Groups 6 and 10 Operable Unit 10 04 Comprehensive Remedial Investigation/Feasibility Study* (DOE-ID 1999). New ecological soil screening levels provided in the new or updated chemical-specific documents from the EPA (2007c) were included for aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium (no value is available for exposure to plants), cobalt, iron, lead, and vanadium.

D-2. INITIAL SCREENING OF RADIONUCLIDES

For radionuclides, the calculated concentrations provided in Table B-3 were used. The initial screening tables are presented in Table D-1. Table D-1 indicates that none of the radionuclides exceed screening values.

Table D-1. Results of radionuclide screening against ecological soil screening levels.

Contaminants	Calculated Concentration (pCi/g)	Screening Value (pCi/g)	Max Concentration > screening values?
Ac-227	2.62E-06	2.04E+05	No
Ag-108m	1.62E-08	1.82E+03	No
Ag-110m	7.75E-07	1.08E+03	No
Am-241	1.24E+00	1.78E+01	No
Am-243	5.60E-05	1.85E+01	No
Be-10	1.04E-08	9.63E+03	No
C-14	8.76E-07	3.94E+04	No
Ce-144	4.41E-09	2.27E+04	No
Cl-36	5.06E-11	7.84E+03	No
Cm-243	3.03E-05	No EBSL	No EBSL
Cm-244	1.62E-04	1.68E+01	No
Cm-245	6.38E-09	No EBSL	No EBSL
Cm-246	1.22E-10	No EBSL	No EBSL
Cm-247	3.46E-17	No EBSL	No EBSL
CM-248	7.63E-18	2.10E+01	No
Co-60	6.54E-06	1.18E+03	No
Cs-134	3.26E-02	1.90E+03	No
Cs-137	3.69E+03	4.95E+03	No
Eu-152	6.53E-02	2.18E+03	No
Eu-154	8.84E-01	2.48E+03	No
I-129	4.62E-04	4.76E+04	No
Mn-54	2.15E-11	3.53E+03	No
Nb-94	4.16E-09	1.87E+03	No
Ni-59	1.70E-08	1.24E+06	No
Ni-63	4.81E-04	1.14E+05	No
Np-237	1.53E-05	1.94E+01	No
Pa-231	2.51E-06	2.37E+01	No
Pb-210	3.36E-07	2.74E+05	No
Pu-238	9.82E-03	1.78E+01	No
Pu-239	4.91E-02	1.89E+01	No
Pu-240	1.43E-02	1.89E+01	No
Pu-241	1.88E-01	3.73E+05	No
Pu-242	1.10E-06	2.00E+01	No
Pu-244	2.38E-15	2.12E+01	No
Ra-226	3.41E-07	2.04E+01	No
Ru-106	4.14E-07	1.94E+05	No
Sb-125	1.17E-01	6.02E+03	No
Sr-90	1.61E+02	3.34E+03	No
Tc-99	3.37E-03	1.60E+04	No
Th-228	4.36E-07	1.81E+01	No

Table D-1. (continued).

Contaminants	Calculated Concentration (pCi/g)	Screening Value (pCi/g)	Max Concentration > screening values?
Th-229	1.88E-11	3.60E+01	No
Th-230	1.96E-05	2.09E+01	No
Th-232	1.11E-13	2.43E+01	No
U-232	6.20E-07	1.54E+01	No
U-233	8.34E-09	2.05E+01	No
U-234	1.05E-01	2.05E+01	No
U-235	4.74E-03	2.27E+01	No
U-236	1.01E-04	2.17E+01	No
U-238	1.37E-03	2.32E+01	No
Zn-65	8.94E-09	5.21E+03	No

D-3. INITIAL SCREENING OF NONRADIONUCLIDES

For nonradionuclides, the calculated concentrations provided in Table C-3 were used. The initial screening results are presented in Table D-2. For PBF, the calculated soil concentrations of chromium III, boron, manganese, lead, and zinc exceed ecological risk-based screening levels. These nonradionuclides will be further assessed in the following section.

Table D-2. Results of nonradionuclide screening against ecological soil screening levels.

Detected Contaminants	Calculated Concentration (mg/kg)	Screening Value (mg/kg)	Calculated Concentration > screening values?
Aluminum	7.27E+02	2.04E+05	No
Boron	5.84E+01	5.00E-01	Yes
Chromium III	7.75E+03	2.60E+01	Yes
Lead	1.78E+01	1.10E+01	Yes
Manganese	7.74E+02	1.85E+01	Yes
Nickel	3.94E+03	9.63E+03	No
Selenium	1.07E-02	8.10E-01	No
Uranium	3.95E-01	1.66E+00	No
Zinc	1.62E+02	5.00E+01	Yes

D-4. ELIMINATION OF NONRADIONUCLIDES

Boron, chromium III, lead, manganese, and zinc had modeled soil concentrations above screening levels. Hazard quotients (HQs) and hazard indices (HIs) were calculated for these nonradionuclides using the approach documented in the *Comprehensive Remedial Investigation/Feasibility Study for Waste Area Groups 6 and 10 Operable Unit 10-04* (DOE-ID 2001).

In the initial screen, the nonradionuclides boron, chromium III, lead, manganese, and zinc exceed the EBSLs. However, the inclusion of these constituents in the overall soil concentration is a highly conservative assumption. As discussed in Section 4, all of the modeled concentrations of these metals in this environment were calculated from a debris mass estimated to remain in the area, including reactor components, control rods, wiring, pipes, and pumps. In the environment at this site, this debris will not degrade to a bioavailable form uniformly throughout this soil, as was modeled. The concentrations of COPCs will be highly localized and will not be in a bioavailable form. It is unreasonable to assume they would pose an unacceptable exposure to ecological receptors. Therefore, the nonradiological materials associated with this debris are eliminated as an ecological concern.

D-5. SUMMARY

This streamlined ecological risk assessment was performed to support the No Action alternative for the D&D of the PBF Reactor Facility. This evaluation used a screening approach to evaluate risk to ecological receptors. The screening for radionuclides indicates that EBSLs are not exceeded for any radionuclide.

In the initial screen, the nonradionuclides boron, chromium III, lead, manganese, and zinc exceed the EBSLs. However, the inclusion of these constituents in the overall soil concentration is a highly conservative assumption. As discussed in Section 4, all of the concentrations of these metals in this environment were calculated from a debris mass estimated to remain in the area, including reactor components, control rods, wiring, pipes, and pumps. In the environment at this site, this debris will not degrade to a bioavailable form uniformly throughout this soil, as was modeled. The concentrations of COPCs will be highly localized and will not be in a bioavailable form. It is unreasonable to assume they would pose an unacceptable exposure to ecological receptors. Therefore, the nonradiological materials associated with this debris are eliminated as an ecological concern.