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Problem Statement: CWI is decontaminating and dismantling (D&D) the Engineering Test Reactor (ETR) at the Reactor Technologies Complex (RTC, formerly the Test Reactor Area) on the INL. This EDF provides a streamlined human risk assessment for contaminants remaining in the surface soil for two D&D alternatives: leaving the ETR vessel in place, and removing the ETR vessel.

Conclusions: Calculations herein indicate that risk from radionuclides could exceed EPA's 1E-04 risk threshold for the ETR vessel left in place alternative. Removal of the vessel would reduce the risk to 3E-07. Non-radiological contaminants screened out for both alternatives, and were therefore not analyzed in detail for risk.

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 ETR Facility

INTRODUCTION

CWI is decontaminating and dismantling (D&D) the Engineering Test Reactor (ETR) at the Reactor Technologies Complex (RTC, formerly the Test Reactor Area) on the INL. This 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 two D&D alternative scenarios: 1) Leaving the ETR vessel in place, and 2) removing and disposing the vessel offsite, with the below-grade portions of the reactor building left in place for both alternatives. The 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 is addressed in EDF-5142, *Groundwater Pathway Risk Assessment for the Engineering Test Reactor Complex Closure*. Risks from contaminated soil and underground piping will be addressed in a separate Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) document.

METHODS/ASSUMPTIONS

Radiological Source Term

Radiological contaminant inventories associated with ETR are documented in Engineering Design File EDF-6304, *ETR Complex Activity vs. Depth*. Table 1 provides the radionuclide inventory initially considered for the surface soil risk assessment. The inventory for ETR was assumed mixed uniformly in a block of soil with cross-sectional area corresponding to the sum of the individual building and structure footprints that make up the ETR Complex.[1] The soil mass was calculated given the following:

- ETR Complex footprint = 4,251 m^2 (45,759 ft^2)
- Soil block 3 m (10 ft) deep
- Soil density = 1500 kg/m^3

Radionuclide Screening. Radionuclides were screened using 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 home-grown 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 soil mass. Any radionuclide exceeding its SSL for one alternative was retained for both alternatives. Results of screening are presented in Table 2.

[1] footprint provided in spreadsheet "TRA-Structure Footprint.xls" sent in A. B. Culp memo to C. Staley dated 11/22/05

Radionuclides retained after screening (Table 2) were then decayed 90 years to the year 2095, and the resultant soil concentrations (Table 3) input to the risk assessment.

Non-Radiological Source Term

Non-radiological contaminant inventories associated with ETR are documented in Engineering Design File EDF-6225, *ETR Complex Chemical Constituent Source Term.* Modifications to inventories from EDF-6225 are documented in Appendix C. Table 4 provides the non-radiological source term prior to screening. Soil concentrations were calculated given the soil mass for the site.

Non-radiological Contaminant Screening. Non-radiological 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 non-carcinogens, were considered in this screening. Results are presented in Table 5. All non-radiological contaminants screened out; therefore, non-radiological risk is not considered further.

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 down to 10 feet below grade remaining after D&D and radioactive decay is mixed uniformly in the top 10 feet (3.05 m) of soil and is available to an intruder in the year 2095 (90 years from present). The scenario also assumes someone will build a house at the site of the removal action, 10 feet of contaminated material will be excavated 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 6 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 at the site. Risks were evaluated for two alternative removal actions:

- ETR vessel is assumed left in place, with reactor building removed to ground level. The contaminant inventory in the vessel and in the reactor building below grade to a depth of 10 feet are used in the risk assessment.

- The ETR vessel, and therefore the vessel's contaminant inventory, is removed and disposed of elsewhere, and the reactor building is removed to ground level. Therefore, for this alternative, the contaminant inventory used in the risk assessment is that in the reactor building below grade, to a depth of 10 feet.

Standard U.S. Environmental Protection Agency risk assessment equations were used to calculate the risks from radionuclides (see Appendix A). 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. Complete analysis of groundwater risk was evaluated separately, in EDF-5142, *Groundwater Pathway Risk Assessment for the ETR Closure*.

Uncertainty

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

- Uncertainty in estimates of radionuclide and non-radioactive 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 action.

RESULTS

Risk from Radionuclide Inventories. Risks by radionuclide and pathway, calculated for the screened inventories, are presented in Tables 6 and 7 for the two alternatives. Leaving the ETR vessel in place results in risks exceeding the EPA cancer risk criterion of 1E-04. Risks less than 1E-04 are considered by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) as within the acceptable carcinogenic risk range.

Tables 8 and 9 summarize quantitative and qualitative results, respectively, of this risk assessment.

Table 1. 2005 Radionuclide inventory (Ci) for ETR removal alternatives.[a]

Nuclide	With Vessel Left In Place	With Vessel Removed
Ac-227	8.49E-09	
Ag-108m	2.04E-03	7.75E-06
Ag-110m	6.20E-13	
Am-241	1.53E-03	1.13E-05
Am-243	2.32E-05	
Be-10	3.13E-03	
C-14	1.11E-01	2.76E-05
Ce-144	1.90E-11	
Cl-36	1.06E-03	
Cm-243	4.23E-06	
Cm-244	2.69E-03	
Cm-245	5.07E-07	
Cm-246	5.60E-07	
Cm-247	3.95E-12	
Cm-248	7.08E-11	
Co-60	1.66E+01	3.24E-02
Cs-134	2.47E-05	
Cs-137	2.44E-02	1.66E-03
Eu-152	1.53E-03	
Eu-154	8.77E-03	
Fe-55	1.52E-02	4.38E-02
H-3	2.76E+02	
I-129	8.06E-07	7.62E-07
Mn-54	2.69E-08	
Nb-94	4.05E-02	
Ni-59	1.11E+00	8.24E-04
Ni-63	2.03E+02	7.87E-02
Np-237	1.80E-08	
Pa-231	1.24E-08	
Pb-210	5.78E-13	
Pu-238	7.15E-04	1.30E-05
Pu-239	1.73E-04	2.05E-05
Pu240	1.87E-04	
Pu-241	1.52E-02	7.53E-06
Pu-242	2.39E-06	
Pu-244	2.24E-12	
Ra-226	9.34E-13	
Ru-106	2.63E-09	
Sb-125	5.53E-05	
Sr-90	7.32E-03	2.32E-04
Tc-99	5.44E-05	1.17E-06
Th-228	1.50E-06	
Th-229	1.01E-08	

Nuclide	With Vessel Left In Place	With Vessel Removed
Th-230	9.83E-11	
Th-232	1.72E-08	
U-232	1.45E-06	
U-233	4.90E-06	1.98E-06
U-234	2.58E-07	
U-235	5.72E-08	5.33E-08
U-236	6.06E-09	
U-238	1.20E-07	4.80E-08
Zn-65	1.43E-12	

a. Source: EDF-6304

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

	Soil concentration exceeds Soil Screening Level?	
	With Vessel	**Without Vessel**
Ag-108m	YES	No
C-14	YES	No
Cl-36	YES	No
Co-60	YES	YES
Cs-137	YES	YES
Eu-152	YES	No
Eu-154	YES	No
H-3	YES	No
Nb-94	YES	No
Ni-63	YES	No
Sr-90	YES	No

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

Nuclide	With Vessel Left In Place	With Vessel Removed
Ag-108m	6.60E-02	2.51E-04
C-14	5.74E+00	1.43E-03
Cl-36	5.54E-02	
Co-60	6.29E-03	1.23E-05
Cs-137+d	1.61E-01	1.10E-02
Eu-152	7.83E-04	
Eu-154	3.22E-04	
H-3	9.06E+01	
Nb-94	2.11E+00	
Ni-63	5.69E+03	2.20E+00
Sr-90+D	4.49E-02	1.42E-03

Table 4. Mass (kg) of non-radioactive contaminants associated with ETR used in screening calculations.

	With Vessel Left In Place	With Vessel Removed
Aluminum	3.34E+03	
Antimony & comp.	6.00E-01	6.00E-01
Boron	5.00E-01	
Chromium	3.54E+04	3.54E+04
Copper & comp.	3.68E+04	3.68E+04
Lead	4.00E+01	4.00E+01
Manganese & comp.	7.67E+03	7.67E+03
Nickel (soluble salts)	1.96E+04	1.96E+04
Silver & comp.	4.00E+01	4.00E+01
Tin (inorganic)	8.00E+01	8.00E+01
Zinc	7.40E+02	7.40E+02

Table 5. Results of screening non-radiological contaminants

	Does Soil Concentration Exceed Soil Screening Level?	
	With Vessel Left In Place	With Vessel Removed
Aluminum	NO	
Antimony & comp.	NO	NO
Boron	NO	
Chromium	NO	NO
Copper & comp.	NO	NO
Lead	NO	NO
Manganese & comp.	NO	NO
Nickel (soluble salts)	NO	NO
Silver & comp.	NO	NO
Tin (inorganic)	NO	NO
Zinc	NO	NO

Table 6. Risk by radionuclide and pathway for ETR, Vessel left in place

Radionuclide	Soil Ingestion	Inhalation	External Exposure	Produce Ingestion	SUM
Ag-108m	1.E-09	1.E-13	3.E-06	1.E-08	3.E-06
C-14	2.E-08	5.E-12	4.E-10	1.E-05	1.E-05
Cl-36	5.E-10	2.E-13	9.E-10	1.E-06	1.E-06
Co-60	2.E-15	2.E-19	5.E-12	2.E-14	5.E-12
Cs-137+d	1.E-09	3.E-14	5.E-07	6.E-09	5.E-07
Eu-152	2.E-13	8.E-17	4.E-10	3.E-14	4.E-10
Eu-154	8.E-15	3.E-18	1.E-11	2.E-15	1.E-11
H-3	2.E-10	1.E-14	0.E+00	8.E-08	8.E-08
Nb-94	5.E-08	9.E-12	1.E-04	5.E-08	1.E-04
Ni-63	7.E-06	6.E-10	0.E+00	3.E-05	4.E-05
Sr-90+D	1.E-09	7.E-14	9.E-10	3.E-08	3.E-08
					2.E-04

Table 7. Risk by radionuclide and pathway for ETR, Vessel removed

Radionuclide	Soil Ingestion	Inhalation	External Exposure	Produce Ingestion	SUM
Ag-108m	6.E-12	8.E-16	2.E-08	8.E-11	2.E-08
C-14	5.E-12	1.E-15	1.E-13	3E-09	5.E-12
Co-60	6.E-13	5.E-17	1.E-09	4.E-12	1.E-09
Cs-137+d	6.E-10	2.E-14	3.E-07	3.E-09	3.E-07
Ni-63	5.E-09	4.E-13	0.E+00	2.E-08	3.E-08
Sr-90+D	3.E-10	2.E-14	2.E-10	8.E-09	9.E-09
					3.E-07

Table 8. Quantitative summary of radiological and non-radiological risk

Alternative	Radiological Cancer Risk	Non-Radiological Cancer Risk	Non-Radiological Hazard Index
Vessel in place	2E-04	Non-radiological contaminants were screened out of risk assessment	
Vessel removed	3E-07		

Table 9. Qualitative summary of radiological and non-radiological risk

Alternative	Exceeds Radiological Cancer Risk Criterion	Exceeds Non-Radiological Cancer Risk Criterion	Exceeds Non-Cancer Risk Criterion
Vessel in place	X	Non-radiological contaminants were screened out of risk assessment	
Vessel removed			

REFERENCES

EDF (Engineering Design File)-6225, 2005,*ETR Complex Chemical Constituent Source Term*

EDF (Engineering Design File)-6304, 2005, *ETR Complex Activity vs. Depth*

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

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

EPA 2005, Integrated Risk Information System (IRIS). Values updated monthly on line at http://www.epa.gov/iris/.

Appendix A

Radiological Soil Screening and Risk Assessment

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A.1 Radionuclide Screening for Soils

Radionuclide screening followed EPA's *Soil Screening Guidance for Radionuclides: User's Guide* (EPA/540-R-00-007, October 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.
SF's = Radionuclide-specific slope factors for pathways – see Table A-2

Other parameters definitions and values are provided in Table A-1.

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

Table A-1

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	5.55E+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 A-2. Slope factors and soil screening levels (SSLs - pCi/g) for ETR radionuclide inventory, ground-level to 10 feet below grade

	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
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-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
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
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
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

	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)
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
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 A-3. Soil concentrations (pCi/g) compared to SSLs

Nuclide	With Vessel Left In Place	With Vessel Removed	Lowest SSL
Ac-227	4.44E-07	0.00E+00	2.08E+00
Ag-108m	1.07E-01	4.05E-04	1.55E-02
Ag-110m	3.24E-11	0.00E+00	8.58E-03
Am-241	8.00E-02	5.91E-04	3.66E+00
Am-243	1.21E-03	0.00E+00	1.18E+00
Be-10	1.64E-01	0.00E+00	3.45E+01
C-14	5.80E+00	1.44E-03	1.28E-01
Ce-144	9.93E-10	0.00E+00	2.22E+00
Cl-36	5.54E-02	0.00E+00	1.59E-02
CM-243	2.21E-04	0.00E+00	2.66E-01
CM-244	1.41E-01	0.00E+00	4.38E+00
CM-245	2.65E-05	0.00E+00	4.69E-01
CM-246	2.93E-05	0.00E+00	3.74E+00
CM-247	2.06E-10	0.00E+00	8.52E-02
CM-248	3.70E-09	0.00E+00	3.26E+03
Co-60	8.68E+02	1.69E+00	9.00E-03
Cs-134	1.29E-03	0.00E+00	1.57E-02
Cs-137	1.28E+00	8.68E-02	4.38E-02
Eu-152	8.00E-02	0.00E+00	2.11E-02
Eu-154	4.58E-01	0.00E+00	1.91E-02
Fe-55	7.95E-01	2.29E+00	3.80E+02
H-3	1.44E+04	0.00E+00	4.50E+00
I-129	4.21E-05	3.98E-05	2.19E-01
Mn-54	1.41E-06	0.00E+00	2.87E-02
Nb-94	2.12E+00	0.00E+00	1.53E-02
Ni-59	5.80E+01	4.31E-02	7.24E+01
Ni-63	1.06E+04	4.11E+00	2.96E+01
Np-237	9.41E-07	0.00E+00	8.49E-01
Pa-231	6.48E-07	0.00E+00	6.23E-01
Pb-210	3.02E-11	0.00E+00	1.19E-01
Pu-238	3.74E-02	6.80E-04	2.92E+00
Pu-239	9.04E-03	1.07E-03	2.88E+00
Pu240	9.78E-03	0.00E+00	2.87E+00
Pu-241	7.95E-01	3.94E-04	2.41E+02
Pu-242	1.25E-04	0.00E+00	3.02E+00
Pu-244	1.17E-10	0.00E+00	2.70E+00
Ra-226	4.88E-11	0.00E+00	6.85E-02
Ru-106	1.37E-07	0.00E+00	1.15E-01
Sb-125	2.89E-03	0.00E+00	6.16E-02
Sr-90	3.83E-01	1.21E-02	4.92E-02
Tc-99	2.84E-03	6.12E-05	7.04E-02
Th-228	7.84E-05	0.00E+00	2.75E+00
Th-229	5.28E-07	0.00E+00	4.96E-01
Th-230	5.14E-09	0.00E+00	6.67E+00

Nuclide	With Vessel Left In Place	With Vessel Removed	Lowest SSL
Th-232	8.99E-07	0.00E+00	5.97E+00
U-232	7.58E-05	0.00E+00	1.46E+00
U-233	2.56E-04	1.04E-04	5.81E+00
U-234	1.35E-05	0.00E+00	5.02E+00
U-235	2.99E-06	2.79E-06	2.15E-01
U-236	3.17E-07	0.00E+00	5.33E+00
U-238	6.27E-06	2.51E-06	6.50E+00
Zn-65	7.48E-11	0.00E+00	3.97E-02

A.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 (NCP) 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:

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

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

$$\text{Soil Ingestion} = (SF_{soil}) \times (IR_{soil}) \times (EF_{Res}) \times (0.001 \frac{kg}{g})$$

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

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

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

Where:

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

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

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

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

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

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

Particulate Emission Factor (m^3/kg)	PEF	5.55E+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-Ch}	6
Exposure Duration-Residential-Adult (yr)	ED_{Res-Ad}	24
Ingestion Rate-Soil-Child (mg/day)	$IR_{Soil-Ch}$	200
Ingestion Rate-Soil-Adult (mg/day)	$IR_{Soil-Ad}$	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)	$CR_{Fruit-Ch}$	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 57.41 (g m^{-2} s^{-1} per kg m^{-3}), assuming 1.5 acre site and Boise climatic zone (Exhibit 10 of Soil Screening Guidance for Radionuclides).

TableA-5. Radionuclide-specific values used in risk assessment

	Toxicity[a]					
	Soil Ingestion Slope Factor-Adult	Food Ingestion Slope Factor	Inhalation Slope Factor	External Exposure Slope Factor	Half Life	Soil to Plant Transfer Factor
	(risk/pCi)	(risk/pCi)	(risk/pCi)	(risk/y per pCi/g)	(yr)	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 taken from EPA Radionuclide PRG web site (http://epa-prgs.ornl.gov/radionuclides)

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Appendix B

Non-Radiological Soil Screening

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Appendix B
Non-Radionuclide Screening for Soils

Non-radionuclide screening followed EPA's *Soil Screening Guidance: User's Guide* (EPA/540/R-96-018, July 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 – non-carcinogens:

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

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 – non-carcinogens:

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

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 non-radiological 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	$(mg/kg\text{-}d)^{-1}$	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		1
BW	Body weight (child)	kg	15
AT_{si}	Non-carcinogen averaging time - soil ingestion	yr	6
RfD_o	oral reference dose	mg/kg-d	chem-spec.
ED_{ing}	Non-carcinogen 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	5.55E+08[b]
AT_{ncinh}	Averaging time-non-carcinogenic inhalation	yr	30
RfC	Inhalation reference concentration	mg/m^3	chem-spec.

b. PEF calculated using Equation 3 from EPA, 2000 and Q/C value of 57.41, which is based on 1.5 acre site and Boise climatic zone (Exhibit 11 of EPA 2000).

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

	Ingestion – Non-Carcinogens		Ingestion - Carcinogens		Inhalation – Carcinogens		Inhalation - Non-Carcinogens		
	RfDo	Soil Screening Level	SFo	Soil Screening Level	URF	Soil Screening Level	RfC	Soil Screening Level	**Minimum SSL**
Aluminum									NA[a]
Antimony & comp.	4.00E-04	3.13E+01							3.13E+01
Boron	2.00E-01	1.56E+04							1.56E+04
Chromium	1.50E+00	1.17E+05							1.17E+05
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	5.63E+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 a risk-based 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 SSL

	With Vessel Left In Place	With Vessel Removed	**Minimum SSL**
Aluminum	1.75E+02		NA[a]
Antimony & comp.	3.14E-02	3.14E-02	3.13E+01
Boron	2.61E-02	2.61E-02	1.56E+04
Chromium	1.85E+03	1.85E+03	1.17E+05
Copper & comp.	1.93E+03	1.93E+03	NA
Lead	2.09E+00	2.09E+00	NA
Manganese & comp.	4.01E+02	4.01E+02	1.10E+04
Nickel (soluble salts)	1.03E+03	1.03E+03	1.56E+03
Silver & comp.	2.09E+00	2.09E+00	3.91E+02
Tin (inorganic)	4.18E+00	4.18E+00	NA
Zinc	3.87E+01	3.87E+01	2.35E+04

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

Appendix C

Notes Documenting Changes to Non-Radiological Source Term

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Appendix C

Notes Documenting Changes to Non-Radiological Source Term

The following is an email communication with specific information affecting risk calculations used in this risk assessment:

From: Walker F Howell [mailto:HOWEWF@inel.gov]
Sent: Tuesday, December 06, 2005 10:29 AM
To: Culp, A
Cc: Staley, Chris; Reno, Scott; Harvego, Lisa; Reno, Scott
Subject: Re: Comments on risk assessment

Mass of constituents: barium, beryllium, and chromium.

No adjustment for the mass of barium was made in the EDF (e.g., the mass of the barytes, or barium sulfate was assumed to be the mass of the barium). However, fractioning out the barium from barium sulfate, which is the ratio of the atomic weight of barium divided by the atomic weight of barium sulfate, yields 0.5884.

Thus, the adjusted mass of (elemental) barium in ETR is 173,080 kg x 0.5884 =101,840 kg.
The adjusted mass of (elemental) barium in MTR is 2,469,280 kg x 0.5884 =1,459,924 kg.

In addition, the barium at ETR is assumed to be present only in the cubicle walls. Thus, the depth of the barium extends from the top of the basement floor (38.25 ft below grade) to the bottom of the console floor, which is 26.25 ft below grade.

Barium at MTR is found within the biological shield and the reactor thermal shield. The majority of the biological shield is above grade. Based on cross-sectional views of the MTR reactor, the biological shield extends to a depth of 16.67 ft below grade. The portion between 0-10-ft below grade is estimated at 25-30 % of the total weight of the biological shield. The portion of the shield greater than 10 ft below grade is roughly 5%. The thermal shield comprises the remaining portion of high density concrete containing barytes. Based on schematics of the MTR, it appears that thermal shield is completely above grade.

No adjustments are necessary for the weight of the beryllium. At both ETR and MTR, the beryllium was assumed to be present only in the reflectors, which are located within the reactor vessels at the respective facilities. At ETR, the top of the beryllium is at an elevation of 81-ft 7 7/8 in. Using a base (first floor elevation) of 96.5 ft provides the depth below grade of the ETR beryllium reflector of 14.83 ft. The reflector is 37.5 in. high.

At MTR, the reflector is 39 3/8 in. high. The top of the beryllium reflector is at an elevation of 101-ft 7 11/16 in. Using a base (first floor elevation) of 96.5 ft for MTR indicates the entire beryllium reflector is above grade.

Finally, I don't understand why the risk assessment partitioned out chromium as trivalent (Cr +3) and hexavalent (Cr+6). Chromium used in the manufacture of a stainless steel alloy would be in the "0" valence. The EDFs that I prepared did not make any distinctions with respect to chromium valence, and in hindsight perhaps should have indicated that the chromium (alloyed to make stainless steel) is assumed to have 0 valence.