ECF-HANFORD-10-0446
Revision 1

Calculation of Radiological Preliminary Remediation Goals in Soil for a Casual User Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Terms

COPC	Contaminant of Potential Concern
EPA	U.S. Environmental Protection Agency
HEAST	EPA's Health Effects Assessment Summary Table
PRG	Preliminary Remediation Goal
RME	Reasonable Maximum Exposure

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1 Purpose

This Environmental Calculation documents assumptions and methods for development of radiological soil Preliminary Remediation Goals (PRGs) for the casual recreational user exposure scenario for use in the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports. PRGs are concentration goals for a specific medium (e.g. soil) that are intended to protect specified receptors from exposure to contaminants through identified exposure pathways.

The PRGs described in the environmental calculation represent concentration goals that are protective of a potential casual recreational user receptor. Potentially complete exposure pathways associated with this scenario include direct contact. The PRGs described in this Environmental Calculation are consistent with the PRGs presented in DOE/RL-96-17, *River Corridor Baseline Risk Assessment*, with the exception that the receptor spends the entire allotted exposure time on the waste site. The exposure assumptions used to calculate the PRG values presented in this Environmental Calculation are described in Section 4.0 and listed in Appendix A.

2 Background

As described in DOE/RL-2008-46, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan* and DOE/RL-2009-30, 3*00 Area Remedial Investigation/Feasibility Study Work Plan for the 300-FF-1, 300-FF-2, and 300-FF-5 Operable Units*, the 100 Areas and 300 Area contains multiple source and groundwater operable units (OUs), that are part of the Hanford Site River Corridor, which encompasses approximately 570 km^2 (220 mi^2) adjacent to the Columbia River. The PRGs that are described in this environmental calculation are consistent with the cleanup levels that were calculated in DOE/RL-2007-21, *River Corridor Baseline Risk Assessment (RCBRA)*. The PRG values in this environmental calculation are modified so that the receptor spends the entire allotted exposure time on the waste site. In addition, the radionuclide toxicity factors were obtained from the "Summary Table" within PRG Download Area of the U.S. Environmental Protection Agency's (EPA's) "Preliminary Remediation Goals for Radionuclides (PRG)" website (EPA 2015a) (http://epa-prgs.ornl.gov/radionuclides/download.html), Dated November 24, 2014 as opposed to the values found in EPA 402/R-99/001, *Health Risks from Low-Level Environmental Exposure to Radionuclides* used in DOE/RL-2007-21. For the purposes of developing radionuclide PRGs within this Environmental Calculation document, the following target objectives are used:

- Prevent unacceptable risk to human health from exposure to soils and/or debris contaminated with radiological contaminants less than 4.6 m (15 ft) below ground surface (bgs). PRGs for radionuclides that achieve this objective achieve the CERCLA cumulative risk range of 10^{-4} to 10^{-6} increased lifetime cancer risk (EPA, 1999). As described in DOE/RL-96-17, Rev 6, these PRGs are intended to limit radiation risks for 1,000 years following the completion of a remedial action. The 1,000-year timeframe (ANL, 2001) ensures that the PRGs account for the decay of radionuclides to daughter products that are more radioactive

This target objective has been developed only for the purpose of calculating PRGs that are presented in this Environmental Calculation. This target objective is not intended to supersede Remedial Action Objectives (RAOs) developed in the 100 Areas RI/FS Reports or the 300 Area RI/FS Report. This Environmental Calculation document will be revised as needed to incorporate updates to these PRGs that may result from changes in RAOs occurring during development of the 100 Areas and 300 Area RI/FS Reports.

2.1 Exposure Routes

The potentially exposed population for this exposure scenario includes both adults and children. Adults and children may be exposed to surface soil contaminants via external gamma exposure to ionizing radiation, incidental soil ingestion, and inhalation of dust and vapors. This scenario is focused primarily on activities such as walking and picnicking near the river, where paths and benches are likely to exist.

Potentially complete exposure routes associated with the direct contact exposure pathway for the casual recreational user exposure scenario are as follows:

- Incidental ingestion of soil
- Inhalation of vapors and dust in soil
- External exposure to ionizing radiation

2.2 References

For the soil direct contact and inhalation exposure pathways, contaminant PRGs are quantified using standard equations and procedures as specified in the following:

- EPA/540/R-92/003, *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals): Interim*
- EPA/630/R-03/003F, *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens*
- EPA/540/R-96/018, *Soil Screening Guidance: User's Guide Second Edition*
- EPA, 2015, "Preliminary Remediation Goals for Radionuclides (PRG)" (http://epa-prgs.ornl.gov/radionuclides/);
- ORNL 2014, *Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models*
- OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*
- OSWER Directive 9285.6-03, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*

3 Methodology

The casual recreational user PRGs were calculated using the PRG equations found at *EPA's Preliminary Remediation Goals for Radionuclides (PRG)* website (EPA, 2015b) using a combination of default and site-specific exposure assumptions that represent a plausible exposure setting for characterizing human health risks to a child and adult casual recreational user. PRGs for direct contact with soil are based on an acceptable target cancer risk level of 1×10^{-4} for radionuclides.

The direct contact and inhalation exposure pathways are considered potentially complete for the casual recreational user scenario. Exposure routes associated with the direct contact exposure pathway include external gamma exposure, incidental soil ingestion; the inhalation exposure pathway considers vapors and dust in soil. The following subsection presents the equations for exposure routes used to calculate total PRGs for radionuclides.

Table 1. Summary of Exposure Assumptions Used to Calculate Preliminary Remediation Goals for the Casual Recreational User

Exposure Route/Exposure Factor	Symbol	Value	Units	Source
Area Correction Factor	ACF	Radioisotope-Specific	unitless	ORNL 2014
Exposure Duration -Adult + Child Casual Recreational User	ED_{a+ccu}	30	years	OSWER Directive 9285.6-03
Exposure Duration - Child Casual Recreational User	ED_{ccu}	6	years	OSWER Directive 9285.6-03
Exposure Frequency - Casual Recreational User	EF_{cu}	30	days/year	DOE/RL-2007-21, Table 3-18
Exposure Time - Casual Recreational User, outdoors	ET_{cu}	6	hour/day	PNNL, 2001; Table 4.9
Age-adjusted inhalation rate – Casual Recreational User	IRA_{adj_cu}	7.50E-01	m^3/hour	Equation 5
Age-adjusted soil ingestion rate, Casual Recreational User, Radioisotopes	$IRS_{adj_cu_rad}$	120	mg/day	Equation 2
Inhalation Rate - Casual Recreational User Child	IRA_{ccu}	4.17E-01	m^3/hour	EPA/540/R-92/003, based on a value of 10 m^3/day
Inhalation Rate - Casual Recreational User Adult	IRA_a	8.33E-01	m^3/hour	EPA/540/R-92/003, based on a value of 20 m^3/day
Soil Ingestion Rate – Adult Casual Recreational User	IRS_a	100	mg/day	OSWER Directive 9285.6-03
Soil Ingestion Rate – Child Casual Recreational User	IRS_{ccu}	200	mg/day	OSWER Directive 9285.6-03
Particulate Emission Factor	PEF	7.30E+10	m^3/kg	Equation 6
PRG– Casual Recreational User, radionuclide, external exposure	$PRG_{cu_rad_ext}$	Radioisotope-Specific	pCi/g	Equation 3
PRG – Casual Recreational User, radionuclide, incidental soil ingestion	$PRG_{cu_rad_ing}$	Radioisotope-Specific	pCi/g	Equation 1
PRG – Casual Recreational User, radionuclide, inhalation	$PRG_{cu_rad_inh}$	Radioisotope-Specific	pCi/g	Equation 4

Table 1. Summary of Exposure Assumptions Used to Calculate Preliminary Remediation Goals for the Casual Recreational User

Exposure Route/Exposure Factor	Symbol	Value	Units	Source
PRG – Casual Recreational User, radionuclide, total	$PRG_{cu_rad_tot}$	Radioisotope-Specific	pCi/g	Equation 10
Slope Factor - Inhalation	SF_i	Radioisotope-Specific	risk/pCi	EPA, 2015a
Slope Factor – Soil Ingestion	SF_s	Radioisotope-Specific	risk/pCi	EPA, 2015a
Slope Factor – External Exposure	SF_x	Radioisotope-Specific	Risk/year per pCi/g	EPA, 2015a
Time - Casual Recreational User	t_{cu}	30	years	Same as Exposure Duration
Target Risk – Radioisotope	TR_rad	1 in 10,000	unitless	OSWER Directive 9355.4-24
Unit Conversion Factor	UCF3	1.00E-03	g/mg	1 g = 1,000 mg
Unit Conversion Factor	UCF4	1000	g/kg	1 kg = 1,000 g
Unit Conversion Factor	UCF5	0.002739726	years/day	1 year = 365 days
Volatilization Factor for Tritium	VF_H3	1.70E+01	m^3/kg	Etnier, 1980
Decay Constant	λ	Radioisotope-Specific	yr^{-1}	=0.693/half-life
Half Life		Radioisotope-Specific	years	EPA, 2015a

Table 1. Summary of Exposure Assumptions Used to Calculate Preliminary Remediation Goals for the Casual Recreational User

Exposure Route/Exposure Factor	Symbol	Value	Units	Source

Notes:

OSWER 9355.4-24, Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites

DOE/RL-2007-21, Rev. 0, Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment

Eckerman, 2007, Ratios of Dose Rates for Contaminated Slabs

Etnier, 1980, Tritium-An Analysis of Key Environmental and Dosimetric Questions

EPA/540/R-92/003, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals)

EPA, 2015a, "Preliminary Remediation Goals for Radionuclides (PRG)", PRG Download, "Summary Tables", (http://epa-prgs.ornl.gov/radionuclides/download.html).

OSWER Directive 9285.6-03, Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors"

PNNL, 2001, Columbia River Recreation Survey – Implications for the Hanford Site

ORNL 2014, Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models, Appendix A, Table 12 for Individual Radionuclides and Appendix B, Table 12 for radionuclides with +D.

3.1 PRG Equations for Incidental Soil Ingestion

The bases for the equations used to calculate PRGs associated with the incidental soil ingestion route are summarized in Table 2. All of the parameters used to calculate PRGs for the incidental soil ingestion route are presented and defined in Table 1. Equations are provided below.

Table 2. Calculated Values and Reference Bases Used for the Incidental Soil Ingestion Route

Effect	Symbol for Calculated Value	Reference
Radioactive	$PRG_{cu_rad_ing}$ $IRS_{adj_cu_rad}$	EPA, 2015b, "PRG Equations", *EPA's Preliminary Remediation Goals for Radionuclides (PRG)* website

PRG = Preliminary Remediation Goal
$IRS_{adj_cu_rad}$ = age-adjusted radionuclide soil ingestion rate.

The equations used to calculate the PRG for the incidental soil ingestion route are presented below:

$$PRG_{cu_rad_ing} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1 - e^{(-\lambda \times t_{cu})}\right) \times SF_s \times IRS_{adj_cu_rad} \times EF_{cu} \times ED_{a+ccu} \times UCF3} \quad (1)$$

Where:

$$IRS_{adj_cu_rad} = \frac{\left(ED_{ccu} \times IRS_{ccu}\right) + \left(\left(ED_{a+ccu} - ED_{ccu}\right) \times IRS_a\right)}{ED_{a+ccu}} \quad (2)$$

3.2 PRG Equations for External Exposure to Ionizing Radiation

The bases for the equations used to calculate PRGs associated with the external exposure to ionizing radiation route are summarized in Table 3. All of the parameters used to calculate PRGs for the external exposure to ionizing radiation route are presented and defined in Table 1. Equations are provided below.

Table 3. Calculated Values and Reference Bases Used for the External Exposure to Ionizing Radiation Route

Effect	Symbol for Calculated Value	Reference
Radioactive	$PRG_{cu_rad_ext}$	EPA, 2015b, "PRG Equations", *EPA's Preliminary Remediation Goals for Radionuclides (PRG)* website

PRG = Preliminary Remediation Goal

The equations used to calculate the PRG for the external exposure to ionizing radiation route are presented below:

$$PRG_{cu_rad_ext} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1 - e^{(-\lambda \times t_{cu})}\right) \times SF_x \times ACF \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \frac{1day}{24hours} \times UCF5} \quad (3)$$

3.3 PRG Equations for the Inhalation of Vapors and Dust in Soil

The bases for the equations used to calculate PRGs associated with the inhalation of vapors and dust in soil are summarized in Table 4. All of the parameters used to calculate PRGs for the inhalation of vapors and dust in soil route are presented and defined in Table 1. Equations are provided below.

Table 4. Calculated Values and Reference Bases Used for the Inhalation of Vapors and Dust in Soil Route

Effect	Symbol for Calculated Value	Reference
Radiation	$PRG_{cu_rad_inh}$ IRA_{adj_cu}	EPA, 2015b, "PRG Equations", *EPA's Preliminary Remediation Goals for Radionuclides (PRG)* website
Particulate Emission Factor	PEF Q/C	OSWER Directive 9355.4-24
Volatilization Factor (tritium only)	VF_H3	Etnier, 1980

Notes: OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*

Etnier, 1980, *Tritium-An Analysis of Key Environmental and Dosimetric Questions.*

PRG = Preliminary Remediation Goal

PEF = particulate emission factor

VF = volatilization factor (tritium only)

Q/C = inverse of mean concentration at center of a source

The equations used to calculate the PRG for the inhalation route are presented below:

$$PRG_{cu_rad_inh} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1 - e^{(-\lambda \times t_{cu})}\right) \times SF_i \times IRA_{adj_cu} \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \left(\frac{1}{PEF} or \frac{1}{VF}\right) \times UCF4} \quad (4)$$

Where:

$$IRA_{adj_cu} = \frac{\left(ED_{ccu} \times IRA_{ccu}\right) + \left(\left(ED_{a+ccu} - ED_{ccu}\right) \times IRA_a\right)}{ED_{a+ccu}} \quad (5)$$

3.3.1 Volatilization Factor

As shown in Table 4, an EPA derived default volatilization factor (VF_H3) value of 17 m^3/kg was used for tritium. The VF replaces the particulate emission factor (PEF) in the PRG equations when tritium is being addressed. This VF value is based on a steady-state model that assumes--on average--tritium in soil pore water and tritium in air (as tritiated water vapor) will be distributed in the environment in proportion to the average water content in soil and air.

3.3.2 Particulate Emission Factor Calculation

The following presents the equations used to calculate the PEF for use in calculating inhalation PRGs for a casual recreational user exposure scenario. Definitions of variables and input values are provided in Table 5.

The particulate emission factor is calculated using the following equations:

$$PEF = \frac{Q}{C} \times \frac{3{,}600}{0.036 \times (1 - V) \times \left(\frac{u_m}{u_t}\right)^3 \times F(x)} \tag{6}$$

Where:

$$\frac{Q}{C} = A \times \exp\left[\frac{(\ln(A_s) - B)^2}{C}\right] \tag{7}$$

And:

$$F(x) = 0.18\,(8\,x^3 + 12\,x)\exp-(x^2) \tag{8}$$

And:

$$x = 0.886\left(\frac{u_t}{u_m}\right) \tag{9}$$

3.4 Total PRG Equation

The following presents the equations used to calculate the total PRGs for all exposure routes combined. The basis for the equation is provided in EPA/540/R-92/003.

$$PRG_{cu_rad_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_rad_ing}}\right) + \left(\frac{1}{PRG_{cu_rad_ext}}\right) + \left(\frac{1}{PRG_{cu_rad_inh}}\right)\right)} \tag{10}$$

Table 5. Summary of Input Parameters Used to Calculate Particulate Emission Factors for the Casual Recreational User Exposure Scenario

Input Parameter	Symbol	Value	Units	Source
A Constant	A	11.3161	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
Site Area	A_s	0.5	acres	OSWER Directive 9355.4-24
B Constant	B	19.6437	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
C Constant	C	224.8172	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
Wind speed distribution function	F(x)	7.21E-03	unitless	Equation 8
Particulate Emission Factor	PEF	7.30E+10	m^3/kg	Equation 6
Inverse of mean concentration at center of a source	Q/C	71.22808	g/m^2-s per kg/m^3	Equation 7
Annual average wind speed	u_m	3.4	m/s	PNNL-15160, Table 5.1
Wind speed at anemometer height equivalent to corrected threshold friction velocity	u_t	11.32	m/s	OSWER Directive 9355.4-24
Fraction of vegetative cover	V	0.5	unitless	OSWER Directive 9355.4-24
	x	2.95E+00	unitless	Equation 9

Notes:

EPA/540/R-96/018, *Soil Screening Guidance: User's Guide Second Edition*

OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*

PNNL-15160, 2005, *Hanford Site Climatological Summary 2004 with Historical Data*

4 Assumptions and Inputs

Assumptions and inputs associated with the casual recreational user exposure scenario and human health toxicity values used in the human health PRG calculations are described below.

4.1 Assumptions and Inputs

The exposure assumptions and radionuclide-specific parameters used to calculate PRGs for the casual recreational user exposure scenario are presented in Tables 1 through 6. Other key assumptions are as follows:

- The PRGs for the casual recreational user exposure scenario are based on a site-specific exposure scenario used to estimate risks in DOE/RL-2007-21. This scenario reflects a reasonably anticipated future land use for the River Corridor.
- The potentially exposed population for this exposure scenario includes both adults and children. This scenario is focused primarily on activities such as walking and picnicking near the river, where paths and benches are likely to exist
- The exposure routes involved with the casual recreational user exposure scenario are incidental soil ingestion, inhalation of volatiles and dust from soil, and external exposure to ionizing radiation (dermal exposure is not evaluated for radionuclides).
- Exposure assumptions used to calculate the casual recreational user PRGs for radionuclides are listed in Table 1. The sources for each of the assumptions are also listed in Table 1.
- With the exception of the exposure frequency and exposure time, the exposure assumptions used to calculate the casual recreational user PRGs are the same as those that would be used to provide a Reasonable Maximum Exposure (RME) for the residential exposure scenario as defined in OSWER Directive 9285.6-03, *Risk Assessment Guidance For Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance, "Standard Default Exposure Factors"*.
- The site-specific exposure frequency of 30 days per year for the casual recreational user scenario is based on seasonal usage as described in DOE/RL-2007-21.
- The site-specific exposure time of 6 hours per day for the casual recreational user scenario is based on a reasonable assumption of recreational usage at the Hanford Site as described in PNNL, *2001 Columbia River Recreation Survey – Implications for the Hanford Site Integrated Assessment*.
- EPA derived a default volatilization factor (VF_H3) value of 17 m^3/kg for tritium. The VF replaces the PEF in the PRG equations when tritium is being addressed. This VF value is based on a steady-state model that assumes--on average--tritium in soil pore water and tritium in air (as tritiated water vapor) will be distributed in the environment in proportion to the average water content in soil and air.
- The analyte-specific Area Correction Factors (ACFs) are based on soil volume and an area of 10,000 square meter (m^2). The ACFs for radionuclides without daughters presented in Table 6 are obtained from Appendix A, Table 12 of *Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models* (ORNL 2014). The ACFs for radionuclides with daughter products are obtained from Appendix B, Table 12 of the same document.

- Due to the lack of indoor exposure for the casual recreational user scenario, a gamma shielding factor (GSF) was not considered when evaluating external exposure to ionizing radiation.
- Input parameters used to calculate the particulate emission factor are listed in Table 5. The input parameters used in these equations are considered generic default values and the sources for each of the input parameters are listed in Table 5.
- The radionuclide-specific half-lives presented in Table 6 are obtained from *Preliminary Remediation Goals for Radionuclides (PRG), PRG Download, Summary Tables (Nov. 24, 2014)* website (EPA 2015a).
- The PRG equations incorporate a decay constant term which is based on the half-life of the isotope (λ), where λ is equal to 0.693 divided by the half life of the isotope. The intention of this term is to make realistic PRGs by including the contributions from their short-lived decay products, assuming equal activity concentrations (i.e. secular equilibrium) with the principal or parent nuclide in the environment.

4.2 Toxicity Values

The radionuclide -specific toxicity values presented Table 6 are obtained from the *Preliminary Remediation Goals for Radionuclides (PRG)* website (EPA 2015a). For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive daughter products (i.e., those daughter products with radioactive half-lives less than or equal to 6 months) are also included. The intention of this designation is to make realistic PRGs by including the contributions from their short-lived daughter products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment.

5 Software Applications

All supporting calculations are performed on electronic spreadsheets using Microsoft Excel[1] for radiological PRGs. The methodology and equations are described in Section 3.0, the exposure assumptions and inputs are provided in Section 4.0, and results for nonradiological PRG calculations are presented in Section 6.0.

6 Calculation

The detailed calculations are presented in Appendix A tables contained in the Microsoft Excel workbook " ECF-Hanford-10-0446 - Casual User Radiological PRGs Attachments.xlsx". PRGs for casual recreational user exposure scenario are calculated using the methodology presented in Section 3. PRGs for exposure to radionuclides in soil by a casual recreational user are validated by comparison with hand calculations. Hand calculations are provided in Figure 6-1.

[1] Excel is a trademark of Microsoft Corporation, Redmond, Washington.

Table 6. Summary of Toxicity Values and Analyte-Specific Exposure Factors used to Calculate Radionuclide PRGs for the Casual Recreational User Exposure Scenario

Analyte Name[a]	CAS ID[b]	Soil Ingestion Slope Factor[c] (SF_s)	External Exposure Slope Factor[c] (SF_x)	Inhalation Slope Factor[c] (SF_i)		Area Correction Factor[d,e]	Half-Life[c]	Decay Constant (λ)
		Risk/pCi	Risk/year per pCi/g	ICRP Lung Absorption Typef	Risk/pCi	Unitless	Years	Yr^{-1}
Americium-241	14596-10-2	1.84E-10	2.77E-08	F	3.80E-08	1.00E+00	4.32E+02	1.60E-03
Carbon-14	14762-75-5	2.77E-12	7.86E-12	S	1.70E-11	1.00E+00	5.70E+03	1.22E-04
Cesium-137+D	10045-97-3	4.26E-11	2.53E-06	S	1.10E-10	9.00E-01	3.02E+01	2.29E-02
Cobalt-60	10198-40-0	3.81E-11	1.24E-05	S	1.00E-10	9.20E-01	5.27E+00	1.31E-01
Curium-243	15757-87-6	1.77E-10	4.20E-07	S	3.70E-08	8.80E-01	2.91E+01	2.38E-02
Curium-243/244[g]	Cm-243/244	1.77E-10	4.20E-07	S	3.70E-08	8.80E-01	2.91E+01	2.38E-02
Curium-244	13981-15-2	1.56E-10	1.40E-10	S	3.60E-08	1.00E+00	1.81E+01	3.83E-02
Curium-245	15621-76-8	1.87E-10	2.74E-07	F	3.80E-08	9.60E-01	8.50E+03	8.15E-05
Europium-152	14683-23-9	1.46E-11	5.41E-06	F	1.90E-10	9.20E-01	1.35E+01	5.13E-02
Europium-154	15585-10-1	2.54E-11	5.85E-06	F	2.10E-10	9.20E-01	8.59E+00	8.07E-02
Europium-155	14391-16-3	5.18E-12	1.25E-07	S	1.90E-11	9.70E-01	4.76E+00	1.46E-01
Iodine-129	15046-84-1	2.78E-10	6.18E-09	V	1.60E-10	7.90E-01	1.57E+07	4.41E-08
Neptunium-237+D	13994-20-2	1.41E-10	8.55E-07	S	2.90E-08	9.10E-01	2.14E+06	3.24E-07
Nickel-59	14336-70-0	6.77E-13	6.77E-11	V	2.40E-12	9.50E-01	1.01E+05	6.86E-06
Nickel-63	13981-37-8	1.71E-12	--	V	5.90E-12	1.00E+00	1.00E+02	6.93E-03
Niobium-94	14681-63-1	1.94E-11	7.22E-06	S	1.30E-10	9.20E-01	2.03E+04	3.41E-05
Plutonium-238	13981-16-3	2.25E-10	6.91E-11	F	5.20E-08	1.00E+00	8.77E+01	7.90E-03

Table 6. Summary of Toxicity Values and Analyte-Specific Exposure Factors used to Calculate Radionuclide PRGs for the Casual Recreational User Exposure Scenario

Analyte Name[a]	CAS ID[b]	Soil Ingestion Slope Factor[c] (SF_s)	External Exposure Slope Factor[c] (SF_x)	Inhalation Slope Factor[c] (SF_i)		Area Correction Factor[d,e]	Half-Life[c]	Decay Constant (λ)
		Risk/pCi	Risk/year per pCi/g	ICRP Lung Absorption Typef	Risk/pCi	Unitless	Years	Yr^{-1}
Plutonium-239/240[h]	PU-239/240	2.28E-10	2.09E-10	F	5.60E-08	1.00E+00	2.41E+04	2.88E-05
Plutonium-241	14119-32-5	2.72E-12	4.06E-12	F	8.70E-10	9.80E-01	1.44E+01	4.81E-02
Silver-108m+D	14391-65-2	1.80E-11	7.17E-06	S	1.10E-10	9.20E-01	4.18E+02	1.66E-03
Strontium-90+D	10098-97-2	1.35E-10	1.95E-08	S	4.30E-10	1.00E+00	2.88E+01	2.41E-02
Technetium-99	14133-76-7	7.25E-12	8.28E-11	S	3.80E-11	1.00E+00	2.11E+05	3.28E-06
Tin-126+D	15832-50-5	7.18E-11	8.78E-06	S	4.30E-10	9.20E-01	2.30E+05	3.01E-06
Tritium	10028-17-8	8.99E-14	--	S	8.50E-13	1.00E+00	1.23E+01	5.63E-02
Uranium-233/234[i]	13966-29-5	1.48E-10	2.53E-10	S	2.80E-08	1.00E+00	2.46E+05	2.82E-06
Uranium-234	13966-29-5	1.48E-10	2.53E-10	S	2.80E-08	1.00E+00	2.46E+05	2.82E-06
Uranium-235+D	15117-96-1	1.54E-10	5.76E-07	S	2.50E-08	8.90E-01	7.04E+08	9.84E-10
Uranium-238+D	U-238	1.97E-10	1.19E-07	S	2.40E-08	9.80E-01	4.47E+09	1.55E-10

Table 6. Summary of Toxicity Values and Analyte-Specific Exposure Factors used to Calculate Radionuclide PRGs for the Casual Recreational User Exposure Scenario

Analyte Name[a]	CAS ID[b]	Soil Ingestion Slope Factor[c] (SF_s)	External Exposure Slope Factor[c] (SF_x)	Inhalation Slope Factor[c] (SF_i)		Area Correction Factor[d,e]	Half-Life[c]	Decay Constant (λ)
		Risk/pCi	Risk/year per pCi/g	ICRP Lung Absorption Typef	Risk/pCi	Unitless	Years	Yr^{-1}

Notes:

For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included.

When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed.

EPA, 2015a, "Preliminary Remediation Goals for Radionuclides (PRG)", PRG Download, "Summary Tables", (November 24, 2014) (http://epa-prgs.ornl.gov/radionuclides/download.html).

ORNL 2014, Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models, Appendix A, Table 12 for Individual Radionuclide and Appendix B, Table 12 for Radionuclides with +D. Available at: http://epa-prgs.ornl.gov/radionuclides/ACF_FINAL.pdf.

When reported value from ORNL, 2014 is greater than 1, the ACF was set equal to 1.

Type F, Type M, and Type S are particulate aerosols that represent, respectively, fast, medium, and slow absorption to the blood. Type V represents vapor.

Values presented are calculated for curium-243; curium-243 is assumed to be the dominant isotope in undifferentiated curium-243/244.

Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.

Values presented are calculated for uranium-234; uranium-234 is assumed to be the dominant isotope in undifferentiated uranium-233/234.

Table 7: Appendix A: Worksheets used in the Calculation of Radiological PRGs for the Casual Recreational User Exposure Scenario

Appendix A, Table A-1	Summary of Incidental Soil Ingestion PRG values for Radionuclides
Appendix A, Table A-2	Summary of External Exposure by Ionizing Radiation PRG values for Radionuclides
Appendix A, Table A-3	Summary of Inhalation PRG values for Radionuclides
Appendix A, Table A-4	Summary of Input Parameters used to Calculate the Particulate Emission Factor

7 Results/Conclusions

The calculated PRGs for the casual recreational user scenario are presented in Table 8.

Table 8. Summary of Total Preliminary Remediation Goals for Radionuclides

		Preliminary Remediation Goals			
		Preliminary Remediation Goal (Ingestion)	**Preliminary Remediation Goal (External Exposure)**	**Preliminary Remediation Goal (Inhalation)**	**Total Preliminary Remediation Goal**
Analyte	**CAS ID[a]**	**pCi/g**	**pCi/g**	**pCi/g**	**pCi/g**
Americium-241	14596-10-2	5.15E+03	6.00E+03	4.86E+07	2.77E+03
Carbon-14	14762-75-5	3.35E+05	2.07E+07	1.06E+11	3.30E+05
Cesium-137+D	10045-97-3	3.01E+04	9.86E+01	2.27E+10	9.82E+01
Cobalt-60	10198-40-0	9.78E+04	5.72E+01	7.25E+10	5.72E+01
Curium-243	15757-87-6	7.32E+03	6.14E+02	6.81E+07	5.67E+02
Curium-243/244[b]	Cm-243/244	7.32E+03	6.14E+02	6.81E+07	5.67E+02
Curium-244	13981-15-2	9.98E+03	1.95E+06	8.42E+07	9.93E+03
Curium-245	15621-76-8	4.96E+03	6.17E+02	4.75E+07	5.49E+02
Europium-152	14683-23-9	1.24E+05	6.39E+01	1.86E+10	6.39E+01
Europium-154	15585-10-1	9.68E+04	8.01E+01	2.28E+10	8.00E+01
Europium-155	14391-16-3	7.91E+05	5.92E+03	4.19E+11	5.87E+03
Iodine-129	15046-84-1	3.33E+03	3.32E+04	1.13E+10	3.03E+03
Neptunium-237+D	13994-20-2	6.57E+03	2.08E+02	6.21E+07	2.02E+02
Nickel-59	14336-70-0	1.37E+06	2.52E+06	7.51E+11	8.87E+05
Nickel-63	13981-37-8	6.00E+05	--	3.38E+11	6.00E+05
Niobium-94	14681-63-1	4.78E+04	2.44E+01	1.39E+10	2.44E+01
Plutonium-238	13981-16-3	4.62E+03	2.64E+06	3.89E+07	4.61E+03

Table 8. Summary of Total Preliminary Remediation Goals for Radionuclides

Analyte	CAS ID[a]	Preliminary Remediation Goals			
		Preliminary Remediation Goal (Ingestion)	Preliminary Remediation Goal (External Exposure)	Preliminary Remediation Goal (Inhalation)	Total Preliminary Remediation Goal
		pCi/g	pCi/g	pCi/g	pCi/g
Plutonium-239/240[c]	PU-239/240	4.06E+03	7.77E+05	3.22E+07	4.04E+03
Plutonium-241	14119-32-5	6.43E+05	7.71E+07	3.91E+09	6.38E+05
Silver-108m+D	14391-65-2	5.27E+04	2.52E+01	1.68E+10	2.52E+01
Strontium-90+D	10098-97-2	9.63E+03	1.17E+04	5.88E+09	5.28E+03
Technetium-99	14133-76-7	1.28E+05	1.96E+06	4.74E+10	1.20E+05
Tin-126+D	15832-50-5	1.29E+04	2.01E+01	4.19E+09	2.01E+01
Tritium	10028-17-8	2.13E+07	--	1.02E+03	1.02E+03
Uranium-233/234[d]	U-233/234	6.26E+03	6.41E+05	6.43E+07	6.20E+03
Uranium-234	13966-29-5	6.26E+03	6.41E+05	6.43E+07	6.20E+03
Uranium-235+D	15117-96-1	6.01E+03	3.16E+02	7.21E+07	3.01E+02
Uranium-238+D	U-238	4.70E+03	1.39E+03	7.51E+07	1.07E+03

Notes:

"+D indicates that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included."

When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed.

Values presented are calculated for curium-243; curium-243 is assumed to be the dominant isotope in undifferentiated curium-243/244.

Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.

Values presented are calculated for uranium-234; uranium-234 is assumed to be the dominant isotope in undifferentiated uranium-233/234.

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Figure 1. Hand Calculations

Casual User Radiological PRGs

ECF-HANFORD-10-0446

D. Evans 11/09/2015

Incidental Soil Ingestion

$$PRG = \frac{TR \times t_{cu} \times \lambda}{1 - e^{(-\lambda(t_{cu}))} \times SF_s \times IRS_{adj-cu} \times EF_{cu} + ED_{at\,cu} \times UCF3} \quad (1)$$

$$IRS_{adj-cu} = \frac{(ED_{ccu} \times IRS_{ccu}) + ((ED_{at\,cu} - ED_{ccu}) \times IRS_a)}{ED_{at\,cu}} \quad (2)$$

Age-Adjusted Soil Ingestion Rate

$$IRS_{adj-cu} = \frac{(6\,yr \times 200\,\frac{mg}{d}) + ((30\,yr - 6\,yr) \times 100\,\frac{mg}{d})}{30\,yr}$$

$$= 120\,\frac{mg}{d} \checkmark$$

Cobalt-60 Incidental Soil Ingestion PRG

$$\text{Decay constant } (\lambda) = \frac{0.693}{\text{half life}} = \frac{0.693}{5.27\,yr} = 0.1315\,yr^{-1}$$

$$PRG = \frac{0.0001\,risk \times 30\,yr \times 0.1315\,yr^{-1}}{1 - e^{(-0.1315\,yr^{-1}(30\,yr))} \times 3.81E{-11}\,\frac{risk}{pCi} \times 120\,\frac{mg}{d} \times 30\,\frac{d}{yr} \times 30\,yr \times 0.001\,\frac{g}{mg}}$$

$$= \frac{3.945E{-4}\,risk}{0.9806 \times 4.115E{-9}\,\frac{risk\text{-}g}{pCi}} = 9.777\,E{+4}\,\frac{pCi}{g} \checkmark$$

External Exposure to Ionizing Radiation

$$PRG = \frac{TR \times t_{cu} \times \lambda}{1 - e^{(-\lambda(t_{cu}))} \times SF_x \times ACF \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \frac{1\,d}{24\,hr} \times UCF5} \quad (3)$$

Cobalt-60 External Exposure PRG

Decay constant (λ) = $0.1315\ yr^{-1}$

$$PRG = \frac{0.0001\ risk \times 30\,yr \times 0.1315\,yr^{-1}}{1 - e^{(-0.1315\,yr^{-1}(30\,yr))} \times 1.24E\text{-}5\ \frac{risk/yr}{pCi/g} \times 0.92 \times 30\ \frac{d}{yr} \times 30\,yr \times 6\ \frac{hr}{d} \times \frac{1\,d}{24\,hr} \times \frac{1\,yr}{365\,d}}$$

$$= \frac{3.945E\text{-}4\ risk}{0.9806 \times 7.032E\text{-}6\ \frac{risk}{pCi/g}} = 5.721\ E+01\ \frac{pCi}{g} \checkmark$$

Inhalation of Dust and Vapors

$$PRG = \frac{TR \times t_{cu} \times \lambda}{1 - e^{(-\lambda(t_{cu}))} \times SF_i \times IRA_{adj\text{-}cu} \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \left[\frac{1}{PEF} \text{ or } \frac{1}{VF}\right] \times UCF4} \quad (4)$$

$$IRA_{adj\text{-}cu} = \frac{(ED_{ccu} \times IRA_{ccu}) + ((ED_{a+ccu} - ED_{ccu}) \times IRA_a)}{ED_{a+ccu}} \quad (5)$$

Particulate Emission Factor

$$PEF = \frac{Q}{C} \times \frac{3{,}600}{0.036 \times (1-V) \times \left(\frac{U_m}{U_t}\right)^3 \times F(x)} \quad (6)$$

$$\frac{Q}{C} = A \times \exp\left[\frac{(\ln(A_s) - B)^2}{C}\right] \quad (7)$$

$$F(x) = 0.18\,(8x^3 + 12x)\exp - (x^2) \quad (8)$$

$$x = 0.886\left(\frac{U_t}{U_m}\right) \quad (9)$$

Calculating PEF

$$x = 0.886\left(11.32\,\tfrac{m}{s} / 3.4\,\tfrac{m}{s}\right) = 2.95 \checkmark$$

$$Fx = 0.18\left[8(2.95)^3 + 12(2.95)\right]\exp\left[-(2.95)^2\right]$$

$$= 0.18\,[205.4 + 35.4] \times 1.662E-4$$

$$= 7.204E-3 \checkmark$$

$$\frac{Q}{C} = 11.3161 \times \exp\left[\frac{[\ln(0.5) - 19.6437]^2}{224.8172}\right]$$

$$= 11.3161 \times \exp(1.840)$$

$$= 71.228 \ \frac{g/m^2\text{-}s}{kg/m^3}$$

$$PEF = 71.228\,\frac{g/m^2\text{-}s}{kg/m^3} \times \frac{3{,}600}{0.036 \times (1-0.5) \times \left[\frac{3.4\,m/s}{11.32\,m/s}\right]^3 \times 7.204E-3}$$

$$= 71.228 \times \frac{3{,}600}{3.514E-6}$$

$$= 7.297E+10 \ m^3/kg \quad \checkmark \text{ rounding}$$

Age-Adjusted Inhalation Rate

$$IRA_{adj-cu} = \frac{(6yr \times 0.417 \frac{m^3}{hr}) + ((30yr - 6yr) \times 0.833 \frac{m^3}{hr})}{30yr}$$

$$= 0.750 \frac{m^3}{hr}$$

Cobalt-60 Inhalation PRG

Decay constant $(\lambda) = 0.1315\ yr^{-1}$

$$PRG = \frac{0.0001\ risk \times 30yr \times 0.1315\ yr^{-1}}{1 - e^{(-0.1315 yr^{-1})(30yr)} \times 1.00E-10 \frac{risk}{pCi} \times 0.75 \frac{m^3}{hr} \times 30 \frac{d}{yr} \times 30yr \times 6 \frac{hr}{d} \times \frac{1}{7.30E+10 \frac{m^3}{kg}} \times 1000 \frac{g}{kg}}$$

$$= \frac{3.945E-4\ risk}{0.9806 \times 5.548E-15 \frac{risk-g}{pCi}}$$

$$= 7.251\ E+10 \frac{pCi}{g} \checkmark$$

Total PRG

$$PRG = \frac{1}{\left[\frac{1}{PRG_{soil-ing}}\right] + \left[\frac{1}{PRG_{ext-exp}}\right] + \left[\frac{1}{PRG_{inh}}\right]} \quad (10)$$

Cobalt-60 Total PRG

$$PRG = \frac{1}{\left[\frac{1}{9.777E+4 \frac{pCi}{g}}\right] + \left[\frac{1}{5.721\ E+01 \frac{pCi}{g}}\right] + \left[\frac{1}{7.251E+10\ pCi/g}\right]}$$

$$= 5.718\ E+01\ pCi/g \checkmark$$

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Appendix A

Casual User Exposure Parameters, Input Values and PRG Summaries

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Summary of Incidental Soil Ingestion PRG values for Radionuclides

Exposure Route/Exposure Factor	Symbol	Value	Units	Source
PRG – radionuclides, incidental soil ingestion	$PRG_{cu_rad_ing}$	Radioisotope-Specific	pCi/g	Equation 1
Exposure Duration -Adult + Child Casual Recreational User	ED_{a+ccu}	30	years	OSWER Directive 9285.6-03
Exposure Duration - Child Casual Recreational User	ED_{ccu}	6	years	OSWER Directive 9285.6-03
Exposure Frequency - Casual Recreational User	EF_{cu}	30	days/year	DOE/RL-2007-21, Table 3-18
Soil Ingestion Rate - Adult	IRS_a	100	mg/day	OSWER Directive 9285.6-03
Soil Ingestion Rate - Child	IRS_{ccu}	200	mg/day	OSWER Directive 9285.6-03
Age-adjusted soil ingestion rate, Casual Recreational User, Radioisotopes	$IRS_{adj_cu_rad}$	120	mg/day	Equation 2
Target Risk – Radioisotope	$TR_{_rad}$	1.E-04	unitless	OSWER Directive 9355.4-24
Slope Factor – Soil Ingestion	SF_s	Radioisotope-Specific	risk/pCi	EPA, 2015a
Time - Casual Recreational User	t_{cu}	30	years	Same as Exposure Duration
Half Life		Radioisotope-Specific	years	EPA, 2015a
Decay Constant	λ	Radioisotope-Specific	yr^{-1}	=0.693/half-life
Unit Conversion Factor	UCF3	1.00E-03	g/mg	1 g = 1,000 mg

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A-1. Summary of Incidental Soil Ingestion PRG values for Radionuclides

Analyte Name	CAS ID[a]	Includes Daughter Products?[b]	Soil Ingestion Slope Factor (SF_s)	Half-Life	Decay Constant (λ)	Preliminary Remediation Goal Radionuclides–Ingestion
			risk/pCi	years	yr^{-1}	pCi/g
Americium-241	14596-10-2	--	1.84E-10	4.32E+02	1.60E-03	5.15E+03
Carbon-14	14762-75-5	--	2.77E-12	5.70E+03	1.22E-04	3.35E+05
Cesium-137	10045-97-3	+D	4.26E-11	3.02E+01	2.29E-02	3.01E+04
Cobalt-60	10198-40-0	--	3.81E-11	5.27E+00	1.31E-01	9.78E+04
Curium-243	15757-87-6	--	1.77E-10	2.91E+01	2.38E-02	7.32E+03
Curium-243/244[c]	Cm-243/244	--	1.77E-10	2.91E+01	2.38E-02	7.32E+03
Curium-244	13981-15-2	--	1.56E-10	1.81E+01	3.83E-02	9.98E+03
Curium-245	15621-76-8	--	1.87E-10	8.50E+03	8.15E-05	4.96E+03
Europium-152	14683-23-9	--	1.46E-11	1.35E+01	5.13E-02	1.24E+05
Europium-154	15585-10-1	--	2.54E-11	8.59E+00	8.07E-02	9.68E+04
Europium-155	14391-16-3	--	5.18E-12	4.76E+00	1.46E-01	7.91E+05
Iodine-129	15046-84-1	--	2.78E-10	1.57E+07	4.41E-08	3.33E+03
Neptunium-237	13994-20-2	+D	1.41E-10	2.14E+06	3.24E-07	6.57E+03
Nickel-59	14336-70-0		6.77E-13	1.01E+05	6.86E-06	1.37E+06
Nickel-63	13981-37-8	--	1.71E-12	1.00E+02	6.93E-03	6.00E+05
Niobium-94	14681-63-1	--	1.94E-11	2.03E+04	3.41E-05	4.78E+04
Plutonium-238	13981-16-3	--	2.25E-10	8.77E+01	7.90E-03	4.62E+03
Plutonium-239/240[d]	PU-239/240	--	2.28E-10	2.41E+04	2.88E-05	4.06E+03
Plutonium-241	14119-32-5	--	2.72E-12	1.44E+01	4.81E-02	6.43E+05
Silver-108m	14391-65-2	+D	1.80E-11	4.18E+02	1.66E-03	5.27E+04
Strontium-90	10098-97-2	+D	1.35E-10	2.88E+01	2.41E-02	9.63E+03
Technetium-99	14133-76-7	--	7.25E-12	2.11E+05	3.28E-06	1.28E+05
Tin-126	15832-50-5	+D	7.18E-11	2.30E+05	3.01E-06	1.29E+04
Tritium	10028-17-8	--	8.99E-14	1.23E+01	5.63E-02	2.13E+07
Uranium-233/234[e]	U-233/234	--	1.48E-10	2.46E+05	2.82E-06	6.26E+03
Uranium-234	13966-29-5	--	1.48E-10	2.46E+05	2.82E-06	6.26E+03
Uranium-235	15117-96-1	+D	1.54E-10	7.04E+08	9.84E-10	6.01E+03
Uranium-238	U-238	+D	1.97E-10	4.47E+09	1.55E-10	4.70E+03

a-When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed

b- For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included.

c- Values presented are calculated for curium-243; curium-243 is assumed to be the dominant isotope in undifferentiated curium-243/244.
d- Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.
f- Values presented are calculated for uranium-234; uranium-234 is assumed to be the dominant isotope in undifferentiated uranium-233/234.

Summary of External Exposure by Ionizing Radiation PRG values for Radionuclides

Exposure Route/Exposure Factor	Symbol	Value	Units	Source
PRG– Casual Recreational User, radionuclide, external exposure	$PRG_{cu_rad_ext}$	Radioisotope-Specific	pCi/g	Equation 3
Area Correction Factor	ACF	Radioisotope-Specific	unitless	ORNL, 2014
Exposure Duration -Adult + Child Casual Recreational User	ED_{a+ccu}	30	years	OSWER Directive 9285.6-03
Exposure Frequency - Casual Recreational User	EF_{cu}	30	days/year	DOE/RL-2007-21, Table 3-18
Exposure Time - Casual Recreational User, outdoors	ET_{cu}	6	hour/day	PNNL, 2001, Table 4.9
Slope Factor – External Exposure	SF_x	Radioisotope-Specific	Risk/year per pCi/g	EPA, 2015a
Half Life		Radioisotope-Specific	years	EPA, 2015a
Decay Constant	λ	Radioisotope-Specific	yr^{-1}	0.693/half-life
Time - Casual Recreational User	t_{cu}	30	years	Same as Exposure Duration
Target Risk – Radioisotope	$TR_{_rad}$	1.E-04	unitless	OSWER Directive 9355.4-24
Unit Conversion Factor	UCF5	0.002739726	years/day	1 year = 365 days

DOE/RL-2007-21, Rev. 0, *Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment*

OSWER Directive 9285.6-03, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors"*

OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*

EPA/540/R-92/003. *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals).*

EPA, 2015a,"Preliminary Remediation Goals for Radionuclides (PRG)", PRG Download, "Summary Tables", (http://epa-prgs.ornl.gov/radionuclides/download.html).

PNNL, 2001 *Columbia River Recreation Survey – Implications for the Hanford Site* Integrated Assessment

ORNL 2014, Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models

A-2. Summary of External Exposure by Ionizing Radiation PRG values for Radionuclides

Analyte Name	CAS ID[a]	Includes Daughter Products?[b]	Area Correction Factor	External Slope Factor (SF_x)	Half-Life	Decay Constant (λ)	Preliminary Remediation Goal External Exposure
			Unitless	Risk/year per pCi/g	years	yr^{-1}	pCi/g
Americium-241	14596-10-2	--	1.00E+00	2.77E-08	4.32E+02	1.60E-03	6.00E+03
Carbon-14	14762-75-5	--	1.00E+00	7.86E-12	5.70E+03	1.22E-04	2.07E+07
Cesium-137	10045-97-3	+D	9.00E-01	2.53E-06	3.02E+01	2.29E-02	9.86E+01
Cobalt-60	10198-40-0	--	9.20E-01	1.24E-05	5.27E+00	1.31E-01	5.72E+01
Curium-243	15757-87-6	--	8.80E-01	4.20E-07	2.91E+01	2.38E-02	6.14E+02
Curium-243/244[c]	Cm-243/244	--	8.80E-01	4.20E-07	2.91E+01	2.38E-02	6.14E+02
Curium-244	13981-15-2	--	1.00E+00	1.40E-10	1.81E+01	3.83E-02	1.95E+06
Curium-245	15621-76-8	--	9.60E-01	2.74E-07	8.50E+03	8.15E-05	6.17E+02
Europium-152	14683-23-9	--	9.20E-01	5.41E-06	1.35E+01	5.13E-02	6.39E+01
Europium-154	15585-10-1	--	9.20E-01	5.85E-06	8.59E+00	8.07E-02	8.01E+01
Europium-155	14391-16-3	--	9.70E-01	1.25E-07	4.76E+00	1.46E-01	5.92E+03
Iodine-129	15046-84-1	--	7.90E-01	6.18E-09	1.57E+07	4.41E-08	3.32E+04
Neptunium-237	13994-20-2	+D	9.10E-01	8.55E-07	2.14E+06	3.24E-07	2.08E+02
Nickel-59	14336-70-0		9.50E-01	6.77E-11	1.01E+05	6.86E-06	2.52E+06
Nickel-63	13981-37-8	--	1.00E+00	--	1.00E+02	6.93E-03	--
Niobium-94	14681-63-1	--	9.20E-01	7.22E-06	2.03E+04	3.41E-05	2.44E+01
Plutonium-238	13981-16-3	--	1.00E+00	6.91E-11	8.77E+01	7.90E-03	2.64E+06
Plutonium-239/240[d]	PU-239/240	--	1.00E+00	2.09E-10	2.41E+04	2.88E-05	7.77E+05
Plutonium-241	14119-32-5	--	9.80E-01	4.06E-12	1.44E+01	4.81E-02	7.71E+07
Silver-108m	14391-65-2	+D	9.20E-01	7.17E-06	4.18E+02	1.66E-03	2.52E+01
Strontium-90	10098-97-2	+D	1.00E+00	1.95E-08	2.88E+01	2.41E-02	1.17E+04
Technetium-99	14133-76-7	--	1.00E+00	8.28E-11	2.11E+05	3.28E-06	1.96E+06
Tin-126	15832-50-5	+D	9.20E-01	8.78E-06	2.30E+05	3.01E-06	2.01E+01
Tritium	10028-17-8	--	1.00E+00	--	1.23E+01	5.63E-02	--
Uranium-233/234[f]	U-233/234	--	1.00E+00	2.53E-10	2.46E+05	2.82E-06	6.41E+05
Uranium-234	13966-29-5	--	1.00E+00	2.53E-10	2.46E+05	2.82E-06	6.41E+05
Uranium-235	15117-96-1	+D	8.90E-01	5.76E-07	7.04E+08	9.84E-10	3.16E+02
Uranium-238	U-238	+D	9.80E-01	1.19E-07	4.47E+09	1.55E-10	1.39E+03

a-When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed

b- For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included.

c- Values presented are calculated for curium-243; curium-243 is assumed to be the dominant isotope in undifferentiated curium-243/244.

d- Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.

Summary of Inhalation PRG values for Radionuclides

Exposure Route/Exposure Factor	Symbol	Value	Units	Source
PRG – Casual Recreational User, radionuclide, inhalation	$PRG_{cu_rad_inh}$	COPC-Specific	pCi/g	Equation 4
Exposure Duration -Adult + Child Casual Recreational User	ED_{a+ccu}	30	years	OSWER Directive 9285.6-03
Exposure Duration - Child Casual Recreational User	ED_{ccu}	6	years	OSWER Directive 9285.6-03
Exposure Frequency - Casual Recreational User	EF_{cu}	30	days/year	DOE/RL-2007-21; Table 3-18
Exposure Time - Casual Recreational User, outdoors	ET_{cu}	6	hour/day	PNNL 2001; Table 4.9
Inhalation Rate - Casual Recreational User Adult	IRA_a	8.33E-01	m^3/hour	EPA/540/R-92/003, based on a value of 20 m^3/day
Inhalation Rate - Casual Recreational User Child	IRA_{ccu}	4.17E-01	m^3/hour	EPA/540/R-92/003, based on a value of 10 m^3/day
Age-adjusted inhalation rate – Casual Recreational User	IRA_{adj_cu}	7.50E-01	m^3/hour	Equation 5
Slope Factor - Inhalation	SF_i	COPC-Specific	risk/pCi	EPA, 2015a
Particulate Emission Factor	PEF	7.30E+10	m^3/kg	OSWER Directive 9355.4-24
Volatilization Factor for Tritium	VF_H3	1.70E+01	m^3/kg	Etnier, 1980
Target Risk – Radioisotope	$TR_{_rad}$	1.E-04	unitless	OSWER Directive 9355.4-24
Time - Casual Recreational User	t_{cu}	30	years	Same as Exposure Duration
Half Life		COPC-Specific	years	EPA, 2015a
Decay Constant	λ	COPC-Specific	yr^{-1}	0.693/half-life
Unit Conversion Factor	UCF4	1000	g/kg	1 kg = 1000 g

DOE/RL-2007-21, Rev. 0, *Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessmen*
Etnier, 1980, *Tritium-An Analysis of Key Environmental and Dosimetric Questions*
EPA/540/R-92/003. *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*
OSWER Directive 9285.6-03, *Risk Assessment Guidance For Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance, "Standard Default Exposure Factors" Interim Fina*
OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Site*
EPA, 2015a,"Preliminary Remediation Goals for Radionuclides (PRG)", PRG Download, "Summary Tables", (http://epa-prgs.ornl.gov/radionuclides/download.html).
PNNL, 2001, *Columbia River Recreation Survey – Implications for the Hanford Site Integrated Assessment*

A-3. Summary of Inhalation PRG values for Radionuclides

Analyte Name	CAS ID[a]	Includes Daughter Products?[b]	Slope Factor–Inhalation (SF_i)	Half-Life	Decay Constant (λ)	Preliminary Remediation Goal Radionuclides–Inhalation
			risk/pCi	years	yr^{-1}	pCi/g
Americium-241	14596-10-2	--	3.80E-08	4.32E+02	1.60E-03	4.86E+07
Carbon-14	14762-75-5	--	1.70E-11	5.70E+03	1.22E-04	1.06E+11
Cesium-137	10045-97-3	+D	1.10E-10	3.02E+01	2.29E-02	2.27E+10
Cobalt-60	10198-40-0	--	1.00E-10	5.27E+00	1.31E-01	7.25E+10
Curium-243	15757-87-6	--	3.70E-08	2.91E+01	2.38E-02	6.81E+07
Curium-243/244[c]	Cm-243/244	--	3.70E-08	2.91E+01	2.38E-02	6.81E+07
Curium-244	13981-15-2	--	3.60E-08	1.81E+01	3.83E-02	8.42E+07
Curium-245	15621-76-8	--	3.80E-08	8.50E+03	8.15E-05	4.75E+07
Europium-152	14683-23-9	--	1.90E-10	1.35E+01	5.13E-02	1.86E+10
Europium-154	15585-10-1	--	2.10E-10	8.59E+00	8.07E-02	2.28E+10
Europium-155	14391-16-3	--	1.90E-11	4.76E+00	1.46E-01	4.19E+11
Iodine-129	15046-84-1	--	1.60E-10	1.57E+07	4.41E-08	1.13E+10
Neptunium-237	13994-20-2	+D	2.90E-08	2.14E+06	3.24E-07	6.21E+07
Nickel-59	14336-70-0		2.40E-12	1.01E+05	6.86E-06	7.51E+11
Nickel-63	13981-37-8	--	5.90E-12	1.00E+02	6.93E-03	3.38E+11
Niobium-94	14681-63-1	--	1.30E-10	2.03E+04	3.41E-05	1.39E+10
Plutonium-238	13981-16-3	--	5.20E-08	8.77E+01	7.90E-03	3.89E+07
Plutonium-239/240[d]	PU-239/240	--	5.60E-08	2.41E+04	2.88E-05	3.22E+07
Plutonium-241	14119-32-5	--	8.70E-10	1.44E+01	4.81E-02	3.91E+09
Silver-108m	14391-65-2	+D	1.10E-10	4.18E+02	1.66E-03	1.68E+10
Strontium-90	10098-97-2	+D	4.30E-10	2.88E+01	2.41E-02	5.88E+09
Technetium-99	14133-76-7	--	3.80E-11	2.11E+05	3.28E-06	4.74E+10
Tin-126	15832-50-5	+D	4.30E-10	2.30E+05	3.01E-06	4.19E+09
Tritium	10028-17-8	--	8.50E-13	1.23E+01	5.63E-02	1.02E+03
Uranium-233/234[f]	U-233/234	--	2.80E-08	2.46E+05	2.82E-06	6.43E+07
Uranium-234	13966-29-5	--	2.80E-08	2.46E+05	2.82E-06	6.43E+07
Uranium-235	15117-96-1	+D	2.50E-08	7.04E+08	9.84E-10	7.21E+07
Uranium-238	U-238	+D	2.40E-08	4.47E+09	1.55E-10	7.51E+07

a-When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed

b- For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included.

c- Values presented are calculated for curium-243; curium-243 is assumed to be the dominant isotope in undifferentiated curium-243/244.
d- Values presented are calculated for plutonium-239; plutonium-239 is assumed to be the dominant isotope in undifferentiated plutonium-239/240.

A-4. Summary of Input Parameters used to Calculate the Particulate Emission Factor

Particulate Emission Factors Calculations				
Factor	**Symbol**	**Value**	**Unit**	**Reference**
A Constant	A	11.3161	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
Site Area	A_s	0.5	acres	OSWER Directive 9355.4-24
B Constant	B	19.6437	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
C Constant	C	224.8172	unitless	OSWER Directive 9355.4-24; Exhibit D-2 for Boise Idaho.
Windspeed Distribution Function	F(x)	7.21E-03	unitless	Equation 8
Particulate Emission Factor	PEF	7.30E+10	m^3/kg	Equation 6
Inverse of mean concentration at center of a source	Q/C	71.2280803	g/m^2-s per kg/m^3	Equation 7
Annual average wind speed	u_m	3.4	m/s	PNNL-15160, Table 5.1
Wind speed at anemometer height equivalent to corrected threshold friction velocity	u_t	11.32	m/s	OSWER Directive 9355.4-24
	x	2.95E+00	unitless	Equation 9
Fraction of vegetative cover	V	0.5	unitless	OSWER Directive 9355.4-24

OSWER 9355.4-24, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*

PNNL-15160, *Hanford Site Climatological Summary 2004 with Historical Data*

Table A-5. Summary of Total Preliminary Remediation Goals for Radionuclides

Analyte	CAS ID[a]	Preliminary Remediation Goals			
		Preliminary Remediation Goal (Ingestion)	Preliminary Remediation Goal (External Exposure)	Preliminary Remediation Goal (Inhalation)	Final Preliminary Remediation Goal
		pCi/g	pCi/g	pCi/g	pCi/g
Americium-241	14596-10-2	5.15E+03	6.00E+03	4.86E+07	2.77E+03
Carbon-14	14762-75-5	3.35E+05	2.07E+07	1.06E+11	3.30E+05
Cesium-137+D	10045-97-3	3.01E+04	9.86E+01	2.27E+10	9.82E+01
Cobalt-60	10198-40-0	9.78E+04	5.72E+01	7.25E+10	5.72E+01
Curium-243	15757-87-6	7.32E+03	6.14E+02	6.81E+07	5.67E+02
Curium-243/244[b]	Cm-243/244	7.32E+03	6.14E+02	6.81E+07	5.67E+02
Curium-244	13981-15-2	9.98E+03	1.95E+06	8.42E+07	9.93E+03
Curium-245	15621-76-8	4.96E+03	6.17E+02	4.75E+07	5.49E+02
Europium-152	14683-23-9	1.24E+05	6.39E+01	1.86E+10	6.39E+01
Europium-154	15585-10-1	9.68E+04	8.01E+01	2.28E+10	8.00E+01
Europium-155	14391-16-3	7.91E+05	5.92E+03	4.19E+11	5.87E+03
Iodine-129	15046-84-1	3.33E+03	3.32E+04	1.13E+10	3.03E+03
Neptunium-237+D	13994-20-2	6.57E+03	2.08E+02	6.21E+07	2.02E+02
Nickel-59	14336-70-0	1.37E+06	2.52E+06	7.51E+11	8.87E+05
Nickel-63	13981-37-8	6.00E+05	--	3.38E+11	6.00E+05
Niobium-94	14681-63-1	4.78E+04	2.44E+01	1.39E+10	2.44E+01
Plutonium-238	13981-16-3	4.62E+03	2.64E+06	3.89E+07	4.61E+03
Plutonium-239/240[c]	PU-239/240	4.06E+03	7.77E+05	3.22E+07	4.04E+03
Plutonium-241	14119-32-5	6.43E+05	7.71E+07	3.91E+09	6.38E+05
Silver-108m+D	14391-65-2	5.27E+04	2.52E+01	1.68E+10	2.52E+01
Strontium-90+D	10098-97-2	9.63E+03	1.17E+04	5.88E+09	5.28E+03
Technetium-99	14133-76-7	1.28E+05	1.96E+06	4.74E+10	1.20E+05
Tin-126+D	15832-50-5	1.29E+04	2.01E+01	4.19E+09	2.01E+01
Tritium	10028-17-8	2.13E+07	--	1.02E+03	1.02E+03
Uranium-233/234[d]	U-233/234	6.26E+03	6.41E+05	6.43E+07	6.20E+03
Uranium-234	13966-29-5	6.26E+03	6.41E+05	6.43E+07	6.20E+03
Uranium-235+D	15117-96-1	6.01E+03	3.16E+02	7.21E+07	3.01E+02
Uranium-238+D	U-238	4.70E+03	1.39E+03	7.51E+07	1.07E+03

+D indicates that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included.

a-When CAS ID is different from HEIS constituent identifier, the HEIS constituent identifier is listed