

Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides Using the IAROD Exposure Scenario for the 100 and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Report

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

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Release Approval

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Project: 100 and 300 Area Remedial Investigation/
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Date: 12/18/2012

Calculation Title & Description: Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides Using the IAROD Exposure Scenario for the 100 and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Report

Calculation of radiological soil preliminary remediation goals for the Interim Action Record of Decision exposure scenario for use in the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports.

| | |
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| Senior Reviewer: Doug Evans | Basis of Qualification: Education & experience |

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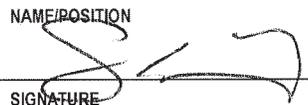
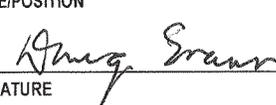
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| Rev. 0 | Initial Issue | 11/05/2010 | All |
| Rev. 1.A | Nickel-59, Plutonium-241, and Tin-126 were added to the list of analytes and a PRG was calculated. The kd for Nickel-63 was updated from 3 cm ³ /g to 30 cm ³ /g and PRG for Nickel-63 was updated to account for the kd value of 30 cm ³ /g; addition of uranium values; | 12/18/2012 | Pages 3-8, and Tables |
| Rev. 1.B | Uranium-234 (same as Uranium-233/234—not calculated), were added to the list of analytes. | 12/18/2012 | Pages 3-8, and Tables |

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Environmental Calculation Cover Page

Part 1: Completed by the Responsible Manager

Project: 100 and 300 Area Remedial Investigation/
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11/7/13

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Terms

| | |
|----------|--|
| DOE | Department of Energy |
| ECF | environmental calculation file |
| EPA | Environmental Protection Agency |
| HISI | Hanford Information Systems Inventory |
| NCP | National Contingency Plan |
| PRG | Preliminary Remediation Goal |
| RAO | Remedial Action Objective |
| RDL | Required Detection Limits |
| RDR/RAWP | Remedial Design Report/Remedial Action Work Plan |
| RI/FS | Remedial Investigation/Feasibility Study |
| IAROD | Interim Action Record of Decision |

1 Purpose

This Environmental Calculation documents assumptions and methods for development of radiological soil Preliminary Remediation Goals (PRGs) for the Interim Action Record of Decision (IAROD) 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 concentrations goals that are protective of a potential future resident receptor. Potentially complete exposure pathways associated with this scenario include direct contact and food chain (i.e., the consumption of homegrown produce and livestock) pathways. The PRGs described in this Environmental Calculation are consistent with the radiological remedial action goals described in DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area* except that exposure assumptions have been updated to reflect current EPA guidance. Exposure assumptions that were updated include the external gamma shielding factor and the outdoor time fraction. The PRGs were also updated from a protective level reflecting an annual dose rate of 15 millirem per year (mrem/yr) to a target risk of 10^{-4} . The exposure assumptions used to calculate the PRG values presented in this Environmental Calculation are described in Section 4.0 and listed in Attachment 1.

2 Background

As described in DOE/RL-2008-46, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan*, and DOE/RL-2009-30, *300 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 contain multiple source and groundwater operable units (OUs), that are part of the Hanford Site River Corridor, which encompasses approximately 570 km² (220 mi²) adjacent to the Columbia River. To date, waste sites within the River Corridor have been remediated to unrestricted land use levels. Cleanup levels corresponding to unrestricted land use in the River Corridor are currently defined in the Interim Action Records of Decision (IAROD), and have been calculated in DOE/RL-96-17, *100 Area Remedial Design Report/Remedial Action Work Plan*. For the purposes of developing PRGs within this Environmental Calculation document, the following target objectives are used¹:

- Prevent unacceptable risk to human health from exposure to soils and/or debris contaminated with radiological contaminants less than 4.6 m (15 ft) bgs. PRGs for radionuclides that achieve this objective achieve the CERCLA cumulative risk range of 10^{-4} to 10^{-6} increased lifetime cancer risk which is consistent with EPA/540/R/99/006, *Radiation Risk Assessment At CERCLA Sites: Q & A*. As described in DOE/RL-96-17, these PRGs are intended to limit radiation risks for 1,000 years following the completion of a remedial action. According to ANL/EAD-4, *User's Manual for RESRAD*, the 1,000-year timeframe 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) being developed as part of 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 and 300 Area RI/FS Report.

¹ The RAO used for calculating PRGs for purposes of this Environmental Calculation have been adapted from RAOs developed for the River Corridor, as presented in DOE/RL-96-17.

3 Methodology

The radionuclide PRGs presented in this Environmental Calculation are single radionuclide soil concentrations corresponding to a target cancer risk level of 1×10^{-4} , 1×10^{-5} , and 1×10^{-6} which are protective of the IAROD exposure scenario. These PRGs have been calculated using RESRAD. According to ANL/EAD-4 the RESRAD model and computer code was developed as a multifunctional tool to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material. The software application of RESRAD is presented in Section 5 of this Environmental Calculation.

The PRGs for protection of human health from radionuclides in soil are based on the following assumptions:

- The future land use will be unrestricted (includes irrigation).
- Future residents are potentially exposed for a 30 year duration.
- The potentially complete exposure pathways considered are external gamma exposure, inhalation of dust, ingestion of homegrown produce, meat and milk ingestion, aquatic foods ingestion, drinking water ingestion, and incidental soil ingestion.

The assumptions used to develop the radionuclide PRGs for protection of human health are presented in Section 4.1 and are listed in Attachment 1. Site-specific assumptions for the 100 and 300 Area have been developed to estimate radionuclide transport to groundwater; this is done to estimate potential future risks from use of groundwater for drinking water and irrigation (referred to in the RESRAD user's guide as "water-dependent" pathways).

The specific steps taken to calculate an IAROD exposure scenario PRG for radionuclides in soil are presented below:

1. Input the parameters from Attachment 1 into RESRAD.
2. Input the arbitrary soil concentration of 1,000 pCi/g and a single radionuclide into RESRAD.
3. Input calculation times of 1, 3, 10, 30, 100, 300, and 1,000 years into RESRAD.
4. Run RESRAD and review the results to identify the year at which the peak cancer risk occurs; record the total cancer risk at the peak year associated with 1,000 pCi/g in the intermediate calculations worksheet (Attachment 2).
5. In the intermediate calculations worksheet (Attachment 2), estimate the concentration in soil required to achieve a 1×10^{-4} risk at the peak risk year; input that soil concentration into RESRAD; add the peak risk year to the calculation parameters.
6. Re-run RESRAD and verify that the estimated concentration corresponds to a 1×10^{-4} risk; perform additional iterations as needed to obtain a soil concentration that corresponds to 1×10^{-4} risk to within 1 percent (this is to allow rounding of the PRG value as appropriate), and record that concentration in the intermediate calculations worksheet (Attachment 2). Save the model inputs and outputs from the final run for documentation purposes (see Step 8 below).
7. Calculate concentrations in soil corresponding to 1×10^{-5} and 1×10^{-6} cancer risks. These are factors of 10 and 100 of the soil concentration corresponding to 1×10^{-4} cancer risk and can be

calculated simply by division – this is done in the intermediate calculations worksheet and does not require re-running the model to obtain these values.

8. Document RESRAD results: save the input file (the *.RAD file) that corresponds to a risk of 1×10^{-4} with a unique file name identifying the project and radionuclide. An electronic copy of this file shall accompany this Environmental Calculation. Save the summary report (SUMMARY.REP) and the health risk report (INTRISK.REP) with unique file names – these files shall accompany this Environmental Calculation.
9. Repeat this process with the next radionuclide.

As an additional step to support the remedy selection process for uranium in 300 Area soils (DOE/RL-2010-99, *Remedial Investigation/Feasibility Study for the 300-FF-1, 300-FF-2, and 300-FF-5*), the RESRAD-calculated PRGs for the uranium isotopes are converted from activity-based concentrations (pCi/g) to mass-based concentrations ($\mu\text{g}/\text{kg}$) to facilitate development of a mass-based PRG for total uranium. The activity-based uranium isotope PRGs (pCi/g) are converted to mass-based PRGs ($\mu\text{g}/\text{kg}$) using the following equation (the conversion calculations are provided in Section 7).

$$\text{PRG } (\mu\text{g isotope}/\text{kg soil}) = [\text{PRG (pCi isotope}/\text{g soil}) / \text{Specific Activity (pCi isotope}/\text{g isotope})] \times 1 \times 10^6 (\mu\text{g isotope}/\text{g isotope}) \times 1000 (\text{g soil}/\text{kg soil}) \quad (1)$$

4 Assumptions and Inputs

The inputs used in the RESRAD code to calculate PRGs for protection of human health from direct contact with radionuclides in soil are presented in Attachment 1.

The IAROD exposure scenario includes the assumption that a future resident would have a well and would obtain drinking water and water for irrigation from that well. The PRG accounts for transport of contaminants through soil to groundwater, and potential exposure through drinking water, consumption of homegrown produce irrigated with contaminated groundwater, and consumption of livestock and milk raised using contaminated groundwater. Parameters associated with the generic site model (e.g., contaminated zone area and thickness, cover depth) and hydrostratigraphic conditions are identified in DOE/RL-96-17:

- It is assumed that the entire 4.6-m (15-ft)-thick shallow zone is contaminated and the entire deep zone (assumed to be 12 m [39 ft]) is assumed uncontaminated. No cover material is assumed to exist on top of the contaminated shallow zone.
- The hydrogeological parameters used for the 15 foot contaminated zone are weighted by the thickness of the stratigraphic units.
- Distribution coefficients (K_d) were selected preferentially from DOE/RL-96-17. In cases where DOE/RL-96-17 did not include a radionuclide, the RESRAD default K_d value was used. The K_d values are summarized in Attachment 3.

Parameter values used to estimate inhalation rates, and ingestion of drinking water, foods and incidental ingestion of soil are consistent with the values used in the DOE/RL-96-17. Those values and their sources are presented in Attachment 1.

To reflect recent guidance, EPA/540-R-00-007, *Soil Screening Guidance for Radionuclides: User's Guide*, the external gamma shielding factor was revised from 0.8 to 0.4 based on current EPA guidance. The fraction of time spent outdoors was revised from 0.2 (based on 5 hr/day x 350 days/yr [1,752 hr

/8,760 hr]) to 0.12 (based on 3 hr/day x 350 days/yr [1,050 hr/8,760 hr]). The health protective level for each PRG was revised to reflect a target cancer risk of 10^{-4} from an annual dose rate of 15 mrem/yr as originally reported in the DOE/RL-96-17.

The specific activities used with Equation 1 to convert uranium isotope PRGs from activity-based concentrations (pCi/g) to mass-based concentrations ($\mu\text{g}/\text{kg}$) are shown in Table 4-1.

Table 4-1. Uranium Isotope Specific Activities

| Isotope | Specific Activity (Bq/g) ^a | Conversion Factor (Bq/Ci) | Conversion Factor (pCi/Ci) | Specific Activity (pCi/g) ^b |
|-----------------|---------------------------------------|---------------------------|----------------------------|--|
| Uranium-233/234 | 2.302E+08 | 3.70E+10 | 1.00E+12 | 6.222E+09 |
| Uranium-234 | 2.302E+08 | 3.70E+10 | 1.00E+12 | 6.222E+09 |
| Uranium-235 | 7.995E+04 | 3.70E+10 | 1.00E+12 | 2.161E+06 |
| Uranium-238 | 1.243E+04 | 3.70E+10 | 1.00E+12 | 3.359E+05 |

a. *Table of Isotopes 8th Edition, 1995, Last update 12th April, 1998.*

b. Formula = Specific Activity (Bq/g) / Conversion Factor (Bq/Ci) x Conversion Factor (pCi/Ci)

5 Software Applications

RESRAD is approved for use by CHPRC at the Hanford Site in accordance with the requirements of PRC-PRO-IRM-309, *Software Control Management*. All supporting calculations were performed on electronic spreadsheets using Microsoft Excel. Electronic versions of all spreadsheets are provided with calculations included to facilitate comparison with hand calculations and checking of logical or lookup functions. This approach meets the requirements for “Single Use Software” as described in PRC-PRO-EP-40205, *CHPRC Environmental Calculation Preparation and Issue*. These spreadsheets are listed below in Section 6.

5.1 Description

The following presents the description of RESRAD used for this Environmental Calculation. See CHPRC-00209, Rev. 0, *RESRAD Software Management Plan* for further details regarding the use of this software:

- RESRAD for Windows,
- Version 6.5, Created October 30, 2009
- HISI Identification Number: 2102
- Workstation type and property number: WC95091 and 0075 Freestone Environmental Property Tag.

5.2 Software Installation and Checkout

The software installation and checkout form for RESRAD is attached to this Environmental Calculation.

5.3 Statement of Valid Software Application

The following presents the statement that RESRAD is a valid software application.

- RESRAD was developed for DOE to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material. RESRAD has been used for this purpose in support of previous decision documents developed at the Hanford Site.
- RESRAD as it has been used in this Environmental Calculation has been implemented within the range of its limitations. The parameters used in the modeling (shown in Attachment 1) are presented in the modeling input files attached to this Environmental Calculation, and also in the modeling output files where they are shown alongside the default parameters provided with the model. As discussed in Section 7, a sensitivity analysis of selected parameters has been performed to evaluate the effects of variations in input values on model results.

6 Calculation

The PRG results for radionuclides in soil are presented in the following tables and attachments contained in the Excel workbook "ECF-HANFORD-10-0429 IAROD Rad PRGs Attachments_Rev_1". Input and output files from RESRAD are also listed below.

The results from the PRG calculations presented in the Excel workbook are organized into the following worksheets:

- Attachment 1 – Input Parameter Values Used in RESRAD to Calculate PRGs for Protection of Human Health from Direct Contact with Soil, 100 and 300 Area (IAROD exposure scenario).
- Attachment 2 - Intermediate Calculations for RESRAD used to Calculate PRGs for Protection of Human Health from Direct Contact with Soil, 100 and 300 Area (IAROD exposure scenario).
- Attachment 3 - Radionuclide-Specific Distribution Coefficients (Kd) by RESRAD Model Layer.
- Attachment 4 – Sensitivity Analysis (site area); this shows the change in PRGs for protection of human health from direct contact with soil with changes in the surface area of the site.
- Attachment 5– Sensitivity Analysis (site thickness); this shows the change in PRGs for protection of human health from direct contact with soil with changes in the thickness of contamination in the site.

Input and output files from RESRAD are organized as follows:

- Input files are grouped into the folder "IAROD RESRAD Inputs 12511.zip"
- Output files are grouped into the folder "IAROD RESRAD Outputs 12511.zip"

CHPRC Software Installation and Checkout Forms as follows:

- SICO-Singleton.pdf
- SICO-Ross.pdf

7 Results/Conclusions

The PRGs for radionuclides in soil are summarized in Table 7-1.

The PRGs in soil for protection of human health from direct contact with soil are based on the year that the peak risk occurs, within a 1,000 year timeframe. For most of the radionuclides examined, this occurs at year zero. The year with the peak risk for Cm-245, I-129, K-40, Np-237, Ra-226, Tc-99, Th-230, Th-232, and U-233/234 occurs later, because of the contribution to risk from the ingrowth of daughter products. The year with the peak risk for I-129 and the uranium isotopes occurs later as a result of breakthrough to groundwater, and potential exposure through water-dependent pathways (i.e. ingestion of drinking water, and ingestion of crops, meat and milk raised with irrigation water contaminated with radionuclides).

A generic site area of 10,000 m² and a generic site thickness of 4.6 m were assumed for developing the PRGs for protection of human health. A sensitivity analysis was performed (see Attachment 4) to determine how sensitive the PRG values are to changes in site area. The results from the uncertainty analysis show for select radionuclides that changes in site area do affect the calculation of the PRG values. The PRG for Am-241 decreases 3.2 percent with an increase in site area from 10,000 m² to 100,000 m². The PRG for Cs-137 decreases about 11 percent with an increase in site area from 10,000 m² to 100,000 m². The PRG for Pu-239/240 decreases about 4 percent with an increase in site area from 10,000 m² to 100,000 m². The PRG for Ra-226 decreases about 4 percent with an increase in site area from 10,000 m² to 100,000 m². The results from this analysis indicate these PRGs are relatively insensitive to changes in site area.

A sensitivity analysis was performed (see Attachment 5) to determine how sensitive the PRG values are to changes in site thickness. The results from the uncertainty analysis show for select radionuclides (Am-241 and Pu-239-240), that changes in site thickness do not affect the calculation of the PRG values. The PRG for Ra-226 increases 1.8 percent with a decrease in site thickness from 4.6 m to 1 m. The PRG for Cs-137 increases 2.3 percent with a decrease in site thickness from 4.6 m to 1 m.

To provide a PRG for total uranium for use in the 300 Area Feasibility Study (DOE/RL-2010-99), the RESRAD-calculated PRGs for the uranium isotopes are converted from activity-based concentrations (pCi/g) to mass-based concentrations (µg/kg), as shown in Table 7-2. The conversions are made using the PRGs protective at the 1×10^{-4} risk level, which represents the upper threshold of the U.S. Environmental Protection Agency (EPA) target risk range of 1×10^{-4} to 1×10^{-6} . To determine an appropriate PRG for total uranium from the mass-based uranium isotope PRGs shown in Table 7-2, consideration is given to the mass fractions of the uranium isotopes in total uranium. For the purposes of this Environmental Calculation, uranium isotope mass fractions are calculated based on the Hanford Site uranium soil background concentrations reported in DOE/RL-96-12, *Hanford Site Soil Background: Part 2, Soil Background for Radioactive Analytes*. The mass fractions are calculated by converting each isotope's reported activity-based background concentration to a mass-based concentration, as shown in Table 7-3. This table shows that by mass, uranium-238 comprises over 98% of the total uranium soil background concentration. The mass-based PRG for uranium-238 of 160,740 µg/kg is therefore recommended for use as a PRG for total uranium. Use of the uranium-238 value is considered conservative in that the uranium-238 value is lower than the total uranium PRG value would be if uranium-233/234, uranium-234, and uranium-235 were also included.

Table 7-1. Summary of Preliminary Remediation Goals for the 100 and 300 Area IAROD Exposure Scenario

| Radionuclide | Selected Radionuclide Direct Exposure PRG at 10⁻⁴ Target Risk Level (pCi/g) | Selected Radionuclide Direct Exposure PRG at 10⁻⁵ Target Risk Level (pCi/g) | Selected Radionuclide Direct Exposure PRG at 10⁻⁶ Target Risk Level (pCi/g) |
|--------------------------------|---|---|---|
| Ag (silver)-108m | 1.37 | 0.137 | 0.0137 |
| Americium-241 | 155 | 15.5 | 1.55 |
| Carbon-14 | 81 | 8.1 | 0.81 |
| Curium-243 | 30.3 | 3.03 | 0.303 |
| Curium-243/244 ^a | 30.3 | 3.03 | 0.303 |
| Curium-244 | 551 | 55.1 | 5.51 |
| Curium-245 | 33.4 | 3.34 | 0.334 |
| Cobalt-60 | 3.1 | 0.31 | 0.031 |
| Cesium-137 | 4.4 | 0.44 | 0.044 |
| Europium-152 | 3.66 | 0.366 | 0.0366 |
| Europium-154 | 4.4 | 0.44 | 0.044 |
| Europium-155 | 327 | 32.7 | 3.27 |
| Tritium (H-3) | 623 | 62.3 | 6.23 |
| Iodine-129 | 0.076 | 0.0076 | 0.00076 |
| Potassium-40 | 1.6 | 0.16 | 0.016 |
| Niobium-94 | 1.35 | 0.135 | 0.0135 |
| Nickel-59 | 1,337 | 133.7 | 13.37 |
| Nickel-63 | 608 | 60.8 | 6.08 |
| Neptunium-237 | 8.9 | 0.89 | 0.089 |
| Plutonium-238 | 236 | 23.6 | 2.36 |
| Plutonium-239/240 ^b | 203 | 20.3 | 2.03 |
| Plutonium-241 | 5,080 | 508 | 50.8 |
| Radium-226 | 0.56 | 0.056 | 0.0056 |
| Radium-228 | 1.6 | 0.16 | 0.016 |
| Strontium-90 | 2.27 | 0.227 | 0.0227 |
| Technetium-99 | 1.5 | 0.15 | 0.015 |
| Thorium-228 | 13.6 | 1.36 | 0.136 |
| Thorium-230 | 1.59 | 0.159 | 0.0159 |
| Thorium-232 | 0.43 | 0.043 | 0.0043 |
| Tin-126 | 0.063 | 0.0063 | 0.00063 |
| Uranium-233/234 ^c | 133 | 13.3 | 1.33 |
| Uranium-234 | 133 | 13.3 | 1.33 |
| Uranium-235 | 16.3 | 1.63 | 0.163 |
| Uranium-238 | 54 | 5.4 | 0.54 |

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

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

c. Values presented are calculated for Uranium-234; uranium-234 is assumed to be the dominant isotope in

Table 7-1. Summary of Preliminary Remediation Goals for the 100 and 300 Area IAROD Exposure Scenario

| Radionuclide | Selected Radionuclide Direct Exposure PRG at 10⁻⁴ Target Risk Level (pCi/g) | Selected Radionuclide Direct Exposure PRG at 10⁻⁵ Target Risk Level (pCi/g) | Selected Radionuclide Direct Exposure PRG at 10⁻⁶ Target Risk Level (pCi/g) |
|-----------------------------------|---|---|---|
| undifferentiated uranium-233/234. | | | |

Table 7-2 Conversion from Activity- to Mass-Based PRGs for Uranium Isotopes

| Uranium Isotope | IAROD Scenario PRG at 10 ⁻⁴ Risk Level (pCi isotope/ g soil) ^a | Specific Activity (pCi isotope/ g isotope) ^b | Conversion Factor (µg isotope/ g isotope) | Conversion Factor (g soil/ kg soil) | IAROD Scenario PRG at 10 ⁻⁴ Risk Level (µg isotope/ kg soil) ^c |
|-----------------|--|---|---|-------------------------------------|--|
| U-233/234 | 133 | 6.222E+09 | 1,000,000 | 1,000 | 21.4 |
| U-234 | 133 | 6.222E+09 | 1,000,000 | 1,000 | 21.4 |
| U-235 | 16.3 | 2.161E+06 | 1,000,000 | 1,000 | 7,543 |
| U-238 | 54 | 3.359E+05 | 1,000,000 | 1,000 | 160,740 |

- a. See Table 7-1.
- b. See Table 4-1.
- c. Calculated using Equation 1 (see Section 3).

Table 7-3 Calculation of Uranium Isotope Mass Fractions

| Uranium Isotope | Background Activity (pCi isotope/ g soil) ^a | Activity Fraction | Specific Activity (pCi isotope/ g isotope) ^b | Background Mass (µg isotope/ kg soil) ^c | Mass Fraction |
|-----------------|--|-------------------|---|--|---------------|
| U-233/234 | 1.10 | 0.458 | 6.222E+09 | 0.177 | 0.00006 |
| U-234 | 1.10 | 0.458 | 6.222E+09 | 0.177 | 0.00006 |
| U-235 | 0.11 | 0.048 | 2.161E+06 | 50.4 | 0.016 |
| U-238 | 1.06 | 0.467 | 3.359E+05 | 3155 | 0.98 |

- a. DOE/RL-96-12, *Hanford Site Soil Background: Part 2, Soil Background for Radioactive Analytes*.
- b. See Table 4-1.
- c. Formula = Background Activity (pCi/g) / Specific Activity (pCi/g) x 1E+06 (µg/g) x 1E+03 (g/kg)

8 References

- ANL/EAD/LD-2, 1993, Manual for Implementing Residual Radioactive Materials Guidelines Using RESRAD, Version 5.0, Environmental Assessment Division, Argonne National Laboratory, Argonne, IL
- ANL/EAD-4, 2001, *User's Manual for RESRAD, Version 6*, Argonne National Laboratory, Environmental Assessment Division, Argonne, Illinois.
- ANL, 2009, RESRAD for Windows, Version 6.5, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois.
- CHPRC-00209, Rev. 0, *RESRAD Software Management Plan*
- DOE/RL-96-12, 1996, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Department of Energy, Richland Operations Office, Richland, Washington
- DOE/RL-2008-66, 2009, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington
- DOE/RL-2009-81, 2009, *Central Plateau Cleanup Completion Strategy*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington
- DOE/RL-2010-99, 2011, *Remedial Investigation/Feasibility Study for the 300-FF-1, 300-FF-2, and 300-FF-5 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- OSWER Directive 9285.6-03, 1991, *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final*, Office of Emergency and Remedial Response, Toxics Integration Branch, U.S. Environmental Protection Agency, Washington, D.C.
- EPA/540/R-92/003, 1991, *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim*, Publication 9285.7-01B, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C.
- EPA/540/R-96/018, 1996, *Soil Screening Guidance: Users Guide*, Publication 9355.4-23, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.
- EPA/540/R/99/006, 1999, *Radiation Risk Assessment At CERCLA Sites: Q & A*, OSWER Directive 9200.4-31P, Office of Emergency and Remedial Response and Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, D.C.
- EPA/540-R-00-007, 2000, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A, Office of Radiation and Indoor Air, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.
- EPA 600/P-95/002Fa, 1997, *Exposure Factors Handbook Volume 1: General Factors*, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

- PNNL-12087, 1999, *Hanford Site Climatological Data Summary 1998 with Historical Data*, Pacific Northwest National Laboratory, Richland, Washington.
- PNNL-14702, 2006, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.
- PNNL-14753, 2006, *Groundwater Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.
- PNNL-15160, 2005, *Hanford Site Climatological Summary 2004 with Historical Data*, Pacific Northwest National Laboratory, Richland, Washington.
- PNNL-18564, 2009, *Selection and Traceability of Parameters to Support Hanford-Specific RESRAD Analyses: Fiscal Year 2008 Status Report*, Pacific Northwest National Laboratory, Richland, Washington.
- PRC-PRO-EP-40205, 2010, *Administrative Procedure, CHPRC Environmental Calculation Preparation and Issue*, Rev. 1, Change 1, CH2M HILL Plateau Remediation Company, Richland, Washington.
- PRC-PRO-IRM-309, 2009, *Software Control Management*
- WDOH/320-015, 1997, *Hanford Guidance for Radiological Cleanup*, Rev. 1, Washington State Department of Health, Olympia, Washington.

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|--|--|-------------------|--|--|--|
| | | | User Input | Rationale | Reference |
| Exposure Pathways | External gamma: Inhalation: Plant ingestion: Meat ingestion: Milk ingestion: Aquatic foods: Drinking water: Soil ingestion: Radon: | NA | Active Active Active Active Active Active Active Active Suppressed | | |
| R011 – Contaminated Zone (CZ) | Area of CZ | m ² | 10,000 | Generic site model | Surface area presented in RESRAD user's guide, ANL/EAD-4 |
| | Thickness of CZ ^c | m | 4.6 | Direct exposure cleanup standards apply to the upper 4.6 m (15 ft) | |
| | Length Parallel to Aquifer Flow | m | 100 | Square root of contaminated site area | |
| | Radiation Dose Limit | mrem/yr | NA | | |
| | Elapsed Time of Waste Placement | yr | 0 | RESRAD default | |
| R012 –Principal Radionuclides Concentrations | All radionuclide contaminants of concern | pCi/g | Contaminant-specific | Contaminant-specific soil remedial action levels (pCi/g) are endpoints of the RESRAD calculations | |
| R013 - Cover and CZ Hydrological Data | Cover Depth | m | 0 | Conservative assumption; assumes cover is not maintained and direct exposure to contamination may occur in the future. | |
| | Density of Cover Material | g/cm ³ | Not used | | |
| | Cover Erosion Rate | m/yr | Not used | | |
| | Density of CZ | g/cm ³ | 1.6 | Hanford 100 Area-specific data | DOE/RL-90-07 |
| | CZ Erosion Rate | m/yr | 0.001 | RESRAD default | |
| | CZ Total Porosity | Unitless | 0.4 | WDOH guidance | WDOH/320-015 |
| | CZ Field Capacity | Unitless | 0.15 | Same as SZ Field Capacity | |
| | CZ Hydraulic Conductivity | m/yr | 250 | Hanford 100 Area-specific data | DOE/RL-96-11 DOE/RL-93-37 |
| | CZ b Parameter | Unitless | 4.05 | WDOH guidance | WDOH/320-015 |
| | Humidity in Air | g/cm ³ | 8 | RESRAD default | |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|-----------------|--|----------------|---|--|-----------------|
| | | | User Input | Rationale | Reference |
| | Evapotranspiration Coefficient | Unitless | 0.91 | | Letter from EPA |
| | Wind Speed | m/s | 3.4 | Hanford Site average | PNNL-12087 |
| | Precipitation | m/yr | 0.16 | Based on 16 cm (6.3 in.) average annual rainfall | DOE/RL-90-07 |
| | Irrigation Rate | m/yr | 0.76 | EPA, Region X guidance | Letter from EPA |
| | Irrigation Mode | NA | Overhead | RESRAD default | |
| | Runoff Coefficient | Unitless | 0.2 | RESRAD default | |
| | Watershed Area for Nearby Stream or Pond | m ² | 1,000,000 | RESRAD default | |
| | Accuracy for Water/Soil Computations | Unitless | 0.001 | RESRAD default | |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|---|---|---------------------|---|---|----------------------------------|
| | | | User Input | Rationale | Reference |
| R014 - SZ Hydrological Data | Density of SZ | g/cm ³ | 1.6 | Hanford 100 Area-specific data | DOE/RL-90-07 |
| | SZ Total Porosity | Unitless | 0.4 | WDOH guidance | WDOH/320-015 |
| | SZ Effective Porosity | Unitless | 0.25 | Agreement among the Tri-Parties ^a | ANL/EAD/LD-2, Table 3.2 |
| | SZ Field Capacity | Unitless | 0.15 | Field capacity = total porosity - effective porosity | ANL/EAD/LD-2, Equation 4.4 |
| | SZ Hydraulic Conductivity | m/yr | 5,530 | Hanford 100-Area specific data | DOE/RL-96-11 DOE/RL-93-37 |
| | SZ Hydraulic Gradient | Unitless | 1.25E-03 | Based on GW velocity = 27.8 m/yr, porosity = 0.25, hydraulic conductivity = 5,530 | DOE/RL-94-136 |
| | SZ b Parameter | Unitless | 4.05 | WDOH guidance | WDOH/320-015 |
| | Water Table Drop Rate | m/yr | 0.001 | RESRAD default | |
| | Well Pump Intake Depth | m below water table | 4.6 | Typical RCRA well screen length | |
| | Nondispersion (ND) or Mass-Balance (MB) | NA | ND | | |
| | Well Pumping Rate | m ³ /yr | 250 | RESRAD default | |
| R015 - Uncontaminated and Unsaturated Strata Hydrological Data | Number of Unsaturated Strata | NA | 1 | Generic site model; one contaminated zone, one uncontaminated zone | |
| | Thickness | m | 12 | Generic site model | |
| | Soil Density | g/cm ³ | 1.6 | Hanford 100 Area-specific data | DOE/RL-90-07 |
| | Total Porosity | Unitless | 0.4 | WDOH guidance | WDOH/320-015 |
| | Effective Porosity | Unitless | 0.25 | Agreement among the Tri-Parties | ANL/EAD/LD-2, 1993, Table 3.2 |
| | Field Capacity | Unitless | 0.15 | Field capacity = total porosity - effective porosity | ANL/EAD/LD-2, 1993, Equation 4.4 |
| | Soil-specific b Parameter | Unitless | 4.05 | WDOH guidance | WDOH/320-015 |
| | Hydraulic Conductivity | m/yr | 250 | Hanford 100-Area specific data | DOE/RL-96-11 DOE/RL-93-37 |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|--|----------------------|------------------|---|--|---|
| | | | User Input | Rationale | Reference |
| R016 - Distribution Coefficients and Leach Rates | CZ K_d | mL/g | Contaminant-specific | Kds values assigned to contaminated zone are for sand-dominated sediment (Hss). Kds values assigned to uncontaminated unsaturated zone and saturated zone are for sandy gravel (Hg). | Kd values are taken from following hierarchy of information sources: DOE/RL-96-17 Table (first preference), and RESRAD default (ANL 2009) |
| | Leach Rate | yr ⁻¹ | Contaminant-specific | RESRAD manual | Note - leach rates are not used; Kd values are used for all radionuclides for leaching calculations |
| | Saturated Solubility | mol/L | 0 | RESRAD default | Not used - Kd values are used for all leaching calculations |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSS

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|---|---|--------------------|---|---|------------------------------|
| | | | User Input | Rationale | Reference |
| R017 - Inhalation and External Gamma | Inhalation Rate | m ³ /yr | 7,300 | WDOH guidance | WDOH/320-015 |
| | Mass Loading for Inhalation | g/m ³ | 0.0001 | WDOH guidance | WDOH/320-015 |
| | Exposure duration | yr | 30 | | EPA/540/R-92/003 |
| | Indoor Dust Filtration Factor | Unitless | 0.4 | RESRAD default | |
| | External Gamma Shielding Factor | Unitless | 0.4 | | EPA/540-R-00-007, Equation 4 |
| | Indoor Time Fraction | Unitless | 0.6 | Based on 15 hr/day x 350 day/yr (5,250 hr/8,760 hr) | |
| | Outdoor Time Fraction | Unitless | 0.12 | Based on 3 hr/day x 350 days/yr (1,050 hr/8,760 hr) | |
| | Shape Factor | NA | Circular | RESRAD default | |
| R018 - Ingestion Pathway Data, Dietary Parameters | Fruits, Vegetables, and Grain Consumption | kg/yr | 110 | WDOH guidance | WDOH/320-015 |
| | Leafy Vegetable Consumption | kg/yr | 2.7 | WDOH guidance | WDOH/320-015 |
| | Milk Consumption | L/yr | 100 | WDOH guidance | WDOH/320-015 |
| | Meat and Poultry Consumption | kg/yr | 36 | WDOH guidance | WDOH/320-015 |
| | Fish Consumption | kg/yr | 19.7 | WDOH guidance | WDOH/320-015 |
| | Other Seafood Consumption | kg/yr | 0.9 | RESRAD default | |
| | Soil Ingestion | g/yr | 36.5 | Based on 100 mg/day x 365 days/yr | EPA/540/R-92/003 |
| | Drinking Water Intake | L/yr | 730 | WDOH guidance | WDOH/320-015 |
| | Drinking Water Contamination Fraction | Unitless | 1 | RESRAD default | |
| | Household Water Contamination Fraction | Unitless | 1 | RESRAD default | |
| | Livestock Water Contamination Fraction | Unitless | 1 | RESRAD default | |
| | Irrigation Water Contamination Fraction | Unitless | 1 | RESRAD default | |
| | Aquatic Food Contamination Fraction | Unitless | 0.5 | RESRAD default | |
| | Plant Food Contamination Fraction | Unitless | -1 | RESRAD default | |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|-----------------|-----------------------------|----------|---|----------------|-----------|
| | | | User Input | Rationale | Reference |
| | Meat Contamination Fraction | Unitless | -1 | RESRAD default | |
| | Milk Contamination Fraction | Unitless | -1 | RESRAD default | |

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|---|--|------------------|---|----------------|--------------|
| | | | User Input | Rationale | Reference |
| R019 - Ingestion Pathway Data, Nondietary | Livestock Fodder Intake for Meat | kg/d | 68 | RESRAD default | |
| | Livestock Fodder Intake for Milk | kg/d | 55 | RESRAD default | |
| | Livestock Water Intake for Meat | L/d | 50 | RESRAD default | |
| | Livestock Water Intake for Milk | L/d | 160 | RESRAD default | |
| | Livestock Intake of Soil | kg/d | 0.5 | RESRAD default | |
| | Mass Loading for Foliar Deposition | g/m ³ | 0.0001 | RESRAD default | |
| | Depth of Soil Mixing Layer | m | 0.15 | RESRAD default | |
| | Depth of Roots | m | 0.9 | RESRAD default | |
| R020 – Groundwater Usage | Groundwater Fractional Usage - Drinking Water | Unitless | 1 | RESRAD default | |
| | Groundwater Fractional Usage - Household Usage | Unitless | 1 | RESRAD default | |
| | Groundwater Fractional Usage - Livestock Water | Unitless | 1 | RESRAD default | |
| | Groundwater Usage – Irrigation | Unitless | 1 | RESRAD default | |
| R021 - Radon | Radon parameters are not used; Radon is not a Hanford Site COPC. | | | WDOH guidance | WDOH/320-015 |

a. Use of an effective porosity of 0.25 as a generic 100 Area input parameter is based upon agreement among the Tri-Parties. An effective porosity of 0.25 corresponds to values for sand and gravel reported in ANL/EAD/LD-2, Table 3.2.

ANL = Argonne National Laboratory

COPC = contaminant of potential concern

CZ = contaminated zone

EPA = U.S. Environmental Protection Agency

NA = not applicable

ND = nondispersion

RCRA = Resource Conservation and Recovery Act of 1976

RESRAD = RESidual RADioactivity code

SZ = saturated zone

WDOH = Washington State Department of Health

ANL/EAD-4, 2001, *User's Manual for RESRAD Version 6*, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois

ANL/EAD/LD-2, 1993, *Manual for Implementing Residual Radioactive Materials Guidelines Using RESRAD, Version 5.0*, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois

ANL, 2009, RESRAD for Windows, Version 6.5, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois

DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6 (For Approval July 2009), U.S. Department of Energy, Richland Operations Office, Richland, Washington.

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Attachment 1. Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs

| RESRAD Category | Parameter | Units | Interim Action Record of Decision Exposure Scenario | | |
|-----------------|-----------|-------|---|-----------|-----------|
| | | | User Input | Rationale | Reference |

DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington

EPA/540/R-92/003, 1991, *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors"* Interim Final OSWER Directive 9285.6-03, Office of Emergency and Remedial Response, Toxics Integration Branch, U.S. Environmental Protection Agency, Washington, D.C.

EPA 540/R/99/006, 1999, *Radiation Risk Assessment at CERCLA Sites: Q & A*, OSWER Directive No. 9200.4-31P, U.S. Environmental Protection Agency, Washington, D.C.

EPA/540-R-00-007, 2000, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER Directive No. 9355.4 16A, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

EPA/600/P-95/002Fa, 1997, *Exposure Factors Handbook Volume I: General Factors*, U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, D.C

PNNL-12087, 1999, *Hanford Site Climatological Data Summary 1998 with Historical Data*, Pacific Northwest National Laboratory, Richland, Washington

PNNL-15160, 2005, *Hanford Site Climatological Summary 2004 With Historical Data*, Pacific Northwest National Laboratory, Richland, Washington

PNNL-14702, 2006, *Vadose Zone Hydrology Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington

PNNL-14753, 2006, *Groundwater Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington

PNNL-18564, 2009, *Selection and Traceability of Parameters to Support Hanford-Specific RESRAD Analyses – Fiscal Year 2008 Status Report*, Pacific Northwest National Laboratory, Richland, Washington

WDOH/320-015, 1997, *Hanford Guidance for Radiological Cleanup*, Rev. 1, Washington State Department of Health, Olympia, Washington.

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Attachment 2. Intermediate Calculations

| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Final PRG (pCi/g) | Target Risk |
|--------------|--------------------|-----------|-----------------------|-------------|---|---------------------------------------|------------------------------------|---|-------------------|-------------|
| Ag-108 | 1000 | 7.316E-02 | 0 | 1.00E-04 | 1.37 | 1.37 | 1.002E-04 | 0.1996% | 1.37 | 1.00E-04 |
| | | | | | | | | | 0.137 | 1.00E-05 |
| | | | | | | | | | 0.0137 | 1.00E-06 |
| Am-241 | 1000 | 6.453E-04 | 0 | 1.00E-04 | 154.97 | 155 | 1.000E-04 | 0.0000% | 155 | 1.00E-04 |
| | | | | | | | | | 15.5 | 1.00E-05 |
| | | | | | | | | | 1.55 | 1.00E-06 |
| C-14 | 1000 | 1.235E-03 | 0 | 1.00E-04 | 80.97 | 81 | 1.002E-04 | 0.1996% | 81 | 1.00E-04 |
| | | | | | | | | | 8.1 | 1.00E-05 |
| | | | | | | | | | 0.81 | 1.00E-06 |
| Cm-243 | 1000 | 3.299E-03 | 0 | 1.00E-04 | 30.31 | 30.3 | 9.997E-05 | -0.0300% | 30.3 | 1.00E-04 |
| | | | | | | | | | 3.03 | 1.00E-05 |
| | | | | | | | | | 0.303 | 1.00E-06 |
| Cm-243/243 | 1000 | 3.299E-03 | 0 | 1.00E-04 | 30.31 | 30.3 | 9.997E-05 | -0.0300% | 30.3 | 1.00E-04 |
| | | | | | | | | | 3.03 | 1.00E-05 |
| | | | | | | | | | 0.303 | 1.00E-06 |
| Cm-244 | 1000 | 1.815E-04 | 0 | 1.00E-04 | 550.96 | 551 | 1.000E-04 | 0.0000% | 551 | 1.00E-04 |
| | | | | | | | | | 55.10 | 1.00E-05 |
| | | | | | | | | | 5.510 | 1.00E-06 |
| Cm-245 | 1000 | 2.993E-03 | 575 | 1.00E-04 | 33.41 | 33.4 | 9.998E-05 | -0.0200% | 33.4 | 1.00E-04 |
| | | | | | | | | | 3.34 | 1.00E-05 |
| | | | | | | | | | 0.334 | 1.00E-06 |
| Co-60 | 1000 | 3.228E-02 | 0 | 1.00E-04 | 3.10 | 3.1 | 1.007E-04 | 0.6951% | 3.1 | 1.00E-04 |
| | | | | | | | | | 0.310 | 1.00E-05 |
| | | | | | | | | | 0.0310 | 1.00E-06 |
| Cs-137 | 1000 | 2.269E-02 | 0 | 1.00E-04 | 4.41 | 4.4 | 9.954E-05 | -0.4621% | 4.4 | 1.00E-04 |
| | | | | | | | | | 0.440 | 1.00E-05 |
| | | | | | | | | | 0.0440 | 1.00E-06 |
| Eu-152 | 1000 | 2.733E-02 | 0 | 1.00E-04 | 3.66 | 3.66 | 1.000E-04 | 0.0000% | 3.66 | 1.00E-04 |
| | | | | | | | | | 0.37 | 1.00E-05 |
| | | | | | | | | | 0.037 | 1.00E-06 |
| Eu-154 | 1000 | 2.277E-02 | 0 | 1.00E-04 | 4.39 | 4.4 | 1.002E-04 | 0.1996% | 4.4 | 1.00E-04 |
| | | | | | | | | | 0.440 | 1.00E-05 |
| | | | | | | | | | 0.0440 | 1.00E-06 |
| Eu-155 | 1000 | 3.062E-04 | 0 | 1.00E-04 | 326.58 | 327 | 1.001E-04 | 0.0999% | 327 | 1.00E-04 |
| | | | | | | | | | 32.7 | 1.00E-05 |
| | | | | | | | | | 3.27 | 1.00E-06 |
| H-3 | 1000 | 1.605E-04 | 0 | 1.00E-04 | 623.05 | 623 | 1.000E-04 | 0.0000% | 623 | 1.00E-04 |

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| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Final PRG (pCi/g) | Target Risk |
|--------------|-----------------------|------|-----------------------------|-------------|---|---|---------------------------------------|---|-------------------|-------------|
| | | | | | | | | | 62.3 | 1.00E-05 |
| | | | | | | | | | 6.23 | 1.00E-06 |

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| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Final PRG (pCi/g) | Target Risk |
|--------------|--------------------|-----------|-----------------------|-------------|---|---------------------------------------|------------------------------------|---|--------------------------|----------------------------------|
| I-129 | 1000 | 1.322E+00 | 189 | 1.00E-04 | 0.076 | 0.076 | 1.005E-04 | 0.4975% | 0.076 0.008 0.0008 | 1.00E-04 1.00E-05 1.00E-06 |
| K-40 | 1000 | 6.193E-02 | 1000 | 1.00E-04 | 1.61 | 1.6 | 9.909E-05 | -0.9184% | 1.6 0.16 0.016 | 1.00E-04 1.00E-05 1.00E-06 |
| Nb-94 | 1000 | 7.392E-02 | 0 | 1.00E-04 | 1.35 | 1.35 | 9.980E-05 | -0.2004% | 1.35 0.135 0.0135 | 1.00E-04 1.00E-05 1.00E-06 |
| Ni-59 | 1000 | 7.480E-05 | 0 | 1.00E-04 | 1336.90 | 1337 | 1.00E-04 | 0.0000% | 1337 133.7 13.37 | 1.00E-04 1.00E-05 1.00E-06 |
| Ni-63 | 1000 | 1.645E-04 | 0 | 1.00E-04 | 607.90 | 608 | 1.00E-04 | 0.0000% | 608 60.8 6.08 | 1.00E-04 1.00E-05 1.00E-06 |
| Np-237 | 1000 | 1.130E-02 | 0 | 1.00E-04 | 8.85 | 8.9 | 1.006E-04 | 0.5964% | 8.9 0.890 0.0890 | 1.00E-04 1.00E-05 1.00E-06 |
| Pu-238 | 1000 | 4.246E-04 | 0 | 1.00E-04 | 235.52 | 236 | 1.002E-04 | 0.1996% | 236 23.6 2.36 | 1.00E-04 1.00E-05 1.00E-06 |
| Pu-239/240 | 1000 | 4.934E-04 | 0 | 1.00E-04 | 202.68 | 203 | 1.001E-04 | 0.0999% | 203 20.3 2.03 | 1.00E-04 1.00E-05 1.00E-06 |
| Pu-241 | 1000 | 1.970E-05 | 56 | 1.00E-04 | 5076.14 | 5080 | 1.001E-04 | 0.0999% | 5080 508.0 50.80 | 1.00E-04 1.00E-05 1.00E-06 |
| Ra-226 | 1000 | 1.778E-01 | 9.20E+01 | 1.00E-04 | 0.56 | 0.56 | 9.957E-05 | -0.4319% | 0.56 0.056 0.0056 | 1.00E-04 1.00E-05 1.00E-06 |
| Ra-228 | 1000 | 6.239E-02 | 0 | 1.00E-04 | 1.60 | 1.6 | 9.983E-05 | -0.1703% | 1.6 0.16 0.016 | 1.00E-04 1.00E-05 1.00E-06 |
| Sr-90 | 1000 | 4.411E-02 | 0 | 1.00E-04 | 2.27 | 2.27 | 1.001E-04 | 0.0999% | 2.27 0.227 0.0227 | 1.00E-04 1.00E-05 1.00E-06 |
| Sn-126 | 1000 | 1.592E+00 | 18.6 | 0.0001 | 0.063 | 0.063 | 1.00E-04 | 0.30% | 0.063 0.0063 | 1.00E-04 1.00E-05 |

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| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Final PRG (pCi/g) | Target Risk |
|--------------|--------------------|-----------|-----------------------|-------------|---|---------------------------------------|------------------------------------|---|-----------------------|----------------------------------|
| | | | | | | | | | 0.00063 | 1.00E-06 |
| Tc-99 | 1000 | 6.560E-02 | 18 | 1.00E-04 | 1.52 | 1.52 | 9.971E-05 | -0.2908% | 1.52 0.15 0.015 | 1.00E-04 1.00E-05 1.00E-06 |
| Th-228 | 1000 | 7.382E-03 | 0 | 1.00E-04 | 13.55 | 13.6 | 1.004E-04 | 0.3984% | 13.6 1.36 0.136 | 1.00E-04 1.00E-05 1.00E-06 |

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| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Final PRG (pCi/g) | Target Risk |
|---|--------------------|-----------|-----------------------|-------------|---|---------------------------------------|------------------------------------|---|-------------------|-------------|
| Th-230 | 1000 | 6.308E-02 | 1000 | 1.00E-04 | 1.59 | 1.59 | 1.003E-04 | 0.2991% | 1.59 | 1.00E-04 |
| | | | | | | | | | 0.2 | 1.00E-05 |
| | | | | | | | | | 0.02 | 1.00E-06 |
| Th-232 | 1000 | 2.319E-01 | 54 | 1.00E-04 | 0.43 | 0.43 | 9.973E-05 | -0.2707% | 0.43 | 1.00E-04 |
| | | | | | | | | | 0.043 | 1.00E-05 |
| | | | | | | | | | 0.0043 | 1.00E-06 |
| U-233/234 | 1000 | 7.516E-04 | 1000 | 1.00E-04 | 133.05 | 133 | 9.996E-05 | -0.0400% | 133 | 1.00E-04 |
| | | | | | | | | | 13.300 | 1.00E-05 |
| | | | | | | | | | 1.3300 | 1.00E-06 |
| Note: Uranium-234 breakthrough occurs at 20,170 years | | | | | | | | | | |
| U-234 | 1000 | 7.516E-04 | 1000 | 1.00E-04 | 133.05 | 133 | 9.996E-05 | -0.0400% | 133 | 1.00E-04 |
| | | | | | | | | | 13.300 | 1.00E-05 |
| | | | | | | | | | 1.3300 | 1.00E-06 |
| Note: Uranium-234 breakthrough occurs at 20,170 years | | | | | | | | | | |
| U-235 | 1000 | 6.146E-03 | 0 | 1.00E-04 | 16.27 | 16.3 | 1.002E-04 | 0.1996% | 16.3 | 1.00E-04 |
| | | | | | | | | | 1.630 | 1.00E-05 |
| | | | | | | | | | 0.1630 | 1.00E-06 |
| Note: Uranium-235 breakthrough occurs at 20,170 years | | | | | | | | | | |
| U-238 | 1000 | 1.863E-03 | 0 | 1.00E-04 | 53.68 | 54 | 1.006E-04 | 0.5964% | 54.00 | 1.00E-04 |
| | | | | | | | | | 5.400 | 1.00E-05 |
| | | | | | | | | | 0.5400 | 1.00E-06 |
| Note: Uranium-238 breakthrough occurs at 20,170 years | | | | | | | | | | |

Attachment 3. Radionuclide-Specific Distribution Coefficients (K_d) by RESRAD Model Layer.

| Radionuclide | K_d (cm ³ /g) | K_d Reference | K_d (cm ³ /g) | K_d Reference |
|-----------------------------|--|-------------------------|---|-------------------------|
| | Contaminated Zone Layer (assumed sand dominated, Hss) | | Uncontaminated Unsaturated Zone and Saturated Zone Layers (assumed sandy gravel, Hg) | |
| | | | | |
| Ag (silver)-108m | 90 | DOE/RL-96-17, Table B-7 | 90 | DOE/RL-96-17, Table B-7 |
| Americium-241 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Carbon-14 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Cesium-137 | 50 | DOE/RL-96-17, Table B-7 | 50 | DOE/RL-96-17, Table B-7 |
| Cobalt-60 | 50 | DOE/RL-96-17, Table B-7 | 50 | DOE/RL-96-17, Table B-7 |
| Curium-243 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Curium-243/244 ^a | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Curium-244 ^a | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Curium-245 ^a | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Europium-152 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Europium-154 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Europium-155 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Iodine-129 | 1 | DOE/RL-96-17, Table B-7 | 1 | DOE/RL-96-17, Table B-7 |
| Neptunium-237 | 15 | DOE/RL-96-17, Table B-7 | 15 | DOE/RL-96-17, Table B-7 |
| Nickel-59 ^b | 30 | DOE/RL-96-17, Table B-7 | 30 | DOE/RL-96-17, Table B-7 |
| Nickel-63 | 30 | DOE/RL-96-17, Table B-7 | 30 | DOE/RL-96-17, Table B-7 |
| Niobium-94 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Plutonium-238 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Plutonium-239/240 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Plutonium-241 ^c | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Potassium-40 | 5.5 | DOE/RL-96-17, Table B-7 | 5.5 | DOE/RL-96-17, Table B-7 |
| Radium-226 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Radium-228 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Strontium-90 | 25 | DOE/RL-96-17, Table B-7 | 25 | DOE/RL-96-17, Table B-7 |
| Technetium-99 | 0 | DOE/RL-96-17, Table B-7 | 0 | DOE/RL-96-17, Table B-7 |
| Thorium-228 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Thorium-230 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Thorium-232 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Tin-126 | 0 | RESRAD default | 0 | RESRAD default |
| Tritium (H-3) | 0 | DOE/RL-96-17, Table B-7 | 0 | DOE/RL-96-17, Table B-7 |
| Uranium-233/234 | 50 | RESRAD default | 50 | RESRAD default |

Attachment 3. Radionuclide-Specific Distribution Coefficients (K_d) by RESRAD Model Layer.

| Radionuclide | K _d (cm ³ /g) | K _d Reference | K _d (cm ³ /g) | K _d Reference |
|--|--|--------------------------|---|--------------------------|
| | Contaminated Zone Layer (assumed sand dominated, Hss) | | Uncontaminated Unsaturated Zone and Saturated Zone Layers (assumed sandy gravel, Hg) | |
| Uranium-234 | 50 | RESRAD default | 50 | RESRAD default |
| Uranium-235 | 50 | RESRAD default | 50 | RESRAD default |
| Uranium-238 | 50 | RESRAD default | 50 | RESRAD default |
| Daughter Radionuclides (included automatically by RESRAD with selection of parent) | | | | |
| Actinium-227 | 20 | RESRAD default | 20 | RESRAD default |
| Americium-243 ^d | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Gadolinium-152 ^e | -1 | RESRAD default | -1 | RESRAD default |
| Lead-210 | 100 | RESRAD default | 100 | RESRAD default |
| Plutonium-240 ^c | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Protactinium-231 | 50 | RESRAD default | 50 | RESRAD default |
| Thorium-229 | 200 | DOE/RL-96-17, Table B-7 | 200 | DOE/RL-96-17, Table B-7 |
| Uranium-236 | 50 | RESRAD default | 50 | RESRAD default |

a. The referenced K_d value for Curium-243 is used

b. The referenced K_d value for Nickel-63 is used

c. The referenced K_d value for Plutonium-239/240 is used

d. The referenced K_d value for Americium-241 is used

e. RESRAD displays a default value of -1 on the K_d input screen for gadolinium-152 indicating the K_d value is derived internally by the code.

RESRAD - RESidual RADioactivity code (ANL 2009)

ANL, 2009, RESRAD for Windows, Version 6.5, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois.

DOE/RL-96-17, 2009, Remedial Design Report/Remedial Action Work Plan for the 100 Area, Rev. 6, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

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Attachment 4. Site Area Sensitivity Analysis

| Radionuclide | Input Conc (pCi/g) | Risk | Time of Max Risk (yr) | Surface Area (m ²) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | Concentration Input to RESRAD (pCi/g) | Calculated Cancer Risk from RESRAD | Percent Difference in Risk Between Estimated and Input Concentrations | Percent Difference in PRGs Between Base Case (10,000 m ²) and Alternate Site Areas |
|--------------|-----------------------|-----------|-----------------------------|-----------------------------------|-------------|---|---|---------------------------------------|---|--|
| Am-241 | 1000 | 6.453E-04 | 0 | 10,000 | 1.00E-04 | 154.97 | 155 | 1.000E-04 | 0.0000% | |
| | 1000 | 6.654E-04 | 0 | 100,000 | 1.00E-04 | 150.29 | 150 | 9.980E-05 | -0.2004% | 3.2% |
| | 1000 | 6.207E-04 | 0 | 1,000 | 1.00E-04 | 161.11 | 161 | 9.993E-05 | -0.0700% | -3.9% |
| Cs-137 | 1000 | 2.269E-02 | 0 | 10,000 | 1.00E-04 | 4.41 | 4.4 | 9.982E-05 | -0.1803% | |
| | 1000 | 2.575E-02 | 0 | 100,000 | 1.00E-04 | 3.88 | 3.9 | 1.004E-04 | 0.3984% | 11.4% |
| | 1000 | 1.961E-02 | 0 | 1,000 | 1.00E-04 | 5.10 | 5.1 | 9.999E-05 | -0.0100% | -15.9% |
| Pu-239/240 | 1000 | 4.934E-04 | 0 | 10,000 | 1.00E-04 | 202.68 | 203 | 1.002E-04 | 0.1996% | |
| | 1000 | 5.131E-04 | 0 | 100,000 | 1.00E-04 | 194.89 | 195 | 1.001E-04 | 0.0999% | 3.9% |
| | 1000 | 4.763E-04 | 0 | 1,000 | 1.00E-04 | 209.95 | 210 | 1.000E-04 | 0.0000% | -3.4% |
| Ra-226 | 1000 | 1.778E-01 | 92 | 10,000 | 1.00E-04 | 0.56 | 0.56 | 9.957E-05 | -0.4319% | |
| | 1000 | 1.872E-01 | 92 | 100,000 | 1.00E-04 | 0.53 | 0.54 | 9.920E-05 | -0.8065% | 3.6% |
| | 1000 | 1.686E-01 | 92 | 1,000 | 1.00E-04 | 0.59 | 0.59 | 9.945E-05 | -0.5530% | -5.4% |

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Attachment 5. Site Thickness Sensitivity Analysis

| Radionuclide | Input Conc (pCi/g) | | Time of Max Risk (yr) | Site Thickness (m) | Target Risk | Estimated concentration at 10 ⁻⁴ target risk (pCi/g) | | Concentration Input to RESRAD (pCi/g) | | Calculated Cancer Risk from RESRAD | Percent Difference in Risk | |
|--------------|--------------------|-----------|-----------------------|--------------------|-------------|---|------|---------------------------------------|------|------------------------------------|--|--|
| | Risk | | | | | | | | | | Between Estimated and Input Concentrations | Between Base Case (4.6 m) and Alternate Site Areas |
| Am-241 | 1000 | 6.453E-04 | 0 | 4.6 | 1.00E-04 | 154.97 | 155 | 1.000E-04 | 155 | 1.000E-04 | 0.0000% | 0.0% |
| | 1000 | 6.454E-04 | 0 | 10 | 1.00E-04 | 154.94 | 155 | 1.000E-04 | 155 | 1.000E-04 | 0.0000% | 0.0% |
| | 1000 | 6.433E-04 | 0 | 1 | 1.00E-04 | 155.45 | 155 | 1.000E-04 | 155 | 9.971E-05 | -0.2908% | 0.0% |
| Cs-137 | 1000 | 2.269E-02 | 0 | 4.6 | 1.00E-04 | 4.41 | 4.4 | 9.982E-05 | 4.4 | 9.982E-05 | -0.1803% | 0.0% |
| | 1000 | 2.266E-02 | 0 | 10 | 1.00E-04 | 4.41 | 4.4 | 9.969E-05 | 4.4 | 9.969E-05 | -0.3110% | 0.0% |
| | 1000 | 2.239E-02 | 0 | 1 | 1.00E-04 | 4.47 | 4.5 | 1.008E-04 | 4.5 | 1.008E-04 | 0.7937% | -2.3% |
| Pu-239/240 | 1000 | 4.934E-04 | 0 | 4.6 | 1.00E-04 | 202.68 | 203 | 1.002E-04 | 203 | 1.002E-04 | 0.1996% | 0.0% |
| | 1000 | 4.933E-04 | 0 | 10 | 1.00E-04 | 202.72 | 203 | 1.001E-04 | 203 | 1.001E-04 | 0.0999% | 0.0% |
| | 1000 | 4.917E-04 | 0 | 1 | 1.00E-04 | 203.38 | 203 | 9.981E-05 | 203 | 9.981E-05 | -0.1904% | 0.0% |
| Ra-226 | 1000 | 1.778E-01 | 92 | 4.6 | 1.00E-04 | 0.56 | 0.56 | 9.957E-05 | 0.56 | 9.957E-05 | -0.4319% | 0.0% |
| | 1000 | 1.784E-01 | 92 | 10 | 1.00E-04 | 0.56 | 0.56 | 9.991E-05 | 0.56 | 9.991E-05 | -0.0901% | 0.0% |
| | 1000 | 1.742E-01 | 75 | 1 | 1.00E-04 | 0.57 | 0.57 | 9.929E-05 | 0.57 | 9.929E-05 | -0.7151% | -1.8% |