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Revision 2

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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

ch2m SM

P.O. Box 1600
Richland, Washington 99352

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ENVIRONMENTAL CALCULATION COVER PAGE

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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	12/18/2012	Pages 3-8, and Tables ☒
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 (CONTINUED)

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Terms

AOC	Area of Contaminated Zone
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CHPRC	CH2M HILL Plateau Remediation Company
DOE	U.S. Department of Energy
ECF	environmental calculation file
EPA	U.S. Environmental Protection Agency
HISI	Hanford Information Systems Inventory
IAROD	Interim Action Record Decision
K_d	Distribution coefficients
mrem/yr	millirem per year
PRGs	Preliminary Remediation Goals
RAO	Remedial Action Objective
RESRAD	RESidual RADioactivity
RI/FS	Remedial Investigation/Feasibility Study
RPD	Relative Percent Difference
SI	Sensitivity index

1 Purpose

This environmental calculation file (ECF) 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, inhalation, and food chain (i.e., the consumption of homegrown produce and livestock) pathways. The PRG values for radionuclides 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 U.S. Environmental Protection Agency (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 and listed in Appendix A, Table A-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, that are part of the Hanford Site River Corridor, which encompasses approximately 570 km^2 (220 mi^2) 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 used[1]:

- 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 *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (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

[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.

these PRGs that may result from changes in RAOs occurring during development of the 100 and 300 Area RI/FS Report.

3 Methodology

RESidual RADioactivity computer code (RESRAD) Version 7.0 (ANL, 2014) was used to calculate the soil PRGs for radiological contaminants based on the IAROD exposure scenario. Default DCFPAK 3.02 Morbidity risk factors within RESRAD version 7.0 were utilized during the calculation of soil PRGs. 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 and are listed in Appendix A, Table A-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 Appendix A, Table A-1 into the RESRAD model.
2. Input the arbitrary soil concentration of 1 pCi/g for each radionuclide evaluated.
3. Input the distribution coefficients from Appendix A, Table A-2 into the RESRAD model.
4. Input calculation times of 1, 3, 10, 30, 100, 300, and 1,000 years into RESRAD.
5. Run RESRAD and review the results to identify the year at which the peak cancer risk occurs. The "Standard Graphics" module located within the "View Output" module is used during this step. Within the "Standard Graphics" module, make the following selections to identify the peak cancer risk for each individual radionuclide.
   - Plot Type: Risk
   - Radionuclide: Individual
   - Pathways: Summed

View each individual radionuclide and record the year associated with peak cancer risk in an intermediate calculations worksheet (Appendix A, Table A-3). For a number of radionuclides, the peak risks occur at year 0 or year 1000. However, the peak risks for some radionuclides could occur within the intermediate years between 0 and 1000. For those radionuclides, by using the tool "Export to Excel" within the "Edit" Menu, obtain the risk output results (display results to four significant figures) to identify the year of peak cancer risk, highlight the results and save the results in the Appendix A, Table A-3.

6. Save the corresponding summary report (SUMMARY.REP) with unique file name.
7. Save the existing RESRAD file with a new name.
8. Input calculation times associated with each unique year of peak risk into RESRAD. Re-run RESRAD.
9. Open the "Health Risk Report" within "View Output" module.
10. For each calculation time, copy and paste the risk results for each individual radionuclide from the "All Pathways" column into an intermediate Microsoft Excel® worksheet (Appendix A, Table A-4). Create a set of headers that identify the calculation times associated with each set of risk outputs. Create a column that identifies the maximum risk per pCi/g for each radionuclide. Create another column that identifies the Year associated with the maximum risk. Create a column that calculates a preliminary PRG for each radionuclide associated with a target risk of 1×10^{-4}. The preliminary PRG is calculated by dividing the target risk of 1×10^{-4} by the maximum risk per pCi/g.
11. Save the corresponding summary report and the health risk report (INTRISK.REP) with a unique file name.
12. Save the existing RESRAD file with a new name.
13. Input the preliminary PRG values for each individual radionuclide into the soil concentrations module.
14. Re-run RESRAD and verify that the estimated PRG value corresponds to a 1×10^{-4} risk (Appendix A, Table A-5); 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) (Appendix A, Table A-6), and those concentrations will be selected as the PRGs for the Site.
15. Save the corresponding summary report and the health risk report with unique file names.
16. 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.

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 (µg/kg) to facilitate development of a mass-based PRG for total

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uranium, The activity-based uranium isotope PRGs (pCi/g) are converted to mass-based PRGs (µg/kg) using the following equation (the conversion calculations are provided in Section 7).

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

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 Appendix A, Table A-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 Appendix A, Table A-2.

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 Appendix A, Table A-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 (µg/kg) are shown in Table 1.

Table 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

Table 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-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 CH2M HILL Plateau Remediation Company (CHPRC) at the Hanford Site in accordance with the requirements of PRC-PRO-IRM-309, *Controlled Software 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, *RESRAD Software Management Plan* for further details regarding the use of this software:

- RESRAD for Windows
- Version 7.0, Created February 24, 2014
- HISI Identification Number: 2102
- Workstation type and property number: INTERA property number -00740 (Subcontractor Supplied Unique Property ID) and INTERA property number -00295.

5.2 Software Installation and Checkout

The software installation and checkout forms for RESRAD are provided as Appendix B 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 U.S. Department of Energy (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 Appendix A, Tables A-1

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and A-2) 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 Appendix A tables contained in the Excel workbook "ECF-HANFORD-10-0429 IAROD Rad PRGs Appendix A Table_Rev_2". Input and output files from RESRAD are also listed below.

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

- Appendix A, Table A-1 – Input Parameters to RESRAD for Calculation of PRGs for Radionuclides in Soil for Protection of Human Health for the 100 Area RI/FSs.
- Appendix A, Table A-2 - Radionuclide-Specific Distribution Coefficients (K_d) by RESRAD Model Layer.
- Appendix A, Table A-3 - Identification of Peak Year based on Peak Cancer Risk.
- Appendix A, Table A-4 - Intermediate Calculation - Results of Cancer Risk at Year of Peak Risk, and Preliminary PRGs for Individual Radionuclides.
- Appendix A, Table A-5 - Intermediate Calculation - Results of Cancer Risk at Year of Peak Risk based on Preliminary PRGs.
- Appendix A, Table A-6 - Intermediate Calculation - Calculation of Relative Percent Difference
- Appendix A, Table A-7 – Sensitivity Analysis - Area of Contaminated Zone and Thickness of Contaminated Zone.

Input file names from RESRAD are organized as follows:

- RESRAD input file name for identifying year at peak cancer risk - "IAROD_PRGs_RAD_V7.0.RAD"
- RESRAD input file name for calculating risk per unit concentration based on year at peak cancer risk – "RISK_IAROD_PRGs_RAD_V7.0.RAD"
- RESRAD input file name for calculating risk based on PRGs – "RISK_PRGs_RAD_V7.0.RAD" "
- RESRAD input file name for sensitivity analysis– "RISK_IAROD_PRGs_RAD_V7.0_SI.RAD"

Output file names from RESRAD are organized as follows:

- RESRAD output summary file name for identifying year at peak cancer risk - "IAROD_PRGs_RAD_V7.0.sum"
- RESRAD output summary file name for calculating risk per unit concentration based on years at peak cancer risk – "RISK_IAROD_PRGs_RAD_V7.0.sum"
- RESRAD output health risk file name for calculating risk per unit concentration based on years at peak cancer risk – "RISK_IAROD_PRGs_RAD_V7.0.int"

- RESRAD output summary file name for calculating risk based on PRGs – "RISK_PRGs_RAD_V7.0.sum"
- RESRAD output health risk file name for calculating risk based on PRGs – "RISK_PRGs_RAD_V7.0.int"

Input and output files - .RAD, .SUM and .INT files are archived under this ECF number (ECF-HANFORD-10-0429 IAROD RAD PRGs_Rev_2) in the ERMA.

CHPRC Software Installation and Checkout Forms for RESRAD are presented in Appendix B and includes the following:

- SICO-RESRAD_Rahman.pdf
- SICO – RESRAD_Doug.pdf

7 Results/Conclusions

The PRGs for radionuclides in soil are summarized in Table 2.

The human health direct contact PRGs for soil are based on the year that the peak risk occurs, within a 1,000 year timeframe. Except for six radionuclides (Cm-245, I-129, Pu-241, Sn-126, Tc-99, and U-233/234), the peak cancer risk for all other radionuclides occur at year zero. The peak cancer risk for U-233/234 occurs at year 1000. The peak risk for Cm-245, I-129, Pu-241, Sn-126, and Tc-99 occur within the intermediate years between 0 and 1,000 as a result of the contribution of risk from ingrowth daughter products. Appendix A, Table A-3 presents the year of peak cancer risk for each radionuclide. Appendix A, Table A-4 presents the results of the preliminary PRG calculation for each radionuclide. Appendix A, Table A-5 presents the result of maximum risk based on the preliminary PRG for each radionuclide to verify that the estimated PRG value corresponds to a 1×10^{-4} risk. An additional evaluation, relative percent difference (RPD) was calculated in Appendix A, Table A-6 using the target cancer risk and risk calculated in Appendix A, Table A-5 to ensure the calculated risks based on the PRGs are within 1 percent of the target cancer risk.

A generic site area of 10,000 m^2 and a generic site thickness of 4.6 m were assumed for developing the human health direct contact PRGs. Two sensitivity analyses were performed (see Appendix A, Table A-7) using the RESRAD sensitivity graphic utility to determine how sensitive the PRG values are to changes in area of contamination (AOC) and thickness of contaminated zone. The RESRAD sensitivity utility operates by both reducing and increasing the selected input parameter by a common factor. A sensitivity index (SI) was calculated to determine which parameters have the greatest influence on the calculated PRGs by using the following formula.

$$SI = 1 - \frac{Risk_{Lower\ Value}}{Risk_{Upper\ Value}}$$

A positive value of the SI indicates that the risk (hence, PRG) is directly proportional to the parameter of interest, whereas a negative value indicates the risk (hence, PRG) is inversely proportional to the parameter of interest. A value less than 0.01 indicates that the risk is independent of the parameter. The further the value of SI is from zero (0), the more sensitive the parameter is.

For the sensitivity analyses of AOC, the common factor of 5 was selected. The risks were then calculated for the base (assigned value, 10,000 m^2), the lower value (2,000 m^2), and upper value (50,000 m^2). A common factor of 2 was selected for the sensitivity analyses for thickness of the contaminated zone. The risks were calculated for the base (assigned value, 4.6 m), the lower value (2.3 m), and upper value (9.2 m). Am-241, Cs-137 and Pu-239/240 were selected for the sensitivity analyses.

Appendix A, Table A-7 presents the results of the sensitivity analyses for both parameters. The maximum risk output for three radionuclides were obtained by using the tool "Export to Excel" within the "Edit" Menu. Risk results are presented in lognormal plot, the maximum risks for all radionuclides were based on Year 1 instead of Year 0, as identified in Appendix A, Table A-3. The maximum risk results based on upper and lower values for each sensitive parameter were used to calculate the SI. The results of SI, based on AOC value showed that the assigned value for AOC is only somewhat sensitive for Cs-137 among three selected radionuclides. The results of SI, based on thickness of contaminated zone values showed that none of the selected radionuclides are sensitive for this parameter.

An additional evaluation was performed for Cs-137 to determine whether changes in AOC affect the PRG value. The PRG for Cs-137 is 4.4 pCi/g. Based on the maximum risk results, the PRG for Cs-137 decreases about 11 percent with an increase in area from 10,000 m^2 to 50,000 m^2. The PRG for Cs-137 increases about 13 percent with a decrease in site area from 10,000 m^2 to 2,000 m^2. When the size of AOC is 50,000 m^2, the PRG for Cs-137 is 3.9 pCi/g and when the AOC is to 2,000 m^2, the PRG for Cs-137 is 5 pCi/g.

To calculate 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 3. The conversions are made using the PRGs protective at the 1×10^{-4} risk level, which represents the upper threshold of the 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 3, 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 4. 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 154,808 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 2. 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	1.3	0.13	0.013
Americium-241	153	15.3	1.53
Carbon-14	81	8.1	0.81
Curium-243	30	3.0	0.30
Curium-243/244[a]	30	3.0	0.30
Curium-244	549	54.9	5.49
Curium-245	30	3.0	0.30

Table 2. 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)
Cobalt-60	3.1	0.31	0.031
Cesium-137	4.4	0.44	0.044
Europium-152	3.6	0.36	0.036
Europium-154	4.5	0.45	0.045
Europium-155	335	33.5	3.35
Tritium (H-3)	624	62.4	6.24
Iodine-129	0.11	0.01	0.001
Niobium-94	1.37	0.137	0.0137
Nickel-59	1,338	133.8	13.38
Nickel-63	594	59.4	5.94
Neptunium-237	8.4	0.84	0.084
Plutonium-238	236	23.6	2.36
Plutonium-239/240[b]	203	20.3	2.03
Plutonium-241	5,033	503.3	50.33
Strontium-90	2.28	0.228	0.0228
Technetium-99	1.53	0.153	0.0153
Tin-126	0.062	0.0062	0.00062
Uranium-233/234[c]	133	13.3	1.33
Uranium-234	133	13.3	1.33
Uranium-235	15.4	1.54	0.154
Uranium-238	52	5.2	0.52

Notes:

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 3. 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	15.4	2.161E+06	1,000,000	1,000	7,126
U-238	52	3.359E+05	1,000,000	1,000	154,808

a. See Table 2.

b. See Table 1.

c. Calculated using Equation 1 (see Section 3).

Table 4. 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 1.

c. Formula = Background Activity (pCi/g) / Specific Activity (pCi/g) x 1E+06 (µg/g) x 1E+03 (g/kg)

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Appendix A

RESRAD Exposure Assumptions, Input Values and Output Summaries

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

			Interim Action Record of Decision Exposure Scenario		
RESRAD Category	**Parameter**	**Units**	**User Input**	**Rationale**	**Reference**
Risk Coefficients	Risk Factors	NA	DCFPAK3.02 Morbidity	Updated risk coefficients based on ICRP 107	ICRP 2008
Graphic Parameters	Number of Points	NA	32	RESRAD Default	
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

Table A-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
	Humidity in Air	g/cm^3	8	RESRAD default	
	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	
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

Table A-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
	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
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 2014)
	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
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

Table A-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
	Other Seafood Consumption	kg/yr	0.9	RESRAD default	
	Soil Ingestion	g/yr	36.5	Based on 100 mg/day x 365 days/yr	OSWER Directive 9285.6 03
	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	
	Meat Contamination Fraction	Unitless	-1	RESRAD default	
	Milk Contamination Fraction	Unitless	-1	RESRAD default	
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	

Table A-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
	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

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Table A-2. Radionuclide-Specific Distribution Coefficients (K_d) by RESRAD Model Layer.

Radionuclide	K_d (cm^3/g)	K_d Reference	K_d (cm3/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

Table A-2. Radionuclide-Specific Distribution Coefficients (K_d) by RESRAD Model Layer.

Radionuclide	K_d (cm^3/g)	K_d Reference	K_d (cm3/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
Neodymium-144	158	RESRAD default	158	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
Samarium-148	-1	RESRAD default	-1	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 Kd value for Curium-243 is used

b. The referenced Kd value for Nicklel-63 is used

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

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

e. RESRAD displays a default value of -1 on the Kd input screen for gadolinium-152 and samarium-148 indicating the Kd value is derived internally by the code.

RESRAD - RESidual RADioactivity code (ANL 2009)

ANL, 2014, RESRAD for Windows, Version 7.0, 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.

Table A-3

Intermediate Calculations - Identification of Peak \Year based on Peak Cancer Risk

Radionuclide	Year of Maximum Risk
Ag (silver)-108m	0
Americium-241	0
Carbon-14	0
Cesium-137	0
Cobalt-60	0
Curium-243	0
Curium-244	0
Curium-245	588
Europium-152	0
Europium-154	0
Europium-155	0
Iodine-129	203
Neptunium-237	0
Nickel-59	0
Nickel-63	0
Niobium-94	0
Plutonium-238	0
Plutonium-239/240	0
Plutonium-241	54
Strontium-90	0
Technetium-99	19
Tin-126	19
Tritium (H-3)	0
Uranium-234	1000
Uranium-235	0
Uranium-238	0

Year	Cm-245	I-129	Pu-241	Sn-126	Tc-99
	Risk - Selected Pathways Summed				
1	3.2081E-06	1.1185E-05	1.4204E-08	1.1263E-03	5.4236E-05
1.30	3.2082E-06	1.1152E-05	1.4312E-08	1.1434E-03	5.4630E-05
1.70	3.2083E-06	1.1109E-05	1.4450E-08	1.1648E-03	5.5119E-05
2.22	3.2085E-06	1.1054E-05	1.4626E-08	1.1918E-03	5.5739E-05
2.89	3.2087E-06	1.0982E-05	1.4849E-08	1.2251E-03	5.6501E-05
3	3.2087E-06	1.0970E-05	1.4883E-08	1.2302E-03	5.6619E-05
3.8	3.2089E-06	1.0888E-05	1.5127E-08	1.2656E-03	5.7428E-05
4.9	3.2093E-06	1.0768E-05	1.5471E-08	1.3138E-03	5.8535E-05
6.4	3.2097E-06	1.0613E-05	1.5889E-08	1.3697E-03	5.9816E-05
8.4	3.2104E-06	1.0414E-05	1.6384E-08	1.4322E-03	6.1249E-05
10	3.2110E-06	1.0251E-05	1.6757E-08	1.4763E-03	6.2261E-05
10.9	3.2113E-06	1.0160E-05	1.6955E-08	1.4988E-03	6.2776E-05
14.3	3.2127E-06	9.8376E-06	1.7585E-08	1.5656E-03	6.4306E-05
18.6	3.2145E-06	9.4329E-06	1.8243E-08	**1.6245E-03**	**6.5605E-05**
24.2	3.2171E-06	8.9300E-06	1.8876E-08	1.1313E-03	4.5460E-05
30	3.2199E-06	8.4458E-06	1.9318E-08	6.7472E-04	2.7113E-05
31.6	3.2207E-06	8.3141E-06	1.9412E-08	5.8322E-04	2.3436E-05
41.2	3.2257E-06	7.5741E-06	1.9768E-08	2.4576E-04	9.8759E-06
53.8	3.2322E-06	6.7070E-06	**1.9870E-08**	7.9610E-05	3.1992E-06
70.2	3.2406E-06	5.7235E-06	1.9670E-08	1.8299E-05	7.3542E-07
91.5	3.2513E-06	4.6541E-06	1.9164E-08	2.6890E-06	1.0807E-07
100	3.2553E-06	4.2873E-06	1.8931E-08	1.2561E-06	5.0486E-08
119.4	3.2642E-06	3.5536E-06	1.8374E-08	2.2042E-07	8.8597E-09
155.7	3.2794E-06	2.5856E-04	1.7324E-08	8.4395E-09	3.3926E-10
203.1	3.2964E-06	**9.1044E-04**	1.6024E-08	1.1971E-10	4.8129E-12
264.9	3.3141E-06	4.9772E-04	1.4470E-08	4.6496E-13	1.8697E-14
300	3.3221E-06	3.5317E-04	1.3656E-08	1.9869E-14	7.9909E-16
345.5	3.3305E-06	2.2635E-04	1.2668E-08	3.3339E-16	1.3410E-17
450.7	3.3419E-06	8.0953E-05	1.0651E-08	2.6382E-20	1.0616E-21
587.8	**3.3428E-06**	2.1155E-05	8.4954E-09	1.1777E-25	4.6994E-27
766.7	3.3253E-06	3.6689E-06	6.3274E-09	0.0000E+00	0.0000E+00
1000	3.2798E-06	3.7225E-07	4.3109E-09	0.0000E+00	0.0000E+00

Table A-4

Intermediate Calculations - Results of Cancer Risks at Year of Peak Risk, and Preliminary PRGs for Individual Radionuclides

Nuclide	Year 0	Year 19	Year 54	Year 203	Year 588	Year 1000	Maximum risk per pCi/g	Year at Peak Risk	PRG at 10^{-4} Target Risk
Ag-108m	7.71E-05	7.46E-05	7.01E-05	5.38E-05	2.71E-05	1.30E-05	7.71E-05	0	1.30
Am-241	6.53E-07	6.33E-07	5.97E-07	4.67E-07	2.47E-07	1.26E-07	6.53E-07	0	153.21
C-14	1.24E-06	1.40E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-06	0	80.84
Cm-243	3.33E-06	2.12E-06	9.18E-07	2.68E-08	6.18E-10	5.85E-10	3.33E-06	0	30.03
Cm-244	1.82E-07	8.85E-08	2.41E-08	1.40E-09	1.27E-09	1.22E-09	1.82E-07	0	549.45
Cm-245	3.21E-06	3.22E-06	3.23E-06	3.30E-06	3.34E-06	3.28E-06	3.34E-06	588	29.91
Co-60	3.25E-05	2.66E-06	2.65E-08	7.94E-17	0.00E+00	0.00E+00	3.25E-05	0	3.080
Cs-137	2.26E-05	1.46E-05	6.47E-06	2.04E-07	2.70E-11	1.91E-15	2.26E-05	0	4.421
Eu-152	2.80E-05	1.06E-05	1.76E-06	8.46E-10	2.28E-18	7.96E-21	2.80E-05	0	3.578
Eu-154	2.24E-05	4.83E-06	2.86E-07	1.71E-12	5.46E-26	0.00E+00	2.24E-05	0	4.470
Eu-155	2.98E-07	1.87E-08	1.15E-10	4.31E-20	0.00E+00	0.00E+00	2.98E-07	0	335.46
H-3	1.60E-07	7.29E-08	2.97E-23	0.00E+00	0.00E+00	0.00E+00	1.60E-07	0	624.22
I-129	1.13E-05	9.40E-06	6.69E-06	9.11E-04	2.11E-05	3.72E-07	9.11E-04	203	0.1097
Nb-94	7.31E-05	7.30E-05	7.27E-05	7.18E-05	6.94E-05	6.69E-05	7.31E-05	0	1.368
Ni-59	7.47E-08	7.42E-08	7.33E-08	6.94E-08	6.02E-08	5.18E-08	7.47E-08	0	1337.97
Ni-63	1.68E-07	1.47E-07	1.14E-07	3.84E-08	2.32E-09	1.15E-10	1.68E-07	0	594.18
Np-237	1.20E-05	1.18E-05	1.15E-05	1.03E-05	7.84E-06	5.84E-06	1.20E-05	0	8.361
Pu-238	4.24E-07	3.65E-07	2.76E-07	8.45E-08	4.15E-09	4.00E-10	4.24E-07	0	235.68
Pu-239	4.94E-07	4.93E-07	4.91E-07	4.85E-07	4.70E-07	4.54E-07	4.94E-07	0	202.59
Pu-241	1.38E-08	1.83E-08	1.99E-08	1.60E-08	8.49E-09	4.31E-09	1.99E-08	54	5032.71
Sn-126	1.07E-03	1.62E-03	7.82E-05	1.21E-10	1.16E-25	0.00E+00	1.62E-03	19	0.0618
Sr-90	4.40E-05	2.76E-05	1.17E-05	3.04E-07	2.42E-11	9.98E-16	4.40E-05	0	2.275
Tc-99	5.29E-05	6.53E-05	3.14E-06	4.85E-12	4.62E-27	0.00E+00	6.53E-05	19	1.531
U-234	5.74E-07	5.72E-07	5.69E-07	5.65E-07	6.18E-07	7.53E-07	7.53E-07	1000	132.87
U-235	6.50E-06	6.48E-06	6.45E-06	6.32E-06	6.00E-06	5.66E-06	6.50E-06	0	15.39
U-238	1.92E-06	1.91E-06	1.90E-06	1.84E-06	1.69E-06	1.55E-06	1.92E-06	0	52.11

Table A-5
Intermediate Calculation - Results of Cancer Risk at Year of Peak Risk based on Preliminary PRGs

Nuclide	Year 0	Year 19	Year 54	Year 203	Year 588	Year 1000	Maximum risk	Year at Peak Risk
Ag-108m	1.00E-04	9.69E-05	9.11E-05	6.99E-05	3.52E-05	1.69E-05	1.00E-04	0
Am-241	9.99E-05	9.68E-05	9.13E-05	7.14E-05	3.78E-05	1.92E-05	9.99E-05	0
C-14	1.00E-04	1.13E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-04	0
Cm-243	9.99E-05	6.35E-05	2.75E-05	8.04E-07	1.85E-08	1.75E-08	9.99E-05	0
Cm-244	9.99E-05	4.86E-05	1.33E-05	7.71E-07	6.99E-07	6.68E-07	9.99E-05	0
Cm-245	9.62E-05	9.64E-05	9.70E-05	9.89E-05	1.00E-04	9.84E-05	1.00E-04	588
Co-60	1.01E-04	8.24E-06	8.20E-08	2.46E-16	0.00E+00	0.00E+00	1.01E-04	0
Cs-137	9.95E-05	6.41E-05	2.85E-05	8.98E-07	1.19E-10	8.42E-15	9.95E-05	0
Eu-152	1.01E-04	3.80E-05	6.32E-06	3.05E-09	8.22E-18	2.86E-20	1.01E-04	0
Eu-154	1.01E-04	2.17E-05	1.29E-06	7.70E-12	2.46E-25	0.00E+00	1.01E-04	0
Eu-155	9.99E-05	6.27E-06	3.84E-08	1.44E-17	0.00E+00	0.00E+00	9.99E-05	0
H-3	1.00E-04	4.55E-05	1.86E-20	0.00E+00	0.00E+00	0.00E+00	1.00E-04	0
I-129	1.24E-06	1.03E-06	7.36E-07	1.00E-04	2.32E-06	4.10E-08	1.00E-04	203
Nb-94	1.00E-04	1.00E-04	9.97E-05	9.84E-05	9.51E-05	9.17E-05	1.00E-04	0
Ni-59	1.005E-04	1.01E-04	1.00E-04	1.00E-04	9.95E-05	9.88E-05	1.01E-04	0
Ni-63	1.00E-04	8.71E-05	6.75E-05	2.28E-05	1.38E-06	6.86E-08	1.00E-04	0
Np-237	1.01E-04	9.91E-05	9.67E-05	8.69E-05	6.59E-05	4.90E-05	1.01E-04	0
Pu-238	1.00E-04	8.61E-05	6.52E-05	2.00E-05	9.79E-07	9.43E-08	1.00E-04	0
Pu-239	1.00E-04	1.00E-04	9.98E-05	9.85E-05	9.54E-05	9.22E-05	1.00E-04	0
Pu-241	6.96E-05	9.21E-05	1.00E-04	8.07E-05	4.27E-05	2.17E-05	1.00E-04	54
Sn-126	6.62E-05	1.0040E-04	4.85E-06	7.48E-12	7.14E-27	0.00E+00	1.00E-04	19
Sr-90	1.00E-04	6.29E-05	2.67E-05	6.92E-07	5.53E-11	2.28E-15	1.00E-04	0
Tc-99	8.09E-05	9.99E-05	4.81E-06	7.43E-12	7.09E-27	0.00E+00	9.99E-05	19
U-234	7.64E-05	7.61E-05	7.57E-05	7.51E-05	8.22E-05	1.00E-04	1.00E-04	1000
U-235	1.00E-04	9.98E-05	9.93E-05	9.73E-05	9.24E-05	8.72E-05	1.00E-04	0
U-238	9.98E-05	9.94E-05	9.86E-05	9.55E-05	8.79E-05	8.04E-05	9.98E-05	0

Table A-6
Intermediate Calculation - Calculation of Relative Percent Difference (RPD)

Nuclide	Target Risk = 1 x 10^{-4}	1st precision run	%RPD	Value entered into RESRAD
Ag-108m	1.00E-04	1.00E-04	-0.30	1.3
Am-241	1.00E-04	9.99E-05	0.14	153
C-14	1.00E-04	1.00E-04	-0.20	81
Cm-243	1.00E-04	9.99E-05	0.10	30
Cm-244	1.00E-04	9.99E-05	0.07	549
Cm-245	1.00E-04	1.00E-04	-0.30	30
Co-60	1.00E-04	1.01E-04	-0.70	3.1
Cs-137	1.00E-04	9.95E-05	0.46	4.4
Eu-152	1.00E-04	1.01E-04	-0.60	3.6
Eu-154	1.00E-04	1.01E-04	-0.70	4.5
Eu-155	1.00E-04	9.99E-05	0.14	335
H-3	1.00E-04	1.00E-04	0.01	624
I-129	1.00E-04	1.00E-04	-0.20	0.11
Nb-94	1.00E-04	1.00E-04	-0.10	1.37
Ni-59	1.00E-04	1.01E-04	-0.50	1338
Ni-63	1.00E-04	1.00E-04	0.03	594
Np-237	1.00E-04	1.01E-04	-0.50	8.4
Pu-238	1.00E-04	1.00E-04	-0.10	236
Pu-239	1.00E-04	1.00E-04	-0.20	203
Pu-241	1.00E-04	1.00E-04	0.00	5033
Sn-126	1.00E-04	1.00E-04	-0.40	0.062
Sr-90	1.00E-04	1.00E-04	-0.20	2.28
Tc-99	1.00E-04	9.99E-05	0.06	1.53
U-234	1.00E-04	1.00E-04	-0.10	133
U-235	1.00E-04	1.00E-04	-0.10	15.40
U-238	1.00E-04	9.98E-05	0.23	52

Table A-7
Sensitivity Analysis - Area of Contaminated Zone and Thickness of Contaminated Zone

Radionuclides	Parameter	Maximum Risk (Risk/Unit Concentration)			SI[1]	Comments[2]	PRGs (pCi/g)		
		Upper Value	Base Value	Lower Value					
	Area of contaminated zone	50000 m^2	10000 m^2	2000 m^2			50,000	10,000	2,000
Am-241		6.6E-07	6.5E-07	6.3E-07	0.04	Not sensitive as SI <0.1	Not Calculated		
Cs-137		2.5E-05	2.2E-05	2.0E-05	0.21	Sensitive	3.9	4.4	5.0
Pu-239/240		5.1E-07	4.9E-07	4.8E-07	0.06	Not sensitive as SI <0.1	Not Calculated		
	Thickness of Contaminated Zone	**9.2 m**	**4.6 m**	**2.3 m**					
Am-241		6.5E-07	6.5E-07	6.5E-07	0.001	Independent	Not Calculated		
Cs-137		2.2E-05	2.2E-05	2.2E-05	0.005	Independent			
Pu-239/240		4.9E-07	4.9E-07	4.9E-07	0.001	Independent			

Notes:

1 The sensitivity index (SI) is SI = 1 – (f(p)min / f(p)max): where: f(p) is the maximum risk associated with the upper and lower parameter values.

2 A positive value of the SI indicates that the risk is directly proportional to the parameter of interest, whereas a negative value indicates the risk is inversely proportional to the parameter of interest. A value less than 0.01 indicates that the risk is independent of the parameter. The further the value of SI is from zero (0), the more sensitive the parameter is.

Appendix B

Software Installation and Checkout Forms

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: RESRAD Software Version No.: 7.0

EXECUTABLE INFORMATION:

2. Executable Name (include path):

   [redacted]\RESWIN6.EXE

3. Executable Size (bytes): 1.876 KB

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

   Compiled by Vendor (ANL)

5. Operating System (include version number):

   Compiled by Vendor (ANL)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

   INTERA-0740

7. Operating System (include version number):

   Windows 8.1

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

   [redacted]RESRAD\7.0

10. Procedure(s):

    per CHPRC-00210 Rev 0, RESRAD Software Test Plan

11. Libraries:

    N/A

12. Input Files:

    Created in RESRAD per installation test instruction

13. Output Files:

    SUMMARY.REP

14. Test Cases:

    RESRAD-ITC-1

15. Test Case Results:

    PASS

16. Test Performed By: M Rahman

17. Test Results: ◉ Satisfactory, Accepted for Use ○ Unsatisfactory

18. Disposition (include HISI update):

    Passed; Installation added to HISI Entry

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: RESRAD Software Version No.: 7.0

Prepared By:

19. William E. Nichols (Digitally signed by William E. Nichols DN: cn=William E. Nichols, o=CHPRC, ou=Risk & Modeling Integration, email=william_e_nichols@rl.gov, c=US Date: 2015.11.16 11:38:56 -08'00') | WE Nichols

Software Owner (Signature) | Print | Date

20. Test Personnel:

Sign	Print	Date
M. Rahman	M RAHMAN	11-16-15

Approved By:

21. N/R per SMP

Software SME (Signature) | Print | Date

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RESRAD, Version 7.0 T« Limit = 180 days 11/16/2015 09:55 Page 10

Summary : RESRAD Installation Test Case 1

File : C:\RESRAD_FAMILY\RESRAD\7.0\USERFILES\RESRAD-ITC-1.RAD

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area:	10000.00 square meters	U-238	1.000E+02
Thickness:	2.00 meters		
Cover Depth:	0.00 meters		

Total Dose TDOSE(t), mrem/yr

Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
TDOSE(t):	1.547E+01	1.542E+01	1.532E+01	1.497E+01	1.400E+01	1.110E+01	5.718E+00	9.423E+01
M(t):	6.188E-01	6.168E-01	6.127E-01	5.986E-01	5.602E-01	4.441E-01	2.287E-01	3.769E+00

Maximum TDOSE(t): 9.423E+01 mrem/yr at t = 1.000E+03 years

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: RESRAD Software Version No.: 7.0

EXECUTABLE INFORMATION:

2. Executable Name (include path):

[redacted]\RESWIN6.EXE

3. Executable Size (bytes): 1.876 MB

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Compiled by Vendor (ANL)

5. Operating System (include version number):

Compiled by Vendor (ANL)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

Intera-00295

7. Operating System (include version number):

Windows 7 Professional Service Pack 1

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]7.0\QAfiles

10. Procedure(s):

per CHPRC-00210 Rev 2, RESRAD Software Test Plan

11. Libraries:

N/A

12. Input Files:

Created in RESRAD per installation test instruction

13. Output Files:

SUMMARY.REP

14. Test Cases:

RESRAD-ITC-1

15. Test Case Results:

Test results matched expected results; pass.

16. Test Performed By: RD Evans

17. Test Results: ◉ Satisfactory, Accepted for Use ○ Unsatisfactory

18. Disposition (include HISI update):

Installation accepted; computer and user added to HISI entry for RESRAD software.

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: RESRAD Software Version No.: 7.0

Prepared By:

19.	WE Nichols	30 APRIL 2015
Software Owner (Signature)	Print	Date

20. Test Personnel:

	RD Evans	4/30/2015
Sign	Print	Date
Sign	Print	Date
Sign	Print	Date

Approved By:

21.	N/R per SMP	
Software SME (Signature)	Print	Date

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