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Risk-Based Radionuclide Derived Concentration Guideline Levels for an Industrial Worker Exposed to Concrete-Slab End States at the Savannah River Site

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Abstract – Dose and risk assessments are an integral part of decommissioning activities. Most human health risk assessments are performed for a reasonable maximum exposure to an individual with assumed intake and exposure parameters that depend on the end state of the decommissioning activities and the likely future use of the site. Regardless of how the potentially exposed individual is defined, the subsequent calculated human health risk is not a measurable quantity. To demonstrate compliance with risk-based acceptance or cleanliness criteria, facility-specific risk assessments usually are performed after final-verification sampling and analysis. Alternatively, conservative, a priori, guideline concentrations for residual contaminants can be calculated and rapidly compared to the subsequently measured contaminant concentrations to demonstrate compliance.

In response to the request for accelerated cleanup at U.S. Department of Energy facilities, the Savannah River Site (SRS) is decommissioning its excess facilities through removal of the facility structures leaving only the concrete-slab foundations in place. Site-specific, risk-based derived concentration guideline levels (DCGLs) for radionuclides have been determined for a future industrial worker potentially exposed to residual contamination on these concrete slabs. When appropriate, these conservative DCGLs will be used at SRS in lieu of facility-specific risk assessments to further accelerate the decommissioning process.

This paper discusses and describes the methods and scenario-specific parameters used to estimate the risk-based DCGLs for the SRS decommissioning end state.

I. INTRODUCTION

The U.S. Department of Energy's Savannah River Site (SRS) is decommissioning many of its excess facilities through removal of the facility structures leaving only the concrete-slab foundations in place. Site-specific, risk-based derived concentration guideline levels (DCGLs) for radionuclides have been determined for a future industrial worker potentially exposed to residual contamination on these concrete slabs. When appropriate, these conservative DCGLs will be used at SRS, in lieu of facility-specific risk assessments, to demonstrate that risk-based acceptance criteria have been met.

For the industrial worker scenario, DCGLs were developed for a risk criterion of 1.0E-06.

Estimation of these risk-based DCGLs was completed in accordance with the US Department of Energy's RESRAD methodology (Version 6.22). [1]

II. DERIVED CONCENTRATION GUIDELINE LEVELS

DCGLs are the uniform residual contaminant concentrations within an exposure area that correspond to an established risk-based release criterion. DCGLs are presented in terms of mass (pCi/g for radionuclides) concentration. If it can be verified that the average measured concentration in a given exposure area is equal to or below the DCGL, then that area, by definition, meets the cleanliness criteria.

Individual concentration guideline levels are derived by dividing the applicable release criteria risk by the calculated risk per unit of contamination. The risk per unit of contamination is determined using exposure pathway modeling as described in subsequent sections.

For example, if the applicable release criterion is a lifetime risk of 1.0E-06 and the calculated risk per unit contamination of a particular radionuclide is 1.0E-07, then the DCGL for that radionuclide is:

$$DCGL = \frac{1.0E-06\ Risk}{1.0E-07\ Risk \big/ 1\ {}^{pCi}\!/_{g}} = 10\ {}^{pCi}\!/_{g} \qquad (1)$$

For slabs with more than one contaminant present, a sum-of-the fractions, or weighted sum of the ratios of the measured residual contaminants to their respective DCGLs must be performed. If the weighted sum DCGL is less than or equal to 1.0, the risk-based acceptance criteria have been met. If the weighted sum is greater than 1.0, the risk-based acceptance criteria have not been met.

III. ENVIRONMENTAL EXPOSURE SCENARIO

Based on current and projected land use plans for SRS, the reasonable future use of most of the areas where facility decommissioning will take place is as an industrial area. Therefore, the reasonable maximum exposure scenario is likely to be an industrial worker potentially exposed to contaminated concrete slabs following facility decommissioning via the exposure pathways illustrated in the conceptual site model (CSM) shown in Figure 1.

As can be seen in Figure 1, the potential exposure pathways include dust inhalation, incidental concrete ingestion, and external gamma.

The industrial worker is assumed to be a typical adult employee who works a standard work year outside on the contaminated area either performing light industrial work or guarding the area. This person will not consume onsite groundwater or work in an office built on the site.

IV. MODELS AND METHODS

The RESRAD (RESidual RADioactivity) family of codes was developed by DOE and the Argonne National Laboratory to evaluate doses and related risks to human health. The RESRAD models allow application of risk strategies based on industry standards consistent with strategies applied throughout the U.S Departement of Energy complex for facility decommissioning. The advantage of using the RESRAD methods is that it allows adjustment of the relevant parameters and exposure factors to evaluate exposure scenarios for a concrete end state.

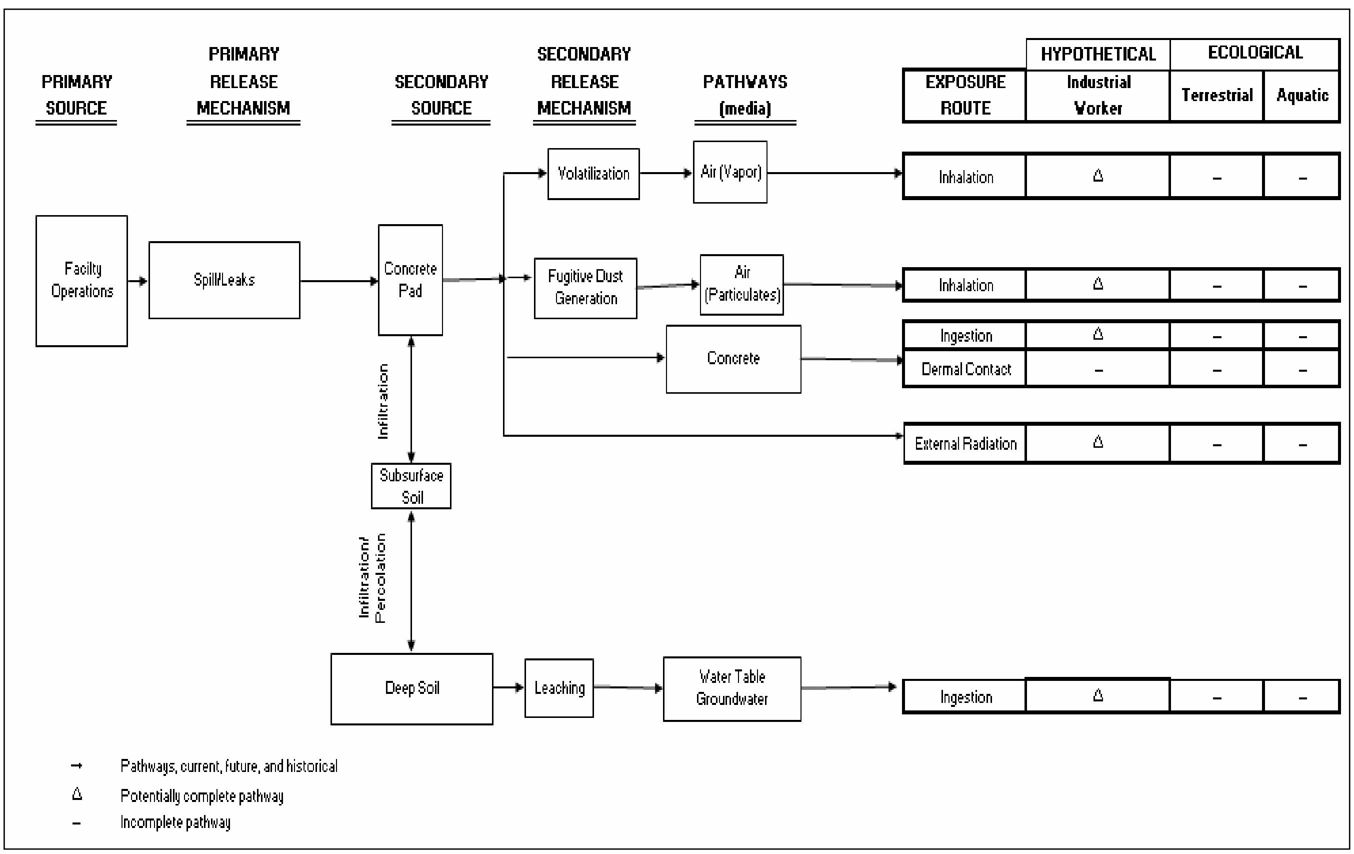

Fig. 1. Conceptual Site Model for Concrete Slabs

In addition, the RESRAD models account for the ingrowth of decay products over time which, for a 25-y industrial worker exposure period, can be significant.

The RESRAD library of radionuclides, with half-lives greater than six months, was used in this assessment.

The RESRAD code is a pathway analysis model that calculates radiation dose and cancer risks and derives cleanup criteria for radioactively contaminated materials (defaults assume soil) taking into account the weathering and migration of contaminants that will take place outdoors. For the concrete slab end state, the assumed human health exposure pathway will be an industrial worker who works outdoors on the contaminated area of the slab. Both the RESRAD and RESRAD-BUILD models can be adapted for use in this scenario. However, the RESRAD-BUILD code requires that building walls be in place and therefore biases the inhalation and incidental ingestion pathways by ignoring the weathering and migration of contaminants that will take place outdoors. Therefore, the RESRAD model should be used for calculating DCGLs for concrete slab end states.

Various input parameters to the RESRAD model need to be adjusted to reflect the contaminated zone media (i.e., concrete instead of soil defaults). All applicable and appropriate exposure and intake parameters are discussed in Section V. The RESRAD model requires volume contamination as the radiological source terms input.

The RESRAD-BUILD model should be used for in situ disposal risk assessments, where the end state will be a building left in place with walls. This model is also appropriate for contaminated areas involving point or line sources that have no inhalation or ingestion pathways.

V. EXPOSURE PARAMETERS

The following site-specific and default exposure parameters, which are applicable to a concrete slab end state and to the onsite industrial worker scenario, were used as input values for the RESRAD calculations. All of the parameters used are summarized in Table 1.

V A. Area of Contaminated Zone

An area of 100 m^2 (about 1,000 ft^2) was used for the area of the contaminated zone. This area, which is assumed to be circular, is sited in the U.S. Department of Energy Order 5400.5 as the appropriate area to determine average residual concentrations of radioactive material in soil. [2] It also is sited in [1] as the appropriate area for daily activity. Since most radiological contamination areas within site facilities were kept as small as possible, it was decided that 100 m^2 was an appropriate exposure area for the future industrial worker scenario.

V B. Thickness of Contaminated Zone

A radiological contaminated zone thickness of 0.05 m (2 in) was used for the volume contamination calculations. This assumed thickness was based on actual field measurements of common radionuclides at SRS. For tritium, which diffuses rapidly in concrete, a typical full-slab thickness of 0.15 m (6 inch) was used. If the contamination is found to be substantially greater than 0.05 m thick, a site-specific assessment should be performed.

V C. Time Since Material Placement

The time since material placement was conservatively assumed to be 0 years, indicating that the calculations are performed for the initial year following the radiological survey. [3]

V D. Cover Depth

The cover depth used was 0 m, indicating no shielding by uncontaminated soil.

V E. Density of Contaminated Zone

The contaminated zone density was assumed to be 2.4 g/cm^3, which is the default concrete density used in the RESRAD-Build model. [4]

V F. Contaminated Zone Erosion Rate

For the concrete slab end state, the contaminated zone erosion rate used was 8.8E-08 m/y (2.4E-08 cm/d). This is the default concrete erosion rate used in the RESRAD-Build codes. [4]

V G. Contaminated Zone Total Porosity

The contaminated zone total porosity used was 0.1. This was determined using the following formula for calculating total porosity:

$$TotalPorosity = 1 - \rho / 2.65 \qquad (2)$$

V H. Contaminated Zone Field Capacity

The contaminated zone field capacity used was 0.01. The field capacity is used as the lower bound of the volumetric water content in the contaminated layer. In the RESRAD code, the default volumetric water content value for building foundation material (i.e. concrete) is 0.01. [3]

V I. Contaminated Zone Hydraulic Conductivity

To conservatively account for fixed contamination in a concrete slab end state, the contaminated zone hydraulic conductively was assumed to be 0.001 m/y. This is the lowest parameter value referenced in [5].

V J. Contaminated Zone b Parameter

To account for the concrete slab end state, the contaminated zone b parameter was conservatively set at 11.4. This is the highest parameter value referenced in [1].

V K. Average Annual Wind Speed

The SRS site-specific value of 3.83 m/s, measured during the years 1997 to 2001, was used for the average annual wind speed parameter.

V L. Evapotranspiration Coefficient

The RESRAD default value of 0.5 was used for the evapotranspiration coefficient. [1]

V M. Precipitation Rate

The SRS site-specific value of 1.3 m/yr was used for the precipitation rate parameter.

V N. Irrigation Rate

The irrigation rate parameter used was 0.0 m/yr, indicating no loss to irrigation.

V O. Runoff Coefficient

The runoff coefficient was conservatively set at 0.8. This is the largest value listed in [1] and it limits the amount of water available for leaching.

V P. Inhalation Rate

The annualized inhalation rate used for the industrial worker was 11,400 m^3/y. This rate is the RESRAD default value for an industrial worker scenario and is based on an hourly average rate of 1.3 m^3/h. [1]

V Q. Mass Loading for Inhalation

To account for the concrete slab end state (where much less material will be available for inhalation as opposed to friable soil), the RESRAD probabilistic base value of 0.00003 g/m^3 was used for mass loading. [5]

V R. Exposure Duration

The exposure duration used for the industrial worker was 25 y (exposure scenario protocol).

V S. Fraction of Time Spent Indoors

The fraction of time spent indoors by the onsite worker was conservatively set at 0, indicating that the onsite worker spends all of the work day outside on the concrete slab, with no shielding by buildings.

V T. Fraction of Time Spent Outdoors

The fraction of time spent outdoors by the onsite worker was set at 0.228, indicating that for a full calendar year the industrial worker spends all of the 8-h workdays outside on the concrete slab, with no shielding. This was determined as follows:

$$\frac{\left(250\,{}^{d}\!/\!_{y}\right)\bullet\left(8\,{}^{h}\!/\!_{d}\right)}{8760\,{}^{h}\!/\!_{y}} = 0.228 \qquad (3)$$

The RESRAD code assumes that the remaining fraction of time (0.772) is spent away from the contaminated zone.

V U. Soil Ingestion Rate

The annualized soil ingestion rate used for the onsite worker was 36.5 g/year. This is the RESRAD industrial worker default parameter. [1]

V V. Sorption Factors

Because the contaminated area is concrete, several of the default sorption (Kd) factors were changed in the RESRAD code. The elemental sorption factors for cement used in the calculations were taken [6]. For those elements not listed in [6], the RESRAD code default Kd factors were used.

VI. RISK FACTORS

The radionuclide risk factors (slope factors) for the industrial worker were obtained from the following U.S. Environmental Protection Agency Radionuclide Preliminary Remediation Guides (PRG) website: http://epa-prgs.ornl.gov/radionuclides/.
The “outdoor worker” (adult) risk factors were used. These risk factors are based on Federal Guidance Report #13.[6]

TABLE I. Input Parameters for Calculating DCGLs

Parameter	Value
Area of Contaminated Zone (m^2)	100
Thickness of Volume	0.05
Time Since Material Placement (y)	0
Cover Depth (m)	0
Density of Contaminated Area (g/cm^3)	2.4
Contaminated Zone Erosion Rate (m/y)	8.8E-08
Contaminated Zone Total Porosity	0.1
Contaminated Zone Field Capacity	0.01
Hydraulic Conductivity (m/y)	0.001
Contaminated Zone b Parameter	11.4
Annual Average Wind Speed (m/s)	3.83
Evapotranspiration Coefficient	0.5
Precipitation Rate (m/y)	1.3
Irrigation Rate	0
Runoff Coefficient	0.8
Annualized Inhalation Rate (m^3/y)	11,400
Mass Loading for Inhalation (g/m^3)	0.00003
Exposure Duration (y)	25
Indoor Time Fraction	0
Outdoor Time Fraction (Ind. Worker)	0.228
Annualized Soil Ingestion Rate (g/y)	36.5

VII. RESULTS

The SRS-specific industrial worker DCGLs for radionuclides are shown in Table II. These DCGLs are based on a 25-y exposure risk criterion of 1.0E-06.

Indication is made for those radionuclides that have associated short-lived decay progeny (half-lives less than 6-months) included in the DCGL value. Also, indication is made for those radionuclides that have ingrowth of associated long-lived decay progeny (half-lives greater than 6 months) included in the DCGL value.

The contamination thickness was assumed to be 0.05 m (2in.) for all radionuclides except tritium. Because of tritium is highly mobile in concrete, the assumed thickness was 0.15 m (6in.), which is a common thickness for many building slab foundations at SRS.

VIII. CONCLUSIONS

In response to the request for accelerated cleanup at U.S. Department of Energy facilities SRS is decommissioning its excess facilities through removal of the facility structures leaving only the concrete-slab foundations in place. Site-specific, risk-based DCGLs for radionuclides have been determined for a future industrial worker potentially exposed to residual contamination on these concrete slabs.

The DCGLs were determined using the Federal Guidance Report #13 adult cancer morbidity risk coefficients.[6] The RESRAD library of radionuclides, with half-lives greater than 6 months, was used.

When appropriate, these conservative DCGLs will be used at SRS in lieu of facility-specific risk assessments to further accelerate the decommissioning process.

ACKNOWLEDGMENTS

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REFERENCES

1. C. Yu, A.J. Zielen, J.-J. Cheng, D.J. LePoire, E. Gnanapragasam, S. Kamboj, Arnish, A.Wallo III, W.A. Williams, and H. Peterson. *Users Manual for RESRAD Version 6*, Argonne National Laboratory Report: ANL/EAD/4, Argonne, IL. July, 2001.
2. *Radiation Protection of the Public and Environment,* DOE Order 5400.5, US Department of Energy, Washington, DC, 1990.
3. C. Yu, C. Loureiro, J.-J. Cheng, L.J. Jones, Y.Y. Wang, Y.P. Chia, and E. Faillace *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil*, Argonne National Laboratory Report: ANL/EAD/4, Argonne, IL, April, 1993.
4. C. Yu, D.J. LePoire, J.-J. Cheng, E. Gnanapragasam, S. Kamboj, J. Arnish, B.M. Biwer, A.J. Zielen, W.A. Williams, A. Wallo III, and H.T. Peterson, Jr. *Users Manual for RESRAD-BUILD Version 3*, Argonne National Laboratory Report: ANL/EAD/03-1, Argonne, IL. June, 2003.
5. C. Yu, D.J. LePoire, J.-J. Cheng, L.J. Jones, E. Gnanapragasam, S. Kamboj, S.Y. Chen, J. Arnish, B.M. Biwer, and A.J. Zielen, *Development of Probabilistic RESRAD 6.0 and RESRAD-Build 3.0 Computer Codes*, Argonne National Laboratory Report: ANL/EAD/TM-98 (NUREG/CR-6697), Argonne, IL. November 2000.
6. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides,* Federal Guidance Report #13, EPA 402-R-99-001, US Environmental Protection Agency, Washington, DC, September, 1999.

TABLE II. Industrial Worker DCGLs for a 1.0E-06 Risk

Radionuclide[a,b,c]	Industrial Worker DCGLs
	(pCi/g)
Ac-227 +D	5.13E-01
Ag-108m +D	2.83E+01
Ag-110m +D	1.72E+01
Al-26	1.76E+01
Am-241 *	7.58E+00
Am-243 +D *	4.29E-01
Au-195	9.70E+02
Ba-133	5.42E-01
Bi-207	3.04E+01
C-14	1.90E+06
Ca-41	1.91E+05
Cd-109	1.53E+04
Ce-144 +D	3.21E+01
Cl-36	3.18E+02
Cm-243 *	9.32E-01
Cm-244 *	3.31E+02
Cm-245 *	1.11E+00
Cm-246 *	1.86E+02
Cm-247 *	2.42E-01
Cm-248 *	2.23E+01
Co-57	1.75E+01
Co-60	1.12E-01
Cs-134	5.00E-01
Cs-135	8.90E+03
Cs-137 +D	3.18E-01
Eu-152 *	1.30E-01
Eu-154	1.53E-01
Eu-155	6.83E+00
Fe-55	5.94E+05
Gd-152	6.41E+02
Gd-153	3.68E+01
Ge-68 +D	4.95E+01
H-3 **	1.20E+06
I-129	4.17E+02
K-40	2.53E+00
Mn-54	1.98E+00
Na-22	3.41E-01
Nb-93m	8.42E+03
Nb-94	5.18E-02
Ni-59	3.73E+05
Ni-63	1.65E+05
Np-237 +D *	4.03E-01
Pa-231 *	6.75E-01
Pb-210 +D	2.08E+01
Pm-147 *	4.39E+04
Pu-238 *	1.62E+02
Pu-239 *	1.38E+02
Pu-240 *	1.46E+02
Pu-241 *	5.30E+02
Pu-242 *	1.55E+02

Radionuclide[a,b]	Industrial Worker DCGLs
	(pCi/g)
Pu-244 +D *	2.41E-01
Ra-226 +D *	5.97E-02
Ra-228 +D *	1.21E-01
Ru-106 +D	2.15E+02
Sb-125 +D	1.10E+02
Se-79	1.18E+06
Sm-147	6.85E+02
Sm-151	1.50E+05
Sr-90 +D	4.31E+02
Tc-99	7.18E+04
Th-228 +D	4.88E-01
Th-229 +D	2.69E-01
Th-230 *	9.34E+00
Th-232 *	5.83E-02
Tl-204	4.80E+04
U-232 *	6.77E-02
U-233 *	9.74E+01
U-234 *	2.83E+02
U-235 +D *	5.35E-01
U-236 *	3.54E+02
U-238 +D *	3.02E+00
Zn-65	8.23E+01
Zr-93 *	8.85E+03

a) +D indicates that associated decay products with half-lives less than 6 months are included in the DCGL.
b) * indicates that the ingrowth of associated decay products with half-lives greater than 6 months are included in the DCGL.
c) ** The tritium DCGL is based on a 0.15 m (6 inch) contaminated thickness.