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Applications of RESRAD Family of Computer Codes to Sites Contaminated with Radioactive Residues*

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ABSTRACT

The RESRAD family of computer codes was developed to provide a scientifically defensible answer to the question "How clean is clean?" and to provide useful tools for evaluating human health risk at sites contaminated with radioactive residues. The RESRAD codes include (1) RESRAD for soil contaminated with radionuclides; (2) RESRAD-BUILD for buildings contaminated with radionuclides; (3) RESRAD-CHEM for soil contaminated with hazardous chemicals; (4) RESRAD-BASELINE for baseline risk assessment with measured media concentrations of both radionuclides and chemicals; (5) RESRAD-ECORISK for ecological risk assessment; (6) RESRAD-RECYCLE for recycle and reuse of radiologically contaminated metals and equipment; and (7) RESRAD-OFFSITE for off-site receptor radiological dose assessment. Four of these seven codes (RESRAD, RESRAD-BUILD, RESRAD-RECYCLE, and RESRAD-OFFSITE) also have uncertainty analysis capabilities that allow the user to input distributions of parameters. RESRAD has been widely used in the United States and abroad and approved by many federal and state agencies. Experience has shown that the RESRAD codes are useful tools for evaluating sites contaminated with radioactive residues. The use of RESRAD codes has resulted in significant savings in cleanup cost. Analysis of 19 site-specific uranium guidelines is discussed in the paper.

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1. RESRAD FAMILY OF CODES

The RESRAD family of computer codes is a suite of dose assessment programs developed by Argonne National Laboratory for the U.S. Department of Energy to evaluate radiologically and chemically contaminated sites and buildings. Table I lists and compares the RESRAD family of codes in terms of contamination source and type evaluated, end points of concern, operating system, and the availability of probabilistic calculations.

The RESRAD codes include (1) RESRAD, for soils contaminated with radionuclides; (2) RESRAD-BUILD, for buildings contaminated with radionuclides; (3) RESRAD-CHEM, for soil contaminated with hazardous chemicals; (4) RESRAD-BASELINE, for baseline risk assessment with measured media concentrations of both radionuclides and chemicals; (5) RESRAD-ECORISK, for ecological risk assessment; (6) RESRAD-RECYCLE, for recycle and reuse of radiologically contaminated metals and equipment; and (7) RESRAD-OFFSITE, for off-site receptor dose/risk assessment. Among these seven codes, RESRAD, RESRAD-BUILD, RESRAD-RECYCLE, and RESRAD-OFFSITE also have probabilistic (uncertainty) analysis capabilities that allow the user to input distributions of parameters. Recent improvements made to the RESRAD family of codes include an inhalation pathway area factor, external dose model, tritium model, and calculation of time-integrated dose and risk. Documents prepared to support the changes are available on the RESRAD web site (http://www.ead.anl.gov/resrad).

2. APPLICATIONS OF THE RESRAD CODE

RESRAD is the most widely used among this family of codes. Several supporting documents have been published for RESRAD*[1-2]*. The RESRAD code has been applied to more than 300 sites in the United States and abroad. RESRAD has been verified and validated *[3]*, and its use has resulted in significant monetary savings in terms of reduced cleanup costs. The U.S. Department of Energy has been using RESRAD to derive soil guidelines (cleanup criteria) at contaminated sites, as well as for dose assessment, for sites contaminated with radioactive residues. Such sites include the Savannah River site, Hanford site, Oak Ridge site, Rocky Flats site, Los Alamos site, and many other sites, including those under the Formerly Utilized Sites Remedial Action Program (FUSRAP). Table II lists 19 site-specific uranium guidelines derived using RESRAD. All uranium guidelines were derived on the basis of site-specific parameters, including distribution coefficients, area and thickness of the

Table I. Comparison of RESRAD family of codes

Computer Code	Source of Contamination	Type of Contamination	Transport Media	End Points of Concern	Operating Systems
RESRAD[a]	Soil	Radionuclides	On-site environmental media	Human health	Windows
RESRAD-BUILD[a]	Buildings	Radionuclides	Rooms in a building	Human health	Windows
RESRAD-CHEM	Soil	Chemicals	Environmental media	Human health	DOS
RESRAD-BASELINE	all media	Radionuclides and chemicals	Environmental media	Human health	Windows
RESRAD-RECYCLE[a]	Scrap metals (Steel, copper, Aluminum)	Radionuclides	Air, intermediate, and end products	Human health	Windows
RESRAD-ECORISK	Soil	Chemicals	Environmental media	Ecological systems	DOS
RESRAD-OFFSITE[a]	Soil	Radionuclides	On-site and off-site environmental media	Human health	Windows

[a] This code also has the probabilistic uncertainty analysis capability.

Table II. Comparison of uranium guidelines for 19 sites

Site	Uranium Guideline Values [Bq/g (pCi/g)]	Important Pathways[a]	Distribution Coefficient (cm^3/g)	Area of Source (m^2)	Thickness of Source (m)	Time of Maximum Dose (years)
Ashland 1 & 2	3.52 (95)	W	10	40000	2	1000[b]
Niagara Falls	2.48 (67)	W	16	37000	6	1000[b]
Peek Street	22.57 (610)	I, P, E	40	16200	0.3	0
Latty Avenue[c]	16.65 (450)	I, P, E	9.5	61000	0.9	0
St. Louis Airport[c]	16.65 (450)	I, P, E	9.5	87000	2.1	0
St. Louis Downtown	12.58 (340)	R, P, E	150	22000	2.4	1000[b]
Linde	2.85 (77)	W	25.3	37000	2	700
Elza Gate	3.52 (95)	W	114 & 6.8	70600	1.5	790
Shpack	2.85 (77)	W	16	32400	0.76	507
Aliquippa Forge	0.74 (20)	W	6	32400	0.5	90
Ventron	17.76 (480)	I, P, E	50	12100	3	0
Alba Craft Lab	11.47 (310)	W	50	3000	0.5	275
BNL	5.92 (160)	W	35	3100	7.9	400
Ottawa Lake	23.31 (630)	P, I, E	200	4000	1	0
Aircraft Tool	28.86 (780)	I, E, P	100	10000	0.3	0
Baker Brothers	18.5 (500)	R, E, P	128	23000	1.5	1000[b]
B&T Metals	32.56 (880)	I, E, P	1410	12000	0.15	0
NBS	15.91 (430)	R, E, P	1500	900	3.8	1000[b]
Windsor	20.72 (560)	E, I, P	59000	2×10^6	0.3	1000[b]

[a] W = water ingestion, I = dust inhalation, E = external exposure, P = plant ingestion, R = radon inhalation.

[b] The 1000th year is the end of the assessment period; maximum dose would occur at some time beyond 1000 years.

[c] For these sites, uranium reaches the water table because of low distribution coefficient, but the maximum dose still occurred at time 0.

contaminated zone, and other soil properties. For the 19 sites analyzed, the uranium guidelines varied from 0.74 to 32.6 Bq/g (20 to 880 pCi/g).

Table II indicates that for a large distribution coefficient (greater than 100 cm^3/g) and a thick source (greater than 1 m), radon inhalation and plant ingestion pathways are very important. For sites with these characteristics, the maximum dose would occur at 1000 years or longer. For low distribution coefficients, water-dependent pathways become important because of leaching of radionuclides. Maximum dose would occur at different times depending on the travel times of uranium through the unsaturated/saturated zone. For small contamination depths, dust inhalation and external exposure are important pathways; while for larger contamination depths, the plant ingestion pathway becomes important. The maximum doses would occur immediately following remediation in both cases. For 19 sites analyzed, most of the contaminated areas were greater than 3000 m^2, and the guideline values were found to be insensitive to this parameter.

3. DISCUSSION AND CONCLUSIONS

The RESRAD family of codes is a suite of user-friendly computer software designed for the evaluation of contaminated soils and buildings. The RESRAD code has been extensively tested and verified and it has been proven to be a useful tool for derivation of soil cleanup criteria. Analysis of 19 site-specific uranium guidelines indicates that the cleanup criteria vary from site to site. Therefore, applying a generic cleanup criterion to all sites is not a good practice; it may result in unnecessary costly cleanup or in releasing of still contaminated sites.

4. REFERENCES

[1] YU, C., et al., Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0, Working Draft For Comment, ANL/EAD/LD-2, Argonne National Laboratory, Argonne, Illinois (1993).

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[3] YU, C. "RESRAD family of codes and comparison with other codes for decontamination and restoration of nuclear facilities", Chapter 11, Decommissioning and Restoration of Nuclear Facilities, (SLOBODIEN, M.J., Ed.), Medical Physics Publishing, Madison, Wisconsin (1999) 207-231.