Verification of the RESRAD-BUILD Computer Code*

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Abstract

RESRAD-BUILD is a pathway analysis model designed to evaluate the potential radiological dose to an individual who works or lives in a building contaminated with radioactive material. The transport of radioactive material inside the building from one compartment (or room) to another is calculated with an indoor air quality model. This paper discusses verification of the models which was performed by using Microsoft Excel® spreadsheets and hand calculations. RESRAD-BUILD calculations verified included the source injection rate, air concentration in a compartment, air particulate deposition, exposure pathway doses, and time dependence in dose calculations. The direct external exposure pathway doses were also compared with Monte Carlo N-particle (MCNP) calculations. The agreement between the code output and spreadsheet calculations was excellent for all pathways. The paper also discusses limitations of the verification process and provides suggestions for future improvement of the RESRAD-BUILD code.

Introduction

RESRAD-BUILD code (Yu et al. 1994) has been developed by Argonne National Laboratory under sponsorship of the U.S. Department of Energy (DOE) to evaluate the potential radiological

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dose to an individual who works or lives in a building contaminated with radioactive material. It considers the releases of radionuclides into the indoor air by diffusion, mechanical removal, or erosion. The transport of radioactive material inside the building from one room or compartment to another is calculated with an indoor air quality model. The air quality model in RESRAD-BUILD evaluates the transport of radioactive dust particulates, tritium, and radon progeny due to (1) air exchange between rooms and with outdoor air, (2) the deposition and resuspension of particulates, and (3) radioactive decay and ingrowth. A single run of the RESRAD-BUILD code can model a building with up to 3 rooms or compartments, 10 distinct source locations, 4 source geometries (point, line, area, and volume), 10 receptor locations, and 8 shielding materials. A shielding object can be specified between each source-receptor pair for external gamma dose calculations.

Seven exposure pathways are considered in RESRAD-BUILD: (1) external exposure directly from the source, (2) external exposure to materials deposited on the floor, (3) external exposure due to air submersion, (4) inhalation of airborne radioactive particulates, (5) inhalation of aerosol indoor radon progeny, (6) inadvertent ingestion of radioactive material directly from the sources, and (7) inadvertent ingestion of materials deposited on the surfaces of the building compartments. Fig. 1 conceptually illustrates the exposure pathways considered in RESRAD-BUILD.

In the RESRAD-BUILD code, two direct exposure models based on source geometry are used. The first model for area and volume sources is based on a semi-infinite slab source with corrections for geometric factors (Kamboj et al. 1998). This exposure model uses the external dose conversion factors (DCFs) from Federal Guidance Report No. 12 (FGR-12) (Eckerman and Ryman 1993). The methodology described by Kamboj et al. (1998) for corrections due to finite size was extended to include differences due to the source material. The second model for point and line contamination is a simple dose integral method (Yu et al. 1994).

RESRAD-BUILD Verification Procedure

The results generated by the RESRAD-BUILD code (version 3.0) were compared with those obtained by using hand-held calculators and spreadsheets. The equations and reference data listed in the RESRAD-BUILD manual (Yu et al. 1994) for different pathways were used in the calculations. For verification purposes, different radionuclides — ^{3}H, ^{14}C, ^{22}Na, ^{26}Al, ^{36}Cl, ^{54}Mn, ^{60}Co, ^{195}Au, ^{226}Ra, ^{228}Ra, ^{228}Th, and ^{238}U — were chosen to effectively test all pathways and models. Tritium, ^{226}Ra, and ^{228}Th were chosen because of the special models used for tritium and radon in the RESRAD-BUILD code. Other radionuclides were selected to represent a spectrum of radiation types and energies.

Verification of the RESRAD-BUILD code was conducted with an initial check of all the input parameters for correctness against their original source documents (Yu et al. 1994). Verification of the calculations was performed external to the RESRAD-BUILD code with Microsoft Excel (version 7) to verify all the major portions of the code. The verification was conducted on a step-by-step basis and used different test cases as templates, since all possible options could not be considered. The following types of calculations were investigated: (1) source injection rate, (2) ar concentration in the room, (3) air particulate deposition, (4) radon pathway model, (5) tritium model for volume source, (6) external exposure model, (7) different pathway doses, and (8) time dependence of dose.

Except for a dose from the direct external exposure pathway, the dose to a receptor in a room depends on the radionuclide concentration in the air of that room. The radionuclide air concentration, in turn, depends on the source injection rate. Therefore, the source injection rate calculations were verified first. Then the air concentration in a one-room and two-room model was verified. Since air deposition depends on the air concentration in the room, air deposition was verified next. The special radon and tritium models in RESRAD-BUILD were then verified. The external exposure models in RESRAD-BUILD were independently benchmarked with the Monte Carlo N-particle (MCNP) transport code (Briesmeister 1993). Finally, the total dose for a single receptor calculated by RESRAD-BUILD was compared and verified with that calculated by the Excel spreadsheets. The time-independent part of the code was tested first (instantaneous dose calculations at time zero, without averaging over one year or the exposure duration). Then the time-integrated dose was verified.

The following parameters used in the RESRAD-BUILD code (version 3.0) were checked and verified for correctness against their original source documents: inhalation, ingestion, air submersion, and external DCFs; external exposure model parameters; and radionuclide half-lives and other decay data. Excel spreadsheets were prepared that calculated the different pathways according to the source receptor configuration. Three spreadsheets were used for all verification runs. The first spreadsheet contains all the RESRAD-BUILD default parameters, the second has lower-bound values of the input parameters, and the third has all the upper-bound values for the input parameters. The lower- and upper-bound values of the parameters were taken from Yu et al. (2000). The verification was performed for these three data sets to cover wide variations in input values. The results of the external exposure models (point and line sources and area and volume sources) were also benchmarked with those from the MCNP transport code. For this comparison, MCNP version 4A was used.

Results and Discussion

Table 1 compares pathway doses for different source types calculated by RESRAD-BUILD and those calculated by Excel spreadsheets. For this comparison, all RESRAD-BUILD default parameters except for external exposure pathways were used. For the direct external exposure pathway comparison, a receptor at a height of 1 m from the center of a large source was assumed. For the deposited material exposure pathway, the deposition was assumed to be in a room with a large floor area. For all pathways except for the radon inhalation pathway (where the contaminant is ^{226}Ra), the contaminant was assumed to be ^{22}Na at unit concentration (volume source = 1 Bq g^{-1}, area source = 1 Bq m^{-2}, line source = 1 Bq m^{-1}, and point source = 1 Bq). No inconsistencies between the code output and spreadsheet calculations were found for the following pathways: submersion, direct inadvertent ingestion, inadvertent ingestion of deposited materials, and inhalation of airborne radioactive particulates. For inhalation of aerosol indoor radon progeny, good agreement, to within 0.1%, was obtained. For direct external exposure, good agreement, to within 2%, was obtained and for external exposure to deposited material, agreement within 3% was obtained.

Table 2 compares the RESRAD-BUILD calculated doses and MCNP simulated doses for four source types (point, line, area, and volume) and for ^{195}Au, ^{54}Mn, and ^{60}Co using all RESRAD-BUILD default parameters to cover a wide energy range. For point sources, good agreement, to within 1% was obtained, and for line, area, and volume sources, agreement within 5% was obtained. The detailed verification results are provided in Kamboj et al. (2001).† Table 3 summarizes the verification results for different types of calculations.

Verification Limitations and Suggestions for Improvement

Verification was limited to an initial check of input parameters and spot checks of major portions of the code by using carefully selected radionuclides. Verifications of the code interface, uncertainty analysis, and all combinations of input values were not performed in this exercise. The verification of the uncertainty analysis was documented in Kamboj et al. (2000). During the verification process, the following suggestions were made for future improvement of the RESRAD-BUILD code. (1) Input and default parameter values and intermediate and complete final results should be stored and made accessible for further verification and processing. (2) Input template files should be provided for typical exposure scenarios. (3) Specifications on volume source regions and their relationships to the receptor should be improved. (4) An independent and comprehensive verification of the code interface and all combinations of input parameter values for all pathways should be performed.

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Figure Caption

Fig. 1 Exposure pathways in the RESRAD-BUILD code

Table 1 Pathway* doses (μSv yr^{-1}) calculated by RESRAD-BUILD and Excel spreadsheet for different source types

Source type	Direct external	Exposure of deposited material	Submersion	Inadvertent ingestion	Inhalation	Radon inhalation
RESRAD-BUILD code output						
Volume	1.77×10^{3}	2.21×10^{-8}	1.57×10^{-6}	2.47×10^{-5}	6.28×10^{-6}	6.13×10^{2}
Area	3.38×10^{-2}	5.26×10^{-8}	3.75×10^{-6}	5.88×10^{-5}	1.49×10^{-5}	8.51×10^{-4}
Line	3.15×10^{-3}	5.26×10^{-8}	3.75×10^{-6}	5.88×10^{-5}	1.49×10^{-5}	8.51×10^{-4}
Point	1.05×10^{-3}	1.46×10^{-9}	1.04×10^{-7}	1.63×10^{-6}	4.15×10^{-7}	2.37×10^{-5}
Spreadsheet calculations						
Volume	1.78×10^{3}	2.17×10^{-8}	1.57×10^{-6}	2.47×10^{-5}	6.28×10^{-6}	6.13×10^{2}
Area	3.32×10^{-2}	5.16×10^{-8}	3.73×10^{-6}	5.88×10^{-5}	1.49×10^{-5}	8.50×10^{-4}
Line	NA	5.16×10^{-8}	3.73×10^{-6}	5.88×10^{-5}	1.49×10^{-5}	8.50×10^{-4}
Point	NA	1.43×10^{-9}	1.04×10^{-7}	1.63×10^{-6}	4.15×10^{-7}	2.36×10^{-5}

* The doses for all pathways are the instantaneous doses for unit concentration (volume source = 1 Bq g^{-1}, area source = 1 Bq m^{-2}, line source = 1 Bq m^{-1}, and point source = 1 Bq) of ^{22}Na except for the radon inhalation pathway, which is for ^{226}Ra contamination. The direct external exposure pathway dose is compared only for volume and area sources; however, all source type doses are benchmarked with MCNP code. The comparison is done with all RESRAD-BUILD default parameters, except for exposure from direct external and deposited material, where the receptor is at a height of 1 m from an infinitely large source area.

Table 2 Direct external exposure pathway dose (μSv yr^{-1}) comparison between RESRAD-BUILD* and MCNP

	Point		Line		Area		Volume	
Radionuclide	RESRAD-BUILD	MCNP	RESRAD-BUILD	MCNP	RESRAD-BUILD	MCNP	RESRAD-BUILD	MCNP
^{195}Au	1.31×10^{-5}	1.30×10^{-5}	7.96×10^{-5}	8.38×10^{-5}	3.08×10^{-4}	2.92×10^{-4}	1.47×10^{1}	1.61×10^{1}
^{54}Mn	1.33×10^{-4}	1.33×10^{-4}	8.29×10^{-4}	8.38×10^{-4}	2.90×10^{-3}	2.97×10^{-3}	4.36×10^{2}	4.32×10^{2}
^{60}Co	3.76×10^{-4}	3.76×10^{-4}	2.36×10^{-3}	2.36×10^{-3}	8.27×10^{-3}	8.38×10^{-3}	1.33×10^{3}	1.32×10^{3}

* The doses are compared for unit concentration (volume source = 1 Bq g^{-1}, area source = 1 Bq m^{-2}, line source = 1 Bq m^{-1}, and point source =1 Bq) of source with all RESRAD-BUILD default parameters.

Table 3 Results and discussion on types of calculations verified in RESRAD-BUILD code

Type of calculation	Results and discussion
Input parameter check	The parameters checked included inhalation, ingestion, air submersion, and external DCFs; external exposure model parameters; and radionuclide half-lives and other decay data.
Source injection rate	Excellent agreement was obtained between the RESRAD-BUILD-generated results and spreadsheet calculations.
Air concentration in the room	Air concentrations for four source types were compared for one- and two-room air quality models. Excellent agreement was obtained between the RESRAD-BUILD and spreadsheet calculations.
Air particulate deposition	Air particulate deposition was computed because it is used in two pathways: external exposure due to deposited material and inadvertent ingestion directly from the deposited materials.
Radon pathway model	The calculations checked were the radon injection rate and the radon progeny concentration. For the point, line, and area sources, there was no difference in the RESRAD-BUILD and spreadsheet calculations of the source injection rates. However, the volume source injection rates for ^{222}Rn and ^{220}Rn were different in two cases. The difference is due to the density used in the calculations. For the spreadsheet calculations, it was assumed that the particle density is input; in RESRAD-BUILD, the source bulk density was assumed. If the same density values are used in RESRAD-BUILD, the results are the same (within round-off errors) as the spreadsheet calculations. No significant differences in the RESRAD-BUILD and spreadsheet calculations were observed in radon progeny concentration.
Tritium model for volume source	The tritium-transport model in RESRAD-BUILD for a volume source estimates the injection rate of tritiated water molecules into the indoor air from evaporation; this injection rate is then added to the source injection from erosion to calculate the total source injection. This sum source injection rate is then used to calculate air concentration, air deposition, etc. No inconsistencies between the code output and spreadsheet calculations were obtained for the injection rate of tritiated water molecules.
External exposure model	In the RESRAD-BUILD code, two direct exposure models based on the source geometry are used. The first model for area and volume sources is based on a semi-infinite slab source with corrections for geometric factors. The second model for point and line contamination is a simple dose integral method. The results of the external models were compared with those from the MCNP transport code. The comparisons were performed at different source-receptor configurations for ^{60}Co, ^{54}Mn, and ^{195}Au. Good agreement (within 5%) was observed.
Different pathway doses	The different pathway doses calculated by the RESRAD-BUILD code were compared with the spreadsheet calculations. No inconsistencies between the code output and spreadsheet calculations were obtained for submersion, direct inadvertent ingestion, inadvertent ingestion of deposited materials, inhalation of airborne radioactive particulates, and tritium volume source. For inhalation of aerosol indoor radon progeny, good agreement, to within 1%, was obtained. For direct external exposure, good agreement to within 2%, and for external exposure to deposited material, agreement within 5% was observed. There was no difference in the spreadsheet-calculated total receptor dose and the code-calculated total receptor dose.
Time dependence in dose calculations	No significant differences in the time-integrated and the average individual pathway dose (obtained by averaging the dose over different time intervals) were obtained.

Fig.1 Exposure Pathways in the RESRAD-BUILD Code