7 RESULTS OF PROBABILISTIC DOSE ANALYSES

The results of the probabilistic dose analyses are presented in this section. The analyses were conducted to assess the effects of parameter distribution on estimated doses from residual radionuclides for the residential and building occupancy scenarios. The total effective dose equivalent (TEDE) was estimated for an average member of the critical group. The RESRAD code was used to analyze the residential scenario, and RESRAD-BUILD was used to analyze the building occupancy scenario.

The uncertainty module used for evaluating dose variability included the input interface and the calculational components of sample generation, calculation for each sample, and compilation of the results. The results were accessible through a set of files that contained the user's input, the sample vectors, and the output dose results for each sample. Supplemental software was developed to extract, manage, analyze, and aggregate the data.

7.1 RESIDENTIAL SCENARIO

As noted in the Parameter Ranking Report (Cheng et al., 1999), certain parameters have significant impacts on calculated radiation doses, and site-specific information for those parameters should always be used in dose calculations. The parameters with significant effect on dose include radionuclide concentrations, source area, and source thickness. Radionuclide concentration would affect the dose linearly, whereas the effect of source area and source thickness may not be linear. For the residential scenario, this report analyzes the influence of parameter values on peak dose for three source configurations: (1) area of 100 m^2, thickness of 15 cm; (2) area of 2,400 m^2, thickness of 15 cm; and (3) area of 10,000 m^2, thickness of 2 m).

Table B.2 (Appendix B) lists the parameter values and distribution types used in the analysis. A stratified Monte-Carlo technique, Latin hypercube sampling (LHS), was used to estimate the dose distribution functions from the assigned parameter distribution functions. Three hundred sample values were generated for each input variable. This set of inputs was then used to generate a set of outputs from which the probability statistics were generated. For the physical parameters, assigned distributions were used in the analysis. For the metabolic and behavioral parameters, mean or median values of the distributions were used. For the parameters not assigned distributions, RESRAD default values were used, or in cases of overlap between RESRAD and DandD input parameters, DandD default input parameter values were used if appropriate.

The results of the parameter sampling are illustrated in Figures B.1 through B.32 in Appendix B. Those figures compare the input frequency of the physical parameter values based on LHS sampling and the probability density of the parameter. Because of the large number of element-specific parameters, distributions for the distribution coefficients and transfer factors (plant, meat, milk, and bioaccumulation) are not shown.

7.1.1 Parameter Correlations

The Parameter Distribution Report (Biwer et al., 2000) indicated that some input parameters in RESRAD are correlated. For some parameters, such as effective porosity and total porosity, strong correlations were indicated. Distributions were not provided for some of the parameters, such as irrigation rate. Some parameters were behavioral parameters, such as soil ingestion rate and drinking water intake. For behavioral parameters, mean or median values were used in the analysis. For these cases, no correlation analysis was performed.

In cases for which a clear relationship was identified, such as density and porosity and effective porosity and total porosity, strong rank correlations were used as input. A rank correlation value of 0.96 between porosity and effective porosity ensured pairing of high porosity value with high effective porosity. In no case among the 300 samples generated by LHS was effective porosity higher than the total porosity. Figure 7.1 shows the scatter plot of effective porosity and total porosity with rank correlation of 0.96. Similarly, a negative rank correlation of 0.99 ensured proper pairing between total porosity and bulk density. The average particle density, calculated on the basis of the total porosity and bulk density sample data set, was 2.64 g/cm^3, with a 0.06 standard deviation. Figure 7.2 shows the scatter plot of sample input for bulk density and total porosity. Figure 7.3 shows the cumulative probability of the sampled particle density with a rank correlation of -0.99. All values are within 2.48 to 2.81 g/cm^3.

7.1.2 Dose Analysis Results

For each set of sampled parameter values, dose to the average member of the critical group was calculated for unit concentrations of each radionuclide. For each source, the distribution describing possible doses to the average member of the critical group was then constructed from these calculated doses. From the resulting dose distributions, the dose quantiles were estimated. The distribution of the dose is the distribution of the peak dose over each 1,000-year period. In all, 90 radionuclides were analyzed for three source configurations (total of 270 radionuclide-source configurations).

Table 7.1 lists the quantile values (at 50th percentile and 90th percentile) of unit-source distribution for three source configurations (source configuration 1: source area = 100 m^2 and thickness = 15 cm; source configuration 2: source area = 2,400 m^2 and thickness = 15 cm; and source configuration 3: source area = 10,000 m^2 and thickness = 2 m) in the residential scenario. Table 7.1 also shows the ratio of the 99th percentile dose to the 50th percentile (median) dose. The dose ratio shows the dose spread for different radionuclides. Dose values at the selected quantiles can be used to calculate the source concentration equivalent to a dose value of 25 mrem/yr.

For source configuration 1, the dose ratio varies from 2.2 (Cs-134, Cs-137, Pu-244, Ru-106, Se-75, and Th-229) to 79 (C-14). For source configuration 2, the dose ratio varies from 2.1 (Am-243) to 39 (S-35). For source configuration 3, the dose ratio varies from 2.0 (H-3) to 28 (S-35). For some radionuclides, the dose ratio remains almost the same for all three source configurations (e.g., Ag-108m, Ag-110m, Al-26, Ba-133, Bi-207, Ce-141, Ce-144, Co-57, Co-60, Eu-152, Eu-154, Eu-155, and Fe-59). Wide variations occur for other radionuclides (e.g., Ac-227, Am-241, Am-243, C-14, Ca-41, and Ca-45). Figures 7.4 to 7.13 show the dose variability for Am-241, C-14, Co-60, Cs-137, H-3, Pu-239, Ra-226, Sr-90, Th-230, and U-238 in the residential scenario for all three source configurations.

For 90 radionuclides and 3 source configurations, there are a total of 270 radionuclide-source configurations. For 186 of these radionuclide-source configurations, peak dose was always at time 0 from all 300 sample runs. For 41 radionuclide-source configurations, peak dose was at time 0 more than 90% of the time (< 30 sample runs). For 41 radionuclide-source configurations, more than 30 samples (10%) produced peak dose at times other than time 0 (>30 - <300 sample runs). In some cases (2 radionuclide-source configurations), peak dose was always at a time other than time 0 (all 300 sample runs). Therefore, the results indicate that in most cases, the peak dose occurred at time zero. The reason was that for most radionuclides, water-dependent pathways were either not significant or the transport time was greater than 1,000 years.

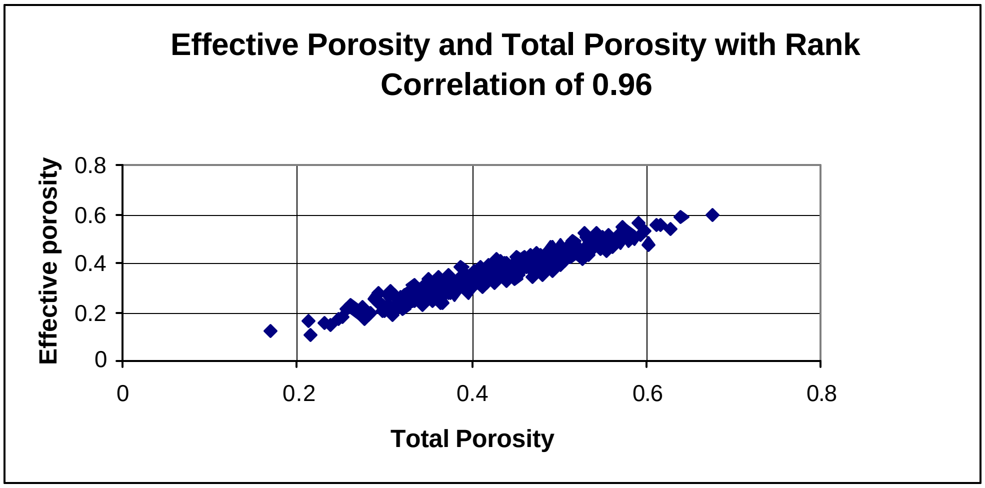


Figure 7.1 Scatter Plot of Effective and Total Porosity in Sample Input with Rank Correlation of 0.96

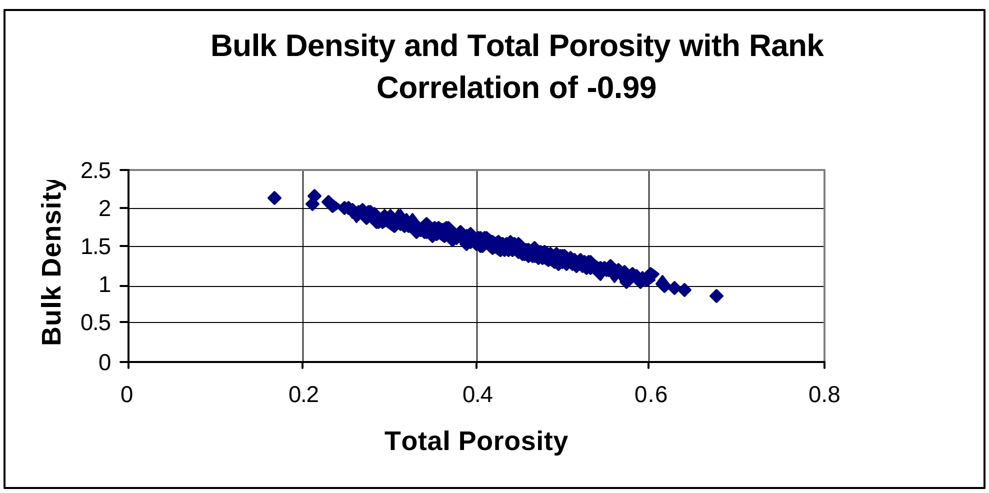


Figure 7.2 Scatter Plot of Bulk Density and Total Porosity in Sample Input with Rank Correlation of -0.99

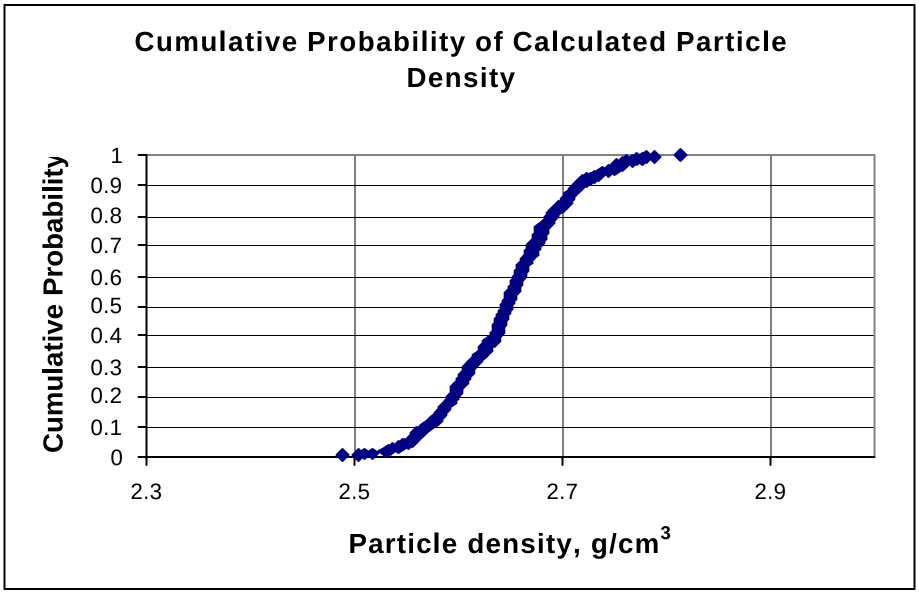


Figure 7.3 Cumulative Probability of Calculated Particle Density

Tables 7.2 through 7.4 give the range of sample runs when the peak dose was at times other than time 0 for the three source configurations. Sensitive parameters for the radionuclides that have peak dose at time other than 0 will change with the dose percentile values.

7.1.3 Dominant Pathways and Sensitive Parameters

The results of the probabilistic dose analysis indicated that the dominant pathways generally were external exposure and plant ingestion at high dose percentiles. The external exposure pathway was dominant because in the residential scenario analyzed, there was no cover present; if cover was present, the dominant pathways and sensitive parameters would be different. The reason plant ingestion was the dominant pathway was that the plant transfer factor has large variability, which results in high plant ingestion doses at high dose percentiles.

The results can be used to identify parameters controlling dose variability for each radionuclide. The dependence of dose on the model parameter values is complex; total dose may depend non-monotonically on the parameter value, or may be sensitive to the parameter value only within certain limits, or only in conjunction with certain ranges of values for other parameters. Because of these complexities, a single regression analysis can not be used to identify the sensitive parameters. RESRAD output provides partial correlation coefficient (PCC), standard regression coefficient (SRC), partial rank correlation coefficient (PRCC), and standardized rank regression coefficient (SRRC) values and scatter plots. (These terms are explained in Section 5.) Sensitive parameters can be identified by the use of these aids along with expert judgment.

The ranking of parameters may be different if different regression analysis, such as PCC, SRC, PRCC, or SRRC, is used. Tables 7.2 through 7.4 list the four most sensitive parameters on the basis of PRCC, along with the dominant pathway for three source configurations. The detailed regression analysis results with PRCC values are provided in

Table 7.1. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Configurations in the Residential Scenario

	Source Configurations								
	Area = 100 m^2; Thickness = 15 cm			Area = 2,400 m^2; Thickness = 15 cm			Area = 10,000 m^2; Thickness = 2 m		
Radionuclide	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**
Ac-227	5.00E-01	7.90E-01	2.30E+00	8.80E-01	1.40E+00	3.80E+00	2.10E+00	6.30E+00	7.10E+00
Ag-108	2.00E+00	3.20E+00	2.30E+00	2.40E+00	3.90E+00	2.30E+00	2.70E+00	4.30E+00	2.30E+00
Ag-110	2.20E+00	3.50E+00	2.30E+00	2.60E+00	4.20E+00	2.30E+00	3.00E+00	4.90E+00	2.30E+00
Al-26	3.30E+00	5.50E+00	2.30E+00	4.00E+00	6.60E+00	2.30E+00	4.80E+00	7.80E+00	2.40E+00
Am-241	2.00E-02	3.30E-02	3.30E+00	8.00E-02	2.00E-01	5.70E+00	3.60E-01	9.70E-01	7.80E+00
Am-243	2.20E-01	3.50E-01	2.30E+00	3.20E-01	5.20E-01	2.10E+00	6.50E-01	1.20E+00	4.40E+00
Au-195	2.60E-02	4.30E-02	2.50E+00	3.00E-02	4.90E-02	2.40E+00	4.10E-02	6.80E-02	2.70E+00
Ba-133	4.10E-01	6.80E-01	2.30E+00	4.80E-01	7.90E-01	2.30E+00	5.40E-01	8.70E-01	2.30E+00
Bi-207	1.80E+00	2.90E+00	2.40E+00	2.10E+00	3.50E+00	2.40E+00	2.70E+00	4.20E+00	2.30E+00
C-14	1.90E-04	1.00E-03	7.90E+01	8.00E-03	2.90E-02	2.40E+01	6.60E-01	1.10E+00	1.00E+01
Ca-41	4.80E-04	2.50E-03	2.30E+01	4.80E-03	2.30E-02	2.30E+01	6.30E-02	2.70E-01	1.00E+01
Ca-45	6.00E-04	3.30E-03	2.40E+01	6.00E-03	3.30E-02	2.40E+01	7.70E-02	3.40E-01	1.10E+01
Cd-109	6.40E-03	2.20E-02	1.50E+01	4.00E-02	2.00E-01	2.40E+01	4.70E-01	2.10E+00	1.10E+01
Ce-141	1.00E-02	1.60E-02	2.30E+00	1.20E-02	1.90E-02	2.30E+00	1.20E-02	2.00E-02	2.30E+00
Ce-144	4.40E-02	7.20E-02	2.30E+00	5.30E-02	8.60E-02	2.20E+00	6.40E-02	1.00E-01	2.20E+00
Cf-252	2.30E-03	5.50E-03	7.60E+00	1.80E-02	5.00E-02	9.50E+00	9.20E-02	3.30E-01	1.20E+01
Cl-36	3.80E-02	2.50E-01	3.30E+01	4.90E-01	3.00E+00	3.10E+01	1.30E+01	5.80E+01	1.30E+01
Cm-243	1.40E-01	2.30E-01	2.40E+00	2.10E-01	3.30E-01	2.80E+00	4.20E-01	8.90E-01	4.20E+00
Cm-244	4.60E-03	9.80E-03	9.40E+00	3.90E-02	8.70E-02	1.10E+01	2.00E-01	5.60E-01	7.80E+00
Cm-246	8.60E-03	1.80E-02	5.60E+00	7.00E-02	1.70E-01	6.60E+00	3.50E-01	1.10E+00	6.90E+00
Cm-247	4.20E-01	6.80E-01	2.40E+00	5.60E-01	8.90E-01	2.30E+00	9.00E-01	1.60E+00	3.20E+00
Cm-248	3.20E-02	6.80E-02	5.60E+00	2.60E-01	6.20E-01	6.80E+00	1.30E+00	3.80E+00	8.30E+00
Co-57	7.60E-02	1.20E-01	2.40E+00	8.80E-02	1.40E-01	2.30E+00	1.10E-01	1.80E-01	2.30E+00
Co-60	2.90E+00	4.80E+00	2.30E+00	3.50E+00	5.80E+00	2.30E+00	4.80E+00	7.80E+00	2.30E+00
Cs-134	1.70E+00	2.70E+00	2.20E+00	2.10E+00	3.30E+00	2.20E+00	3.00E+00	5.00E+00	2.50E+00
Cs-135	3.30E-04	1.30E-03	1.60E+01	4.40E-03	1.60E-02	1.40E+01	6.50E-02	2.30E-01	8.60E+00
Cs-137	7.00E-01	1.10E+00	2.20E+00	8.90E-01	1.40E+00	2.40E+00	1.50E+00	2.60E+00	3.30E+00
Eu-152	1.30E+00	2.20E+00	2.40E+00	1.60E+00	2.60E+00	2.40E+00	1.90E+00	3.10E+00	2.30E+00
Eu-154	1.40E+00	2.40E+00	2.30E+00	1.70E+00	2.90E+00	2.30E+00	2.00E+00	3.30E+00	2.30E+00

Eu-155	4.00E-02	6.50E-02	2.40E+00	4.50E-02	7.30E-02	2.40E+00	4.90E-02	7.90E-02	2.30E+00
Fe-55	2.90E-06	5.40E-06	4.30E+00	5.30E-05	1.00E-04	3.50E+00	3.70E-04	6.70E-04	3.20E+00
Fe-59	2.70E-01	4.40E-01	2.30E+00	3.20E-01	5.30E-01	2.30E+00	3.80E-01	6.20E-01	2.30E+00

Table 7.1. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Configurations in the Residential Scenario (Continued)

	Source Configurations								
	Area = 100 m^2; Thickness = 15 cm			Area = 2,400 m^2; Thickness = 15 cm			Area = 10,000 m^2; Thickness = 2 m		
Radionuclide	Dose @ 50%	Dose @ 90%	Dose @ 99%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 99%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 99%/ Dose @ 50%
Gd-152	1.40E-03	3.10E-03	9.80E+00	7.10E-03	1.80E-02	1.40E+01	4.20E-02	1.50E-01	9.60E+00
Gd-153	3.60E-02	5.90E-02	2.40E+00	4.00E-02	6.60E-02	2.40E+00	4.40E-02	7.10E-02	2.30E+00
Ge-68	7.30E-01	1.20E+00	2.40E+00	8.80E-01	1.40E+00	2.50E+00	1.40E+00	2.50E+00	4.80E+00
H-3	3.40E-05	1.80E-04	1.80E+01	3.00E-04	8.40E-04	6.80E+00	1.40E-02	2.20E-02	2.00E+00
I-125	1.20E-03	2.10E-03	3.20E+00	4.40E-03	1.10E-02	8.40E+00	4.30E-02	1.30E-01	6.60E+00
I-129	1.10E-02	9.90E-02	7.80E+01	1.00E-01	4.60E-01	3.10E+01	1.40E+00	5.70E+00	1.30E+01
Ir-192	2.80E-01	4.60E-01	2.30E+00	3.30E-01	5.40E-01	2.30E+00	3.70E-01	6.00E-01	2.30E+00
K-40	1.90E-01	3.10E-01	2.40E+00	3.00E-01	5.30E-01	4.20E+00	1.10E+00	3.70E+00	8.60E+00
Mn-54	7.10E-01	1.20E+00	2.30E+00	8.50E-01	1.40E+00	2.30E+00	1.10E+00	1.70E+00	2.20E+00
Na-22	2.30E+00	3.70E+00	2.40E+00	2.80E+00	4.50E+00	2.30E+00	3.60E+00	5.80E+00	2.20E+00
Nb-93	3.60E-05	5.90E-05	3.00E+00	7.50E-05	2.30E-04	1.20E+01	4.60E-04	1.70E-03	8.40E+00
Nb-94	1.90E+00	3.20E+00	2.30E+00	2.30E+00	3.80E+00	2.30E+00	2.70E+00	4.30E+00	2.30E+00
Nb-95	1.40E-01	2.30E-01	2.30E+00	1.60E-01	2.70E-01	2.30E+00	1.90E-01	3.00E-01	2.30E+00
Ni-59	9.90E-06	4.10E-05	1.70E+01	1.30E-04	4.60E-04	1.60E+01	1.70E-03	5.50E-03	7.60E+00
Ni-63	2.70E-05	1.10E-04	1.70E+01	3.50E-04	1.30E-03	1.60E+01	4.60E-03	1.50E-02	7.50E+00
Np-237	3.40E-01	6.30E-01	6.60E+00	1.00E+00	3.50E+00	1.00E+01	8.50E+00	2.80E+01	1.00E+01
Pa-231	3.00E-01	7.60E-01	5.00E+00	1.20E+00	4.70E+00	1.20E+01	1.10E+01	4.00E+01	1.20E+01
Pb-210	4.30E-02	1.50E-01	7.70E+00	4.50E-01	1.50E+00	7.60E+00	4.20E+00	1.00E+01	5.80E+00
Pm-147	1.40E-05	2.50E-05	2.60E+00	4.60E-05	1.10E-04	6.00E+00	2.40E-04	8.10E-04	9.60E+00
Po-210	8.30E-03	3.30E-02	1.60E+01	9.50E-02	3.50E-01	1.40E+01	9.30E-01	3.10E+00	8.10E+00
Pu-238	7.60E-03	1.40E-02	8.70E+00	6.20E-02	1.30E-01	1.00E+01	3.20E-01	9.20E-01	6.20E+00
Pu-239	8.30E-03	2.10E-02	5.50E+00	6.50E-02	1.90E-01	6.70E+00	3.50E-01	9.30E-01	7.90E+00
Pu-240	8.30E-03	1.80E-02	7.20E+00	6.90E-02	1.70E-01	8.60E+00	3.40E-01	1.00E+00	7.10E+00
Pu-241	4.10E-04	6.80E-04	3.20E+00	1.90E-03	4.30E-03	5.70E+00	1.30E-02	3.40E-02	6.40E+00
Pu-242	7.80E-03	1.60E-02	7.60E+00	6.50E-02	1.50E-01	8.30E+00	3.40E-01	9.50E-01	7.40E+00
Pu-244	1.60E+00	2.60E+00	2.20E+00	2.00E+00	3.20E+00	2.20E+00	2.60E+00	4.20E+00	2.20E+00
Ra-226	2.30E+00	3.70E+00	2.30E+00	3.50E+00	6.00E+00	2.60E+00	1.30E+01	2.50E+01	3.90E+00
Ra-228	1.90E+00	3.10E+00	2.40E+00	2.70E+00	5.00E+00	2.70E+00	7.10E+00	1.90E+01	6.70E+00

Table 7.1. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Configurations in the Residential Scenario (Continued)

	Source Configurations								
	Area = 100 m^2; Thickness = 15 cm			Area = 2,400 m^2; Thickness = 15 cm			Area = 10,000 m^2; Thickness = 2 m		
Radionuclide	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 99%/ Dose @ 50%**
Ru-106	1.90E-01	3.20E-01	2.20E+00	2.40E-01	3.90E-01	2.30E+00	3.40E-01	5.50E-01	2.20E+00
S-35	1.80E-03	1.00E-02	2.80E+01	2.60E-02	1.70E-01	3.90E+01	7.60E-01	4.20E+00	2.80E+01
Sb-124	5.30E-01	8.70E-01	2.30E+00	6.30E-01	1.00E+00	2.30E+00	7.60E-01	1.20E+00	2.30E+00
Sb-125	4.60E-01	7.30E-01	2.40E+00	5.40E-01	8.70E-01	2.40E+00	6.10E-01	1.00E+00	2.30E+00
Sc-46	7.90E-01	1.30E+00	2.30E+00	9.50E-01	1.60E+00	2.30E+00	1.10E+00	1.80E+00	2.30E+00
Se-75	1.90E-01	3.00E-01	2.20E+00	2.30E-01	3.70E-01	2.30E+00	4.00E-01	9.10E-01	7.30E+00
Se-79	1.00E-03	5.00E-03	2.00E+01	1.60E-02	7.20E-02	2.00E+01	2.90E-01	1.40E+00	2.00E+01
Sm-147	8.70E-04	2.10E-03	1.60E+01	7.00E-03	1.90E-02	1.70E+01	4.70E-02	1.70E-01	9.90E+00
Sm-151	1.60E-06	4.10E-06	1.50E+01	1.40E-05	4.00E-05	1.60E+01	9.80E-05	3.50E-04	9.70E+00
Sn-113	1.30E-01	2.10E-01	2.30E+00	1.60E-01	2.50E-01	2.40E+00	2.30E-01	3.90E-01	3.50E+00
Sr-85	1.50E-01	2.50E-01	2.30E+00	1.90E-01	3.00E-01	2.30E+00	2.30E-01	3.80E-01	2.20E+00
Sr-89	9.00E-04	2.70E-03	1.10E+01	5.10E-03	2.40E-02	1.90E+01	6.00E-02	2.40E-01	9.90E+00
Sr-90	4.00E-02	1.70E-01	1.90E+01	3.70E-01	1.70E+00	2.20E+01	4.90E+00	1.90E+01	1.00E+01
Ta-182	6.20E-01	1.00E+00	2.30E+00	7.50E-01	1.20E+00	2.30E+00	8.90E-01	1.40E+00	2.40E+00
Tc-99	2.80E-03	1.70E-02	2.90E+01	2.70E-02	1.70E-01	3.10E+01	5.60E-01	2.10E+00	8.20E+00
Te-125	9.90E-04	1.60E-03	2.40E+00	1.80E-03	4.40E-03	8.70E+00	9.50E-03	3.50E-02	9.50E+00
Th-228	1.60E+00	2.60E+00	2.30E+00	2.00E+00	3.20E+00	2.20E+00	2.50E+00	4.00E+00	2.30E+00
Th-229	3.70E-01	5.90E-01	2.20E+00	5.30E-01	8.30E-01	2.20E+00	9.30E-01	1.70E+00	3.40E+00
Th-230	3.20E-02	4.20E-01	3.30E+01	6.00E-02	9.60E-01	3.30E+01	2.20E+00	5.80E+00	5.80E+00
Th-232	2.40E+00	4.00E+00	2.60E+00	3.50E+00	5.80E+00	2.70E+00	1.00E+01	2.20E+01	4.60E+00
Ti-204	1.50E-03	3.50E-03	8.60E+00	6.60E-03	3.10E-02	2.00E+01	8.60E-02	3.90E-01	1.40E+01
U-232	1.30E+00	2.30E+00	2.80E+00	1.60E+00	2.90E+00	2.80E+00	2.90E+00	4.60E+00	2.30E+00
U-233	2.10E-03	7.70E-03	2.10E+01	1.10E-02	4.00E-02	2.00E+01	9.10E-02	2.50E-01	1.80E+01
U-234	1.50E-03	3.70E-03	1.40E+01	9.90E-03	2.60E-02	1.40E+01	7.20E-02	2.10E-01	9.60E+00
U-235	1.70E-01	2.70E-01	2.30E+00	2.10E-01	3.20E-01	2.30E+00	3.40E-01	5.80E-01	4.00E+00
U-236	1.30E-03	3.60E-03	1.20E+01	9.10E-03	2.50E-02	7.70E+00	6.20E-02	1.90E-01	1.00E+01
U-238	2.90E-02	4.90E-02	3.40E+00	4.30E-02	7.40E-02	4.30E+00	1.00E-01	2.30E-01	1.30E+01
Zn-65	4.40E-01	7.50E-01	2.30E+00	6.10E-01	1.00E+00	2.50E+00	1.80E+00	4.40E+00	5.30E+00
Zr-93	4.40E-05	3.70E-04	1.40E+01	2.10E-04	2.10E-03	2.10E+01	5.60E-03	3.60E-02	1.10E+01
Zr-95	4.50E-01	7.30E-01	2.30E+00	5.40E-01	8.80E-01	2.30E+00	6.10E-01	9.90E-01	2.30E+00

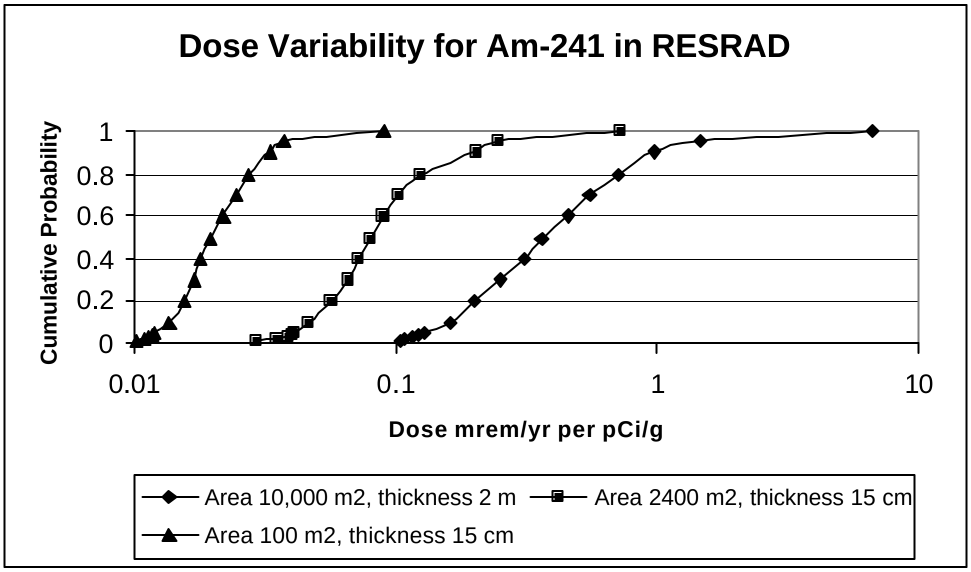


Figure 7.4 Dose Variability of Am-241 for Three Source Configurations in RESRAD

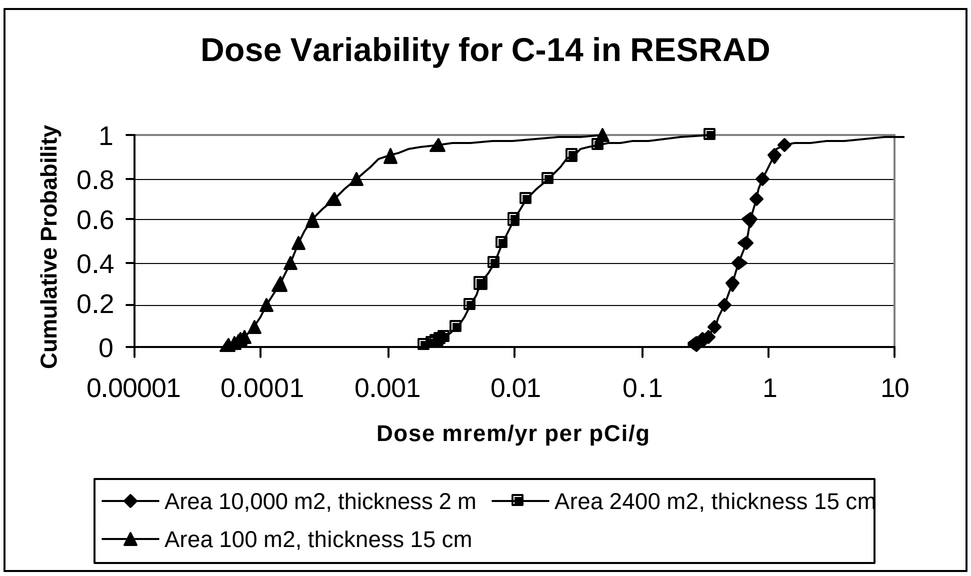


Figure 7.5 Dose Variability of C-14 for Three Source Configurations in RESRAD

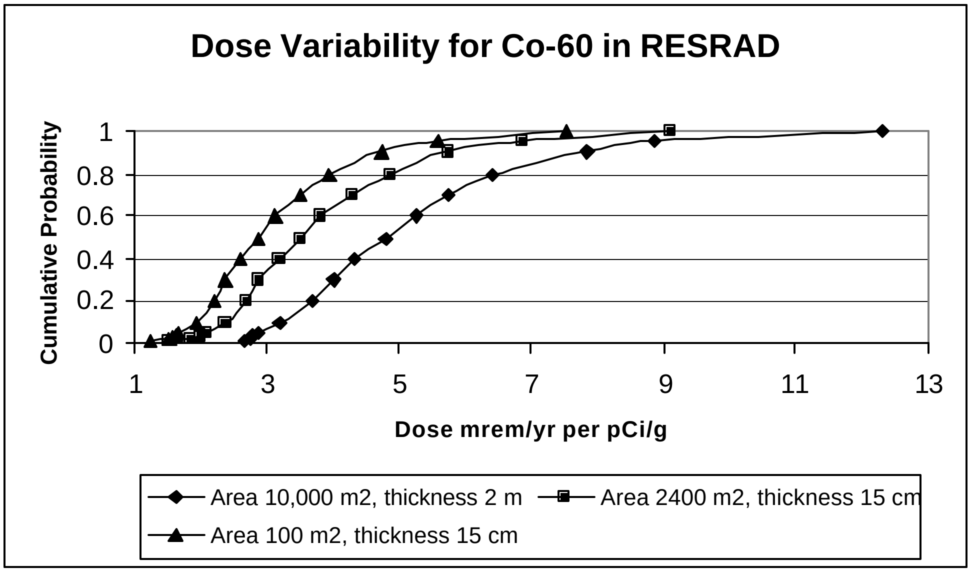


Figure 7.6 Dose Variability of Co-60 for Three Source Configurations in RESRAD

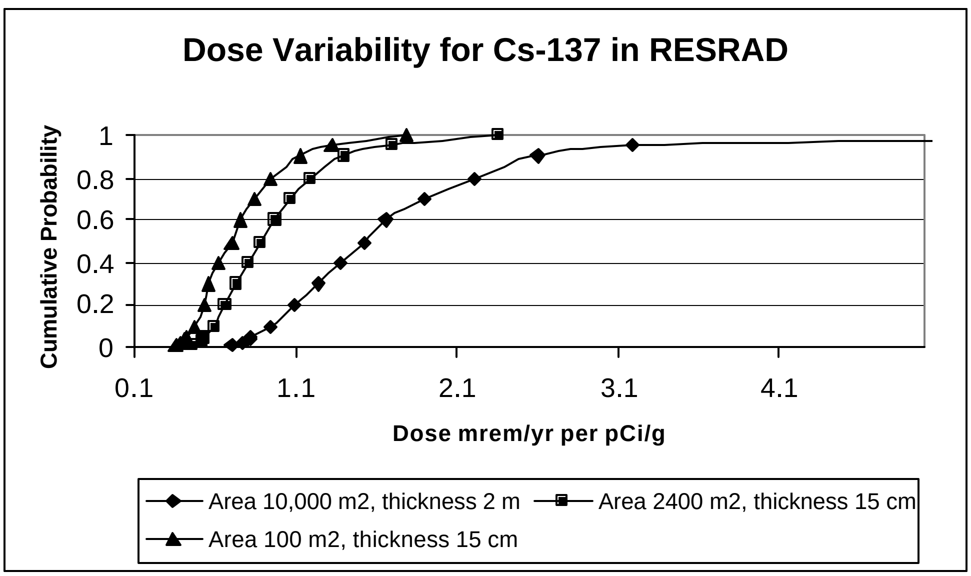


Figure 7.7 Dose Variability of Cs-137 for Three Source Configurations in RESRAD

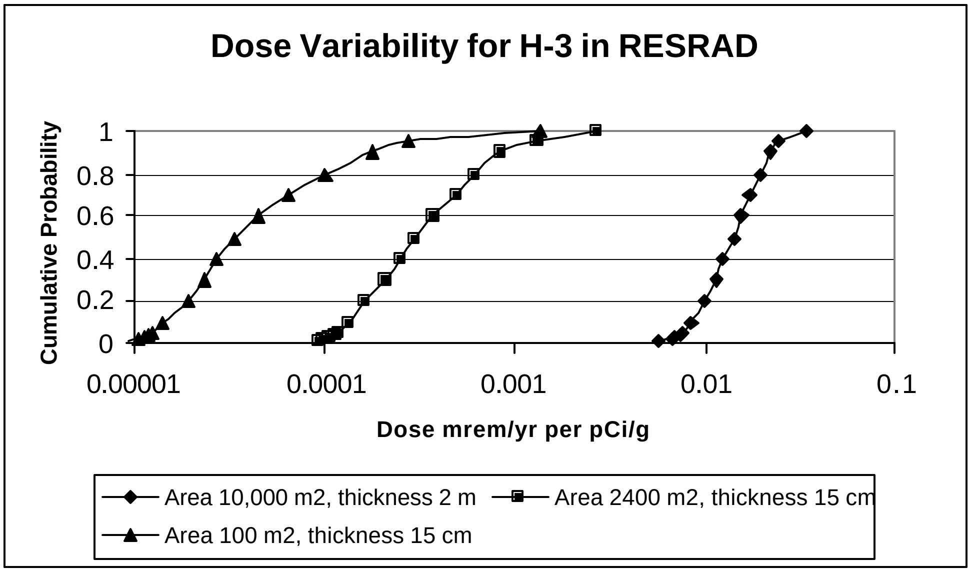


Figure 7.8 Dose Variability of H-3 for Three Source Configurations in RESRAD

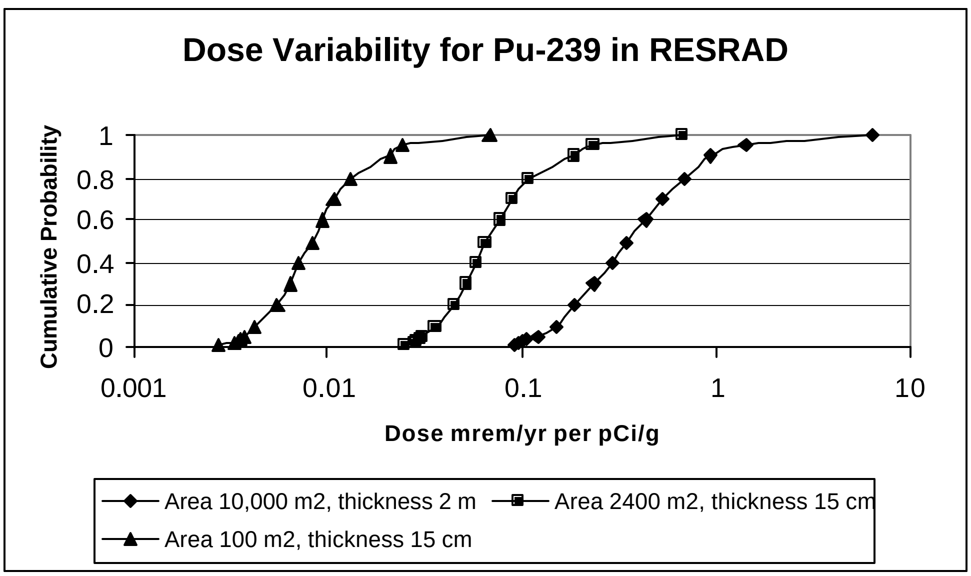


Figure 7.9 Dose Variability of Pu-239 for Three Source Configurations in RESRAD

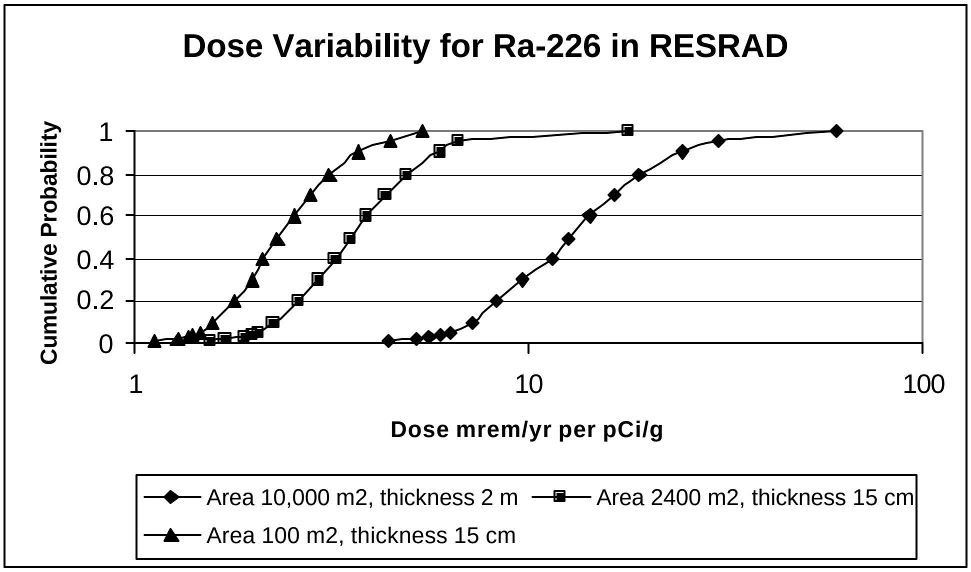


Figure 7.10 Dose Variability of Ra-226 for Three Source Configurations in RESRAD

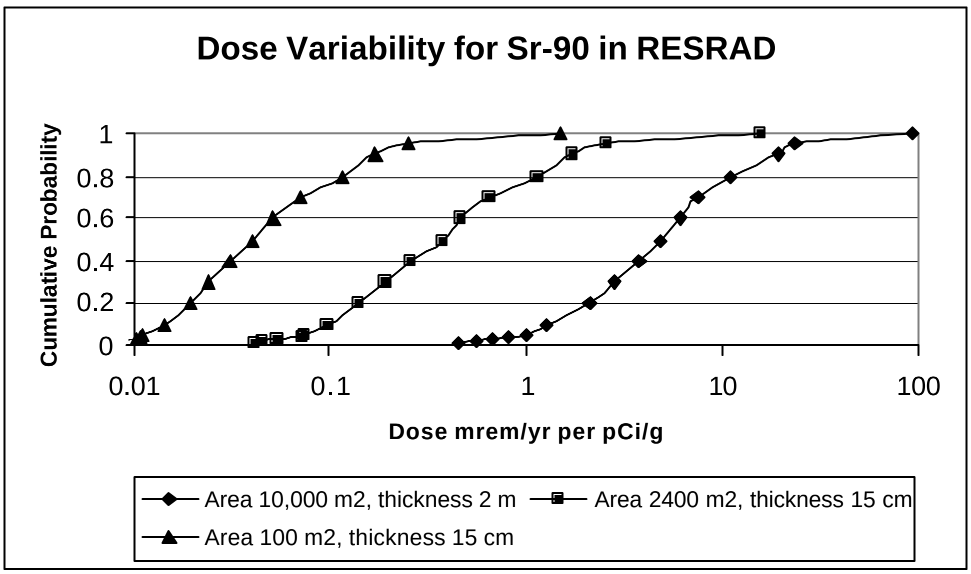


Figure 7.11 Dose Variability of Sr-90 for Three Source Configurations in RESRAD

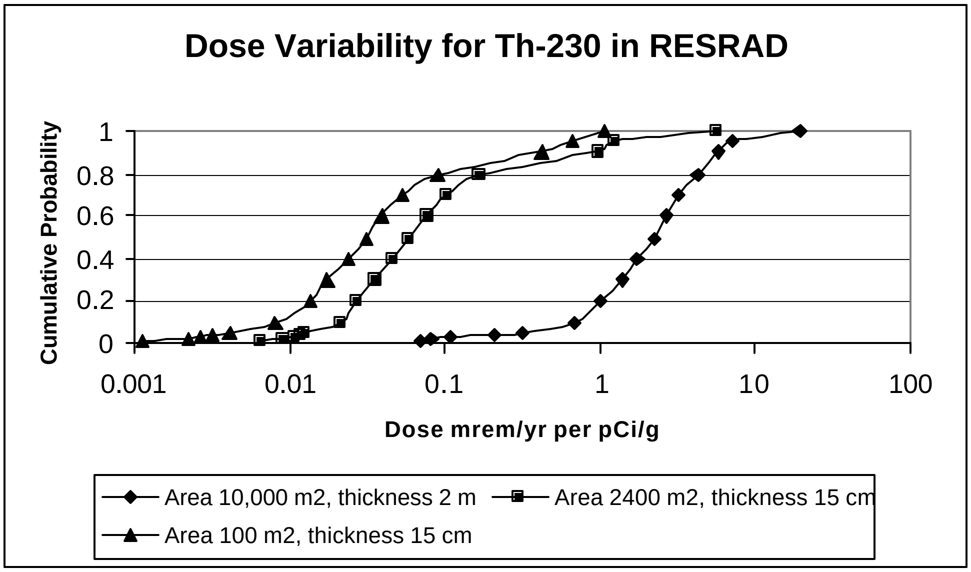


Figure 7.12 Dose Variability of Th-230 for Three Source Configurations in RESRAD

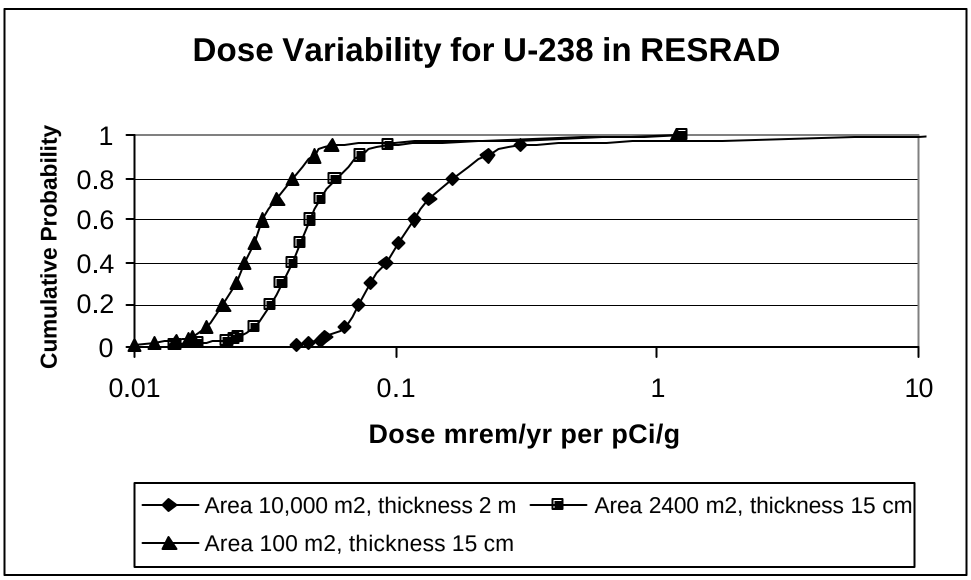


Figure 7.13 Dose Variability of U-238 for Three Source Configurations in RESRAD

Table 7.2. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 100 m^2 with Source Thickness of 15 cm						
Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Ac-227+D[c]	ext	None	SHF1	DCACTC(1)	BRTF(89,1)	DM
Ag-108m+D	ext	None	SHF1	DCACTC(1)		
Ag-110m+D	ext	None	SHF1	DCACTC(1)		
Al-26	ext	None	SHF1	DCACTC(1)		
Am-241	plant + ext	< 30	SHF1	BRTF(95,1)	DROOT	DM
Am-243+D	ext	None	SHF1	DROOT		
Au-195	ext	None	SHF1	DCACTC(1)		
Ba-133	ext	None	SHF1	DCACTC(1)		
Bi-207	ext	None	SHF1	DCACTC(1)		
C-14	plant	> 30 - < 300	DROOT	DMC	DCACTS(1)	DCACTU1(1)
Ca-41	plant	> 30 - < 300	BRTF(20,1)	DROOT	HCSZ	
Ca-45	plant	None	BRTF(20,1)	DROOT		
Cd-109	plant	None	BRTF(48,1)	DROOT	DCACTC(1)	SHF1
Ce-141	ext	None	SHF1			
Ce-144+D	ext	None	SHF1			
Cf-252	plant	None	BRTF(98,1)	DM	DROOT	MLINH
Cl-36	plant	< 30	BRTF(17,1)	DROOT	DCACTC(1)	RUNOFF
Cm-243	ext	None	SHF1	BRTF(96,1)	DROOT	DM
Cm-244	plant	None	BRTF(96,1)	DM	DROOT	SHF3
Cm-246	plant	None	BRTF(96,1)	DROOT	DM	WIND
Cm-247	ext	< 30	SHF1	BRTF(96,1)	VCZ	
Cm-248	plant	None	BRTF(96,1)	DROOT	DM	MLINH
Co-57	ext	None	SHF1	DCACTC(1)		
Co-60	ext	None	SHF1	DCACTC(1)		
Cs-134	ext	None	SHF1	DCACTC(1)		
Cs-135	plant	< 30	BRTF(55,1)	DROOT	BRTF(55,2)	DM
Cs-137+D	ext	None	SHF1	DCACTC(1)		
Eu-152	ext	None	SHF1	DCACTC(2)		
Eu-154	ext	None	SHF1	DCACTC(1)		
Eu-155	ext	None	SHF1	DCACTC(1)		
Fe-55	meat + plant	None	DM	BRTF(26,2)	BRTF(26,1)	DROOT
Fe-59	ext	None	SHF1	DCACTC(1)		
Gd-152	plant + inh	< 30	BRTF(64,1)	DM	MLINH	DROOT
Gd-153	ext	None	SHF1	DCACTC(1)		
Ge-68+D	ext	None	SHF1	DCACTC(1)		
H-3	water + plant	> 30 - < 300	DROOT	HCSZ	HGWT	H(1)
I-125	ext	None	SHF1	BRTF(53,1)	DCACTC(1)	DROOT
I-129	water + plant	> 30 - < 300	BRTF(53,1)	DROOT	DCACTC(1)	HCSZ
Ir-192	ext	None	SHF1	DCACTC(1)		
K-40	ext	None	SHF1	DCACTC(1)	BRTF(19,1)	RUNOFF
Mn-54	ext	None	SHF1	DCACTC(1)		

Table 7.2. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 100 m^2 with Source Thickness of 15 cm (Continued)						
Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Na-22	ext	None	SHF1	DCACTC(1)		
Nb-93m	ext + plant	None	SHF1	BRTF(41,1)	DROOT	DCACTC(1)
Nb-94	ext	None	SHF1	DCACTC(1)		
Nb-95	ext	None	SHF1	DCACTC(1)		
Ni-59	plant	None	BRTF(28,1)	DROOT	BRTF(28,3)	
Ni-63	plant	None	BRTF(28,1)	DROOT	BRTF(28,3)	
Np-237+D	plant + ext	< 30	BRTF(93,1)	SHF1	DROOT	DCACTC(1)
Pa-231	plant	> 30 - < 300	BRTF(91,1)	DCACTC(2)	VCZ	DROOT
Pb-210+D	plant	> 30 - < 300	DROOT	BRTF(82,1)	BRTF(84,1)	DM
Pm-147	ext + plant	None	SHF1	BRTF(61,1)	DROOT	BCZ
Po-210	plant	None	BRTF(84,1)	DROOT	DM	BRTF(84,2)
Pu-238	plant	None	BRTF(94,1)	DM	DROOT	MLINH
Pu-239	plant	None	BRTF(94,1)	DM	DROOT	MLINH
Pu-240	plant	None	BRTF(94,1)	DM	DROOT	MLINH
Pu-241+D	plant	> 30 - < 300	VCZ	SHF1	DCACTC(1)	DROOT
Pu-242	plant	None	BRTF(94,1)	DM	DROOT	MLINH
Pu-244+D	ext	None	SHF1	VCZ		
Ra-226+D	ext	< 30	SHF1	BRTF(88,1)	DROOT	VCZ
Ra-228+D	ext	> 30 - < 300	SHF1	VCZ	DROOT	BRTF(88,1)
Ru-106+D	ext	None	SHF1	DCACTC(1)		
S-35	plant + meat	None	BRTF(16,1)	DROOT	BRTF(16,2)	DCACTC(1)
Sb-124	ext	None	SHF1	DCACTC(1)		
Sb-125+D	ext	None	SHF1	DCACTC(2)		
Sc-46	ext	None	SHF1	DCACTC(1)		
Se-75	ext	None	SHF1			
Se-79	plant	None	BRTF(34,1)	DROOT	BRTF(34,2)	
Sm-147	plant	< 30	BRTF(62,1)	DROOT	DM	MLINH
Sm-151	plant	< 30	BRTF(62,1)	DROOT	DM	BRTF(62,2)
Sn-113	ext	None	SHF1	DCACTC(1)		
Sr-85	ext	None	SHF1	DCACTC(1)		
Sr-89	plant	None	BRTF(38,1)	DROOT	SHF1	DCACTC(1)
Sr-90+D	plant	< 30	BRTF(38,1)	DROOT	DCACTC(1)	SHF1
Ta-182	ext	None	SHF1	DCACTC(1)		
Tc-99	plant	< 30	BRTF(43,1)	DROOT	DCACTC(1)	RUNOFF
Te-125m	ext	None	SHF1	BRTF(52,1)	DCACTC(1)	DROOT
Th-228+D	ext	None	SHF1	DCACTC(1)		
Th-229+D	ext	None	SHF1	DCACTC(1)		
Th-230+D	ext	> 30 - < 300	VCZ	DCACTC(4)	SHF1	
Th-232	ext	> 30 - < 300	SHF1	VCZ	DCACTC(3)	
Tl-204	plant	None	BRTF(81,1)	SHF1	DROOT	DCACTC(1)
U-232	ext	> 30 - < 300	SHF1	DCACTC(2)	VCZ	

Table 7.2. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 100 m^2 with Source Thickness of 15 cm (Continued)

Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
U-233	ext + plant	> 30 - < 300	DCACTC(2)	VCZ	BRTF(92,1)	DROOT
U-234	plant	> 30 - < 300	BRTF(92,1)	DROOT	DM	VCZ
U-235+D	ext	< 30	SHF1	DCACTC(3)		
U-236	plant	< 30	BRTF(92,1)	DROOT	DM	MLINH
U-238+D	ext	< 30	SHF1	DCACTC(6)		
Zn-65	ext	None	SHF1	DCACTC(1)		
Zr-93	water	>30 - < 300	HCSZ	HGWT	H(1)	VCZ
Zr-95	ext	None	SHF1	DCACTC(3)		

[a] Pathways: ext = external, inh = inhalation, plant = plant ingestion, meat = meat ingestion, fish = fish ingestion, water = water ingestion.

[b] Parameters are listed only if PRCC was greater than 0.25. Descriptive name of the parameters is provided in Table B.1 in Appendix B. There are two indexes associated with BRTF, the first index represents the listing order of the responsible radionuclide in the RESRAD database and the second index represents whether it is plant ingestion (1), meat ingestion (2), or milk ingestion (3). DCACT's have one index associated with them, it indicates whether it is a principal radionuclide (index of 1) or a progeny in the chain.

[c] +D indicates, that associated radionuclides with half-lives less than 30 days are in secular equilibrium with the principal radionuclide.

Tables C.1 through C.3 in Appendix C. These tables also list radionuclides with their dominant pathways. Our analysis of the results indicated that only PRCC values of greater than 0.25 were significant; therefore, only the sensitive parameters with PRCC values of 0.25 or greater are listed in Tables 7.2 through 7.4 and Tables C.1 through C.3 in Appendix C.

For the external exposure pathway, the external gamma shielding factor was found to be the main contributor to dose variability. Three radionuclides (Co-60, Na-22, and Ag-108) for which external exposure was the dominant pathway were selected to study the effects of shielding factor on dose variability. Uncertainty runs were performed after removing the uncertainty on shielding factor for Co-60, Na-22, and Ag-108 for all three source configurations. It was observed that the dose variability was significantly reduced. Figure 7.14 shows the dose ratio (99th percentile dose to 50th percentile dose) with and without the shielding factor uncertainty.

For the plant ingestion pathway, plant transfer factors were found to be the main contributors to the dose variability. Three radionuclides

(Ca-41, Sr-90, and Cm-244) for which plant ingestion was the dominant pathway were selected to study the effect of the plant transfer factor. Uncertainty runs were performed after removing the uncertainty on plant transfer factor for Ca-41, Sr-90, and Cm-244 for all three source configurations. The dose variability was significantly reduced. Figure 7.15 shows the dose ratio (99th percentile dose to 50th percentile dose) with and without the plant transfer factor uncertainty. It was observed that for radionuclides for which peak dose was always at time 0, it was possible to get more than 90th percentile dose by just setting the external gamma shielding factor, plant transfer factor, and meat transfer factor at 90th percentile values (all other parameters were set at mean or median values).

As mentioned above, no single correlation or regression coefficient can be used to identify sensitive parameters in all the cases. The rankings based on the SRRC were not reliable in the residential scenario because of the strong input correlations between total porosity, effective porosity, and bulk density. It was observed that a large numerical value of SRRC for one parameter was being negated or

Table 7.3. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 2,400 m^2 with Source Thickness of 15 cm						
Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Ac-227+D[c]	plant	None	SHF1	BRTF(89,1)	DROOT	DM
Ag-108m+D	ext	None	SHF1	DCACTC(1)		
Ag-110m+D	ext	None	SHF1	DCACTC(1)		
Al-26	ext	None	SHF1	DCACTC(1)		
Am-241	plant	None	BRTF(95,1)	DROOT	DM	SHF1
Am-243+D	ext	None	SHF1	BRTF(95,1)	DROOT	DM
Au-195	ext	None	SHF1	DCACTC(1)		
Ba-133	ext	None	SHF1	DCACTC(1)		
Bi-207	ext	None	SHF1	DCACTC(1)		
C-14	plant	> 30 - < 300	DROOT	DMC	WIND	DCACTU1(1)
Ca-41	plant	< 30	BRTF(20,1)	DROOT	DCACTC(1)	HCSZ
Ca-45	plant	None	BRTF(20,1)	DROOT		
Cd-109	plant	None	BRTF(48,1)	DROOT	DCACTC(1)	
Ce-141	ext	None	SHF1			
Ce-144+D	ext	None	SHF1			
Cf-252	plant	None	BRTF(98,1)	DROOT	DM	
Cl-36	plant	None	BRTF(17,1)	DROOT	DCACTC(1)	BRTF(17,2)
Cm-243	ext	None	SHF1	BRTF(96,1)	DROOT	DM
Cm-244	plant	None	BRTF(96,1)	DROOT	DM	
Cm-246	plant	None	BRTF(96,1)	DROOT	DM	
Cm-247	ext	< 30	SHF1	BRTF(96,1)	DROOT	DM
Cm-248	plant	None	BRTF(96,1)	DROOT	DM	
Co-57	ext	None	SHF1	DCACTC(1)		
Co-60	ext	None	SHF1	DCACTC(1)		
Cs-134	ext	None	SHF1	DCACTC(1)	BRTF(55,1)	
Cs-135	plant	< 30	BRTF(55,1)	DROOT	BRTF(55,2)	DM
Cs-137+D	ext	None	SHF1	BRTF(55,1)	DCACTC(1)	DROOT
Eu-152	ext	None	SHF1	DCACTC(2)		
Eu-154	ext	None	SHF1	DCACTC(1)		
Eu-155	ext	None	SHF1	DCACTC(1)		
Fe-55	meat	None	DM	BRTF(26,2)	BRTF(26,1)	DROOT
Fe-59	ext	None	SHF1	DCACTC(1)		
Gd-152	plant	< 30	BRTF(64,1)	DROOT	DM	BRTF(64,2)
Gd-153	ext	None	SHF1	DCACTC(1)		
Ge-68+D	ext	None	SHF1	DCACTC(1)		
H-3	plant	> 30 - < 300	DROOT	RUNOFF	HCSZ	H(1)
I-125	plant	None	BRTF(53,1)	DROOT	DCACTC(1)	DM
I-129	water + plant	> 30 - < 300	BRTF(53,1)	DROOT	DCACTC(1)	HCSZ
Ir-192	ext	None	SHF1	DCACTC(1)		
K-40	ext + plant	None	SHF1	BRTF(19,1)	DROOT	DCACTC(1)

Mn-54	ext	None	SHF1	DCACTC(1)		
Na-22	ext	None	SHF1	DCACTC(1)		

Table 7.3. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 2,400 m^2 with Source Thickness of 15 cm (Continued)

Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Nb-93m	plant	None	BRTF(41,1)	DROOT	SHF1	DCACTC(1)
Nb-94	ext	None	SHF1	DCACTC(1)		
Nb-95	ext	None	SHF1	DCACTC(1)		
Ni-59	plant	None	BRTF(28,1)	DROOT	BRTF(28,3)	DM
Ni-63	plant	None	BRTF(28,1)	DROOT	BRTF(28,3)	DM
Np-237+D	plant	< 30	BRTF(93,1)	DROOT	DCACTC(1)	SHF1
Pa-231	plant	> 30 - < 300	BRTF(91,1)	DROOT	VCZ	DCACTC(2)
Pb-210+D	plant	> 30 - < 300	DROOT	BRTF(82,1)	BRTF(84,1)	DM
Pm-147	plant	None	BRTF(61,1)	DROOT	DM	BRTF(61,2)
Po-210	plant	None	BRTF(84,1)	DROOT	BRTF(84,2)	DM
Pu-238	plant	None	BRTF(94,1)	DROOT	DM	
Pu-239	plant	None	BRTF(94,1)	DROOT	DM	
Pu-240	plant	None	BRTF(94,1)	DROOT	DM	
Pu-241+D	plant	> 30 - < 300	DROOT	DM	BRTF(94,1)	BRTF(95,1)
Pu-242	plant	None	BRTF(94,1)	DROOT	DM	
Pu-244+D	ext	None	SHF1	BRTF(94,1)	DROOT	
Ra-226+D	ext + plant	> 30 - < 300	SHF1	BRTF(88,1)	DROOT	
Ra-228+D	ext + plant	> 30 - < 300	SHF1	BRTF(88,1)	DROOT	VCZ
Ru-106+D	ext	None	SHF1	BRTF(44,1)	DCACTC(1)	DROOT
S-35	meat	None	BRTF(16,1)	BRTF(16,2)	DROOT	DCACTC(1)
Sb-124	ext	None	SHF1	DCACTC(1)		
Sb-125+D	ext	None	SHF1	DCACTC(2)		
Sc-46	ext	None	SHF1	DCACTC(1)		
Se-75	ext	None	SHF1	BRTF(34,1)	DROOT	BRTF(34,2)
Se-79	meat	None	BRTF(34,1)	DROOT	BRTF(34,2)	DM
Sm-147	plant	< 30	BRTF(62,1)	DROOT	DM	BRTF(62,2)
Sm-151	plant	< 30	BRTF(62,1)	DROOT	BRTF(62,2)	DM
Sn-113	ext	None	SHF1	BRTF(50,1)	DCACTC(1)	DROOT
Sr-85	ext	None	SHF1	DCACTC(1)	RUNOFF	
Sr-89	plant	None	BRTF(38,1)	DROOT		
Sr-90+D	plant	None	BRTF(38,1)	DROOT	DCACTC(1)	
Ta-182	ext	None	SHF1	DCACTC(1)		
Tc-99	plant	< 30	BRTF(43,1)	DCACTC(1)	DROOT	RUNOFF
Te-125m	plant	None	BRTF(52,1)	DROOT	SHF1	DCACTC(1)
Th-228+D	ext	None	SHF1	DCACTC(1)		
Th-229+D	ext	None	SHF1	BRTF(90,1)	DROOT	DM
Th-230+D	ext	> 30 - < 300	VCZ	DCACTC(4)	SHF1	DROOT
Th-232	ext	> 30 - < 300	SHF1	VCZ	DCACTC(3)	BRTF(88,1)
Tl-204	plant	None	BRTF(81,1)	DROOT	DCACTC(1)	BRTF(81,2)
U-232	ext	> 30 - < 300	DCACTC(2)	SHF1	VCZ	
U-233	plant	> 30 - < 300	BRTF(92,1)	DROOT	DM	DCACTC(2)

Table 7.3. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 2,400 m^2 with Source Thickness of 15 cm (Continued)						
Radionuclid e	**Dominant Pathway[a]**	**Sample Runs with Peak Doses at Times Other Than Zero**	**Four Most Sensitive Parameters[b] Based on PRCC Analysis**			
			1	**2**	**3**	**4**
U-234	plant	< 30	BRTF(92,1)	DROOT	DM	
U-235+D	ext	< 30	SHF1	DCACTC(3)	BRTF(92,1)	
U-236	plant	< 30	BRTF(92,1)	DROOT	DM	DCACTC(4)
U-238+D	ext + plant	< 30	SHF1	BRTF(92,1)	DROOT	DCACTC(6)
Zn-65	ext	None	SHF1	BRTF(30,1)	DCACTC(1)	DROOT
Zr-93	water	> 30 - < 300	HCSZ	HGWT	H(1)	VCZ
Zr-95	ext	None	SHF1			

[a] Pathways: ext = external, inh = inhalation, plant = plant ingestion, meat = meat ingestion, fish = fish ingestion, water = water ingestion.

[b] Parameters are listed only if PRCC was greater than 0.25. Descriptive name of the parameters is provided in Table B.1 in Appendix B. There are two indexes associated with BRTF, the first index represents the listing order of the responsible radionuclide in the RESRAD database and the second index represents whether it is plant ingestion (1), meat ingestion (2), or milk ingestion (3). DCACT's have one index associated with them, it indicates whether it is a principal radionuclide (index of 1) or a progeny in the chain.

[c] +D indicates, that associated radionuclides with half-lives less than 30 days are in secular equilibrium with the principal radionuclide.

countered by the contributions of other correlated parameters for many radionuclides. Analysis of U-233 is presented as an example. Table 7.5 gives the PRCC and SRRC values for the four top ranked parameters for U-233 in two source configurations (100 m^2 area with a thickness of 15 cm and 10,000 m^2 area with a thickness of 2 m).

For the first source configuration (area = 2,400 m^2 and thickness = 15 cm), SRRC identified density of unsaturated zone (DENSUZ), total porosity of unsaturated zone (TPUZ), plant transfer factor for U-233 [BRTF(92,1)], and effective porosity of the unsaturated zone (EPUZ) as the top four ranked parameters. PRCC identified plant transfer factor for U-233 [BRTF(92,1)], depth of roots (DROOT), depth of mixing layer (DM), and distribution coefficient of contaminated zone [DCACTC(2)] as the top four ranked parameters. Figures 7.16 through 7.19 show the scatter plots of the four top ranked parameters identified by SRRC with the total dose. Scatter plots of DENSUZ (Figure 7.17), TPUZ (Figure 7.18), and EPUZ (Figure 7.19) show no clear relationship between dose and the respective parameter. High SRRC values are the artifact of the strong correlation between bulk density, total porosity, and effective porosity. The scatter plot of plant transfer factor for U-233 (Figure 7.16) shows some relationship with total dose.

For the second source configuration (area = 10,000 m^2 and thickness = 2 m) SRRC identified density of the saturated zone (DENSAQ), effective porosity of the saturated zone (EPSZ), total porosity of the saturated zone (TPSZ), and plant transfer factor for U-233 [BRTF(92,1)] as the top four ranked parameters. PRCC identified plant transfer factor for U-233 [BRTF(92,1)], depth of roots (DROOT), distribution coefficient of contaminated zone [DCACTC(2)], and erosion rate of contaminated zone (VCZ) as the top four ranked parameters. Figures 7.20 through 7.23 show the scatter plots of the four top ranked parameters identified by SRRC with the total dose. Scatter plots of DENSAQ (Figure 7.21), EPSZ (Figure 7.22), and TPSZ (Figure 7.23) show no clear relationship between dose and the respective parameter. High SRRC values are the artifact of the strong correlation between bulk density, total porosity, and effective porosity. The scatter plot of plant transfer factor for U-233 (Figure 7.20) shows some relationship with total dose.

Table 7.4. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 10,000 m^2 with Source Thickness of 2 m

Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Ac-227+D[c]	plant	None	BRTF(89,1)	SHF1	DROOT	
Ag-108m+D	ext	None	SHF1	DCACTC(1)		
Ag-110m+D	ext	None	SHF1			
Al-26	ext	< 30	SHF1	DCACTC(1)		
Am-241	plant	< 30	BRTF(95,1)	DROOT		
Am-243+D	plant	< 30	BRTF(95,1)	SHF1	DROOT	
Au-195	ext + plant	None	SHF1	BRTF(79,1)	DROOT	
Ba-133	ext	None	SHF1	BRTF(56,1)	DCACTC(1)	
Bi-207	ext	None	SHF1	BRTF(83,1)	DCACTC(1)	
C-14	plant	< 30	WIND	DROOT	DMC	DCACTS(1)
Ca-41	plant	> 30 - < 300	BRTF(20,1)	DROOT	BBIO(20,1)	HCSZ
Ca-45	plant	None	BRTF(20,1)	DROOT	BRTF(20,3)	
Cd-109	plant	None	BRTF(48,1)	DROOT	BRTF(48,3)	
Ce-141	ext	None	SHF1	BRTF(58,1)		
Ce-144+D	ext	None	SHF1	BRTF(58,1)		
Cf-252	plant	None	BRTF(98,1)	DROOT		
Cl-36	meat	None	BRTF(17,1)	BRTF(17,2)	DROOT	BRTF(17,3)
Cm-243	plant	None	BRTF(96,1)	SHF1	DROOT	BRTF(95,3)
Cm-244	plant	None	BRTF(96,1)	DROOT		
Cm-246	plant	None	BRTF(96,1)	DROOT		
Cm-247	plant	> 30 - < 300	BRTF(96,1)	SHF1	DROOT	
Cm-248	plant	None	BRTF(96,1)	DROOT		
Co-57	ext	None	SHF1	BRTF(27,1)	BRTF(27,2)	DROOT
Co-60	ext	None	SHF1	BRTF(27,1)	BRTF(27,2)	
Cs-134	ext	None	SHF1	BRTF(55,1)	DROOT	BRTF(55,2)
Cs-135	meat	None	BRTF(55,1)	BRTF(55,2)	DROOT	BRTF(55,3)
Cs-137+D	plant + ext	None	BRTF(55,1)	SHF1	DROOT	BRTF(55,2)
Eu-152	ext	None	SHF1	DCACTC(2)		
Eu-154	ext	None	SHF1	DCACTC(1)		
Eu-155	ext	None	SHF1	BRTF(63,1)	DCACTC(1)	
Fe-55	meat	None	BRTF(26,2)	BRTF(26,1)	DROOT	
Fe-59	ext	None	SHF1			
Gd-152	plant	< 30	BRTF(64,1)	BRTF(64,2)	DROOT	
Gd-153	ext	None	SHF1	BRTF(64,1)	DCACTC(1)	
Ge-68+D	ext + meat	None	SHF1	BRTF(32,1)	BRTF(32,2)	DROOT
H-3	plant	< 30	DROOT	RUNOFF	HCCZ	DCACTC(1)
I-125	plant+meat	None	BRTF(53,1)	BRTF(53,2)	DROOT	BRTF(53,3)
I-129	meat + water	> 30 - < 300	BRTF(53,1)	BRTF(53,2)	DROOT	HCSZ
Ir-192	ext	None	SHF1	BRTF(77,1)	DCACTC(1)	
K-40	plant	< 30	BRTF(19,1)	DROOT	SHF1	BRTF(19,3)
Mn-54	ext	None	SHF1	BRTF(25,1)	DROOT	

Na-22	ext	None	SHF1	BRTF(11,1)	DCACTC(1)	
Nb-93m	plant	None	BRTF(41,1)	DROOT	SHF1	

Table 7.4. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 10,000 m^2 with Source Thickness of 2 m (Continued)						
Radionuclide	Dominant Pathway[a]	Sample Runs with Peak Doses at Times Other Than Zero	Four Most Sensitive Parameters[b] Based on PRCC Analysis			
			1	2	3	4
Nb-94	ext	< 30	SHF1	DCACTC(1)		
Nb-95	ext	None	SHF1	BRTF(41,1)	DCACTC(1)	
Ni-59	plant	None	BRTF(28,1)	BRTF(28,3)	DROOT	BRTF(28,2)
Ni-63	plant	None	BRTF(28,1)	BRTF(28,3)	DROOT	BRTF(28,2)
Np-237+D	plant	< 30	BRTF(93,1)	DROOT	HCSZ	
Pa-231	plant	> 30 - < 300	BRTF(91,1)	DROOT	BRTF(89,1)	
Pb-210+D	plant	> 30 - < 300	BRTF(82,1)	BRTF(84,1)	DROOT	BRTF(84,2)
Pm-147	plant	None	BRTF(61,1)	BRTF(61,2)	DROOT	
Po-210	plant	None	BRTF(84,1)	DROOT	BRTF(84,2)	
Pu-238	plant	None	BRTF(94,1)	DROOT		
Pu-239	plant	None	BRTF(94,1)	DROOT		
Pu-240	plant	None	BRTF(94,1)	DROOT		
Pu-241+D	plant	> 30 - < 300	BRTF(95,1)	BRTF(94,1)	DROOT	
Pu-242	plant	< 30	BRTF(94,1)	DROOT		
Pu-244+D	ext	> 30 - < 300	SHF1	BRTF(94,1)	DROOT	
Ra-226+D	plant	> 30 - < 300	BRTF(88,1)	DROOT	BRTF(82,1)	BRTF(84,1)
Ra-228+D	plant	>30 - < 300	BRTF(88,1)	DROOT	SHF1	
Ru-106+D	ext + plant	None	SHF1	BRTF(44,1)	DROOT	
S-35	meat	None	BRTF(16,1)	BRTF(16,2)	DROOT	
Sb-124	ext	None	SHF1	BRTF(51,1)	DCACTC(1)	
Sb-125+D	ext	None	SHF1	BRTF(52,1)	DCACTC(2)	
Sc-46	ext	None	SHF1	DCACTC(1)	TPUZ(1)	
Se-75	meat	None	BRTF(34,1)	SHF1	BRTF(34,2)	DROOT
Se-79	meat	None	BRTF(34,1)	BRTF(34,2)	DROOT	BRTF(34,3)
Sm-147	plant	< 30	BRTF(62,1)	BRTF(62,2)	DROOT	
Sm-151	plant	< 30	BRTF(62,1)	BRTF(62,2)	DROOT	
Sn-113	ext + plant	None	SHF1	BRTF(50,1)	DROOT	BRTF(50,2)
Sr-85	ext	None	SHF1	BRTF(38,1)	DROOT	
Sr-89	plant	None	BRTF(38,1)	DROOT	BRTF(38,2)	
Sr-90+D	plant	None	BRTF(38,1)	DROOT	BRTF(38,2)	
Ta-182	ext	None	SHF1	DCACTC(1)		
Tc-99	plant	< 30	BRTF(43,1)	DROOT	DCACTC(1)	EVAPTR
Te-125m	plant	None	BRTF(52,1)	DROOT	BRTF(52,2)	SHF1
Th-228+D	ext	None	SHF1	BRTF(90,1)		
Th-229+D	plant	None	BRTF(90,1)	SHF1	DROOT	
Th-230+D	plant	> 30 - < 300	VCZ	DROOT	DCACTC(4)	BRTF(88,1)
Th-232	plant	300	BRTF(88,1)	SHF1	DROOT	BRTF(90,1)
Tl-204	plant+meat	None	BRTF(81,1)	BRTF(81,2)	DROOT	
U-232	ext	300	SHF1	DCACTC(2)	BRTF(92,1)	DROOT
U-233	plant	> 30 - < 300	BRTF(92,1)	DROOT	DCACTC(2)	VCZ
U-234	water + plant	> 30 - < 300	BRTF(92,1)	DROOT	DCACTU1(5)	

Table 7.4. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 10,000 m^2 with Source Thickness of 2 m (Continued)

U-235+D	plant	> 30 - < 300	SHF1	BRTF(92,1)	BRTF(91,1)	DCACTC(3)
U-236	plant	< 30	BRTF(92,1)	DROOT		
U-238+D	plant	< 30	BRTF(92,1)	SHF1	DROOT	

Table 7.4. Four Most Sensitive Parameters Based on PRCC Analysis, Dominant Pathways, and Number of Sample Runs with Peak Dose at Times Other Than Time Zero for Source Area of 10,000 m^2 with Source Thickness of 2 m (Continued)

Zn-65	meat	None	BRTF(30,1)	SHF1	DROOT	BRTF(30,2)
Zr-93	water	> 30 - < 300	H(1)	HCSZ	HGWT	FR9
Zr-95	ext	None	SHF1			

[a] Pathways: ext = external, inh = inhalation, plant = plant ingestion, meat = meat ingestion, fish = fish ingestion, water = water ingestion.

[b] Parameters are listed only if PRCC was greater than 0.25. Descriptive name of the parameters is provided in Table B.1 in Appendix B. There are two indexes associated with BRTF, the first index represents the listing order of the responsible radionuclide in the RESRAD database and the second index represents whether it is plant ingestion (1), meat ingestion (2), or milk ingestion (3). DCACT's have one index associated with them, it indicates whether it is a principal radionuclide (index of 1) or a progeny in the chain.

[c] +D indicates, that associated radionuclides with half-lives less than 30 days are in secular equilibrium with the principal radionuclide.

The example shown for U-233 illustrates that no single correlation or regression coefficient can be used to rank parameters in all cases. For some cases, SRRC would be appropriate, for example when the input parameters are not strongly correlated. Sometimes, PRCC would be appropriate, for example when nonlinear relationships are present. In still other cases, especially when combinations are involved, none of the correlation or regression coefficients may give an indication of the most significant parameter.

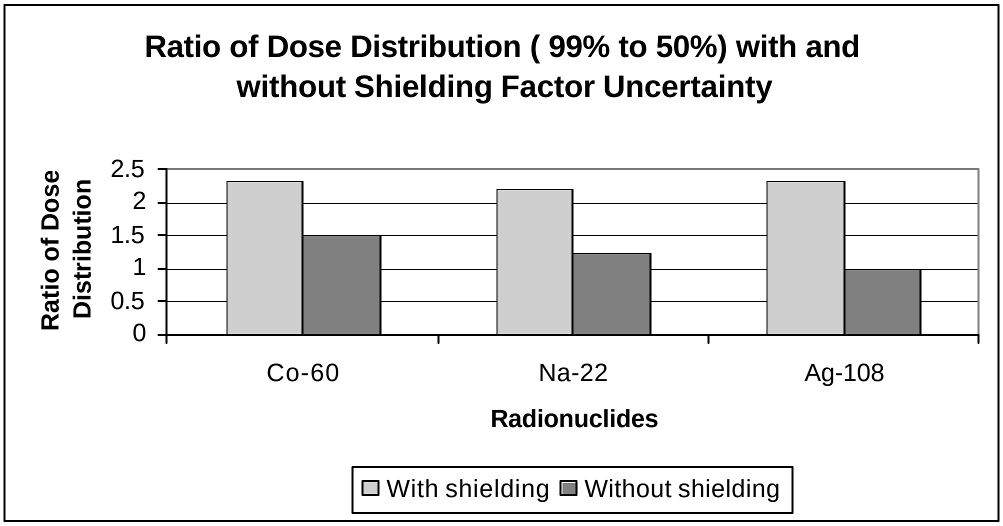
7.2 BUILDING OCCUPANCY SCENARIO

As was noted in the Parameter Ranking Report (Cheng et al., 1999), certain parameters have profound impacts on radiation doses, and for those parameters, site-specific information should always be used in dose calculations. For use of RESRAD-BUILD in evaluating the building occupancy scenario, such parameters include radionuclide concentrations and source area. The radionuclide concentration would affect the dose linearly, while the effect of source area may not be linear. This report analyzes the effect of parameter values on dose for area and volume sources for three different areas (36 m^2, 200 m^2, and 900 m^2).

Table B.3 (Appendix B) lists the parameter values and distribution types used in the analysis. As for the residential scenario using RESRAD, the stratified Monte-Carlo technique, LHS, was used with RESRAD-BUILD to estimate the dose distribution functions from the assigned parameter distribution functions. For each input variable, 300 sample values were generated. This set of inputs was then used to generate a set of outputs from which the probability statistics were generated. For the physical parameters, assigned distributions were used in the analysis. For the metabolic and behavioral parameters, mean or median values of the distributions were used. For the parameters not assigned distributions, RESRAD-BUILD default values were used, or in cases of overlap between RESRAD-BUILD and DandD input parameters, DandD default input parameter values were used if appropriate.

The results of the parameter sampling for the volume source for the building occupancy scenario are illustrated in Figures B.33 through B.41 in Appendix B. Two of the input parameters for the area source in the building occupancy scenario are different from the volume source. These two are the removable fraction and source lifetime; they are illustrated in Figures B.42 and B.43. Tritium volume source has a few different parameters, such as wet + dry zone thickness. Those parameters are illustrated in Figures B.44 through B.48. All those figures compare the sampling frequency or the cumulative probability of the physical

Figure 7.14 Ratio of Dose Distribution with and without Shielding Factor Distribution Uncertainty



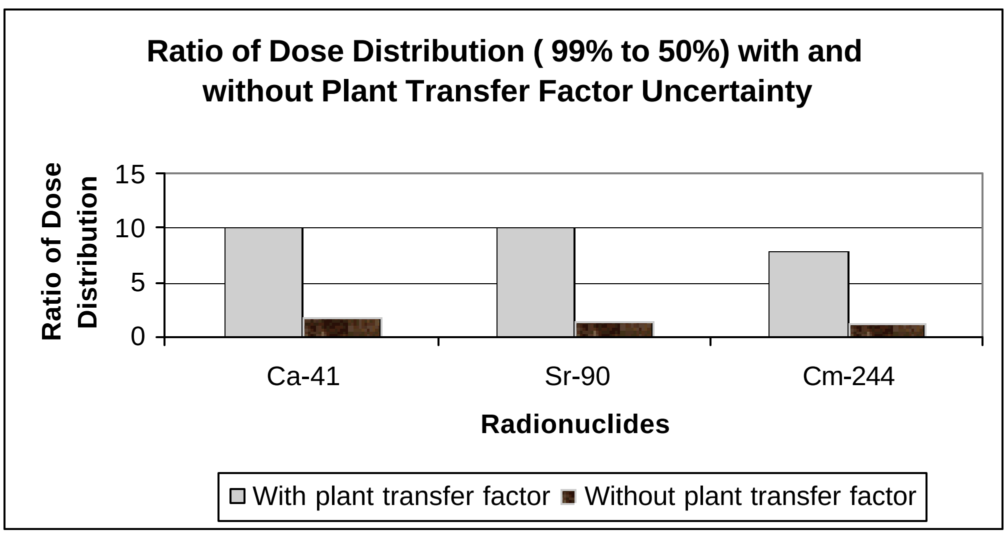


Figure 7.15 Ratio of Dose Distribution with and without Plant Transfer Factor Uncertainty

Table 7.5. PRCC and SRRC for Four Top Ranked Parameters for U-233 in Two Source Configurations								
Coefficient	Parameter	Coefficient Value	Parameter	Coefficient Value	Parameter	Coefficien t Value	Parameter	Coefficient Value
Source Configuration: Area = 2,400 m², thickness = 15 cm								
PRCC	BRTF(92,1)	0.67	DROOT	-0.58	DM	-0.45	DCACTC(2)	0.29
SRRC	DENSUZ(1)	0.98	TPUZ(1)	0.55	BRTF(92,1)	0.52	EPUZ(1)	0.49
Source Configuration: Area = 10,000 m², thickness = 2 m								
PRCC	BRTF(92,1)	0.78	DROOT	-0.40	DCACTC(2)	0.38	VCZ	-0.32
SRRC	DENSAQ	-1.58	EPSZ	-0.83	TPSZ	-0.82	BRTF(92,1)	0.67

parameter values based on LHS sampling and the probability density or the cumulative distribution function of the parameter.

7.2.1 Parameter Correlations

The Parameter Distribution Report (Biwer et al., 2000) identified correlations among the input parameters in RESRAD-BUILD. The parameters identified were air release fraction, deposition velocity, direct ingestion rate, indirect ingestion rate, indoor fraction, resuspension rate, source erosion rate, and source lifetime. The air release fraction, direct and indirect ingestion rate, and indoor fraction are behavioral parameters. These parameters were kept at a fixed value in the analysis. Source erosion rate and source lifetime are correlated with the fixed behavioral parameters. Positive correlation between deposition velocity and resuspension rate was studied for selected radionuclides. Results of the correlation analyses are presented in Section 7.2.4. However, no correlations were used in the dose distribution analyses for the radionuclides.

7.2.2 Dose Analysis Results

For each set of sampled parameter values, the dose to the average member of the critical group was calculated for unit concentrations of each radionuclide. For each source, the distribution describing possible doses to the average member of the critical group was then constructed from these calculated doses. The dose quantiles were estimated from the resulting dose distributions. The resultant dose distribution is for the dose at time zero. In all, 67 radionuclides for three source configurations (each for area and volume source) were analyzed.

7.2.2.1 Volume Source Analysis

Table 7.6 lists the quantile values (at 50th percentile and 90th percentile) of unit-source distribution for three volume sources (source1: source area = 36 m^2; source 2: source area = 200 m^2; and source 3: source area = 900 m^2) in the building occupancy scenario. Table 7.6 also shows the ratio of dose at the 95th percentile to that of the 50th percentile (median) dose. The dose ratio shows the dose spread for different radionuclides. Dose values at the selected quantiles can be used to calculate the source concentration equivalent to a dose value of 25 mrem/yr.

For source 1, the dose ratio varies from 3.35 (U-232) to 501 (I-129). For source 2, the dose ratio varies from 3.38 (Th-232) to 180 (I-129). For source 3, the dose ratio varies from 3.15 (U-232) to 144 (Au-195). For some radionuclides, the dose ratio remains almost the same for the three source configurations (e.g., Ca-41, Cm-244, Cm-248, Fe-55, Gd-152, H-3, Ni-59, and Ni-63), while wide variations are observed for others (e.g., C-14, Am-241,

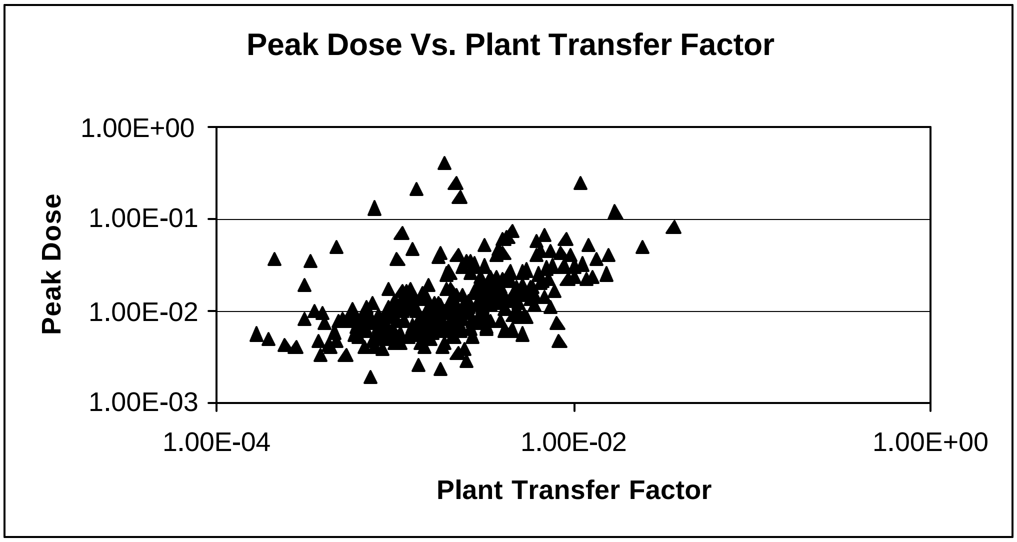


Figure 7.16 Scatter Plot of the Peak Dose vs. U-233 Plant Transfer Factor for Source Area = 2,400 m^2 and Thickness = 15 cm

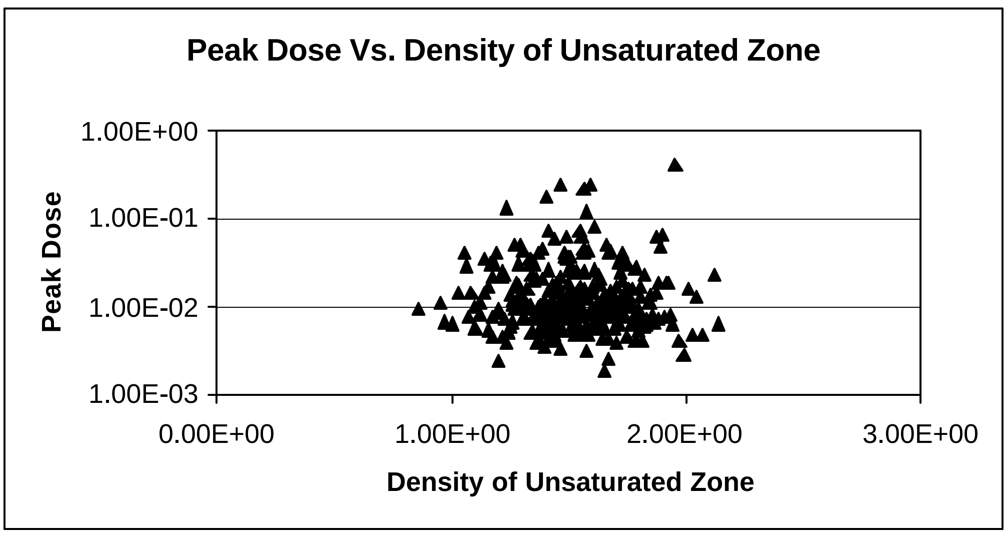


Figure 7.17 Scatter Plot of the Peak Dose vs. Density of Unsaturated Zone for Source Area = 2,400 m^2 and Thickness = 15 cm

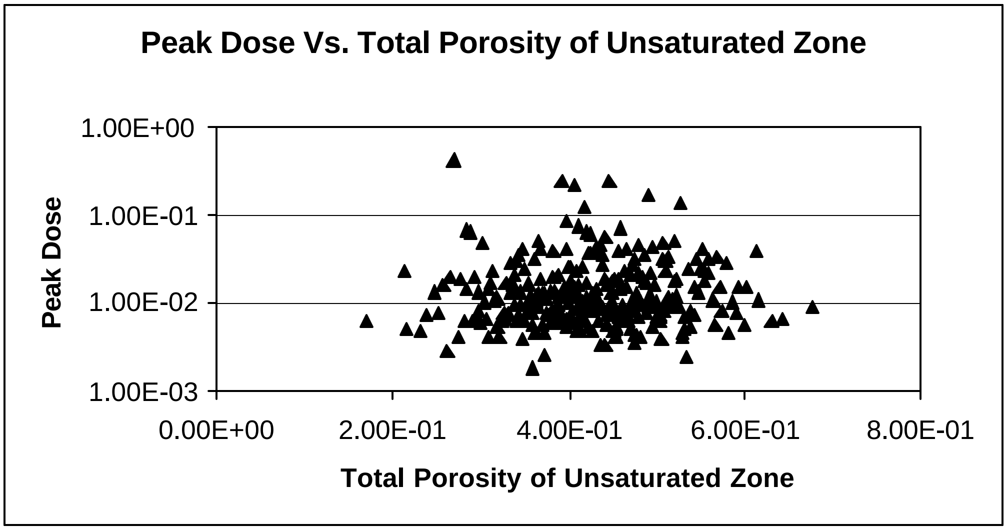


Figure 7.18 Scatter Plot of the Peak Dose vs. Total Porosity of Unsaturated Zone for Source Area = 2,400 m^2 and Thickness = 15 cm

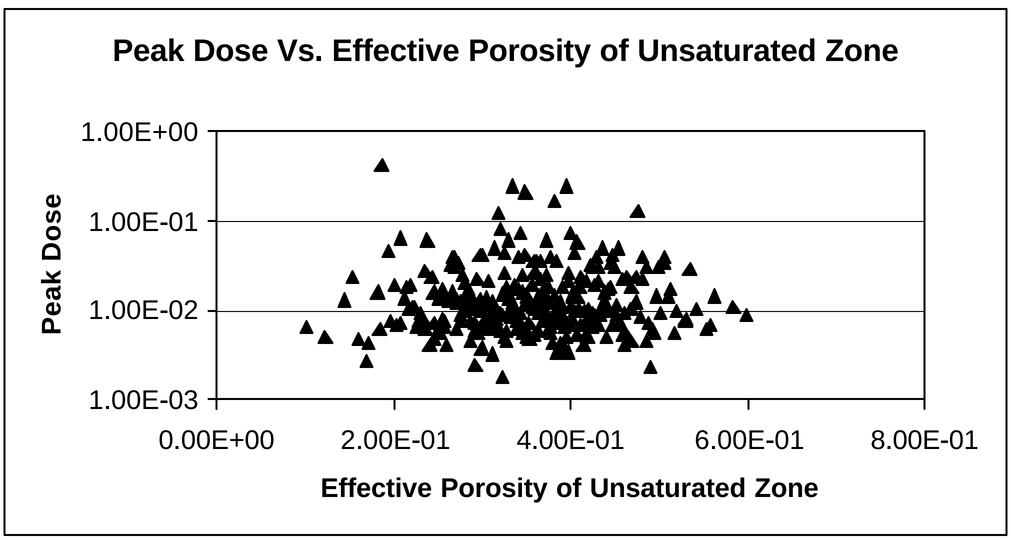


Figure 7.19 Scatter Plot of the Peak Dose vs. Effective Porosity of Unsaturated Zone for Source Area = 2,400 m^2 and Thickness = 15 cm

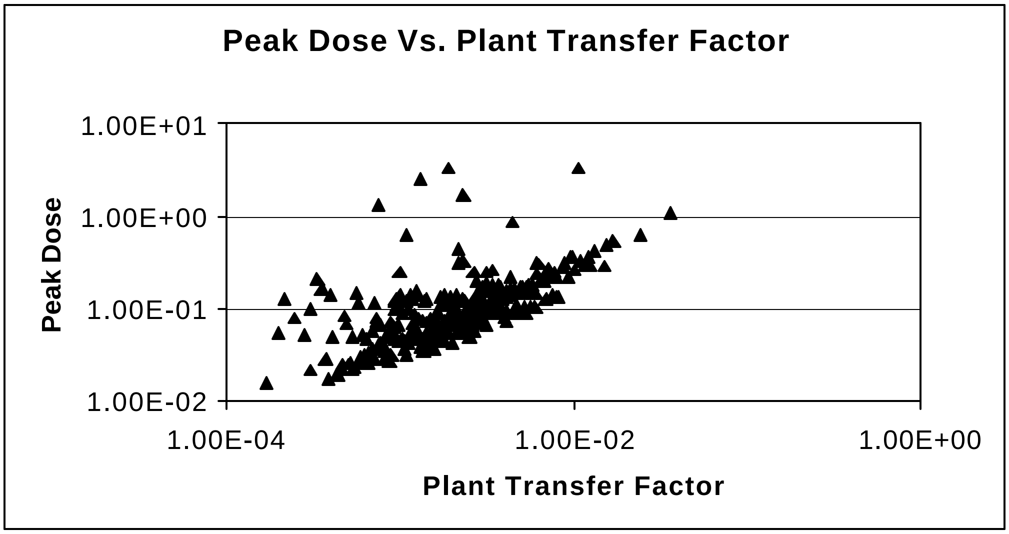


Figure 7.20 Scatter Plot of the Peak Dose vs. U-233 Plant Transfer Factor for Source Area = 10,000 m^2 and Thickness = 2 m

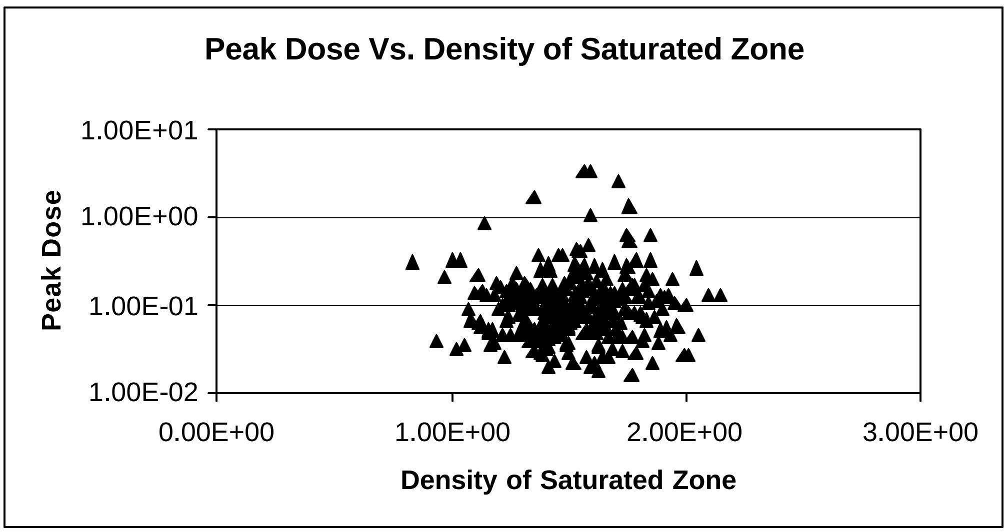


Figure 7.21 Scatter Plot of the Peak Dose vs. Density of Saturated Zone for Source Area = 10,000 m^2 and Thickness = 2 m

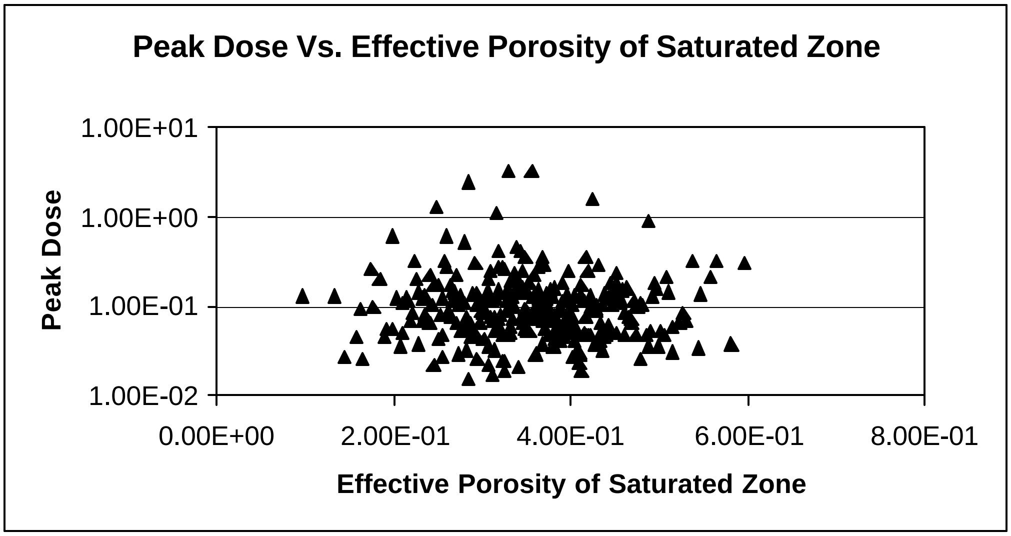


Figure 7.22 Scatter Plot of the Peak Dose vs. Effective Porosity of Saturated Zone for Source Area = 10,000 m^2 and Thickness = 2 m

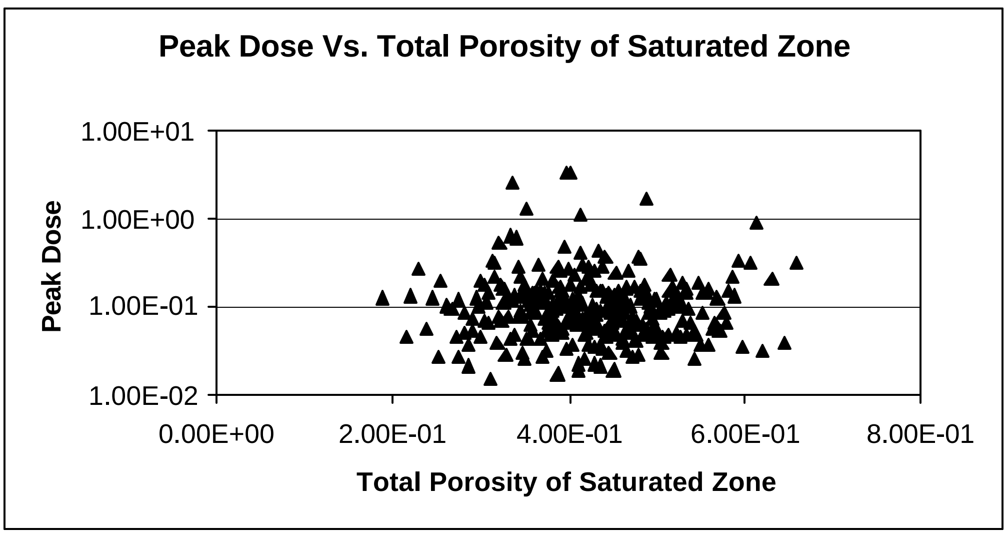


Figure 7.23 Scatter Plot of the Peak Dose vs. Total Porosity of Saturated Zone for Source Area = 10,000 m^2 and Thickness = 2 m

Table 7.6. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Areas for a Volume Source in the Building Occupancy Scenario									
	Source 1: Area = 36 m^2			Source 2: Area = 200 m^2			Source 3: Area = 900 m^2		
Radionuclide	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**
Ac-227	7.44E-02	3.72E-01	5.86E+00	1.34E-01	5.21E-01	4.68E+00	2.88E-01	8.73E-01	4.38E+00
Ag-108	4.39E-01	1.85E+00	4.83E+00	4.40E-01	2.11E+00	5.75E+00	4.40E-01	2.16E+00	5.95E+00
Ag-110	5.62E-01	2.10E+00	4.23E+00	5.67E-01	2.42E+00	4.97E+00	5.67E-01	2.51E+00	5.24E+00
Al-26	1.05E+00	3.40E+00	3.59E+00	1.07E+00	3.97E+00	4.23E+00	1.07E+00	4.05E+00	4.39E+00
Am-241	6.75E-04	4.80E-03	1.03E+01	2.94E-03	1.20E-02	7.28E+00	1.16E-02	5.10E-02	7.91E+00
Am-243	1.12E-02	1.35E-01	1.48E+01	1.68E-02	1.56E-01	1.15E+01	3.55E-02	1.88E-01	6.39E+00
Au-195	1.16E-04	9.77E-03	1.33E+02	1.16E-04	1.00E-02	1.43E+02	1.16E-04	1.00E-02	1.44E+02
Bi-207	4.63E-01	1.80E+00	4.38E+00	4.78E-01	2.07E+00	5.02E+00	4.78E-01	2.12E+00	5.36E+00
C-14	1.56E-08	7.59E-07	7.18E+01	4.46E-08	1.20E-06	4.91E+01	1.50E-07	2.00E-06	3.82E+01
Ca-41	2.00E-09	3.53E-08	6.80E+01	1.11E-08	1.96E-07	6.79E+01	4.99E-08	8.82E-07	6.79E+01
Cd-109	2.26E-05	8.91E-04	5.66E+01	2.31E-05	9.35E-04	6.10E+01	2.86E-05	9.74E-04	4.97E+01
Ce-144	9.28E-03	3.85E-02	4.74E+00	9.85E-03	4.43E-02	5.34E+00	9.85E-03	4.53E-02	5.56E+00
Cf-252	1.24E-04	5.21E-04	8.05E+00	6.82E-04	2.90E-03	8.06E+00	3.06E-03	1.30E-02	8.10E+00
Cl-36	5.23E-05	3.96E-04	9.22E+00	5.25E-05	4.57E-04	1.09E+01	5.33E-05	4.91E-04	1.11E+01
Cm-243	1.09E-02	9.68E-02	1.06E+01	1.43E-02	1.14E-01	9.65E+00	2.61E-02	1.34E-01	6.09E+00
Cm-244	2.24E-04	9.68E-04	8.17E+00	1.24E-03	5.38E-03	8.23E+00	5.56E-03	2.42E-02	8.24E+00
Cm-248	1.64E-03	7.68E-03	8.29E+00	9.11E-03	4.27E-02	8.32E+00	4.10E-02	1.92E-01	8.32E+00
Co-57	3.07E-03	4.82E-02	1.97E+01	3.07E-03	5.14E-02	2.22E+01	3.07E-03	5.14E-02	2.30E+01
Co-60	9.37E-01	2.98E+00	3.52E+00	9.53E-01	3.47E+00	4.14E+00	9.53E-01	3.54E+00	4.30E+00
Cs-134	3.87E-01	1.56E+00	4.57E+00	3.98E-01	1.80E+00	5.23E+00	3.98E-01	1.83E+00	5.55E+00
Cs-135	8.43E-08	2.88E-06	4.93E+01	1.85E-07	4.47E-06	4.03E+01	4.54E-07	6.72E-06	4.38E+01
Cs-137	1.60E-01	6.52E-01	4.64E+00	1.61E-01	7.47E-01	5.45E+00	1.61E-01	7.64E-01	5.73E+00
Eu-152	3.72E-01	1.31E+00	3.98E+00	3.75E-01	1.52E+00	4.67E+00	3.75E-01	1.55E+00	4.91E+00
Eu-154	4.10E-01	1.39E+00	3.85E+00	4.15E-01	1.62E+00	4.51E+00	4.15E-01	1.66E+00	4.80E+00
Eu-155	5.07E-04	1.74E-02	4.97E+01	5.07E-04	1.79E-02	5.40E+01	5.08E-04	1.80E-02	5.43E+01
Fe-55	2.58E-09	1.15E-08	8.49E+00	1.43E-08	6.40E-08	8.46E+00	6.45E-08	2.87E-07	8.47E+00
Gd-152	2.28E-04	9.66E-04	8.03E+00	1.27E-03	5.37E-03	8.03E+00	5.70E-03	2.42E-02	8.04E+00
Gd-153	2.53E-04	1.28E-02	7.75E+01	2.53E-04	1.29E-02	8.14E+01	2.53E-04	1.29E-02	8.14E+01
Ge-68	1.64E-01	7.16E-01	5.02E+00	1.64E-01	8.24E-01	6.03E+00	1.64E-01	8.32E-01	6.22E+00
H-3	1.74E-04	1.40E-03	1.44E+01	9.68E-04	7.80E-03	1.44E+01	4.35E-03	3.51E-02	1.44E+01
I-129	5.79E-07	8.17E-05	5.01E+02	2.78E-06	2.46E-04	1.80E+02	9.70E-06	5.05E-04	1.29E+02

K-40	6.48E-02	2.03E-01	3.46E+00	6.71E-02	2.37E-01	4.02E+00	6.71E-02	2.43E-01	4.20E+00
Mn-54	1.78E-01	6.81E-01	4.32E+00	1.82E-01	7.84E-01	5.01E+00	1.82E-01	8.06E-01	5.33E+00

Table 7.6. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Areas for a Volume Source in the Building Occupancy Scenario (Continued)

	Source 1: Area = 36 m^2			Source 2: Area = 200 m^2			Source 3: Area = 900 m^2		
Radionuclide	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%
Na-22	6.26E-01	2.35E+00	4.23E+00	6.30E-01	2.70E+00	4.97E+00	6.30E-01	2.76E+00	5.24E+00
Nb-94	4.71E-01	1.87E+00	4.52E+00	4.92E-01	2.17E+00	5.10E+00	4.92E-01	2.21E+00	5.43E+00
Ni-59	3.12E-09	2.23E-08	1.48E+01	1.73E-08	1.24E-07	1.49E+01	7.79E-08	5.58E-07	1.48E+01
Ni-63	7.20E-09	4.81E-08	1.39E+01	4.00E-08	2.67E-07	1.40E+01	1.80E-07	1.20E-06	1.39E+01
Np-237	3.02E-02	1.99E-01	7.68E+00	3.63E-02	2.29E-01	7.63E+00	6.14E-02	2.65E-01	5.15E+00
Pa-231	1.00E-02	4.36E-02	5.04E+00	2.15E-02	6.70E-02	4.02E+00	5.00E-02	1.69E-01	5.98E+00
Pb-210	1.19E-04	6.98E-04	7.68E+00	3.17E-04	1.81E-03	8.90E+00	8.78E-04	7.62E-03	1.45E+01
Pm-147	1.58E-07	4.27E-06	3.68E+01	3.84E-07	4.77E-06	1.79E+01	1.11E-06	6.68E-06	7.98E+00
Pu-238	3.78E-04	1.64E-03	8.28E+00	2.07E-03	9.13E-03	8.41E+00	9.31E-03	4.11E-02	8.41E+00
Pu-239	4.52E-04	1.99E-03	7.85E+00	2.37E-03	1.11E-02	8.31E+00	1.07E-02	4.98E-02	8.29E+00
Pu-240	4.26E-04	1.99E-03	8.33E+00	2.37E-03	1.10E-02	8.31E+00	1.07E-02	4.96E-02	8.29E+00
Pu-241	8.95E-06	3.32E-05	7.39E+00	4.37E-05	1.84E-04	8.08E+00	1.93E-04	8.30E-04	8.13E+00
Pu-242	4.08E-04	1.91E-03	8.33E+00	2.27E-03	1.06E-02	8.33E+00	1.02E-02	4.77E-02	8.32E+00
Pu-244	3.73E-01	1.51E+00	4.56E+00	3.83E-01	1.73E+00	5.22E+00	4.01E-01	1.79E+00	5.31E+00
Ra-226	6.24E-01	2.16E+00	3.91E+00	6.35E-01	2.53E+00	4.58E+00	6.35E-01	2.58E+00	4.72E+00
Ra-228	3.79E-01	1.37E+00	4.09E+00	3.86E-01	1.59E+00	4.77E+00	3.86E-01	1.64E+00	5.00E+00
Ru-106	4.33E-02	1.80E-01	4.73E+00	4.35E-02	2.06E-01	5.61E+00	4.35E-02	2.10E-01	5.86E+00
Sb-125	9.11E-02	4.13E-01	5.24E+00	9.13E-02	4.75E-01	6.25E+00	9.13E-02	4.78E-01	6.42E+00
Sm-147	7.04E-05	3.07E-04	8.01E+00	3.91E-04	1.71E-03	8.01E+00	1.76E-03	7.68E-03	8.01E+00
Sm-151	3.06E-08	1.37E-07	8.07E+00	1.69E-07	7.50E-07	8.11E+00	7.42E-07	3.38E-06	8.33E+00
Sr-90	1.89E-04	1.77E-03	1.24E+01	2.12E-04	1.77E-03	1.11E+01	3.17E-04	1.86E-03	7.54E+00
Tc-99	3.83E-07	1.25E-05	4.62E+01	5.74E-07	1.39E-05	3.48E+01	1.10E-06	1.60E-05	1.89E+01
Th-228	5.34E-01	1.66E+00	3.43E+00	5.69E-01	1.95E+00	3.88E+00	5.84E-01	2.00E+00	3.99E+00
Th-229	5.30E-02	2.79E-01	6.28E+00	7.77E-02	3.49E-01	5.34E+00	1.51E-01	4.65E-01	4.05E+00
Th-230	5.37E-04	1.61E-03	5.07E+00	1.94E-03	7.58E-03	7.27E+00	7.99E-03	3.40E-02	7.75E+00

Table 7.6. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per pCi/g) for Three Source Areas for a Volume Source in the Building Occupancy Scenario (Continued)

Th-232	2.46E-02	7.57E-02	3.53E+00	3.93E-02	1.06E-01	3.38E+00	7.56E-02	2.12E-01	4.55E+00
Tl-204	7.24E-06	3.51E-04	7.25E+01	7.25E-06	3.59E-04	7.82E+01	7.38E-06	3.59E-04	7.71E+01
U-232	9.58E-02	2.92E-01	3.35E+00	1.09E-01	3.47E-01	3.67E+00	1.42E-01	3.93E-01	3.15E+00
U-233	2.07E-04	6.55E-04	5.41E+00	7.75E-04	3.18E-03	7.60E+00	3.35E-03	1.41E-02	7.67E+00
U-234	1.32E-04	5.50E-04	7.80E+00	7.19E-04	3.06E-03	7.75E+00	3.13E-03	1.36E-02	7.96E+00
U-235	1.29E-02	1.27E-01	1.18E+01	1.41E-02	1.46E-01	1.26E+01	2.08E-02	1.53E-01	8.94E+00
U-236	1.25E-04	5.21E-04	7.65E+00	6.59E-04	2.88E-03	7.97E+00	2.96E-03	1.29E-02	7.97E+00
U-238	6.59E-03	2.37E-02	4.14E+00	7.64E-03	2.76E-02	4.42E+00	1.22E-02	3.56E-02	3.75E+00
Zn-65	1.27E-01	4.45E-01	3.96E+00	1.29E-01	5.21E-01	4.66E+00	1.29E-01	5.34E-01	4.82E+00

Cs-135, I-129, and Pm-147). Figures 7.24 through 7.33 show the dose variability for Am-241, C-14, Co-60, Cs-137, H-3, Pu-239, Ra-226, Sr-90, Th-230, and U-238 in the building occupancy scenario for all three volume sources.

7.2.2.2 Area Source Analysis

Table 7.7 lists the quantile values (at 50th percentile and 90th percentile) of unit-source distribution for three area sources [source 1: source area = 36 m^2; source 2: source area = 200 m^2; and source 3: source area = 900 m^2] in the building occupancy scenario. Table 7.7 also shows the ratio of dose at the 95th percentile to that at the 50th percentile (median). The dose ratio shows the dose spread for different radionuclides. Dose values at the selected quantiles can be used to calculate the source concentration equivalent to a dose value of 25 mrem/yr.

For source 1, the dose ratio varies from 2.55 (K-40) to 135 (Au-195). For source 2, the dose ratio varies from 3.34 (Ra-228) to 121 (Au-195). For source 3, the dose ratio varies from 4.50 (K-40) to 81.9 (Au-195). For some radionuclides, the dose ratio remains almost the same in all three source configurations (e.g., Am-241, Ca-41, Cm-244, and Cm-248), while wide variations are observed for others (e.g., Au-195, C-14, and Cs-135). Figures 7.34 through 7.43 show the dose variability for Am-241, C-14, Co-60, Cs-137, H-3, Pu-239, Ra-226, Sr-90, Th-230, and U-238 in the building occupancy scenario for all three area sources.

7.2.3 Dominant Pathways and Sensitive Parameters

The results of the probabilistic dose calculations can be processed to identify parameters controlling dose variability for each radionuclide. The dependence of dose on the model parameter values is complex; total dose may depend non-monotonically on the parameter value, or may be sensitive to the parameter value only within certain limits, or only in conjunction with certain ranges of values for other parameters. Because of these complexities, no single regression analysis can be used to identify the sensitive parameters. RESRAD-BUILD output provides PCC, SRC, PRCC, and SRRC values and scatter plots. These aids, along with expert judgment, should be used to identify sensitive parameters. In this analysis, SRRC was used as an example to identify sensitive parameters. The effect of sensitive parameters was then studied for selected radionuclides by determining the dose variability with and without the uncertainty of the sensitive parameter. For the RESRAD-BUILD code, either the default value or the mean value of the distribution of the sensitive parameter was used to determine sensitivity on these parameters.

7.2.3.1 Dominant Pathways and Sensitive Parameters in Volume Source

Tables 7.8 through 7.10 list the four most sensitive parameters based on SRRC along with the dominant pathway for three sources. Tables C.4 through C.6 in Appendix C present detailed information, including SRRC values. Only sensitive parameters with SRRC values of 0.1 or greater are listed in these tables. An SRRC value of 0.1 means that one standard deviation change in the parameter value will change the resultant dose by 0.1 times the standard deviation of the dose.

For radionuclides for which external exposure was the dominant pathway, shielding thickness was found to be the dominant contributor to the dose variability. Three radionuclides (Cs-137, Mn-54, and Pu-244) were selected to study the effect of shielding thickness. It was observed after removing the shielding thickness from the uncertainty analysis that dose variability was significantly reduced. The dose ratio (95th percentile dose to 50th percentile dose) with

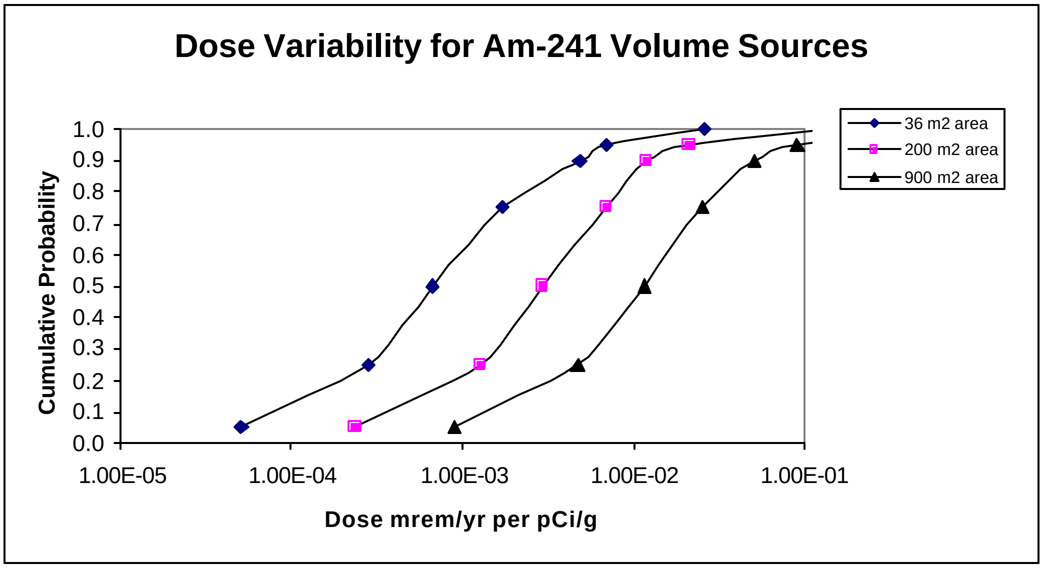


Figure 7.24 Dose Variability of Am-241 for a Volume Source with Three Source Areas in Building Occupancy Scenario

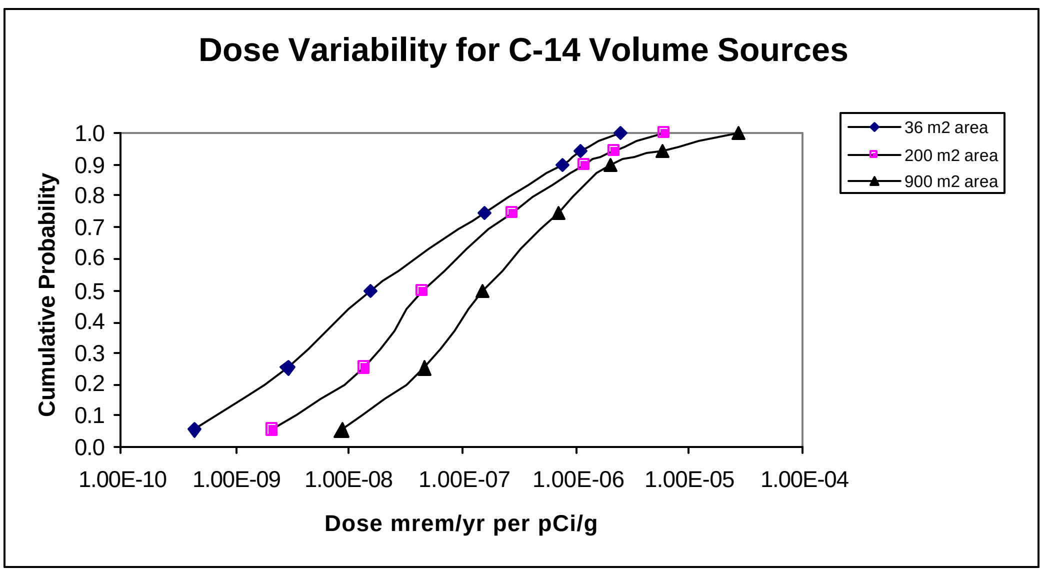


Figure 7.25 Dose Variability of C-14 for a Volume Source with Three Source Areas in Building Occupancy Scenario

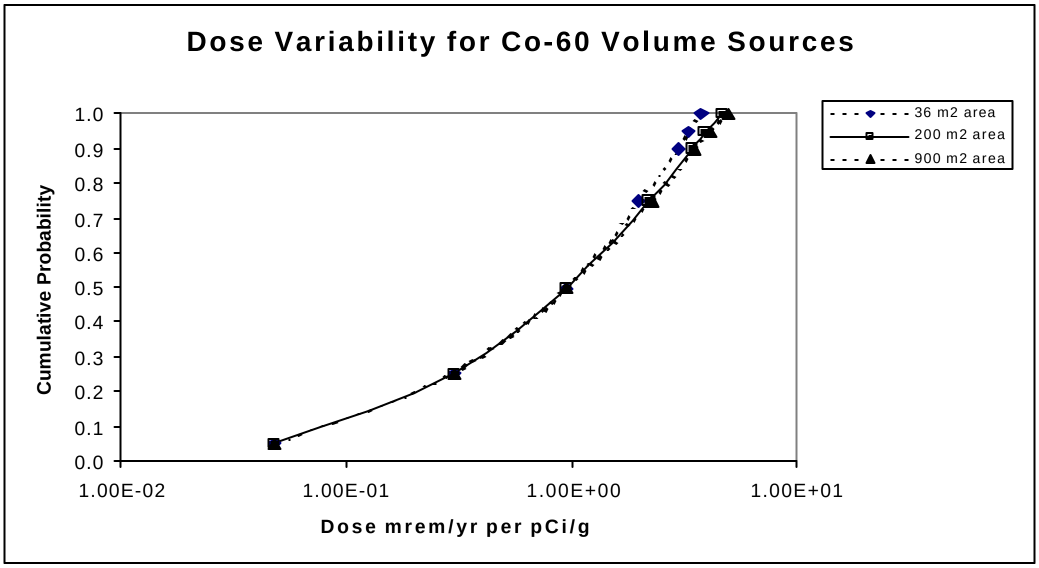


Figure 7.26 Dose Variability of Co-60 for a Volume Source with Three Source Areas in Building Occupancy Scenario

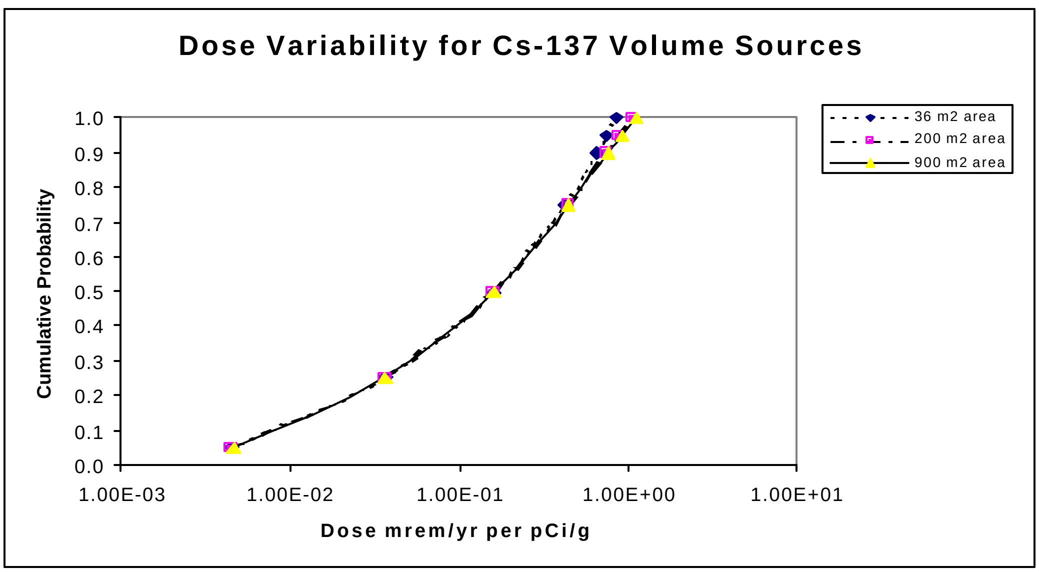


Figure 7.27 Dose Variability of Cs-137 for a Volume Source with Three Source Areas in Building Occupancy Scenario

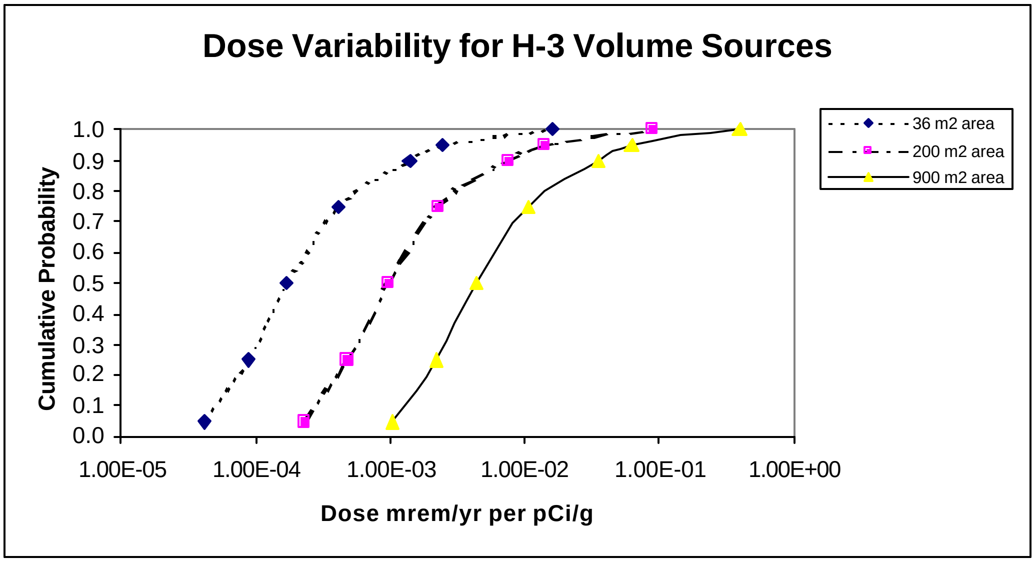


Figure 7.28 Dose Variability of H-3 for a Volume Source with Three Source Areas in Building Occupancy Scenario

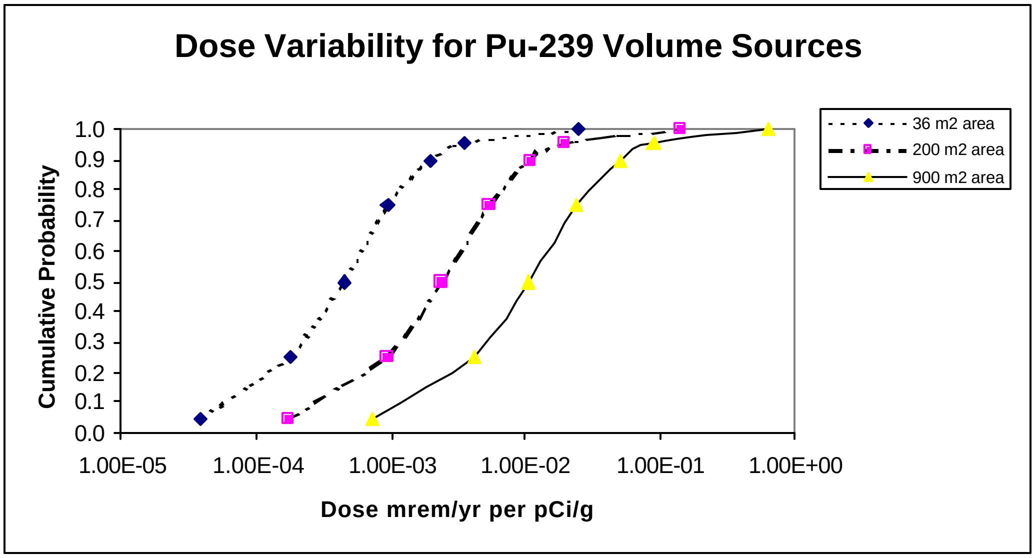


Figure 7.29 Dose Variability of Pu-239 for a Volume Source with Three Source Areas in Building Occupancy Scenario

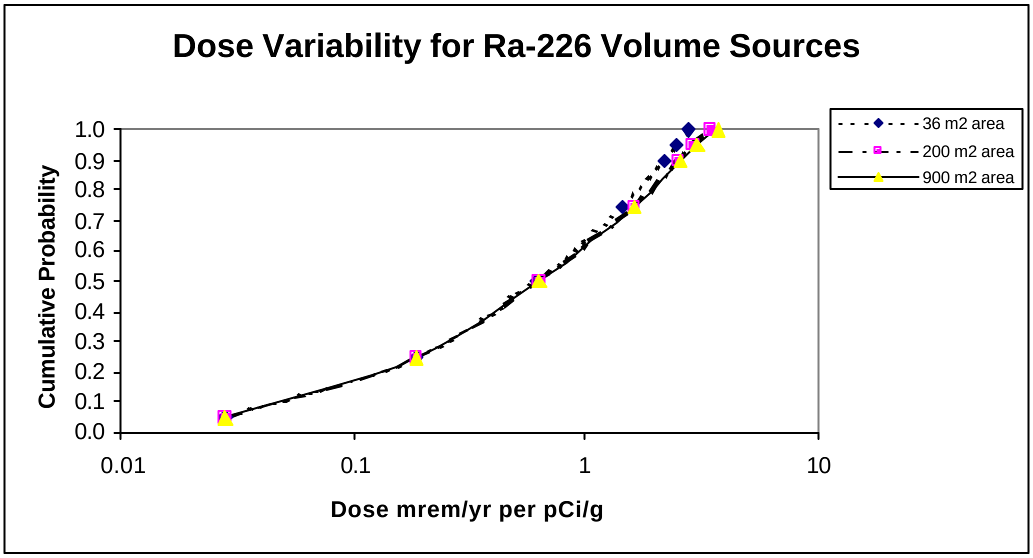


Figure 7.30 Dose Variability of Ra-226 for a Volume Source with Three Source Areas in Building Occupancy Scenario

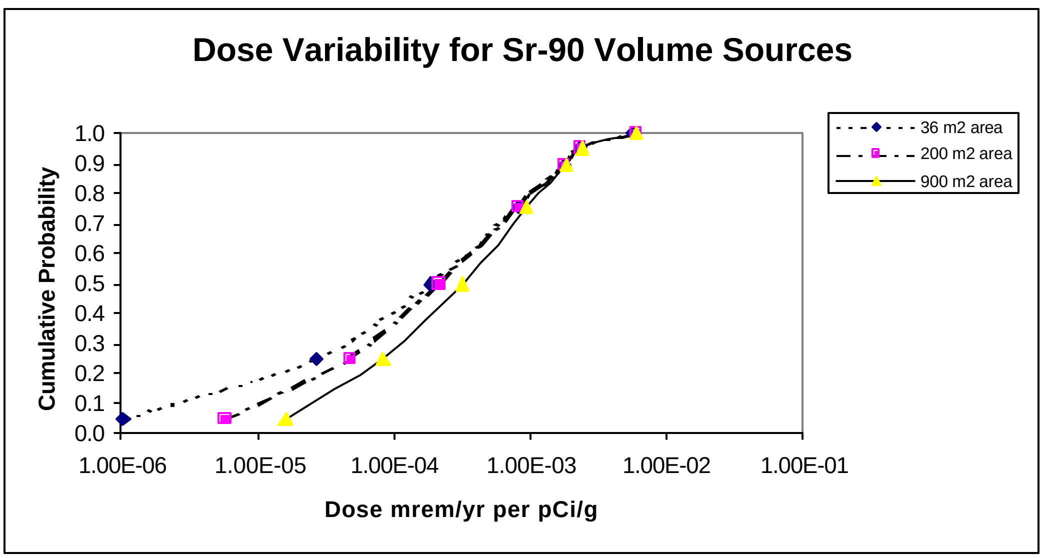


Figure 7.31 Dose Variability of Sr-90 for a Volume Source with Three Source Areas in Building Occupancy Scenario

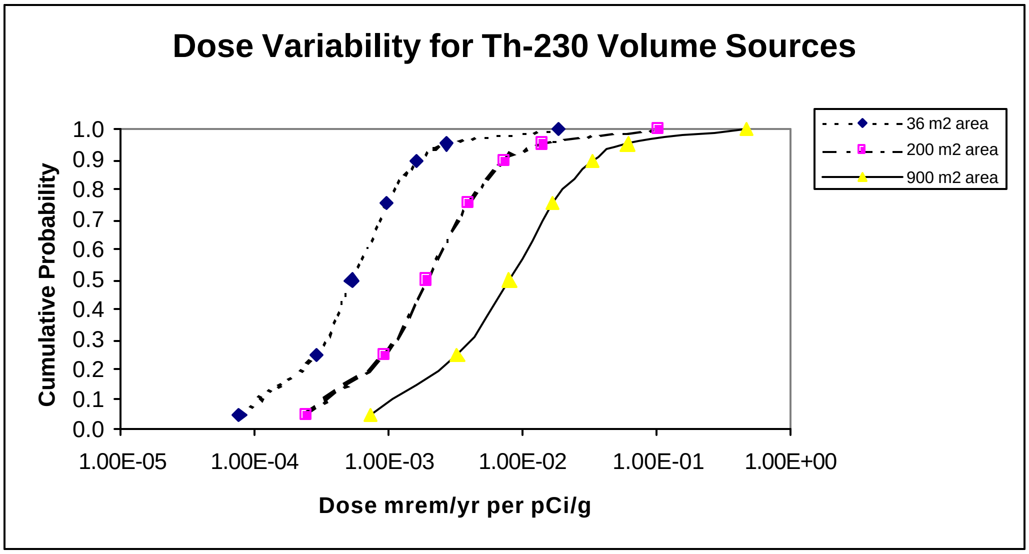


Figure 7.32 Dose Variability of Th-230 for a Volume Source with Three Source Areas in Building Occupancy Scenario

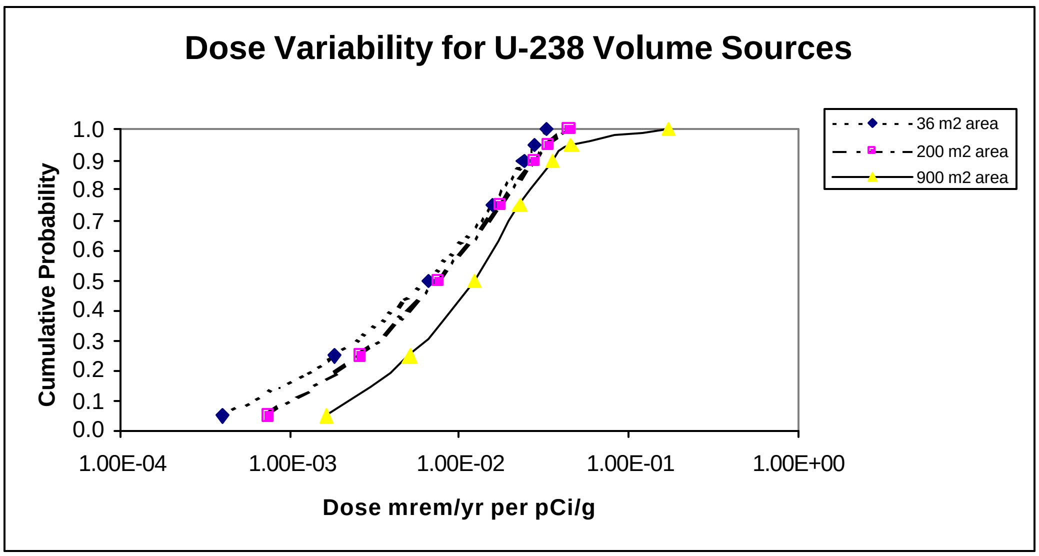


Figure 7.33 Dose Variability of U-238 for a Volume Source with Three Source Areas in Building Occupancy Scenario

Table 7.7. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per dpm/cm^2) for Three Source Areas for a Surface Source in the Building Occupancy Scenario

	Source 1: Area = 36 m^2			Source 2: Area = 200 m^2			Source 3: Area = 900 m^2		
Radionuclide	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%	Dose @ 50%	Dose @ 90%	Dose @ 95%/ Dose @ 50%
Ac-227	8.96E-02	4.86E-01	1.41E+01	4.77E-01	2.68E+00	1.45E+01	2.11E+00	1.21E+01	1.48E+01
Ag-108	1.71E-02	6.17E-02	3.69E+00	1.76E-02	9.10E-02	5.78E+00	2.08E-02	1.03E-01	6.14E+00
Ag-110	2.11E-02	6.26E-02	3.09E+00	2.18E-02	9.32E-02	4.79E+00	2.21E-02	1.05E-01	5.94E+00
Al-26	3.56E-02	9.19E-02	2.69E+00	3.83E-02	1.37E-01	4.01E+00	4.12E-02	1.59E-01	4.72E+00
Am-241	5.99E-03	3.39E-02	1.57E+01	3.27E-02	1.88E-01	1.58E+01	1.47E-01	8.47E-01	1.59E+01
Am-243	9.37E-03	3.45E-02	1.08E+01	3.56E-02	1.87E-01	1.48E+01	1.51E-01	8.42E-01	1.54E+01
Au-195	1.23E-05	1.14E-03	1.35E+02	1.79E-05	1.25E-03	1.21E+02	2.71E-05	1.26E-03	8.19E+01
Bi-207	1.77E-02	5.50E-02	3.25E+00	1.83E-02	8.11E-02	5.00E+00	1.90E-02	9.10E-02	6.03E+00
C-14	6.94E-08	9.10E-07	4.11E+01	3.05E-07	4.95E-06	5.19E+01	1.31E-06	2.08E-05	5.43E+01
Ca-41	3.17E-08	5.00E-07	5.81E+01	1.76E-07	2.77E-06	5.81E+01	7.93E-07	1.25E-05	5.80E+01
Cd-109	6.35E-06	8.96E-05	1.64E+01	1.78E-05	1.35E-04	1.05E+01	5.18E-05	2.73E-04	1.04E+01
Ce-144	3.77E-04	1.34E-03	3.82E+00	4.55E-04	1.91E-03	4.99E+00	5.59E-04	2.29E-03	5.30E+00
Cf-252	1.73E-03	1.00E-02	1.45E+01	9.59E-03	5.59E-02	1.45E+01	4.33E-02	2.51E-01	1.45E+01
Cl-36	4.82E-06	1.89E-05	5.15E+00	9.01E-06	3.88E-05	7.10E+00	1.96E-05	1.04E-04	1.09E+01
Cm-243	6.22E-03	2.35E-02	1.07E+01	2.33E-02	1.28E-01	1.49E+01	1.00E-01	5.77E-01	1.55E+01
Cm-244	3.11E-03	1.82E-02	1.58E+01	1.73E-02	1.01E-01	1.57E+01	7.75E-02	4.55E-01	1.58E+01
Cm-248	2.19E-02	1.26E-01	1.59E+01	1.22E-01	7.03E-01	1.59E+01	5.50E-01	3.15E+00	1.58E+01
Co-57	1.80E-04	3.11E-03	1.88E+01	1.85E-04	4.02E-03	2.80E+01	2.11E-04	4.10E-03	2.86E+01
Co-60	3.15E-02	7.93E-02	2.66E+00	3.32E-02	1.18E-01	4.04E+00	3.58E-02	1.36E-01	4.74E+00
Cs-134	1.49E-02	4.95E-02	3.42E+00	1.52E-02	7.34E-02	5.40E+00	1.54E-02	8.15E-02	6.70E+00
Cs-135	2.06E-07	2.59E-06	4.00E+01	8.15E-07	1.40E-05	5.58E+01	3.28E-06	6.31E-05	6.27E+01
Cs-137	6.13E-03	2.11E-02	3.54E+00	6.49E-03	3.13E-02	5.38E+00	6.98E-03	3.60E-02	6.28E+00
Eu-152	1.35E-02	3.86E-02	3.12E+00	1.41E-02	5.68E-02	4.71E+00	1.60E-02	6.49E-02	5.20E+00
Eu-154	1.45E-02	4.11E-02	3.21E+00	1.53E-02	6.04E-02	4.87E+00	1.66E-02	6.98E-02	5.63E+00
Eu-155	4.19E-05	1.61E-03	5.33E+01	5.86E-05	1.85E-03	5.16E+01	9.32E-05	1.85E-03	3.39E+01
Fe-55	3.47E-08	1.84E-07	1.64E+01	1.93E-07	1.02E-06	1.63E+01	8.65E-07	4.59E-06	1.64E+01
Gd-152	3.19E-03	1.85E-02	1.54E+01	1.77E-02	1.03E-01	1.54E+01	7.97E-02	4.64E-01	1.54E+01
Gd-153	2.22E-05	1.32E-03	8.98E+01	3.17E-05	1.39E-03	7.60E+01	4.82E-05	1.40E-03	5.05E+01
Ge-68	6.49E-03	2.45E-02	3.85E+00	6.58E-03	3.61E-02	6.16E+00	6.76E-03	4.00E-02	7.53E+00
H-3	1.86E-09	1.92E-08	1.82E+01	1.04E-08	1.07E-07	1.81E+01	4.64E-08	4.82E-07	1.82E+01
I-129	6.08E-06	2.37E-04	1.22E+02	3.20E-05	7.12E-04	6.97E+01	1.33E-04	2.51E-03	6.08E+01
K-40	2.19E-03	5.32E-03	2.55E+00	2.47E-03	8.06E-03	3.65E+00	2.71E-03	9.82E-03	4.50E+00
Mn-54	6.76E-03	2.06E-02	3.27E+00	6.98E-03	3.05E-02	5.06E+00	6.98E-03	3.43E-02	6.37E+00

Table 7.7. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per dpm/cm^2) for Three Source Areas for a Surface Source in the Building Occupancy Scenario (Continued)									
	Source 1: Area = 36 m^2			Source 2: Area = 200 m^2			Source 3: Area = 900m^2		
Radionuclide	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**	**Dose @ 50%**	**Dose @ 90%**	**Dose @ 95%/ Dose @ 50%**
Na-22	2.36E-02	6.98E-02	3.08E+00	2.42E-02	1.04E-01	4.82E+00	2.45E-02	1.16E-01	5.98E+00
Nb-94	1.82E-02	5.81E-02	3.29E+00	1.95E-02	8.65E-02	4.94E+00	2.27E-02	9.95E-02	5.35E+00
Ni-59	4.25E-08	3.89E-07	1.86E+01	2.36E-07	2.16E-06	1.86E+01	1.06E-06	9.73E-06	1.86E+01
Ni-63	9.86E-08	8.92E-07	1.62E+01	5.50E-07	4.95E-06	1.61E+01	2.47E-06	2.23E-05	1.62E+01
Np-237	1.13E-02	4.23E-02	1.08E+01	4.41E-02	2.30E-01	1.46E+01	1.86E-01	1.03E+00	1.53E+01
Pa-231	1.91E-02	1.05E-01	1.52E+01	1.02E-01	5.81E-01	1.58E+01	4.55E-01	2.61E+00	1.58E+01
Pb-210	4.19E-04	4.09E-03	1.69E+01	2.22E-03	2.27E-02	1.76E+01	1.00E-02	1.02E-01	1.75E+01
Pm-147	3.96E-07	1.75E-06	1.08E+01	1.73E-06	9.23E-06	1.38E+01	7.34E-06	4.16E-05	1.46E+01
Pu-238	5.18E-03	2.98E-02	1.59E+01	2.87E-02	1.65E-01	1.58E+01	1.29E-01	7.43E-01	1.59E+01
Pu-239	5.68E-03	3.28E-02	1.60E+01	3.16E-02	1.82E-01	1.58E+01	1.42E-01	8.20E-01	1.59E+01
Pu-240	5.68E-03	3.28E-02	1.60E+01	3.16E-02	1.82E-01	1.58E+01	1.42E-01	8.20E-01	1.59E+01
Pu-241	1.05E-04	6.08E-04	1.59E+01	5.81E-04	3.48E-03	1.60E+01	2.66E-03	1.56E-02	1.57E+01
Pu-242	5.45E-03	3.14E-02	1.59E+01	3.03E-02	1.74E-01	1.59E+01	1.36E-01	7.84E-01	1.59E+01
Pu-244	2.97E-02	6.71E-02	3.69E+00	6.58E-02	2.05E-01	8.15E+00	1.64E-01	7.75E-01	1.35E+01
Ra-226	2.61E-02	6.26E-02	2.59E+00	3.02E-02	9.77E-02	3.76E+00	3.90E-02	1.27E-01	4.54E+00
Ra-228	1.70E-02	4.17E-02	2.72E+00	2.61E-02	7.43E-02	3.34E+00	4.68E-02	1.39E-01	6.10E+00
Ru-106	1.75E-03	5.95E-03	3.47E+00	1.91E-03	8.92E-03	5.19E+00	2.34E-03	1.01E-02	5.63E+00
Sb-125	3.68E-03	1.45E-02	3.97E+00	3.71E-03	2.12E-02	6.38E+00	3.78E-03	2.33E-02	7.84E+00
Sm-147	9.82E-04	5.68E-03	1.55E+01	5.45E-03	3.16E-02	1.55E+01	2.46E-02	1.42E-01	1.55E+01
Sm-151	3.98E-07	2.28E-06	1.58E+01	2.21E-06	1.27E-05	1.58E+01	9.95E-06	5.72E-05	1.58E+01
Sr-90	5.09E-05	2.12E-04	8.19E+00	1.57E-04	9.10E-04	1.21E+01	5.45E-04	4.04E-03	1.56E+01
Tc-99	3.78E-07	2.22E-06	1.09E+01	1.24E-06	9.23E-06	1.44E+01	4.04E-06	3.99E-05	1.90E+01
Th-228	2.74E-02	5.54E-02	2.91E+00	5.45E-02	1.45E-01	5.93E+00	1.22E-01	5.50E-01	1.10E+01
Th-229	3.21E-02	1.65E-01	1.40E+01	1.61E-01	9.14E-01	1.52E+01	7.16E-01	4.11E+00	1.53E+01
Th-230	4.30E-03	2.48E-02	1.54E+01	2.38E-02	1.38E-01	1.54E+01	1.07E-01	6.22E-01	1.54E+01
Th-232	2.26E-02	1.25E-01	1.48E+01	1.22E-01	6.94E-01	1.52E+01	5.41E-01	3.12E+00	1.54E+01
Tl-204	1.02E-06	3.67E-05	4.91E+01	2.00E-06	4.11E-05	3.35E+01	4.43E-06	5.59E-05	1.91E+01
U-232	1.29E-02	5.59E-02	1.13E+01	5.50E-02	2.95E-01	1.43E+01	2.32E-01	1.32E+00	1.52E+01
U-233	1.78E-03	1.03E-02	1.54E+01	9.86E-03	5.72E-02	1.55E+01	4.45E-02	2.57E-01	1.54E+01
U-234	1.74E-03	1.00E-02	1.54E+01	9.64E-03	5.59E-02	1.55E+01	4.34E-02	2.51E-01	1.55E+01
U-235	4.15E-03	1.28E-02	6.83E+00	1.20E-02	5.23E-02	1.23E+01	4.28E-02	2.34E-01	1.48E+01
U-236	1.64E-03	9.50E-03	1.55E+01	9.14E-03	5.27E-02	1.54E+01	4.11E-02	2.38E-01	1.54E+01

Table 7.7. Quantile Values (at 50 percentile and 90 percentile) of Unit-Source Dose Distributions (mrem/yr per dpm/cm²) for Three Source Areas for a Surface Source in the Building Occupancy Scenario (Continued)

U-238	1.88E-03	9.10E-03	1.32E+01	9.01E-03	5.00E-02	1.49E+01	3.93E-02	2.25E-01	1.52E+01
Zn-65	4.59E-03	1.28E-02	2.91E+00	4.77E-03	1.91E-02	4.48E+00	4.86E-03	2.17E-02	5.54E+00