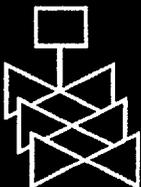
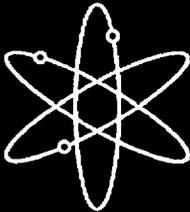
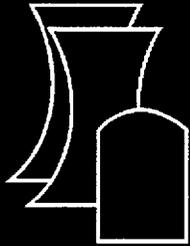


Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes

Argonne National Laboratory

**U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes

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ABSTRACT

The existing RESRAD 6.0 and RESRAD-BUILD 3.0 codes for site-specific radiation dose modeling applications are being developed and adapted for use with the U.S. Nuclear Regulatory Commission's (NRC's) Standard Review Plan for decommissioning and as tools for demonstrating compliance with the license termination rule in a risk-informed manner. Computer interfaces and software modules have been developed under NRC sponsorship to perform the probabilistic simulation of dose. RESRAD and RESRAD-BUILD are part of the RESRAD family of codes that have been developed by the U.S. Department of Energy (DOE) and for many years have been successfully applied to cleanup efforts at sites contaminated with radioactive materials. Specifically, the RESRAD code applies to cleanup of soil, and RESRAD-BUILD applies to the cleanup of buildings and structures at a site. This report describes the use of these codes to perform probabilistic dose analysis. The dose analysis presented in this report has fully

demonstrated the process of using the integrated system of RESRAD 6.0 and RESRAD-BUILD 3.0 codes and the probabilistic modules, together with distributions of input parameters, for dose assessment at a relatively complex site. This demonstration enables site-specific application of the codes for dose analysis where pertinent parameters and their distributions are available or can be developed. Results of the uncertainty analysis and sensitivity analysis of dose to input parameter values indicated that because the dependence of dose on the input parameters is complex, no single correlation or regression coefficient can be used alone to identify sensitive parameters in all cases. However, the results could give an indication of the degree of sensitivity of the calculated dose to changes in input parameter values for each exposure situation. Therefore, the coefficients are useful guides, but they have to be used in conjunction with the other aids, such as scatter plots and further analysis, to accurately identify the sensitive parameters.

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EXECUTIVE SUMMARY

In 1999, the U.S. Nuclear Regulatory Commission (NRC) tasked Argonne National Laboratory (Argonne) to adapt the existing RESRAD and RESRAD-BUILD codes for use in site-specific modeling with the NRC's license termination compliance process and the Standard Review Plan (SRP) on Decommissioning. The RESRAD code has been used extensively for dose analysis in cleanup of sites, and the RESRAD-BUILD code is used in cleanup of buildings. For use in this NRC process, the codes are being revised to be consistent with the current NRC guidance for dose modeling being developed in the SRP on Decommissioning. Thus, the primary objectives of Argonne's effort are to (1) develop parameter distribution functions and parametric analysis for the RESRAD and RESRAD-BUILD codes and (2) develop necessary computer modules for conducting probabilistic analyses.

The RESRAD and RESRAD-BUILD computer codes have been developed by Argonne under sponsorship of the U.S. Department of Energy (DOE) for use in evaluating radioactively contaminated sites and structures, respectively. Both are widely used in cleanup operations in the United States and abroad. The two codes are pathway analysis models designed to evaluate the potential radiological dose to an average individual of the *critical group* who lives or works at a site or in a structure contaminated with residual radioactive materials.

As part of the ongoing effort to meet NRC's objectives, external modules equipped with probabilistic sampling and analytical capabilities are being developed for RESRAD and RESRAD-BUILD. The modules are further equipped with user-friendly input and output interface features to accommodate numerous parameter distribution functions and result display requirements. The integrated system, consisting of the codes and the interface modules, is designed to operate on Microsoft Windows™ 95, 98, and NT platforms.

Completion and publication of the entire code system is scheduled for a later date. For the analysis described in this report, a preliminary version of the system was used.

This report emphasizes probabilistic dose analysis using parameter distributions developed for the RESRAD and RESRAD-BUILD codes. The objective is to establish and demonstrate the process for site-specific analysis using the integrated code system. This site-specific approach is emphasized despite the fact that the parameter distributions have been compiled from national databases. In the future, when site-specific distributions are available for an actual application, the same process can be readily used with site-specific data.

Development of distributions contained in this report has entailed extensive data gathering and analysis to obtain the most up-to-date information. Relevant data were obtained from NRC-sponsored work (including NUREG/CR-5512) combined with an extensive literature search using library and Internet resources. The focus of this data collection and analysis effort was to analyze the available data and to make the most plausible distribution assignments for each selected parameter for use in dose calculations. A total of about 200 parameters are used in the RESRAD and RESRAD-BUILD codes for describing the exposure pathways and the associated exposure conditions. The data distribution for these parameters has been developed through the following three steps.

Step 1: Parameter Categorization (Kamboj et al., 1999) — The parameters were classified relative to physical, behavioral, or metabolic attributes. Any parameter that would not change if a different group of receptors was considered was classified as a physical parameter. Any parameter that would depend on the receptor's behavior and the scenario definition was classified as a behavioral parameter. Any

parameter representing the metabolic characteristics of the potential receptor and that would be independent of the scenario being considered was classified as a metabolic parameter.

Step 2: Parameter Ranking (Cheng et al., 1999) — A strategy was developed to rank the input parameters and identify parameters according to their importance for meeting the objective of the analysis. The parameter rankings were divided into three levels: 1 (high priority), 2 (medium priority), and 3 (low priority). The parameters were ranked on the basis of four criteria: (1) relevance of the parameter in dose calculations, (2) variability of the radiation dose as a result of changes in the parameter value, (3) parameter type (physical, behavioral, or metabolic), and (4) availability of data on the parameter in the literature. A composite scoring system was developed to rank the parameters. Overall, 14 parameters were ranked as “high priority,” 59 were ranked as “medium priority,” and the remainder of 120 as “low priority” for RESRAD and RESRAD-BUILD combined.

Step 3: Parameter Distribution (Biber et al., 2000) — Parameter distributions were developed for a total of 73 parameters identified as high or medium priority in Step 2. The data were obtained from a variety of published information representative of a national distribution. Potential correlation among parameters was also studied and discussed in the report (Biber et al., 2000).

For this probabilistic dose analysis report, RESRAD was used to analyze a residential scenario, and RESRAD-BUILD was used to analyze a building occupancy scenario. These are the same baseline scenarios (together with assumptions) used for the NRC screening analysis (Wernig et al., 1999). As is the case for parameter distributions, such generic scenarios serve only as a baseline exercise for analytical purposes. For site-specific applications, more detailed descriptions, including the use of site-specific input parameters such as thickness and area of contamination, as well as the soil cover and shielding factors, are to be used. It should

be noted that the parameter sensitivities for doses are influenced by the input assumptions selected.

The analysis takes into account long-term transport of residual radionuclides in the environmental media and associated exposure pathways. For RESRAD, the peak dose within a 1,000-year time frame was captured, and for RESRAD-BUILD, the initial dose (i.e., at time 0) was calculated. In the dose assessment, the total effective dose equivalent (TEDE) to the average member of the critical group under the scenarios analyzed was estimated.

The probabilistic analysis was performed by using the stratified sampling of the Latin hypercube sampling (LHS) method for a collection of input parameter distributions. The LHS method provides a rather efficient process for multiparameter sampling. The dose estimate is generated in quantile value (at 50th percentile and 90th percentile) of the resulting analysis. Dose spread for different radionuclides was identified by the ratio of dose at 99th percentile to that at the 50th percentile for the residential scenario and by the ratio of dose at 95th percentile to that at the 50th percentile for the building occupancy scenario. Regression analysis was used to identify sensitive parameters. As an example, the partial rank correlation coefficients (PRCCs) and standardized rank regression coefficients (SRRCs) were used in residential and building occupancy scenarios, respectively. The effects of sensitive parameters on dose distribution were studied for selected radionuclides.

To illustrate the sensitivity of site-specific parameters such as source area and thickness, three source configurations were analyzed in RESRAD: (1) area of 100 m² and thickness of 15 cm; (2) area of 2,400 m² and thickness of 15 cm; (3) area of 10,000 m² and thickness of 2 m. For RESRAD-BUILD, three different areas (36 m², 200 m², and 900 m²) were analyzed for area sources, and the same three areas (36 m², 200 m², and 900 m²) along with the probability distribution on source thickness were used for volume sources. Results for the residential

scenario indicate that a change from the baseline configuration (i.e., source configuration 1) to an increased area (i.e., source configuration 2) could produce a 19-fold increase in the estimated dose, while a change from the baseline case to an extended thickness and area (i.e., source configuration 3) could lead to a 100-fold increase in the estimated dose. Similarly for the building occupancy scenario, a change in source area could lead to a 25-fold increase in the estimated dose.

The analysis has fully demonstrated the process of using the integrated RESRAD and RESRAD-BUILD codes and the probabilistic modules, together with the parameter distributions, for dose assessment at a relatively complex site. This demonstration enables a site-specific application where pertinent site data can be developed.

Results of the analysis indicated that no single correlation or regression coefficient (e.g., PRCC, SRR) can be used alone to identify sensitive parameters in all the cases, because the dependence of dose on the input parameter values is complex. The coefficients are useful guides but have to be used in conjunction with other aids, such as scatter plots and further analysis, to identify sensitive parameters.

Probabilistic dose analysis conducted with RESRAD for 90 principal radionuclides in three source configurations for the residential scenario indicated that the resulting doses appear reasonable and show a consistent pattern. The ratio between the 99th percentile dose and 50th percentile dose ranges from 2.0 to 79, depending on the source configurations and on the type of radionuclide. External shielding factor was the most sensitive

parameter in many cases where the external exposure pathway was the dominant pathway. Plant transfer factor was the most sensitive parameter in many cases where plant ingestion was the dominant pathway. The total dose variability could be explained by just the variability in the external shielding factor or the plant transfer factor in those cases.

Probabilistic dose analyses for 67 principal radionuclides for two source types (volume and area) with three source areas were performed for the building occupancy scenario with RESRAD-BUILD. For radionuclides with a dominant external exposure pathway, shielding thickness between the source and receptor was the dominant contributor to the dose variability for volume and area sources for the building occupancy scenario. For radionuclides with a dominant inhalation pathway, for a volume source, the room area and source erosion rate were the two most sensitive parameters. In area sources, the room area, removable fraction, and source lifetime all contributed to the dose variability.

For radionuclides with a dominant ingestion pathway, apart from the sensitive parameters identified for the inhalation pathway, deposition velocity and resuspension rate also contributed to dose variability for the building occupancy scenario.

The results indicated that all parameter distributions are reasonable and consistent for all cases and radionuclides analyzed. However, site-specific distributions should be used whenever available, especially for sensitive parameters such as shielding thickness and room area. RESRAD-BUILD dose variability for the building occupancy scenario for both volume and area sources was much greater than the variability observed in RESRAD results for the residential scenario.

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ABBREVIATIONS

| | |
|-----------------|-----------------------------------------------------|
| CDF | cumulative distribution function |
| CEDE | committed effective dose equivalent |
| CFR | Code of Federal Regulations |
| cm | centimeter(s) |
| cm ² | square centimeter(s) |
| cm ³ | cubic centimeter(s) |
| d | day(s) |
| DCF | dose conversion factor |
| DCGL | derived concentration guideline level |
| DOE | U.S. Department of Energy |
| dpm | disintegration(s) per minute |
| EDE | effective dose equivalent |
| g | gram(s) |
| GI | gastrointestinal |
| GUI | graphic-user interface |
| h | hour(s) |
| ICRP | International Commission on Radiological Protection |
| kg | kilogram(s) |
| L | liter(s) |
| LHS | Latin hypercube sampling |
| m | meter(s) |
| m ² | square meter(s) |
| μg | microgram(s) |
| mrem | millirem |
| NRC | U.S. Nuclear Regulatory Commission |
| PCC | partial correlation coefficient |
| pCi | picocurie(s) |
| PRCC | partial rank correlation coefficient |
| s | second(s) |
| SRC | standardized regression coefficient |
| SRP | Standard Review Plan |
| SRRC | standardized rank regression coefficient |
| SRS | simple random sampling |
| TEDE | total effective dose equivalent |
| yr | year(s) |

1 INTRODUCTION

On July 21, 1997, the U.S. Nuclear Regulatory Commission (NRC) published the License Termination Rule (Title 10, Code of Federal Regulations, Part 20 [10 CFR 20], Subpart E), which establishes requirements for nuclear facility licensees who are terminating their licensed operations. The NRC's approach to demonstrate compliance with the license termination rule is based on a philosophy of moving from simple, prudently conservative calculations toward more realistic simulations, as necessary, using dose modeling to evaluate exposure to residual radioactivity in soil and structures. Such potential exposures are evaluated for two scenarios: building occupancy (for contamination on indoor building surfaces) and residential (for contaminated soil).

The objective of dose modeling is to assess the total effective dose equivalent (TEDE) to an average member of the *critical group*¹ from residual contamination, including any contamination that has reached ground sources of drinking water. The assessment offers a reasonable translation of residual contamination into estimated radiation doses to the public. Compliance with the NRC-prescribed dose criteria can then be assessed by the modeling results.

As part of the development of site-specific implementation guidance supporting the License Termination Rule and development of a Standard Review Plan (SRP) on Decommissioning, the NRC recognized the

need to perform probabilistic analysis with codes that could be used for site-specific modeling. Such modeling capabilities exist with the RESRAD (Yu et al., 1993) and RESRAD-BUILD (Yu et al., 1994) codes. These two codes were developed at Argonne National Laboratory (Argonne) under sponsorship of the U.S. Department of Energy (DOE). These DOE codes possess the following attributes: (1) the software has been widely accepted and there is already a large user base, (2) the models in the software were designed for and have been successfully applied at sites with relatively complex physical and contamination conditions, and (3) verification and validation of the codes are well documented (Yu, 1999; NUREG/CP-0163 [NRC, 1998c]). The RESRAD codes have been used primarily to derive site-specific cleanup guidance levels (the derived concentration guideline levels, or DCGLs) based on the deterministic method.

In 1999, the NRC tasked Argonne to modify RESRAD and RESRAD-BUILD codes for use with the NRC's license termination compliance process and SRP. For use in this NRC process, the codes must meet specifications consistent with the current NRC modeling guidelines. Thus, the primary objectives of this project are for Argonne to (1) develop parameter distribution functions and perform probabilistic analysis with the RESRAD and RESRAD-BUILD computer codes, and (2) develop necessary computer modules, external to the RESRAD and RESRAD-BUILD codes, that incorporate the parameter distribution functions for conducting the probabilistic analyses. These modules will contain user-friendly features based on a specially designed graphic-user interface (GUI). They will be tailored to use the RESRAD and RESRAD-BUILD codes to perform site-specific probabilistic dose assessments in support of decontamination and decommissioning of potentially radioactively contaminated sites.

¹ The *critical group* is defined as an individual or relatively homogenous group of individuals expected to receive the highest exposure under the assumptions of the particular scenario considered (NUREG/CR-5512). The average member of the critical group is an individual assumed to represent the most likely exposure situation on the basis of prudently conservative exposure assumptions and parameter values within the model calculations.

This document reports on one of a series of steps undertaken by Argonne to meet NRC's requirements. The effort reported here builds on the information provided in a series of letter reports to the NRC leading to development of parameter distributions and the required probabilistic capabilities for RESRAD and RESRAD-BUILD. Those reports are described in the following paragraphs.

Parameter Categorization (Kamboj et al., 1999): All the input parameters used in the RESRAD and RESRAD-BUILD codes (totaling about 200 parameters) were listed, categorized, and defined. The parameters were classified as relating to physical, behavioral, or metabolic attributes. Any parameter that would not change if a different group of receptors was considered was classified as a physical parameter. Any parameter that would depend on the receptor's behavior and the scenario definition was classified as a behavioral parameter. A parameter representing the metabolic characteristics of the potential receptor and that would be independent of the scenario being considered was classified as a metabolic parameter.

Parameter Ranking (Cheng et al., 1999): A strategy was developed to rank the RESRAD and RESRAD-BUILD input parameters and identify parameters for detailed distribution analysis. The parameters were divided into three levels of priority: 1 (high priority), 2 (medium priority), and 3 (low priority). The parameters were ranked on the basis of four criteria: (1) relevance of the parameter in dose calculations, (2) variability of the radiation dose as a result of changes in the parameter value, (3) parameter type (physical, behavioral, or metabolic), and (4) availability of data on the parameter in the literature. For each criterion, a numeric score (0-9) was assigned to each parameter, with a low score assigned to parameters with a higher priority and a high score assigned to parameters with lower priority under the considered criterion. The final priority ranking of each parameter was assigned on the basis of its total numeric score for the four

ranking criteria. The lower the total score, the higher the priority assigned.

Parameter Distribution (Biwer et al., 2000): Value distributions were developed for those parameters identified as of high or medium priority in the RESRAD and RESRAD-BUILD codes. A total of about 70 parameters were selected for analysis. These parameters were deemed to be the ones most relevant to the NRC objective of demonstrating compliance with the radiological criteria for decommissioning and license termination. Development of distributions entailed gathering and analyzing relevant data from NRC-sponsored work and from an extensive literature search using library and Internet resources. However, it was recognized that many of the parameters in question have not been well tested or can vary significantly from site to site or even within the same site. Therefore, the focus was on analyzing the available data and making the most plausible distribution assignments for each selected parameter for use in an initial round of dose calculations. The parameter distributions are summarized in Section 6 of this report.

Probabilistic Dose Analysis (current report): This report presents probabilistic dose analysis and evaluation of the results for the derived parameter distributions for the RESRAD and RESRAD-BUILD codes. This effort entails the application of the probabilistic modules being developed for the two codes. Since the development of the modules is not yet final, interim RESRAD version 5.95+ and RESRAD-BUILD version 2.9+ were used for this analysis. The report focuses on the effects of parameter distributions on the distribution of estimated doses, taking into account parameter correlations.

This report is organized into nine major sections. Section 1 (the current section) provides background information and summarizes the previous tasks accomplished in this project. Section 2 describes the scope and purpose of the parameter analysis. Overviews

of the RESRAD and RESRAD-BUILD computer codes are provided in Section 3. Section 4 discusses the two scenarios (residential and building occupancy) evaluated in license termination dose analyses and lists the input parameters. Section 5 discusses the probabilistic analysis methodology. Parameter distributions used in the analysis are described in Section 6. Results of the analyses are discussed in Section 7. Section 8 provides an overall summary of the results. References cited are listed in Section 9. Appendix A presents the details of the probabilistic module used to evaluate dose distribution. Appendix B contains tables and figures for parameter distribution used in probabilistic dose analyses. Appendix C contains the detailed results of the sensitivity analyses.

For residential scenario, this report calculates the peak dose over 1,000 years for each sample run and focuses on several percentile values characterizing the distribution of peak doses. The RESRAD uncertainty module can also calculate the mean dose at each specified time from all sample runs (i.e., the mean dose can be reported as a function of time). From this

time-dependent mean dose, the peak of the mean can be identified. Probabilistic analysis can be conducted for the time when the peak of the mean dose occurs.

For both analyses, peak dose for each sample run and the peak of the mean dose will provide similar results if the peak always occurs at the same time (say at time zero or at 1,000 years) from all sample runs. The results of the analysis may be different if the peak time is different for any sample run. Therefore, for radionuclides such as Co-60 and Cs-137, for which the peak dose always occurs at time zero (water-dependent pathways are not significant in any sample run), there will not be any significant difference in the two analyses. On the other hand, for radionuclides such as Th-232 and U-238, for which the peak dose occurs at different times (water-dependent pathways may become significant in any sample run), there will be differences in the two analyses. The probabilistic dose analyses done for the peak dose will be more conservative than the analyses done for the peak of the mean dose.

2 SCOPE AND PURPOSE OF THE PROBABILISTIC DOSE ANALYSIS

Deterministic analysis (as previously employed in the RESRAD and RESRAD-BUILD codes) uses a single value for each parameter, resulting in a single dose value. The probabilistic approach uses systematic uncertainty analysis to quantify the uncertainty in dose estimates due to uncertainty in the input parameters. Figure 2.1 shows the concept of parameter uncertainty analysis.

In the probabilistic analysis, a probability distribution is specified for each model input parameter of uncertain value (Figure 2.1). Samples are generated from each of the input distributions. One sample from each input distribution is selected. A model is run repeatedly (for a specified number of iterations), each time using different values for each of the uncertain input parameters. The model results are stored. Instead of obtaining a single number for model outputs as in a deterministic run, a set of outputs (equal in number to the number of iterations) is obtained. These outputs can be represented as probability density functions (PDFs) and as cumulative distribution functions (CDFs). The CDF helps provide quantitative insight regarding the percentiles of the distributions. Although the generation of sample values for model input parameters is probabilistic, the execution of the model for a given set of samples in a repetition is deterministic.

Probabilistic analysis is a tool that can be used to support the decision-making process by showing changes in potential doses for a range of possible input parameter values. Probabilistic analysis in RESRAD and RESRAD-BUILD codes is discussed in Section 5.

An external module (a preprocessor and a postprocessor) equipped with probabilistic sampling and analytical capabilities is being developed for RESRAD and RESRAD-BUILD. The module is further equipped with user-friendly input and output features to

accommodate numerous parameter distribution functions and display requirements. The integrated system, consisting of the codes and interface modules, is designed to operate on Microsoft Windows™ 95, 98, and NT platforms. Completion and publication of the entire code system is scheduled for a later date. For the analysis described in this report, a preliminary version of the system was used. Appendix A describes the probabilistic module used to evaluate dose distribution.

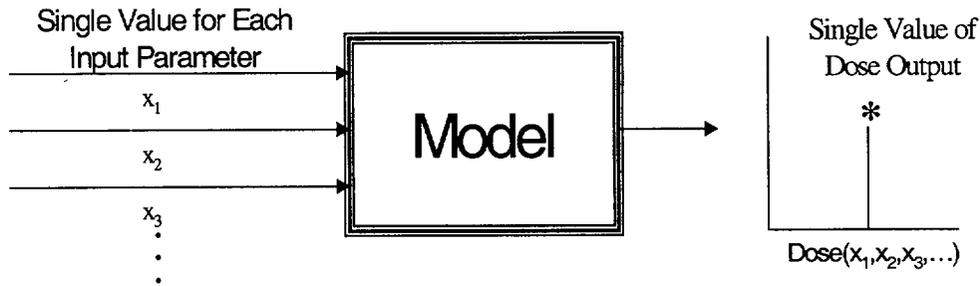
The objective of the probabilistic dose analyses discussed in this report is to use parameter distributions developed for the RESRAD and RESRAD-BUILD codes to establish and demonstrate the process for site-specific analysis using the integrated code system. RESRAD was used to analyze a residential scenario, and RESRAD-BUILD was used to analyze a building occupancy scenario. The RESRAD and RESRAD-BUILD codes are described in Section 3. The two scenarios, residential and building occupancy, evaluated as part of the NRC's license termination process are described in Section 4. Detailed discussion on the approach used for the analysis is provided in the following subsections.

2.1 PROBABILISTIC DOSE ANALYSIS APPROACH FOR SCREENING ANALYSIS

The site-specific modeling approach complements the generic screening approach described in NUREG/CR-5512 (Kennedy and Streng, 1992). The screening analysis approach is evaluated to contrast similarity and differences in areas that are common to the site-specific analysis discussed in Section 2.2.

Because the underlying premise of a screening model analysis is to make an informed decision

Deterministic Analysis



Probabilistic Analysis

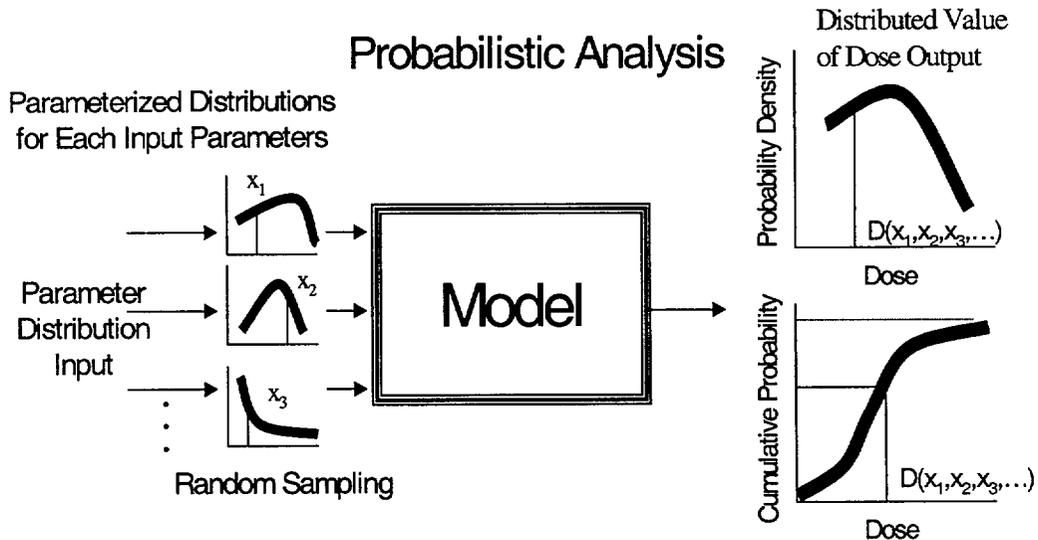


Figure 2.1 Concepts of Deterministic and Probabilistic Analyses

on the basis of a minimal amount of user input data, those data used in the model that are not input by the user must ensure a certain level of conservatism. In the case of the DandD code (Wernig et al., 1999), such a default parameter set was developed through an analysis of radionuclide-specific dose distributions. The dose distributions were obtained with a modified Monte Carlo approach using Latin hypercube sampling (LHS) (Beyeler et al., 1999).

In the screening methodology used for the DandD code, model parameters representing the physical characteristics of a site were assigned default values by using the following steps:

- The parameters were assigned input distributions deemed to be representative of conditions across all contaminated sites.
- Using these input distributions, a distribution of doses was obtained for each potential radionuclide contaminant.
- Each subset of values sampled from the input distributions (a sample vector, one set of all input parameters) that resulted in a dose greater than or equal to a specific percentile value was identified for each radionuclide.
- Those subsets that satisfied the condition for *all* radionuclides would be those best

suited to be a deterministic default set of parameters for use in the screening model.

The use of such subsets would result in conservatively high doses. Thus, sites with estimated doses below regulatory limits have a high probability of meeting the limits if a site-specific analysis were to be performed.

On the other hand, a site-specific analysis, as performed by RESRAD or RESRAD-BUILD, requires input distributions that best characterize the variability found at a given site rather than those that maximize dose. The site-specific approach strives to calculate more realistic estimates of dose for each particular site. As discussed below, the site-specific approach relies on the same LHS sampling method as the screening approach. However, in the site-specific analysis, the distributions of the inputs capture the expected variability and the uncertainty in the inputs at a particular site (as opposed to the screening approach, which accounts for variability across sites).

2.2 PROBABILISTIC DOSE ANALYSIS APPROACH FOR SITE- SPECIFIC ANALYSIS

The RESRAD and RESRAD-BUILD codes were designed to consider a relatively complex contamination situation and incorporate relatively complex transport mechanisms to simulate partitioning of contaminants in the environment. Therefore, they can be used for site-specific analysis to obtain more realistic dose estimates. To determine the potential dose distributions, the same LHS sampling methods used in the screening analysis should be used. However, parameter distributions that best characterize the variability found at a given site, rather than those that maximize dose, should be used.

The dose distribution analysis conducted for this report used the generic distributions developed in the Parameter Distribution Report (Biwier et al., 2000) to test the distribution data and to

demonstrate the capability of RESRAD and RESRAD-BUILD to perform a site-specific analysis. The specific strategy used to select the input values depended on the parameter category.

Parameters representing metabolic characteristics were defined by the average values for the general population (International Commission on Radiological Protection [ICRP], 1984). These values would not be expected to change for a site-specific analysis because they would be independent of site conditions.

The behavioral parameters used in a site-specific analysis characterize the average member of the "critical group" (as defined in Section 1) at the site. Default values for behavioral parameters were defined by stipulating a generic group for the scenario, which was a site-independent population appropriate for use at all sites. Therefore, behavioral parameters were set at mean values or at a median value of probability distributions. However, behavioral parameter distributions could vary among different population groups. The user should confirm the appropriateness of the parameters for the population being considered.

Physical parameters can vary from site to site, and to capture the variability in estimated doses due to variability in such parameters, probability distributions for those parameters that were analyzed in the Parameter Distribution Report (Biwier et al., 2000) were used in the analysis. For other physical parameters not assigned distributions, RESRAD and RESRAD-BUILD default values were used, or in cases of overlap among RESRAD, RESRAD-BUILD, and DandD input parameters, DandD default input parameter values were used if appropriate.

As was noted in the Parameter Ranking Report (Cheng et al., 1999), some site-specific parameters have significant impacts on estimated radiation doses. For those parameters, site-specific information should always be used in dose calculations, and thus

no distributions were provided for them in the Parameter Distribution Report (Biber et al., 2000). For RESRAD, such parameters include radionuclide concentrations, source area, and source thickness. For RESRAD-BUILD, such parameters include radionuclide concentrations and source area. The radionuclide concentration would affect the dose linearly, whereas the effect of source area and thickness may not be linear. For RESRAD, this report analyzes three source configurations: (1) area of 100 m² and thickness of 15 cm; (2) area of 2,400 m² and thickness of 15 cm; (3) area of 10,000 m² and thickness of 2 m. For RESRAD-BUILD, three different areas (36 m², 200 m², and 900 m²) are analyzed for area sources, and the same three areas (36 m², 200 m², and 900 m²) along with the probability distribution on source thickness were used for volume sources.

Parameter Distribution Report (Biber et al., 2000) indicated that some input parameters are clearly related, such as effective porosity and total porosity. Care was taken to ensure that consistent minimum and maximum distribution values were assigned in such cases. Such relationships were identified for performing dose variability in this task.

The stratified Monte-Carlo LHS technique was used to sample the assigned parameter distributions in estimating the dose distribution functions.

2.3 HIGHLIGHTS OF DOSE DISTRIBUTION ANALYSIS

Some key elements for the site-specific analysis are furnished by the major attributes of the RESRAD and RESRAD-BUILD codes. This section highlights these attributes together with considerations specific to probabilistic analysis:

- RESRAD was used to analyze the residential scenario, and RESRAD-BUILD was used to analyze the building occupancy scenario.
- Probabilistic analysis was performed for the radionuclides in the RESRAD and

- RESRAD-BUILD databases. RESRAD has 91 principal radionuclides in its database, and RESRAD-BUILD has 67 principal radionuclides.
- Three source configurations were analyzed for the residential scenario.
- Two source types (volume and area) with three source areas were analyzed for the building occupancy scenario.
- The time frame used for the residential scenario was 0-1,000 years.
- For the physical parameters, distributions presented in the Parameter Distribution Report (Biber et al., 2000) were used in the analysis. For the metabolic and behavioral parameters, mean or median values of the distributions were used.
- A total of 300 samples each were generated for RESRAD and RESRAD-BUILD with the LHS technique.
- Parameters were divided into radionuclide-independent and radionuclide-dependent categories. Input files were created for all radionuclides.
- Quantile values (at 50th percentile and 90th percentile) of unit-source dose distributions were generated. For the residential scenario, the dose distribution is for the peak dose over each 1,000-year period, and for the building occupancy scenario, it is for the dose at time zero.
- Regression analysis was used to identify sensitive parameters.
- The effect of sensitive parameters on dose distribution was studied for selected radionuclides.
- The effect of correlation of input parameters on dose distribution was studied.

3 OVERVIEW OF RESRAD AND RESRAD-BUILD CODES

RESRAD (Yu et al., 1993) and RESRAD-BUILD (Yu et al., 1994) computer codes have been developed by Argonne National Laboratory (Argonne) under sponsorship of the U.S. Department of Energy (DOE) for use in evaluating radioactively contaminated sites and buildings, respectively, and are widely used in the United States and abroad (Yu, 1999). Both codes are pathway analysis models designed to evaluate the potential radiological dose incurred by an individual who lives at a site with radioactively contaminated soil or who works in a building containing residual radioactive material.

The radiation dose calculated by the codes from the resulting exposure is defined as the effective dose equivalent (EDE) from external radiation plus the committed effective dose equivalent (CEDE) from internal radiation. The total dose is the sum of the external radiation EDE and the internal radiation CEDE and is referred as the total effective dose equivalent (TEDE).

To perform probabilistic dose analyses, external modules (a preprocessor and a post-processor) for both RESRAD and RESRAD-BUILD were developed to serve as "drivers" for providing an input/output and sampling mechanism. Appendix A describes the probabilistic module, and Section 5 describes the sampling mechanism.

3.1 RESRAD

RESRAD (Yu et al., 1993) implements the methodology described in DOE's manual for developing residual radioactive material guidelines and calculates radiation dose and excess lifetime cancer risk to a chronically exposed individual at a site with residual contamination.

The RESRAD code focuses on radioactive contaminants in soil and their transport in air, water, and biological media to a single receptor. Nine exposure pathways are considered in RESRAD: direct exposure, inhalation of particulates and radon, and ingestion of plant foods, meat, milk, aquatic foods, water, and soil. Figure 3.1 illustrates conceptually the exposure pathways considered in RESRAD.

The code uses a pathway analysis method in which the relation between radionuclide concentrations in soil and the dose to a member of a critical population group is expressed as a pathway sum, which is the sum of products of "pathway factors." Pathway factors correspond to pathway segments connecting compartments in the environment between which radionuclides can be transported or from which radiation can be emitted.

Radiation doses, health risks, soil guidelines, and media concentrations are calculated over user-specified time intervals. The source is adjusted over time to account for radioactive decay and ingrowth, leaching, erosion, and mixing. RESRAD uses a one-dimensional groundwater model that accounts for differential transport of parent and progeny radionuclides with different distribution coefficients. (A three-dimensional groundwater model has been implemented in another code in the RESRAD family — RESRAD-OFFSITE.)

RESRAD is designed to evaluate sites with soil that contains residual radioactive material. It can be used to derive cleanup criteria for a contaminated site, as well as for site screening and pre- and post-remediation dose/risk assessment. The initial source of contamination is assumed to be anthropogenic radionuclides in soil at a contaminated site; however, measured concentrations of radionuclides in a downgradient well can also be included in code calculations.

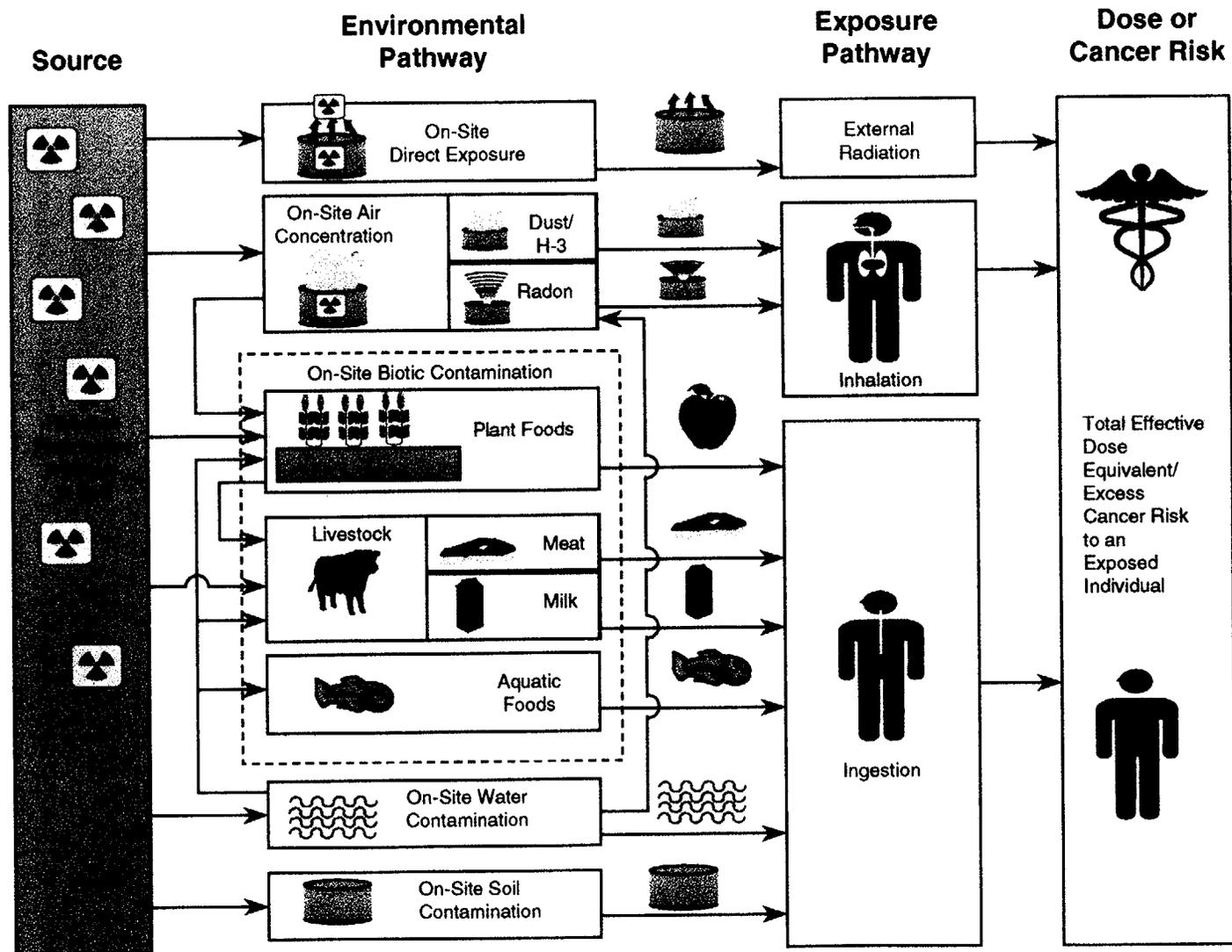


Figure 3.1 Graphical Representation of Pathways Considered in RESRAD

The RESRAD code is used to analyze doses to on-site individuals under current or plausible future land uses of the site. The default land use scenario in RESRAD assumes the presence of an on-site subsistence farmer with all exposure pathways active. By suppressing selected pathways and modifying applicable intake or occupancy parameter values, any number of potential scenarios and sets of conditions can be simulated.

RESRAD calculates time-integrated annual dose, soil guidelines, radionuclide concentrations, and lifetime cancer risks as a function of time. The user may request results for up to nine different times (time zero is always calculated). Any time horizon up to 100,000 years may be selected. The code estimates at which time the peak dose occurs for each radionuclide and for all radionuclides summed.

It is assumed that the short-lived decay products with half-lives of 30 days or less, referred to as the associated radionuclides, are in secular equilibrium with their parent. The RESRAD database includes 91 principal radionuclides and more than 50 associated radionuclides in the decay chains. Table 3.1 lists principal radionuclides in RESRAD (and RESRAD-BUILD).

The chemical form of the radionuclide is considered in dose conversion factors (DCFs) for radionuclides taken up internally. For ingestion, the user may select the DCF for one or more gastrointestinal (GI) tract fractions; for inhalation; the user may select the DCF for one or more inhalation classes. RESRAD defaults are for the most conservative DCFs when more than one GI fraction or inhalation class is available. Short-lived radionuclides (with half-lives of less than 1 month) are considered to be in secular equilibrium with their parents. Thus, their DCF values and slope factors are added to the DCF values and slope factors of the parent radionuclide. Special models are developed that take into account the different chemical forms and transport of tritium (as tritiated water and

water vapor) and carbon-14 (as organic carbon and carbon-dioxide) in the environment.

The RESRAD methodology requires parameter values for the homogeneous layers (one optional cover layer, one contaminated zone, one to five optional unsaturated zones, and one optional saturated zone). The code can assess doses from small areas of contamination, and no constraints are placed on the area or thickness of any layer. In most cases, the receptor is assumed to be located on the site (outdoors and/or indoors, 1 m above the soil surface) and may obtain water from a well or pond located in the middle of the site (mass-balance model) or at the downgradient edge of the site (nondispersion model). For the external gamma pathway, the default source area is assumed to be circular, with the receptor located above the center. However, the user may select a noncircular area, with the receptor located anywhere, including at off-site locations.

In the RESRAD computations, longer-lived progeny of all radionuclides are tracked separately from their parents. This procedure allows the user to account for the different properties of the decay products during transport from the contaminated zone through the unsaturated zone and into the saturated zone. The distribution coefficient for each long-lived radionuclide within each zone may be different and will depend on the chemical form of the radionuclide and the properties of the soil through which it is traveling. The distribution coefficient values may be entered by the user, or the code may be used to estimate these values by any of four separate methodologies: (1) concentration input for radionuclide in a downgradient well and time since material placement, (2) direct input of the leach rate from the contaminated zone, (3) input of solubility limit, and (4) correlation with the soil/plant transfer factor.

The RESRAD code permits sensitivity and uncertainty analysis for various parameters. A probabilistic interface for the RESRAD is being enhanced (Appendix A).

| Table 3.1. List of Principal Radionuclides ^a in RESRAD and RESRAD-BUILD | | | | | |
|------------------------------------------------------------------------------------|-----------------------|-----------|-----------------------|-----------|-----------------------|
| Source ID | Radionuclide | Source ID | Radionuclide | Source ID | Radionuclide |
| 1 | Ac-227+D ^b | 32 | Fe-55 | 63 | S-35 ^c |
| 2 | Ag-108m+D | 33 | Fe-59 ^c | 64 | Sb-124 ^c |
| 3 | Ag-110m+D | 34 | Gd-152 | 65 | Sb-125+D ^e |
| 4 | Al-26 | 35 | Gd-153 | 66 | Sc-46 ^c |
| 5 | Am-241 | 36 | Ge-68+D | 67 | Se-75 ^c |
| 6 | Am-243+D | 37 | H-3 | 68 | Se-79 ^c |
| 7 | Au-195 | 38 | I-125 ^c | 69 | Sm-147 |
| 8 | Ba-133 ^c | 39 | I-129 | 70 | Sm-151 |
| 9 | Bi-207 | 40 | Ir-192 ^c | 71 | Sn-113 ^c |
| 10 | C-14 | 41 | K-40 | 72 | Sr-85 ^c |
| 11 | Ca-41 | 42 | Mn-54 | 73 | Sr-89 ^c |
| 12 | Ca-45 ^c | 43 | Na-22 | 74 | Sr-90+D |
| 13 | Cd-109 | 44 | Nb-93m ^c | 75 | Ta-182 ^c |
| 14 | Ce-141 ^c | 45 | Nb-94 | 76 | Tc-99 |
| 15 | Ce-144+D | 46 | Nb-95 ^c | 77 | Te-125m ^c |
| 16 | Cf-252 | 47 | Ni-59 | 78 | Th-228+D |
| 17 | Cl-36 | 48 | Ni-63 | 79 | Th-229+D |
| 18 | Cm-243 | 49 | Np-237+D | 80 | Th-230+D |
| 19 | Cm-244 | 50 | Pa-231 | 81 | Th-232 |
| 20 | Cm-245 ^e | 51 | Pb-210+D ^d | 82 | Tl-204 |
| 21 | Cm-246 ^c | 52 | Pm-147 | 83 | U-232 |
| 22 | Cm-247 ^c | 53 | Po-210 ^c | 84 | U-233 |
| 23 | Cm-248 | 54 | Pu-238 | 85 | U-234 |
| 24 | Co-57 | 55 | Pu-239 | 86 | U-235+D |
| 25 | Co-60 | 56 | Pu-240 | 87 | U-236 |
| 26 | Cs-134 | 57 | Pu-241+D | 88 | U-238+D |
| 27 | Cs-135 | 58 | Pu-242 | 89 | Zn-65 |
| 28 | Cs-137+D | 59 | Pu-244+D | 90 | Zr-93 ^c |
| 29 | Eu-152 | 60 | Ra-226+D | 91 | Zr-95 ^c |
| 30 | Eu-154 | 61 | Ra-228+D | | |
| 31 | Eu-155 | 62 | Ru-106+D | | |

^a Associated radionuclides with half-lives of less than 30 days in RESRAD and of less than 6 months in RESRAD-BUILD are in secular equilibrium with their parent.

^b +D indicates that associated radionuclides are in secular equilibrium with the principal radionuclide.

^c Radionuclide is not in RESRAD-BUILD database.

^d For RESRAD-BUILD, associated radionuclide Po-210 is in secular equilibrium with Pb-210, whereas for RESRAD, Po-210 can be either a principal radionuclide or an associated radionuclide.

^e For RESRAD-BUILD, associated radionuclide Te-125m is in secular equilibrium with Sb-125 whereas for RESRAD, Te-125m can be either a principal radionuclide or an associated radionuclide.

3.2 RESRAD-BUILD

The RESRAD-BUILD code (Yu et al., 1994) 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. 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. 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, 10 receptor locations, and 8 shielding materials. A shielding material 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 rooms or compartments. Figure 3.2 conceptually illustrates the exposure pathways considered in RESRAD-BUILD.

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. With RESRAD-BUILD, the user can construct the exposure scenario by adjusting the input parameters. Typical building exposure scenarios include long-term occupancy (resident and office worker) and short-term occupancy (remediation worker and visitor).

RESRAD-BUILD can take into account the attenuation afforded by the shielding material between each source-receptor combination when calculating the external dose. The user can select the shielding material from eight material types and input the thickness and density of the material. The user can define the source as point, line, area, or volume source. The volume source can consist of five layers of different materials, with each layer being porous, homogeneous, and isotropic. Currently, 67 radionuclides are included in the RESRAD-BUILD database. All 67 radionuclides have half-lives of 6 months or greater and are referred to as principal radionuclides. It is assumed that the short-lived decay products with half-lives of 6 months or less, referred to as the associated radionuclides, are in secular equilibrium with their parent. Table 3.1 lists radionuclides in both the RESRAD-BUILD and RESRAD databases. A probabilistic interface for the RESRAD-BUILD is being enhanced (Appendix A).

RESRAD-BUILD Pathways

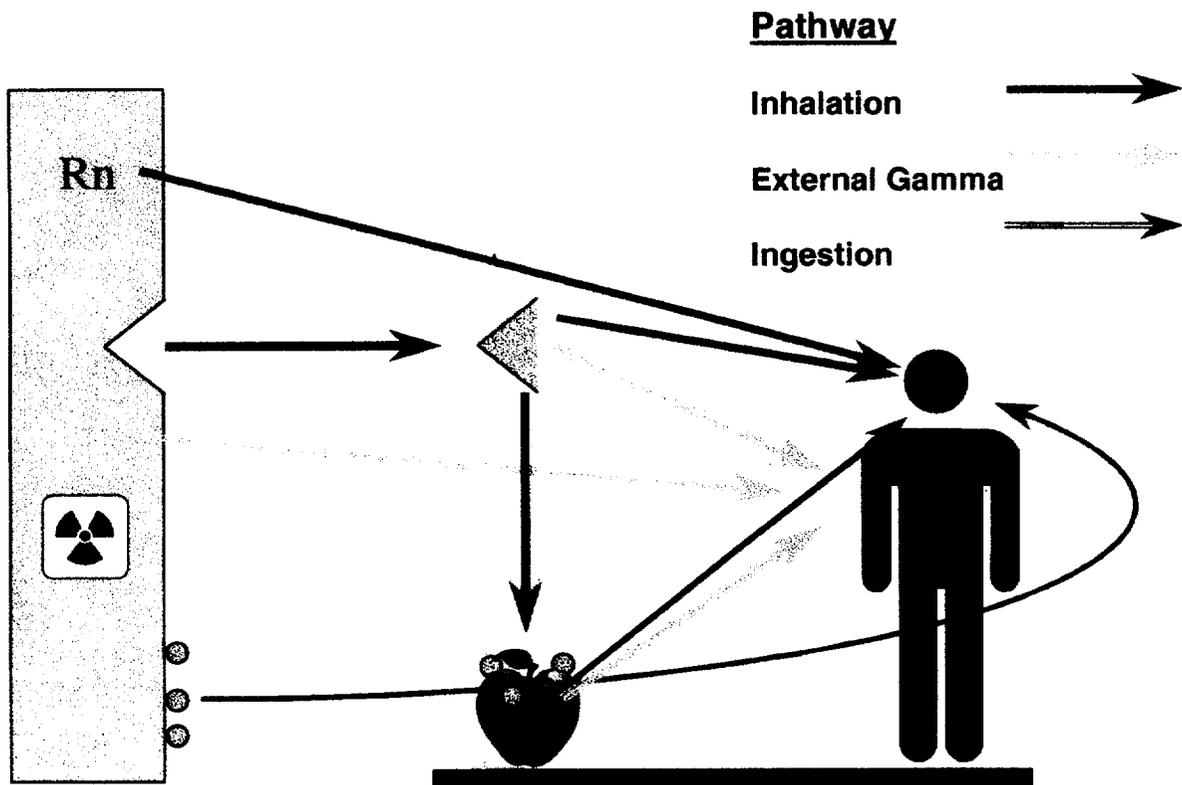


Figure 3.2 Graphical Representation of Pathways Considered in RESRAD-BUILD

4 SCENARIOS USED IN ESTIMATING DOSE DISTRIBUTIONS

As mentioned in Section 1, to assess compliance with the NRC's prescribed dose criteria for decommissioning and license termination of a facility, potential doses to an average member of the critical group should be evaluated for realistic future use scenarios involving a number of possible exposure pathways. For sites with residual contamination in soil, a "residential scenario" is evaluated. For a building with residual contamination indoors, a "building occupancy" scenario is evaluated.

Significant assumptions made for these two scenarios are summarized in the following subsections. These are the same baseline scenarios (together with the assumptions) used for the NRC screening analysis. As is the case for parameter distributions, such generic scenarios serve only as a baseline exercise for analytical purposes. For site-specific analyses, more detailed descriptions, including site-specific data for input parameters such as thickness and area of contamination, as well as the soil cover and shielding factors, are to be used.

4.1 RESIDENTIAL SCENARIO ASSUMPTIONS

The residential scenario model, as defined in NUREG/CR-5512, Volume 1 (Kennedy and Strenge, 1992) as the baseline screening scenario, is based on the following assumptions. These assumptions are followed in the RESRAD analysis for this report:

- Radioactive contamination occurs in a surface soil layer.
- The property can be used for residential and light farming activities.
- Residency can occur immediately after release of the property.

- Radioactive dose results from exposure via external exposure, inhalation, and ingestion. The model includes 12 exposure pathways created by the activities considered in the scenario:

- external exposure to penetrating radiation from volume soil sources while outdoors,
- external exposure to penetrating radiation from volume sources while indoors,
- inhalation exposure to resuspended soil while outdoors,
- inhalation exposure to resuspended soil while indoors,
- inhalation exposure to resuspended surface sources of soil tracked indoors,
- direct ingestion of soil,
- inadvertent ingestion of soil tracked indoors,
- ingestion of drinking water from a contaminated groundwater source,
- ingestion of plant products grown in contaminated soil,
- ingestion of plant products irrigated with contaminated groundwater,
- ingestion of animal products (meat and milk) grown on the site, and
- ingestion of fish from a contaminated surface water source.

It should be noted that the RESRAD code considers all the above pathways, although some pathways are considered through the use

of occupancy, shielding, and filtration factors. RESRAD also considers the following three pathways:

- inhalation of indoor radon aerosol,
- inhalation of outdoor radon aerosol, and
- ingestion of drinking water from a surface water source.

Although RESRAD can calculate radon inhalation doses, they were not included in this analysis. Figure 4.1 conceptually illustrates the exposure pathways in a typical residential scenario. The time frame used is up to 1,000 years, and the peak dose in this time horizon (0 - 1,000 years) is used in the analysis.

4.2 BUILDING OCCUPANCY SCENARIO ASSUMPTIONS

The building occupancy scenario, as defined in NUREG/CR-5512, Volume 1 (Kennedy and Streng, 1992) as the baseline screening scenario, is based on the following assumptions. These assumptions are followed in the RESRAD-BUILD analysis for this report:

- Radioactive dose results from exposure via three major exposure pathways:
 - external exposure to penetrating radiation from surface sources,

- inhalation of resuspended surface contamination, and
- inadvertent ingestion of surface contamination.

- The building will be commercially used after decommissioning.
- The occupancy of the building will occur immediately after its release.
- The residual contamination will be represented by a thin surface layer left on the inner building surfaces.
- The exposure type will be a long-term chronic exposure to low-level radioactive contamination because major contamination will have been cleaned up before decommissioning of the building.

It should be noted that the RESRAD-BUILD code considers all the above pathways and the following three additional pathways:

- external exposure during submersion in airborne radioactive dust,
- external exposure from deposited material, and
- inhalation of indoor radon aerosol.

However, radon inhalation doses were not included in this analysis.

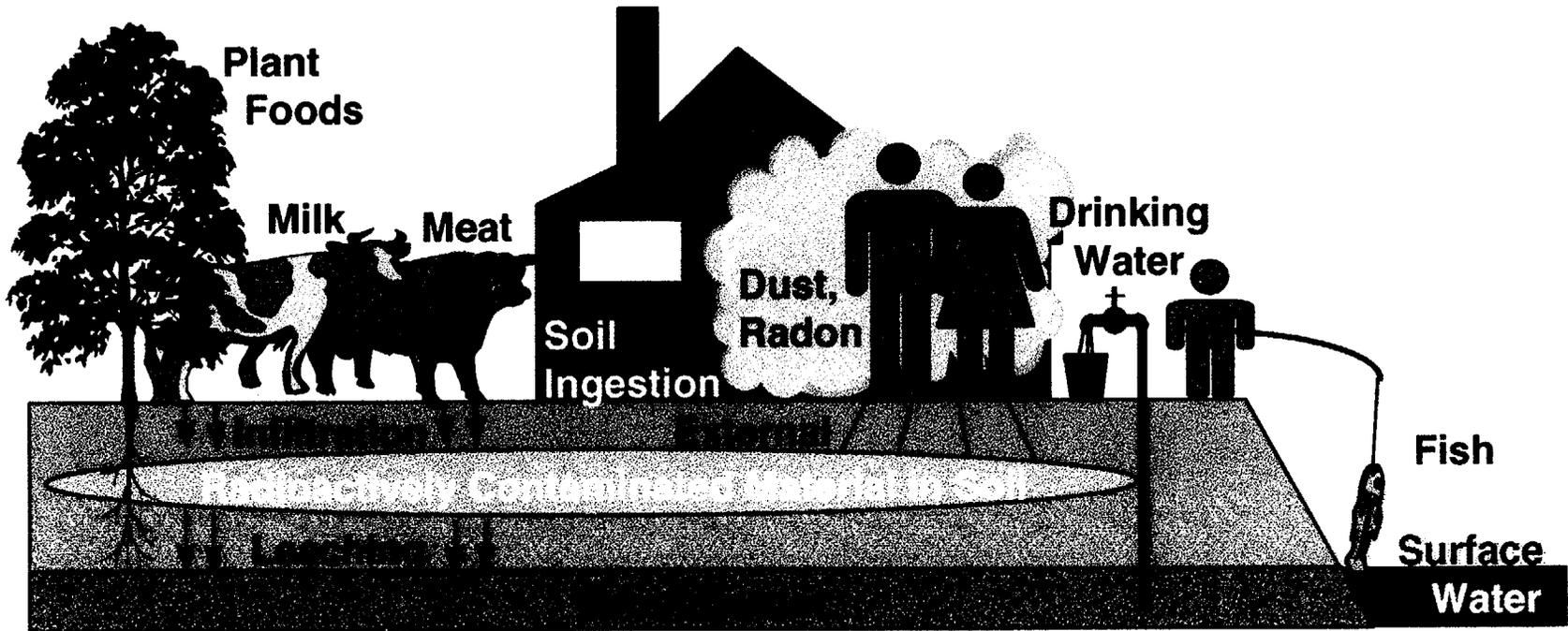


Figure 4.1 Schematic Representation of Exposure Pathways in a Typical Residential Scenario

5 PROBABILISTIC ANALYSIS IN RESRAD AND RESRAD-BUILD

Probabilistic analysis in RESRAD or RESRAD-BUILD is the computation of the total uncertainty induced in the output (resultant dose) as a result of either the uncertainty in or the variability of the input parameters. This kind of quantitative analysis helps determine the relative importance of the contributions of the uncertainties in the input parameters to the total uncertainty. Also, the results of probabilistic analysis can be used as a basis for determining the cost-effectiveness of obtaining additional information or data on input parameters. The analysis can be conducted by using correlations and rank correlations based on regression methodology to examine how much of the uncertainty in the results is attributable to which input parameters.

A pre-processor and a post-processor are being incorporated into the RESRAD and RESRAD-BUILD codes to facilitate analysis of the effects of uncertainty in or the probabilistic nature of input parameters in the model. A standard Monte Carlo method or a modified Monte Carlo method, that is, Latin hypercube sampling (LHS) (McKay et al. 1979), can be applied to generate random samples of input parameters. Each set of input parameters is used to generate one set of output results.

The results from all input samples are analyzed and presented in a statistical format in terms of the average value, standard deviation, minimum value, and maximum value. The cumulative probability distribution of the output is obtained and presented in a tabular form in terms of percentile values. Further analysis using regression methods is performed to find the correlation of the resultant doses (peak dose over 1,000-year period for RESRAD and dose at time zero for RESRAD-BUILD) with the input parameters. Partial correlation coefficients, partial rank correlation coefficients, standardized partial regression coefficients, and partial ranked regression coefficients are computed and ranked to provide a tool for

determining the relative importance of input parameters in influencing the resultant dose.

5.1 SAMPLING METHOD

Samples of the input parameters are generated with an updated version of the LHS computer code (Iman and Shortencarier, 1984). The uncertainty input form of the user interface collects all the data necessary for the sample generation and prepares the input file for the LHS code. When the code is executed (run), the LHS code will be called if the user has requested a probabilistic/uncertainty analysis. Table 5.1 lists the input data and information needed for sample generation.

The input data required for sample generation are divided in three categories: (1) sampling specifications data, (2) statistical distributions data, and (3) input rank correlation data. The input data and information needed for the sample generation include the initial seed value for the random number generator, the number of observations (N_{obs}), the number of repetitions (N_{rep}), the sampling technique, the method of grouping the samples generated for the different parameters, the type of statistical distribution for each input parameter, the parameters defining each of the distributions, and any correlations between input parameters.

Two sampling techniques are available, LHS and simple random (Monte Carlo) sampling (SRS). The LHS technique is an enhanced, stratified sampling scheme developed by McKay et al. (1979). It divides the distribution of each input parameter into N_{obs} nonoverlapping regions of equal probability. One sample value is obtained at random (using the current random seed) from each region on the basis of the probability density function for that region. Each time a sample is obtained, a new random seed for use in the next region is also generated by

| Table 5.1. Listing of Input Data and Information Needed for Sample Generation | |
|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Input Data | Description |
| Sampling Parameters | |
| Random Seed | Determines the series of random numbers generated. |
| Number of Observations | Number of sample values to be generated for each input variable for each repetition. |
| Number of Repetitions | Number of times probabilistic analysis is repeated. |
| Sampling Techniques | |
| Latin Hypercube | The distribution to be sampled is split into a number of equally probable distribution segments; the number being equal to desired number of observations. |
| Monte Carlo | The desired number of observations are obtained at random from the whole distribution. |
| Grouping of Observations | |
| Correlated or Uncorrelated | The samples of each variable are grouped together according to the specified correlation or are not correlated at all. |
| Random | The samples of each variables are grouped together at random. |
| Statistical Distributions | |
| Variable Descriptions | List of parameters for which distributions are specified. |
| Statistics of Uncertain Variable | Assigned distribution for the uncertain variable and the statistical parameters for the distribution. |
| Input Rank Correlations | |
| Variable 1, Variable 2 | Two variables for which rank correlation is specified. |
| RCC | The specified input rank correlation coefficient between two variables. |

using the current random seed. The sequence of random seeds generated in this manner can be reproduced if there is ever a need to regenerate the same set of samples. After a complete set of N_{obs} samples of one probabilistic/uncertain parameter has been generated, the same procedure is repeated to generate the samples for the next parameter.

The Monte Carlo sampling, or SRS, technique also obtains the N_{obs} samples at random; however, it picks out each sample from the entire distribution using the probability density function for the whole range of the parameter. Report No. 100 of the International Atomic Energy Agency safety series (IAEA, 1989) discusses the advantages of the two sampling techniques.

The N_{obs} samples generated for each probabilistic/uncertain parameter must be combined to produce N_{obs} sets of input parameters. Two methods of grouping (or combining) are available — random grouping or correlated/uncorrelated grouping. Under the random grouping, the N_{obs} samples generated for each of the parameters are combined randomly to produce (N_{obs}) sets of inputs. For N_{var} probabilistic/uncertain parameters, there are $(N_{obs})^{N_{var}}$ ways of combining the samples. It is possible that some pairs of parameters may be correlated to some degree in the randomly selected grouping, especially if N_{obs} is not sufficiently larger than N_{var} .

In the correlated/uncorrelated grouping, the user specifies the degree of correlation between each correlated parameter by inputting the

correlation coefficients between the ranks of the parameters. The pairs of parameters for which the degree of correlation is not specified are treated as being uncorrelated. For the residential and building occupancy scenario analyses, few input parameters were correlated (seven for the residential scenario and none for the building occupancy scenario). The code checks whether the user-specified rank correlation matrix is positive definite and suggests an alternative rank correlation matrix if necessary. It then groups the samples so that the rank correlation matrix is as close as possible to the one specified. Both matrices are in the LHS.REP file (which is generated by the RESRAD or RESRAD-BUILD code after the probabilistic analysis is run), and the user should examine the matrices to verify that the grouping is acceptable.

Iman and Helton (1985) suggest ways of choosing the number of samples for a given situation. The minimum and maximum doses and risk vary with the number of samples chosen. The accuracies of the mean dose and of the dose values for a particular percentile are dependent on the percentile of interest and on the number of samples. The confidence interval or the (upper or lower) confidence limit of the mean can be determined from the results of a single set of samples. Distribution-free upper ($u\%$, $v\%$) statistical tolerance limits can be computed by using the SRS technique according to the methodology in IAEA Report No. 100 (IAEA, 1989).

If LHS is used, the best way to determine the statistical accuracy is to run the same problem and only vary the initial seed value of the random number generator. For this analysis, the same problem was run with different random seed values, and the number of observations was changed from 100 sample runs to 300. For the few radionuclides tested, it was found that 300 sample runs would give 5% accuracy in the 50th percentile and 90th percentile dose values if the run was repeated with different random numbers.

5.2 DISTRIBUTION OF PARAMETERS

A set of input parameters for uncertainty analysis is chosen through the code's interface. Each parameter may have a probability distribution assigned to it and may be correlated with other input parameters included in the uncertainty analysis. A total of 34 different distribution types are available for selection. The distribution of parameters required for the uncertainty analysis depend on the selected distribution type. Table A.1 in the Parameter Distribution Report (Biwer et al., 2000) lists the different distribution types and the required distribution data. The input parameters can be correlated by specifying a pairwise rank correlation matrix. The induced correlation is applied to the ranks of the parameters; hence, the name "rank correlation." This technique of using correlation on ranks rather than on actual data is used because, in general, linear relationships among parameters may not exist. For the residential scenario analyses, rank correlations between density and total porosity, density and effective porosity, and total porosity and effective porosity were used.

5.3 PROBABILISTIC RESULTS

The results of the probabilistic analysis handled by the post-processor are presented in the summary text files MCSUMMAR.REP in RESRAD and RESBMC.RPT in RESRAD-BUILD. In each case, the file contains statistical data for a collection of resultant doses as a function of time, pathway, and radionuclide. The statistical data provided for the resultant dose include the average value, standard deviation, minimum value, and maximum value. The cumulative probability distribution of the resultant dose is presented in a tabular form in terms of percentile values in steps of 2.5%. Tabulations of the correlation of the resultant doses with the input parameters using regression methods are provided. The input parameters are ranked according to their relative importance and their contribution to the

overall uncertainty. The parameter ranks are presented in the correlation tables.

The correlation analysis of the input parameters and the resultant dose (peak dose over 1,000-year period for RESRAD and dose at time zero for RESRAD-BUILD) is based on the methodology of Iman et al. (1985). The correlation results in RESRAD and RESRAD-BUILD include a table for PCC, SRC, partial rank correlation coefficients (PRCCs), and the standardized rank regression coefficient (SRRC), and their associated correlation ranks. The coefficients of determination are provided at the end of the table. If the correlation and rank are desired for a dose resulting from a specific radionuclide and pathway, it is suggested that the user run the same problem with only the radionuclide and pathway of interest.

The coefficient of determination varies between 0 and 1 and presents a measure of the variation in the peak dose explained by the regression on the input parameters involved in the analysis. Thus, a value of 0 is displayed if the selected input parameters do not influence the calculated dose, and regression on these parameters does not yield an estimate of the output. The coefficient of determination is set to 0 in the code if the resultant correlation matrix is singular.

The correlation ranking of the parameters is based on the absolute value of the correlation coefficients; rank 1 is assigned to the parameter with the highest value. Thus, a parameter with a correlation rank of 1 has the strongest

relationship with the total dose. The correlation rank is set to 0 in the code if the correlation of the resultant doses is 0, or if the resulting correlation matrix is singular.

The PCC is calculated in the code by using the actual values of the input parameter and the resultant dose. It provides a measure of the linear relationship between the input parameter and the dose. The SRC is calculated by using the standardized values (i.e., [actual value-mean]/standard deviation) of the input parameter and the dose. It provides a direct measure of the relative importance of the input parameter independent of the units being used to measure the different parameters.

When nonlinear relationships are involved, it is often more revealing to calculate SRCs and PCCs on parameter ranks than on the actual values for the parameters; such coefficients are the SRRCs and PRCCs. The smallest value of each parameter is assigned the rank 1, the next smallest value is assigned rank 2, and so on up to the largest value, which is assigned the rank n, where n denotes the number of samples. The standardized regression coefficients and partial correlation coefficients are then calculated on these ranks. In general, PRCC and SRRC are recommended over PCC and SRC when nonlinear relationships, widely disparate scales, or long tails are present in the inputs and outputs.

Table 5.2 compares the approaches available for correlating the uncertainty in the distribution of doses to the uncertainty in the input parameter.

| Table 5.2. Comparison of Approaches for Correlating the Uncertainty in the Distribution of Doses to the Uncertainty in the input Parameter | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Approach | Advantages | Disadvantages |
| PCC | Measures linear relationship and gives the unique contribution of an input parameter to the resultant dose. | Large variations in scale distort PCC values and is not of much use when the relationships are nonlinear. |
| SRC | Measures linear relationship without influence of scale between input parameter and resultant dose. It provides "shared" contribution of an input parameter to the resultant dose. | Less useful when the relationship between input parameter and resultant dose is nonlinear and the input parameters are highly correlated. |
| PRCC | Estimates nonlinear monotonic relationship and gives the unique contribution of an input parameter to the resultant dose. | Not useful when the relationship between input parameter and resultant dose is nonmonotonic |
| SRRC | Estimates nonlinear monotonic relationship and provides "shared" contribution of an input parameter to the resultant dose. | Less useful when input parameters are highly correlated. |
| Source: Based in part on information from Cullen and Frey (1999). | | |

6 OVERVIEW OF PARAMETER DISTRIBUTION ASSIGNMENT

The parameter distributions assigned in the Parameter Distribution Report (Biwer et al., 2000) were selected to be representative of adult male workers or farmers in generic site conditions that might be found on average throughout the United States. The most recent data were gathered for the selected input parameters. The starting point for this step was NUREG/CR-5512 (Kennedy and Strenge, 1992) and supporting documents. Additional data on the selected parameters were collected through a search of available electronic databases (library and Internet resources). Only data provided directly from the NRC or obtained from readily available, citable, published sources were used. The process that was used in prioritizing parameters and assigning distribution is summarized below.

6.1 PARAMETERS ASSIGNED DISTRIBUTION

In the Parameter Ranking Report (Cheng et al., 1999), parameters were ranked and placed in one of three priority categories (Priorities 1 through 3). Priority 1 was assigned to the most relevant (high priority) parameters and Priority 3 to the least relevant (low priority) parameters. Argonne and the NRC Dose Modeling Working Group agreed that Priority 3 parameters would be excluded from distribution analysis at the present time because parameters in this category had already been determined to be of low priority and of insignificant impact on the overall results of dose estimation. The Parameter Distribution Report (Biwer et al., 2000) assigned distributions to most Priority 1 and 2 parameters in RESRAD and RESRAD-BUILD. However, a few directly measurable, site-specific-input parameters, such as radionuclide concentration, area of contamination, and thickness of contaminated zone, were not assigned distributions. Table 6.1 lists the parameters assigned distributions; it

also lists the parameter type and assigned distribution type for each.

6.2 ASSIGNMENT OF DISTRIBUTIONS

Assignment of an appropriate distribution to a RESRAD or RESRAD-BUILD input parameter was determined primarily by the quantity of relevant data available. Documented distributions were used where available. However, data are often lacking for environmental exposure pathways. As fewer data became available, secondary types of information were used in conjunction with existing sample data in the distribution assignment task.

Empirical distributions were available for some parameters within the context of the critical group or national average. For those parameters for which additional sampling was not expected to significantly change the distribution's shape (i.e., the variability of the parameter was well represented), direct use of the statistical data was made.

Sufficient relevant statistical data (data sets/matching function and parameter characteristics) were available for some parameters to clearly show a distribution type. If the use of an empirical distribution was not appropriate, the data were fit to the identified distribution. Goodness-of-fit may have been determined through the use of probability plots or other graphical representations.

Certain parameters had some data available, but those data were not sufficient to define a distribution type. These parameters were assigned a distribution on the basis of supporting information. If there was a mechanistic basis for assigning a given distribution to the data, such a distribution was used in the case of a sparse data set. In another

| Table 6.1. Parameters Assigned Probability Density Functions | | |
|----------------------------------------------------------------------------------------------------------|-----------------------------------|-----------------------------------|
| Parameter | Parameter Type^a | Assigned Distribution Type |
| RESRAD | | |
| Density of contaminated zone (g/cm ³) | P | Normal |
| Density of cover material (g/cm ³) | P | Normal |
| Density of saturated zone (g/m ³) | P | Normal |
| Depth of roots (m) | P | Uniform |
| Distribution coefficients (contaminated zone, unsaturated zones, and saturated zone)(cm ³ /g) | P | Lognormal |
| Saturated zone effective porosity | P | Normal |
| Saturated zone hydraulic conductivity (m/yr) | P | Lognormal |
| Saturated zone total porosity | P | Normal |
| Transfer factors for plants | P | Lognormal |
| Unsaturated zone thickness (m) | P | Lognormal |
| Aquatic food contaminated fraction | B, P | Triangular |
| Bioaccumulation factors for fish [(pCi/kg)/(pCi/L)] | P | Lognormal |
| C-14 evasion layer thickness in soil (m) | P | Triangular |
| Contaminated zone b parameter | P | Lognormal |
| Contaminated zone erosion rate (m/yr) | P, B | Empirical |
| Contaminated zone hydraulic conductivity (m/yr) | P | Lognormal |
| Contaminated zone total porosity | P | Normal |
| Cover depth (m) | P | None recommended |
| Cover erosion rate (m/yr) | P, B | Empirical |
| Depth of soil mixing layer (m) | P | Triangular |
| Drinking water intake (L/yr) | M, B | Lognormal |
| Evapotranspiration coefficient | P | Uniform |
| External gamma shielding factor | P | Lognormal |
| Fruit, vegetables, and grain consumption (kg/yr) | M, B | Triangular |
| Indoor dust filtration factor | P, B | Uniform |
| Mass loading for inhalation (μg/m ³) | P, B | Empirical |
| Milk consumption (L/yr) | M, B | Triangular |
| Runoff coefficient | P | Uniform |
| Saturated zone b parameter | P | Lognormal |
| Saturated zone hydraulic gradient | P | Lognormal |
| Soil ingestion rate (g/yr) | M, B | Triangular |
| Transfer factors for meat [(pCi/kg)/(pCi/d)] | P | Lognormal |
| Transfer factors for milk [(pCi/L)/(pCi/d)] | P | Lognormal |
| Unsaturated zone density (g/cm ³) | P | Normal |
| Unsaturated zone effective porosity | P | Normal |
| Unsaturated zone hydraulic conductivity (m/yr) | P | Lognormal |
| Unsaturated zone, soil-b parameter | P | Lognormal |
| Unsaturated zone total porosity | P | Normal |
| Weathering removal constant (1/yr) | P | Triangular |

Table 6.1. Parameters Assigned Probability Density Functions (Continued)

| Parameter | Parameter Type ^a | Assigned Distribution Type |
|-----------------------------------------------------------------------------|-----------------------------|----------------------------|
| Well pumping rate (m ³ /yr) | B, P | None recommended |
| Well pump intake depth (below water table) (m) | P | Triangular |
| Wet foliar interception fraction for leafy vegetables | P | Triangular |
| Wet-weight crop yields for non-leafy vegetables (kg/m ²) | P | Lognormal |
| Wind speed (m/s) | P | Lognormal |
| Humidity in air (g/m ³) | P | Lognormal |
| Indoor fraction | B | Empirical |
| Inhalation rate (m ³ /yr) | M, P | Triangular |
| RESRAD-BUILD | | |
| Removable fraction | P, B | Uniform |
| Resuspension rate (1/s) | P, B | Loguniform |
| Shielding density (g/cm ³) | P | Uniform |
| Source density, volume source (g/cm ³) | P | Uniform |
| Air exchange rate for building and room (1/h) | B | Lognormal |
| Air release fraction ^c | B | Triangular |
| Deposition velocity (m/s) | P | Loguniform |
| Direct ingestion rate (g/h for volume source and 1/h for all other sources) | B | None recommended |
| Humidity (g/m ³) | P, B | Uniform |
| Indoor fraction | B | Empirical |
| Receptor indirect ingestion rate (m ² /h) | B | Loguniform |
| Receptor inhalation rate (m ³ /d) | M, B | Triangular |
| Room area (m ²) | P | Triangular |
| Room height (m) | P | Triangular |
| Shielding thickness (cm) | P, B | Triangular |
| Source erosion rate, volume source (cm/d) | P, B | Triangular |
| Source porosity | P | Uniform |
| Source thickness, volume source (cm) | P | Triangular |
| Time for source removal or source lifetime (d) | P, B | Triangular |
| Volumetric water content | P | Uniform |
| Water fraction available for evaporation | P | Triangular |
| Wet + dry zone thickness (cm) | P | Uniform |

^a P = physical, B = behavioral, and M = metabolic; when more than one type is listed, the first is primary and next is secondary (Kamboj et al., 1999).

Source: Modified from Biwer et al. (2000), Table 2.1-1.

case, surrogate data may have been used. If a distribution was well known for a parameter on a regional basis, the same distribution was used on a national basis. In either case, care was taken to ensure that the existing data for the target scenario were complemented.

In the case of a parameter for which sufficient data were not available, a distribution that fit a similar class of parameters or similar body of data was assigned. If an appropriate distribution was not found, a maximum entropy approach was used. In such a case, the distribution was restricted only by what was known. Examples included the use of a uniform distribution if only

potential lower and upper bounds were available, or the use of a triangular distribution if a most likely value was known in addition to potential lower and upper bounds.

For the parameters not assigned distributions, RESRAD and RESRAD-BUILD default values were used, or in cases of overlap among RESRAD, RESRAD-BUILD, and DandD input parameters, the DandD default values were used if appropriate. Table B.1 in Appendix B lists the assigned distributions for the Priority 1 and 2 parameters in the RESRAD and the RESRAD-BUILD codes.

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 m², thickness of 15 cm; (2) area of 2,400 m², thickness of 15 cm; and (3) area of 10,000 m², 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 (Biber 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/cm³, 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/cm³.

7.1.2 Dose Analysis Results

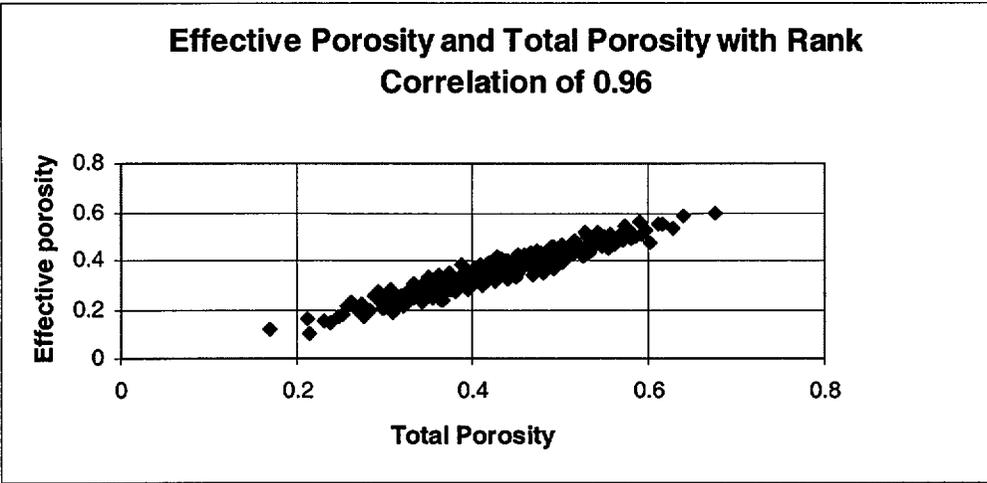
For each set of sampled parameter values, dose to the average member of the critical group was calculated for unit concentrations of each radionuclide. For each source, the distribution describing possible doses to the average member of the critical group was then constructed from these calculated doses. 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 m² and thickness = 15 cm; source configuration 2: source area = 2,400 m² and thickness = 15 cm; and source configuration 3:

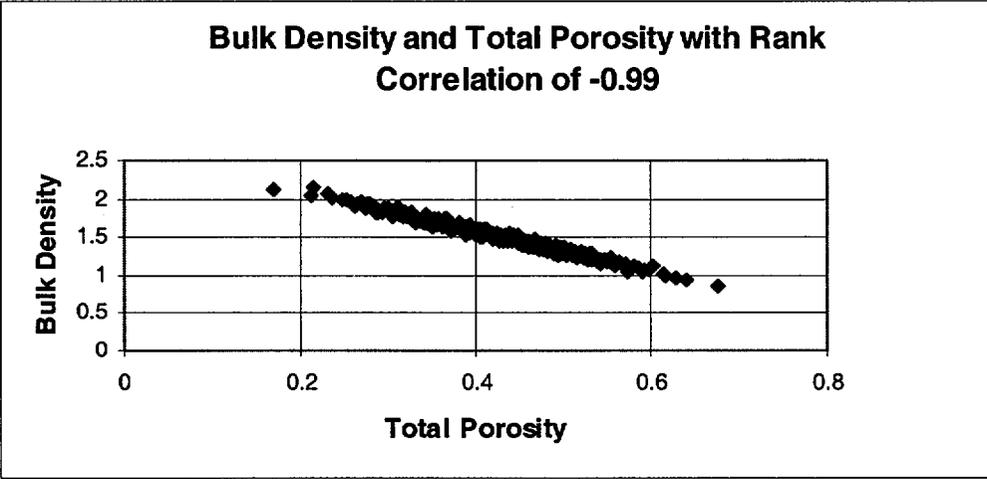
source area = 10,000 m² and thickness = 2 m) in the residential scenario. Table 7.1 also shows the ratio of the 99th percentile dose to the 50th percentile (median) dose. The dose ratio shows the dose spread for different radionuclides. Dose values at the selected quantiles can be used to calculate the 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**

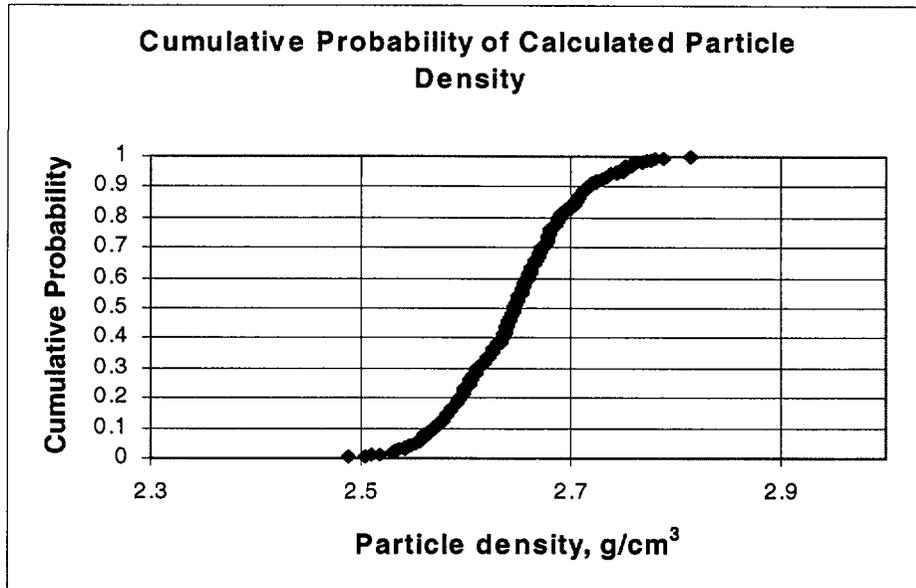


Figure 7.3 Cumulative Probability of Calculated Particle Density

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**

| Radionuclide | 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 | | |
| | 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)**

| Radionuclide | 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 | | |
| | 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 |
| 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 |

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)

| Radionuclide | 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 | | |
| | Dose @ 50% | Dose @ 90% | Dose @ 99%/ Dose @ 50% | Dose @ 50% | Dose @ 90% | Dose @ 99%/ Dose @ 50% | Dose @ 50% | Dose @ 90% | Dose @ 99%/ Dose @ 50% |
| 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 |
| | | | | | | | | | |
| | | | | | | | | | |

7-7

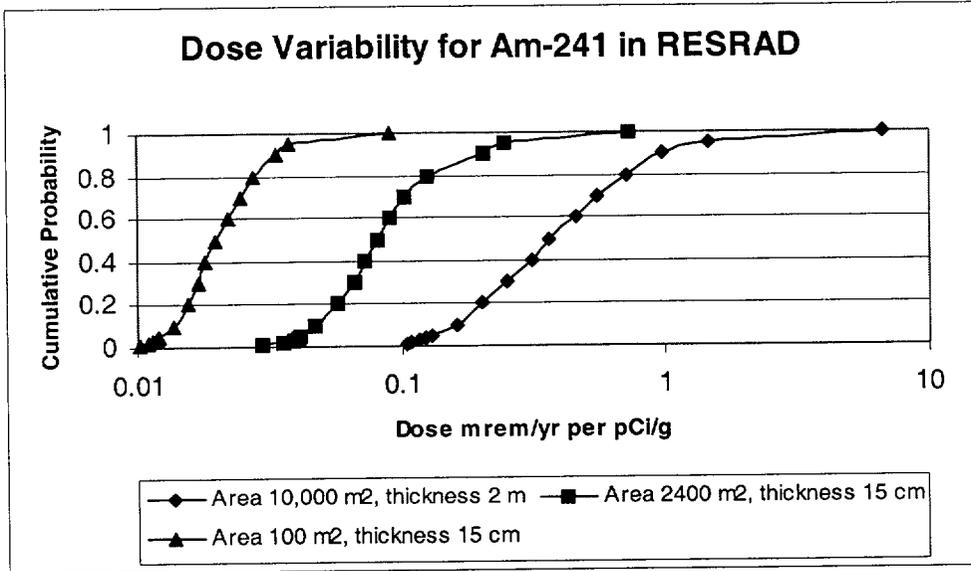


Figure 7.4 Dose Variability of Am-241 for Three Source Configurations in RESRAD

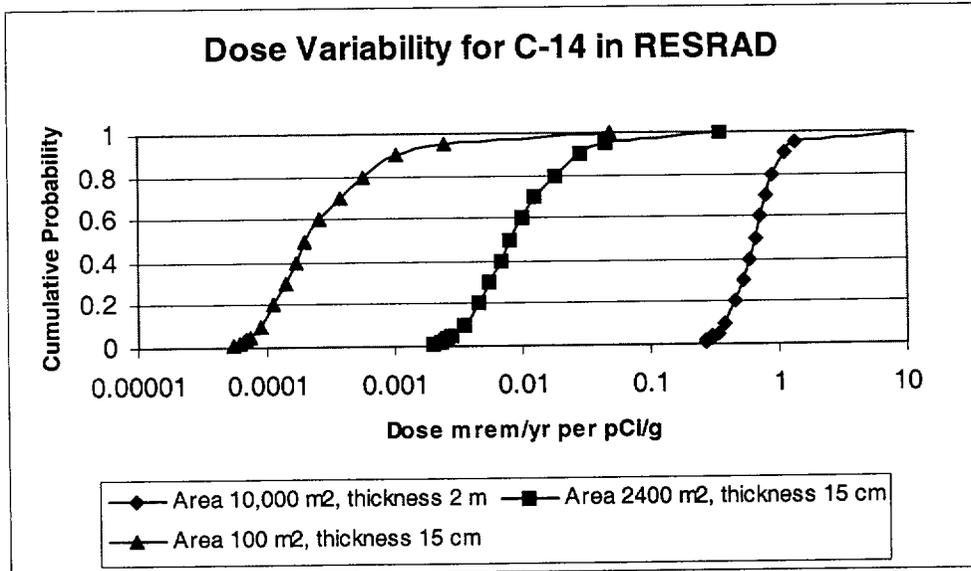


Figure 7.5 Dose Variability of C-14 for Three Source Configurations in RESRAD

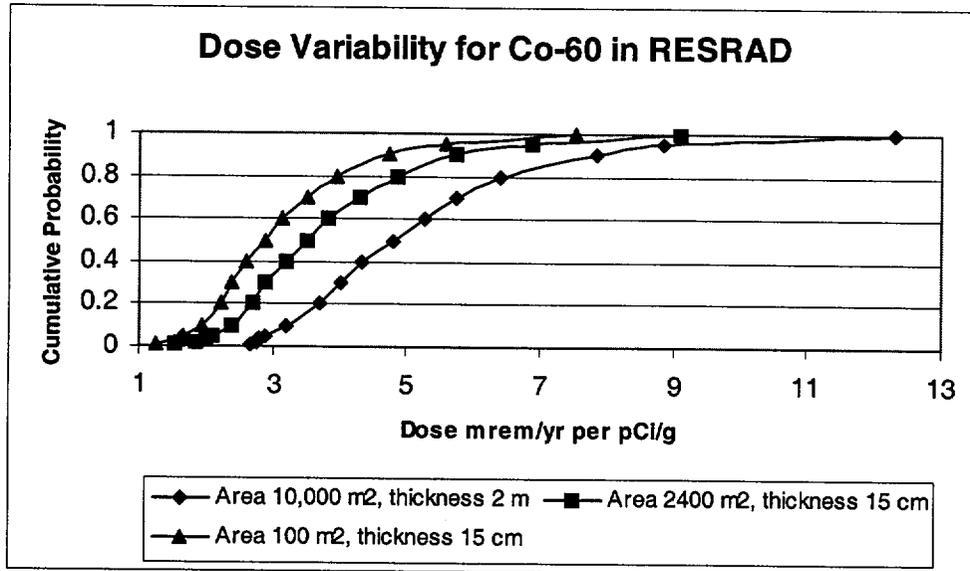


Figure 7.6 Dose Variability of Co-60 for Three Source Configurations in RESRAD

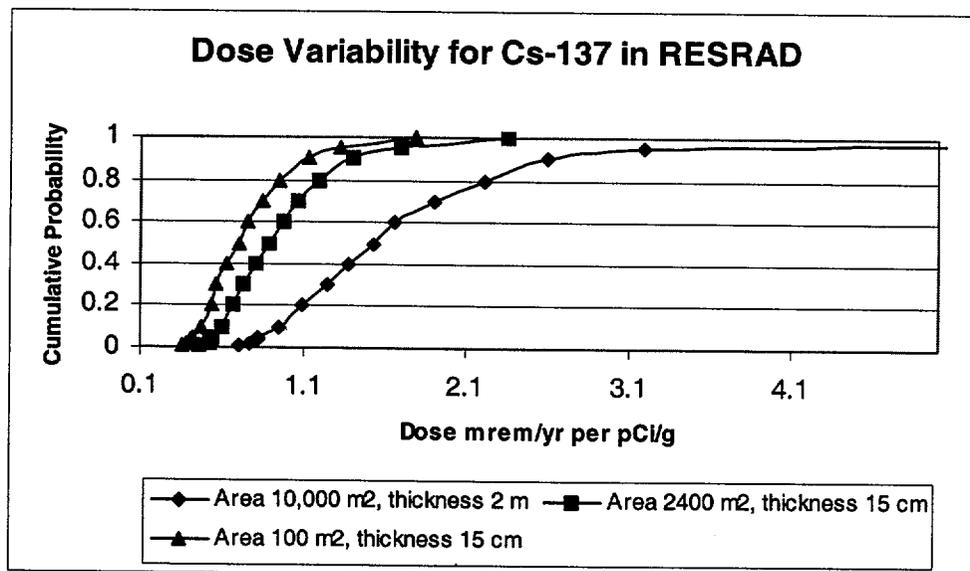


Figure 7.7 Dose Variability of Cs-137 for Three Source Configurations in RESRAD

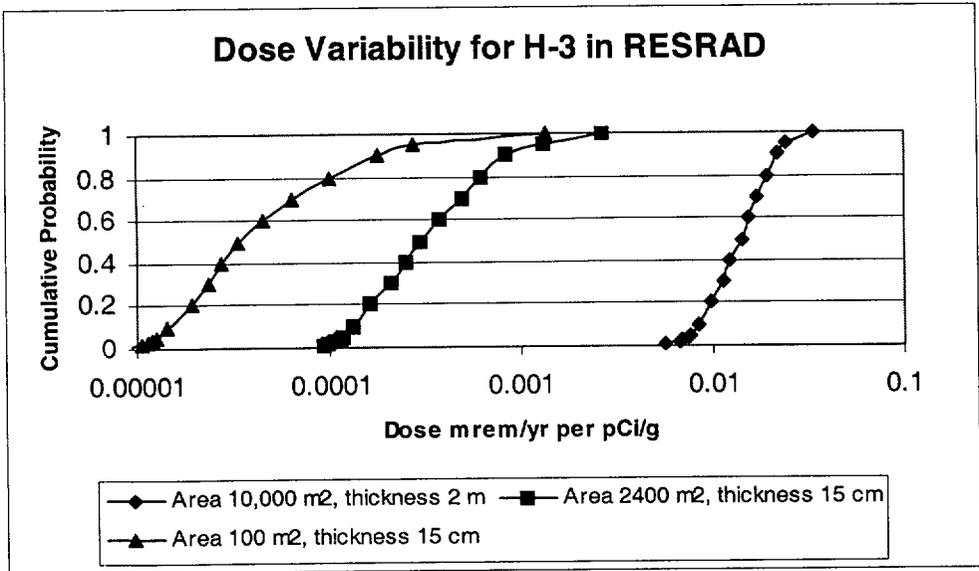


Figure 7.8 Dose Variability of H-3 for Three Source Configurations in RESRAD

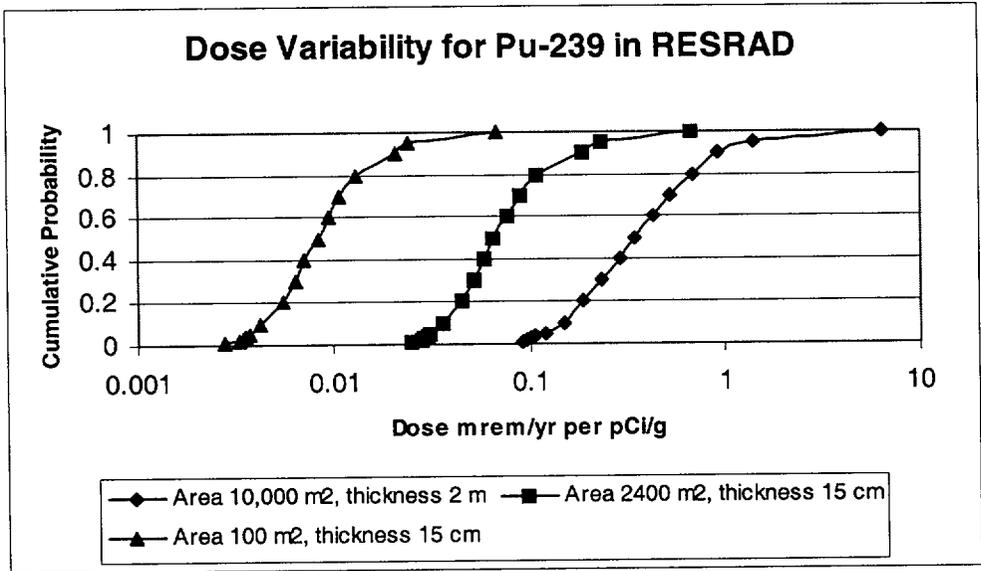


Figure 7.9 Dose Variability of Pu-239 for Three Source Configurations in RESRAD

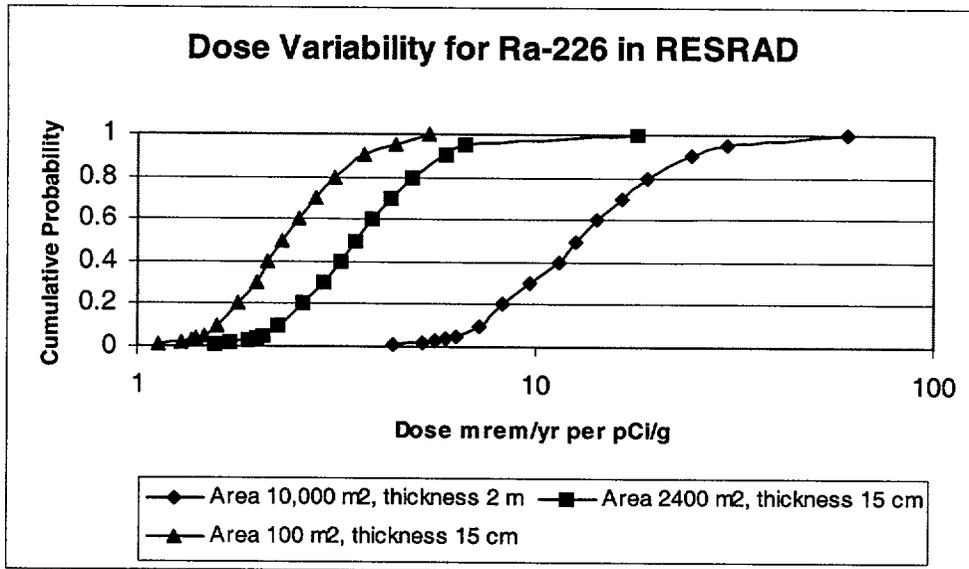


Figure 7.10 Dose Variability of Ra-226 for Three Source Configurations in RESRAD

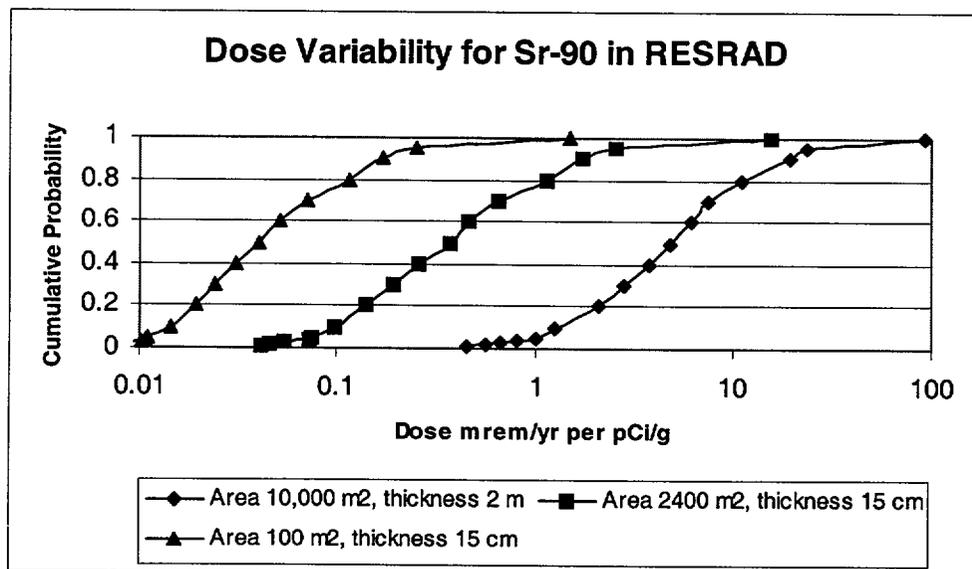


Figure 7.11 Dose Variability of Sr-90 for Three Source Configurations in RESRAD

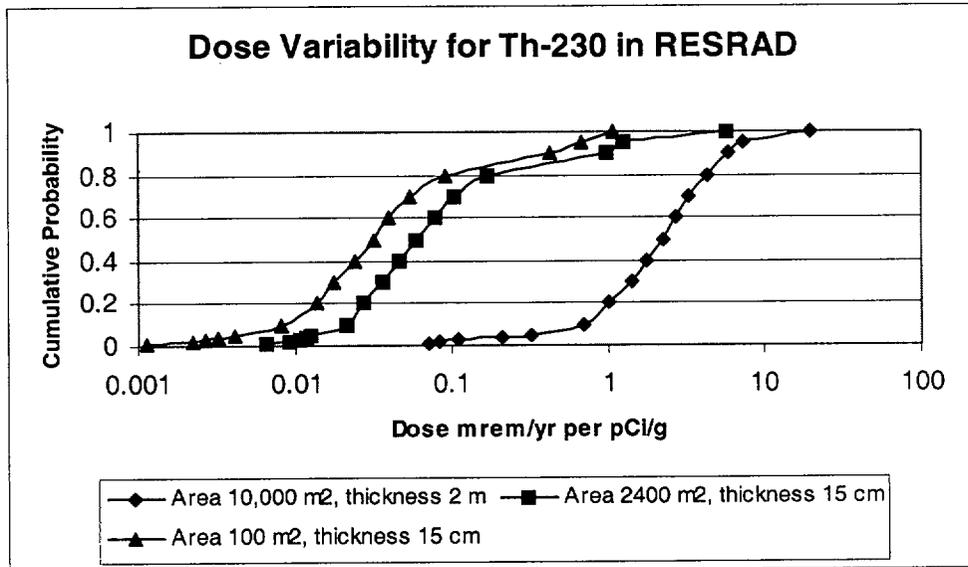


Figure 7.12 Dose Variability of Th-230 for Three Source Configurations in RESRAD

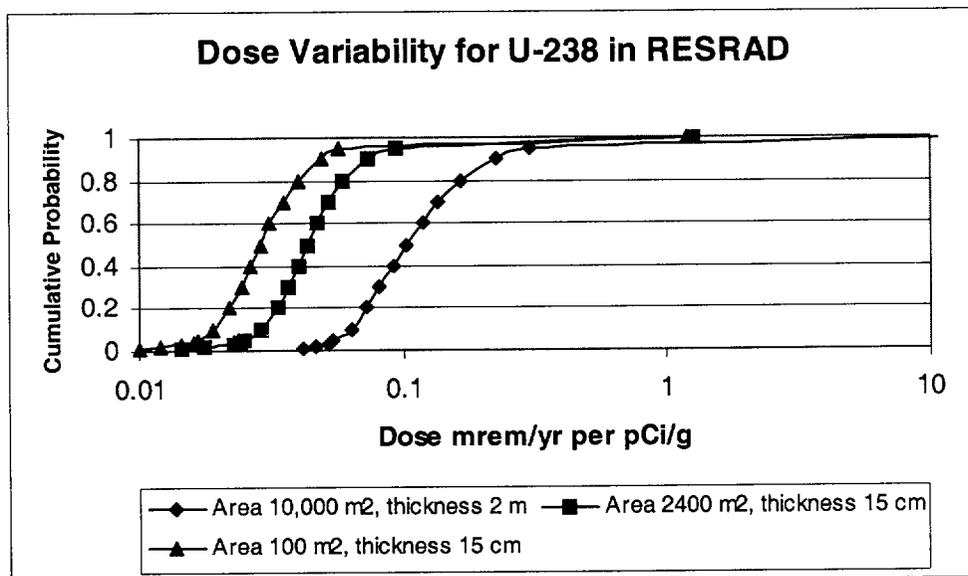


Figure 7.13 Dose Variability of U-238 for Three Source Configurations in RESRAD

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 m² 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 m² 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 | |
| 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) | | |

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 m² 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 |
| 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 m² 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 m² 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) |
| 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 |

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 m² 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 |
| 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 m² area with a thickness of 15 cm and 10,000 m² area with a thickness of 2 m).

For the first source configuration (area = 2,400 m² 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 m² 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 DENSQAQ (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 m² 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 | BPIO(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 m² 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) | |
| 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 m² 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 m², 200 m², and 900 m²).

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

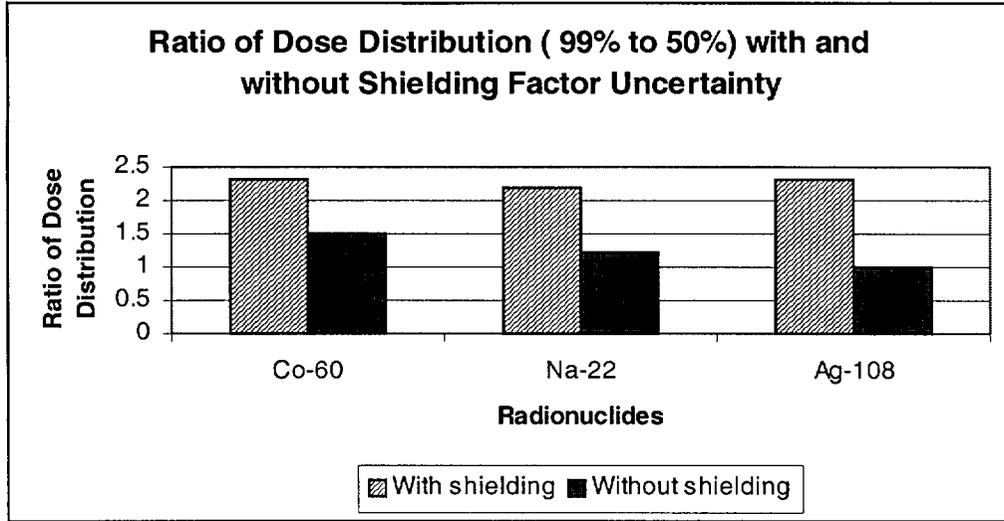


Figure 7.14 Ratio of Dose Distribution with and without Shielding Factor Distribution Uncertainty

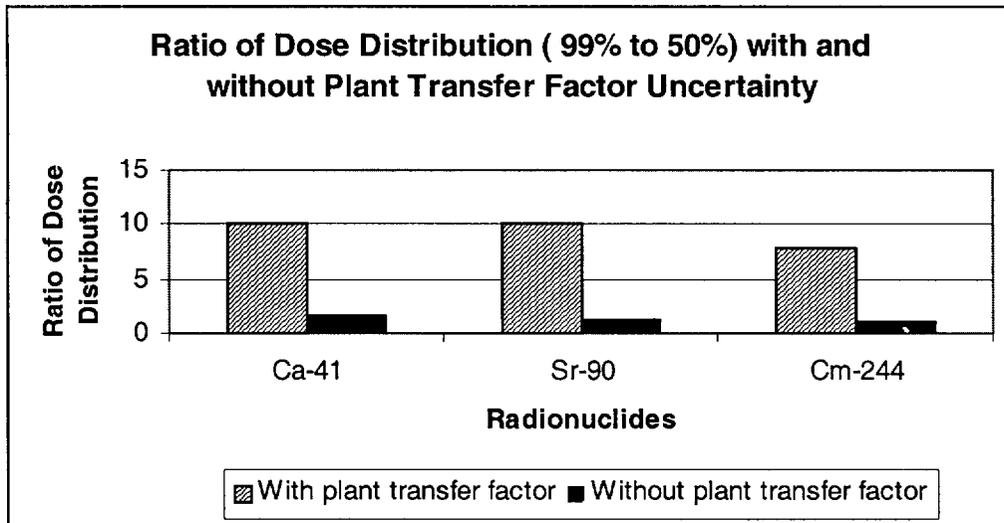


Figure 7.15 Ratio of Dose Distribution with and without Plant Transfer Factor Uncertainty

**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 | Coefficient Value | Parameter | Coefficient Value |
|----------------------------------------------------------------------------|------------|-------------------|-----------|-------------------|------------|-------------------|------------|-------------------|
| <i>Source Configuration: Area = 2,400 m², thickness = 15 cm</i> | | | | | | | | |
| 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 |
| <i>Source Configuration: Area = 10,000 m², thickness = 2 m</i> | | | | | | | | |
| 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 (source 1: source area = 36 m²; source 2: source area = 200 m²; and source 3: source area = 900 m²) 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,

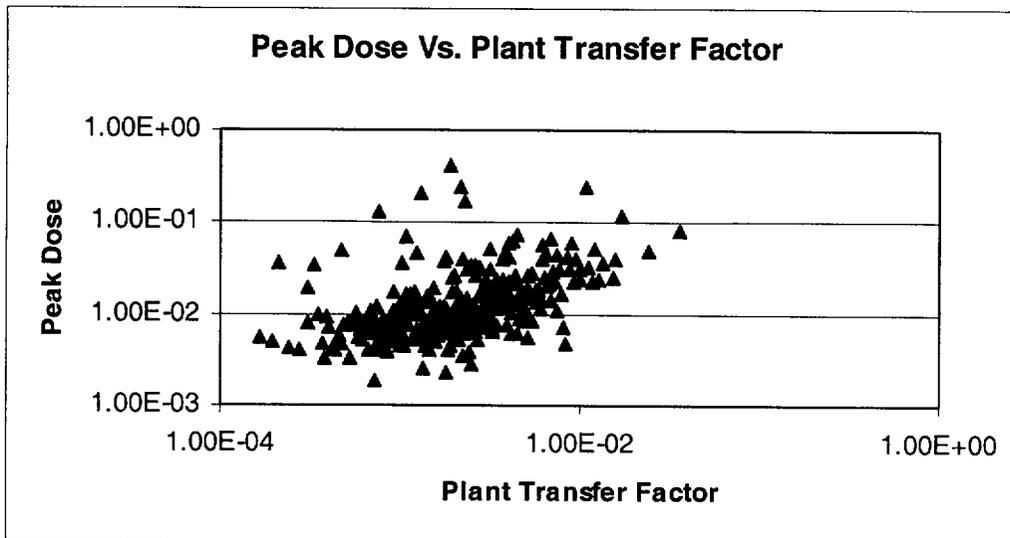


Figure 7.16 Scatter Plot of the Peak Dose vs. U-233 Plant Transfer Factor for Source Area = 2,400 m² and Thickness = 15 cm

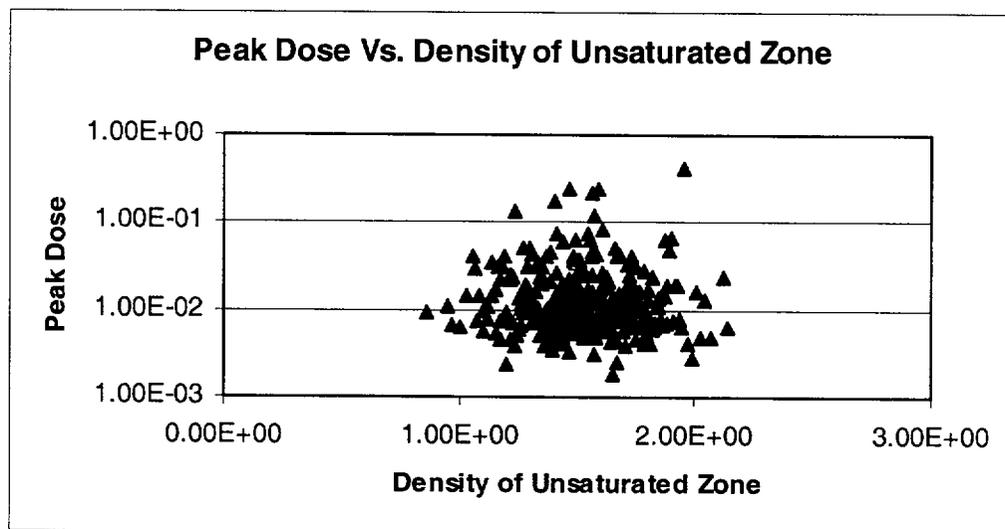


Figure 7.17 Scatter Plot of the Peak Dose vs. Density of Unsaturated Zone for Source Area = 2,400 m² and Thickness = 15 cm

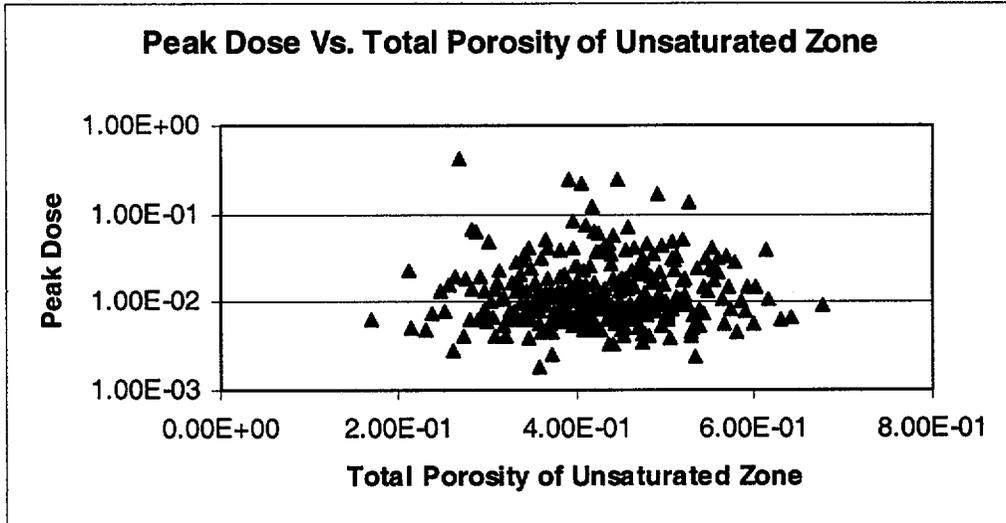


Figure 7.18 Scatter Plot of the Peak Dose vs. Total Porosity of Unsaturated Zone for Source Area = 2,400 m² and Thickness = 15 cm

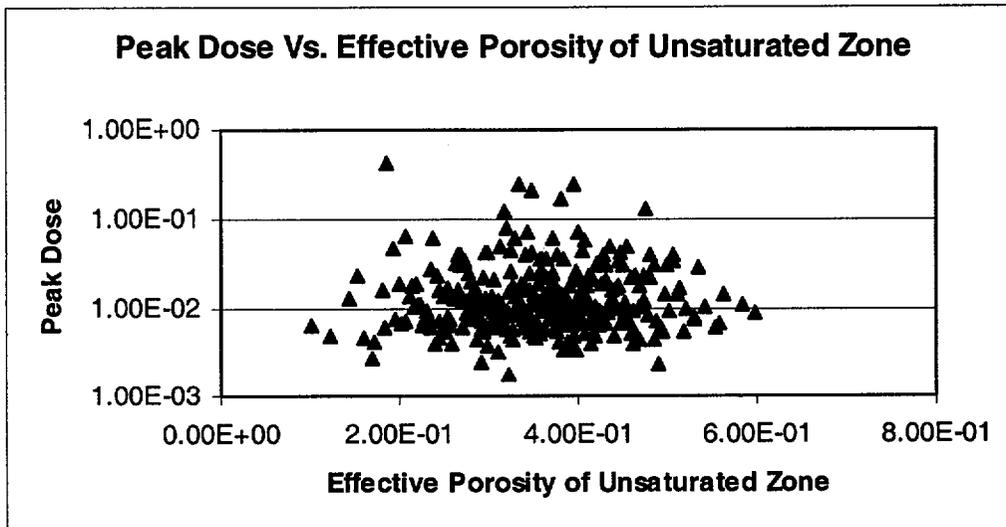


Figure 7.19 Scatter Plot of the Peak Dose vs. Effective Porosity of Unsaturated Zone for Source Area = 2,400 m² and Thickness = 15 cm

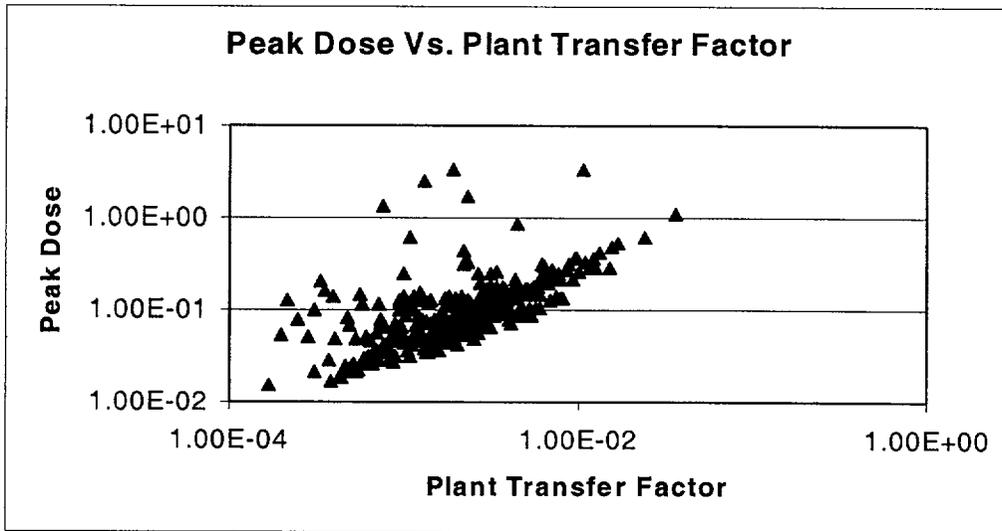


Figure 7.20 Scatter Plot of the Peak Dose vs. U-233 Plant Transfer Factor for Source Area = 10,000 m² and Thickness = 2 m

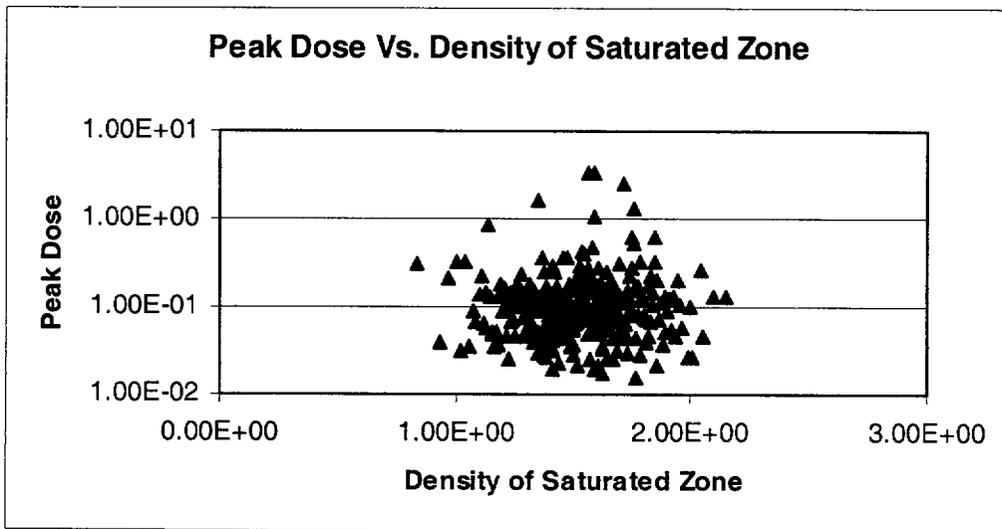


Figure 7.21 Scatter Plot of the Peak Dose vs. Density of Saturated Zone for Source Area = 10,000 m² and Thickness = 2 m

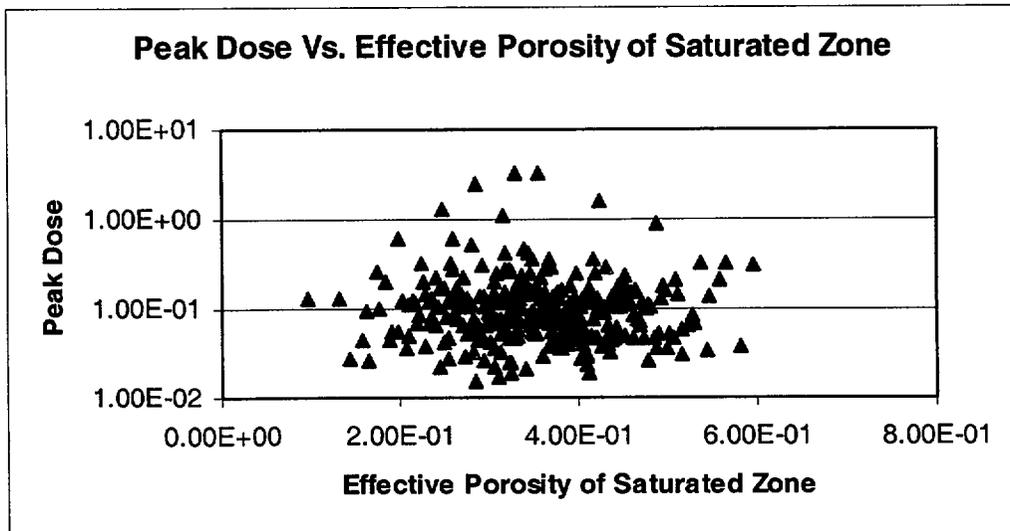


Figure 7.22 Scatter Plot of the Peak Dose vs. Effective Porosity of Saturated Zone for Source Area = 10,000 m² and Thickness = 2 m

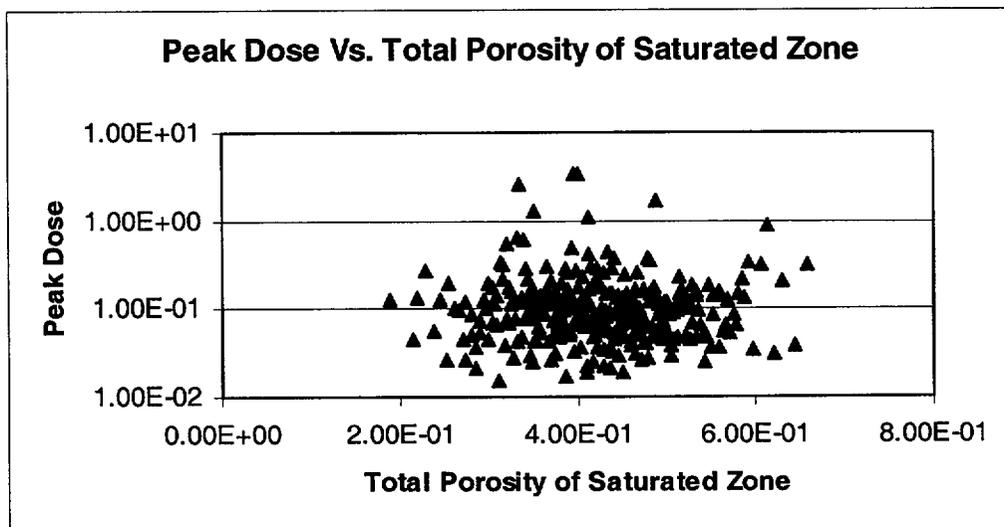


Figure 7.23 Scatter Plot of the Peak Dose vs. Total Porosity of Saturated Zone for Source Area = 10,000 m² and Thickness = 2 m

**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**

| Radionuclide | Source 1: Area = 36 m ² | | | Source 2: Area = 200 m ² | | | Source 3: Area = 900 m ² | | |
|--------------|------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|
| | 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)**

| Radionuclide | Source 1: Area = 36 m ² | | | Source 2: Area = 200 m ² | | | Source 3: Area = 900 m ² | | |
|--------------|------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|
| | 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 |
| 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 m²; source 2: source area = 200 m²; and source 3: source area = 900 m²] 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

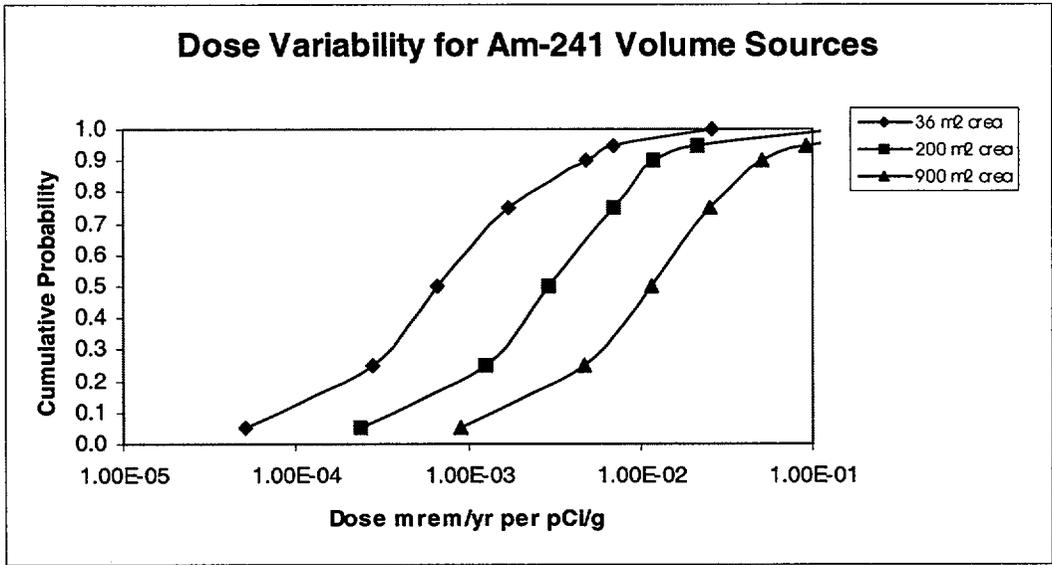


Figure 7.24 Dose Variability of Am-241 for a Volume Source with Three Source Areas in Building Occupancy Scenario

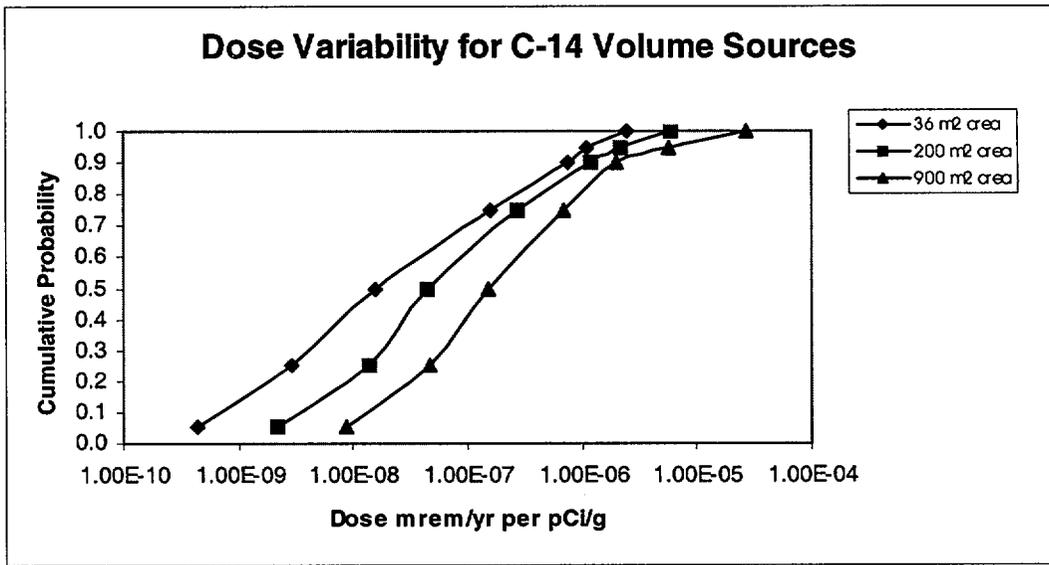


Figure 7.25 Dose Variability of C-14 for a Volume Source with Three Source Areas in Building Occupancy Scenario

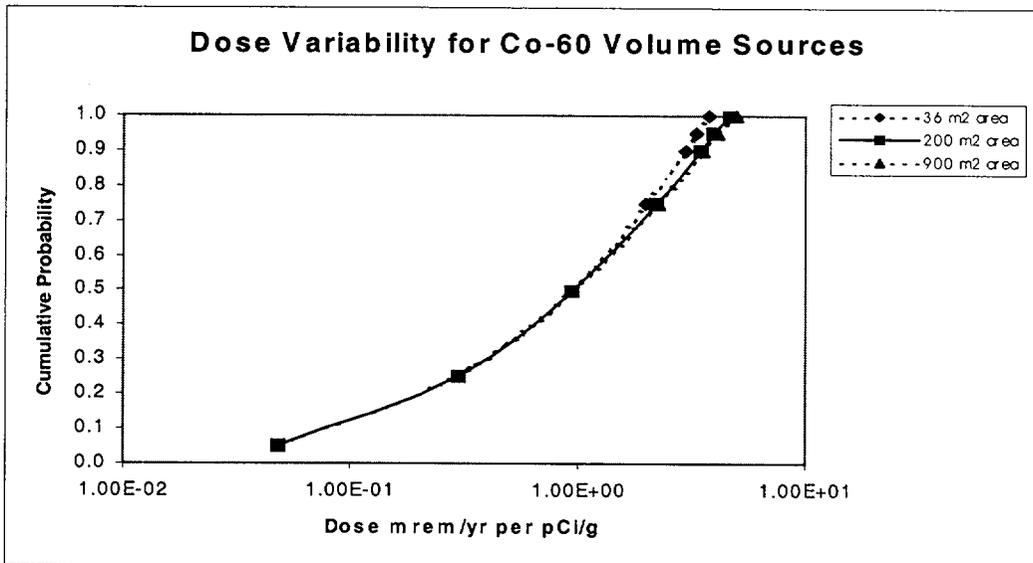


Figure 7.26 Dose Variability of Co-60 for a Volume Source with Three Source Areas in Building Occupancy Scenario

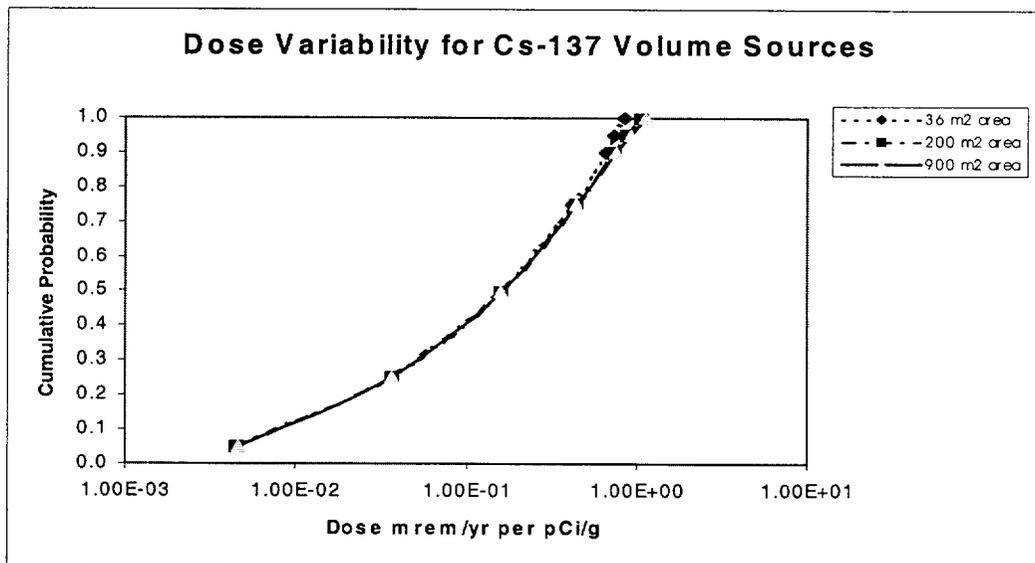


Figure 7.27 Dose Variability of Cs-137 for a Volume Source with Three Source Areas in Building Occupancy Scenario

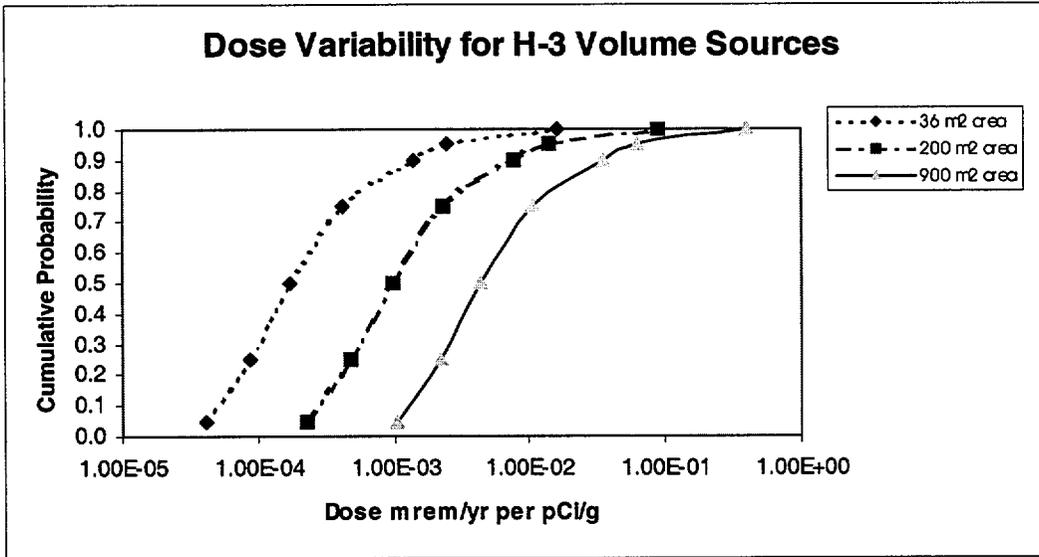


Figure 7.28 Dose Variability of H-3 for a Volume Source with Three Source Areas in Building Occupancy Scenario

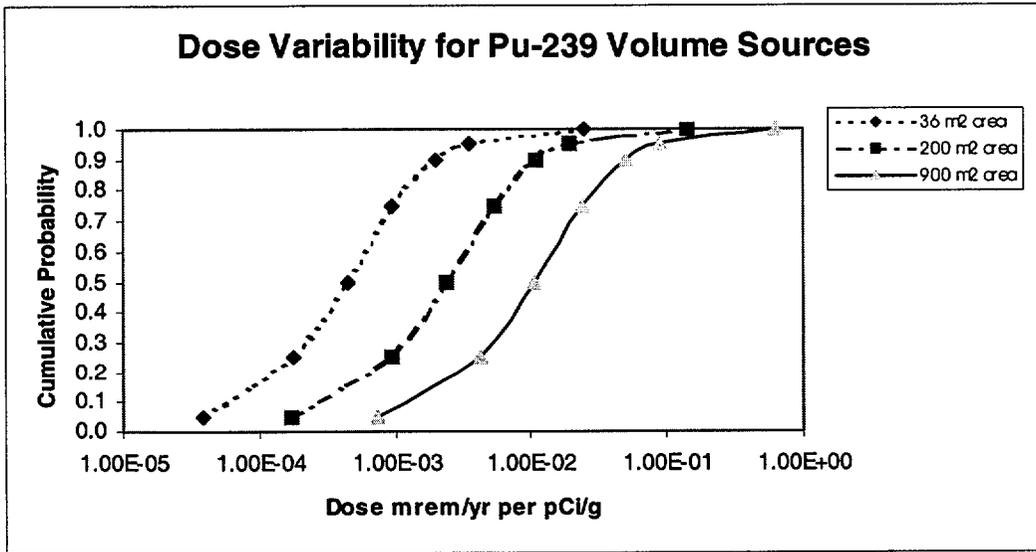


Figure 7.29 Dose Variability of Pu-239 for a Volume Source with Three Source Areas in Building Occupancy Scenario

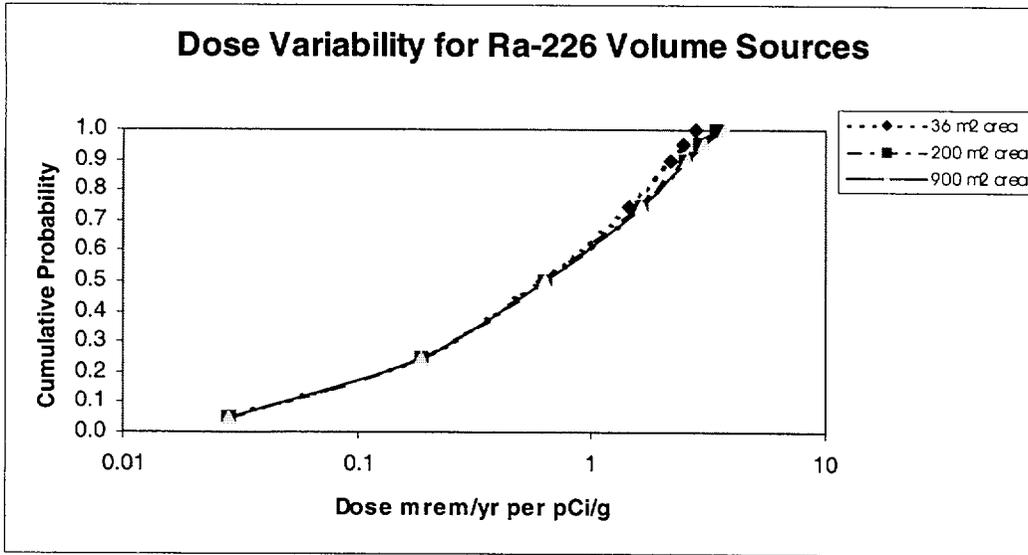


Figure 7.30 Dose Variability of Ra-226 for a Volume Source with Three Source Areas in Building Occupancy Scenario

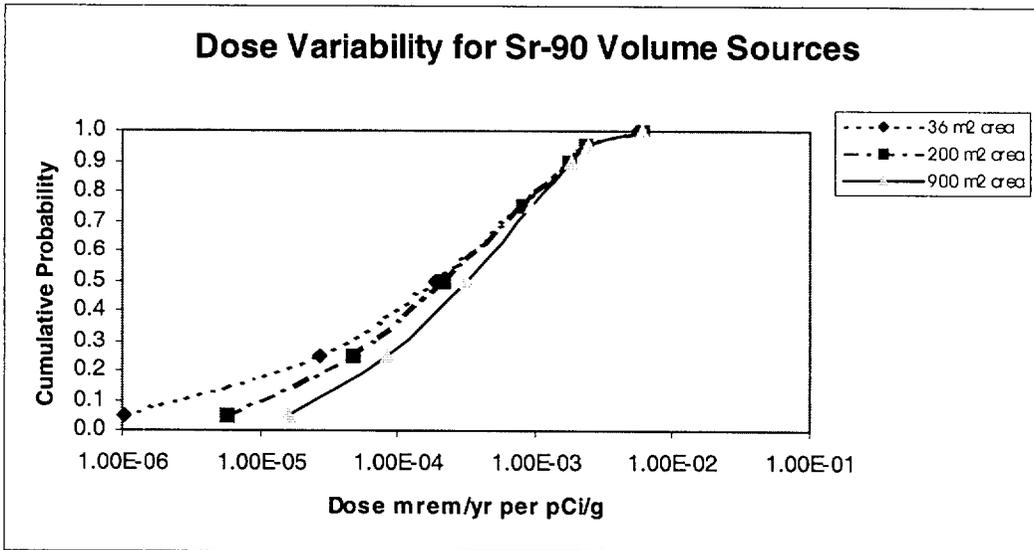


Figure 7.31 Dose Variability of Sr-90 for a Volume Source with Three Source Areas in Building Occupancy Scenario

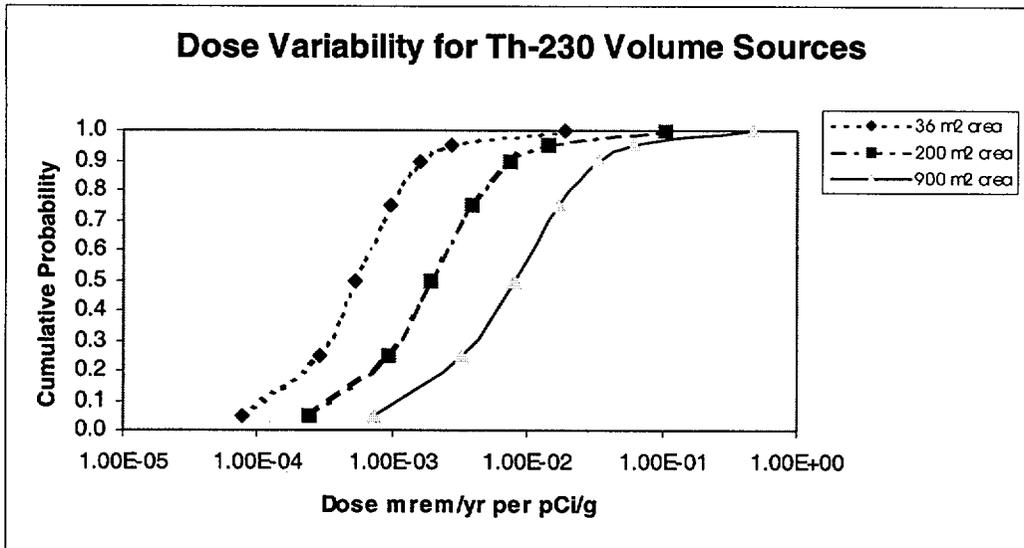


Figure 7.32 Dose Variability of Th-230 for a Volume Source with Three Source Areas in Building Occupancy Scenario

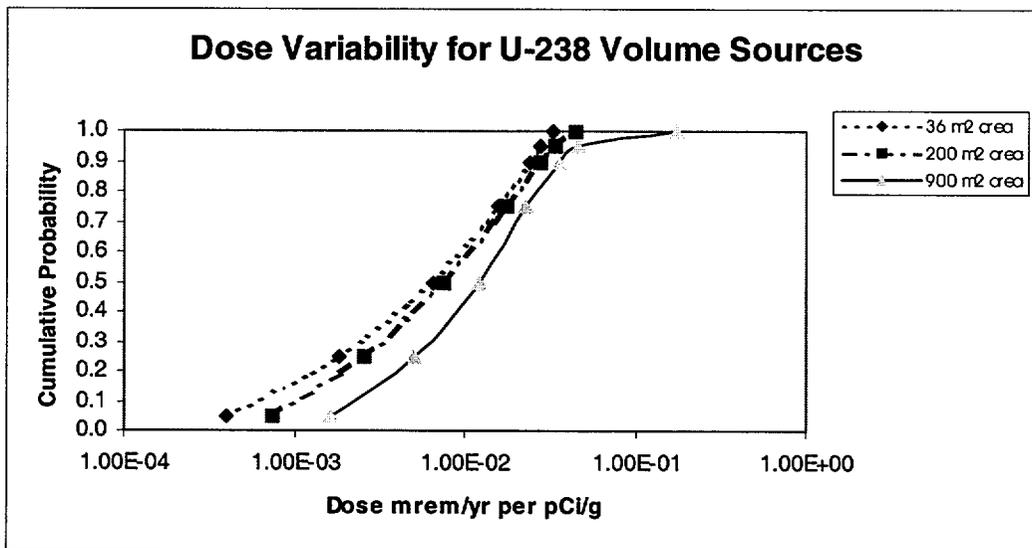


Figure 7.33 Dose Variability of U-238 for a Volume Source with Three Source Areas in Building Occupancy Scenario

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

| Radionuclide | Source 1: Area = 36 m ² | | | Source 2: Area = 200 m ² | | | Source 3: Area = 900 m ² | | |
|--------------|------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|
| | 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/cm²) for Three Source Areas for a Surface Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Source 1: Area = 36 m ² | | | Source 2: Area = 200 m ² | | | Source 3: Area = 900m ² | | |
|--------------|------------------------------------|------------|---------------------------|-------------------------------------|------------|---------------------------|------------------------------------|------------|---------------------------|
| | 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 | 5.88E-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 |
| 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 |

7-37

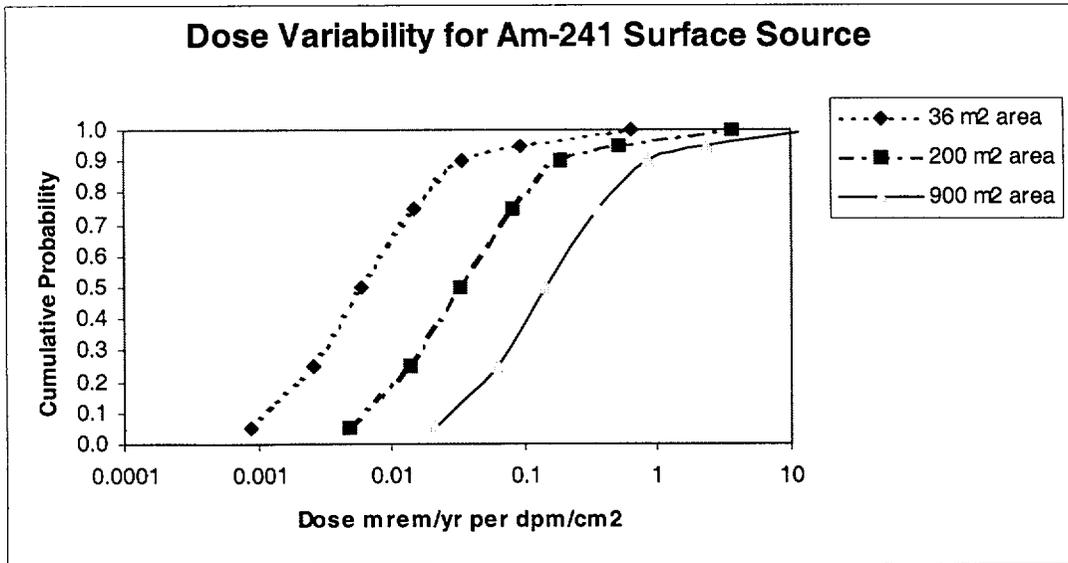


Figure 7.34 Dose Variability of Am-241 for a Surface Source with Three Source Areas in Building Occupancy Scenario

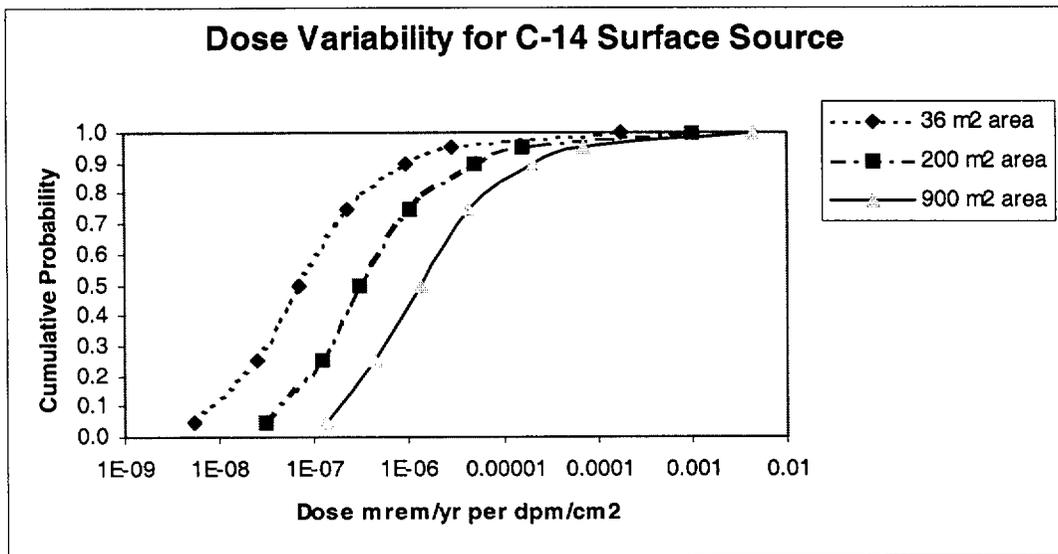


Figure 7.35 Dose Variability of C-14 for a Surface Source with Three Source Areas in Building Occupancy Scenario

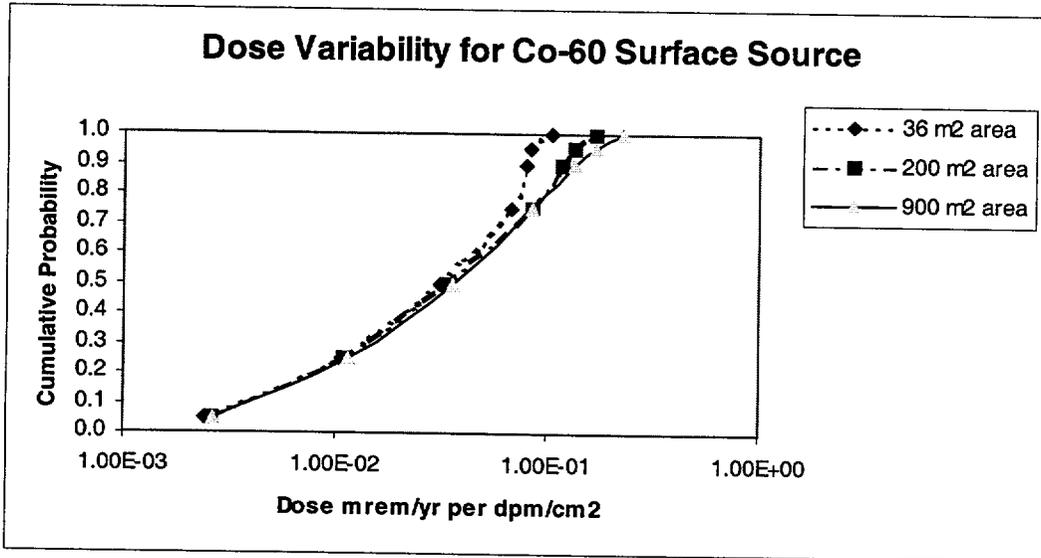


Figure 7.36 Dose Variability of Co-60 for a Surface Source with Three Source Areas in Building Occupancy Scenario

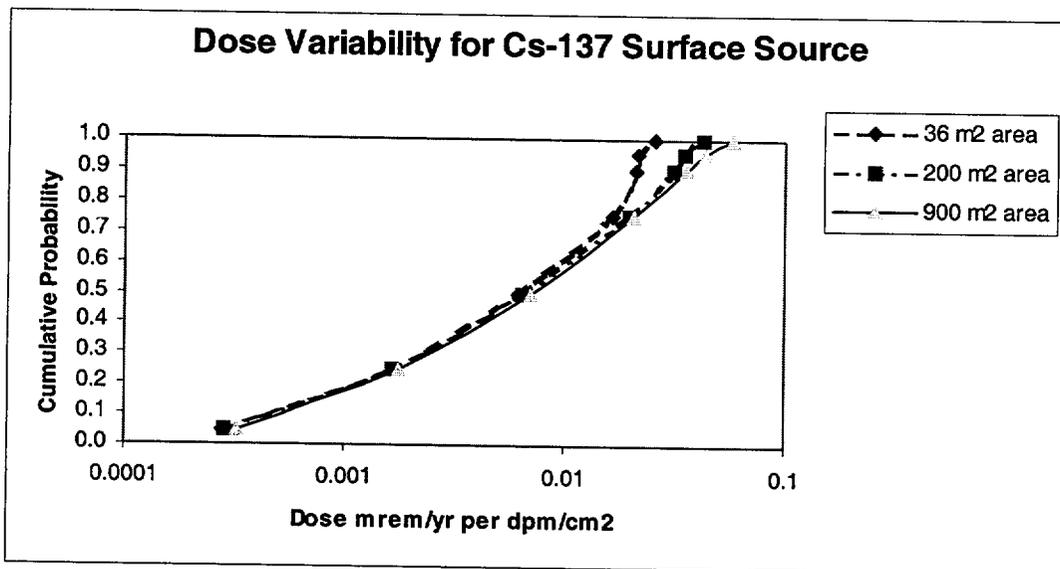


Figure 7.37 Dose Variability of Cs-137 for a Surface Source with Three Source Areas in Building Occupancy Scenario

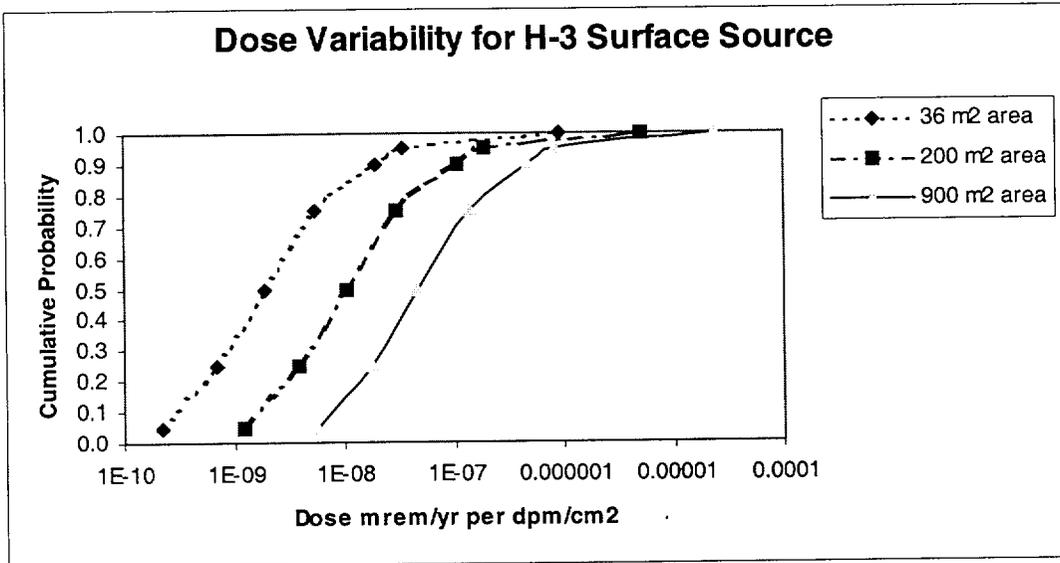


Figure 7.38 Dose Variability of H-3 for a Surface Source with Three Source Areas in Building Occupancy Scenario

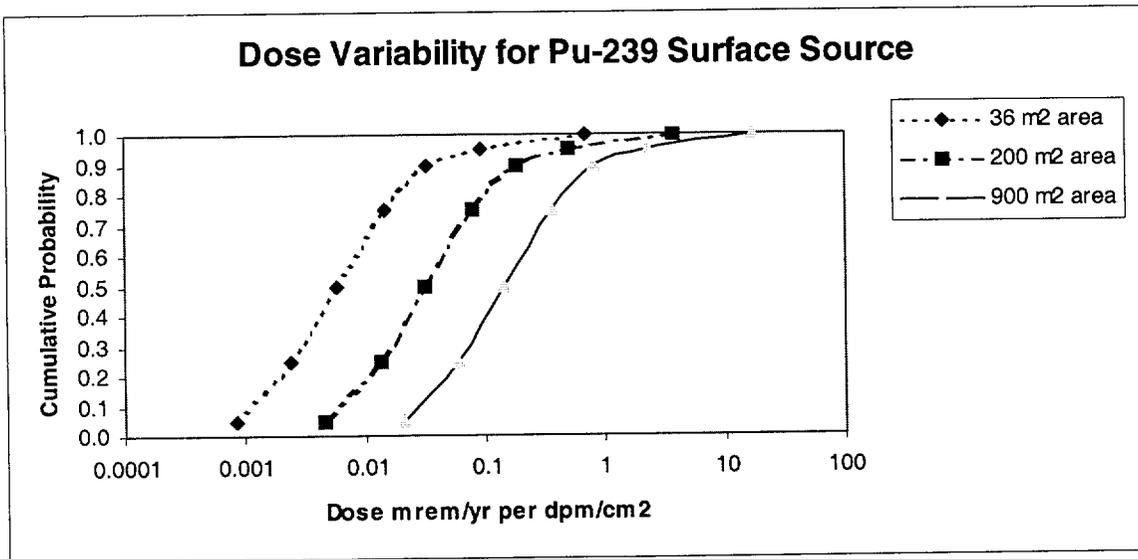


Figure 7.39 Dose Variability of Pu-239 for a Surface Source with Three Source Areas in Building Occupancy Scenario

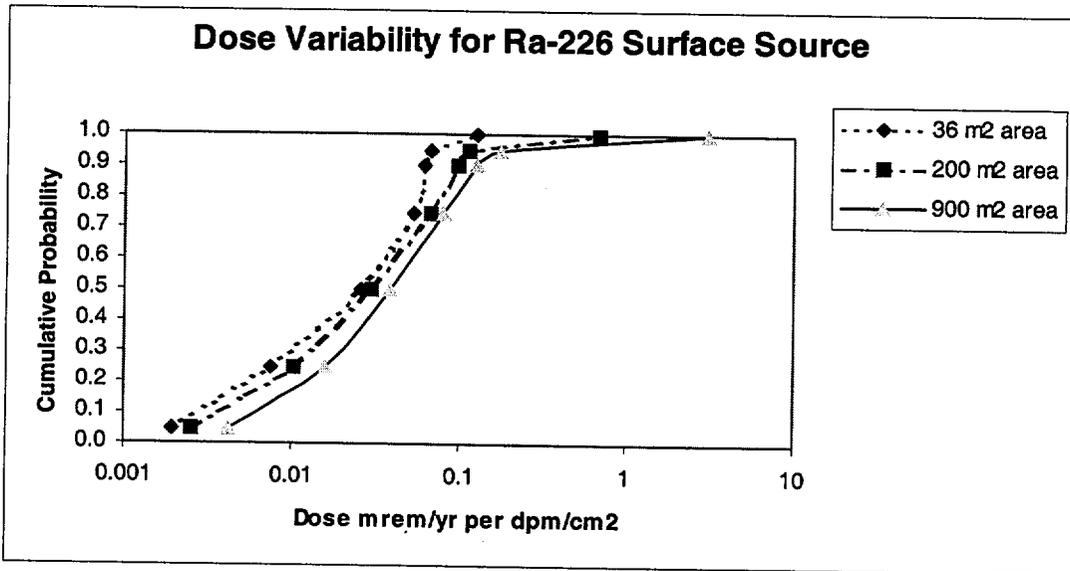


Figure 7.40 Dose Variability of Ra-226 for a Surface Source with Three Source Areas in Building Occupancy Scenario

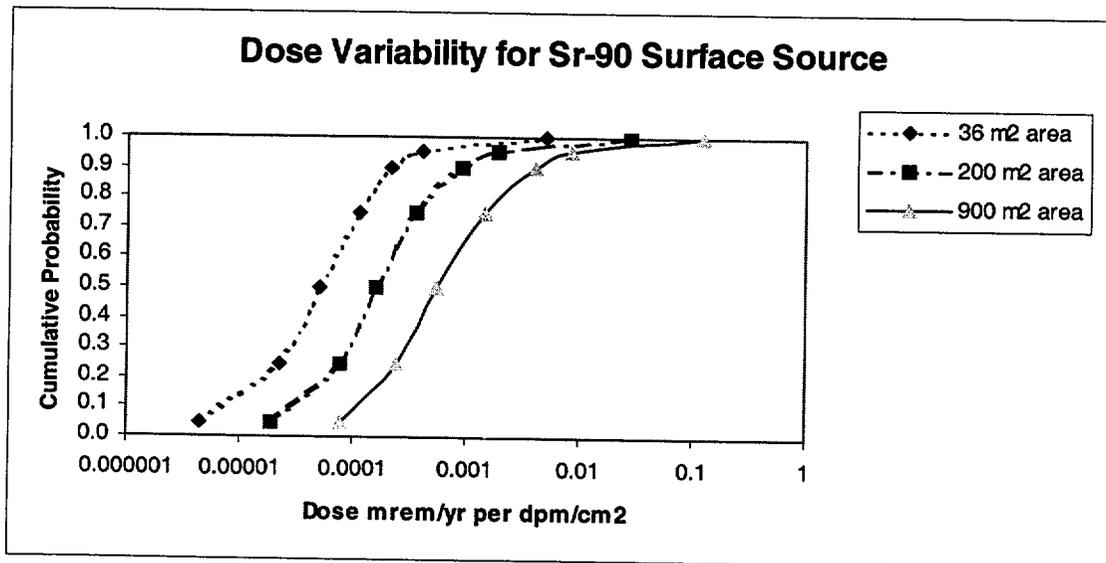


Figure 7.41 Dose Variability of Sr-90 for a Surface Source with Three Source Areas in Building Occupancy Scenario

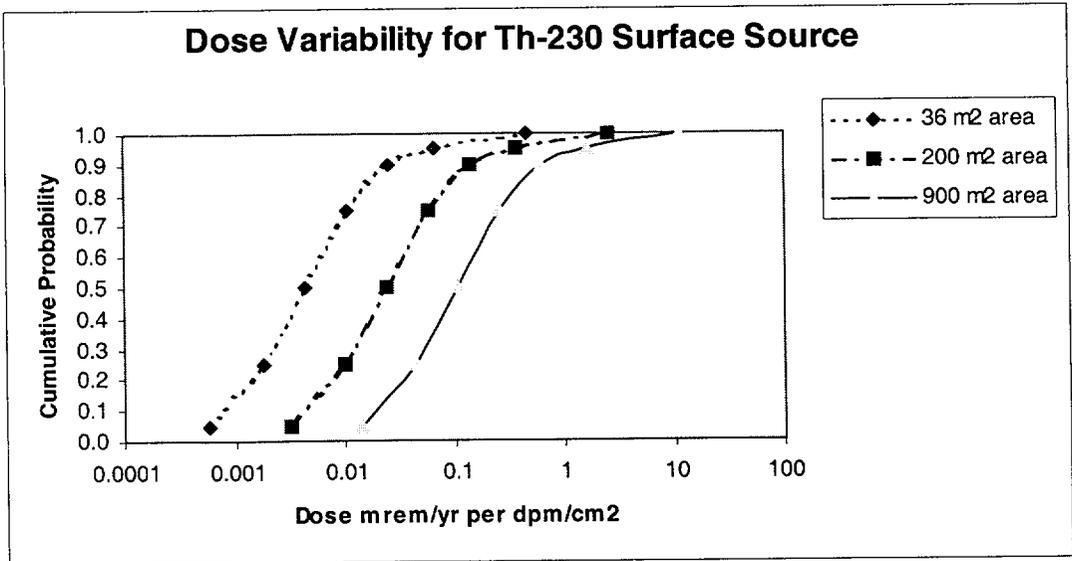


Figure 7.42 Dose Variability of Th-230 for a Surface Source with Three Source Areas in Building Occupancy Scenario

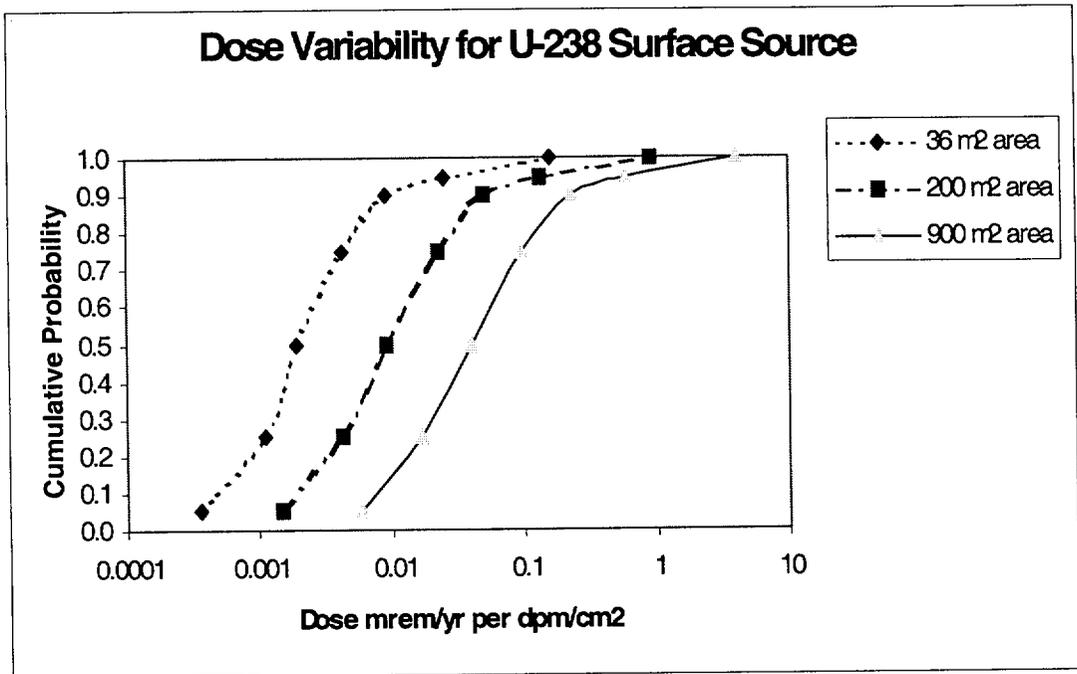


Figure 7.43 Dose Variability of U-238 for a Surface Source with Three Source Areas in Building Occupancy Scenario

Table 7.8. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for a Volume Source of 36-m² Area in a Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|-----------------------------------------------------------------------|--------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | ext | DSTH | EROS0 | AREA | |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | THICK0 | | |
| Am-241 | inh + ext | EROS0 | DSTH | AREA | H |
| Am-243+D | ext | DSTH | | | |
| Au-195 | ext | DSTH | | | |
| Bi-207 | ext | DSTH | | | |
| C-14 | ext | DSTH | EROS0 | DKSUS | UD |
| Ca-41 | inh + ing | EROS0 | AREA | DKSUS | UD |
| Cd-109 | ext | DSTH | | | |
| Ce-144+D | ext | DSTH | | | |
| Cf-252 | inh | EROS0 | AREA | H | |
| Cl-36 | ext | DSTH | | | |
| Cm-243 | ext | DSTH | | | |
| Cm-244 | inh | EROS0 | AREA | H | |
| Cm-248 | inh | EROS0 | AREA | H | DKSUS |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | THICK0 | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | ext | DSTH | DKSUS | EROS0 | UD |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | | | |
| Fe-55 | inh | EROS0 | AREA | H | UD |
| Gd-152 | inh | EROS0 | AREA | H | |
| Gd-153 | ext | DSTH | | | |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | DKSUS | UD | H |
| I-129 | ext | DSTH | EROS0 | DKSUS | UD |
| K-40 | ext | DSTH | THICK0 | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | EROS0 | AREA | DKSUS | H |
| Ni-63 | inh | EROS0 | AREA | DKSUS | H |
| Np-237+D | ext | DSTH | | | |
| Pa-231 | ext | DSTH | AREA | EROS0 | |

Table 7.8. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for a Volume Source of 36-m² Area in a Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|-----------------------------------------------------------------------|--------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Pb-210+D | ext | DSTH | EROS0 | AREA | DKSUS |
| Pm-147 | ext | DSTH | EROS0 | AREA | |
| Pu-238 | inh | EROS0 | AREA | H | |
| Pu-239 | inh | EROS0 | AREA | H | |
| Pu-240 | inh | EROS0 | AREA | H | |
| Pu241+D | inh | EROS0 | AREA | H | DSTH |
| Pu-242 | inh | EROS0 | AREA | H | |
| Pu-244+D | ext | DSTH | | | |
| Ra-226+D | ext | DSTH | | | |
| Ra-228+D | ext | DSTH | | | |
| Ru-106+D | ext | DSTH | | | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | EROS0 | AREA | H | |
| Sm-151 | inh | EROS0 | AREA | H | |
| Sr-90+D | ext | DSTH | UD | DSDEN | |
| Tc-99 | ext | DSTH | EROS0 | | |
| Th-228+D | ext | DSTH | THICK0 | | |
| Th-229+D | ext | DSTH | | | |
| Th-230+D | inh | AREA | EROS0 | DSTH | H |
| Th-232 | ext | DSTH | AREA | EROS0 | |
| Tl-204 | ext | DSTH | DSDEN | | |
| U-232 | ext | DSTH | THICK0 | | |
| U-233 | inh | EROS0 | AREA | DSTH | H |
| U-234 | inh | EROS0 | AREA | H | |
| U-235+D | ext | DSTH | | | |
| U-236 | inh | EROS0 | AREA | H | |
| U-238+D | ext | DSTH | | | |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

Table 7.9. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for a Volume Source of 200-m² Area in a Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|-----------------------------------------------------------------------|-------|-------|--------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | ext | DSTH | AREA | EROS0 | H |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | | | |
| Am-241 | inh | EROS0 | AREA | DSTH | H |
| Am-243+D | ext | DSTH | EROS0 | AREA | |
| Au-195 | ext | DSTH | | | |
| Bi-207 | ext | DSTH | | | |
| C-14 | ext | DSTH | EROS0 | DKSUS | AREA |
| Ca-41 | inh + ing | EROS0 | AREA | DKSUS | UD |
| Cd-109 | ext | DSTH | | | |
| Ce-144+D | ext | DSTH | | | |
| Cf-252 | inh | EROS0 | AREA | H | |
| Cl-36 | ext | DSTH | | | |
| Cm-243 | ext | DSTH | EROS0 | AREA | |
| Cm-244 | inh | EROS0 | AREA | H | |
| Cm-248 | inh | EROS0 | AREA | H | |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | ext | DSTH | DKSUS | EROS0 | UD |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | | | |
| Fe-55 | inh | EROS0 | AREA | H | UD |
| Gd-152 | inh | EROS0 | AREA | H | DENSIO |
| Gd-153 | ext | DSTH | | | |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | DKSUS | UD | H |
| I-129 | ext | EROS0 | DSTH | DKSUS | AREA |
| K-40 | ext | DSTH | | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | EROS0 | AREA | DKSUS | H |
| Ni-63 | inh | EROS0 | AREA | DKSUS | H |
| Np-237+D | ext | DSTH | AREA | EROS0 | |
| Pa-231 | ext | DSTH | AREA | EROS0 | H |

Table 7.9. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for a Volume Source of 200-m² Area in a Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|-----------------------------------------------------------------------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Pb-210+D | ext | DSTH | EROS0 | AREA | DKSUS |
| Pm-147 | ext | DSTH | EROS0 | AREA | |
| Pu-238 | inh | EROS0 | AREA | H | |
| Pu-239 | inh | EROS0 | AREA | H | |
| Pu-240 | inh | EROS0 | AREA | H | |
| Pu241+D | inh | EROS0 | AREA | H | |
| Pu-242 | inh | EROS0 | AREA | H | |
| Pu-244+D | ext | DSTH | | | |
| Ra-226+D | ext | DSTH | | | |
| Ra-228+D | ext | DSTH | | | |
| Ru-106+D | ext | DSTH | | | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | EROS0 | AREA | H | |
| Sm-151 | inh | EROS0 | AREA | H | |
| Sr-90+D | ext | DSTH | AREA | DSDEN | UD |
| Tc-99 | ext | DSTH | EROS0 | AREA | DKSUS |
| Th-228+D | ext | DSTH | | | |
| Th-229+D | ext | DSTH | AREA | EROS0 | |
| Th-230+D | inh | EROS0 | AREA | H | DSTH |
| Th-232 | ext | DSTH | AREA | EROS0 | |
| Tl-204 | ext | DSTH | | | |
| U-232 | ext | DSTH | | | |
| U-233 | inh | EROS0 | AREA | H | DSTH |
| U-234 | inh | EROS0 | AREA | H | |
| U-235+D | ext | DSTH | AREA | | |
| U-236 | inh | EROS0 | AREA | H | |
| U-238+D | ext | DSTH | AREA | EROS0 | |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

**Table 7.10. Four Most Sensitive Parameters
Based on SRRC Analysis and Dominant Pathways for a Volume
Source of 900-m² Area in a Building Occupancy Scenario**

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|-----------------------------------------------------------------------|-------|-------|------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | ext | DSTH | EROS0 | AREA | H |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | | | |
| Am-241 | inh | EROS0 | AREA | H | |
| Am-243+D | ext | DSTH | EROS0 | AREA | |
| Au-195 | ext | DSTH | | | |
| Bi-207 | ext | DSTH | | | |
| C-14 | ext | DSTH | EROS0 | DKSUS | AREA |
| Ca-41 | inh + ing | EROS0 | AREA | DKSUS | UD |
| Cd-109 | ext | DSTH | EROS0 | AREA | |
| Ce-144+D | ext | DSTH | | | |
| Cf-252 | inh | EROS0 | AREA | H | |
| Cl-36 | ext | DSTH | | | |
| Cm-243 | ext | DSTH | EROS0 | AREA | |
| Cm-244 | inh | EROS0 | AREA | H | |
| Cm-248 | inh | EROS0 | AREA | H | |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | ext | DSTH | DKSUS | EROS0 | |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | | | |
| Fe-55 | inh | EROS0 | AREA | H | UD |
| Gd-152 | inh | EROS0 | AREA | H | |
| Gd-153 | ext | DSTH | | | |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | DKSUS | UD | H |
| I-129 | inh + ing | EROS0 | DKSUS | AREA | UD |
| K-40 | ext | DSTH | | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | EROS0 | AREA | DKSUS | H |
| Ni-63 | inh | EROS0 | AREA | DKSUS | H |
| Np-237+D | ext | DSTH | AREA | EROS0 | |
| Pa-231 | inh | EROS0 | AREA | DSTH | H |

**Table 7.10. Four Most Sensitive Parameters
Based on SRRC Analysis and Dominant Pathways for a Volume
Source of 900-m² Area in a Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|-----------------------------------------------------------------------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Pb-210+D | inh | EROS0 | AREA | DKSUS | UD |
| Pm-147 | ext | DSTH | EROS0 | AREA | H |
| Pu-238 | inh | EROS0 | AREA | H | |
| Pu-239 | inh | EROS0 | AREA | H | |
| Pu-240 | inh | EROS0 | AREA | H | |
| Pu241+D | inh | EROS0 | AREA | H | |
| Pu-242 | inh | EROS0 | AREA | H | |
| Pu-244+D | ext | DSTH | | | |
| Ra-226+D | ext | DSTH | | | |
| Ra-228+D | ext | DSTH | | | |
| Ru-106+D | ext | DSTH | | | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | EROS0 | AREA | H | |
| Sm-151 | inh | EROS0 | AREA | H | |
| Sr-90+D | ext | DSTH | AREA | EROS0 | DSDEN |
| Tc-99 | ext | DSTH | EROS0 | AREA | DKSUS |
| Th-228+D | ext | DSTH | | | |
| Th-229+D | ext | DSTH | AREA | EROS0 | H |
| Th-230+D | inh | EROS0 | AREA | H | |
| Th-232 | inh + ext | AREA | EROS0 | DSTH | H |
| Tl-204 | ext | DSTH | | | |
| U-232 | ext | DSTH | AREA | EROS0 | |
| U-233 | inh | EROS0 | AREA | H | |
| U-234 | inh | EROS0 | AREA | H | |
| U-235+D | ext | DSTH | EROS0 | AREA | |
| U-236 | inh | EROS0 | AREA | H | |
| U-238+D | ext | DSTH | AREA | EROS0 | |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

and without the uncertainty on shielding thickness is shown in Figure 7.44.

For radionuclides for which inhalation was the dominant pathway, room area and source erosion rate were two dominant parameters that contributed to large dose variability. Three radionuclides (Am-241, Cm-244, and Pu-238) were selected to study the effect of room area and erosion rate on the dose variability. Figures 7.45 and 7.46 show the dose ratio (95th percentile dose to 50th percentile dose) with and without the uncertainty on room area and source erosion rate.

7.2.3.2 Dominant Pathways and Sensitive Parameters in Area Source

Tables 7.11 through 7.13 list the four most sensitive parameters based on SRRC along with the dominant pathway for the three sources. Tables C.7 through C.9 in Appendix C present detailed information, including SRRC values. Only sensitive parameters with SRRC values of ≥ 0.1 are only 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 (Co-60, Al-26, and Eu-152) were selected to study the effect of shielding thickness. It was observed that after removing the shielding thickness from uncertainty analysis, dose variability was significantly reduced. Figure 7.47 shows the dose ratio (95th percentile dose to 50th percentile dose) with and without the uncertainty on shielding thickness.

For radionuclides for which inhalation was the dominant pathway, many parameters (e.g., room area, removable fraction, source lifetime) contributed to the dose variability. Figures 7.48 through 7.50 show the dose ratio (95th percentile dose to 50th percentile dose) with and without the uncertainty for room area, removable fraction, and source lifetime, respectively, for Am-241, Pu-239, and U-238.

For radionuclides with the ingestion pathway as the dominant contributor to the dose, apart from three parameters (room area, removable fraction, source life-time) that contributed to dose variability in the inhalation pathway, deposition velocity and resuspension rate also showed high sensitivity. Figures 7.51 and 7.52 show the effect of deposition velocity and resuspension rate on the dose variability for C-14, I-129, and Cs-135.

7.2.4 Parameter Correlation Results

The results showed that resuspension rate and deposition velocity were sensitive parameters for some radionuclides (e.g., C-14, Ca-41, Cs-135, and I-129) in the case of volume sources. A positive rank correlation of 0.9 was used between deposition velocity and resuspension rate. Four radionuclides (Ca-41, I-129, C-14, and Cs-135) were selected to study the effect of correlation. Figure 7.53 shows the difference in dose variability with and without correlation between deposition velocity and resuspension rate. Dose variability was considerably reduced by the use of correlation. In the absence of knowledge of real correlation between deposition velocity and resuspension rate, rank correlation was not used in the analysis.

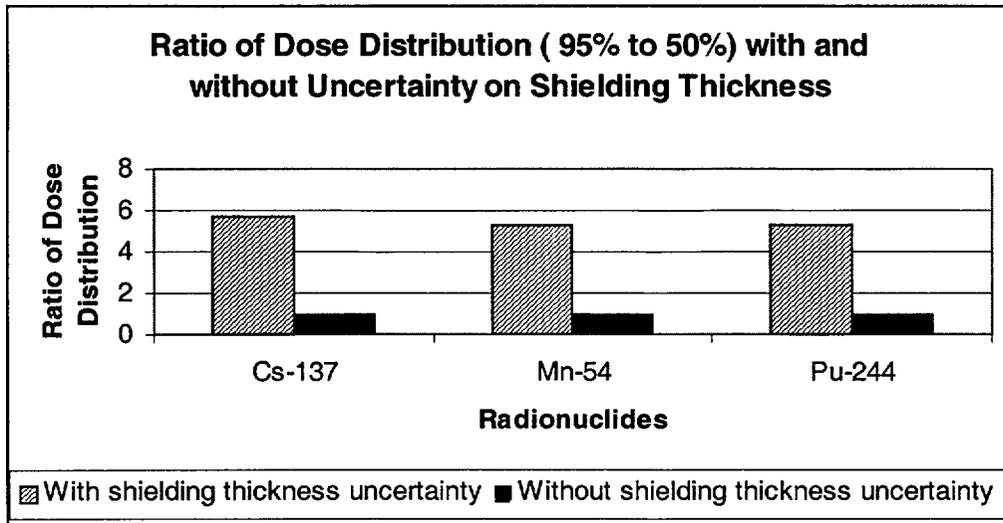


Figure 7.44 Ratio of Dose Distribution with and without Uncertainty on Shielding Thickness for a Volume Source in Building Occupancy Scenario

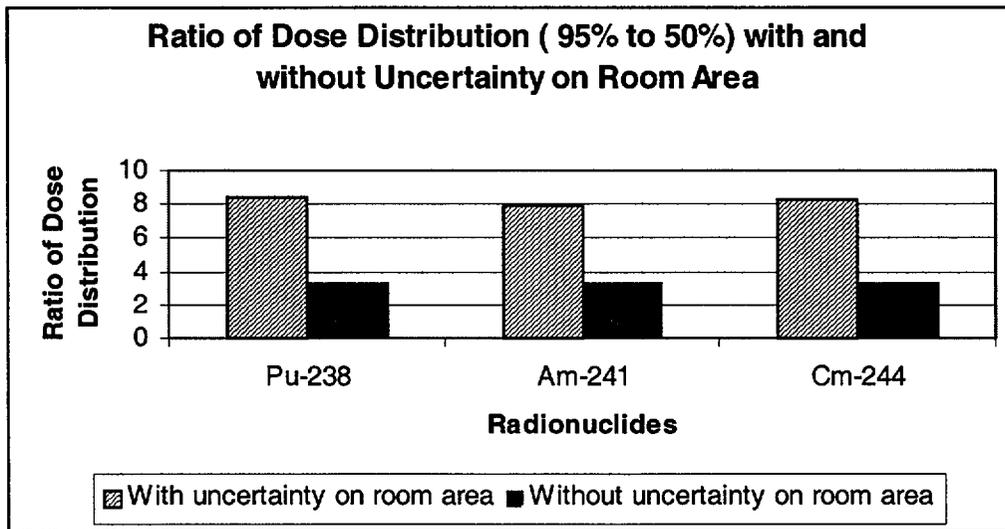


Figure 7.45 Ratio of Dose Distribution with and without Uncertainty on Room Area for a Volume Source in Building Occupancy Scenario

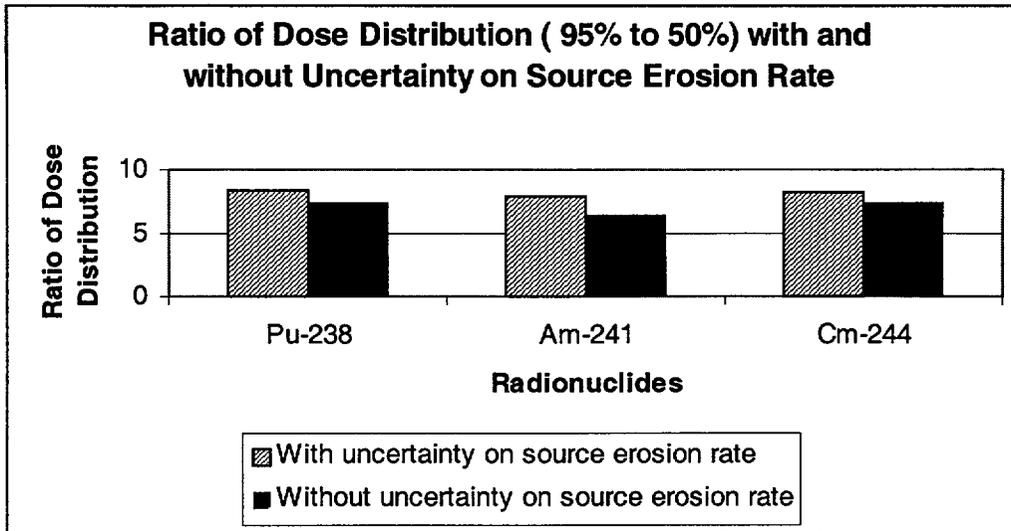


Figure 7.46 Ratio of Dose Distribution with and without Uncertainty on Source Erosion Rate for a Volume Source in Building Occupancy Scenario

Table 7.11. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 36-m² Area in a Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|--------------------------------------------------------------------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | inh | AREA | RF0 | RMVFR | H |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | | | |
| Am-241 | inh | AREA | RF0 | RMVFR | H |
| Am-243+D | inh | AREA | RF0 | RMVFR | DSTH |
| Au-195 | ext | DSTH | | | |
| Bi-207 | ext | DSTH | | | |
| C-14 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Ca-41 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Cd-109 | ext | DSTH | AREA | RF0 | RMVFR |
| Ce-144+D | ext | DSTH | | | |
| Cf-252 | inh | AREA | RF0 | RMVFR | H |
| Cl-36 | ext | DSTH | AREA | RF0 | UD |
| Cm-243 | inh | AREA | RF0 | RMVFR | DSTH |
| Cm-244 | inh | AREA | RF0 | RMVFR | H |
| Cm-248 | inh | AREA | RF0 | RMVFR | H |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | inh + ing | DKSUS | AREA | RF0 | DSTH |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | | | |
| Fe-55 | inh | AREA | RF0 | RMVFR | H |
| Gd-152 | inh | AREA | RF0 | RMVFR | H |
| Gd-153 | ext | DSTH | | | |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| I-129 | ing | DKSUS | AREA | RF0 | RMVFR |
| K-40 | ext | DSTH | | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | AREA | RF0 | RMVFR | H |
| Ni-63 | inh | AREA | RF0 | RMVFR | H |
| Np-237+D | inh | AREA | RF0 | RMVFR | DSTH |
| Pa-231 | inh | AREA | RF0 | RMVFR | H |

Table 7.11. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 36-m² Area in a Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|--------------------------------------------------------------------|------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Pb-210+D | inh | AREA | RF0 | RMVFR | DKSUS |
| Pm-147 | inh | AREA | RF0 | RMVFR | DSTH |
| Pu-238 | inh | AREA | RF0 | RMVFR | H |
| Pu-239 | inh | AREA | RF0 | RMVFR | H |
| Pu-240 | inh | AREA | RF0 | RMVFR | H |
| Pu241+D | inh | AREA | RF0 | RMVFR | H |
| Pu-242 | inh | AREA | RF0 | RMVFR | H |
| Pu-244+D | ext | DSTH | AREA | RF0 | RMVFR |
| Ra-226+D | ext | DSTH | | | |
| Ra-228+D | ext | DSTH | AREA | RF0 | RMVFR |
| Ru-106+D | ext | DSTH | | | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | AREA | RF0 | RMVFR | H |
| Sm-151 | inh | AREA | RF0 | RMVFR | H |
| Sr-90+D | inh | AREA | RF0 | DSTH | RMVFR |
| Tc-99 | inh + ext | DSTH | AREA | RF0 | RMVFR |
| Th-228+D | ext | DSTH | AREA | RF0 | RMVFR |
| Th-229+D | inh | AREA | RF0 | RMVFR | H |
| Th-230+D | inh | AREA | RF0 | RMVFR | H |
| Th-232 | inh | AREA | RF0 | RMVFR | H |
| Tl-204 | ext | DSTH | AREA | RF0 | UD |
| U-232 | inh | AREA | RF0 | RMVFR | DSTH |
| U-233 | inh | AREA | RF0 | RMVFR | H |
| U-234 | inh | AREA | RF0 | RMVFR | H |
| U-235+D | inh + ext | DSTH | AREA | RF0 | RMVFR |
| U-236 | inh | AREA | RF0 | RMVFR | H |
| U-238+D | inh | AREA | RF0 | RMVFR | H |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

Table 7.12. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 200-m² Area in a Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|--------------------------------------------------------------------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | inh | AREA | RF0 | RMVFR | H |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | | | |
| Am-241 | inh | AREA | RF0 | RMVFR | H |
| Am-243+D | inh | AREA | RF0 | RMVFR | H |
| Au-195 | ext | DSTH | AREA | RF0 | RMVFR |
| Bi-207 | ext | DSTH | | | |
| C-14 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Ca-41 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Cd-109 | ext | DSTH | AREA | RF0 | RMVFR |
| Ce-144+D | ext | DSTH | | | |
| Cf-252 | inh | AREA | RF0 | RMVFR | H |
| Cl-36 | ext | DSTH | AREA | RF0 | RMVFR |
| Cm-243 | inh | AREA | RF0 | RMVFR | H |
| Cm-244 | inh | AREA | RF0 | RMVFR | H |
| Cm-248 | inh | AREA | RF0 | RMVFR | H |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | inh + ing | DKSUS | AREA | RF0 | RMVFR |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | AREA | RF0 | RMVFR |
| Fe-55 | inh | AREA | RF0 | RMVFR | H |
| Gd-152 | inh | AREA | RF0 | RMVFR | H |
| Gd-153 | ext | DSTH | AREA | RF0 | RMVFR |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| I-129 | inh + ing | DKSUS | AREA | RF0 | RMVFR |
| K-40 | ext | DSTH | | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | AREA | RF0 | RMVFR | H |

Table 7.12. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 200-m² Area in a Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|--------------------------------------------------------------------|------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Ni-63 | inh | AREA | RF0 | RMVFR | H |
| Np-237+D | inh | AREA | RF0 | RMVFR | H |
| Pa-231 | inh | AREA | RF0 | RMVFR | H |
| Pb-210+D | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| Pm-147 | inh | AREA | RF0 | RMVFR | H |
| Pu-238 | inh | AREA | RF0 | RMVFR | H |
| Pu-239 | inh | AREA | RF0 | RMVFR | H |
| Pu-240 | inh | AREA | RF0 | RMVFR | H |
| Pu241+D | inh | AREA | RF0 | RMVFR | H |
| Pu-242 | inh | AREA | RF0 | RMVFR | H |
| Pu-244+D | inh | AREA | DSTH | RF0 | RMVFR |
| Ra-226+D | ext | DSTH | AREA | RF0 | |
| Ra-228+D | ext | DSTH | AREA | RF0 | RMVFR |
| Ru-106+D | ext | DSTH | | | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | AREA | RF0 | RMVFR | H |
| Sm-151 | inh | AREA | RF0 | RMVFR | H |
| Sr-90+D | inh | AREA | RF0 | RMVFR | UD |
| Tc-99 | inh | AREA | RF0 | RMVFR | DSTH |
| Th-228+D | ext | DSTH | AREA | RF0 | RMVFR |
| Th-229+D | inh | AREA | RF0 | RMVFR | H |
| Th-230+D | inh | AREA | RF0 | RMVFR | H |
| Th-232 | inh | AREA | RF0 | RMVFR | H |
| Tl-204 | ext | DSTH | AREA | RF0 | UD |
| U-232 | inh | AREA | RF0 | RMVFR | H |
| U-233 | inh | AREA | RF0 | RMVFR | H |
| U-234 | inh | AREA | RF0 | RMVFR | H |
| U-235+D | inh | AREA | RF0 | RMVFR | DSTH |
| U-236 | inh | AREA | RF0 | RMVFR | H |
| U-238+D | inh | AREA | RF0 | RMVFR | H |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

Table 7.13. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 900-m² Area in a Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|-----------------------|-------------------------------|--------------------------------------------------------------------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Ac-227+D ^c | inh | AREA | RF0 | RMVFR | H |
| Ag-108m+D | ext | DSTH | | | |
| Ag-110+D | ext | DSTH | | | |
| Al-26 | ext | DSTH | | | |
| Am-241 | inh | AREA | RF0 | RMVFR | H |
| Am-243+D | inh | AREA | RF0 | RMVFR | H |
| Au-195 | ext | DSTH | AREA | RF0 | RMVFR |
| Bi-207 | ext | DSTH | | | |
| C-14 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Ca-41 | inh + ing | AREA | DKSUS | RF0 | RMVFR |
| Cd-109 | inh | AREA | DSTH | RF0 | RMVFR |
| Ce-144+D | ext | DSTH | AREA | RF0 | RMVFR |
| Cf-252 | inh | AREA | RF0 | RMVFR | H |
| Cl-36 | inh | AREA | DSTH | RF0 | RMVFR |
| Cm-243 | inh | AREA | RF0 | RMVFR | H |
| Cm-244 | inh | AREA | RF0 | RMVFR | H |
| Cm-248 | inh | AREA | RF0 | RMVFR | H |
| Co-57 | ext | DSTH | | | |
| Co-60 | ext | DSTH | | | |
| Cs-134 | ext | DSTH | | | |
| Cs-135 | ing | DKSUS | AREA | RF0 | RMVFR |
| Cs-137+D | ext | DSTH | | | |
| Eu-152 | ext | DSTH | | | |
| Eu-154 | ext | DSTH | | | |
| Eu-155 | ext | DSTH | AREA | RF0 | RMVFR |
| Fe-55 | inh | AREA | RF0 | RMVFR | H |
| Gd-152 | inh | AREA | RF0 | RMVFR | H |
| Gd-153 | ext | DSTH | AREA | RF0 | RMVFR |
| Ge-68+D | ext | DSTH | | | |
| H-3 | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| I-129 | inh + ing | DKSUS | AREA | RF0 | RMVFR |
| K-40 | ext | DSTH | | | |
| Mn-54 | ext | DSTH | | | |
| Na-22 | ext | DSTH | | | |
| Nb-94 | ext | DSTH | | | |
| Ni-59 | inh | AREA | RF0 | RMVFR | H |
| Ni-63 | inh | AREA | RF0 | RMVFR | H |
| Np-237+D | inh | AREA | RF0 | RMVFR | H |

Table 7.13. Four Most Sensitive Parameters Based on SRRC Analysis and Dominant Pathways for an Area Source of 900-m² Area in a Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Four Most Sensitive Parameters ^b Based on SRRC Analysis | | | |
|--------------|-------------------------------|--------------------------------------------------------------------|------|-------|-------|
| | | 1 | 2 | 3 | 4 |
| Pa-231 | inh | AREA | RF0 | RMVFR | H |
| Pb-210+D | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| Pm-147 | inh | AREA | RF0 | RMVFR | H |
| Pu-238 | inh | AREA | RF0 | RMVFR | H |
| Pu-239 | inh | AREA | RF0 | RMVFR | H |
| Pu-240 | inh | AREA | RF0 | RMVFR | H |
| Pu241+D | inh | AREA | RF0 | RMVFR | H |
| Pu-242 | inh | AREA | RF0 | RMVFR | H |
| Pu-244+D | inh | AREA | RF0 | RMVFR | H |
| Ra-226+D | ext | DSTH | AREA | RF0 | UD |
| Ra-228+D | ext | DSTH | AREA | RF0 | RMVFR |
| Ru-106+D | ext | DSTH | AREA | RF0 | |
| Sb-125 | ext | DSTH | | | |
| Sm-147 | inh | AREA | RF0 | RMVFR | H |
| Sm-151 | inh | AREA | RF0 | RMVFR | H |
| Sr-90+D | inh | AREA | RF0 | RMVFR | H |
| Tc-99 | inh + ing | AREA | RF0 | RMVFR | DKSUS |
| Th-228+D | inh | AREA | RF0 | RMVFR | DSTH |
| Th-229+D | inh | AREA | RF0 | RMVFR | H |
| Th-230+D | inh | AREA | RF0 | RMVFR | H |
| Th-232 | inh | AREA | RF0 | RMVFR | H |
| Tl-204 | ext | DSTH | AREA | RF0 | UD |
| U-232 | inh | AREA | RF0 | RMVFR | H |
| U-233 | inh | AREA | RF0 | RMVFR | H |
| U-234 | inh | AREA | RF0 | RMVFR | H |
| U-235+D | inh | AREA | RF0 | RMVFR | H |
| U-236 | inh | AREA | RF0 | RMVFR | H |
| U-238+D | inh | AREA | RF0 | RMVFR | H |
| ZN-65 | ext | DSTH | | | |

^a Pathways: ext = external, inh = inhalation, ing = ingestion.

^b Parameters are only listed if SRRC was greater than 0.1. Descriptive name of the parameter is given in Table B.1.

^c +D indicates that associated radionuclides with half-lives less than 6 months are in secular equilibrium with the principal radionuclides.

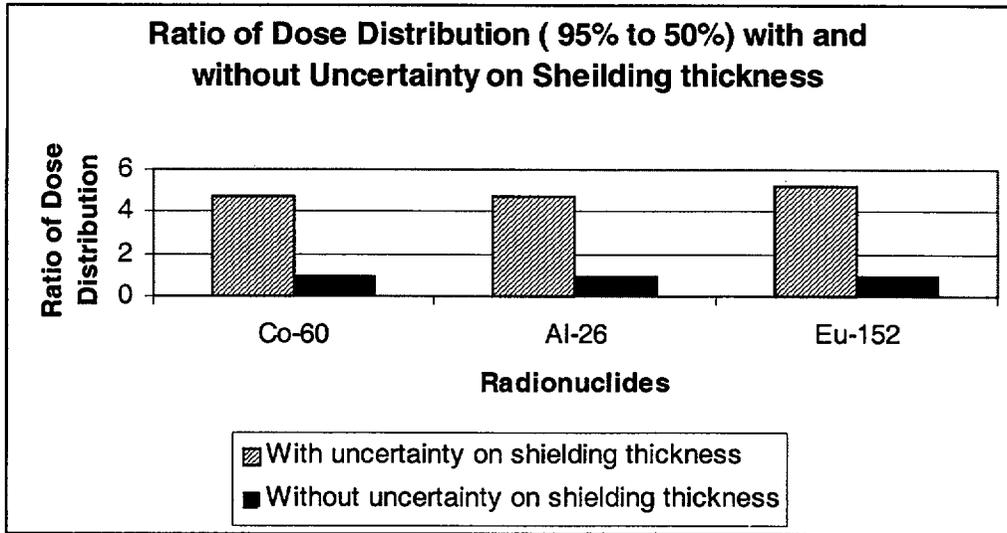


Figure 7.47 Ratio of Dose Distribution with and without Uncertainty on Shielding Thickness for a Surface Source in Building Occupancy Scenario

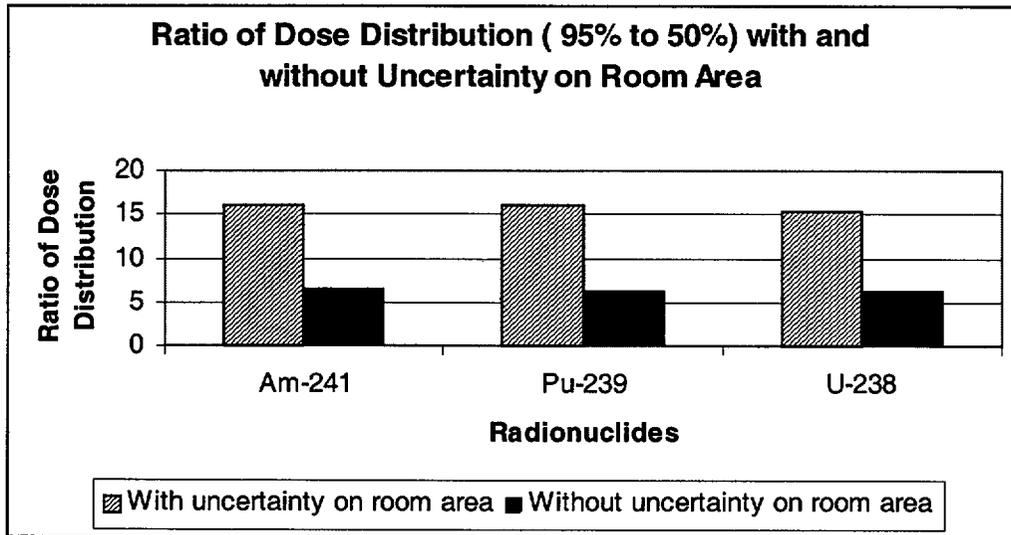


Figure 7.48 Ratio of Dose Distribution with and without Uncertainty on Room Area for a Surface Source in Building Occupancy Scenario

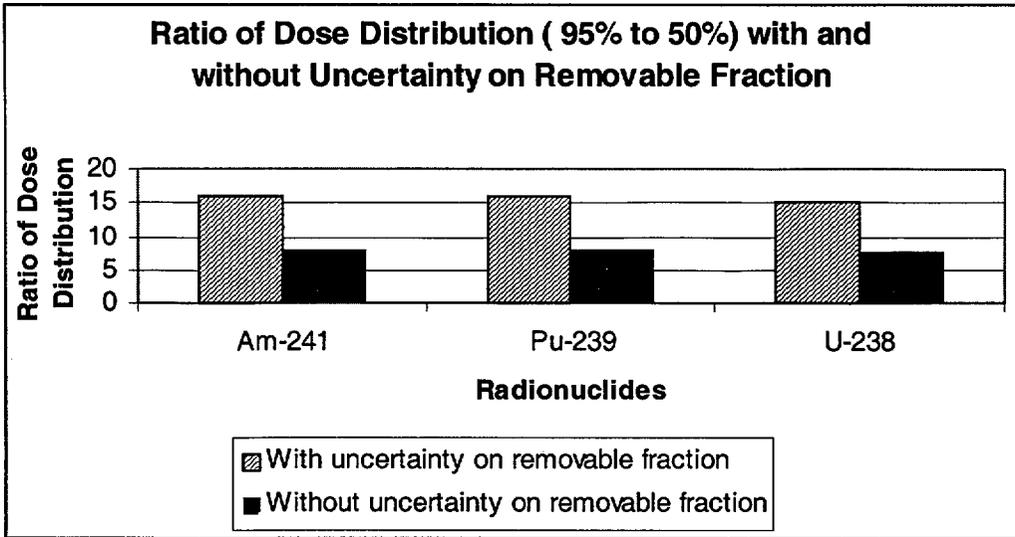


Figure 7.49 Ratio of Dose Distribution with and without Uncertainty on Removable Fraction for a Surface Source in Building Occupancy Scenario

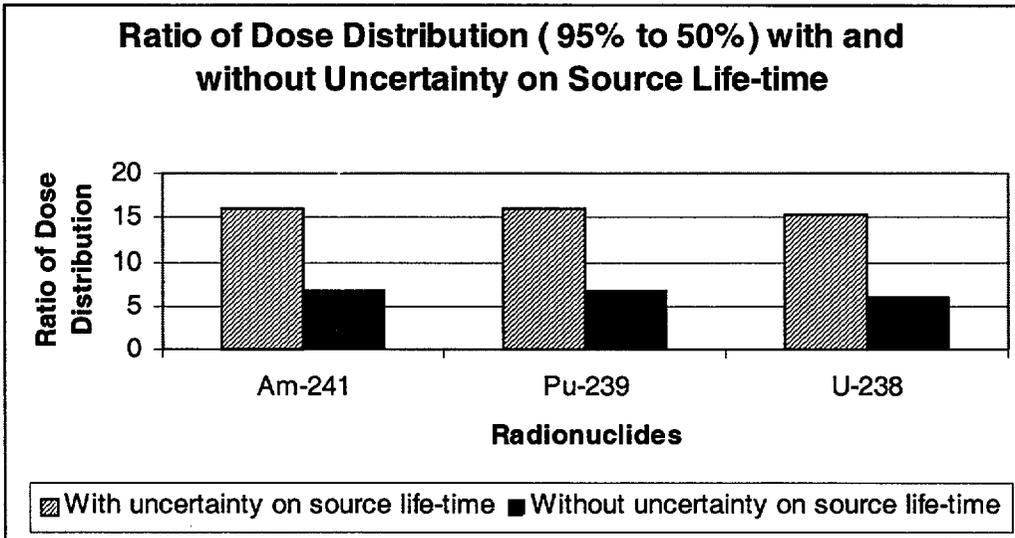


Figure 7.50 Ratio of Dose Distribution with and without Uncertainty on Source Lifetime for a Surface Source in Building Occupancy Scenario

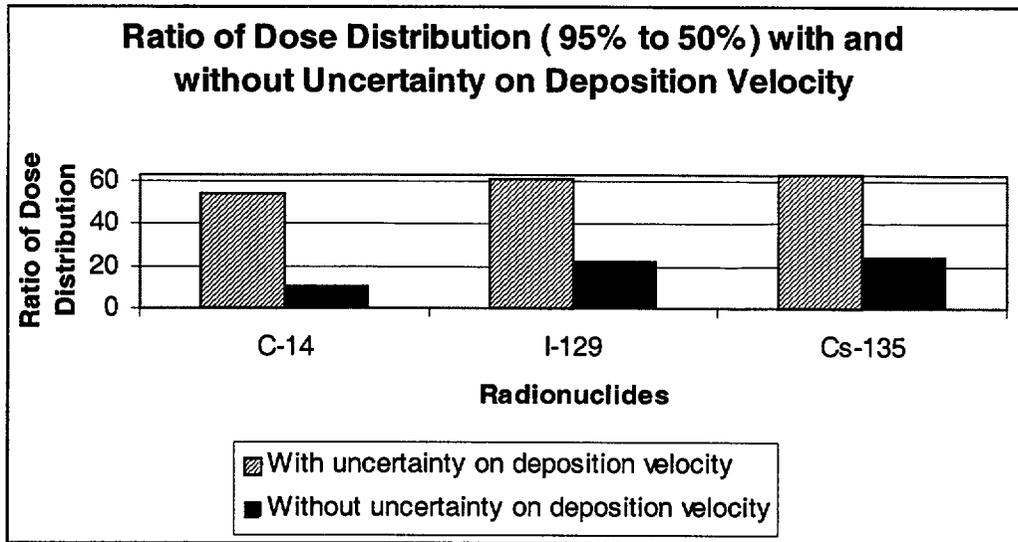


Figure 7.51 Ratio of Dose Distribution with and without Uncertainty on Deposition Velocity for a Surface Source in Building Occupancy Scenario

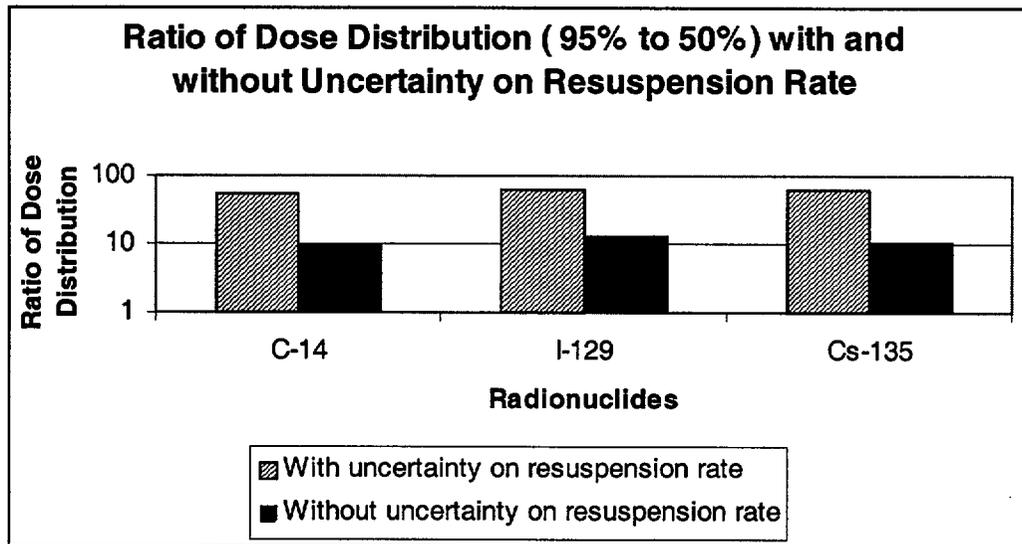


Figure 7.52 Ratio of Dose Distribution with and without Uncertainty on Resuspension Rate for a Surface Source in Building Occupancy Scenario

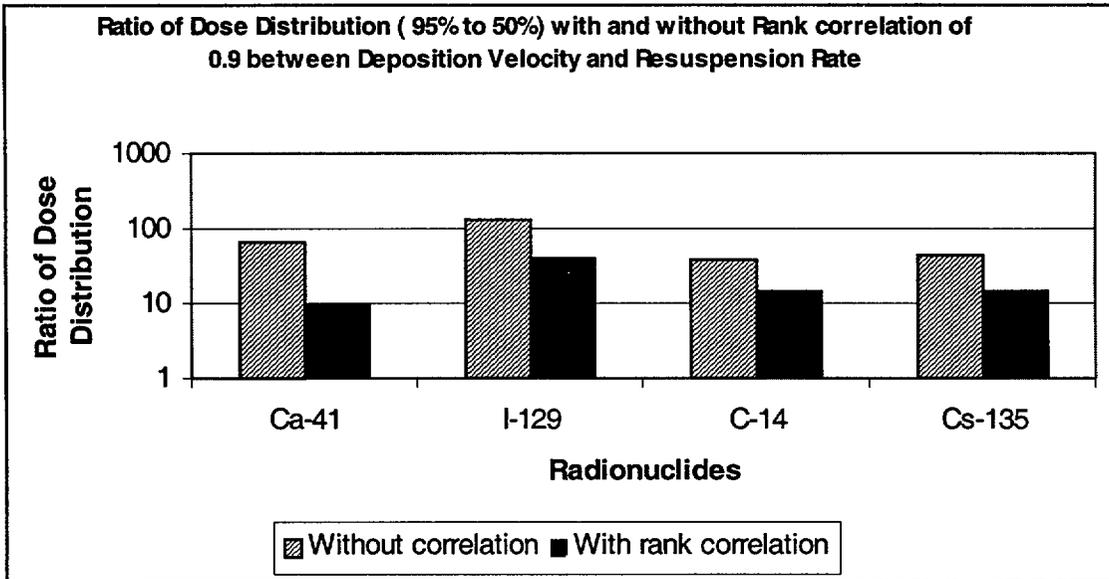


Figure 7.53 Ratio of Dose Distribution with and without Rank Correlation between Deposition Velocity and Resuspension Rate for a Surface Source in Building Occupancy Scenario

8 SUMMARY AND DISCUSSION

The probabilistic dose analysis discussed in this report was conducted to assess the effects of parameter distributions on estimated doses for residual radionuclides as calculated with the RESRAD and RESRAD-BUILD codes for the residential and building occupancy scenarios, respectively. Parameter distributions developed by Biber et al. (2000) were successfully incorporated into the RESRAD and RESRAD-BUILD codes, and the capability of the two codes to conduct site-specific analyses was tested.

The probabilistic dose analysis was performed by using the stratified sampling of the Latin hypercube sampling (LHS) method to obtain a collection of input distributions. This method provides a rather efficient process for multiparameter sampling. In the analysis, the total effective dose equivalent (TEDE) was estimated for an average member of the critical group under the two scenarios used to assess compliance with the U.S. Nuclear Regulatory Commission's (NRC's) decommissioning and license termination criteria. For RESRAD, the peak dose within a time frame of 1,000 years was captured; for RESRAD-BUILD, the dose at time 0 was computed.

The dose distribution analysis conducted for this report used the generic distributions developed in the Parameter Distribution Report (Biber et al., 2000) to test the distribution data and to demonstrate the capability of RESRAD and RESRAD-BUILD to perform a site-specific analysis. The specific strategy used to select input values depended on the parameter categories (physical, behavioral, or metabolic). The effect of correlation of input parameter distribution was studied. In cases when a clear relationship was identified (such as bulk density and total porosity and total porosity and effective porosity), strong rank correlations were used.

Some parameters previously identified to be important to dose values (Cheng et al., 1999) were confirmed in the analysis. For RESRAD, such parameters include radionuclide concentrations, source area, and source thickness. For RESRAD-BUILD, these parameters include radionuclide concentrations and source area. To illustrate the sensitivity of the parameters, three source configurations were analyzed for RESRAD: (1) area of 100 m² and thickness of 15 cm; (2) area of 2,400 m² and thickness of 15 cm; (3) area of 10,000 m² and thickness of 2 m. For RESRAD-BUILD, three different areas (36 m², 200 m², and 900 m²) were analyzed for area sources, and the same three areas (36 m², 200 m², and 900 m²) along with the probability distribution on source thickness were used for volume sources.

Results for the residential scenario indicate that for a change from the baseline configuration (source configuration 1) to an increased area (source configuration 2), a 19-fold increase in the estimated dose could occur, while a change from the baseline case to an extended thickness and area (source configuration 3) could lead a 100-fold increase in the estimated dose. Similarly for the building occupancy scenario, a change in source area could lead to a 25-fold increase in the estimated dose.

Quantile values (at 50th percentile and 90th percentile) of the dose distributions were generated. Dose spread for different radionuclides was identified by the ratio of dose at the 99th percentile to that at the 50th percentile for the residential scenario and by the ratio of dose at the 95th percentile to that at the 50th percentile for the building occupancy scenario. Regression analysis was used to identify sensitive parameters. The partial rank correlation coefficients and standardized rank regression coefficients were used as illustrative examples in the residential and building occupancy scenarios, respectively. The effects

of sensitive parameters on distribution were studied for selected radionuclides.

Results demonstrate the successful integration of the parameter distributions developed for the residential and building occupancy scenarios with the probabilistic module developed for the RESRAD and RESRAD-BUILD codes to support NRC's license termination effort. The results demonstrate that the codes and the developed input parameter distributions can be used to accomplish a probabilistic analysis. Application of the process is therefore shown to be feasible for site-specific modeling and analysis in the future when data pertinent to a specific site can be developed.

In a site-specific application, however, some general aspects must be taken into account to ensure accurate modeling and analysis:

- Parameter sensitivity depends on the contamination configuration, and, therefore, it is site specific. It is important that ranking of key parameters be assessed for each individual site.
- Potential correlation between a parameter and the estimated dose varies from radionuclide to radionuclide. Special considerations, experience, and judgment would be needed in obtaining an accurate assessment.
- Site-specific data collection may be needed for parameters consistently identified to be important to the dose analysis in this report.

8.1 HIGHLIGHTS OF RESIDENTIAL SCENARIO RESULTS

- Probabilistic dose analyses for 90 principal radionuclides in three source configurations were performed with distributions for 33 radionuclide-independent parameters and many radionuclide-dependent parameters for the residential scenario.

- Results indicate that the doses calculated appear reasonable and show a consistent pattern. The ratio between the 99th percentile dose and 50th percentile dose ranges from 2.0 to 79 for all radionuclides. Such variations depend on the source configurations and on the type of radionuclide. For radionuclides with a dominant external pathway, the ratio between the 99th percentile dose and 50th percentile dose was close to 2.3 (Ag-108m and Eu-152). For radionuclides with other dominant pathways, dose variabilities were higher. However, site-specific distributions should be used whenever available, especially for sensitive parameters such as the external shielding factor and the plant transfer factor.
- Input rank correlations between total porosity and effective porosity and between bulk density and total porosity were studied, and the results were used in the probabilistic dose analysis to ensure proper pairing between the parameters.
- Significant changes in dose values were observed among the three source configurations (i.e., changes in source thickness or source area resulted in significant changes in dose). For some radionuclides (e.g., Ca-145 and H-3), dose values changed by an order of magnitude. The dose at 90th percentile increased by 12% to 2,900% when the source area changed from 100 m² to 2,400 m² with a constant source thickness of 15 cm. When the source thickness was changed to 2 m and the source area to 10,000 m² from a source thickness of 15 cm and an area of 2,400 m², dose at 90th percentile increased by 5% to 2,600%.
- For about 30 radionuclides, the upper 10% of the peak doses occurred at times other than time 0. For these radionuclides, sensitive parameters would change with the dose percentile selected.

- The external shielding factor was the most sensitive parameter in many cases when external exposure was the dominant pathway (this factor accounts for the shielding provided by the structure of the house when the receptor is inside), and the total dose variability could be explained with just the variability in the external shielding factor.
- The plant transfer factor was the most sensitive parameter in many cases when plant ingestion was the dominant pathway (such as for Ca-45 and Cs-135).
- It was observed that no single correlation or regression coefficient (e.g., PRCC, SRRC) can be used alone to identify sensitive parameters in all the cases. The coefficients are useful guides, but they have to be used in conjunction with other aids, such as scatter plots, and must undergo further analysis.
- Significant changes (by as much as 25-fold) in dose values were observed with change in source area (from 36 m² to 900 m²) for many radionuclides (such as Cm-244 and Ni-63). For radionuclides with a dominant external pathway (e.g., Co-60, Cs-137), dose changes with source area occurred only at high dose percentile values. Because of shielding between the source and receptor, dose values did not change at low dose percentile values.
- For radionuclides with a dominant external exposure pathway (e.g., Co-60, Cs-137), shielding thickness between the source and receptor was the dominant contributor to the dose variability (ratio between the 95th percentile dose and 50th percentile dose) for volume as well as area sources.
- For radionuclides such as Am-241 and Pu-238 with a dominant inhalation pathway, room area and source erosion rate were the two most sensitive parameters for volume sources. For area sources, the parameters room area, removable fraction, and source lifetime all contributed to the dose variability.

8.2 HIGHLIGHTS OF BUILDING OCCUPANCY SCENARIO RESULTS

- Probabilistic dose analyses were performed for 67 principal radionuclides for two source types (volume and area), with three source areas, with distributions for 15 parameters.
- Results indicate that all parameter distributions are reasonable and consistent for all cases and radionuclides analyzed. However, site-specific distributions should be used whenever available, especially for sensitive parameters.
- Dose variability in the RESRAD-BUILD results for the building occupancy scenario for both volume and area sources was much more than the dose variability observed in RESRAD results for the residential scenario.
- For a volume source, the ingestion pathway was dominant only for two radionuclides (Ca-41 and H-3). For surface sources, the ingestion pathway was dominant for a few more radionuclides (C-14, Cs-135, I-129).
- For radionuclides with a dominant ingestion pathway (such as C-14 and Cs-135), in addition to the sensitive parameters identified for the inhalation pathway, deposition velocity and resuspension rate also contributed to dose variability.
- When a rank correlation coefficient of 0.9 between deposition velocity and resuspension rate was used, the dose variability was significantly reduced (by a factor of 7).

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APPENDIX A

**DESCRIPTION OF PROBABILISTIC MODULE
USED TO EVALUATE DOSE DISTRIBUTION**

APPENDIX A

DESCRIPTION OF PROBABILISTIC MODULE USED TO EVALUATE DOSE DISTRIBUTION

This appendix discusses the details of the probabilistic module used to evaluate dose distribution. The details presented include integration of the module with the RESRAD and RESRAD-BUILD codes, general navigation, and input forms.

A.1 INTEGRATION WITH RESRAD CODES

The probabilistic module is integrated into both the RESRAD and RESRAD-BUILD software packages. The system has been designed so that the details of file, data, and calculational modules are hidden from the user. The high-level details of this system are shown in Figure A.1. The user can start the programs, specify cases, and run the codes in a manner similar to the previous versions. The probabilistic module input is displayed through either the toolbar or by pressing the "F8" key when the windows focus is on a specific parameter. The output module is displayed through the menu. (See Figure A.2 for a diagram of this process.)

A.2 NAVIGATION

The procedures for using the probabilistic analysis module are as follows:

- Users run the standard software interface (RESRAD or RESRAD-BUILD) to set deterministic values for parameters not involved with probabilistic analysis.
- Probabilistic analysis is set by finding parameters in the standard interface and pressing the "F8" key. The probabilistic input window with four tab screens will appear.

- The parameter will be automatically added, with its default distribution, to the list of parameters for probabilistic analysis.
- If the probabilistic analysis is activated, after running the standard software, the probabilistic runs will begin.
- After the calculations are completed, the interactive output window will appear so tables and graphics can be created to display results. Access is available to both the textual report and the detailed data dump files.

The probabilistic modules have been designed to be flexible and quite independent of the original RESRAD or RESRAD-BUILD application, yet easily applied and integrated with the application and utilizing previously written software for Latin hypercube sampling (LHS) and correlation analysis.

The input window (see Section A.3) takes information from the default distribution database and from the user's commands to construct the list of parameters, their distributions and correlations, and general sampling options. At run time, the LHS code is activated to perform the sampling. The code is then run on these samplings, and the results are stored for incorporation into textual reports.

A.3 INPUT WINDOWS

A.3.1 Sample Specifications

The user is allowed to specify details of the sample generation (Figure A.3). Included in this

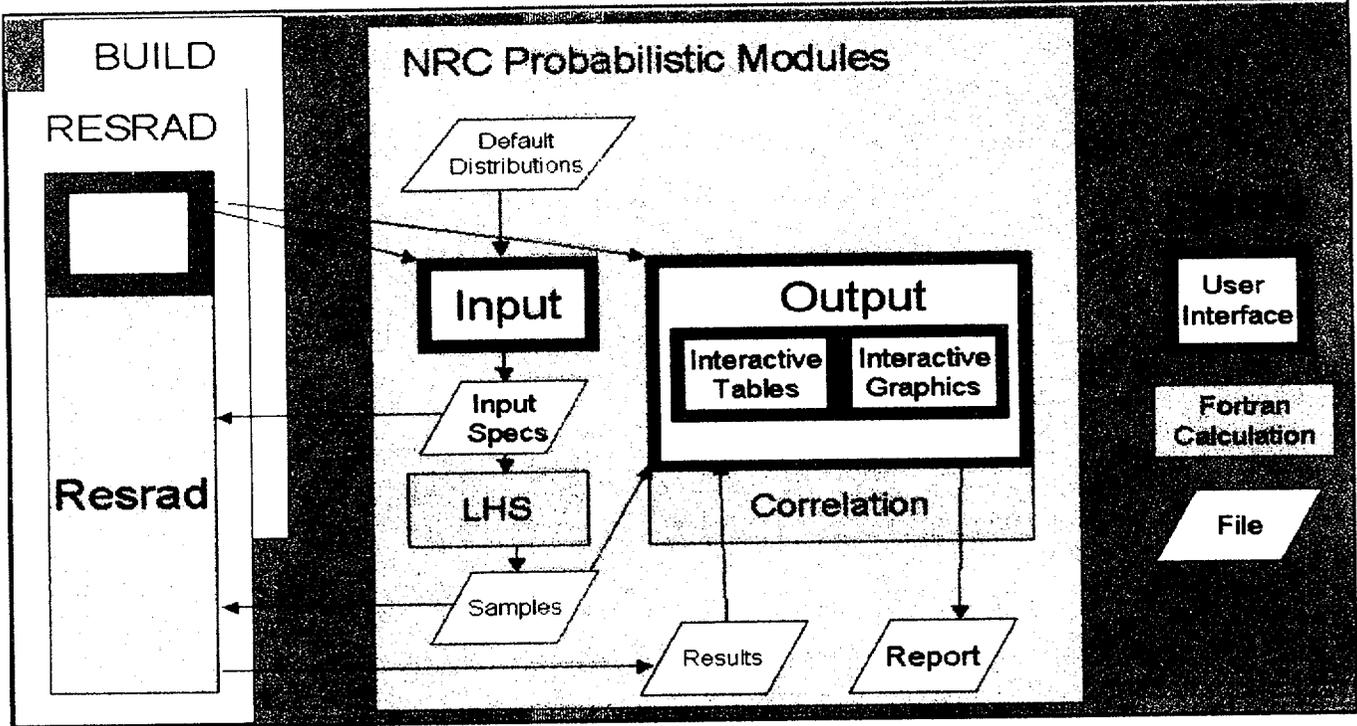


Figure A.1 Integration of Probabilistic Modules with RESRAD/RESRAD-BUILD Codes

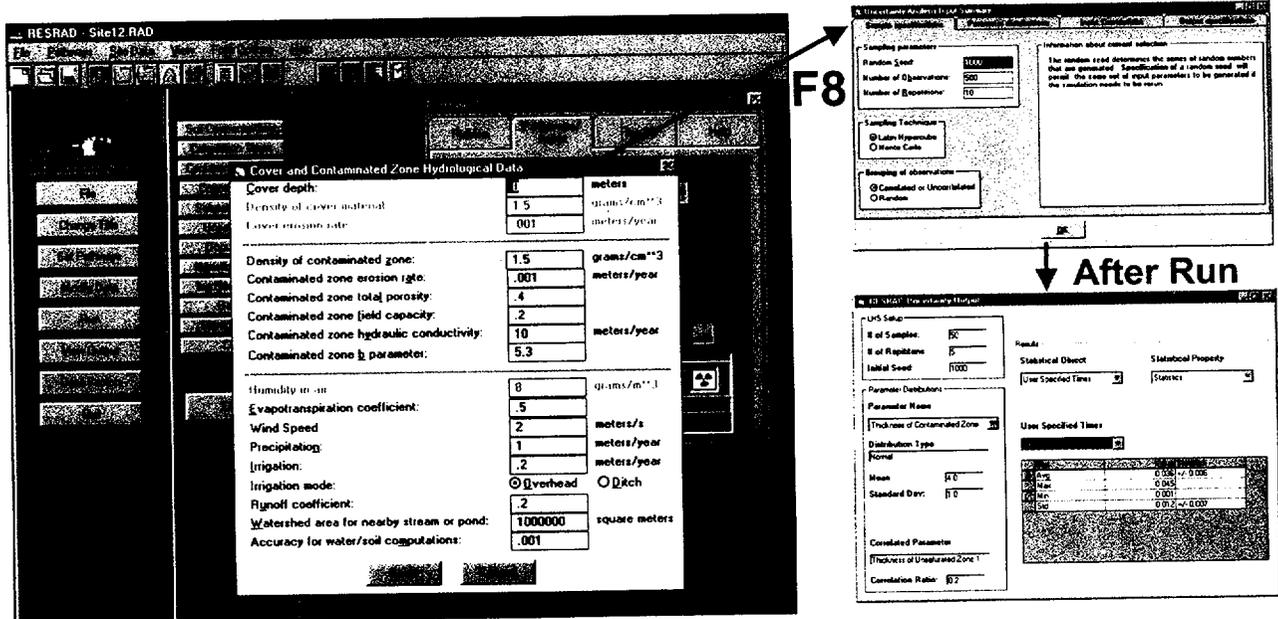


Figure A.2 Diagram Showing User's Access from RESRAD Interface (left) to Probabilistic Input Window (upper right) and Probabilistic Output Window (lower right).

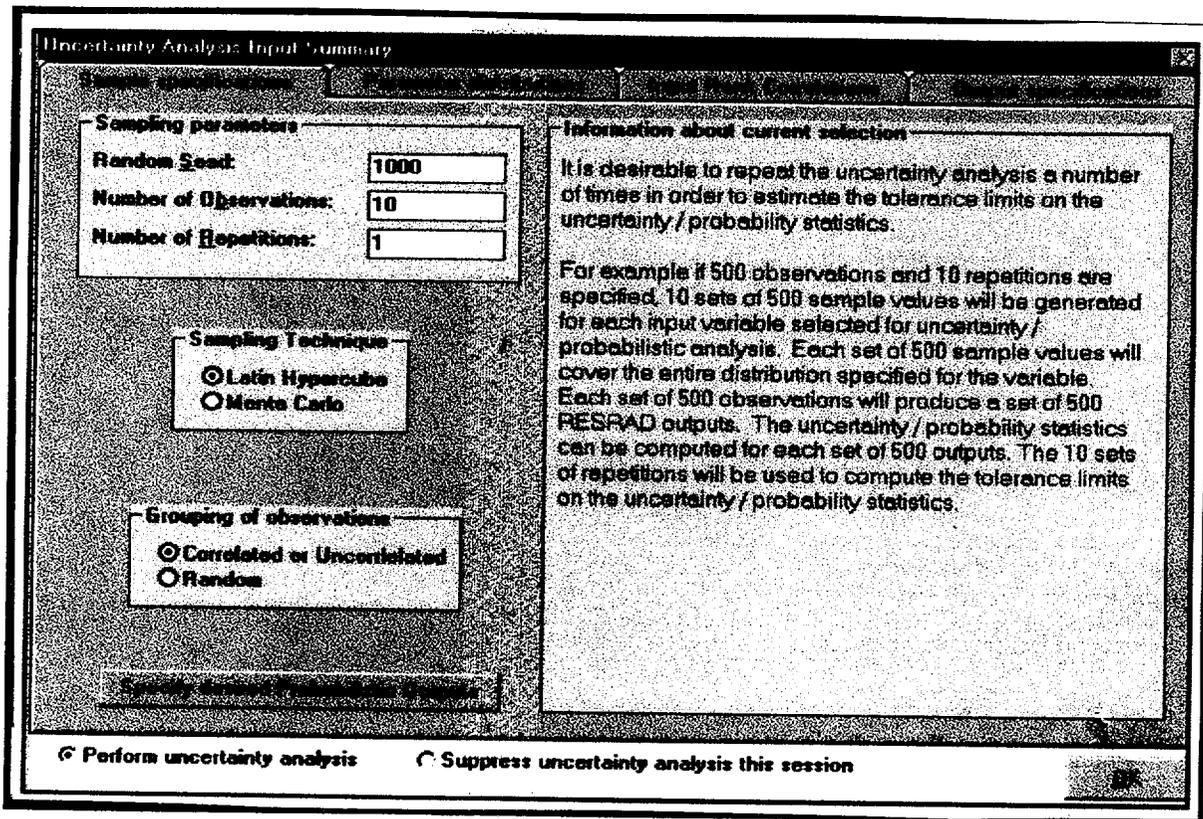


Figure A.3 Probabilistic Analysis Sample Specification

specification are the beginning random seed, the number of observations and repetitions, the sampling technique, and the grouping of observations. Detailed information about these options is displayed on the right-hand side of this window as the user navigates through the options. Usually the user will be concerned with the number of observations and repetitions.

Sampling Technique: The LHS option will split the distribution to be sampled into a number of equally probable distribution segments (the number is equal to the desired number of observations) and will obtain one sample at random from within each segment. This procedure ensures that the samples cover the entire range of the distribution. The Monte Carlo option will obtain the specified number of samples randomly from within the whole distribution.

Grouping of Observations: Correlated or uncorrelated grouping will order the samples for each variable so that (1) the correlations between the specified variables are as close as possible to the specified input correlations, and (2) the correlations between the variables that are not specified to be correlated will be as close to zero as possible. Random grouping will group the variables in the order that they were obtained. It is possible that some of the variables so sampled will be correlated just by chance.

A.3.2 Parameter Distributions

The parameter distribution tab screen allows the user to view and edit all currently specified parameter distributions for probabilistic analysis (Figure A.4). The parameters are listed in the left frame. The detailed distribution properties are shown in the right frame.

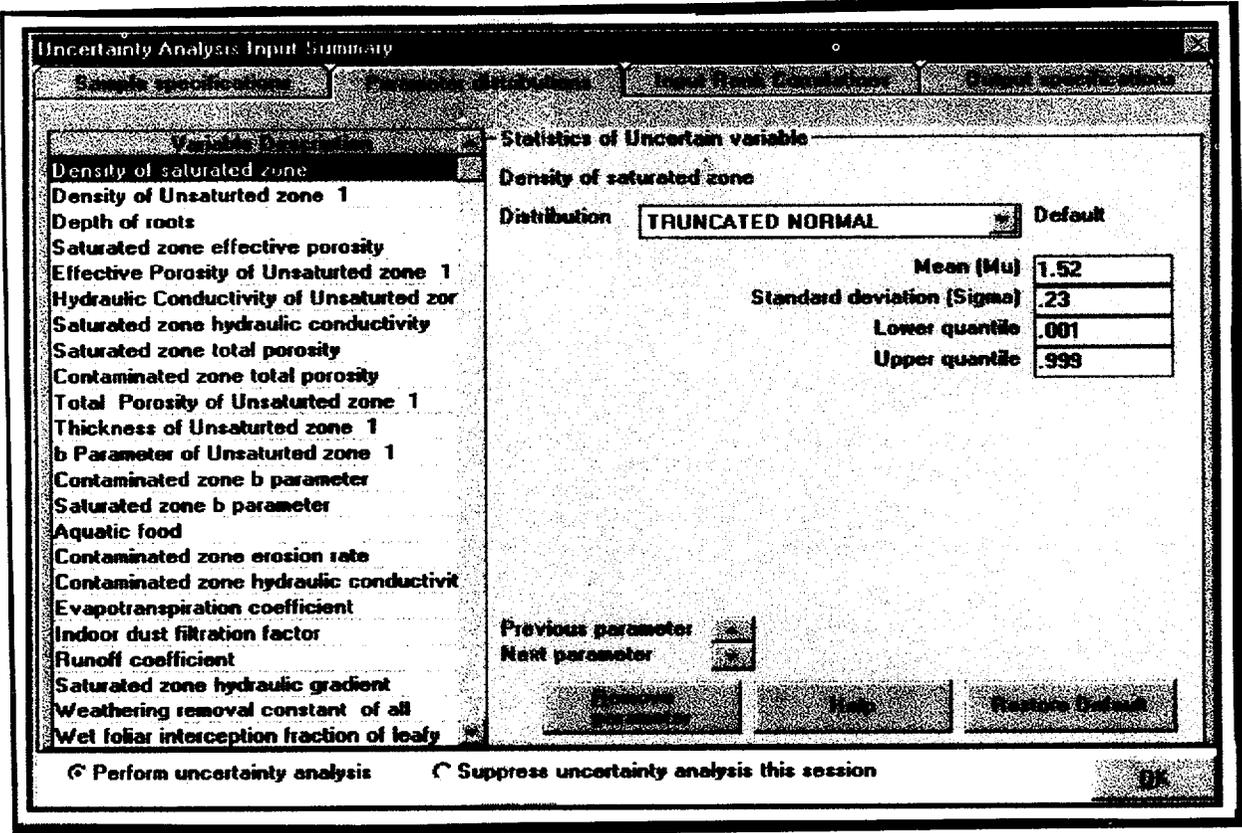


Figure A.4 Specified Parameter Distributions for Probabilistic Analysis

Navigation: Navigation to other parameter distributions is achieved by either clicking on the parameter on the left side or using the “Up-Down” arrow control on the left side.

Parameter List for Probabilistic Analysis: The list of the currently chosen parameters is shown on the left in a three-column table displaying the variable description, variable name in the code, and the distribution type. If the user clicks on any element in the row, complete distribution properties for the variable will appear for review and edit on the right.

Statistics of Uncertain Variable: The properties involved are the distribution type, shape parameters concerning the specific distribution type, and upper and lower truncation bounds. In the particular example shown in Figure A.4, the shape parameters are for the normal distribution, that is, the mean and standard deviation. If the user wishes to accept

the default distribution for this parameter, the “Default for assumptions” can be selected. These assumptions also include those specified on the “Sample Specification” tab that are beyond the input specifications of the deterministic RESRAD codes. The user can also remove the parameter from further probabilistic consideration by clicking the “Remove Parameter” button.

A.3.3 Input Rank Correlations

The input correlations tab screen allows the user to view and edit all correlations between input parameters for probabilistic analysis (Figure A.5). The paired parameters with non-zero correlations are listed in the left frame. Correlations can be modified, added, or deleted in the right frame.

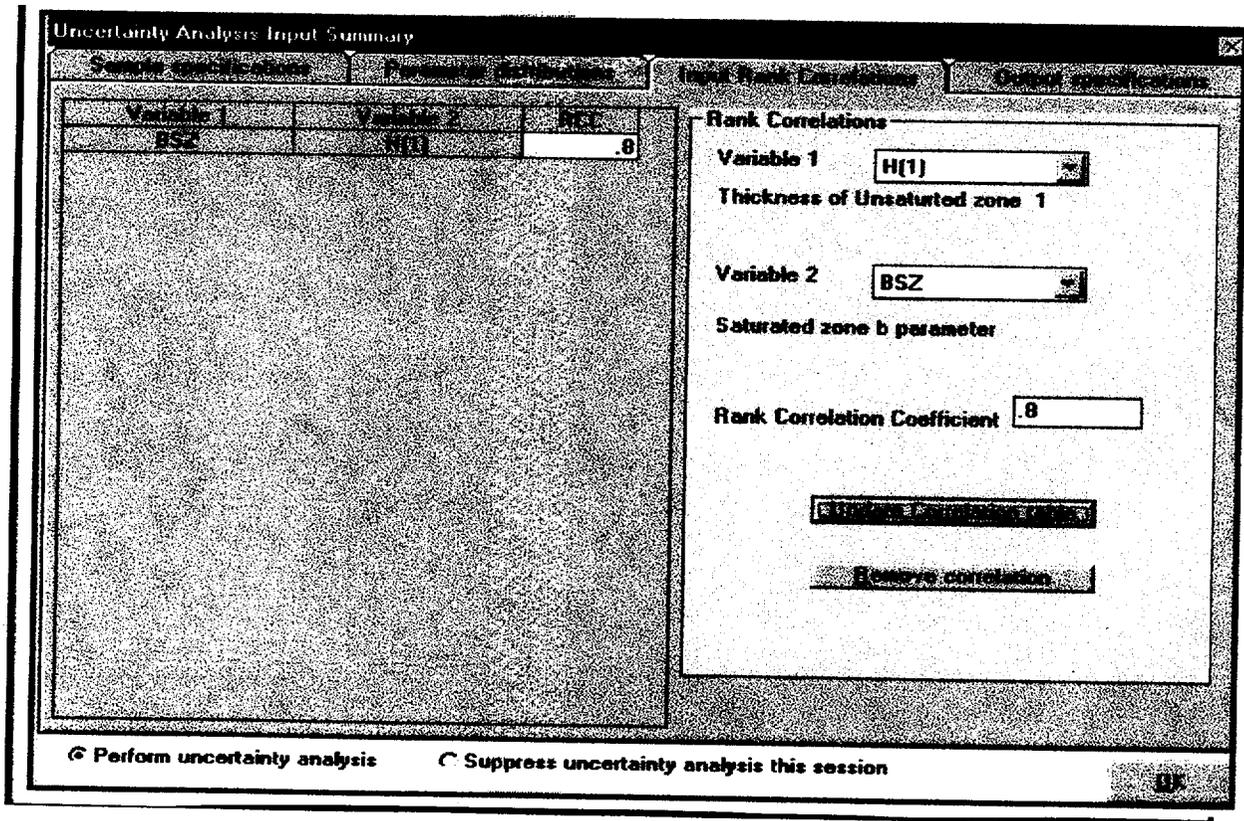


Figure A.5 Specified Input Rank Correlation for Probabilistic Analysis

Navigation: The user can select an existing correlation pair by clicking on its row in the left frame. New pairs are chosen on the right side by selecting the two variables. The edits in this frame are incorporated after clicking the “Update Correlation Table” button. The pair is removed by selecting the “Remove Correlation” button.

Parameter List for Correlation: The currently chosen pairs of parameters are listed in the left frame in a three-column table that shows the variable names in the code and the correlation coefficient. If the user clicks on any element in any row of the table, the correlation can be modified or deleted in the right frame. The

range of correlation coefficient is -1.00 to 1.00 . The correlation for all pairs not specified here is assumed to be 0.0 . The user can check the results of the sampling correlation after the run has been completed. Full descriptions of the variables can be seen in the right frame. If more parameters are chosen for correlation than fit in the window, the left side becomes a scrolling table.

Correlation Edit: The two parameters in the correlation and the correlation coefficient are shown and editable in the right frame. The user can also remove the parameter from further probabilistic consideration by clicking the “Remove Correlation” button.

APPENDIX B

**PARAMETER DISTRIBUTIONS USED IN
PROBABILISTIC DOSE ANALYSES**

APPENDIX B

PARAMETER DISTRIBUTIONS USED IN PROBABILISTIC DOSE ANALYSES

This appendix contains data tables and figures for parameter distribution and probabilistic dose analyses. Table B.1 provides the assigned distribution types and each distribution's statistical parameters for the RESRAD and RESRAD-BUILD codes on the basis of the Parameter Distribution Report (Biwer et al., 2000). Tables B.2 and B.3 list the parameter values, type, and distribution types used in the

probabilistic dose analysis for the RESRAD and RESRAD-BUILD codes, respectively.

Figures B.1 through B.48 provide the sampling frequency or the cumulative probability of the physical parameter values based on Latin hypercube sampling and the probability density or the cumulative distribution function of the parameter for the residential and building occupancy scenarios.

| Table B.1. Assigned Distribution Types and Distribution's Statistical Parameters for RESRAD and RESRAD-BUILD Parameters | | | | | | |
|----------------------------------------------------------------------------------------------------------------------------|------------------------------|----------------------------------|------------------------------------------------------------|--------|-------|-------|
| Parameter | Name ^a | Assigned Distribution Type | Distribution's Statistical Parameters ^b | | | |
| | | | 1 | 2 | 3 | 4 |
| RESRAD | | | | | | |
| Density of contaminated zone (g/cm ³) | DENSCZ | Normal (truncated) | 1.52 | 0.23 | 0.001 | 0.999 |
| Density of cover material (g/cm ³) | DENSCV | Normal (truncated) | 1.52 | 0.23 | 0.001 | 0.999 |
| Density of saturated zone (g/m ³) | DENSAQ | Normal (truncated) | 1.52 | 0.23 | 0.001 | 0.999 |
| Depth of roots (m) | DROOT | Uniform | 0.3 | 4.0 | | |
| Distribution coefficients (contaminated zone, unsaturated zones, and saturated zone)(cm ³ /g) | DCACTC, DCACTU, DCACTS | Lognormal-n (truncated) | Radionuclide specific (Table 3.9-1, Biwer et al., 2000) | | | |
| Saturated zone effective porosity | EPSZ | Normal (truncated) | 0.355 | 0.0906 | 0.001 | 0.999 |
| Saturated zone hydraulic conductivity (m/yr) | HCSZ | Lognormal-n (bounded) | 2.3 | 2.11 | 0.004 | 9250 |
| Saturated zone total porosity | TPSZ | Normal (truncated) | 0.425 | 0.0867 | 0.001 | 0.999 |
| Transfer factors for plants | BRTF(1) | Lognormal-n (truncated) | Element specific (Table 6.2-1, Biwer et al., 2000) | | | |
| Unsaturated zone thickness (m) | H | Lognormal-n (bounded) | 2.296 | 1.276 | 0.18 | 320 |
| Aquatic food contaminated fraction | FR9 | Triangular | 0 | 1 | 0.39 | |
| Bioaccumulation factors for fish [(pCi/kg)/(pCi/L)] | BBIO(1) | Lognormal-n | Element specific (Table 6.8-1, Biwer et al., 2000) | | | |
| C-14 evasion layer thickness in soil (m) | DMC | Triangular | 0.2 | 0.6 | 0.3 | |
| Contaminated zone b parameter | BCZ | Lognormal-n (bounded) | 1.06 | 0.66 | 0.5 | 30 |
| Inhalation rate (m ³ /yr) | INHALAR | Triangular | 4380 | 13100 | 8400 | |

| Table B.1. Assigned Distribution Types and Distribution's Statistical Parameters for RESRAD and RESRAD-BUILD Parameters (Continued) | | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------|----------------------------|---------------------------------------------------------------------|--------|-------|-------|
| Parameter | Name ^a | Assigned Distribution Type | Distribution's Statistical Parameters ^b | | | |
| | | | 1 | 2 | 3 | 4 |
| Contaminated zone erosion rate (m/yr) | VCZ | Empirical | Defined by cumulative probability (Table 3.8-1, Biber et al., 2000) | | | |
| Contaminated zone hydraulic conductivity (m/yr) | HCCZ | Lognormal-n (bounded) | 2.3 | 2.11 | 0.004 | 9250 |
| Contaminated zone total porosity | TPCZ | Normal (truncated) | 0.425 | 0.0867 | 0.001 | 0.999 |
| Cover depth (m) | COVER0 | None recommended | | | | |
| Cover erosion rate (m/yr) | VCV | Empirical | Defined by cumulative probability (Table 3.8-1, Biber et al., 2000) | | | |
| Depth of soil mixing layer (m) | DM | Triangular | 0 | 0.6 | 0.15 | |
| Drinking water intake (L/yr) | DWI | Lognormal-n (truncated) | 6.015 | 0.489 | 0.001 | 0.999 |
| Evapotranspiration coefficient | EVAPTR | Uniform | 0.5 | 0.75 | | |
| External gamma shielding factor | SHF1 | Lognormal-n (bounded) | -1.3 | 0.59 | 0.044 | 1.0 |
| Fruit, vegetables, and grain consumption (kg/yr) | DIET(1) | Triangular | 135 | 318 | 178 | |
| Indoor dust filtration factor | SHF3 | Uniform | 0.15 | 0.95 | | |
| Mass loading for inhalation ($\mu\text{g}/\text{m}^3$) | MLINH | Empirical | Defined by cumulative probability (Table 4.6-1, Biber et al., 2000) | | | |
| Milk consumption (L/yr) | DIET(3) | Triangular | 60 | 200 | 102 | |
| Runoff coefficient | RUNOFF | Uniform | 0.1 | 0.8 | | |
| Saturated zone b parameter | BSZ | Lognormal-n (bounded) | 1.06 | 0.66 | 0.5 | 30 |
| Saturated zone hydraulic gradient | HGWT | Lognormal-n (bounded) | -5.11 | 1.77 | 7E-5 | 0.5 |

| Table B.1. Assigned Distribution Types and Distribution's Statistical Parameters for RESRAD and RESRAD-BUILD Parameters (Continued) | | | | | | |
|----------------------------------------------------------------------------------------------------------------------------------------|-------------------|----------------------------------|----------------------------------------------------|--------|-------|-------|
| Parameter | Name ^a | Assigned Distribution Type | Distribution's Statistical Parameters ^b | | | |
| | | | 1 | 2 | 3 | 4 |
| Soil ingestion rate (g/yr) | SOIL | Triangular | 0 | 36.5 | 18.3 | |
| Transfer factors for meat [(pCi/kg)/(pCi/d)] | BRTF(2) | Lognormal-n (truncated) | Element specific (Table 6.3-1, Biwer et al., 2000) | | | |
| Transfer factors for milk [(pCi/L)/(pCi/d)] | BRTF(3) | Lognormal-n (truncated) | Element specific (Table 6.4-1, Biwer et al., 2000) | | | |
| Unsaturated zone density (g/cm ³) | DENSUZ | Normal (truncated) | 1.52 | 0.23 | 0.001 | 0.999 |
| Unsaturated zone effective porosity | EPUZ | Normal (truncated) | 0.355 | 0.0906 | 0.001 | 0.999 |
| Unsaturated zone hydraulic conductivity (m/yr) | HCUZ | Lognormal-n (bounded) | 2.3 | 2.11 | 0.004 | 9250 |
| Unsaturated zone, soil-b parameter | BUZ | Lognormal-n (bounded) | 1.06 | 0.66 | 0.5 | 30 |
| Unsaturated zone total porosity | TPUZ | Normal (truncated) | 0.425 | 0.0867 | 0.001 | 0.999 |
| Weathering removal constant (1/yr) | WLAM | Triangular | 5.1 | 84 | 18 | |
| Well pumping rate (m ³ /yr) | UW | None recommended | | | | |
| Well pump intake depth (below water table) (m) | DWIBWT | Triangular | 6 | 30 | 10 | |
| Wet foliar interception fraction for leafy vegetables | RWET(2) | Triangular | 0.06 | 0.95 | 0.67 | |
| Wet-weight crop yields for non-leafy vegetables (kg/m ²) | YU(1) | Lognormal-n (truncated) | 0.56 | 0.48 | 0.001 | 0.999 |
| Wind speed (m/s) | WIND | Lognormal-n (bounded) | 1.445 | 0.2419 | 1 | 16 |
| Humidity | HUMIDITY | Lognormal-n (truncated) | 1.98 | 0.334 | 0.001 | 0.999 |

**Table B.1. Assigned Distribution Types and Distribution's Statistical Parameters
for RESRAD and RESRAD-BUILD Parameters (Continued)**

| Parameter | Name ^a | Assigned Distribution Type | Distribution's Statistical Parameters ^b | | | |
|-----------------------------------------------------------------------------|-------------------|----------------------------|---------------------------------------------------------------------|--------|-------|-------|
| | | | 1 | 2 | 3 | 4 |
| Indoor fraction | FTIN | Empirical | Defined by cumulative probability (Table 7.6-1, Biwer et al., 2000) | | | |
| RESRAD-BUILD | | | | | | |
| Removable fraction | RMVFR | Triangular | 0.0 | 1.0 | 0.2 | |
| Resuspension rate (1/s) | DKSUS | Loguniform | 2.8E-10 | 1.4E-5 | | |
| Shielding density (g/cm ³) | DSDEN | Uniform | 2.2 | 2.6 | | |
| Source density, volume source (g/cm ³) | DENSIO | Uniform | 2.2 | 2.6 | | |
| Air exchange rate for building and room (1/h) | LAMBDAT | Lognormal-n (truncated) | 0.4187 | 0.88 | 0.001 | 0.999 |
| Air release fraction | AIRFR | Triangular | 1E-6 | 1 | 0.07 | |
| Deposition velocity (m/s) | UD | Loguniform | 2.7E-6 | 2.7E-3 | | |
| Direct ingestion rate (g/h for volume source and 1/h for all other sources) | INGE1 | None recommended | | | | |
| Humidity (g/m ³) | HUMIDITY | Uniform | 6.5 | 13.1 | | |
| Indoor fraction | FTIN | Empirical | Defined by cumulative probability (Table 7.6-1, Biwer et al., 2000) | | | |
| Receptor indirect ingestion rate (m ² /h) | INGE2 | Loguniform | 2.8E-5 | 2.9E-4 | | |
| Receptor inhalation rate (m ³ /d) | BRTRATE | Triangular | 12 | 46 | 33.6 | |
| Room area (m ²) | AREA | Triangular | 3 | 900 | 36 | |
| Room height (m) | H | Triangular | 2.4 | 9.1 | 3.7 | |
| Shielding thickness (cm) | DSTH | Triangular | 0.0 | 30 | 0.0 | |
| Source erosion rate, volume source (cm/d) | EROS0 | Triangular | 0.0 | 5.6E-7 | 0.0 | |
| Source porosity | H3POROSITY | Uniform | 0.04 | 0.25 | | |
| Source thickness, volume source (cm) | THICK | Triangular | 2.5 | 30 | 15 | |

Table B.1. Assigned Distribution Types and Distribution's Statistical Parameters for RESRAD and RESRAD-BUILD Parameters (Continued)

| Parameter | Name ^a | Assigned Distribution Type | Distribution's Statistical Parameters ^b | | | |
|------------------------------------------------|-------------------|----------------------------|----------------------------------------------------|---------|--------|---|
| | | | 1 | 2 | 3 | 4 |
| Time for source removal or source lifetime (d) | RF0 | Triangular | 1,000 | 100,000 | 10,000 | |
| Volumetric water content | H3VOLFRACT | Uniform | 0.04 | 0.25 | | |
| Water fraction available for evaporation | H3RMFR | Triangular | 0.5 | 1.0 | 0.75 | |
| Wet + dry zone thickness (cm) | H3THICK | Uniform | 5 | 30 | | |

^a Name of the parameter by which parameters are identified in sensitivity tables.

^b For normal and lognormal distribution, statistical parameter 1 is the mean, 2 is the standard deviation, 3 is the lower quantile value, and 4 is the upper quantile. For the bounded lognormal distribution, parameters 3 and 4 are the actual lower and upper bounds. Parameters for element specific or distribution defined by cumulative probability distributions are not provided in this table (see Parameter Distribution Report [Biwer et al., 2000]). For uniform distribution, statistical parameter 1 is the minimum and parameter 2 is the maximum of the distribution. For triangular distribution, parameter 1 is the minimum value, parameter 2 is the maximum value, and parameter 3 is the most likely value of the distribution.

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|---------------------------------------------------------------------------------------|--------------------|-----------------------------|--------------------------------------------|--------------------|----------------------------------------------------|------------------|------------------|------------------|
| | | | | | 1 | 2 | 3 | 4 |
| Nuclide concentration | pCi/g | P | 1 | | NR ^c | NR | NR | NR |
| Distribution coefficients (contaminated zone, unsaturated zones, and saturated zones) | cm ³ /g | P | Lognormal-n (truncated) | Biwer et al., 2000 | Element specific | Element specific | Element specific | Element specific |
| Number of unsaturated zones | - ^d | P | 1 | RESRAD | NR | NR | NR | NR |
| Time since placement of material | yr | P | 0 | RESRAD | NR | NR | NR | NR |
| Groundwater concentration | pCi/L | P | 0 | RESRAD | NR | NR | NR | NR |
| Leach rate | 1/yr | P | 0 | RESRAD | NR | NR | NR | NR |
| Solubility limit | mol/L | P | 0 | RESRAD | NR | NR | NR | NR |
| Use plant/soil ratio | check box | NA ^e | NA | RESRAD | NR | NR | NR | NR |
| Basic radiation dose limit | mrem/yr | NA | 25 | DandD | NR | NR | NR | NR |
| Times for calculations | yr | P | 1, 3, 10, 30, 100, 300, 1000 | RESRAD | NR | NR | NR | NR |
| Area of contaminated zone | m ² | P | 100, 2400, 10,000 | RESRAD | NR | NR | NR | NR |
| Thickness of contaminated zone | m | P | 0.15, 0.15, 2.0 | RESRAD | NR | NR | NR | NR |
| Length parallel to aquifer flow | m | P | 10, 49, 100 | RESRAD | NR | NR | NR | NR |
| Cover depth | m | P | 0 | RESRAD | NR | NR | NR | NR |
| Density of cover material | g/cm ³ | P | Normal (truncated) | Biwer et al., 2000 | 1.52 | 0.23 | 0.001 | 0.999 |
| Cover erosion rate | m/yr | P, B | NA | Biwer et al., 2000 | NR | NR | NR | NR |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|------------------------------------------|-------------------|-----------------------------|-----------------------------------------------|-----------------------------------|----------------------------------------------------|--------|-------|-------|
| | | | | | 1 | 2 | 3 | 4 |
| Density of contaminated zone | g/cm ³ | P | Normal (truncated) | Biwer et al., 2000 | 1.52 | 0.23 | 0.001 | 0.999 |
| Contaminated zone total porosity | - | P | Normal (truncated) | Biwer et al., 2000 | 0.425 | 0.0867 | 0.001 | 0.999 |
| Contaminated zone field capacity | - | P | 0.2 | RESRAD | NR | NR | NR | NR |
| Contaminated zone erosion rate | m/yr | P, B | Defined by cumulative probability | Biwer et al., 2000 | | | | |
| Contaminated zone hydraulic conductivity | m/yr | P | Lognormal-n (bounded) | Biwer et al., 2000 | 2.3 | 2.11 | 0.004 | 9250 |
| Contaminated zone b parameter | - | P | Lognormal-n (bounded) | Biwer et al., 2000 | 1.06 | 0.66 | 0.5 | 30 |
| Humidity in air | g/m ³ | P | Lognormal-n (truncated) | Biwer et al., 2000 | 1.98 | 0.334 | 0.001 | 0.999 |
| Evapotranspiration coefficient | - | P | Uniform | Biwer et al., 2000 | 0.5 | 0.75 | | |
| Wind speed | m/s | P | Lognormal-n (bounded) | Biwer et al., 2000 | 1.445 | 0.2419 | 1 | 16 |
| Precipitation rate | m/yr | P | 1.0 | RESRAD | NR | NR | NR | NR |
| Irrigation rate | m/yr | B | 0.1125 | Calculated based on DandD default | NR | NR | NR | NR |
| Irrigation mode | - | B | Overhead | RESRAD | NR | NR | NR | NR |
| Runoff coefficient | - | P | Uniform | Biwer et al., 2000 | 0.1 | 0.8 | | |
| Watershed area for nearby stream or pond | m ² | P | 1,000,000 | RESRAD | NR | NR | NR | NR |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|------------------------------------------------|--------------------|-----------------------------|--------------------------------------------|--------------------|----------------------------------------------------|--------|-------|-------|
| | | | | | 1 | 2 | 3 | 4 |
| Accuracy for water soil computation | - | NA | 0.001 | RESRAD | NR | NR | NR | NR |
| Density of saturated zone | g/cm ³ | P | Normal (truncated) | Biwer et al., 2000 | 1.52 | 0.23 | 0.001 | 0.999 |
| Saturated zone total porosity | - | P | Normal (truncated) | Biwer et al., 2000 | 0.425 | 0.0867 | 0.001 | 0.999 |
| Saturated zone effective porosity | - | P | Normal (truncated) | Biwer et al., 2000 | 0.355 | 0.0906 | 0.001 | 0.999 |
| Saturated zone field capacity | - | P | 0.2 | RESRAD | NR | NR | NR | NR |
| Saturated zone hydraulic conductivity | m/yr | P | Lognormal-n (bounded) | Biwer et al., 2000 | 2.3 | 2.11 | 0.004 | 9250 |
| Saturated zone hydraulic gradient | - | P | Lognormal-n (bounded) | Biwer et al., 2000 | -5.11 | 1.77 | 7E-5 | 0.5 |
| Saturated zone b parameter | - | P | Lognormal-n (bounded) | Biwer et al., 2000 | 1.06 | 0.66 | 0.5 | 30 |
| Water table drop rate | m/yr | P | 0.001 | RESRAD | NR | NR | NR | NR |
| Well pump intake depth (below water table) | m | P | Triangular | Biwer et al., 2000 | 6 | 30 | 10 | |
| Model: nondispersion (ND) or mass-balance (MB) | - | NA | ND | RESRAD | NR | NR | NR | NR |
| Well pumping rate | m ³ /yr | B, P | 409.3, 668, 1523 | Biwer et al., 2000 | | | | |
| Unsaturated zone thickness | m | P | Defined by cumulative probability | Biwer et al., 2000 | | | | |
| Unsaturated zone density | g/cm ³ | P | Normal (truncated) | Biwer et al., 2000 | 1.52 | 0.23 | 0.001 | 0.999 |
| Unsaturated zone total porosity | - | P | Normal (truncated) | Biwer et al., 2000 | 0.425 | 0.0867 | 0.001 | 0.999 |

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Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|----------------------------------------------------|--------------------|-----------------------------|--------------------------------------------|----------------------|----------------------------------------------------|--------|-------|-------|
| | | | | | 1 | 2 | 3 | 4 |
| Unsaturated zone effective porosity | - | P | Normal (truncated) | Biwer et al., 2000 | 0.355 | 0.0906 | 0.001 | 0.999 |
| Unsaturated zone field capacity | - | P | 0.2 | RESRAD | NR | NR | NR | NR |
| Unsaturated zone, soil-specific b parameter | | P | Lognormal-n (bounded) | Biwer et al., 2000 | 1.06 | 0.66 | 0.5 | 30 |
| Unsaturated zone hydraulic conductivity | m/yr | P | Lognormal-n (bounded) | Biwer et al., 2000 | 2.3 | 2.11 | 0.004 | 9250 |
| Inhalation rate | m ³ /yr | M, B | 8400 | Biwer et al., 2000 | NR | NR | NR | NR |
| Mass loading for inhalation | μ/m ³ | P, B | Defined by cumulative probability | Biwer et al., 2000 | | | | |
| Exposure duration | yr | B | 30 | RESRAD | NR | NR | NR | NR |
| Indoor dust filtration factor | - | P, B | Uniform | Biwer et al., 2000 | 0.15 | 0.95 | | |
| External gamma shielding factor | - | P | Lognormal-n (bounded) | Biwer et al., 2000 | -1.4 | 0.84 | 0 | 1 |
| Indoor time fraction | - | B | 0.65 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Outdoor time fraction | - | B | 0.12 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Shape of the contaminated zone (shape factor flag) | - | P | Circular | RESRAD | NR | NR | NR | NR |
| Fruit, vegetables, and grain consumption | kg/yr | M, B | 178 | Biwer et al., 2000 | NR | NR | NR | NR |
| Leafy vegetable consumption | kg/yr | M, B | 21.4 | DandD | NR | NR | NR | NR |
| Milk consumption | L/yr | M, B | 102 | Biwer et al., 2000 | NR | NR | NR | NR |

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Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|----------------------------------------|-------|-----------------------------|--------------------------------------------|--------------------|----------------------------------------------------|----|------|----|
| | | | | | 1 | 2 | 3 | 4 |
| Meat and poultry consumption | kg/yr | M, B | 65.1 | DandD | NR | NR | NR | NR |
| Fish consumption | kg/yr | M, B | 20.6 | DandD | NR | NR | NR | NR |
| Other seafood consumption | kg/yr | M, B | 0.9 | RESRAD | NR | NR | NR | NR |
| Soil ingestion rate | g/yr | M, B | 18.3 | Biwer et al., 2000 | NR | NR | NR | NR |
| Drinking water intake | L/yr | M, B | 461.5 | Biwer et al., 2000 | NR | NR | NR | NR |
| Drinking water contaminated fraction | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Household water contaminated fraction | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Livestock water contaminated fraction | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Irrigation water contaminated fraction | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Aquatic food contaminated fraction | - | B, P | Triangular | Biwer et al., 2000 | 0 | 1 | 0.39 | |
| Plant food contaminated fraction | - | B, P | -1 | RESRAD | NR | NR | NR | NR |
| Meat contaminated fraction | - | B, P | -1 | RESRAD | NR | NR | NR | NR |
| Milk contaminated fraction | - | B, P | -1 | RESRAD | NR | NR | NR | NR |
| Livestock fodder intake for meat | kg/d | M | 68 | RESRAD | NR | NR | NR | NR |
| Livestock fodder intake for milk | kg/d | M | 55 | RESRAD | NR | NR | NR | NR |
| Livestock water intake for meat | L/d | M | 50 | RESRAD | NR | NR | NR | NR |
| Livestock water intake for milk | L/d | M | 160 | RESRAD | NR | NR | NR | NR |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|---------------------------------------------------|-------------------|-----------------------------|--------------------------------------------|----------------------|----------------------------------------------------|------|-------|-------|
| | | | | | 1 | 2 | 3 | 4 |
| Livestock intake of soil | kg/d | M | 0.5 | RESRAD | NR | NR | NR | NR |
| Mass loading for foliar deposition | g/m ³ | P | 4E-4 | DandD | NR | NR | NR | NR |
| Depth of soil mixing layer | m | P | Triangular | Biwer et al., 2000 | 0 | 0.6 | 0.15 | |
| Depth of roots | m | P | Uniform | Biwer et al., 2000 | 0.3 | 4.0 | | |
| Groundwater fractional usage for drinking water | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Groundwater fractional usage for household water | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Groundwater fractional usage for livestock water | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Groundwater fractional usage for irrigation water | - | B, P | 1 | RESRAD | NR | NR | NR | NR |
| Wet-weight crop yields for non-leafy vegetables | kg/m ² | P | Lognormal-n (truncated) | Biwer et al., 2000 | 0.56 | 0.48 | 0.001 | 0.999 |
| Wet-weight crop yields for leafy vegetables | kg/m ² | P | 2.9 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Wet-weight crop yields for fodder | kg/m ² | P | 1.8868 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Length of growing season for non-leafy vegetables | yr | P | 0.2466 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Length of growing season for leafy vegetables | yr | P | 0.123 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Length of growing season for fodder | yr | P | 0.082 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Translocation factor for non-leafy vegetables | - | P | 0.1 | DandD | NR | NR | NR | NR |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|-----------------------------------------------------------|-------------------|-----------------------------|--------------------------------------------|----------------------|----------------------------------------------------|------|------|----|
| | | | | | 1 | 2 | 3 | 4 |
| Translocation factor for leafy vegetables | - | P | 1 | DandD | NR | NR | NR | NR |
| Translocation factor for fodder | - | P | 1 | DandD | NR | NR | NR | NR |
| Weathering removal constant | 1/yr | P | Triangular | Biwer et al., 2000 | 5.1 | 84 | 18 | |
| Wet foliar interception fraction for non-leafy vegetables | - | P | 0.35 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Wet foliar interception fraction for leafy vegetables | - | P | Triangular | Biwer et al., 2000 | 0.06 | 0.95 | 0.67 | |
| Wet foliar interception fraction for fodder | - | P | 0.35 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Dry foliar interception fraction for non-leafy vegetables | - | P | 0.35 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Dry foliar interception fraction for leafy vegetables | - | P | 0.35 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Dry foliar interception fraction for fodder | - | P | 0.35 | Beyeler et al., 1999 | NR | NR | NR | NR |
| Cover total porosity | - | P | NA | RESRAD | NR | NR | NR | NR |
| Cover volumetric water content | - | P | NA | RESRAD | NR | NR | NR | NR |
| Cover radon diffusion coefficient | m ² /s | P | NA | RESRAD | NR | NR | NR | NR |
| Building foundation thickness | m | P | 0.15 | RESRAD | NR | NR | NR | NR |
| Building foundation density | g/cm ³ | P | 2.4 | RESRAD | NR | NR | NR | NR |

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Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

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| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|-----------------------------------------------------------|-------------------|-----------------------------|--------------------------------------------|--------|----------------------------------------------------|----|----|----|
| | | | | | 1 | 2 | 3 | 4 |
| Building foundation total porosity | - | P | 0.1 | RESRAD | NR | NR | NR | NR |
| Building foundation volumetric water content | - | P | 0.03 | RESRAD | NR | NR | NR | NR |
| Building foundation radon diffusion coefficient | m ² /s | P | 3.0E-7 | RESRAD | NR | NR | NR | NR |
| Contamination radon diffusion coefficient | m ² /s | P | 2.0E-6 | RESRAD | NR | NR | NR | NR |
| Radon vertical dimension of mixing | m | P | 2 | RESRAD | NR | NR | NR | NR |
| Building air exchange rate | 1/h | P, B | 0.5 | RESRAD | NR | NR | NR | NR |
| Building height | m | P | 2.5 | RESRAD | NR | NR | NR | NR |
| Building indoor area factor | - | P | 0 | RESRAD | NR | NR | NR | NR |
| Foundation depth below ground surface | m | P | -1 | RESRAD | NR | NR | NR | NR |
| Radon-222 emanation coefficient | - | P | 0.25 | RESRAD | NR | NR | NR | NR |
| Radon-220 emanation coefficient | - | P | 0.15 | RESRAD | NR | NR | NR | NR |
| Storage times for fruits, non-leafy vegetables, and grain | d | B | 14 | RESRAD | NR | NR | NR | NR |
| Storage times for leafy vegetables | d | B | 1 | RESRAD | NR | NR | NR | NR |
| Storage times for milk | d | B | 1 | RESRAD | NR | NR | NR | NR |
| Storage times for meat | d | B | 20 | RESRAD | NR | NR | NR | NR |
| Storage times for fish | d | B | 7 | RESRAD | NR | NR | NR | NR |
| Storage times for crustacea and mollusks | d | B | 7 | RESRAD | NR | NR | NR | NR |
| Storage times for well water | d | B | 1 | RESRAD | NR | NR | NR | NR |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|--------------------------------------------------|-----------------------|-----------------------------|--------------------------------------------|----------------------|----------------------------------------------------|------------------|------------------|------------------|
| | | | | | 1 | 2 | 3 | 4 |
| Storage times for surface water | d | B | 1 | RESRAD | NR | NR | NR | NR |
| Storage times for livestock fodder | d | B | 45 | RESRAD | NR | NR | NR | NR |
| C-12 concentration in local water | g/cm ³ | P | 2E-5 | RESRAD | NR | NR | NR | NR |
| C-12 concentration in contaminated soil | g/g | P | 0.03 | RESRAD | NR | NR | NR | NR |
| Fraction of vegetation carbon absorbed from soil | - | P | 0.02 | RESRAD | NR | NR | NR | NR |
| Fraction of vegetation carbon absorbed from air | - | P | 0.98 | RESRAD | NR | NR | NR | NR |
| C-14 evasion layer thickness in soil | m | P | Triangular | Biwer et al., 2000 | 0.2 | 0.6 | 0.3 | |
| C-14 evasion flux rate from soil | 1/s | P | 7E-07 | RESRAD | NR | NR | NR | NR |
| C-12 evasion flux rate from soil | 1/s | P | 1E-10 | RESRAD | NR | NR | NR | NR |
| Grain fraction in livestock feed | - | B | 0.25 (beef cattle) 0.1 (cow) | Beyeler et al., 1999 | NR | NR | NR | NR |
| Inhalation dose conversion factors | mrem/pCi | M | Nuclide specific | RESRAD | NR | NR | NR | NR |
| Ingestion dose conversion factors | mrem/pCi | M | Nuclide specific | RESRAD | NR | NR | NR | NR |
| Slope factor - external | (risk/yr)/ (pCi/g) | M | Nuclide specific | RESRAD | NR | NR | NR | NR |
| Slope factor - inhalation | risk/pCi | M | Nuclide specific | RESRAD | NR | NR | NR | NR |
| Slope factor - ingestion | risk/pCi | M | Nuclide specific | RESRAD | NR | NR | NR | NR |
| Plant transfer factor | - | P | Lognormal (truncated) | Biwer et al., 2000 | Element specific | Element specific | Element specific | Element specific |

Table B.2. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD Code (Continued)

| RESRAD Parameter | Unit | Parameter Type ^a | Parameter Value/ Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|------------------------------------------------------|----------------------|-----------------------------|-----------------------------------------------|-----------------------|----------------------------------------------------|---------------------|---------------------|---------------------|
| | | | | | 1 | 2 | 3 | 4 |
| Meat transfer factor | (pCi/kg)/ (pCi/d) | P | Lognormal (truncated) | Biwer et al., 2000 | Element specific | Element specific | Element specific | Element specific |
| Milk transfer factor | (pCi/L)/ (pCi/d) | P | Lognormal (truncated) | Biwer et al., 2000 | Element specific | Element specific | Element specific | Element specific |
| Bioaccumulation factor for fish | (pCi/kg)/ (pCi/L) | P | Lognormal (truncated) | Biwer et al., 2000 | Element specific | Element specific | Element specific | Element specific |
| Bioaccumulation factor for crustacea and mollusks | (pCi/kg)/ (pCi/L) | P | Element specific | RESRAD | NR | NR | NR | NR |

^a P = physical, B = behavioral, and M = metabolic; when more than one parameter type is listed, the first is primary and next is secondary (Kamboj et al., 1999).

^b For normal and lognormal distribution, distribution parameter 1 is the mean, 2 is the standard deviation, 3 is the lower quantile value, and 4 is the upper quantile. For bounded lognormal distribution, parameters 3 and 4 are the actual lower and upper bounds. Parameters for element-specific values or distribution defined by cumulative probability distributions are not provided in this table (see the Parameter Distribution Report [Biwer et al., 2000]). For uniform distribution, parameter 1 is the minimum and parameter 2 is the maximum of the distribution. For triangular distribution, parameter 1 is the minimum value, parameter 2 is the maximum value, and parameter 3 is the most likely value of the distribution.

^c NR = not required (RESRAD parameters for which distributions are not developed and for which statistical parameters are not required).

^d Hyphen indicates that the parameter is dimensionless.

^e NA = not applicable.

Table B.3. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD-BUILD Code

| Parameter | Units | Parameter Type ^a | Parameter Value/Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|-----------------------------------------|---------------------------------|-----------------------------|----------------------------------------|--------------------|----------------------------------------------------|--------|-----|----|
| | | | | | 1 | 2 | 3 | 4 |
| External dose conversion factor | (mrem/yr)/(pCi/g) | M | Nuclide specific | RESRAD-BUILD | NR ^c | NR | NR | NR |
| Inhalation dose conversion factor | mrem/pCi | M | Nuclide specific | RESRAD-BUILD | NR | NR | NR | NR |
| Ingestion dose conversion factors | mrem/pCi | M | Nuclide specific | RESRAD-BUILD | NR | NR | NR | NR |
| Air Submersion dose conversion factors | (mrem/yr)/(pCi/m ³) | M | Nuclide specific | RESRAD-BUILD | | | | |
| Exposure duration | d | B | 365 | RESRAD-BUILD | NR | NR | NR | NR |
| Indoor fraction | - ^d | B | 0.365 | Biwer et al., 2000 | NR | NR | NR | NR |
| Number of evaluation times | - | P | 2 | RESRAD-BUILD | NR | NR | NR | NR |
| Time | yr | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Number of rooms | - | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Deposition velocity | m/s | P | Loguniform | Biwer et al., 2000 | 2.7E-6 | 2.7E-3 | | |
| Resuspension rate | 1/s | P, B | Loguniform | Biwer et al., 2000 | 2.8E-10 | 1.4E-5 | | |
| Room height | m | P | Triangular | Biwer et al., 2000 | 2.4 | 9.1 | 3.7 | |
| Room area | m ² | P | Triangular | Biwer et al., 2000 | 3 | 900 | 36 | |
| Air exchange rate for building and room | 1/h | B | 1.52 | Biwer et al., 2000 | NR | NR | NR | NR |
| Net flow | m ³ /h | B | 0 | RESRAD-BUILD | NR | NR | NR | NR |
| Outdoor inflow | m ³ /h | B, P | 60 | RESRAD-BUILD | NR | NR | NR | NR |

Table B.3. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD-BUILD Code (Continued)

| Parameter | Units | Parameter Type ^a | Parameter Value/Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|--------------------------------------------|------------------------------|-----------------------------|----------------------------------------|--------------------|----------------------------------------------------|---------|--------|----|
| | | | | | 1 | 2 | 3 | 4 |
| Number of receptors | - | B | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Receptor room | - | B | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Receptor location | m | B | 1,1,1 (Cartesian coordinates) | RESRAD-BUILD | NR | NR | NR | NR |
| Receptor time fraction | - | B | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Receptor inhalation rate | m ³ /d | M, B | 33.6 | Biwer et al., 2000 | NR | NR | NR | NR |
| Receptor indirect ingestion rate | m ² /h | B | 1.1E-4 | Biwer et al., 2000 | NR | NR | NR | NR |
| Number of sources | - | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Source type | - | P | Area, volume | RESRAD-BUILD | NR | NR | NR | NR |
| Source room or primary room | - | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Source direction | - | P | X | RESRAD-BUILD | NR | NR | NR | NR |
| Source location | - | P | 0,0,0 | RESRAD-BUILD | NR | NR | NR | NR |
| Source length or area | m or m ² | P | 36 | RESRAD-BUILD | NR | NR | NR | NR |
| Air release fraction | - | B | 0.07 | Biwer et al., 2000 | NR | NR | NR | NR |
| Direct ingestion rate | g/h (volume) and 1/h (other) | B | 0 | Biwer et al., 2000 | NR | NR | NR | NR |
| Removable fraction | - | P, B | Triangular | Biwer et al., 2000 | 0.0 | 1.0 | 0.2 | |
| Time for source removal or source lifetime | d | P, B | Triangular | Biwer et al., 2000 | 1000 | 100,000 | 10,000 | |
| Radon release fraction | - | P, B | 0 | RESRAD-BUILD | NR | NR | NR | NR |

Table B.3. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD-BUILD Code (Continued)

| Parameter | Units | Parameter Type ^a | Parameter Value/Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|---------------------------------------|----------------------------|-----------------------------|----------------------------------------|--------------------|----------------------------------------------------|--------|-----|----|
| | | | | | 1 | 2 | 3 | 4 |
| Radionuclide concentration | pCi/g, dpm/cm ² | P | 1 (Co-60) | RESRAD-BUILD | NR | NR | NR | NR |
| Number of regions in volume source | - | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Contaminated region-volume source | - | P | 1 | RESRAD-BUILD | NR | NR | NR | NR |
| Source thickness, volume source | cm | P | Triangular | Biwer et al., 2000 | 2.5 | 30 | 15 | |
| Source density, volume source | g/cm ³ | P | Uniform | Biwer et al., 2000 | 2.2 | 2.6 | | |
| Source erosion rate, volume source | cm/d | P, B | Triangular | Biwer et al., 2000 | 0.0 | 5.6E-7 | 0.0 | NR |
| Source porosity | - | P | Uniform | Biwer et al., 2000 | 0.04 | 0.25 | | |
| Radon effective diffusion coefficient | m ² /s | P | 3E-7 | RESRAD-BUILD | NR | NR | NR | NR |
| Radon emanation coefficient | - | P | 0 | RESRAD-BUILD | NR | NR | NR | NR |
| Shielding thickness | cm | P, B | Triangular | Biwer et al., 2000 | 0.0 | 30 | 0.0 | |
| Shielding density | g/cm ³ | P | Uniform | Biwer et al., 2000 | 2.2 | 2.6 | | |
| Shielding material | - | P | Concrete | RESRAD-BUILD | NR | NR | NR | NR |
| Dry zone thickness | cm | P | 0 | RESRAD-BUILD | NR | NR | NR | NR |
| Wet + dry zone thickness | cm | P | Uniform | Biwer et al., 2000 | 5 | 30 | | |
| Volumetric water content | - | P | Uniform | Biwer et al., 2000 | 0.04 | 0.25 | | |

Table B.3. Parameter Values and Distribution Types Used in the Probabilistic Dose Analysis for the RESRAD-BUILD Code (Continued)

| Parameter | Units | Parameter Type ^a | Parameter Value/Distribution Type Used | Source | Distribution's Statistical Parameters ^b | | | |
|------------------------------------------|------------------|-----------------------------|----------------------------------------|--------------------|----------------------------------------------------|------|------|---|
| | | | | | 1 | 2 | 3 | 4 |
| Water fraction available for evaporation | - | P | Triangular | Biwer et al., 2000 | 0.5 | 1.0 | 0.75 | |
| Humidity | g/m ³ | P, B | Uniform | Biwer et al., 2000 | 6.5 | 13.1 | | |

^a P = physical, B = behavioral, and M = metabolic; when more than one parameter type is listed, the first is primary and next is secondary (Kamboj et al., 1999).

^b For normal and lognormal distribution, distribution parameter 1 is the mean, 2 is the standard deviation, 3 is the lower quantile value, and 4 is the upper quantile. For bounded lognormal distribution, parameters 3 and 4 are the actual lower and upper bounds. Parameters for element-specific values or distribution defined by cumulative probability distributions are not provided in this table (see the Parameter Distribution Report [Biwer et al., 2000]). For uniform distribution, parameter 1 is the minimum and parameter 2 is the maximum of the distribution. For triangular distribution, parameter 1 is the minimum value, parameter 2 is the maximum value, and parameter 3 is the most likely value of the distribution.

^c NR = not required (RESRAD parameters for which distributions are not developed and for which statistical parameters are not required).

^d A hyphen indicates that the parameter is dimensionless.

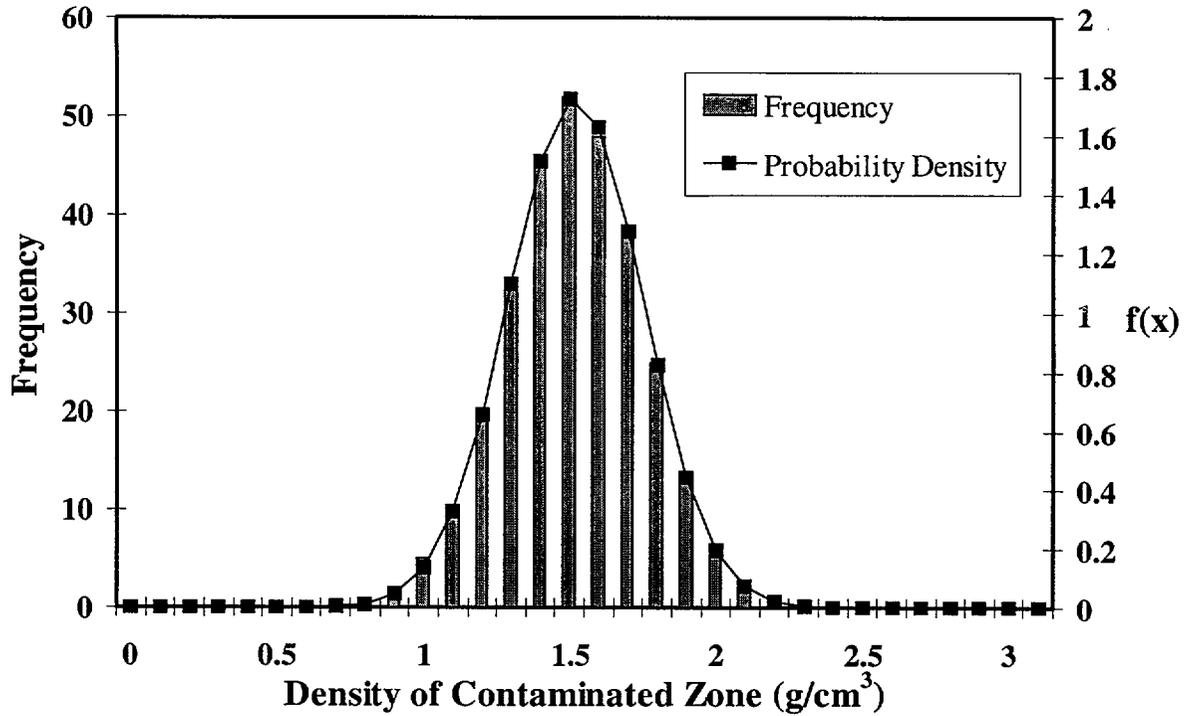


Figure B.1 Sampling Frequency and Probability Density of the Density of Contaminated Zone

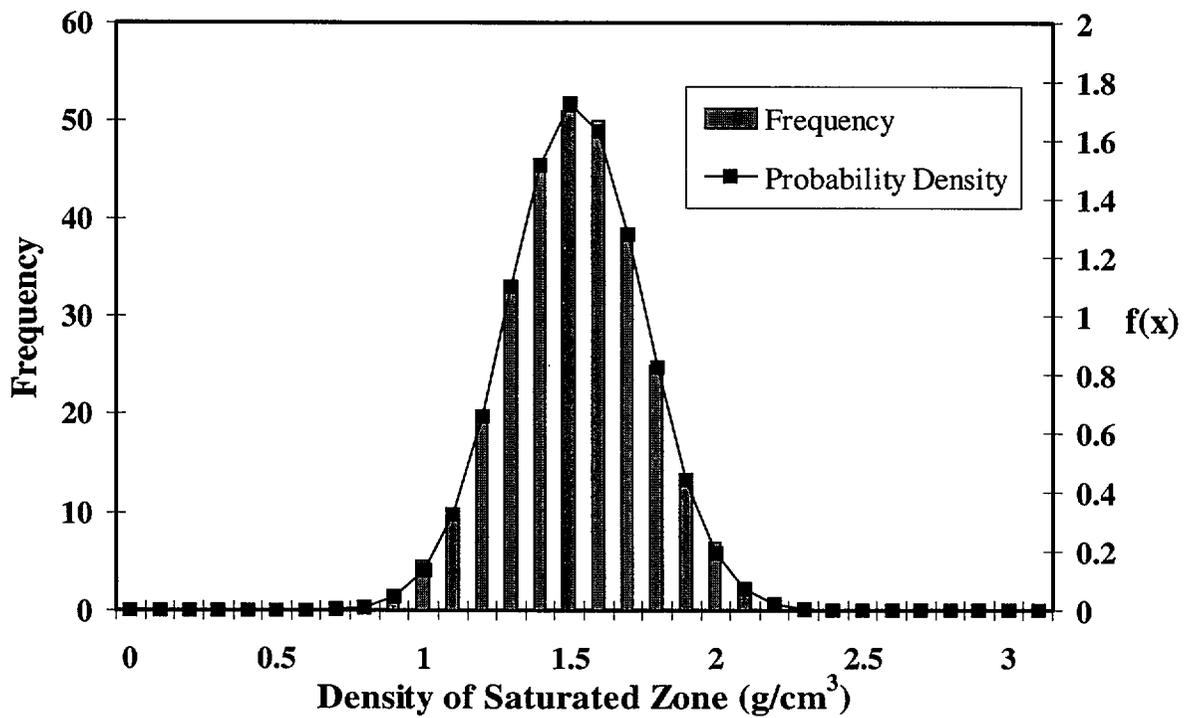


Figure B.2 Sampling Frequency and Probability Density of the Density of Saturated Zone

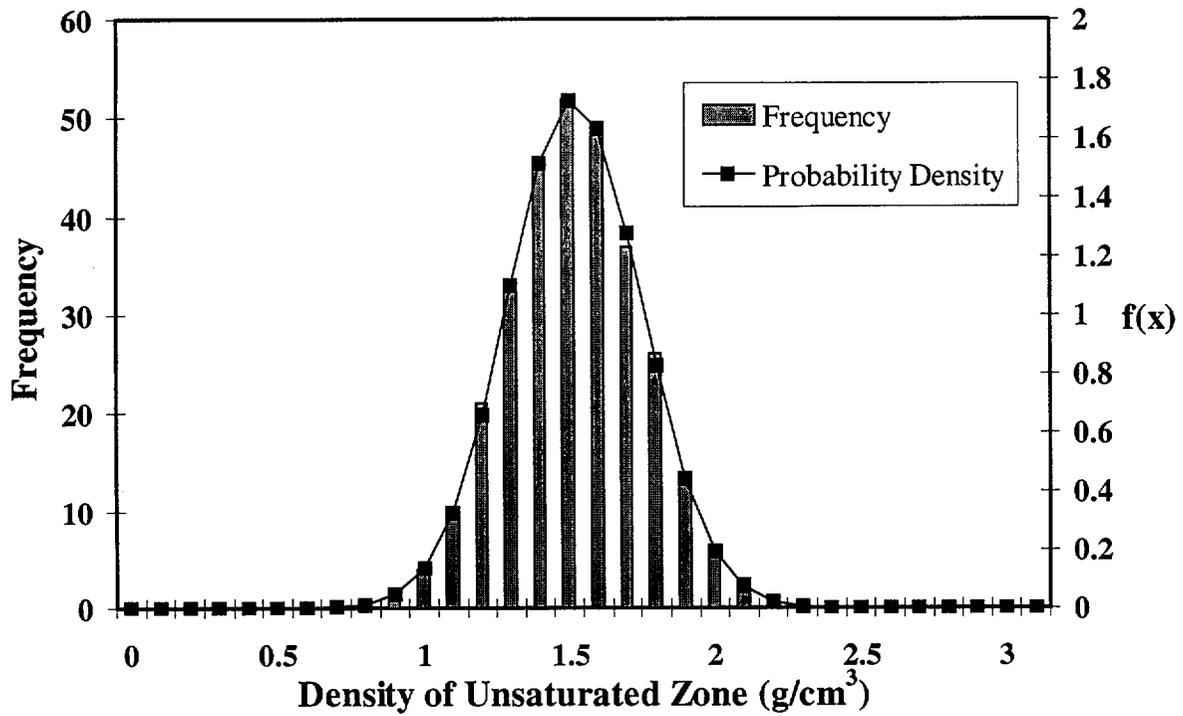


Figure B.3 Sampling Frequency and Probability Density of the Density of Unsaturated Zone

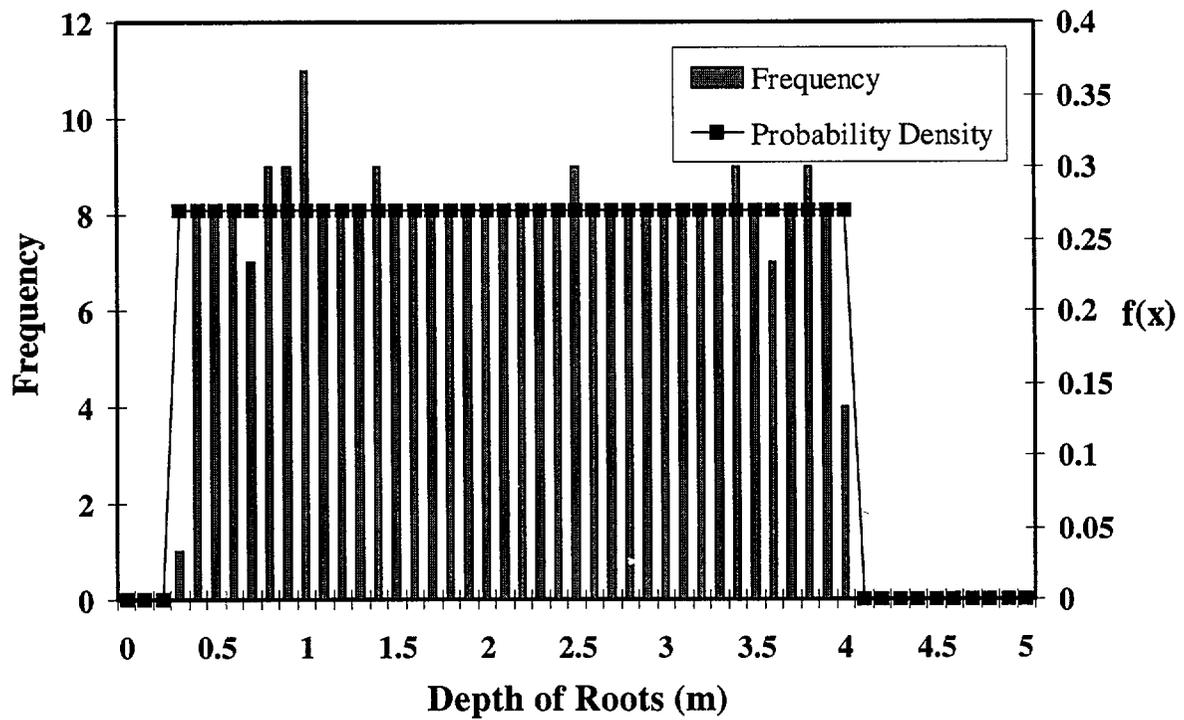


Figure B.4 Sampling Frequency and Probability Density of the Depth of Roots

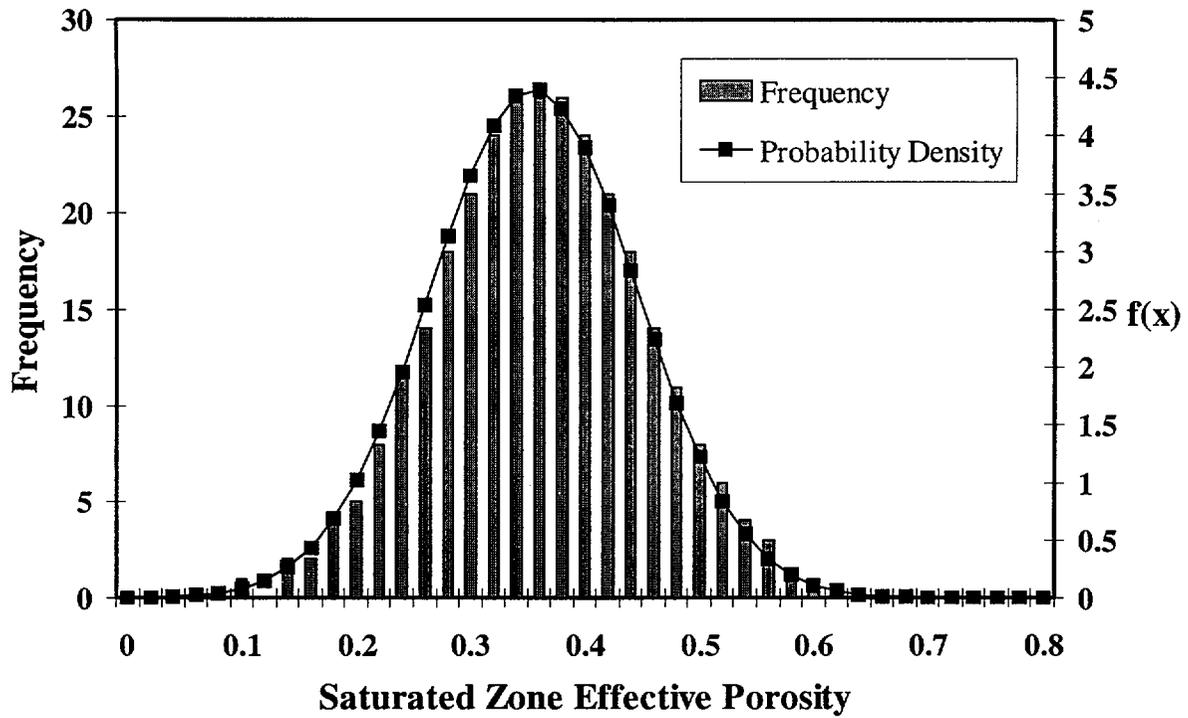


Figure B.5 Sampling Frequency and Probability Density of the Saturated Zone Effective Porosity

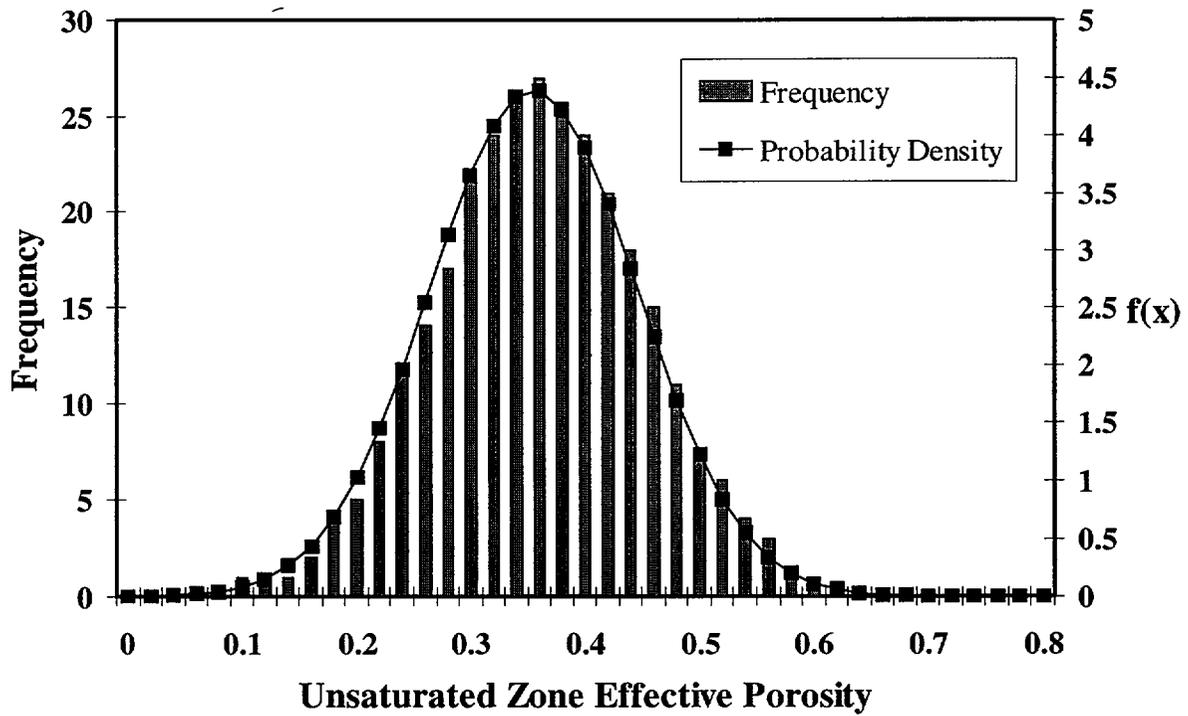


Figure B.6 Sampling Frequency and Probability Density of the Unsaturated Zone Effective Porosity

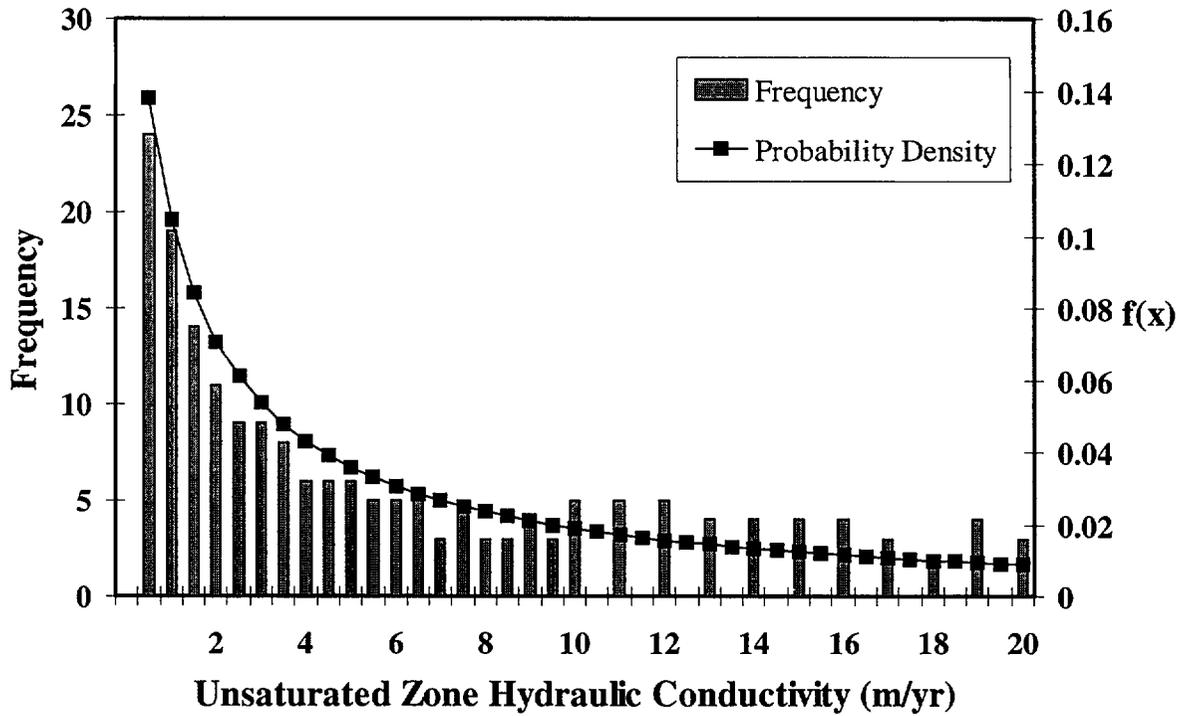


Figure B.7 Sampling Frequency and Probability Density of the Unsaturated Zone Hydraulic Conductivity

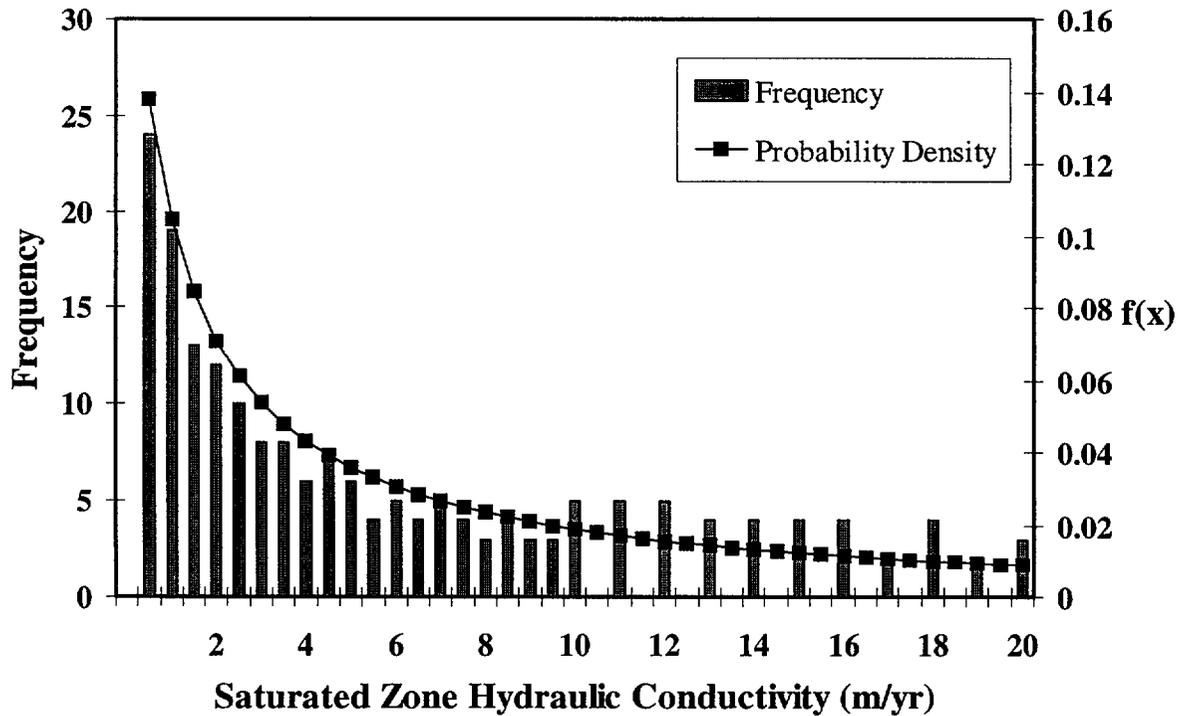


Figure B.8 Sampling Frequency and Probability Density of the Saturated Zone Hydraulic Conductivity

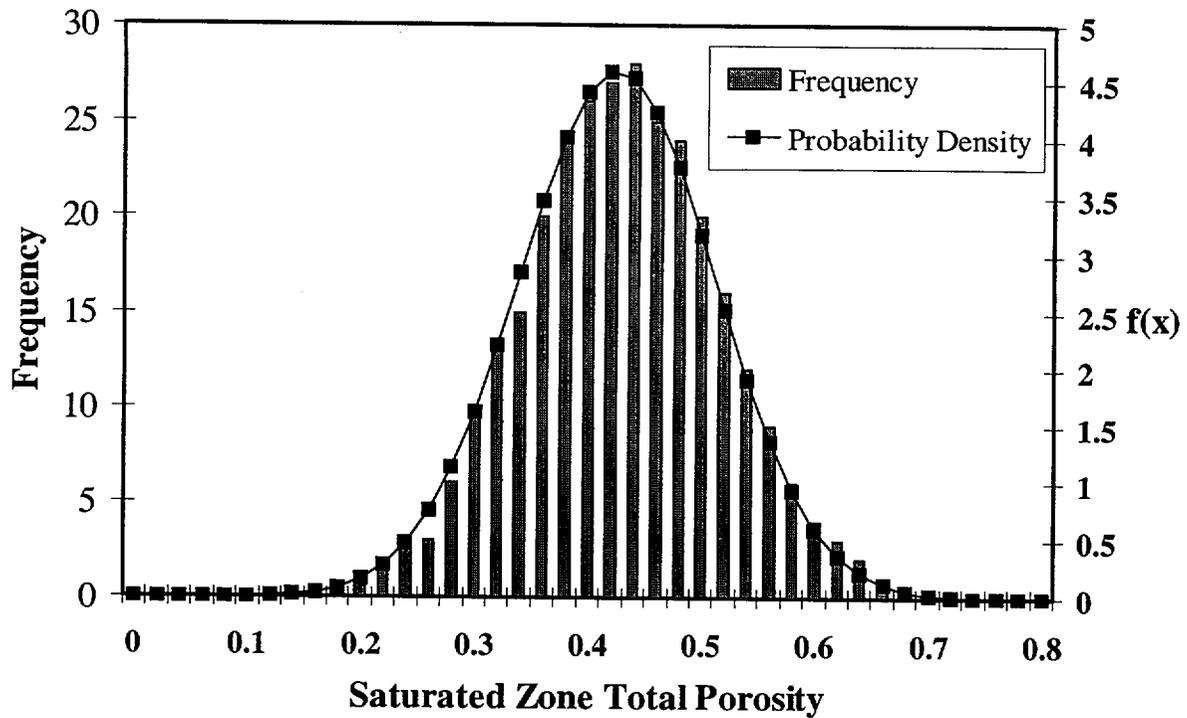


Figure B.9 Sampling Frequency and Probability Density of the Saturated Zone Total Porosity

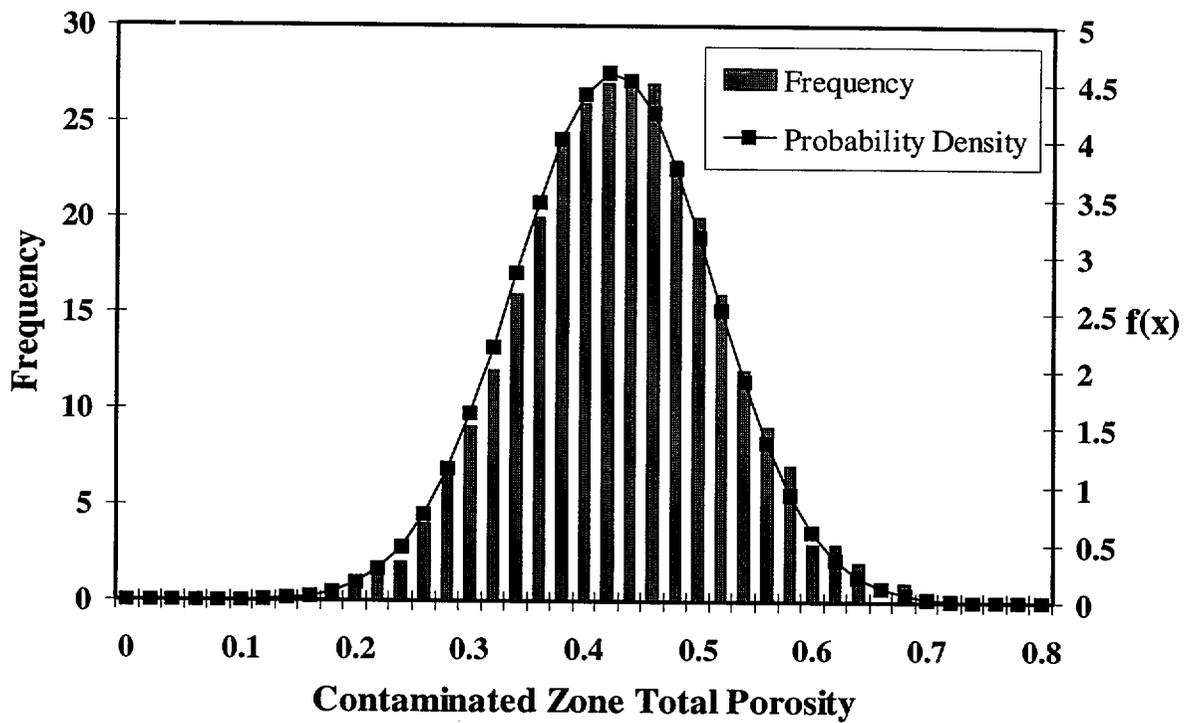


Figure B.10 Sampling Frequency and Probability Density of the Contaminated Zone Total Porosity

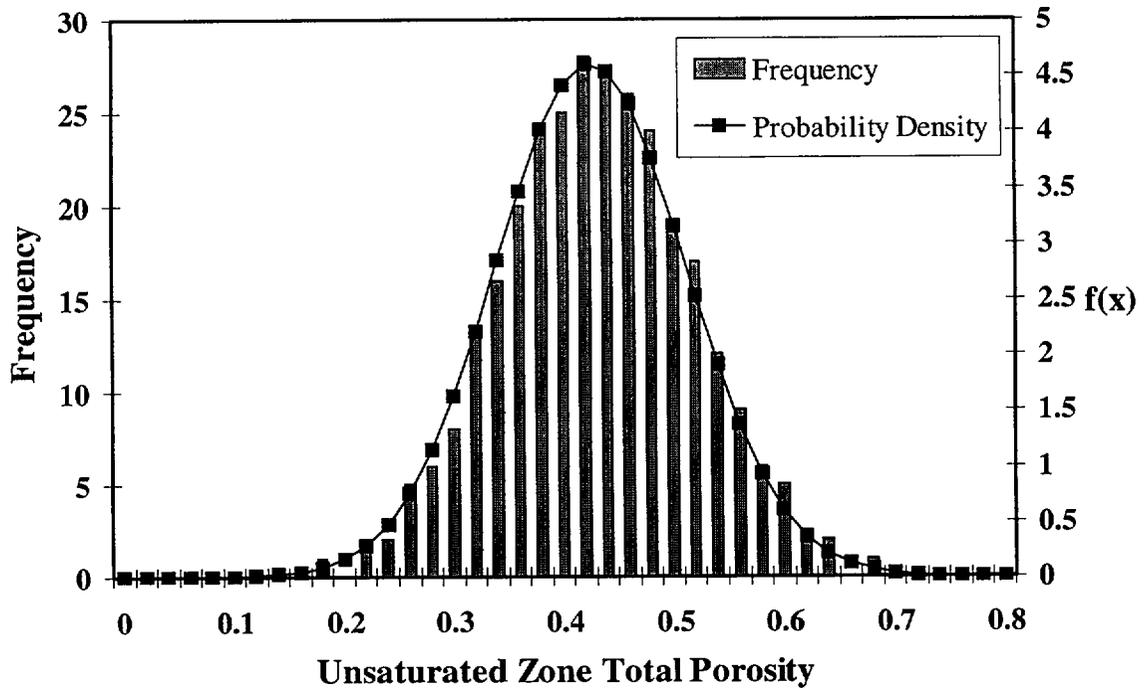


Figure B.11 Sampling Frequency and Probability Density of the Unsaturated Zone Total Porosity

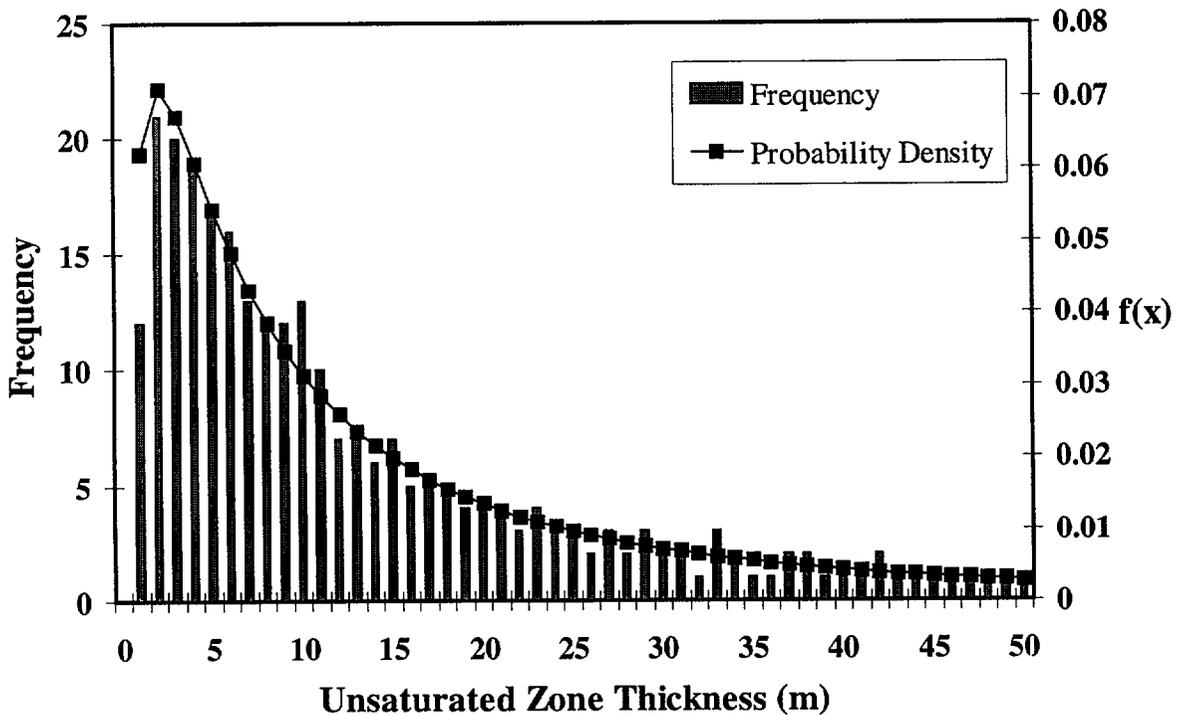


Figure B.12 Sampling Frequency and Probability Density of the Unsaturated Zone Thickness

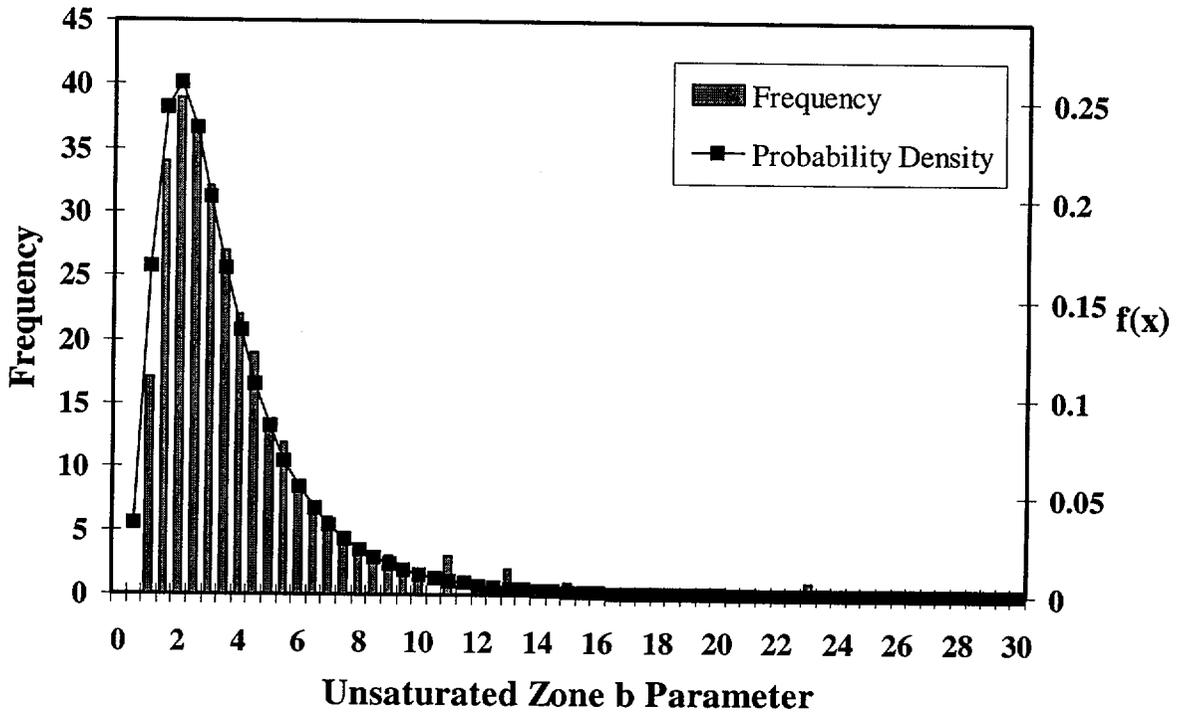


Figure B.13 Sampling Frequency and Probability Density of the Unsaturated Zone b Parameter

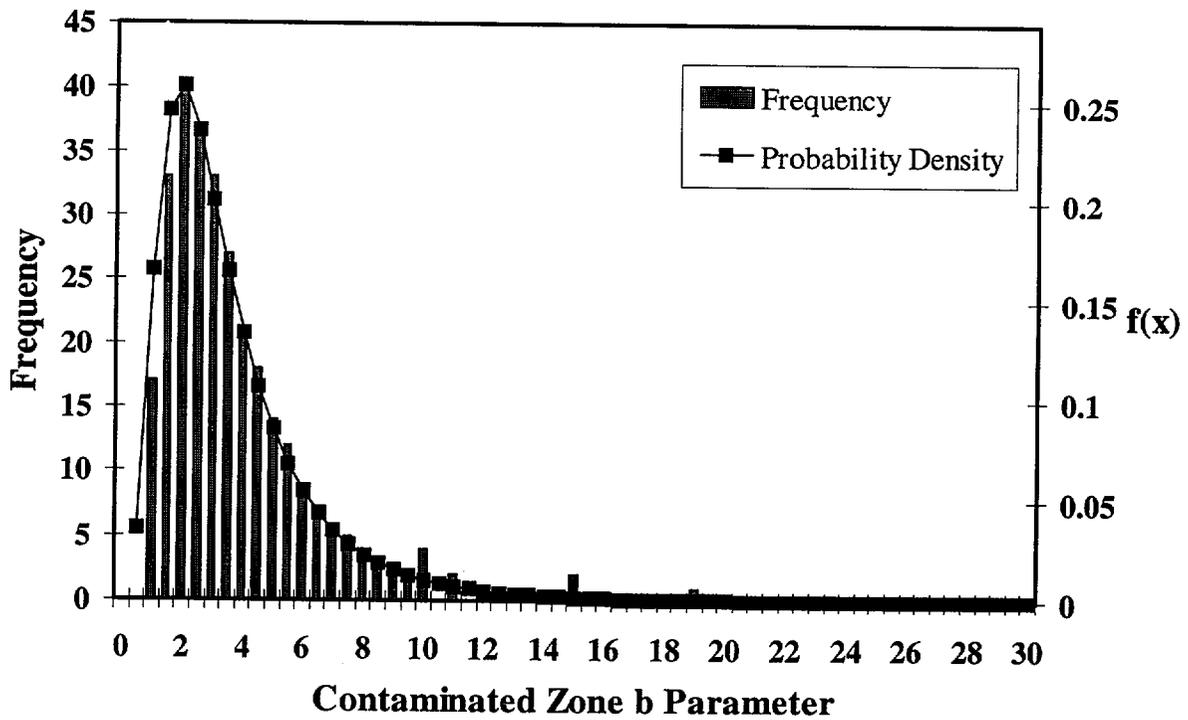


Figure B.14 Sampling Frequency and Probability Density of the Contaminated Zone b Parameter

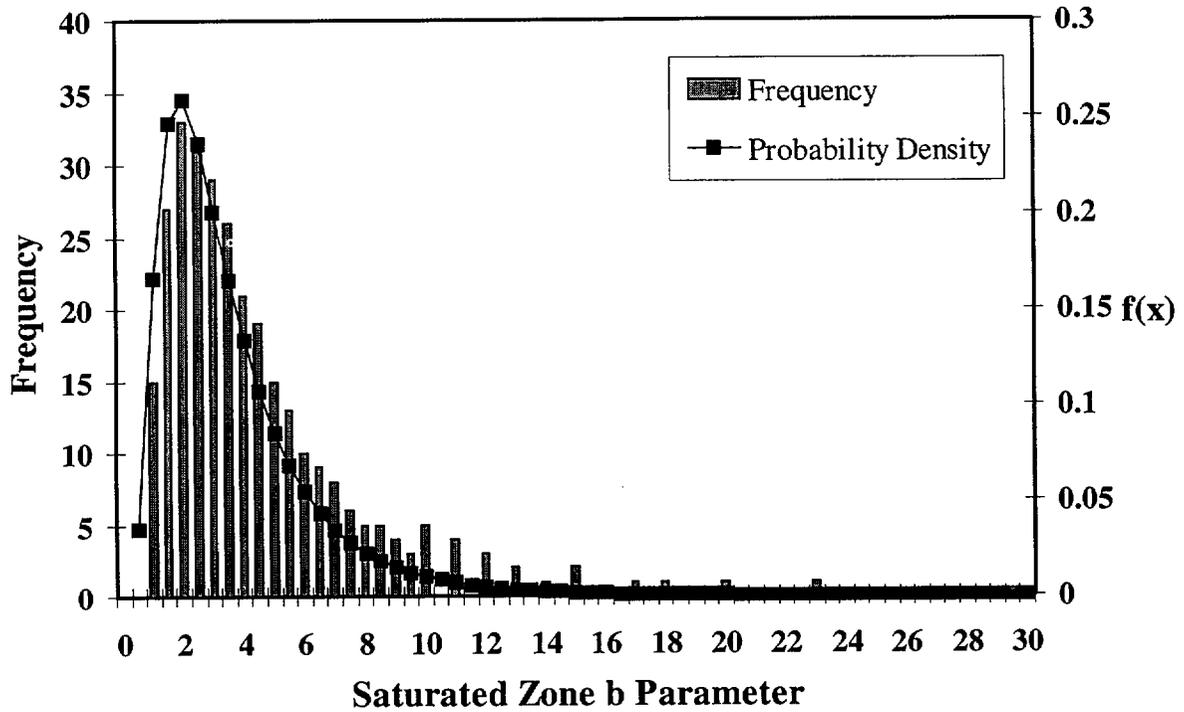


Figure B.15 Sampling Frequency and Probability Density of the Saturated Zone b Parameter

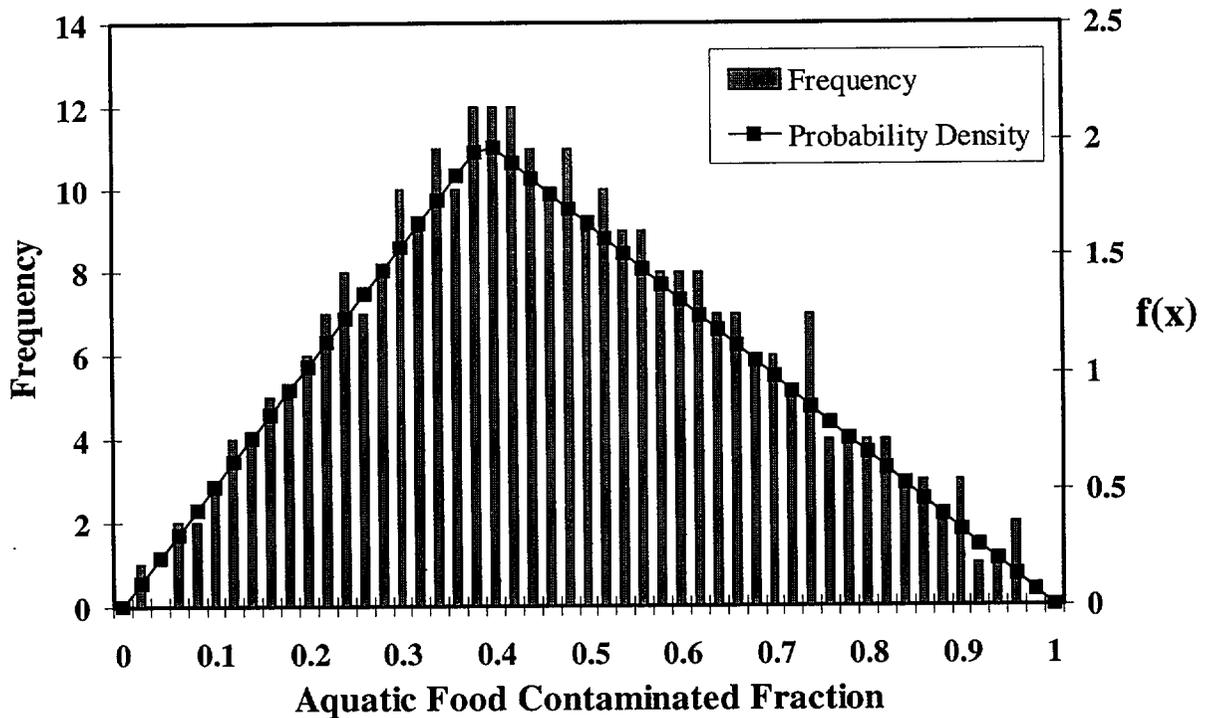


Figure B.16 Sampling Frequency and Probability Density of the Aquatic Food Contaminated Fraction

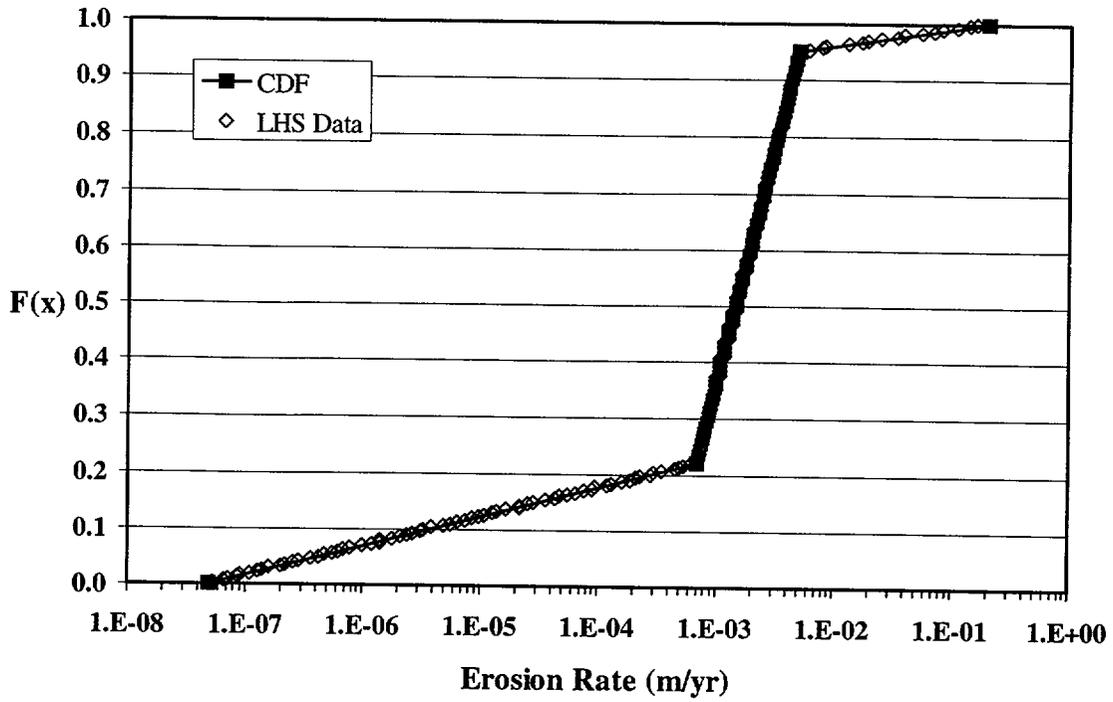


Figure B.17 Sampled Cumulative Probability and the Cumulative Distribution Function of the Erosion Rate

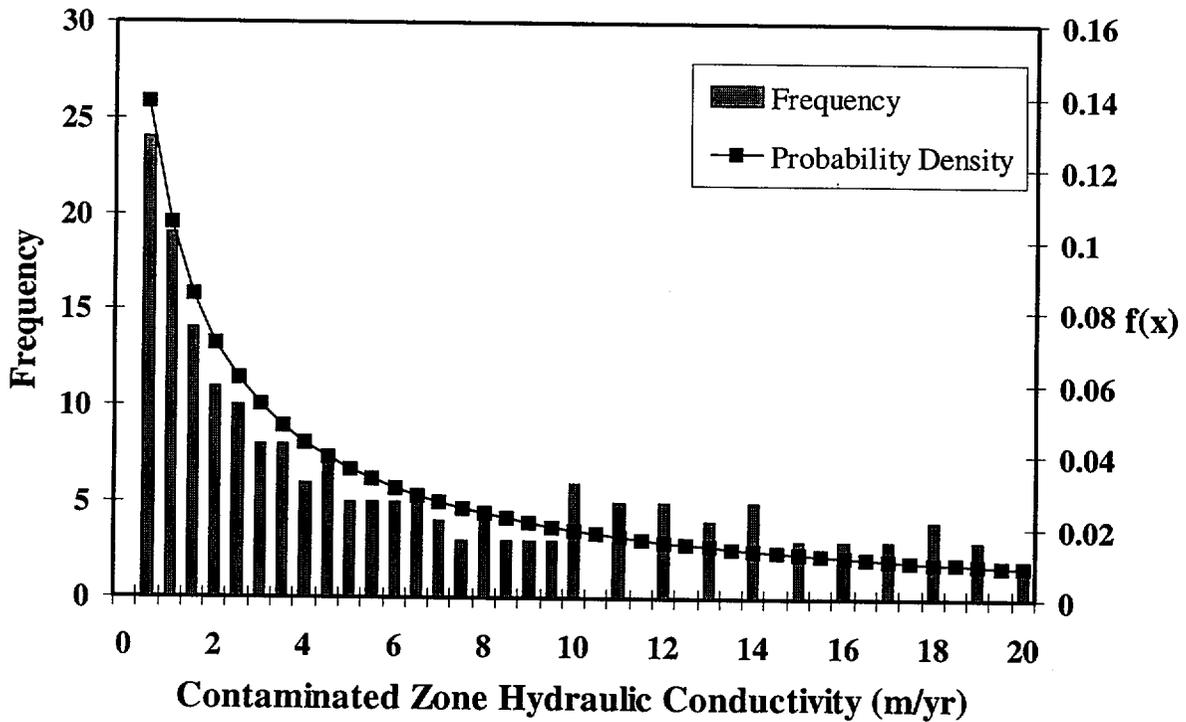


Figure B.18 Sampling Frequency and Probability Density of the Contaminated Zone Hydraulic Conductivity

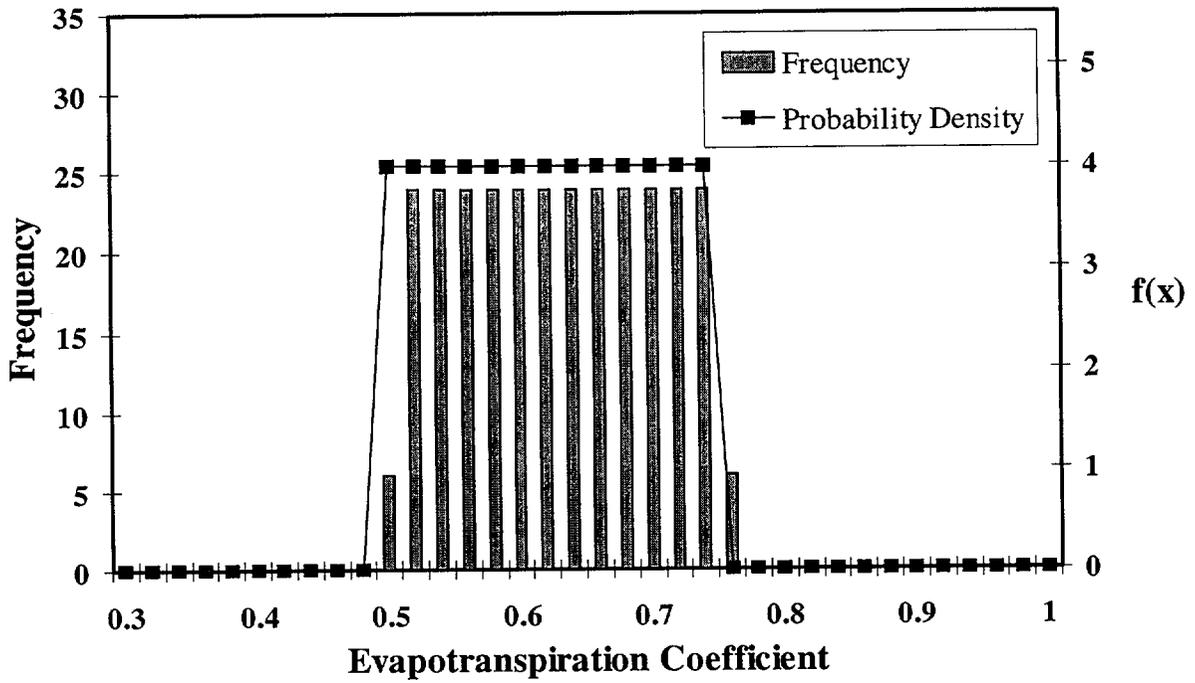


Figure B.19 Sampling Frequency and Probability Density of the Evapotranspiration Coefficient

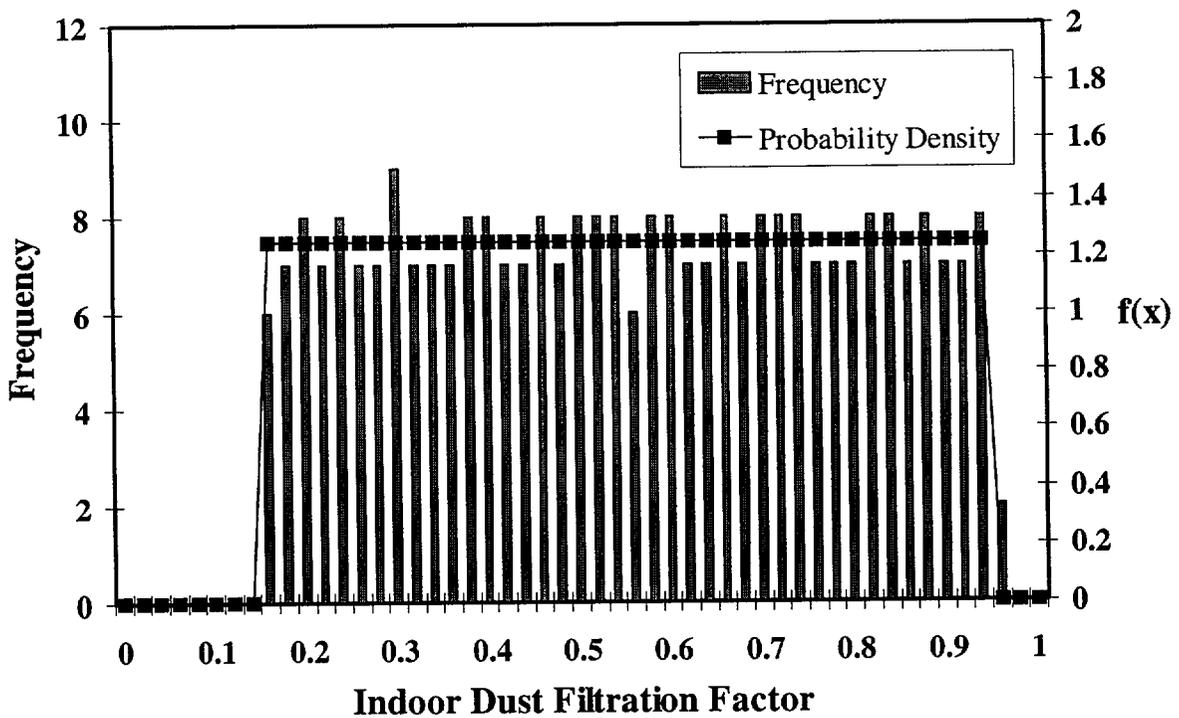


Figure B.20 Sampling Frequency and Probability Density of the Indoor Dust Filtration Factor

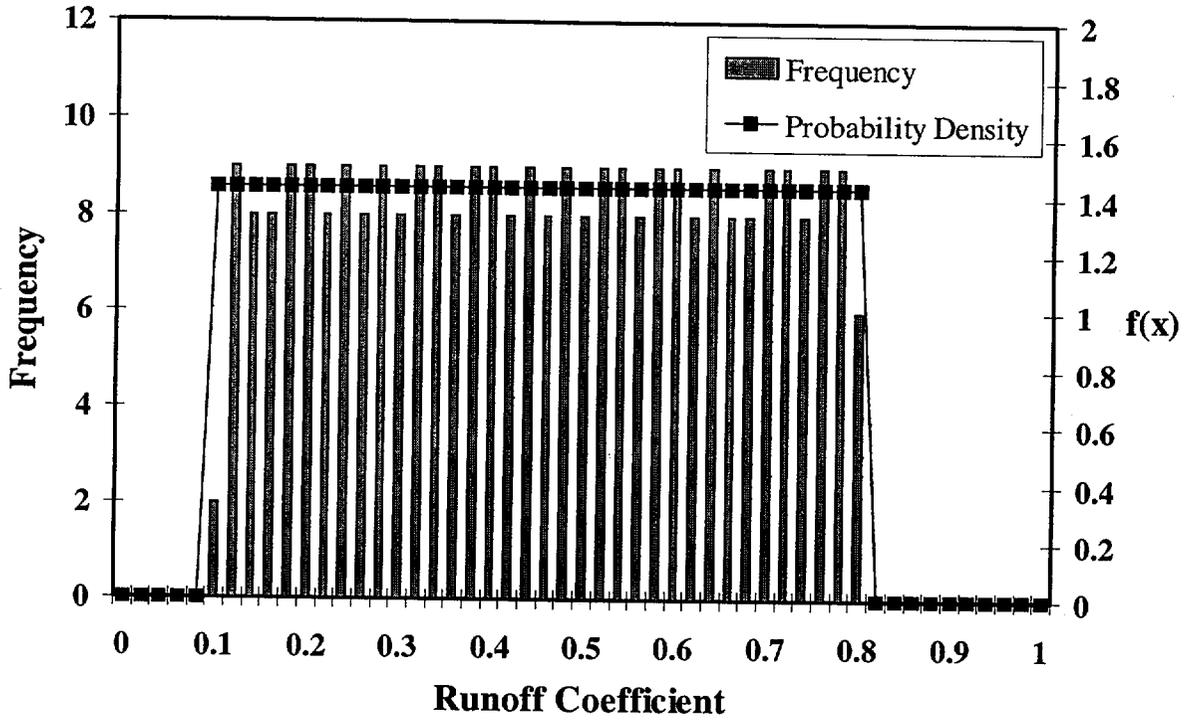


Figure B.21 Sampling Frequency and Probability Density of the Runoff Coefficient

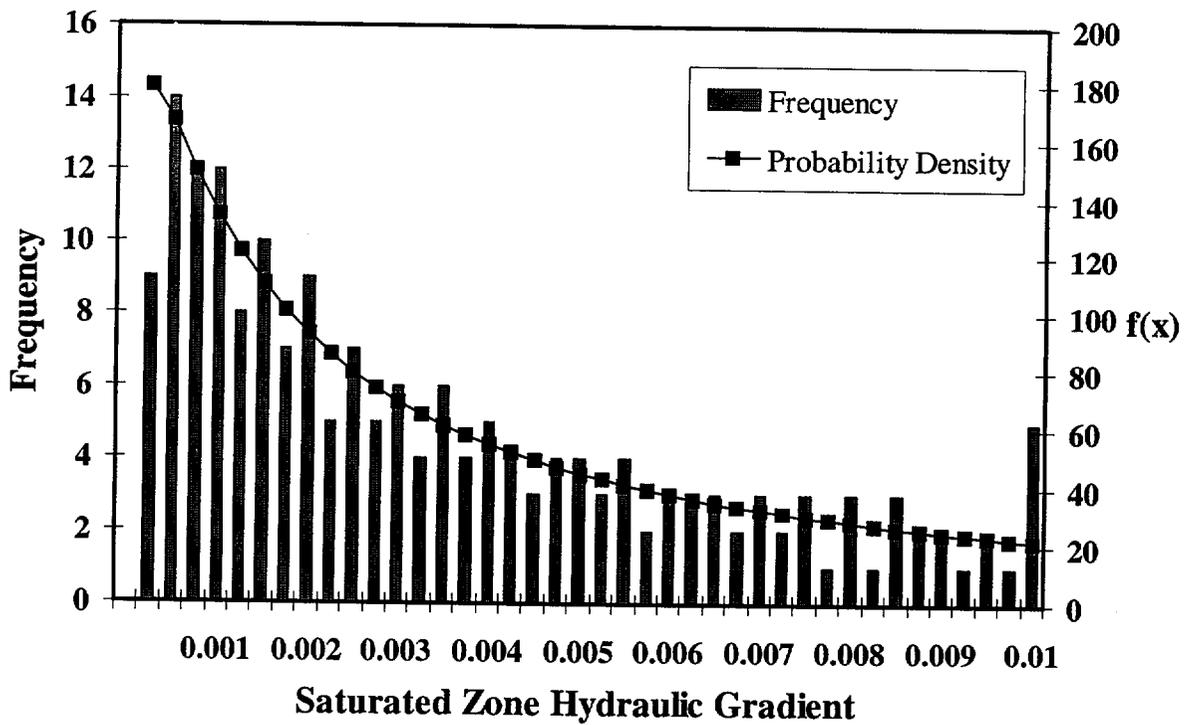


Figure B.22 Sampling Frequency and Probability Density of the Saturated Zone Hydraulic Gradient

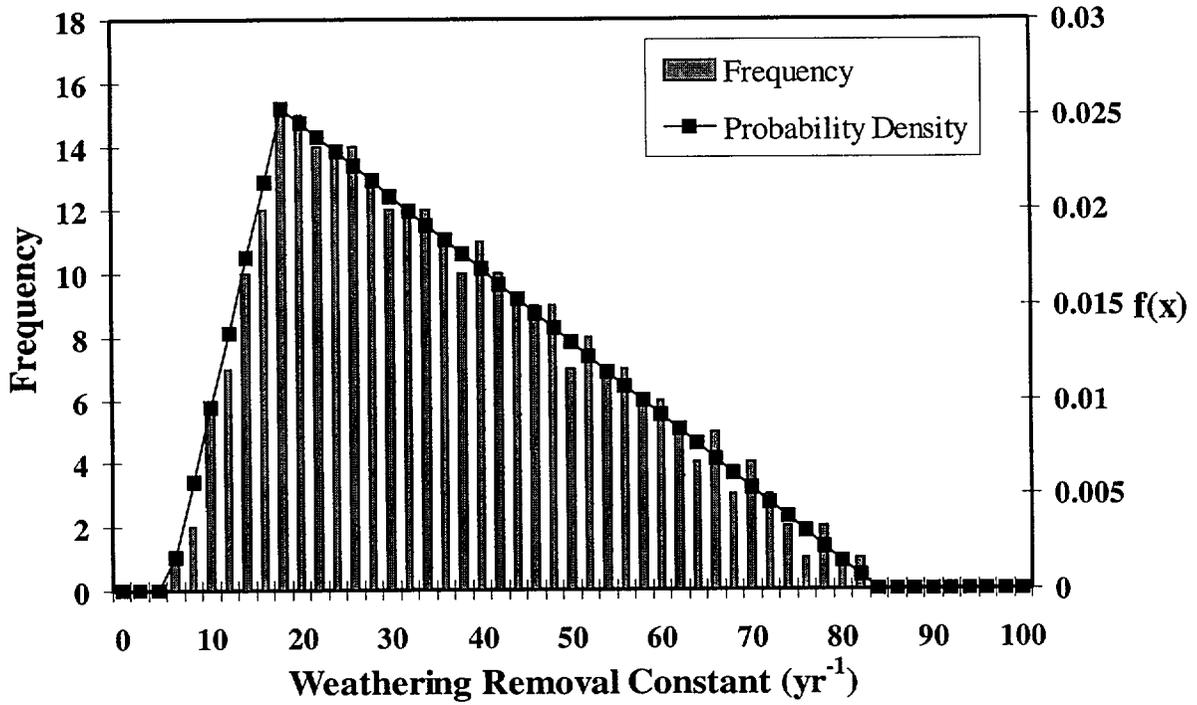


Figure B.23 Sampling Frequency and Probability Density of the Weathering Removal Constant

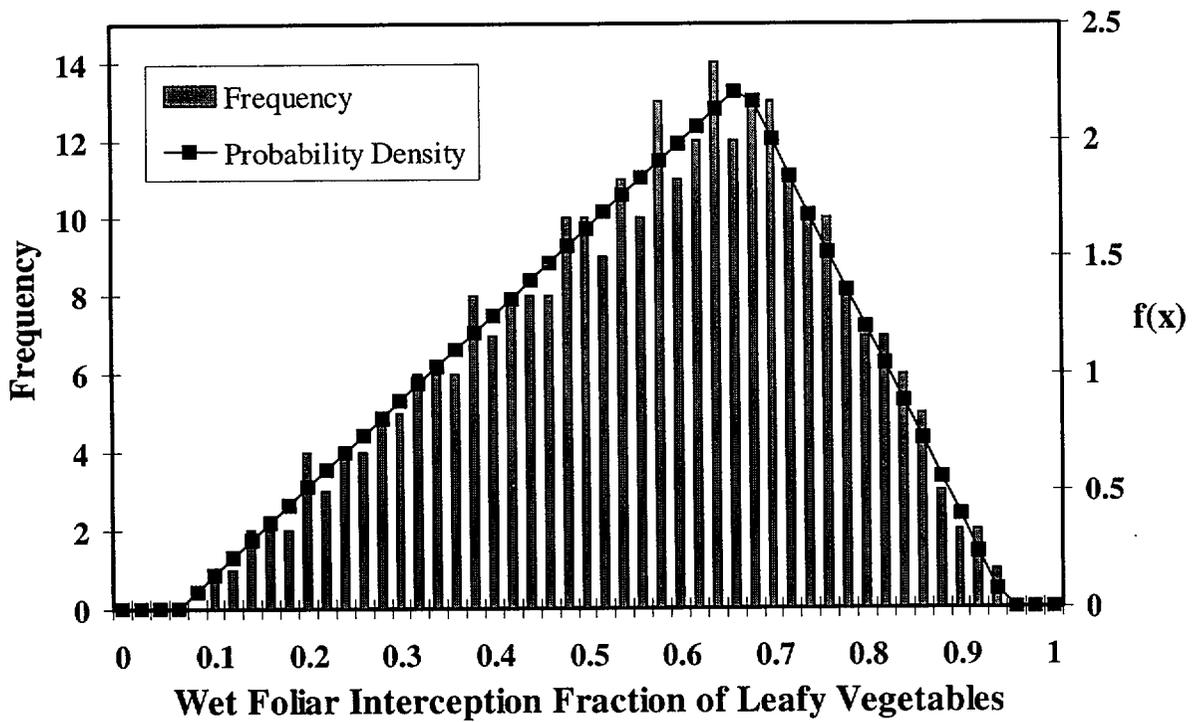


Figure B.24 Sampling Frequency and Probability Density of the Wet Foliar Interception Fraction of Leafy Vegetables

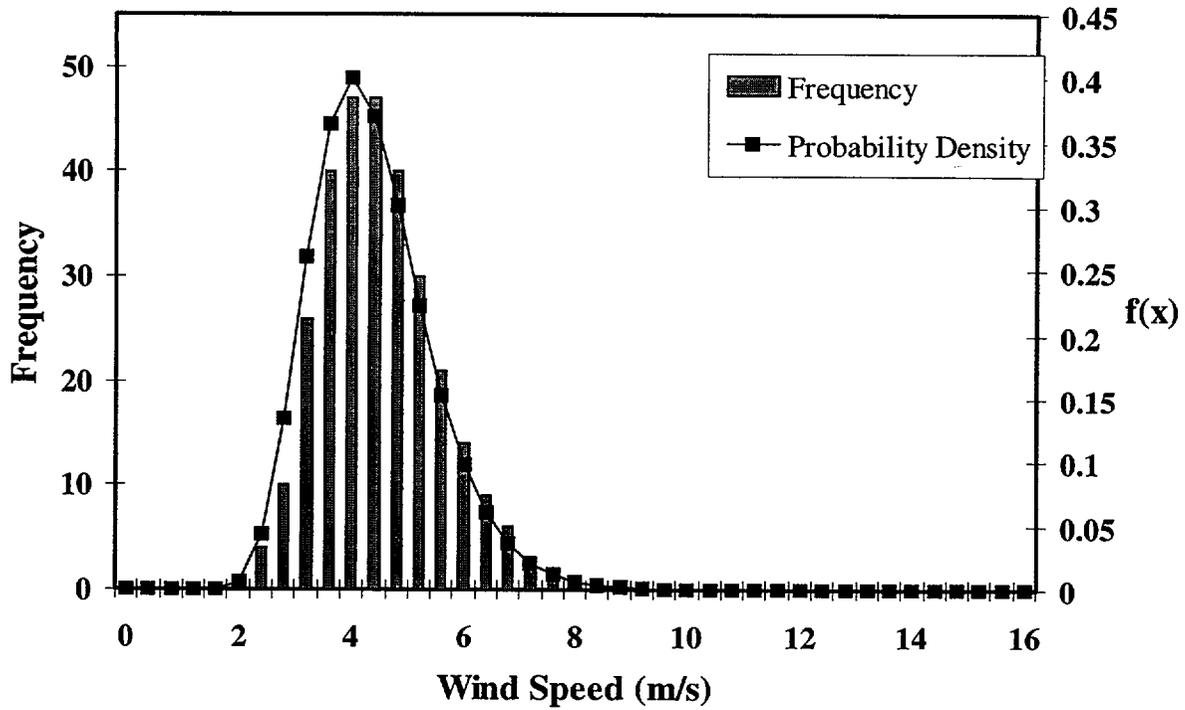


Figure B.25 Sampling Frequency and Probability Density of the Wind Speed

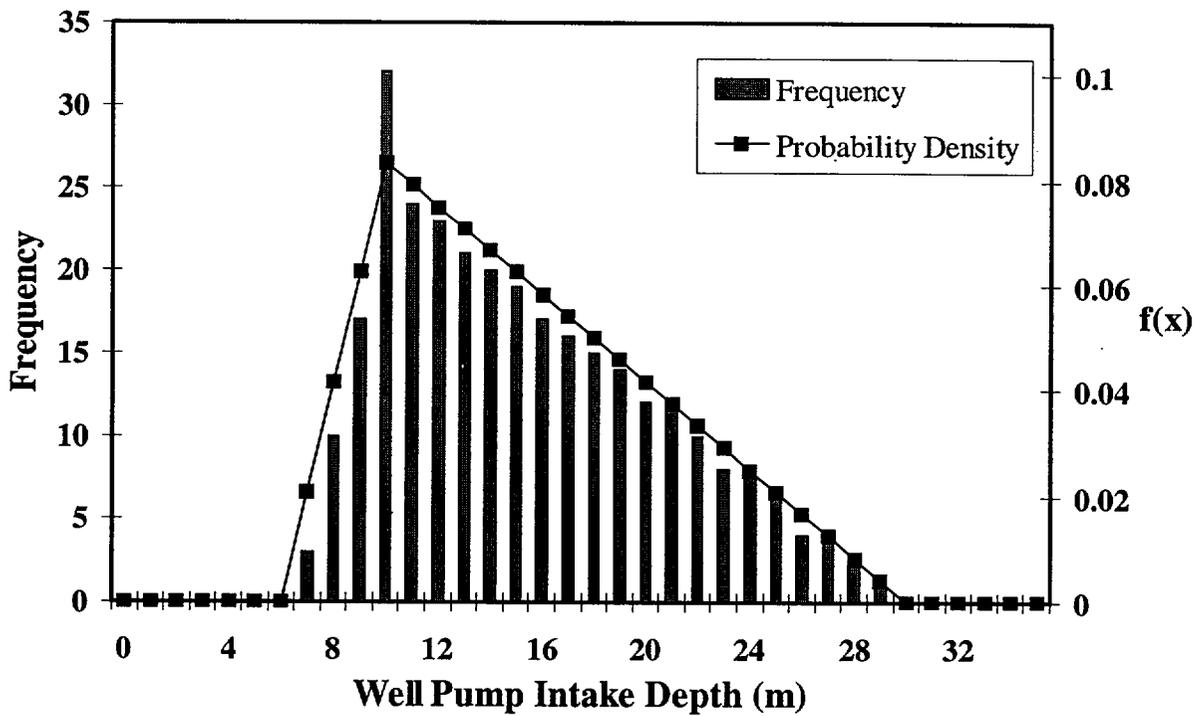


Figure B.26 Sampling Frequency and Probability Density of the Well Pump Intake Depth

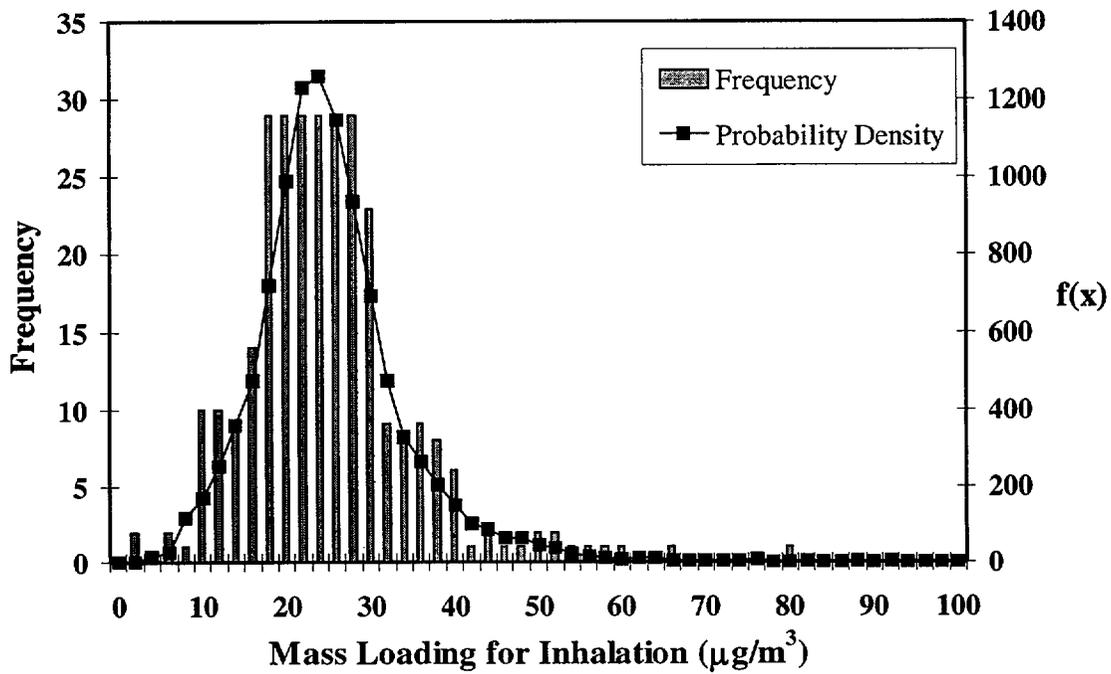


Figure B.27 Sampling Frequency and Probability Density of the Mass Loading for Inhalation

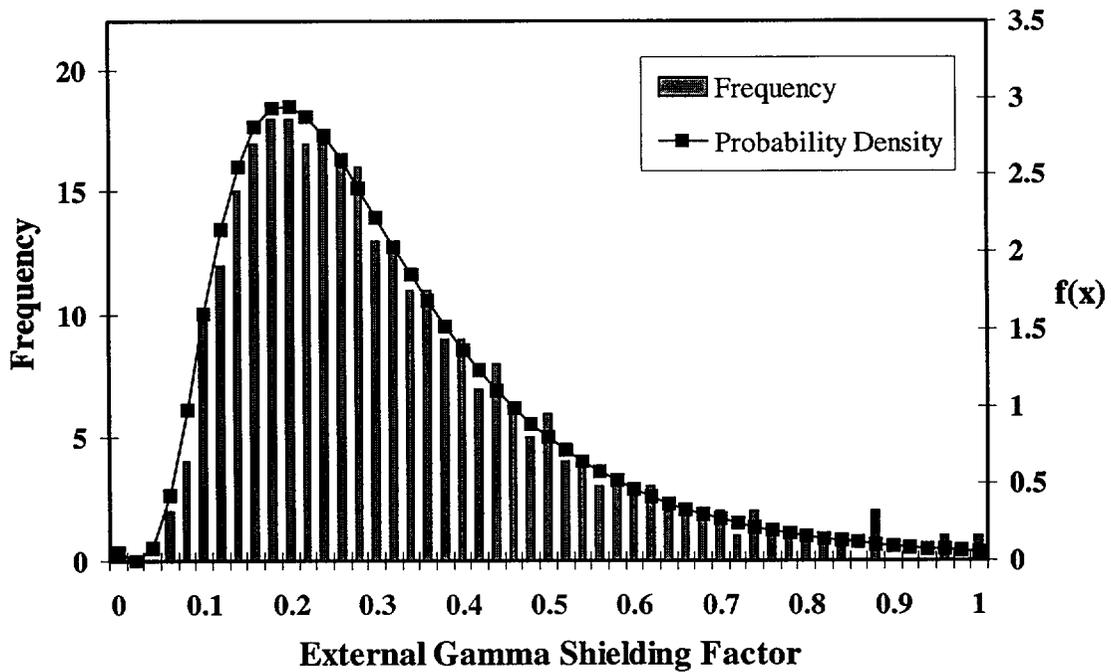


Figure B.28 Sampling Frequency and Probability Density of the External Gamma Shielding Factor

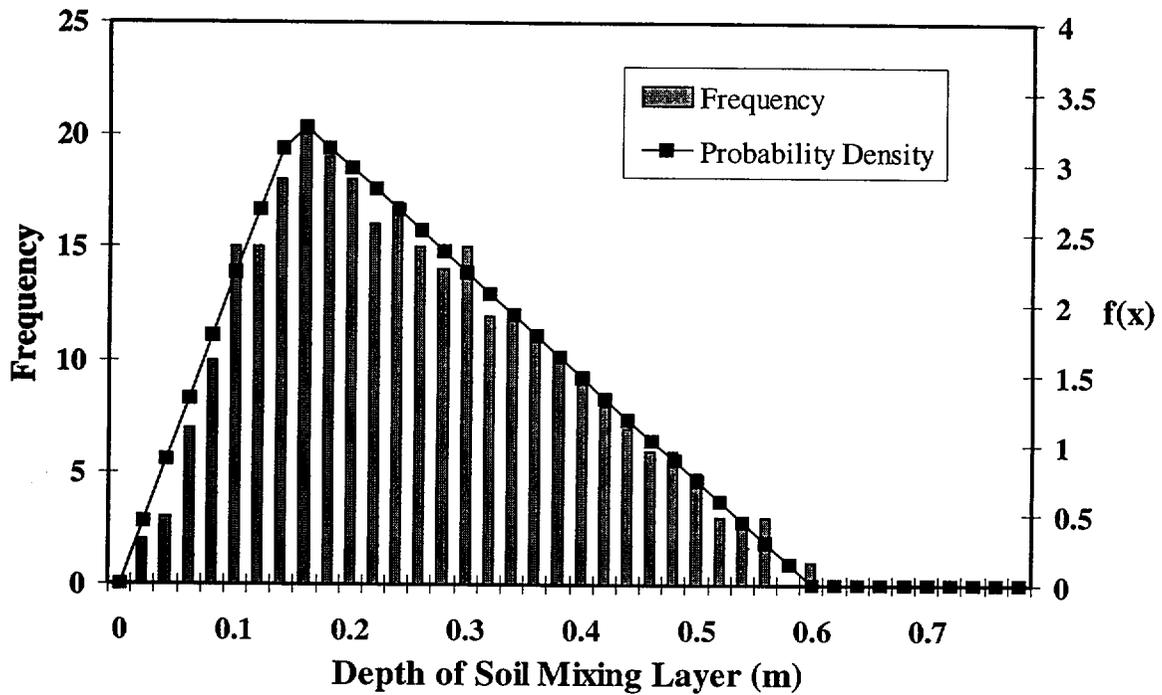


Figure B.29 Sampling Frequency and Probability Density of the Depth of Soil Mixing Layer

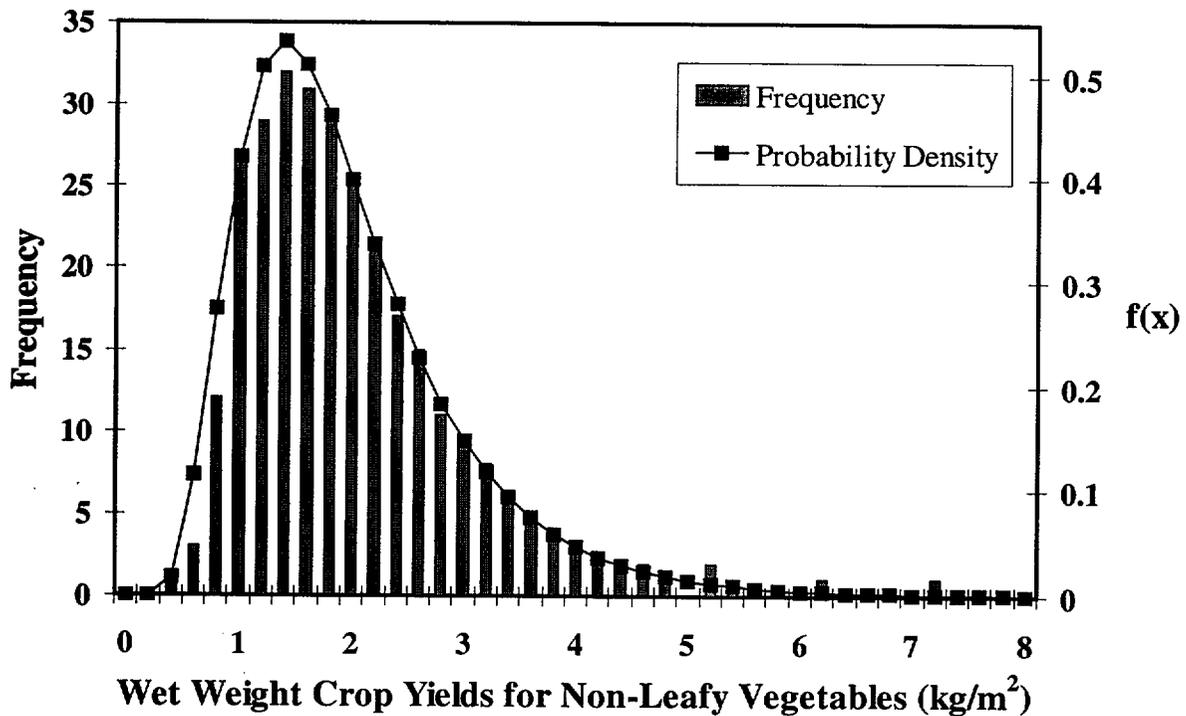


Figure B.30 Sampling Frequency and Probability Density of the Wet Weight Crop Yields for Non-Leafy Vegetables

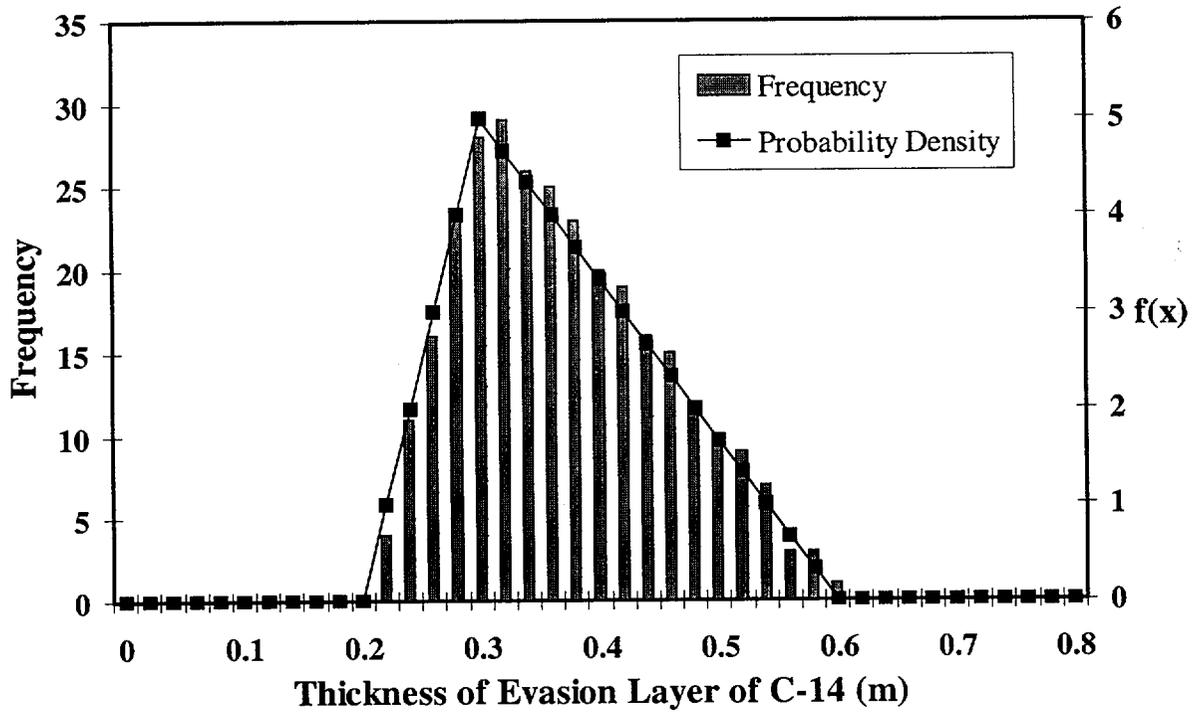


Figure B.31 Sampling Frequency and Probability Density of the Thickness of Evasion Layer of C-14

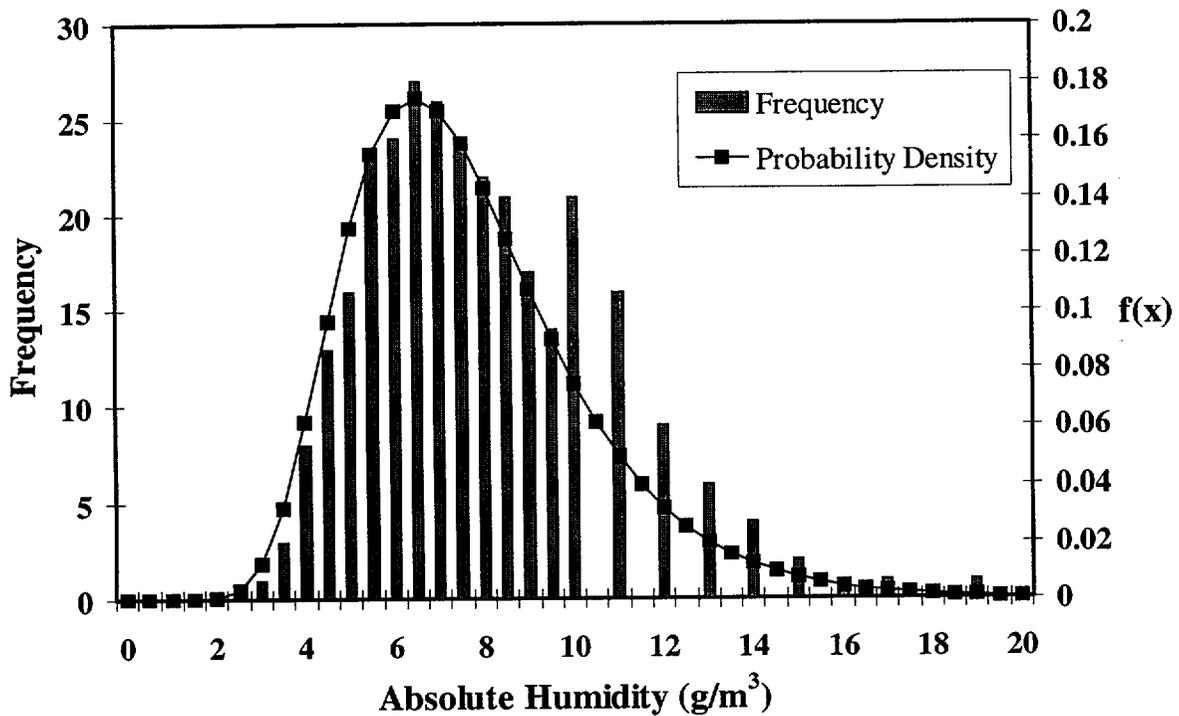


Figure B.32 Sampling Frequency and Probability Density of the Absolute Humidity

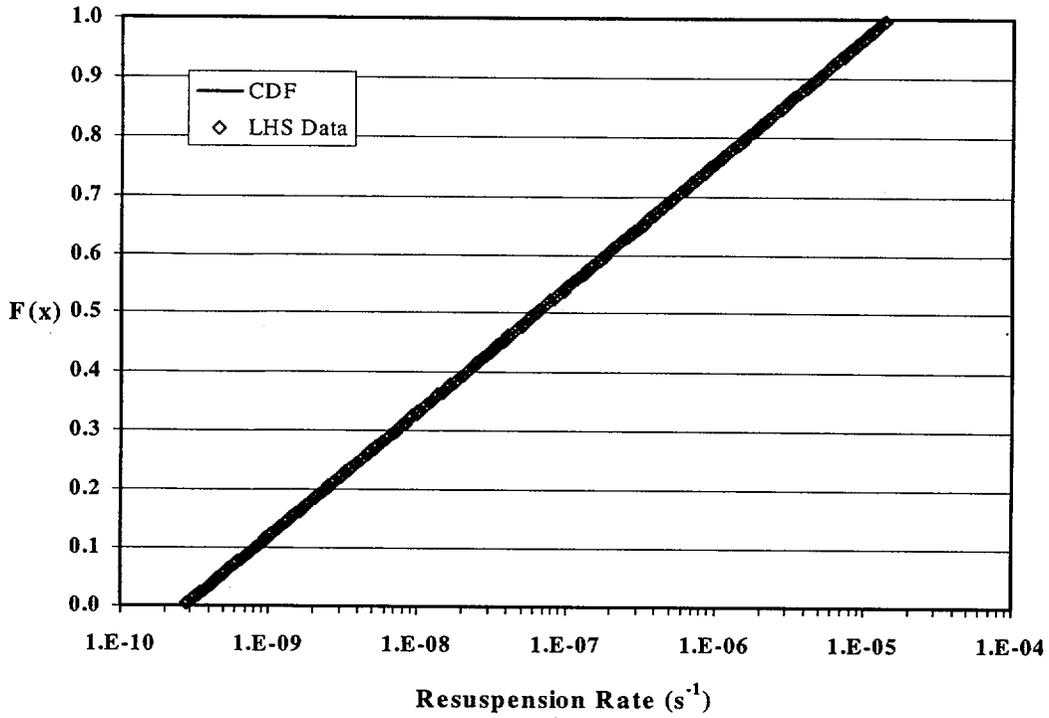


Figure B.33 Sampled Cumulative Probability and the Cumulative Distribution Function of the Resuspension Rate

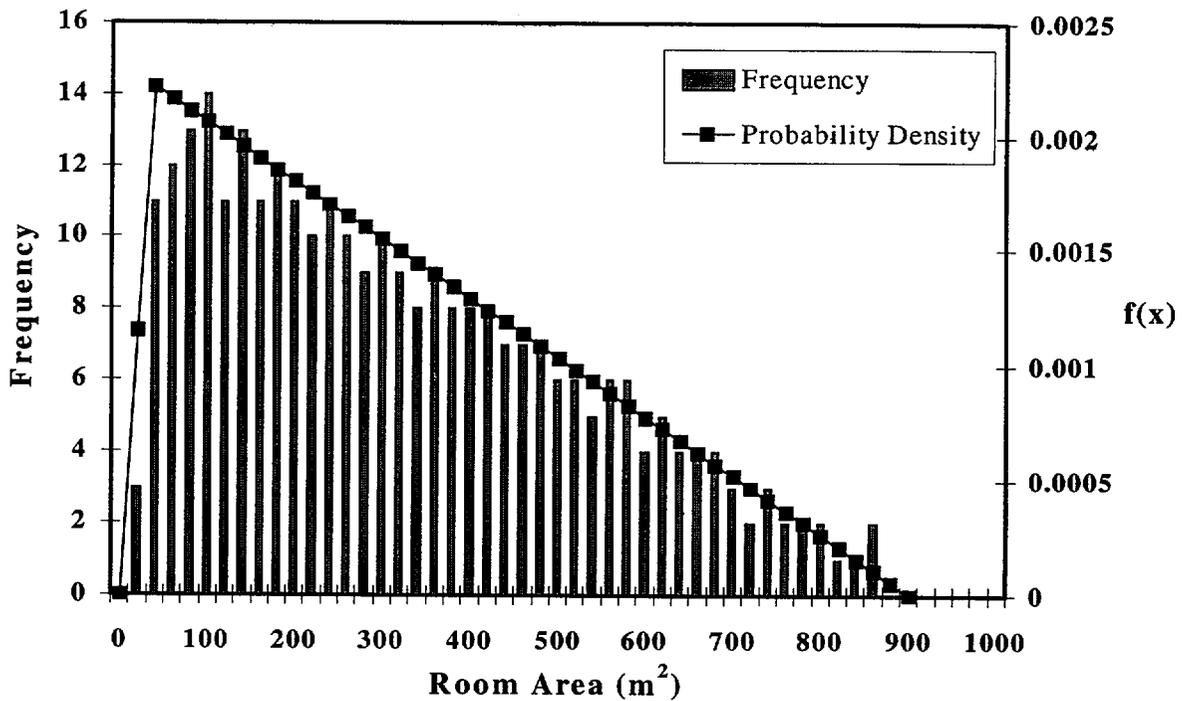


Figure B.34 Sampling Frequency and Probability Density of the Room Area

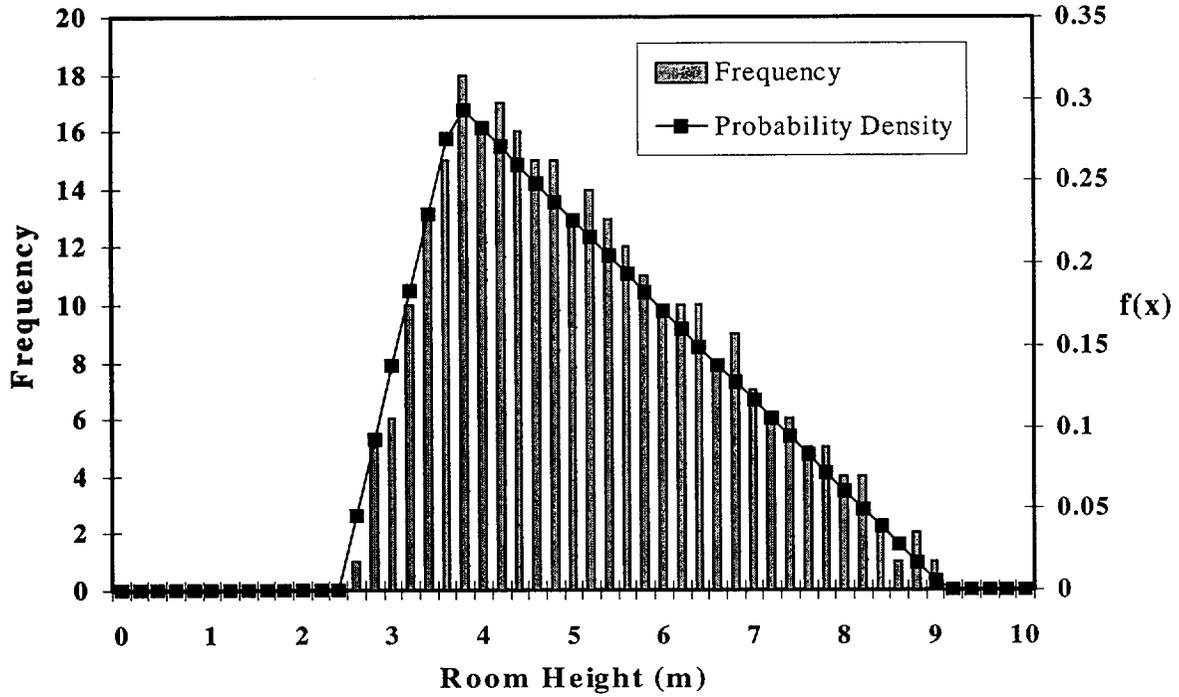


Figure B.35 Sampling Frequency and Probability Density of the Room Height

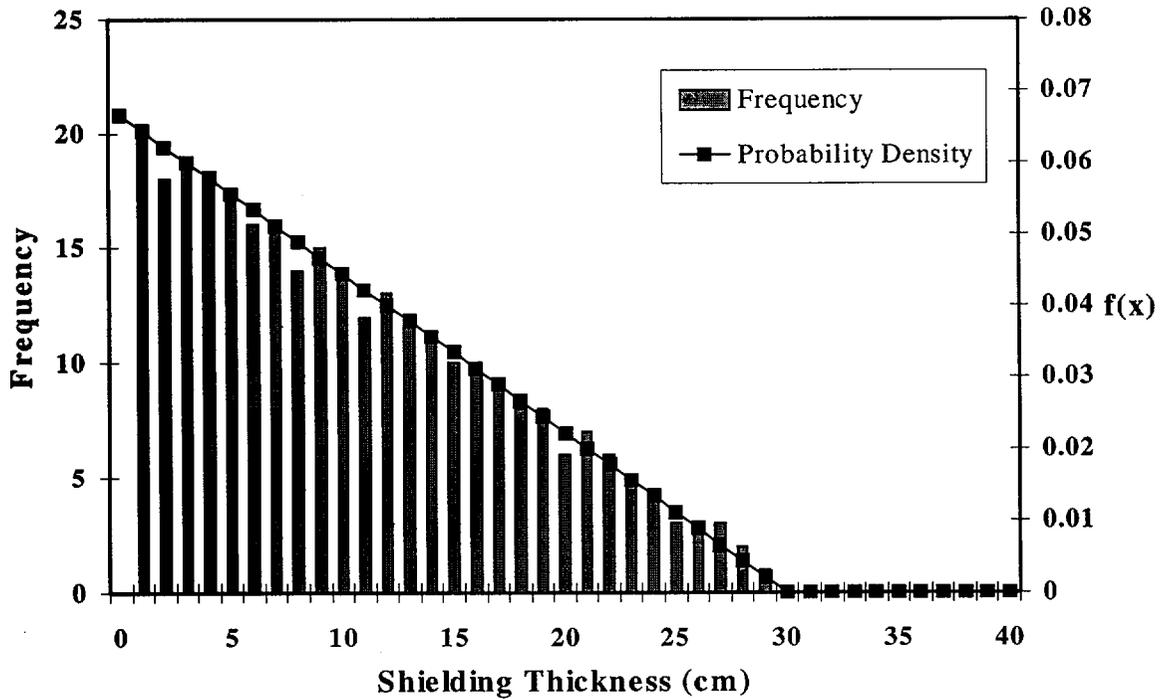


Figure B.36 Sampling Frequency and Probability Density of the Shielding Thickness

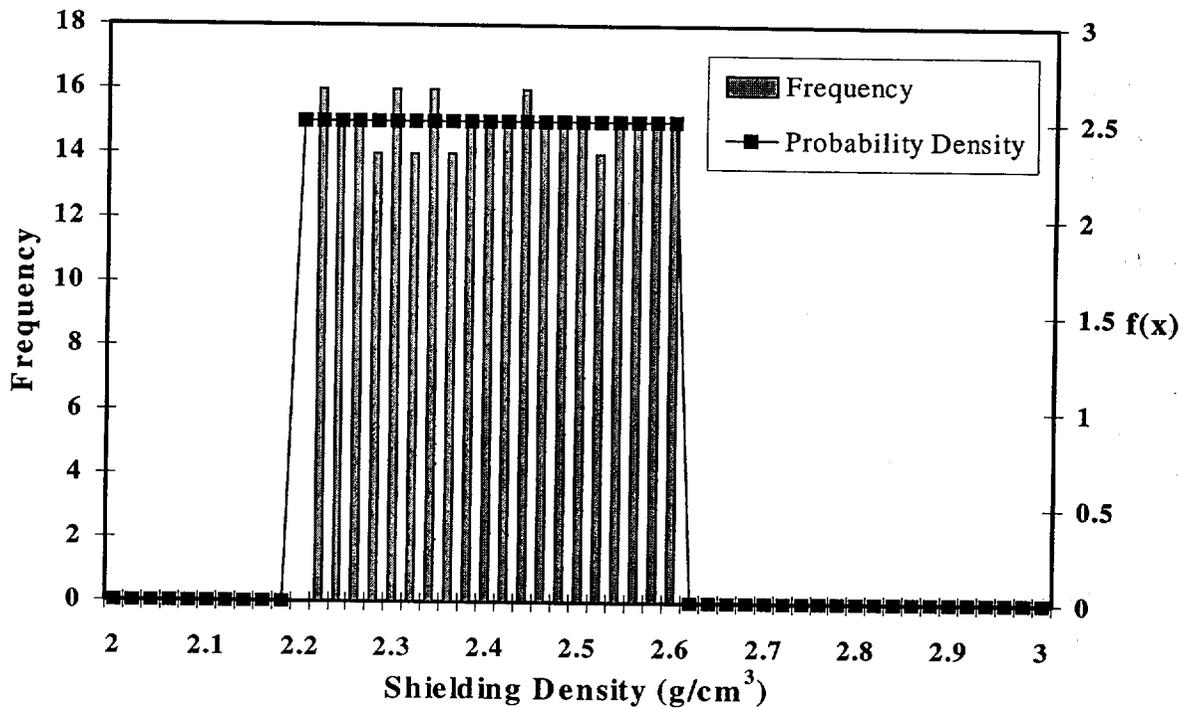


Figure B.37 Sampling Frequency and Probability Density of the Shielding Density

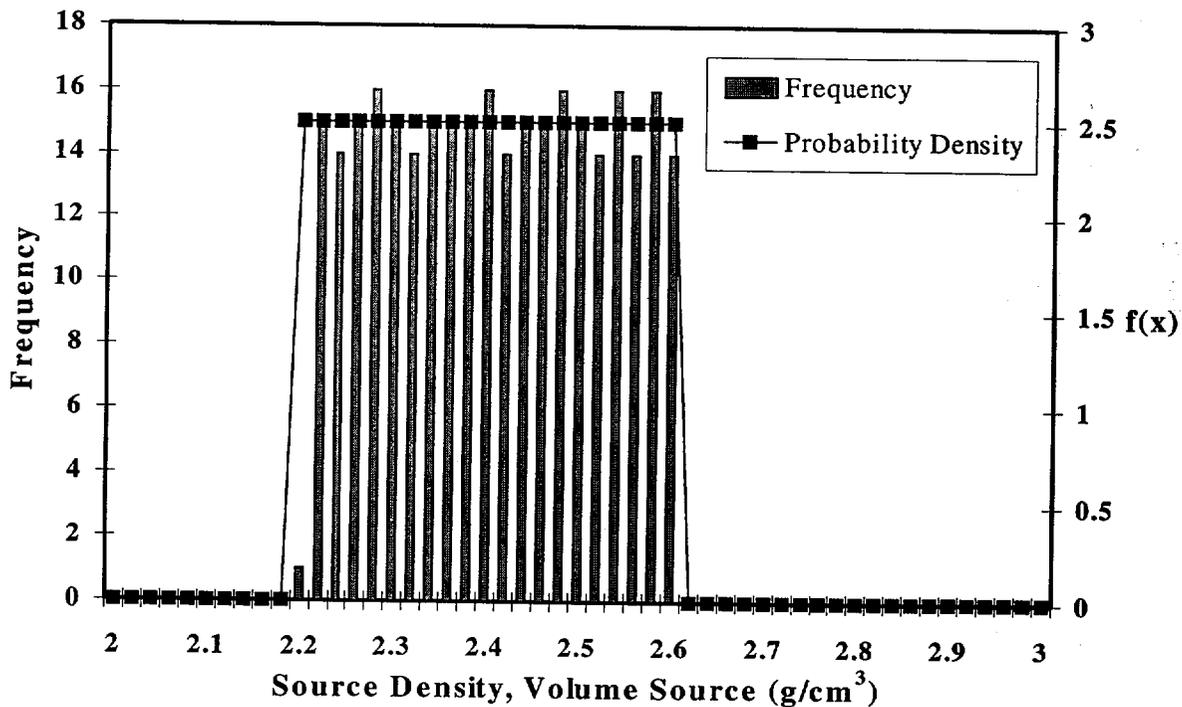


Figure B.38 Sampling Frequency and Probability Density of the Source Density, Volume Source

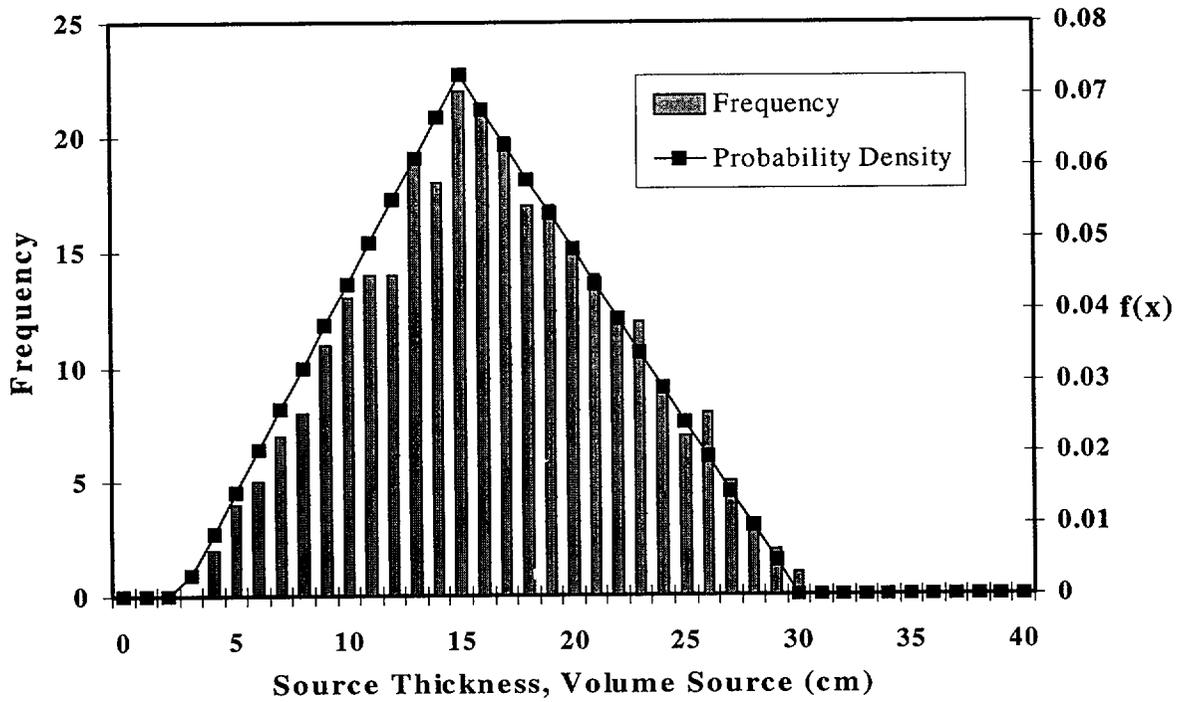


Figure B.39 Sampling Frequency and Probability Density of the Source Thickness, Volume Source

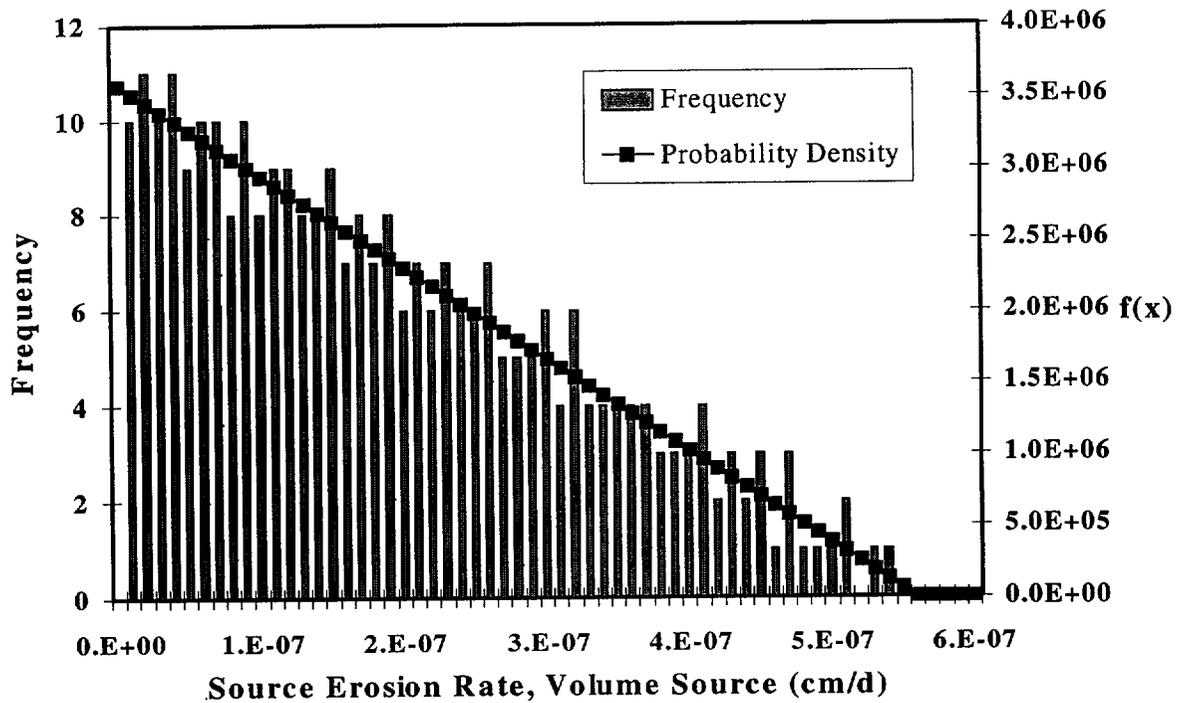


Figure B.40 Sampling Frequency and Probability Density of the Source Erosion Rate, Volume Source

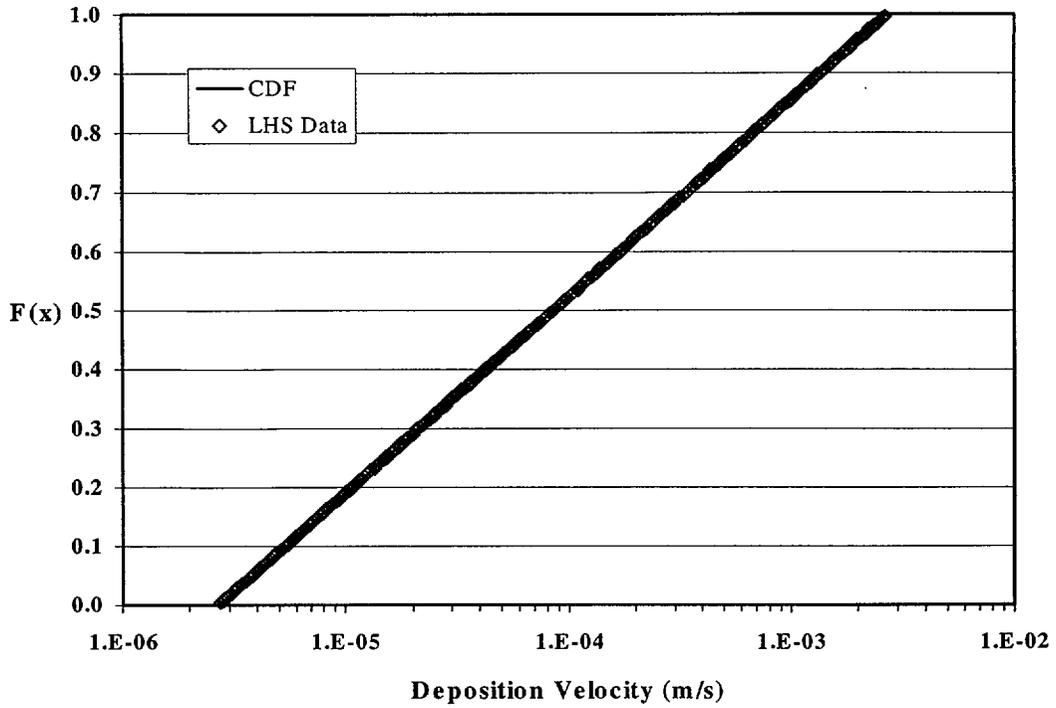


Figure B.41 Sampled Cumulative Probability and the Cumulative Distribution Function of the Deposition Velocity

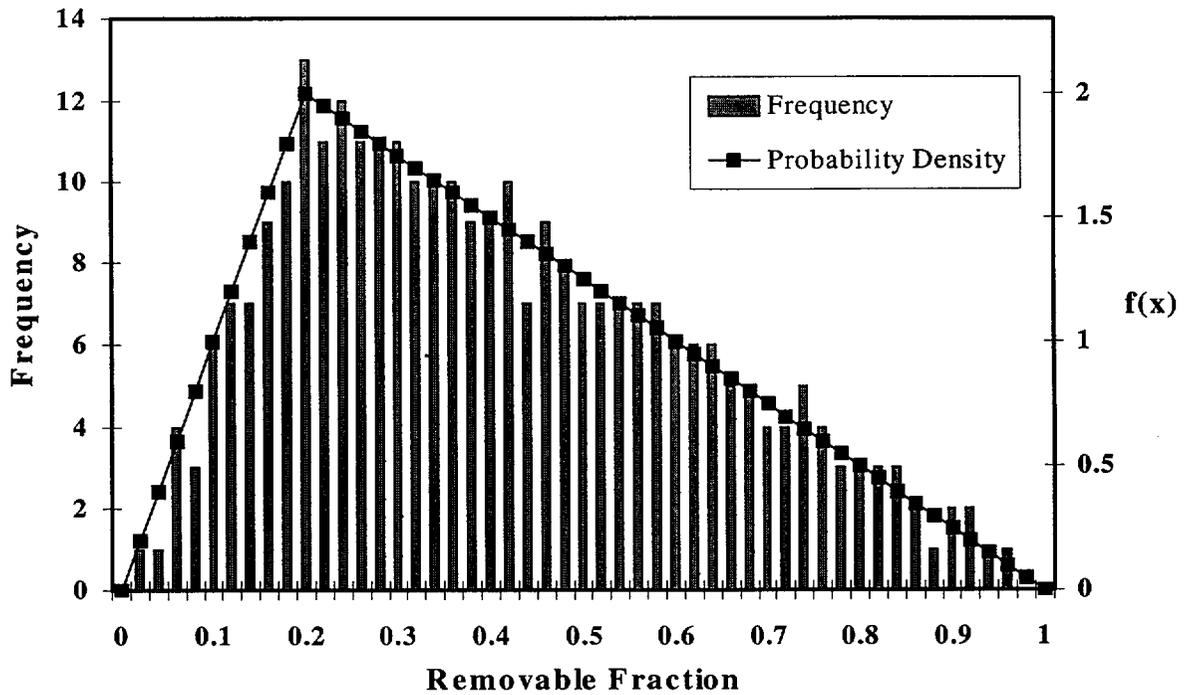


Figure B.42 Sampling Frequency and Probability Density of the Removable Fraction

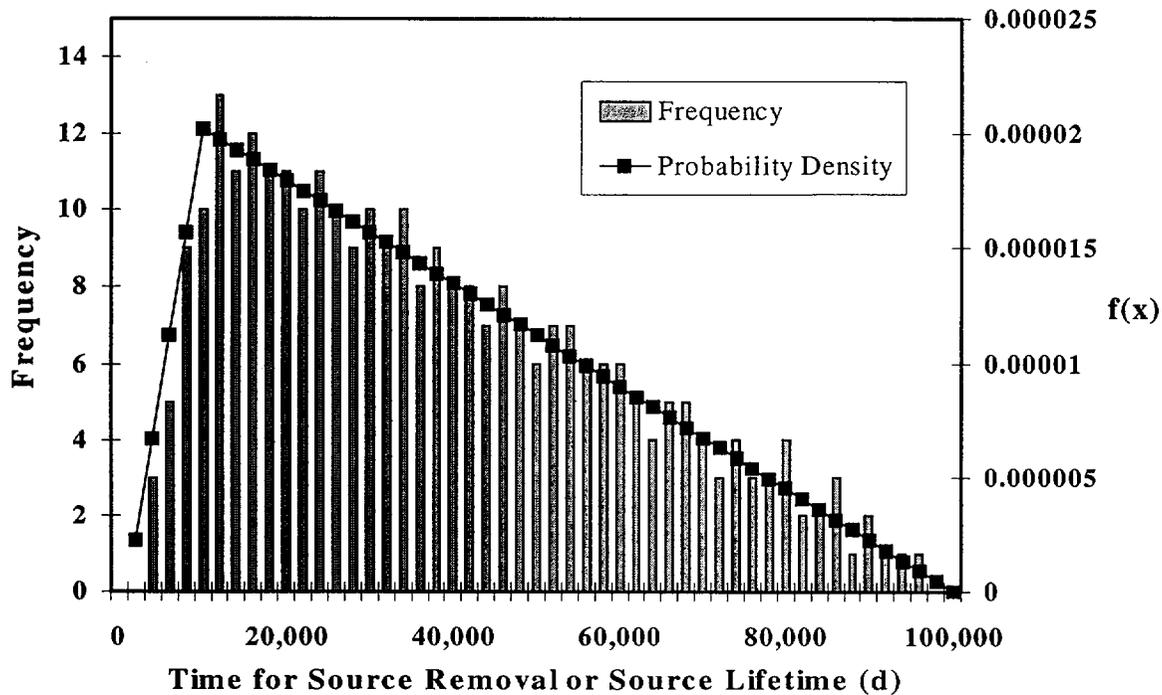


Figure B.43 Sampling Frequency and Probability Density of the Source Lifetime

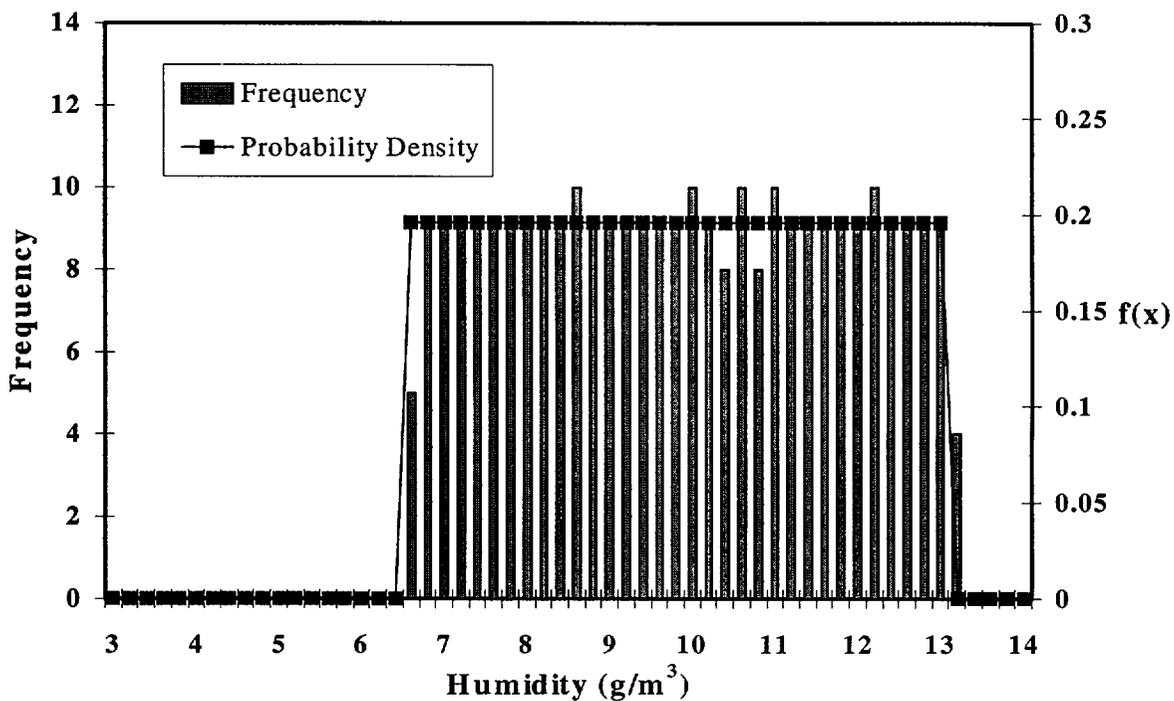


Figure B.44 Sampling Frequency and Probability Density of the Humidity

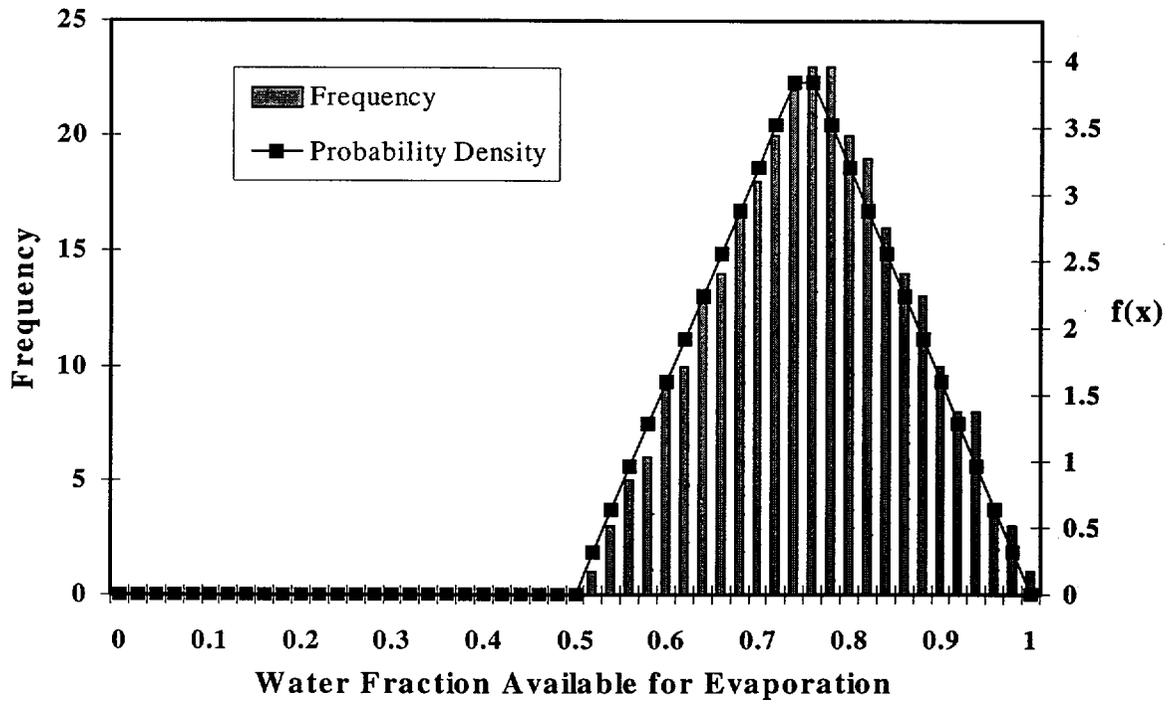


Figure B.45 Sampling Frequency and Probability Density of the Water Fraction Available for Evaporation

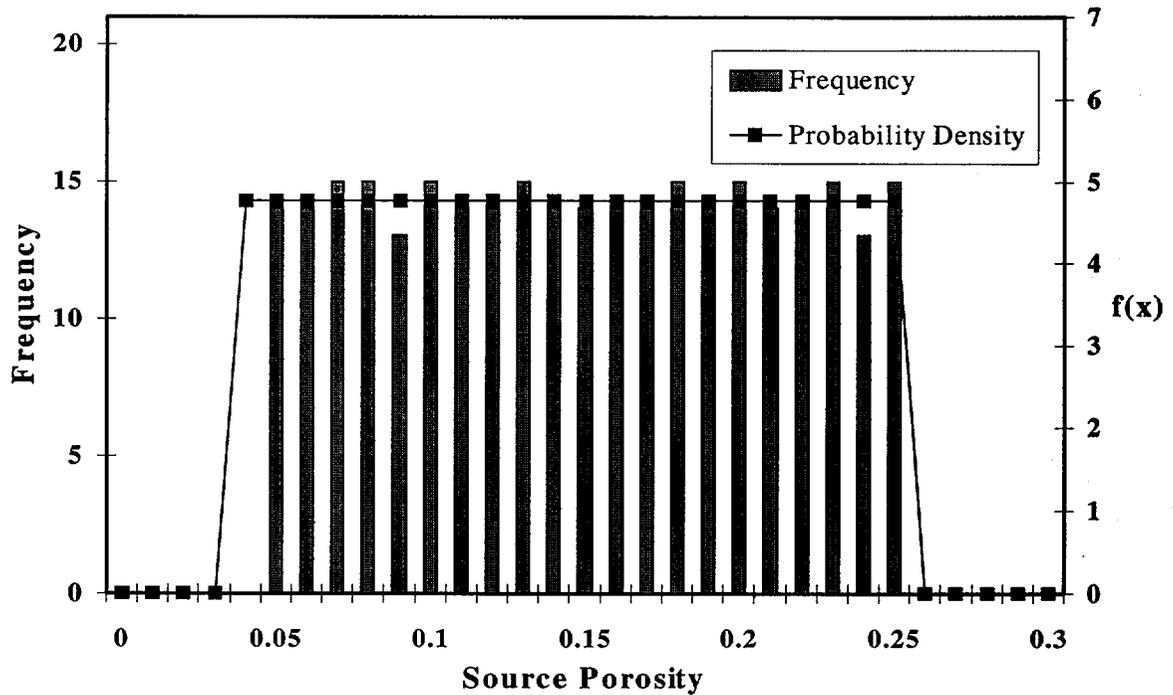


Figure B.46 Sampling Frequency and Probability Density of the Source Porosity

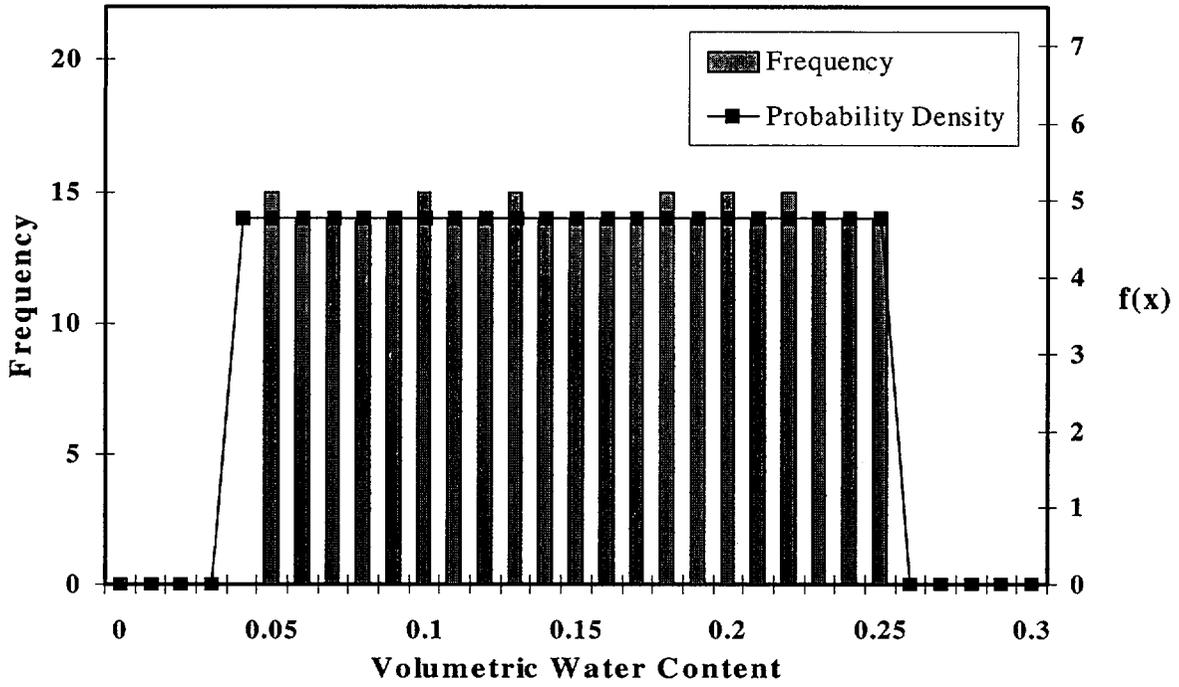


Figure B.47 Sampling Frequency and Probability Density of the Volumetric Water Content

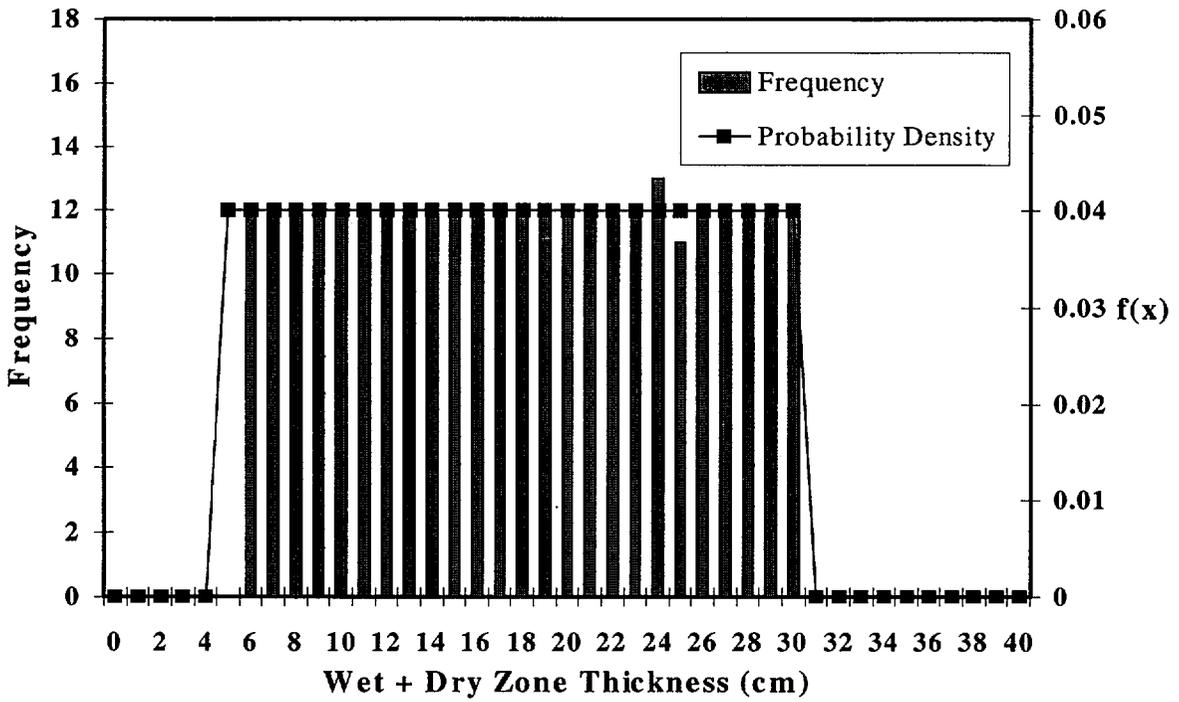


Figure B.48 Sampling Frequency and Probability Density of the Wet + Dry Zone Thickness

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Biwer, B.M., et al. "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes, Revision 1." Letter report prepared by Argonne National Laboratory, Argonne, Ill., for U.S. Nuclear Regulatory Commission, Washington, D.C. 2000.

Kamboj, S. et al. "Parameters and Parameter Types in RESRAD and RESRAD-BUILD Codes." Letter report prepared by Argonne National Laboratory, Argonne, Ill., for U.S. Nuclear Regulatory Commission, Washington, D.C. 1999.

APPENDIX C
SENSITIVITY ANALYSIS RESULTS

APPENDIX C

SENSITIVITY ANALYSIS RESULTS

This appendix contains the detailed sensitivity analysis results for both residential and building occupancy scenarios. Tables C.1 through C.3 list the sensitive parameters and most important pathways based on partial rank correlation coefficients for the three source configurations in the residential scenario.

Tables C.4 through C.9 list sensitive parameters for three source areas and most important pathways based on standardized rank regression coefficients in the building occupancy scenario for volume and area sources.

Table C.1 Four Most Sensitive Parameters Based on PRCC for a Source of 100-m² Area and 15-cm Thickness in the Residential Scenario

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Ac-227 | ext | SHF1 | 0.94 | DCACTC(1) | 0.41 | BRTF(89,1) | 0.4 | DM | -0.28 |
| Ag-108 | ext | SHF1 | 0.98 | DCACTC(1) | 0.42 | | | | |
| Ag-110 | ext | SHF1 | 0.98 | DCACTC(1) | 0.4 | | | | |
| Al-26 | ext | SHF1 | 0.96 | DCACTC(1) | 0.45 | | | | |
| Am-241 | plant + ext | SHF1 | 0.82 | BRTF(95,1) | 0.79 | DROOT | -0.69 | DM | -0.62 |
| Am-243 | ext | SHF1 | 0.98 | DROOT | -0.29 | | | | |
| Au-195 | ext | SHF1 | 0.93 | DCACTC(1) | 0.6 | | | | |
| Ba-133 | ext | SHF1 | 0.96 | DCACTC(1) | 0.47 | | | | |
| Bi-207 | ext | SHF1 | 0.9 | DCACTC(1) | 0.62 | | | | |
| C-14 | plant | DROOT | -0.73 | DMC | 0.38 | DCACTS(1) | -0.35 | DCACTU1(1) | -0.33 |
| Ca-41 | plant | BRTF(20,1) | 0.91 | DROOT | -0.78 | HCSZ | 0.32 | | |
| Ca-45 | plant | BRTF(20,1) | 0.97 | DROOT | -0.91 | | | | |
| Cd-109 | plant | BRTF(48,1) | 0.9 | DROOT | -0.73 | DCACTC(1) | 0.55 | SHF1 | 0.5 |
| Ce-141 | ext | SHF1 | 1 | | | | | | |
| Ce-144 | ext | SHF1 | 0.99 | | | | | | |
| Cf-252 | plant | BRTF(98,1) | 0.87 | DM | -0.78 | DROOT | -0.74 | MLINH | 0.39 |
| Cl-36 | plant | BRTF(17,1) | 0.95 | DROOT | -0.82 | DCACTC(1) | 0.74 | RUNOFF | 0.28 |
| Cm-243 | ext | SHF1 | 0.99 | BRTF(96,1) | 0.45 | DROOT | -0.39 | DM | -0.27 |
| Cm-244 | plant | BRTF(96,1) | 0.87 | DM | -0.8 | DROOT | -0.78 | SHF3 | 0.4 |
| Cm-246 | plant | BRTF(96,1) | 0.88 | DROOT | -0.79 | DM | -0.78 | WIND | -0.36 |
| Cm-247 | ext | SHF1 | 0.99 | BRTF(96,1) | 0.32 | VCZ | -0.31 | | |
| Cm-248 | plant | BRTF(96,1) | 0.89 | DROOT | -0.82 | DM | -0.81 | MLINH | 0.35 |
| Co-57 | ext | SHF1 | 0.98 | DCACTC(1) | 0.47 | | | | |
| Co-60 | ext | SHF1 | 0.97 | DCACTC(1) | 0.46 | | | | |
| Cs-134 | ext | SHF1 | 0.98 | DCACTC(1) | 0.37 | | | | |

C-4

Table C.1 Four Most Sensitive Parameters Based on PRCC for a Source of 100-m² Area and 15-cm Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Cs-135 | plant | BRTF(55,1) | 0.96 | DROOT | -0.88 | BRTF(55,2) | 0.4 | DM | -0.36 |
| Cs-137 | ext | SHF1 | 0.98 | DCACTC(1) | 0.38 | | | | |
| Eu-152 | ext | SHF1 | 0.95 | DCACTC(2) | 0.31 | | | | |
| Eu-154 | ext | SHF1 | 0.96 | DCACTC(1) | 0.44 | | | | |
| Eu-155 | ext | SHF1 | 0.97 | DCACTC(1) | 0.45 | | | | |
| Fe-55 | meat + plant | DM | -0.85 | BRTF(26,2) | 0.78 | BRTF(26,1) | 0.75 | DROOT | -0.53 |
| Fe-59 | ext | SHF1 | 0.99 | DCACTC(1) | 0.4 | | | | |
| Gd-152 | plant + inh | BRTF(64,1) | 0.7 | DM | -0.67 | MLINH | 0.59 | DROOT | -0.49 |
| Gd-153 | ext | SHF1 | 0.97 | DCACTC(1) | 0.43 | | | | |
| Ge-68 | ext | SHF1 | 0.9 | DCACTC(1) | 0.68 | | | | |
| H-3 | water + plant | DROOT | -0.73 | HCSZ | 0.46 | HGWT | 0.43 | H(1) | -0.42 |
| I-125 | ext | SHF1 | 0.85 | BRTF(53,1) | 0.69 | DCACTC(1) | 0.67 | DROOT | -0.55 |
| I-129 | water + plant | BRTF(53,1) | 0.6 | DROOT | -0.45 | DCACTC(1) | 0.41 | HCSZ | 0.36 |
| Ir-192 | ext | SHF1 | 0.96 | DCACTC(1) | 0.5 | | | | |
| K-40 | ext | SHF1 | 0.97 | DCACTC(1) | 0.6 | BRTF(19,1) | 0.5 | RUNOFF | 0.46 |
| Mn-54 | ext | SHF1 | 0.97 | DCACTC(1) | 0.47 | | | | |
| Na-22 | ext | SHF1 | 0.92 | DCACTC(1) | 0.57 | | | | |
| Nb-93 | ext + plant | SHF1 | 0.86 | BRTF(41,1) | 0.69 | DROOT | -0.54 | DCACTC(1) | 0.4 |
| Nb-94 | ext | SHF1 | 0.94 | DCACTC(1) | 0.49 | | | | |
| Nb-95 | ext | SHF1 | 0.99 | DCACTC(1) | 0.39 | | | | |
| Ni-59 | plant | BRTF(28,1) | 0.96 | DROOT | -0.9 | BRTF(28,3) | 0.39 | | |
| Ni-63 | plant | BRTF(28,1) | 0.96 | DROOT | -0.9 | BRTF(28,3) | 0.39 | | |
| Np-237 | plant + ext | BRTF(93,1) | 0.72 | SHF1 | 0.68 | DROOT | -0.55 | DCACTC(1) | 0.51 |
| Pa-231 | plant | BRTF(91,1) | 0.58 | DCACTC(2) | 0.57 | VCZ | -0.52 | DROOT | -0.49 |
| Pb-210 | plant | DROOT | -0.88 | BRTF(82,1) | 0.82 | BRTF(84,1) | 0.76 | DM | -0.27 |
| Pm-147 | ext + plant | SHF1 | 0.86 | BRTF(61,1) | 0.68 | DROOT | -0.61 | BCZ | -0.27 |
| Po-210 | plant | BRTF(84,1) | 0.96 | DROOT | -0.9 | DM | -0.36 | BRTF(84,2) | 0.3 |
| Pu-238 | plant | BRTF(94,1) | 0.88 | DM | -0.78 | DROOT | -0.77 | MLINH | 0.47 |

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**Table C.1 Four Most Sensitive Parameters Based on PRCC for a Source of 100-m² Area
and 15-cm Thickness in the Residential Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|------|------------|-------|------------|-------|------------|------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Pu-239 | plant | BRTF(94,1) | 0.88 | DM | -0.79 | DROOT | -0.77 | MLINH | 0.37 |
| Pu-240 | plant | BRTF(94,1) | 0.87 | DM | -0.79 | DROOT | -0.79 | MLINH | 0.41 |
| Pu-241 | plant | VCZ | -0.6 | SHF1 | 0.59 | DCACTC(1) | 0.51 | DROOT | -0.5 |
| Pu-242 | plant | BRTF(94,1) | 0.88 | DM | -0.82 | DROOT | -0.77 | MLINH | 0.38 |
| Pu-244 | ext | SHF1 | 0.99 | VCZ | -0.28 | | | | |
| Ra-226 | ext | SHF1 | 0.98 | BRTF(88,1) | 0.43 | DROOT | -0.42 | VCZ | -0.3 |
| Ra-228 | ext | SHF1 | 0.96 | VCZ | -0.47 | DROOT | -0.31 | BRTF(88,1) | 0.25 |
| Ru-106 | ext | SHF1 | 0.98 | DCACTC(1) | 0.36 | | | | |
| S-35 | plant + meat | BRTF(16,1) | 0.96 | DROOT | -0.85 | BRTF(16,2) | 0.75 | DCACTC(1) | 0.31 |
| Sb-124 | ext | SHF1 | 0.97 | DCACTC(1) | 0.44 | | | | |
| Sb-125 | ext | SHF1 | 0.95 | DCACTC(2) | 0.39 | | | | |
| Sc-46 | ext | SHF1 | 0.98 | DCACTC(1) | 0.38 | | | | |
| Se-75 | ext | SHF1 | 1 | | | | | | |
| Se-79 | plant | BRTF(34,1) | 0.96 | DROOT | -0.85 | BRTF(34,2) | 0.7 | | |
| Sm-147 | plant | BRTF(62,1) | 0.83 | DROOT | -0.64 | DM | -0.61 | MLINH | 0.41 |
| Sm-151 | plant | BRTF(62,1) | 0.89 | DROOT | -0.71 | DM | -0.55 | BRTF(62,2) | 0.33 |
| Sn-113 | ext | SHF1 | 0.98 | DCACTC(1) | 0.42 | | | | |
| Sr-85 | ext | SHF1 | 0.97 | DCACTC(1) | 0.58 | | | | |
| Sr-89 | plant | BRTF(38,1) | 0.93 | DROOT | -0.83 | SHF1 | 0.68 | DCACTC(1) | 0.25 |
| Sr-90 | plant | BRTF(38,1) | 0.95 | DROOT | -0.87 | DCACTC(1) | 0.35 | SHF1 | 0.25 |
| Ta-182 | ext | SHF1 | 0.95 | DCACTC(1) | 0.5 | | | | |
| Tc-99 | plant | BRTF(43,1) | 0.9 | DROOT | -0.8 | DCACTC(1) | 0.77 | RUNOFF | 0.38 |
| Te-125 | ext | SHF1 | 0.89 | BRTF(52,1) | 0.58 | DCACTC(1) | 0.57 | DROOT | -0.4 |
| Th-228 | ext | SHF1 | 0.98 | DCACTC(1) | 0.31 | | | | |
| Th-229 | ext | SHF1 | 0.98 | DCACTC(1) | 0.33 | | | | |
| Th-230 | ext | VCZ | -0.9 | DCACTC(4) | 0.57 | SHF1 | 0.56 | | |
| Th-232 | ext | SHF1 | 0.83 | VCZ | -0.72 | DCACTC(3) | 0.5 | | |
| Tl-204 | plant | BRTF(81,1) | 0.85 | SHF1 | 0.67 | DROOT | -0.67 | DCACTC(1) | 0.46 |

Table C.1 Four Most Sensitive Parameters Based on PRCC for a Source of 100-m² Area and 15-cm Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|------|-----------|-------|------------|-------|-----------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| U-232 | ext | SHF1 | 0.72 | DCACTC(2) | 0.72 | VCZ | -0.37 | | |
| U-233 | ext + plant | DCACTC(2) | 0.48 | VCZ | -0.46 | BRTF(92,1) | 0.4 | DROOT | -0.35 |
| U-234 | plant | BRTF(92,1) | 0.61 | DROOT | -0.59 | DM | -0.48 | VCZ | -0.31 |
| U-235 | ext | SHF1 | 0.95 | DCACTC(3) | 0.57 | | | | |
| U-236 | plant | BRTF(92,1) | 0.65 | DROOT | -0.49 | DM | -0.44 | MLINH | 0.36 |
| U-238 | ext | SHF1 | 0.9 | DCACTC(6) | 0.48 | | | | |
| Zn-65 | ext | SHF1 | 0.92 | DCACTC(1) | 0.52 | | | | |
| Zr-93 | water | HCSZ | 0.71 | HGWT | 0.66 | H(1) | -0.61 | | |
| Zr-95 | ext | SHF1 | 0.99 | | | | | | |

^a ext = external, fish = fish ingestion, inh = inhalation, meat = meat ingestion, plant = plant ingestion, water = water ingestion.

Table C.2 Four Most Sensitive Parameters Based on PRCC for a Source of 2,400-m² Area and 15-cm Thickness in the Residential Scenario

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Ac-227 | plant | SHF1 | 0.79 | BRTF(89,1) | 0.76 | DROOT | -0.58 | DM | -0.41 |
| Ag-108 | ext | SHF1 | 0.98 | DCACTC(1) | 0.43 | | | | |
| Ag-110 | ext | SHF1 | 0.98 | DCACTC(1) | 0.4 | | | | |
| Al-26 | ext | SHF1 | 0.96 | DCACTC(1) | 0.46 | | | | |
| Am-241 | plant | BRTF(95,1) | 0.9 | DROOT | -0.79 | DM | -0.76 | SHF1 | 0.35 |
| Am-243 | ext | SHF1 | 0.92 | BRTF(95,1) | 0.66 | DROOT | -0.58 | DM | -0.36 |
| Au-195 | ext | SHF1 | 0.92 | DCACTC(1) | 0.6 | | | | |
| Ba-133 | ext | SHF1 | 0.96 | DCACTC(1) | 0.48 | | | | |
| Bi-207 | ext | SHF1 | 0.91 | DCACTC(1) | 0.62 | | | | |
| C-14 | plant | DROOT | -0.83 | DMC | 0.48 | WIND | -0.46 | DCACTU1(1) | -0.3 |
| Ca-41 | plant | BRTF(20,1) | 0.96 | DROOT | -0.86 | DCACTC(1) | 0.25 | | |
| Ca-45 | plant | BRTF(20,1) | 0.97 | DROOT | -0.91 | | | | |
| Cd-109 | plant | BRTF(48,1) | 0.95 | DROOT | -0.84 | DCACTC(1) | 0.48 | | |
| Ce-141 | ext | SHF1 | 1 | | | | | | |
| Ce-144 | ext | SHF1 | 0.99 | | | | | | |
| Cf-252 | plant | BRTF(98,1) | 0.92 | DROOT | -0.8 | DM | -0.77 | | |
| Cl-36 | plant | BRTF(17,1) | 0.95 | DROOT | -0.83 | DCACTC(1) | 0.73 | BRTF(17,2) | 0.38 |
| Cm-243 | ext | SHF1 | 0.91 | BRTF(96,1) | 0.72 | DROOT | -0.62 | DM | -0.35 |
| Cm-244 | plant | BRTF(96,1) | 0.9 | DROOT | -0.83 | DM | -0.78 | | |
| Cm-246 | plant | BRTF(96,1) | 0.91 | DROOT | -0.84 | DM | -0.78 | | |
| Cm-247 | ext | SHF1 | 0.95 | BRTF(96,1) | 0.61 | DROOT | -0.53 | DM | -0.27 |
| Cm-248 | plant | BRTF(96,1) | 0.92 | DROOT | -0.87 | DM | -0.81 | | |
| Co-57 | ext | SHF1 | 0.98 | DCACTC(1) | 0.48 | | | | |
| Co-60 | ext | SHF1 | 0.97 | DCACTC(1) | 0.48 | | | | |
| Cs-134 | ext | SHF1 | 0.98 | DCACTC(1) | 0.39 | BRTF(55,1) | 0.36 | | |

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Table C.2 Four Most Sensitive Parameters Based on PRCC for a Source of 2,400-m² Area and 15-cm Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Cs-135 | plant | BRTF(55,1) | 0.95 | DROOT | -0.85 | BRTF(55,2) | 0.57 | DM | -0.5 |
| Cs-137 | ext | SHF1 | 0.97 | BRTF(55,1) | 0.49 | DCACTC(1) | 0.36 | DROOT | -0.35 |
| Eu-152 | ext | SHF1 | 0.96 | DCACTC(2) | 0.32 | | | | |
| Eu-154 | ext | SHF1 | 0.96 | DCACTC(1) | 0.44 | | | | |
| Eu-155 | ext | SHF1 | 0.97 | DCACTC(1) | 0.45 | | | | |
| Fe-55 | meat | DM | -0.89 | BRTF(26,2) | 0.86 | BRTF(26,1) | 0.66 | DROOT | -0.39 |
| Fe-59 | ext | SHF1 | 0.99 | DCACTC(1) | 0.39 | | | | |
| Gd-152 | plant | BRTF(64,1) | 0.85 | DROOT | -0.64 | DM | -0.61 | BRTF(64,2) | 0.52 |
| Gd-153 | ext | SHF1 | 0.98 | DCACTC(1) | 0.44 | | | | |
| Ge-68 | ext | SHF1 | 0.89 | DCACTC(1) | 0.67 | | | | |
| H-3 | plant | DROOT | -0.88 | RUNOFF | 0.6 | HCSZ | 0.35 | H(1) | -0.29 |
| I-125 | plant | BRTF(53,1) | 0.88 | DROOT | -0.74 | DCACTC(1) | 0.54 | DM | -0.53 |
| I-129 | water + plant | BRTF(53,1) | 0.7 | DROOT | -0.51 | DCACTC(1) | 0.47 | HCSZ | 0.31 |
| Ir-192 | ext | SHF1 | 0.96 | DCACTC(1) | 0.51 | | | | |
| K-40 | ext + plant | SHF1 | 0.86 | BRTF(19,1) | 0.82 | DROOT | -0.67 | DCACTC(1) | 0.37 |
| Mn-54 | ext | SHF1 | 0.97 | DCACTC(1) | 0.48 | | | | |
| Na-22 | ext | SHF1 | 0.92 | DCACTC(1) | 0.58 | | | | |
| Nb-93 | plant | BRTF(41,1) | 0.91 | DROOT | -0.78 | SHF1 | 0.56 | DCACTC(1) | 0.29 |
| Nb-94 | ext | SHF1 | 0.94 | DCACTC(1) | 0.5 | | | | |
| Nb-95 | ext | SHF1 | 0.99 | DCACTC(1) | 0.39 | | | | |
| Ni-59 | plant | BRTF(28,1) | 0.95 | DROOT | -0.87 | BRTF(28,3) | 0.6 | DM | -0.36 |
| Ni-63 | plant | BRTF(28,1) | 0.95 | DROOT | -0.87 | BRTF(28,3) | 0.6 | DM | -0.36 |
| Np-237 | plant | BRTF(93,1) | 0.86 | DROOT | -0.74 | DCACTC(1) | 0.39 | SHF1 | 0.31 |
| Pa-231 | plant | BRTF(91,1) | 0.89 | DROOT | -0.79 | VCZ | -0.39 | DCACTC(2) | 0.34 |
| Pb-210 | plant | DROOT | -0.88 | BRTF(82,1) | 0.8 | BRTF(84,1) | 0.75 | DM | -0.33 |
| Pm-147 | plant | BRTF(61,1) | 0.85 | DROOT | -0.72 | DM | -0.55 | BRTF(61,2) | 0.53 |
| Po-210 | plant | BRTF(84,1) | 0.95 | DROOT | -0.87 | BRTF(84,2) | 0.49 | DM | -0.43 |
| Pu-238 | plant | BRTF(94,1) | 0.91 | DROOT | -0.82 | DM | -0.76 | | |

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Table C.2 Four Most Sensitive Parameters Based on PRCC for a Source of 2,400-m² Area and 15-cm Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Pu-239 | plant | BRTF(94,1) | 0.9 | DROOT | -0.8 | DM | -0.78 | | |
| Pu-240 | plant | BRTF(94,1) | 0.9 | DROOT | -0.83 | DM | -0.77 | | |
| Pu-241 | plant | DROOT | -0.77 | DM | -0.66 | BRTF(94,1) | 0.63 | BRTF(95,1) | 0.62 |
| Pu-242 | plant | BRTF(94,1) | 0.92 | DROOT | -0.83 | DM | -0.82 | | |
| Pu-244 | ext | SHF1 | 0.98 | BRTF(94,1) | 0.36 | DROOT | -0.34 | | |
| Ra-226 | ext + plant | SHF1 | 0.86 | BRTF(88,1) | 0.73 | DROOT | -0.67 | VCZ | -0.33 |
| Ra-228 | ext + plant | SHF1 | 0.89 | BRTF(88,1) | 0.71 | DROOT | -0.68 | VCZ | -0.32 |
| Ru-106 | ext | SHF1 | 0.97 | BRTF(44,1) | 0.4 | DCACTC(1) | 0.36 | DROOT | -0.3 |
| S-35 | meat | BRTF(16,1) | 0.95 | BRTF(16,2) | 0.84 | DROOT | -0.84 | DCACTC(1) | 0.28 |
| Sb-124 | ext | SHF1 | 0.98 | DCACTC(1) | 0.44 | | | | |
| Sb-125 | ext | SHF1 | 0.96 | DCACTC(2) | 0.41 | | | | |
| Sc-46 | ext | SHF1 | 0.98 | DCACTC(1) | 0.38 | | | | |
| Se-75 | ext | SHF1 | 0.98 | BRTF(34,1) | 0.62 | DROOT | -0.46 | BRTF(34,2) | 0.31 |
| Se-79 | meat | BRTF(34,1) | 0.94 | DROOT | -0.81 | BRTF(34,2) | 0.81 | DM | -0.29 |
| Sm-147 | plant | BRTF(62,1) | 0.88 | DROOT | -0.67 | DM | -0.58 | BRTF(62,2) | 0.58 |
| Sm-151 | plant | BRTF(62,1) | 0.88 | DROOT | -0.68 | BRTF(62,2) | 0.59 | DM | -0.56 |
| Sn-113 | ext | SHF1 | 0.96 | BRTF(50,1) | 0.47 | DCACTC(1) | 0.38 | DROOT | -0.31 |
| Sr-85 | ext | SHF1 | 0.97 | DCACTC(1) | 0.58 | RUNOFF | 0.26 | | |
| Sr-89 | plant | BRTF(38,1) | 0.97 | DROOT | -0.91 | | | | |
| Sr-90 | plant | BRTF(38,1) | 0.96 | DROOT | -0.89 | DCACTC(1) | 0.33 | | |
| Ta-182 | ext | SHF1 | 0.95 | DCACTC(1) | 0.5 | | | | |
| Tc-99 | plant | BRTF(43,1) | 0.94 | DCACTC(1) | 0.87 | DROOT | -0.86 | RUNOFF | 0.44 |
| Te-125 | plant | BRTF(52,1) | 0.88 | DROOT | -0.73 | SHF1 | 0.69 | DCACTC(1) | 0.44 |
| Th-228 | ext | SHF1 | 0.98 | DCACTC(1) | 0.32 | | | | |
| Th-229 | ext | SHF1 | 0.94 | BRTF(90,1) | 0.63 | DROOT | -0.53 | DM | -0.36 |
| Th-230 | ext | VCZ | -0.89 | DCACTC(4) | 0.51 | SHF1 | 0.44 | DROOT | -0.33 |
| Th-232 | ext | SHF1 | 0.77 | VCZ | -0.64 | DCACTC(3) | 0.47 | BRTF(88,1) | 0.44 |
| Tl-204 | plant | BRTF(81,1) | 0.94 | DROOT | -0.81 | DCACTC(1) | 0.45 | BRTF(81,2) | 0.39 |

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Table C.2 Four Most Sensitive Parameters Based on PRCC for a Source of 2,400-m² Area and 15-cm Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|------|------------|-------|------------|-------|-----------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| U-232 | ext | DCACTC(2) | 0.72 | SHF1 | 0.72 | VCZ | -0.33 | | |
| U-233 | plant | BRTF(92,1) | 0.67 | DROOT | -0.58 | DM | -0.45 | DCACTC(2) | 0.29 |
| U-234 | plant | BRTF(92,1) | 0.79 | DROOT | -0.73 | DM | -0.53 | | |
| U-235 | ext | SHF1 | 0.94 | DCACTC(3) | 0.59 | BRTF(92,1) | 0.31 | | |
| U-236 | plant | BRTF(92,1) | 0.76 | DROOT | -0.63 | DM | -0.45 | DCACTC(4) | 0.28 |
| U-238 | ext + plant | SHF1 | 0.81 | BRTF(92,1) | 0.52 | DROOT | -0.4 | DCACTC(6) | 0.38 |
| Zn-65 | ext | SHF1 | 0.87 | BRTF(30,1) | 0.52 | DCACTC(1) | 0.48 | DROOT | -0.42 |
| Zr-93 | water | HCSZ | 0.71 | HGWT | 0.64 | H(1) | -0.64 | VCZ | -0.25 |
| Zr-95 | ext | SHF1 | 0.99 | | | | | | |

^a ext = external, fish = fish ingestion, inh = inhalation, meat = meat ingestion, plant = plant ingestion, water = water ingestion.

**Table C.3 Four Most Sensitive Parameters Based on PRCC for a Source of 10,000-m²
Area and 2-m Thickness in the Residential Scenario**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Ac-227 | plant | BRTF(89,1) | 0.99 | SHF1 | 0.77 | DROOT | -0.75 | | |
| Ag-108 | ext | SHF1 | 1 | DCACTC(1) | 0.25 | | | | |
| Ag-110 | ext | SHF1 | 1 | | | | | | |
| Al-26 | ext | SHF1 | 1 | DCACTC(1) | 0.3 | | | | |
| Am-241 | plant | BRTF(95,1) | 0.99 | DROOT | -0.88 | | | | |
| Am-243 | plant | BRTF(95,1) | 0.96 | SHF1 | 0.79 | DROOT | -0.61 | | |
| Au-195 | ext + plant | SHF1 | 0.92 | BRTF(79,1) | 0.85 | DROOT | -0.28 | | |
| Ba-133 | ext | SHF1 | 1 | BRTF(56,1) | 0.38 | DCACTC(1) | 0.32 | | |
| Bi-207 | ext | SHF1 | 0.99 | BRTF(83,1) | 0.57 | DCACTC(1) | 0.38 | | |
| C-14 | plant | WIND | -0.71 | DROOT | -0.69 | DMC | 0.35 | DCACTS(1) | -0.25 |
| Ca-41 | plant | BRTF(20,1) | 0.97 | DROOT | -0.61 | BBIO(20,1) | 0.29 | HCSZ | 0.28 |
| Ca-45 | plant | BRTF(20,1) | 0.99 | DROOT | -0.86 | BRTF(20,3) | 0.29 | | |
| Cd-109 | plant | BRTF(48,1) | 0.99 | DROOT | -0.83 | BRTF(48,3) | 0.4 | | |
| Ce-141 | ext | SHF1 | 1 | BRTF(58,1) | 0.6 | | | | |
| Ce-144 | ext | SHF1 | 0.99 | BRTF(58,1) | 0.75 | | | | |
| Cf-252 | plant | BRTF(98,1) | 0.99 | DROOT | -0.9 | | | | |
| Cl-36 | meat | BRTF(17,1) | 0.99 | BRTF(17,2) | 0.78 | DROOT | -0.71 | BRTF(17,3) | 0.42 |
| Cm-243 | plant | BRTF(96,1) | 0.97 | SHF1 | 0.8 | DROOT | -0.71 | BRTF(95,3) | -0.18 |
| Cm-244 | plant | BRTF(96,1) | 0.99 | DROOT | -0.88 | | | | |
| Cm-246 | plant | BRTF(96,1) | 0.99 | DROOT | -0.89 | | | | |
| Cm-247 | plant | BRTF(96,1) | 0.93 | SHF1 | 0.87 | DROOT | -0.58 | | |
| Cm-248 | plant | BRTF(96,1) | 0.99 | DROOT | -0.89 | | | | |
| Co-57 | ext | SHF1 | 0.96 | BRTF(27,1) | 0.77 | BRTF(27,2) | 0.5 | DROOT | -0.25 |
| Co-60 | ext | SHF1 | 0.97 | BRTF(27,1) | 0.74 | BRTF(27,2) | 0.47 | | |

C-12

Table C.3 Four Most Sensitive Parameters Based on PRCC for a Source of 10,000-m² Area and 2-m Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Cs-134 | ext | SHF1 | 0.92 | BRTF(55,1) | 0.87 | DROOT | -0.35 | BRTF(55,2) | 0.3 |
| Cs-135 | meat | BRTF(55,1) | 0.99 | BRTF(55,2) | 0.8 | DROOT | -0.77 | BRTF(55,3) | 0.37 |
| Cs-137 | plant + ext | BRTF(55,1) | 0.91 | SHF1 | 0.88 | DROOT | -0.44 | BRTF(55,2) | 0.38 |
| Eu-152 | ext | SHF1 | 1 | DCACTC(2) | 0.33 | | | | |
| Eu-154 | ext | SHF1 | 1 | DCACTC(1) | 0.26 | | | | |
| Eu-155 | ext | SHF1 | 1 | BRTF(63,1) | 0.43 | DCACTC(1) | 0.26 | | |
| Fe-55 | meat | BRTF(26,2) | 0.93 | BRTF(26,1) | 0.88 | DROOT | -0.34 | | |
| Fe-59 | ext | SHF1 | 1 | | | | | | |
| Gd-152 | plant | BRTF(64,1) | 0.97 | BRTF(64,2) | 0.74 | DROOT | -0.54 | | |
| Gd-153 | ext | SHF1 | 1 | BRTF(64,1) | 0.33 | DCACTC(1) | 0.27 | | |
| Ge-68 | ext + meat | SHF1 | 0.88 | BRTF(32,1) | 0.8 | BRTF(32,2) | 0.66 | DROOT | -0.26 |
| H-3 | plant | DROOT | -0.87 | RUNOFF | 0.67 | HCCZ | 0.57 | DCACTC(1) | -0.57 |
| I-125 | plant + meat | BRTF(53,1) | 0.98 | BRTF(53,2) | 0.8 | DROOT | -0.75 | BRTF(53,3) | 0.47 |
| I-129 | meat + water | BRTF(53,1) | 0.85 | BRTF(53,2) | 0.4 | DROOT | -0.38 | HCSZ | 0.34 |
| Ir-192 | ext | SHF1 | 1 | BRTF(77,1) | 0.61 | DCACTC(1) | 0.26 | | |
| K-40 | plant | BRTF(19,1) | 0.98 | DROOT | -0.67 | SHF1 | 0.62 | BRTF(19,3) | 0.25 |
| Mn-54 | ext | SHF1 | 0.99 | BRTF(25,1) | 0.77 | DROOT | -0.27 | | |
| Na-22 | ext | SHF1 | 0.98 | BRTF(11,1) | 0.74 | DCACTC(1) | 0.28 | | |
| Nb-93 | plant | BRTF(41,1) | 0.99 | DROOT | -0.86 | SHF1 | 0.32 | | |
| Nb-94 | ext | SHF1 | 1 | DCACTC(1) | 0.33 | | | | |
| Nb-95 | ext | SHF1 | 1 | BRTF(41,1) | 0.31 | DCACTC(1) | 0.28 | | |
| Ni-59 | plant | BRTF(28,1) | 0.97 | BRTF(28,3) | 0.8 | DROOT | -0.69 | BRTF(28,2) | 0.36 |
| Ni-63 | plant | BRTF(28,1) | 0.97 | BRTF(28,3) | 0.8 | DROOT | -0.69 | BRTF(28,2) | 0.36 |
| Np-237 | plant | BRTF(93,1) | 0.92 | DROOT | -0.46 | HCSZ | 0.31 | | |
| Pa-231 | plant | BRTF(91,1) | 0.96 | DROOT | -0.66 | BRTF(89,1) | 0.53 | | |
| Pb-210 | plant | BRTF(82,1) | 0.88 | BRTF(84,1) | 0.85 | DROOT | -0.67 | BRTF(84,2) | 0.26 |
| Pm-147 | plant | BRTF(61,1) | 0.96 | BRTF(61,2) | 0.75 | DROOT | -0.58 | | |
| Po-210 | plant | BRTF(84,1) | 0.99 | DROOT | -0.8 | BRTF(84,2) | 0.68 | | |

C-13

**Table C.3 Four Most Sensitive Parameters Based on PRCC for a Source of 10,000-m²
Area and 2-m Thickness in the Residential Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Pu-238 | plant | BRTF(94,1) | 0.99 | DROOT | -0.88 | | | | |
| Pu-239 | plant | BRTF(94,1) | 0.99 | DROOT | -0.89 | | | | |
| Pu-240 | plant | BRTF(94,1) | 0.99 | DROOT | -0.88 | | | | |
| Pu-241 | plant | BRTF(95,1) | 0.85 | BRTF(94,1) | 0.69 | DROOT | -0.56 | | |
| Pu-242 | plant | BRTF(94,1) | 0.99 | DROOT | -0.87 | | | | |
| Pu-244 | ext | SHF1 | 0.97 | BRTF(94,1) | 0.85 | DROOT | -0.42 | | |
| Ra-226 | plant | BRTF(88,1) | 0.89 | DROOT | -0.67 | BRTF(82,1) | 0.61 | BRTF(84,1) | 0.6 |
| Ra-228 | plant | BRTF(88,1) | 0.97 | DROOT | -0.74 | SHF1 | 0.74 | | |
| Ru-106 | ext + plant | SHF1 | 0.94 | BRTF(44,1) | 0.86 | DROOT | -0.38 | | |
| S-35 | meat | BRTF(16,1) | 0.97 | BRTF(16,2) | 0.93 | DROOT | -0.57 | | |
| Sb-124 | ext | SHF1 | 1 | BRTF(51,1) | 0.32 | DCACTC(1) | 0.31 | | |
| Sb-125 | ext | SHF1 | 1 | BRTF(52,1) | 0.45 | DCACTC(2) | 0.29 | | |
| Sc-46 | ext | SHF1 | 1 | | | | | | |
| Se-75 | meat | BRTF(34,1) | 0.9 | SHF1 | 0.8 | BRTF(34,2) | 0.72 | DROOT | -0.35 |
| Se-79 | meat | BRTF(34,1) | 0.97 | BRTF(34,2) | 0.91 | DROOT | -0.58 | BRTF(34,3) | 0.33 |
| Sm-147 | plant | BRTF(62,1) | 0.97 | BRTF(62,2) | 0.75 | DROOT | -0.53 | | |
| Sm-151 | plant | BRTF(62,1) | 0.97 | BRTF(62,2) | 0.76 | DROOT | -0.54 | | |
| Sn-113 | ext + plant | SHF1 | 0.89 | BRTF(50,1) | 0.88 | DROOT | -0.33 | BRTF(50,2) | 0.28 |
| Sr-85 | ext | SHF1 | 0.97 | BRTF(38,1) | 0.8 | DROOT | -0.28 | | |
| Sr-89 | plant | BRTF(38,1) | 0.99 | DROOT | -0.84 | BRTF(38,2) | 0.43 | | |
| Sr-90 | plant | BRTF(38,1) | 0.99 | DROOT | -0.84 | BRTF(38,2) | 0.43 | | |
| Ta-182 | ext | SHF1 | 1 | DCACTC(1) | 0.34 | | | | |
| Tc-99 | plant | BRTF(43,1) | 0.99 | DROOT | -0.84 | DCACTC(1) | 0.4 | EVAPTR | 0.25 |
| Te-125 | plant | BRTF(52,1) | 0.99 | DROOT | -0.78 | BRTF(52,2) | 0.65 | SHF1 | 0.37 |
| Th-228 | ext | SHF1 | 1 | BRTF(90,1) | 0.7 | | | | |
| Th-229 | plant | BRTF(90,1) | 0.95 | SHF1 | 0.86 | DROOT | -0.57 | | |
| Th-230 | plant | VCZ | -0.79 | DROOT | -0.53 | DCACTC(4) | 0.49 | BRTF(88,1) | 0.47 |
| Th-232 | plant | BRTF(88,1) | 0.93 | SHF1 | 0.66 | DROOT | -0.6 | BRTF(90,1) | 0.26 |

Table C.3 Four Most Sensitive Parameters Based on PRCC for a Source of 10,000-m² Area and 2-m Thickness in the Residential Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|------------|-------|------------|-------|------------|-------|------------|-------|
| | | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC | Parameter | PRCC |
| Tl-204 | plant + meat | BRTF(81,1) | 0.98 | BRTF(81,2) | 0.82 | DROOT | -0.67 | | |
| U-232 | ext | SHF1 | 0.92 | DCACTC(2) | 0.54 | BRTF(92,1) | 0.48 | DROOT | -0.32 |
| U-233 | plant | BRTF(92,1) | 0.78 | DROOT | -0.4 | DCACTC(2) | 0.38 | VCZ | -0.32 |
| U-234 | water + plant | BRTF(92,1) | 0.91 | DROOT | -0.58 | DCACTU1(5) | -0.29 | | |
| U-235 | plant | SHF1 | 0.73 | BRTF(92,1) | 0.65 | BRTF(91,1) | 0.46 | DCACTC(3) | 0.42 |
| U-236 | plant | BRTF(92,1) | 0.93 | DROOT | -0.5 | | | | |
| U-238 | plant | BRTF(92,1) | 0.92 | SHF1 | 0.65 | DROOT | -0.43 | | |
| Zn-65 | meat | BRTF(30,1) | 0.97 | SHF1 | 0.75 | DROOT | -0.64 | BRTF(30,2) | 0.63 |
| Zr-93 | water | H(1) | -0.74 | HCSZ | 0.7 | HGWT | 0.63 | FR9 | 0.47 |
| Zr-95 | ext | SHF1 | 1 | | | | | | |

^a ext = external, fish = fish ingestion, meat = meat ingestion, plant = plant ingestion, water = water ingestion.

Table C.4 First Four Most Sensitive Parameters Based on SRRC for a 36-m² Volume Source in the Building Occupancy Scenario

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | ext | DSTH | -0.94 | EROS0 | 0.14 | AREA | -0.14 | | |
| Ag-108 | ext | DSTH | -0.99 | | | | | | |
| Ag-110 | ext | DSTH | -0.99 | | | | | | |
| Al-26 | ext | DSTH | -0.98 | THICK0 | 0.1 | | | | |
| Am-241 | inh + ext | EROS0 | 0.5 | DSTH | -0.48 | AREA | -0.45 | H | -0.16 |
| Am-243 | ext | DSTH | -0.97 | | | | | | |
| Au-195 | ext | DSTH | -1 | | | | | | |
| Bi-207 | ext | DSTH | -0.99 | | | | | | |
| C-14 | ext | DSTH | -0.72 | EROS0 | 0.26 | DKSUS | -0.25 | UD | 0.21 |
| Ca-41 | inh + ing | EROS0 | 0.54 | AREA | -0.47 | DKSUS | -0.42 | UD | 0.29 |
| Cd-109 | ext | DSTH | -0.99 | | | | | | |
| Ce-144 | ext | DSTH | -0.99 | | | | | | |
| Cf-252 | inh | EROS0 | 0.69 | AREA | -0.61 | H | -0.19 | | |
| Cl-36 | ext | DSTH | -1 | | | | | | |
| Cm-243 | ext | DSTH | -0.98 | | | | | | |
| Cm-244 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Cm-248 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Co-57 | ext | DSTH | -1 | | | | | | |
| Co-60 | ext | DSTH | -0.98 | THICK0 | 0.1 | | | | |
| Cs-134 | ext | DSTH | -0.99 | | | | | | |
| Cs-135 | ext | DSTH | -0.79 | DKSUS | -0.23 | EROS0 | 0.2 | UD | 0.18 |
| Cs-137 | ext | DSTH | -0.99 | | | | | | |
| Eu-152 | ext | DSTH | -0.99 | | | | | | |
| Eu-154 | ext | DSTH | -0.99 | | | | | | |

Table C.4 First Four Most Sensitive Parameters Based on SRRC for a 36-m² Volume Source in the Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Eu-155 | ext | DSTH | -1 | | | | | | |
| Fe-55 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.18 | UD | 0.11 |
| Gd-152 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Gd-153 | ext | DSTH | -1 | | | | | | |
| Ge-68 | ext | DSTH | -0.99 | | | | | | |
| H-3 | inh + ing | AREA | -0.71 | DKSUS | -0.33 | UD | 0.25 | H | -0.22 |
| I-129 | ext | DSTH | -0.49 | EROS0 | 0.37 | DKSUS | -0.35 | UD | 0.29 |
| K-40 | ext | DSTH | -0.98 | THICK0 | 0.1 | | | | |
| Mn-54 | ext | DSTH | -0.99 | | | | | | |
| Na-22 | ext | DSTH | -0.99 | | | | | | |
| Nb-94 | ext | DSTH | -0.99 | | | | | | |
| Ni-59 | inh | EROS0 | 0.63 | AREA | -0.57 | DKSUS | -0.22 | H | -0.18 |
| Ni-63 | inh | EROS0 | 0.64 | AREA | -0.58 | DKSUS | -0.2 | H | -0.18 |
| Np-237 | ext | DSTH | -0.99 | | | | | | |
| Pa-231 | ext | DSTH | -0.9 | AREA | -0.2 | EROS0 | 0.2 | | |
| Pb-210 | ext | DSTH | -0.74 | EROS0 | 0.29 | AREA | -0.28 | DKSUS | -0.18 |
| Pm-147 | ext | DSTH | -0.91 | EROS0 | 0.18 | AREA | -0.16 | | |
| Pu-238 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Pu-239 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-240 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-241 | inh | EROS0 | 0.66 | AREA | -0.6 | H | -0.18 | DSTH | -0.17 |
| Pu-242 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-244 | ext | DSTH | -0.99 | | | | | | |
| Ra-226 | ext | DSTH | -0.99 | | | | | | |
| Ra-228 | ext | DSTH | -0.99 | | | | | | |
| Ru-106 | ext | DSTH | -0.99 | | | | | | |
| Sb-125 | ext | DSTH | -0.99 | | | | | | |
| Sm-147 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |

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Table C.4 First Four Most Sensitive Parameters Based on SRRC for a 36-m² Volume Source in the Building Occupancy Scenario (Continued)

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Sm-151 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.2 | | |
| Sr-90 | ext | DSTH | -0.27 | UD | -0.14 | DSDEN | -0.13 | | |
| Tc-99 | ext | DSTH | -0.95 | EROS0 | 0.1 | | | | |
| Th-228 | ext | DSTH | -0.98 | THICK0 | 0.11 | | | | |
| Th-229 | ext | DSTH | -0.97 | | | | | | |
| Th-230 | inh | AREA | -0.55 | EROS0 | 0.55 | DSTH | -0.43 | H | -0.17 |
| Th-232 | ext | DSTH | -0.95 | AREA | -0.12 | EROS0 | 0.12 | | |
| Tl-204 | ext | DSTH | -0.99 | | | | | | |
| U-232 | ext | DSTH | -0.98 | THICK0 | 0.11 | | | | |
| U-233 | inh | EROS0 | 0.56 | AREA | -0.55 | DSTH | -0.4 | H | -0.17 |
| U-234 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| U-235 | ext | DSTH | -0.99 | | | | | | |
| U-236 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-238 | ext | DSTH | -0.98 | | | | | | |
| Zn-65 | ext | DSTH | -0.99 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

**Table C.5 First Four Most Sensitive Parameters Based on SRRC for a 200-m²
Volume Source in the Building Occupancy Scenario**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | ext | DSTH | -0.8 | AREA | -0.31 | EROS0 | 0.31 | | |
| Ag-108 | ext | DSTH | -0.99 | | | | | | |
| Ag-110 | ext | DSTH | -0.99 | | | | | | |
| Al-26 | ext | DSTH | -0.99 | | | | | | |
| Am-241 | inh | EROS0 | 0.62 | AREA | -0.56 | DSTH | -0.24 | H | -0.19 |
| Am-243 | ext | DSTH | -0.9 | EROS0 | 0.19 | AREA | -0.18 | | |
| Au-195 | ext | DSTH | -1 | | | | | | |
| Bi-207 | ext | DSTH | -0.99 | | | | | | |
| C-14 | ext | DSTH | -0.57 | EROS0 | 0.34 | DKSUS | -0.32 | AREA | -0.28 |
| Ca-41 | inh + ing | EROS0 | 0.54 | AREA | -0.47 | DKSUS | -0.42 | UD | 0.29 |
| Cd-109 | ext | DSTH | -0.97 | | | | | | |
| Ce-144 | ext | DSTH | -0.99 | | | | | | |
| Cf-252 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.18 | | |
| Cl-36 | ext | DSTH | -0.99 | | | | | | |
| Cm-243 | ext | DSTH | -0.93 | EROS0 | 0.16 | AREA | -0.16 | | |
| Cm-244 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.18 | | |
| Cm-248 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Co-57 | ext | DSTH | -1 | | | | | | |
| Co-60 | ext | DSTH | -0.99 | | | | | | |
| Cs-134 | ext | DSTH | -0.99 | | | | | | |
| Cs-135 | ext | DSTH | -0.65 | DKSUS | -0.32 | EROS0 | 0.28 | UD | 0.26 |
| Cs-137 | ext | DSTH | -0.99 | | | | | | |
| Eu-152 | ext | DSTH | -0.99 | | | | | | |
| Eu-154 | ext | DSTH | -0.99 | | | | | | |

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**Table C.5 First Four Most Sensitive Parameters Based on SRRC for a 200-m²
Volume Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Eu-155 | ext | DSTH | -1 | | | | | | |
| Fe-55 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.18 | UD | 0.11 |
| Gd-152 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | DENSIO | 0.03 |
| Gd-153 | ext | DSTH | -1 | | | | | | |
| Ge-68 | ext | DSTH | -0.99 | | | | | | |
| H-3 | inh + ing | AREA | -0.71 | DKSUS | -0.33 | UD | 0.25 | H | -0.22 |
| I-129 | ext | EROS0 | 0.41 | DSTH | -0.39 | DKSUS | -0.39 | AREA | -0.33 |
| K-40 | ext | DSTH | -0.99 | | | | | | |
| Mn-54 | ext | DSTH | -0.99 | | | | | | |
| Na-22 | ext | DSTH | -0.99 | | | | | | |
| Nb-94 | ext | DSTH | -0.99 | | | | | | |
| Ni-59 | inh | EROS0 | 0.63 | AREA | -0.57 | DKSUS | -0.22 | H | -0.18 |
| Ni-63 | inh | EROS0 | 0.64 | AREA | -0.58 | DKSUS | -0.2 | H | -0.18 |
| Np-237 | ext | DSTH | -0.94 | AREA | -0.14 | EROS0 | 0.13 | | |
| Pa-231 | ext | DSTH | -0.68 | AREA | -0.4 | EROS0 | 0.39 | H | -0.12 |
| Pb-210 | ext | DSTH | -0.47 | EROS0 | 0.46 | AREA | -0.43 | DKSUS | -0.24 |
| Pm-147 | ext | DSTH | -0.8 | EROS0 | 0.29 | AREA | -0.26 | | |
| Pu-238 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Pu-239 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-240 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-241 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Pu-242 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-244 | ext | DSTH | -0.99 | | | | | | |
| Ra-226 | ext | DSTH | -0.99 | | | | | | |
| Ra-228 | ext | DSTH | -0.99 | | | | | | |
| Ru-106 | ext | DSTH | -0.99 | | | | | | |
| Sb-125 | ext | DSTH | -0.99 | | | | | | |
| Sm-147 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |

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**Table C.5 First Four Most Sensitive Parameters Based on SRRC for a 200-m²
Volume Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Sm-151 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Sr-90 | ext | DSTH | -0.3 | AREA | -0.14 | DSDEN | -0.13 | UD | -0.12 |
| Tc-99 | ext | DSTH | -0.88 | EROS0 | 0.17 | AREA | -0.15 | DKSUS | -0.11 |
| Th-228 | ext | DSTH | -0.99 | | | | | | |
| Th-229 | ext | DSTH | -0.89 | AREA | -0.21 | EROS0 | 0.21 | | |
| Th-230 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.19 | DSTH | -0.13 |
| Th-232 | ext | DSTH | -0.81 | AREA | -0.31 | EROS0 | 0.29 | | |
| Tl-204 | ext | DSTH | -0.99 | | | | | | |
| U-232 | ext | DSTH | -0.97 | | | | | | |
| U-233 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.19 | DSTH | -0.12 |
| U-234 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-235 | ext | DSTH | -0.97 | AREA | -0.1 | | | | |
| U-236 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-238 | ext | DSTH | -0.94 | AREA | -0.15 | EROS0 | 0.14 | | |
| Zn-65 | ext | DSTH | -0.99 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | ext+inh | DSTH | -0.51 | EROS0 | 0.51 | AREA | -0.51 | H | -0.15 |
| Ag-108 | ext | DSTH | -0.99 | | | | | | |
| Ag-110 | ext | DSTH | -0.99 | | | | | | |
| Al-26 | ext | DSTH | -0.99 | | | | | | |
| Am-241 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.19 | | |
| Am-243 | ext | DSTH | -0.76 | EROS0 | 0.33 | AREA | -0.32 | | |
| Au-195 | ext | DSTH | -0.99 | | | | | | |
| Bi-207 | ext | DSTH | -0.99 | | | | | | |
| C-14 | ext | DSTH | -0.42 | EROS0 | 0.41 | DKSUS | -0.38 | AREA | -0.35 |
| Ca-41 | inh + ing | EROS0 | 0.54 | AREA | -0.47 | DKSUS | -0.42 | UD | 0.29 |
| Cd-109 | ext | DSTH | -0.94 | EROS0 | 0.14 | AREA | -0.13 | | |
| Ce-144 | ext | DSTH | -0.99 | | | | | | |
| Cf-252 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.18 | | |
| Cl-36 | ext | DSTH | -0.98 | | | | | | |
| Cm-243 | ext | DSTH | -0.8 | EROS0 | 0.31 | AREA | -0.3 | | |
| Cm-244 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.18 | | |
| Cm-248 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Co-57 | ext | DSTH | -1 | | | | | | |
| Co-60 | ext | DSTH | -0.99 | | | | | | |
| Cs-134 | ext | DSTH | -0.99 | | | | | | |
| Cs-135 | ext | DSTH | -0.51 | DKSUS | -0.38 | EROS0 | 0.35 | UD | 0.31 |
| Cs-137 | ext | DSTH | -0.99 | | | | | | |
| Eu-152 | ext | DSTH | -0.99 | | | | | | |
| Eu-154 | ext | DSTH | -0.99 | | | | | | |

**Table C.6 First Four Most Sensitive Parameters Based on SRRC for a 900-m²
Volume Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Eu-155 | ext | DSTH | -0.99 | | | | | | |
| Fe-55 | inh | EROS0 | 0.67 | AREA | -0.61 | H | -0.18 | UD | 0.11 |
| Gd-152 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Gd-153 | ext | DSTH | -0.99 | | | | | | |
| Ge-68 | ext | DSTH | -0.99 | | | | | | |
| H-3 | inh + ing | AREA | -0.71 | DKSUS | -0.33 | UD | 0.25 | H | -0.22 |
| I-129 | inh + ing | EROS0 | 0.45 | DKSUS | -0.42 | AREA | -0.36 | UD | 0.32 |
| K-40 | ext | DSTH | -0.99 | | | | | | |
| Mn-54 | ext | DSTH | -0.99 | | | | | | |
| Na-22 | ext | DSTH | -0.99 | | | | | | |
| Nb-94 | ext | DSTH | -0.99 | | | | | | |
| Ni-59 | inh | EROS0 | 0.63 | AREA | -0.57 | DKSUS | -0.22 | H | -0.18 |
| Ni-63 | inh | EROS0 | 0.64 | AREA | -0.58 | DKSUS | -0.2 | H | -0.18 |
| Np-237 | ext | DSTH | -0.83 | AREA | -0.27 | EROS0 | 0.27 | | |
| Pa-231 | inh | EROS0 | 0.58 | AREA | -0.57 | DSTH | -0.34 | H | -0.18 |
| Pb-210 | inh | EROS0 | 0.58 | AREA | -0.52 | DKSUS | -0.26 | UD | 0.24 |
| Pm-147 | ext | DSTH | -0.62 | EROS0 | 0.43 | AREA | -0.4 | H | -0.12 |
| Pu-238 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Pu-239 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-240 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-241 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Pu-242 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Pu-244 | ext | DSTH | -0.98 | | | | | | |
| Ra-226 | ext | DSTH | -0.99 | | | | | | |
| Ra-228 | ext | DSTH | -0.99 | | | | | | |
| Ru-106 | ext | DSTH | -0.99 | | | | | | |
| Sb-125 | ext | DSTH | -0.99 | | | | | | |
| Sm-147 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Sm-151 | inh | EROS0 | 0.67 | AREA | -0.62 | H | -0.19 | | |
| Sr-90 | ext | DSTH | -0.32 | AREA | -0.24 | EROS0 | 0.19 | DSDEN | -0.13 |
| Tc-99 | ext | DSTH | -0.77 | EROS0 | 0.26 | AREA | -0.23 | DKSUS | -0.17 |
| Th-228 | ext | DSTH | -0.98 | | | | | | |
| Th-229 | ext | DSTH | -0.69 | AREA | -0.4 | EROS0 | 0.39 | H | -0.11 |
| Th-230 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| Th-232 | inh + ext | AREA | -0.52 | EROS0 | 0.51 | DSTH | -0.5 | H | -0.16 |
| Tl-204 | ext | DSTH | -0.97 | | | | | | |
| U-232 | ext | DSTH | -0.9 | AREA | -0.2 | EROS0 | 0.19 | | |
| U-233 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-234 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-235 | ext | DSTH | -0.9 | EROS0 | 0.2 | AREA | -0.19 | | |
| U-236 | inh | EROS0 | 0.68 | AREA | -0.62 | H | -0.19 | | |
| U-238 | ext | DSTH | -0.79 | AREA | -0.32 | EROS0 | 0.31 | | |
| Zn-65 | ext | DSTH | -0.99 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | inh | AREA | -0.6 | RF0 | -0.53 | RMVFR | 0.47 | H | -0.21 |
| Ag-108 | ext | DSTH | -1 | | | | | | |
| Ag-110 | ext | DSTH | -1 | | | | | | |
| Al-26 | ext | DSTH | -1 | | | | | | |
| Am-241 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Am-243 | inh | AREA | -0.55 | RF0 | -0.47 | RMVFR | 0.4 | DSTH | -0.3 |
| Au-195 | ext | DSTH | -0.98 | | | | | | |
| Bi-207 | ext | DSTH | -1 | | | | | | |
| C-14 | inh + ing | AREA | -0.42 | DKSUS | -0.4 | RF0 | -0.35 | RMVFR | 0.28 |
| Ca-41 | inh + ing | AREA | -0.47 | DKSUS | -0.43 | RF0 | -0.41 | RMVFR | 0.35 |
| Cd-109 | ext | DSTH | -0.83 | AREA | -0.26 | RF0 | -0.2 | RMVFR | 0.17 |
| Ce-144 | ext | DSTH | -1 | | | | | | |
| Cf-252 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.2 |
| Cl-36 | ext | DSTH | -0.88 | AREA | -0.19 | RF0 | -0.17 | UD | 0.1 |
| Cm-243 | inh | AREA | -0.57 | RF0 | -0.47 | RMVFR | 0.41 | DSTH | -0.31 |
| Cm-244 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Cm-248 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Co-57 | ext | DSTH | -1 | | | | | | |
| Co-60 | ext | DSTH | -1 | | | | | | |
| Cs-134 | ext | DSTH | -1 | | | | | | |
| Cs-135 | inh + ing | DKSUS | -0.43 | AREA | -0.39 | RF0 | -0.32 | DSTH | -0.3 |
| Cs-137 | ext | DSTH | -1 | | | | | | |
| Eu-152 | ext | DSTH | -1 | | | | | | |
| Eu-154 | ext | DSTH | -1 | | | | | | |
| Eu-155 | ext | DSTH | -0.98 | | | | | | |
| Fe-55 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.46 | H | -0.21 |
| Gd-152 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |

**Table C.7 First Four Most Sensitive Parameters Based on SRRC for a 36-m² Area
Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Gd-153 | ext | DSTH | -0.98 | | | | | | |
| Ge-68 | ext | DSTH | -1 | | | | | | |
| H-3 | inh + ing | AREA | -0.53 | RF0 | -0.47 | RMVFR | 0.39 | DKSUS | -0.29 |
| I-129 | inh + ing | DKSUS | -0.42 | AREA | -0.39 | RF0 | -0.31 | RMVFR | 0.27 |
| K-40 | ext | DSTH | -1 | | | | | | |
| Mn-54 | ext | DSTH | -1 | | | | | | |
| Na-22 | ext | DSTH | -1 | | | | | | |
| Nb-94 | ext | DSTH | -1 | | | | | | |
| Ni-59 | inh | AREA | -0.55 | RF0 | -0.51 | RMVFR | 0.42 | H | -0.2 |
| Ni-63 | inh | AREA | -0.55 | RF0 | -0.52 | RMVFR | 0.43 | H | -0.2 |
| Np-237 | inh | AREA | -0.56 | RF0 | -0.48 | RMVFR | 0.4 | DSTH | -0.3 |
| Pa-231 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pb-210 | inh | AREA | -0.54 | RF0 | -0.48 | RMVFR | 0.4 | DKSUS | -0.24 |
| Pm-147 | inh | AREA | -0.57 | RF0 | -0.46 | RMVFR | 0.42 | DSTH | -0.29 |
| Pu-238 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-239 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-240 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-241 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-242 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-244 | ext | DSTH | -0.75 | AREA | -0.35 | RF0 | -0.3 | RMVFR | 0.21 |
| Ra-226 | ext | DSTH | -0.98 | | | | | | |
| Ra-228 | ext | DSTH | -0.94 | AREA | -0.14 | RF0 | -0.13 | | |
| Ru-106 | ext | DSTH | -1 | | | | | | |
| Sb-125 | ext | DSTH | -1 | | | | | | |
| Sm-147 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Sm-151 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Sr-90 | inh | AREA | -0.42 | RF0 | -0.38 | DSTH | -0.26 | RMVFR | 0.23 |
| Tc-99 | inh + ext | DSTH | -0.53 | AREA | -0.4 | RF0 | -0.34 | RMVFR | 0.24 |
| Th-228 | ext | DSTH | -0.81 | AREA | -0.3 | RF0 | -0.26 | RMVFR | 0.17 |
| Th-229 | inh | AREA | -0.59 | RF0 | -0.52 | RMVFR | 0.46 | H | -0.22 |
| Th-230 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |

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**Table C.7 First Four Most Sensitive Parameters Based on SRRC for a 36-m² Area
Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Th-232 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Tl-204 | ext | DSTH | -0.93 | AREA | -0.13 | RF0 | -0.1 | | |
| U-232 | inh | AREA | -0.59 | RF0 | -0.49 | RMVFR | 0.42 | DSTH | -0.28 |
| U-233 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-234 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-235 | inh + ext | DSTH | -0.56 | AREA | -0.47 | RF0 | -0.38 | RMVFR | 0.33 |
| U-236 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-238 | inh | AREA | -0.59 | RF0 | -0.51 | RMVFR | 0.44 | H | -0.22 |
| Zn-65 | ext | DSTH | -1 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

**Table C.8 First Four Most Sensitive Parameters Based on SRRC for a 200-m² Area
Source in the Building Occupancy Scenario**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Ag-108 | ext | DSTH | -1 | | | | | | |
| Ag-110 | ext | DSTH | -1 | | | | | | |
| Al-26 | ext | DSTH | -1 | | | | | | |
| Am-241 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Am-243 | inh | AREA | -0.58 | RF0 | -0.52 | RMVFR | 0.45 | H | -0.22 |
| Au-195 | ext | DSTH | -0.95 | AREA | -0.11 | | | | |
| Bi-207 | ext | DSTH | -1 | | | | | | |
| C-14 | inh + ing | AREA | -0.46 | DKSUS | -0.42 | RF0 | -0.39 | RMVFR | 0.32 |
| Ca-41 | inh + ing | AREA | -0.47 | DKSUS | -0.43 | RF0 | -0.41 | RMVFR | 0.35 |
| Cd-109 | ext | DSTH | -0.67 | AREA | -0.39 | RF0 | -0.3 | RMVFR | 0.26 |
| Ce-144 | ext | DSTH | -0.98 | | | | | | |
| Cf-252 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.2 |
| Cl-36 | ext | DSTH | -0.69 | AREA | -0.33 | RF0 | -0.29 | RMVFR | 0.18 |
| Cm-243 | inh | AREA | -0.6 | RF0 | -0.52 | RMVFR | 0.46 | H | -0.21 |
| Cm-244 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Cm-248 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Co-57 | ext | DSTH | -1 | | | | | | |
| Co-60 | ext | DSTH | -1 | | | | | | |
| Cs-134 | ext | DSTH | -1 | | | | | | |
| Cs-135 | inh + ing | DKSUS | -0.46 | AREA | -0.44 | RF0 | -0.36 | RMVFR | 0.3 |
| Cs-137 | ext | DSTH | -1 | | | | | | |
| Eu-152 | ext | DSTH | -1 | | | | | | |
| Eu-154 | ext | DSTH | -1 | | | | | | |

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**Table C.8 First Four Most Sensitive Parameters Based on SRRC for a 200-m² Area
Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Eu-155 | ext | DSTH | -0.94 | AREA | -0.13 | RF0 | -0.11 | | |
| Fe-55 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.46 | H | -0.21 |
| Gd-152 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Gd-153 | ext | DSTH | -0.95 | AREA | -0.11 | RF0 | -0.1 | | |
| Ge-68 | ext | DSTH | -1 | | | | | | |
| H-3 | inh + ing | AREA | -0.53 | RF0 | -0.47 | RMVFR | 0.39 | DKSUS | -0.29 |
| I-129 | inh + ing | DKSUS | -0.44 | AREA | -0.41 | RF0 | -0.34 | RMVFR | 0.29 |
| K-40 | ext | DSTH | -0.98 | | | | | | |
| Mn-54 | ext | DSTH | -1 | | | | | | |
| Na-22 | ext | DSTH | -1 | | | | | | |
| Nb-94 | ext | DSTH | -1 | | | | | | |
| Ni-59 | inh + ing | AREA | -0.55 | RF0 | -0.51 | RMVFR | 0.42 | H | -0.2 |
| Ni-63 | inh + ing | AREA | -0.55 | RF0 | -0.52 | RMVFR | 0.43 | H | -0.2 |
| Np-237 | inh | AREA | -0.58 | RF0 | -0.53 | RMVFR | 0.45 | H | -0.22 |
| Pa-231 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pb-210 | inh + ing | AREA | -0.54 | RF0 | -0.49 | RMVFR | 0.4 | DKSUS | -0.25 |
| Pm-147 | inh | AREA | -0.6 | RF0 | -0.52 | RMVFR | 0.46 | H | -0.21 |
| Pu-238 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-239 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-240 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-241 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-242 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-244 | inh | AREA | -0.52 | DSTH | -0.45 | RF0 | -0.43 | RMVFR | 0.36 |
| Ra-226 | ext | DSTH | -0.94 | AREA | -0.11 | RF0 | -0.1 | | |
| Ra-228 | ext | DSTH | -0.81 | AREA | -0.3 | RF0 | -0.25 | RMVFR | 0.17 |
| Ru-106 | ext | DSTH | -0.99 | | | | | | |
| Sb-125 | ext | DSTH | -1 | | | | | | |
| Sm-147 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |

**Table C.8 First Four Most Sensitive Parameters Based on SRRC for a 200-m² Area
Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Sm-151 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.21 |
| Sr-90 | inh | AREA | -0.54 | RF0 | -0.48 | RMVFR | 0.36 | UD | 0.19 |
| Tc-99 | inh | AREA | -0.49 | RF0 | -0.42 | RMVFR | 0.32 | DSTH | -0.28 |
| Th-228 | ext | DSTH | -0.54 | AREA | -0.49 | RF0 | -0.39 | RMVFR | 0.33 |
| Th-229 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.47 | H | -0.22 |
| Th-230 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Th-232 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Tl-204 | ext | DSTH | -0.85 | AREA | -0.23 | RF0 | -0.17 | UD | 0.13 |
| U-232 | inh | AREA | -0.6 | RF0 | -0.53 | RMVFR | 0.46 | H | -0.21 |
| U-233 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-234 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-235 | inh | AREA | -0.58 | RF0 | -0.48 | RMVFR | 0.43 | DSTH | -0.26 |
| U-236 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-238 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.47 | H | -0.22 |
| Zn-65 | ext | DSTH | -1 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

**Table C.9 First Four Most Sensitive Parameters Based on SRRC for a 900-m²
Area Source in the Building Occupancy Scenario**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Ac-227 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Ag-108 | ext | DSTH | -0.99 | | | | | | |
| Ag-110 | ext | DSTH | -1 | | | | | | |
| Al-26 | ext | DSTH | -0.99 | | | | | | |
| Am-241 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Am-243 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Au-195 | ext | DSTH | -0.9 | AREA | -0.18 | RF0 | -0.14 | RMVFR | 0.13 |
| Bi-207 | ext | DSTH | -0.99 | | | | | | |
| C-14 | inh + ing | AREA | -0.46 | DKSUS | -0.43 | RF0 | -0.4 | RMVFR | 0.33 |
| Ca-41 | inh + ing | AREA | -0.47 | DKSUS | -0.43 | RF0 | -0.41 | RMVFR | 0.35 |
| Cd-109 | inh | AREA | -0.51 | DSTH | -0.45 | RF0 | -0.4 | RMVFR | 0.36 |
| Ce-144 | ext | DSTH | -0.91 | AREA | -0.19 | RF0 | -0.16 | RMVFR | 0.1 |
| Cf-252 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.2 |
| Cl-36 | inh | AREA | -0.46 | DSTH | -0.44 | RF0 | -0.39 | RMVFR | 0.28 |
| Cm-243 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Cm-244 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Cm-248 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Co-57 | ext | DSTH | -0.99 | | | | | | |
| Co-60 | ext | DSTH | -1 | | | | | | |
| Cs-134 | ext | DSTH | -1 | | | | | | |
| Cs-135 | ing | DKSUS | -0.47 | AREA | -0.45 | RF0 | -0.38 | RMVFR | 0.32 |
| Cs-137 | ext | DSTH | -0.98 | | | | | | |
| Eu-152 | ext | DSTH | -1 | | | | | | |
| Eu-154 | ext | DSTH | -0.99 | | | | | | |

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**Table C.9 First Four Most Sensitive Parameters Based on SRRC for a 900-m²
Area Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Eu-155 | ext | DSTH | -0.88 | AREA | -0.22 | RF0 | -0.17 | RMVFR | 0.14 |
| Fe-55 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.46 | H | -0.21 |
| Gd-152 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Gd-153 | ext | DSTH | -0.9 | AREA | -0.19 | RF0 | -0.15 | RMVFR | 0.13 |
| Ge-68 | ext | DSTH | -1 | | | | | | |
| H-3 | inh + ing | AREA | -0.53 | RF0 | -0.47 | RMVFR | 0.39 | DKSUS | -0.29 |
| I-129 | inh + ing | DKSUS | -0.45 | AREA | -0.43 | RF0 | -0.36 | RMVFR | 0.3 |
| K-40 | ext | DSTH | -0.97 | | | | | | |
| Mn-54 | ext | DSTH | -1 | | | | | | |
| Na-22 | ext | DSTH | -1 | | | | | | |
| Nb-94 | ext | DSTH | -0.98 | | | | | | |
| Ni-59 | inh | AREA | -0.55 | RF0 | -0.51 | RMVFR | 0.42 | H | -0.2 |
| Ni-63 | inh | AREA | -0.55 | RF0 | -0.52 | RMVFR | 0.43 | H | -0.2 |
| Np-237 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pa-231 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pb-210 | inh + ing | AREA | -0.54 | RF0 | -0.49 | RMVFR | 0.4 | DKSUS | -0.25 |
| Pm-147 | inh | AREA | -0.6 | RF0 | -0.53 | RMVFR | 0.47 | H | -0.2 |
| Pu-238 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-239 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-240 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-241 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| Pu-242 | inh | AREA | -0.58 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.22 |
| Pu-244 | inh | AREA | -0.58 | RF0 | -0.51 | RMVFR | 0.43 | H | -0.22 |
| Ra-226 | ext | DSTH | -0.83 | AREA | -0.23 | RF0 | -0.2 | UD | 0.12 |
| Ra-228 | ext | DSTH | -0.56 | AREA | -0.48 | RF0 | -0.38 | RMVFR | 0.32 |
| Ru-106 | ext | DSTH | -0.95 | AREA | -0.13 | RF0 | -0.12 | | |
| Sb-125 | ext | DSTH | -1 | | | | | | |
| Sm-147 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |

**Table C.9 First Four Most Sensitive Parameters Based on SRRC for a 900-m²
Area Source in the Building Occupancy Scenario (Continued)**

| Radionuclide | Dominant Pathway ^a | Rank 1 | | Rank 2 | | Rank 3 | | Rank 4 | |
|--------------|-------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC | Parameter | SRRC |
| Sm-151 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.46 | H | -0.21 |
| Sr-90 | inh | AREA | -0.56 | RF0 | -0.51 | RMVFR | 0.41 | H | -0.2 |
| Tc-99 | inh + ing | AREA | -0.52 | RF0 | -0.46 | RMVFR | 0.37 | DKSUS | -0.26 |
| Th-228 | inh | AREA | -0.59 | RF0 | -0.49 | RMVFR | 0.43 | DSTH | -0.26 |
| Th-229 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Th-230 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Th-232 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Tl-204 | ext | DSTH | -0.71 | AREA | -0.32 | RF0 | -0.23 | UD | 0.18 |
| U-232 | inh | AREA | -0.6 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.21 |
| U-233 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-234 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-235 | inh | AREA | -0.59 | RF0 | -0.53 | RMVFR | 0.46 | H | -0.22 |
| U-236 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| U-238 | inh | AREA | -0.59 | RF0 | -0.54 | RMVFR | 0.47 | H | -0.22 |
| Zn-65 | ext | DSTH | -1 | | | | | | |

^a ext = external, ing = ingestion, inh = inhalation.

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11. ABSTRACT (200 words or less)

The existing RESRAD 6.0 and RESRAD-BUILD 3.0 codes for site-specific radiation dose modeling applications are being developed and adapted for use with the U.S. Nuclear Regulatory Commission's (NRC's) Standard Review Plan for decommissioning and as tools for demonstrating compliance with the license term ination rule in a risk-informed manner. Computer interfaces and software modules have been developed under NRC sponsorship to perform the probabilistic simulation of dose. RESRAD and RESRAD-BUILD codes are part of the RESRAD family of codes that have been developed by the U.S. Department of Energy (DOE) and for many years have been successfully applied to cleanup efforts at sites contaminated with radioactive materials. Specifically, the RESRAD code applies to cleanup of soil and RESRAD-BUILD applies to the cleanup of buildings and structures at a site. This report describes the use of these codes to perform probabilistic dose analysis. The dose analysis presented in this report has fully demonstrated the process of using the integrated system of RESRAD 6.0 and RESRAD-BUILD 3.0 codes and the probabilistic modules, together with distributions of input parameters, for dose assessment at a relatively complex site. This demonstration enables site-specific application of the codes for dose analysis where pertinent parameters and their distributions are available or can be developed. Results of the uncertainty analysis and sensitivity analysis of dose to input parameter values indicated that because the dependence of dose on the input parameters is complex, no single correlation or regression coefficient can be used alone to identify sensitive parameters in all cases. However, the results could give an indication of the degree of sensitivity of the calculated dose to changes in input parameter values for each exposure situation. Therefore, the coefficients are useful guides, but they have to be used in conjunction with other aids, such as scatter plots and further analysis, to accurately identify the sensitive parameters.

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