Probabilistic Modules for the RESRAD and RESRAD-BUILD Computer Codes

User Guide

Argonne National Laboratory

U.S. Nuclear Regulatory Commission
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Probabilistic Modules for the RESRAD and RESRAD-BUILD Computer Codes

User Guide

ABSTRACT

RESRAD and RESRAD-BUILD codes are part of the RESRAD family of codes developed by the U.S. Department of Energy. For many years these deterministic codes have been used as dose assessment tools for cleanup efforts at sites contaminated with radioactive materials. The RESRAD code applies to the cleanup of soil, and the RESRAD-BUILD code applies to the cleanup of buildings and structures.

The existing (deterministic) RESRAD and RESRA-BUILD codes were adapted for use with the U.S. Nuclear Regulatory Commission's (NRC's) Standard Review Plan (NRC, 2000) for Decommissioning as site-specific and probabilistic dose analysis tools for demonstrating compliance with the license termination rule in a risk-informed manner.

This report includes a user's guide for the probabilistic modules included in RESRAD version 6.0 and RESRAD-BUILD version 3.0. It iiiiiishould be used in conjunction with the technical reference manuals for the deterministic RESRAD and RESRAD-BUILD codes (Yu et al., 1993, 1994, respectively, or future updates of these manuals). These manuals describe the technical basis (models and methods) and the input parameters for the models. This report also includes background information and summaries of the previous tasks accomplished in this project, a description of the software design and requirements, and description of a sample case for probabilistic dose analysis. A detailed discussion of the Latin hypercube sampling method, a summary of parameter distributions, and a "guided tour" that demonstrates the use of the probabilistic modules are included in the appendices.

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EXECUTIVE SUMMARY

The RESRAD and RESRAD-BUILD computer codes have been developed by Argonne National Laboratory under U.S. Department of Energy (DOE) sponsorship 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 incorporate 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. The RESRAD code has been used extensively for dose analysis in site cleanups, and the RESRAD-BUILD code is used for the cleanup of buildings.

In 1999, the U.S. Nuclear Regulatory Commission (NRC) tasked Argonne National Laboratory (Argonne) with adapting the existing RESRAD and RESRAD-BUILD codes for use in site-specific and probabilistic radiation dose analysis in accordance with NRC's guidance in the Standard Review Plan (SRP) for Decommissioning (NRC, 2000) to demonstrate compliance with the license termination rule. For NRC's intended use, the codes have been revised to be consistent with the current NRC guidance for dose modeling being developed in the SRP. Thus, the primary objectives of Argonne's effort are to (1) develop parameter distribution functions and parametric analyses for the RESRAD and RESRAD-BUILD codes and (2) develop necessary computer modules for conducting probabilistic analyses.

As part of the ongoing effort to meet NRC's objectives, external modules equipped with probabilistic sampling and analytical capabilities were 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.

This report documents the requirements, design, and operation of the probabilistic modules developed for the RESRAD and RESRAD-BUILD codes. The objective is to establish and demonstrate the features and functionality of the integrated system for site-specific analysis. The features incorporated include the previously identified parameter distributions, sampling with the stratified Latin hypercube sampling (LHS) method, an easily accessible probabilistic setup procedure, and a variety of formats (tabular, graphical, and database) for interpreting results. This report includes a user's guide for the probabilistic modules included in RESRAD version 6.0 and RESRAD-BUILD version 3.0. It should be used in conjunction with the technical reference manuals for the deterministic RESRAD and RESRAD-BUILD codes (Yu et al., 1993, 1994, respectively, and future updates), which describe the methods and parameters. This report also includes a "guided tour" to assist first-time users.

The software was designed with a user-centered approach. The result is an accessible, integrated package that leverages the user's familiarity with standard Windows tools and the family of RESRAD software tools. The probabilistic screens are tightly integrated with the previously identified default distributions for the input variables. However, the user also has the choice of entering site-specific distributions. The software offers feedback to quickly identify the default and site-specific distributions. The user can also graphically preview the distribution shape.

The previously developed and accepted LHS sampling method is used to perform the dose calculations. The user can specify details about this sampling method or accept the default method. The details of the sampling are stored in a report and database format to allow the user to review and query the input samples. Design considerations included methods to integrate the calculations efficiently into the standard deterministic software to ensure reasonable calculation times.

The output results are accessible through interactive tabular windows; interactive graphical windows; fixed tabular reports; and a complete, formatted database. The output results were chosen to support resultant dose distribution statistics, distributions, and correlations with the input variables. These results can be queried on the basis of environmental pathway, initial nuclide contamination, and time since contaminant placement. Special emphasis is placed on the analysis of both the "mean of the peaks" and the "peak of the means." The "mean of the peaks" analysis is based on the time at which the dose is maximum for each sample. The "peak of the means" analysis is based on the time at which the average dose (averaged over all samples) is maximum.

Since interactive reports and fixed reports can offer only a limited, selected subset of possible results, the software stores all the information about the samples and results in a formatted database to allow further postprocessing, thereby greatly extending a user's ability to analyze the data.

The software modules were developed under an approved software quality assurance plan and underwent continuous testing through unit development, system integration, and beta testing phases. The testing procedures and results will be published later.

Development of distributions contained in the modules 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 that made use of 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 to describe the exposure pathways and the associated exposure conditions. The data distribution for these parameters was developed through the following four 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 them according to their importance with regard to 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 remaining 120 were ranked as low priority for RESRAD and RESRAD-BUILD combined.

- **Step 3: Parameter Distribution** (Biwer 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 sources representative of a national distribution. Because they are based on national average data, many of these distributions may not be appropriate for a site-specific assessment. However, their development was necessary for the testing of the probabilistic modules in Step 4. Potential correlation among parameters was also studied and discussed in the report (Biwer et al., 2000).

- **Step 4: Parameter Analysis** (Kamboj et al., 2000) — The analysis 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 indicates that a site-specific application could be implemented in cases where pertinent site data could be developed.

Results of the analysis indicated that no single correlation or regression coefficient 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.

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.

FOREWORD

This contractor technical report, NUREG/CR-6692 was prepared by Argonne National Laboratory[1] staff under their U.S. Department of Energy (DOE) Interagency Work Order (JCN Y6112) with the Radiation Protection, Environmental Risk and Waste Management Branch, Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission. The report is a user's guide for the probabilistic system of RESRAD and RESRAD-BUILD codes developed and customized for NRC use. A detailed discussion of the Latin Hypercube sampling method used to generate random samples of input parameters, a summary of parameter distributions, and a "guided tour" that demonstrates the use of the probabilistic modules are included in the appendices.

The purpose of the probabilistic system of RESRAD codes is to provide a site-specific and probabilistic dose analysis approach for demonstrating compliance with the license termination rule, 10 CFR Part 20, Subpart E in a risk informed manner. The codes may be used to demonstrate compliance with the dose criteria in 10 CFR Part 20, Subpart E, as described in NUREG-1727, "NMSS Decommissioning Standard Review Plan," and draft NUREG-1549, "Decision Methods for Dose Assessment to Comply with Radiological Criteria for License Termination."

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ABBREVIATIONS

CDF	cumulative distribution function
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
DWI	drinking water intake
EDE	effective dose equivalent
FIND	indoor time fraction
FOTD	outdoor time fraction
g	gram(s)
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)
MB	megabyte(s)
MHZ	megahertz
µg	microgram(s)
mrem	millirem
NRC	U.S. Nuclear Regulatory Commission
PCC	partial correlation coefficient
pCi	picocurie(s)
PRCC	partial rank correlation coefficient
PRRC	partial rank regression coefficient
s	second(s)
SPRC	standardized partial regression coefficient
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. The estimated doses can then be used to assess licensee's compliance with the NRC dose criteria.

As part of the development of a Standard Review Plan (SRP) for Decommissioning and guidance on site-specific demonstration of compliance with the License Termination Rule (NRC, 2000), the NRC recognized the need to perform probabilistic

dose 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, 1998]). The RESRAD codes have been used primarily to derive site-specific cleanup guidance levels (the derived concentration guideline levels, or DCGLs) with the deterministic method.

In 1999, the NRC tasked Argonne to develop site-specific and probabilistic dose analysis capabilities for the RESRAD and RESRAD–BUILD codes for use with the guidance in NRC's SRP for demonstration of compliance with the license termination rule. Thus, the primary objectives of this project are for Argonne to (1) develop parameter distribution functions and perform probabilistic analyses 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). The modules were customized for use with the RESRAD and RESRAD-BUILD codes to perform site-specific probabilistic dose assessments in support of decontamination and decommissioning of radioactively contaminated sites.

This document reports on one of a series of steps undertaken by Argonne to meet NRC's

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[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 [Kennedy and Strenge, 1992]). The average member of the critical group is an individual who is assumed to represent the most likely exposure situation on the basis of prudently conservative exposure assumptions and parameter values within the model calculations.

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 here.

- **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 having 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.

- **Probabilistic Dose Analysis** (Kamboj et al., 2000): The effects of parameter distribution on the estimated doses, taking into account parameter correlations, for the residential scenario in RESRAD and for the building occupancy scenario in RESRAD-BUILD were assessed. The interim versions of the probabilistic modules for the two codes (RESRAD version 5.95+ and RESRAD-BUILD version 2.9+) were used. The analysis took 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 and used as the peak dose. 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 probabilistic analysis 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.

- **Probabilistic Modules** (current report): This report is a user's guide for the probabilistic modules included in the RESRAD version 6.0 and RESRAD-BUILD version 3.0. This report is to be used in conjunction with the RESRAD and RESRAD-BUILD technical reference manuals (Yu et al., 1993, 1994, respectively, and future updates) that describe the methods and parameters. This report is organized into four major sections. Section 1 (the current section) provides background information and summaries of the previous tasks accomplished in this project. Section 2 describes the software design and requirements. A user's guide for the probabilistic modules that facilitates the uncertainty analysis is presented in Section 3. Section 4 demonstrates the use of the probabilistic modules for performing probabilistic dose analysis for sample decommissioning cases. A detailed discussion of the LHS sampling method and a summary of parameter distributions are included in the appendices.

2 SOFTWARE DESIGN

The software requirements and their implementation to develop and integrate the interface modules are discussed in this section. The requirements were gathered from the work proposal and a series of meetings with the U.S. Nuclear Regulatory Commission (NRC). The major aspects of the design are as follows: (1) module integration with the previously developed deterministic software and the Latin hypercube sampling (LHS) software (Iman and Helton, 1985; Iman and Shortencarier, 1984; Iman et al., 1985); (2) incorporation of the default parameter distributions identified in earlier subtasks; (3) development of input and output interfaces; (4) development of testing methods; and (5) incorporation of software quality assurance methods.

2.1 Requirements

The requirements for this effort, on the basis of information in the basic proposal and as developed at subsequent meetings with NRC staff, include the following:

- Operating Systems: Windows 95, 98, and NT

- Integration with: RESRAD and RESRAD-BUILD

- Input:

  - Design new interface that separates functions of general input, parameter distributions, parameter correlations, and output options

  - Support most of the distributions from the LHS routine (Iman and Helton, 1985; Iman and Shortencarier, 1984; Iman et. al., 1985)

  - Support ability to handle 250 simultaneous input parameter distributions

  - Integrate data from Subtask 1.3, that is, the default distribution for a parameter will be entered into the uncertainty window

  - Show graphic representation of input distribution

  - Include some method to estimate time for completion

- Output:

  - Support peak dose and peak of average dose results

  - Support feedback on tolerance limit of output results

  - Support interactive tabular results

    - Average, minimum, maximum, standard deviation

    - Percentiles of output variables

  - Support graphic results

    - Scatterplots of input versus output

    - Time dependence of statistical measures

  - Generate a full output report

  - Generate a formatted file that contains all the output data to facilitate further analysis by users

  - Where possible, use full variable names instead of FORTRAN names

- Configuration Management: Use professional practices for change control and documentation

2.2 Integration with RESRAD Codes

The new modules will be integrated with both the RESRAD and RESRAD-BUILD deterministic codes and the LHS code (Figure 1). Parts of the software will be programmed with the FORTRAN language; the interface will be written in Visual Basic language. Integration of the various codes will be accomplished with system calls and command files. Most of the data-passing between codes will be accomplished with system ASCII files. The results will be compiled into an MS ACCESS database. The details of the integration will be transparent to the user.

When a user-defined case is run, the standard deterministic calculation will always be performed with the values entered in the standard interface. If (1) there is at least one parameter specified in the probabilistic interface and (2) the number of repetitions and number

of observations are greater than zero, a probabilistic analysis will be performed.

2.3 Integration with Parameter Distributions

Default parameter distributions identified in Subtask 1.3 (Biwer et al., 2000) are included with the software as the default distributions when the parameters are selected. Feedback on the input screen indicates whether the distribution is still set at the default or if it has been modified. The settings for the distributions are saved in a file associated with the standard input file; that is, if a case with previously defined probabilistic analysis is opened, both the deterministic and probabilistic distributions will be read and displayed.

When the user-specified case is run, the deterministic input parameter values will be used to generate the standard deterministic analysis. The deterministic analysis uses no information from
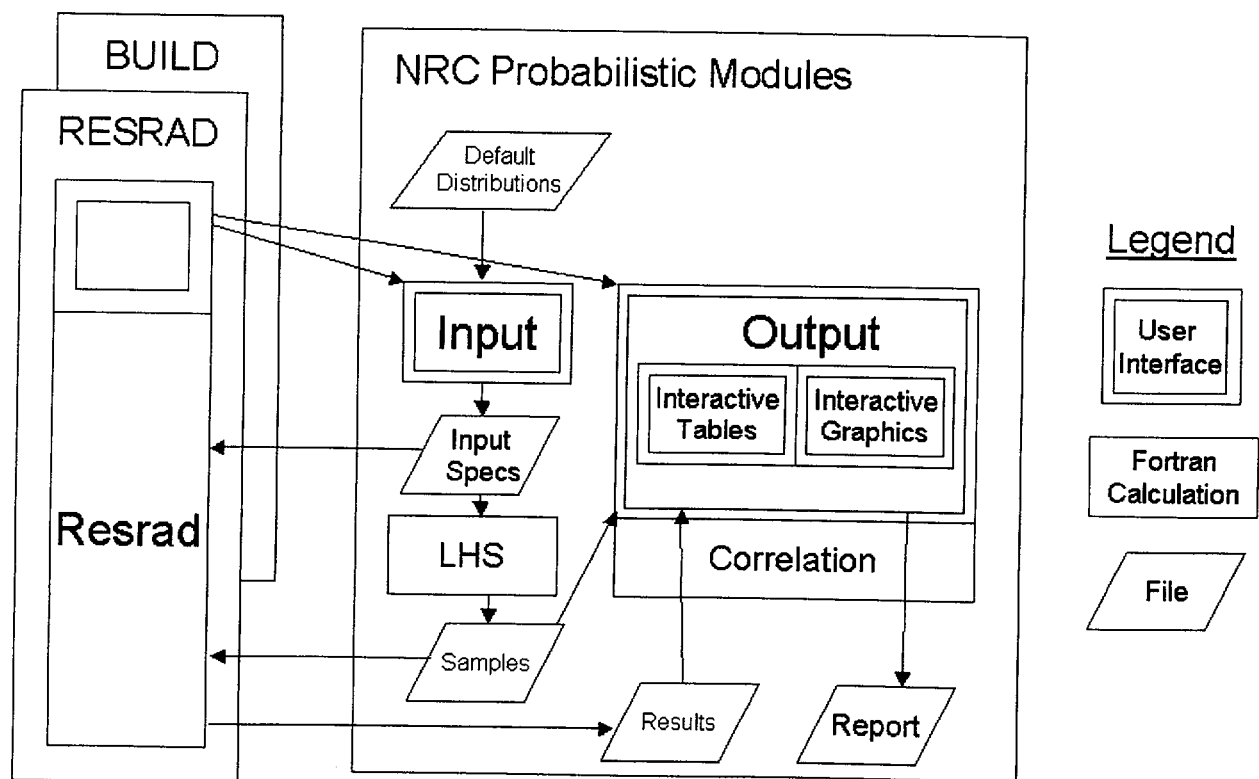
Figure 1 Diagram of the Integration of the RESRAD and RESRAD-BUILD Codes with the NRC Probabilistic Modules and the LHS Code

the specified probabilistic distributions (Figure 2). If probabilistic analysis has been specified by choosing one or more parameters for analysis, and the number of observations and number of repetitions is at least 1, then the probabilistic calculations will be performed. The calculations use all the distributions specified for the chosen parameters. These distributions could be the default distributions or site-specific distributions specified by the user. For the parameters not chosen for probabilistic analysis, the deterministic values will be used, which could be the default values or site-specific values inputted by the user. Figure 2 shows the progression of specification and what values are used for the deterministic and probabilistic calculations. In this particular case, the user has specified the variables Y and Z for probabilistic analysis. The standard default deterministic values for X and S will be used throughout the calculations. The site-specific single value of V will also be used. When this case is run, the deterministic results will have used the second column of values (i.e., a site-specific Y value and the default Z value).
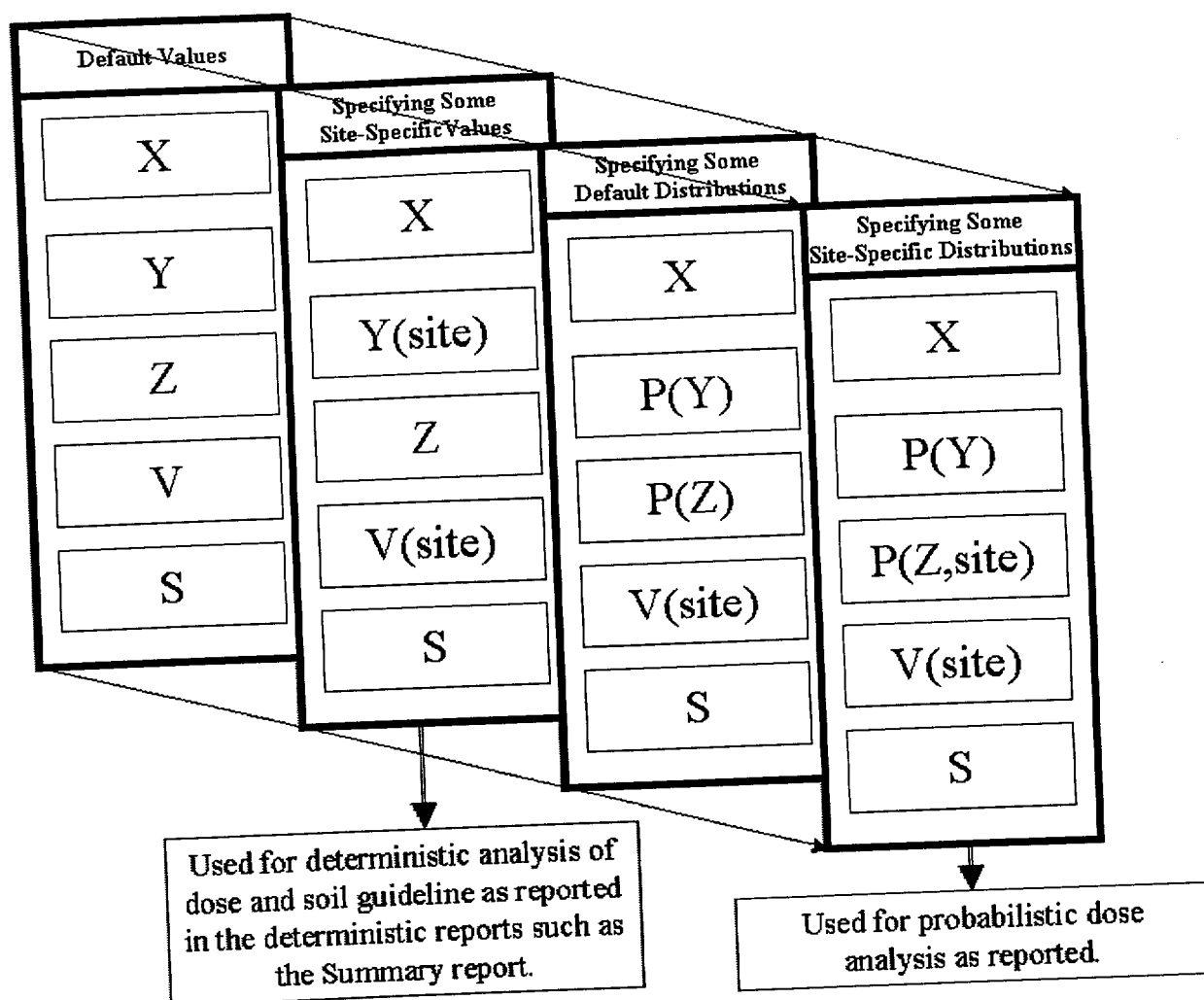
Figure 2 Relationship of Variables and Distributions Used for Deterministic and Probabilistic Calculations

2.4 Interface

The interface was designed after reviewing other probabilistic software, considering comments about an earlier version of probabilistic support in RESRAD, and eliciting feedback from an NRC focus group. The interface has three components: input specifications, output results display, and feedback during the calculations. Standard window components, such as tabbed forms and input controls, were used. The probabilistic modules forms are accessed through the standard RESRAD user interface (Figure 3).

2.5 Testing Methods

The testing of the software has been performed and documented in a letter report to NRC for Subtask 1.7 (LePoire et al., 2000)[2]. Testing activities include the testing phases of development unit testing, integrated testing, and beta testing for the input interface, calculations, output interface, and distribution.

2.6 Software Quality Assurance Methods

The development of the probabilistic modules follows the same configuration and quality control/quality assurance methods used for the RESRAD family of codes.

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[2] This letter report will be included as Attachment D to a NUREG/CR report: "Development of Probabilistic RESRAD and RESRAD-BUILD Codes" (in publication).
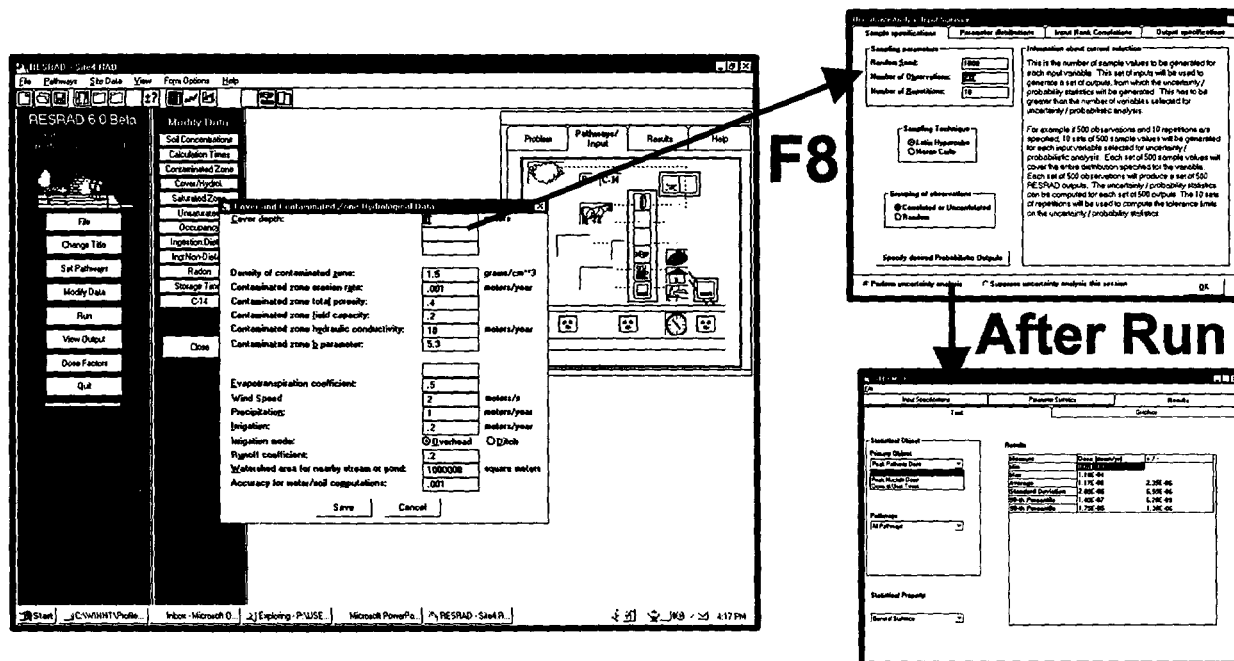
Figure 3 Accessing Probabilistic Input Module from Standard RESRAD User Interface

3 USER'S GUIDE

This user's guide covers the issues of installation and operation of the probabilistic modules. Details about the dose assessment methodology and operation are provided in the RESRAD and RESRAD-BUILD manuals (Yu et al., 1993, 1994). Details about the generation of Latin hypercube sampling (LHS) are provided in the LHS manual (Iman and Helton, 1985; Iman and Shortencarier, 1984; Iman et al., 1985). Test results and an example of interpretation are provided in a letter report to NRC (LePoire et al., 2000). The probabilistic modules in RESRAD and RESRAD-BUILD are very similar, although there are slight differences in the output files and interactive output that are discussed in Section 3.4.

3.1 Installation

3.1.1 Requirements

- Windows 95, 98, NT or later.

- 200-MHZ Pentium-compatible processor (recommended: 400-MHZ Pentium III or AMD K6-2 or better).

- RAM: Minimum requirements for selected Windows operating system (recommended: 128 MB or greater).[3]

- 8 MB for a download installation file (web-based installation only); 25-MB free disk space (15 MB for RESRAD, 10 MB for RESRAD-BUILD).

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[3] The RESRAD probabilistic modules are known to run 300 samples on a Pentium-compatible 150-MHZ/32-MB RAM/Windows 95 computer and a Pentium-compatible 200-MHZ/64-MB RAM/Windows NT computer.

- A printer driver must be installed, although a physical printer need not be attached.

3.1.2 Installing from CD-ROM

- Insert the installation CD-ROM into the appropriate drive.

- Run the appropriate program from the drive (e.g., E:\RESRAD 6.0 Beta.exe).

- Enter the information requested by the standard installation program.

- After installation, a new RESRAD icon will be placed in the RESRAD group. Double-clicking on this icon will start RESRAD.

3.1.3 Installing from the Web Site

- Register at the RESRAD web site: web.ead.anl.gov/resrad/register.

- Download the latest RESRAD self-extracting executable to your computer. The download files are large (22 MB for RESRAD, 18 MB for RESRAD-BUILD).

- Run this executable.

- Enter the information requested by the standard installation program.

- After installation, a new RESRAD icon will be placed in the RESRAD group. Double-clicking on this icon will start RESRAD.

3.1.4 Uninstalling

- Click on the "Uninstall RESRAD" icon.

- Files will be removed from the system.

- Note: user-specific data files will not be removed.

3.2 Operation Overview

3.2.1 Procedures for Using Probabilistic Analysis

The procedures for using probabilistic analysis with the two codes are as follows:

- Run the standard software interface (i.e., RESRAD or RESRAD-BUILD) to set deterministic values for all parameters not involved with probabilistic analysis. If the probabilistic analysis is to include the complete set of non-nuclide-specific parameters that have a defined default distribution, first read the template file "NONNUCL.TEM" with the File|Open menu options.

- The Title screen includes settings for the dose and risk time-integration settings. These settings determine the accuracy of the integration over a period of time. Larger values tend to increase the calculation time. If risk is not an important result for the probabilistic analysis, uncheck the box next to the words "Time Integrated Probabilistic Risk." The dose integration settings can also be lowered to save calculation time, although the accuracy of the results may change.

- By default, the output results are saved in temporary files that are overwritten for each calculation. If it is desired to save the output results with base filenames that match the input file name (with different extensions, see Tables 1 and 2 in Section 3.4 below), then check the box next to the "Save All files after each run" option on the Title screen.

- Set probabilistic analysis for a specific parameter by finding that parameter 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 (if available), to the list of parameters for probabilistic analysis. The default distribution can be replaced with the site-specific distribution. If the parameter does not have a default distribution, when the "F8" key is pressed, the probabilistic input window still appears. However, the "Parameter Distributions" tab shows a blank distribution type argument. The user can specify a distribution type and distribution arguments. When a distribution specification is complete, the input is automatically saved.

- Run the case. The standard deterministic calculations are performed first, then the probabilistic calculations begin. The estimated time for completion is continually updated and displayed.

- After the calculations are completed, the interactive output window will appear so that tables and graphics can be displayed. Access is available to both the textual report and the detailed data dump files containing the results.

- When the input file is saved to disk, the probabilistic input is also automatically saved and associated with the case. If the user wishes to share or archive the case, the two files necessary to specify a probabilistic case should be included. The two files have the extensions ".rad" and ".lhs." For RESRAD-BUILD, the two file extensions are .rad and .lhs.

If the user wants to have all non-nuclide-specific parameters that have defined default distributions to be set for probabilistic analysis, the template file containing this setup should be read in immediately after the software is launched. Then the above procedure can be followed for setting deterministic values and nuclide-specific probabilistic analysis. The template file contains the default single-value data and the setup for probabilistic analysis on

all non-nuclide-specific parameters that have defined default distributions.

To set up a case with this template, the user should open the template file (File|Open|NonNucl.tem), save the case under a different file name (File|SaveAs|filename), and set up the single valued variables as necessary. The user can then modify the distributions, delete variables from probabilistic analysis, and add nuclide-specific probabilistic analysis. The nuclide-specific variables that have defined default distributions to be set for probabilistic analysis are listed below:

- Initial concentration;

- Distribution coefficient in each zone; and

- Transfer factors for plant, meat, milk, fish, and crustacea.

The probabilistic modules have been designed to be flexible and quite independent of the original RESRAD or RESRAD-BUILD application, yet they are easily applied and integrated with the application and utilize previously written software for LHS and correlation analysis.

3.2.2 Input

The input window 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 sampling code is activated.

3.2.3 Output

The code is run on the samplings, and the results are stored for incorporation into interactive text and graphs, textual reports, and formatted output for user-controlled processing.

3.3 Input Window

The input window has four tabs that cover aspects of the sample specification, parameter distributions, input rank correlations, and output specifications (Figure 4). This window is displayed either by selecting to add or modify probabilistic analysis for a parameter, or by selecting to view the probabilistic input from the main menu's "View" submenu.

3.3.1 Sample Specifications

The general sampling requirements, including the number of samples and the technique used to generate and correlate samples, are specified on the "Sample Specifications" tab. Information about the possible selections are shown in the right-hand frame. Up to 2,000 observations can be specified. There is no software limit on the number of repetitions, although the memory available on the computer will determine an effective limit.

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 process 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 correlation 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.

Figure 4 Uncertainty Analysis Input Summary

3.3.2 Parameter Distributions

The parameter distribution tab screen (Figure 5) allows the user to view and edit all currently specified parameter distributions for probabilistic analysis. The parameters are listed in the left-hand frame. The detailed distribution properties are shown in the right-hand frame.

Parameter distributions are set by pressing the "F8" key while highlighting the parameter in the input window or reading previously saved cases with uncertainty analysis. A complete set of non-nuclide-specific parameters that have a defined default distribution can be set by first reading the template file "NONNUCL.TEM".

Navigation: Navigation to other parameter distributions is achieved by either clicking on the parameter in the left-hand frame or using the "Up-Down" arrow control in the right-hand frame.

Variable Description List for Probabilistic Analysis: The list of the currently chosen parameters is shown in the left-hand frame. By clicking on the variable description, the complete distribution properties for the variable will appear for review and edit on the right. Up

to 250 variables can be chosen for probabilistic analysis.

Statistics of Uncertain Variable: The properties displayed are the distribution type, shape parameters concerning the specific distribution type, and upper and lower truncation bounds. In the example shown in Figure 5, the shape parameters are for the normal distribution, that is, the mean and standard deviation.

If the user does not even select a distribution for the parameter for which a default is not defined, the parameter will be removed from the list of parameters being considered for probabilistic analysis.

If the user does not finish defining distribution statistics for a parameter after selecting a distribution or if the user inputs distribution statistics that do not satisfy the conditions for the selected distribution, the offending distribution statistics will be highlighted in red. The user must either input a satisfactory set of distribution statistics or remove the parameters from the probabilistic analysis screen before any other task can be performed in RESRAD or RESRAD-BUILD.

Uncertainty Analysis Input Summary

| Sample specifications | Parameter distributions | Input Rank Correlations | Output specifications |

Variable Description

Kd of U-238 in Contaminated Zone
Kd of U-238 in Unsaturated Zone 1
Kd of U-238 in Saturated Zone
Plant transfer factor for U

Statistics of Uncertain variable

Plant transfer factor for U

Distribution LOGNORMAL-N ▼ Default

Mean (Mu) of underlying normal -6.21
Standard deviation (Sigma) of underlying normal .916291

Previous parameter ▲
Next parameter ▼

Remove parameter | Help | Restore Default

○ Perform uncertainty analysis   ○ Suppress uncertainty analysis this session   OK

Figure 5 Parameter Distributions Tab of the Uncertainty Analysis Input Summary

If, after making changes, the user wishes to restore the default distribution for this parameter, "Restore Default" can be selected. The user can also remove the parameter from further probabilistic consideration by clicking on the "Remove Parameter" button.

Nuclide-specific parameters can remain in the list of parameters being considered for probabilistic analysis even if the nuclide they are referring to is removed from the list of contaminants.

3.3.3 Input Rank Correlations

The input rank correlations tab screen (Figure 6) allows the user to view and edit all correlations among input parameters for probabilistic analysis. The paired parameters with non-zero correlations are listed in the left-hand frame. Correlations can be modified, added, or deleted in the right-hand frame.

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

Parameter List for Correlation: The currently chosen pairs of parameters are listed in the left-hand frame in a three-column table that shows the variable names in the code and the correlation coefficient. By clicking on any element in any row of the table, the user can modify or delete the correlation in the right-hand frame. The range of the correlation coefficient is from greater than −1.00 to less than 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-hand frame. If

**Figure 6 Input Rank Correlations Tab of the Uncertainty
Analysis Input Summary**

more parameters are chosen for correlation than fit in the window, the left-hand side becomes a scrolling table.

Correlation Edit: The two correlated parameters and the correlation coefficient are shown and editable in the right-hand frame. The user can also remove the correlation from further probabilistic consideration by clicking on the "Remove Correlation" button.

3.3.4 Output Specifications

The user selects from output options on the output specifications tab (Figure 7). More detailed output options (e.g., by pathway, by nuclide, by user-specified times) take longer to run.

Navigation: The output options are selected with the check boxes on the left-hand side of the screen. These options are the only inputs on this tab screen. The columns on the right show

what output options the user will be able to obtain for each of the checked options, after running RESRAD. The user will be able to specify and view these options from the interactive table and interactive graphic screens. Various correlation types are available (definitions can be found in Appendix A): partial correlation coefficient (PCC), partial rank correlation coefficient (PRCC), standardized partial regression coefficient (SPRC), and partial ranked regression coefficient (PRRC) (Iman et al., 1985).

3.4 Output Results

The case calculations are performed when the "Run" button is clicked. A pop-up window, shown in Figure 8, displays calculation progress feedback and an estimation of the time remaining for completion. The "Cancel" button in the lower right of this window allows the user to stop the calculations at any time. Upon completion of the calculations, the deterministic

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Uncertainty Analysis Input Summary

| Sample specifications | Parameter distributions | Input Rank Correlations | Output specifications |

PRE RESRAD run specifications

Check the outputs on which you want to perform probabilistic statistical analysis

☑ Peak total dose (summed over nuclides and pathways)

☑ Peak dose from each pathway (summed over all nuclides)

☑ Peak dose from each nuclide in the source (summed over all pathways)

☑ Dose from each nuclide and pathway at each of the user specified times

☑ Average dose at graphic time points for temporal plots

Proababilistic outputs available for current selection

The following probabilistic analysis options will be available for Peak total Dose:= 1. Scatter plots against each of the inputs, and against each of the peak component doses, 2. Cumulative frequency plot 3. Table of percentile values, 4. Statistics (mean, standard deviation, minimum, maximum), 5. Confidence intervals on mean and Statistical Tolerance limit on percentile doses, 6. Correlation statistics (Partial Correlation Coefficient, Partial Rank Correlation Coefficient, Standardized Partial Regression Coefficient, Partial Ranked Regression Coefficients)."

Set Parameter distributions and statistics

Output-Input correlation and regression options

Check the coefficients to be computed

	PCC	SRC	PRCC	SRRC
Dose at time of Peak mean dose	☑	☑	☑	☑
Peak total dose	☑	☑	☑	☑
Peak pathway dose	☑	☑	☑	☑
Peak nuclide dose	☑	☑	☑	☑

⊙ Perform uncertainty analysis   ○ Suppress uncertainty analysis this session   OK

Figure 7 Output Specifications Tab of the Uncertainty Analysis Input Summary

---

Run

Doing Calculations

UN   1, LAP 4, ITERATION   2,   3, 4, WSFACT   Co-60

Calculation Time 12.   Seconds   [Cancel]

Estimated time to completion 3 minutes 25 Seconds   217

Figure 8 Pop-up Window Showing Progress of Calculations and Estimated Time Remaining to Completion

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summary report appears in the viewer window. This report contains a complete list of all single-valued variables used in the case. This report contains the results from the deterministic calculations only, not any results of probabilistic analyses.

The output results are accessed in three different ways to assist the user in interpretation. They can be accessed by clicking on the "Results" tab of the Navigator window (Figure 9) that is usually in the upper right of the main interface window. The uncertainty analysis output is accessed through the buttons below the purple line. Also, the user can access the output through the "Results" button in the left-hand side blue column, through the menu's View options, or through the uncertainty toolbar buttons.

The "Interactive Output" window contains interactive tabular and graphical results to facilitate quick exploration of the data. The "Uncertainty Report" specifies the applied input and detailed results. The "LHS Report"

contains details of the sampling. The "Correlate Output" button in the Navigator window allows the user to specify additional output after the main calculation has been performed. Also, a formatted file (Access database) with the case name, but an ".MCO" extension, allows the user to access the raw input and output data for specific analysis needs.

Normally all the output results are stored in files that are overwritten the next time the software is run. If the user wants to save the results in files that will not be overwritten, the "Save All" option from the "File" menu of the report viewer must be run. When the user selects the "Save All" option, the output files are saved with the base name being the base of the input (.inp) file. A list of files saved are provided in Tables 1 and 2.

3.4.1 Interactive Output

The user can review the probabilistic inputs (Figure 10), including sampling specifications (repetitions, observations, random seed) and
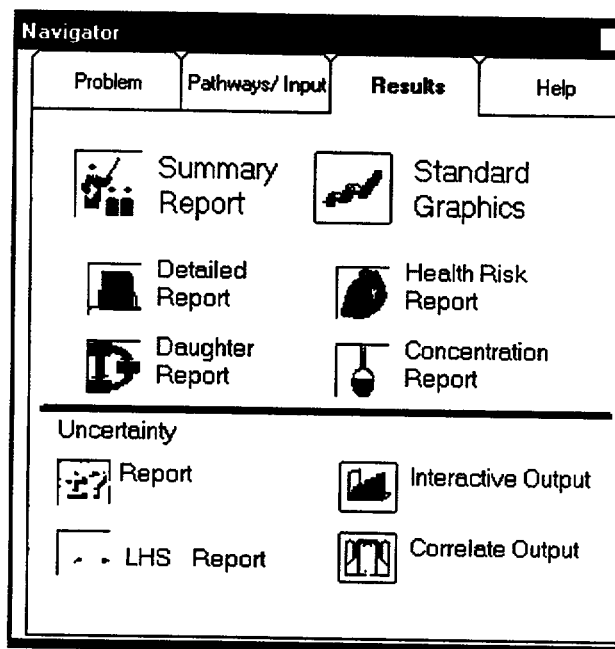
Figure 9 Navigator Window Showing the Results Tab Allowing Access to the Probabilistic Outputs

Table 1 List of Deterministic Files	
File Extension	**Description**
.sum	Summary file including the single values for nonprobabilistic variables, dose reports from the deterministic calculation, and single radionuclide soil guidelines
.det	Detailed report for intermediate deterministic calculations
.dau	Progeny report containing details about progeny ingrowth, decay, and contribution to the dose
.int	Risk report
.con	Concentration report detailing the concentration in the various media during environmental transport from the soil

Table 2 List of Probabilistic Files	
File Extension	**Description**
.prb	Probabilistic output report
.smp	Latin hypercube sampling report
.buo	Access database file containing the data for RESRAD-BUILD probabilistic analysis
.mco	Access database file containing the data for RESRAD probabilistic analysis

Figure 10 Interactive Output Windows Showing the Review of the Probabilistic Input Settings

input distributions and correlations, and can select what type of interactive output should be generated.

The third tab allows the user to explore the tabular and graphical results (Figure 11). For each table, the user can select from a set of primary statistical objects. These objects include the "Peak Pathway Dose," "Peak Nuclide Dose," and "Dose at User Times." Each of these primary statistical objects has a series of secondary statistical objects. In the case of the "Peak Pathway Dose" object, for example, the secondary statistical objects include each individual pathway, all pathways summed, and the time when the peak dose occurs. For the "Peak Nuclide Dose" object, the secondary objects include each individual nuclide. The secondary objects for the "Dose at User Times" include each individual pathway, all pathways, each nuclide, all nuclides, and each user time. After selecting the appropriate statistical object,

the user must specify the statistical property for analysis. The statistical properties include either "General Statistics" or "Percentile." The "General Statistics" table provides the minimum, maximum, mean standard deviation, and the 50th and 90th percentile of the statistical object selected. The "Percentile" property provides the 5th through 95th percentile at every 5th percentile for the statistical object selected.

Navigation: The user selects the type of output at the top of the left-hand frame by specifying the "Statistical Object" and the "Statistical Property." The results table is shown at the right of the screen. If the output is time dependent, the user must select from the previously entered specified times.

Statistical Objects: The objects include peak dose, peak nuclide dose, peak pathway dose, and doses at user-specified times.

Figure 11 RESRAD Uncertainty Output Window

Statistical Properties: The statistical properties include statistics (average, maximum, minimum, standard deviation) and percentile. The right-hand column of the results for these properties includes an estimate of how well these values are known based on the variation within the repetitions. The numbers under the "±" column are an estimate of the statistical uncertainty in the reported value of the selected statistic. It is defined as $1.96*S/sqrt(N)$, where S is the standard deviation of the values of the selected statistic from the repetitions and N is the number of repetitions. This uncertainty level is affected by both the number of repetitions and the number of observations. The values in this column have the same units as the selected statistic. For example, if the values for the average dose distribution for five repetitions are 5.5, 6.0, 6.5, 5.7, and 6.3, the reported average statistic is 6.0. The standard deviation of the distribution is approximately 0.41. The reported uncertainty in the combined average dose will be this standard deviation divided by the square root of 5, or 0.185.

3.4.2 Interactive Graphical Output

For the RESRAD and RESRAD-BUILD computer codes, graphical plots are available for viewing (Figures 12 through 14). The graphical plots include cumulative probability plots, scatter plots, and temporal plots (not available in RESRAD-BUILD). The cumulative probability plots provide a plot of the statistical object selected versus the cumulative probability. The same statistical objects available for the tables are available for the cumulative probability plots. The scatter plots provide a plot of the statistical object selected versus an input vector. Scatter plots should be used in conjunction with the correlation analysis to determine the correlation between the input vector(s) and the output. The temporal plot is a plot of dose versus time. For each repetition, the user can select a plot of either the mean dose versus time, 90th percentile dose versus time, or 95th percentile dose versus time. The user can also view all repetitions for a set percentile on a single graph. The temporal plot is used to identify the "peak of the means."
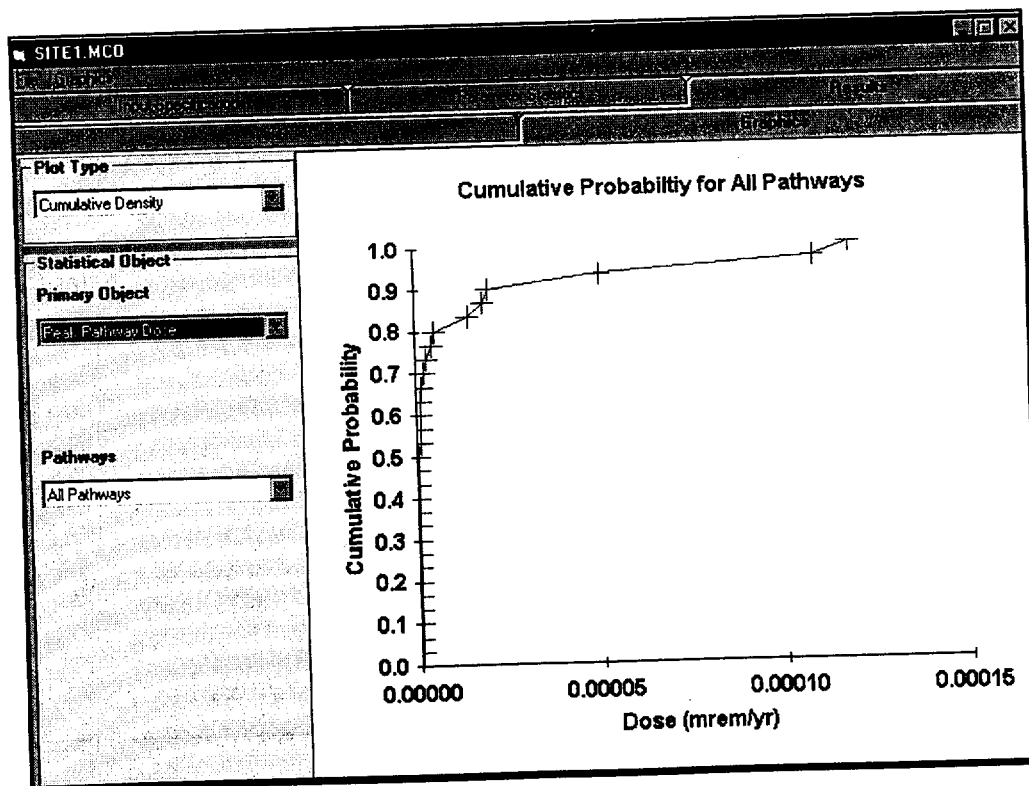
Figure 12 Interactive Graphical Output

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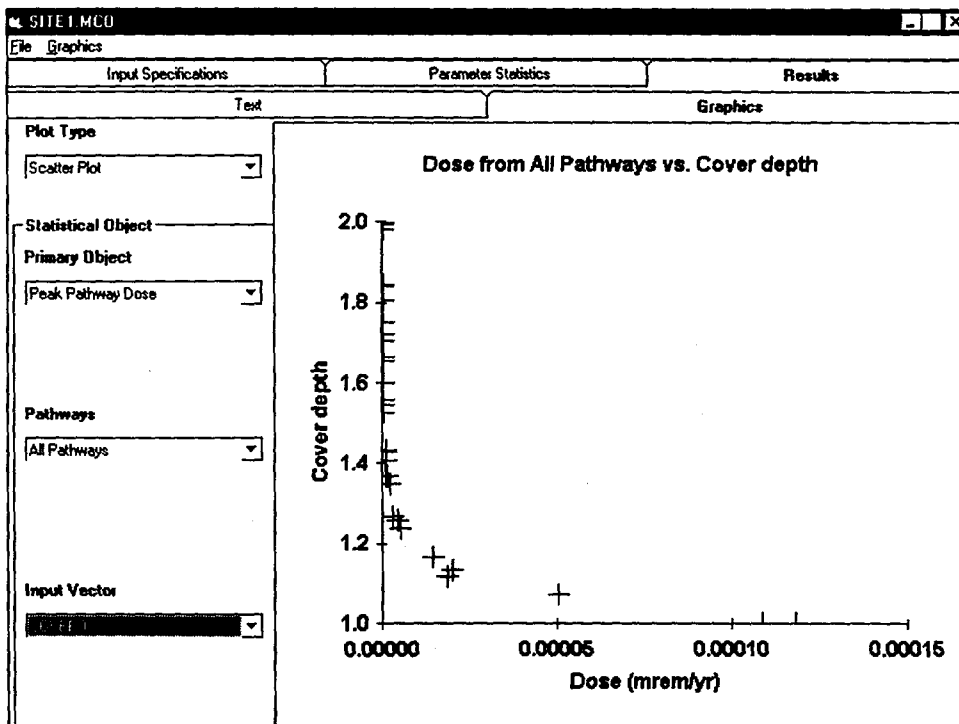
Figure 13 Scatter Plot
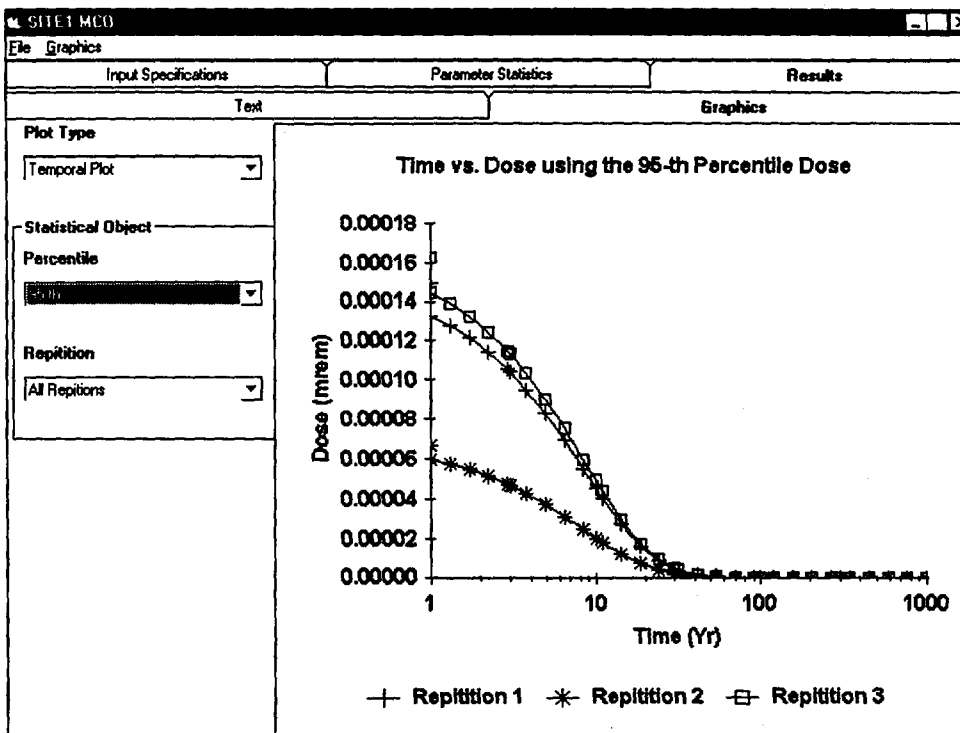
Figure 14 Temporal Plot

Navigation: The user selects the type of output at the top of the left-hand frame by specifying the "Statistical Object" and the "Statistical Property." The resulting graph is shown in the right-hand frame. If the output is time dependent, the user must then select from the previously entered specified times.

Statistical Objects: The objects include peak dose, peak nuclide dose, peak pathway dose, and doses at user-specified times.

Statistical Properties: The properties include output-input scatter plots, cumulative probability distributions, and temporal plots.

3.4.3 Complete Tabular Report

The RESRAD code generates two probabilistic report files. One pertains to the input, and the other pertains to the output.

RESRAD Input Report File: The Input Report File can be accessed via the View, Text output, LHS report menu option, among other ways. It is generated by the LHS program and is used by RESRAD. It includes the following information for each repetition (or replication) requested by the user:

- The initial random seed;

- The number of probabilistic variables;

- The current repetition;

- A description of each probabilistic variable, the specified distribution, parameters defining the distribution, and the label (FORTRAN name in RESRAD);

- The rank correlation matrix, if one was specified by the user;

- The adjusted rank correlation matrix, if the user-specified rank correlation matrix is not positive definite;

- A list of all the input samples (or vectors) that were generated;

- A list of the rank of all the input samples that were generated;

- A matrix of correlations among the raw values of the variable generated by the sampling program; and

- A matrix of correlations among the rank of values of the variable generated by the sampling program.

RESRAD Output Report File: The Output Report File can be accessed via the View, Text output, Uncertainty report menu option, among other ways. It is generated by RESRAD. The output tabular report (Figure 15) includes the following information:

- The distribution specified for each probabilistic variable and its parameters.

- User-specified times:

  a. A table of dose summed over all pathways.

  b. A table of risk summed over all pathways.

  c. A table for the dose from each of the 13 pathways, listing the minimum value, the maximum value, the average, and the standard deviation of a, b, and c above, respectively, for each nuclide and also for the sum over all nuclides.

  d. A table listing the cumulative probability (cumulative distribution function, CDF) of total dose (summed over nuclides and pathways) in CDF increments of 0.025.

- Graphical times:

  - A table of the minimum, maximum, mean, median, 90th, 95th, 97.5, and

```
┌────────────────────────────────────────────────────────────────┐
│ ▢ View - MCSUMMAR REP                              _ □ ☒         │
│ File  Edit  Help                                                 │
│ Font: │MS LineDraw ▼│10 ▼│      ▧ ▣ ▧    Page: │0 ▼│▼▲           │
│ RESRAD, Version 5.99     T½ Limit = 0.5 year   04/27/2000  11:48  Page ▲│
│ MCSummar: RESRAD Default Parameters                   File: SITE1.RA│
│                                                                  │
│                       Table of Contents                          │
│                      ──────────────────                          │
│                   Part V: Uncertainty Analysis                   │
│                   ────────────────────────────                   │
│                                                                  │
│ RESRAD Uncertainty Analysis Results                              │
│    Monte Carlo Input ......................................   2   │
│    Total Dose ............................................   3   │
│    Total Risk ............................................   4   │
│    Dose vs Pathway:  Ground External .....................   5   │
│    Dose vs Pathway:  Inhalation (w/o Radon) ..............   6   │
│    Dose vs Pathway:  Radon (Water Ind.) ..................   7   │
│    Dose vs Pathway:  Plant (Water Ind.) ..................   8   │
│    Dose vs Pathway:  Meat  (Water Ind.) ..................   9   │
│    Dose vs Pathway:  Milk  (Water Ind.) .................. 10   │
│    Dose vs Pathway:  Soil Ingestion ...................... 11   │
│    Dose vs Pathway:  Water Ingestion ..................... 12   │
│    Dose vs Pathway:  Fish Ingestion ...................... 13   │
│    Dose vs Pathway:  Radon (Water Dep.) .................. 14   │
│    Dose vs Pathway:  Plant (Water Dep.) .................. 15   │
│    Dose vs Pathway:  Meat  (Water Dep.) .................. 16   │
│    Dose vs Pathway:  Milk  (Water Dep.) .................. 17   │
│    MC Cumulative Probability Summary...................... 18   │
│    Summary of dose at graphical times, repetition 1..... 19   │
│    Summary of dose at graphical times, repetition 2..... 20   │
│    Summary of dose at graphical times, repetition 3..... 21   │
│    Peak of the mean dose at graphical times.............. 22   │
│                                                              ▼   │
│ ◄│                                                         │►│   │
└────────────────────────────────────────────────────────────────┘
```

Figure 15 Output Tabular Report

99th percentile of total dose (summed over nuclides and pathways). (A separate table is generated for each repetition.)

- A table summarizing the peak of the mean dose summed over all pathways and nuclides, and the time of the peak. There is a row of values for each of the repetitions.

• Time of the peak of the mean dose: A table of regression and correlation coefficients between the total dose (summed over nuclides and pathways) and each of the probabilistic inputs. The coefficients included are the partial correlation coefficient (PCC), the standardized regression coefficient (SRC), the partial rank correlation coefficient (PRCC), and the standardized rank regression coefficient (SRRC). The coefficients for the different repetitions are listed in different columns.

• Peak Dose

- A table of dose values summed over all pathways.

- A table each for the dose from each of the 13 pathways, listing the regression and correlation coefficients between the specified output and each of the probabilistic inputs. The coefficients included are the PCC, the SRC, the PRCC, and the SRRC. The coefficients for the different repetitions are listed in different columns.

Navigation: The user navigates through the report by using methods similar to those used for standard output reports of the RESRAD family of codes.

Adding Additional Calculations with Correlate Output: The "Correlate Output" button in the Navigator allows access to a

window (Figure 16) that allows the user to specify additional correlations after the main calculation has been completed. The new correlation is appended to the complete tabular report. By default, all the correlations on this screen are run. This form should be used only when some correlations have been turned off in the "Output Specification" tab of the Probabilistic Input Window.

3.4.4 Complete, Formatted Results File

The user has access to a complete, formatted set of output results and input sample vectors in Microsoft Access format (Figure 17). This access permits any type of analysis or graphing of the data. For example, the user can easily identify and analyze sample vectors that result in output values between certain percentiles.

Navigation: The user's own spreadsheet, database, or software program must be used to read the specified formatted data and to perform analyses. The database file name is the case base name with an ".MCO" extension. For example, if the case was saved in siteA.rad, then the database would be saved as siteA.MCO. The format of the file is Access version 2, which can be read by later Access versions.

(Note: The opened database file can be saved in an MS Access97 format, although it cannot be saved directly as a MS Access2000 format. To save the data in MS Access 2000 format the data must first be converted to MS Access97 and then converted with MS Access2000.)

The table listing (Figure 17) contains all input and output results. The details of the specifications for these tables are shown in Figure 18.

Figure 16 Adding Correlations to the Main Uncertainty Report after the Main Calculations Are Complete
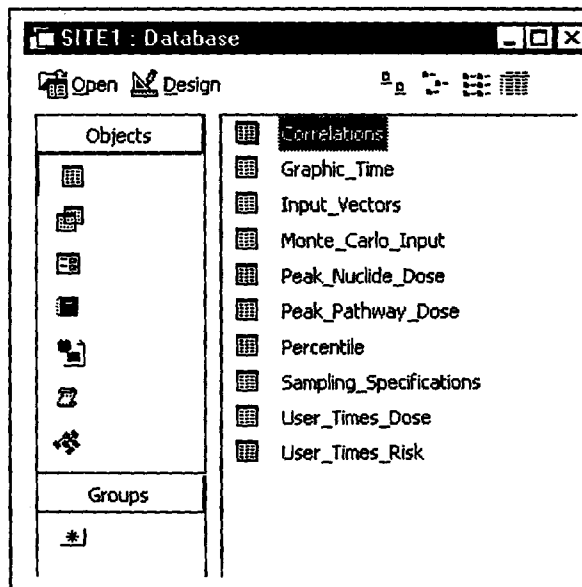
**Figure 17 Case ".MCO" File Table
List in Microsoft Access**

Field Name | Data Type | Description

Field Name	Data Type	Description
Rep	Number	
Observation	Number	
Isotope	Text	Isotope
Time	Number	Evaluation Time
External	Number	External Pathway
Inhalation w/o Rn	Number	Inhalation
Radon (WI)	Number	Radon Water Independent
Plant Ingestion (WI)	Number	Plant Ingestion Water Independen
Meat Ingestion (WI)	Number	Meat Ingestion Water Independen
Milk Ingestion (WI)	Number	Milk Ingestion Water Independent
Soil Ingestion	Number	Soil Ingestion
Water Ingestion	Number	Water Ingestion
Aquatic Foods	Number	Fish Ingestion
Radon (WD)	Number	Radon Water Dependent
Plant Ingestion (WD)	Number	Plant ingestion Water Dependent
Meat Ingestion (WD)	Number	Meat ingestion Water Dependent
Milk Ingestion (WD)	Number	milk ingestion Water Dependent
All Pathways	Number	Total Dose

Field Name	Data Type	Description
Rep	Number	Repitition
Time	Number	Graphic Time
Median	Number	Median dose at graphic time
90	Number	90percentile at graphic time
95	Number	95 percentile at graphic time

Field Name	Data Type	Description
Variable_Name	Text	
Distribution_Name	Text	
Stat_data	Memo	
Isotope	Text	
Parameter_Desc	Memo	
Index	Number	Index to sort variable names

Field Name	Data Type	Description
Seed	Number	
Observations	Number	
Repetitions	Number	
Sampling_technique	Text	Latin Hypercube or Monte Carlo
Grouping	Text	Correlated or Random
Title	Memo	Title from RESRAD output file
Variables	Number	Number of Variables for LHS

Field Name	Data Type	Description
Rep	Number	
Observation	Number	
Co-60	Number	

Field Name	Data Type	Description
Observ	Number	Repition
Percentile	Number	
Value	Number	Value at the desired percentile

Field Name	Data Type	Description
Rep	Number	
Observation	Number	
S(Co-60)	Number	
COVER0	Number	
DENSCZ	Number	

Peak_Pathway_Dose : Table

Field Name	Data Type	Description
Rep	Number	
Observation	Number	
All Pathways	Number	Total Dose
External	Number	External Pathway
Inhalation w/o Rn	Number	Inhalation
Radon (WI)	Number	Radon Water Independent
Plant Ingestion (WI)	Number	Plant Ingestion Water Indepe
Meat Ingestion (WI)	Number	Meat Ingestion Water Indepe
Milk Ingestion (WI)	Number	Milk Ingestion Water Indepen
Soil Ingestion	Number	Soil Ingestion
Water Ingestion	Number	Water Ingestion
Aquatic Foods	Number	Fish Ingestion
Radon (WD)	Number	Radon Water Dependent
Plant Ingestion (WD)	Number	Plant ingestion Water Depend
Meat Ingestion (WD)	Number	Meat ingestion Water Depend
Milk Ingestion (WD)	Number	milk ingestion Water Depende
Time of Peak Total Dose	Number	Time of peak pathway dose fo

Field Properties

Figure 18 Detailed Specification of Table Structure for Database File

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4 SAMPLE CASE

This section analyzes a hypothetical test case to demonstrate the use of the various features of the probabilistic RESRAD code. The case used was selected because it is relatively simple but still illustrates the workings of the code.

additive. Knowing, *a priori*, how the variables influence the endpoint of interest, the peak of the mean doses at the graphical times used in this case helps illustrate the use of the various outputs available in RESRAD.

4.1 Scenario Description

One radionuclide, Ra-226, is considered at an initial concentration of 30 pCi/g. Probabilistic analysis is performed on a total of 8 input variables; details are given in Table 3.

While most of the distributions used here are those identified as national (default) distributions, the distributions for outdoor time fraction and indoor time fraction were specified for this illustrative example only. The variables selected for this simple case all have a linear effect on the dose; that is, the contributions of each of these variables to the total dose are

4.2 Case Implementation and Interpretation

The variables for the probabilistic analysis were specified by opening the input form containing the variable and then selecting that variable for uncertainty analysis. If a national (default) distribution was identified for that variable in Task 1.3 (Biwer et al., 2000), that distribution along with the defining parameters were automatically filled into the uncertainty input screen from the database. When a national (default) distribution was not available, a distribution was chosen from the drop-down list box, and appropriate defining parameters were input for this illustrative example.

Table 3 Input Parameters and Their Distributions Selected for Probabilistic Analysis			
Input Variable	**FORTRAN Name**	**Distribution**	**Distribution's Statistical Parameters**
Fish transfer factor for Ra	BBIO(88,1)	LOGNORMAL-N	3.9 1.1
Milk transfer factor for Ra	BRTF(88,3)	LOGNORMAL-N	-6.91 0.47
Meat transfer factor for Ra	BRTF(88,2)	LOGNORMAL-N	-6.91 0.693147
Plant transfer factor for Pb	BRTF(82,1)	LOGNORMAL-N	-5.52 0.916291
Fish transfer factor for Pb	BBIO(82,1)	LOGNORMAL-N	5.7 1.1
Outdoor time fraction	FOTD	UNIFORM	0.01 0.4
Indoor time fraction	FIND	UNIFORM	0.33 0.67
Drinking water intake	DWI	TRUNCATED LOGNORMAL-N	6.015 0.489 0.001 0.999

A negative correlation was specified between the indoor and outdoor time fractions because these two variables are likely to be inversely related. A negative correlation between the indoor and outdoor time fractions was also necessary to ensure that the total time fraction did not exceed 1. For the purpose of this example, a rank correlation coefficient of -0.75 was used. As shown in Figure 19, a rank correlation coefficient of -0.6 is sufficient to ensure that the time constraint is not violated.

Correlation between the drinking water intake and the outdoor time fraction was added to illustrate the care that needs to be taken when specifying multiple correlations for a given variable. If, for example, a rank correlation coefficient of 0.7 is specified between the drinking water intake and the outdoor time fraction, and no (or zero) correlation is specified between the drinking water intake and the

indoor time fraction, then the sampling program will not be able to find a set of inputs that satisfy the specified correlations. This situation occurs because there will be some correlation between the drinking water intake (DWI) and the indoor time fraction (FIND) when the correlations specified between DWI and the outdoor time fraction (FOTD) and between the indoor and outdoor time fractions are satisfied. This situation will be indicated in the LHS report. The report will caution that the specified rank correlation matrix is not positive definite. It will suggest an adjusted rank correlation matrix. The rank correlations suggested by the code between the three pairs of variables in this case are: FIND ↔ FOTD = -0.7345, DWI ↔ FOTD = +0.6856, and DWI ↔ FIND = -0.0105. While the suggested adjusted rank correlation matrix is quite close to the specified one in this example, that does not always happen, and the user must look at the LHS report to ensure that
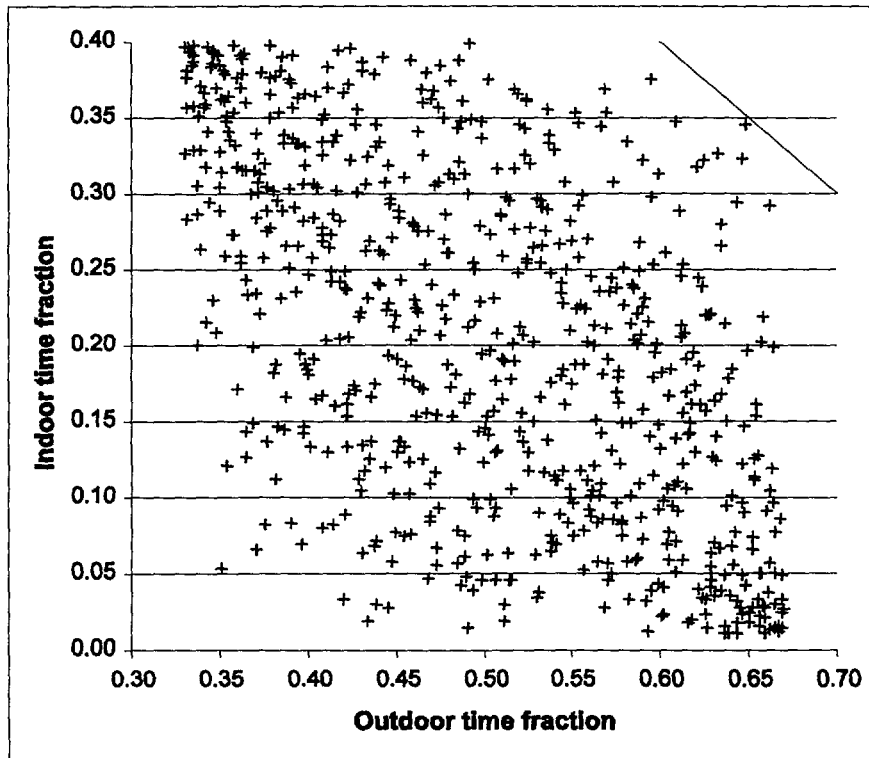

Figure 19 Scatter Plot of Indoor Time Fraction
against Outdoor Time Fraction for a Rank
Correlation Coefficient of -0.6

any adjustments to the rank correlation matrix suggested by the code are acceptable.

The number of observations taken from each distribution affects the accuracy of the predicted probabilistic outputs. An indication of the accuracy of the prediction can be obtained by repeating the probabilistic runs with a different set of observations. The user can accomplish this by specifying the number of repetitions. The range of the predicted outputs for different sample sizes (i.e., number of observations) is shown in Figures 20 through 22. Five different sample sizes of 10, 12, 25, 50, and 100 were analyzed, each with seven repetitions. The three outputs considered were the peak of the mean dose at graphical times, the median dose at 299 years, and the 90% dose at 299 years. (The peak of the mean dose occurred at 299 years for all seven repetitions of each of the five sample sizes.) As would be expected, the predictions of the peak of the mean dose are of a narrower range than the 90% dose for any given sample size. The user may wish to increase the sample size until the desired accuracy is achieved.

One way of judging the relative importance of the different probabilistic variables for their influence on the output is by the regression and correlation coefficients. The probabilistic RESRAD code offers the user a choice of four different coefficients: the partial correlation coefficient (PCC), the standardized regression coefficient (SRC), the partial rank correlation coefficient (PRCC), and the standardized rank regression coefficient (SRRC). Each is appropriate for different situations. In this example, the outputs are linearly related to the probabilistic input variables. The PCC and the SRC are more appropriate for a case where this relationship is linear or nearly so. On the other hand, the PRCC and the SRRC are suitable for cases where the output is nonlinearly related to the inputs. The user can decide on the set of parameters to be used by comparing the coefficient of determination (R-square) shown in the uncertainty report for the linear model and the nonlinear model. The coefficient of determination is a measure of the variation in the output that is explained by the probabilistic input variables. In this example, the coefficient of determination for the linear model is close to
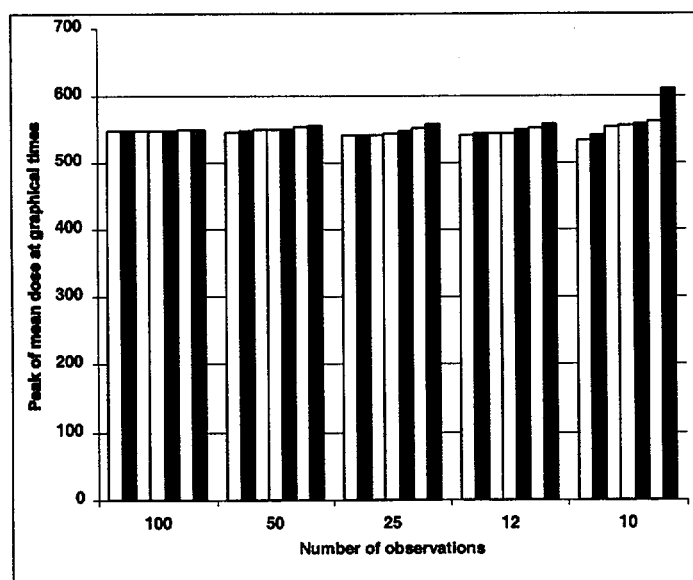

**Figure 20 Variation of the Peak of the
Mean Dose at Graphical Times with
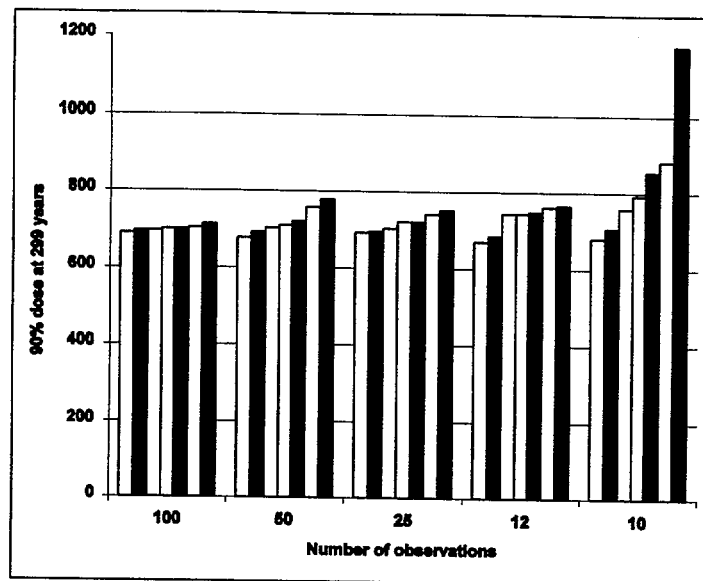Sample Size, for Seven Repetitions**

29

**Figure 21 Variation of 90% Dose at
299 Years with Sample Size,
for Seven Repetitions**
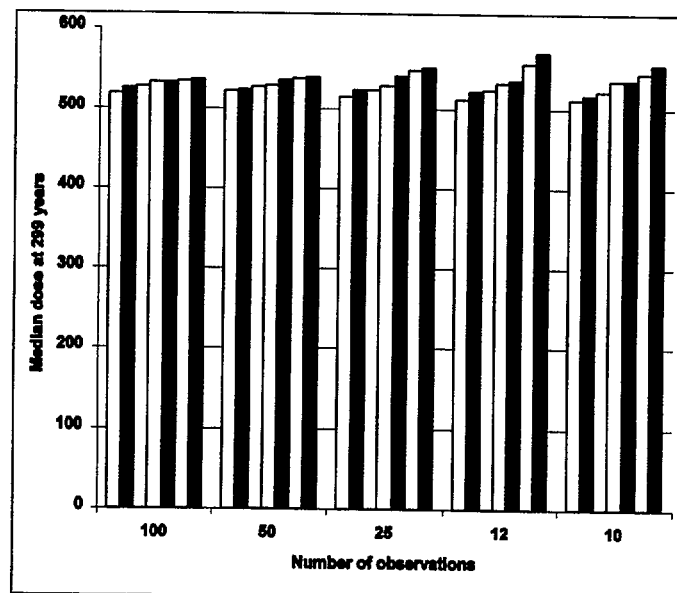
**Figure 22 Variation of Median (50%)
Dose at 299 Years with Sample Size,
for Seven Repetitions**

1.0, while that for the nonlinear model is close to 0.9.

The selection of the appropriate model (linear or nonlinear) narrows the available coefficients to two. Each of the two are again suitable under different circumstances. This example was chosen so the outputs are strictly linear in the inputs. When the output is strictly linearly related to the inputs (or is very nearly so), the PCCs for all input variables will be unity (or very nearly so). In such a case, the SRC is the appropriate coefficient for judging the relative importance of the influence of the input variables on the predicted output. Strong correlations between the input variable will give rise to large, spurious SRCs. When strong correlations exist between the input variables, the PRC would be a better indicator of their relative importance. Tables 4 through 7, extracted from the uncertainty output, show the coefficients for the case with 100 observations and 7 repetitions.

Another way of evaluating the influence of the input variables on the predicted output is to view the scatter plots between the output and each of the inputs. The interactive results screen of the code allows the user to view these scatter plots. Scatter plots of the two most significant parameters, on the basis of their influence on the peak dose from all pathways, are shown in Figures 23 and 24. These are the same two parameters that were identified as being the most significant by the SRC.

4.3 Summary

The identification of the parameters that have a significant influence on the chosen output is not always straightforward. RESRAD provides a number of tools, including scatter plots, temporal plots of the mean dose and selected dose percentiles, and four correlation and regression coefficients to facilitate their identification. Each of these tools is appropriate under different circumstances. Sometimes additional analysis is required to determine the significant parameters.

Table 4 Partial Correlation Coefficients for Peak of the Mean Dose

Coefficient = Repetition = Variable	PCC 1		PCC 2		PCC 3		PCC 4		PCC 5		PCC 6		PCC 7	
	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff
BBIO(88,1)	8	1.00	8	1.00	8	1.00	8	1.00	8	1.00	8	1.00	8	1.00
BRTF(88,3)	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00
BRTF(88,2)	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00	6	1.00
BRTF(82,1)	2	1.00	2	1.00	2	1.00	3	1.00	2	1.00	2	1.00	2	1.00
BBIO(82,1)	4	1.00	5	1.00	5	1.00	3	1.00	4	1.00	4	1.00	5	1.00
FOTD	5	1.00	5	1.00	5	1.00	5	1.00	5	1.00	5	1.00	5	1.00
FIND	2	1.00	2	1.00	2	1.00	3	1.00	2	1.00	2	1.00	2	1.00
DWI	2	1.00	2	1.00	2	1.00	3	1.00	2	1.00	2	1.00	2	1.00
R-SQUARE		1.00		1.00		1.00		1.00		1.00		1.00		1.00

Table 5 Standardized Regression Coefficients for Peak of the Mean Dose

Coefficient = Repetition = Variable	SRC 1		SRC 2		SRC 3		SRC 4		SRC 5		SRC 6		SRC 7	
	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff
BBIO(88,1)	8	0.00	8	0.00	8	0.00	8	0.00	8	0.00	8	0.00	8	0.00
BRTF(88,3)	7	0.01	7	0.02	7	0.01	7	0.01	7	0.02	7	0.01	7	0.02
BRTF(88,2)	6	0.02	6	0.02	6	0.02	6	0.02	6	0.02	6	0.02	6	0.02
BRTF(82,1)	2	0.46	2	0.46	2	0.47	2	0.45	2	0.48	2	0.45	2	0.48
BBIO(82,1)	5	0.05	5	0.05	5	0.05	5	0.07	5	0.06	5	0.06	5	0.05
FOTD	4	0.14	4	0.14	4	0.14	4	0.13	4	0.15	4	0.14	4	0.13
FIND	3	0.35	3	0.35	3	0.35	3	0.33	3	0.37	3	0.34	3	0.33
DWI	1	0.75	1	0.76	1	0.77	1	0.74	1	0.80	1	0.74	1	0.78
R-SQUARE		1.00		1.00		1.00		1.00		1.00		1.00		1.00

Table 6 Partial Rank Correlation Coefficients for Peak of the Mean Dose														
Coefficient = Repetition =	PRCC 1		PRCC 2		PRCC 3		PRCC 4		PRCC 5		PRCC 6		PRCC 7	
Variable	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff
BBIO(88,1)	6	-0.05	7	-0.05	8	-0.02	8	0.01	7	0.04	7	-0.04	7	-0.07
BRTF(88,3)	8	0.02	5	-0.09	6	-0.11	3	0.20	4	0.25	6	-0.09	5	-0.10
BRTF(88,2)	4	0.25	6	0.05	4	0.26	7	0.06	8	0.03	4	0.21	8	0.02
BRTF(82,1)	1	0.84	1	0.74	1	0.80	1	0.79	1	0.82	1	0.76	1	0.79
BBIO(82,1)	5	0.18	4	0.22	5	0.13	5	0.17	6	0.12	5	0.12	4	0.28
FOTD	7	0.03	8	0.01	7	0.03	6	-0.14	5	0.22	8	0.01	6	0.1
FIND	3	0.32	3	0.25	3	0.27	4	0.17	3	0.50	3	0.26	3	0.38
DWI	2	0.75	2	0.68	2	0.66	2	0.73	2	0.64	2	0.67	2	0.65
R-SQUARE		0.95		0.90		0.92		0.92		0.93		0.92		0.93

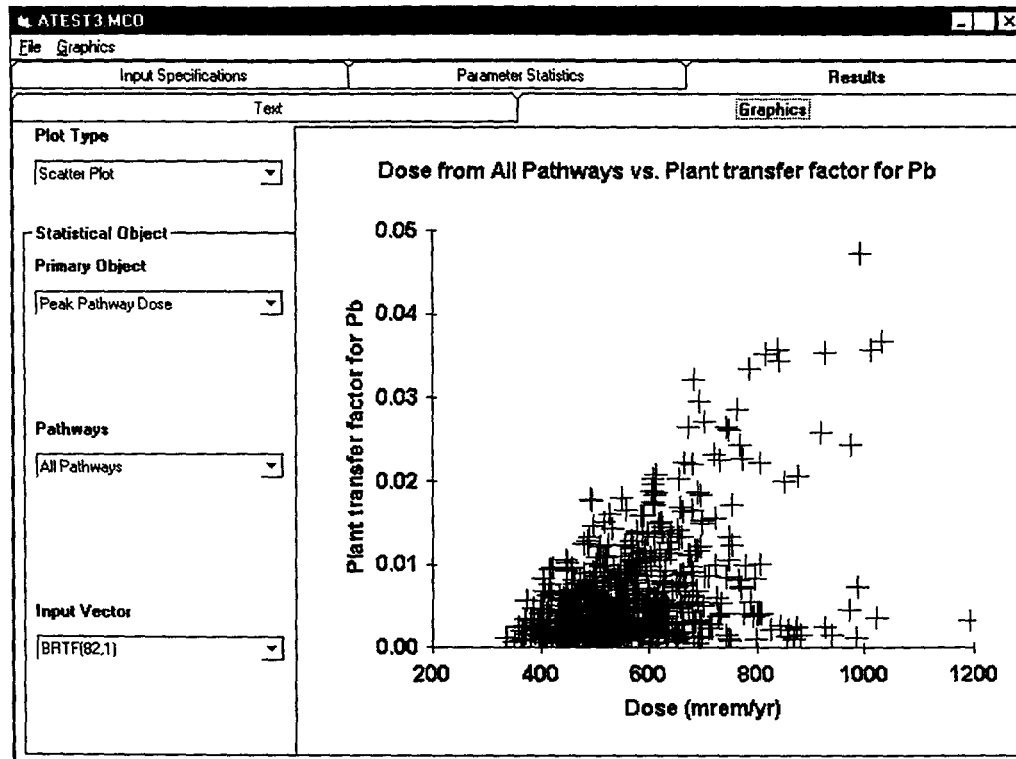| Table 7 Standardized Rank Regression Coefficients for Peak of the Mean Dose														
Coefficient = Repetition =	SRRC 1		SRRC 2		SRRC 3		SRRC 4		SRRC 5		SRRC 6		SRRC 7	
Variable	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff	Sig	Coeff
BBIO(88,1)	7	-0.01	7	-0.02	8	-0.01	8	0.00	7	0.01	7	-0.01	7	-0.02
BRTF(88,3)	8	0.00	5	-0.03	7	-0.03	5	0.06	5	0.07	6	-0.03	6	-0.03
BRTF(88,2)	4	0.06	6	0.02	4	0.08	7	0.02	8	0.01	4	0.06	8	0.01
BRTF(82,1)	2	0.36	2	0.35	2	0.38	2	0.37	3	0.40	2	0.33	3	0.36
BBIO(82,1)	5	0.04	4	0.07	6	0.04	6	0.05	6	0.03	5	0.03	5	0.08
FOTD	6	0.03	8	0.01	5	0.04	3	-0.17	4	0.27	8	0.01	4	0.12
FIND	3	0.27	3	0.26	3	0.27	4	0.15	2	0.53	3	0.28	2	0.38
DWI	1	0.85	1	0.85	1	0.80	1	0.96	1	0.66	1	0.86	1	0.76
R-SQUARE		0.95		0.90		0.92		0.92		0.93		0.92		0.93
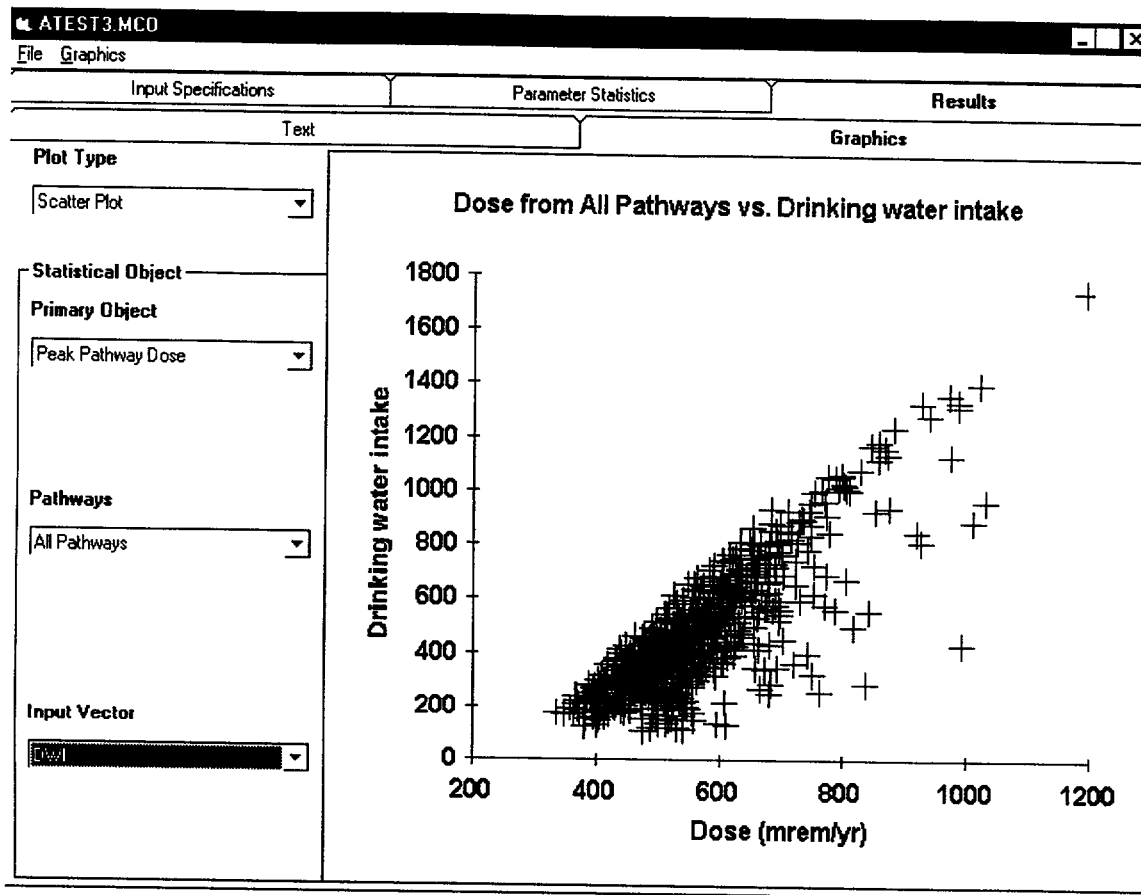
**Figure 23 Scatter Plot of Drinking Water Intake and
Peak Total Dose from All Pathways,
All Repetitions Combined**

File Graphics

| Input Specifications | Parameter Statistics | Results |

| Text | Graphics |

Plot Type

Scatter Plot

Statistical Object

Primary Object

Peak Pathway Dose

Pathways

All Pathways

Input Vector

BRTF(82,1)

Dose from All Pathways vs. Plant transfer factor for Pb

Plant transfer factor for Pb

0.05

0.04

0.03

0.02

0.01

0.00

200   400   600   800   1000   1200

Dose (mrem/yr)

**Figure 24 Scatter Plot of Soil-to-Plant Transfer Factor
for Lead and the Peak Dose from All Pathways,
All Repetitions Combined**

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APPENDIX A

PROBABILISTIC ANALYSIS IN RESRAD AND RESRAD-BUILD

A.1 INTRODUCTION

Probabilistic analysis in RESRAD or RESRAD-BUILD is the computation of the total uncertainty induced in the output (calculated 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 in the calculated dose. 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 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 rank regression coefficients are computed and ranked to provide a tool for determining the relative importance of input parameters in influencing the calculated dose.

A.2 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 A.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 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.

Table A.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 the 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.

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.

A.3 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.

A.4 PROBABILISTIC ANALYSIS 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 A.2 compares the approaches available for correlating the uncertainty in the distribution of doses to the uncertainty in the input parameter.

Table A.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).		

A.5 REFERENCES FOR APPENDIX A

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, IL, for U.S. Nuclear Regulatory Commission, Washington, DC. March 2000. *This letter report will be included as Attachment C to a NUREG/CR report: "Development of Probabilistic RESRAD and RESRAD-BUILD Codes" (in publication).*

Cullen, A.C. and H.C. Frey. *Probabilistic Techniques in Exposure Assessment.* Plenum Press: New York. 1999.

Iman, R.L. and J.C. Helton. NUREG/CR-3904, SAND84-1461 RG, "A Comparison of Uncertainty and Sensitivity Analysis Techniques for Computer Models." Prepared by Sandia National Laboratories, Albuquerque, NM, for the U.S. Nuclear Regulatory Commission, Washington, DC. March 1985.

Iman, R.L. and M.J. Shortencarier. NUREG/CR-3624, SAND83-2365 RG, "A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models." Prepared by Sandia National Laboratories, Albuquerque, NM, for U.S. Nuclear Regulatory Commission, Washington, DC. March 1984.

Iman, R.L., et al. NUREG/CR-4122, SAND85-0044 RG, "A FORTRAN 77 Program and User's Guide for the Calculation of Partial Correlation and Standard Regression Coefficients." Prepared by Sandia National Laboratories, Albuquerque, NM, for U.S. Nuclear Regulatory Commission, Washington, DC. June 1985.

International Atomic Energy Agency. "Evaluating Reliability of Predictions Made Using Environmental Transfer Models." IAEA Report No. 100. IAEA: Vienna. 1989.

McKay, M.D., et al. "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code." *Technometrics,* Vol. 21, pp. 239-245.

APPENDIX B

OVERVIEW OF ASSIGNMENT OF PARAMETER DISTRIBUTIONS

B.1 INTRODUCTION

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.

B.2 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 B.1 lists the parameters assigned distributions; it also lists the parameter type and assigned distribution type for each.

B.3 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 fitted 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 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.

Table B.1 Parameters Assigned Probability Density Functions		
Parameter	**Parameter Type[a]**	**Assigned Distribution Type**
RESRAD		
Density of contaminated zone (g/cm³)	P	Normal
Density of cover material (g/cm³)	P	Normal
Density of saturated zone (g/m³)	P	Normal
Depth of roots (m)	P	Uniform
Distribution coefficients (contaminated zone, unsaturated zones, and saturated zone)(cm³/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/m³)	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/cm³)	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 B.1 Parameters Assigned Probability Density Functions (Continued)	Parameter Type[a]	Assigned Distribution Type
Parameter		
Well pumping rate (m³/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 nonleafy vegetables (kg/m²)	P	Lognormal
Wind speed (m/s)	P	Lognormal
Humidity in air (g/m³)	P	Lognormal
Indoor fraction	B	Empirical
Inhalation rate (m³/yr)	M, P	Triangular
RESRAD-BUILD		
Removable fraction	P, B	Uniform
Resuspension rate (1/s)	P, B	Loguniform
Shielding density (g/cm³)	P	Uniform
Source density, volume source (g/cm³)	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/m³)	P, B	Uniform
Indoor fraction	B	Empirical
Receptor indirect ingestion rate (m²/h)	B	Loguniform
Receptor inhalation rate (m³/d)	M, B	Triangular
Room area (m²)	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 the next is secondary (Kamboj et al., 1999).

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

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 (Wernig et al., 1999) input parameters, the DandD default values were used if appropriate. Table B.1 in Appendix B of Kamboj et al. (2000) lists the assigned distributions for the Priority 1 and 2 parameters in the RESRAD and the RESRAD-BUILD codes.

B.4 REFERENCES FOR APPENDIX B

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, IL, for U.S. Nuclear Regulatory Commission, Washington, DC. March 2000. *This letter report will be included as Attachment C to a NUREG/CR report: "Development of Probabilistic RESRAD and RESRAD-BUILD Codes" (in publication).*

Cheng, J.-J., et al. "Selection of RESRAD and RESRAD-BUILD Input Parameters for Detailed Distribution Analysis, Revision 1." Letter report prepared by Argonne National Laboratory, Argonne, IL, for U.S. Nuclear Regulatory Commission, Washington, DC. October 1999. *This letter report will be included as Attachment B to a NUREG/CR report: "Development of Probabilistic RESRAD and RESRAD-BUILD Codes" (in publication).*

Kamboj, S., et al. "Parameters and Parameter Types in RESRAD and RESRAD-BUILD Codes." Letter report prepared by Argonne National Laboratory, Argonne, IL, for U.S. Nuclear Regulatory Commission, Washington, DC. September 1999. *This letter report will be included as Attachment A to a NUREG/CR report: "Development of Probabilistic RESRAD and RESRAD-BUILD Codes" (in publication).*

Kamboj, S., et al. NUREG/CR-6676, ANL/EAD/TM-89, "Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes." Prepared by Argonne National Laboratory, Argonne, IL, for U.S. Nuclear Regulatory Commission, Washington, DC. July 2000.

Kennedy, W.E. and D.L. Strenge. NUREG/CR-5512, PNL 7994, Vol. 1, "Residual Radioactive Contamination from Decommissioning; A Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent." Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, Washington, DC. October 1992.

Wernig, M.A., et al. NUREG/CR-5512, Vol. 2, "Residual Radioactive Contamination from Decommissioning." May 1999.

APPENDIX C

QUICK TOUR OF RESRAD

C.1 INTRODUCTION

This appendix introduces the user to the interface through the definition, input, and interpretation of a simple case. It is not meant to be complete but rather to help the user to quickly become familiar with some common features of the software. It is assumed that the user has already installed the software as specified in Section 3.1. The following presentation consists of a series of steps to execute the software for the sample case. To make the process easier to follow, each step, along with the associated software screen, is presented on a separate page. For this example, "Case Input" consists of 20 steps and "Case Output" consists of 22 steps.

C.2 SAMPLE CASE DEFINITION

Probabilistic analysis needs to be conducted for a site where the soil is contaminated with 100 pCi/g U-238. Probabilistic analysis will be conducted on the distribution coefficients and the plant transfer factor. Other site-specific values for the thicknesses of the contaminated zone and unsaturated zone will be used.

C.3 CASE INPUT

Step 1: Launch the RESRAD 6 interface and code. Click on the "OK" button in the upper right of the "About RESRAD" screen to get started.
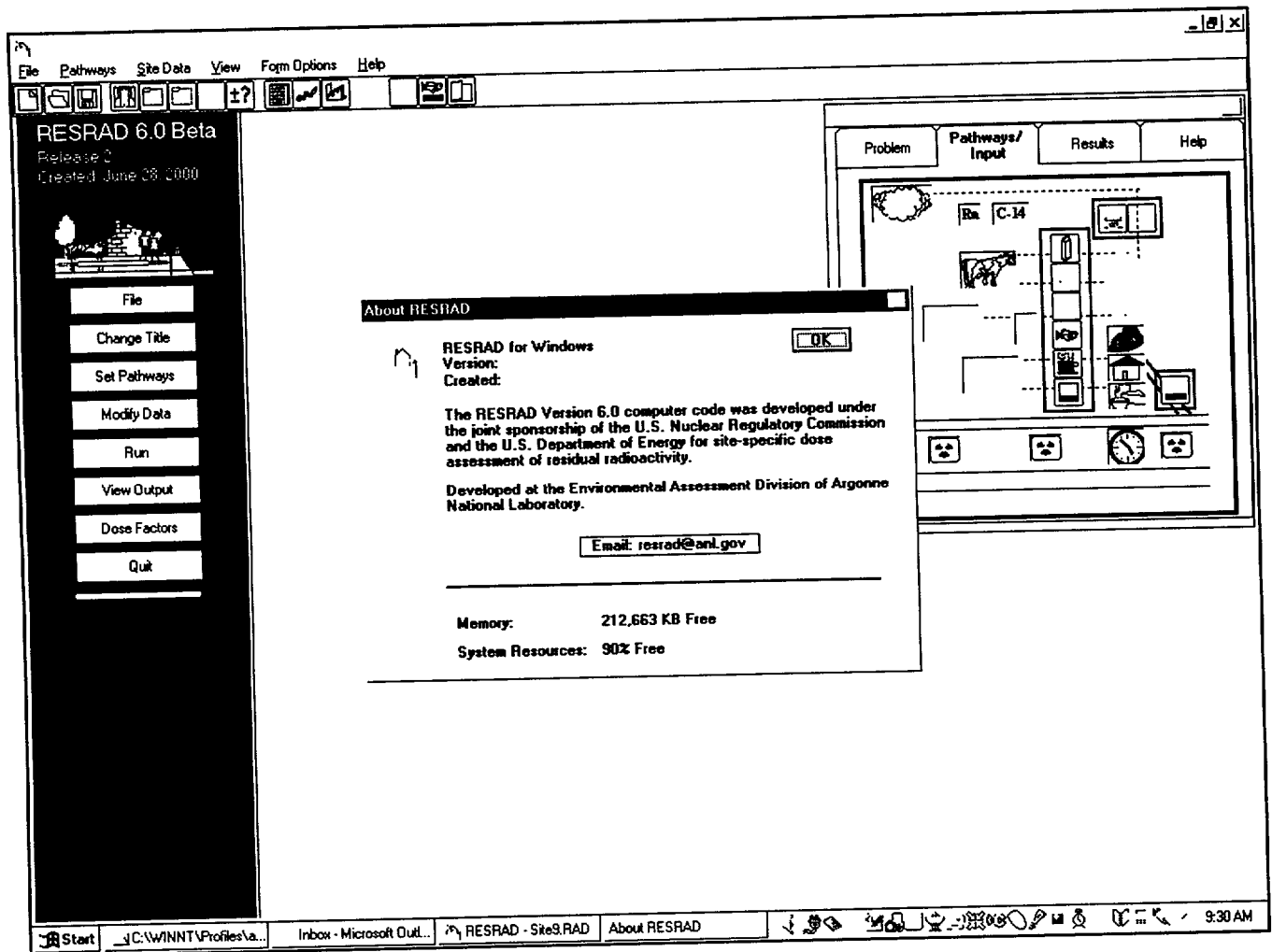
Step 2: Change the title by clicking on the "Change Title" button in the main (blue) column on the left. Type in a title, such as "Guided Tour Example" shown below.

Click on the "OK" button when done. For faster calculations, reduce the "Time Integration Parameters" to 1 for both dose and risk.
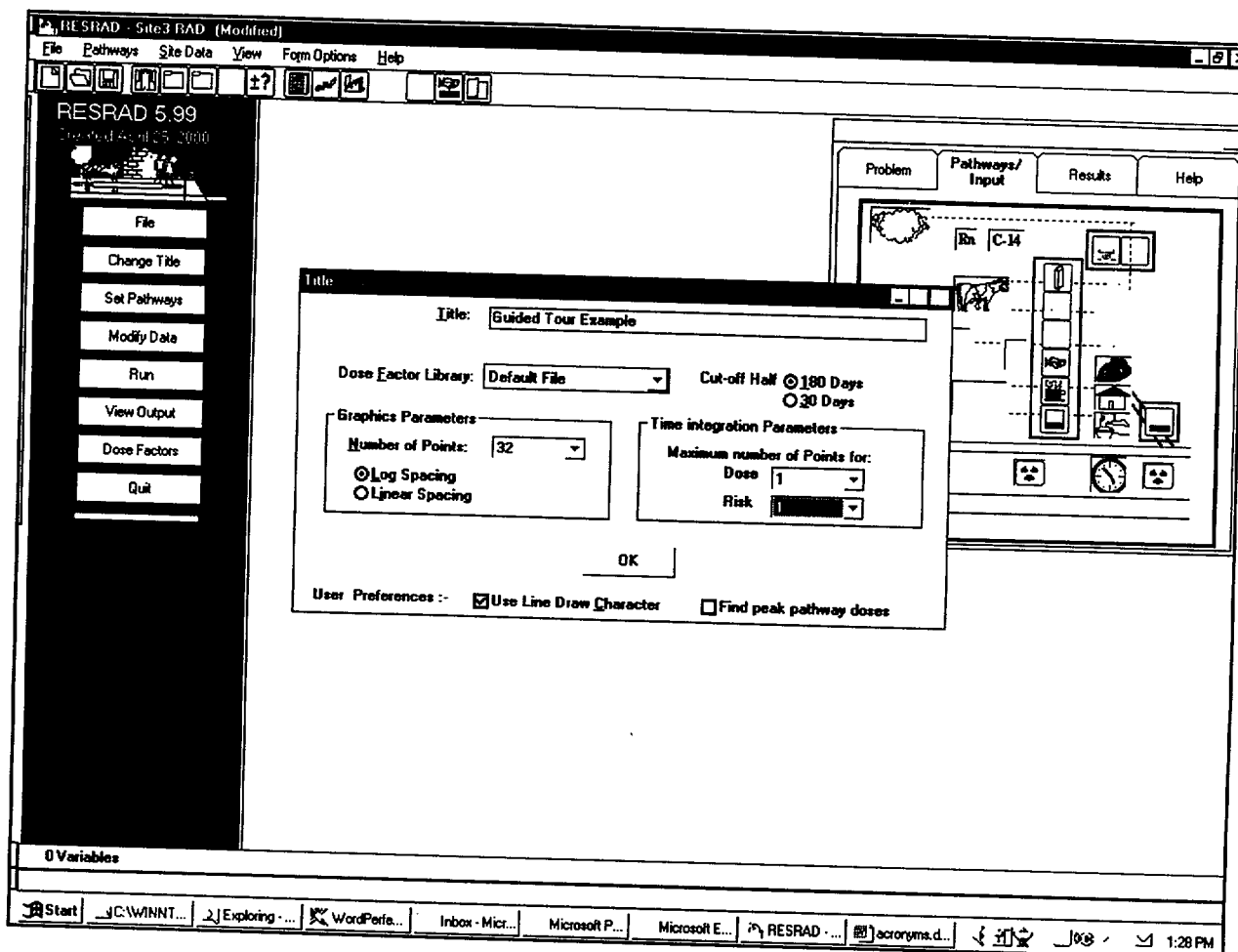
Step 3: Change the parameters by clicking on "Modify Data" in the first (main, blue) column on the left. Specify the contamination by clicking on the first button, "Soil Concentrations," in the second column on the left. Specify the concentration (100 pCi/g) in the input box in the center top of the "Source" window, and select U-238 from the nuclide list on the right side. Then click on the "Add Nuclide" button, adding U-238 at 100 pCi/g and its long-term decay products at 0 pCi/g to the left side.
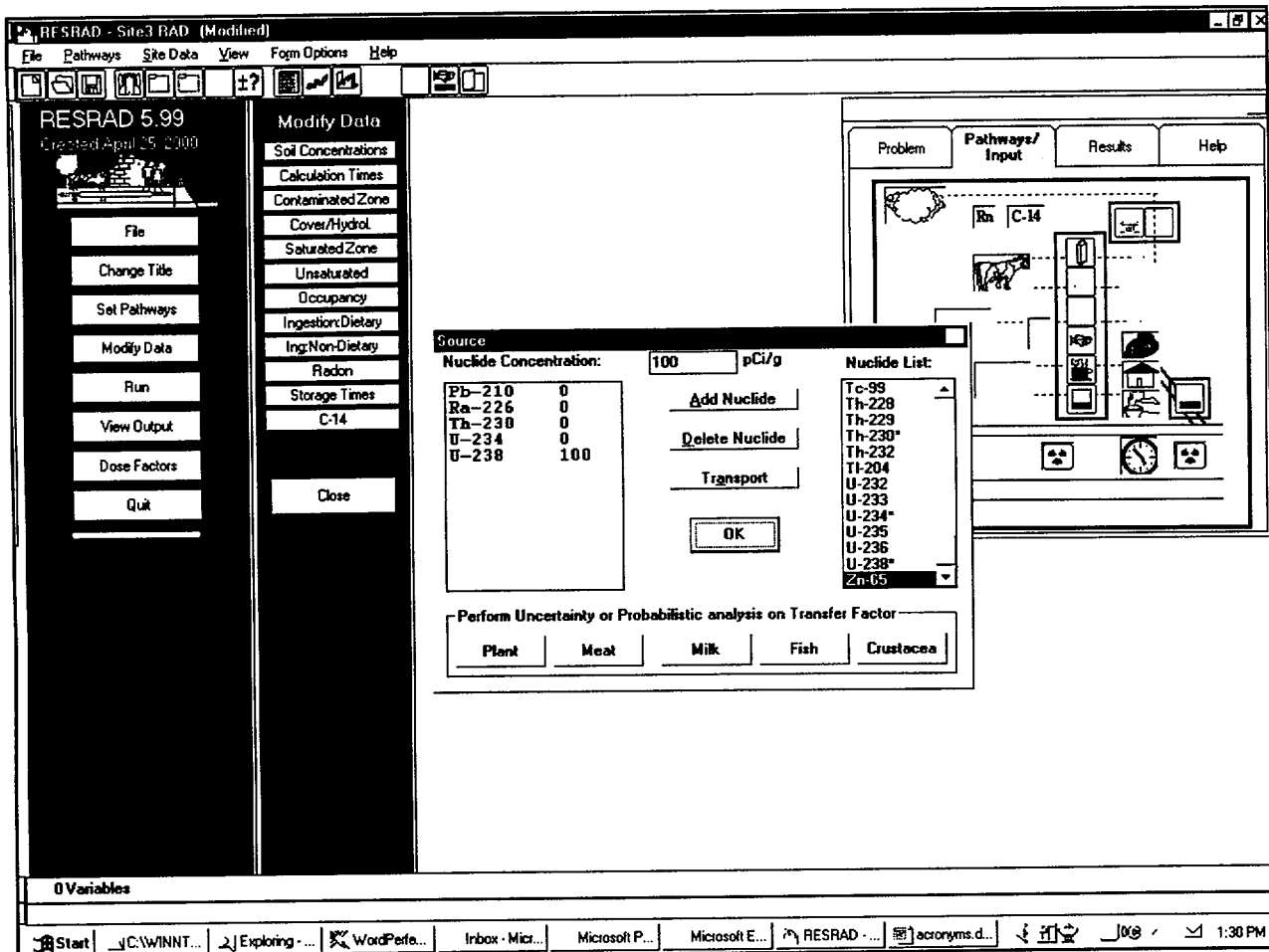
Step 4: Click on the "Transport" button in the "Source" window while U-238 is highlighted (in blue) on the left side.
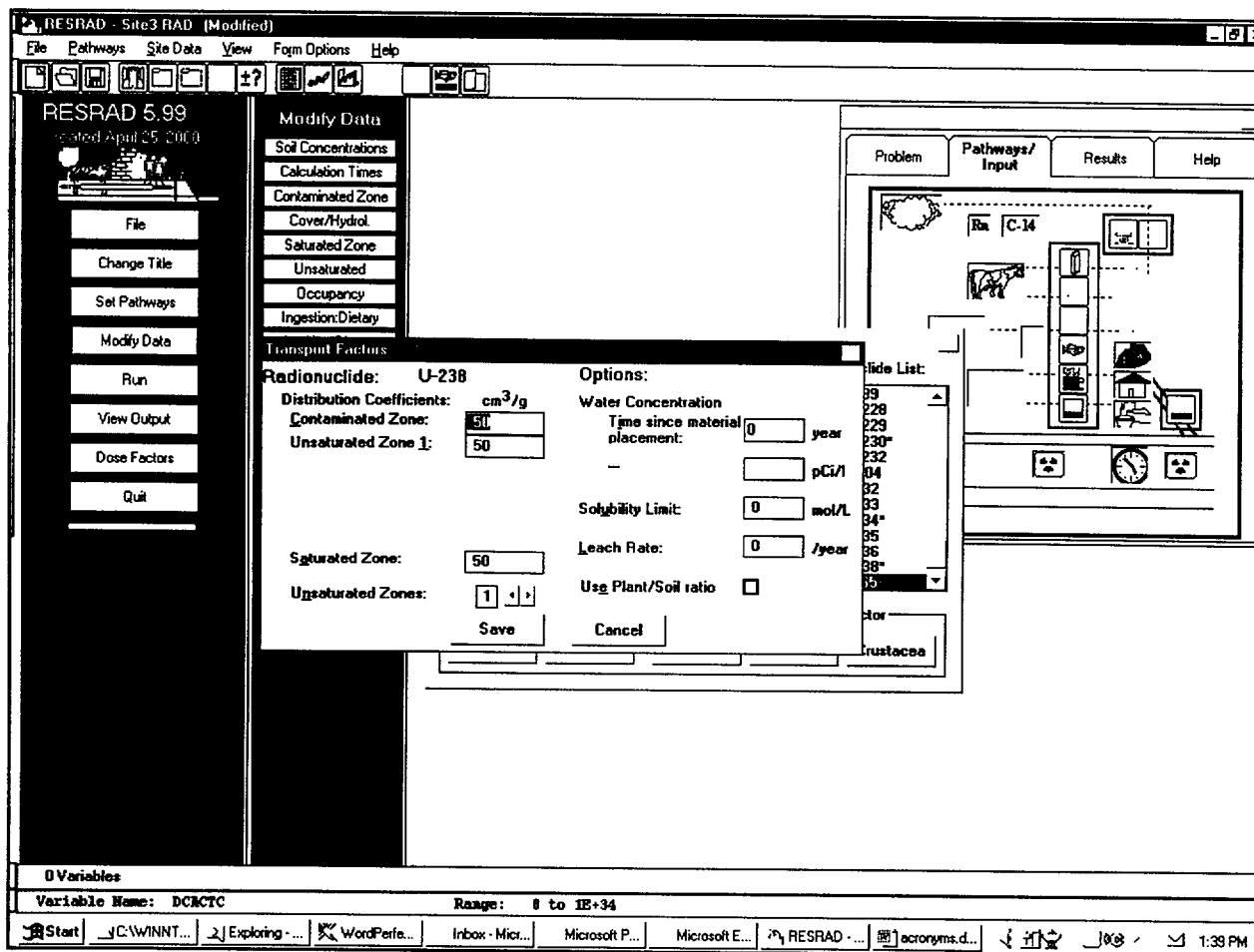
Step 5: Set probabilistic analysis on the "Contaminated Zone Distribution Coefficient" by highlighting the value as shown on the last figure and then pressing the "F8" key (or by clicking on the "±?" toolbar button).
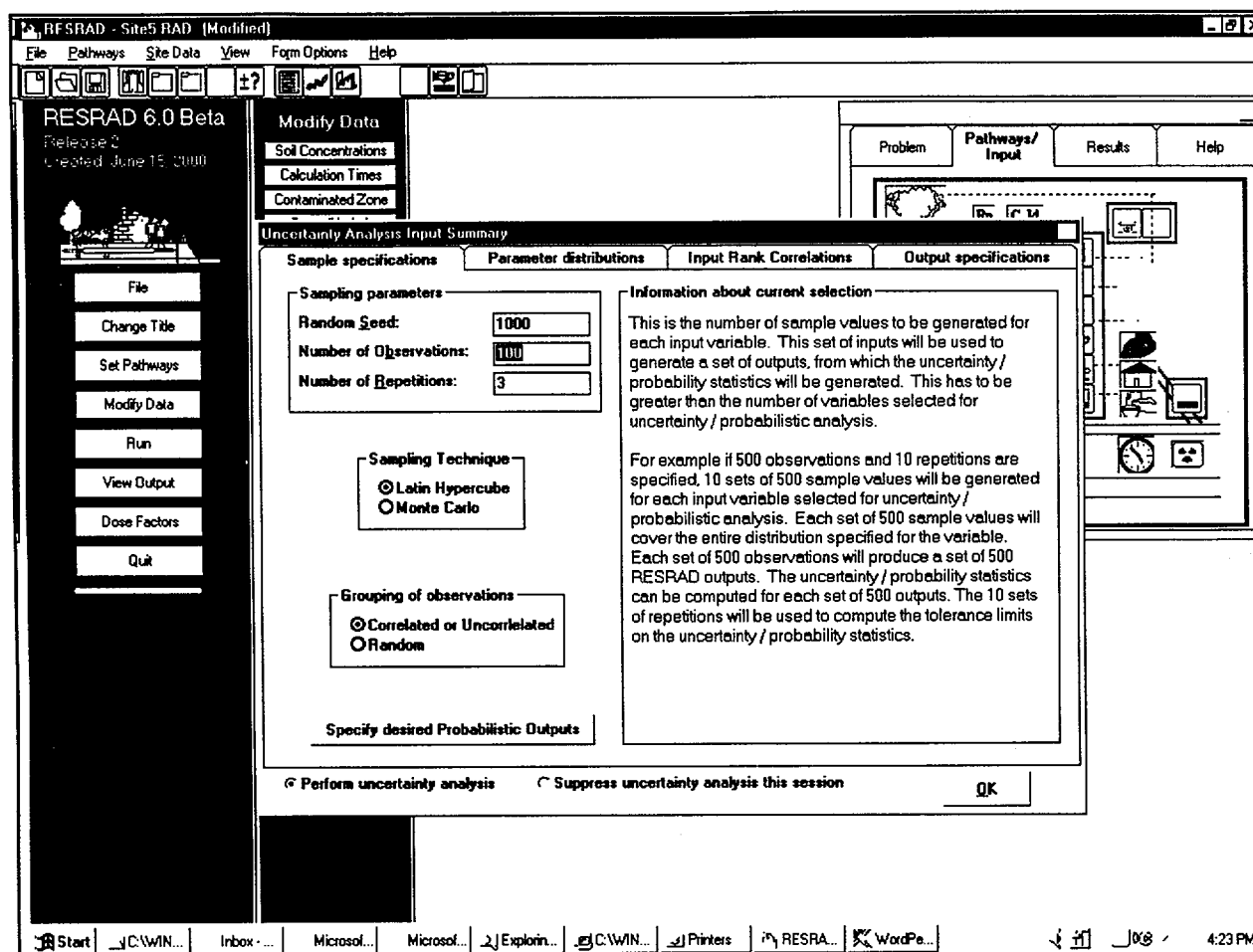
Step 6: The new window is the "Uncertainty Analysis Input Summary." To simply test this case and get an idea of how many samples are necessary for analysis, keep the number of observations to 100 and the number of repetitions to 3. By doing a number of repetitions, the software will estimate the precision of the percentile results. Leave the "Sampling Technique" and the "Grouping of Observations" at their default settings. Option descriptions are found on the right side.
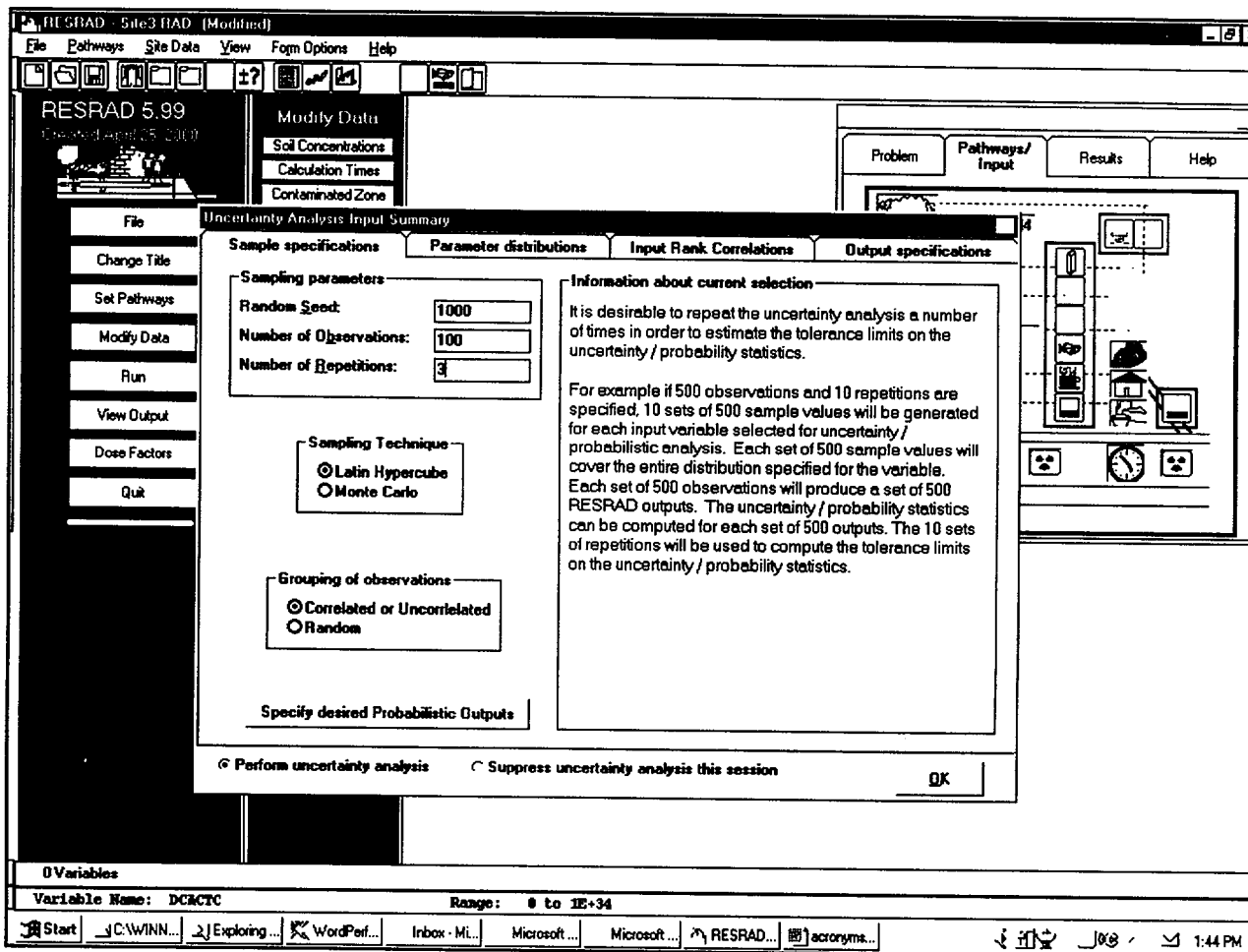
Step 7: Next, specify the desired output by clicking on the "Specify Desired Probabilistic Outputs" button on the lower left side. This moves the focus to the last tab of the window.

By default, all output is chosen, including all output-to-input correlations in the textual report. For this run, keep the default options.
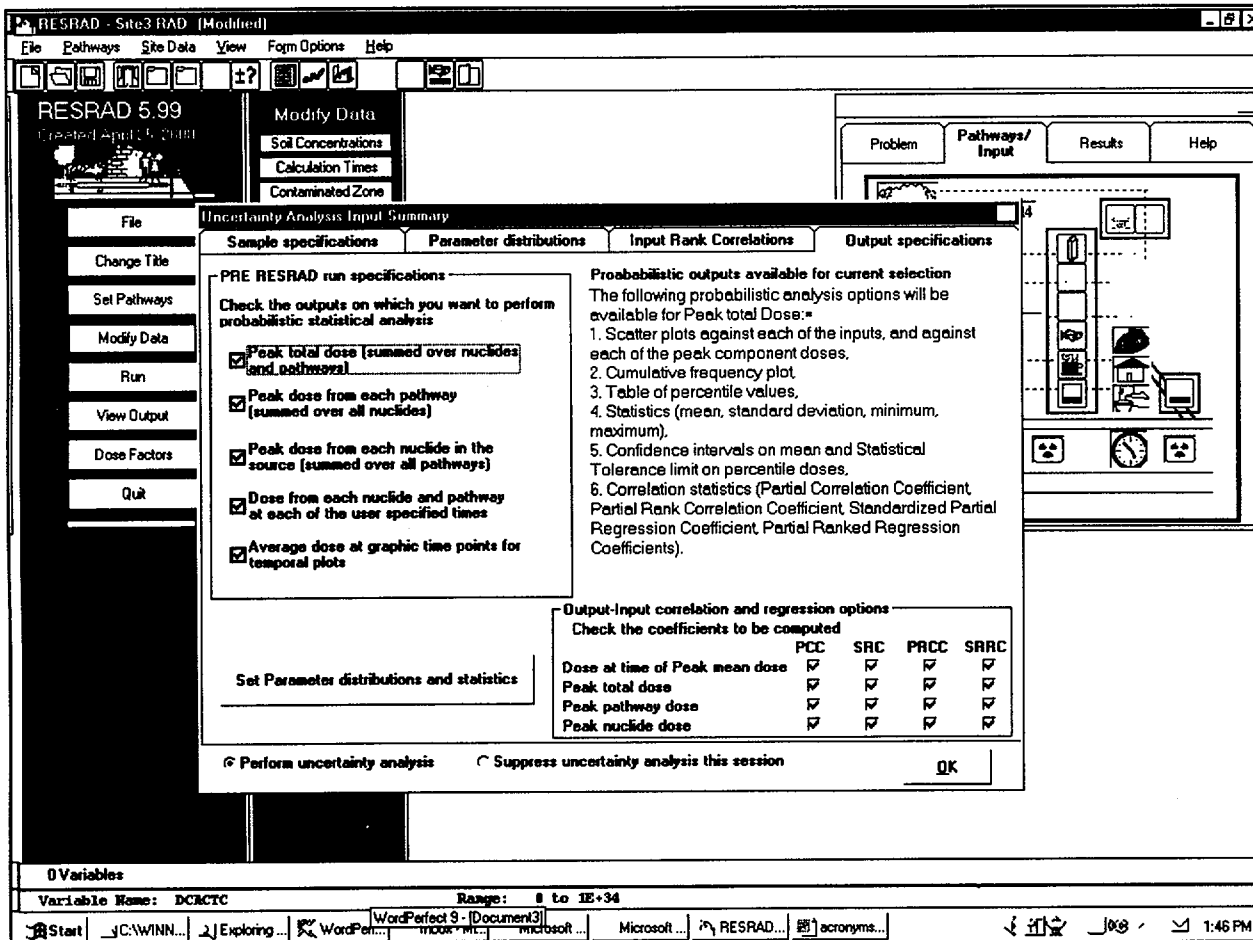
Step 8: Click on the "Parameter Distributions" tab (second from the left). This tab shows the default distribution for the U-238 distribution coefficient as identified in Task 1.3 (Biwer et al., 2000, "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes, Revision 1"). The left side lists the one variable set for probabilistic analysis. The right side shows the distribution assigned to that variable.
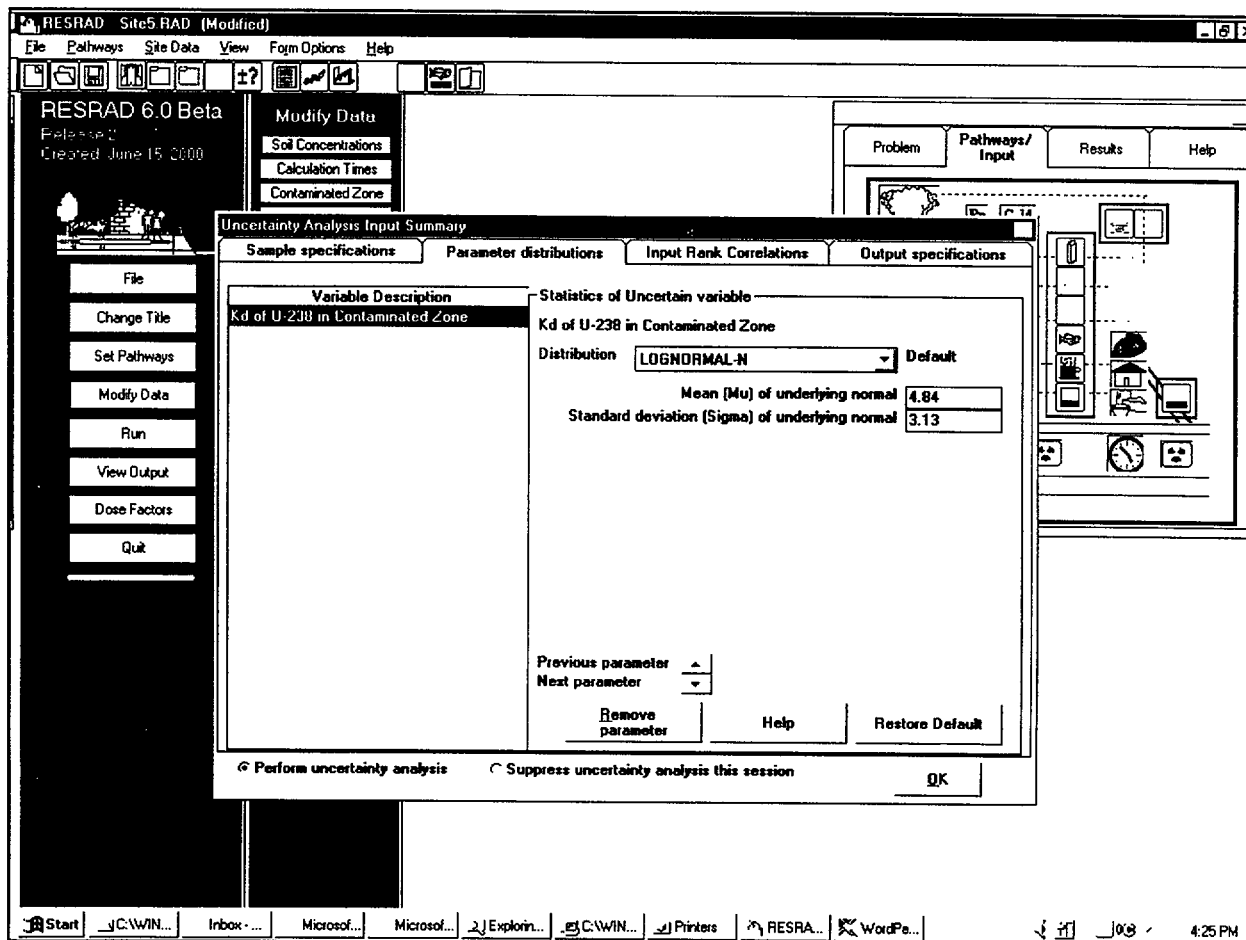
Step 9: Click on "OK" in the "Uncertainty Analysis Input Summary" window. The code will return to the "Transport Factors" window. Select the "Unsaturated Zone" input box and press the "F8" key to set probabilistic analysis on that variable.
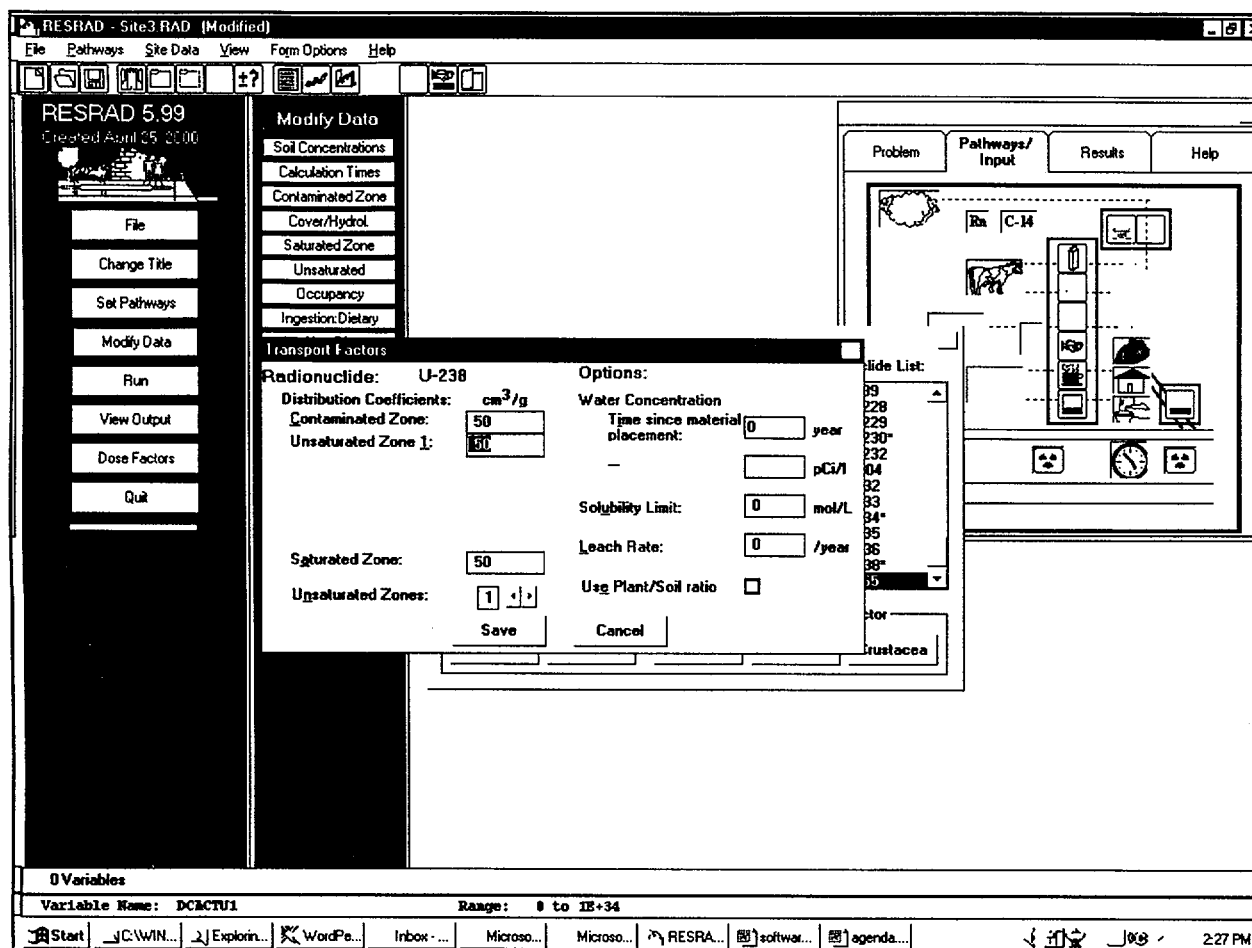
Step 10: The "Parameter Distributions" tab comes up in the "Uncertainty Analysis Input Summary" window. The first tab for general sampling settings appears by default only the first time this window is accessed.
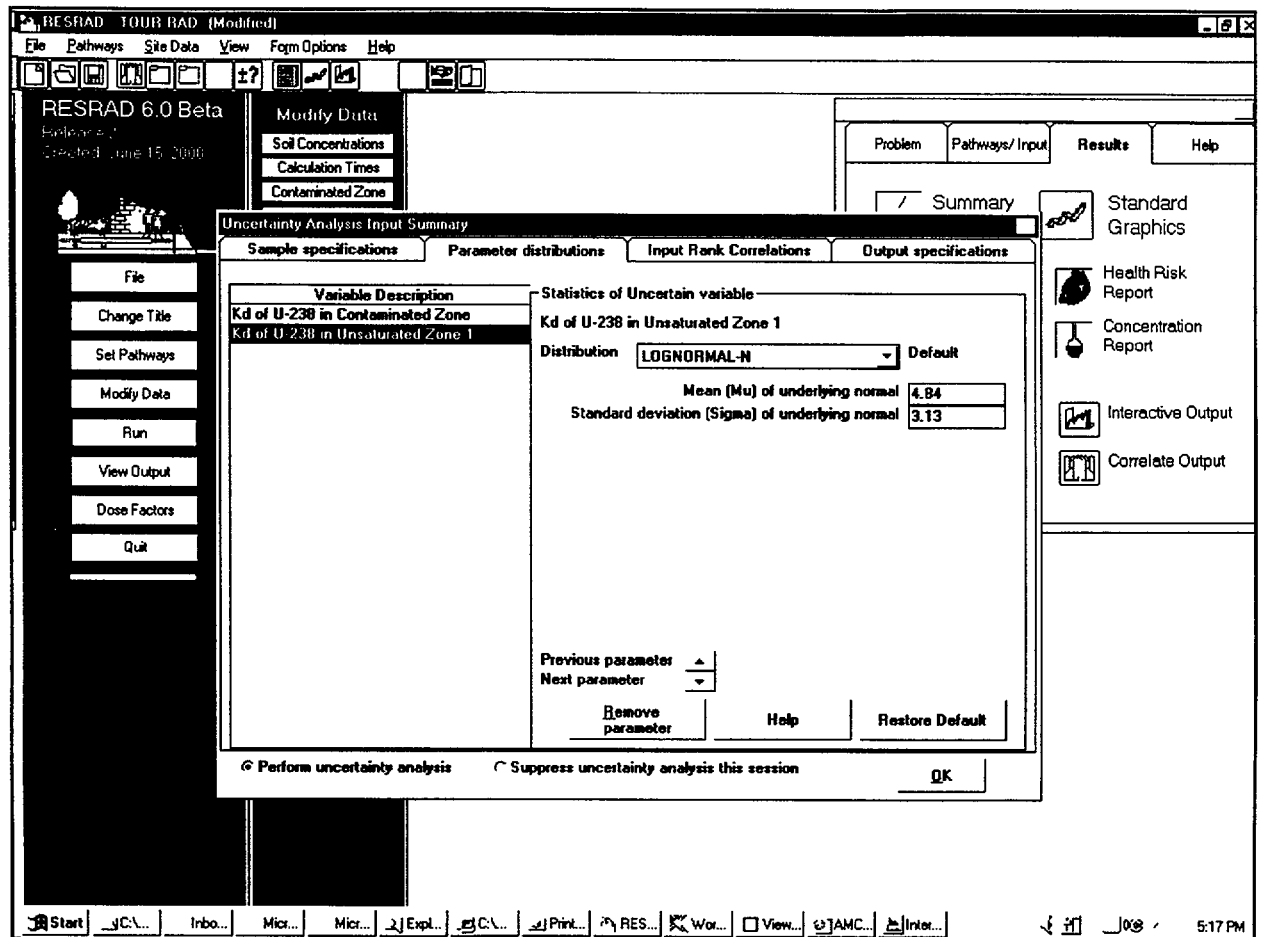
Step 11: Repeat the last two steps for the third variable — the "Saturated Zone" distribution coefficient for U-238. Note that the distribution is the same for all three distribution coefficient variables. By default, it is assumed that the distribution coefficients in the three zones are independent. However, this might not be true because of geological correlations or similar chemical forms of U-238 in the three zones. Nevertheless, for this problem, the distribution coefficients are left uncorrelated.
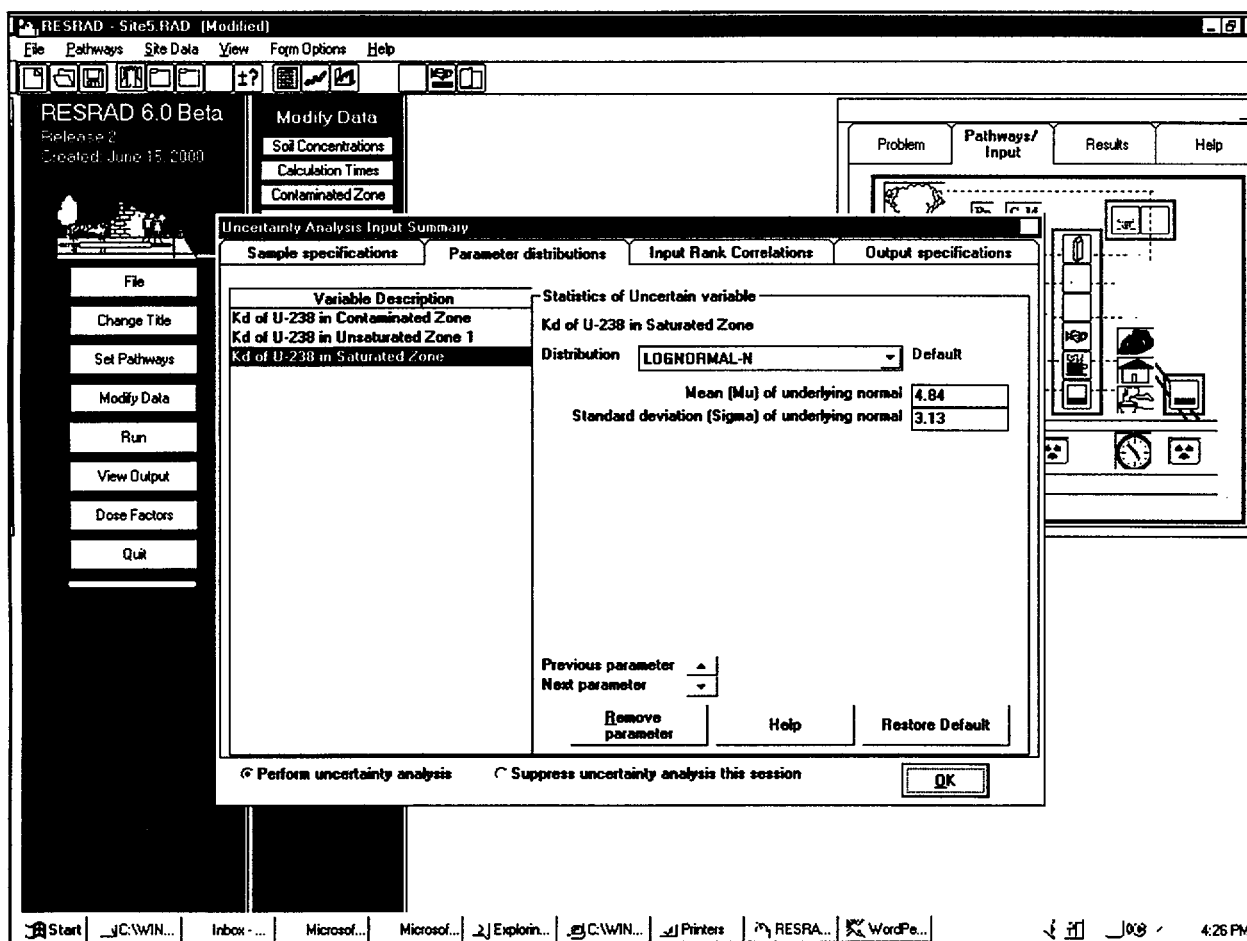
Step 12: Click on the "OK" button in the "Uncertainty Analysis Input Summary" window, then click on the "Save" button in the "Transport Factors" window. The "Source" window should be showing. Click on the "Plant" button in the lower left to set probabilistic analysis on the plant transfer. This method of setting probabilistic analysis is an exception used for these transfer factors only.
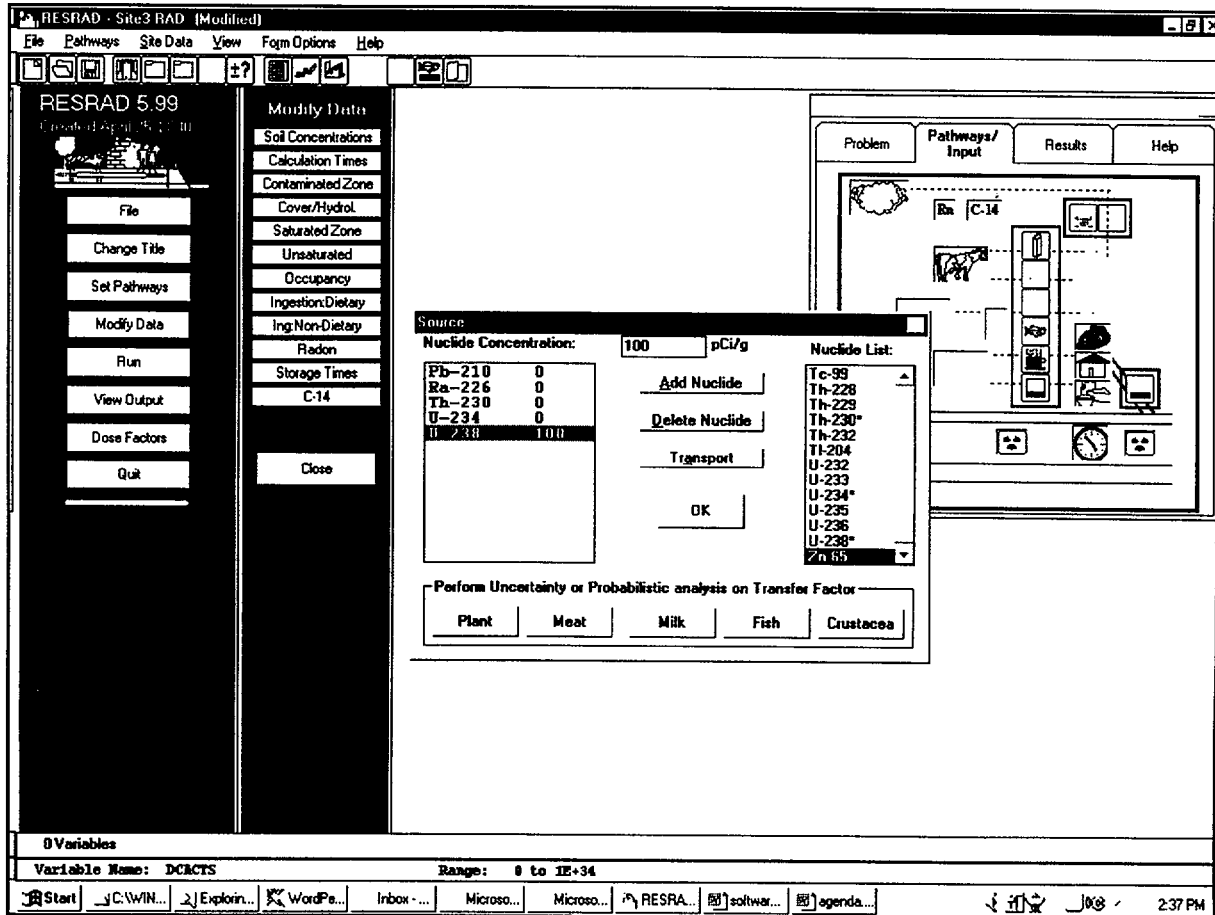
Step 13: The "Parameter Distributions" tab shows the "Plant transfer factor for U" added to the variable description list. To view this distribution, click on the "Help" button in the lower right.
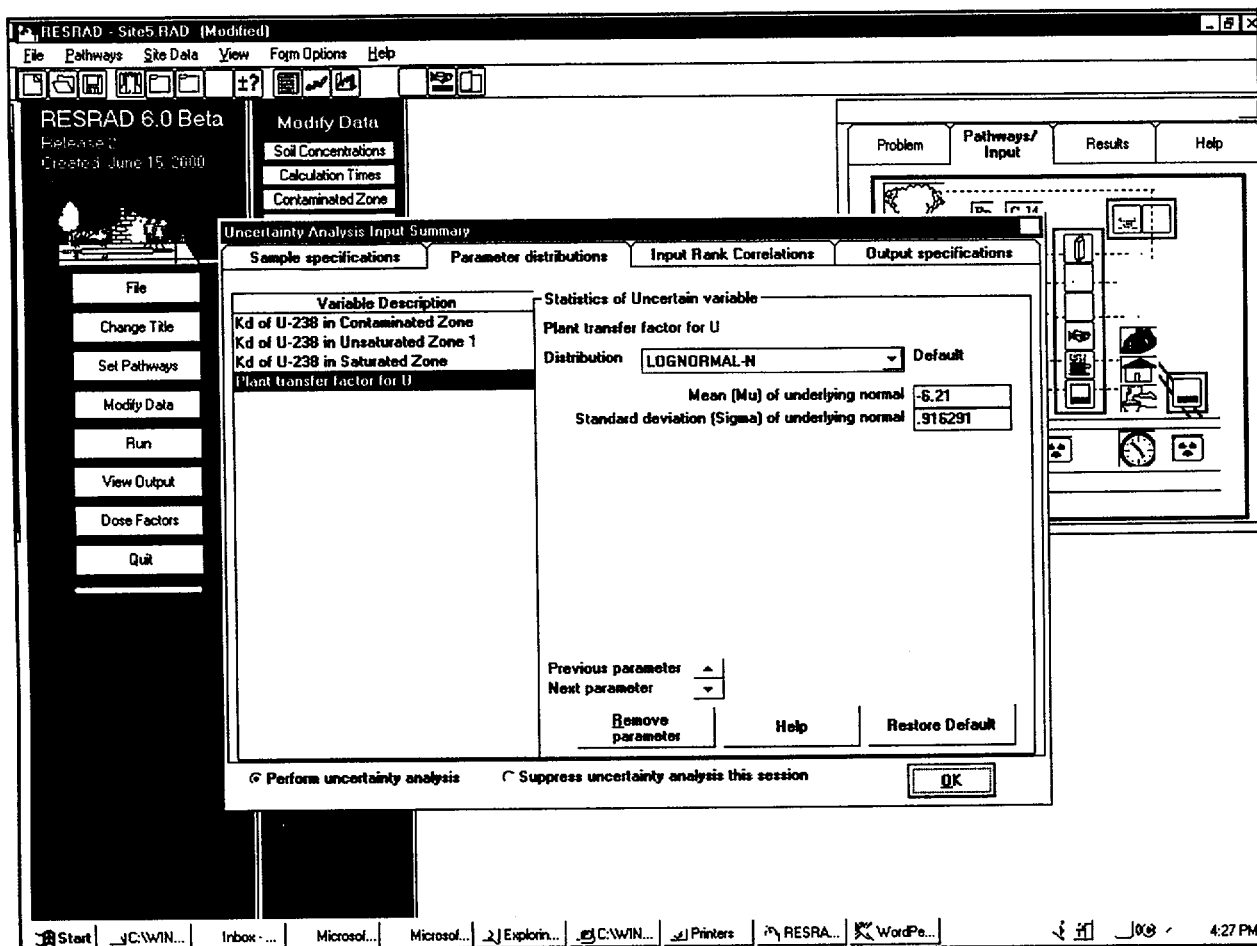
Step 14: The distribution shape and a description of the parameters and conditions are shown. The vertical axis on the left (red line) indicates the bounds for use in RESRAD. Click on the close button (the X button in the upper right) to close this window. Then click on "OK" in the "Uncertainty Analysis Input Summary" window. Then click on "OK" in the "Source" window.

There are three ways of specifying a lognormal distribution, "lognormal", "lognormal-B" and "lognormal-N". The code actually cuts off the lower and upper 0.1% tails and samples between $V_{0.001}$ and $V_{0.999}$. The relationship between the three sets of defining parameters are

$$\mu = (\ln V_{0.999} + \ln V_{0.001})/2$$

$$\sigma = (\ln V_{0.999} - \ln V_{0.001})/2/3.09$$

$$\mu = \ln M - \sigma^2/2$$

$$\sigma = (\ln BF)/1.645$$

The pdf is

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2\right]$$

Conditions

0 < Standard deviation (Sigma) of underlying normal distribution

Step 15: This is the complete set-up of the probabilistic variables. Click on the "Contaminated Zone" button in the second (blue) column at the left.
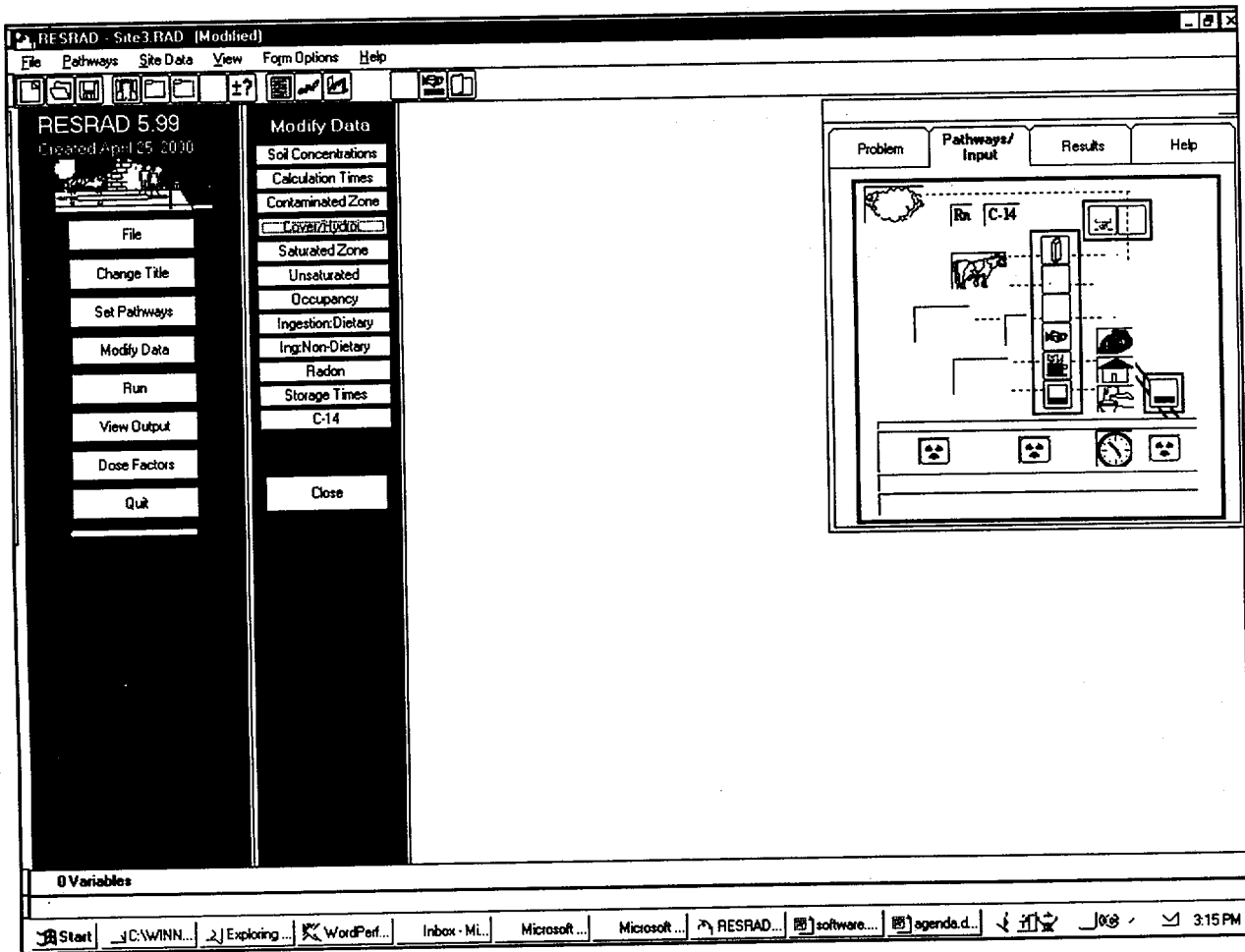
Step 16: Next highlight the middle variable ("Thickness of Contaminated Zone") and enter the site-specific thickness as 0.05 m. This site-specific single value of the contaminated zone thickness will be used in both the deterministic calculations and the probabilistic analysis. Click on the "Save" button and then click on the "Unsaturated" button in the second column on the left.
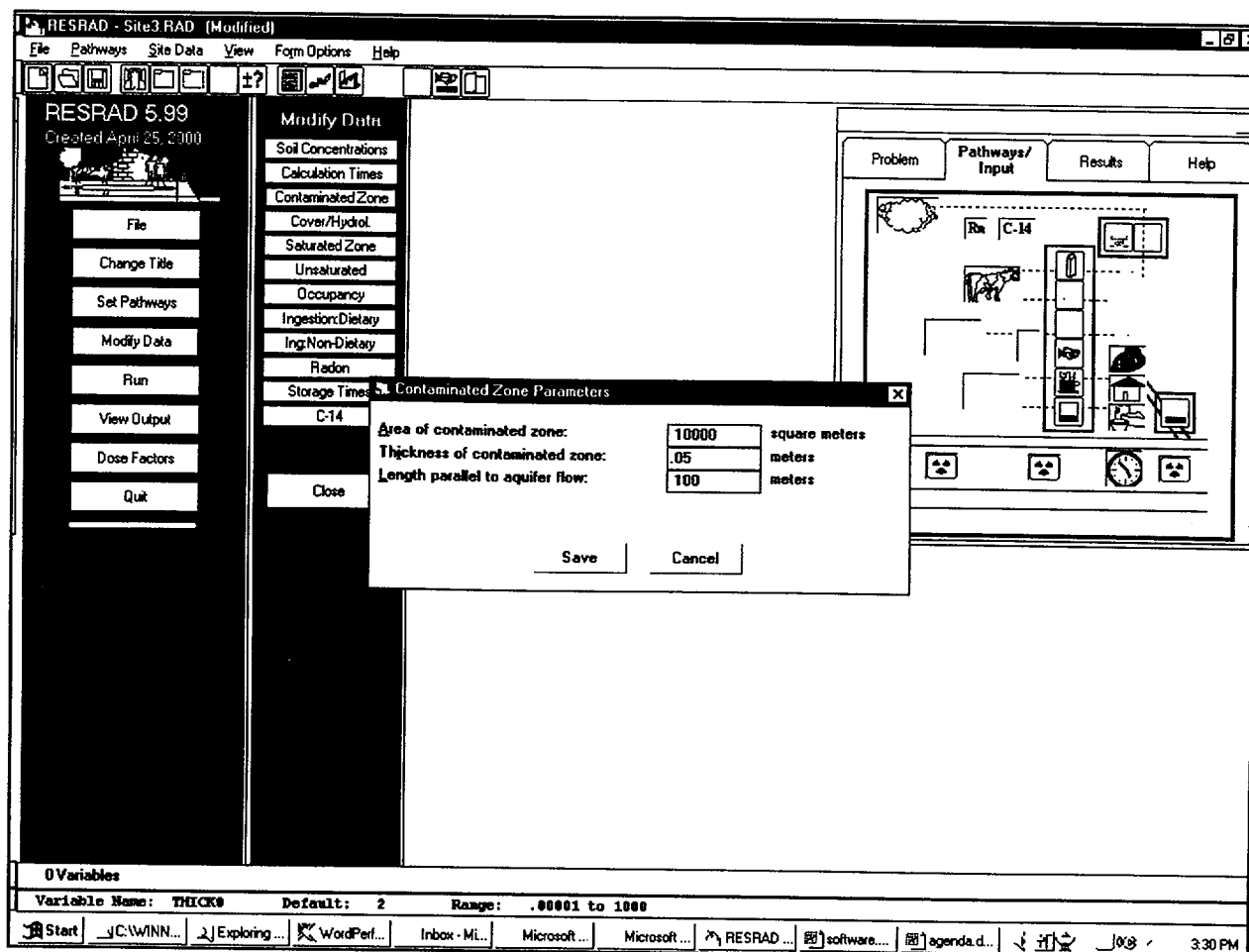
Step 17: Change the first value for the
thickness of the unsaturated zone to 3.4 m.
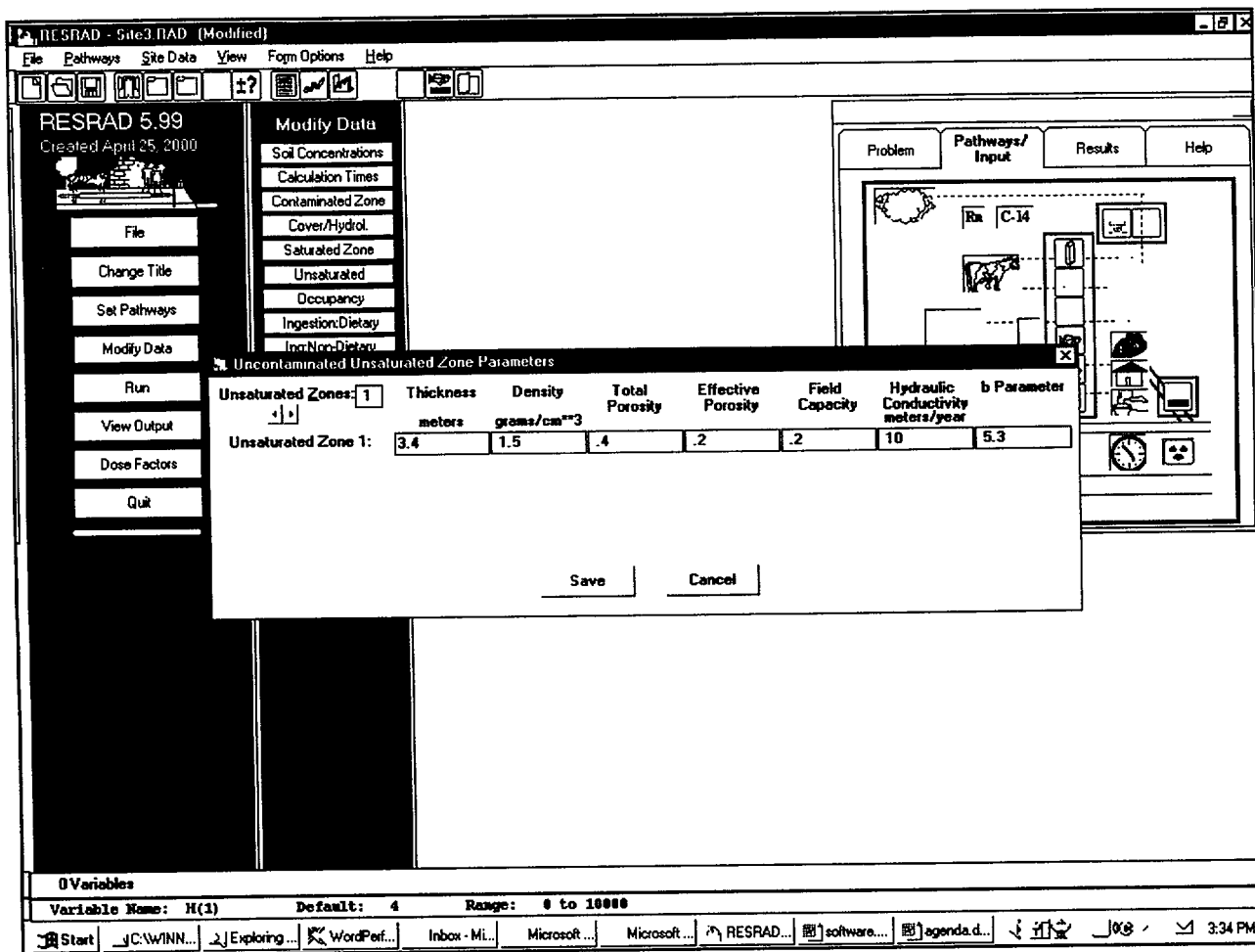
Step 18: Click on the "Save" button on this form. The input preparation is complete. Next save the file as "tour. rad" by clicking on the "File" option then the "Save As" option from the menu.
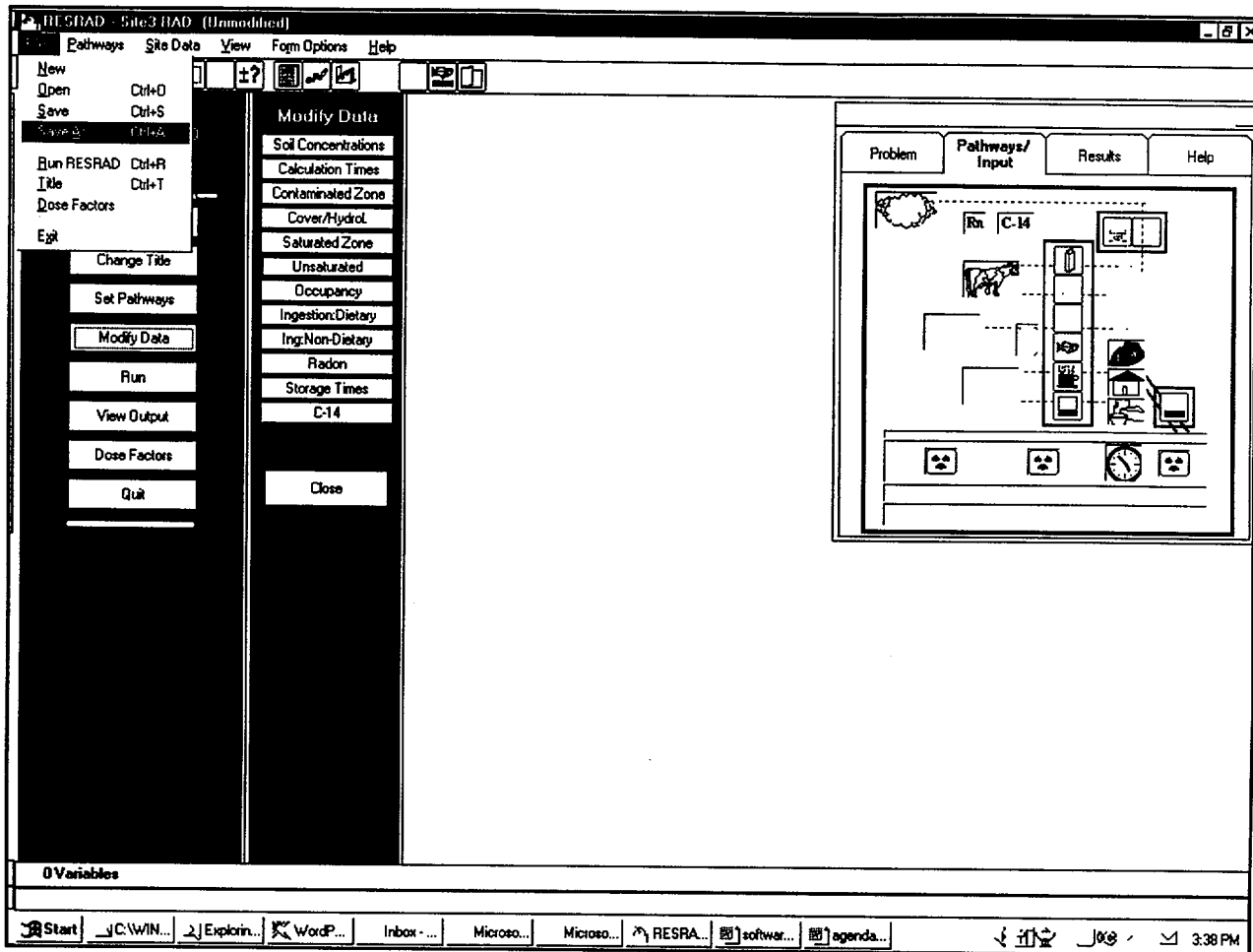
Step 19: Type "tour. rad" in the file dialog box and then press the "OK" button. Both the deterministic and the probabilistic analysis information is saved to the disk in file format.
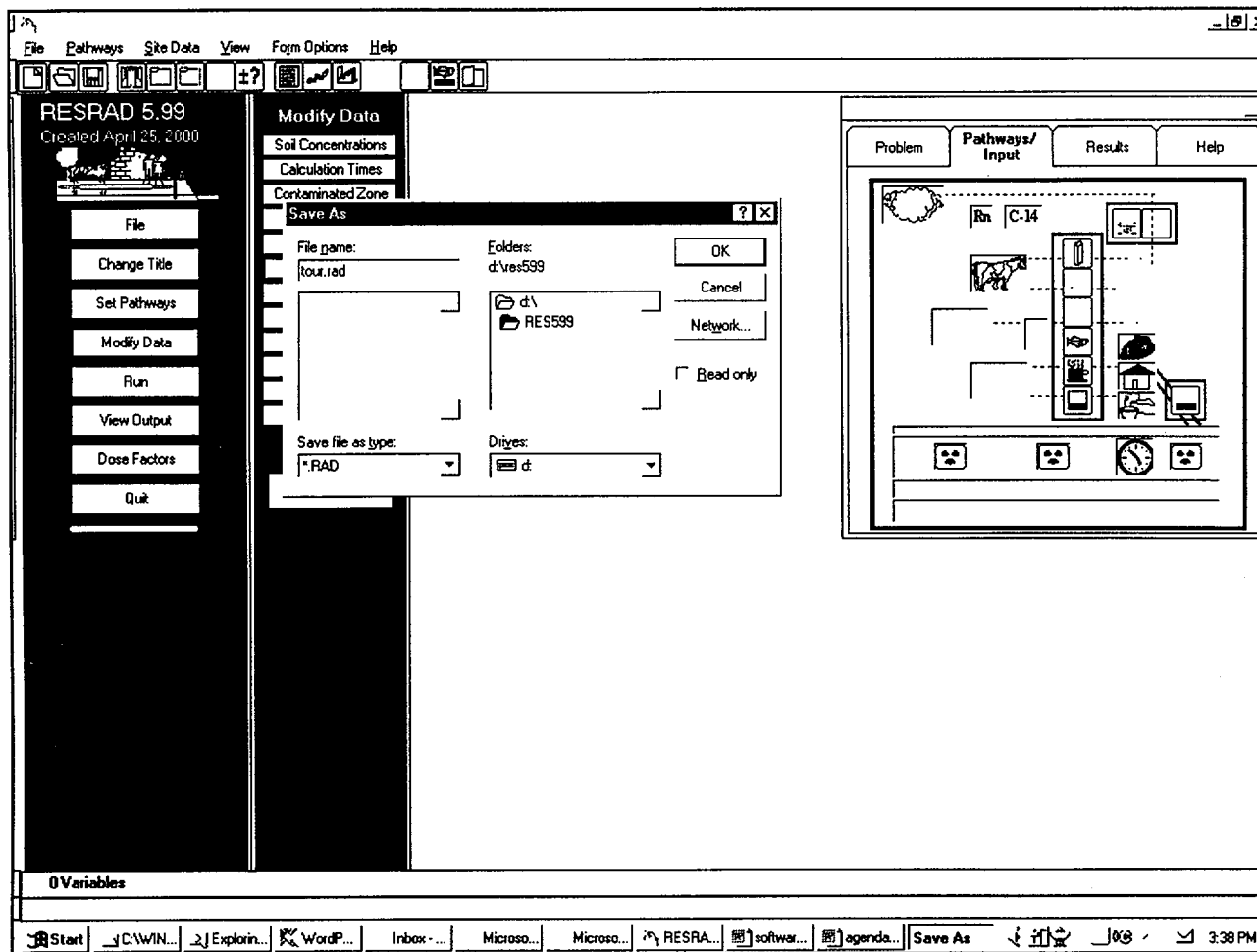
Step 20: Next click on the "Run" button (5th button in the first column on the left). The "Run" pop-up window will appear. A highlighted (blue) line will show some feedback from the calculations. An estimate of the time remaining for the calculations to complete will show at the bottom of the window. There is also a cancel button to stop the calculation. This run took approximately 8 minutes on a Pentium II, 450-MHZ, 192-MB RAM computer running Windows NT.
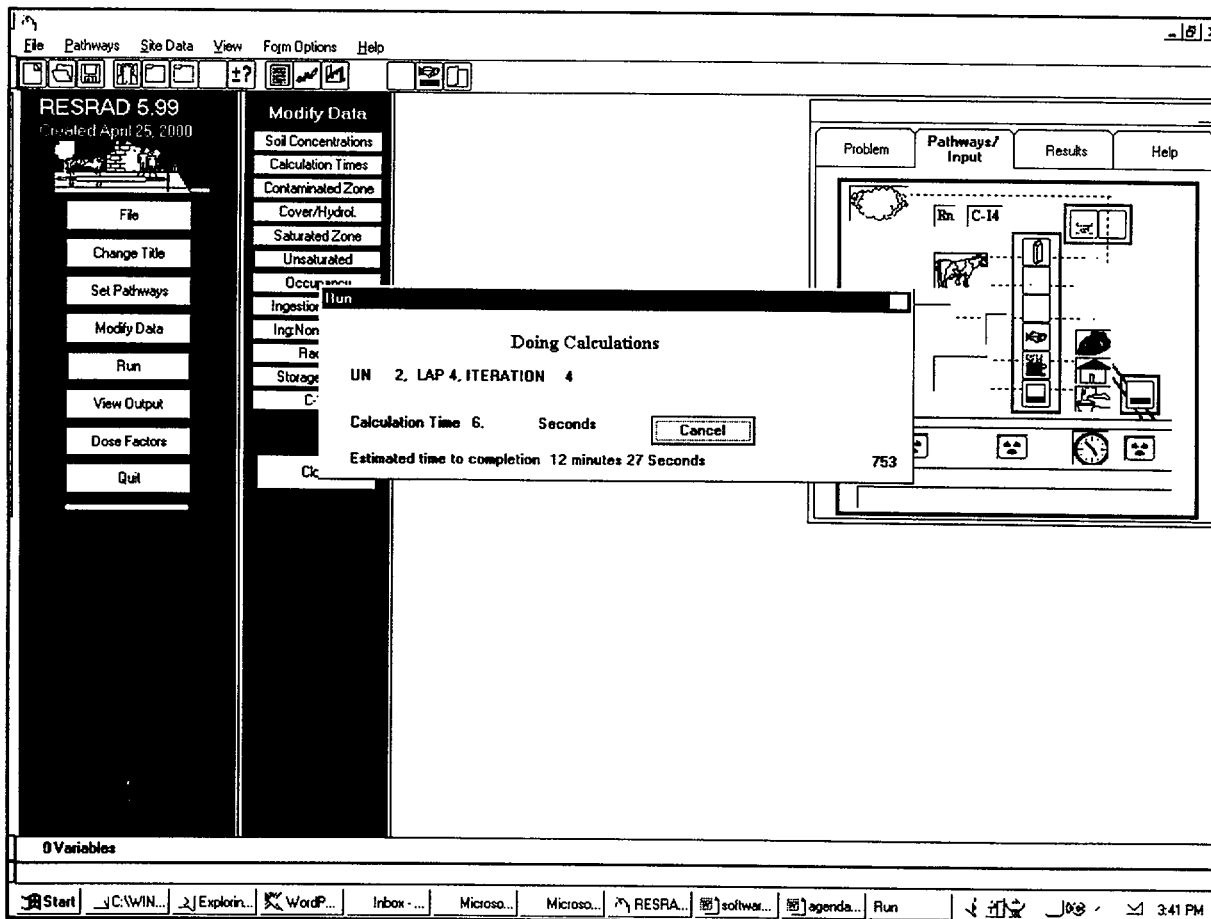
C.4 CASE OUTPUT

Step 1: Immediately after the calculations are complete, the summary report will display. This is the standard deterministic summary report, which is not of interest for this specific case. It does, however, contain a complete list of the non-probabilistic variable values used in the calculations.

Step 2: Click on the close button (the X button in upper right) to close this View window. Next click on the "Results" tab of the "Navigator" window in the upper right of the main window. The deterministic reports and output are shown above the purple line. The four uncertainty outputs are shown below the purple line. Click on the "Interactive Output" button near the lower right of the "Navigator" window.
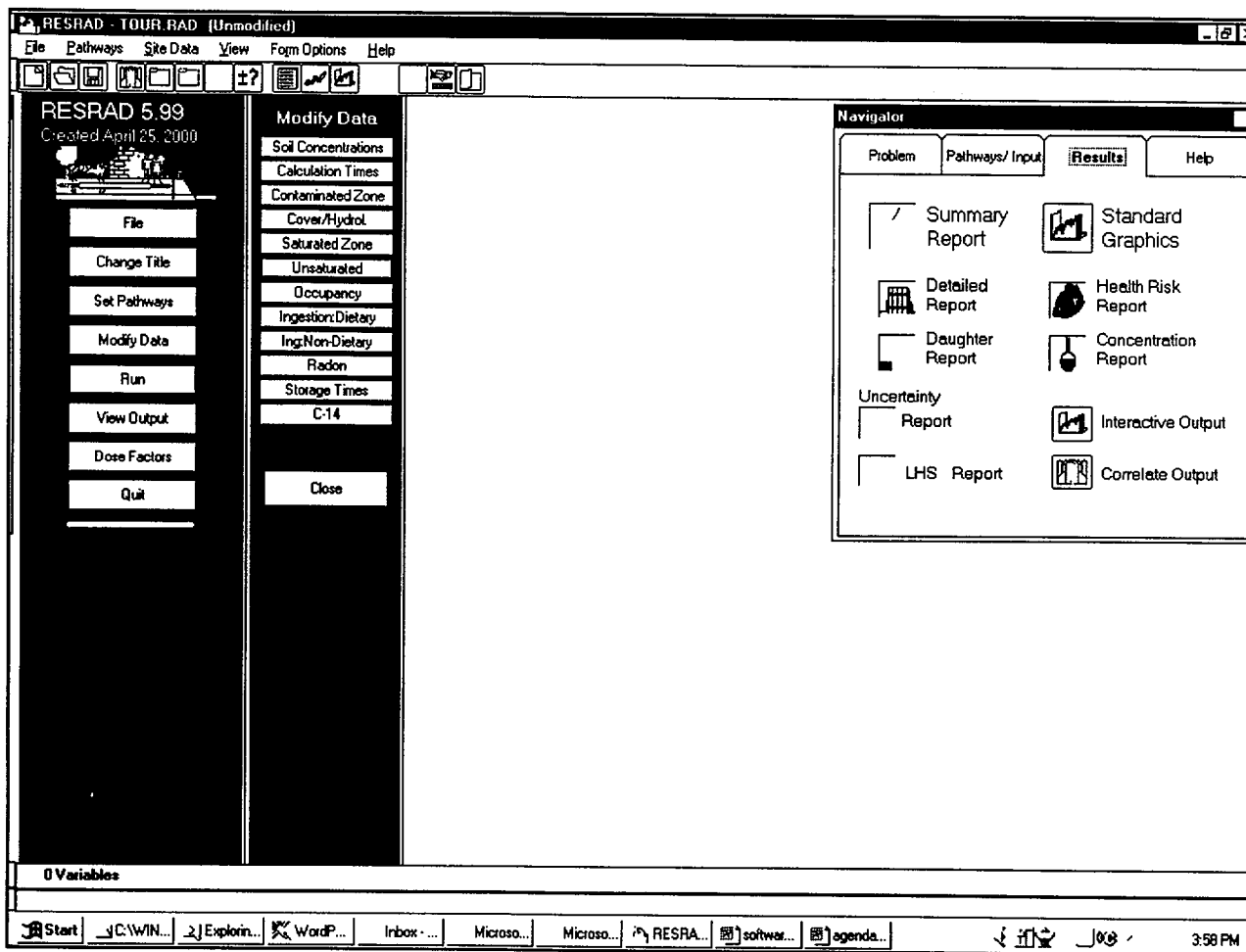
Step 3: The default of the three tabs is the "Input Specifications" to review the probabilistic input. The second tab, "Parameter Statistics," contains the detailed variable distribution parameters. Next click on the "Results" tab on the right.

Step 4: The message "Calculating General Statistics, Please Wait" is displayed on the right side. After the calculations are complete, the table showing the results for the general statistics of the Peak Pathway Dose summed over all pathways appears. This table indicates that the average dose over the 300 samples was 9.35 mrem/yr. The variation in the three repetitions indicates that this value is known to about 20% (2.03 out of 9.35). The 50th percentile dose of 5.56 is known much better (about 0.4%), indicating that there might have been some very large values in repetitions that affected the mean but had little effect on the 50th percentile.

Measure	Dose (mrem/yr)	+ / -
Min	5.28E+00	
Max	4.34E+02	
Mean	9.35E+00	2.03E+00
Standard Deviation	2.30E+01	2.10E+01
50-th Percentile	5.56E+00	1.88E-02
90-th Percentile	7.84E+00	2.11E+00
95-th Percentile	1.36E+01	8.09E+00

Step 5: Next click on the "Statistical Property" pull-down list and select "Percentile." A yellow box indicating that the calculations are being performed on the raw data appears in the right frame. After the calculations are done, the percentile table is shown in the right frame titled "Results."

Percentile	Dose (mrem/yr)	+ / -
5-th Percentile	5.32E+00	1.92E-03
10-th Percentile	5.34E+00	2.82E-03
15-th Percentile	5.37E+00	5.09E-03
20-th Percentile	5.39E+00	4.80E-03
25-th Percentile	5.41E+00	7.22E-03
30-th Percentile	5.44E+00	1.07E-02
35-th Percentile	5.47E+00	1.02E-02
40-th Percentile	5.49E+00	1.04E-02
45-th Percentile	5.52E+00	1.39E-02
50-th Percentile	5.56E+00	1.88E-02
55-th Percentile	5.60E+00	2.35E-02
60-th Percentile	5.65E+00	1.61E-02
65-th Percentile	5.71E+00	1.58E-02
70-th Percentile	5.79E+00	5.54E-02
75-th Percentile	5.89E+00	7.60E-02
80-th Percentile	6.05E+00	1.70E-01
85-th Percentile	6.33E+00	3.54E-01
90-th Percentile	7.84E+00	2.11E+00
95-th Percentile	1.36E+01	8.09E+00

Step 6: Now look at the dose at 30 years after initial contamination specification. This is done by selecting "Dose at User Times" for the "Primary Object" and "30" for the "User Times." The "General Statistics" are automatically displayed in the right frame.


RESRAD 6.0 Beta screenshot showing the Interactive Output - TOUR.MCO window with Statistical Object settings.

| Measure	Dose (mrem/yr)	+ / -
Min	9.19E-10	
Max	5.81E+01	
Mean	2.06E+00	2.52E-01
Standard Deviation	4.87E+00	1.83E+00
50-th Percentile	8.60E-01	6.37E-02
90-th Percentile	3.15E+00	4.99E-02
95-th Percentile	3.79E+00	4.10E-01

Step 7: Click on the "Graphics" subtab under the "Results" tab. The cumulative density function (CDF) for the "Peak Pathway Dose" for

"All Pathways" is automatically displayed. This graph shows that a few samples have large doses when compared with others.
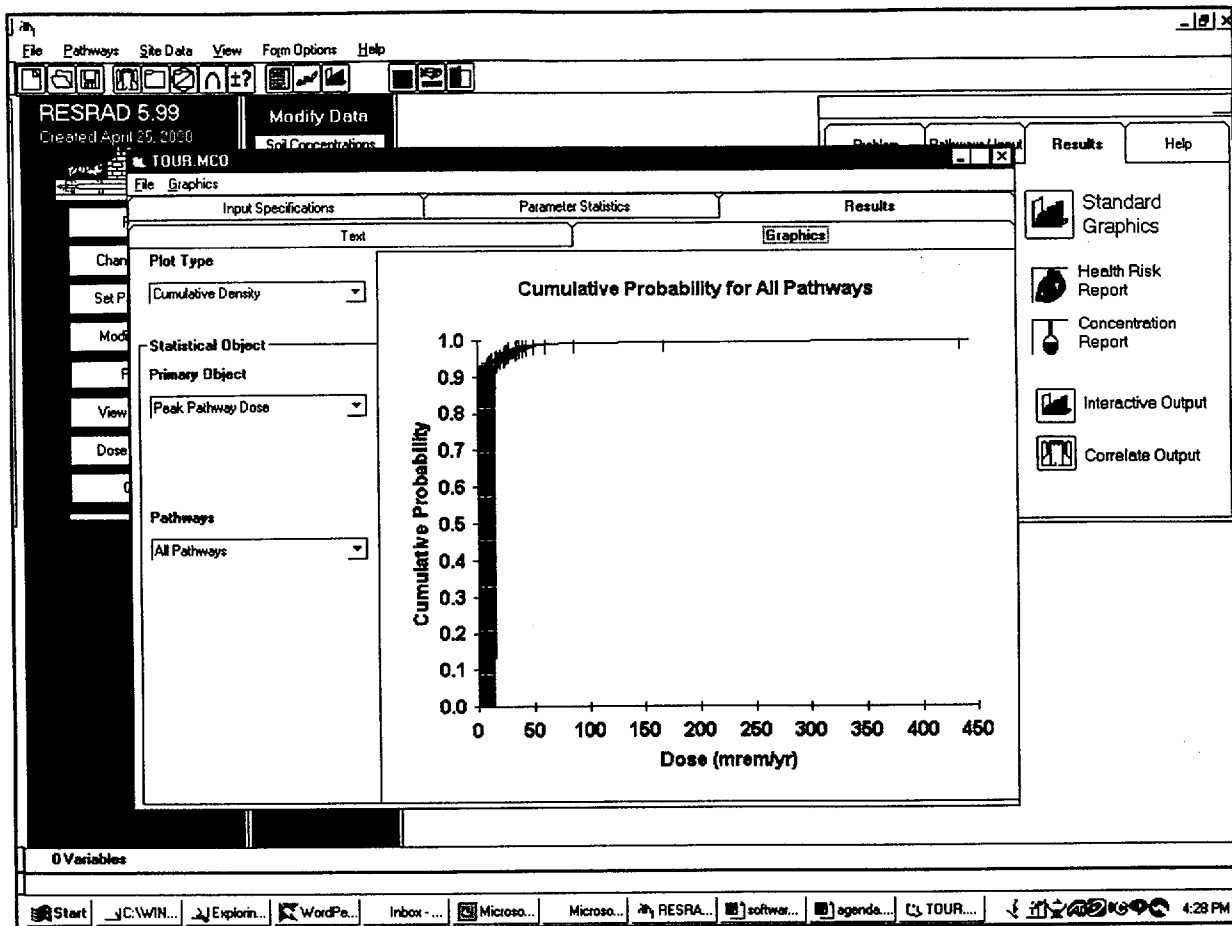
Step 8: To investigate further, click on the "Graphics Option" on the Menu. Select "X Axis" and then select the "Logarithmic" suboption. The screen should show details about the lower doses. The graph is automatically updated, showing some more detail — about 90% of the doses are tightly distributed between 5 and 7 mrem/yr. The remaining 10% of the samples have doses that range up to 400 mrem/yr.
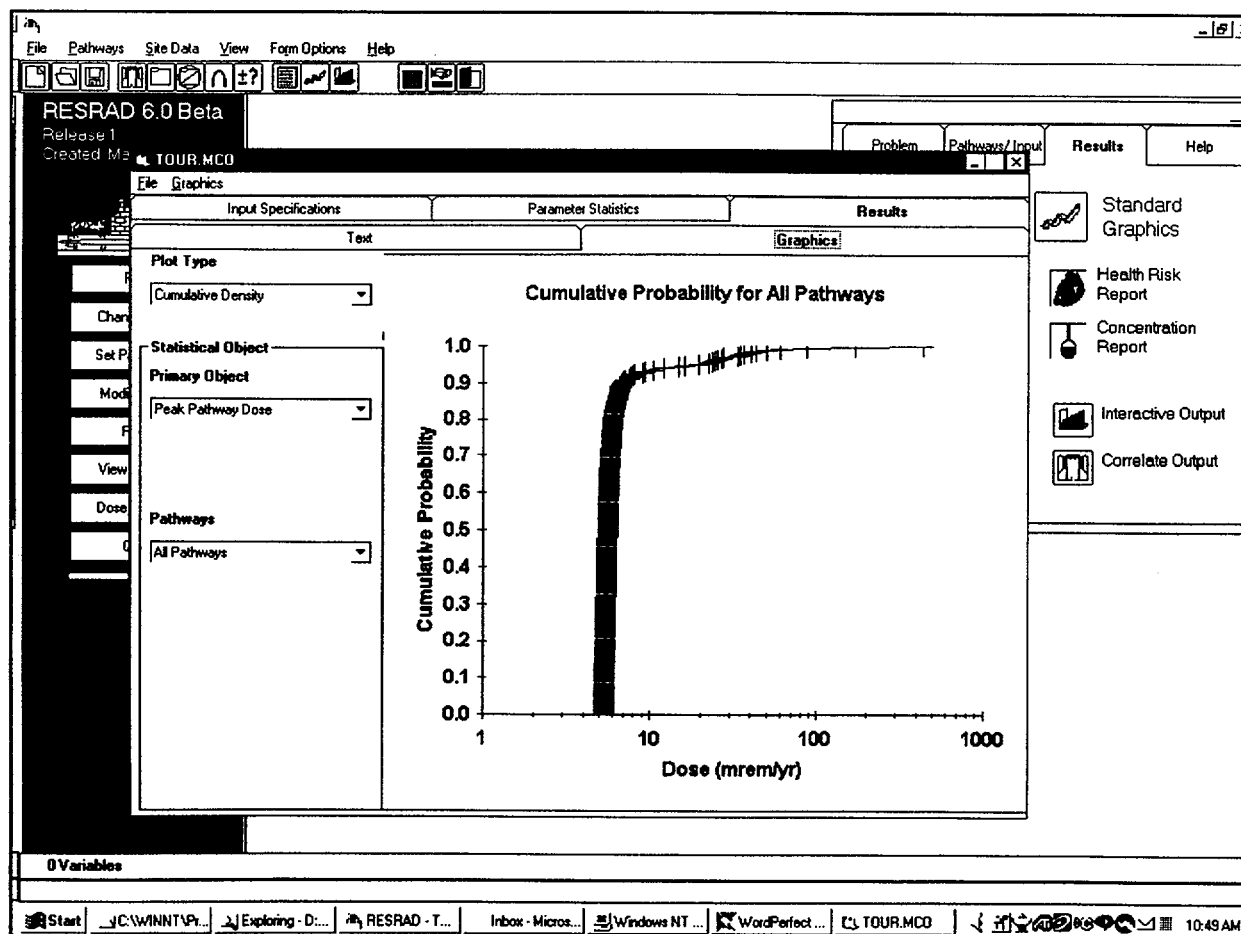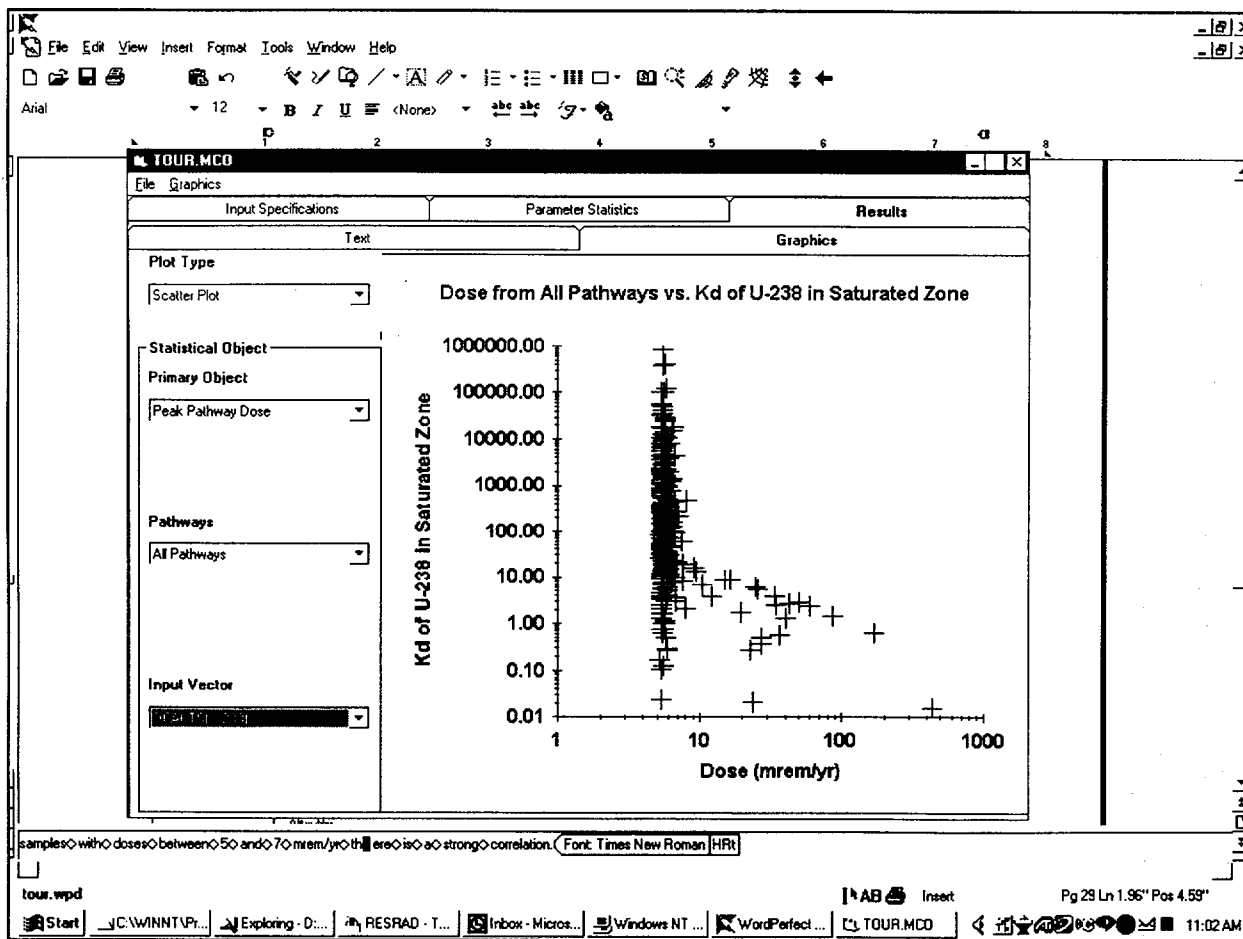
Step 9: Next change the "Plot Type" to "Scatter Plot." Change the "Input Vector" to "BRTF(92,1)." Although this setting is not easy to interpret, the graph is automatically updated and shows the interpretation in the title that the scatter plot of the total dose versus U plant transfer factor is displayed. Next change the X axis scale again to logarithmic (select from the menu "Graphics/X Axis/ Logarithmic"). The screen shows that for the samples with doses between 5 and 7 mrem/yr there is a strong correlation.
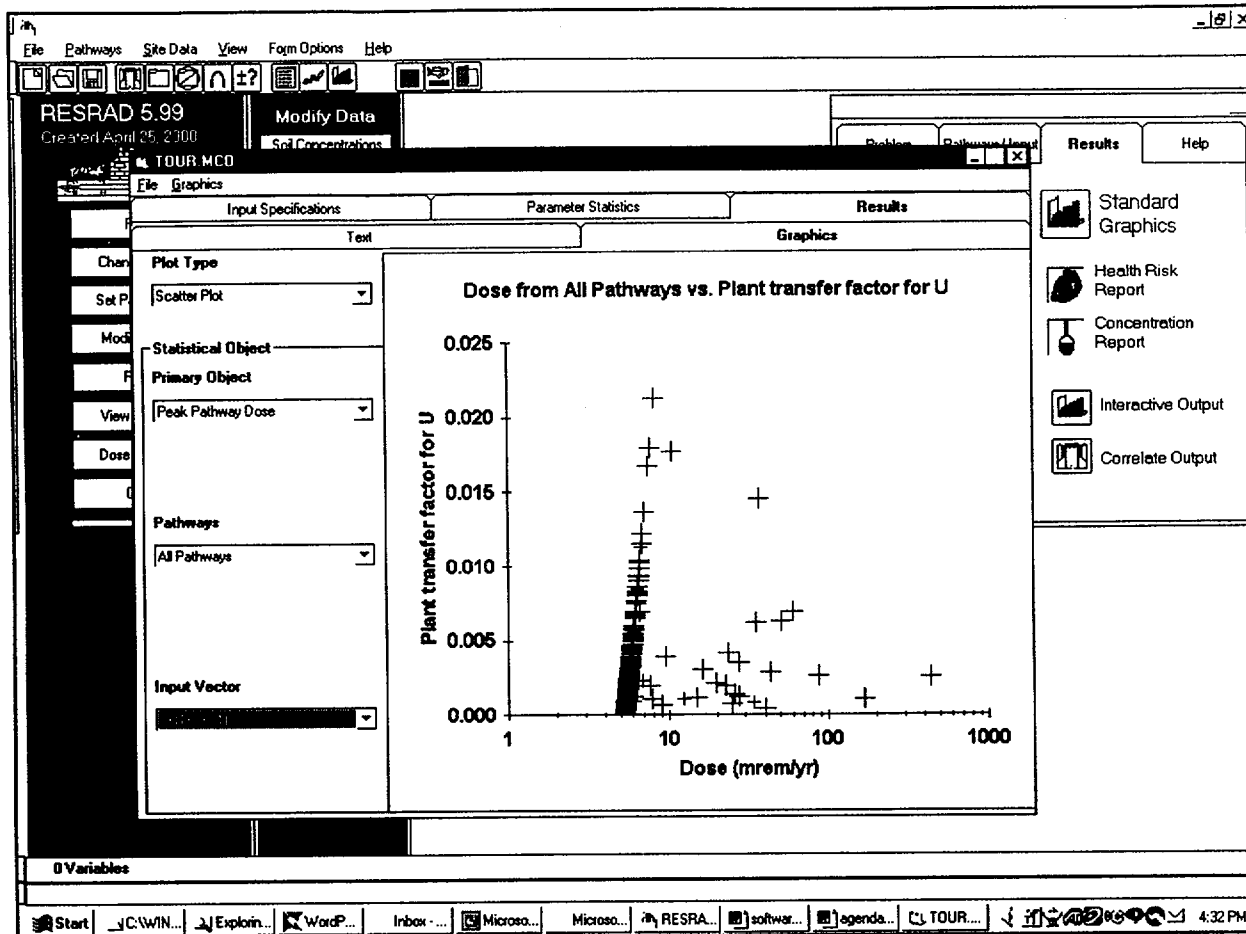
Step 10: The other variables in the uncertainty analysis can be investigated for further correlation. The screen below shows the log-log graph of the total dose with the saturated zone distribution coefficient (DCACTS).

File Edit View Insert Format Tools Window Help

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TOUR.MCO

File Graphics

| Input Specifications | Parameter Statistics | Results |

| Text | Graphics |

Plot Type

Scatter Plot

Dose from All Pathways vs. Kd of U-238 in Saturated Zone

Statistical Object

Primary Object

Peak Pathway Dose

Pathways

All Pathways

Input Vector

Kd of U-238 in Saturated Zone

1000000.00
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01

Dose (mrem/yr)

1   10   100   1000

samples◇with◇doses◇between◇5◇and◇7◇mrem/yr◇th■ere◇is◇a◇strong◇correlation. Font: Times New Roman HRt

tour.wpd

Insert   Pg 29 Ln 1.96" Pos 4.59"

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Step 11: To view the distribution of peak times for this analysis, change "Plot Type" back to "Cumulative Density" and the "Pathway" selection to "Time of Peak Total Dose" (last item in the pull-down list). Most of the samples (90%) have the peak total dose early (<1).
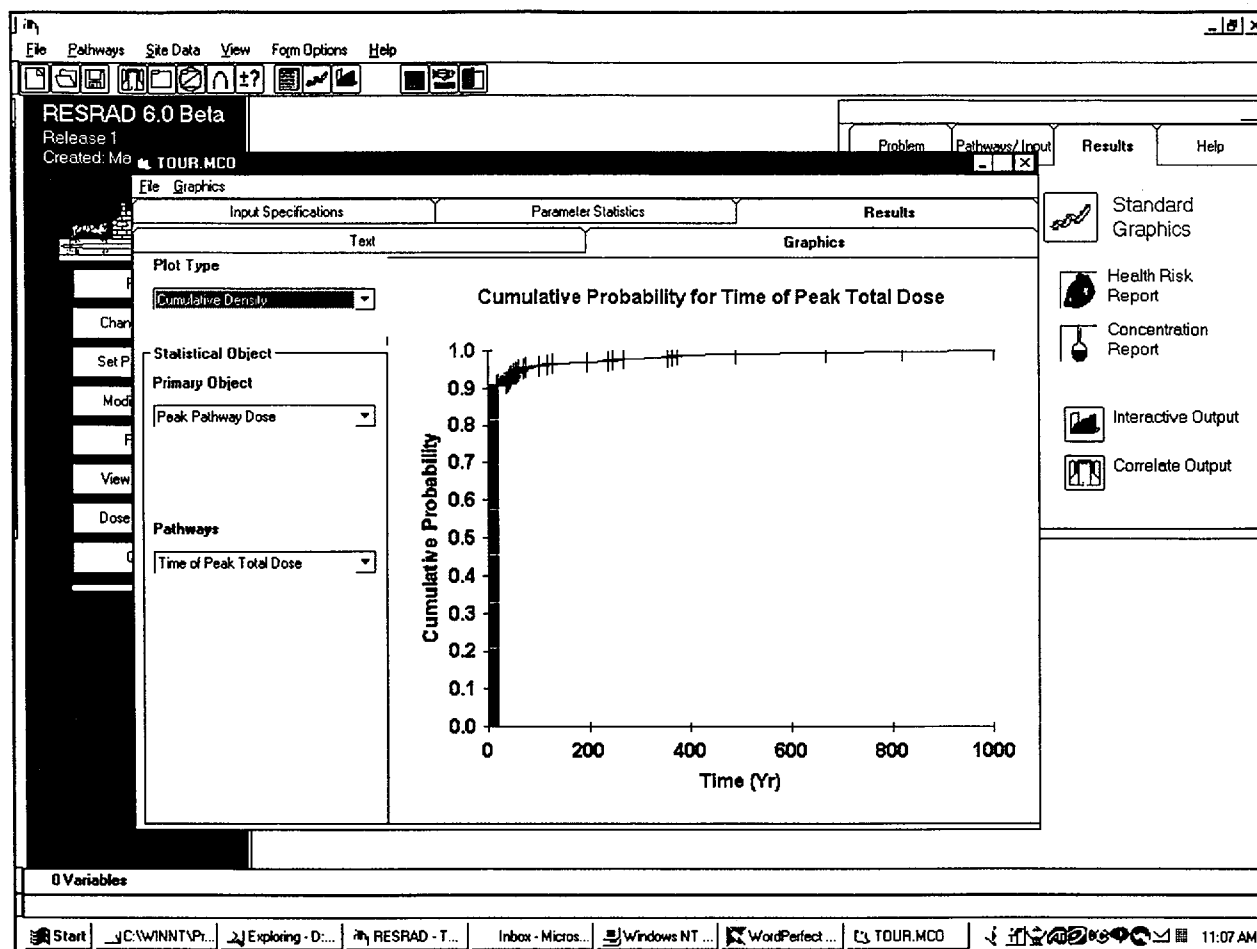
Step 12: The peak of the means can be identified graphically by choosing the "Temporal Plot" plot type. By default, this plot is shown with a logarithmic x (time) axis. The peak is seen to occur on the far left. Two points are plotted on the left, at a time labeled 1 year. The top point (5.8 mrem/yr) is the dose at 0 year. It is plotted here since it would not fit on a standard logarithmic scale. The lower point (4.2 mrem/yr) is the dose at 1 year.
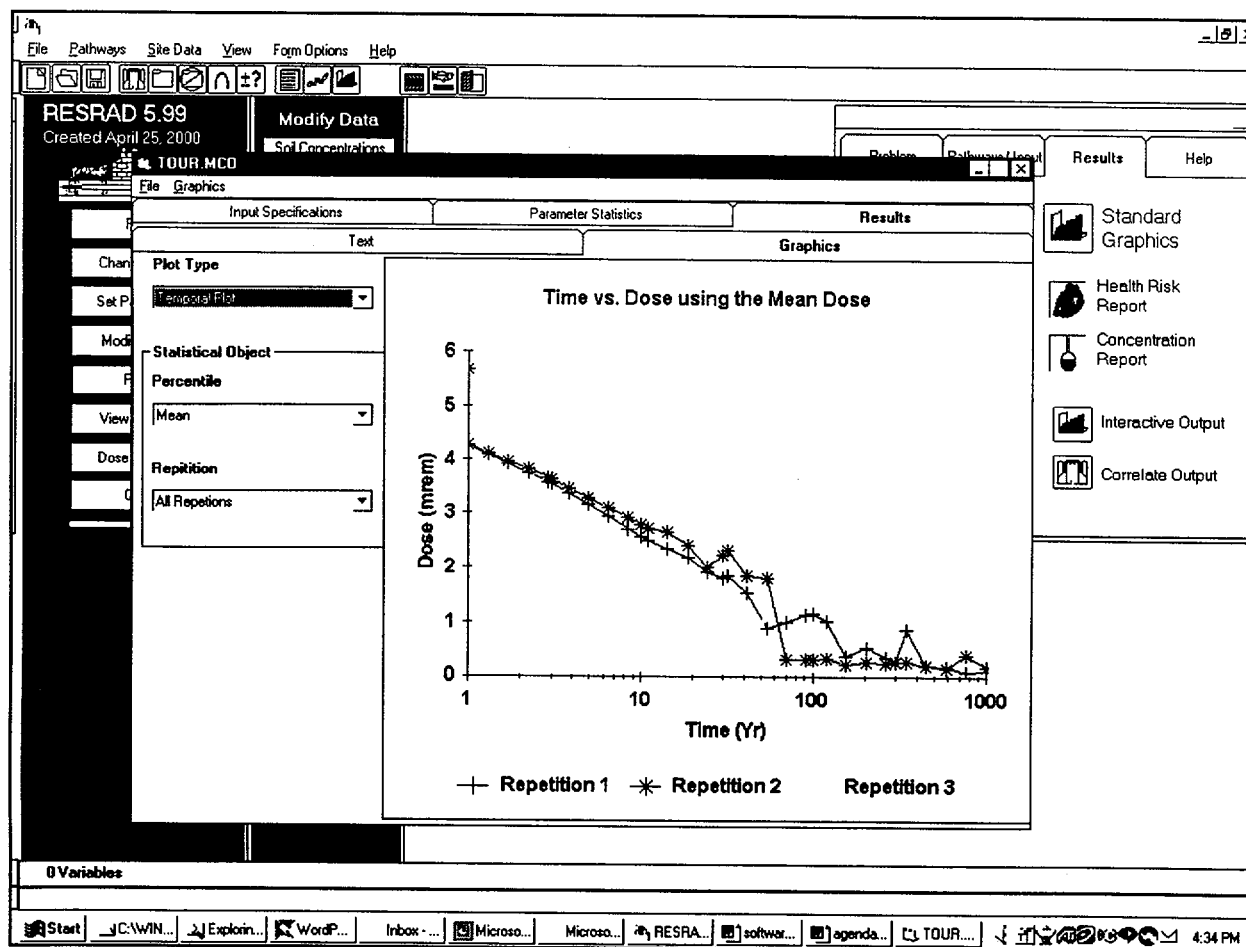
Step 13: The full text report is accessed by clicking on the "Uncertainty Report" button in the "Navigator" window. (This can also be accessed through the menu selection "View/Text Output/ Uncertainty Report.") The table of contents on the first page is shown.

Step 14: Press the "Page Down" key twice to get to page 3 of the output (or use the double arrow up and down buttons on the toolbar).

The "Total Dose Summary" table is displayed. The second and third columns show the statistics for the peak time and dose.

Step 15: Go to page 18 of the output, where the total dose CDF at each user-specified time is reported.

Step 16: Go to page 22 of the output, which reports information about the peak of the mean dose. The screen indicates that for all three repetitions, the peak of the mean dose occurs at time 0 with a dose of 5.66 mrem/yr with less than 0.1% deviation between the repetitions.

Step 17: Further probabilistic analysis of the time at which the peak of the mean dose occurs is found on page 23 of the output. Since the default settings for the correlations were accepted, all four correlation definitions are reported for all repetitions and all probabilistic variables. It is seen that the BRTF variable has a high correlation with dose, confirming the interpretation of the graphical scatter plot.

Step 18: Go to page 24 of the output, where the analysis is performed on the sample peaks, which occur at various times.

The correlations are much different. This completes the tour of the text report. The formatted database output will be looked at next.

```
File   Pathways   Site Data   View   Form Options   Help                                    _|8|x

RESRAD 5.99          Modify Data
Created April 25, 2000      Soil Concentrations
                                                         Problem  Pathways/ Input  Results   Help

                 View - MCSUMMAR.REP                                                 _|□|x
                 File   Edit   Help
   File          Font: MS LineDraw  10          Page: 24                    put
 Change Title    RESRAD Regression and Correlation output  05/01/00 15:49 Page: Coef   2
                 Title     : Guided Tour Example
 Set Pathways    Input File :  TOUR.RAD
 Modify Data
   Run           Coefficients for peak All Pathways Dose
                      Coefficient =   PCC    PCC    PCC    SRC    SRC    SRC    PRCC
 View Output          Repetition  =    1      2      3      1      2      3      1

 Dose Factors    Variable         Sig Coeff Sig Coeff Sig Coeff Sig Coeff Sig Coeff Sig Coeff Sig Coeff S  put
                 DCACTC(5)          2 -0.06  4 -0.02  3 -0.02  2 -0.06  4 -0.02  3 -0.02  4 -0.13
   Quit          DCACTU1(5)         3 -0.06  1 -0.02  4 -0.02  3 -0.06  1 -0.03  4 -0.02  3 -0.41  ut
                 DCACTS(5)          4 -0.05  2 -0.02  2 -0.03  4 -0.05  2 -0.02  2 -0.03  2 -0.47
                 BRTF(92,1)         1  0.13  3  0.02  1 -0.04  1  0.13  3  0.02  1 -0.04  1  0.86

                 R-SQUARE              0.03     0.00     0.00     0.03     0.00     0.00     0.76

                 -Rank is set to zero if the dose is zero or the correlation matrix is singular.
                 -R-SQUARE varies between 0 and 1 and is called the coefficient of determination; it provides a me
                  variation in the dependent variable (Dose) explained by regression on the independent variables.

 0 Variables

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```

Step 19: The database file name is formed from the base of the site file name ("tour") with an extension of ".MCO". This is in Microsoft Access Version 2 format that can be read into more recent versions of Access or other desktop database applications. Launch the database application (Access 2000 shown below) and open a database. Point the file dialog box to the directory that contains the case files (by default, this is the directory in which RESRAD is installed). Find the file "Tour.mco" in this directory and open it.
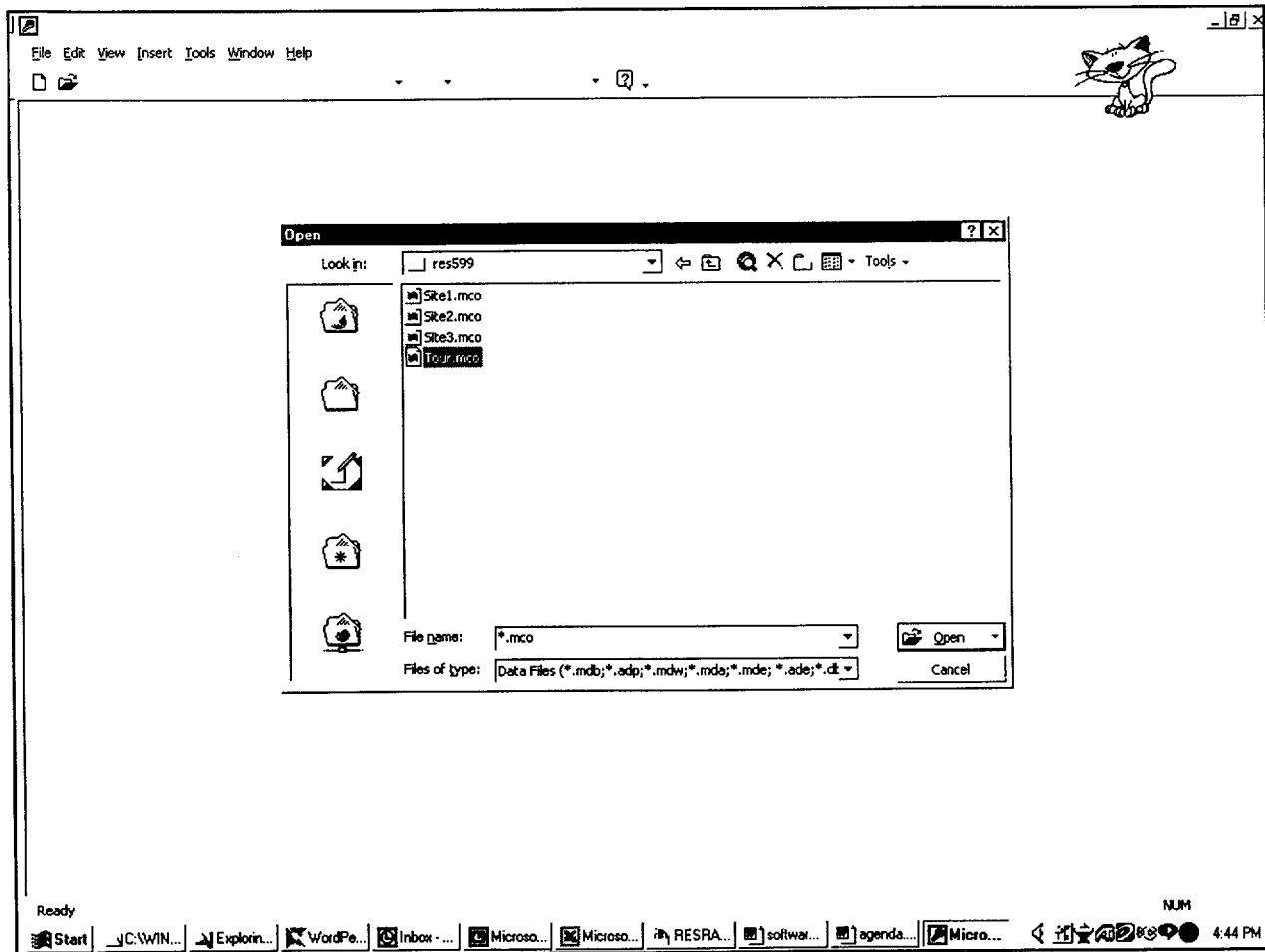
Step 20: Later versions of Access need to either convert the database or open it for read-only. Generally, either option is fine; however, the database must be converted if user-specific queries are to be defined.
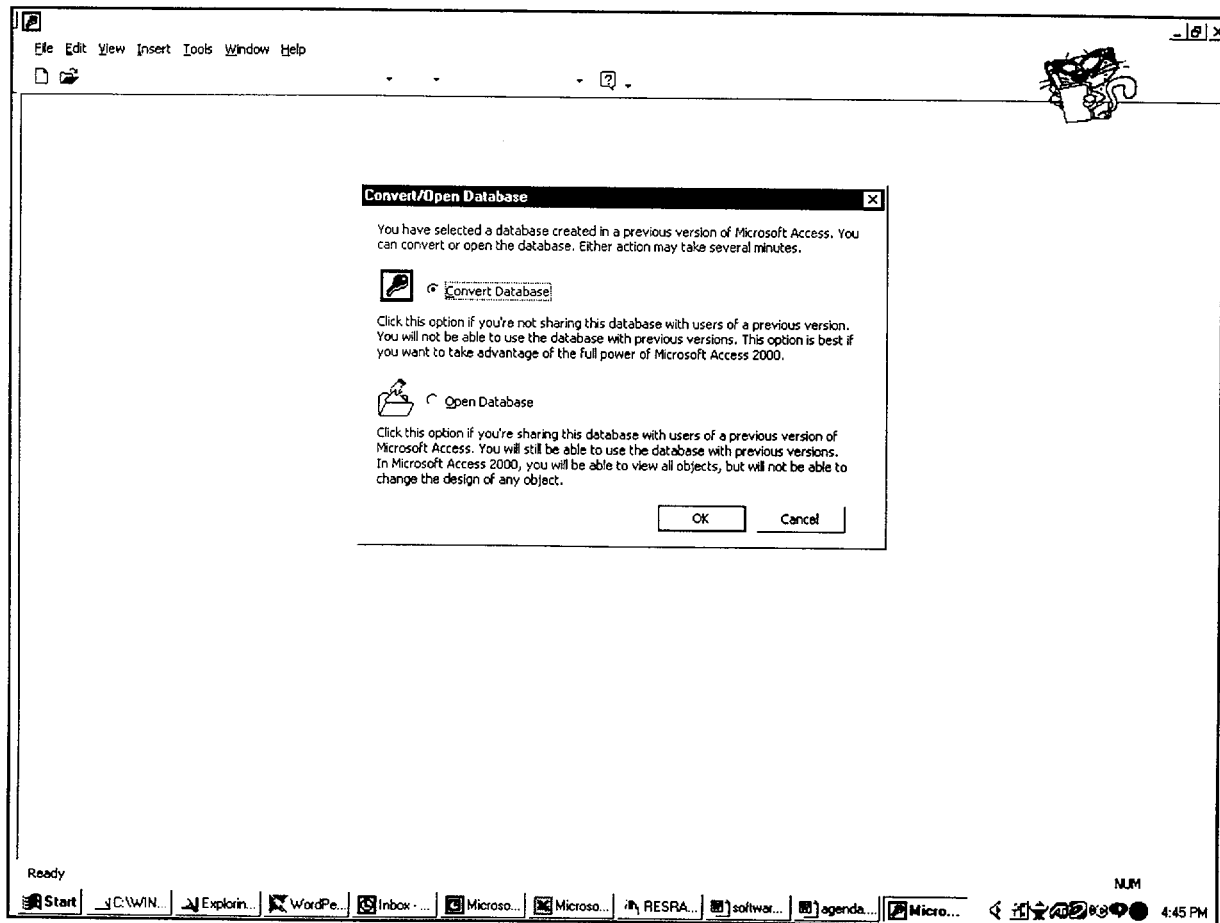
Step 21: Each table's fields are documented in "Design" view. The input sample vectors used in the case are stored in the "Input_Vectors" table. Double clicking on this table name gives the table of values and their reference sample number as the repetition and observation.

```
Microsoft Access                                                                              _ 8 x
File Edit View Insert Format Records Tools Window Help
```

Input_Vectors : Table

Rep	Observation	DCACTC(U-238)	DCACTU1(U-23)	DCACTS(U-238)	BRTF(92,1)
1	1	74.8159	4436.81	77.3565	0.00127549
1	2	14535.1	0.195043	25.855	0.000131046
1	3	27.7825	1037.31	269.231	0.000646709
1	4	3.38825	6300.03	0.752343	0.000971493
1	5	1043.1	19610.9	47.7992	0.000610857
1	6	80.6537	246.177	1533.75	0.00302442
1	7	45.8895	461.745	17.6137	0.00183498
1	8	431.458	29.2184	467.892	0.00501453
1	9	86.8459	2042.51	56.8	0.00289834
1	10	254.238	168.007	167.058	0.00846791
1	11	2268.19	47.377	120.602	0.00671498
1	12	7287.34	1190.51	3.02993	0.0113027
1	13	364.489	114.054	1947.06	0.00426533
1	14	14.4056	72.3874	1596.57	0.00138125
1	15	3257.51	629.256	3925.19	0.00536518
1	16	4257.07	53912.4	112.266	0.00189027
1	17	391.984	0.607123	3.8515	0.00111182
1	18	19.2069	517.283	1137.83	0.000726595
1	19	1.59677	3.58534	35.1968	0.0012982
1	20	5933.71	5150.33	515.704	0.00474406
1	21	1174.42	59.6393	7.63391	0.00259324
1	22	0.171191	5.54202	21.9469	0.00228861
1	23	229.357	317.758	385.541	0.0026958
1	24	1.13677	43546.8	24.4596	0.00370138
1	25	1983.54	10770.1	3304.72	0.00310546
1	26	1.28696	6.45034	604.688	0.000950223
1	27	100.953	22220.7	15.0547	0.00554511
1	28	130466	3118.67	0.121656	0.00218331
1	29	35.6328	12.8319	3.70858	0.000869536
1	30	182.278	0.354903	1307.99	0.000667439
1	31	132.794	102.983	767.66	0.00748106

Record: 1 of 300

Objects: Correlations, Graphic_Time, Input_Vectors, Monte_Carlo_Input, Peak_Nuclide_Dose, Peak_Pathway_Dose, Percentile, Sampling_Specifications, User_Times_Dose, User_Times_Risk

Datasheet View

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Step 22: The results are similarly stored. For example, the "User_Times_Dose" table shows the nuclide and pathway breakdown of the dose for each sample for each time. The user can define queries within Access or database programming languages to further explore the relationships between the input and output data. This step concludes the quick tour.

Microsoft Access

File Edit View Insert Format Records Tools Window Help

Rep	Time	Median	90	95
1	0	5.662	6.154	6.562

Objects:
- Correlations
- Graphic_Time
- Input_Vectors
- Monte_Carlo_Input
- Peak_Nuclide_Dose
- Peak_Pathway_Dose
- Percentile
- Sampling_Specifications
- User_Times_Dose
- User_Times_Risk

User_Times_Dose : Table

Rep	Observation	Isotope	Time	External	Inhalation w/o	Radon (WI)	Plant Ingestion	Me
1	1	U-238	0	4.591E+00	2.517E-01	0.000E+00	1.668E 01	
1	1	U-238	1	4.155E+00	2.257E-01	0.000E+00	1.501E-01	
1	1	U-238	3	3.399E+00	1.812E-01	0.000E+00	1.206E-01	
1	1	U-238	10	1.668E+00	8.282E-02	0.000E+00	5.509E-02	
1	1	U-238	30	1.900E-01	7.004E-03	0.000E+00	4.663E-03	
1	1	U-238	100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	1	U-238	300	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	1	U-238	1000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
2	1	U-238	0	4.591E+00	2.517E-01	0.000E+00	2.074E-01	
2	1	U-238	1	4.478E+00	2.433E-01	0.000E+00	2.007E-01	
2	1	U-238	3	4.257E+00	2.270E-01	0.000E+00	1.872E-01	
2	1	U-238	10	3.531E+00	1.753E-01	0.000E+00	1.446E-01	
2	1	U-238	30	1.801E+00	6.638E-02	0.000E+00	5.482E-02	
2	1	U-238	100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
2	1	U-238	300	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
2	1	U-238	1000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
3	1	U-238	0	4.591E+00	2.517E-01	0.000E+00	5.786E-01	
3	1	U-238	1	4.495E+00	2.442E-01	0.000E+00	5.619E-01	
3	1	U-238	3	4.306E+00	2.296E-01	0.000E+00	5.282E-01	
3	1	U-238	10	3.668E+00	1.821E-01	0.000E+00	4.190E-01	
3	1	U-238	30	2.018E+00	7.440E-02	0.000E+00	1.714E-01	
3	1	U-238	100	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
3	1	U-238	300	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
3	1	U-238	1000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	
1	2	U-238	0	4.591E+00	2.517E-01	0.000E+00	1.798E-02	
1	2	U-238	1	4.539E+00	2.466E-01	0.000E+00	1.762E-02	
1	2	U-238	3	4.432E+00	2.363E-01	0.000E+00	1.689E-02	

Datasheet View

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10. SUPPLEMENTARY NOTES

T. Mo, NRC Project Manager

11. ABSTRACT *(200 words or less)*

RESRAD and RESRAD-BUILD codes are part of the RESRAD family of codes developed by the U.S. Department of Energy. For many years these deterministic codes have been used as dose assessment tools for cleanup efforts at sites contaminated with radioactive materials. The RESRAD code applies to the cleanup of soil, and the RESRAD-BUILD code applies to the cleanup of buildings and structures.

The existing (deterministic) RESRAD 6.0 and RESRAD-BUILD 3.0 codes were adapted for use (with the U.S. Nuclear Regulatory Commission's (NRC's) Standard Review Plan for Decommissioning, NUREG-1727) as site-specific and probabilistic dose analysis tools for demonstrating compliance with the license termination rule in a risk-informed manner.

This report includes a user guide for the probabilistic modules included in RESRAD version 6.0 and RESRAD-BUILD version 3.0. It also includes background information and summaries of the previous tasks accomplished in this project, a description of the software design and requirements, and description of a sample case for probabilistic dose analysis. A detailed discussion of the Latin hypercube sampling method, a summary of parameter distributions, and a "guided tour" that demonstrates the use of the probabilistic modules are included in the appendices.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

User Guide for Probabilistic Modules for RESRAD and RESRAD-BUILD computer codes, NMSS Decommissioning Standard Review Plan (NUREG-1727), demonstrating compliance with the license termination rule, risk informed regulation, probabilistic and site-specific radiation dose analysis, parameter distributions, uncertainty analysis of calculated dose and sensitivity analysis of the dose to input parameters, Latin Hypercube sampling, regression analysis, correlation co-efficients, scatter plots, U.S. Nuclear Regulatory Commission, U.S. Department of Energy

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unlimited
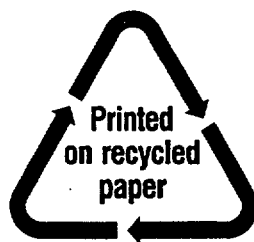
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