Argonne
NATIONAL LABORATORY

User's Manual for RESRAD-BUILD Code Version 4

Vol. 2 – User's Guide for RESRAD-BUILD Version 4

Environmental Science Division

About Argonne National Laboratory
Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC
under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago,
at 9700 South Cass Avenue, Lemont, Illinois 60439. For information about Argonne
and its pioneering science and technology programs, see www.anl.gov.

User's Manual for RESRAD-BUILD Code Version 4

Vol. 2 – User's Guide for RESRAD-BUILD Version 4

by
J.-J. Cheng, E. Gnanapragasam, C. Wang, D. LePoire, S. Kamboj, K. Beckman, and C. Yu
Environmental Science Division, Argonne National Laboratory

December 2022

CONTENTS

CONTENTS (CONT.)

FIGURES (CONT.)

FIGURES (CONT.)

FIGURES (CONT.)

TABLES

This page intentionally left blank.

1 INTRODUCTION

The RESRAD-BUILD computer code is designed to assess radiological doses to individuals who live or work in a building contaminated with radioactive material. The code is equipped with a user-friendly interface that has many features to facilitate using the computer code and understanding the results. The design of the interface provides various options, from entering data and performing calculations to displaying calculation results. General and context-specific help are available, providing information on editing and viewing the radionuclide database, the definitions of input parameters and their use in the calculations, and the selection of the calculation results for placement into other applications. Two types of sensitivity analysis are supported by the code, i.e., deterministic and probabilistic, that can be used to study the influence of input parameters on the calculation results.

After the release of Version 3.0 in year 2000 and a RESRAD-BUILD user's manual in 2003 (Yu et al. 2003), several versions of the RESRAD-BUILD code were released; the last one was Version 3.5, released in 2009, as can be seen on RESRAD-BUILD Version History webpage (https://resrad.evs.anl.gov/codes/resrad-build/history.cfm). The major enhancements in these versions over Version 3.0 include: (1) conducting sensitivity analysis; (2) performing risk calculations; (3) considering rectangular sources; (4) providing a choice of age-dependent internal dose coefficients from International Commission on Radiological Protection (ICRP)-72 (ICRP 1996), which are based on ICRP-60 methodology (ICRP 1991), and external dose coefficients based on ICRP-60 methodology for dose calculations; (5) allowing different units for radioactivity and radiation dose to be used in specifying inputs and presenting calculation results; and (6) linking the RESRAD Dose Conversion Factor (DCF) Editor to the RESRAD-BUILD code in the same way as the DCF Editor is linked to the RESRAD-ONSITE and RESRAD-OFFSITE codes, so the features of viewing, editing, and creating DCF libraries available in RESRAD-ONSITE and RESRAD-OFFSITE are also available in RESRAD-BUILD.

The RESRAD-BUILD code Version 4.0 offers many new features and enhancements in modeling and calculational approaches. The major improvements include: (1) expanding the number of rooms from 3 to 9, (2) adding the option of using ICRP-107 (ICRP 2008) nuclide transformation data and ICRP-60-based DCFPAK 3.02 dose and risk coefficients in calculations, (3) incorporating both numerical and analytical solutions of the transient concentrations of the dynamic ventilation model, (4) considering periodical vacuuming and its efficiency, (5) allowing time-variant removal rates for non-volume sources, (6) implementing efficient numerical and analytical time-integration to obtain dose/risk results, (7) redefining the basis for a volume source's coordinate system and its erosion direction, (8) outputting intermediate results, (9) introducing new appearances for several input forms, (10) linking the code to the new and enhanced DCF Editor, (11) providing comprehensive context-specific help, and (12) improving the summary report.

This user's guide provides instructions to help users on how to install the RESRAD-BUILD code, navigate the interface, and use the various features, including those discussed above, to set up a dose/risk analysis and to view/print the results in text and graphical outputs. This user's guide supersedes and replaces the user's guide contained in Chapter 4 of the User's Manual for Version 3 (Yu et al. 2003). Both the updated RESRAD-BUILD User's Manual

Vol. 1—Methodology and Models Used in the RESRAD-BUILD Code (Yu et al. 2022) and Vol. 2—User's Guide for RESRAD-BUILD Code Version 4 (this report) can be viewed from the Help menu in the code. They also can be downloaded from the RESRAD website Documents page (https://resrad.evs.anl.gov/documents).

This user's guide contains nine chapters with the following topics:

1. Introduction.

2. Installation: Discusses installation and uninstallation procedures and system requirements.

3. Navigation and File Management: Contains instructions for moving around the interface to accomplish various tasks and to save input and output.

4. Input Forms: Contains descriptions for each input form and for each parameter in the input form.

5. RESRAD Dose Conversion Factor Editor: Contains information on using and accessing various dose and risk coefficient libraries.

6. Results: Provides instructions on finding results in text and graphical outputs, as well as in the intermediate output files.

7. Parameter Sensitivity Analysis: Explains the deterministic and probabilistic sensitivity analysis features.

8. Help: Discusses various sources for obtaining help.

9. References.

2 INSTALLATION

The RESRAD family of codes, including RESRAD-BUILD Version 4.0, is distributed through the RESRAD website (https://resrad.evs.anl.gov). A printer must be installed, which could be, for example, a physical printer, an offline printer, a PDF printer, or a document writer. The code has been tested and is fully compatible with the Windows 10 operating system. The following sections describe the procedure for downloading and installing the code (Section 2.1), checking the installation (Section 2.2), and uninstalling the code (Section 2.3).

2.1 INSTALLING FROM THE RESRAD WEBSITE

- Connect to the RESRAD website at https://resrad.evs.anl.gov/.

- Click on the Download option.

- Fill in the requested information and submit. An email with the download link will be sent to the email address supplied. Click on the link to download the installation program.

  (Note: Administrative rights to the computer are required to install the program.)

- When the installation program launches, follow the instructions to enter the information requested. (Note: First-time users are advised to accept the default selections.)

  o The code should not be installed in the program files directory, as it needs to write temporary files and modify data files in the installation directory every time it is executed.

- If the default installation selections are used, the files needed to execute RESRAD-BUILD Version 4.0 will be installed at C:\RESRAD_Family\BUILD\4.0\, and the RESRAD DCF Editor and the DCF database files that provide the libraries needed to support the dose and risk calculations (e.g., dose coefficients, risk coefficients, etc.) will be installed at C:\RESRAD_Family\DCF\3.3.

The installation would also have created the following subdirectories:

- C:\RESRAD_Family\BUILD\4.0\QA_files—quality assurance (QA) files are saved under this subdirectory.

- C:\RESRAD_Family\BUILD\4.0\UserFiles—the default directory for saving the input files with the Save As command, unless the user navigates to a different directory.

  (Note: Directories different than the default directories can be specified for storing the RESRAD-BUILD code Version 4.0 and the DCF Editor

Version 3.3 during installation. In that case, the subdirectories "QA_files" and "UserFiles" will be created under the specified directory for storing the code.)

- After installation, the program will be placed under the RESRAD family group in the Start menu and a new RESRAD-BUILD 4.0 icon will appear on the computer desktop.

- Double-click the RESRAD-BUILD 4.0 icon to start RESRAD-BUILD.

   (Note: If "Launch RESRAD-BUILD" is selected before finishing the installation, the program will start automatically after the installation is completed.)

2.2 CHECKING THE INSTALLATION

Six quality assurance input files are placed in the C:\RESRAD_Family\BUILD\4.0\QA_files\ subdirectory (for brevity purposes, this folder is referred as ...\QA_files\ herein) during the installation of the code. Five of them check the installation of the code for deterministic analyses, and the sixth one checks the installation of the code for conducting sensitivity analyses, both deterministic and probabilistic. These files can be run on RESRAD-BUILD to obtain output files for comparison with those generated by the code developers to verify successful installation. The latter are placed in the...\QA_files\QAoutputforComparison\ subdirectory during installation. (For brevity purposes, this folder is referred as "…\QAoutputforComparison\" herein.)

- Double-click the RESRAD-BUILD 4.0 icon on the computer desktop to start RESRAD-BUILD.

- Click File in the Menu Bar on top of the interface and Open the "qa1.bld" input file in the …\QA_files subdirectory.

- Click File in the Menu Bar and then Run to start the calculations.

- When the calculations are completed, a View window showing the RESRADB.RPT output file appears.

   o Use the File – Save menu command or press the F3 key in the text viewer to save the summary report to qa1_rpt.txt.

   o The summary report generated from the run will be saved in the...\4.0\QA_files directory.

   o Click the "X" icon to close the View window.

- Open the text output file, qa1_rpt.txt, that was saved in the ...\QA_files\ subdirectory and compare it with the corresponding output file, qa1.rpt, in the …\QAoutputforComparison\ subdirectory, that was generated by the code developers. The input information and dose results listed in the two output

files are expected to be the same, although the time and date listed in 1st line of each page will be different.

(Note: The text output file can be opened with any word processor or automated file comparison software.)

- Run RESRAD-BUILD with the QA input file, qa2.bld, provided (in the ...\QA_files\ subdirectory), save the RESRADB.RPT output file to qa2_rpt.txt, and compare it with qa2.rpt that was generated by the code developers (in the …\QAoutputforComparison\ subdirectory).

- The different input choices between the two input files, qa1.bld and qa2.bld, include (1) transformation database, (2) dose coefficient and risk factor libraries, (3) cutoff half-life, (4) Traditional vs. New input appearance, and (5) different radionuclides that are initially present in the sources. The RESRAD-BUILD code has many other features and generates numerous output files. Additional QA files are included in the distribution package and installed in the ...\QA_files\ and …\QAoutputforComparison\ subdirectories. The instructions for using them to conduct additional installation checking are provided in the two pdf files, "Basic Installation QA Procedure for RESRAD-BUILD.pdf" and "Comprehensive Installation QA Procedure for RESRAD-BUILD.pdf," that are installed in the ...\QA_files\ subdirectory.

(Note: More QA files may be available at the User Center on the RESRAD website)

2.3 UNINSTALLATION

To uninstall RESRAD-BUILD Version 4.0:

- In the Start Menu, expand the RESRAD Family folder, highlight the RESRAD-BUILD 4.0 menu option, then right-click to access the Uninstall option. This will launch the Programs and Features utility.

- In the Programs and Features utility, right-click RESRAD-BUILD Version 4.0 and select Uninstall.

- Installed files will be removed from the system. User files in the installation directory will not be removed, but they may be deleted manually.

3   NAVIGATION AND FILE MANAGEMENT

Figure 1 shows the Main Interface that appears when RESRAD-BUILD is started. This interface contains six input forms: Case, Building Parameters, Radiological Data, Receptor Parameters, Shielding Parameters, and Source Parameters. These six forms show most of the input parameters necessary to run RESRAD-BUILD. Three of the forms (Case and Building and Source Parameters) contain buttons to access more detailed input forms. The Shielding Parameters form contains buttons to facilitate specification of multiple shields.
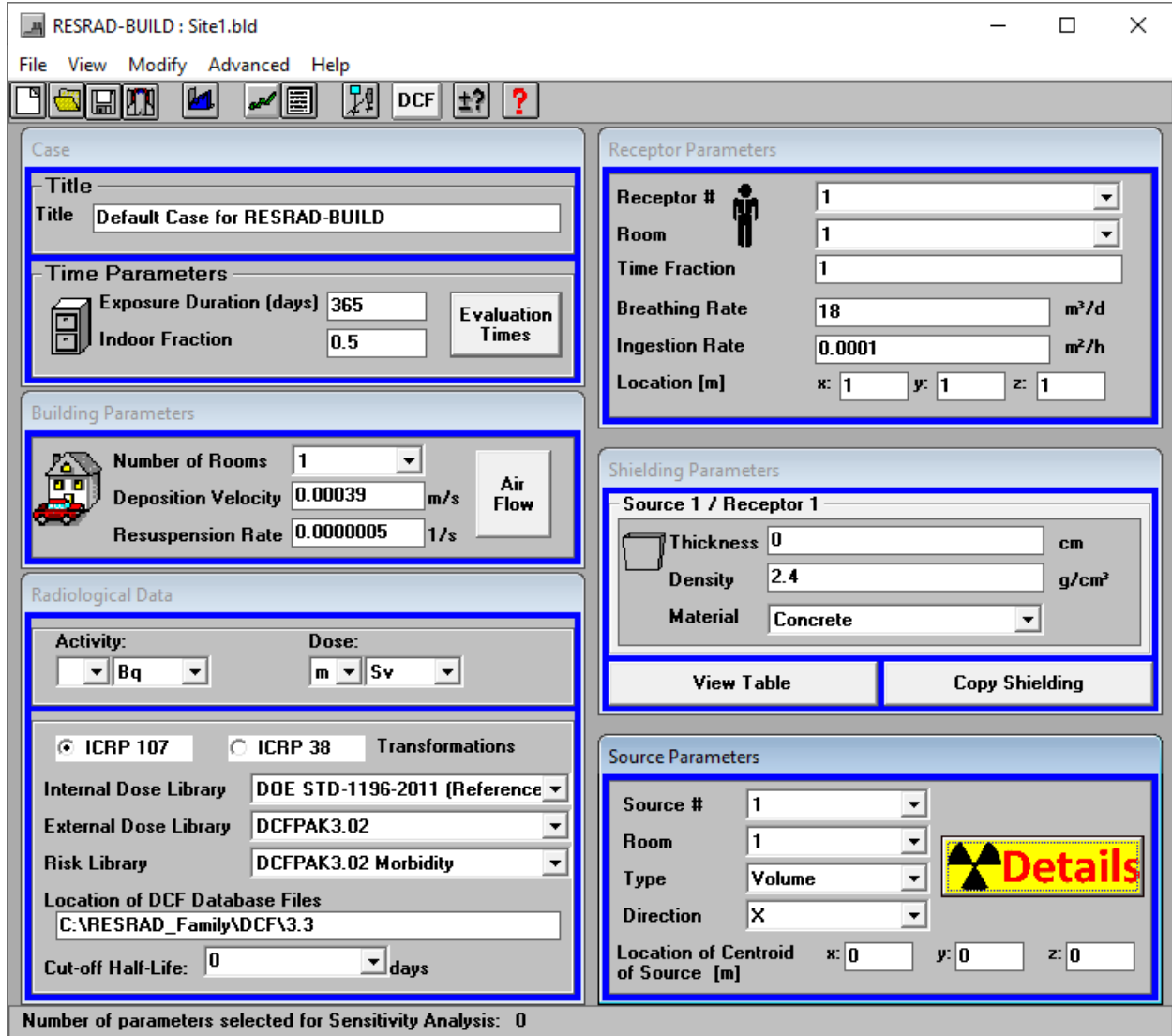
Figure 1   The Main Interface of RESRAD-BUILD

The Main Interface contains a Menu and a Toolbar at the top. The File tab on the Menu Bar contains the standard functions for file management, which pertain to only the input file. The File menu also includes a Run option, which starts the calculations after all the parameters have been specified. These functions are also available by activating the first four Toolbar buttons. The View menu allows retrieval of the output files lastly generated, which were saved under standard file names after each run. These output files are automatically overwritten unless they are saved using the menu commands in the Output Report Viewer. The Modify menu allows changing the number of sources and receptors. The Advanced menu allows the selection of either the Traditional Appearance or the New Appearance for the detailed input forms that can be opened within the Case and Building and Source Parameters forms, as well as the selection to Write Intermediate Output and Save Preferences settings, as well as to handle missing dose and risk coefficients. The Help menu brings up different resources to provide additional information.

3.1 MENU BAR

The top horizontal bar at the Main Interface, i.e., the Menu Bar, includes five menus that provide venues to change the number of radiation sources and receptors, perform operational functions, and utilize features of the RESRAD-BUILD code. The five menus and the submenus that branch from each of them are shown in Figure 2 and described below.
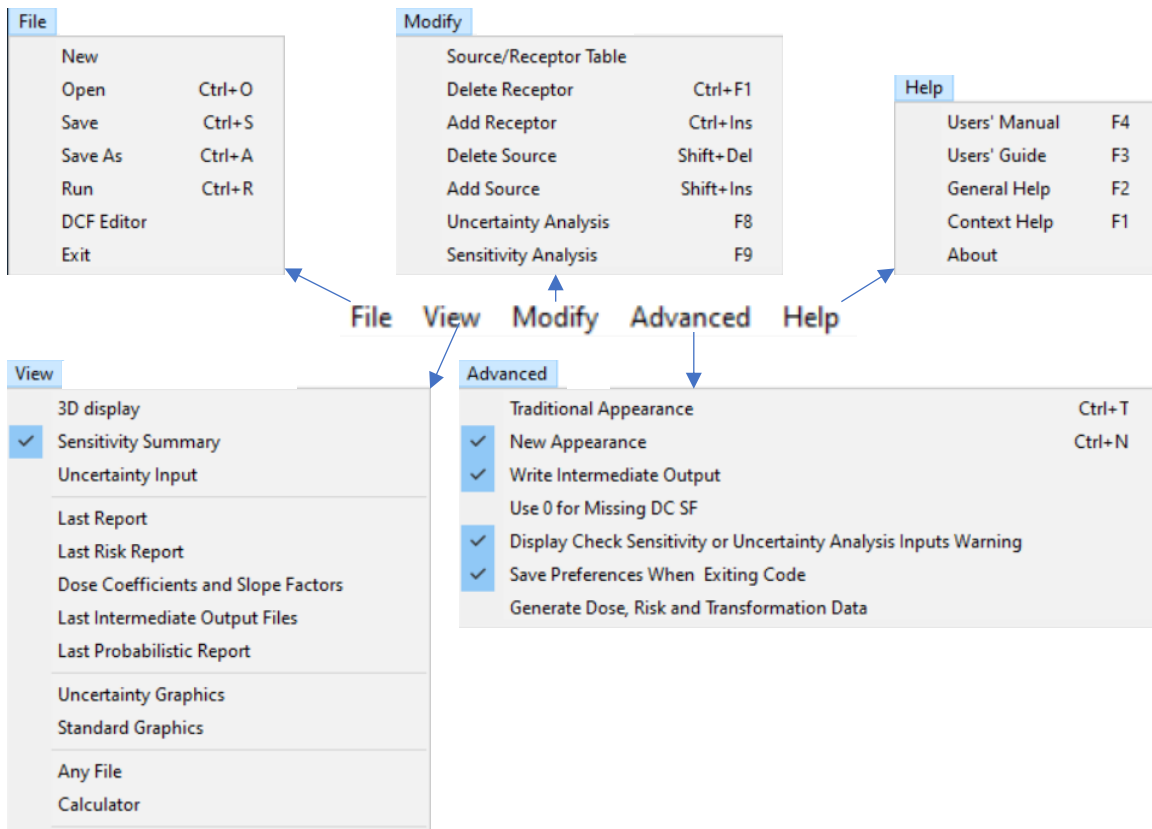
Figure 2 Main Menu and Submenus

File Submenu: The first four options of the submenu perform common file operations. The Run option can be used to perform an analysis using the current inputs. The last option terminates the navigation and exits the RESRAD-BUILD code.

- **New:** Starts afresh with a set of default or placeholder values for all input parameters.

- **Open:** Brings up the dialogue box to open a previously saved input file. The RESRAD-BULD input files have a .bld file extension by default. The shortcut key Ctrl+O is also defined for this option.

  Only files with extension .bld or .TEM can be opened in RESRAD-BUILD Version 4.0. The code is case sensitive with respect to these extensions.

  The code is backward compatible and can open RESRAD-BUILD Version 3.5 input files.

- **Save:** Saves the current input file. To share input files, for deterministic cases, the *.bld file (* denotes the given name of the file) is all that is required. For probabilistic cases, two additional files, *.LHS and *.CR, are also required. These files are automatically saved whenever the *.bld file is saved. The shortcut key Ctrl+S is also defined for this option.

- **Save As:** Brings up the dialogue box to allow saving the current inputs under a different filename. The shortcut key Ctrl+A is also defined for this option.

- **Run:** Saves the input file, generates all the data files that are necessary to execute the computations, and launches the computations. The shortcut key Ctrl+R is also defined for this option. Only files with extension .bld can be run on RESRAD-BUILD Version 4.0.

- **DCF Editor:** Accesses the DCF Editor for viewing, creating, editing, making a copy of, or renaming a dose/risk conversion factor library. See Section 5 for more information.

- **Exit:** Close the Main Interface and exit.

View Submenu: This submenu allows the user to view certain windows, including the report viewing window, graphic output selection window, the three-dimensional (3-D) display window, the uncertainty analysis input window, the dose and risk coefficients report window, and the intermediate output files selection window. (Note: "uncertainty analysis" and "probabilistic analysis" refer to the same type of analysis. Both terms are used in this document.) The first three submenu commands act as toggles, to display and then to close the corresponding form; the other nine commands will display, but not close, the corresponding forms or windows.

- **3-D Display:** Allows access to the three-dimensional display of the source and receptor input locations.

- **Sensitivity Summary:** Displays the gray horizontal bar at the bottom of the interface that summarizes the sensitivity analysis selections.

- **Uncertainty Input:** Displays the Uncertainty Analysis Input Summary window that shows the current input settings for a probabilistic analysis.

- **Last Report:** Displays the deterministic radiation dose report from the last run.

- **Last Risk Report:** Displays the deterministic cancer risk report from the last run.

- **Dose Coefficients and Slope Factors:** Displays the dose coefficients and slope factors report from the last run.

- **Last Intermediate Output Files:** Displays the View Intermediate Output for the Last Run window that allows the selection of an output file with specific intermediate results from last run for viewing.

- **Last Probabilistic Report:** Displays the probabilistic analysis report from the last run.

- **Uncertainty Graphics:** Displays the probabilistic analysis graphic output window for presenting the probabilistic analysis results.

- If uncertainty output is available for the input file that is open in the RESRAD-BUILD interface when this menu command is clicked, that output will be displayed in the uncertainty graphics viewer. If not, a file dialog box will be displayed; the user can navigate to any existing RESRAD-BUILD uncertainty output file (.BUO) file to view its content.

- **Standard Graphics:** Displays the deterministic analysis graphic output window for presenting the deterministic analysis results, including the base case and sensitivity analysis results.

- **Any File:** Displays the file selection window to allow viewing of any file in Notepad.

- **Calculator:** Opens the Windows calculator for quick calculations.

Modify Submenu: The Modify submenu has options allowing the user to open the source/receptor table, add and delete receptors and sources, and select inputs for sensitivity and/or uncertainty analysis. Shortcut keys are defined for these options.

- **Source/Receptor Table:** Displays the source/receptor table to allow users to input shielding information between each source and each receptor.

- **Delete Receptor:** At least one receptor must be considered for radiation exposure analysis in RESRAD-BUILD. A receptor can be deleted if more than one receptor is specified. The shortcut key Ctrl+F1 is also defined for this option.

- **Add Receptor:** Allows adding one more receptor to the analysis. A maximum of 10 receptors is allowed in each RESRAD-BUILD analysis. The shortcut key Ctrl+Ins is also defined for this option.

- **Delete Source:** At least one radiation source must be specified for a radiation exposure analysis with RESRAD-BUILD. A source can be deleted if more than one source is specified. The shortcut key Shift+Del is also defined for this option.

- **Add Source:** Allows adding one more source to the analysis. A maximum of 10 sources is allowed in each RESRAD-BUILD analysis. The shortcut key Shift+Ins is also defined for this option.

- **Uncertainty Analysis:** Selects the highlighted input for uncertainty analysis, if it is eligible for uncertainty analysis (Section 7.2). Displays the uncertainty analysis input window to allow the specifications of distribution information for the highlighted parameter as well as its correlation with the other parameters that have been included in the uncertainty analysis. The shortcut key F8 is also defined for this option.

- **Sensitivity Analysis:** Selects the highlighted parameter for sensitivity analysis, if it is eligible for sensitivity analysis (Section 7.1). Displays the sensitivity analysis input window for the highlighted parameter to allow the specification of a sensitivity analysis range. The shortcut key F9 is also defined for this option.

Advanced Submenu: The first two commands in this submenu allow the selection of either the Traditional or the New Appearance option for the interface and the functionality associated with it. One of the commands can be used to instruct the code to write the intermediate results to output files. The others have the functions of saving the preference setting; handling missing dose or risk coefficients; managing warning messages related to sensitivity or uncertainty analysis; and generating transformation diagrams.

- **Traditional Appearance:** Uses the traditional input forms to specify detailed options/characteristics associated with the Evaluation Times form, Building Parameters form, Room Details form, and Details of Source form and accesses the computational functionality associated with these forms. The traditional input forms are very similar to input forms in Version 3.5 and earlier versions. When the traditional input forms are selected, several new features in Version 4.0 will not be available, because additional required inputs are not included in the traditional input forms.

The choice of the appearance applies to the entire interface and forms and to the functionality, not just to a specific form that might be open. If data is entered under the New Appearance before switching to the Traditional Appearance, the inputs for the additional parameters will be preserved in case the user switches back to the New Appearance again. The information will be preserved until one of the following occurs: an existing input file is opened, a new input file is created, or the code is exited. But these additional inputs will not be used in the computational code for an input file that is saved under the Traditional Appearance.

If any of the inputs that are eligible only under the New Appearance were selected for sensitivity or probabilistic analysis prior to changing to Traditional Appearance, those selections too will be retained until one of the three actions mentioned in the previous paragraph is performed. But those selected for sensitivity analysis will not be written to an input file that is saved under the Traditional Appearance because they will not have any effect on the results. Those selected for uncertainty analysis will be written to the uncertainty input file even though they too will not have any effect on the results, because they do not change the run time and doing so allows the use of the same set of probabilistic samples under both appearances, if desired.

If any of the three forms, Evaluation Times (Section 4.1), Air Flows and Particulates (Section 4.2.2), or Details of Source (Section 4.6.3) are open when the appearance is switched from New to Traditional, the information in the open forms will be saved; the forms that were open will be changed to the Traditional Appearance. The inputs in these forms will correspond, to the extent possible, to the information that was in the forms that were saved.

If the maximum number of time-integration points specified in the New Appearance were greater than 257, they will be limited to 257 only if the Evaluation Times form is opened. In the Source Details form, the release phase 1 values from the New Appearance will be used for the "Removable Fraction" and the "Air Fraction"; the phase 1 "End Time" will be used for the "Lifetime" in the Traditional Appearance. The values specified under the New Appearance for the volumes of the rooms, the room-specific resuspension rates, and the air flows will not be used to populate the parallel inputs in the Room Details form for the reasons listed below.

o   The Room Details form uses exchange rates to populate the flows, but the Air Flows form does not use or compute them.

o   The Room Details form for three rooms does not have an input of air flows between rooms 1 and 3, while the Air Flows form does.

o   A single resuspension rate is applicable to all rooms.

o   The volume of a room is not an input in the Traditional Appearance.

- **New Appearance:** Uses the advanced (new) input forms to specify detailed options/characteristics associated with the Evaluation Times form (Section 4.1), Air Flows and Particulates form (Section 4.2.2), and Details of Source form (Section 4.6.3). The advanced input forms allow the specification of additional input parameters needed to use the new enhanced features in Version 4.0.

  The choice of the appearance applies to the entire interface and forms, not just to a specific form that might be open. If data were entered under the Traditional Appearance of the forms and the information in the forms were saved before switching to the New Appearance, the values in the New Appearance forms will correspond to the information that was saved under the Traditional Appearance where possible.

  o If the Evaluation Times form (Section 4.1) were open and the data had not been saved before the appearance is switched from Traditional to New, the information in the open forms will be saved and also displayed in the New Appearance of the form.

  o If the Room Details form (Section 4.2.1) were open and the data had not been saved before the appearance is switched from Traditional to New, the information in the open forms will be saved and also displayed in the New Appearance of the form. The area and height from the traditional form will be used to compute the volume to be displayed in the new form.

  o The single resuspension rate from the Building Parameters form is not transferred to the Air Flows and Particulates form; the latter has resuspension rate inputs for each room.

  o If Details of Source form (Section 4.6.3) were open when the appearance is switched from Traditional to New, the information in the open forms will not be saved; the forms that were open will be changed to the New Appearance. They will show the values that were last saved, except that the radionuclide selection from the traditional form will be retained without being saved.

  If any of the inputs that are eligible only under the Traditional Appearance were selected for sensitivity or probabilistic analysis prior to changing to the New Appearance, those selections too will be retained until one of the following occurs: an existing input file is opened, a new input file is created, or the code is exited. But those selected for sensitivity analysis will not be written to an input file that is saved under the New Appearance because they will not have any effect on the results. Those selected for uncertainty analysis will be written to the uncertainty input file even though they too will not have any effect on the results, because they do not change the run time and doing so allows the use of the same set of probabilistic samples under both appearances, if desired.

- **Write Intermediate Output:** Instructs the code to write the intermediate calculation results to output files, so the results can be viewed later to obtain insights to the modeling or for debugging purposes.

- **Use 0 for Missing DC SF:** The interface generates a number of files containing dose, risk, and transformation data for the all the radionuclides that are relevant to the current input file, when either the command to "Run" the file or the command to "Generate Dose, Risk and Transformation data" for the file is issued. If the necessary dose coefficients or slope factors are not available in the specified libraries, the action that the code takes depends on whether this menu is check or not.

  If this menu is checked, the code will use 0 in place of the missing values without prompting the user. If not, the code displays a message (Figure 3) presenting the user with three courses of action to choose from.
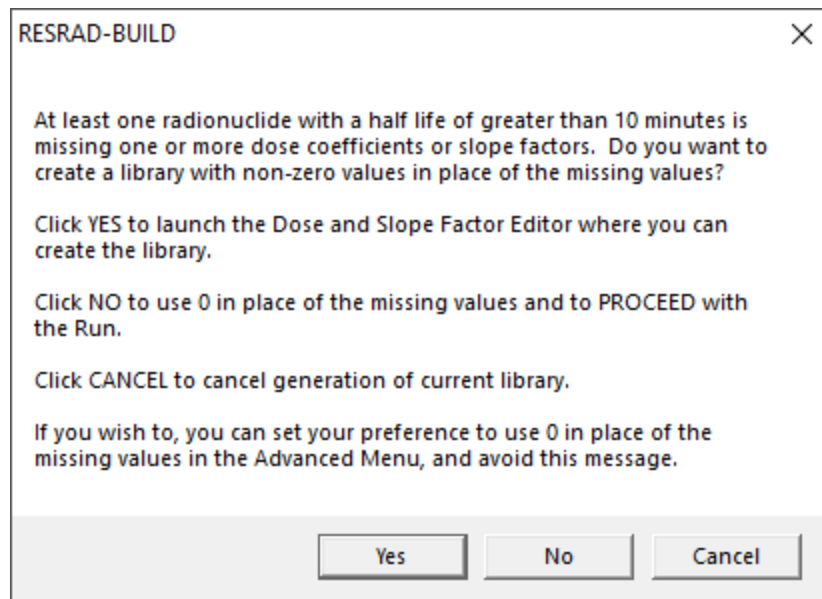
Figure 3 Message Window Associated with Missing Dose Coefficients or Slope Factors

- **Display Check Sensitivity or Uncertainty Analysis Inputs Warning:** When this menu is checked, the code displays one of the four warning messages shown in Figure 4, as appropriate, under the following conditions.

  o The current input file contains inputs selected for sensitivity and/or uncertainty analysis, and one of the next four actions is performed.

    ▪ A source is deleted (message on top-right of Figure 4),

    ▪ A receptor is deleted (message on top-left of Figure 4),

- The number of regions in a source is changed (message on bottom left of Figure 4), or

- The number of rooms in a building is changed (message on bottom right of Figure 4).

This submenu can be unchecked to suppress these messages and to avoid repeated interruptions when a file containing sensitivity or uncertainty analysis is being edited.
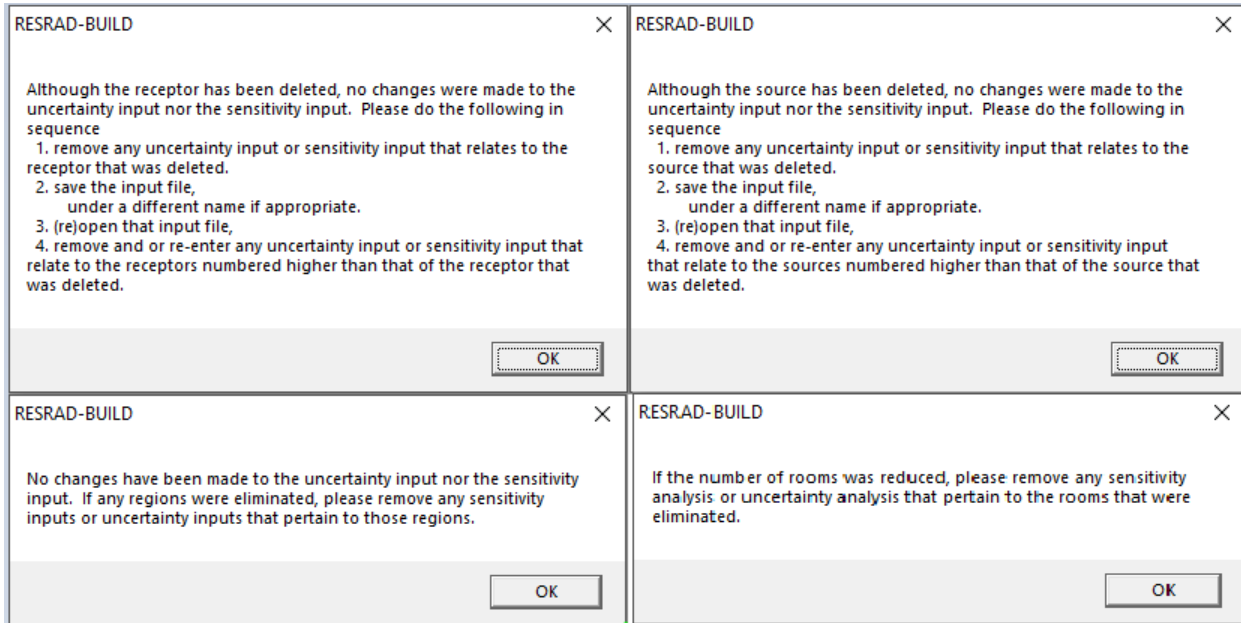
Figure 4 The Four Warning Messages That Can Be Displayed or Suppressed

- **Save Preferences When Exiting Code:** When this menu is checked, the code saves the current selection or setting for the items listed below before closing the interface.

  o The units of radiological activity and its prefix;

  o The units of radiological dose and its prefix;

  o The source of radiological transformation data;

  o The internal dose library;

  o The external dose library;

  o The risk library;

  o The location of dose and risk database files;

  o The cut-off half-life;

  o Whether to display traditional interface or new interface and expand functionality;

- o   Whether or not to write intermediate output;

- o   Whether or not to use 0 for missing dose or risk factor without prompting;

- o   Whether or not to warn when a source or receptor is deleted, or the number of rooms, or regions is changed in files that include sensitivity analysis or uncertainty analysis;

- o   Whether or not to save preferences when exiting the code;

- o   Whether or not to display the sensitivity analysis bar;

- o   Whether or not to display the uncertainty analysis form when an input file containing uncertainty analysis is opened;

- o   The directory where input files are saved.

These selections and settings will be activated/restored in the interface when the code is launched subsequently. The current choices are not saved when the menu is unchecked; but the choices that were saved when the menu was last checked are retained and are used when the code is launched again. If this menu were never checked, the user's choices would never have been saved; the initial settings in the code will be used in this case.

- **Generate Dose, Risk, and Transformation Data:** Instructs the code to write a number of dose coefficient and slope factor files and to display the radiological transformation diagram and the dose coefficients and risk factors for the radionuclides relevant to the current analysis. The data written to the files and those displayed in the graphic are based on the current choice of transformation data, dose, and risk libraries and the cut-off half-life.

A cut-off half-life may be used, if necessary, to reduce the execution time. The code models all the radionuclides in the transformation chain of an initially present radionuclide, regardless of whether a cut-off half-life is used, i.e., the cut-off half-life is greater than zero, or not.

- o   If a cut-off half-life of zero is used, the code will calculate the concentration of each radionuclide, initially present and progeny, using the Bateman equation or in the case of a branching transformation, using a modified Bateman equation.

- o   If a cut-off half-life of greater than zero is specified, the concentration of radionuclides that have a half-life greater than the cut-off half-life are calculated using the Bateman equation or the modified Bateman equation, as appropriate. These radionuclides are called principal radionuclides in RESRAD-BUILD. The radionuclides with a half-life of less than or equal to the cut-off half-life are called associated radionuclides in RESRAD-BUILD. The concentration of an associated radionuclide is modeled as being equal to the product of the concentration of its immediate parent, whether principal or associated, and the branching factor of the transformation of the immediate parent to the progeny in question. An

immediate parent radionuclide is one that transforms directly to the progeny in question, not one that transforms through other radionuclides to the progeny in question.

o Any associated radionuclide that is connected to a principal radionuclide, either directly or through only associated radionuclides in at least one branch of the transformation chain, is said to be associated with that principal radionuclide.

The files generated are described below.

o Current.lib contains the dose coefficients and slope factors, in U.S. customary units, from the selected libraries, for all the radionuclides in the transformation data choice for the four exposure pathways: direct external radiation from an infinite volume source, external radiation from the radionuclides suspended in an infinite volume of air, inhalation of radionuclides in particulates and gases, and ingestion of radionuclides in soil.

o Current_External_Fitted_Parameters.txt lists the dose coefficients for direct external radiation from an infinite volume source, in U.S. customary units, from the selected external dose library; the corresponding fitting factors for depth or thickness of the source; and the condensed energies and their fractions for all the radionuclides in the transformation data choice.

o DCF Individual.lib contains the dose coefficients and slope factors, in U.S. customary units, from the selected libraries, for all the radionuclides that are relevant to the current input file for the four exposure pathways: external radiation from an infinite volume source, external radiation from the radionuclide suspended in an infinite volume of air, inhalation of radionuclides in particulates and gases, and ingestion of radionuclides in soil.

o DCF Integrated.lib contains the associated progeny integrated dose coefficients and slope factors, in U.S. customary units, from the selected libraries, for all the principal radionuclides that are relevant to the current input file for the three exposure pathways: external radiation from the radionuclide suspended in an infinite volume of air, inhalation of radionuclides in particulates and gases, and ingestion of radionuclides in soil. Associated progeny integrated factors are not computed for direct external radiation from an infinite volume source because the external dose and risk from all progeny are computed individually without regard to the cut-off half-life.

The indices of the principal progeny radionuclide and the branching fractions to each principal progeny are also written to this file. The transformation chain that involves only principal radionuclides is describe later in this topic.

- o coeff_bd.lib lists the dose coefficients for direct external radiation from an infinite volume source, from the selected external dose library; the corresponding fitting factors for depth or thickness of the source; and the condensed energies and their fractions for all the radionuclides that are relevant to the current input file.

- o RnDCFL.dat contains the working level month-to-dose conversion factors and the slope factors for the two radon isotopes ^{220}Rn and ^{222}Rn. It also contains the inhalation slope factors for radon exposure for three of the progeny of each of those radon isotopes.

- o Principal Progeny.dat has a listing of the transformation chains relevant to the input file. The principal radionuclides in the transformation chain are listed such that no progeny is listed ahead of its parent. There are two listings for each transformation chain, the first in terms of indices of the radionuclides for use by the FORTRAN code and the second in alphanumeric symbols.

- o Plus Associated Progeny.dat has two entries for each principal radionuclide relevant to the input file listing the radionuclides that are associated with it, the first in terms of indices of the radionuclides for use by the FORTRAN code and the second in alphanumeric symbols. The radionuclides that are deemed to be associated with a principal radionuclide were defined in the bulleted item discussing the use of the cut-off half-life.

These files will be generated and the transformation diagram will be displayed, if the specified dose and risk libraries contain the necessary dose coefficients and slope factors for all the radionuclides that are relevant to the input file. If not, the message window shown in Figure 3 will pop up urging the user to take an action unless the "Advanced"–"Use 0 for missing DC SF" menu option is checked. The transformation diagram window will be displayed after the user takes the appropriate action.

Figure 5 shows an example of the "Transformations, Dose Coefficients and Slope Factors" window associated with this menu option for an input file with a cut-off half-life of 0 days, and with initially present radionuclides Co-60 and Ra-226, when using ICRP-107 (ICRP 2008) transformation data. When the "initially present radionuclides only" check box in the window is checked, the radionuclides specified to be initially present in the input file are listed in the upper list box. The transformation chain for the radionuclide selected in that list box, Ra-226, in this example, is displayed in the graphic on the right.
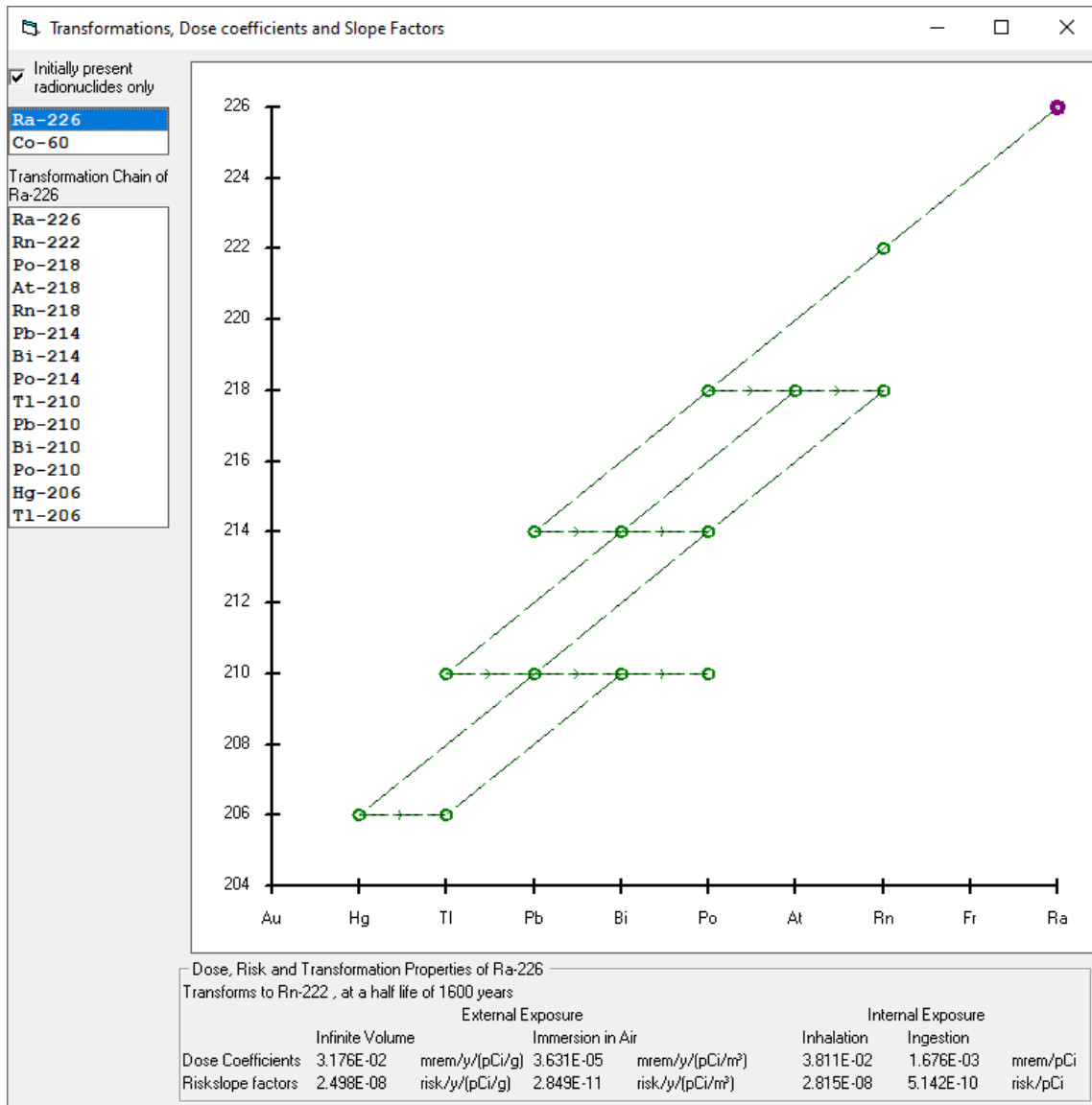
Figure 5 ICRP-107-Based Transformation Chain for Ra-226 at a Cut-off Half-life of 0 Day

Below the list of the initially present radionuclides is the list of radionuclides in the transformation chain of the selected initially present radionuclide. If the user were to choose any of the radionuclides in this list, its transformation properties and dose coefficients and risk factors from the selected libraries will be displayed at the bottom of the window, as shown in Figure 6. The selected radionuclide in the transformation chain is highlighted in the graphic.
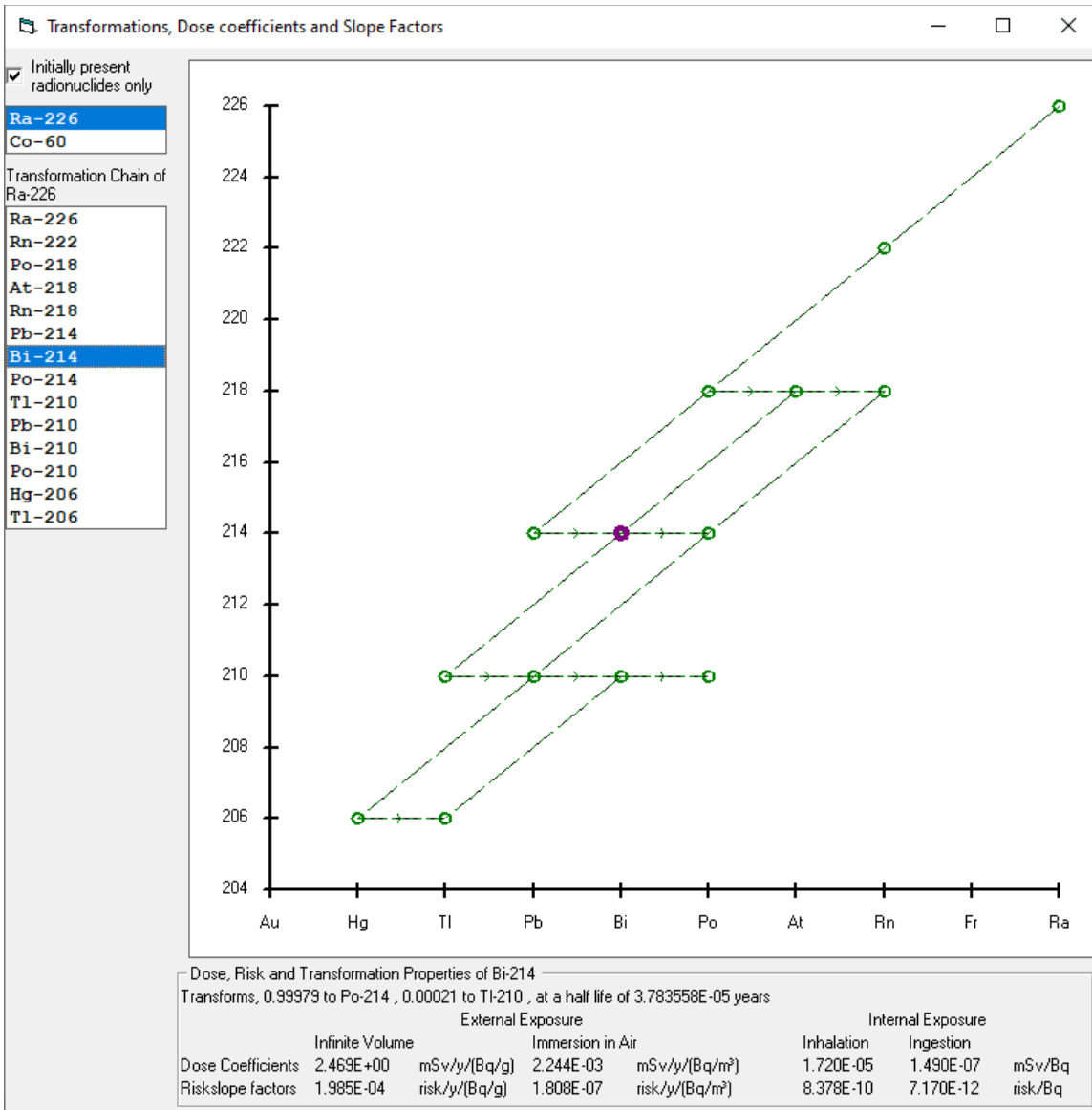
Figure 6 ICRP-107-Based Transformation Chain for Ra-226 Showing Dose, Risk, and Transformation Properties of Bi-214

The transformation graphic for an initially present radionuclide may have two chains when a non-zero cut-off half-life is specified. Figure 7 shows the transformation diagram for Ra-226 using ICRP-107 transformations with a cut-off half-life of 30 days. In the diagram, the black long-dashed lines depict the complete transformation chain of Ra-226. The green short-dashed lines depict the transformation chain consisting only of principal radionuclides used to compute the concentrations of the principal radionuclides, those with a half-life greater than the specified cut-off half-life of 30 days in this example; these radionuclides are shown in green. The associated progeny radionuclides are shown in black.
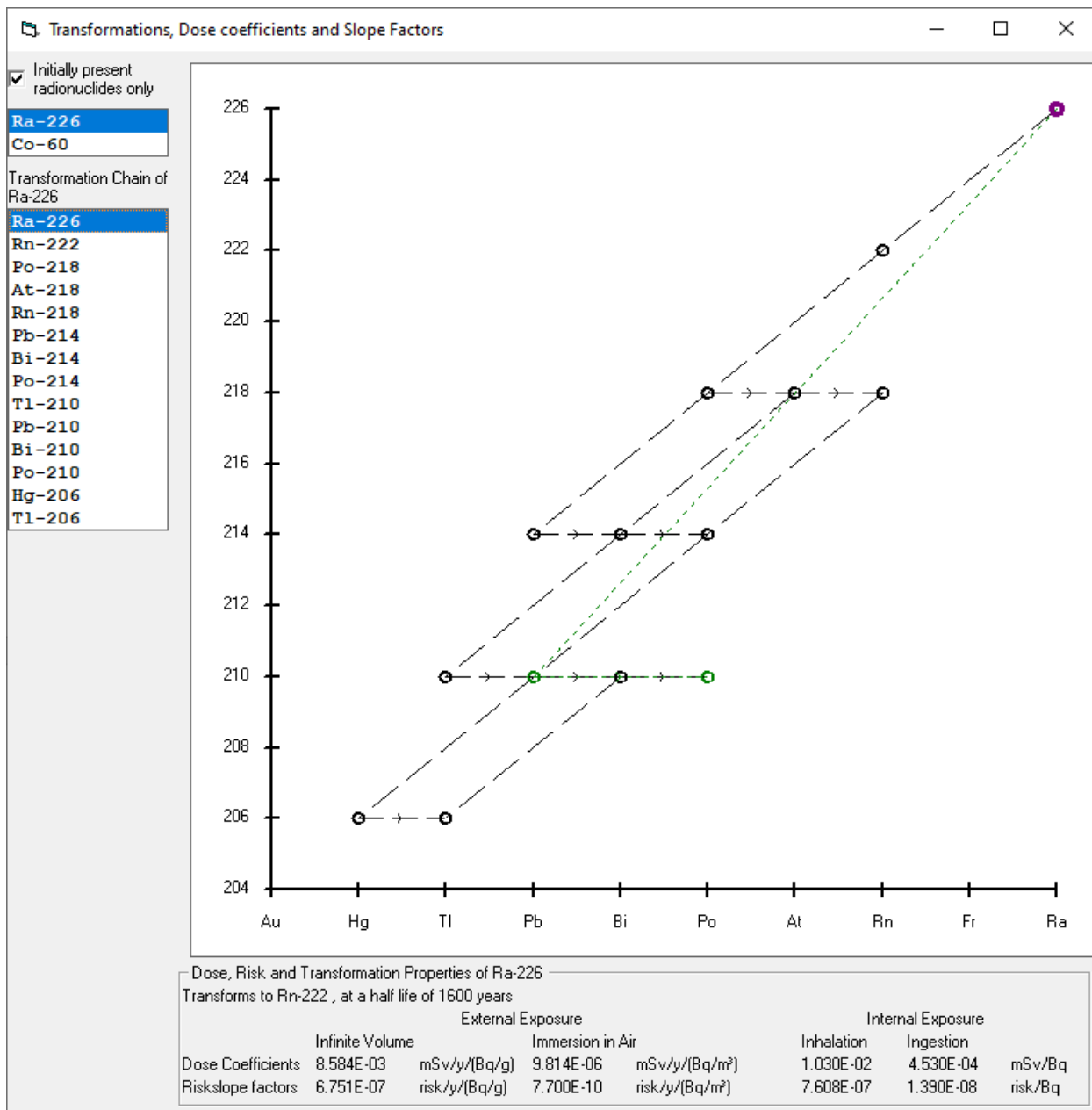
Figure 7 ICRP-107-Based Transformation Chain for Ra-226 at a Cut-off Half-life of 30 Days

The radionuclides that are associated with any principal radionuclide relevant to the current input file can be viewed in the transformation graphics window by unchecking the "initially present radionuclides only" check box at the top left (Figure 8). All the principal radionuclides relevant to the current input file are listed in the list box at the top left. The associated progeny of the principal radionuclide selected in that box will be listed in the list box below with an informative title. The portion of the transformation chain from the principal radionuclide to its associated progeny is shown in the graphic. Clicking on an associated progeny radionuclide in the latter list box shows the fraction of the

transformations of the principal parent that leads to the selected associated progeny, called the associated fraction in RESRAD-BUILD, in the yellow shaded box.
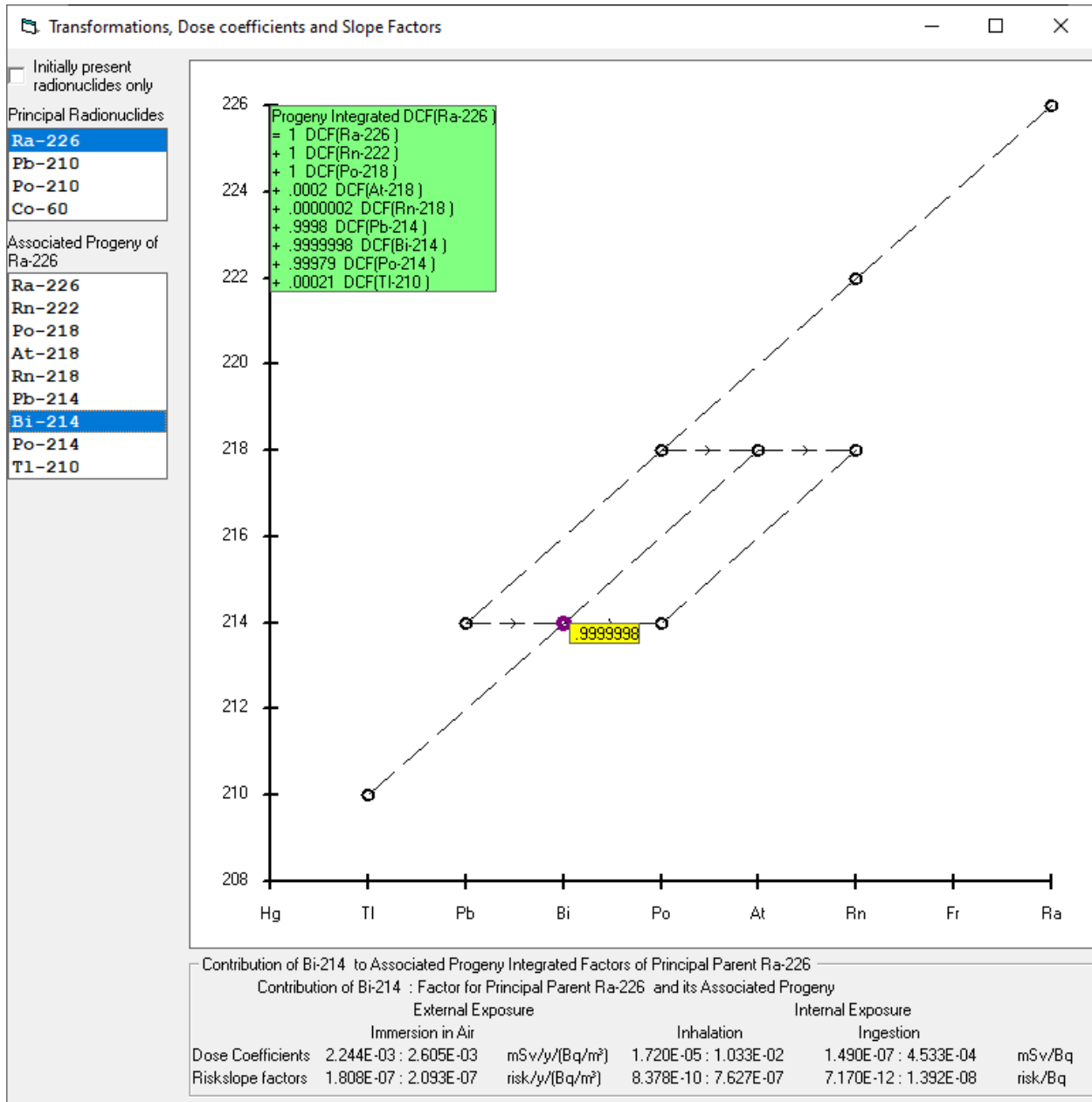
Figure 8 ICRP-107-Based Associated Progeny of Ra-226 at a Cut-off Half-life of 30 Days, with Contribution from Bi-214 Listed

Rather than multiplying the concentrations of each of the associated progeny radionuclides by their respective dose coefficients or slope factors and then summing the results, the code sums the product of the dose coefficients or slope factors of the associated progeny radionuclides and their respective associated fractions and adds that sum to the corresponding dose coefficient or slope factor of the principal radionuclide that they are associated with. The dose coefficients and slope factors obtained by including the associated fraction weighted dose coefficients and slope factors of the progeny are called associated progeny integrated coefficients or factors in RESRAD-BUILD; their use can reduce the computational effort appreciably in some case and minimally in others. The progeny integrated factors are computed for internal exposure pathways and for external radiation from radionuclides in air. They are not computed for the direct external radiation pathway from the volume source because the external dose and risk from all progeny for that pathway are computed individually without regard to the cut-off half-life. The green-shaded box at the top-left of the diagram shows the expression used to calculate the progeny integrated dose coefficients and slope factors.

Clicking on an associated radionuclide in the latter list box shows the contribution of that radionuclide to the progeny integrated factor of the principal parent radionuclide in the table below the graphic. The contribution of the selected progeny is shown separated by a ":" from the progeny integrated factor. The fraction of the transformations of the principal parent that leads to the selected associated progeny are shown in the yellow-shaded box.

Help Submenu: The commands in this submenu allow access to the current RESRAD-BUILD User's Manual, User's Guide, help in using the interface, and information about the current version of the RESRAD-BUILD code.

- **User's Manual:** Opens the RESRAD-BUILD User's Manual for Version 4.0 in the pdf file format.

- **User's Guide:** Opens the RESRAD-BUILD User's Guide for Version 4.0 in the pdf file format.

- **General Help:** Opens the RESRAD-BUILD Help window and displays information for the "Help on help" topic.

- **Context Help:** Opens the RESRAD-BUILD Help window and displays information for the current input parameter.

  RESRAD-BUILD Version 4.0 is equipped with typical help functions seen with Windows application programs. The Help window includes a Contents tab and a Search tab that will display a list of help topics for selection or a text box for typing in specific word(s) or phrase to be searched for. When a help topic is selected, the corresponding help contents will be displayed in the right panel. The search function will look for a match in the help topics as well as

in the help contents and will list the help topics that include the searched for word(s) or phrase. Selecting a help topic from the matched results will bring up the corresponding help contents in the right panel.

- **About:** Displays the About window, which shows the version number of the RESRAD-BUILD code installed on the computer and currently being used. In addition, the window contains information on the e-mail contact with the RESRAD team and the link to the RESRAD program website.

3.2 TOOLBAR

The Toolbar contains command buttons that perform some of the operations associated with the Menu options. These operations are discussed in the previous section.

Figure 9 shows the Toolbar with the 11 command buttons it contains. These command buttons perform operations associated with files, input parameters, calculation results, and display. The specific operation performed by each button is also shown.
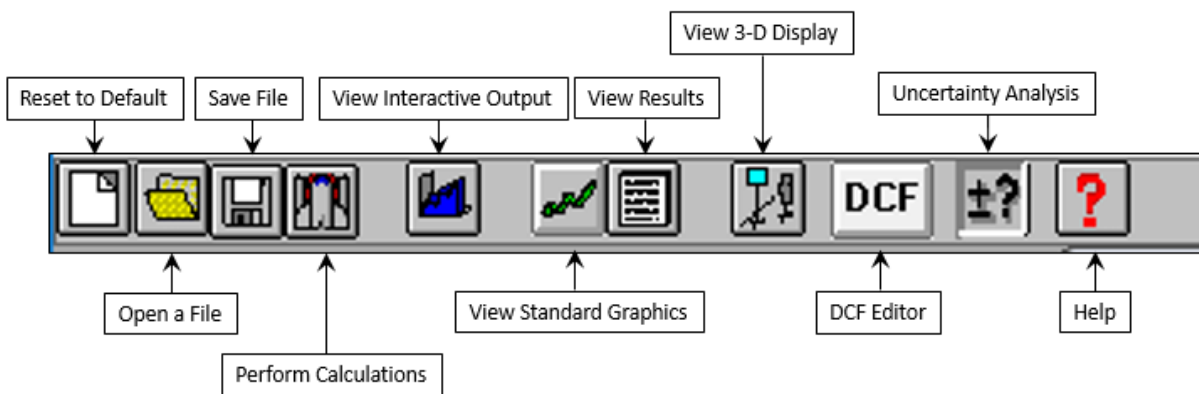
Figure 9 Toolbar

3.3 SENSITIVITY ANALYSIS INFORMATION BAR

The sensitivity analysis information bar is displayed at the bottom of the interface when it is chosen from the View submenu. The Sensitivity Analysis Summary Bar (the information bar at the bottom in Figure 10) shows the number of input parameters selected for a sensitivity analysis and a button for each selected parameter. The button shows the FORTRAN variable name of the parameter and the analysis range specified. Left-clicking on the button will display the Set Sensitivity Analysis Range input window in which the sensitivity analysis range can be changed, or the input parameter can be deleted from the selection list. Right-clicking will delete the button without further confirmation.
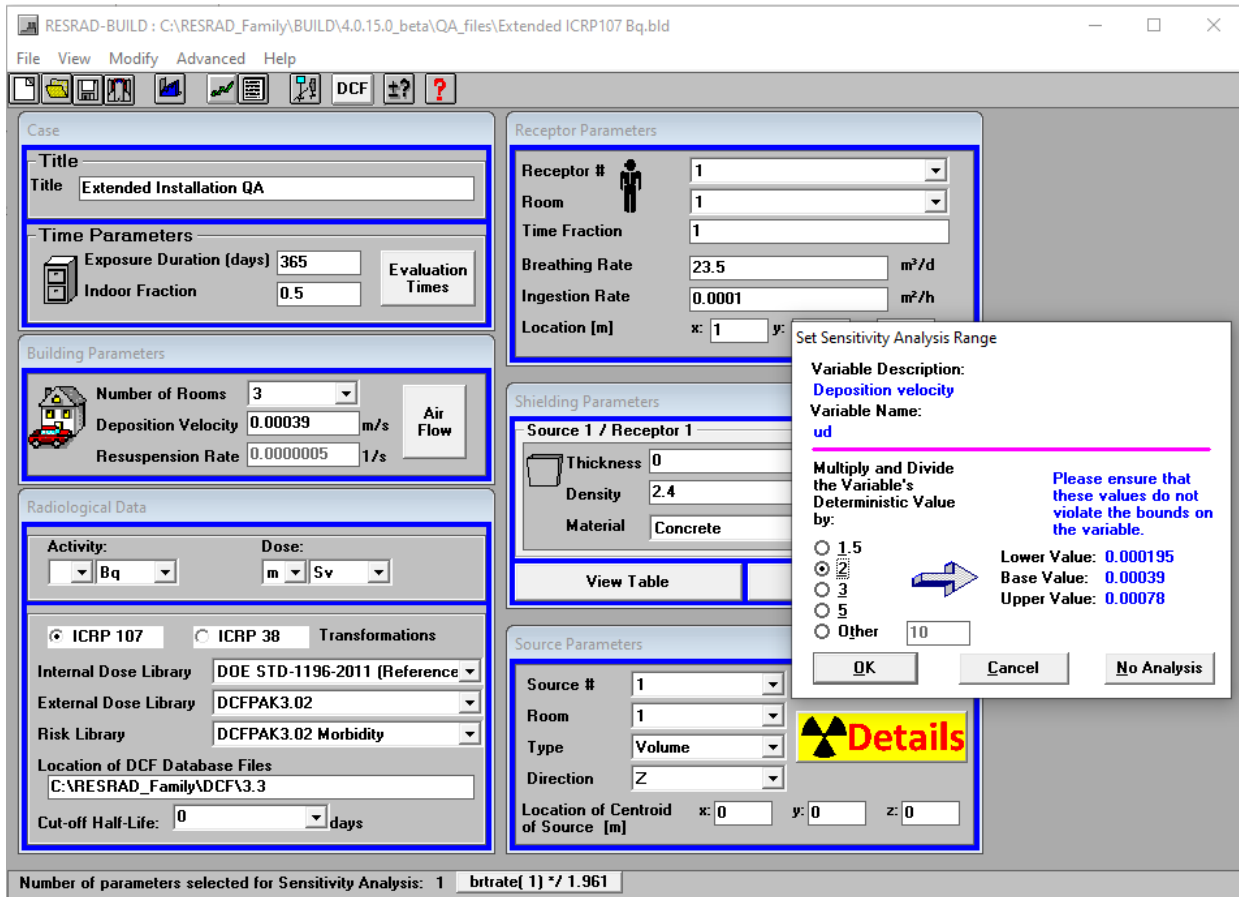
Figure 10 The Main Interface with the Sensitivity Analysis Information Bar and Set Range Window

4   INPUT FORMS

4.1   CASE

The Case form (Figure 11) has two boxes, the Title box and the Time Parameters box. The Title box allows for a user-specified title. The Time Parameters box accepts input values for the exposure duration, indoor fraction, and the start times of the time periods for output of dose and risk results. These time parameters are common for all the receptors considered in the analysis. Another time parameter, Time Fraction, appears in the Receptor Parameters form (Figure 20) and is receptor-specific, which is discussed later in Section 4.4. The amount of time a receptor spends at a given location is the product of the exposure duration, indoor fraction, and the time fraction.
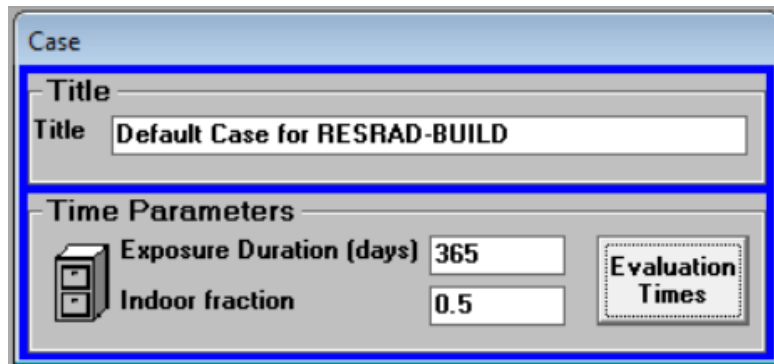
Figure 11 The Case Form

Title: This box is used to enter the text to describe the problem being modeled. This text will appear at the top of each page in a text report.

Exposure Duration: Exposure duration is specified in terms of days. It is the period of time over which the exposure takes place. The dose/risk will be integrated over this time period. The calculated dose/risk results represent the total dose/risk a receptor would receive over the exposure duration.

Indoor Fraction: Indoor fraction specifies the fraction of the exposure duration that a receptor is inside the building of concern.

Evaluation Times: Clicking the Evaluation Times button will bring up the corresponding detailed input form. The appearance of the detailed input form depends on whether the Traditional Appearance or New Appearance was selected with the Advanced menu. Figure 12 shows the Traditional Appearance while Figure 13 shows the New Appearance. Either one allows the user to specify up to 10 time points. The specification can be made by either entering the time points in the text boxes or by moving the clock icons along the horizontal bar. Press the Add or Remove button to add or remove a text box or clock icon. The time point t = 0 is automatically included; therefore, the integrated dose and risk over the exposure duration that starts at t = 0 are always calculated.

Figure 12 Traditional Appearance of the Evaluation Times Form

Figure 13 New Appearance of the Evaluation Times Form

RESRAD-BUILD tracks the decay and ingrowth of radionuclides and the erosion or removal of the contaminated material over time to calculate the integrated dose/risk at each specified time point, which is the beginning of the exposure duration. This allows users to gauge the change in radiation dose/risk over time and to project the radiation conditions at a future time.

Maximum Number of Points for Dose/Risk: The radiation dose and cancer risk reported by RESRAD-BUILD for a receptor at any specified evaluation time point is obtained by integrating the dose rate and the risk rate, respectively, over the exposure duration starting at that time point. Time integration of some of the dose and the risk rates may be performed numerically [see discussions in Appendix B of the User's Manual (Yu et al. 2022)]. When numerical integration is performed, the maximum number of time points to obtain the instantaneous dose and risk rates for integration can be specified. The traditional Evaluation Times form offers choices of 1, 2, 3, 5, 9, 17, 33, 65, 129, and 257 for the input of the Maximum Number of Points for Dose/Risk. The choice extends up to 2049 in the new Evaluation Times form. If the maximum number of points is 1, then the dose/risk reported is based on the instantaneous dose/risk rate at the beginning time point, assuming the dose/risk rate stays the same over the exposure duration.

Convergence Criterion: When the time integration is performed numerically, the RESRAD-BUILD code uses the convergence criterion and the maximum number of points to determine how many time points to use to perform the time integration. The code will use as many time-integration points as is necessary to achieve the convergence criterion, subject to the limit specified for the maximum number of (time integration) points. The convergence criterion can be changed only with the new Evaluation Times form. If the traditional input form is used, the convergence criterion is fixed at 0.001, unless it was previously changed under the New Appearance.

These last two inputs have no effect when the time integration is preformed analytically. Time integration is performed analytically in the following cases/situations:

1. Direct ingestion of the source;

2. Direct external dose and risk from point, line, and surfaces sources;

3. Direct external dose and risk from volume sources in which the thicknesses of the contaminated and shielding regions do not change over the exposure duration; and

4. Dose and risk from inhalation of and immersion in suspended particulates and gases and from external radiation and ingestion of materials deposited on floors, when the distribution of suspended and deposited material is computed analytically.

4.2 BUILDING PARAMETERS

The second main form accepts input parameters representing the characteristics of the building of concern (Figure 14). The parameters in the main form and in the associated detailed input form are used in the air ventilation model to determine the air concentration and deposition concentration of radionuclides in each room. Depending on the selection of Traditional

Appearance or New Appearance with the Advanced menu, the maximum number of rooms allowed in the building and the detailed inputs associated with "Air Flow" are different. The common inputs include the number of rooms in the building, the area of each room, the deposition velocity, the resuspension rate, and the average air flow rates between rooms and between each room and the outside environment. The resuspension rate can be different for different rooms in the new input form. With the new detailed input form, the inputs also include the frequency of vacuuming and vacuuming efficiency.
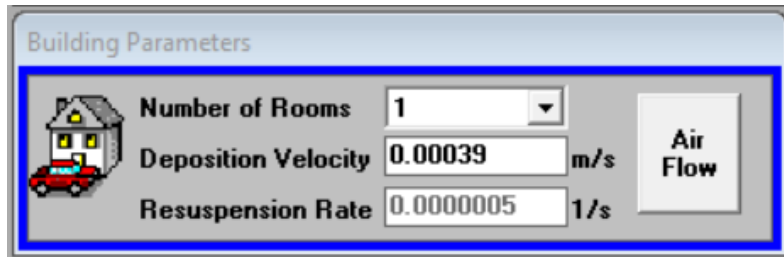
Figure 14 Building Parameters Form

Number of Rooms: Allows entering the number of rooms in the building being modeled. With the Traditional Appearance selection, the maximum number of rooms allowed is three. With the New Appearance selection, the maximum number of rooms allowed is nine.

Deposition Velocity: The indoor deposition velocity of contaminated particles from the building air; the same value for all rooms.

Resuspension Rate: The fraction of the deposited particles resuspended into the air per unit of time. The same value is used for all rooms under the Traditional Appearance.

Air Flow: By pressing the Air Flow button, the Room Details input form will appear, if Traditional Appearance is selected. If New Appearance is selected, the Room Air Flows and Particulates input form will appear. The following two Sections, 4.2.1 and 4.2.2, discuss the parameters in the two input forms, respectively.

4.2.1 The Room Details Input Form

4.2.1.1 Room Details for One-Room Model

For the one-room air flow model (Figure 15), the only airflow parameter necessary is the building air exchange rate.
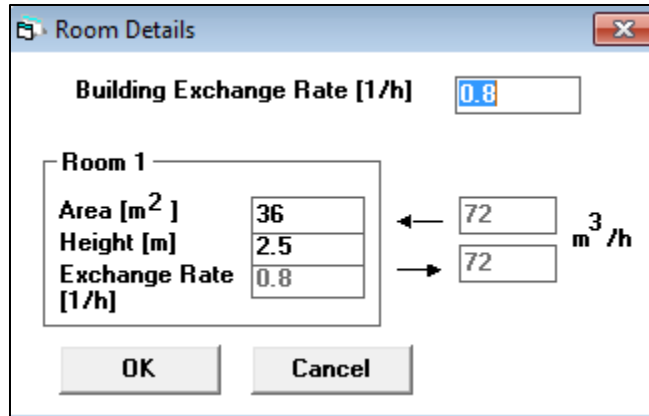
Figure 15 Room Details for One-Room Model

Building Exchange Rate: The building exchange rate is the rate at which the total amount of air contained within the building is replaced or renewed per unit time. The building exchange rate along with other parameters are used in calculating the air concentration of particulates inside the building.

Area: This is the floor area of each distinct airflow volume. For a one-room model, only one room area is required.

Height: This is the height of each distinct airflow volume. For a one-room model, only one room height is required.

Outdoor Inflow and Outflow Rate for Room: For the one-room model, the air exchange rate between the room and the outdoor is the same as the air exchange rate between the building and the outdoor; therefore, the outdoor inflow and outflow rates for the room are not required. They are both calculated using the dimensions of the room and the building exchange rate.

4.2.1.2   Room Details for Two-Room Model

For the two-room model (Figure 16), the airflow parameters necessary are the outdoor inflow for both rooms and the flow rate between the two rooms. The air flow rates from each room to the outdoors is computed using the air flow balance for each room. If the air flow rates entered can satisfy the mass balance principle, then the positive air exchange rate for each room and for the entire building can be determined. The interface calculates the building exchange rates and the exchange rates for each room using the user inputs.

Figure 16 Room Details for Two-Room Model

Area: This is the floor area of each distinct airflow volume. For a two-room model, two room areas, one for each room, are required.

Height: This is the height of each distinct airflow volume. For a two-room model, two room heights, one for each room, are required.

Flow Rate between Rooms: These are the rates at which air flows in each direction between adjacent rooms. Different rates may be specified for the flows in opposite directions.

Outdoor Inflow and Outflow Rates for Rooms: These are the rates at which air flows between each room and the outside.

4.2.1.3   Room Details for Three-Room Model

For a three-room model (Figure 17), the airflow parameters necessary are the outdoor inflow to all three rooms and the air flow between adjacent rooms. The airflow rates from each room to the outdoors is computed using the airflow balance for each room. It is assumed that there is no direct inflow between room 1 and room 3. If the airflow rates entered can satisfy the mass balance principle, then the positive air exchange rate for each room and for the entire building can be determined. The interface calculates the building exchange rates and the exchange rates for each room using the user inputs.

Figure 17 Room Details for Three-Room Model

Area: This is the floor area of each distinct airflow volume. For a three-room model, three room areas, one for each room, are required.

Height: This is the height of each distinct airflow volume. For a three-room model, the room height of each room is required.

Flow Rate between Rooms: These are the rates at which air flows in each direction between adjacent rooms. Different rates may be specified for the flows in opposite directions.

Outdoor Inflow and Outflow Rates for Rooms: These are the rates at which air flows between each room and the outside.

4.2.2 The Room Air Flows and Particulates Input Form

Up to nine rooms can be considered with the Room Air Flows and Particulates input form (Figure 18). In this form, the airflow rates between any pair of rooms and between any room and the outdoors can be specified. The air exchange rate is not required in this input form.

The following keys facilitate data entry by moving the focus between the input boxes and other controls in the form.

- The Tab key can be used to move left through the controls, wrapping around down and right at the end of each row; the Shift-Tab key combination can be used to move in reverse.

- The Enter key can be used to move down through the grid of input boxes, wrapping around up and left at the end of each column. This facilitates data entry using only the numeric keypad portion of the keyboard.

- The up, down, left, and right arrow keys can be used to move in the respective directions within the air flow data grid.

When an airflow input box on the one-, two-, or three-room building graphics on the New Appearance form is clicked, control is transferred to the corresponding input box in the data grid. The number input in the grid is reflected in the corresponding input box in the building graphics.

Room Air Flows and Particulates

Number of Rooms: 9

	Outdoors	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9	
Area		36	36	36	36	36	36	36	36	36	m²
Volume		90	90	90	90	90	90	90	90	90	m³
Resuspension Rate		5.E-7	5.E-7	5.E-7	5.E-7	5.E-7	5.E-7	5.E-7	5.E-7	5.E-7	1/s
Air flow from Outdoors to		72	72	72	72	72	72	72	72	72	m³/hr
Air flow from room 1 to	72		72	72	72	72	72	72	72	72	m³/hr
Air flow from room 2 to	72	72		72	72	72	72	72	72	72	m³/hr
Air flow from room 3 to	72	72	72		72	72	72	72	72	72	m³/hr
Air flow from room 4 to	72	72	72	72		72	72	72	72	72	m³/hr
Air flow from room 5 to	72	72	72	72	72		72	72	72	72	m³/hr
Air flow from room 6 to	72	72	72	72	72	72		72	72	72	m³/hr
Air flow from room 7 to	72	72	72	72	72	72	72		72	72	m³/hr
Air flow from room 8 to	72	72	72	72	72	72	72	72		72	m³/hr
Air flow from room 9 to	72	72	72	72	72	72	72	72	72		m³/hr

Efficiency of Vacuuming: 0   Vacuum once every 7 days

☑ Analytical Solution when Possible   Maximum Time Step 8.911E-2 days

OK   ☑ Write Intermediate Output   Cancel

Figure 18 The Room Air Flow and Particulates Input Form for Nine-Room Model

Area: This is the floor area of each distinct airflow volume. The room area for each room is required.

Volume: This is the volume of air in the room that is modeled as being continuously mixed and of uniform concentration. It is required for each room. The volume is used to model the fate of the particulates released to air: suspended in air, deposited on the floor, or ventilated out of the building.

Air Flow Rates between Rooms: These are the rates at which air flows in each direction between adjacent rooms. Different rates may be specified for the flows in opposite directions.

Air Flow Rate from Room to Outdoors: These are the rates at which air flows from each room to the outdoors.

The airflow rate from the outdoors to each room is not an input; it is computed using the airflow balance for each room. The input data error-checking code in the interface flags situations where the calculated value is negative (highlighted in red). It also highlights the inputs (in yellow) that can be changed to correct this issue.

Frequency of Vacuuming: The frequency of the vacuuming event is specified by the time interval in days between two consecutive events. The concentration of particulates on the floor (and the radionuclides contained in the particulates) is reduced at the end of each vacuuming time interval. The reduction is equal to the Efficiency of Vacuuming.

Efficiency of Vacuuming: This is the fraction of particulates deposited on the floor that are removed from the building after each vacuuming/cleaning event.

Analytical Solution When Possible: When the box is checked, the code will calculate the transient concentrations of particulates suspended in air and deposited on the floor in each room using analytical solutions to the air ventilation model, if feasible. Otherwise, the code will use a numerical solution.

Maximum Time Step: This input is used with the numerical solution to the transient air model. It allows the user to specify an upper bound to the time step used to obtain the transient solutions. See Appendix B of the User's Manual (Yu et al. 2022) for more discussion on the time step used in the transient solution.

4.3 RADIOLOGICAL DATA

Users can specify the units they prefer to use for input of the activity concentration and for output of the resultant dose (Figure 19) in the Radiological Data form. In addition, they can specify the radiological transformation database, the dose and risk (conversion factor) library, the location of these libraries, and the cut-off half-life for the code to use to establish radiological decay chains in the dose/risk modeling.

The list of the dose/risk libraries available for selection depends on the radiological transformation database selected. Only the dose and risk libraries that are based on the selected transformation database will be listed, including the standard libraries that come with the RESRAD-BUILD code as well as the libraries that were created by the user, if any. The code will also check for compatibility between the internal dose library and the external dose library and will list the external dose libraries that are compatible not only with the selected transformation database, but also with the selected internal dose library.

Figure 19 Radiological Data Form

Activity: Available choices are Curie (Ci), Becquerel (Bq), disintegrations per second (dps), and disintegrations per minute (dpm). The Ci and Bq can be combined with metric prefixes ranging from atto (10^{-18}) through exa (10^{18}).

Dose: Available choices are Roentgen equivalent man (rem) and Sievert (Sv); these can be combined with metric prefixes ranging from atto (10^{-18}) through exa (10^{18}).

Transformations Database: The user can choose between the ICRP-38 (ICRP 1983) and ICRP-107 (ICRP 2008) radiological transformation database. The ICRP-38 database has 838 nuclides, while the ICRP-107 database has 1,252 nuclides.

Internal Dose Library: The standard internal dose libraries based on ICRP-38 transformations include FGR 11 (Eckerman et al. 1988) and the ICRP-72 age-dependent libraries (ICRP 1996). The standard internal dose libraries based on ICRP-107 transformations include the DOE STD-1196-2011 Reference Person (DOE 2011) and the DCFPAK3.02 age-dependent libraries.

External Dose Library: The code displays the list of external dose libraries that are consistent/ compatible with the internal dose library that is selected in the preceding dropdown list. The standard external dose library that goes with the FGR 11 is FGR 12 (Eckerman and Ryman 1993), and the standard external dose library that goes with the ICRP-72 libraries is the ICRP-60 library. When the DOE STD-1196-2011 Reference Person or DCFPAK3.02 library is selected as the internal dose library, the consistent standard external dose library is the DCFPAK 3.02 library.

A user-created library can be selected as the external dose library; however, as mentioned in Section 0, the standard adjustment parameters for external dose conversion factors will be used in the external dose modeling.

Risk Library: The code displays the risk libraries that are consistent/compatible with the selection for the internal dose library. If FGR 11, ICRP-72, or a user-created internal dose library based on FGR 11 or ICRP-72 is selected, the slope factor (for risk calculation) libraries available for selection are the FGR 13 morbidity and FGR 13 mortality libraries (Eckerman et al. 1999). If DOE STD-1196-2011 Reference Person, DCFPAK3.02, or a user-created internal dose library based on DOE STD-1196-2011 Reference Person or DCFPAK 3.02 is selected, the slope factor libraries available for selection are the DCFPAK 3.02 morbidity and mortality libraries.

Location of DCF Database Files: The directory where the dose and risk factor libraries are located can be specified by clicking in this box and then navigating to that directory.

The dose/risk libraries can be viewed by using the DCF Editor (click the DCF button in the Toolbar to access), which is a standalone utility program shared by the RESRAD family of codes. As detailed in Section 5, users can also create their own dose/risk libraries based on a standard library by using the DCF Editor. If the default path is selected during the installation of the code, the database file containing the dose/risk libraries will be saved to the directory C:\RESRAD_Family\DCF\3.3; however, a different path can be specified during the installation of the code.

Cut-off Half-life: A cut-off half-life may be used, if necessary, to reduce the execution time. The code models all the radionuclides in the transformation chain of an initially present radionuclide, regardless of whether a cut-off half-life is used, i.e., the cut-off half-life is greater than zero, or not.

- If a cut-off half-life of zero is used, the code will calculate the concentration of each radionuclide, initially present and progeny, using the Bateman equation or, in the case of a branching transformation, using a modified Bateman equation.

- If a cut-off half-life greater than zero is specified, the concentration of radionuclides that have a half-life greater than the cut-off half-life are calculated using the Bateman equation or the modified Bateman equation, as appropriate. These radionuclides are called principal radionuclides in RESRAD-BUILD. The radionuclides with a half-life less than or equal to the cut-off half-life are called associated radionuclides in RESRAD-BUILD. The concentration of an associated radionuclide is modeled as being equal to the product of the concentration of its immediate parent, whether principal or associated, and the branching factor of the transformation of the immediate parent to the progeny in question. An immediate parent radionuclide is one that transforms directly to the progeny in question, not one that transforms through other radionuclides to the progeny in question.

- Any associated radionuclide that is connected to a principal radionuclide, either directly or through only associated radionuclides in at least one branch of the transformation chain, is said to be associated with that principal radionuclide.

There are four cut-off half-lives to choose from, 1, 7, 30, and 180 days. The user can also type in any non-negative number, including 0, to the input field.

4.4 RECEPTOR PARAMETERS

The Receptor Parameters form (Figure 20) allows users to specify the exposure characteristics of each receptor. To differentiate receptors, each receptor should be numbered first, and then his/her exposure characteristics should be specified. Multiple receptors can be used to represent the same individual spending time at different locations. The radiation exposure incurred by the individual can then be calculated by summing the exposures of the multiple receptors representing him at the different locations.

The amount of time a receptor spends at a particular location is the product of the exposure duration, indoor fraction, and the time fraction specified in the Receptor Parameters form. The location of each receptor within a building is determined by the room number and the x, y, and z coordinates for that receptor. The air concentration and deposition concentration in the specified room, along with the time fraction, breathing rate, and ingestion rate, are used to determine the radiation dose/risk from the inhalation, external radiation from air submersion, external radiation from deposition, and secondary incidental ingestion pathways. The x, y, and z coordinates of the receptor are used only to calculate the radiation dose/risk from the direct external radiation pathway. (Note: The room number is not used to calculate the direct external dose/risk.)

Figure 20 Receptor Parameters Form

Number of Receptor: The number used to identify a receptor whose characteristics are being input/displayed. RESRAD-BUILD calculates the dose/risk for each receptor that is specified to be at a fixed location in a building during the exposure duration. In addition to the room number and x, y, and z coordinates that specify a receptor's location, other input parameters such as time fraction, breathing rate, and indirect ingestion rate are also used to characterize the exposure patterns that are specific to the receptor. The maximum number of receptors allowed in a single run is 10.

Receptor Room: The room in which an individual receptor is located. This parameter is important for all pathways except for the direct external radiation pathway. The receptor is only exposed to the contaminated air in the room in which he is located. The air concentration of radionuclide in each room is assumed to be uniform.

Receptor Location: The location of the receptor in terms of the absolute x, y, and z coordinates according to the origin chosen by the user. The coordinates reflect the center of the body at the fixed location where the receptor spends his time in the building. The same reference origin should be used for all receptors and radiation sources. These coordinates are used in calculating the direct external radiation dose that the receptor would receive.

Receptor Time Fraction: The fraction of time spent by the receptor of concern at a given location while inside the building.

Receptor Breathing Rate: The rate at which the receptor of concern inhales air at the specified location. The dose could be zero from the inhalation and radon pathways if the inhalation rate is zero.

Receptor Indirect Ingestion Rate: The rate at which the receptor of concern ingests deposited dust particles after they transferred from the air to the surface of objects with which the receptor has contact by hand(s) that results in the ingestion of the dust particles. It is expressed in terms of the contact area per unit time (m^2/h). The indirect ingestion is one of the two ingestion pathways modeled by RESRAD-BUILD. The other ingestion pathway is direct ingestion that considers direct contact with the primary radiation source by hand(s) that results in the ingestion of the source particles. The ingestion dose from indirect ingestion would be zero if the indirect ingestion rate or the deposition velocity is zero, in which case there would not be deposition. A nonzero dose is possible even if the receptor and the primary source are not in the same room. This is because airborne dust particles can transfer from one room to another by air ventilation.

4.5 SHIELDING PARAMETERS

To calculate the dose/risk from the direct external pathway, information about the shielding between the source and a receptor is required. This information is gathered in the Shielding Parameters form (Figure 21). The RESRAD-BUILD model is simplified so that the user specifies just one effective shield between each source-receptor pair. This shield is characterized by the material type, thickness, and density parameters. In the Shielding Parameters form, the inputs are for the shield between the receptor and the source being considered, as reflected by the "Source No./Receptor No." displayed under the form title. Upon choosing a different receptor (in the Receptor Parameters form) or source (in the Source Parameter form), the "Source No./Receptor No." display will be updated automatically. The View Table button on this form opens a screen that allows the specifications of shielding for every receptor/source combination (Figure 22). The Copy Shielding button in the Shielding Parameters form opens a screen that allows the user to use the current shield properties for another shield that involves the same receptor or the same source or every other receptor/source combination (Figure 23).

Figure 21 Shielding Parameters Form

Shielding Thickness: The effective (line-of-sight) thickness of shielding between a receptor and a source.

Shielding Density: The effective density of shielding between a receptor and a source.

Shielding Material: The type of material of the shield between a receptor and a source. The code can handle concrete, water, aluminum, iron, copper, tungsten, lead, or uranium (Figure 21).

Figure 22 The Source Receptor Table for Shielding

Figure 23 The Copy Shielding Screen

4.6 SOURCE PARAMETERS

The Source Parameters form collects data on the source type and location (Figure 24) and the source details. The location of the source includes the room and the coordinates of the source, based on the center point for non-volume sources or the center point of the contaminated region for volume sources. The coordinates of the source are based on the origin chosen by the user, which must be the same as used for the coordinates of the receptors so that the distance vector between the source and the receptors in the x, y, and z directions can be correctly determined. This is important for the calculation of the direct external radiation dose. The other pathways require only the room location of the receptor and the source for dose calculations.

The source details are specified in secondary input screens that show up when the Details button with the radiation symbol is pressed. The secondary input screens (Figures 25 through 30) accept specifications on radionuclides in the source, source dimensions, removable fraction, air release fraction, and radon release parameters (if applicable). For direct external dose calculations, a volume or area source can assume a circular or rectangular shape. If a radon release is concerned, depending on the source type, the release parameters required for dose/risk calculation are different.
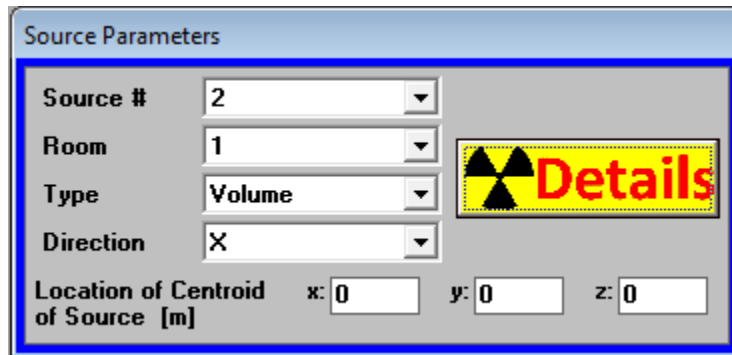
Figure 24 Source Parameters Form

Number of Source: The number used to identify a source whose characteristics are being input/displayed. RESRAD-BUILD calculates the radiation doses incurred by each receptor from each radiation source. Each source is characterized by its location, i.e., room number and x, y, and z coordinates and several geometrical, physical, and radiological parameters. Each RESRAD-BUILD run can analyze up to 10 radiation sources.

Source Type: The source could be one of the four types considered by RESRAD-BUILD— volume, area, line, or point. Different input parameters are required for each type of source. For a volume source, its cross-sectional area can be circular (the default) or rectangular and there is some finite depth perpendicular to this area. Up to five different regions can be considered within the finite depth. An area source can assume a circular or rectangular shape, but with no depth. The modeling of releases of source material into the air is different for a volume source than for an area, line, or point source [see Appendix B of the User's Manual (Yu et al. 2022)]. Because radon is a gas, a special model is implemented in the code to estimate its release rate into the indoor air [see Appendix F of the User's Manual (Yu et al. 2022)]. Tritium (H-3) release in a gas

form from a volume source is also handled with a special model [see Appendix G of the User's Manual (Yu et al. 2022)].

Source Room: The room number where the source considered is located.

Source Direction: The direction of the source being considered, x, y, or z direction. For volume and area sources, it is the direction perpendicular to the exposed area. For the line source, it is the direction of the line. No direction is required for a point source. The source direction is used only for direct external dose/risk calculations; it determines the distance between each point within the source and the receptor.

Source Location: The source location is determined by the x, y, and z coordinates of the source center when a point, line, or area source is involved. When a volume source is involved, the center of the contaminated region should be considered when determining the x, y, and z coordinates for the source. The x, y, and z coordinates are used only in the calculation of the direct external dose.

Secondary input screen will appear when the Details tab is pressed. Figures 25, 28, 29, and 30 show the secondary input screen for a volume, area, line, and point source, respectively. The following sections provide information on the secondary input screens.

4.6.1 Detailed Radiological Contamination Inputs

The detailed (secondary) input form for a radiation source varies by the source type. The right side of the secondary input forms (Figures 25, 28, 29, 30) looks mostly the same; the main difference is in the left side. The right side allows for the specifications of radiological contamination, which is described by radionuclides of concern and their concentrations in the source material.

Radionuclide of Concern: The radionuclides of concern can be specified one after another by choosing them from the dropdown list. After a radionuclide is selected, its concentration can be specified by entering a value in the rectangular box next to the radionuclide's name. By pressing the Add Nuclide button, the selected radionuclide will be moved to the nuclide list box. A nuclide in the list box can be deleted by pressing the Delete Nuclide button after selecting that nuclide. To change the concentration of a nuclide in the list box, first select that nuclide, then type the new concentration value followed by the enter key. By default, Co-60 with a unit concentration always appears in the selection display window. Remember to delete Co-60 if it is not a radionuclide of concern.

The nuclide list box displays all radionuclides specified for the current source as well as the principal progenies in their decay chains with a zero initial concentration, unless the option, "Initially present radionuclides only," is checked.

Radionuclide Concentration: The radionuclide concentration is the activity (for a point source) or activity concentration of radionuclides (for other source types) distributed evenly in a source or in the contaminated region within a source. The unit of measure depends on the type of source (traditional unit, volume sources: pCi/g; area sources: pCi/m^2; line sources: pCi/m; point sources: pCi).

Save Source Data and Load Data for Another Source: This input is available only in the New Appearance of the detailed input form and when there are more than one sources considered in the analysis. It is located near the bottom on the right side of the screen, allowing quick access to a different source for detailed data entry without clicking the OK button to return to the Source Parameter form and then choosing another source from that form. Enter the number of another source in the input box to bring up its detailed input form.

4.6.2 Detailed Source Materials Inputs for Volume Sources

Besides the radiological contamination inputs, other detailed inputs required for a volume source include those concerning its geometry, material characteristics and erosion, regional (layered) structure of materials, the region of contamination, as well as the direction from the center of the source to the eroding surface (Figure 25).

Figure 25 The Details Input Form for a Volume Source

Geometry: The geometry describes the shape of the exposed surface (faced by the receptors) of the source. The shape can be either circular or rectangular.

Source Area for Circular Source: The area needs to be specified for a circular shape. The area is a measure of the extent of contamination from the center point of the exposed surface.

Length and Width for Rectangular Source: If the exposed surface assumes a rectangular shape, then the length along one direction and the width along the other direction are used to calculate the area of the surface.

Air Release Fraction: The air release fraction is the fraction of the source materials that, after erosion occurs, would be released into the air and cause subsequent exposures. The eroded

materials included in this fraction are assumed to have a particle size in the respirable range. The remaining balance of the material that is eroded, i.e., not included in the air release fraction, would drop to the floor and be removed from the room immediately, except for any that might be inadvertently ingested directly, thereby not resulting in subsequent radiation exposure.

Direct ingestion Rate: The direct ingestion rate is expressed as the mass of the source material ingested per unit time. Only a receptor who is in the same room as the source could incur direct ingestion exposure from that source. The same direct ingestion rate for a source is used for the different receptors in the same room.

For a volume source, the direct ingestion rate has a unit of g/h. It is multiplied by the radionuclide concentration in the exposed region at the time of exposure to obtain the amount of radioactivity ingested per unit time (pCi/h or Bq/h) by a receptor. Only removable material that is not being released to the air can be directly ingested. Therefore, the direct ingestion rate of a source by each receptor is limited, with the limit determined by the erosion (removal) rate of the source, the air release fraction, the number of receptors in the room, and the time fractions of those receptors in the room [see Appendix B of the User's Manual (Yu et al. 2022)]. In case that the rate of removal is not sufficient to satisfy the specified direct ingestion rate at the specified time fractions, the portion of the source being removed per unit time that is not released to air is apportioned between the receptors in proportion to their time fractions.

Number of Wall Regions in Volume Source: This is the number of distinct layers (regions) in a volume source. Up to five regions can be considered in a volume source. The contamination is within a specific region. The thickness of the volume source is the sum of the thicknesses of all the regions.

Material Type: The code can handle concrete, water, aluminum, iron, copper, tungsten, lead, or uranium as a source material. The selection applies to all regions of the source.

The Layer Region Parameters button opens another secondary input screen for providing the detailed information of each region, such as thickness, density, and erosion rate, specifying the direction of erosion as well as denoting the region that is contaminated (Figure 26). If the contaminant(s) include a radon precursor such as Ra-226 or Ra-228, then the secondary input screen also allows specification of the radon diffusion coefficient, porosity, and radon emanation fraction of each region. The radon emanation fraction need only be specified for the contaminated region.

**Figure 26 The Layer Region Parameters Form
without Radon Parameters for a Volume Source**

4.6.2.1 Layered Regions Parameters for Volume Sources

Figure 26 shows the Layer Region Parameters input form (for one region) associated with the Layer Region Parameters button in the Details input form for volume sources (Figure 25). An idealized volume source is modeled as consisting of up to 5 distinct regions. (The number of regions can be specified in the Details input form.) Only one region can be modeled as contaminated, which can be indicated by checking the corresponding circle for that region. The properties of each region include thickness, density, erosion rate, and the "Direction from Interior to Eroding Surface."

The RESRAD-BUILD code incorporates a special radon diffusion model to analyze the release of radon gas from a volume source to the indoor air [see Appendix F of the User's Manual (Yu et al. 2022)]. If a radon precursor exists in a volume source, the Layer Region Parameters input form for that source will include additional parameters for the radon modeling (Figure 27).

44

**Figure 27 The Layer Region Parameters
Form with Radon Parameters for a
Volume Source**

Source Thickness: The source thickness is the thickness of each layer in an idealized volume source.

Source Density: The source density is the effective density of each layer in an idealized volume source.

Source Erosion Rate: The source erosion rate is the erosion rate of each layer in an idealized volume source when the layer is exposed. It is used to calculate the amount of source material that becomes loose and detached from the source location per unit time. The loose material has the potential of getting into the air. The erosion is assumed to proceed sequentially starting from Region 1.

Direction from Interior to Eroding Surface: In RESRAD-BUILD, the erosion of a volume source is considered to occur with only one of the surfaces along the axial direction, i.e., the eroding surface. The direction from the interior to the eroding surface should be specified as "+" or "-" along the source axial direction. If a volume source has multiple regions, this direction would be the direction from Region 2 to Region 1, as Region 1 is the region to be eroded first.

This input of Direction from Interior to the Eroding Surface, along with the locations (characterized with x, y, and z-coordinates) of the source and the receptor, determine the exposed surface that the receptor is facing, which is critical in the direct external dose calculations because the attenuation provided by uncontaminated region(s) as well as the remaining contaminated region can be properly accounted for.

Source Porosity: The source porosity is the ratio of the pore volume to the total volume in each region. Radon generated in the contaminated region needs to diffuse through the pore space to be

released to the indoor air. Although a value of "0" is accepted by the RESRAD-BUILD code, it would result in no release of radon to the air, thereby no radiation exposure associated with the radon pathway will be calculated.

Radon Diffusion Coefficient: The radon diffusion coefficient is the diffusion coefficient of radon in the pore space of each region.

Radon Emanation Fraction: The radon emanation fraction is the fraction of the total amount of radon produced by the decay of radon precursor in the contaminated region that escapes to the pore space and can diffuse to the indoor air. It need only be specified for the contaminated region.

4.6.3   Detailed Source Release Inputs for Non-volume Sources

4.6.3.1   The Traditional Appearance

Figures 28-30 show the Traditional Appearance of the Details for Source input form for an area, line, and point source, respectively. The detailed parameters used for source release modeling include air fraction, direct ingestion, removable fraction, lifetime, and radon release fraction, if radon precursor(s) are present in the source.

Figure 28 The Traditional Details for Source Form for an Area Source

Figure 29 The Traditional Details for Source Form for a Line Source

Figure 30 The Traditional Details for Source Form for a Point Source

Air Fraction: The air fraction is the fraction of the source materials that, after erosion occurs, would be released into the air and cause subsequent exposures. The eroded materials included in this fraction are assumed to have a particle size in the respirable range. The remaining balance of the eroded material, i.e., not included in the air release fraction, would drop to the floor and be removed from the room immediately, except for any that might be inadvertently ingested directly, thereby not resulting in subsequent radiation exposure.

Direct Ingestion: The direct ingestion rate is expressed as the fraction of the source ingested per unit time. Only a receptor who is in the same room as the source could incur direct ingestion exposure from that source. The same direct ingestion rate for a source is used for the different receptors in the same room.

For a point, line, or area source, the direct ingestion rate has a unit of 1/h. The input fraction is multiplied by the total activity in the source at the exposure time to obtain the amount of radioactivity ingested per unit time (pCi/h or Bq/h). Only removable material that is not being released to the air can be directly ingested. After the removable fraction of a source is depleted, the direct ingestion would no longer be a viable exposure pathway associated with that source. The direct ingestion rate of a source by each receptor is limited; the limit is determined by the erosion (removal) rate of the source (equivalent to the removable fraction divided by lifetime), the air fraction, the number of receptors in the room, and the time fractions of those receptors. In case that the rate of removal is not sufficient to satisfy the specified direct ingestion rate at the specified time fractions, the portion of the source being removed that remains after accounting for what is released to the air per unit time is apportioned between the receptors in proportion to their time fractions [see Appendix B of the User's Manual (Yu et al. 2022)].

Removable Fraction: The removable fraction is the fraction of a point, line, or area source that is subject to removal, i.e., the fraction that could become loose and be removed (eroded) from the source location over time. This fraction of the source is assumed to be linearly removed over the specified lifetime starting from time 0.

Lifetime: The lifetime is the time period during which the removable fraction of an area, line, or point source is linearly eroded or removed. If the entire source materials are fixed, i.e., nothing would be removed over time, then the removable fraction should be set to zero, and the source lifetime would be immaterial.

Radon Release Fraction: The radon release fraction is the fraction of the total amount of radon produced by the decay of a radon precursor in a point, line, or area source that is released to the air. This parameter appears only when there is radon precursor in the source.

4.6.3.2 The New Appearance

Figure 31 shows the New Appearance of the Details for Source input form for an area source. The difference between the New Appearance and the Traditional Appearance (Figure 28) is in the release input section of the form. The new input form allows the consideration of up to 10 release phases in time; the release rate in a time phase stays constant but it can be different for different time phases. The parameters used for modeling the releases include the start time and end time of each time phase, the fraction of the source material removed in each time phase, and the air release as a fraction of the source material removed in each time phase. The Timed Release section also includes the direct ingestion rate parameter for use to calculate the direct ingestion exposure. This same Timed Release section also appears in the New Appearance of the Details for Source input form for a point and a line source.

Figure 31 The New Details for Source Form for an Area Source

Direct Ingestion: The direct ingestion rate is expressed as the fraction of the source ingested per unit time by each receptor in the same room. The same direct ingestion rate for a source is used for the different receptors in the same room.

For a point, line, or area source, the direct ingestion rate has a unit of 1/h. The input fraction is multiplied by the total activity in the source at the exposure time to obtain the amount of radioactivity ingested per unit time (pCi/h or Bq/h). Only removable material that is not being released to the air can be directly ingested. Therefore, the limit of the direct ingestion rate of a source by each receptor in each time phase is determined by the erosion (removal) rate of the source during that time phase (fraction removed divided by the duration between the beginning time and the end time), the air fraction, the number of receptors in the room, and the time fractions of those receptors. In case that the rate of removal is not sufficient to satisfy the specified direct ingestion rate at the specified time fractions, the portion of the source being removed per unit time that is not released to air is apportioned between the receptors in proportion to their time fractions in that room. See Appendix B of the User's Manual (Yu et al. 2022) for more information.

Starting Time, End Time: The length of each release phase is characterized by a start time and an end time. The end time of a release phase should be no less than the start time. Any lapse in time between two successive phases, i.e., the start time of a phase is greater than the end time of the previous phase, is treated automatically as a period without erosion (removal), i.e., the fraction removed is zero during the lapsed time.

Fraction Removed: This is the fraction of the source removed linearly during each release phase.

49

Released as a Fraction Removed: This is the fraction of the removed source getting into the air during each release phase.

4.6.4 Detailed Inputs for Tritium in Volume Sources

A special model is implemented in RESRAD-BUILD to estimate the air release rate of tritium from a volume source which is porous. The tritium in the volume source is assumed to be of the tritiated water or hydrogen tritium oxide (HTO) chemical form that can vaporize to the pore space and release to the indoor air. A fraction of the HTO can be considered attaching to the source material like other nuclides and is not vaporizable. The HTO molecules that are not vaporizable can be released to the indoor air via the erosion of the source material.

To use the special tritium model, a volume source containing only H-3 needs to be created. If there are other radionuclides in the same source, they can be considered with a second source at the same location. In this case, care should be exercised so that consistent input parameters are used for both sources.

Figure 32 shows the Tritium Parameters input section in a Details for Source input form.

Figure 32 Tritium Parameters in the Details for Source Form for a Volume Source

Area: The measure of the size of the cross sectional plane perpendicular to the specified direction of the volume source.

Dry Zone Thickness: The HTO contamination is considered inside a volume source and characterized by a contamination thickness. This layer of contamination is called the wet zone, so the thickness of the wet zone is the thickness of contamination. There could be a layer of uncontaminated material without HTO between the wet zone and the exposed surface, i.e., the interface with the indoor air, called the dry zone. The dry zone thickness is the thickness between the uppermost plane of the wet zone and the interface with the indoor air. As HTO moves across the interface, H-3 is released to the indoor air and could result in radiation exposure.

Wet + Dry Zone Thickness: The wet + dry zone thickness is the thickness between the interface with the air and the bottom of the wet zone.

Volumetric Water Content: The volumetric water content is the volume of water per unit volume of the source material in the wet zone. This value should be less than the total porosity of the source material.

Water Fraction Available for Vaporization: The water fraction available for vaporization is the fraction of the total amount of water in the wet zone that will evaporate. A value of less than 1 accounts for the retention of some water molecules by the solid source material so that the water molecules would not evaporate. Water molecules retained by the solid source material could be released to the air when the source materials are removed/eroded away.

Total Porosity of Contaminated Material: The total porosity of contaminated material is the volume of the pore space per unit volume of the source material. Although a value of "0" is accepted by the code for total porosity, there will not be a release of HTO to the air; therefore, no radiation exposure will occur.

Density of Material: The effective density of the source material.

Humidity: The average humidity in the room where the volume source is located. The value is dependent on the air conditioning and ventilation in the building.

Erosion Rate: The erosion rate of the source material. It is used to determine the rate of removal of non-vaporizable tritium that is attached to the source.

Direct Ingestion Rate: See explanations in Section 4.6.2. If the Water Fraction Available for Evaporation is 1, all HTO molecules would evaporate, resulting in direct ingestion being unlikely to occur. Direct ingestion would occur only for the non-vaporizable HTO, i.e., if the Water Fraction Available for Evaporation is less than 1.

Air Release Fraction: This parameter applies to the HTO molecules that are not vaporizable and are attached to the source material. It is the fraction of the eroded source material that would get into the air, resulting in subsequent exposures to tritium.

4.7   3-D DISPLAY OF SOURCE AND RECEPTOR OBJECTS

A 3-D display of source and receptor objects (Figures 33, 34) can be viewed and manipulated by selecting the View/3-D display option at the Menu Bar or the View 3-D display button at the Toolbar. Each type of object is represented with a different icon: gray person for a receptor, square for a volume source, circle with thickness for an area source, rectangular bar for a line source, and small circle without thickness for a point source. Each object is positioned in the 3-D display based on its x, y, and z coordinates representing its location. The projection on the x-y plane is indicated by an oblique crosshair (pedestal). The height (z dimension) is represented as a column from the pedestal.

The scale (in meters) of the axes is given by the number above the Reset Scale button near the bottom of the display window with the Traditional Appearance. To change the scale, the user enters a new number in the input box and presses the Reset Scale button. With the New Appearance of the display window, the scale is shown by the Set Length of Grid Box To button near the top of the display window. To change the scale, the user enters a new number in the input box and presses the Set Length of Grid Box To button. The objects also can be manipulated in 3-D by clicking on the pedestal or object and then dragging. Dragging the pedestal changes the x and y coordinates. Dragging the object changes the z coordinate. The object number is also directly displayed on the object (e.g., the second receptor is indicated by the number 2 in the middle of the gray bubble person icon). The room assignment can also be determined by the color of the number (e.g., red [room 1], green [room 2], or blue [room3]). The origin of the 3-D display can be moved up/down and right/left. Enter a positive number to move up and right. Enter a negative number to move down and left. Click the Move Origin button after entering numbers to see the origin moved.
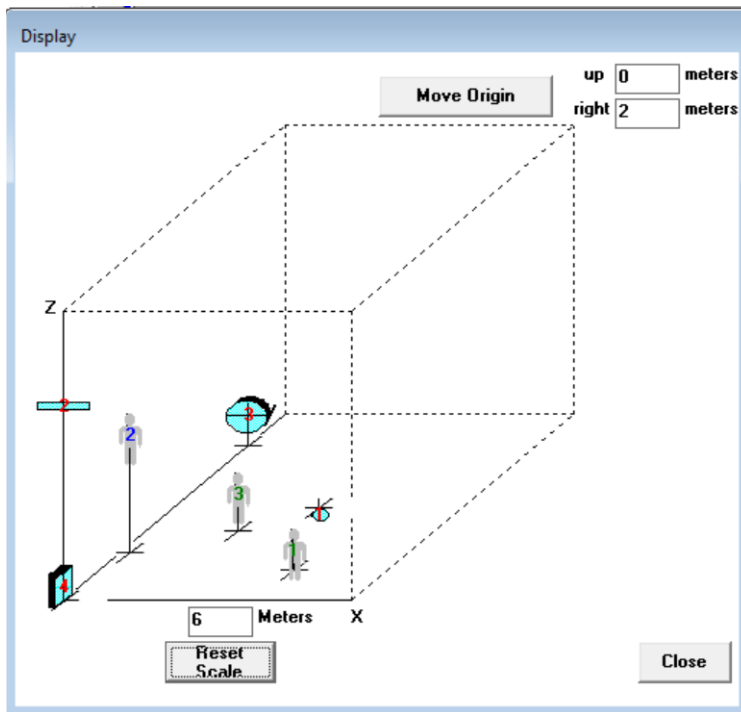

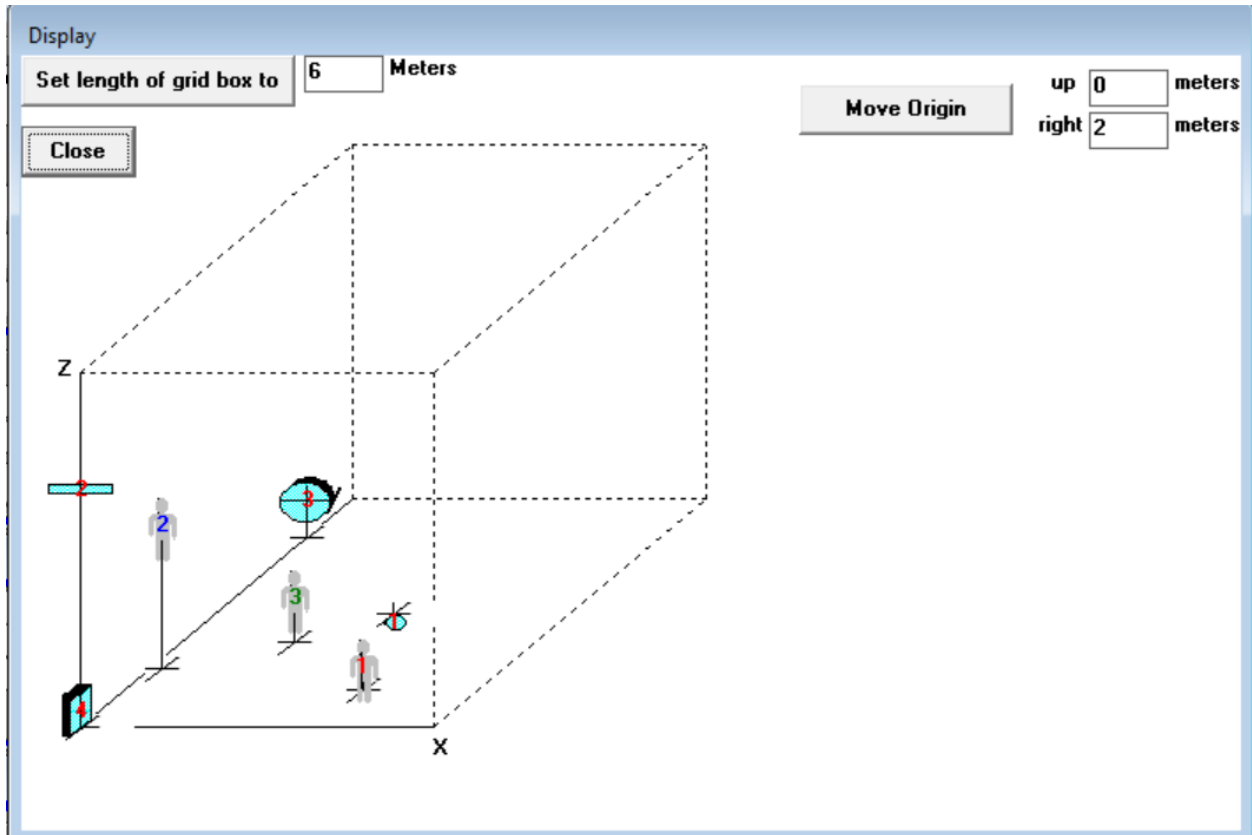**Figure 33 Traditional Appearance of the Interactive 3-D Display Window**

Figure 34 New Appearance of the Interactive 3-D Display Window

5 RESRAD DOSE CONVERSION FACTOR EDITOR

The RESRAD dose conversion factor (DCF) Editor can be accessed by clicking on the DCF command button at the Toolbar or selecting the File->DCF Editor menu option. The DCF Editor is a standalone utility program. In addition to using it to view the dose conversion factors, transfer factors, and slope factors included in the standard libraires, e.g., the ICRP-72 (adults) library, the DCF editor also can be used to create new DCF libraries. The user-created libraries are based on a combination of the standard libraries but contain user-specified dose conversion factors, slope factors, and/or transfer factors for one or more radionuclides. A DCF library created by users can be edited, copied, or renamed with the DCF Editor. A user-created DCF library also can be selected for use in the dose/risk calculations performed by a RESRAD family of codes that is linked to the DCF Editor, including the RESRAD-BUILD code.

The dose/risk conversion factors saved and displayed by the DCF Editor are for each individual radionuclide. During the dose/risk calculations, the RESRAD codes use the composite dose or risk conversion factors for radionuclides with short-lived decay progenies, incorporating the dose or risk factors of their progeny which have half-lives that are less than the selected cut-off value. The composite factor of a radionuclide is the sum of its dose or risk conversion factor and those of its short-lived decay progenies adjusted by the branch fractions of the progeny. In this way, it is implied that the short-lived decay progenies are of the same concentrations as the parent radionuclide, i.e., in secular equilibrium; the dose/risk results calculated for the parent radionuclide would include contributions from the short-lived decay progenies.

The RESRAD-BUILD Code Version 4.0 is linked to the RESRAD DCF Editor Version 3.3. The DCF Editor displays: (1) the dose conversion factors for inhalation, ingestion, air submersion, and direct external radiation (volume and surface); (2) the depth and cover fitted parameters and the area and shape fitted parameters for external radiation; (3) the slope factors for inhalation, ingestion, air submersion, and direct external radiation (volume); (4) the slope factors and dose conversion factors (from working level-month, WLM to dose) for radon progenies; and (5) the transfer factors for plant, meat, milk, fish, and crustacean. For (1), (3), and (4), the values displayed can be selected to come from a variety of libraries which are based either on ICRP-38 (ICRP 1983) or ICRP-107 transformations. Depending on the library selection, the corresponding fitted parameter values for external radiation, in (2), will be displayed. The values of the fitted parameters for cover and depth were developed based on the external radiation dose conversion factors for volume sources with different thicknesses (Kamboj et al. 1998). The base values for (1), (3), and (4), except for the dose conversion factors for external radiation (surface), can be changed by users to create a new user's DCF library. The exception is due to the external radiation dose conversion factors (surface) that are not used by any RESRAD family of codes. In RESRAD-BUILD Version 4.0, an area source is simulated by a concrete volume source that has a thickness of 0.001 cm and a density of 1 g/cc. The base values for fitted parameters in (2) cannot be changed by users. The base values for transfer factors in (5) can be changed, but the transfer factors are not used in the RESRAD-BUILD code.

5.1 MAIN INTERFACE SCREEN

Figure 35 shows the Main Interface of the DCF Editor when it is used to view a default library. The Main Interface includes two menu commands at the top-left corner (File and Help), two banners under the menu commands displaying the welcome statement and showing the version number of the DCF Editor, a choice of transformation database and a Library Options frame on the left, and a library selection field and an action button (the View Library button in Figure 35) on the right. To close the DCF Editor, press the Exit Program button at the lower-left corner of the interface.
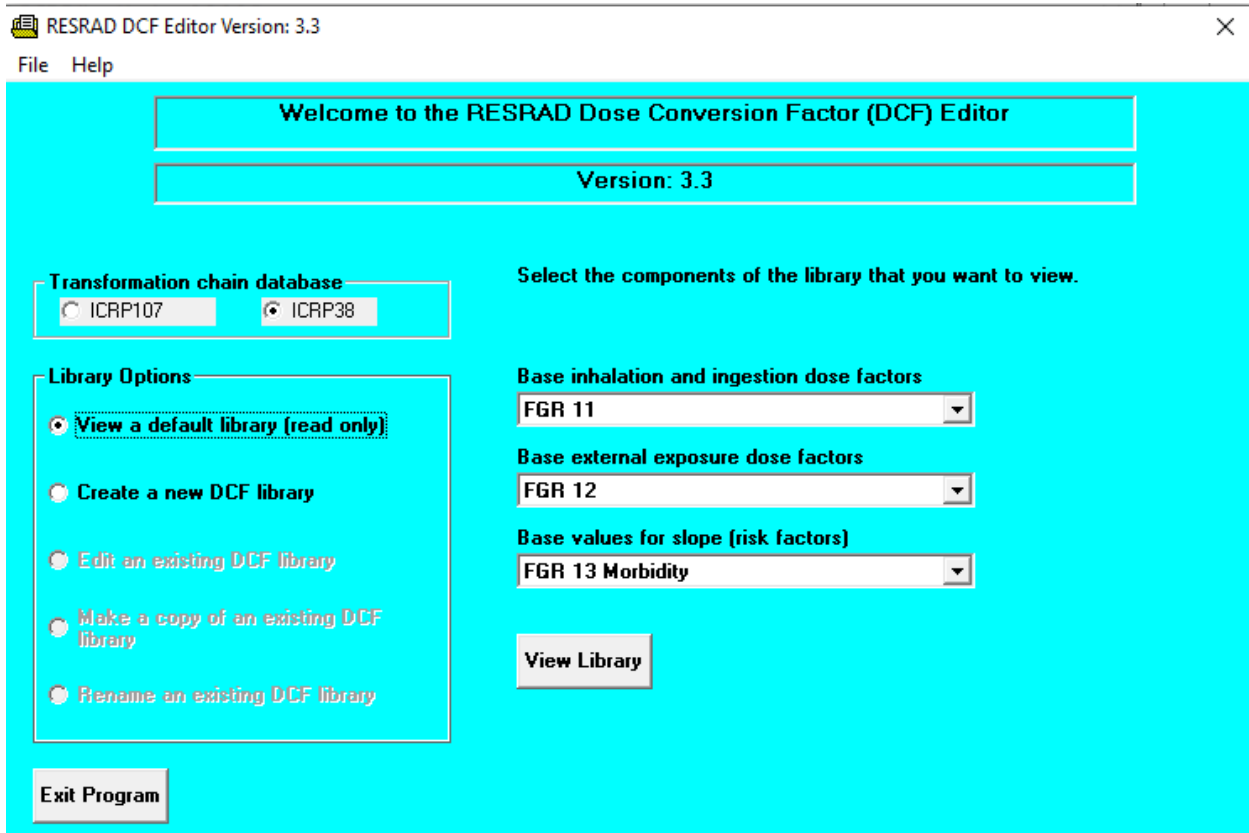
Figure 35 The Main Interface Screen of the DCF Editor with the View Option Selected

5.1.1 Selecting a Transformation Database

The DCF Editor is associated with two database files, Master_dcf_2k.mdb and Master_dcf_ICRP07.mdb, which contain the dose factors, slope factors, and transfer factors based on the transformation data in ICRP-38 and ICRP-107, respectively. The DCF Editor processes the data in Master_dcf_2k.mdb when the choice is to use ICRP-38 transformations. It processes the data in Master_dcf_ICRP07.mdb when ICRP-107 transformations are chosen.

5.1.2 Performing Library Operations

The user has multiple library operation options to choose from—viewing a default (base) library (View), creating a new DCF library (Create), editing an existing DCF library (Edit), making a copy of an existing DCF library (Copy), or renaming an existing DCF library (Rename). The Edit, Copy, or Rename options are enabled when a user-created library is available for the DCF Editor to retrieve from the selected database file.

Multiple DCF libraries could be available for performing the library operation selected; in the Library Selection field, they are listed in one or three dropdown boxes for selection. If applicable, a new DCF library name input box and a Library Description box are also displayed in the Library Selection field.

View a Default Library (Read Only): Select this option to view a default (standard, base) library with inhalation and ingestion dose factors, external exposure dose factors, or slope (risk) factors. The default (base) values of dose or risk factors are saved in default libraries, which users cannot modify. After choosing the View option, select a default library from each of the dropdown boxes, then click the View Library action button to proceed to the Data Screen (see Section 5.2).

Create a New DCF Library: Select this option to create a new DCF library based on default/base libraries. After choosing the Create option, choose a base external dose factor library, inhalation and ingestion dose factor library, and slope factor library as the starting point for making changes, then enter a name for the new DCF library to be created (the name of the new DCF library is limited to 20 characters), provide a description for the new library in the Library Description input box, and press the Create Library action button to proceed to the Data Screen, Figure 36. See Section 5.2 for the options for specifying data that differ from the data in the base libraries.
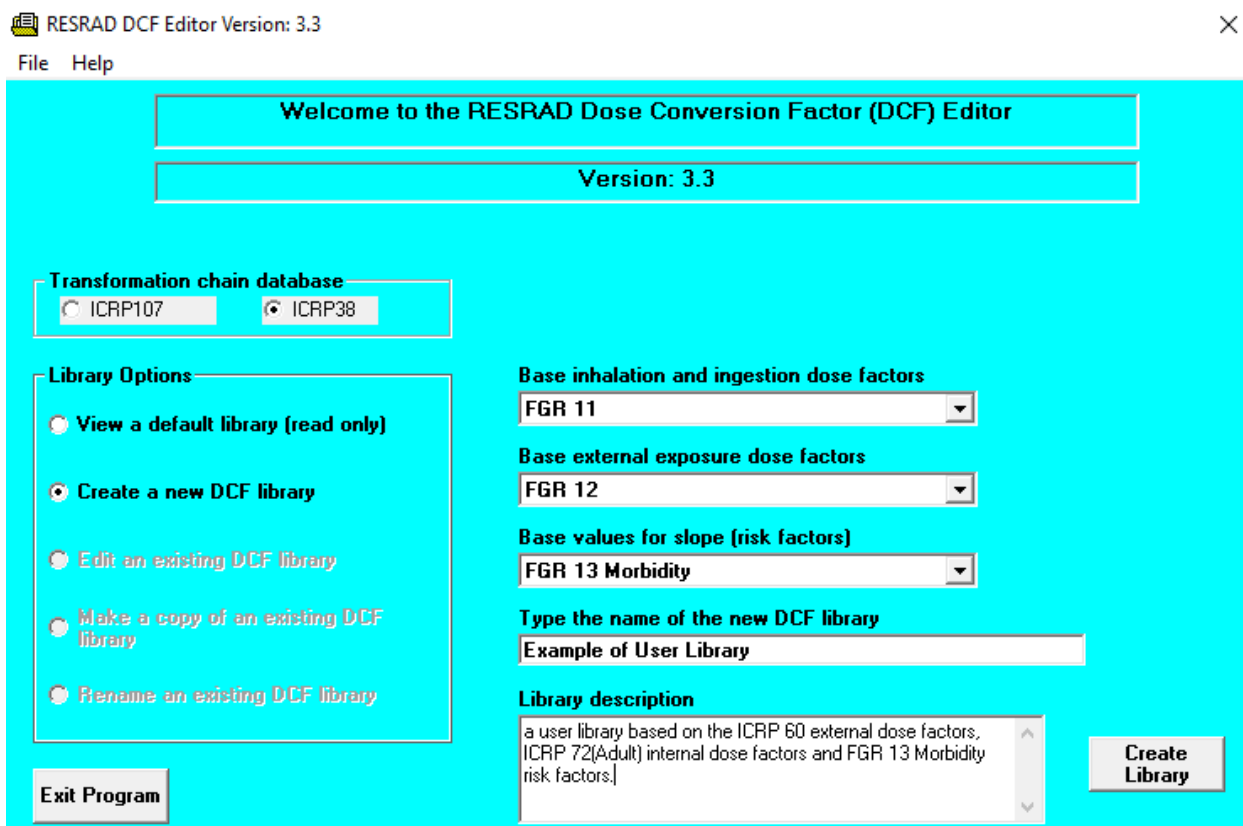
Figure 36 Initiating the Creation of a DCF Library

Edit an Existing DCF Library: Select this option to edit a previously created DCF library (or one imported into the database). After the Edit option was selected, select the library from the dropdown list. Edit the library description, if necessary, in the Library Description input box, and click the Edit Library action button to proceed to Data Screen (see Section 5.2).

Make a Copy of an Existing DCF Library: Select this option to make a copy of an existing DCF library for editing and to save the changes to a new library. After the Copy option was selected, select an existing DCF library from the dropdown list, enter the name of the new library in the designated text box, and then press the Copy Library action button to copy data to the new library and to proceed to the Data Screen (see Section 5.2).

Rename an Existing DCF Library: Select this option to rename an existing, non-default DCF library. After the Rename option is selected, select an existing DCF library from the dropdown list, type the new name for the library in the designated text box, and then click the Rename Library action button to complete the action.

5.1.3   Import and Export of DCF Library

If an input file that uses a user DCF library is to be shared with others, then that user library must be exported and shared along with the input file that uses it. The users who receive the input file must import the user library file if they want to run the input file that uses that user-created library. The user-created library can be exported or imported using the submenus under the File menu of the Main Interface. Figure 37 shows the export and import options under the File menu and the Main Interface, showing information about the user-created library "BUILD ICRP-68" after the Export option is selected.
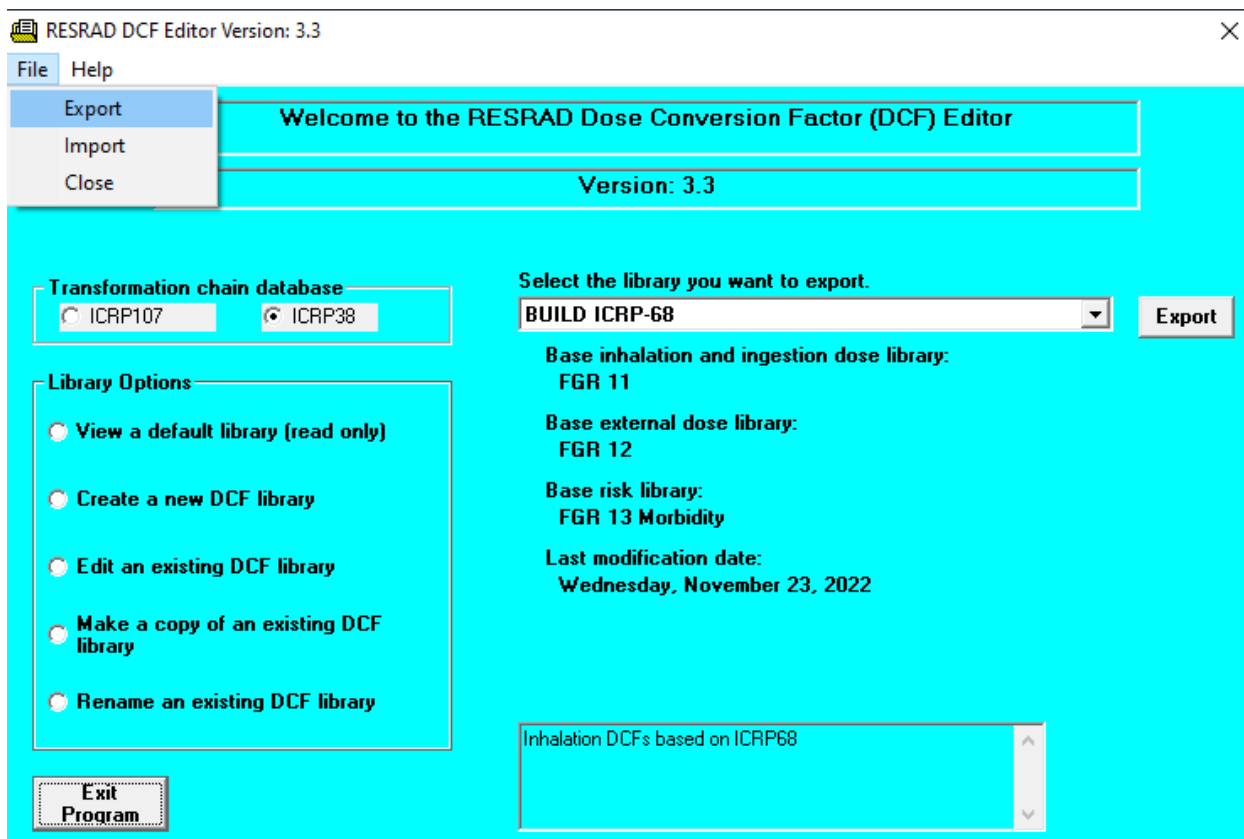
Figure 37 Export and Import Options in the DCF Editor

To Export a DCF Library: Click on the Export option under the File menu, select the library from the dropdown list in the Library Selection field, and then click on the Export action button. A file explorer window (Figure 38) will appear to allow the specification of a file and its location to save the exported library. The file name can be different from the library name, which is not changed during this export.

To Import a DCF Library: When the Import option under the File menu is clicked, a file explorer window (Figure 39) will appear to allow the search and specification of a file that contains the library to be imported. After the file is located, click the Open button to complete the import process. The process of importing a library that was created on a default database file

typically ends at this point. Any input file that uses the library that was imported can then be analyzed.

If a library with the same name as the one to be imported already exists in the DCF database, a message like the one shown in Figure 40 will appear. To continue the import process, click the OK button and another window (Figure 41) will appear. This window displays the name of the library to be imported and the other libraries already included in the database file. Type a new name for the library that is being imported, in the text box, to complete the import process. Any input file that uses the library that was imported can be analyzed after changing, in the Radiological Data form of the RESRAD-BUILD interface, the choice of library in that input file to the newly named one that was imported. To terminate the import process without importing the library, when the database file already contains a library with the same name, close the message window.
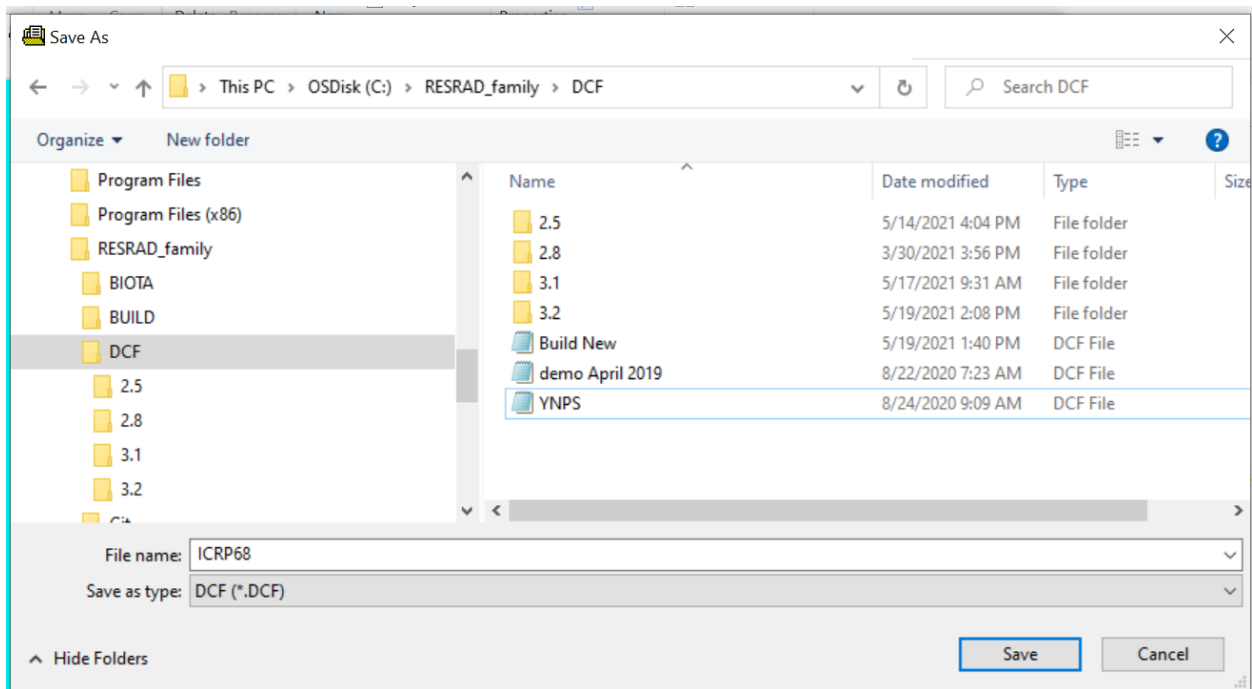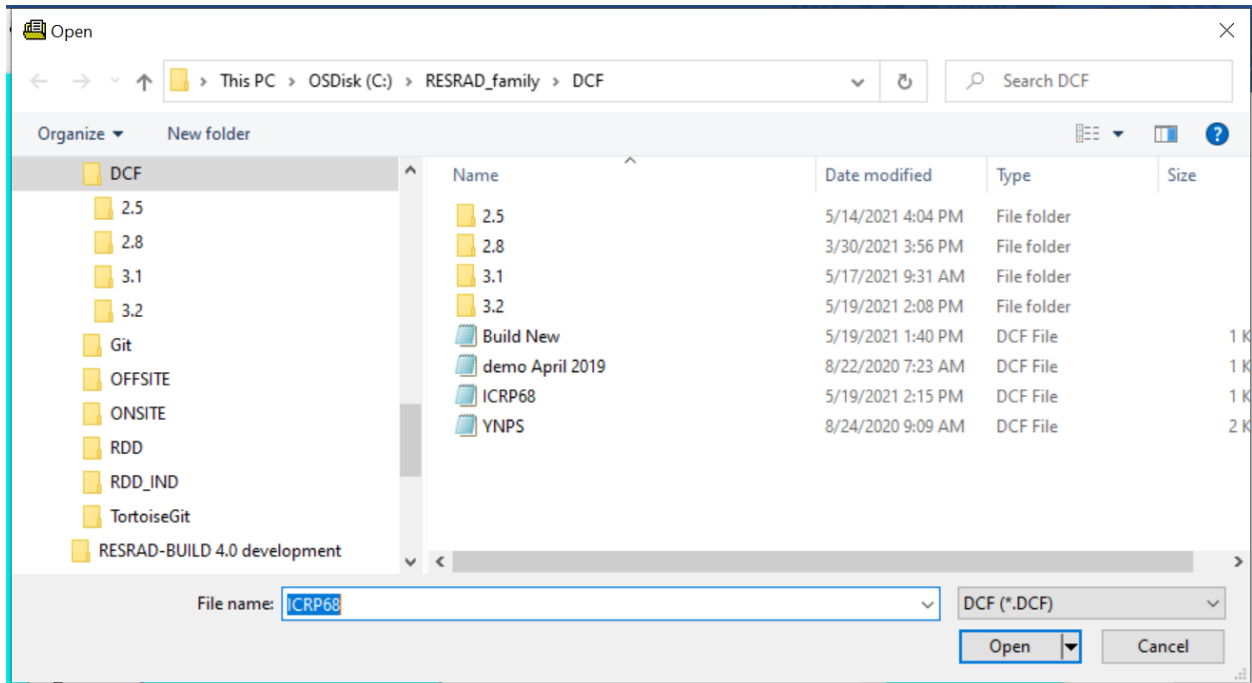

Figure 38 Saving an Exported DCF Library

Figure 39 Specifying a DCF Library to Import
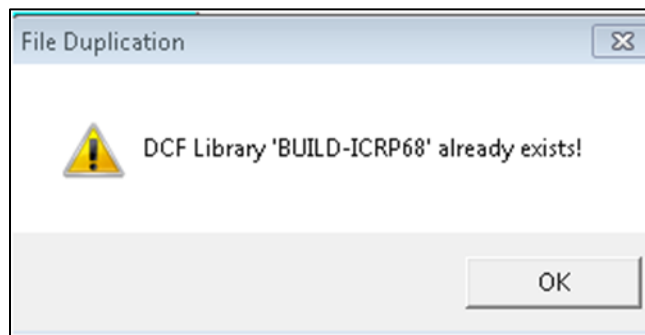
Figure 40 DCF Library File Duplication Message

**Figure 41 Provide a New Name to Save the
Imported DCF Library**

5.2 DATA SCREEN

The Data Screen will appear after the selection(s) associated with the View, Create, Edit, or Copy option is completed in the Main Interface screen. This data screen displays the dose conversion factors, slope factors, radon factors, and transfer factors in the selected library/libraries for viewing (Figure 42) or editing (Figure 43). The data screen always displays the name of the selected library/libraries at the top and is equipped with a radionuclide selection scroll at the left. At the upper-right corner is the Dose Factors Help button, which can be clicked on to get more information on the data displayed in the data screen. If the DCF Editor was launched from RESRAD-BUILD, RESRAD-ONSITE, or RESRAD-OFFSITE, then the data in this screen will be in the same units as in the code from which the DCF Editor was launched. If the DCF Editor was launched independent of a RESRAD code, the data will be displayed in pCi and mrems. The units used to display the data cannot be changed from within the DCF Editor. Regardless of the units in which the data is displayed in the DCF Editor, the data is saved in mrem and in pCi in the two database files.

Library Name: FGR 12, FGR 11, and FGR 13 Morbidity

Selected Nuclide: U-234

Dose Factors Help

| Th-228 |
| Th-229 |
| Th-230 |
| Th-231 |
| Th-232 |
| Th-234 |
| Ti-44 |
| Ti-45 |
| Tl-194 |
| Tl-194m |
| Tl-195 |
| Tl-197 |
| Tl-198 |
| Tl-198m |
| Tl-199 |
| Tl-200 |
| Tl-201 |
| Tl-202 |
| Tl-204 |
| Tl-206 |
| Tl-207 |
| Tl-208 |
| Tl-209 |
| Tl-210 |
| Tm-162 |
| Tm-166 |
| Tm-167 |
| Tm-170 |
| Tm-171 |
| Tm-172 |
| Tm-173 |
| Tm-175 |
| U-230 |
| U-231 |
| U-232 |
| U-233 |
| U-234 |

<- Back

Exit Program

Dose Conversion Factors | **Slope Factors** | **Radon** | **Transfer Factors**

Ingestion Dose Conversion Factors

Reference	(mSv/Bq)
○ FGR 11, f_1 = 0.002	7.054E-6
◉ FGR 11, f_1 = 0.05	7.649E-5

Inhalation Dose Conversion Factors

Reference	(mSv/Bq)
○ FGR 11 Class = D	7.378E-4
○ FGR 11 Class = W	2.13E-3
◉ FGR 11 Class = Y	3.568E-2

External Dose Conversion Factors, Volume

Reference	(mSv/yr)/(Bq/g)
◎ Default FGR 12	1.086E-4

Adjustment Parameters

External Dose Conversion Factors, Surface

Reference	(mSv/yr)/(Bq/cm^2)
◉ Default FGR 12	2.361E-4

Air Submersion Dose Conversion Factors

Reference	(mSv/yr)/(Bq/m^3)
◉ Default FGR 12	2.407E-7

Figure 42 Dose Conversion Factors from the "FGR 12, FGR 11, and FGR 13 Morbidity" Library for Viewing

Figure 43 Base Dose Conversion Factors in FGR 11 and FGR 12 Ready for Editing to Create a New Library "BUILD ICRP68-New"

5.2.1 Dose Conversion Factors

Choose the radionuclide of interest from the scroll list and click on the Dose Conversion Factors tab (Figure 34) to display the values of that radionuclide.

Ingestion Dose Conversion Factors: There could be multiple ingestion dose conversion factors corresponding to different gastrointestinal (GI) tract absorption fractions in a base (standard) library as shown in Figure 42. In that case, the maximum value is selected as the default value. If the Create, Edit, or Copy option is selected in the Main Interface screen, the option of choosing a different value or specifying a new value is available (Figure 43). To use a value different from the base library, click the option button associated with that value. To specify a value that is not in the base library, click the option button associated with two input boxes at the bottom of the frame and enter the new value (to the smaller box) and the reference for the new value (to the larger box).

For some radionuclides, a "-1" or "-2" is listed as the dose conversion factor or slope factor value. The negative values show that no data are associated with that specific radionuclide. A "-1" value can be replaced with a non-zero value by creating a new DCF library, which can be done before such radionuclides are included for dose/risk calculations. Otherwise, after the launch of dose/risk calculations, a message window will pop up providing the user with three options: (1) replace "-1" with "0" and proceed with calculations; (2) access the DCF Editor to create a user library with non-zero values, then the user can choose the new user library and relaunch dose/risk calculations; and (3) cancel dose/risk calculations. A "-2" value is used in a base library for radionuclides with a half-life < 10 minutes. It is assumed that the ingestion dose conversion factor or slope factor for such a short-lived nuclide is already included in the dose conversion factor or slope factor of its parent nuclide. Therefore, a value of "0" is used for such a radionuclide when dose/risk calculations involving it are performed.

Inhalation Dose Conversion Factors: Like the ingestion dose conversion factors, when there are multiple inhalation dose conversion factors for different lung clearance categories in a base library, the maximum value is selected as the default value. The procedure to use a different value or specify a new value is the same as that discussed above for the ingestion dose conversion factors. Like the ingestion dose conversion/slope factors, some nuclides have "-1" or "-2" as the default value. The handling of such a situation is the same as discussed above for the ingestion conversion/slope factors.

External Dose Conversion Factors: For external dose conversion factors, the value for an infinite volume source and an infinite surface source are listed. The dose conversion factor for an infinite surface source can only be viewed. The dose conversion factor for an infinite volume source can be viewed and modified. To specify a new value for the volume source factor, click the option button associated with two input boxes and enter the new value (to the smaller box) and the reference for the new value (to the larger box). The depth and cover fitted parameters as well as the area and shape fitted parameters used in external dose calculations (Figure 44) can be viewed but not changed by clicking the Adjustment Parameters button. See Appendix C of the RESRAD-BUILD User's Manual (Yu et al. 2022) for more information on the use of these fitted parameters.

Figure 44 Adjustment Parameters for the External DCF of Ac-223 for an Infinite Volume Source

Some nuclides have "-1" as the default value for external dose conversion/slope factors, indicating no data are associated with that nuclide. The handling of such situation is the same as discussed above for the ingestion dose conversion/slope factors.

Air Submersion Dose Conversion Factors: Like the inhalation, ingestion, and external dose conversion factors for volume, the air submersion dose conversion factors can be viewed and edited. The procedure to specify a new value is the same as that discussed above for the ingestion dose conversion factors, so is the handling of "-1" as the default value for some nuclides.

5.2.2 Slope Factors

In the data screen, select the radionuclide of interest from the scroll list, choose the Slope Factors tab, and then choose the Ingestion, Inhalation, External, or Air Submersion tab to display the slope factor values for that radionuclide. Figure 45 shows the FGR 13 (Eckerman et al.1999) ingestion slope factors for morbidity for S-35.
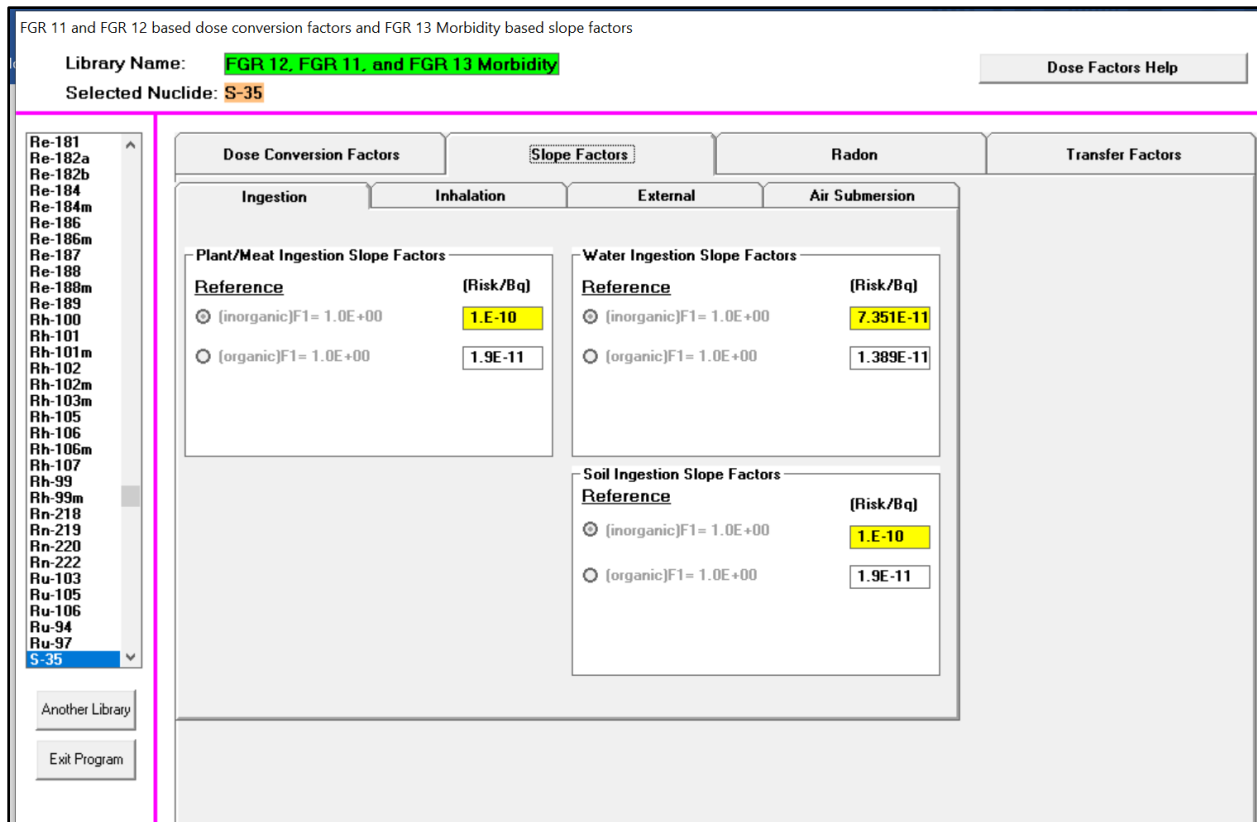
Figure 45 FGR 13 Ingestion Slope Factors for Morbidity for S-35

If there could be multiple slope factors in a base library, the maximum value is selected as the default value. If the Create, Edit, or Copy option is selected in the Main Interface Screen, the option of choosing a different value or specifying a new value is available. To use a different value, click the option button associated with that value. To specify a new value, click the option button associated with two input boxes and enter the new value (to the smaller box) and the reference for the new value (to the larger box).

To calculate cancer risks associated with the direct ingestion and secondary ingestion (i.e., ingestion of deposited nuclides) exposures, RESRAD-BUILD uses the slope factor value for soil ingestion.

5.2.3 Radon Factors

By clicking on the Radon tab in the data screen, the radon progeny slope factors and radon dose conversion factors in the selected library will be displayed (Figure 46).
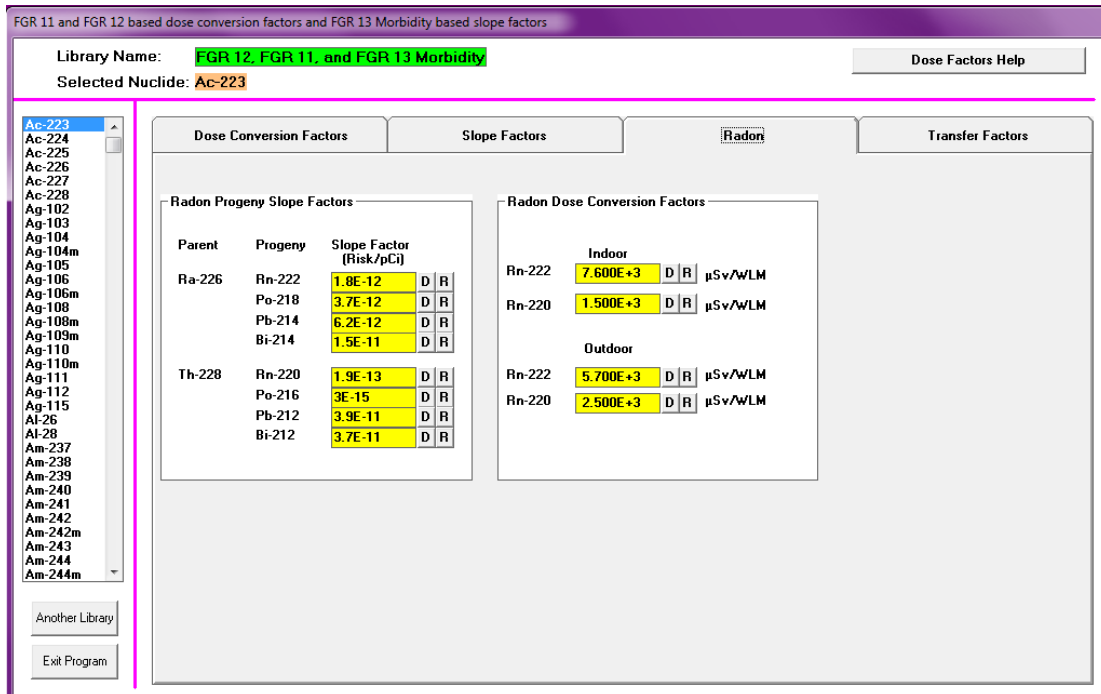
Figure 46 ICRP-30-Based Radon Progeny Slope Factors and Radon Dose Conversion Factors in the "FGR 12, FGR 11, and FGR 13 Morbidity" Library

Radon Progeny Slope Factors: If the Create, Edit, or Copy option is selected in the Main Interface screen, the option of specifying a new value is available. To change the displayed value, enter a new value in the value box and then click on the R button to enter the reference for the new value. Click the D button to set the value back to the default value.

Radon Dose Conversion Factors: To change the default value, follow the same procedure for changing the radon progeny slope factors.

There are two radon dose conversion factors, one for indoor exposure and one for outdoor exposure. Because RESRAD-BUILD considers indoor exposures, it uses only the indoor conversion factor in the dose calculation for the radon pathway. Appendix F in the User's Manual (Yu et al. 2022) provides discussions on the calculations of dose and risk associated with radon exposure.

5.2.4 Transfer Factors

Although the DCF Editor allows viewing and editing the transfer factors, the transfer factors are not used in RESRAD-BUILD calculations.

By clicking on the Transfer Factors tab in the data screen, the plant, meat, milk, fish, and crustacean transfer factors saved in the selected library will be displayed for viewing/editing (Figure 47). To change the displayed value, enter a new value in the value box and then click on the R button to enter the reference for the new value. Click the D button to set the value back to the default value.
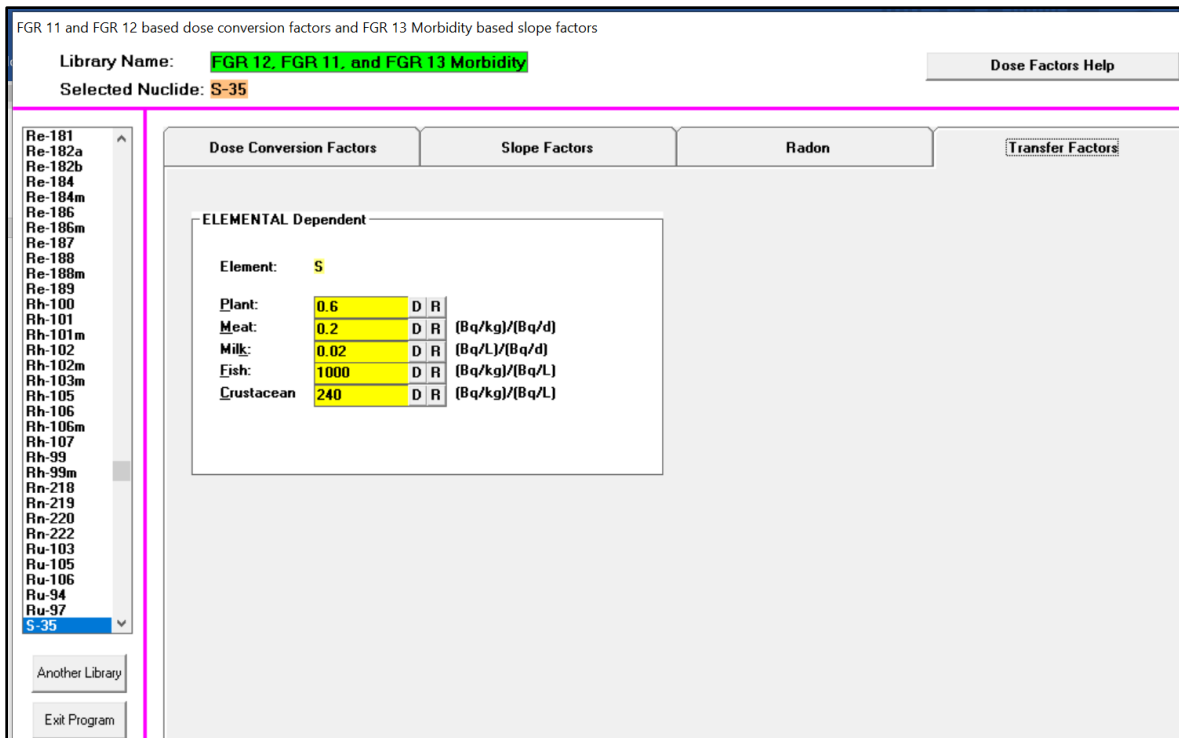
Figure 47 Transfer Factors in the "FGR 12, FGR 11, and FGR 13 Morbidity" Library

5.3 GENERAL AND CONTEXT-SPECIFIC HELP

General help (function key F2) and context-specific help (function key F1) are available when using the DCF Editor. General help information can be obtained by pressing the F2 key at any time. In the Main Interface screen, it can also be obtained with the General Help option under the Help menu, which is located at the upper-left corner of the screen. In the data screen, clicking the Dose Factors Help button in the upper-right corner brings up summary information about the DCF Editor and its functions. Specific help information on an input selection or conversion/transfer factor can be obtained by pressing the F1 key on the keyboard when that input selection or conversion/transfer factor is the current highlight.

The general or context-specific help information is displayed in the Help window. The left panel of the Help window has two tabs close to the top, Contents and Search. They can be used to bring up help information on specific topics of interest. Select the Contents tab to see a list of help topics, then select a topic of interest to display the help information in the right panel (Figure 48). The help topics are categorized so that a specific topic can be easily located. Another way of locating a specific help topic is to use the Search tab. Click the tab and then type a keyword in the input text box to be searched. Press the List Topics button to start the search. If there is a match, the help topics with contents that include the keyword will be listed in the results box below (Figure 49). Scroll down the list to the topic of interest and click the Display button to display its contents in the right panel.
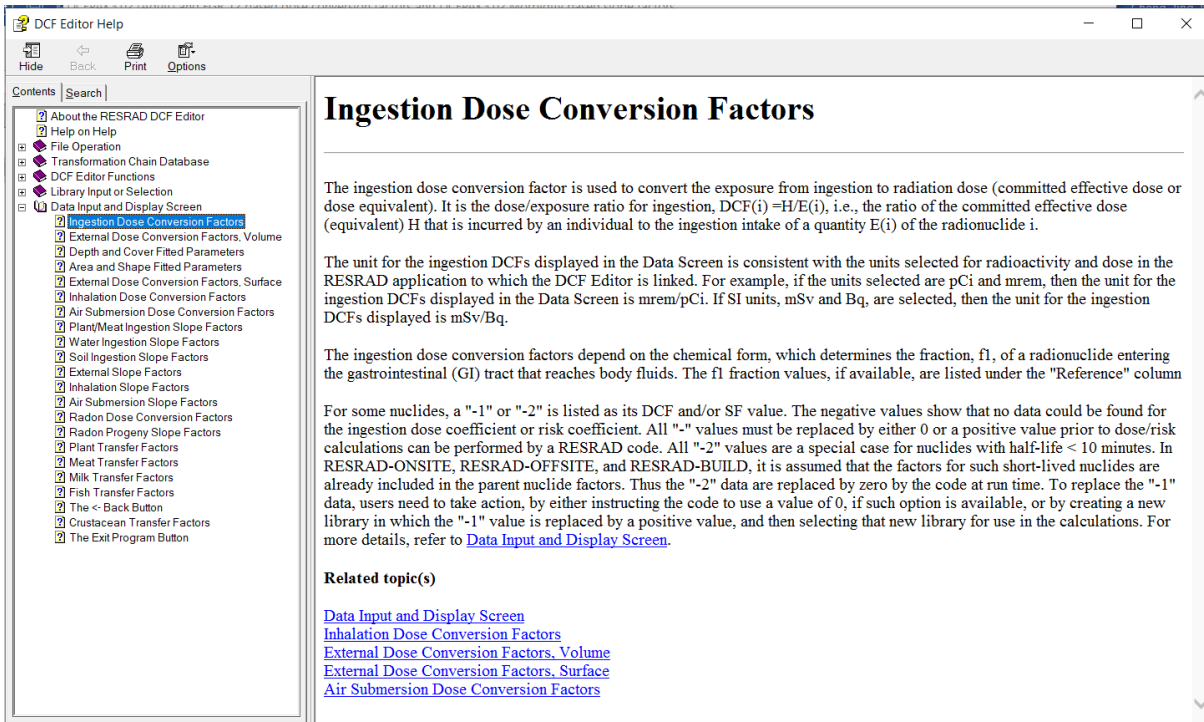
Figure 48 The DCF Editor Help Window Showing the List of Help Topics in the Left Panel and the Information for the Highlighted Topic in the Right Panel
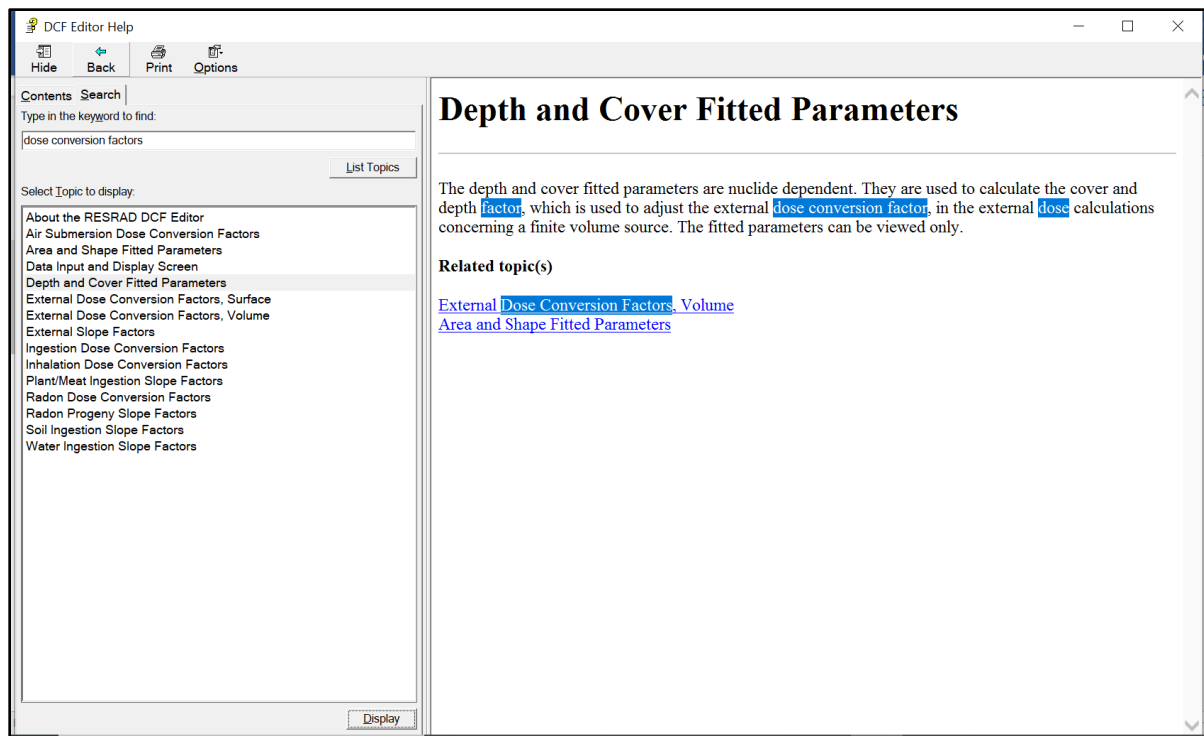

Figure 49 The DCF Editor Help Window Showing the Search Results in the Left Panel and the Information for the Highlighted Topic in the Right Panel

6 RESULTS

The user must select the Run option from the File menu (or use the Toolbar button that looks like the space shuttle) to perform dose/risk calculations for the input case that has been set up. While the calculations are taking place, the Run window (Figure 50) is displayed. This window contains (1) a short feedback line, (2) the amount of time spent so far on the calculation, and (3) a button to cancel the current calculation and return to the main user interface. After the calculations are completed, the report file (RESRADB.RPT) is automatically opened in the report viewer.
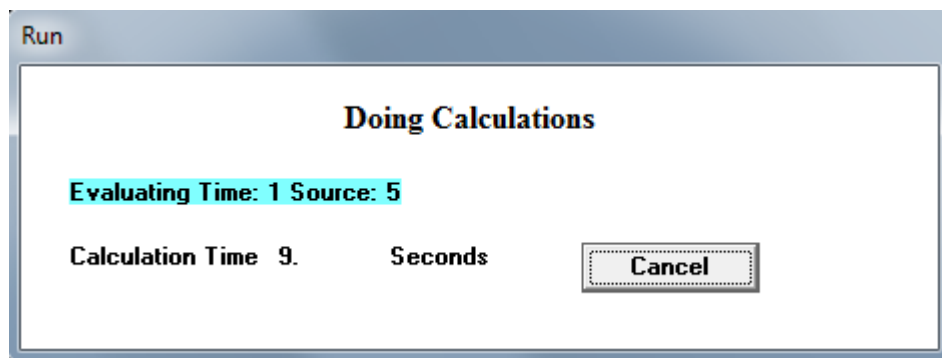

Figure 50 Window Displayed during Calculations

RESRAD-BUILD produces four text reports and several intermediate results output files. The text reports produced include the summary report (RESRADB.RPT) containing dose results for the deterministic base case, the risk report (RESRADB_R.RPT) containing risk results for the deterministic base case, the dose coefficients and slope factors report (Dose and Slope Factors.RPT), and the probabilistic report (RESBMC.RPT) containing the statistics of the dose results from the probabilistic analysis. If a probabilistic analysis is not performed, no probabilistic report will be produced. The number of intermediate results output files produced depends on how the time-integrated concentrations are calculated (analytical vs. numerical), the presence of H-3 in the source(s), the presence of radon precursor(s) in the source(s), and the number of sources considered in the run. Regardless of the calculation approach and nuclides and sources analyzed in each run, five intermediate output files are produced—three tabulating breakdowns of the component doses and the component risks at three different levels of detail, one listing all the dose and slope factors used for the analysis, and the fifth one listing the distances and densities for the direct external exposure from the source to the receptor—if the Write Intermediate Output menu option is selected. Figure 51 shows the intermediate results that could be output from each run.
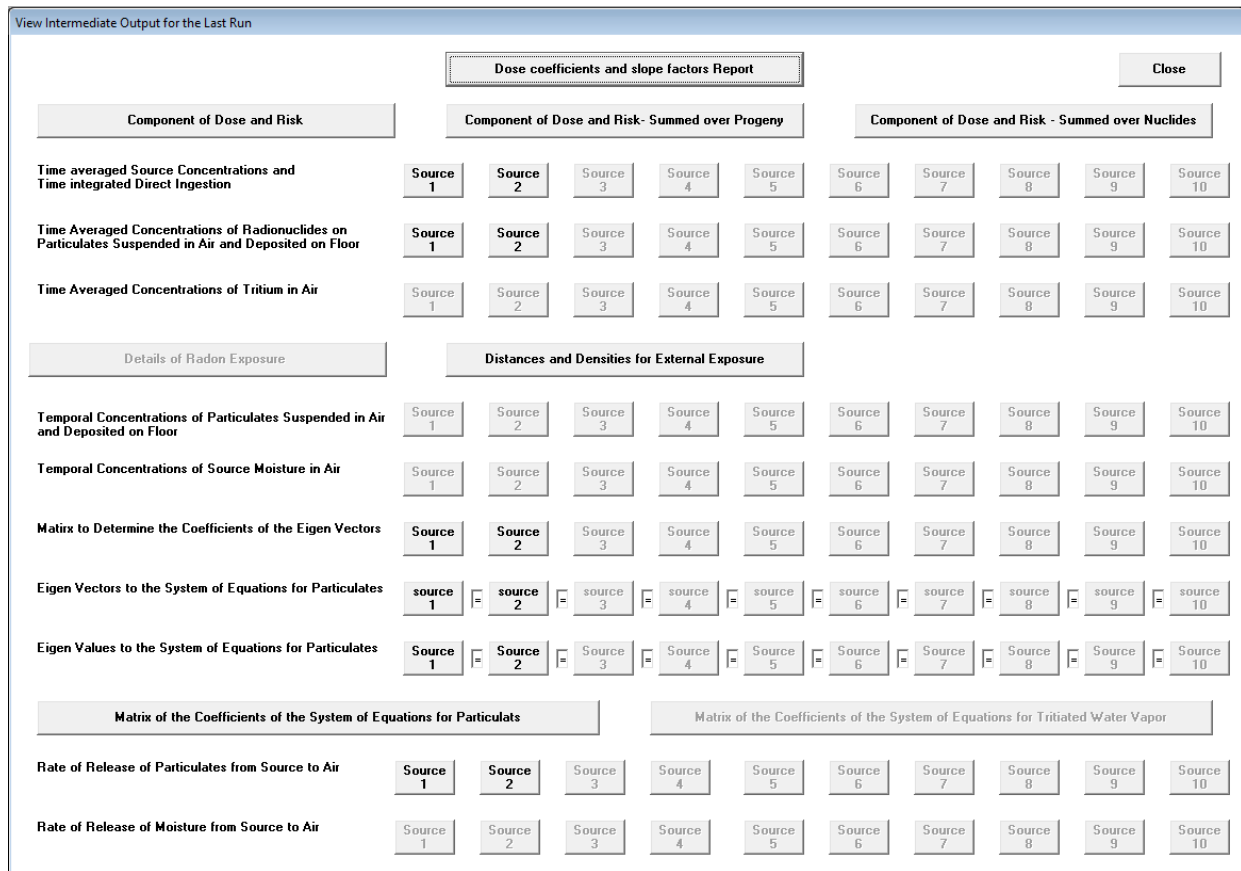
Figure 51 View Window Showing the Intermediate Results Produced by RESRAD-BUILD

RERSAD-BUILD features many graphical options for displaying the deterministic and probabilistic analysis results. Sensitivity analyses are deterministic analyses. The sensitivity analysis results are not included in a text report; they can be displayed graphically with the base case results in the standard (deterministic) graphics window.

The remainder of this chapter discusses the contents of the text reports, use of the report viewer, and display options of the graphics windows.

6.1 CONTENTS OF THE TEXT REPORTS

The first page of each report consists of the table of contents. The following summarize the contents of the text reports:

- Deterministic Summary Report (RESRADB.RPT)

    o Input parameters

    o Building information

    o Source information

- o Temporal dose summary for each receptor

- o For each input evaluation time point:

    - Receptor-dose by source summary

    - Receptor-dose by pathway details from each source

    - Receptor-dose by nuclide details from each source

- Risk Report (RESRADB_R.RPT)

  - o Input parameters

  - o Building information

  - o Source information

  - o Temporal risk summary for each receptor

  - o For each input evaluation time point:

    - Receptor-risk by source summary

    - Receptor-risk by pathway details from each source

    - Receptor-risk by nuclide details from each source

- Dose Coefficients and Slope Factors Report (Dose and Slope Factors.RPT)

  - o Individual radionuclide dose and slope factors for all exposure pathways

  - o Dose and slope factors including the contributions of associated radionuclides (for principal radionuclides), for all but the direct external radiation from an infinite volume source

  - o If applicable, the expressions used to compute the second set of factors, above, from the first.

- Probabilistic Report (RESBMC.RPT)

  - o Probabilistic input

  - o For each input time point:

  - o Receptor-general statistics of dose from each source and total dose from all sources

    - Receptor-general statistics and percentiles of dose by pathway from each source

- Receptor-general statistics and percentiles of dose by nuclide from each source

  o Regression and correlation output

6.2 REPORT VIEWER

The Report Viewer is launched automatically at the end of each run; it displays the Summary Report file named RESRADB.RPT (Figure 52). The Report Viewer may be accessed, however, at any time from the Menu or Toolbar. If the viewer is minimized before the code is run, the new report will be loaded in the viewer, but the viewer will remain minimized.
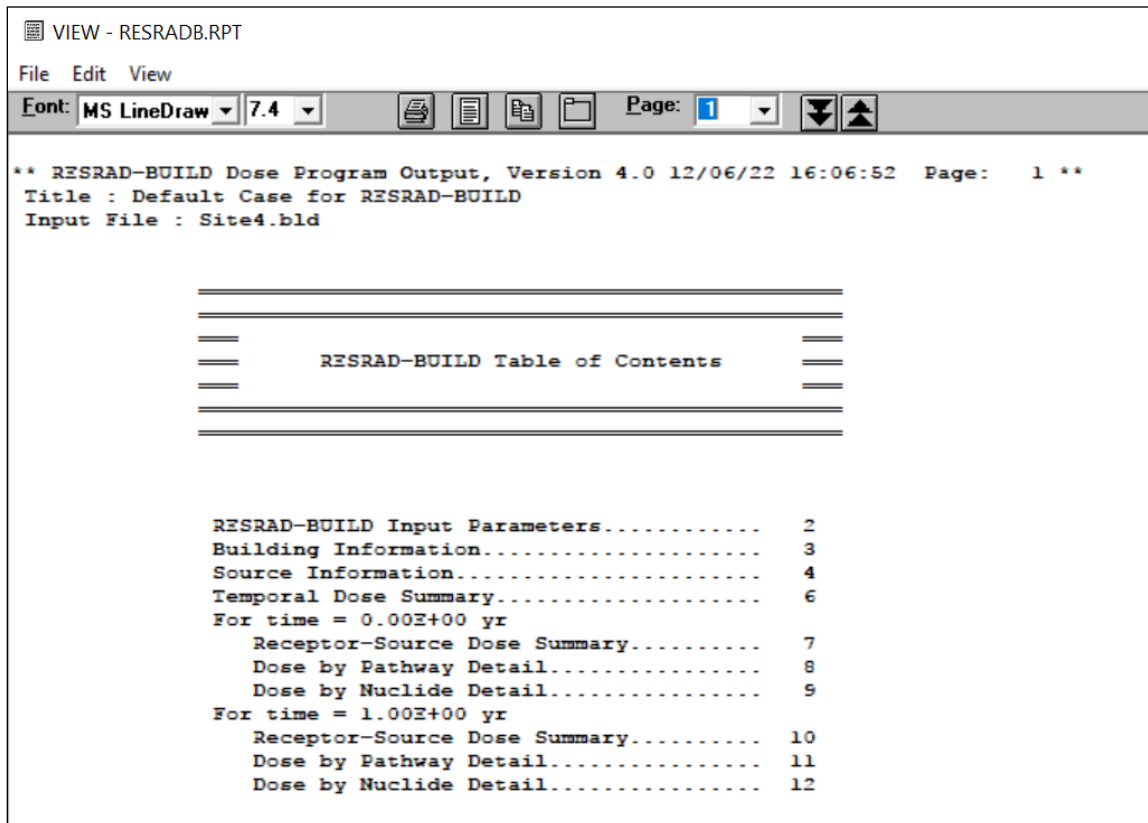
```
VIEW - RESRADB.RPT
File  Edit  View
Font: MS LineDraw ▼ 7.4 ▼      🖨 📄 📋 🗅   Page: 1  ▼  ▼▲

** RESRAD-BUILD Dose Program Output, Version 4.0 12/06/22 16:06:52  Page:   1 **
 Title : Default Case for RESRAD-BUILD
 Input File : Site4.bld


                        ═══════════════════════════════
                        ══                            ══
                        ══      RESRAD-BUILD Table of Contents      ══
                        ══                            ══
                        ═══════════════════════════════


            RESRAD-BUILD Input Parameters.............  2
            Building Information......................  3
            Source Information.......................  4
            Temporal Dose Summary....................  6
            For time = 0.00E+00 yr
                Receptor-Source Dose Summary..........  7
                Dose by Pathway Detail................  8
                Dose by Nuclide Detail................  9
            For time = 1.00E+00 yr
                Receptor-Source Dose Summary.......... 10
                Dose by Pathway Detail................ 11
                Dose by Nuclide Detail................ 12
```

Figure 52 RESRAD-BUILD Summary Report

To Get to the Report Viewer:

- From the Menu Bar: select View/Last Report or any other report.

- From the Toolbar: press the report page icon (Summary Report only).

To Move around in the Report Viewer:

- **Pages:** To go to another page, choose one of the following methods:

    o Enter the page number in the page text box and hit return.

    o Advance a page by pressing the Page Down key from the keyboard or by clicking the double down arrows on the Toolbar.

    o Go back a page by pressing the Page Up key from the keyboard or clicking the double up arrows on the Toolbar.

- **Within a Page:** Use the scroll bar at the right edge of the screen to position text.

- **Between Reports:** Select the View/Another File option from the Menu Bar to view another report or close the viewer and go back to the Main Interface window to select a different file.

To Save a Report File:

Select the File/Save option from the Menu Bar. This will prompt for a file name to save the currently displayed report.

Note: *Every time the RESRAD-BUILD code is run, the previous reports and graphics files are overwritten. The results can be saved under different names, thus allowing for later retrieval.*

To Save All the Output Files:

Select the File/Save All option from the Menu Bar of the text report viewer (Figure 53).

The output files listed below are saved to the directory where the input file is located. The output files have the same root name as the input file (denoted as *). The contents of the output files with the different extensions are described below.
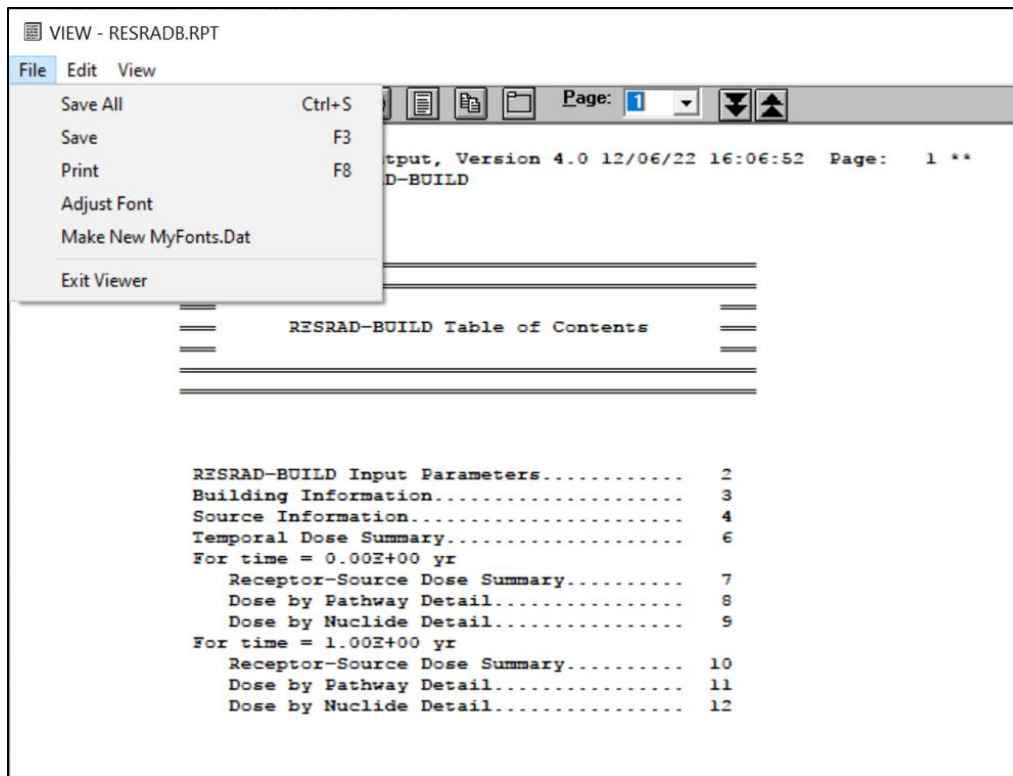
Figure 53 Saving All Output Files

*.BUO is the data for the probabilistic output viewer. This database file is saved automatically at the end of a probabilistic run.

*.ddb is the dose data for a deterministic graphics viewer. This database file is saved automatically at the end of a run.

*_r.ddb is the risk data for a deterministic graphics viewer. This database file is saved automatically at the end of a run.

*.**det** is a text report of the deterministic dose.

*.**exp** is a formatted ASCII/plain text report containing detailed dose and risk output for the deterministic, probabilistic, and sensitivity runs. It is saved if the Write Intermediate Output submenu is checked, Figure 2.

*.pds is a formatted ASCII/plain text report of the probabilistic dose data for regression analysis.

*.pin is a formatted ASCII/plain text report of the probabilistic input data.

*.prb is a text report of the probabilistic dose.

*.rsk is a formatted ASCII/plain text report of the probabilistic risk data for regression analysis.

*.sam is the text report of the probabilistic sampling code, LHS.exe.

Note: *Every time the RESRAD-BUILD code is run, the previous reports and graphics files in the code directory are overwritten or deleted.*

To Copy Selections:

- **Copy the Highlighted Selection:** Highlight the text to be copied, then select the Edit/Copy option from the Menu Bar. The highlighted text will be placed on the Windows clipboard and can be placed into any document such as a spreadsheet or text report.

- **Copy the Current Page:** Select the Edit/Select All option followed by the Edit/Copy option from the Menu Bar to place the entire page on the Windows clipboard for use in a spreadsheet or text report. Alternatively, press the icon with the image of two pages of a report to place the entire page on the Windows clipboard.

To Print the Report:

- **Select a Printer:** RESRAD-BUILD uses the standard Windows Print utility program. A printer can be accessed by selecting the File/Print option from the Menu Bar. The dialogue box that pops up includes options for printer and page(s) to print.

- **Set Up the Report for Printing:** Press the single-page icon on the Toolbar to automatically select the best font size to fit the report to a single page width.

- **Print the Report:** Print the entire report by selecting the printer icon on the Toolbar. To print the entire report or a part of it, select the File/Print option from the Menu Bar and enter the page selection in the dialogue box that pops up.

6.3 GRAPH VIEWER

The users can view the results of a deterministic analysis graphically with the built-in Standard Graphics Wizard, as shown in Figure 54, which can be accessed by selecting the View/Standard Graphics option from the Menu Bar or clicking on the View Standard Graphics icon, , from the Toolbar.
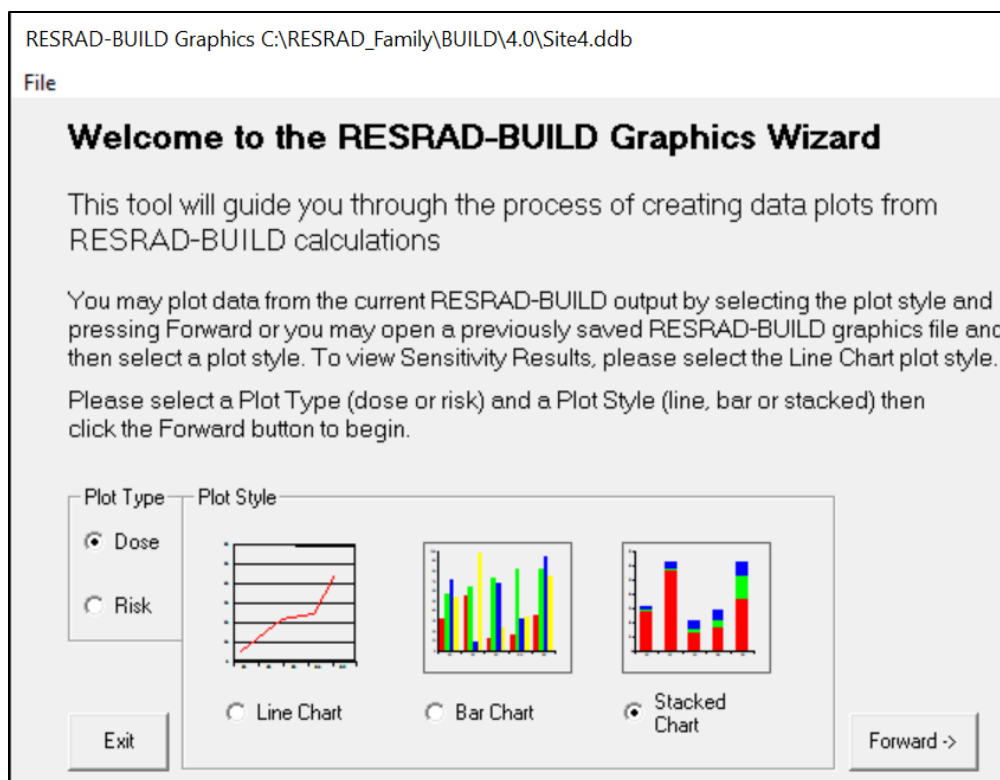
Figure 54 RESRAD-BUILD Deterministic Graphics Wizard

Once the graphics wizard opens, the user can create a new graph to display the dose/risk results in one of the three different chart styles: line, bar, or stacked. Line charts are most informative when one wishes to view results over multiple user-specified times. Bar and stacked charts are similar except that stacked charts are useful to display the total dose for a specific set of groupings. Bar charts provide an excellent way to display dose/risk subtotals for specific groupings. Choose the Plot Type and Plot Style, then click on the Forward button to move to the next step. Click on the Exit button to return to the Main Interface of RESRAD-BUILD.

Normally after the Standard Graphics Wizard is opened, it automatically accesses the database file that stores the dose results from the most recent run (*.ddb, where * denotes the input file name for the most recent run) and sets the plot type to "Dose." If the user resets the plot type to "Risk," then the wizard will access the database file that stores the risk results from the same run (*_r.ddb). The File/Open menu option at the top-left corner allows the user to open a previously generated database file that stores dose or risk results. In that case, the Plot Type options will not be available because the type will be determined by the indication contained in the selected database file (which should keep the .ddb extension although the file name maybe changed).

After the Forward button is clicked, a Plot Options form and a graph display window will appear side by side. The Plot Options form accepts selections for the Plot Axis and Data Grouping, which are inputs of dose/risk attributes. The dose/risk results calculated by RESRAD-BUILD have five attributes—time, source, receptor, pathway, and nuclide. When bar and

stacked charts are selected, the user can select up to two attributes for the x-axis (primary and secondary axis). For example, a user may wish to view the dose to each receptor from every pathway from a specific radionuclide and a specific source at a specific time. In this case, the two attributes for the x-axis would be receptor (primary axis) and pathway (secondary axis). Figure 55 illustrates a stacked chart for such a case. By selecting different primary and secondary axes, the user can plot the dose/risk results from different perspectives. For example, a user may want to determine which nuclide-pathway combination contributes the most dose to a particular receptor from all sources combined at a given time. In this case, the primary axis would be radionuclide and the secondary axis would be pathway. Figure 56 illustrates a bar chart for such a case. The flexibility provided by the Standard Graphic Wizard allows users to analyze the dose/risk results in much greater detail than what is possible with the text-based report alone. The graph display window displays the chart based on inputs in the Plot Options form.

All charts can be printed with the File/Print menu option (the File menu is located at the top-left corner of the graph display window). As an added feature, data for the chart created using the RESRAD-BUILD Standard Graphics Wizard can be exported to Microsoft Excel^{TM} for further analysis (select the File/Export to Excel menu option). The Plot Type menu options allow making a change of plot type in the graphic display window without the trouble of clicking the <-Back button to return to the graphic wizard screen to do so.
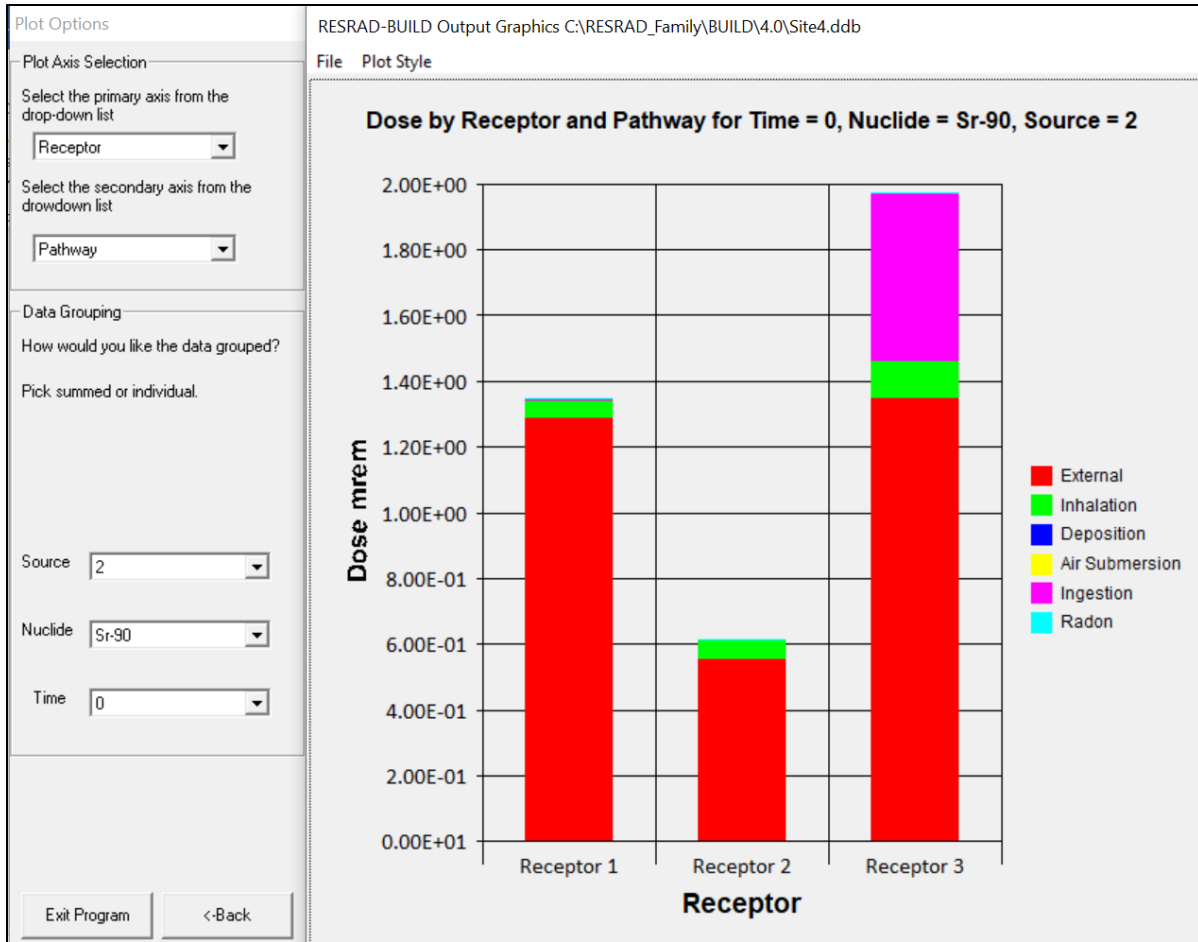
Figure 55 Stacked Chart Showing the Dose to Each Receptor from Each Pathway Caused by Sr-90 in Source 2 at Time 0
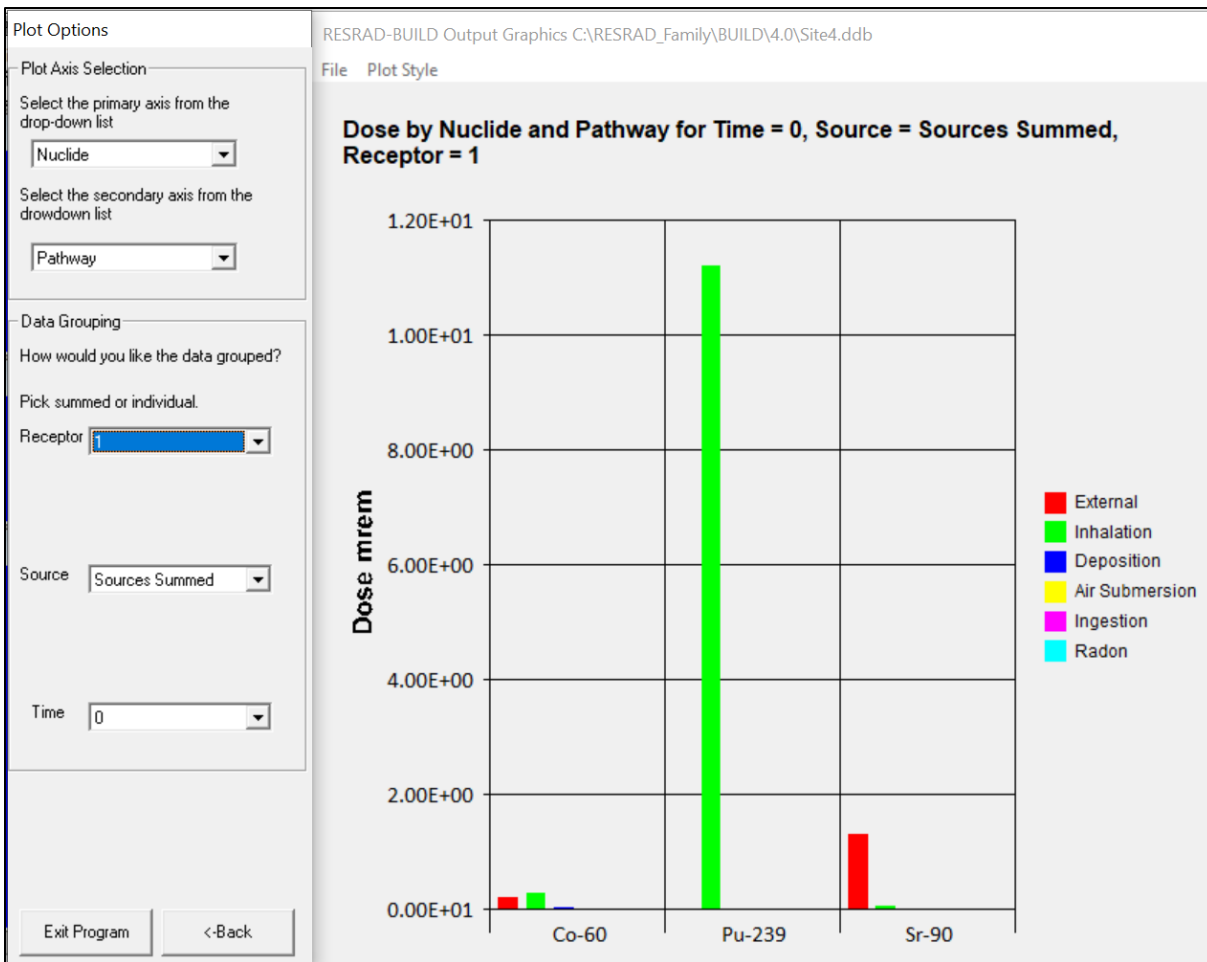
Figure 56 Bar Chart of Dose to Receptor 1 at Time 0 from Each Radionuclide and Pathway Combination

7 PARAMETER SENSITIVITY ANALYSIS

RESRAD-BUILD Version 4.0 includes deterministic and probabilistic sensitivity analysis features to analyze the influence of input parameters on the dose/risk results, which can be used to enhance the understanding of the case analyzed and identify important input parameters. The deterministic sensitivity analysis, or "sensitivity analysis" for short, can be used to observe the independent influence of each individual parameter. The probabilistic sensitivity analysis, or "probabilistic analysis" for short, can be used to study the collective influence of multiple parameters when they are varied simultaneously over their likely range and to determine the importance of each individual parameter based on input-output correlation analyses.

7.1 SENSITIVITY ANALYSIS

Sensitivity analysis is used to study the independent influence of each individual parameter on the modeled dose and risk results. Each of the selected parameters is varied in turn by a factor, first by multiplying the base value with the factor and then by dividing the base value with the same factor. In this way, a higher and a lower value than the base value are obtained, and two additional runs of the code are performed for each parameter selected for sensitivity analysis while all the other parameters are held at their base values. To present the sensitivity analysis results in the graphic display with the line chart style, three curves are plotted to show the variation of the modeled dose/risk results obtained with the three values (low, base, high) of the parameter. The inputs eligible for sensitivity analysis are listed in Table 1. Up to 10 input variables can be subjected to sensitivity analysis in a single input file. Figure 57 shows the Sensitivity Analysis Setup screen.

Table 1 Inputs Eligible for Sensitivity Analysis

FORTRAN Name	Description
airfr(idx1)	"Fraction of material removed from source idx1 that is released to air" (traditional interface and volume source in new interface)
area(1)	"Area of room 1" (1 room case of traditional interface)
area(idx1)	"Area of room idx1" (new interface)
brtrate(idx1)	"Breathing rate of receptor idx1"
densi0(idx1, idx2)	"Density of region idx2 of source idx1"
dksus(1)	"Resuspension rate in all rooms" (traditional interface)
dksus(idx1)	"Resuspension rate in room idx1" (new interface)
drythick(idx1)	"Initial thickness of dry zone of (tritium volume) source idx1"
dsden(idx1, idx2)	"Density of shielding between receptor idx1 and source idx2"
dsth(idx1, idx2)	" Thickness of shielding between receptor idx1 and source idx2"
dx(idx1, idx2)	"X:idx2 = 1, Y:idx2 = 2 and Z:idx2 = 3 coordinates of receptor idx1"
efdif0(idx1, idx2)	"Diffusion coefficient of radon in region idx2 of source idx1"

Table 1 (Cont.)

FORTRAN Name	Description
emana0(idx1, idx2, idx3)	"Radon emanation fraction of region idx2 of source idx1" ^{220}Rn:idx3 = 1, ^{222}Rn:idx3 = 2
eros0(idx1, idx2)	"Erosion rate of region idx2 of source idx1"
ftin	"Indoor time fraction"
h(1)	"Height of room 1" (1 room case of traditional interface)
h3porosity(idx1)	"Total porosity of contaminated material in (tritium volume) source idx1"
h3rmvf(idx1)	"Water fraction available for vaporization in (tritium volume) source idx1"
h3thick(idx1)	"Thickness of wet plus dry zones in (tritium volume) source idx1"
h3volfract(idx1)	"Volumetric water content of (tritium volume) source idx1"
humidity(idx1)	"Humidity in building"
Inge1(idx1, idx2)	"Direct ingestion rate of source idx1"
inge2(idx1)	"Ingestion rate of deposited material by receptor idx1"
lambdat	"Building exchange rate" (1 room case of traditional interface)
poros0(idx1, idx2)	"Porosity of region idx2 of source idx1"
rf0(idx1, idx2)	"Lifetime of source idx1" (traditional interface)
rmvfr(idx1)	"Removable Fraction of source idx1" (traditional interface)
rrf(idx1)	"Radon release fraction of source idx1"
slw(idx1, idx2)	"Length of source idx1 along axis idx2"
sx(idx1, idx2)	"X:idx2 = 1, Y:idx2 = 2 and Z:idx2 = 3 coordinates of source idx1"
sarea(idx1)	"Area of source idx1"
thick0(idx1, idx2)	"Thickness of region idx2 of source idx1"
ttime	"Exposure duration"
Twght(idx1)	Time fraction at receptor location idx1
ud	"Deposition velocity"
VacEff	"Efficiency of vacuuming" (new interface)
VacuumInterval	"Time between vacuuming" (new interface)
Volume(idx1)	"Volume of room idx1" (new interface)
wall_density(idx1)	"Density of material in (tritium volume) source idx1"

Figure 57 Sensitivity Analysis Setup Screen

To Activate Sensitivity Analysis:

- While maintaining focus on the parameter of interest, i.e., positioning the mouse cursor at the input field of the parameter, select the Modify/Sensitivity Analysis menu option or press the function key F9.

- The sensitivity summary bar (shown at the bottom of the Main Interface if the View/Sensitivity Summary menu option has been selected) will include a button for each parameter selected for sensitivity analysis. The information on each button includes the parameter's FORTRAN variable name and an indicator of the factor to multiply and divide the base value. Left-click a button to bring up the Sensitivity Analysis Setup screen to review, set, or cancel the sensitivity analysis on the parameter. Right-click a button to remove that parameter from the sensitivity analysis.

- In the Sensitivity Analysis Setup screen, choose one of the options for the multiplication and division factor. The resultant parameter values for the two additional sensitivity runs will be shown at the right, along with the base value. If Other is selected, specify a non-zero value. Choose OK to add sensitivity analysis for that parameter. Choose No Analysis to cancel or remove sensitivity analysis for that parameter.

To View the Sensitivity Analysis Results:

Sensitivity analysis results are only shown in the line chart graphics, not in any text report. After a case has been run with sensitivity analysis, access the Standard Graphics Wizard and choose to display dose/risk results in the line chart style. In the Plot Option form, there should be a Sensitivity selection field at the bottom. Choose the Base Case option to display dose/risk results obtained with the base values of all input parameters. Choose any input

parameter from the dropdown list to display dose/risk results for the base case as well as the results from the two additional sensitivity runs for that parameter. Figure 58 shows the sensitivity analysis results for the receptor 2 breathing rate parameter.
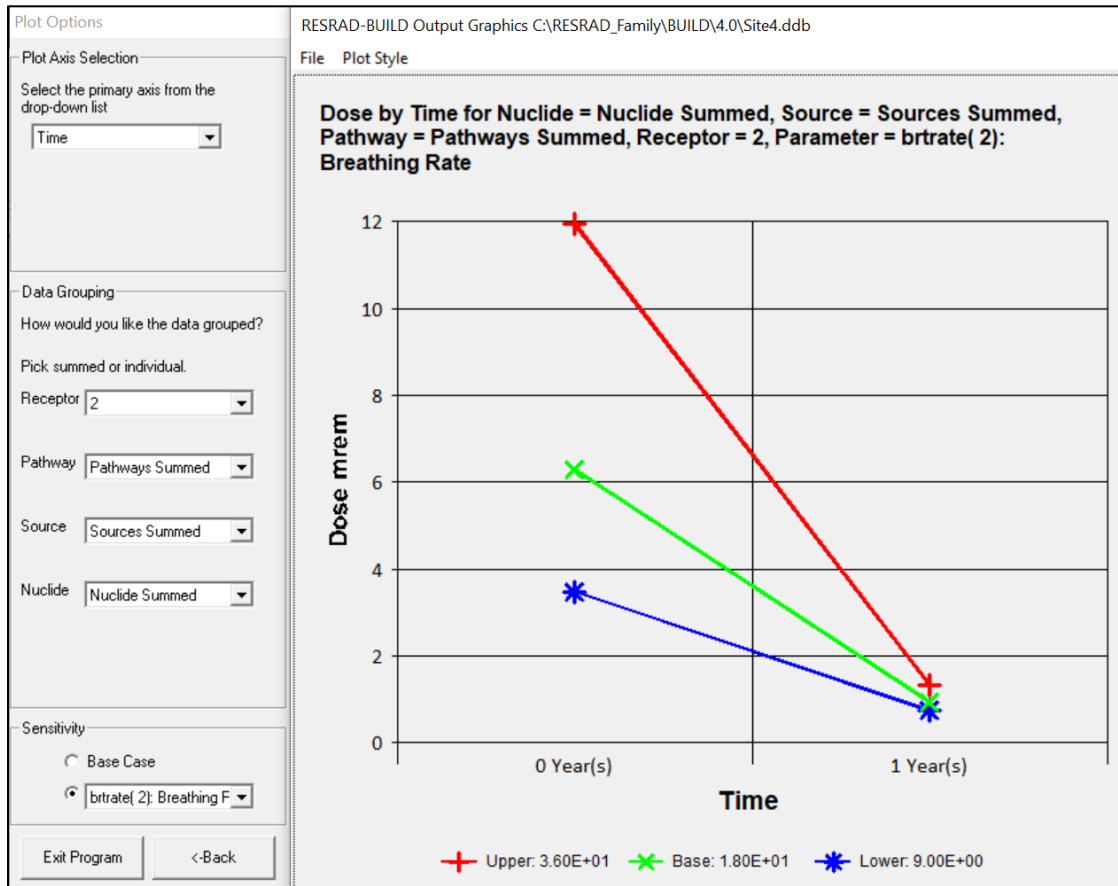
Figure 58 Sensitivity Analysis Results

7.2 PROBABILISTIC ANALYSIS

The probabilistic analysis modules are independent from the deterministic calculation modules. They were developed based on the software for Latin hypercube sampling (LHS) and correlation analysis written by Iman and Shortencarier (1984) and Iman et al. (1985), respectively, and integrated into the RESRAD-BUILD code.

Probabilistic analysis is performed after the calculations for the Base Case are completed and, if applicable, is followed by sensitivity analysis in a RESRAD-BUILD run. The user needs to select input parameters to be included in a probabilistic analysis and provide information on the distributions of their values and their correlations with other selected parameters; this information is used by the code to generate a specific number of input datasets (the number is determined by the user). In these input sets, the values of the selected parameters are varied simultaneously while the values of the unselected parameters are kept at their base values. The dose/risk calculations are then repeated with each of the generated input sets so that the same

number of results datasets are generated. These results datasets are analyzed to provide statistics of the potential dose/risk, and regression analysis is conducted to characterize their correlation with the input parameters to determine the influence of each selected parameter on the dose/risk results. The inputs eligible for probabilistic analysis are given in Table 2.

Table 2 Inputs Eligible for Probabilistic Analysis

FORTRAN Name	Description
airfr(idx1)	"Fraction of material removed from source idx1 that is released to air" (traditional interface and volume source in new interface)
area(1)	"Area of room 1" (1 room case of traditional interface)
area(idx1)	"Area of room idx1" (new interface)
brtrate(idx1)	"Breathing rate of receptor idx1"
densi0(idx1, idx2)	"Density of region idx2 of source idx1"
dksus(1)	"Resuspension rate in all rooms" (traditional interface)
dksus(idx1)	"Resuspension rate in room idx1" (new interface)
drythick(idx1)	"Initial thickness of dry zone of (tritium volume) source idx1"
dsden(idx1, idx2)	"Density of shielding between receptor idx1 and source idx2"
dsth(idx1, idx2)	" Thickness of shielding between receptor idx1 and source idx2"
efdif0(idx1, idx2)	"Diffusion coefficient of radon in region idx2 of source idx1"
emana0(idx1, idx2, idx3)	"Radon emanation fraction of region idx2 of source idx1" ^{220}Rn:idx3 = 1, ^{222}Rn:idx3 = 2
eros0(idx1, idx2)	"Erosion rate of region idx2 of source idx1"
ftin	"Indoor time fraction"
h(1)	"Height of room" (1 room case of traditional interface)
h3porosity(idx1)	"Total porosity of contaminated material in (tritium volume) source idx1"
h3rmvf(idx1)	"Water fraction available for vaporization in (tritium volume) source idx1"
h3thick(idx1)	"Thickness of wet plus dry zones in (tritium volume) source idx1"
h3volfract(idx1)	"Volumetric water content of (tritium volume) source idx1"
humidity(idx1)	"Humidity in building"
Inge1(idx1, idx2)	"Direct ingestion rate of source idx1"
inge2(idx1)	"Ingestion rate of deposited material by receptor idx1"
lambdat	"Building exchange rate" (1 room case of traditional interface)
poros0(idx1, idx2)	"Porosity of region idx2 of source idx1"
rf0(idx1, idx2)	"Lifetime of source idx1" (traditional interface)

Table 2 (Cont.)

FORTRAN Name	Description
rmvfr(idx1)	"Removable fraction of source idx1" (traditional interface)
rrf(idx1)	"Radon release fraction of source idx1"
sarea(idx1)	"Area of source idx1"
thick0(idx1, idx2)	"Thickness of region idx2 of source idx1"
ttime	"Exposure duration"
ud	"Deposition velocity"
VacEff	"Efficiency of vacuuming" (new interface)
VacuumInterval	"Time between vacuuming" (new interface)
Volume(idx1)	"Volume of room idx1" (new interface)
wall_density(idx1)	"Density of material in (tritium volume) source idx1"

7.2.1 Overview of Performing a Probabilistic Analysis

This overview is followed by a section that provides background information about each step.

Selecting an Input Parameter for Probabilistic Analysis:

- While maintaining focus on the parameter of interest, i.e., positioning the cursor in the input field of the parameter, select the Modify/Uncertainty Analysis Menu option, press the function key F8, or click on the Uncertainty Analysis button ±? on the Toolbar.

- The Uncertainty Analysis Input window containing four tabs will appear with the second tab titled Parameter Distributions active (Figure 59).

  If the parameter is eligible for uncertainty analysis, it will be added to the left most column titled "Variable Description", which list of parameters selected for probabilistic analysis. If the code has a default distribution for the parameter, it will be displayed in the frame titled "Statistics of Uncertain Variable". If not, the distribution information will be empty awaiting user input. The user can and should replace the default distribution with a site-specific distribution, if available. Figure 59 shows the distribution information of the Indoor Fraction input parameter.

  If the parameter is ineligible for uncertainty analysis, it will not be added to the list of parameters. The focus will be on the first parameter selected for uncertainty analysis if any had been selected before.
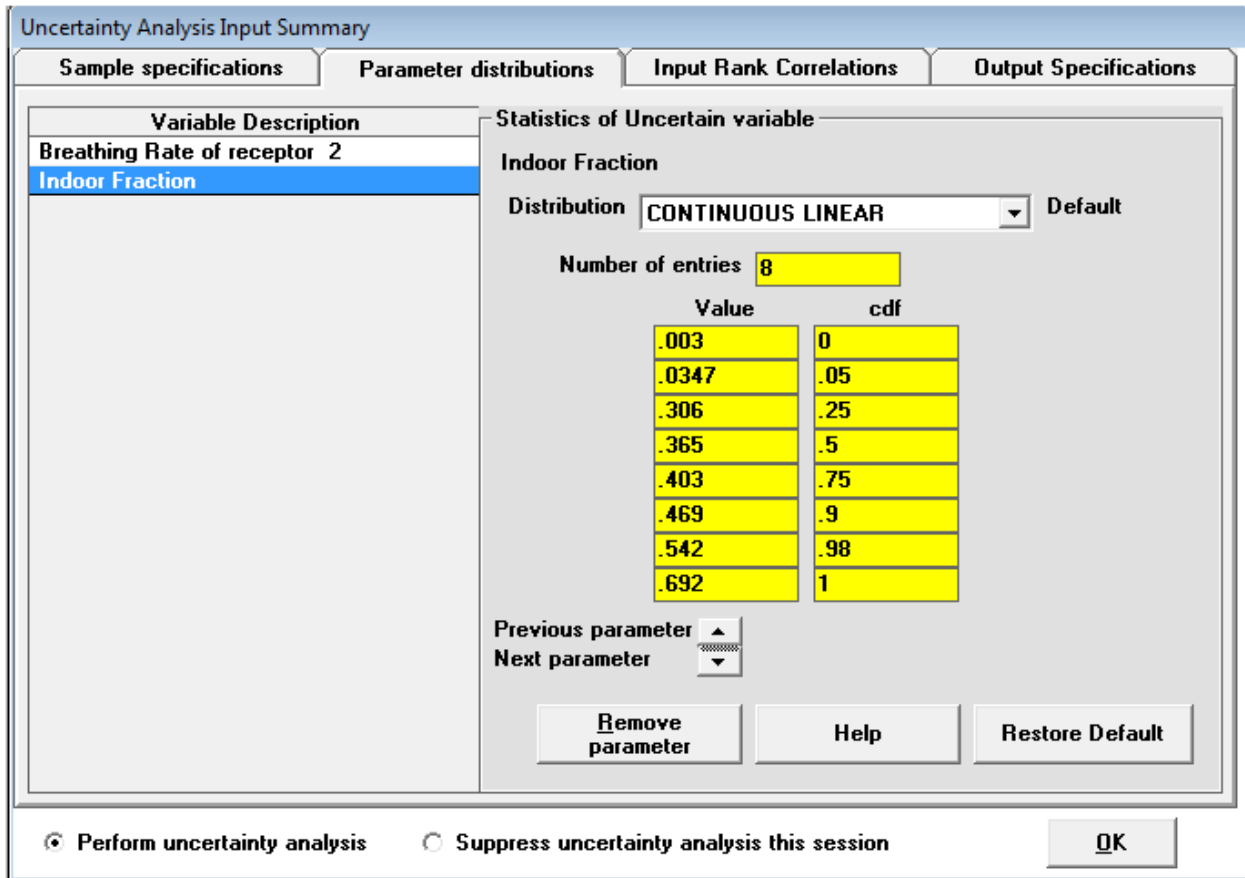
Figure 59 Parameter Distributions Tab Screen

Setting the Sampling Specifications:

- Set the desired number of observations. This is the number of times the distribution will be sampled for each input.

- Set the number of repetitions. This is the number of times the whole procedure of sampling the distributions, grouping the samples, running the group of samples through the code, is repeated.

- Choose the method of sampling the distributions.

- Choose whether you want to specify any correlations between inputs or whether you want the samples of different inputs to be grouped together at random.

Specifying Correlations between Input Parameters Selected for Probabilistic Analysis:

- Specify any correlations between the input parameters selected for probabilistic analysis.

Run RESRAD-BUILD and Then the Interactive Uncertainty Graphics Wizard:

- During the calculations, the results generated are stored for later use. The summary report will appear in the text viewer after the calculations are completed, unless regression analysis was specified between the probabilistic dose and the probabilistic inputs. In that case, the uncertainty text report, RESBMC.RPT, will be displayed in the text viewer.

- If correlations were specified between the inputs, verify that the correlations between the inputs are satisfactory. Open either "EXAMPLE1.UN6" or, if the output files were saved, "filename.sam." Compare the "Correlations among input variables created by the Latin Hypercube Sample for rank data" for each repetition with the "Input Rank Correlation Matrix." Also check whether an "Adjusted Rank Correlation Matrix" is present in the file. Make any necessary corrections/adjustments to the correlations specified between inputs and or to the number of observations and rerun the analysis.

- Launch the Interactive Output Viewer using the View/Uncertainty Graphics menu command or the uncertainty graphic button ▨ on the Toolbar. View the tabular data of the percentiles of the cumulative distribution of the dose from the desired pathway. Verify that there is agreement between the repetitions by comparing the data in the +/- column with the data in the Dose column. Rerun with a larger number of observations, if the deviation between repetitions is too large.

- To view the probabilistic analysis text report, the user will need to select the View/Last Probabilistic Report menu option.

7.2.2 Inputs for a Probabilistic Analysis

There are four tabs with input screens that accept detailed specifications for a probabilistic analysis—Sample Specifications, Parameter Distributions, Input Rank Correlations, and Output Specifications.

- **Sample Specifications:** This tab specifies how the distributions specified in the Parameter Distributions tab are sampled and how the samples for the different input parameters are to be combined to produce the set of input files for the analysis (Figure 60). The frame on the right side of this tab screen describes the purpose and effect of the item selected on the left. Uncertainty analysis can be turned off temporarily during the execution of an input file while the uncertainty input settings are preserved by selecting the "Suppress uncertainty analysis this session" option at the bottom of this window.

- **Number of Observations:** This is the number of values that will be generated from sampling the distribution of each input parameter specified in the Parameter Distributions tab. This is also the number of realizations or the number of samples. At a minimum, this number must exceed the number of

parameters selected for probabilistic analysis, if correlations are specified between the parameters or if regression analysis is to be conducted to quantify the influence of the selected parameters. The accuracy in the statistics, e.g., mean, median, percentiles, minimum, and maximum, of the dose/risk results calculated improves with increasing the number of observations; but comes at the cost of longer execution time.
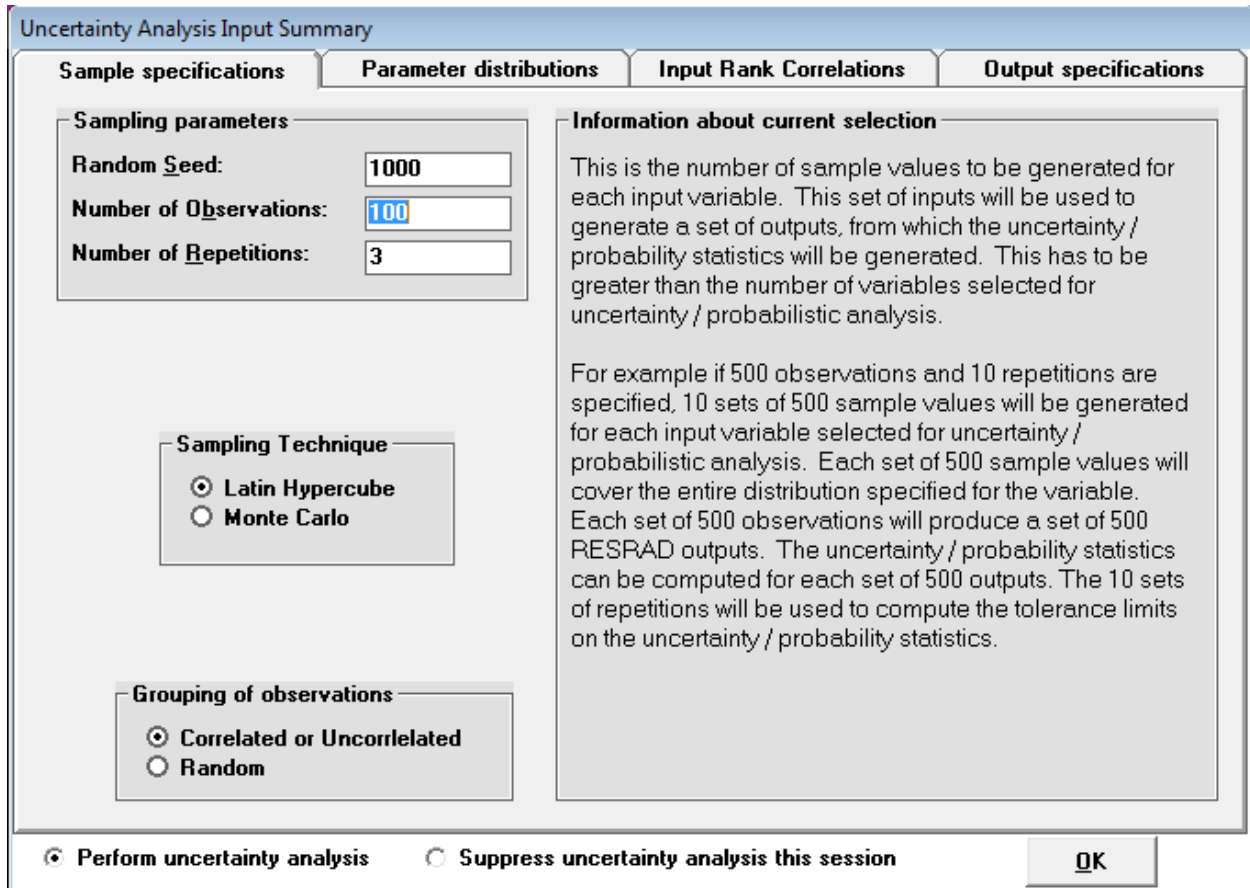

Figure 60 Sample Specifications Tab Input Screen

- **Sampling Technique:** The code offers a choice between two sampling techniques—Latin Hypercube sampling (LHS) or Monte Carlo sampling. In the LHS technique, the distribution is divided into equally probable segments, equal in number to the desired number of observations. Then a value is picked at random from each segment according to the probability density function within that segment. This ensures that the sample covers the entire range of the distribution, even when the number of samples is relatively small. In the Monte Carlo technique, the samples (observations) are each picked at random from the entire distribution according to the probability density function. When the number of samples is small, the sampled values do not represent the distribution as well as the sampled values obtained by using the LHS technique. But there is little difference between the two choices when using

89

the number of samples needed when a probabilistic analysis is performed on a large number of input parameters in RESRAD-BUILD.

- **Random Seed:** Both sampling techniques choose the sample value from the appropriate part of the distribution at random according to the probability density function. The sampling code has a random number generator to produce the pseudo-random numbers needed to do the random sampling. The random number generator produces a random number based on the seed it receives. It also increments the seed to the next integer every time a random number is generated. Thus, the sequence of random numbers that are generated to obtain the samples can be exactly reproduced, if the same starting seed is used again. The Random Seed input is the starting seed; it allows the code to reproduce the same set of probabilistic inputs, should there be a need to rerun the same analysis later on a different computer.

- **Grouping of Observations:** After the code obtains the required number of samples for each input parameter, it combines the samples over all selected parameters to form the set of inputs for probabilistic analysis. The RESRAD-BUILD code offers two choices on how the samples from each input parameter are combined to make the set of inputs: (1) random grouping or (2) correlated or uncorrelated grouping. If it is necessary to have correlations between some of the parameters, or if it is necessary to ensure that there is no correlation between some of the parameters (i.e., zero correlation), the correlated grouping must be used.

- **Number of Repetitions:** This is the number of times the probabilistic analysis needs to be repeated in order to obtain a measure of accuracy in the predicted distributions of the dose/risk results. Increasing the number of observations increases the accuracy of the predictions, but a measure of the accuracy can be obtained only if the analysis is repeated. The closeness of the predicted results from the repeated analyses, or the lack thereof, is an indication of the accuracy, or lack of accuracy, of the predicted distributions.

- **Parameters Distributions:** The Parameter Distributions tab screen (Figure 59) allows the user to view and edit the distribution of each of the input parameters selected for probabilistic analysis. The parameters are listed in the left frame. The detailed distribution properties are shown in the right frame.

- **Variable Description:** The currently selected parameters are shown in the left frame of the screen, each by its variable description. By clicking on any parameter in the left frame, the complete distribution properties for that parameter will appear for review and edit on the right frame. Navigation to another parameter can also be achieved by using the Up- and Down-arrow control to move to the previous or next parameter in the right frame.

- **Statistics of Uncertain Variable:** The distribution of an input parameter is characterized by a distribution function (or type) and specific parameters

concerning the shape (type) and upper and lower truncation bounds of the distribution. In Figure 59, the shape parameters, i.e., number of entries, value, and cdf, are for the continuous linear distribution.

After making changes to the distribution, if it is desired to restore the default distribution, the Restore Default button can be selected. The user can also remove a parameter from probabilistic analysis by clicking the Remove Parameter button while the parameter is highlighted. Clicking on the Help button on the right frame brings up a window providing additional information on the specified distribution (see Figure 61).

The cumulative distribution function is assumed to vary linearly between the cdfs specified by the user for the N_{pts} points. This distribution is identical to the "uniform*" distribution. The probability density function of each individual linearly interpolated segment is given by

$$f_i(x) = \frac{cdf_i - cdf_{i-1}}{V_i - V_{i-1}}$$

Conditions
cdf of first point = 0
Value of i th point < Value of i+1 th point
cdf of i th point < cdf of i+1 th point
cdf of last point = 1

Close Graphical Help

Figure 61 Help on Parameter Distribution

Input Rank Correlations: The Input Rank Correlations tab screen (Figure 62) allows the user to view and edit all correlations between the input parameters selected for probabilistic analysis. The paired parameters with nonzero correlations are listed in the left frame. The correlation between any pair of probabilistic inputs that is not specified in this table are set to 0. Correlations can be modified, added, or deleted in the right frame.
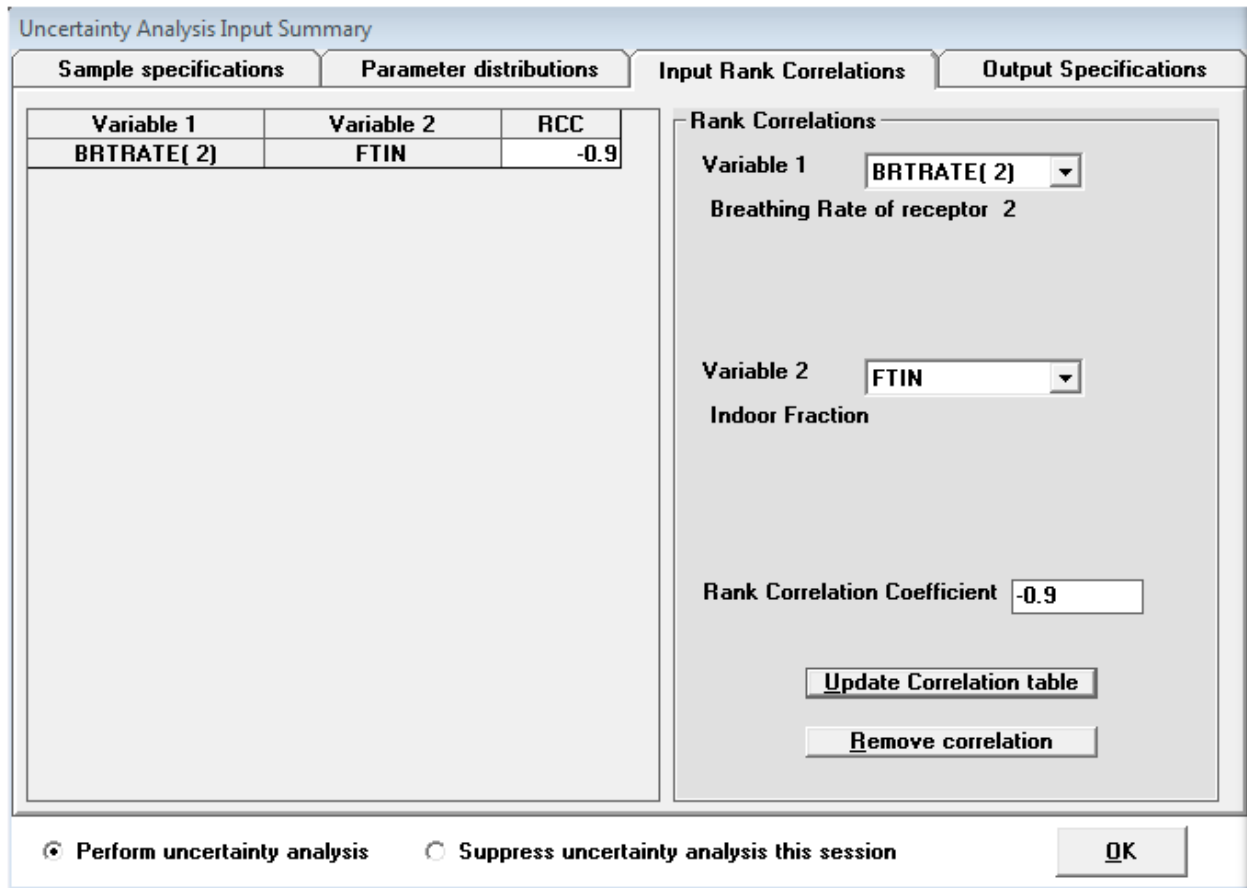
Figure 62 Input Rank Correlations Tab Screen

- **Rank Correlations Specification:** The user can specify the correlation between two parameters by selecting them from the dropdown list for Variable 1 and Variable 2 in the right frame of the screen and then entering a rank correlation coefficient (Figure 62). The range of the correlation coefficient is –0.999999 to 0.999999. The new pair of parameters and their correlation coefficient will be listed in a three-column table in the left frame of the screen after the Update Correlation Table button is clicked. All pairs of parameters selected are listed in the table. If the list of correlations is too long, a scroll bar will appear to allow moving up or down the table.

- **Rank Correlations Edit:** Clicking any element in any row of the table in the left frame will display the full description of the correlation in the right frame, which can be modified or deleted. After making any changes to the correlation, remember to click on the Update Correlation table button to save the changes. Click on the Remove Correlation button to remove the correlation. The user can and should check the results of the sampling correlation in the text report of the LHS program (EXAMPLE1.UN6 or filename.sam, if the output files were saved) after the run has been completed.

- **Output Specifications:** This tab screen (Figure 63) allows users to specify when and what type of correlation/regression analysis the code should perform. The user can select to perform correlation and regression analysis right after the uncertainty run has completed (1st option listed from the top) or later (2nd option listed from the top). If the 2nd option is selected, an additional rectangular action button (Determine correlation and regression coefficients) (Figure 64) will appear in the screen. The user can access this Output Specifications tab screen and click on that action button to initiate the correlation/regression analysis at any time after the uncertainty run has completed, as long as the saved probabilistic analysis outputs are still available.

Figure 63 Output Specifications Tab Screen
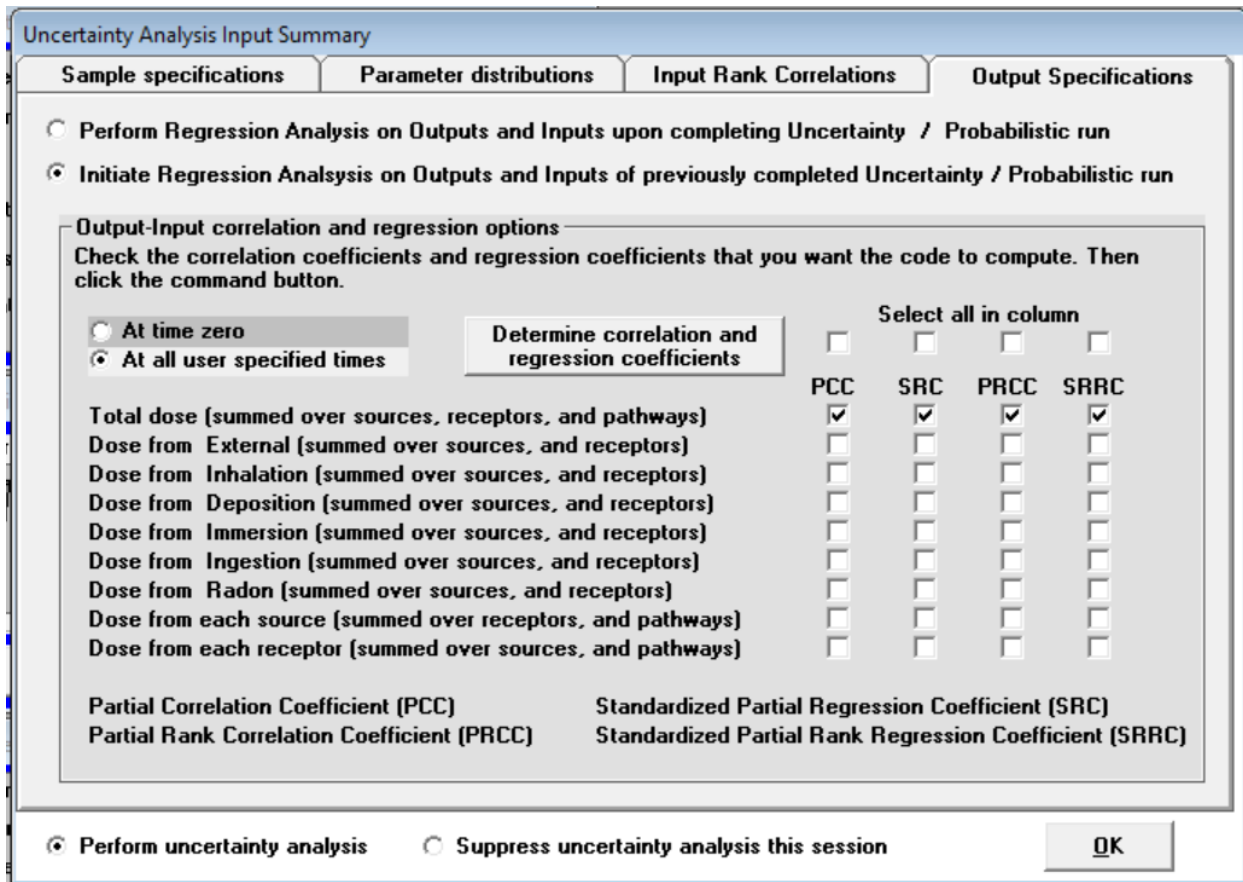
Figure 64 Output Specifications Tab Screen with a Rectangular Action Button

The user selects what type of correlation/regression analysis (PCC, SRC, PRCC, SRRC) (see note below) should be performed with which dose results (total, from individual pathway, from individual source, to individual receptor) by clicking on the corresponding check boxes. By default, none is checked; therefore, no correlation/regression analysis is performed after the completion of the uncertainty run. The correlation and regression can be performed with the dose results either at time zero or at all user-specified times (the two options are listed above the four columns of check boxes). Note: PCC—partial correlation coefficient, PRCC—partial rank correlation coefficient, SRC—standardized partial regression coefficient, and SRRC—standardized partial rank regression coefficient.

7.2.3   Text Report Generated by the Probabilistic Input Sampling Program

The LHS module generates a text report named "EXAMPLE1.UN6." This file contains the input dataset, i.e., different combinations of parameter values that were generated from sampling, which can be accessed via the View/Any File menu option. The following information is included in EXAMPLE1.UN6 for each repetition (or replication) of the analysis requested by the user:

- The initial random seed.

- The number of input parameters selected for probabilistic analysis.

- The number of observations.

- The current repetition.

- The input parameters selected for probabilistic analysis, the specified distributions, parameters defining the distributions, as well as the labels (FORTRAN name in the RESRAD-BUILD code).

- The rank correlation matrix, if specified by the user.

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

- A list of all input vectors generated. (Note: A vector is a combination of samples of the selected parameters.)

- A list of the ranks of all the input samples generated.

- A matrix of correlations among the raw values of the input parameters generated by the sampling program.

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

7.2.4 Viewing Results of a Probabilistic Analysis

The dose/risk calculations are performed upon the clicking of the Run button. A pop-up window, shown in Figure 65, displays the calculation progress. The Cancel button of this window allows the user to stop the calculations at any time. When the calculations are completed, the probabilistic analysis summary report, RESBMC.RPT, appears in the viewer window (Figure 66) if regression analysis had been selected between the probabilistic dose and the probabilistic inputs. Otherwise, the deterministic dose text report, RESRADB.RPT, will be displayed. The probabilistic text report, RESBMC.RPT, can be opened using the View–Last Probabilistic Report menu command. This report contains a complete list of all input parameters and their specified distribution functions and distribution parameters used in the probabilistic calculations.
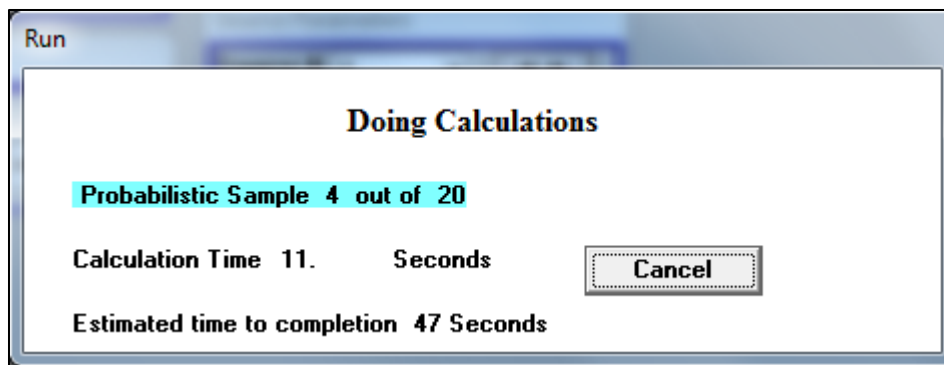
Figure 65 Window Displayed When a Probabilistic Analysis Is Being Performed
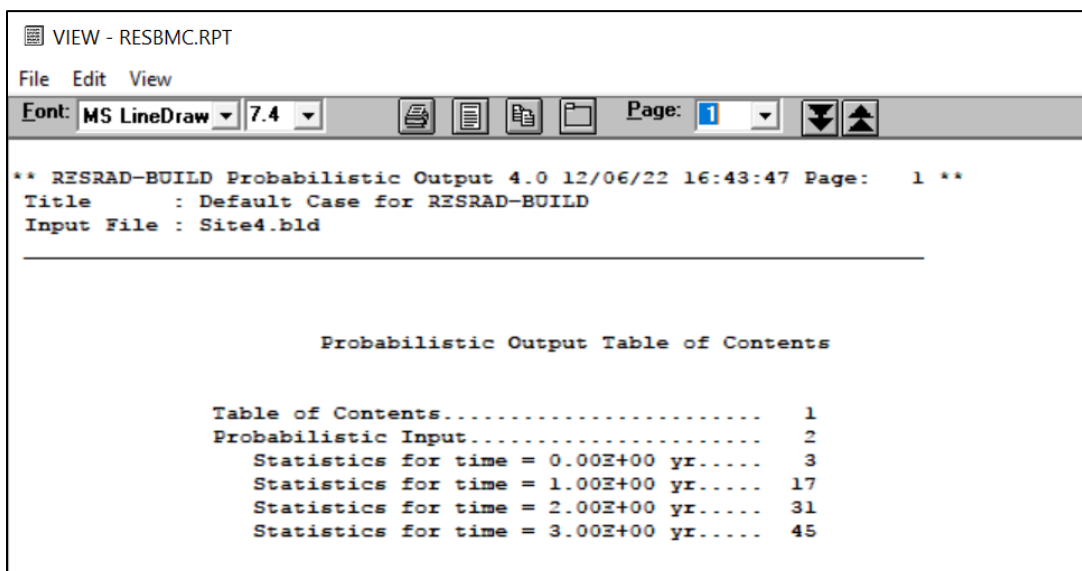
Figure 66 RESRAD-BUILD Probabilistic Analysis Text Report

The output results of the deterministic analysis, RESRADB.RPT, which is also performed in the same run, can be accessed via the View/Last Report menu option.

The probabilistic analysis text report, RESBMC.RPT, contains the following information:

- Probabilistic analysis inputs, including the number of observations and repetitions, input parameters selected for probabilistic analysis, their specified distributions, and parameters defining the distributions.

- For each user-specified time:

    o Statistics of the total dose (minimum, maximum, average, and standard deviation) for all pathways and all radionuclides summed for each source and receptor.

- For each source and receptor, statistics of the dose for each pathway (minimum, maximum, average, and standard deviation) summed over the source radionuclides.

- For each source and receptor, percentile doses for each pathway (starting at the 5th percentile, incrementing every 5th percentile to the 100th percentile) summed over the source radionuclides.

- For each source and receptor, statistics of the dose for each radionuclide (minimum, maximum, average, and standard deviation) summed over the pathways.

- For each source and receptor, percentile doses for each radionuclide (starting at the 5th percentile, incrementing every 5th percentile to the 100th percentile) summed over the pathways.

- A table of regression and correlation coefficients between the selected dose and each of the probabilistic input parameters for each repetition, if regression analysis was selected. The coefficients included are the PCC, SRC, PRCC, and SRRC.

In addition to the RESBMC.RPT report, various text and graphics outputs can be generated interactively using the Uncertainty Graphics Wizard, which can be accessed by selecting the View/Uncertainty Graphics Menu option or by clicking on the button, , on the Toolbar. The interface of the Uncertainty Graphics Wizard has three tabs at the top; depending on which tab is selected, the corresponding tab screen is displayed. The Input Specifications tab (Figure 67) and the Parameter Statistics tab (Figure 68) display input specifications for the probabilistic analysis. These specifications are for viewing only. The Results tab (Figure 69) has two interactive screens that accept output specifications by the user and display the probabilistic analysis results accordingly. The results can be displayed in both text and graphic forms.

To view results in the text form, choose the Text option under the Results tab. A table with the statistics of a calculated dose at a specific User Time, which is the Primary Object, will be displayed. The attributes of the dose of interest—receptor, time, pathway, source, and nuclide—need to be specified with the Receptor, User Times, Pathways, Source, and Radionuclide input. Either the General Statistics, i.e., minimum, maximum, mean, standard deviation, and the 50th, 90th, and 95th percentile, or the Percentile, i.e., the 5th through 95th percentile at every 5th percentile, for the dose of interest can be displayed. Make this selection with the Statistical Property input. The statistics or percentiles displayed contain an estimate of how well these properties are known based on the variation within the repetitions. The numbers listed under the +/- column are the standard deviation of the properties from the repetitions divided by the square root of the number of repetitions. They are measured in the same units as the property.
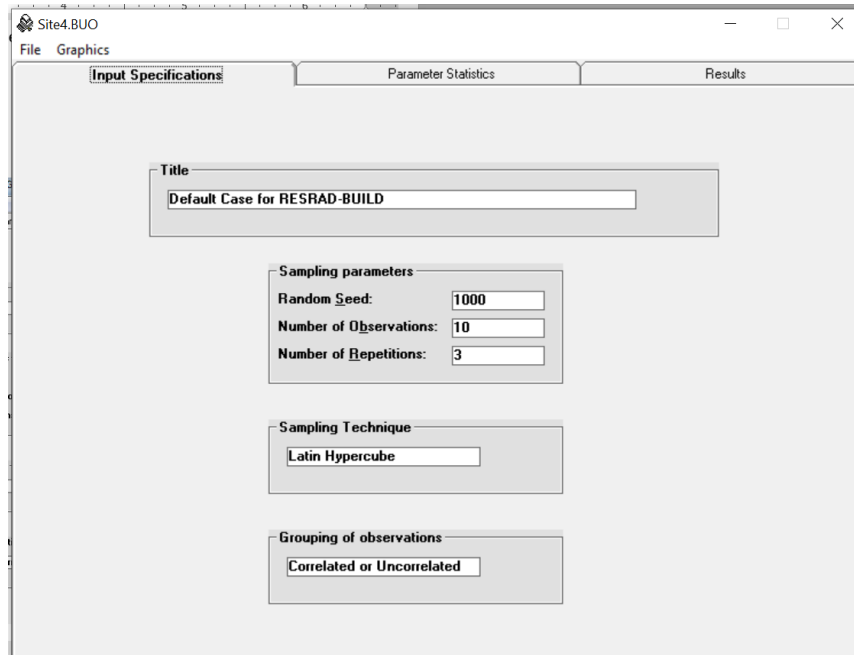
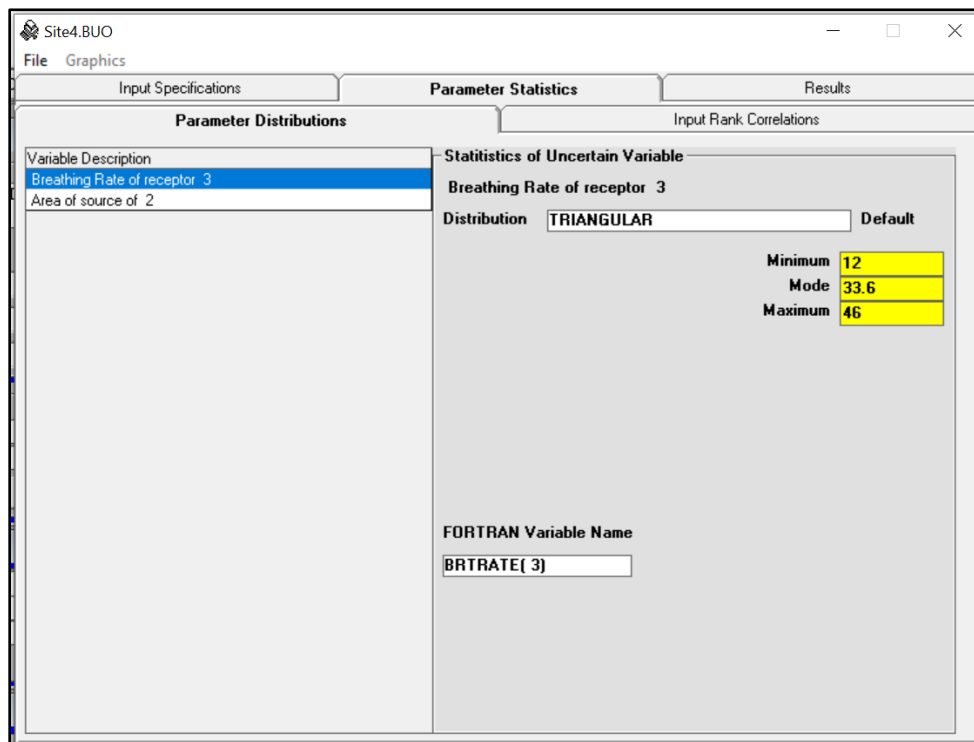**Figure 67 The Input Specification Screen Displayed by the Uncertainty Graphics Wizard**

Figure 68 The Parameter Distribution Screen Displayed by the Uncertainty Graphics Wizard
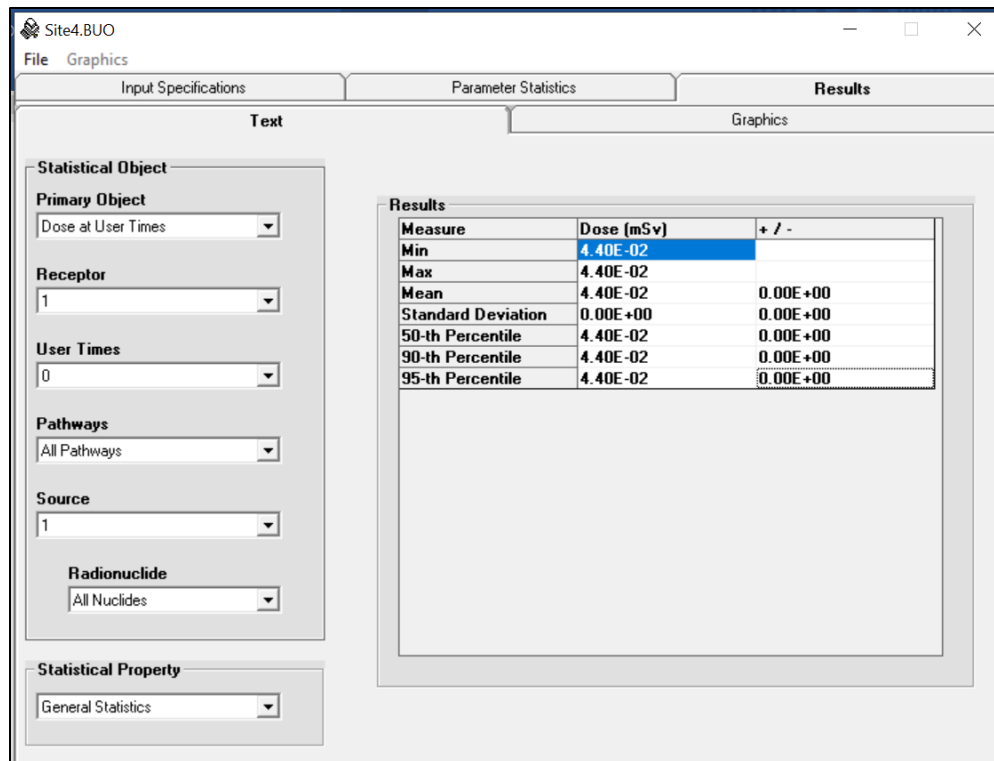
Figure 69 The Interactive Text Results Screen Displayed by the Uncertainty Graphics Wizard

To view results in the graphic form (Figure 70), choose the Graphics option under the Results tab. Two types of plots are available, cumulative distribution plots and scatter plots. Make a selection with the Plot Type input. A cumulative distribution plot shows the cumulative probability of a calculated dose at a specific user time (Dose at User Times as the primary object) or the cumulative probability of an input parameter (Input Vector as the primary object). When the former is selected, the attributes of the dose of interest—receptor, time, pathway, source, and nuclide—need to be specified with the Receptor, User Times, Pathways, Source, and Radionuclide object. A scatter plot can be selected to show the variation of a calculated dose at a specific user time (Dose at User Times as the primary object) versus the variation of an input parameter. Again, the attributes of the dose of interest—receptor, time, pathway, source, and nuclide—need to be specified with the Receptor, User Times, Pathways, Source, and Radionuclide object. The input parameter of interest can be specified with the Input Parameter object. This kind of scatter plot can be used in conjunction with the regression/correlation analysis to determine the correlation between input parameter(s) and dose results. Another type of scatter plot showing the pairings of two input parameters used in the probabilistic analysis also can be generated. In this case, Input Vector should be selected as the primary object, and the two input parameters of interest can be specified with the two Input Parameter objects.
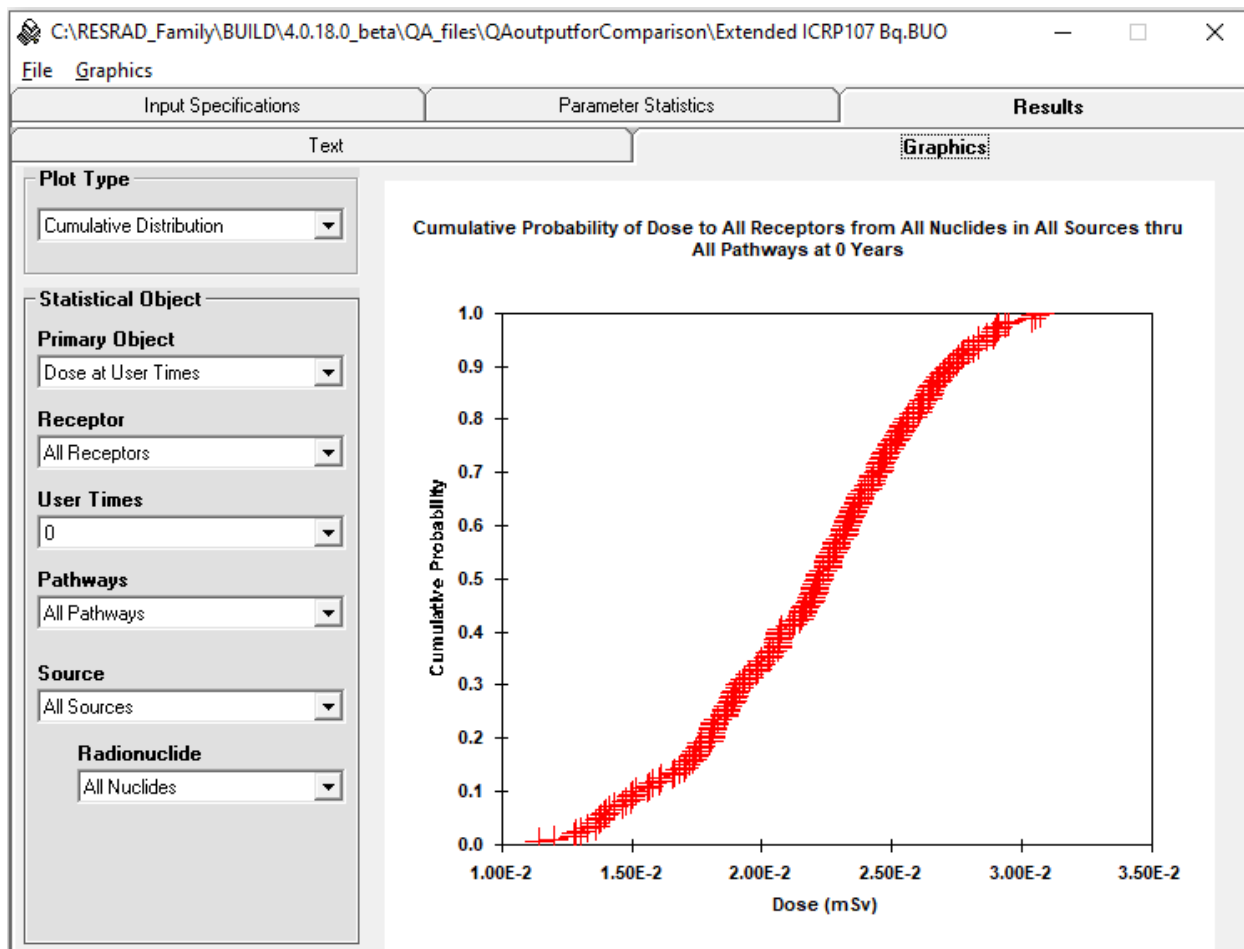
Figure 70 The Interactive Graphic Results Screen Displayed by the Uncertainty Graphics Wizard

7.2.5 Output Data File Generated by a Probabilistic Analysis

A complete set of output data generated by a probabilistic analysis is saved in a database and can be accessed by the user. This set of output data includes the input vectors, i.e., the different combinations of sampling values of the input parameters, and the detailed dose results obtained with each input vector during each repetition of the probabilistic calculations. This output database is saved with the same name as the input file but with a .BUO extension. For example, if the input file is siteA.bld, then this output database is saved as siteA.BUO. The user can access the output data with Microsoft Access that is installed in his computer. These output data permit the user to perform further analysis or graphing of his choice and allow the linking of an input vector to the dose results that it produced.

8   HELP

Various forms of help are available to the user to assist in the use of the RESRAD-BUILD code. They include (1) application help, accessible from the code, to provide descriptions of each input parameter and explain how the parameter is used in the dose modeling; (2) two message logs, saved in the files ResBMain.Sum and ResBMain.Err, which are generated during the execution of the computational modules and are useful for debugging in case the execution terminates before completion; (3) RESRAD website, https://resrad.evs.anl.gov, to allow download of the latest version of the code and access to related RESRAD documents such as the User's Manual and this User's Guide (the link to the website is also included in the About form of the code, which can be accessed by selecting the Help/About menu option); and (4) e-mail communication with the RESRAD team at resrad@anl.gov, to provide assistance to solve issues not covered by the other forms of help.

8.1   APPLICATION HELP

The RESRAD-BUILD Version 4.0 code provides general help and context-specific help accessible from the interface like the DCF Editor (see Section 5.3 for obtaining help information in the DCF Editor). To access the general help information, press the F2 function key on the keyboard or select the General Help menu option from the Menu Bar. To access the help information for a specific input selection or parameter, press the F1 function key or select the Context Help menu option from the Menu Bar while the selection/parameter is highlighted, i.e., the mouse cursor is in the selection circle/check box or input field of the parameter. The general help information and context-specific help information are displayed in the right panel of a Help window. The left panel of the Help window contains two tabs, Contents and Search, for use to locate a help topic of interest and to display the associated help information (see Section 5.3 for the use of these two tabs). Figure 71 shows part of the list of help topics included in RESRAD-BUILD. Figure 72 shows the search results in the Help window.

The entire RESRAD-BUILD User's Manual for Version 4.0 is also available for viewing, by choosing the Help/Manual menu option. To get additional information on a parameter of interest, including how to obtain site-specific values, refer to the RESRAD Data Collection Handbook (Yu et al. 2015), which can be accessed by selecting the Help/RESRAD Data Collection Handbook menu option.
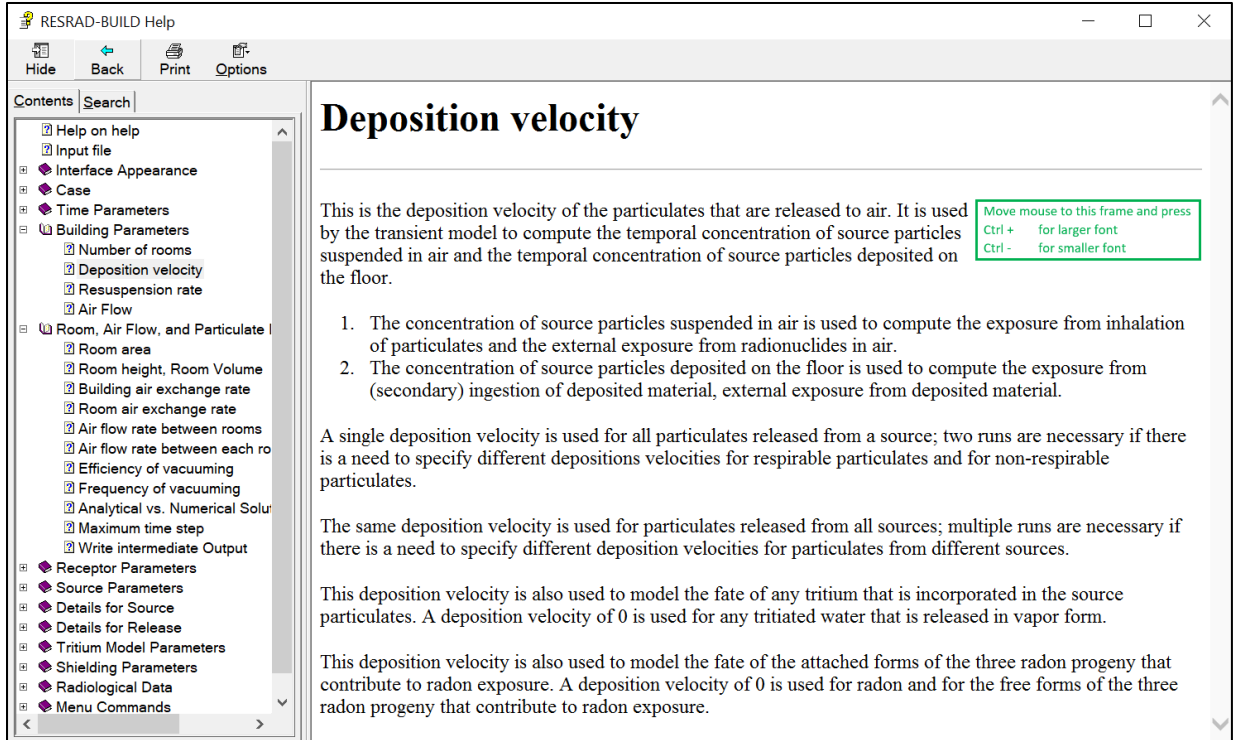
Figure 71 The RESRAD-BUILD Help Window Showing the List of Help Topics in the Left Panel and Help Information in the Right Panel
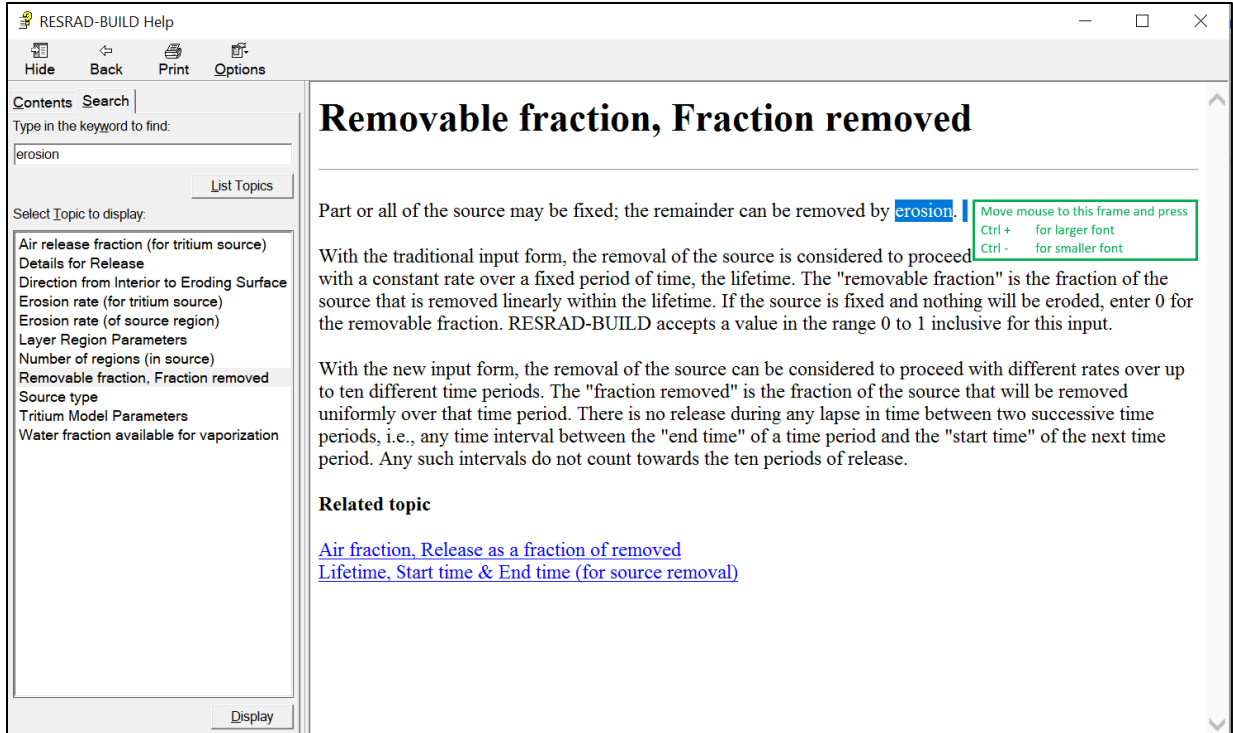
Figure 72 The RESRAD-BUILD Help Window Showing the Search Results in the Left Panel and Help Information in the Right Panel

8.2 MESSAGE LOG

The files RESBMAIN.SUM and RESBMAIN.ERR are generated during the execution of the calculation modules. They can be opened and viewed with a word processor program or Notepad, or, while the RESRAD-BUILD is in use, by choosing the View/Any File menu option and locating it in the root directory of RESRAD-BUILD. This file contains calculation execution information that normally can be disregarded. However, if there are any issues with the calculations, the information contained in this file can help diagnose the cause and solve the issues (Figure 73).

Figure 73 Message Log after a Successful RESRAD-BUILD Run

8.3 RESRAD WEBSITE

Type the RESRAD website address, https://resrad.evs.anl.gov, in the Internet browser to get to the home page of the RESRAD family of codes (Figure 74). The link to download the RESRAD family of codes, including RESRAD-BUILD, and to access the RESRAD documents can be found on the home page via the DOWNLOAD and DOCUMENTS option, respectively, at the top of the page. In addition to related documents, the user may find the answers to the frequently asked questions helpful, which can be accessed via the FAQs option. The following are available on the RESRAD website:

- General descriptions of each of the RESRAD family of codes.

- Current released versions of the maintained codes (RESRAD-ONSITE, RESRAD-OFFSITE, RESRAD-BUILD, RESRAD-RDD, and RESRAD-BIOTA).

- Version history of the maintained codes.

- General and code-specific documents (see Figure 75).

- Information on upcoming training workshops.

- Frequently asked questions and answers.

- RESRAD team and contact information for each team member.

- Subscription to e-mail services to receive news on updates and related information about the RESRAD program.

Figure 74 Home Page of the RESRAD Family of Codes

Figure 75 RESRAD-BUILD Documents Available at the RESRAD Website

9 REFERENCES

DOE (U.S. Department of Energy), 2011, *DOE Standard: Derived Concentration Technical Standard*, DOE-STD-1196-2011, Washington, DC, April.

Eckerman, K.F., et al. 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, EPA-520/1-88-020, Federal Guidance Report No. 11, prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, DC.

Eckerman, K.F., and J.C. Ryman, 1993, *External Exposure to Radionuclides in Air, Water, and Soil, Exposure to Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*, EPA 402-R-93-076, Federal Guidance Report No. 12, prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.

Eckerman, K.F., et al., 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, EPA-402-R-99-001, Federal Guidance Report No. 13, prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, DC.

ICRP, 1983, *Radionuclide Transformations: Energy and Intensity of Emissions*, ICRP Publication 38, Annals of the ICRP, Vols. 11−13, Pergamon Press, New York, NY.

ICRP, 1991, *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60, Annals of the ICRP, 21(1-3), Pergamon Press, New York, NY.

ICRP, 1996, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5—Compilation of Ingestion and Inhalation Dose Coefficients*, ICRP Publication 72, Annals of the ICRP, Vol. 26(1), Pergamon Press, New York, NY.

ICRP, 2008, *Nuclear Decay Data for Dosimetric Calculations,* ICRP Publication 107, Pergamon Press, New York, NY.

Iman, R.L., and M.J. Shortencarier, 1984, *A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models*, NUREG/CR3624, SAND83-2365 RG, prepared by Sandia National Laboratories, Albuquerque, NM, for U.S. Nuclear Regulatory Commission, Washington, DC, March.

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

Kamboj, S., C. Yu, D.J. LePoire, 1998, *External Exposure Model Used in the RESRAD Code for Various Geometries of Contaminated Soil*, ANL/EAD/TM-84, Argonne National Laboratory, Argonne, IL, September.

Yu, C., et al., 2003, *User's Manual for RESRAD-BUILD Version 3*, ANL/EAD/03-1, Argonne National Laboratory, Argonne, IL, June.

Yu, C., S. Kamboj, C. Wang, J.J. Cheng, 2015, *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil and Building Structures*, ANL/EVS/TM-14/4, Argonne National Laboratory, Lemont, IL, September.

Yu, C., et al., 2022, *User's Manual for RESRAD-BUILD Code Version 4, Vol. 1—Methodology and Models Used in RESRAD-BUILD Code*, ANL/EVS-21/17 Vol. 1, Argonne National Laboratory, Lemont, IL, Dec.

Environmental Science Division

Argonne National Laboratory
9700 South Cass Avenue, Bldg. 240
Lemont, IL 60439-4832

www.anl.gov