RASCAL 4.3 User's Guide (Draft)

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Abstract

RASCAL 4.3 contains a number of new features and revision of several old features in response to the lessons learned by the U.S. Nuclear Regulatory Commission staff during its response to the events at the Fukushima Dai-ichi nuclear power plants following the March 11, 2011 earthquake off the coast of Japan and the tsunami that it triggered. This document is a user's guide to the updated version of the RASCAL STDose module and to several new RASCAL tools.   To a large extent, this document is a compilation of the RASCAL help text for the STDose module, and new tools. The help text for STDose has undergone extensive revision for RASCAL 4.3 and much more comprehensive.

The document also includes summaries of information on exposure guidelines prepared by other agencies and health effects of exposure to radiation and uranium, uranium hexafluoride, and hydrogen fluoride. These additional topics are presented here to provide context for evaluating the environmental consequences (doses and chemical exposures) calculated by RASCAL. RASCAL does not calculate health effects.

Contents

Introduction

RASCAL 4.3 contains a number of new features and revision of several old features in response to the lessons learned by the U.S. Nuclear Regulatory Commission staff during its response to the events at the Fukushima Dai-ichi nuclear power plants following the March 11, 2011 earthquake off the coast of Japan and the tsunami that it triggered. This document is a user's guide to the updated version of the RASCAL STDose module and to several new RASCAL tools. To a large extent, this document is a compilation of the RASCAL help text for the STDose module and new tools. The help text for STDose has undergone extensive revision for RASCAL 4.3 and is much more comprehensive. This document may be read piece by piece because this document is primarily a compilation of help text. If it is read end to end, the reader will find a good deal of repetition.

The document also includes summaries of information on exposure guidelines prepared by other agencies and health effects of exposure to radiation and uranium, uranium hexafluoride, and hydrogen fluoride. These additional topics are presented here to provide context for evaluating the environmental consequences (doses and chemical exposures) calculated by RASCAL. RASCAL does not calculate health effects.

This User's Guide is one of a set of documents that describe RASCAL. *RASCAL 4: Description of Models and Methods* (NUREG-1940) (referred to as the RASCAL technical document) which presents the technical bases for the RASCAL computation codes describes RASCAL 4.2. *RASCAL 4.3 Technical Supplement* describes the changes from RASCAL 4.2 to RASCAL 4.3 and provides the technical bases for those changes. The *RASCAL 4.3 Workbook* provides a systematic approach to learning how to use RASCAL through a set of problems.

The RASCAL workbooks have been living documents; they have been updated from time-to-time based on comments from RASCAL users and experiences gained in training classes. It is expected that the RASCAL User's Guide will also be a living document. This initial version addresses the STDose module and the new tools in the RASCAL tool box. It does not address several of the old tools including the FMDose module and the Radionuclide Data Viewer. Guides to these tools will be added as the RASCAL User's Guide is updated.

There are eight chapters in the User's Guide. The first chapter contains a general description of RASCAL and the STDose module in RASCAL 4.3. The second chapter covers the STDose user interface; the STDose result types are discussed in the third chapter. There are extensive references to the RASCAL technical document and *RASCAL 4.3 Technical Supplement* throughout these chapters. Chapters 4 and 5 deal with new RASCAL tools. Chapter 4 provides guidance related to the creation of a reactor-specific base file that is used to build custom nuclide inventories for reactor cores and spent fuel. Chapter 5 provides guidance related to use of the Source Term Merge / Export Utility code. Chapter 6 provides guidance related to the use of the MetFetch utility tool that is used to download meteorological data from the internet. Finally, Chapters 7 and 8 provide information that may be used to put the results of RASCAL calculations in context. Chapter 7 discusses exposure guidelines provided by other agencies, and Chapter 8 describes health effects of exposure to radiation and to uranium and hydrogen fluoride. Both Chapters 7 and 8 contain links to internet site where additional information may be obtained.

1 General Information

This is the User's Guide for RASCAL 4.3. Specifically, it covers the STDose module in RASCAL 4.3 and two new tools included as part of RASCAL 4.3. The following three documents provide more detailed information about RASCAL, the models it includes, and the results it produces: *RASCAL 4: Description of Models and Methods, RASCAL 4.3 Technical Supplement,* and *RASCAL 4.3 Workbook.* These documents are available as PDF downloads or upon request from the NRC. *RASCAL 4: Description of Models and Methods* is referred to as the RASCAL Technical Document. Pertinent sections of the RASCAL Technical Document and Technical Supplement are referenced throughout the help as appropriate.

1.1 RASCAL

The Radiological Assessment System for Consequence Analysis (RASCAL) has been developed for the U.S. Nuclear Regulatory Commission. It is designed to be used in the independent assessment of dose projections during response to radiological emergencies. RASCAL will be used by response personnel to conduct an independent evaluation of dose and consequence projections and for training and drills. It allows consideration of the dominant aspects of source term, transport, dose, and consequences and supplements assessments based on plant and environmental conditions.

RASCAL 4.3 consists of seven tools. Four tools are designed for use in consequence assessments. These tools include: Source Term to Dose (STDose), Field Measurement to Dose (FMDose), Radionuclide Data Viewer, and Decay Calculator.   STDose and FMDose are the primary tools used to estimate doses. The Radionuclide Data Viewer provides users with direct access to the RASCAL radionuclide database which contains information on decay and dose conversion factors. The Decay Calculator is a legacy code that provides users estimates of the activities in the decay chain of a parent radionuclide at some time given the activity of the parent at time zero.

The three remaining tools provide flexibility in use of RASCAL 4.3. The Create Inventory Base File permits users to use reactor core and coolant inventories in consequence assessments that are based on the operation of a specific reactor instead of default end-of-cycle inventories by creating a file that contains the relevant reactor operation details (Technical Supplement, Chapter 4).   The Source Term Merge/Export tool provides users with a method of dealing with simultaneous accidents at more than one facility on a site.   It may also be used to export a RASCAL 4.3 source term for use by other organizations (See the RASCAL 4.3 Technical Supplement). Finally, the Configure Met Downloads tool is used to set up automatic acquisition of meteorological observations and forecasts from the internet for use in STDose (Technical Supplement, Chapter 3).

1.2 RASCAL Models

RASCAL uses a variety of models to estimate the consequences of a nuclide or UF_6 release. The first set of models estimates the amount of activity released to the environment as a function of time. The second set of models distributes the activity in the environment, and the third set of model calculates the consequences of the activity in the environment. The models used in RASCAL are described in detail in the RASCAL Technical Document and the Technical Supplement.

1.2.1 Source Term / Release Path Models

The first set of models that one encounters when running RASCAL are the source term release path models. These models determine what nuclides and how much activity of each nuclide is available for

release to the environment. They also determine how the activity gets from the source to the environment and how much activity is actually released as a function of time. Separate models are used for reactor accidents, spent fuel accidents, and fuel cycle facility accidents. RASCAL Technical Document Chapter 1 and Technical Supplement Chapters 1 and 4 describe the source term /release path models used for reactor accidents. RASCAL Technical Document Chapter 2 describes the source term/release path models used for spent fuel accidents, and Technical Document Chapter 5 describes the source term/release path models used for fuel cycle (UF_6) facilities.

Reactors Models RASCAL depicts reactors as simple boxes connected by transfer paths. The initial box is the reactor vessel and the final box is the environment. The number of intermediate boxes and the paths depend on the reactor type as do the processes that occur in the boxes and along the paths. In general, nuclide decay and daughter ingrowth may occur in any box. A reactor type (e.g. PWR or BWR) is a specific set of boxes and paths. RASCAL knows the following reactor types: PWR (U-Tube), PWR (Once Through), BWR, and VVER.

Fuel Cycle Facility Models RASCAL has source term models for a variety of accidents that might occur in fuel cycle facilities. These models include a dense gas model for UF_6 releases, models for releases from fires and explosions involving uranium oxide, and a model for releases from a criticality accident.

Other Models   Reactors and Fuel Cycle Facilities are not the only facilities that could have an accident involving a release of radiological material. RASCAL provides three options for specifying source terms for other facilities:

- Effluent Release Rates – by Nuclide
- Effluent Release Concentrations – by Nuclide
- Sources and Materials in a Fire.

The first two options are similar. In the first option, the nuclide release rate (e.g., Ci/s) is specified for each nuclide being release. In the second, the nuclide concentration (e.g., Ci/m^3) and flow (e.g., m^3/s) are specified for each nuclide. In the third option, the activity at risk (e.g., Ci) along with an airborne release fraction and a respirable fraction is specified for each nuclide.

1.2.2 Atmospheric Transport, Dispersion, and Deposition

RASCAL uses a variety of models in its atmospheric calculations. There is a meteorological model that prepares the meteorological data files used by RASCAL. RASCAL Technical Document Chapter 6 describes this model. There are two straight-line Gaussian plume models that are described in RASCAL Technical Document Chapters 4 and 5. And, there is a Gaussian puff model described in RASCAL Technical Document Chapter 4. Within each of the main models there are many individual process models. The RASCAL Technical Document sections cited above also describe these process models.

Meteorological Models RASCAL uses time-dependent meteorological data in its atmospheric transport dispersion, and deposition calculations. The data may be from real observations and forecasts, or they may be made up for use in an exercise or for training. RASCAL includes a meteorological data processing model that converts meteorological data from the form in which it is entered to a form required by the atmospheric transport and dispersion models. RASCAL Technical Document Chapter 6 and Technical Supplement Chapter 3 describe Meteorological data entry and processing in RASCAL.

Near Field (Gaussian Plume/Polar Grid) RASCAL uses a straight-line Gaussian plume model for near field atmospheric transport, dispersion, and deposition calculations. The model includes decay and ingrowth of nuclides, but does not otherwise take transit time into account. The release point is assumed to be at the center of a polar grid and calculations are made at 288 locations in the grid (36 directions x 8

radii). The near field domain radii are keyed to the size of the far field domain, but may be adjusted by the user. The model is described in detail in Chapter 4 of the RASCAL Technical Document.

A modified version of the Gaussian plume model is used for transport and dispersion calculations for UF_6 releases. The modified model considers both the buoyancy of the plume due to the heat generated by its reaction with water vapor and slumping of the plume caused by its high density. The model is described in detail in Chapter 5 of the RASCAL Technical Document. If UF_6 is released within a building, the UF_6 is assumed to react with water vapor within the building and the release to the environment is assumed to consist of only HF and UO_2F_2. In this instance, RASCAL does not do thermodynamic calculations and the transport and dispersion calculations do not include plume rise.

Far Field (Gaussian Puff/Cartesian Grid) RASCAL uses a Lagrangian Gaussian puff model for far field atmospheric transport, dispersion, deposition calculations.   The Gaussian puff model is fully time dependent. It treats the decay and ingrowth of nuclides, and the transport, dispersion, and deposition of activity in a puff may vary in time and space as the puff moves the model domain.   Users have the choice of four model domain sizes ranging from 20 miles on a side to 200 miles on a side. In each case, the release point is assumed to be at the center of the domain.   Calculations are made at 1681 nodes uniformly spaced on a Cartesian grid (41 x 41). This model is described in detail in Chapter 4 of the RASCAL Technical Document and in Section 2.1 of the Technical Supplement.

1.2.3 Dose Models

RASCAL calculates doses for three exposure pathways: submersion, inhalation, and groundshine.   It does not calculate ingestion pathway doses. However, it does estimate the relative importance of nuclides released to the environment to the ingestion pathway doses. RASCAL Technical Document Section 4.9 and Technical Supplement Sections 2.2 and 2.3 discuss early phase dose calculations. Technical Document Section 7.2.1 discusses intermediate phase dose calculations, and Technical Supplement Chapter 6 discusses importance.

Submersion   RASCAL calculates external doses from reactor and spent fuel accident plumes using both finite plume and semi-infinite plume models. Near the source where plume dimensions are small compared to the mean free path of gamma rays in air, RASCAL uses a finite plume model that accounts for the spatial variation in activity in the air. When the plume dimensions become large compared to the mean gamma path, RASCAL uses a semi-infinite model that assumes that the activity concentration is uniform in space. RASCAL Technical Document Sections 4.9.3.1 and 4.9.3.2 describe the RASCAL cloudshine dose calculations.

Inhalation   RASCAL calculates inhalation doses from time-varying airborne activity concentrations at a point. Specifically, it calculates adult inhalation CEDE, thyroid CDE, and acute bone marrow, lung, and colon doses. It also calculates a child (1 yr) thyroid dose from iodines if the ICRP-60 inhalation dose conversion factors have been selected.

During the early phase of an accident, the inhalation doses are from activity inhaled during plume passage. During the intermediate phase, the inhalation doses are from deposited activity that has been resuspended. Early phase inhalation doses are generally several orders of magnitude larger than intermediate phase inhalation doses. RASCAL Technical Document Section 4.9.1 describes the early phase inhalation dose calculations; Section 7.2.1.2 describes the intermediate phase dose calculation.

Groundshine RASCAL calculates groundshine doses from nuclide activity deposited on the ground. The activity is corrected for decay and ingrowth from the time of deposition. It is also corrected for

surface roughness. RASCAL Technical Document Section 4.5 discusses the deposition of nuclides. Section 4.9.2 discusses the calculation of early-phase groundshine doses.

RASCAL Technical Document Section 7.2.1.1 discusses the calculation of intermediate phase groundshine doses. This calculation is similar to the calculation of early phase groundshine doses with the addition of a factor that accounts for the long-term weathering of activity.

Ingestion   RASCAL only deals with ingestion doses in the context of determining the relative importance to ingestion dose of nuclides released to the environment. RASCAL Technical Document Section 6.1 describes the importance model, and Technical Supplement Section 2.3 discusses the dose conversion factors used in the ingestion importance calculation.

1.3 Getting Started

This is a brief introduction to using the RASCAL Source Term to Dose model. It outlines the steps in setting up a modeling run, performing the calculations, and examining the results. The following three documents provide more detailed information: RASCAL 4.3 Workbook, RASCAL 4: Description of Models and Methods (NUREG-1940), and RASCAL 4.3 Technical Supplement. These documents are available as PDF downloads or upon request from the NRC. RASCAL 4: Description of Models and Methods is referred to as the RASCAL Technical Document, and RASCAL 4.3 Technical Supplement is referred to as the Technical Supplement. Pertinent sections of the RASCAL Technical Document and Technical Supplement are referenced throughout the help as appropriate. A complete, step-by-step walk-through is provided in the first section of the RASCAL Workbook.

1.3.1 Starting the Model

RASCAL can be started from the Windows Start menu. Select Start > Programs > RASCAL. This will start the main access program which provides a common starting point to all the component tools. Start the model by clicking on the Source Term to Dose button.

When the user interface is first started, no information is available for a modeling run. The buttons along the left-hand side of the main screen are used to control the program. In general you will work from the top button to the bottom button. A set of three tabs in the middle of the screen display information. Note that initially only the Event Type button is active. As you progress with the problem definition, other buttons will become available. As a step is completed the button will display a checkmark. Also, as you progress through the problem definition the Case Summary tab will be updated to reflect your entries.

1.3.2 Defining and Running a Problem

Following are the basic steps in the order that you would follow to enter data, calculates doses, view results, and save the work. The bold headings correspond to the main screen buttons.

Event Type   Select the type of event to be modeled. This selection will limit the types of facilities and releases that can be modeled.

Event Location   Pick a location from the list of sites in the facility database or define your own site.

Source Term   Select a source term type and then proceed to define the source term characteristics. (See RASCAL Technical Document Section 1.2)

Release Path Select a release pathway type and then proceed to define the release characteristics. (See RASCAL Technical Document Sections 1.3 through 1.6)

Meteorology Select the meteorological dataset to be used for the calculations. A number of test datasets have been provided in the Predefined Data (Non Site-Specific) area. These can be used for any location at any time. For more site and/or time specific data you will need to create new datasets of actual observations and forecasts. (See RASCAL Technical Document Chapter 6)

Calculate Doses Calculations are started from this screen. Set the desired calculation distance, the building wake correction On or Off, the end date and time for the simulation, and enter a case description. (See RASCAL Technical Document Chapter 4)

Detailed Results Some results are viewable from the main screen tabs. Specifically, the maximum dose values and the computed source term summary are viewed by clicking the appropriate tab. More detailed source term details are available from the Details button on the source term tab. More detailed dose results are available from the View Results button. This will display a menu of all dose types and formats for viewing. Select a type and format and click the View button.

Save Case A modeling run can be saved as a single file (extension .STD)for later recall. Either click the Save button in the bottom-left corner of the main screen or use the File menu. The default file name will be the description entered on the calculations screen. The file name and the saving location can be changed.

1.4 Support
Support for RASCAL is provided by the U.S. NRC.

1.4.1 Contacts
Please direct any questions, suggestions, or problem reports concerning this software to:
RASCAL_Help@nrc.gov

1.4.2 Reporting Problems
While every effort has been made to make RASCAL trouble-free, there may be unanticipated circumstances that lead to problems. To report a problem with the program, first collect as much information about the problem as possible. This may include answers to the following questions:
- What version of the program are you running? This information can be found on the screen displayed at startup or by using the Help | About menu item.
- What computer operating system is in use?
- Is the problem reproducible?
- What are the steps leading up to the problem?
- What are the exact symptoms? program crash, error message, etc.

Report the problem via e-mail to the address shown above.

2 STDose User Interface

The RASCAL User Interface is designed to guide users through the process of setting up problem and running RASCAL in an easy to follow, step-by-step manner. The initial screen provides users with the list of tools that are available in RASCAL. The tool that is likely to be used most frequently is *Source Term to Dose (STDose)*. It leads users from identification of the site where the problem occurs through definition of the problem, estimation of the activity released to the environment, and evaluation of the potential dose consequences of the activity released.   This is the Help for STDose.
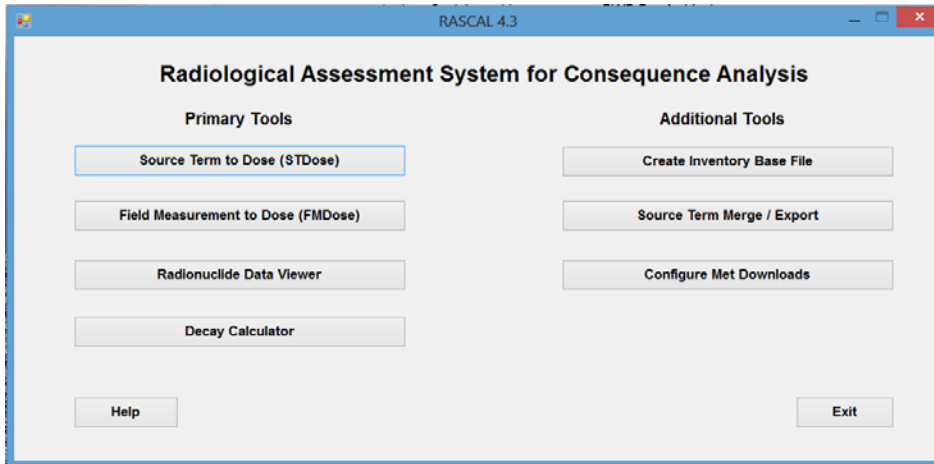
When the STDose option is selected from among the RASCAL Tools, the main STDose screen is displayed. This screen guides users through the process of entering the data and running RASCAL.
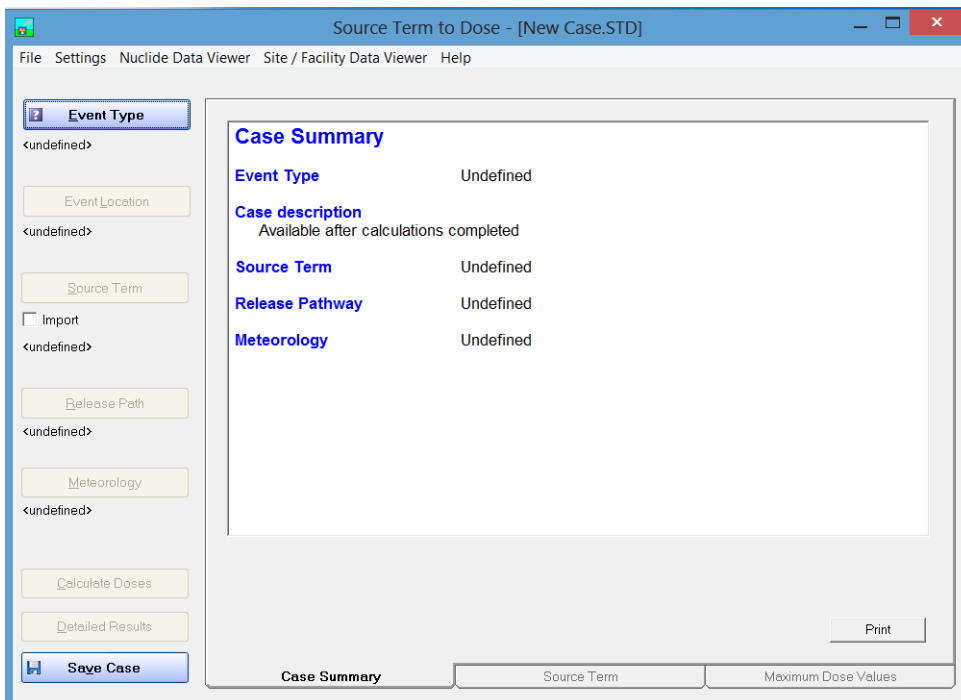
There is a column of eight buttons on the left side of the initial STDose screen. Starting at the top, the first five buttons provide a logical sequence for entering the data needed to run RASCAL. All of the

buttons, except the *Event Type* button, are greyed out at the beginning of a new case. The buttons are activated as soon as the option becomes available as data are entered. A green check mark appears on each button as input is completed. The sixth button is initially grayed out. When all of the required information is complete, it is activated. Click on the button to enter the remaining information needed to run RASCAL and start the calculations. The *Detailed Results* button provides access to the detailed RASCAL output including the dose footprints as a function of time, dose plots as a function of time, surface contamination estimates, etc. The bottom button is used to save the input and output files associated with the RASCAL model run.

The box on the right of the button has three tabs along the bottom. The only tab active during data entry is the *Case Summary* tab. While it is active, the box displays a summary of the data, as they are entered. After the RASCAL has been run, the *Maximum Dose Values* tab will be active. When it is active, the displays the initial results of the RASCAL calculations. The third tab below the box is the *Source Term* tab. When the tab is activated, information about the source term is displayed.

2.1 Event Type

The *Event Type* button activates the *Event Type Selection* screen. This screen provides users with an option to select one of four event types known to RASCAL. These event types are

- Nuclear Power Plant
- Spent Fuel
- Fuel Cycle / UF6 / Criticality
- Other Radioactive Materials Releases.

The *Event Type* option controls the screens and options presented to the user in *Source Term* and *Release Path* data entry.
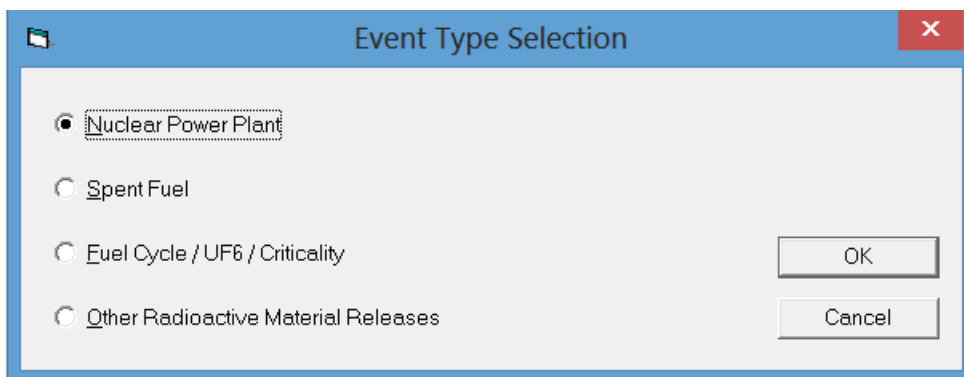
2.1.1 Nuclear Power Plant

The *Nuclear Power Plant* event type can be used most radiological releases from nuclear power plants except releases from spent fuel accidents. The RASCAL database includes information for all nuclear power plants in the United States and the Laguna Verde power plant in Mexico. A generic power plant site may be defined if the accident does not occur at an existing reactor site.

2.1.2 Spent Fuel

The *Spent Fuel* event type is used for radiological releases involving spent fuel. The accident is assumed to occur at a reactor site. A generic power plant site may be defined if the accident does not occur at an existing reactor site.

2.1.3 Fuel Cycle / UF6 Releases / Criticality

The *Fuel Cycle / UF6 Releases / Criticality* event type is used for releases from fuel cycle facilities. The RASCAL database includes information for fuel cycle facilities in the United States. A generic fuel cycle facility site may be defined if the accident does not occur at a site in the database.

2.1.4 Other Radiological Material Release

The *Other Radioactive Material Release* event type is used for radiological releases at locations other than nuclear power plants and fuel cycle facilities. The RASCAL database includes information for a number of these facilities in the United States. A generic site may be defined if the accident does not occur at a site in the database.

2.2 Nuclear Power Plant

The most frequently used RASCAL Event Type is the *Nuclear Power Plant*. The *Nuclear Power Plant* event is used for nuclear power plant accidents including Long-Term Station Blackout Accidents, Loss-of-Coolant Accidents, and various Coolant Release Accidents. RASCAL 4.3 has a facility database that lists features of all nuclear power plant in the United States. When the Nuclear Power Plant event type is selected, RASCAL 4.3 will obtain available information from this database for use in setting default values.

2.2.1 Event Location

The *Event Location* button activates the event location screen. The *Event Location* screen has two options: 1) load an event location from the RASCAL database, or 2) define a generic site.   If option 1 is selected, the site must be selected from the dropdown list in the box.   Pertinent characteristics of the selected site are displayed below the site list. If option 2 is selected, a data entry screen will appear for use in entering the requisite site data.
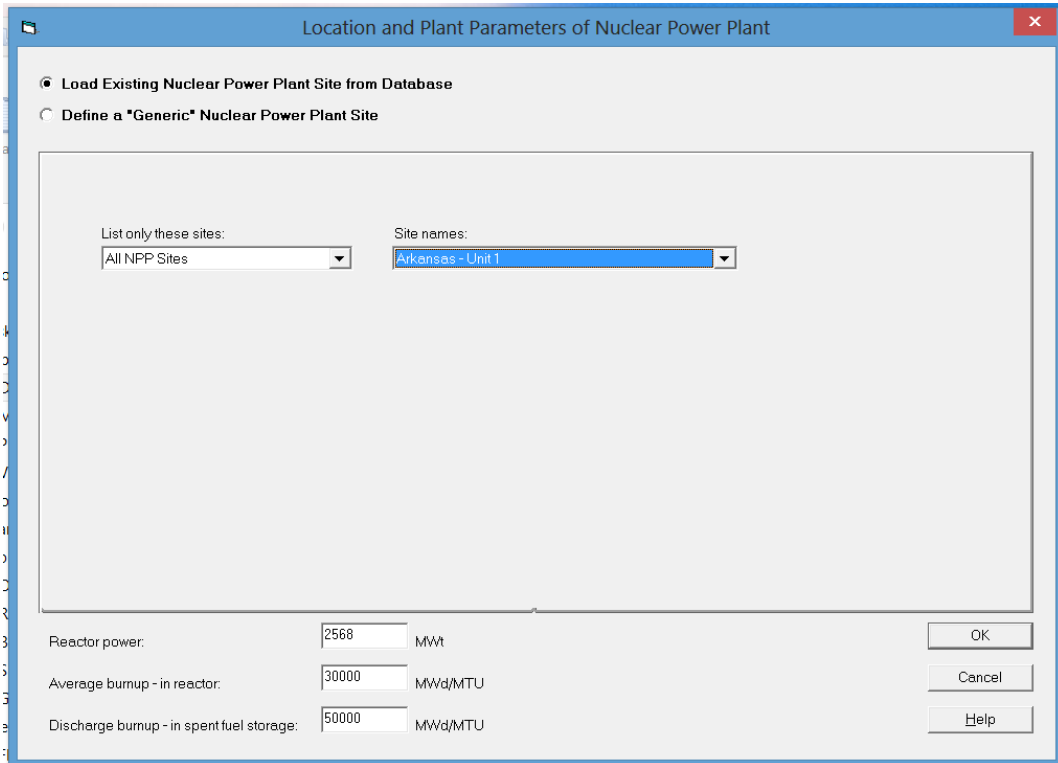
There are two options for defining the location of the power plant:
- the location information can be loaded from the facility database
- a generic nuclear power plant site can be defined.

RASCAL 4.3 includes a database with information on all operating nuclear reactors in the United States and the Laguna Verde Reactors in Mexico. Site information for any of these reactors will be <u>loaded automatically</u> when the reactor name is selected from the dropdown list of site names. The number of sites in the list can be reduced by picking one of the filters in the "list only" drop-down. Selecting a site name will update the plant parameters section at the bottom of the screen.

 If the option to define a "Generic" site is selected, RASCAL displays a site data entry form. Most of the information to be entered in the form is descriptive only and does not influence the calculations. However, the information entered will appear in the case summary and is very useful in labeling the model runs.

When a reactor *Type* is selected, information on reactor parameters is pulled from the facility database. Some of it may need to be revised to reflect the actual status of the reactor at the time of the event (see the discussion of Reactor Parameters).

Latitude and *Longitude* are required information and are entered as decimal degrees (e.g. 35.5056 rather than 35 deg 30 min 20 sec). Use negative numbers for west longitudes and south latitudes. The latitude and longitude are important because they establish the location of center of the computational grids. All meteorological station positions in the model domain are determined using the longitude and latitude of the center of the grid. Longitude and latitude are also used in estimating stability class. If RASCAL is

being run with meteorological data from a single station approximate values for longitude and latitude are adequate.

Time Zone can be selected by name if in the United States or specified as an offset from Greenwich for all other time zones. The *Time Zone* is used to determine sunrise and sunset times, which are used when stability class is estimated from meteorological data rather than being entered directly. The sunrise and sunset times are also used in determining if entered stability information is reasonable.

2.2.2 Reactor Source Term
When the STDose module of RASCAL is started, the initial screen that appears guides users through the steps of setting up the input needed to run RASCAL. The steps are listed on the buttons on the left side of the screen. The first two steps define the event type and event location.   The third step is to define the source term (e.g., release rate from the reactor core).   When the *Source Term* button is clicked, a screen appears that lists source term options.   After an option is selected, a second screen appears that allows users to provide details about the event. There is also an option to import a source term generated external to RASCAL. If this option is selected, the next screen requests name of the file containing the source term data.

RASCAL provides users with several methods for estimating nuclear power plant source terms.   There are four methods that are defined accident sequences and five methods that are based on sample or monitoring data. The defined accident sequences are: *Long Term Station Blackout (SOARCA)* accident, large break *Loss-of-Coolant Accident (LOCA)*, *Coolant Release Accidents*, and *Containment Radiation Monitor*. The methods of estimating or defining the source term are: *Coolant Sample*, *Containment Air Sample*, *Effluent Release – by Mixtures*, *Effluent Release Rates – by Nuclide,* and *Effluent Release Concentrations – by Nuclide*.
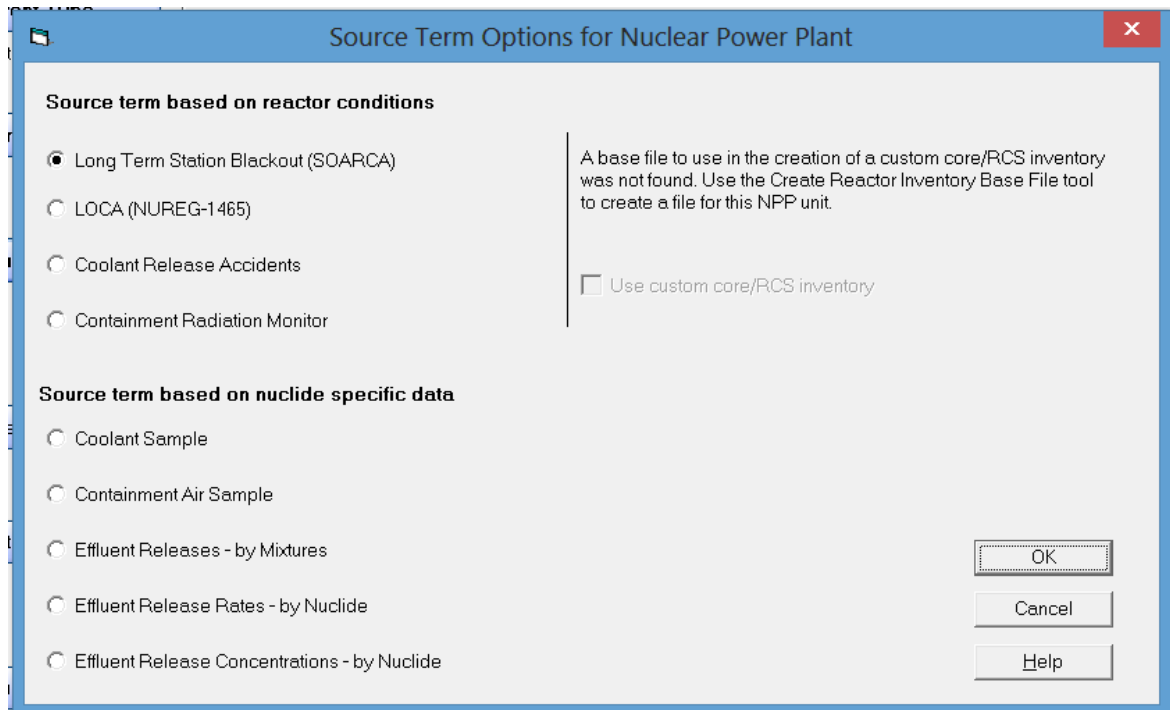
There is an option to *Use custom core /RCS inventory* for estimating source terms based on reactor conditions. If this option is not selected, RASCAL uses default core and RCS inventories described in

Sections 1.1.1 and 1.1.2, respectively, of the RASCAL Technical Document. If the option is selected, RASCAL calculates inventories based on site-specific reactor operations as described in Chapter 4 of the Technical Supplement.   A site specific base file containing reactor operational data must be created before the custom fuel option can be used. The Create Inventory Base File tool accessible from the main RASCAL menu may be used to create this file.

2.2.2.1 Long-Term Station Blackout (LTSBO)

RASCAL has two sequences for estimating releases from core-melt accidents. The first is the LTSBO accident and the other is the LOCA accident. Of the two sequences, the LTSBO sequence is a slowly developing sequence, in which the reactor coolant is gradually as decay heat evaporates the coolant. Core temperature does not start increasing until after the coolant evaporates. The LOCA sequence assumes a rapid loss of coolant through a large break in cooling system line and a rapid increase in core temperature.

The RASCAL LTSBO source term is based on the accident sequences modeled by MELCOR and reported in NUREG-1935. Specifics of the nuclide release rates were extracted from data files supplied by Sandia National Laboratory. The RASCAL LTSBO source term model is described in detail in Technical Supplement Section 1.1. In this model releases to the containment and environment typically begin 10 to 12 hours after the loss of station power. Reactor vessel release duration for an LTSBO is typically about 6 hours.

The LTSBO data entry form is used to input data for this event. RASCAL requires information to determine the date and time of the start of the release to the containment. The start of release to the

environment is calculated from the date and time of the *Reactor Shutdown*, the delay between shutdown and loss of cooling, and the delay between loss of cooling and the onset of core damage. The delay between shutdown and loss of cooling is a function of whether emergency cooling is available and operating or not. If emergency cooling is not available, this delay is zero. If the emergency cooling system is available, the *Expected duration of cooling* is a function of the expected battery life. RASCAL assumes a default battery life of 4 hours.   Longer battery life is possible. RASCAL assumes a delay of 6 hours between loss of cooling and core damage for BWRs and a delay of 8 hours for PWRs. The LTSBO data entry screen shows the date and time that the release to the containment will begin.

RASCAL provides two options for the end of the release from the reactor. If the *Core recovered* option is selected. The release from the reactor will continue until the core is recovered or until the end of the RASCAL calculations.   If the *Specified damage amount* option is selected, the release from the core will occur until the specified damage endpoint is reached. RASCAL 4.3 Technical Supplement Section 1.2 discusses the core damage state option.

2.2.2.2 Loss-of-Coolant Accident (LOCA)

The RASCAL *LOCA* source term sequences are based on the accident sequences described in NUREG-1465. The reactor core temperature begins to increase immediately following the occurrence of the initiating event. Releases from the reactor vessel follow the timing set forth in Table 3.6 of NUREG-1465. Reactor vessel release durations for a LOCA are typically 4 to 5 hours.

The amount of fission products released from the core is estimated based on the amount of time the core is uncovered (if at all) as shown below:

Core condition / release	BWR time since core uncovered (hours)	PWR time since core uncovered (hours)
Start of gap release	0.0	0.0
100% gap release; start of melt release	0.5	0.5
100% melt release; start of vessel melt through	2.0	1.8
100% vessel melt through	5.0	3.8

Radioactive decay is only calculated when the reactor is shutdown. Core damage begins when the core is uncovered. The core damage state is dependent on the amount of time that the core has been uncovered. If the core is recovered, core damage stops, and the core damage state remains the same. See RASCAL Technical Document Section 1.2.2.

Users of the time-core-is-uncovered source term option should understand that RASCAL is likely to overestimate the speed and magnitude of the release and thus also overestimate the projected radiological doses. Users should inform decision makers of that fact.

For PWRs, the time the core is uncovered should be the time that the coolant drops below the top of the active fuel. At this level cladding failure will begin. The gap activity in each fuel rod is released suddenly when the cladding melts at the top. The rods will start to melt at the center and move to the cooler outside fuel elements. This process takes about half an hour.

For BWRs, the cladding damage does not start until the water uncovers about 1/3 of the way down the fuel element. Prior to that time boiling water below will keep the fuel cool enough to prevent melting of the cladding.

For a LOCA, RASCAL requires the dates and times that 1) the reactor was shut down and 2) the core became uncovered. By default, the dates and times will be the same. However, dates and times can be changed. The date and time that the core is uncovered can be later than the date and time the reactor shutdown, but it cannot be before.

RASCAL provides two options for the end of the release from the reactor. If the *Core recovered* option is selected. The release from the reactor will continue until the core is recovered or until the end of the RASCAL calculations.   If the *Specified damage amount* option is selected, the release from the core will occur until the specified damage endpoint is reached. RASCAL 4.3 Technical Supplement Section 1.2 discusses the core damage state option.

2.2.2.3 Coolant Release Accidents

RASCAL has a *Coolant Release Accidents* model for both PWRs and BWRs. The primary accidents sequence for PWRs involves steam generator tube ruptures (SGTR).   Other coolant release accidents such as small line breaks and safety valve releases are modeled for both PWR and BWR accidents. Either the RASCAL default coolant inventory or a custom coolant inventory may be used as a basis for source

term estimates.   In either case, the inventory of halogens (iodine) and alkali metals (Cs and Rb) may be increased to account for spiking caused by rapid changes in reactor power.

RASCAL requires the *Reactor shutdown* date and time to determine the initial coolant inventory and the date and *Time of the coolant release*. By default, the dates and times will be the same. However, dates and times can be changed. The date and time of the coolant release can be later than the date and time the reactor shutdown, but it cannot be before.

As mentioned above, the coolant inventory can be modified to include the effects of rapid changes in reactor power. If the *Increased fuel pin leakage* option is selected, the inventory of iodines and alkali metals in the coolant will be increased by a spiking factor.   RASCAL uses a default spiking factor of 30. However, users may change the spiking factor to a value within the range of 1 to 1,000. RASCAL Technical Document Section 1.2.3.2 discusses spiking factors.

2.2.2.4 Containment Radiation Monitor

RASCAL estimates reactor source terms from *Containment Radiation Monitor* readings by first estimating a core damage state and then estimating nuclide activities released from the reactor from the core damage state. RASCAL Technical Document Section 1.2.4 describes method used to estimate the core release activities. It is based on containment monitor readings predicted for typical 3000 MWt reactors.

Note that there are several significant assumptions in this method. Among them are the assumptions that the containment atmosphere is uniformly mixed and the containment monitor sees a large fraction of the containment volume. These assumptions should not be taken lightly as they may lead to large errors in estimated doses in the environment.   It should also be noted that the method assumes that the release to the environment is limited to noble gases, iodines, and alkali metals (Cs and Rb).

Information required by RASCAL for estimating source terms from containment monitor readings is limited.   It includes the date and time of *Reactor shutdown*, the radiation *Monitor units*, and *Date* and

Time of monitor readings.   For BWR reactors, RASCAL also requires monitor location, dry well or wet well.

2.2.2.5 Coolant Sample

RASCAL source term estimates may be based on a *Coolant Sample*. PWR coolant samples are assumed to have been taken from the primary side coolant. RASCAL Technical Document Section 1.2.5 discusses the coolant sample source term.

Data entry for coolant sample source terms consists of the *Coolant activity units*, the *Nuclide*, and *Activity* of each nuclide in the coolant. RASCAL assumes that the activity is the activity at the time of the beginning of release to the environment. It is the user's responsibility to adjust the activity for decay between the time of the sample and the time that the release to the environment begins. RASCAL decays the source term after the beginning of release to the environment. The time of release to the environment is specified in the release path data entry.

The *Sample ID* is not required, but entry of an ID will facilitate post-event analysis. It should be entered as a matter of good practice.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness.   Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.2.2.6 Containment Air Sample

RASCAL source term estimates may be based on a *Containment Air Sample*. BWR containment air samples are assumed to have been taken from the dry well. However, volumes of both the dry well and wet well are included in calculation of the source term from the sample. RASCAL Technical Document Section 1.2.6 discusses the containment air sample source term.

Note that this method of estimating source terms assumes that the containment atmosphere is uniformly mixed. This assumption should be considered when basing RASCAL calculations on a containment air sample as it could lead to significant errors in dose estimates.

Data entry for *Containment Air Sample* source terms consists of the containment air *Sample activity units*, *Nuclide*, and *Activity* of each nuclide in the containment air. RASCAL assumes that the activity is the activity at the time of the beginning of release to the environment. It is the user's responsibility to adjust the activity for decay between the time of the sample and the time that the release to the environment begins. RASCAL decays the source term after the beginning of release to the environment.   The time of release to the environment is specified in the release path data entry.

The *Sample ID* is not required, but entry of an ID will facilitate post-event analysis. It should be entered as a matter of good practice.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness. Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.2.2.7 Effluent Releases – by Mixtures
RASCAL permits users to enter source term information as a mixture release rates or concentrations for noble gases activity, iodine activity, and particle activity. This source term option may be used for monitored releases made while the reactor is operating.

For this source term, RASCAL does not calculate nuclide decay and ingrowth until the activity is released to the environment. RASCAL Technical Document Section 1.2.8 describes how the nuclide activity is estimated from the mixtures. RASCAL uses the entered data to estimate the activity release rates for individual nuclides. RASCAL treats the calculated release rates entered as release rates to the environment.

Data entry for the *Effluent Releases – by Mixtures* source term begins with specification of reactor status. If the reactor is shut down, the date and time of *Reactor shutdown* are entered.   The date and time of the monitor reading (*Sample taken*) are entered next.

The *Release rate unit* must be set. The RASCAL default units of Ci/s may be different than the units reported by the monitor.

The monitoring readings are entered last. These readings are entered by mixture component. RASCAL assumes that the monitoring instruments will provide separate release rates for *Noble gases*, *Iodines*, and *Particulates*.   Make sure that the release rates for the components are in the same units.   If release rates are only available for one or two components, the release rates for the other components may be left as zero.   The data entry form provides access to a tool to convert activity concentrations and flows to release rates.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness.   Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.2.2.8 Effluent Release Rates – by Nuclide
RASCAL permits users to specify source term directly by entering the nuclide name and activity release rate (e.g., Ci/s).   RASCAL treats the release rates entered as release rates to the environment.   For this source term, RASCAL does not calculate nuclide decay and ingrowth until the activity is released to the environment. RASCAL Technical Document Section 1.2.7 discusses source terms based on effluent release rates.

The *Description of measurement* is not required, but entry of a description will facilitate post-event analysis. It should be entered as a matter of good practice.

Effluent release rate units must be adjusted to reflect the actual measurement units.

One to three *Release period definitions* may be defined. If more than one period is defined, the periods may be separated, end-to-end, or overlapping.

Nuclide names and release rates should be entered next. Each nuclide name is entered followed by its release rate. Nuclide names may be entered manually, or they may be selected from a dropdown list. An error message will be displayed if the name of a nuclide is entered manually and the nuclide name is not in the list of nuclides known to RASCAL. After a nuclide name is entered, a release rate may be entered for each defined release period. There should be at least one nuclide release rate for each period, but all nuclides are not required to have a release rates for each period. If overlapping periods are defined the release rates for each nuclide during the overlapping period will be the sum of the release rates for the two periods.

Uranium enrichment is used only if nuclide name is U-Enrch.   The U-Enrch nuclide is likely to be used only for fuel cycle or materials facilities.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness.   Unreasonably large values could exceed the inventory available for release. They might

also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.2.2.9 Effluent Release Concentrations – by Nuclide

RASCAL permits users to specify source term directly by entering the nuclide name, activity concentration (e.g., Ci/cm^3), and release flow (e.g., cm^3/s).   From this information, RASCAL calculates activity release rates. RASCAL treats the calculated release rates entered as release rates to the environment.   For this source term, RASCAL does not calculate nuclide decay and ingrowth until the activity is released to the environment. RASCAL Technical Document Section 1.2.7 discusses source terms based on effluent release rates.

The *Description of measurement* is not required, but entry of a description will facilitate post-event analysis. It should be entered as a matter of good practice.

Effluent flow rate units and *effluent concentration units* must be adjusted to reflect the units of the flow to the environment and actual measurement units.   These units must be consistent so that the product of the flow rate and the concentrations has units of activity/time.

One to three *Release periods* may be defined. If more than one period is defined, the periods may be separated, end-to-end, or overlapping.

Nuclide names and activity concentrations are entered next. Each nuclide name is entered followed by its concentrations.   Nuclide names may be entered manually, or they may be selected from a dropdown list.

An error message will be displayed if the name of a nuclide is entered manually and the nuclide name is not in the list of nuclides known to RASCAL. After a nuclide name is entered, a concentration may be entered for each defined release period. There should be at least one nuclide concentration for each period, but all nuclides are not required to have concentrations for each period. If overlapping periods are defined the concentrations for each nuclide during the overlapping period will be the sum of the concentrations for the two periods.

Uranium enrichment is used only if nuclide name is U-Enrch. The U-Enrch nuclide is likely to be used only for fuel cycle or materials facilities.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness. Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.2.3 Reactor Release Paths

When the STDose module of RASCAL is started, the initial screen guides users through the steps of setting up the input needed to run RASCAL. The steps are listed on the buttons on the left side of the screen. The first three steps define the *Event Type*, the *Event Location*, and the *Source Term*. The fourth step is to define the *Release Path* from the source to the environment. When the *Release Path* button is clicked, a screen appears that lists available release path options. After an option is selected, a second screen appears that allows users to provide details about the release path. The release path details include release height, leak types and rates, spray status, and filter status. RASCAL Technical Document Section 1.3 discusses reactor release pathways.

2.2.3.1 PWR Reactor Accidents

For PWR reactors, there are three *Release Path* options for events in which the source term is based on reactor conditions or a coolant or containment air sample. These pathways are *Containment leakage/failure*, *Steam generator tube rupture*, and *Containment bypass*. One or more of the pathway options may not be available for some source term types. Pathways that are not available are shown grayed out. For example, the *Containment leakage/failure* pathway is not available for a coolant release source because the release is assumed to be outside of containment.

2.2.3.1.1 Containment Leakage/Failure without Ice Condenser

The schematic diagram shown on the screen shows a simplified representation of the pathway. The diagram also shows the safety features in the pathway that might be used to mitigate the release consequences.

When a release path option is selected a second screen appears. Details of the release path are entered on this screen. The contents of the screen are a function of the release path selected. They include a *Pathway description* (optional) and a *Release height*. The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice. A 10-m height should be used for ground level releases. The bottom portion of the screen is used to enter information on leak rates, hole sizes, spray status, steam generator rupture location, release point, and filters.

There are two options for describing the leak. The first is to specify the containment leak rate as *Percent volume/time*, and the other is to describe the leak by *Containment pressure/hole size*. When the *Percent volume/time* option is selected, RASCAL sets the default leak rate to the containment design leak rate. The RASCAL facility database contains design basis leak rates for all reactors. RASCAL

Technical Document Section 1.5.1 describes how RASCAL uses the *Percent volume/time* release rate to calculate the activity release to the environment.

When the *Containment pressure/hole size* option is selected, RASCAL sets the containment pressure to the design pressure, assumes that the hole in containment is the result of a small pipe break, and assumes that the containment temperature is 120 ⁰C. RASCAL obtains the design pressure from the RASCAL database.

The box at the bottom of the screen contains a table that is used to set the leak rate, if there is reason to suspect that the actual leak rate is different than the design leak rate. The leak rate may be changed during the release. To change the leak rate, click on the button at the right end of the event setting column of the leak rate row in the table. This will display a screen on which to enter leak rate information.

The box on the *PWR - Dry Containment Leakage or Failure* screen is also used to control containment sprays. The sprays may be turned on or off using the button at the right end of the *Event* setting column of the sprays row in the table. RASCAL Technical Document Section 1.4.1 describes the modeling of containment sprays. Technical document Table 1-11 lists the reduction factors for sprays and ice condensers.

2.2.3.1.2 Containment Leakage/Failure – with Ice Condenser
The schematic diagram shown on the screen shows a simplified representation of the pathway. The diagram also shows the safety features in the pathway that might be used to mitigate the release consequences.

When a release path option is selected a second screen appears. Details of the release path are entered on this screen. The contents of the screen are a function of the release path selected. They include a *Pathway description* (optional) and a *Release height*. The *Path description* is not required, but entry of a description will facilitate post-event analysis. It should be entered as a matter of good practice. A 10-m height should be used for ground level releases. The bottom portion of the screen is used to enter information on leak rates, hole sizes, spray status, steam generator rupture location, release point, and filters.
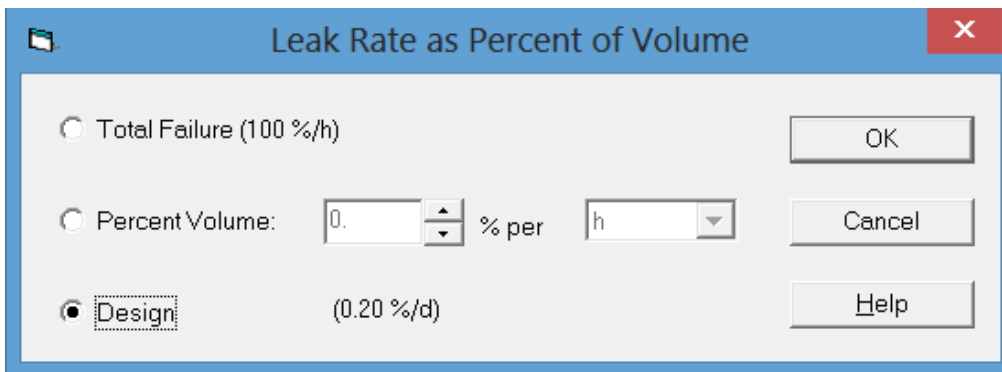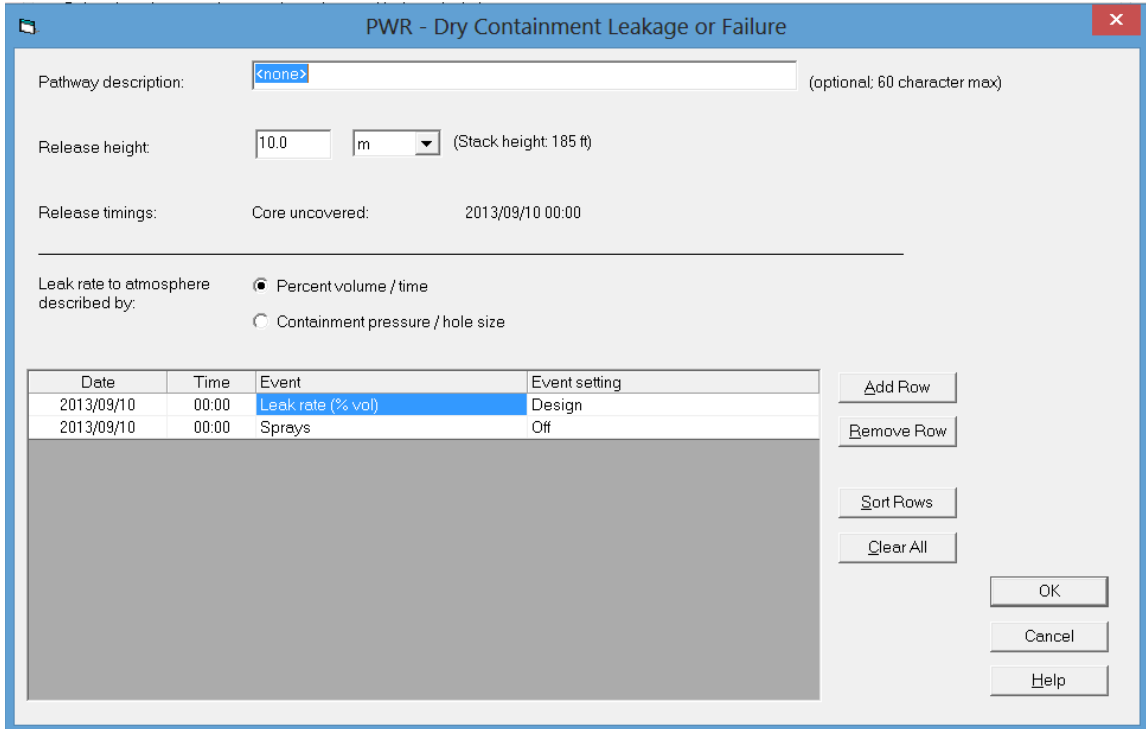
There are two options for describing the leak. The first is to specify the containment leak rate as *Percent volume/time*, and the other is to describe the leak by *Containment pressure/hole size*. When the *Percent volume/time* option is selected, RASCAL sets the default leak rate to the containment design leak rate. The RASCAL facility database contains design basis leak rates for all reactors. RASCAL Technical Document Section 1.5.1 describes how RASCAL uses the percent volume/time release rate to calculate the activity release to the environment.

When the *Containment pressure/hole size* option is selected, RASCAL sets the containment pressure to the design pressure, assumes that the hole in containment is the result of a small pipe break, and assumes that the containment temperature is 120 ⁰C. RASCAL obtains the design pressure from the RASCAL database.
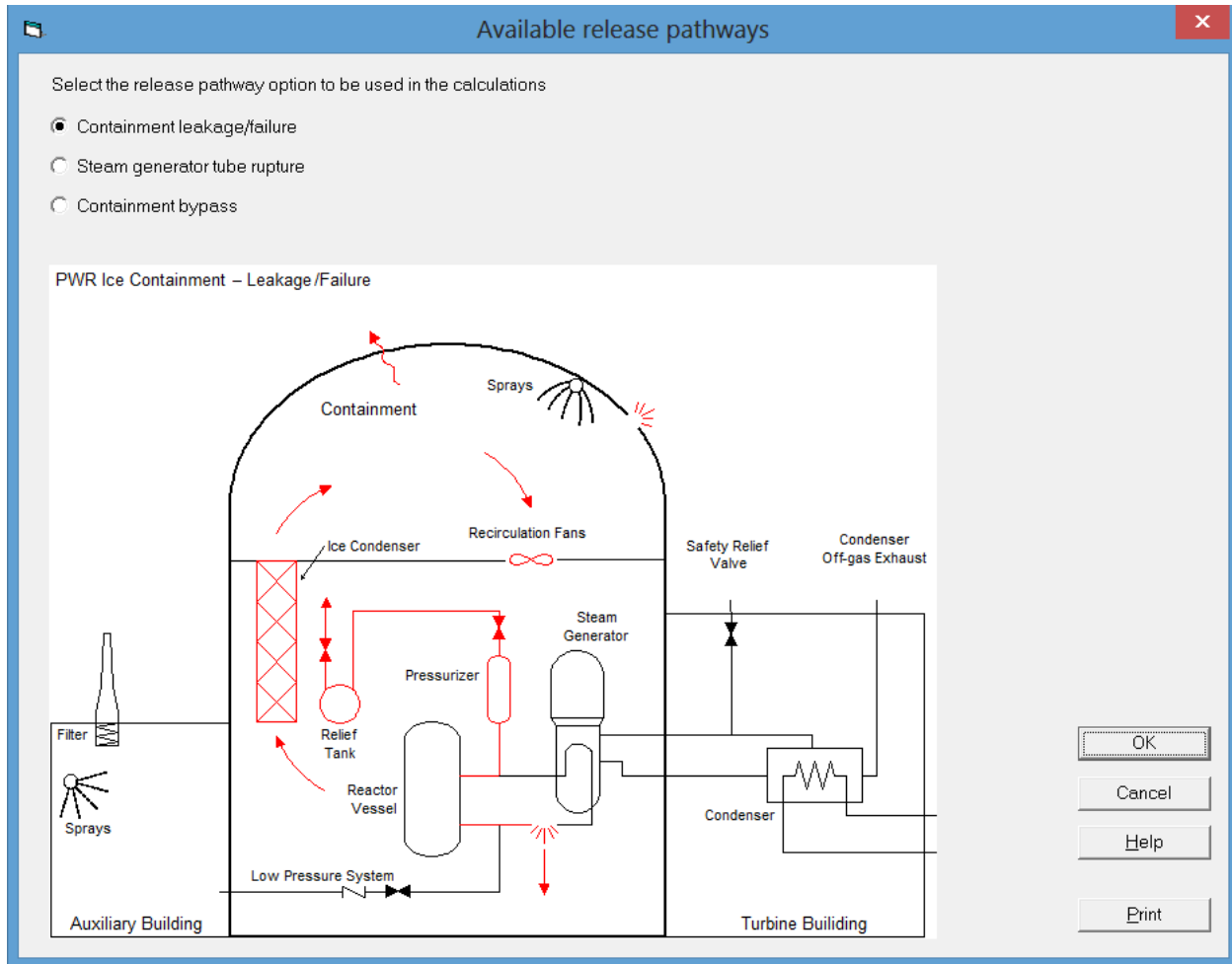
The box at the bottom of the screen contains a table that is used to set the *Leak Rate*, if there is reason to suspect that the actual leak rate is different than the design leak rate. The leak rate may be changed during the release. To change the *Leak Rate*, click on the button at the right end of the event setting column of the leak rate row in the table. This will display a screen on which to enter leak rate information.

The box on the *PWR - Dry Containment Leakage or Failure* screen is also used to enter containment sprays and ice condenser status. The sprays may be turned on or off using the button at the right end of the *Event* setting column of the sprays row in the table. RASCAL Technical Document Section 1.4.1

describes the modeling of the source term reduction associated with containment sprays and ice condensers. Technical document Table 1-11 lists the reduction factors for sprays and ice condensers.

2.2.3.1.3 Steam Generator Tube Rupture

The second RASCAL release path for PWR reactor accident effluents is through the *Steam generator tube rupture*.   If a coolant release accident source term has been selected, the accident will be modeled as a steam generator tube rupture accident.   If one of the other source term types specifically associated with reactors has been selected, a steam generator tube rupture is assumed and fission products from the core are released through the steam generator pathway. RASCAL Technical Document Section 1.4.4 describes the Steam Generator Tube Rupture pathway.   RASCAL 4.3 Technical Supplement describes minor changes to the pathway for RASCAL 4.3.
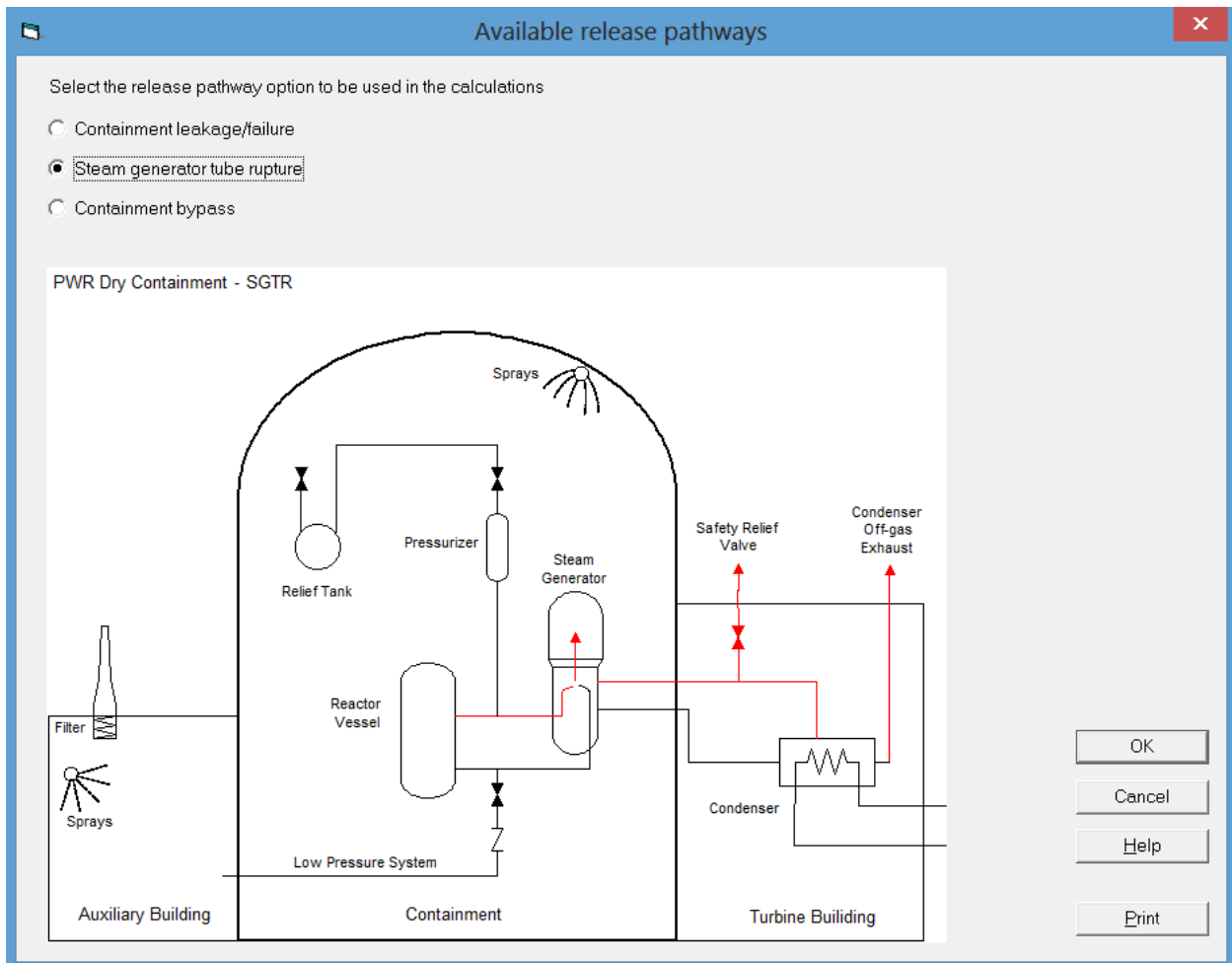
When the *Steam generator tube rupture* release path option is selected a second screen appears. Details of the release path are entered on this screen. The contents of the screen include a pathway description (optional), a release height, and a table in which to enter the path details.

The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice.

A default *Release height* of 10-m is entered by RASCAL. This height may be changed. If the plant has a stack and it is listed in the facility database, the stack height will be shown on the screen. Unless the release is known to be through the stack, a 10-m height should be used for the release.

The table in the box at the bottom of the screen is used to enter information on leak rates, steam generator rupture location, steaming rate, and release point. All of these items are time dependent and may change during the release. The *Add Row* button on the right is used to add a row when an event changes. Clicking on the event cell in the new row will bring up a list of event options. Enter the date and time of the event.   The event setting cell is use to enter the value after an event has been selected. Data entry screens are provided the *Leak rate into SG* (recharge rate) and *Steaming Rate* events.   Options are provided for the *Rupture location* and *Release point* events.

The RASCAL user must specify whether the radionuclides that leak into the steam generator are above or below the water level on the secondary side of the steam generator. When the leak is below the water level most of the radionuclides will mix with the bulk water and will be held up so that the release rate of all radionuclides that are not noble gases is reduced by a factor of 50. When the leak is above the steam generator water level most of the primary coolant will flash into steam and most of the radionuclides will be available for release. In this case, RASCAL reduces the release of all radionuclides that are not noble gases by a factor of 2. Leak location has no effect on noble gases. Noble gases in the primary coolant leakage are assumed to immediately enter the steam generator steam space and be available for release without any reduction or holdup.

How does the RASCAL user know whether to select above or below the water level? Although the actual tube break location may be unknown, the steam generator water level relative to the top of the tube bundle should be available. If the water level is near or above the top of the tubes, the user should select below the water level. Otherwise select above the water level. If the reactor has a once-through steam

generator, the only option is above the water level because most of the tube length in a once-through steam generator is not covered by water.

The time dependent information on the release path must be in proper sequence.   The Sort Rows button on the right is used to put the events in proper sequence after the event information has been entered. Sorting is not necessary if the event data are entered in sequence.

2.2.3.1.4 Containment Bypass
The RASCAL *Containment Bypass* release pathway assumes that the release path is through the reactor coolant system to an auxiliary building or directly to the environment without first entering the containment building. RASCAL Technical Document Section 1.4.3 describes this pathway.

When the containment bypass option is selected, the bypass data entry screen appears.   Details of the release path are entered on this screen. The contents of the screen include a *Pathway description* (optional), *Release height*, and information on flows and filters in the pathway.
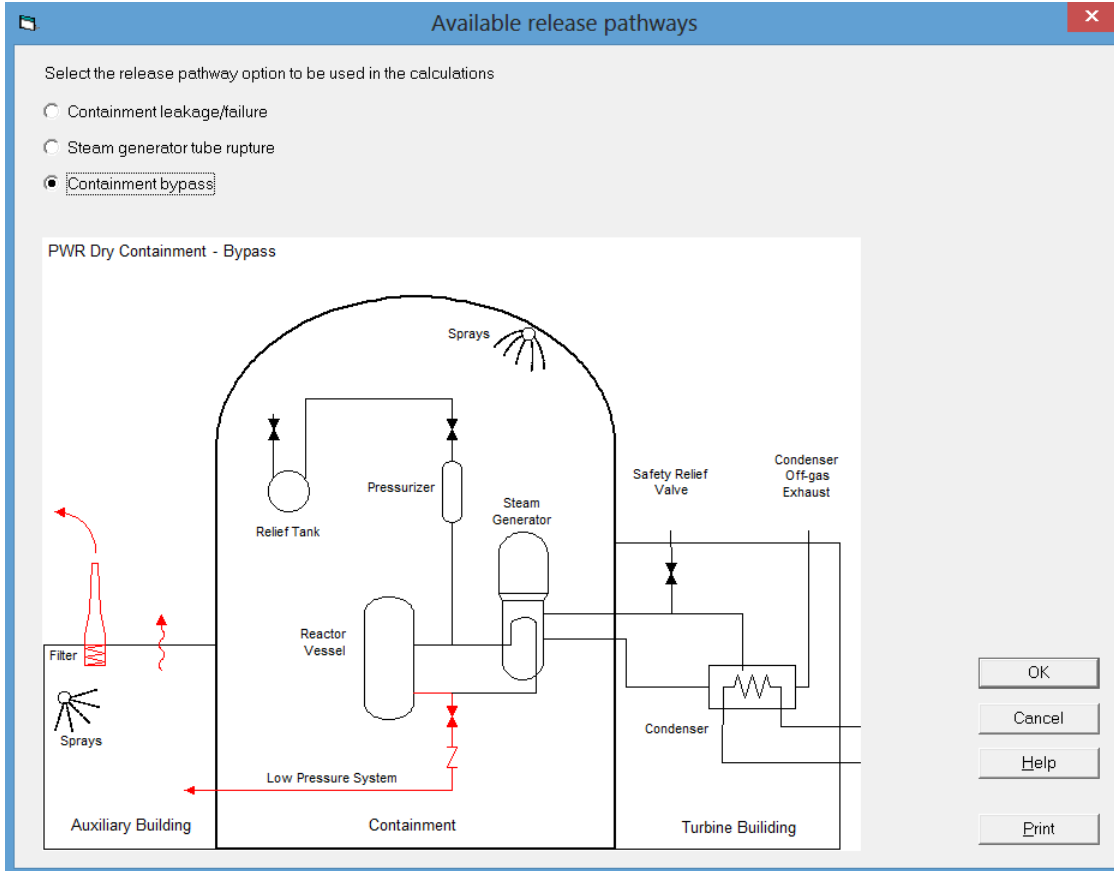
.

The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice.

RASCAL enters a default 10-m (ground level) *Release height*. This should be used for ground level releases and for other releases that are not through isolated stacks. If the plant has a stack listed in the RASCAL facility database, the stack height is shown on the screen.

The bottom portion of the screen contains a table used for entering information on leak rates and filters. These items are time dependent and may change during the release.   The *Add Row* button on the right is used to add a row when an event changes. Clicking on the event cell in the new row will bring up a list of event options. Enter the date and time of the event.   The event setting cell is use to enter the value after an event has been selected. A data entry screens is provided the *Bypass flow rate* event.   On and off options are provided for the *Filters* event.

2.2.3.1.5 Direct Release to Environment
When one of the following source term options is selected,
- Effluent Release – by Mixtures
- Effluent Release Rates – by Nuclide
- Effluent Release Concentrations – by Nuclide

 RASCAL assumes that the release is directly to the environment.   The following screen is used to enter release height and information about the time and duration of the release.

The default release height is 10 m (ground level). The user may change the stack height. If the facility has a stack and the height is listed in the database, the stack height will be shown on the screen.   A date and time must be entered for the beginning of release to the atmosphere. The end of the release must also

be entered. It may be entered as either a *Start* and *End* date/time or as *Release duration*. The maximum release duration is 4 days.

2.2.3.2 BWR Reactor Accidents

For BWR reactors there are two options for release paths from the reactor to secondary containment. These are through the *suppression pool* and through the *dry well wall*. Containment Bypass and Coolant releases are assumed to be directly into the turbine building. The paths from secondary containment and the turbine building the environment may be either *direct* or though the *Standby Gas Treatment System* (*SBGTS*). One or more of the pathway options may not be available for some source term types. Pathways that are not available are shown grayed out. Users must select one option from the list of pathways from the reactor to containment on the left, and they must select an option from the list of pathways to the atmosphere on the right. RASCAL Technical Document Sections 1.4.2, 1.4.3, and 1.4.5 discuss the BWR release pathways.

The schematic diagram on the screen shows a simplified representation of the pathways selected. The diagram also shows the safety features in the pathway that might be used to mitigate the release consequences.

2.2.3.2.1   Wet Well (Suppression Pool) Release Pathway

The Wet Well (*suppression pool*) release pathway assumes that the reactor releases activity into the dry well atmosphere. The activity then passes through the wet well into the containment atmosphere and is ultimately released to the atmosphere, either directly or through the standby gas treatment system.
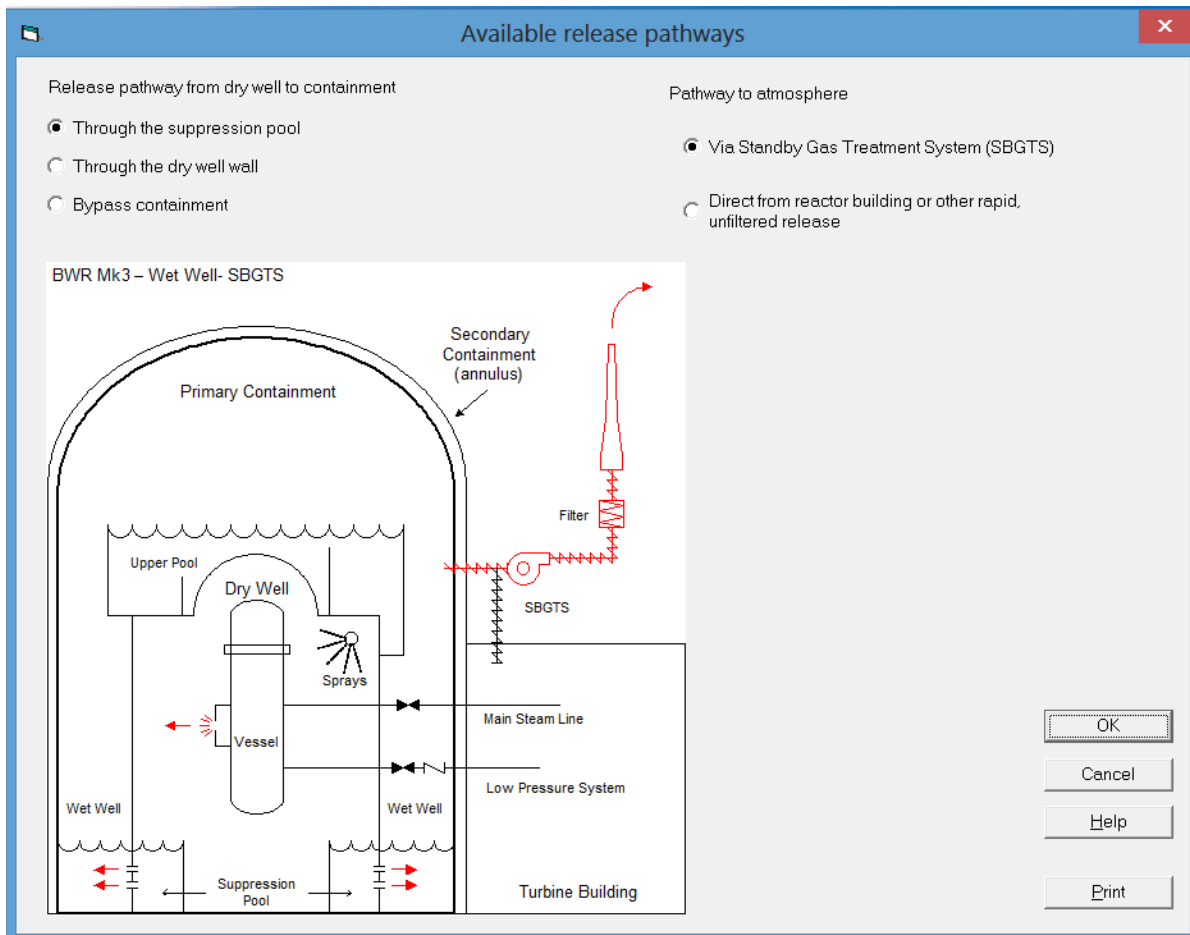
When the wet well (*suppression pool*) release path option is selected, the wet well release path data entry screen appears. Details of the release path are entered on this screen. The contents of the screen include a *Pathway description* (optional), a *Release height*, two options for specifying *Leak rate*, and a table in which to enter the release path details.

The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice.

RASCAL enters the stack *Release height* from the facility database. If the release to the atmosphere is through the standby gas treatment system, this height cannot be changed. However, if the release to the atmosphere is direct, the release height may be changed.

The options for specifying *Leak rate* are *Percent volume/time* and *Containment pressure/hole size*. The *Percent volume/time* option should generally be selected for the wet well release path. Use the *Containment pressure/hole size* option with caution.

The bottom portion of the screen contains a table used for entering information on leak rates and filters. These items are time dependent and may change during the release. The *Add Row* button on the right is used to add a row when an event changes. Clicking on the event cell in the new row will bring up a list of event options. Enter the date and time of the event. The event setting cell is use to enter the value after an event has been selected. One of two data entry screens is used to obtain input for the *Leak rate* event. One data entry screen is for the *Percent volume/time* option, and the other is for the *Containment pressure/hole size* option. RASCAL Technical Document Section 1.5.1 discusses the *Percent volume/time* option. RASCAL Technical Supplement Section 1.4 discusses the *Containment pressure/hole size* option. *Saturated* and *Subcooled* options are provided for the *Wet Well* event.

2.2.3.2.2 Dry Well Release Pathway

The *Dry Well* release pathway assumes that the reactor releases activity into the dry well atmosphere. The activity then passes through the dry well into the containment atmosphere and is ultimately released to the atmosphere, either directly or through the standby gas treatment system.

When the *Dry Well* release path option is selected, the *Dry Well* release path data entry screen appears. Details of the release path are entered on this screen. The contents of the screen include a *Pathway description* (optional), a *Release height*, two options for specifying *Leak rate*, and a table in which to enter the release path details.

The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice.

RASCAL enters the stack *Release height* from the facility database. If the release to the atmosphere is through the standby gas treatment system, this height cannot be changed. However, if the release to the atmosphere is direct, the release height may be changed.

The options for specifying *Leak rate* are *Percent volume/time* and *Containment pressure/hole size*. The *Percent volume/time* option is the default option. The *Containment pressure/hole size* option can be used if there is information on a hole in the dry well wall.

The bottom portion of the screen contains a table used for entering information on *Leak rates* and *Sprays*. These items are time dependent and may change during the release.   The *Add Row* button on the right is used to add a row when an event changes. Clicking on the event cell in the new row will bring up a list of event options. Enter the *Date* and *Time* of the event.   The *Event setting* cell is use to enter the value after an event has been selected. One of two data entry screens is used to obtain input for the *Leak rate* event. One data entry screen is for the *Percent volume/time* option, and the other is for the *Containment pressure/hole size* option. RASCAL Technical Document Section 1.5.1 discusses the *Percent volume/time* option. RASCAL Technical Supplement Section 1.4 discusses the *Containment pressure/hole size* option.   The options for the *Sprays* event are *On* and *Off*. RASCAL Technical Document Section 1.4.1 discusses *Sprays*.

Leak Rate as Percent of Volume

- ○ Total Failure (100 %/h)
- ○ Percent Volume: [0.] ⬆⬇ % per [h] ▼
- ● Design   (0.65 %/d)

OK   Cancel   Help

Leak Rate as Pressure and Hole Size

Containment pressure: [15] ⬆⬇ [lb/in²] ▼ (gauge)

Containment: [120.] ⬆⬇ [°C] ▼

Hole area or

- ● Small pipe (10 sq in)
- ○ Large pipe (100 sq in)
- ○ Small hatch (10 sq ft)
- ○ Large hatch (30 sq ft)
- ○ User defined: [0.] ⬆⬇ [in² area] ▼

OK   Cancel   Help
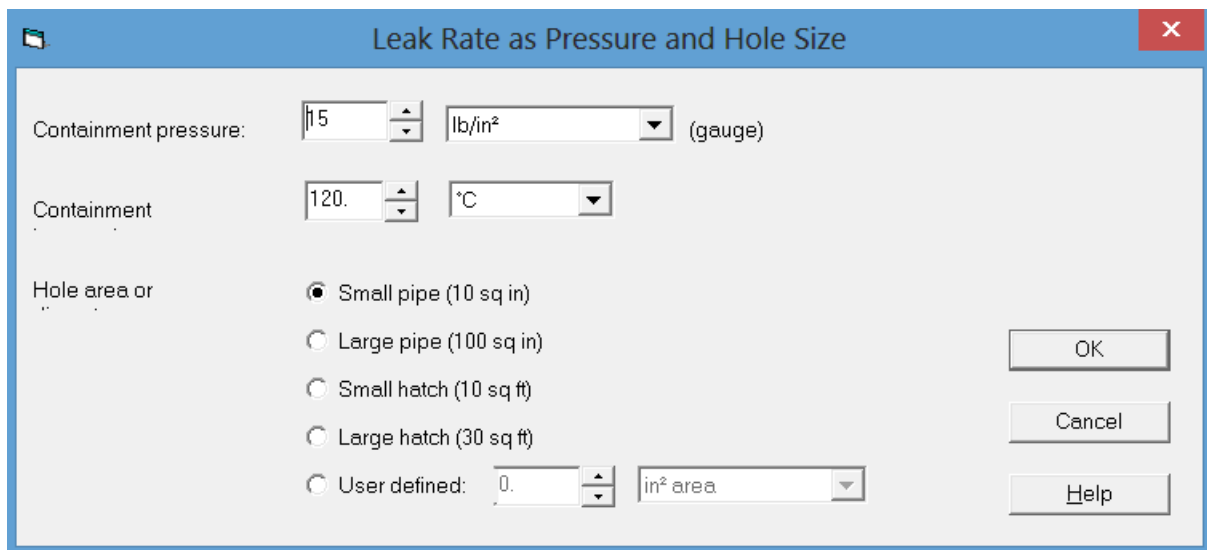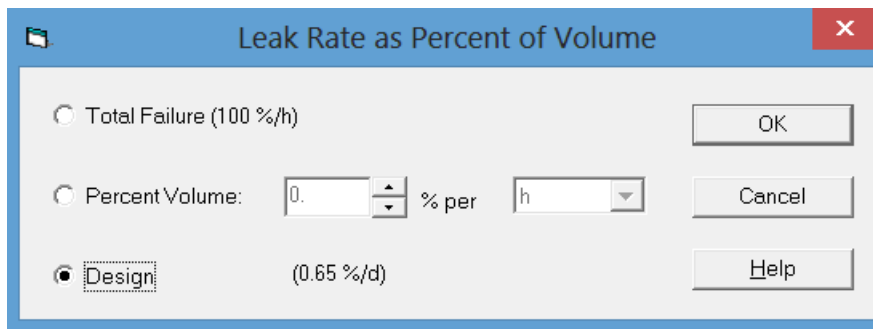
2.2.3.2.3 Containment Bypass Release Pathway
The RASCAL *Containment* release pathway assumes that the release path is through the reactor coolant system to an auxiliary building or directly to the environment without first entering the containment building. RASCAL Technical Document Section 1.4.3 describes this pathway.

When the containment bypass release path option is selected, the *Bypass Containment* release path data entry screen appears. Details of the release path are entered on this screen. The contents of the screen include a *Pathway description* (optional), a *Release height*, two options for specifying *Leak Rate*, and a table in which to enter the release path details.
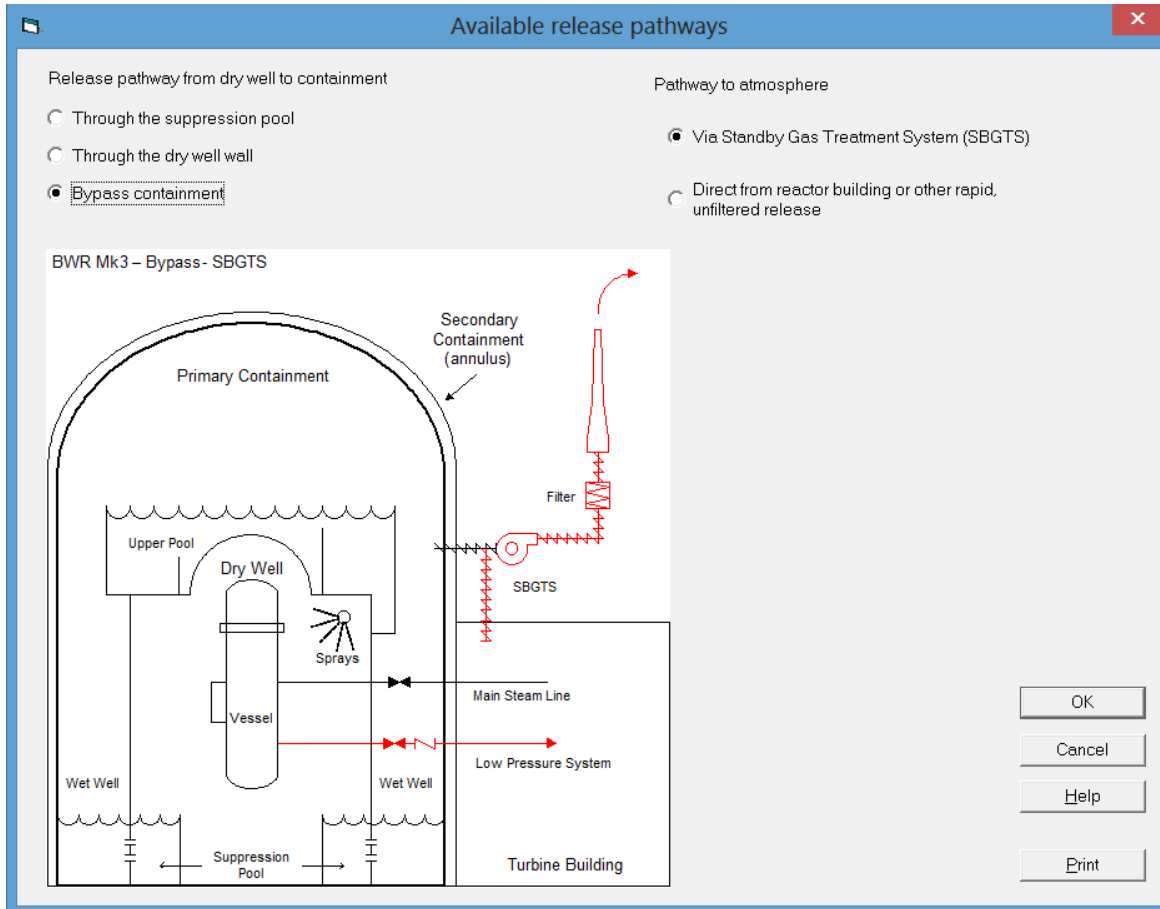
The Path description is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice.

RASCAL enters the stack *Release height* from the facility database. If the release to the atmosphere is through the Standby Gas Treatment System (SBGTS), this height cannot be changed. However, if the release to the atmosphere is *Direct*, the release height may be changed.
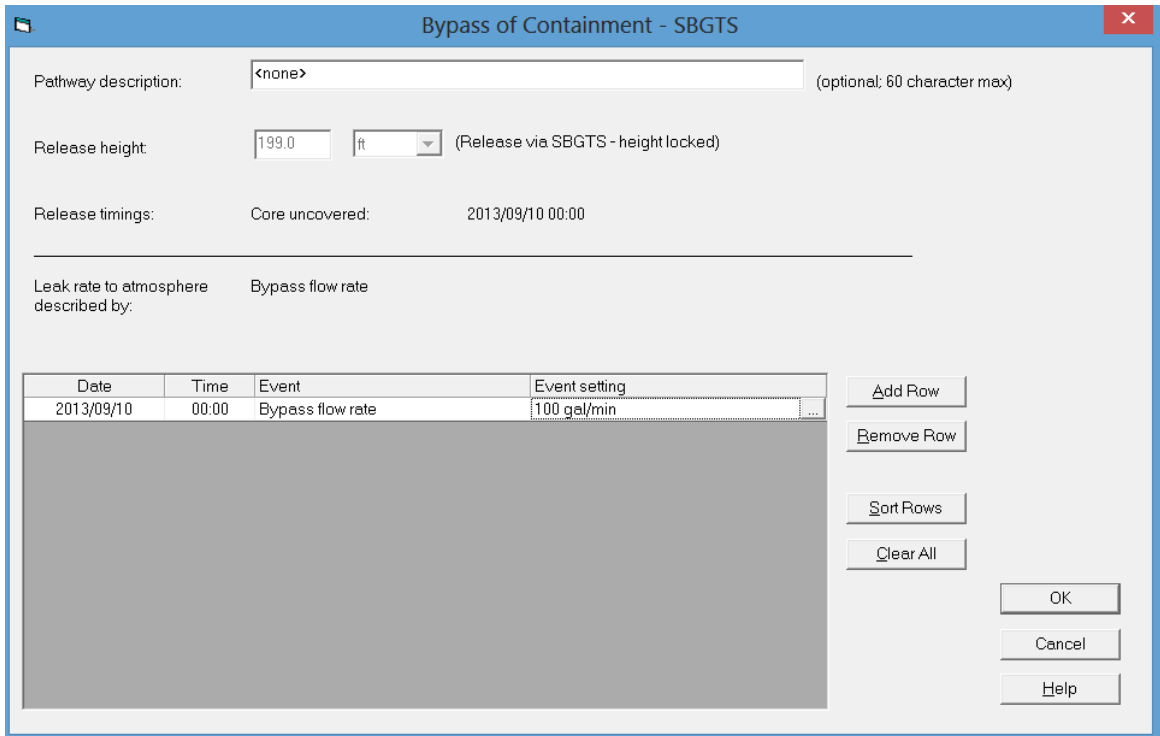
The bottom portion of the screen contains a table used for entering information on the *Bypass flow rate*. This item is time dependent and may change during the release.   The *Add Row* button on the right is used to add a row when an event changes. Clicking on the event cell in the new row will bring up a list of event options. Enter the *Date* and *Time* of the event.   The *Event* setting cell is use to enter the value after an event has been selected. A data entry screen is used to obtain input for the *Bypass flow rate* event.
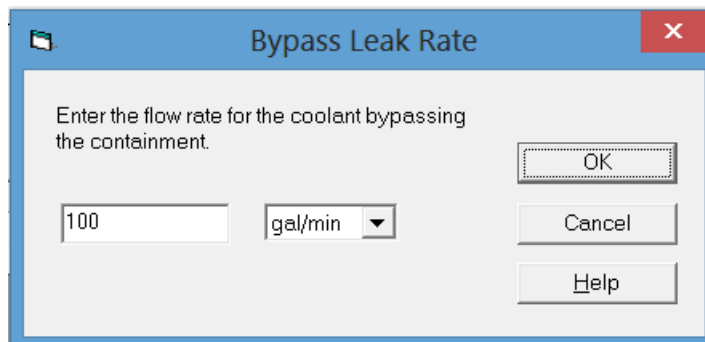
2.2.3.2.4 Direct Release to Environment
When one of the following source term options is selected,
- Effluent Release – by Mixtures
- Effluent Release Rates – by Nuclide
- Effluent Release Concentrations – by Nuclide

RASCAL assumes that the release is directly to the environment. The following screen is used to enter release height and information about the time and duration of the release.

The default *Release height* is 10 m (ground level). The use may change the stack height. If the facility has a stack and the height is listed in the database, the stack height will be shown on the screen. The *Release Timings* may be entered as a *Start Date* and *Time* and an *End Date and Time* or *Release duration*. A *Start Date* and *Time* must be entered for the beginning of release to the atmosphere. The maximum release duration is 4 days.

2.3 Spent Fuel

The *Spent Fuel Event Type* is used accidents at nuclear power plants involving spent fuel. The accidents include drained spent fuel pool, mechanical damage to spent fuel underwater, and damage to spent fuel in dry cask storage. RASCAL 4.3 has a facility database that lists features of all nuclear power plant in the United States. When the Spent Fuel event type is selected, RASCAL 4.3 will obtain available information from this database for use in setting default values.

2.3.1 Event Location

Spent Fuel events are assumed to occur at nuclear power plant sites. The *Event Location* button activates the nuclear power plant event location screen. The event location screen has two options: 1) load an event location from the RASCAL database, or 2) define a generic site. If option 1 is selected, the site must be selected from the dropdown list in the box. Pertinent characteristics of the selected site are displayed below the site list. If option 2 is selected, a data entry screen will appear for use in entering the requisite site data.

RASCAL 4.3 includes a database with information on all operating nuclear reactors in the United States and the Laguna Verde Reactors in Mexico. Site information for any of these reactors will be loaded automatically when the reactor name is selected from the dropdown list of site names. The number of sites in the list can be reduced by picking one of the filters in the *List only* drop-down. Selecting a site name will update the plant parameters section at the bottom of the screen.

If the option to define a *Generic* site is selected, RASCAL displays a site data entry form. Most of the information to be entered in the form is descriptive only and does not influence the calculations. However, the information entered will appear in the case summary and is very useful in labeling the model runs.

When a reactor *Type* is selected, information on reactor parameters is pulled from the facility database. Some of it may need to be revised to reflect the actual status of the reactor at the time of the event (see the discussion of Reactor Parameters).

Latitude and *Longitude* are required information and are entered as decimal degrees (e.g. 35.5056 rather than 35 deg 30 min 20 sec). Use negative numbers for west longitudes and south latitudes. The latitude and longitude are important because they establish the location of center of the computational grids. All meteorological station positions in the model domain are determined using the longitude and latitude of the center of the grid. Longitude and latitude are also used in estimating stability class. If RASCAL is being run with meteorological data from a single station approximate values for longitude and latitude are adequate.

Time Zone can be selected by name if in the United States or specified as an offset from Greenwich for all other time zones. The *Time Zone* is used to determine sunrise and sunset times. Sunrise and sunset times are used when the stability class is estimated from meteorological data rather than being entered directly. The sunrise and sunset times are also used in determining if entered stability information is reasonable.

2.3.2 Spent Fuel Source Terms

RASCAL models three types of spent fuel accidents: *Pool Storage – Uncovered Fuel*, *Pool Storage – Damaged Assembly Underwater*, and *Dry Storage – Cask Release*. These options appear when the *Source Term* button on the main screen is clicked if a spent fuel accident has been selected on the *Event Type* screen. The consequences of these accidents are a function of the fuel burn-up, the time since last irradiation, and the type and extent of the damage to the fuel.   The appropriate data entry screen will appear when the accident type is selected.

2.3.2.1 Pool Storage – Uncovered Fuel

The nuclide inventory at risk when the fuel in the spent fuel pool is uncovered is a function of the number, age, and burn-up of the fuel assemblies in the pool at the time the pool is drained.

RASCAL 4.3 calculates the inventory at risk starting with the fuel from the most recent refueling outage. If the spent fuel pool is drained during a refueling outage, there may be a full core of recently exposed fuel in the pool. If there is, then RASCAL 4.3 calculates the nuclide inventory for each batch of fuel in

the core offload. Otherwise, RASCAL only calculates the inventory for the oldest batch of fuel in the reactor at the last refueling. The nuclides inventories of fuel in the spent fuel pool from previous refueling are calculated assuming that one batch of fuel is removed from the reactor at each refueling and the time between refueling is equal to the plant refueling cycle.

There may also be fuel in the spent fuel pool from other reactors. This is likely to be the case when reactors share a common spent fuel pool. RASCAL 4.3 includes an option to add the inventory of nuclides in spent fuel from a second reactor to the spent fuel pool inventory at risk in the event of a drained pool. The basic assumptions for the spent fuel from the other reactor are as follows:
1. The other reactor is the same type as the first reactor and is operated in the same manner, e.g., both reactors are PWRs, have the same fuel management, and have same spent fuel burnup.
2. The spent fuel from the other reactor has full burnup.
3. The ages of the spent fuel batches increase from the youngest to oldest in increments of the fuel cycle length.

Sections 2.3.1 of the RASCAL Technical Manual and 1.5.1 of RASCAL Technical Supplement deal with the drained spent fuel pool accident.

2.3.2.2 Pool Storage – Damaged Assembly Underwater
The at risk nuclide inventory in a damaged fuel accident is limited to the nuclide inventories in the damaged fuel assemblies. RASCAL 4.3 calculates the at risk nuclide inventory in the damaged fuel assemblies based on the burnup of the damaged fuel assemblies and the time since exposure. The burnup is estimated using the reactor power and the number of days that the fuel was exposed in the reactor. The default time since exposure is based on technical specification for each reactor type related to minimum time between shutdown and removing the reactor head.   The actual time between reactor shutdown and fuel damage is likely to be longer than the minimum and may be significantly longer if the damage occurs during re-racking of the fuel or movement of fuel assemblies to dry cask storage.

Sections 2.3.2 of the RASCAL Technical Manual and 1.5.2 of RASCAL Technical Supplement deal with the damaged fuel assembly accident.

2.3.2.3 Dry Storage – Cask Release

RASCAL has the capability to model an accident in which there is damage to the cladding of fuel assemblies stored in a cask and the integrity of the fuel cask is lost. Only one cask can be involved but the user may vary the number of assemblies damaged. If the assemblies are damaged but have not lost cooling for greater than the thermal limit, a cold gap release fraction is used. If cooling has been lost long enough to allow the cladding to melt, then the hot gap release fraction is assumed. No release is assumed if the cladding does not melt or if the cask is engulfed in a fire. See RASCAL Technical Document Section 2.3.3.

Estimation of a dry cask source term requires specification of the:
- Average burn-up of fuel in the cask
- Specification of the cask type or number of fuel assemblies in the cask
- Age of the damaged fuel assemblies.

The *Average fuel burn-up* is set in the *Reactor Parameters* section of the *Reactor Location* screen. RASCAL sets a default burn-up from the site database. It may be changed by the user, if necessary.

If the *Type of cask* is known, RASCAL will set the number of assemblies per cask. If it is unknown, choose the type unknown option and enter the number of assemblies in a cask.

An estimate of the *Age of damaged fuel assemblies* in the cask is needed to estimate the activity at risk. The age of the fuel assemblies may be entered either as the date of last irradiation, or as the length of time in storage. An approximate age is acceptable because fuel assemblies in casks have typically been out of the reactor for more than 5 years, and as a result, only long-lived nuclides are at risk.

RASCAL treats three *Types of Events*: physical damage, loss of cooling, and fire. Select from the available types of events. RASCAL Technical Document Section 2.3.3 discusses the releases from dry

cask event. No release will occur if cooling is lost for less than the thermal limit or the cask is engulfed in a fire because the casks are designed to maintain their integrity in those situations.

2.3.3 Spent Fuel Release Paths
The release path routings for spent fuel accidents are defined by default. When the Release Path button is selected, a screen appears that collects the following information as needed to complete the definition of the paths: release height, release timing, pathway conditions (filtered or not) , and leak rate to the atmosphere.   RASCAL Technical Document Section 2.4 and 2.5 discuss spent fuel release pathways.

2.3.3.1 Drained Pool
The *Drained Pool* data entry from will be displayed if the *Pool Storage – Uncovered Fuel* option has been selected for the *Spent Fuel* source term. This form is used to enter information on the release height, the release timing, and the pathway condition.

RASCAL enters a default *Release height* of 10 m (ground level).   The *Release height* may be changed, but the default release height should be used unless the release is through a stack that is at least three times as high as nearby structures.

RASCAL enters a default *Date* and *Time* for the beginning of release to the atmosphere that is 2 hours after the time that the fuel was uncovered.   This date and time may be changed to a later date and time, but it cannot be changed to an earlier date and time. It is unlikely that the beginning of release will be as soon as 2 hours after the fuel is uncovered unless there is fresh fuel in the pool.   The latest that the start of the release to the atmosphere can occur is 24 hours after the fuel is uncovered.

The pathway condition is a simple option related to the operation of filters.   The default option is filters off. This option should be used unless the release pathway is known to be filtered and the filters are known to be operating. RASCAL Technical Document Section 2.4 describes the treatment of filters.

2.3.3.2 Damaged Spent Fuel or Dry Cask Storage
The Damaged Spent Fuel or Dry Cask Storage release path data entry from will be displayed if either the *Pool Storage – Damaged Assembly Underwater* option or the *Dry Storage – Cask Release* option has been selected for the spent fuel source term. This form is used to enter information on the release height, the release timing, the pathway condition and the leak rate.

RASCAL enters a default *Release height* of 10 m (ground level).   The *Release height* may be changed, but the default release height should be used unless the release is through a stack that is at least three times as high as nearby structures.

RASCAL enters a default *Date* and *Time* for the beginning of release to the atmosphere that is the time that the fuel was damaged if the source is damaged fuel under water.   This date and time may be changed to a later date and time, but it cannot be changed to an earlier date and time. If the release is

from dry cask storage, RASCAL enters a default start time that is the beginning of the day that the RASCAL data entry started.   This date and time must be updated to the time of the beginning of release

to the atmosphere.   In either case, the maximum release duration is 48 hours.

The *Pathway condition* is a simple option related to the operation of filters.   The default option is filters off. The filter option is not available for releases from Dry Cask Storage. This option should be changed for releases from damaged fuel unless the release pathway is known to be filtered and the filters are known to be operating. RASCAL Technical Document Section 2.4 describes the treatment of filters.

There are two *Leak rate* options: *Total failure (100% per hour)* or the user may specify a different *Percent volume* leak rate. The limits for user-specified *Percent volume* leak rate are 0 to 100% per hour.

2.4 Fuel Cycle / UF6 / Criticality

RASCAL includes a set of source term/release path options specifically for fuel cycle facilities and materials sites. In these options, the primary focus is on release of uranium oxide (UO_2) and uranium hexafluoride (UF_6). There are also options that deal with criticality events.

2.4.1 Event Location

There are two ways to specify materials event location information. The site can be selected from the list of *Materials Sites* in the database.   Or, the site information can be entered manually if the site is not in the database.

The *Load Existing Material Site from Database* option loads site data from the database if the site is in the database. The site is selected using the list of in the box below. The site name list can be filtered to show only certain sites using the List only these sites list. All data related to the site will be loaded automatically.

The *Describe a Material Site not in the Database* option is used to information about the site can be entered manually if the site is not among the sites listed in the database. Most of the information is descriptive only and does not influence the calculations. The descriptive information will appear in the case summary and will be used in labeling the model runs.

Latitude and *Longitude* are required information and are entered as decimal degrees (e.g., 35.5056 rather than 35 deg 30 min 20 sec). Use negative numbers for west longitudes and south latitudes. The latitude and longitude are important because they establish the location of the center of the computational grids. All meteorological station positions in the model domain are determined using the longitude and latitude of the center of the grid. Longitude and latitude are also used in estimating stability class. If RASCAL is being run with meteorological data from a single station approximate values for longitude and latitude are adequate.

Time Zone can be selected by name if in the United States or specified as an offset from Greenwich for all other time zones. The *Time Zone* is used to determine sunrise and sunset times. Sunrise and sunset times are used when stability class is estimated from meteorological data rather than being entered directly. The sunrise and sunset times are also used in determining if entered stability information is reasonable.

2.4.2 Fuel Cycle / UF6 / Criticality Source Terms and Release Paths

The Fuel Cycle / UF6 / Criticality *Source Term* screen lists four source term options that are more likely to occur at fuel cycle and materials facilities. It also provides options for entering nuclide specific releases either as release rates or concentration release rates. The selection of the *Source Term*

determines the possible *Release Path*; both the *Source Term* and *Release Path* are described for each *Fuel Cycle / UF6 / Criticality* event.
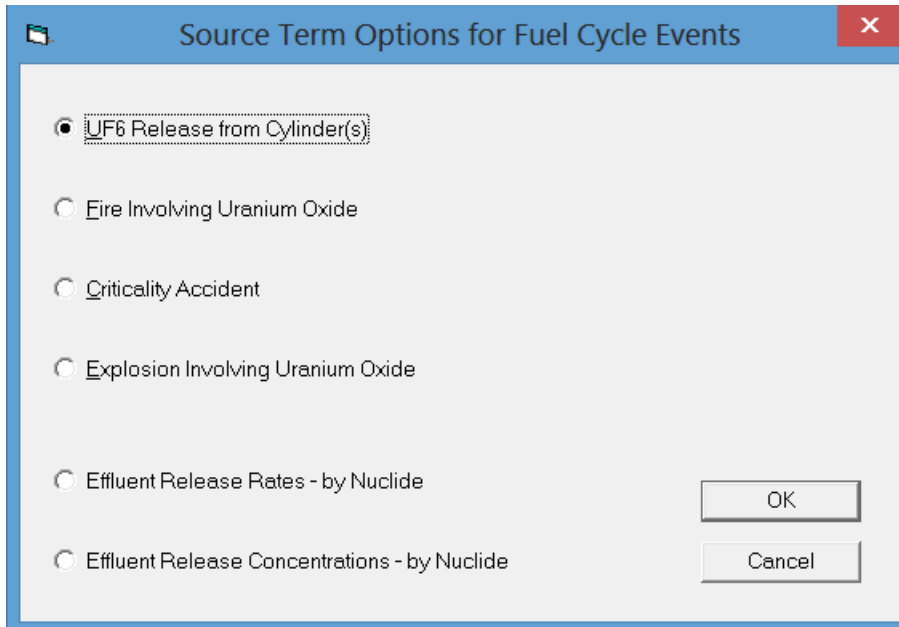
2.4.3 UF$_6$ Release from Cylinder(s) (Source Term)

Fuel cycle facilities store UF$_6$ in cylinders. When the *UF$_6$ Release from Cylinders* option is selected, a data entry screen appears that collects information on the UF$_6$ inventory at risk, the physical form of the UF$_6$ in the leaking cylinders, and the type of damage that has occurred to the cylinders.

The inventory at risk may be specified by entering either the type and number of cylinders or the UF_6 mass. The actual number of kilograms of UF_6 for each cylinder type is listed below:

Cylinder type	Kilograms of UF_6
14 ton	12,338
10 ton	9,539
2.5 ton	2,277

The physical form of the UF$_6$ and the type of damage are used to determine the maximum release fraction of UF$_6$ that can be released and the release rate. The user interface provides default estimates of release fractions and release rates based on user specified UF$_6$ form and cylinder damage types.   These default values may be modified by the user, if appropriate. RASCAL Technical Document Section 3.2.2 discusses the determination of UF$_6$ release fractions and release rates.

Users are also required to enter a time for the start of the release, and a uranium enrichment. Typical uranium enrichments for reactor fuel are in the 4 to 5 percent range.

2.4.4 UF$_6$ Release from Cylinder(s) (Release Path)

RASCAL has three release paths of UF$_6$ releases from cylinders:

1. *Direct* to the atmosphere
2. *Through building* (unfiltered pathway)
3. *Through filters*.

If release is *Direct* to the atmosphere, RASCAL treats the release as a UF$_6$ dense gas release. The UF$_6$ is allowed to react with moisture in the atmosphere and the resulting HF and UO$_2$F$_2$ plumes are allowed to rise as a result of the heat of reaction between UF$_6$ and the atmospheric moisture.   No further release path information is required.

If the release occurs in a building, the UF$_6$ is assumed to react with the moisture within the building. The release to the atmosphere is assumed to consist of HF and UO$_2$F$_2$. For dispersion and deposition, HF is assumed to be a neutral trace gas, and UO$_2$F$_2$ is assumed to be small particles. When the *Through Building* path is selected a box will be displayed for entry of information related to the release path. The data to be entered include release fractions from the building, air exchange rates, and release timing.   A similar box is displayed when the *Through filters* path option is selected.   The only difference is that the released fraction is from the filters rather than from the building.

RASCAL Technical Document Section 3.2.3 discusses release pathways for UF$_6$ releases from cylinders. RASCAL Technical Document Chapter 5 describes the UF$_6$ atmospheric model.

2.4.5 Fire Involving Uranium Oxide (Source Term)

This source term option is used for radioactive material in a fire. See RASCAL Technical Document Section 3.4. The release to the atmosphere is calculated by:

amount involved x atmosphere release fraction x inhalation fraction

The amount involved is the amount that is or may be in the fire. The atmospheric release fraction is the fraction that is expected to become airborne due to the fire. The inhalation fraction is the fraction of the airborne material expected to be the size that can/or will be inhaled. Suggested values are provided that were taken from NUREG-1140.

The data entry screen for fires involving uranium oxide has two boxes.   The box on the left shows five potential fire locations. The box on the right contains the data entry form for the location option selected. This data entry form changes as the location selection changes. The uranium enrichment level, entered below the left box, is used to calculate the uranium isotopic mix and dose conversion factors for the uranium. The boxes on the right are used to enter the information about the release. This information varies as a function of fire location.

Fire Involving Uranium Oxide

Location of fire:

- ● Production Process
- ○ HEPA Filter
- ○ Incinerator Exhaust
- ○ Waste Area
- ○ Uranium Mill

Uranium enrichment level: 5.0 percent

Source term conditions:

Production process

☑ Dry process (including pelletizing, sintering and rod loading)

Material at risk:	1.00E+00	kg
Airborne release fraction:	1.00E-03	
Respirable fraction:	1.00E+00	

☐ Wet process (including uranium recovery)

Material at risk:	1.00E+00	kg
Airborne release fraction:	3.00E-05	
Respirable fraction:	1.00E+00	

[OK]   [Cancel]   [Help]

Fire Involving Uranium Oxide

Location of fire:

- ○ Production Process
- ● HEPA Filter
- ○ Incinerator Exhaust
- ○ Waste Area
- ○ Uranium Mill

Uranium enrichment level: 5.0 percent

Source term conditions:

HEPA Filter

Material at risk:
- ● Actual amount
  - 1.00E-01 kg
- ○ Filter loading
  - 100 percent of 0.00E+00 kg

Filter condition:
- ● Filter at high temperature (480 deg F for 1 hr)
- ○ Filter failure

Airborne release fraction: 1.00E-04

Respirable fraction: 1.00E+00

[OK]   [Cancel]   [Help]

Fire Involving Uranium Oxide

Location of fire:

- ○ Production Process
- ○ HEPA Filter
- ● Incinerator Exhaust
- ○ Waste Area
- ○ Uranium Mill

Uranium enrichment level: 5.0 percent

Source term conditions:

Incinerator Exhaust

Material at risk:	1.00E+00	kg
Airborne release fraction:	4.00E-01	
Respirable fraction:	1.00E+00	

[OK]   [Cancel]   [Help]

Fire Involving Uranium Oxide

Location of fire:

- ○ Production Process
- ○ HEPA Filter
- ○ Incinerator Exhaust
- ● Waste Area
- ○ Uranium Mill

Uranium enrichment level: 5.0 percent

Source term conditions:

Waste

Material at risk:	1.00E+00	kg

Form of material: Solid form
                            ● Packaged in drums
                            ○ Loosely packed

                         Liquid form
                            ○ Combustible
                            ○ Non-Combustible

Airborne release fraction:	5.00E-04	
Respirable fraction:	1.00E+00	

[OK]   [Cancel]   [Help]
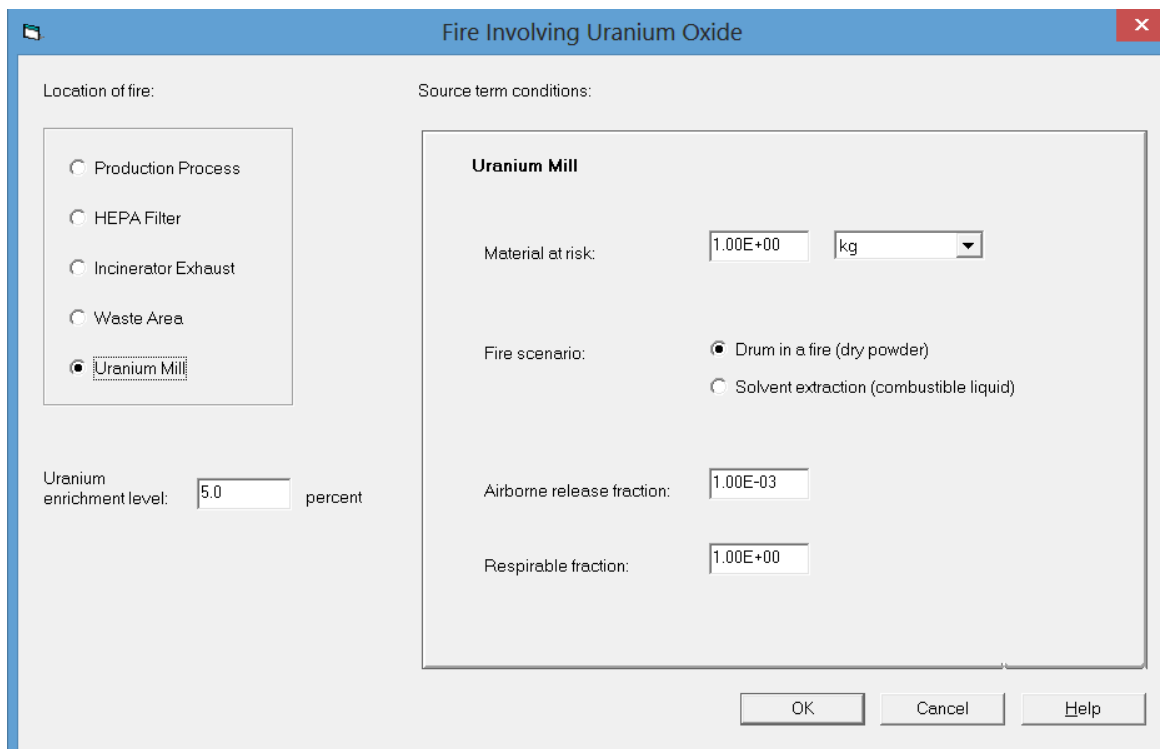
RASCAL Technical Document Section 3.4 discusses fires involving uranium oxide. The following table provides guidance on the airborne release fractions and respirable fractions for uranium oxide particles from the various fire locations.

Default Airborne Release Fractions (ARF) and Respirable (or Inhalation) Fractions (RF)

Scenario	Sub-type	ARF	RF
Production process	Dry process	0.001	1
	Wet process	0.00003	1
HEPA Filter	At high temperature	0.0001	1
	Filter failure	1	1
Incinerator exhaust		0.4	1
Waste fire	Solid packaged in drums	0.0005	1
	Solid loosely packed	0.05	1
	Combustible liquid	0.03	1
	Non-combustible liquid	0.002	1
Uranium mill	Drum in a fire	0.001	1
	Solvent extraction	0.03	1

2.4.6 Fire Involving Uranium Oxide (Release Path)

The release paths for fires involving uranium oxide are simple; a single release path form is used for data entry. The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice. The *Release height* is the height at which the fumes will be vented; a 10-m release height (ground level) is generally reasonable unless the fire is in location where the fumes might be vented through an isolated stack.

There are two options for *Pathway condition*, outside a building and inside a building. If the fire is outside there are no reduction mechanisms to reduce the consequences of the release. If the fire is inside, the release pathway may or may not contain filters. If the pathway is not filtered, RASCAL will reduce the release to the environment by a factor of 2 to account for deposition in the building. If the pathway is filtered, select the filter option and RASCAL will reduce the release to the atmosphere by a factor of 100 to account for the filters.

The last information to be entered is *Release timings*.   Enter the time of the start of the release to the atmosphere; it is likely the same as the time the fire started. Estimate the end of the release or the duration of the release.

RASCAL Technical Document Section 3.4.2 discusses the release pathway for uranium oxide fires.

2.4.7 Criticality Accident (Source Term)

The RASCAL *Criticality Accident* source term model calculates both the fission products being released to the atmosphere and the shine dose from the criticality. See RASCAL Technical Document Section 3.6.

When the *Criticality Accident* source term is selected, the user must first decide if there is or may be a *Single Burst* or *Multiple bursts*. The user must then *Define Fission Yield* of the criticality.   The fission yield may be specified either by selecting a *Type of system* having the criticality or *User defined* by defining the characteristics of the bursts.

If the user opts to select the system type, a menu of system types is presented to the user with the yield for each system type as shown below:

System	Initial Burst Yield (fissions)	Total Yield (fissions)
Solutions under 100 gal	1E17	3E18
Solutions over 100 gal	1E18	3E19
Liquid / powder	3E20	3E20
Liquid / metal pieces	3E18	1E19
Solid uranium	3E19	3E19
Solid plutonium	1E18	1E18
Large storage arrays - below prompt critical	None	1E19
Large storage arrays - above prompt critical	3E22	3E22

(from Table 3.4 of NUREG-1741 which were taken from NUREG/CR-6410)

If the user opts to define the characteristics of the bursts, the user must specify the fraction of the noble gases, iodine, and other isotopes generated by the criticality that will become airborne. RASCAL provides defaults that are considered conservative (i.e., will overestimate the release).

RASCAL calculates the shine dose from the criticality and reduction due to shielding. The criticality shine dose is proportional to $\exp(-A \times \text{shielding thickness})$, where A has a different value for each type of shielding material. The shine dose can be reduced due to shielding provided by a vessel, building, etc.

RASCAL determines the fission product release to the atmosphere from the fission yield, the atmospheric dispersion of those fission products, and the doses from the plume. RASCAL also calculates the direct gamma and neutron shine dose. The user can reduce the amount of material released to the atmosphere by specifying release fractions for noble gases, iodines, and other radionuclides. Further reductions can be specified by having a filtered release pathway. The user can also specify shielding to reduce the direct shine dose.

2.4.8 Criticality Accident (Release Path)

The *Criticality Accident* release path form is used to enter information about the release pathway and release timing. The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice. The *Release height* is the height at which the fumes will be vented; a 10-m release height (ground level) is generally reasonable unless the fumes might be vented through an isolated stack.

The *Release timings* for criticality accidents should start at the time of the initial criticality and continue at least until after the last burst.   Enter the *Start Date* and *Time* and the *End* Date and *Time* or *Duration* on the form.

RASCAL 4.3 assumes that criticality events occur within a building.   Information related to the release rate from the building is entered at the bottom portion of the *Criticality Accident Release Path* data entry form. Reduction factors may be entered to account for deposition within the building and filters if appropriate. Reduction factors are the fraction available for release. They vary from 0.0 (nothing released) to 1.0 (everything released). A noble gas reduction factor other than 1.0 is unlikely. The *Leak Rate to atmosphere* is related to the air exchange rate between the building and the environment.   Options are provided for typical release rates.

2.4.9 Explosion Involving Uranium Oxide (Source Term)

RASCAL can model the release of uranium oxide from an explosion. See RASCAL Technical Document Section 3.5.

First the user must characterize the explosion as one of the following:

- *detonation*; a shattering such as from a high explosive
- *deflagration*; enveloping with no shattering such as from a propane explosion
- *venting*; a result of over-pressurization such as a container rupture from high internal pressure

Next, the *Material form of the uranium oxide* must be specified as *Liquid*, *Solid*, *Powder*, or *Surface contamination*. Each combination of type and form has a default *Airborne release fraction* (ARF) and *Respirable fraction* (RF) as shown below. These values may be changed by the user.

Explosion Involving Uranium Oxide

Characterize the explosion:
- ● Detonation (shatter)
- ○ Deflagration (envelops - no shattering)
- ○ Venting (over-pressurization)

Material form of the uranium oxide:
- ○ Liquid
- ● Solid
- ○ Powder
- ○ Surface contamination

Material at risk: 1.00E+00 kg

Airborne release fraction: 1.000

Respirable fraction: 0.200

Uranium enrichment: 5.0 percent

OK   Cancel   Help

Airborne release fractions and respirable fractions for explosions involving Uranium oxide

Explosion characteristics	Material form	ARF	RF
Detonation (high explosive)	Liquid	1	1
	Solid	1	0.2
	Powder	1	0.2
	Surface contamination	0.001	1
Deflagration (fire)	Liquid	1x10-6	1
	Solid	0	0
	Powder	0.005	0.3
	Surface contamination	0.001	1
Venting

(sudden pressure change) | Liquid | 0.002 | 1 |
	Solid	0	0
	Powder	0.1	0.7
	Surface Contamination	0.001	1

(from Table 3.3 of NUREG-1741, corrected and taken from Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Nuclear Facilities: DOE Handbook. Vol. 1, 1994)

The source term is calculated using the airborne release fraction and the user specified mass of material at risk (mass of uranium oxide). The mass of uranium oxide is converted to a mass of uranium by multiplying by 0.88. Then, the mass of uranium is converted to an activity based on the user specified enrichment value. The respirable fraction is used in the calculation of inhalation dose.

2.4.10 Explosion Involving UO$_2$ (Release Path)

The release paths for explosions involving uranium oxide are simple; a single release path form is used for data entry. The *Path description* is not required, but entry of a description will facilitate post-event analysis; it should be entered as a matter of good practice. The *Release height* is the height at which the fumes will be vented; a 10-m release height (ground level) is generally reasonable unless the fire is in location where the fumes might be vented through an isolated stack.

There are two options for *Pathway condition*: *Outside building* and *Inside building*. If the explosion is outside there are no reduction mechanisms to reduce the consequences of the release. If the explosion is inside, the release pathway may or may not contain filters. If the pathway is not filtered, RASCAL will reduce the release to the environment by a factor of 2 to account for deposition in the building. If the pathway is filtered, select the filter option and RASCAL will reduce the release to the atmosphere by a factor of 100 to account for the filters.

The last information to be entered is *Release timings*. Enter the time of the *Start* of the release to the atmosphere; it is likely the same as the time of the explosion. Estimate the *End of the Release* or the *Duration* of the release.

RASCAL Technical Document Section 3.4.5 discusses the release pathway for explosions involving uranium oxide.

2.4.11 Effluent Release Rates – by Nuclide (Source Term)

RASCAL permits users to specify source term directly by entering the nuclide name and activity release rate (e.g., Ci/s).   RASCAL treats the release rates entered as release rates to the environment.   For this source term, RASCAL does not calculate nuclide decay and ingrowth until the activity is released to the environment.

Release rates may be entered for three release periods. The periods may be separated, end-to-end, or overlapping. If overlapping periods are defined the release rates for each nuclide during the overlapping period will be the sum of the release rates for the two periods. RASCAL Technical Document Section 1.2.7 discusses source terms based on effluent release rates.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness.   Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.4.12 Effluent Release Concentrations – by Nuclide (Source Term)

RASCAL permits users to specify source term directly by entering the nuclide name, activity concentration (e.g., Ci/cm^3), and release flow (e.g., cm^3/s).   From this information, RASCAL calculates activity release rates. RASCAL treats the calculated release rates entered as release rates to the environment.   For this source term, RASCAL does not calculate nuclide decay and ingrowth until the activity is released to the environment.

Nuclide concentrations and effluent flows may be entered for three release periods. The periods may be separated, end-to-end, or overlapping. If overlapping periods are defined, the calculated release rates for each nuclide during the overlapping period will be the sum of the release rates for the two periods. RASCAL Technical Document Section 1.2.7 discusses source terms based on effluent release rates.

Note: RASCAL 4.3 does not evaluate the numerical values entered for this source term type for reasonableness.   Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.4.13 Effluent Release Rate or Concentration (Release Path)

The *Release Path* for all source terms in RASCAL that are specified by user entered rates is assumed to be direct to the environment.   RASCAL does not include any mechanisms such as filters or sprays in the path between the source and the environment. *Release height* may be ground level (10 m) or elevated.   A ground level release should be assumed unless the facility has stack that extends well above the level of structures in the area. If the facility has a stack and the stack height has been entered in the database, the stack height will be listed to the right of the release height data entry fields.

Release timings set in the *Release Path* form controls the release to the environment.   The user sets both the *Start Date* and *Time* of the release to the environment and the *End Date* and *Time* of the release or *Release duration*.

For *release rate* and *release concentration* source terms, the beginning of the release to the environment can be at the beginning of the first release period, or it may be after the beginning of the first release period. It cannot be before the beginning of the first release period.   Note if the release to the environment begins after the beginning of the first release period, activity released by the source term prior to the beginning of the release to the environment will not be released to the environment. For fires, the beginning of the fire and the beginning of the release to the environment are assumed to be coincident. The end of the release may be defined either by date and time or by duration.

2.5 Other Radioactive Material Releases
There are a number of facilities that process nuclear material for medical and industrial uses that are not fuel cycle facilities. RASCAL 4.3 may be used to estimate the consequences of radiological release from these facilities.

2.5.1 Event Location
There are two ways to specify location information for a radiological materials release event at site that use nuclear material. The site can be selected from the list of *Materials Site* in the database.   RASCAL 4.3 has a list of sites using nuclear material. Site information can be entered manually for *Material sites not in the database*. The require information consists of the site *Name*, *Time Zone* and location (*Latitude* and *Longitude*). The other information is optional.

2.5.2 Other Radiological Material Releases Source Terms

When the site has been selected, the source term may be entered. There are there options for entering a materials facility source term:

- *Effluent Release Rate - by Nuclide*
- *Effluent Concentration - by Nuclide*
- *Sources and Material in a Fire*.

These options are presented on the Source Term Options screen; select one as appropriate.

2.5.2.1 *Effluent Release Rate and Effluent Concentration (Source Term)*

Effluent Release Rates - by Nuclide and *Effluent Release Concentrations - by Nuclide* data entry forms are nearly identical.   It is not necessary to enter anything in The *Description of measurement* field; however, information entered in the field will be extremely useful when the calculation is reviewed at a later time. For an *Effluent Release Rates - by Nuclide* source term, the *Effluent release rate units* must be selected;

the default set of units for nuclide release rates is µCi/s. For the *Effluent Release Concentrations - by Nuclide* source term, both *Effluent flow rate units* and *Effluent concentration units* must be selected; the default flow units are cm^3/s, and the default concentration units are Ci/cm^3. Other units may be selected from the options provided.

Separate source terms may be provided for three *Release period definitions*. The periods may be consecutive; they may overlap; or they may be separated by periods with no release.   RASCAL assumes that all releases occur through a common release pathway.

Release rates or *Release Concentrations* for individual nuclides are entered in the table at the bottom of the screen. Use caution in specifying overlapping release periods to avoid double counting. If there are overlapping release periods, the release rates or concentrations for any nuclide that occurs in both periods will be combined for the period overlap.

Note: RASCAL 4.3 does not evaluate the numerical values entered for these source term types for reasonableness. Unreasonably large values could exceed the inventory available for release. They might also cause numerical problems in the interface or calculations. Further, use of these release rates for an extended period may not be reasonable and may lead to unreasonable consequence estimates.

2.5.2.2 Sources and Material in a Fire (Source Term)

The *Sources and Material in a Fire* source term form is similar to the other materials source term data entry forms. It includes a *Fire Location* field to identify the fire location. It is not necessary to enter anything in the *Fire Location* field; however, information entered in the field will be extremely useful when the calculation is reviewed at a later time. The *Activity units for material at risk* must be selected. The default set of units for activity is Ci. Other units may be selected from the options provided.

There is a *U enrichment level* field that should be used if there is uranium activity at risk in the fire. Uranium in typical reactor fuel has an enrichment of 5% or less. RASCAL Technical Document Section 3.9, Table 3-13 discusses the specific activity of uranium as a function of enrichment.

The bottom portion of the entry form is used to enter a *List of material at risk in the fire*. The nuclides may be selected from a drop down list, or they may be entered manually. The total activity at risk must be entered for each nuclide. When nuclides are entered, RASCAL populates the form with default *Airborne Release Fractions* and *Respirable Fractions* that are appropriate for common chemical forms of the nuclides. The default values may be changed when appropriate. The table to the right of the nuclide list provides guidance related to airborne fire release fraction and respirable fraction values. See RASCAL Technical Document Section 3.7, Tables 3-11 and 3-12 for more information on release fractions.

2.5.3 Other Radioactive Material Releases (Release Path)
The *Release Path* for all Materials facilities release in RASCAL are assumed to be direct to the environment. RASCAL does not include any mechanisms such as filters or sprays in the path between the source and the environment.

The release pathway data entry form is used to enter release height and release timing. No other information is required. *Release height* may be ground level (10 m) or elevated. A ground level release should be assumed unless the facility has stack that extends well above the level of structures in the area. If the facility has a stack and the stack height has been entered in the database, the stack height will be listed to the right of the release height data entry fields.

Release timings set in the Release Pathway form controls the release to the environment.   The user sets both the beginning of the release to the environment and the end of the release.   For *Effluent Release Rates – by Nuclide* and *Effluent Release Concentrations – by Nuclide* source terms, the beginning of the release to the environment can be at the beginning of the first release period, or it may be after the beginning of the first release period. It cannot be before the beginning of the first release period.   Note if the release to the environment begins after the beginning of the first release period, activity released by the source term prior to the beginning of the release to the environment will not be released to the environment. For *Sources and Material in a Fire*, the beginning of the fire and the beginning of the release to the environment are assumed to be coincident.   The end of the release may be defined either by date and time or by duration.

2.6 Meteorology

When the STDose module of RASCAL is started, the initial screen guides users through the steps of setting up the input needed to run RASCAL. The steps are listed on the buttons on the left side of the screen. The first four steps define the *Event Type*, the *Event Location*, the *Source Term*, and the *Release Path*. The fifth step is to define the meteorological conditions that affect material once it is released to the environment.   The meteorological conditions determine where the material goes, the concentrations in the environment, and how fast it deposits on surfaces. When the *Meteorology* button is selected a screen appears that presents three options: *Actual Observations and Forecasts*, *Predefined Data (Non Site-specific)*, and *Predefined Data (Site Specific).*

2.6.1 Actual Observations and Forecasts

If the *Actual Observations and Forecasts* option is selected, a list of available (existing) meteorological datasets will appear in the *Available Datasets*. A dataset is selected from the list by clicking on the dataset name. An action must be specified. The action option buttons are: *Create New*, *Edit Existing*, *Import*, and *Delete*. If the *Create New* button is selected, the user will be guided through the meteorological data entry process. If the *Edit Existing* button is selected, the selected dataset will be presented for editing.   If the *Import* button is selected, a browser window will open that will allow you to navigate to a file containing the meteorological data to be imported. If the *Delete* button is selected, the selected dataset will be deleted. Note: a dataset selection must be made before clicking on either the *Edit Existing* button or the *Delete* button.
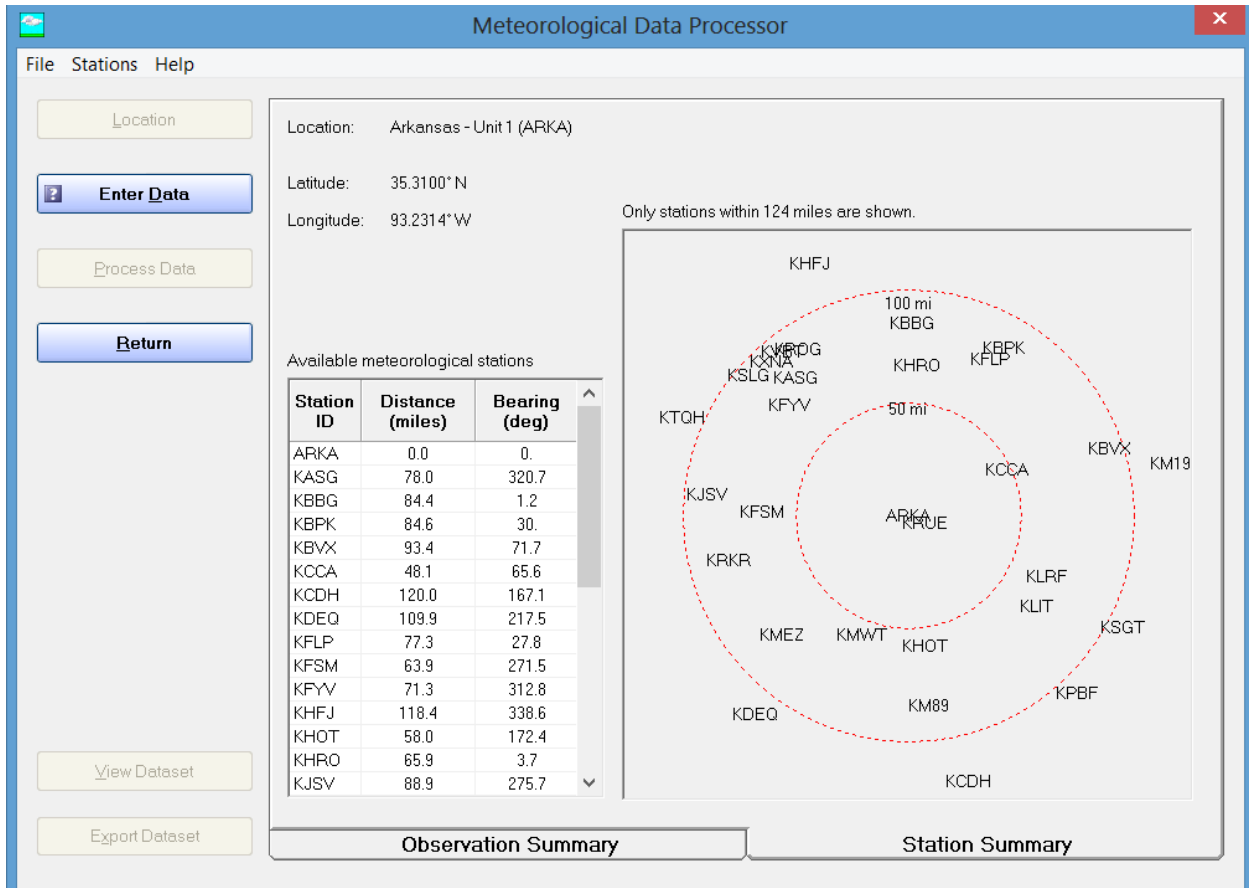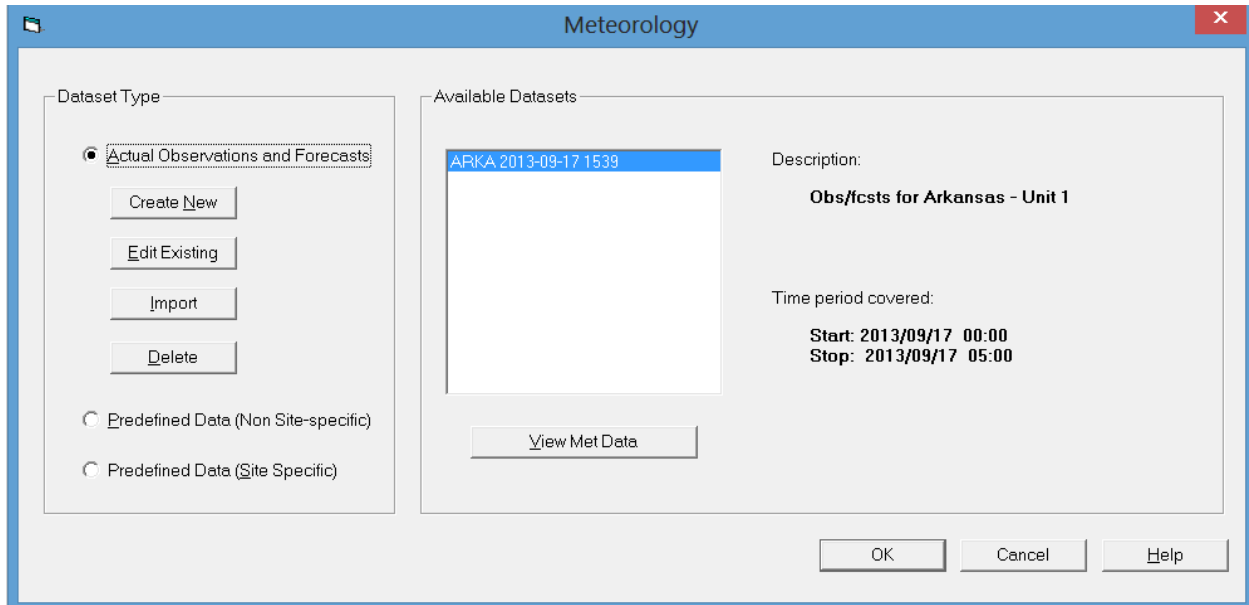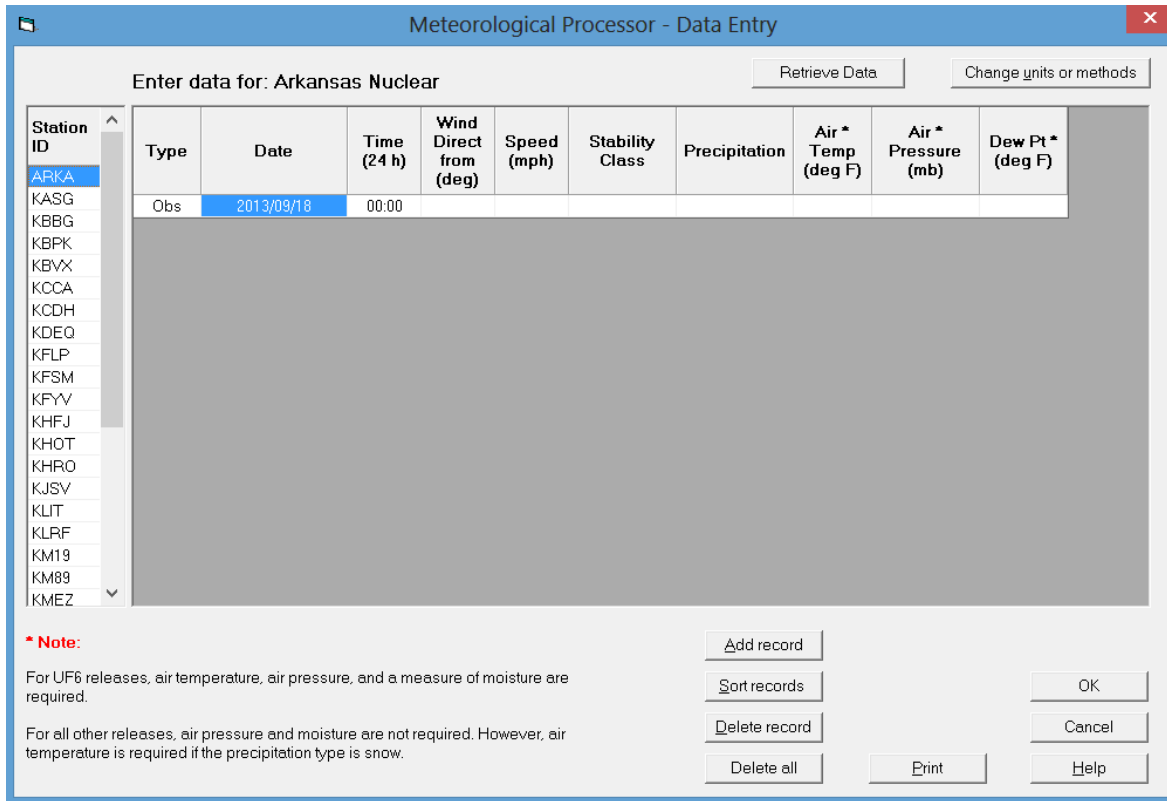
2.6.2 Predefined Data (Non Site-specific)

If the *Predefined Data (Non Site-specific)* option is selected, a list of available datasets will appear in the *Available Datasets* list.   RASCAL includes several default (typical) datasets that may be used before onsite data become available. A data set may be selected by clicking on the name. A dataset description is shown to the right of the dataset list. All datasets assume a west (270°) wind direction (plume to the east). Dates and times of the data will be adjusted to match the time of release.
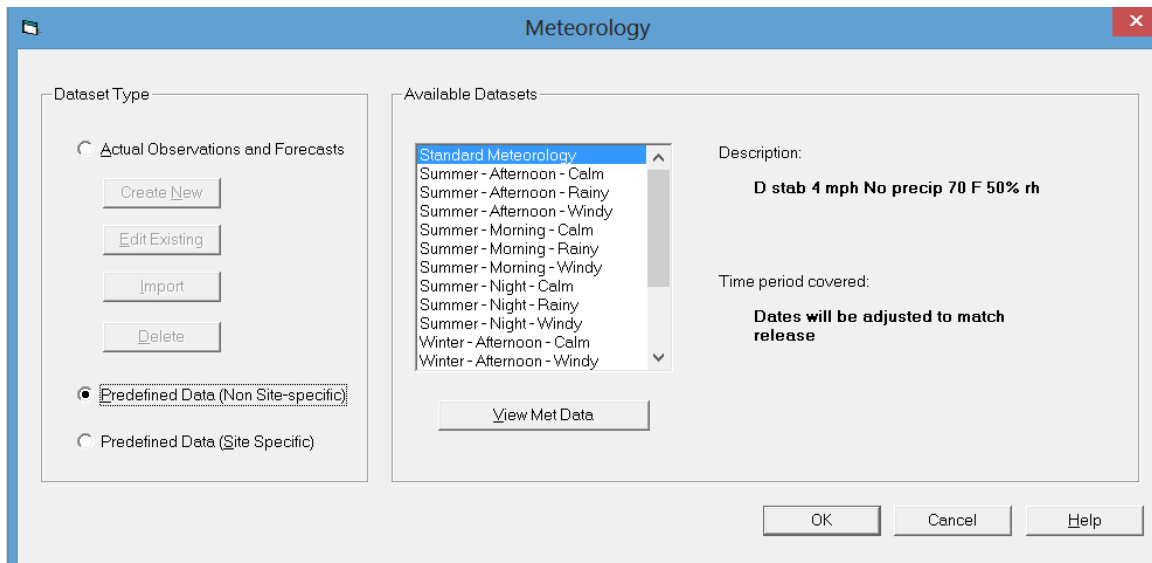
2.6.3 Predefined Data (Site-specific)

If the *Predefined Data (Site-specific)* option is selected, a list of available datasets will appear in the *Available Datasets* list.   RASCAL has the option to use site specific meteorological datasets. However, RASCAL does not include any of these sets. Predefined site specific datasets can be created for frequently occurring meteorological conditions. If a predefined site-specific meteorological dataset has been created and saved in the site file, it will appear in the *Available Datasets* list.
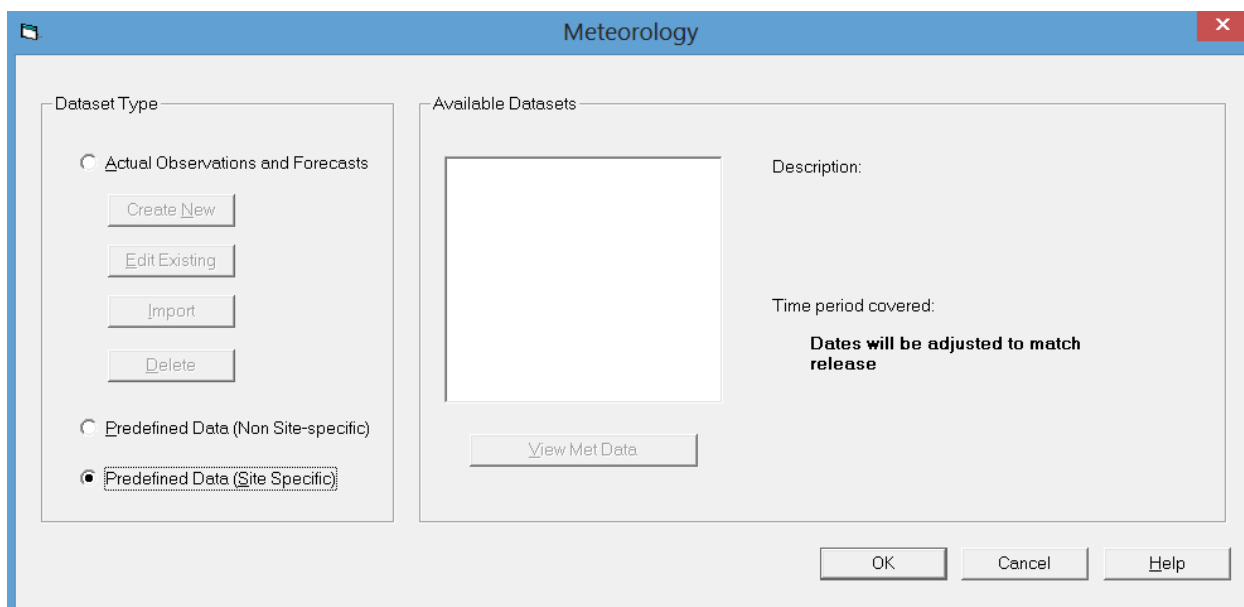
2.7 Calculate Doses

The *Calculate Doses* button is used to initiate dose calculations. A *Start the Calculations* form will appear when the button is clicked. The calculations will begin when this form is completed. RASCAL computational results are displayed as soon as the dose calculations are complete. The initial display will show the results of the dose calculations.   The results of the source term calculations are also available. These results may be viewed by selecting the *Source Term* tab.   A *Case Summary* tab provides access to a detailed summary of information related to the calculations.

2.7. 1 Dose Calculation Options

There are three sets of dose calculation options: distances, release timing (*End Calculations at*), and inhalation dose conversion factors. The options are selected on the left side of the *Start the Calculations screen.*

2.7.1.1 Distances

Close-in doses are calculated for a polar grid centered on the point of release. The receptors are spaced every 10 degrees around 8 concentric circles. Default radii for the circles are set by RASCAL 4.3 based on the choice of the far field grid. The radii are shown on the screen. If the user opts not to make calculations on the far field grid, the radii of the polar grid range from 0.1 mi to 2.0 mi or 0.1 km to 2.0 km. There are separate settings for the close-in grids used for UF_6 releases.

The radii may be changed by the user by selecting the "user defined" option. User defined distances may be in miles or kilometers and must be entered in order of increasing distance from the release point. The allowed range for the distances is 0.01 to 12.5 miles (0.01 to 20.0 km). A warning will be shown if distances are set less than 0.062 mi (0.1 km). Doses calculated for distances less than 0.062 mi (100 m) from the release point should be used with caution because point source release assumptions may have been violated. See Chapter 4 of the RASCAL 4 technical manual for more information.

The far field doses are calculated on a Cartesian grid assuming that the release point is at the center of the grid. RASCAL 4.3 has four Cartesian grids. The distances from the center to the edge of the grids are 10 mi (16 km), 25 mi (40 km), 50 mi (80 km), and 100 mi (160 km), respectively.   Spacing between computational nodes on the Cartesian grid increases as the dimensions of the grid increases.   The node

spacings are 0.5 mi (0.8 km), 1.25 mi (2.0 km), 2.5 mi (4.0 km), and 5.0 mi (8.0 km), respectively. Far field calculations should be made starting with the smallest grid that includes areas of interest to ensure maximum spatial resolution in dose estimates. Calculations may be rerun on a larger grid if necessary by simply changing the grid selection and clicking *OK*.

Note that the far field calculations take plume transit time into account explicitly. Therefore, the plume will not reach the edge of the grid unless the end of calculations is long enough after the start of release to permit plume travel to the edge of the grid. The 8 hour default end of calculations is generally sufficient for short releases and the 10 mi grid. However, it may not be sufficient for short releases using the 50 mi or 100 mi grids and will not be sufficient for long duration releases. See the Section 4.2 of the RASCAL Technical Document for discussion of plume transport.

RASCAL keeps track of material beyond this distance so it can account for recirculation of material if the wind reverses.

2.7.1.2 End Calculations at

The far-field calculations take plume transit time into account explicitly. Therefore, the plume will not reach the edge of the grid unless the end of calculations is long enough after the start of release to permit plume travel to the edge of the grid. The 8 hour default end of calculations is generally sufficient for short releases and the 10 mi grid. It is may not be sufficient for short releases using the 50 mi or 100 mi grids, and is will not be sufficient for long duration releases.

As a general rule of thumb, the end of calculations should be set equal to the release duration plus the time require to travel to the edge of the grid (distance divided by wind speed) plus an hour or two. Note, however, that dose calculations made for long duration releases or to distances of more than a few miles using limited meteorological data should be used with extreme caution. Variations in atmospheric conditions (wind direction, wind speed, and atmospheric stability) in time and space may lead to errors in model estimates of plume positions and estimated doses.

2.7.1.3 Inhalation Dose Factors

RASCAL 4.3 includes two sets of inhalation dose conversion factors, dose conversion factors from ICRP-26/30 (FGR-11) and ICRP-60/72 (FGR-13). In general, the differences in CEDE dose conversion factors are small compared to the uncertainties in the source term and dispersion. Changing from the ICRP-26/30 dose conversion factors to the ICRP-60/72 dose conversion factors decreases the total CEDE doses by about 29 percent. There are larger differences in the thyroid dose conversion factors. However, the nuclides with the largest differences account for less than 1 percent of the ICRP-60/72 thyroid dose potential. Overall, changing from ICRP-26/30 to ICRP-60/72 dose conversion factors decreases the thyroid dose potential by about 3 percent. See RASCAL Technical Document Sections 4.9 and 4.9.1 for a more detailed discussion of these dose conversion factors.

The ICRP-60/72 inhalation dose conversion factors must be used if RASCAL 4.3 dose calculations are to be used to evaluate recommendations related to administration of KI. The EPA PAGs related to KI are based on child thyroid dose. RASCAL 4.3 only calculates a child thyroid dose if the ICRP-60/72 dose conversion factors are selected. ICRP-26/30 does not include child thyroid dose conversion factors. See RASCAL 4.3 Technical Supplement Section 2.2 for a discussion of child thyroid dose calculations.

2.7.1.4 Case Information

The right side of the Dose Calculation Options screen is for information related to the case. The case title is required. While limited in length, it should be descriptive. If the case is one of a set of cases, the title may be used to identify both the set and the case within the set.

The case description is optional; however, it may be extremely important for post event analysis. The case description should list items such as

- purpose of the calculation
- sources of information about reactor status and conditions
- underlying assumptions related to source term and release path
- rationale for deviation from assumptions and input in previous cases.

The case *Title* is a required entry for the model run and should be entered in the text field. The *Title* should be unique in order to differentiate it easily from other sets of similar calculations. The case *Title* will appear on all printed output. There is a limit of 60 characters for the case *Title*.

The *Case Description* is an optional item. It is entered in a text field and may contain a description of the modeling run. The *Case Description* is a good place to record assumptions and provide details that will allow others to understand the user-selected model options. There is a limit of 600 characters for the *Case Description*.

The *Dose Analyst* entry is also optional. For formal training, exercises, and real events, the name of the dose analyst should be entered. In general this should be the initial point of contact for questions about the RASCAL run. The two options on this screen allow use of the analyst name set as a default (on the Settings screen) or use of an entered name.

2.7.2 Maximum Dose Values Tab
When RASCAL dose calculations are complete, the *Maximum Dose Values* tab becomes available. The screen displays *Maximum Dose Values* as a function of distance from the release point. The dose values displayed initially have been extracted from the Cartesian grid. The doses are the highest values for nodes at about the distances shown. The nodes are neither likely to be located at the exact distances indicated nor under the plume centerline. However, the values provide a quick insight to the significance of the release relative to the EPA's Protective Action Guides (PAGs). The *Detailed Results* output should be used to obtain more detailed information about the consequences of the release.
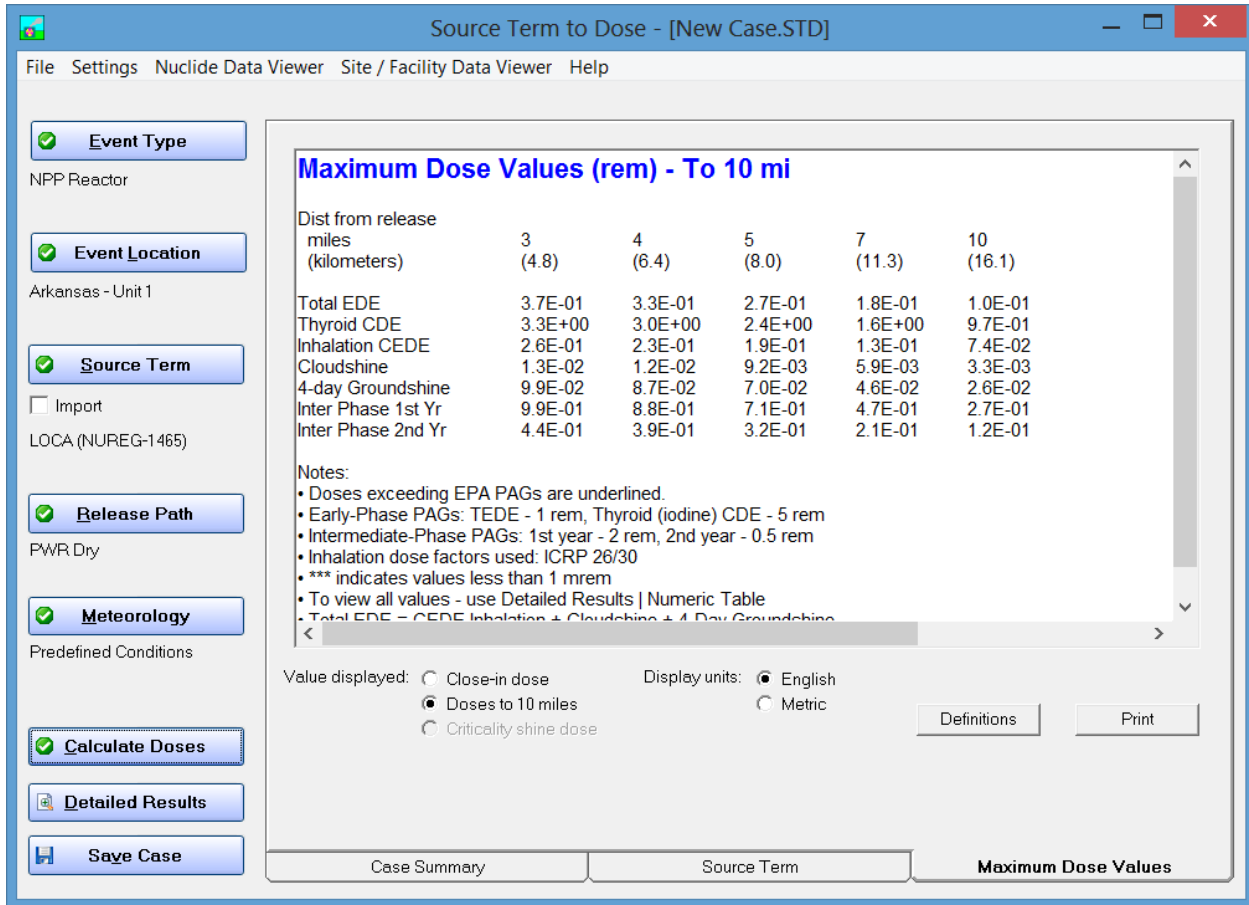
Maximum Dose Values close to the release point may be viewed by changing the *Value displayed* option. Close-in doses are extracted from the polar grid; they are plume center-line values. Be sure to look at the maximum value table notes, as these notes contain important information related to the table.
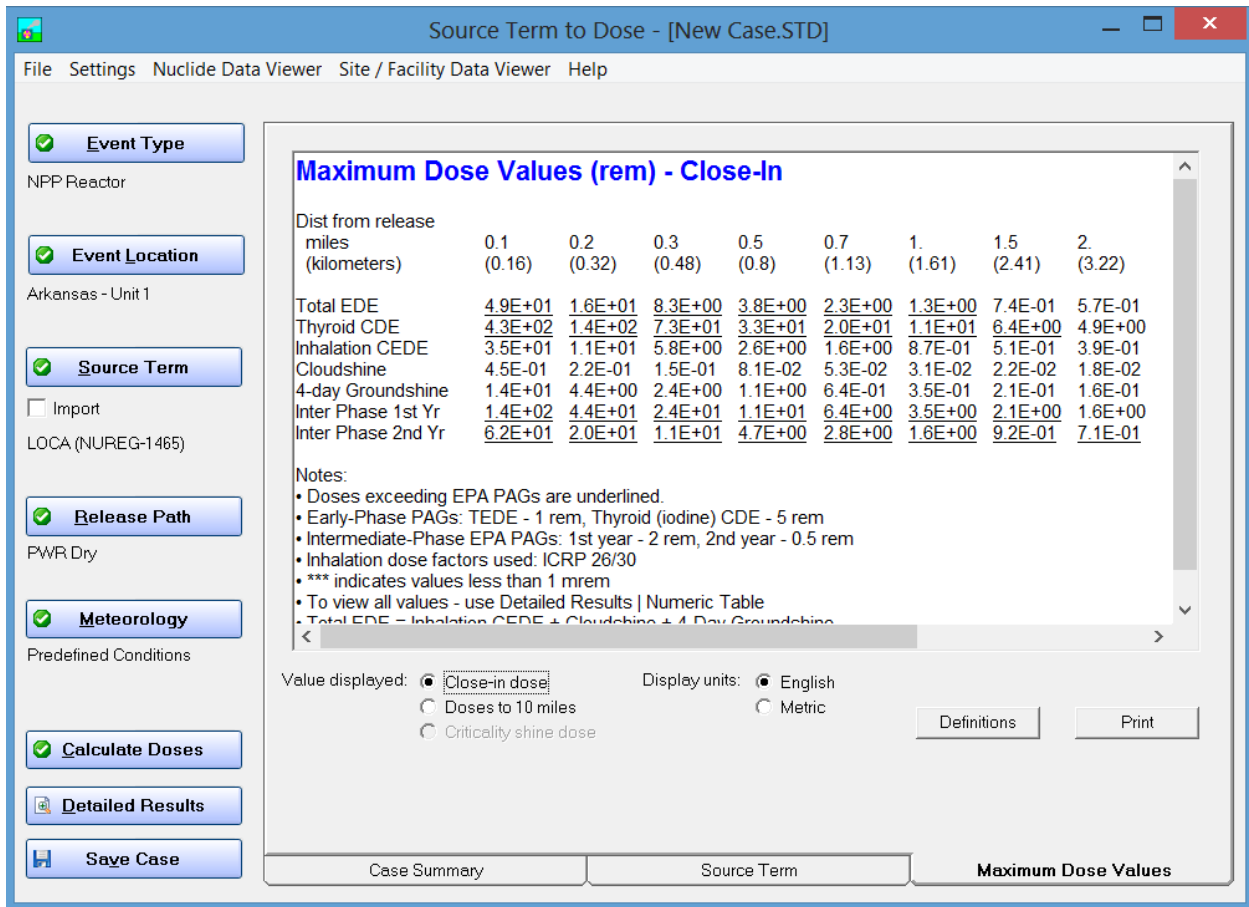
The RASCAL 4.3 dose calculations are described in detail in Section 4.9 of the RASCAL Technical Document and Section 2.2 of the Technical Supplement.

2.7.3 Source Term Tab

The *Source Term* tab provides users with easy access to the output of the RASCAL source term models. These models are described in detail in Chapter 1 of the RASCAL technical document and Chapters 1 and 4 of the RASCAL Technical Supplement.

There are four sections to the information displayed on the *Source Term* tab for reactor accidents. They are:

- A summary of the activity by type (noble gas, iodine, other)
- A summary of the location of activity at the end of the simulation (e.g. core, containment, environment)
- A list of the activity released to the environment by nuclide Lists of the 10 nuclides most important to the submersion, inhalation, and
- groundshine dose pathways along with the cumulative contribution to dose potential.

The location of activity is based on activity balance calculations of the source term model. The activity balance calculations are described in Chapter 5 of the RASCAL 4.3 Technical Supplement. Dose potential and the importance model are described in Chapter 6 of the RASCAL 4.3 Technical Supplement.   Use the scroll slide on the right side of the box to see the complete list of nuclides and lists of important nuclides.
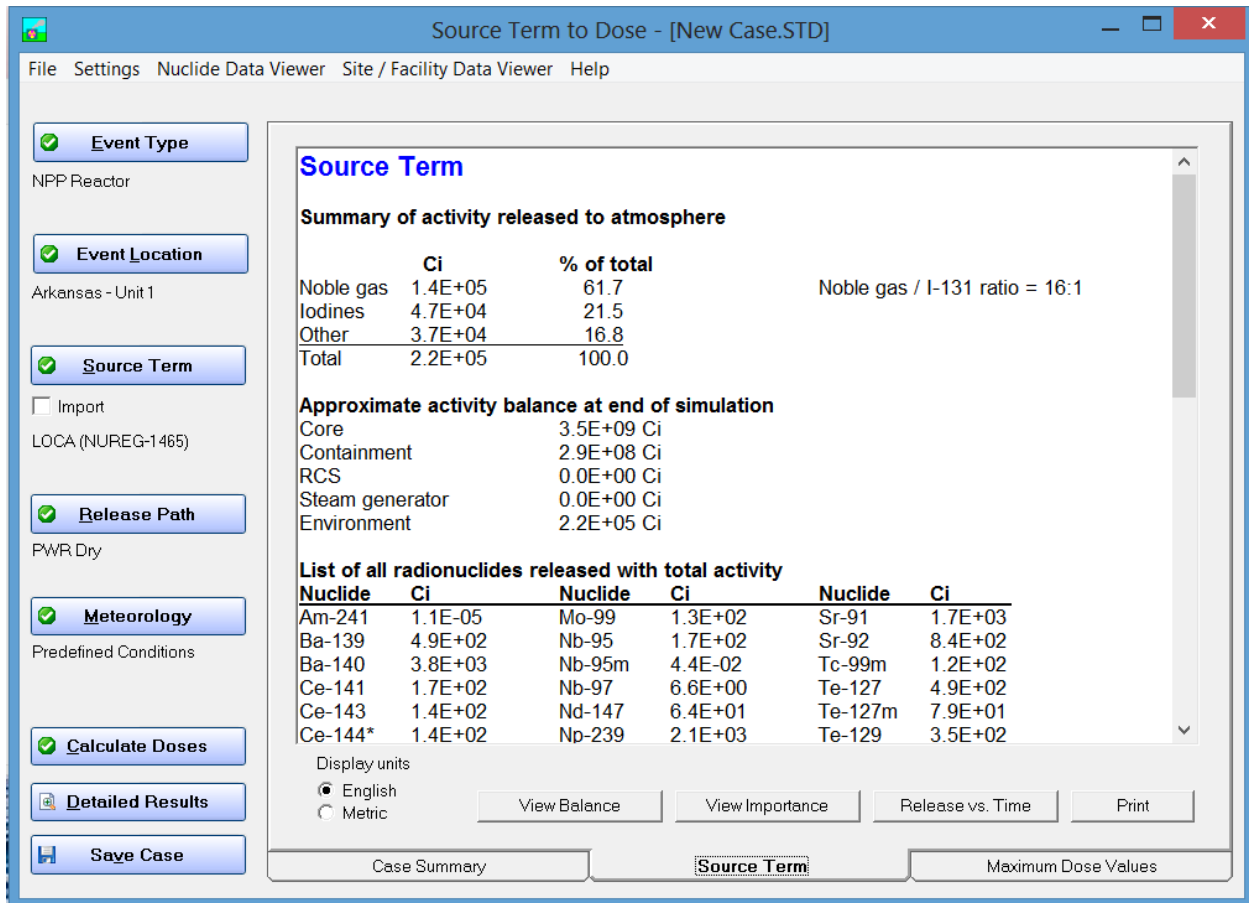
Three buttons at the bottom of the screen (*View Balance*, *View Importance*, and *Release vs. Time*) provide access to more detailed source term information.

2.7.3.1 View Balance

The *View Balance* button displays the location and transfer of activity in the plant and to the environment for selected nuclides and nuclide groups as a function of time starting with reactor shut down. The list on the left of the screen determines the nuclide or nuclide group for activity. The reactor locations and transfers are determined by the reactor accident type and release path.

The following table shows the locations and transfers that are displayed. The location and transfer abbreviations are described in RASCAL 4.3 Technical Supplement Chapter 5. The activity shown in the *Rx Core* (reactor core), *Cont* (containment), and *Env* (environment) columns is the activity at the end of the time period. The activity in the core and containment is adjusted for decay and depletion. The activity in the *Env* column is the total activity released to the environment, not corrected for decay. The activity shown in the *Rx-Cont* and *Cont-Env* columns is the activity transfer during the period.

Time (h)	Rx Core	Rx-Cont	Cont	Cont-Env	Env
SD	6.86E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rel Start	6.86E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.25	6.68E+07	1.71E+06	1.27E+06	2.65E+01	2.65E+01
0.50	6.50E+07	1.71E+06	2.21E+06	4.60E+01	7.25E+01
0.75	6.04E+07	4.61E+06	5.04E+06	1.05E+02	1.78E+02
1.00	5.58E+07	4.61E+06	7.14E+06	1.49E+02	3.27E+02
1.25	5.11E+07	4.60E+06	8.69E+06	1.81E+02	5.08E+02
1.50	4.65E+07	4.60E+06	9.84E+06	2.05E+02	7.13E+02
1.75	4.19E+07	4.60E+06	1.07E+07	2.23E+02	9.36E+02
2.00	3.92E+07	2.63E+06	9.85E+06	2.05E+02	1.14E+03
2.25	3.71E+07	2.13E+06	1.02E+07	2.13E+02	1.35E+03
2.50	3.49E+07	2.13E+06	1.19E+07	2.47E+02	1.60E+03
2.75	3.28E+07	2.13E+06	1.35E+07	2.81E+02	1.88E+03
3.00	3.06E+07	2.13E+06	1.50E+07	3.13E+02	2.20E+03
3.25	2.85E+07	2.13E+06	1.65E+07	3.44E+02	2.54E+03
3.50	2.63E+07	2.13E+06	1.79E+07	3.74E+02	2.91E+03
3.75	2.42E+07	2.12E+06	1.93E+07	4.02E+02	3.32E+03
4.00	2.38E+07	4.25E+05	1.90E+07	3.96E+02	3.71E+03
4.25	2.38E+07	0.00E+00	1.83E+07	3.81E+02	4.09E+03
4.50	2.38E+07	0.00E+00	1.76E+07	3.67E+02	4.46E+03
4.75	2.37E+07	0.00E+00	1.69E+07	3.53E+02	4.81E+03
5.00	2.37E+07	0.00E+00	1.63E+07	3.40E+02	5.15E+03
5.25	2.37E+07	0.00E+00	1.57E+07	3.27E+02	5.48E+03
5.50	2.37E+07	0.00E+00	1.51E+07	3.15E+02	5.79E+03
5.75	2.37E+07	0.00E+00	1.45E+07	3.03E+02	6.09E+03
6.00	2.37E+07	0.00E+00	1.40E+07	2.91E+02	6.39E+03
6.25	2.37E+07	0.00E+00	1.34E+07	2.80E+02	6.67E+03
6.50	2.37E+07	0.00E+00	1.29E+07	2.70E+02	6.94E+03

Source Term Type	Release Path	Activity Locations and Transfers
PWR Events		
Station Blackout	Cont Leak	Rx Core, Rx-→Cont, Cont, Cont→Env, Env
	SGTR	Rx Core, Rx→RCS, RCS, RCS→SG, SG, SG→Env, Env
	Bypass	Rx Core, Rx→RCS, RCS,RCS→Env, Env
LB Loss-of-Coolant	Cont Leak	Rx Core, Rx→Cont, Cont, Cont→Env, Env
	SGTR	Rx Core, Rx→RCS, RCS, RCS→SG, SG, SG→Env, Env
	Bypass	Rx Core, Rx→RCS,RCS, RCS→Env, Env
Coolant Release	Cont Leak	NA
	SGTR	RCS, RCS→SG, SG, S→Env, Env
	Bypass	RCS, RCS→Env, Env

BWR Events

Station Blackout	Wet Well	Rx Core, Rx→Cont, Cont, Cont→Env, Env
	Dry Well	Rx Core, Rx→Cont, Cont, Cont→Env, Env
	Bypass	Rx Core, Rx→RCS, RCS, RCS→Env, Env
LB Loss-of-Coolant	Wet Well	Rx Core, Rx→Cont, Cont, Cont→Env, Env
	Dry Well	Rx Core, Rx→Cont, Cont, Cont→Env, Env
	Bypass	Rx Core, Rx→RCS, RCS, RCS→Env, Env
Coolant Release	Wet Well	NA
	Dry Well	NA
	Bypass	RCS, RCS-Env, Env

2.7.3.2 View Importance

The *View Importance* button displays information on the importance of nuclides to the dose pathways. Importance is based on the amount of each nuclide released to the environment and the dose conversion factors for the nuclides.   Importance does not consider atmospheric dispersion as the nuclides are transported downwind. However it does include consideration of deposition, weathering, resuspension, and breathing rate. It also considers decay after the end of the model run.   Chapter 6 of the RASCAL 4.3 Technical Supplement describes the model used to evaluate importance and the importance results.

Results of the Importance Calculations

Relative Importance of TEDE at End of Release

Days	0	1	7	30	183	365	1825	3650
rTEDE	1.0E+00	5.2E-07	3.1E-07	1.2E-07	7.1E-08	5.7E-08	1.7E-08	8.8E-09

Relative Importance of Pathways to TEDE

Days	0	1	7	30	183	365	1825	3650
Submersion	1.8E-02	4.3E-04	2.8E-04	5.7E-05	3.0E-07	2.4E-07	9.1E-08	8.7E-08
Inhalation	9.8E-01	4.5E-02	4.4E-02	1.5E-02	9.9E-05	8.3E-05	5.7E-05	8.5E-05
Groundshine	5.4E-07	9.6E-01	9.6E-01	9.8E-01	1.0E+00	1.0E+00	1.0E+00	1.0E+00

Cumulative Importance to Dose at t = 0 days

0 1 7 30 183 365 1825 3650	Rank	Submersion Nuclide	Submersion Cumulative Fraction	Inhalation Nuclide	Inhalation Cumulative Fraction	Ground Shine Nuclide	Ground Shine Cumulative Fraction	Ingestion Nuclide	Ingestion Cumulative Fraction	TEDE Nuclide	TEDE Cumulative Fraction
	1	Xe-133	0.31	Sr-90	0.22	La-140	0.40	I-131	0.26	Sr-90	0.22
	2	I-132	0.55	I-131	0.43	I-132	0.57	Cs-134	0.50	I-131	0.43
	3	La-140	0.75	Pu-241	0.55	Cs-134	0.70	Cs-137*	0.61	Pu-241	0.55
	4	I-131	0.81	Sr-89	0.64	Cs-136	0.75	Te-132	0.69	Sr-89	0.63
	5	Cs-134	0.87	Cm-242	0.72	Te-132	0.80	Ba-140	0.77	Cm-242	0.71
	6	Cs-136	0.90	Cs-134	0.79	I-131	0.85	La-140	0.83	Cs-134	0.78
	7	Te-132	0.92	Ce-144*	0.85	Ba-140	0.89	Sr-90	0.88	Ce-144*	0.83
	8	Ba-140	0.94	Te-132	0.88	Cs-137*	0.92	Sr-89	0.93	Te-132	0.87
	9	Cs-137*	0.95	Cs-137*	0.91	Te-131m	0.93	Cs-136	0.94	Cs-137*	0.90
	10	I-133	0.96	Ru-106*	0.93	Sb-127	0.94	Te-129m	0.95	La-140	0.92
	11	Te-131m	0.97	La-140	0.94	I-133	0.95	Ce-144*	0.96	Ru-106*	0.93
	12	Sb-127	0.98	Ba-140	0.96	Sr-89	0.96	I-133	0.96	Ba-140	0.95

Print full file   Help   Close

There are three sections to the Importance results output, *Relative Importance of TEDE at End of Release*, *Relative Importance of Pathways to TEDE*, and *Cumulative Importance to Dose*. The first two sections provide information that puts the importance of the pathways in perspective.

The first section of the Importance display shows how the TEDE dose potential decreases the release point as the decay time increases near. *rTEDE* at 0 days includes the dose potential from initial plume passage, *rTEDE* after day 0 only include the dose potential from deposited activity. See RASCAL Technical Supplement Section 6.1 for the definition of dose potential.

The second section of the Importance display shows how the contributions of the three dose pathways contributing to TEDE near the release point change as the decay time increases. Initially, the inhalation pathway is dominant because the importance calculation includes the period of plume passage. After plume passage, the primary pathway contributing to TEDE is the external dose from deposited activity.

The third section of the Importance display lists the nuclides released in order of importance for each dose pathway and the cumulative importance of the nuclide and all more importance nuclides. Separate lists are presented for the submersion, inhalation, and groundshine pathways. Importance lists are also provided for the ingestion pathway and for TEDE. The list on the left side of the display controls the delay between the end of the model run and the time of the importance calculation. The effects of radioactive decay and daughter ingrowth on importance can be seen by changing the delay time. Scrolling through the importance list clearly shows that most nuclides in the source term do not have a significant contribution to dose following a reactor accident. Note: when the cumulative importance reaches 1.00, the remaining nuclides in the list are not shown. They have a combined importance of less than 0.005 (0.5%). For some source terms the cumulative importance for all nuclides may be 0.0 for times greater than 0 days. This indicates that all nuclides have decayed to extremely low levels.

2.7.3.3 Release vs. Time

The *Release vs. Time* button provides users with access to the full time-dependent RASCAL 4.3 source term. The activity (Ci) of each radionuclide released to the environment is shown for each 15-min period. The size of the activity table shown in the display is directly proportional to the length of the release period. In general, it will be necessary to scroll in the vertical to see all of the nuclides and to scroll in the horizontal to see all time periods.

Using the *Plot* button on the right side of the display, users may simultaneously view the releases of up to four nuclides as a function of time.
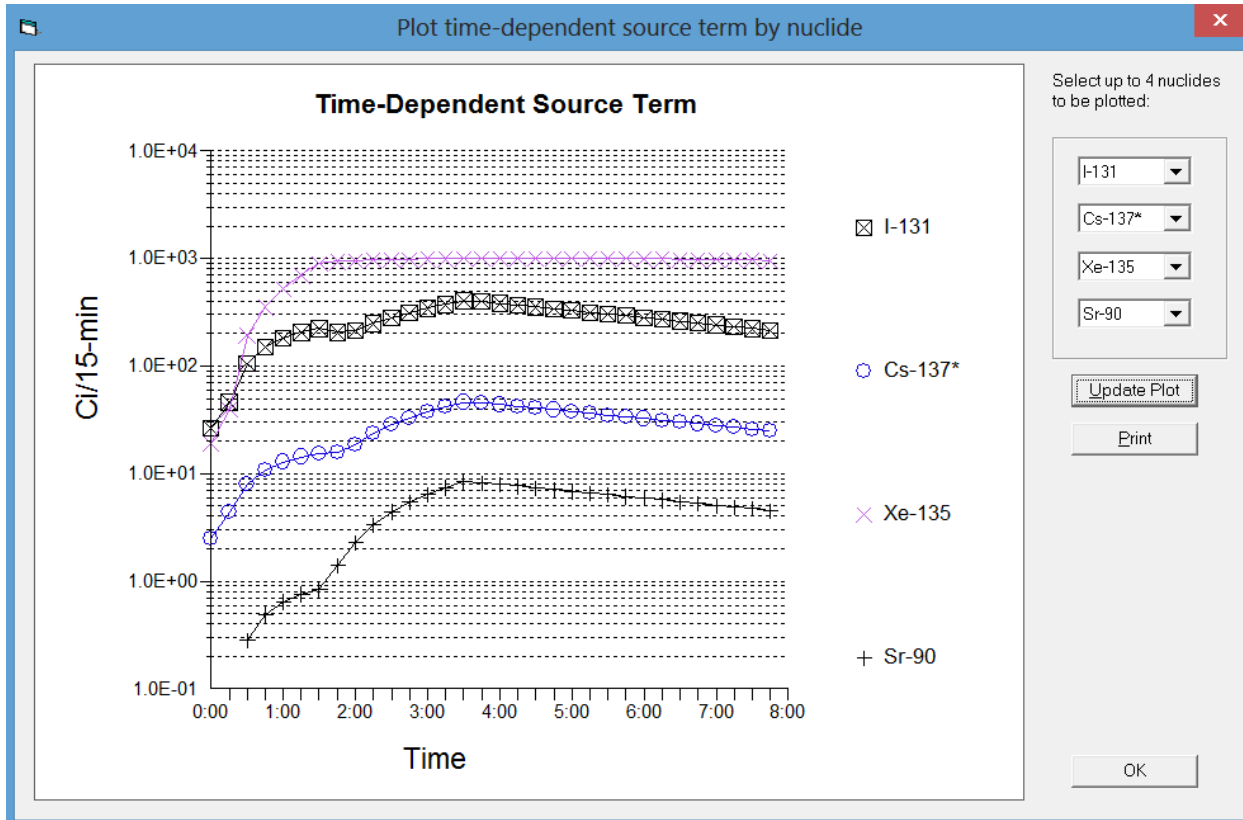
The *Export* button on the right side of the display may be used to create a source term file that may be used as input to other models. The upper portion of the export screen allows users to specify the format of the output file, and the lower portion controls the nuclides included in output file. The output file can include release rates for all nuclides, or the file contents can be limited to a subset of the nuclides selected based on importance to dose.
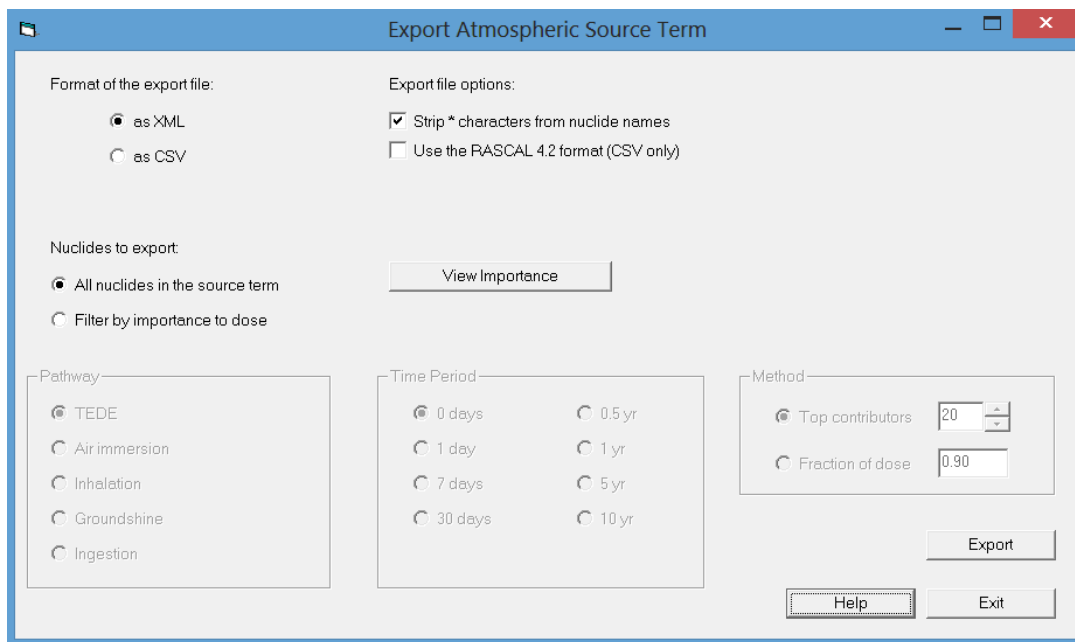
If the option to produce a file containing a subset of nuclides is selected, the subset is defined by dose pathway for determining importance, time period following the end of the simulation, and method of limiting the number of nuclides. A separate export file must be created for each subset of nuclides if subsets are required for more than one dose pathway. The time period option controls the decay, ingrowth, and weathering of nuclides. Plume passage is only considered if 0 days is selected. Importance for other periods is based only on deposited and activity that is resuspended. The method option allows users to set the number of nuclides in the file by choosing the Top contributors option or to allow RASCAL to set the number of nuclides based on fraction of dose potential. If the fraction of dose potential option is selected, the nuclides that contribute most to the dose potential will be included in the file until the dose potential reaches the user defined fraction of the total dose potential.

See the RASCAL Technical Supplement for a description of the export file.   RASCAL Technical Supplement Chapter 6 discusses importance and dose potential.

2.7.4 Case Summary
The *Case Summary* tab provides users with a description of the case. The description includes the event type; case description; the location of the event and the parameters of the event facility; descriptions of the source term, release pathway, and meteorology; and computational parameters. Use the scroll control on the right side of the box to view the entire summary.

There should be sufficient information in the case summary to permit another analyst to recreate the case. If the case description is adequate, another analyst should understand why various options were selected and what use was to be made of the results.
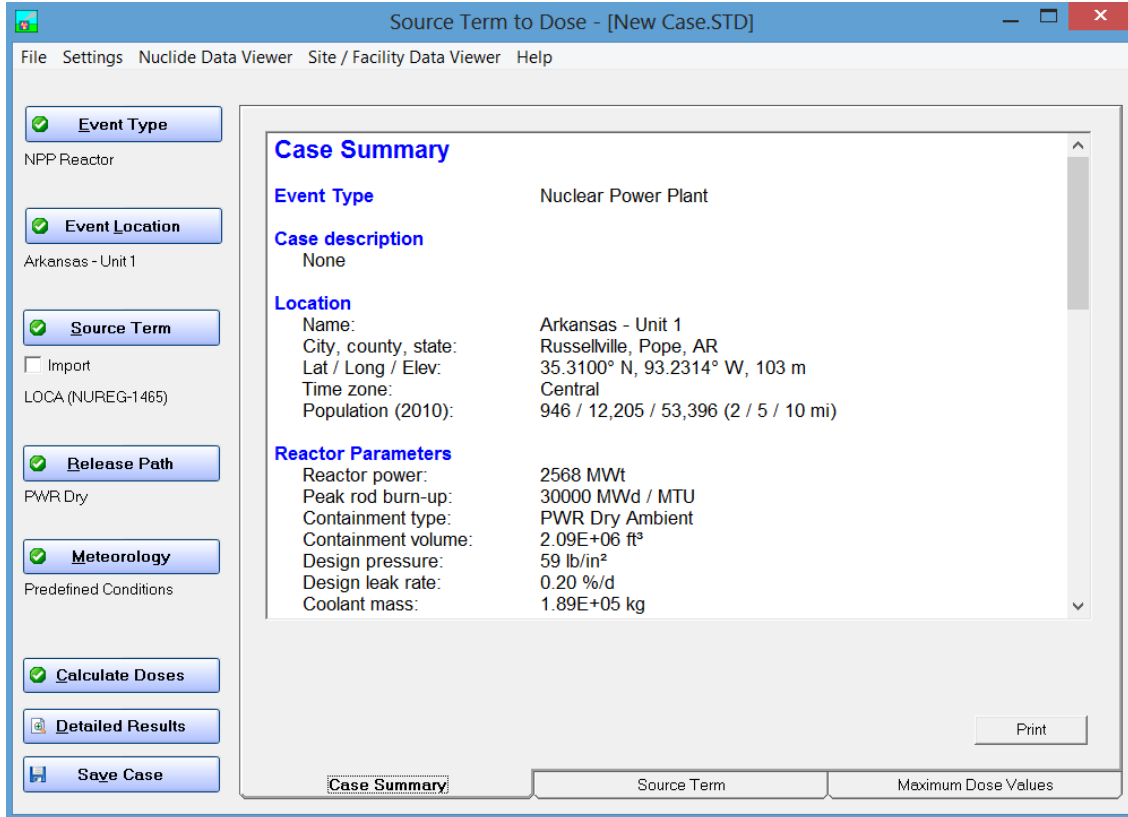
2.8 Detailed Results

The *Detailed Results* button is used to access the complete set of RASCAL computational results. Clicking on the button brings up the menu used to choose the result to be displayed. RASCAL Technical Document Section 4.9 discusses dose calculations.

The top part of the option menu lists the various computational products that are available. From left to right the options are TEDE, the components of TEDE, external exposure rates, and acute dose estimates for important organs. Below these options are estimates of the thyroid CDE and ground shine and surface contamination. At the bottom of this part of the screen are intermediate phase TEDE estimates and I-131 air concentrations.

The bottom part of the menu controls the display. The left box is used to control the time period used to summarize the results. The time period may be the entire period from the beginning of the release to the environment and the end of calculation, 15-minute period ending at a specific time, or a specified period (minimum of 15 minute resolution) between the start of release and the end of calculation. The center box controls the display grid and format. The model results for either grid can be displayed as a color-coded footprint overlaid on a background map or as numerical values in tabular form. In addition, locations for special receptors such as schools can be defined and results obtained for these locations by interpolation of values on the Cartesian grid. The right box controls the display units. The by default the results are displayed in English (conventional) units (e.g., Ci and rem). If the SI option is selected the results will be displayed in SI units (e.g., Bq and Sv).

Close-In Footprint

Inhalation CEDE

Accumulated between 2013/09/18 00:00 and 2013/09/18 08:00

Example Case

Arkansas - Unit 1

Legend

- 🟩 0.01 to 1 rem
- 🟨 1 to 5 rem
- 🟥 > 5 rem

Data at individual model receptors

Position cursor over cell to display

- - - - -

at

- - - - -

from release point

Click cell to plot dose rate vs time

Impact Area

Export

Save Image

Print

OK

Help

RASCAL v4.3

Show on display: ☑ Radius circles   ☑ 22½° sectors   ☑ Map background

Close-In Numeric Table

Inhalation CEDE (rem)

Accumulated between 2013/09/18 00:00 and 2013/09/18 08:00

Distance		Bearing from release point									
mi	km	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°
0.10	0.16	—	—	—	1.54E-03	2.52E-01	3.42E+00	1.38E+01	2.79E+01	3.46E+01	2.79E+01	1.38E+01
0.20	0.32	—	—	—	3.14E-04	6.10E-02	9.34E-01	4.10E+00	8.67E+00	1.09E+01	8.67E+00	4.10E+00
0.30	0.48	—	—	—	1.08E-04	2.51E-02	4.33E-01	2.06E+00	4.56E+00	5.83E+00	4.56E+00	2.06E+00
0.50	0.80	—	—	—	2.08E-05	6.79E-03	1.48E-01	8.25E-01	2.00E+00	2.63E+00	2.00E+00	8.25E-01
0.70	1.13	—	—	—	5.19E-06	2.39E-03	6.64E-02	4.34E-01	1.16E+00	1.57E+00	1.16E+00	4.34E-01
1.00	1.61	—	—	—	—	5.59E-04	2.28E-02	1.95E-01	6.10E-01	8.74E-01	6.10E-01	1.95E-01
1.50	2.41	—	—	—	—	5.90E-05	5.07E-03	7.41E-02	3.21E-01	5.13E-01	3.21E-01	7.41E-02
2.00	3.22	—	—	—	—	6.38E-06	1.30E-03	3.51E-02	2.18E-01	3.94E-01	2.18E-01	3.51E-02

Color all cells with a value equal to or greater than: [0.0]   Color   Clear Color

Click cell to plot dose rate vs time

Export   OK

Print   Help

10-mile Footprint

Inhalation CEDE

Accumulated between 2013/09/18 00:00 and 2013/09/18 08:00

Example Case

Arkansas - Unit 1

Data at individual model receptors

Position cursor over cell to display

- - - - -

at

- - - - -

from release point

Click cell to plot dose rate vs time

Legend

- 🟩 0.01 to 1 rem
- 🟨 1 to 5 rem
- 🟥 > 5 rem

RASCAL v4.3

Impact Area

Export

Save Image

Print

OK

Help

Show on display: ☑ Radius circles ☑ 22½° sectors ☑ Map background

---

10-mile Numeric Table

Inhalation CEDE (rem)

Accumulated between 2013/09/18 00:00 and 2013/09/18 08:00

Distances are in miles from release point

	00.50 W	00.00	00.50 E	01.00 E	01.50 E	02.00 E	02.50 E	03.00 E	03.50 E	04.00 E	04.50 E	05
05.50 N	—	—	—	—	—	—	—	—	—	—	—	—
05.00 N	—	—	—	—	—	—	—	—	—	—	—	—
04.50 N	—	—	—	—	—	—	—	—	—	—	—	—
04.00 N	—	—	—	—	—	—	—	—	—	—	—	—
03.50 N	—	—	—	—	—	—	—	—	—	—	—	—
03.00 N	—	—	—	—	—	—	—	—	—	—	—	—
02.50 N	—	—	—	—	—	—	—	—	—	—	—	—
02.00 N	—	—	—	—	—	—	—	—	—	—	—	—
01.50 N	—	—	—	—	—	—	—	—	—	—	1.52E-03	—
01.00 N	—	—	—	—	—	3.94E-04	5.60E-03	1.06E-02	1.69E-02	2.25E-02	2.86E-02	—
00.50 N	—	—	—	3.94E-02	8.46E-02	1.06E-01	1.11E-01	1.18E-01	1.28E-01	1.29E-01	1.27E-01	—
00.00	—	—	2.39E+00	7.99E-01	4.85E-01	3.65E-01	2.93E-01	2.61E-01	2.53E-01	2.33E-01	2.11E-01	—
00.50 S	—	—	—	3.94E-02	8.46E-02	1.06E-01	1.11E-01	1.18E-01	1.28E-01	1.29E-01	1.27E-01	—
01.00 S	—	—	—	—	—	3.94E-04	5.60E-03	1.06E-02	1.69E-02	2.25E-02	2.86E-02	—
01.50 S	—	—	—	—	—	—	—	—	—	—	1.52E-03	—
02.00 S	—	—	—	—	—	—	—	—	—	—	—	—
02.50 S	—	—	—	—	—	—	—	—	—	—	—	—
03.00 S	—	—	—	—	—	—	—	—	—	—	—	—
03.50 S	—	—	—	—	—	—	—	—	—	—	—	—
04.00 S	—	—	—	—	—	—	—	—	—	—	—	—
04.50 S	—	—	—	—	—	—	—	—	—	—	—	—
05.00 S	—	—	—	—	—	—	—	—	—	—	—	—

Color all cells with a value equal to or greater than: `0.0`   Color   Clear Color

Position cursor over cell to see bearing and distance

Click cell to plot dose rate vs time

Export   Print   OK   Help

Double clicking on a cell in most of the detailed results displays will bring up a display of the time variation at the cell location. The left part of the display shows the cumulative dose as a function of time, and the right shows the dose or dose commitment rate as a function of time.
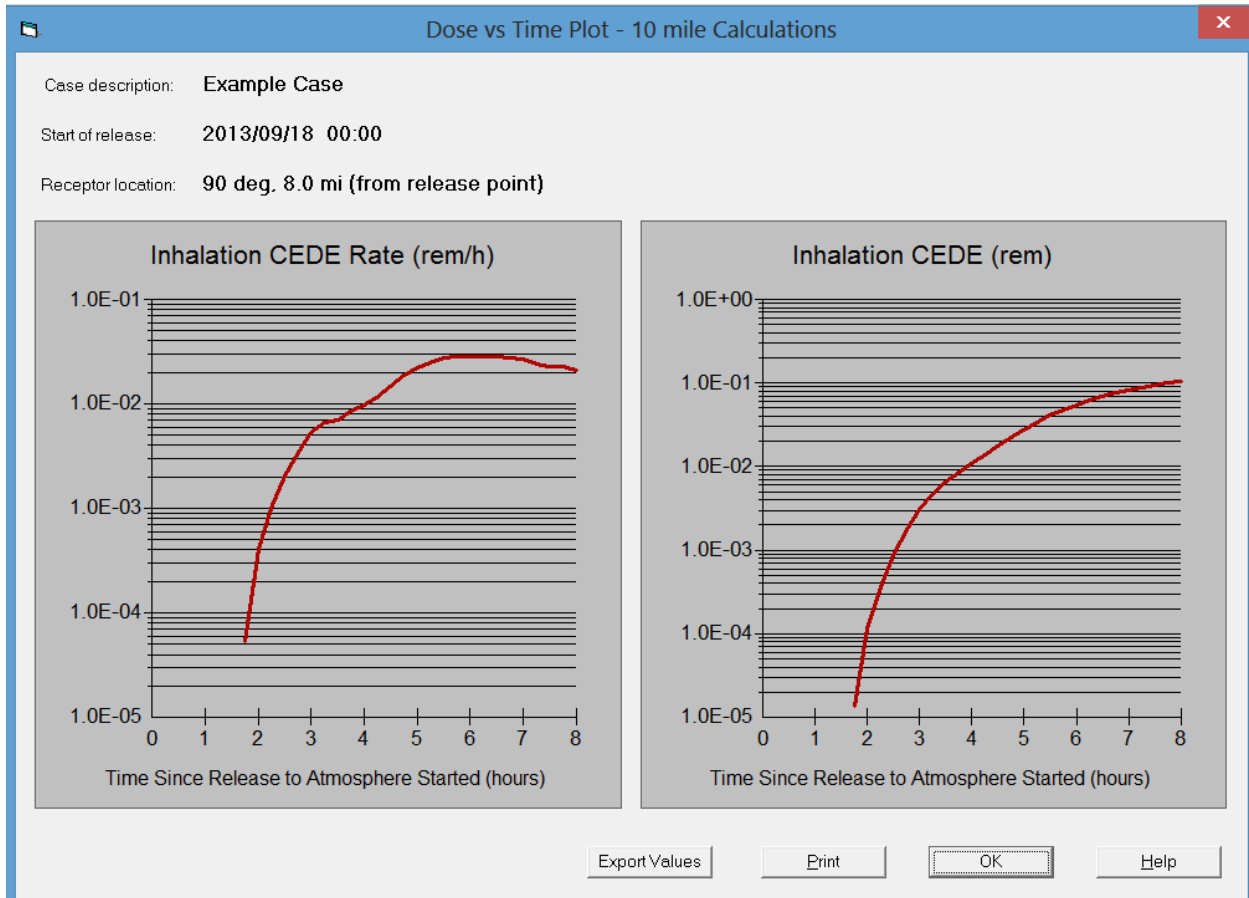
2.9 Save Case
A modeling run can be saved as a single file (extension .STD) for later recall. Either click the *Save Case* button in the bottom-left corner of the main screen or use the *File* menu. The default file name will be the description entered on the calculations screen. The file name and the saving location can be changed.
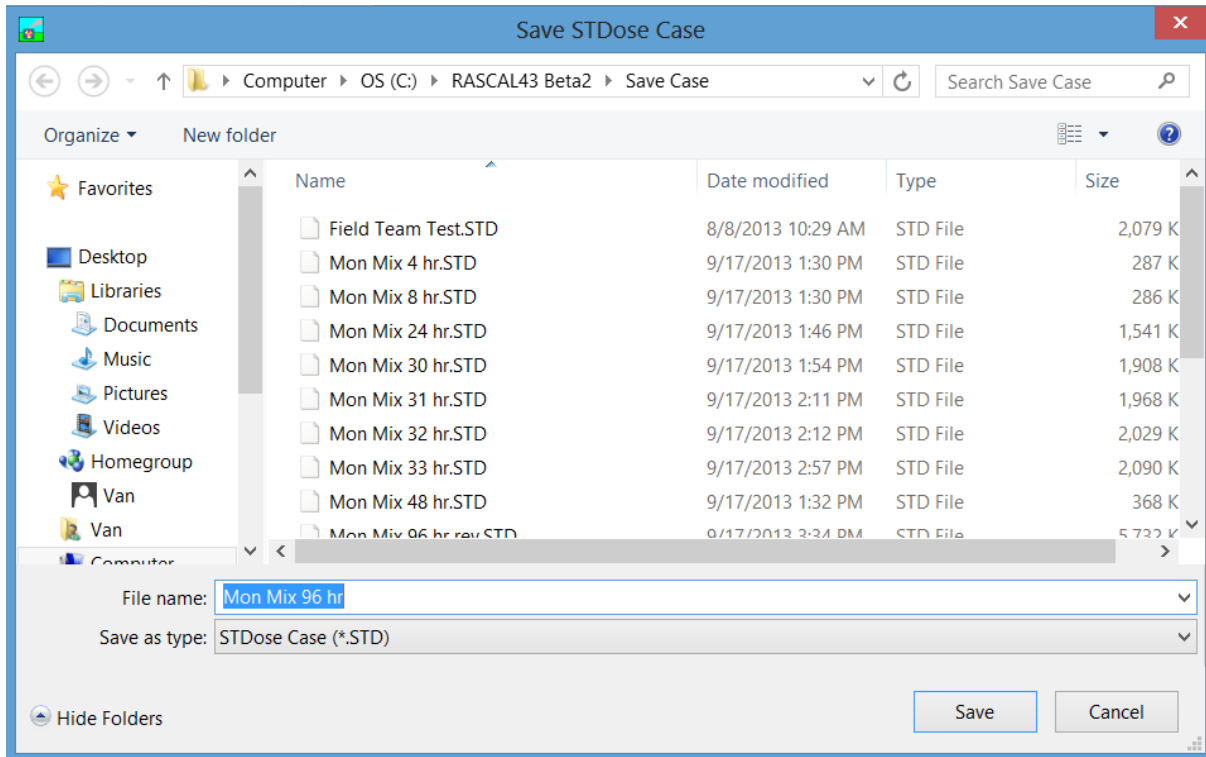
3 Result Types

RASCAL generates a large number of results. The results of the dose calculations and some of the results of the results of the source term calculations are available to users through the user interface. The following table lists result types available to the user, where they are found in the RASCAL output and the where the calculations leading to the result are described in the RASCAL 4.3 documentation.

Result Type	RASCAL Output[a]	RASCAL Documentation[b]
Total Effective Dose Equivalent (TEDE)	MVT, DR	TD 4.9.5
Thyroid Committed Dose Equivalent (CDE)	MVT, DR	TD 4.9.1
Child Thyroid CDE (ICRP-60/72 only)	MVT, DR	TS 2.2
Acute Doses (Bone, Lung, Colon)	DR	TD 4.9.6, TD 4.9.1
Inhalation Committed Effective Dose Equivalent (CEDE)	MVT, DR	TD 4.9.1
Cloudshine Dose	MVT, DR	TD 4.9.3
Groundshine Dose	MVT, DR	TD 4.9.2
4-Day Groundshine Dose	MVT, DR	TD 4.9.2
External Gamma Exposure Rate	DR	TD 4.9.4
External Gamma Plus Exposure Rate	DR	TD 4.9.4
Field Team Dose Projections	DR→ Ext Gamma, Ext Gamma + Beta	TS 2.4
Source Term Model Activity Balance	ST	TS 5.0
Importance	ST, DR→Ground Concentration	TS 6.1
Ground Activity Concentration	DR	TD 4.5
Intermediate Phase Dose Estimates	MVT, DR	TD 4.9.7, TD 7.2
HF Lung	MVT, DR	TD 5.4
HF Lung 1-hr Equivalent	MVT, DR	TD 5.4
HF Deposition	MVT, DR	TD 5.4
Uranium Exposure	MVT, DR	TD 5.4
Uranium Intake	MVT, DR	TD 5.4
Uranium TEDE	MVT, DR	TD 5.4
Uranium Deposition	MVT,DR	TD 5.4

a) MVT = Maximum Value Table, ST = Source Term Tab, DR = Detailed Results

b) TD = RASCAL Technical Document, TS = RASCAL 4.3 Technical Supplement

3.1 Radiological Releases
RASCAL results are generally presented in two locations: the *Maximum Dose Values* table that appears when the calculations are complete, and the *Detailed Results* section. The *Maximum Dose Values* table provides a quick look at the results along the nominal "plume centerline" at the end of the calculations. The *Detailed Results* Section presents the complete results including their temporal and spatial variations. Results are presented for both the near field and far field calculations.

3.1.1 Total Effective Dose Equivalent (TEDE)
TEDE includes cloudshine dose and inhalation committed effective dose equivalent (CEDE) and groundshine dose. The early phase TEDE as defined by EPA includes cloud shine dose, inhalation CEDE, and the groundshine dose accumulated during the first 96 hours after the beginning of the release to the environment. The TEDE listed at the top of the *Maximum Dose Values* table and at the top of the *Detail Results* output are early phase TEDEs as defined by EPA. They should be used for comparison with EPA early phase PAGs.   Intermediate phase TEDEs include groundshine doses for the full exposure period. They should be used for comparison with EPA intermediate phase PAGs. RASCAL Technical Document Section 4.9.5 discusses TEDE calculations.

Doses (rem)	Early Phase PAGs			
	Normal Environmental Conditions		Hazardous Environmental Conditions	
TEDE		High Risk Population	General Population	High Risk Population
1	Evacuate	Shelter	Shelter	Shelter
5	Evacuate	Evacuate	Evacuate	Shelter
10	Evacuate	Evacuate	Evacuate	Evacuate

3.1.2 Inhalation Committed Effective Dose Equivalent (CEDE)
The *Inhalation CEDE* calculated is a 50-year committed dose to an adult man and is a component of the TEDE. RASCAL Technical Document Section 4.9.1 discusses the calculation of inhalation committed dose equivalents. Inhalation CEDE **should not** be used as an indicator of early health effects. Total Acute Bone and Acute Lung doses are used for insight into possible early health effects.

3.1.3 Cloudshine Dose
RASCAL calculates *Cloudshine* (submersion) doses using both finite-plume and semi-infinite cloud models. Finite-plume models account for the spatial variation of nuclide concentrations and are use near the release point. The semi-infinite cloud model assumes that the nuclide concentrations are uniform in space. It is used when the plume is large and after plume passage. RASCAL Technical Document Section 4.9.3 discusses cloudshine dose calculations.   RASCAL uses cloudshine dose conversion factors from FGR-13 in the semi-infinite cloud model.

3.1.4 4-Day Groundshine Dose
RASCAL calculates the *4-day Ground shine Dose* from the nuclide activity deposited on the surface between the beginning of the release to the environment and the end of calculation. The 4-day ground shine dose is calculated as the sum of the groundshine dose during the model calculation period plus the groundshine dose that would be incurred in the first 96 hours from the end of calculation to 96 hours. Both portions of the 4-day groundshine dose calculation include decay and daughter ingrowth. Neither portion considers weathering. RASCAL Technical Document Section 4.9.2 discusses groundshine dose calculations.

3.1.5 External Gamma Exposure Rate

RASCAL calculates an *External Gamma Exposure Rate* (mrad/hr) from the cloudshine and groundshine. The gamma exposure rate is the sum of the cloudshine and groundshine dose rates corrected for the difference in energy absorption coefficients of tissue and air. RASCAL Technical Document Section 4.9.4 discusses the calculation of the gamma exposure rate.

RASCAL 4.3 includes a tool to provide short term dose projections for field teams. This tool is accessed from the *External Gamma Exposure Rate* or *External Gamma + Beta Exposure Rate* output displayed as part of the Detailed Results. Clicking on an exposure rate value will display the exposure rate vs. time at the location. The right side of the screen will show field team dosimeter projections for a 15 min period ending at the specified time. The projections include DRD reading in mR. They also include an estimated TEDE for the period for individuals who have and have not taken KI prior to exposure. Factors for conversion from DRD reading to TEDE are provided.

RASCAL Technical Supplement Section 2.4 discusses projected field team doses. The method of estimating field team doses is to multiply the RASCAL estimate of the TEDE at the field team location by the ratio of the field team dosimeter reading divided by the RASCAL estimate of the gamma or gamma plus beta exposure at the location. EPA PAGs related to administration of KI are discussed in Section 2.2 of the technical supplement.

3.1.6 External Gamma + Beta Exposure Rate

RASCAL estimates the *External Gamma + Beta Exposure Rate* in a two-step process. The first step is to calculate an initial estimate of the gamma plus beta exposure rate as the sum of the skin dose rate from groundshine and the skin dose rate from cloudshine (submersion). This calculation assumes that 1) the skin dose rates include contributions from both gamma and beta exposure and 2) the correction factor for adjusting dose rate to exposure rate is 1.0. The second step is to compare the initial estimate of the gamma plus beta exposure rate with the gamma exposure rate. If the initial estimate of the gamma plus beta exposure rate is larger than the gamma exposure rate, the initial estimate of the gamma plus beta exposure rate is used as the final gamma plus beta exposure rate. If the gamma exposure rate is larger than the gamma plus beta exposure rate, the gamma exposure rate is used as the gamma plus beta exposure rate. RASCAL Technical Document Section 4.9.4 discusses the calculation of the gamma plus beta exposure rate.

3.1.7 Acute Bone Dose Total

RASCAL calculates the *Acute Bone Dose Total* for use in evaluating early health effects. The total acute bone dose is the sum of effective doses from groundshine, cloudshine, and acute inhalation dose to bone marrow. The acute inhalation dose to bone marrow is calculated using International Atomic Energy Agency (IAEA) acute dose conversion factors. RASCAL Technical Document Section 4.9.6 discusses calculation of acute doses. Acute doses **should not** be compared with EPA protective actions guides (PAGs) that are based on 50-year committed doses.

3.1.8 Acute Bone Dose from Inhalation Only

The *Acute Bone from Inhalation Dose* is a component of the total acute bone dose. The dose calculated is a 30-day committed dose to an adult man. Total acute bone and acute lung doses are used for insight into possible early health effects. The acute lung dose should be used for early health effects insights for accidents where the lung dose will dominate (e.g., Pu releases). Use TEDE or Thyroid doses for comparisons with EPA early-phase PAGs. RASCAL Technical Document Section 4.9.6 discusses calculation of acute doses.

3.1.9 Acute Lung Dose

The *Acute Lung Dose* is a 30-day committed dose to an adult man.   It is associated with the early health effects due to loss of lung function. The acute lung dose is calculated using International Atomic Energy Agency (IAEA) acute dose conversion factors. RASCAL Technical Document Section 4.9.6 discusses calculation of acute doses.

3.1.10 Acute Colon Dose

The *Acute Colon Dose* is a 30-day committed dose to an adult man.   It is associated with the early health effects in the gastrointestinal tract. The acute colon dose is calculated using International Atomic Energy Agency (IAEA) acute dose conversion factors. RASCAL Technical Document Section 4.9.6 discusses calculation of acute doses.

3.1.11 Thyroid Committed Dose Equivalent (CDE)

The *Thyroid CDE* is a 50-year committed dose to an adult man. It includes contributions from all radionuclides. Use thyroid dose for comparison with EPA early-phase PAGs for thyroid. Due to the short half-life of the iodine isotopes that dominate thyroid dose, the thyroid 50-year committed dose and thyroid acute dose are very similar.

Doses (rem)	Early Phase PAGs			
	Normal Environmental Conditions		Hazardous Environmental Conditions	
Thyroid	General Population	High Risk Population	General Population	High Risk Population
5	Evacuate	Shelter	Shelter	Shelter
25	Evacuate	Evacuate	Evacuate	Shelter
50	Evacuate	Evacuate	Evacuate	Evacuate

DO NOT USE the adult thyroid CDE for evaluation of recommendations for administration of KI because it includes the thyroid CDE includes dose contributions from nuclides other than iodines that are not blocked by KI. Use the ICRP-60 DCF option and child thyroid dose for comparison with PAGs associated with administration of KI.

3.1.12 Child Thyroid Committed Dose Equivalent (CDE)

The *Child Thyroid CDE* is a 50-year committed dose to a one year old child. It only includes contributions from iodines. Use the child thyroid dose for evaluation of the appropriateness of administration of KI. Table of 2-1 of the Environmental Protection Agency draft PAG manual for interim use and public comment suggests administration of KI when the projected dose to the child thyroid from exposure to iodines exceeds 5 rem (0.05 Sv).

The breathing rates and dose conversion factors in the following table may be used to scale the RASCAL 4.3 dose estimates for a 1-year old child to estimates of thyroid doses for children of other ages and for adults (20 years). According to FDA, there is generally little value in use of KI for adults over the age of 40.

Dose Conversion Factors (Sv/Bq)

Age	Breathing Rate (m/s)	I-131	I-132	I-133	I-134	I-135
100 days	5.28E-05	2.52E-06	3.40E-08	6.78E-07	7.02E-09	1.39E-07
1 year	9.72E-05	2.47E-06	3.03E-08	6.12E-07	6.24E-09	1.24E-07
5 years	1.58E-04	1.40E-06	1.57E-08	3.18E-07	3.23E-09	6.43E-08
10 years	3.11E-04	7.10E-07	7.02E-09	1.42E-07	1.44E-09	2.88E-08
15 years	3.83E-04	4.59E-07	4.53E-09	9.09E-08	9.30E-10	1.85E-08
20 years	4.17E-04	2.93E-07	2.87E-09	5.70E-08	5.90E-10	1.17E-08

RASCAL only calculates the Child Thyroid CDE when ICRP-60 dose conversion factors are used. RASCAL Technical Supplement Section 2.2 discusses child thyroid dose calculations.

3.1.13 Groundshine Dose Over Defined Time Period

RASCAL calculates groundshine dose from the nuclide activity deposited on the surface between the beginning of the release to the environment and the end of calculation.   At any time within this period, the groundshine dose rate is the dose rate based on all activity deposited from the beginning of release to the environment. RASCAL Technical Document Section 4.9.2 discusses groundshine dose calculations.

The *Groundshine Dose Over Defined Time Period* option allows users to look at the dose for any interval (15 minutes or greater) between the beginning of release to the environment and the end of calculations or the dose rate at any time between the beginning of release and the end of calculations. Clicking on a dose value for a specific location in the display will activate a screen showing the groundshine dose rate and cumulative groundshine dose at the location. Note that the plots of groundshine dose rate and cumulative groundshine dose as a function of time for cells on the close-in polar grid do not account for plume transit time between the release point and the cell. Use the groundshine dose rate and cumulative groundshine dose as a function of time plots from the far-field, Cartesian grid if timing is important.

3.1.14 Ground Concentration – Total

The *Ground Concentration – Total* option displays the total activity on the ground (e.g., Ci/m^2) at the end of the calculation period either as a footprint or in tabular form. The total activity deposited in a specific time interval and the total deposition rate can also be displayed with the appropriate choices in the Time Period for Exposure box. The activities are decayed from the time of release to the time of the footprint. They are not decayed beyond the end of calculation, and they are not adjusted for weathering. RASCAL Technical Manual Section 4.5 discusses deposition of nuclides.

Clicking on a cell in any of these displays will bring up a screen that shows a list of all deposited nuclides sorted in order of decreasing activity. Using the options to the right of the list, the nuclides can be resorted by contribution to groundshine or ingestion dose.

3.1.15 Ground Concentration of

The *Ground Concentration of* option provides access to the surface contamination from specific nuclides. The nuclide activity deposited in a specific time interval and the deposition rate in a specific 15 minute

interval can also be displayed with the appropriate choices in the Time Period for Exposure box. RASCAL Technical Manual Section 4.5 discusses deposition of nuclides.

Clicking on a cell in any of the Ground Concentration of screens will bring up a screen that shows the deposition rate and surface contamination as a function of time at the cell location. Note that the plots of deposition rate and surface concentration as a function of time for cells on the close-in polar grid do not account for plume transit time between the release point and the cell. Use the deposition rate and surface contamination as a function of time plots from the far-field, Cartesian grid if timing is important.

3.1.16 1st Year Intermediate Phase TEDE

The *1st year Intermediate Phase* TEDE is the TEDE that would be incurred by an adult residing in a contaminated area for the first year following the plume passage. It is based on the surface contamination at the end of the early phase. It includes consideration of decay and ingrowth of daughters, weathering, and resuspension. RASCAL Technical Document Section 4.9.7 and 7.2 discuss the calculation of intermediate phase doses.

The first year TEDE should be used for comparison with EPA intermediate phase protective action guides (PAGs) related to relocation. The EPA first year TEDE PAG is 2 rem.

3.1.17 2nd Year Intermediate Phase TEDE

The *2nd year Intermediate Phase TEDE* is the TEDE that would be incurred by an adult residing in a contaminated area the second year following the plume passage. It is based on the surface contamination at the end of the early phase. It includes consideration of decay and ingrowth of daughters, weathering, and resuspension. It does not include the TEDE incurred during the first year after plume passage. RASCAL Technical Document Section 4.9.7 and 7.2 discuss the calculation of intermediate phase doses.

The second year TEDE should be used for comparison with EPA intermediate phase dose objectives related to relocation. The EPA second year TEDE objective is 0.5 rem.

3.1.18 50 Year Intermediate Phase TEDE

The *50 year Intermediate Phase TEDE* is the TEDE that would be incurred by an adult residing in a contaminated area for 50 years following the plume passage. It is based on the surface contamination at the end of the early phase. It includes consideration of decay and ingrowth of daughters, weathering, and resuspension. The 50 TEDE includes the TEDE incurred during the first and second years. For short-lived nuclides such as I-131, the first year TEDE and the fifty year TEDE are the same. RASCAL Technical Document Section 4.9.7 and 7.2 discuss the calculation of intermediate phase doses.

The 50 year TEDE should be used for comparison with EPA intermediate phase dose objectives related to relocation. The EPA 50 year TEDE objective is 5 rem.

3.1.19 I-131 Air Concentration

I-131 air concentration is the time-integrated concentration (e.g., µCi-s/cm^3) (air exposure) at a location. I-131 air exposure is directly related to thyroid dose. The I-131 air exposure option provides access to the spatial distribution of I-131 exposure. The I-131 air exposure in a specific time interval and the average I-131 air concentration in a specific 15 minute interval can also be displayed with the appropriate choices in the Time Period for Exposure box. Exposure is defined in RASCAL Technical Document Section 4.1.2

Clicking on a cell in any of the I-131 air exposure screens will bring up a screen that shows the average I-131 air concentration and the I-131 exposure as a function of time at the cell location. Note that the plots

of average concentration and exposure as a function of time for cells on the close-in polar grid do not account for plume transit time between the release point and the cell. Use the average concentration and exposure as a function of time plots from the far-field Cartesian grid if timing is important.

3.2 UF$_6$ and Other Uranium Releases

RASCAL results are generally presented in two locations: the *Maximum Dose Values* table that appears when the calculations are complete, and the *Detailed Results* section. The *Maximum Dose Values* table provides a quick look at the results along the nominal "plume centerline" at the end of the calculations. The *Detailed Results* section presents the complete results including their spatial variations.   UF$_6$ model calculations are only made for the near field. Consequently, time-dependent results, e.g., plots of exposure rates vs time, are not available for UF$_6$ releases.

3.2.1 HF Lung

The *HF Lung* is the average concentration (e.g. ppm) of HF in the lung calculated by RASCAL during plume passage. The HF lung concentration includes inhaled HF and HF formed by the reaction of inhaled UF$_6$ with moisture in the lungs. RASCAL assumes that UF$_6$ is a trace gas rather than a dense gas for this calculation. RASCAL Technical Document Section 5.4 discusses the results of UF$_6$ model calculations.

3.2.2 HF Lung – 1 Hour Equivalent

The *HF Lung 1-hour Equivalent* is a concentration (e.g. ppm) provides a measure of short term exposure to HF, which is associated with the degree of acute lung edema that may result and cause death. See RASCAL Technical Document Section 5.4 for calculation of the 1-hour equivalent HF Lung concentration.

NUREG-1391 describes the concept of "toxic load". The toxic load is the square of the 1-hour equivalent HF concentration. The implications of this relationship are: A doubling of concentration requires reduction of the exposure time by a factor of 4 to maintain the same toxic load level. Or, the exposure duration could be doubled while maintaining the same toxic load if the concentration were to be reduced to about 71% of the original level.

3.2.3 HF Deposition

The *HF Deposition* (g/m²) may be used to reconstruct the path of the plume and the HF concentration in the plume. HF deposition is calculated from the atmospheric HF exposure assuming that HF is a reactive gas and that its deposition is similar to the deposition of I$_2$ gas. The deposition velocity for reactive gases is a function of stability and wind speed. The estimation of deposition velocities for reactive gases is discussed in Section 4.5.1 and representative values for deposition velocities are listed in Table 4.1. Typical deposition velocities for reactive gases range from about 0.2 cm/s to about 1.6 cm/s.

3.2.4 Uranium Exposure

The *Uranium Exposure* (g-s/m³) is the time integral of the uranium concentration in the air. The uranium exposure includes contributions from uranium in both UF$_6$ and UO$_2$F$_2$. It provides a measure of potential kidney damage due to heavy metal poisoning. See RASCAL Technical Document Section 5.4.

3.2.5 Uranium Intake

RASCAL calculates the *Uranium Intake* (e.g., mg) from the uranium exposure assuming a breathing rate of 3.33×10^{-4} m^3/s. The external dose rates from uranium are negligible. As a result all of the health effects of uranium exposure are from inhaled uranium. RASCAL Technical Document Section 5.4 discusses inhaled uranium.

3.2.6 Uranium TEDE

The committed effective dose equivalent (CEDE) from inhaled uranium (rem) provides the radiation dose to people in the plume. It is a measure of the long-term risk due to radiation exposure. There is essentially no external radiation exposure from airborne uranium so the CEDE is also the TEDE. RASCAL computes the CEDE for inhaled uranium using the dose conversion factor for soluble uranium. RASCAL Technical Document Section 5.4 discusses the inhalation of uranium.

3.2.7 Uranium Deposition

The *Uranium Deposition* may be used to reconstruct the path of the plume and also the uranium concentration in the plume if the deposition velocity of the uranium particles can be estimated. Conversely, if the concentration of uranium in the plume is known, the deposition provides a measure of the deposition velocity. See RASCAL Technical Document Section 5.4.

4 Create Inventory Base File

The *Create Inventory Base File* tool is used to generate a reactor specific file that describes how the reactor has been operated. This file is used when RASCAL creates custom fuel, coolant, and spent fuel inventories. RASCAL Technical Supplement Chapter 4 describes the models used to create these custom inventories , and RASCAL Technical Supplement Section 4.6 discusses utility code used to create the custom inventory files.

Options to create and use the custom files are found on the source term data entry screens for the Nuclear Power Plant and Spent Fuel options of the RASCAL 4.3 STDose module.   A single data entry screen is used to collect the required data. It appears when the Create Inventory Base File tool is selected.

When the form appears, the first entry should be selection of the reactor for which the custom inventories are to be created. There is a dropdown list that may be used to make this selection.   Based on this entry, RASCAL will enter the reactor type and default values for the rated reactor power and total uranium in core. These latter two values are obtained from the RASCAL nuclear power plant database and may be changed by the user.

The next entries are related to the reactor cooling system.   There are two boxes for this information; one for BWRs and the other for PWRs. The appropriate box will be activated and the other will be greyed out. RASCAL will enter default cooling system data obtained from the RASCAL nuclear power plant database in the appropriate box.   This information may be changed if appropriate.

The remainder of the information is related to how the reactor is operated (fuel management) and the last refueling outage. Fuel management describes the typical reactor operating cycle. A dropdown list shows the characteristics of five operating cycles that can be modeled by RASCAL. One of these cycles must be selected. The cycle number of the oldest batch of fuel in the core is used to describe how long the reactor has been operating. For most US reactors the number of the oldest batch should be equal to the number of cycles in the fuel management characteristics. For a reactor that has just started for the first time, the oldest number of the oldest batch would be 1. The final fuel management characteristic is the length in days of a typical refueling outage. Table 4.6.1 in the RASCAL Technical Supplement shows the distribution of refueling outage durations for 2011. The most likely duration is 30 to 39 days, with a median duration of 41 days.

The final inventories are not particularly sensitive to the typical refueling outage length. However, the inventories are sensitive to the information on the last refueling outage, especially if the event occurs shortly after refueling. The duration of the last refueling outage and the date that it ended must be updated. This information should be available from the NRC staff assigned to the plant. It may also be extracted from NRC records of daily operating status.

The reactor inventory model may be run directly from the Create Inventory Base File data entry form. If this option is selected, the Inventory Base File will be created and the inventory model will be run. To run the model, users must enter the date of the accident and the reactor power at the time of the accident. The reactor status is not currently used for inventory calculations. The inventory base file will be named xxxx.inv where xxxx is the plant name and unit number. It will be stored where the other RASCAL files for the site. The results of the model run will be placed in a file named core_inventory.tmp. It will be stored with other STDose temporary files.

5 Source Term Merge / Export

The *Source Term Merge / Export* tool adds an external capability to the RASCAL 4.3 Source Term to Dose model. It provides two basic capabilities. First, it will export a RASCAL 4.3 atmospheric source term in either an XML format or an expanded CSV format. Second, it will merge source terms from multiple RASCAL STDose runs. The new source term can then be exported.
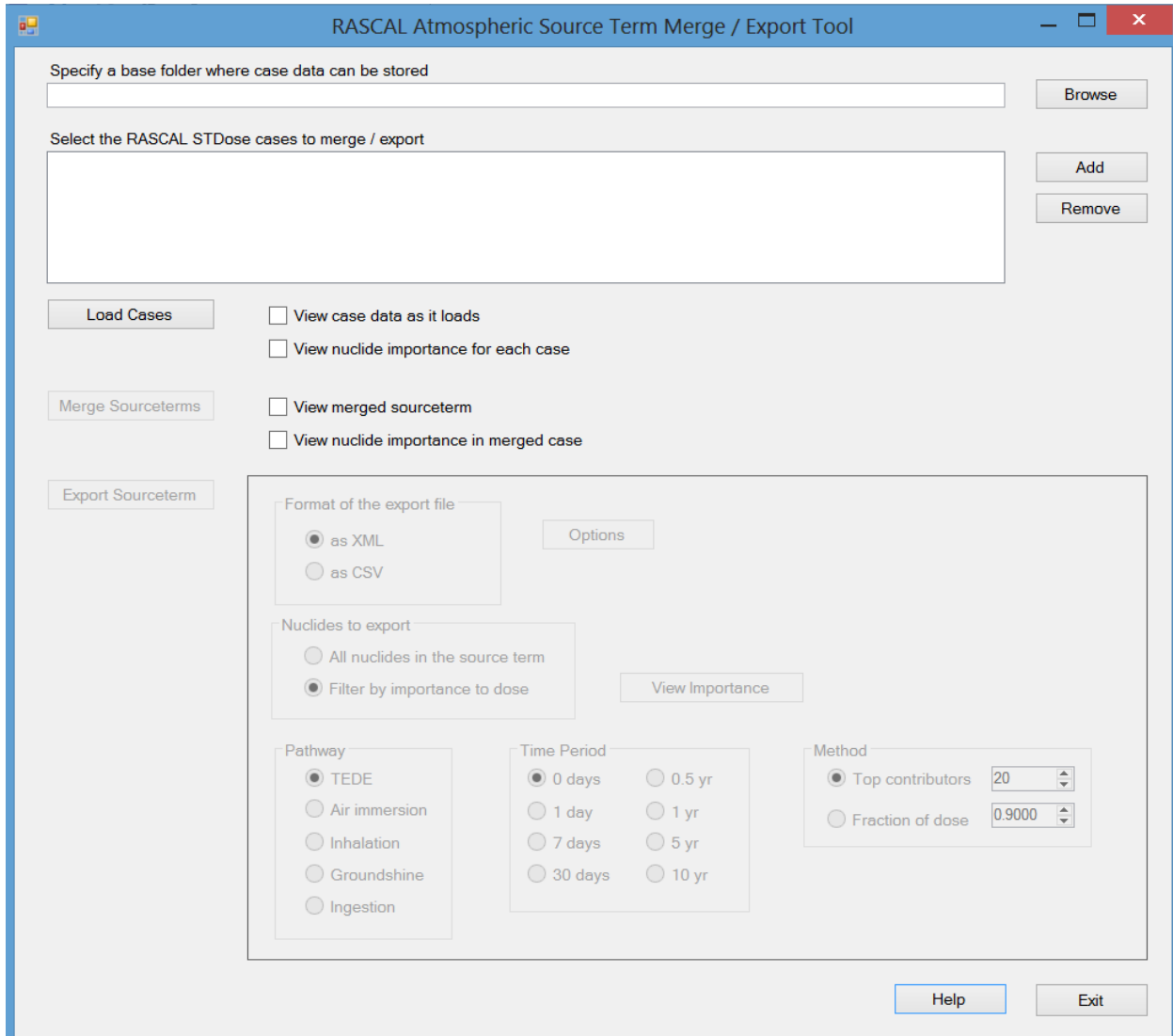
5.1 Base Folder

The base folder is the location where all the processing of the source term files occurs. The software will create files and sub-folders as needed to contain the RASCAL case information. This folder can be anywhere on your system. The recommended location is just under the folder containing the program itself. The basic installation creates the folder \TempCases for this purpose if you choose to use it. During program execution, one of more sub-folder will be created under this base folder. All the sub-folders and their files are deleted when the program is closed.

5.2 Select Cases

Use the Add button to select one or more RASCAL 4.3 STDose cases to work with. If you select only one case, you can export it. If you select more than one, you will be able to merge them and then export the new source term. The saved case must include the calculated results. Cases saved before doing the dose calculations do not contain the source term information and cannot be used.

5.3 Load Cases

After at least one case has been added, the Load Cases button becomes active. Clicking this button will do the following for each case in the list:

1. Create a sub-folder to hold the case information
2. Open the case file and extract the needed files
3. Optionally, display the source term related case data as it is loaded
4. Optionally, run the importance calculation on the source term and display the results.

5.4 Merge

If more than one case has been loaded, then the Merge Source terms button becomes active. Clicking the button starts the merge process.

There are a number of parameters in each case that cannot be merged. For example, only a single release height is allowed. If your cases used differing release heights, you must choose one of the heights to be used in the merge file. Before the merge begins, you need to review these parameters and select which value to use. The following must be specified:

- o release height
- o latitude / longitude
- o case title
- o analyst name
- o site name

The last 3 can be edited as needed.

Additionally, the case descriptions are concatenated and presented in an editable form. Modify this text to adequately describe the merged source terms.

Like the load case operation, you have the option to display the case information and the importance data for the merged source term.

5.5 Export

After the loading of a single case or the merging of multiple cases, you can export the source term file. The export function support 2 formats: the new XML format being proposed for the exchange of source term information, and the CSV (comma-separated variables) format. The CSV format is the same format used from within RASCAL itself but with additional information about the release point. Both formats include all the information about the release with no need to open the case in RASCAL.

There are 2 options for the export file (use the Options button):
1. Strip * characters from nuclide names. This is useful when the export file is to be used with other software (e.g. NARAC) that handles daughters differently.
2. Use the RASCAL 4.2 format. This will not include all the release information but is retained for backward compatibility. This option applies to the CSV format only.

The export file may be filtered by radionuclide importance. Select the option button to enable and then select the filter options: pathway, filter method, and time period

5.6 Case Information
This form displays the case information related to the modeling run and the generated source term. It is particularly important to include detailed information about the case or cased if the output file is to be exported or recalled at a later date.

5.7 Importance
The importance calculation examines the contribution of each nuclide in a source term to 5 dose pathways: TEDE, air immersion, groundshine, inhalation, and ingestion. Eight time periods are examined from 0 days out to 10 years. The user may specify the filter to export only the top X contributors to dose or to export all the nuclide needed to get X% of the dose.

The importance display shows the calculated contributions for each pathway and time period. The lists are truncated when the cumulative percentage dose becomes greater than 99.5%.   Those nuclides that are not shown in the truncated list contribute a combined total of less than 0.5% of the dose.   In some instances the list may be empty because all nuclides in the source term will have decayed to an extremely small value that is essentially 0.0.

6 MetFetch

The MetFetch application retrieves meteorological observations and forecasts from the internet for use in RASCAL. Therefore, a connection to the internet is necessary to use this program. Meteorological observations are available to download at first-order National Weather Service (NWS) and Federal Aviation Administration (FAA) stations. Additionally, maritime observation stations are available for select coastal locations. NWS forecasts are available for every observation location.

In normal operation, a user will simply enter their site location, select the desired meteorological stations, and then download the observations and/or forecasts; these data can then be imported directly into RASCAL through the RASCAL interface (see the RASCAL User Guide for information about importing observations/forecasts). The user can also set up MetFetch to run in an "Automated Download" mode, whereby the observations and forecasts are downloaded at routine time intervals (e.g., hourly); this option is useful if an archive is desired. However, the user is cautioned that an archive can become large in size and will likely need to be managed.

6.1 Configuration File Data Entry

This section describes the user inputs that are required to run MetFetch. These entries can be saved in a user-defined "Configuration File" for subsequent use in the MetFetch program.

MetFetch has two primary user input tabs—"Select Stations" and "Meteorological Files Settings"—that need to completed to download observations and/or forecasts. These tabs, and the associated user inputs, are described in this section.
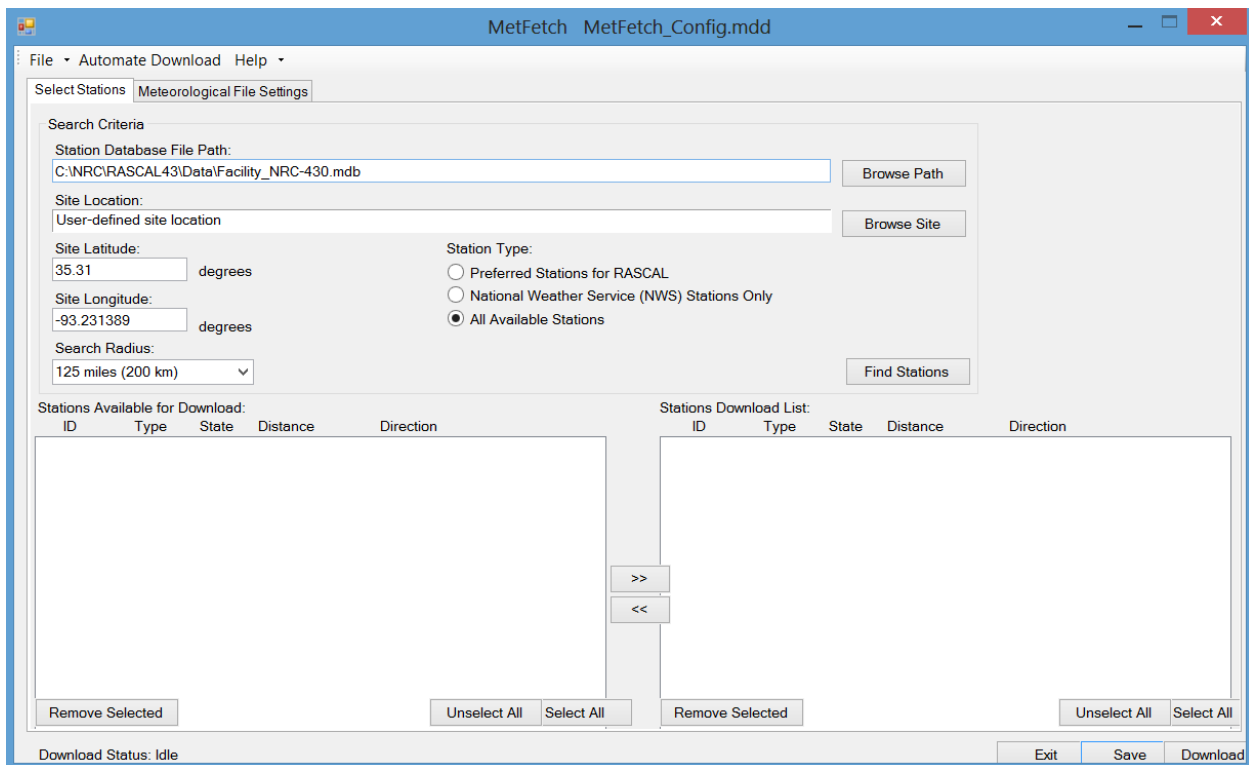
6.1.1 Select Stations

The "Select Stations" tab allows the user to select the desired meteorological stations for a given site location. The user inputs on the "Select Stations" tab are described further below:

Station Database File Path: MetFetch utilizes the RASCAL facility database, which contains information about facility and meteorological station locations. Select the path to this database file using the "Browse Path" button. *Note: The RASCAL database is normally located in the "Data" subdirectory of the RASCAL install directory; the database name is "Facility_NRC-XX.mdb", where XX is the RASCAL version number.*

Site Location: Once the station database path is set, the user can either download data for a "User-defined site location" or a pre-defined site in RASCAL. To select a pre-defined RASCAL site, click the "Browse Site" button and select a site from the "Select Site Location" list.

Site Latitude: If a RASCAL "Site Location" has been selected, the "Site Latitude" will automatically be populated with site's latitude coordinate. If a "User-defined site location" is preferred, then enter the user-defined site latitude coordinates in decimal degrees (*positive* for north).

Site Longitude: If a RASCAL "Site Location" has been selected, the "Site Longitude" will automatically be populated with site's longitude coordinate. If a "User-defined site location" is preferred, then enter the user-defined site longitude coordinates in decimal degrees (*negative* for west).
Search Radius: Select the desired "Search Radius" from the site to use when searching for meteorological stations. Five radii are available, out to a maximum distance of 125 miles (200 km); these distances correspond to model domain sizes in RASCAL.

Station Type: Set the "Station Type" to filter the list of "Stations Available for Download". Three options are available, including:

- *Preferred Stations for RASCAL*: This option is only available when a "Site Location" has been selected from the RASCAL database; if the "Site Location" is a "User-defined site location", this option is not available. The "Preferred Stations for RASCAL" option limits the number of meteorological stations to no more than four meteorological stations per cardinal direction surrounding a RASCAL site location. Thus, no more than 64 stations will be available in the "Stations Available for Download" list when this option is selected. The "Preferred Stations for RASCAL" are generally considered the best meteorological stations to use for a given RASCAL site location and include NWS/FAA and maritime station types.
- *National Weather Service (NWS) Stations Only*: This option limits the meteorological stations type to NWS/FAA only; thus only NWS/FAA meteorological stations will display in the "Stations Available for Download" list.
- *All Available Stations*: This option displays all meteorological stations available for downloading at a given site location. In addition to NWS/FAA stations, the "Stations Available for Download" list may contain maritime and other available meteorological networks.

Stations Available for Download: Upon entering the "Site Latitude", "Site Longitude", "Search Radius", and "Station Type", click the "Find Stations" button to generate a list of "Stations Available for Download". Stations in the list are ordered clockwise on cardinal direction (starting with North) and then distance from the site. Information in the "Stations Available for Download" list includes:

- *ID*: The meteorological station id.
- *Type*: The meteorological station type.

- *State:* The state where the meteorological station is located. Some maritime stations do not belong to a "State".
- *Distance*: The distance (in miles) the meteorological station is from the site location.
- *Direction*: The cardinal direction from the site location to the meteorological station.

Select the checkbox next to a given station "ID" and then click the right arrow ">>" button to move the station over to the "Stations Download List". The "Removed Selected" button can be used to remove a station from the "Stations Available for Download" list. The "Unselect All" and "Select All" buttons can be used to batch-select multiple stations.

Stations Download List: The "Stations Download List" contains the stations MetFetch will attempt to download observations and/or forecasts for. There is no limit to the number of stations that can be downloaded; however, download times will increase as the number of stations increases.
Select the checkbox next to a given station "ID" and then click the left arrow "<<" button to move the station back into the "Stations Available for Download" list. The "Removed Selected" button can be used to remove a station from the "Stations Available for Download" list. The "Unselect All" and "Select All" buttons can be used to batch-select multiple stations.

6.1.2 Meteorological File Settings

The "Meteorological File Settings" tab allows the user to set certain file specifications that are used to write the downloaded observation/forecast to files. The user inputs on the "Meteorological File Settings" tab are described further below:
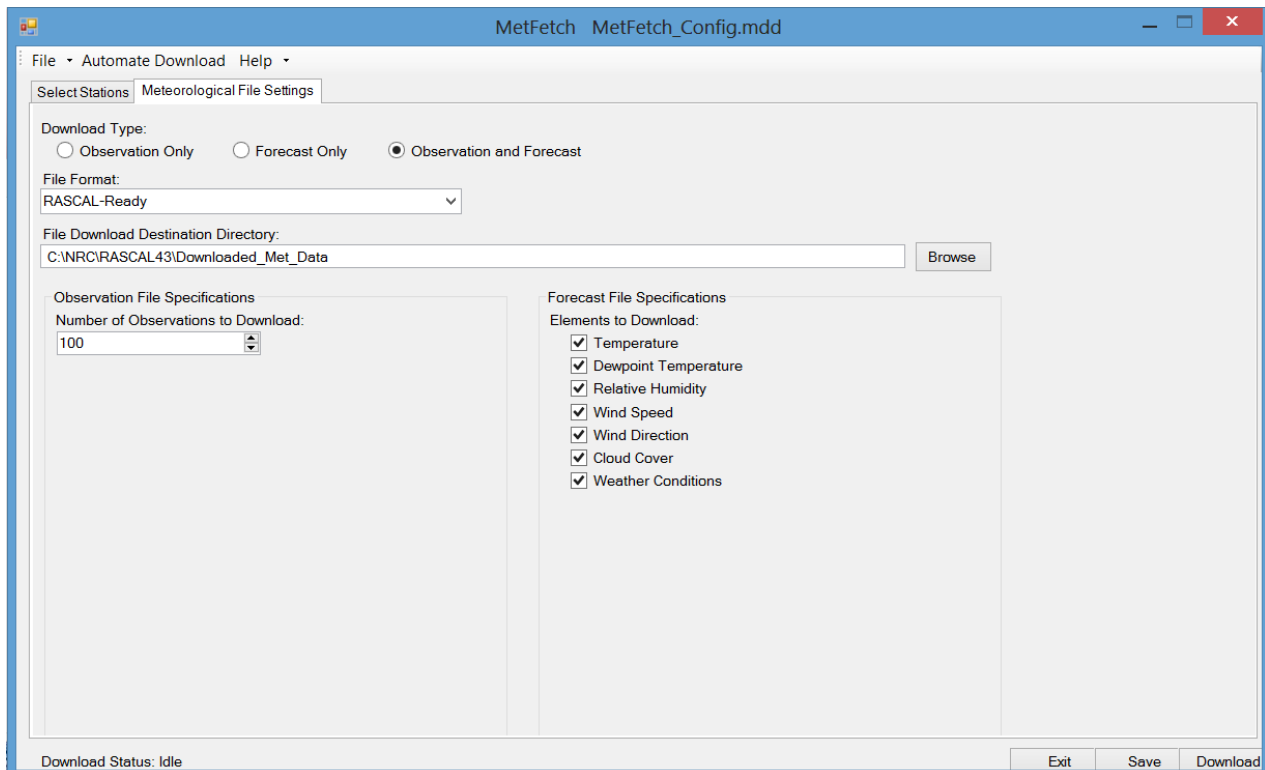
Download Type: For a given station, MetFetch can download the "Observation", "Forecast", or "Observation and Forecast". For RASCAL, a user will generally want to select the "Observation and Forecast" option. Forecasts are available at every station location.

File Format: Two file formats—"Native XML" and "RASCAL-Ready"—are available for writing the meteorological observations/forecasts to file. The "Native XML" option is the native observations/forecast file as downloaded from the internet; the file is in eXtensible Markup Language (XML) format. The "RASCAL-Ready" option is a comma-delimited file format that can be imported directly into RASCAL; see the RASCAL User Guide for importing observation/forecast files of this format.

File Download Destination Directory: The "File Download Destination Directory" is the directory path where the observation/forecast files will be written. Use the "Browse" button to set this directory path. *Note: RASCAL-ready observation/forecast files must be written to the "Downloaded_Met_Data" subdirectory within the RASCAL install directory.*

Observation File Specifications: If the "Download Type" includes "Observation", then the "Observation File Specifications" are available.

- *Number of Observations to Download***:**   Specify the number of observations to be downloaded for each station. If a station reports hourly observations, then a specification of "100" would download the last 100 hours of observations. However, if a station reports observations every 15-minutes, then a specification of "100" would download only 25 hours of past observations. In general, downloading "100" observations is adequate for most RASCAL runs. Most stations have a rolling, one-month archive of observations available.

Forecast File Specifications: If the "Download Type" includes "Forecast", then the "Forecast File Specifications" is available.

- **Elements to Download:** Select the meteorological elements to download; options include: "Temperature", "Dewpoint Temperature", "Relative Humidity", "Wind Speed", "Wind Direction", "Cloud Cover", and "Weather Conditions". *Note: All weather elements should be downloaded if the forecasts will be used in RASCAL.*

6.1.3 Downloading Observations and Forecasts

Once user input has been supplied on the "Select Stations" and "Meteorological Files Settings" tabs, the observation/forecast files are ready to be downloaded. To download observation/forecast files, simply click the "Download" button on the main application interface. A "Download Status" bar will appear, indicating the status of the observation/forecast download. Download times will depend on the number of stations being downloaded, internet speed, and server traffic. If the download takes too much time, consider limiting the number of stations or downloading the data at a later time.

6.2 Menu Options

MetFetch has three menu options, including "File", "Automate Download", and "Help". The "File" menu is used to manage configuration files or observation/forecast files within the download directory. The "Automate Download" menu option is used to automate the download of observations/forecasts at routine time intervals to build a data archive. The "Help" menu provides access to the MetFetch User Guide. The following sections describe the MetFetch menu options in more detail.

6.2.1 File Menu

The "File" menu is used to open and save a MetFetch "Configuration File" or manage the "Download Directory". A "Configuration File" saves user inputs to file so that they can be opened within MetFetch at a later time. The "Manage Download Directory" allows a user to manage previously downloaded observation/forecast files in the download directory. The "File" menu options include:

- *Open Configuration File*: Select this option to open a previously saved configuration file. A configuration file stores MetFetch user inputs and has a *.mdd file extension. Once a configuration file is opened, the filename is displayed in the MetFetch application title bar.
- *Save Configuration File*: Select this option to save the current MetFetch user inputs to the configuration file; the configuration filename is displayed in the MetFetch application title bar.
- *Save Configuration File As*: Select this option to save the current MetFetch user inputs to a different configuration filename. A "Save As" dialog box will appear, and the directory and filename must be set. A configuration file stores MetFetch user inputs and has a *.mdd file extension. Once the configuration file is saved, the filename is displayed in the MetFetch application title bar.
- *Manage Download Directory*: Select this option to bring up the "Download Folder Manager" dialog box; previously downloaded observation/forecast files can be managed (deleted) by using the "Select All", "Unselect All", and "Delete Selected" buttons. Additionally, individual files can be selected by clicking on the checkbox next to the files name. *Note: The "File Download Destination Directory" on the "Meteorological File Settings" is the directory path where the observation/forecast files are written; this is also the default directory used by the "Manage Download Directory" dialog box.*
- *Exit*: Select this option to exit the MetFetch application.

6.2.2 Automate Download

MetFetch can be configured to run automatically at select time intervals (e.g., hourly) using the "Automate Download" menu option; this option is useful if a user would like to create an ongoing observation/forecast data archive. Multiple archives can be created/maintained by configuring multiple "Automate Download" tasks.

The "Automate Download" menu option is used to register MetFetch with the Windows Task Scheduler. The following user entries are required to automate a forecast/observation download:

Downloader Executable Path: Set the filepath to the executable file that enables the MetFetch auto download. *Note: This file, called "MetFetch_Auto.exe", is located in the RASCAL install directory.* Use the "Browse" button to select the filepath to the "MetFetch_Auto.exe" executable.

Configuration File to Automate Download: Set the filepath to the desired MetFetch "Configuration File" that will be used to automate the download. The "Configuration File" is created in MetFetch and contains the meteorological stations and file settings to use when downloading observations/forecasts. Use the "Browse" button to select the filepath to the desired configuration file.

Task Manager Configuration: The "Task Manager Configuration" contains inputs used to define a task within the Windows Task Scheduler, including:
- *Task Name*: Provide a task name to use in the Windows Task Scheduler; "MetFetch_Auto" is used as a default task name. The task name will need to be unique if multiple "Automate Download" tasks are created.
- *Download Interval*: Set the interval (i.e., how frequent) the automated download task will be executed; "Hourly" and "Daily" are the available intervals.
- *Start Date (mm/dd/yy)*: Enter a "Start Date" to begin the automated download task. A date *before* the current date means the task will begin immediately. A date *after* the current date means the task will be delayed until that date.
- *End Date (mm/dd/yy)*: Enter an "End Date" in which to terminate the automate download task. If you would like the task to run indefinitely, enter a date far into the future (e.g., 01/31/2500).
- *Start Hour:* Select the "Start Hour" for the automate download task to begin.

- *Start Minutes:* Select the "Start Minutes" for the automate download task to begin. <u>*Note:*</u> *Since meteorological observations are typically not available until a couple of minutes past the hour, a "Start Minutes" of "00:10" or more is likely to be preferred.*

Preserve Download Archive: "The Preserve Download Archive" is used to manage the archive size; downloaded files can be deleted after a user-defined "Period" (in days) or stored "Indefinite".
The "Run downloader application minimized" checkbox can be used to run the MetFetch automation with the application window minimized; this allows the user to work on other applications without the routine interruption of the MetFetch application.

Once the "Task Scheduler Configuration" settings have been entered, click the "Register" button to register the entries with the Windows Task Scheduler. A "Task Registration" window will appear indicating the registration is complete. A prompt will then ask if you would like to test the automated task; if "Yes" and the task is successful, observation/forecast files will be downloaded according to the specifications contained in the user-defined configuration file. If the task is not successful, verify the configuration file is valid or verify the task registered properly within the Window Task Scheduler.

- On Windows XP, scheduled tasks can be found under "Programs> Accessories> System Tools> Scheduled Tasks".
- On Windows 7, scheduled tasks can be found under "Control Panel>All Control Panel Items>Administrative Tools>Task Scheduler".

The scheduled task should appear with the user-defined "Task Name" in the list of scheduled tasks.

7 Exposure Guidelines

Various guidelines have been established for limiting exposure to chemicals based on health effects. RASCAL does not calculate health effects, but it does reference various exposure guidelines set to protect public health. RASCAL results exceeding guidelines are highlighted in the Maximum Value Table and in the Detailed Results displays.

7.1 EPA Protective Action Guides

Protective Action Guides (PAGs) suggest precautions that state and local authorities can take during an emergency to keep people from receiving an amount of radiation that might be dangerous to their health. EPA developed the PAG Manual to provide guidance on actions to protect the public, such as having people evacuate an area or stay indoors.

The EPA manual provides recommended numerical protective action guides for the principal protective actions available to public officials during a radiological incident. A PAG is defined for purposes of this document as the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs are guides to help officials select protective actions under emergency conditions during which exposures would occur for relatively short time periods. They are not meant to be applied as strict numeric criteria, but rather as guidelines to be considered in the context of incident-specific factors. PAGs do not establish an acceptable level of risk for normal, nonemergency conditions, nor do they represent the boundary between safe and unsafe conditions. The PAGs are not legally binding regulations or standards and do not supersede any environmental laws. For information on roles, responsibilities and authorities during emergency response and recovery, please refer to the National Response Framework: http://www.fema.gov/national-response-framework and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a,b).

Some protective actions are not associated with a numerical PAG. For example, the control of access to areas is a protective action implemented in concert with other protective actions; it does not have its own PAG. Any reasonable action to reduce radiation dose is encouraged even if it is not associated with a PAG, such as recommending that individuals use ad hoc respiratory protection with a handkerchief or piece of folded cloth. Or in areas where PAGs are not exceeded, but airborne radioactivity is present, people might be asked to stay indoors to the extent practicable to reduce their exposures. To further develop radiological emergency plans, brief planning guides have been provided for reentry to relocation areas, the cleanup planning process and considerations for radioactive waste disposal. (Source: http://www.epa.gov/radiation/rert/pags.html accessed 9/9/2013)

7.2 Immediately Dangerous to Life or Health (IDLH)

The immediately dangerous to life or health (IDLH) values used by the National Institute for Occupational Safety and Health (NIOSH) as respirator selection criteria were first developed in the mid-1970's. The Documentation for Immediately Dangerous to Life or Health (IDLH) Concentrations is a compilation of the rationale and sources of information used by NIOSH during the original determination of 387 IDLH values. In addition, NIOSH continues to review, document, and revise the science and methodology behind the existing IDLH values when appropriate, and derive new IDLH. (Source: http://www.cdc.gov/niosh/idlh/idlhintr.html accessed 9/9/2013)

7.3 Emergency Response Planning Guidelines (ERPGs)

ERPGs estimate the concentrations at which most people will begin to experience health effects if they are exposed to a hazardous airborne chemical for 1 hour. (Sensitive members of the public—such as old, sick, or very young people—aren't covered by these guidelines and they may experience adverse effects

at concentrations below the ERPG values.) A chemical may have up to three ERPG values, each of which corresponds to a specific tier of health effects.

The three ERPG tiers are defined as follows:

- **ERPG-3** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.
- **ERPG-2** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.
- **ERPG-1** is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient health effects or perceiving a clearly defined, objectionable odor.

(Source: http://response.restoration.noaa.gov/erpgs accessed 9/9/2013))

7.4 Acute Exposure Guideline Levels (AEGLs)

AEGLs represent threshold exposure limits for the general public and are applicable to emergency exposure periods ranging from 10 minutes to 8 hours. AEGL-2 and AEGL-3, and AEGL-1 values, as appropriate, will be developed for each of five exposure periods (10 and 30 minutes, 1 hour, 4 hours, and 8 hours) and will be distinguished by varying degrees of severity of toxic effects. It is believed that the recommended exposure levels are applicable to the general population including infants and children, and other individuals who may be susceptible. The three AEGLs have been defined as follows:

- **AEGL-1** is the airborne concentration, expressed as parts per million or milligrams per cubic meter (ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
- **AEGL-2** is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- **AEGL-3** is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

Airborne concentrations below the AEGL-1 represent exposure levels that can produce mild and progressively increasing but transient and nondisabling odor, taste, and sensory irritation or certain asymptomatic, nonsensory effects. With increasing airborne concentrations above each AEGL, there is a progressive increase in the likelihood of occurrence and the severity of effects described for each corresponding AEGL. Although the AEGL values represent threshold levels for the general public, including susceptible subpopulations, such as infants, children, the elderly, persons with asthma, and those with other illnesses, it is recognized that individuals, subject to unique or idiosyncratic responses, could experience the effects described at concentrations below the corresponding AEGL. (Source: http://www.epa.gov/oppt/aegl/pubs/define.htm accessed 9/9/2013)

7.5 Use of Potassium Iodide (KI)

NRC has published a "Spotlight" article on Consideration of Potassium Iodide in Emergency Planning (http://wwwnrc.gov/about-nrc/emerg-preparedness/potassium-iodide.html) on it web site. NRC emergency preparedness regulations require that States with a population within the 10-mile emergency planning guide consider including potassium iodide (KI) as a protective measure for the general public.

The Food and Drug Administration (FDA) is the definitive medical authority in the United States on the use of KI. FDA guidance related to the use of KI may be found at http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm319791.htm. The Environmental Protection Agency Draft PAG Manual for Interim Use and Public Comment (http://www.epa.gov/radiation/rert/pags/html) includes specific guidance for the administration of KI in response to releases of radioactive iodine.   The EPA guidance is based on child (1-yr old) thyroid dose.

RASCAL 4.3 calculates a child thyroid dose for the purpose of evaluating recommendations related to administration of KI. RASCAL 4.3 Technical Supplement Section 2.2 discusses the calculation of child thyroid doses.   Child thyroid doses are only calculated if the ICRP-60/72 dose conversion factors are selected on the Calculate Doses data entry form.

8 Health Effects

RASCAL does not calculate health effects.   The health effects that are presented in the RASCAL 4.3 Technical Supplement and RASCAL Help summarize the work of others. They are presented as background material only.

8.1 Radiation Health Effects

The following table presents a summary of radiation-induced health effects from whole-body irradiation. It is adapted from ICRP Publication 96.

Radiation-Induced Health Effects – Whole-body Irradiation[a]

Expected Dose	Effects	Outcome
Very-low dose: ~ 10 mSv ~1 rem	No acute effects, Extremely small additional cancer risk, <0.1%	No observable increase in incidence of cancer, even in large exposure population, 10^6
Low dose: toward 100 mSv 10 rem	No acute effects, subsequent additional cancer risk, <1%	Possible observable increase in the incidence of cancer in a large population, ~ 10^5
Moderate dose: towards 1 Sv 100 rem	Nausea, vomiting possible, mild bone marrow depression; subsequent additional cancer risk of ~ 10%	Probable observable increase in the incidence of cancer if the exposed population is more than a few hundred.
High dose: >1 Gy >100 rad	Certain nausea, likely bone-marrow syndrome, high risk of death above 4 Gy (400 rad) of acute dose without medical treatment. Significant additional cancer risk.	

[a]ICRP Publication 96, *Ann. ICRP 35*(1), 2005.

(Source: K. Eckerman, ORNL, Radiation Toolbox 3.0)

8.1.1 Acute Radiation Syndrome

According to the Centers for Disease Control,

"Acute Radiation Syndrome (ARS) (sometimes known as radiation toxicity or radiation sickness) is an acute illness caused by irradiation of the entire body (or most of the body) by a high dose of penetrating radiation in a very short period of time (usually a matter of minutes)."

The required conditions for Acute Radiation Syndrome (ARS) are:

- **The radiation dose must be large** (i.e., greater than 0.7 Gray (Gy) or 70 rads). Mild symptoms may be observed with doses as low as 0.3 Gy or 30 rads.

- **The dose usually must be external** (i.e., the source of radiation is outside of the patient's body). Radioactive materials deposited inside the body have produced some ARS effects only in extremely rare cases.
- **The radiation must be penetrating** (i.e., able to reach the internal organs). High energy X-rays, gamma rays, and neutrons are penetrating radiations.
- **The entire body** (or a significant portion of it) must have received the dose. Most radiation injuries are local, frequently involving the hands, and these local injuries seldom cause classical signs of ARS.
- **The dose must have been delivered in a short time** (usually a matter of minutes). Fractionated doses are often used in radiation therapy. These large total doses are delivered in small daily amounts over a period of time. Fractionated doses are less effective at inducing ARS than a single dose of the same magnitude.

According to the CDC, there are three classic ARS syndromes: bone marrow syndrome, gastrointestinal (GI) syndrome, and cardiovascular (CV) / central nervous system (CNS) syndrome.   CDC fact sheets also address cutaneous radiation syndrome. (Source: http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp accessed 9/9/2013)

8.1.2 Bone Marrow Syndrome
Bone marrow syndrome (sometimes referred to as hematopoietic syndrome)**:** the full syndrome will usually occur with a dose greater than approximately 0.7 Gy (70 rads) although mild symptoms may occur as low as 0.3 Gy or 30 rads. The survival rate of patients with this syndrome decreases with increasing dose. The primary cause of death is the destruction of the bone marrow, resulting in infection and hemorrhage.   (Source: http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp)

8.1.3 Gastrointestinal (GI) Syndrome
Gastrointestinal (GI) syndrome will usually occur with a dose greater than approximately 10 Gy (1000 rads) although some symptoms may occur as low as 6 Gy or 600 rads. Survival is extremely unlikely with this syndrome. Destructive and irreparable changes in the GI tract and bone marrow usually cause infection, dehydration, and electrolyte imbalance. Death usually occurs within 2 weeks. (Source: http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp accessed 9/9/2013))

8.1.4 Cardiovascular (CV)/ Central Nervous System (CNS) Syndrome
Cardiovascular (CV)/ Central Nervous System (CNS) syndrome will usually occur with a dose greater than approximately 50 Gy (5000 rads) although some symptoms may occur as low as 20 Gy or 2000 rads. Death occurs within 3 days. Death likely is due to collapse of the circulatory system as well as increased pressure in the confining cranial vault as the result of increased fluid content caused by edema, vasculitis, and meningitis. (Source: http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp accessed 9/9/2013))

8.1.5 Cutaneous Radiation Syndrome (CRS)
The concept of cutaneous radiation syndrome (CRS) was introduced in recent years to describe the complex pathological syndrome that results from acute radiation exposure to the skin. ARS usually will be accompanied by some skin damage. It is also possible to receive a damaging dose to the skin without symptoms of ARS, especially with acute exposures to beta radiation or X-rays. Sometimes this occurs when radioactive materials contaminate a patient's skin or clothes.

When the basal cell layer of the skin is damaged by radiation, inflammation, erythema, and dry or moist desquamation can occur. Also, hair follicles may be damaged, causing epilation. Within a few hours after

irradiation, a transient and inconsistent erythema (associated with itching) can occur. Then, a latent phase may occur and last from a few days up to several weeks, when intense reddening, blistering, and ulceration of the irradiated site are visible. In most cases, healing occurs by regenerative means; however, very large skin doses can cause permanent hair loss, damaged sebaceous and sweat glands, atrophy, fibrosis, decreased or increased skin pigmentation, and ulceration or necrosis of the exposed tissue. (Source: http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp accessed 9/9/2013))

8.2 Chemical Health Effects

RASCAL does not calculate health effects.   The health effects that are presented in the RASCAL 4.3 Technical Supplement and RASCAL Help summarize the work of others. They are presented as background material only.

8.2.1 HF Lung -- HF

Acute exposure guideline levels (AEGLs) have been established for exposure to HF. They are applicable to the general population, including infants and children and other individuals who may be susceptible. The AEGLs are as follows:

Hydrogen fluoride	7664-39-3	(Final)			
ppm					
	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	1.0	1.0	1.0	1.0	1.0
AEGL 2	95	34	24	12	12
AEGL 3	170	62	44	22	22

(Source: http://www.epa.gov/oppt/aegl/pubs/results53.htm accessed 9/9/2013)

8.2.2 HF Lung -- 1 Hour Equivalent

A 1-hour equivalent HF concentration in the lungs of about 1070 mg/m3 for one hour has about a 50% chance of fatality without emergency medical treatment. A concentration of 1670 mg/m3 for 30 minutes has about a 50% chance of fatality without emergency medical treatment. The NIOSH Immediately Dangerous to Life or Health (IDLH) concentration is 25 mg/m3 for 30 minutes. IDLH is defined as "a maximum concentration from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects." (NUREG-1391, Chemical Toxicity of Uranium Hexafluoride Compared to Acute Effects of Radiation, 1991).

8.2.3 Inhaled Uranium

Uranium intake provides the best measure of potential acute kidney damage due to heavy metal poisoning as shown below. There are no known long term chemical injuries from uranium intake that are sub-lethal.

U intake by inhalation Health effect

U intake by inhalation	Health effect
Below 5 mg	None
8 mg	threshold for clinically observable transient chemical changes in urine indicating renal distress
50 mg	threshold for permanent renal damage (speculative—never observed in humans)
230 mg	50% fatality without medical treatment

(From: S. McGuire, NUREG-1391).

8.2.4 Uranium Hexafluoride

Acute exposure guideline levels (AEGLs) have been established for exposure to UF_6. They are applicable to the general population, including infants and children and other individuals who may be susceptible. The AEGLs are as follows:

Uranium hexafluoride   7783-81-5   (Final)
[mg/m^3]

	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	3.6 mg/m^3	3.6 mg/m^3	3.6 mg/m^3	NR	NR
AEGL 2	28 mg/m^3	19 mg/m^3	9.6 mg/m^3	2.4 mg/m^3	1.2 mg/m^3
AEGL 3	216 mg/m^3	72 mg/m^3	36 mg/m^3	9.0 mg/m^3	4.5 mg/m^3

NOTE THAT VALUES ARE IN **mg/m^3**, NOT ppm.
NR = Not recommended due to insufficient data (Source:
http://www.epa.gov/oppt/aegl/pubs/results58.htm accessed 9/9/2013)