Use of the SNAP/RADTRAD Code for LOCA and non-LOCA Dose Analysis

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Objective

- The objective of this training is to show participants how to use the SNAP/RADTRAD code for performing licensing dose analysis for nuclear power plants.

- This presentation focuses on accident dose analysis and the methods coded into SNAP/RADTRAD and is intended to provide participants with the background needed to perform dose analysis using SNAP/RADTRAD.

- The training presentation is based on a representative PWR plant and is intended to provide participants with the background needed to perform dose analysis for LOCA and non-LOCA accidents using SNAP/RADTRAD.

Purpose of SNAP/RADTRAD

- Purpose of SNAP/RADTRAD is to determine the dose from a release of radionuclides during a design basis accident to the following locations:
  - Exclusion Area Boundary (EAB)
  - Low Population Zone (LPZ)
  - Control Room (or Emergency Offsite Facility)

- Focus of SNAP/RADTRAD is dose analysis for licensing applications to show compliance with nuclear plant siting and control room dose limits for various LOCA and non-LOCA accidents.

SNAP/RADTRAD Overview

- **S**ymbolic **N**uclear **A**nalysis **P**ackage – suite of applications that interface with nuclear analysis/safety computer codes:
  - Developed by Applied Programming Technology, Inc.
  - Initial focus was the thermal hydraulics codes (TRACE, RELAP5)
  - Later, other codes added (MELCOR, FRAPTRAN, FRAPCON, etc.)
  - Current version is V2.6.0 as of Nov. 9, 2017

- SNAP provides a standard graphical user interface to simplify the development of models for the supported analytical codes. SNAP is used to:
  - Construct, maintain and document models
  - Run analyses and analyze results

SNAP/RADTRAD Overview

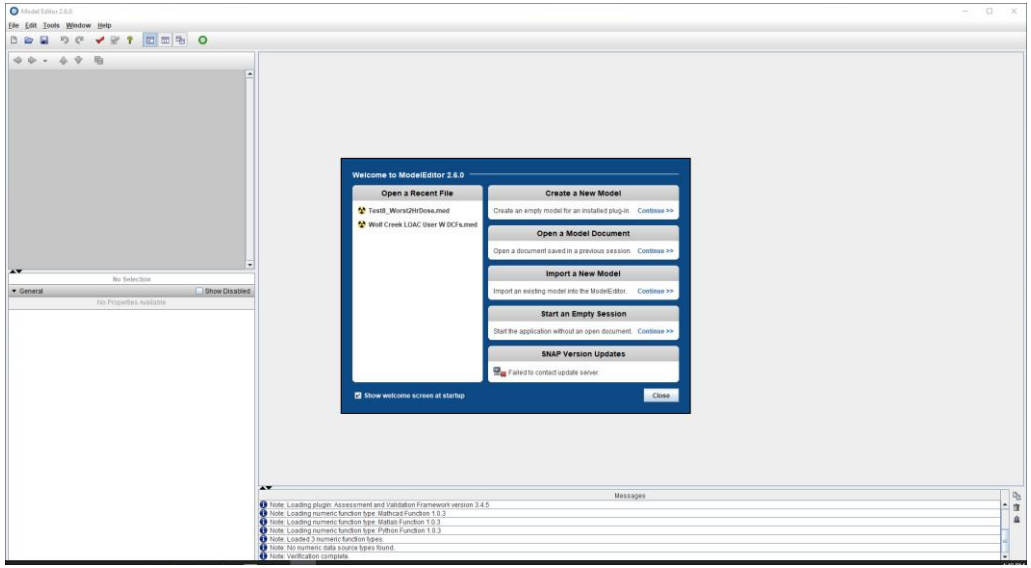
- The primary apps in SNAP for RADATRAD analysis are:
  - Model Editor – primary interface for developing models.
  - Configuration Tool – used to configure SNAP for operation on a given computer.
  - Job Status Tool – used to check job progress and view results,
  - Calculation Server – operates in the background and controls code execution. Allows current jobs on multicore processors.

- SNAP is developed in JAVA and is platform-independent.
  - Uses a plug-in architecture.
  - Can be adapted to any engineering code.

SNAP/RADTRAD Overview

- RADTRAD was incorporated into SNAP in two parts:
  - RADTRAD plugin to SNAP which, along with the Model Editor interface, provides the user with the ability to prepare RADTRAD models. This code is referred to as the RADTRAD plugin and is maintained by APT. The current version is V4.11.6.
  - A separate analytical code that actually performs the calculations and generates the output. This code is maintained by ISL, Inc. The current version is V4.5.6.
- Documentation is available on SNAP/RADTRAD and the RADTRAD analytical code from the RAMP website. Link is:
  https://www.usnrc-ramp.com/content/snapradtrad-overview

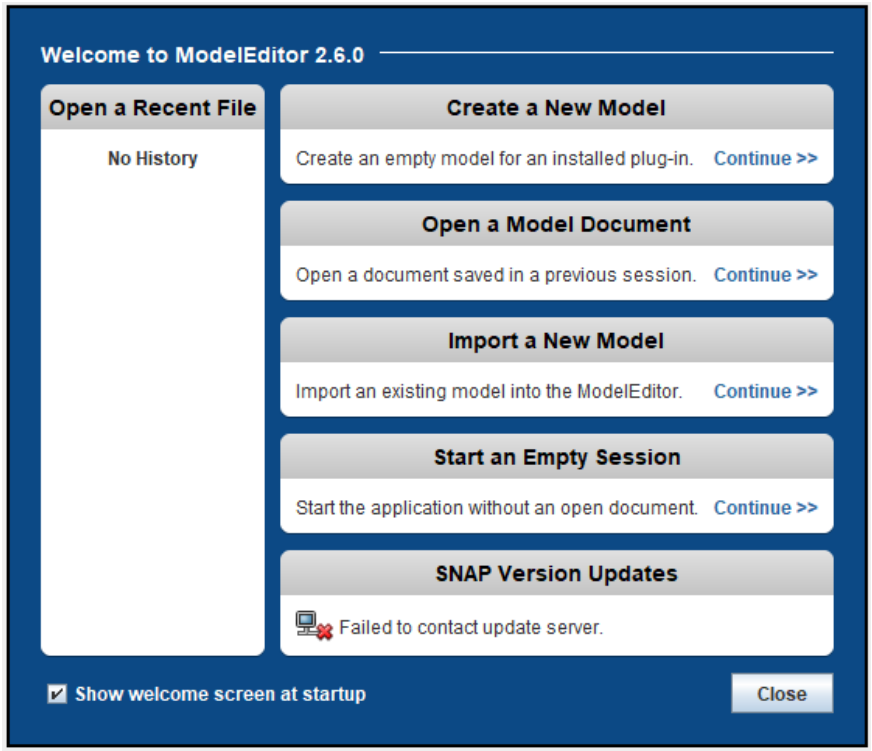
SNAP/RADTRAD Model Development



- To start the Model Editor, click on
  Start->All Programs->
  SNAP->Model Editors

  Alternately, you can type Model Editor in the "Search Programs and Files" textbox under Start.
  - A "splash screen" will appear with NRC credit, code version, etc. Then the Model Editor opens.

SNAP/RADTRAD Model Development

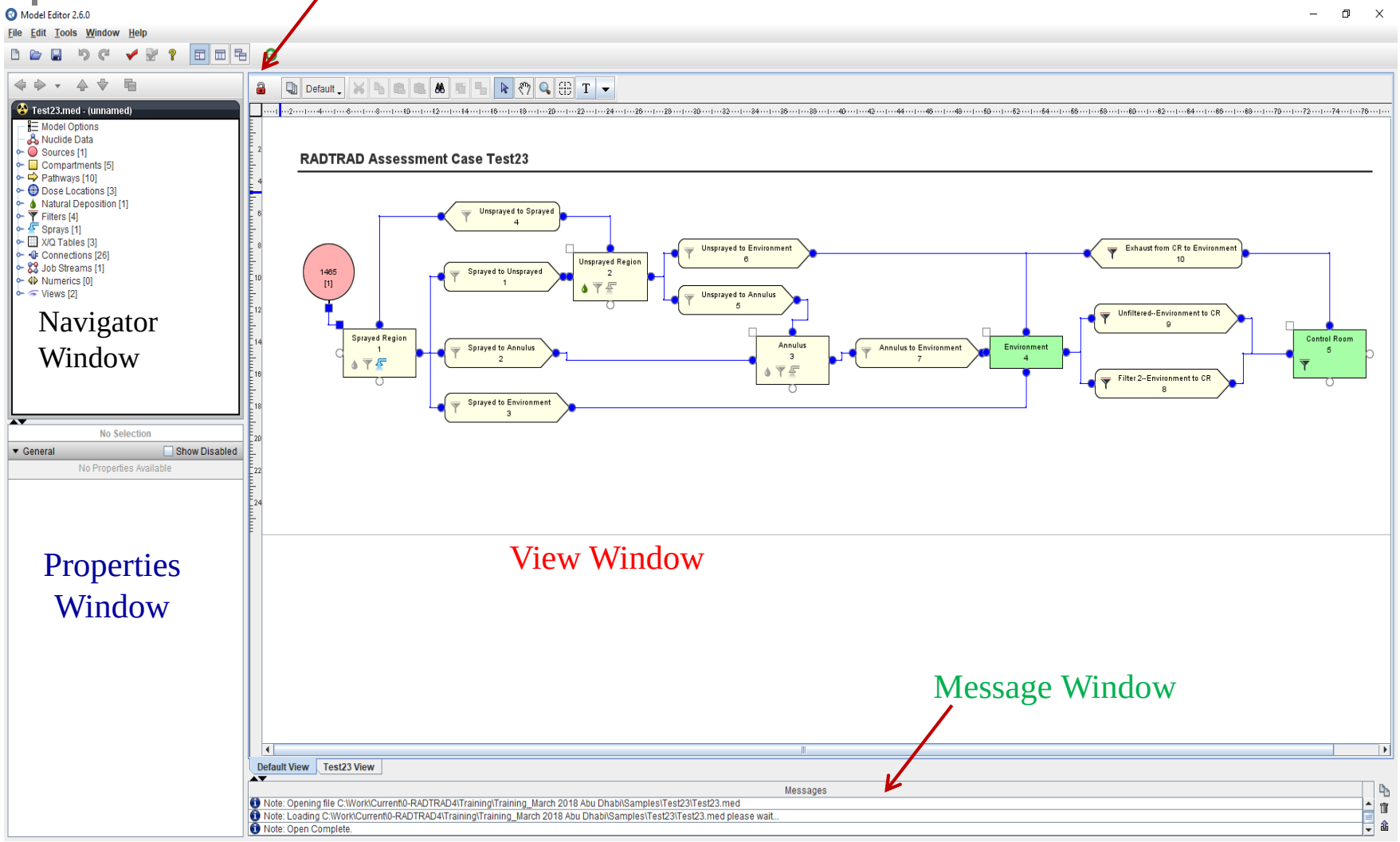


- Five options available as shown on the Welcome Screenshot – typical of Windows programs
- Most of the time, users will create a new model, open an existing model or import a existing model from a .psx file.
- There are multiple ways that you can perform any of the above functions. Some examples:
  - File->New to create a new model
  - File->Open to open a previously saved model
  - File->Import to import a model

SNAP/RADTRAD Model Development

- We'll start by opening a previously created model Test23. The test23.med file is found in Samples/Test23. Steps are as follow:
  1. Open the Model Editor as before.
  2. Select Continue under Open a Model Document on the Welcome Screen. Navigate to the location of the Test23 subdirectory under the Samples directory.
  3. Click on Test23.med. The Model Editor rendering of Test23 will open.

SNAP/RADTRAD Model Development



Component Navigator Window

Current Model

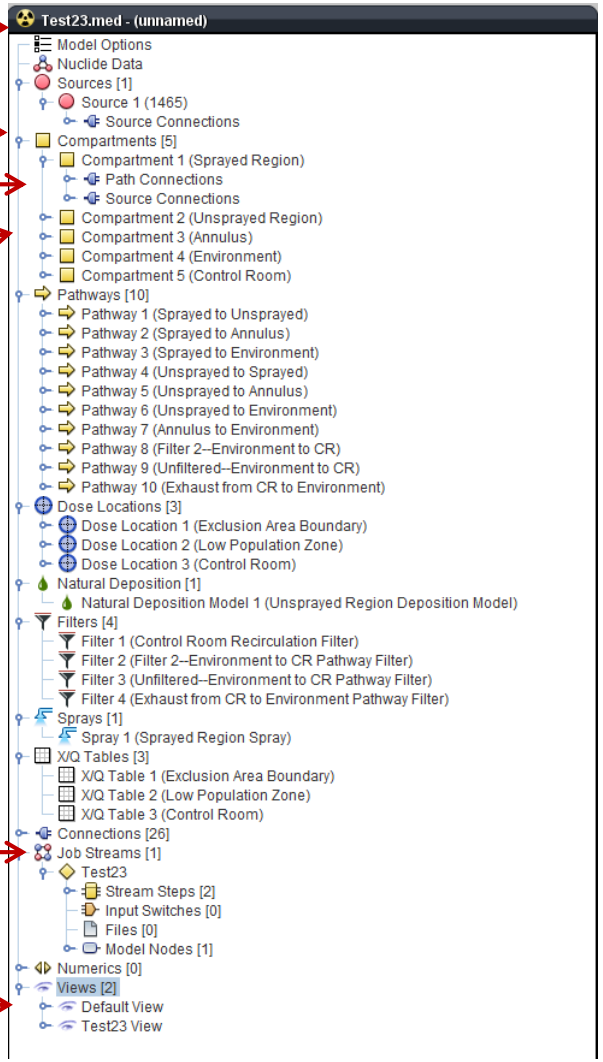
Categories

Connections

Components

Job Streams

2D Views



SNAP/RADTRAD Model Options

- Model Options node is where various options are available. Includes:

- Title/Description
- Plant Power Level (MW)
- Decay Options:
  - no decay,
  - decay only,
  - decay and daughter production
- Onset of Gap Release (hrs) – typically 0.
- Start of Accident (hrs) – typically 0.
- Duration of Accident (hrs) – typically 720 hrs
- Dose Conversion Factors: FGR 11&12 or User-Specified
- Dose Conversions: allows user to view FGR defaults or specify alternate DCFs.

- Time Step Algorithm:
  - Adaptive
  - Default
  - Default with error calculation.

- Output Parameters
  - Dose/Activity Output Units
    - Activity/Dose Units (Ci, Rem)
    - Si Activity/Dose Units (MBq, mSv)
  - Echo Model Definition (T, F)
  - Show event results (T, F)

SNAP/RADTRAD Model Options

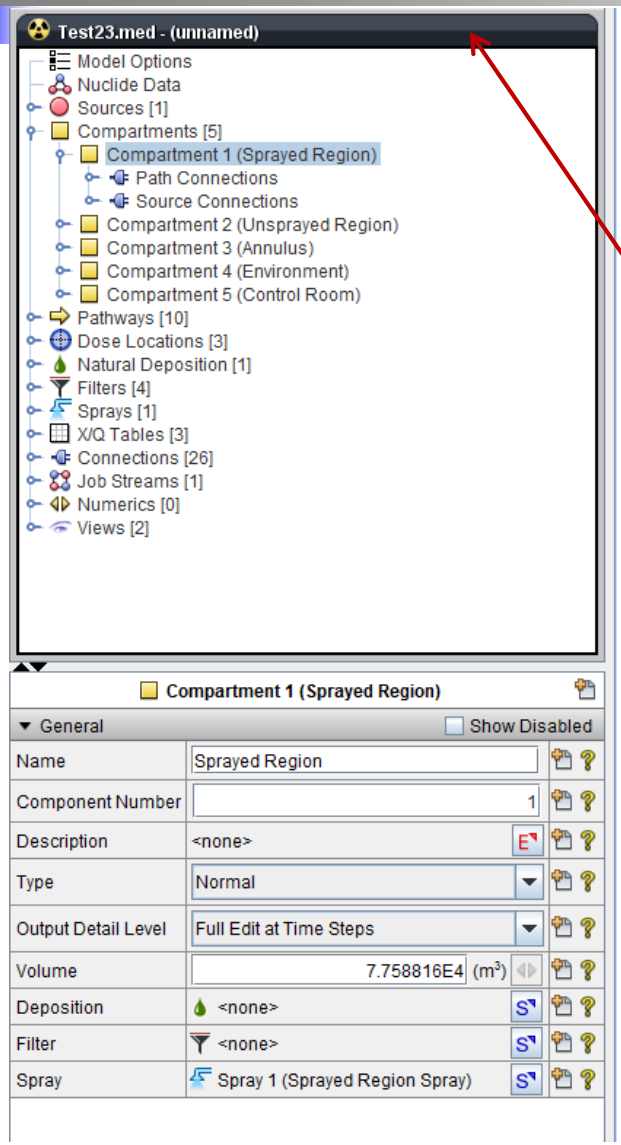
- Model Options - continued

• NRC Output:
  • Dose results listed by nuclide for various dose components.
  • Formatted output (page layout) to allow insertion into a Word document.
  • Lines per page can be set as well as a tolerance for displaying output.
	• Diagnostic Flags:
	  • Used for debugging

SNAP/RADTRAD Model Editor

- Click on Default View to see model nodalization. Click on Test23View tab to see the job stream representation.
- Click on Lock icon () to unlock the model. Note the change in the toolbar.
- Click on Expand icon () to expand each node in the Model Navigator Window to see the input fields for SNAP/RADTRAD.
- Click on Tools -> Check Model to perform an input check on the model. Note the message “Note: Model check complete. No errors found” in the Messages Window at the bottom of the screen.

SNAP/RADTRAD Model Editor



- Click on the Expand node icon ( ) next to Compartments, then click on Compartment 1.
- Note that the compartment 1 input appears in the Properties Window
- To switch units to English, right-click on the "black bar" in the Navigator Window, select Engineering Units -> British to change the units.
- Experiment with other input groups – approach is the same – we'll get to specifying input later.

SNAP/RADTRAD Model Development

Compartment Types in RADTRAD that are principally used:

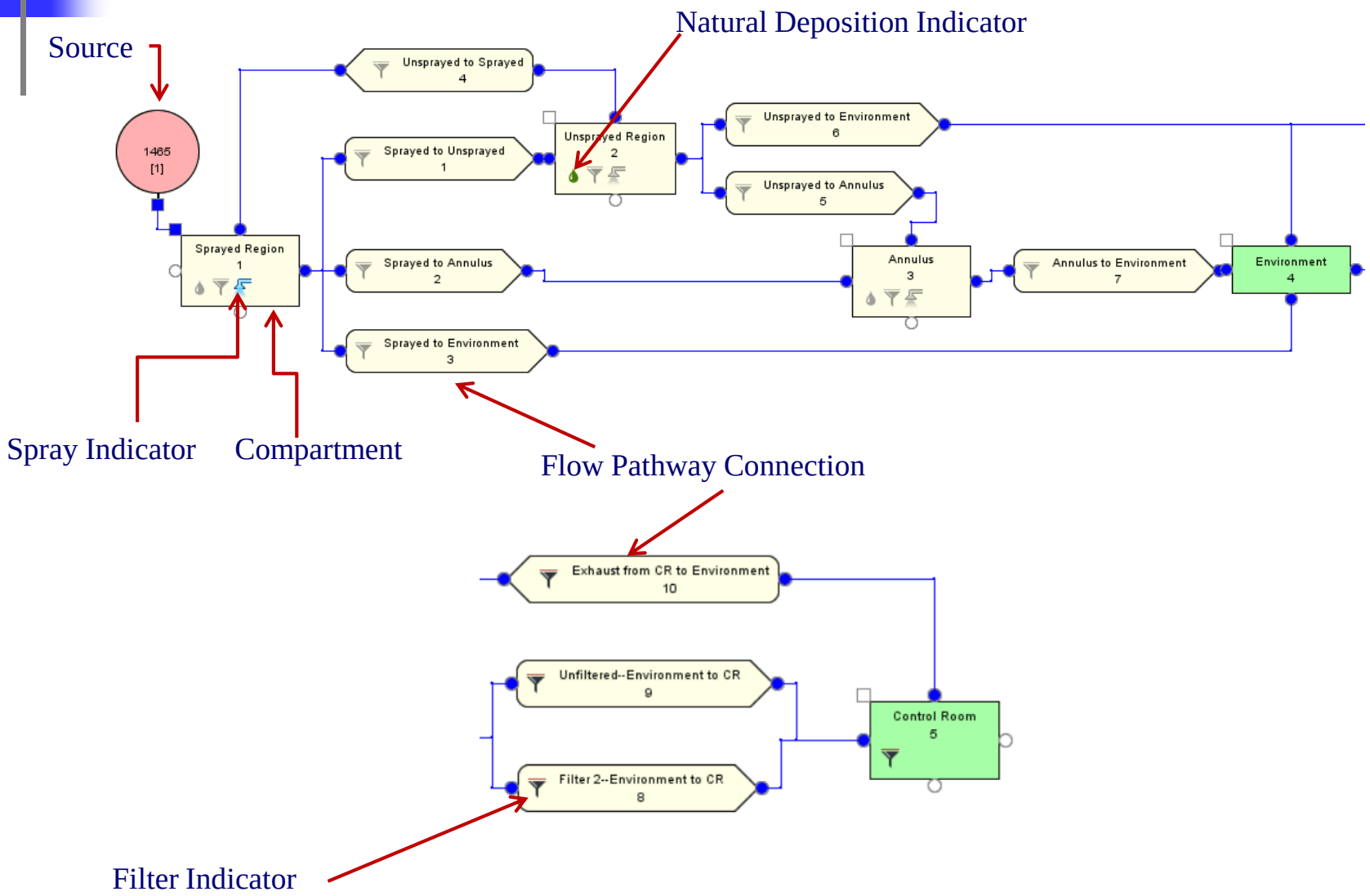
- Normal compartment:
  - Used to model plant structures (ex containment).
  - Radionuclides can be released to the compartment, transferred to/from other compartments and removed (filtered, sprays, natural deposition).
  - Various removal processes models available for normal (other) compartments.

- Control Room Dose compartments:
  - Used to model control rooms.
  - Control room intake and exhaust is from the environment (release at intakes is X/Q dependent).
  - Can model filtration in control room (both direct and recirculation filters).

SNAP/RADTRAD Model Development

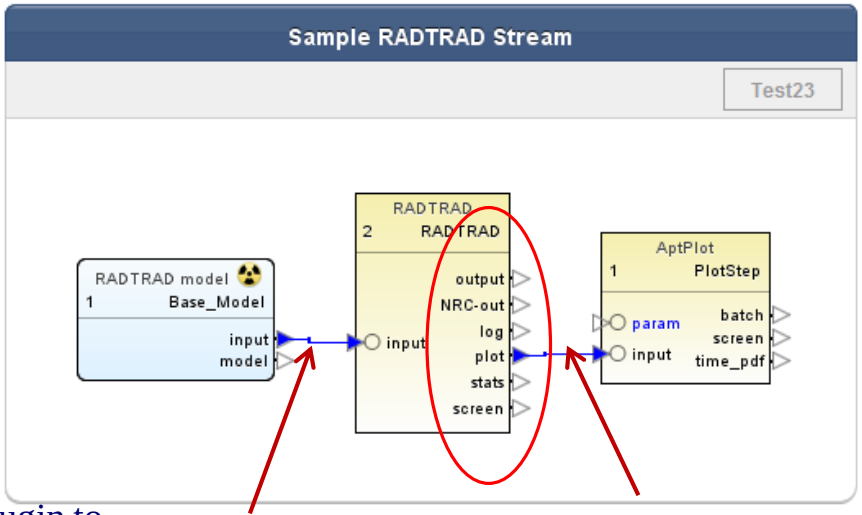
- Environment Compartment
  - Compartment used to model the Exclusion Area Boundary (EAB) and Low Population Zone (LPZ) doses.
    - Control room HVAC intake draws from the environment compartment.
    - Coupling with the EAB and LPZ locations as well as the control room intake is through X/Q values.
- Normal dose compartment – used to compute the dose at an arbitrary dose point (ex. in containment).

SNAP/RADTRAD Model Development



SNAP/RADTRAD Model Development

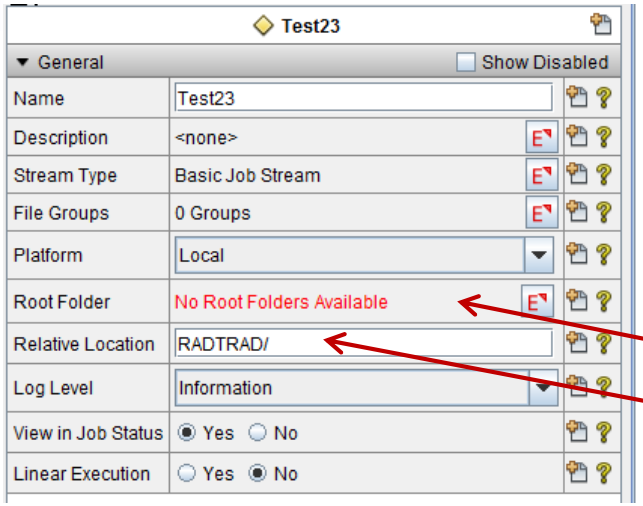
- Case execution – depends on the Job Stream. Job streams are used to pass input and output data from one code to another. Mostly of interest to thermal hydraulic analysts. A default job stream is automatically set up by the Model Editor for SNAP/RADTRAD.
- The default job stream for RADTRAD passes input from the Model Editor to the RADTRAD analytical code. Plot file results are passed from RADTRAD analytical code output to APTPlot input.

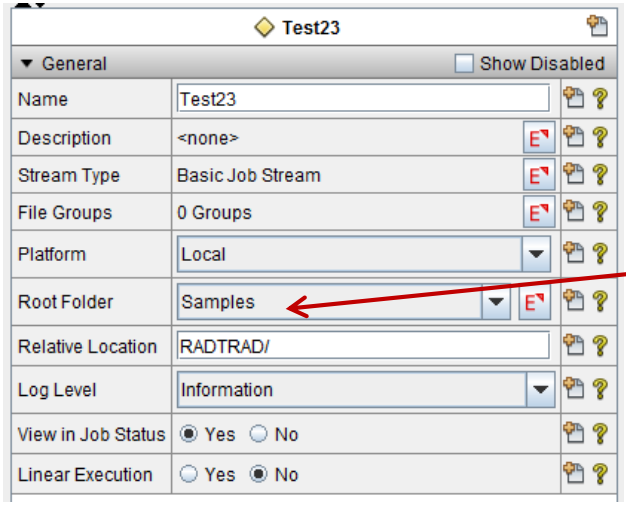


SNAP plugin to RADTRAD analytical code.

RADTRAD analytical code to AptPlot.

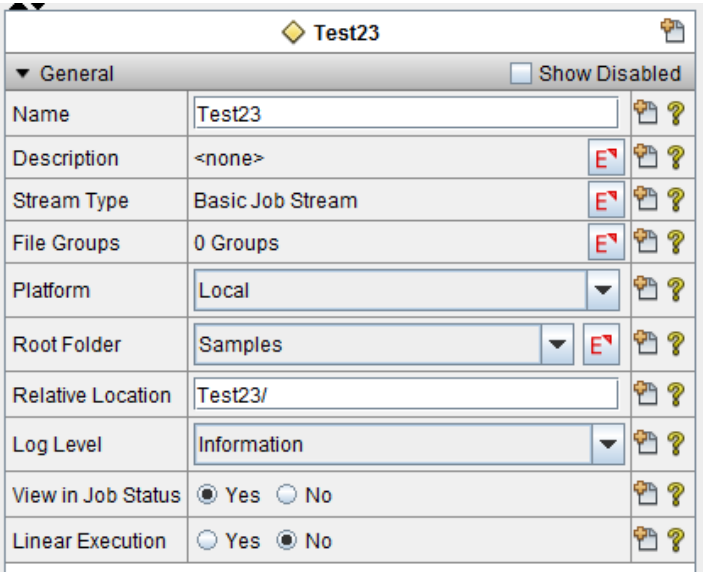
SNAP/RADTRAD Model Development

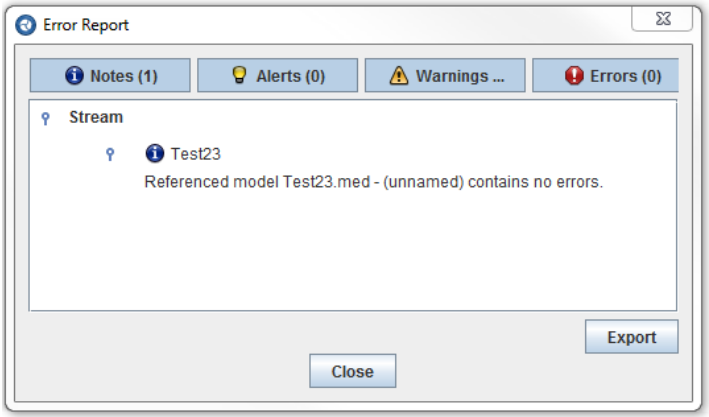




- Job stream settings can be checked in the Model Editor. In the case of Test23, expand the Job Stream node, select Test23 and right-click, then select "Check Stream". A Error Report window will appear.
- Common error (for me) is to forget to set the Root Folder, which, in combination with the Relative Location is where the output files are written.
- To set the Root Folder, click on . An "Edit Calculation Server Root Folders" window will appear. Click on the New ( ) icon and navigate to the desired location in the "Select Folder Location" window. The Root Folder name will change to the last folder name in the directory path.
- If you don't like that name, click on , then double click in the Name field, then change the name as desired. The Root Folder name will be changed.

SNAP/RADTRAD Model Development



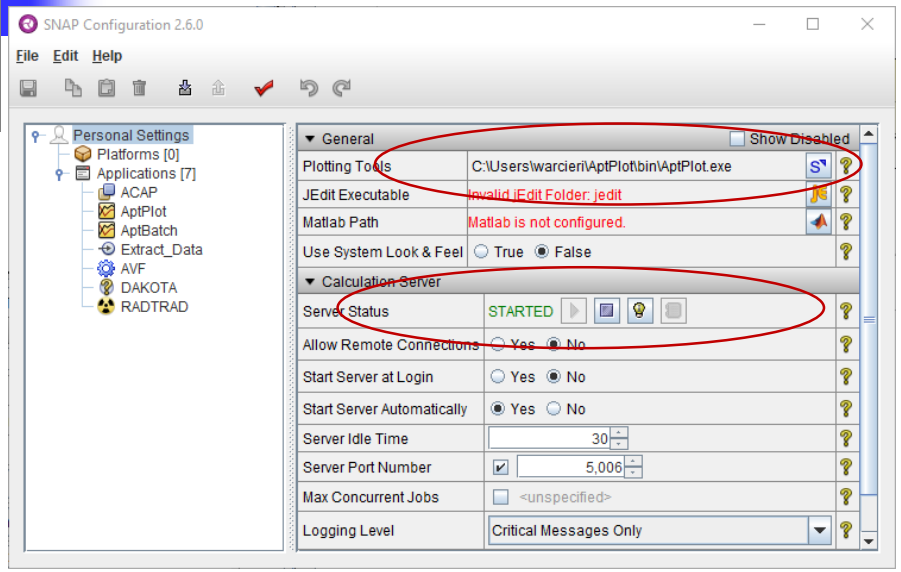


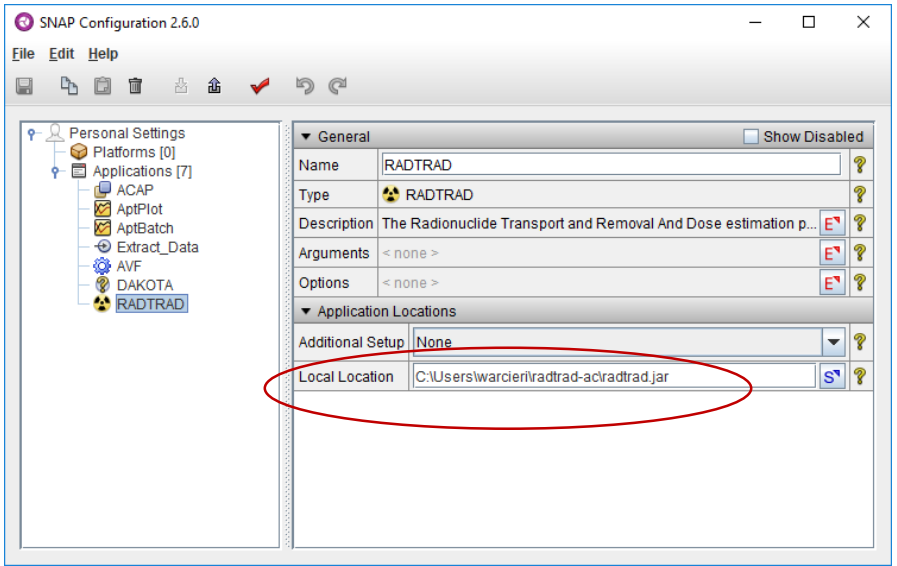
- Relative location can also be reset. You should reset this to a name more nmemonic so you can track your cases.
- To change the name, highlight the Relative Location Name and type in a new name (Ex. Test23).
- Note the / is automatically appended, so no need to add it.
- Run a Job Stream check to determine if everything is OK. Expand the Job Stream Node ( ), then right-click on the Job Stream Name (Test23) and select Check Stream. An Error Report window will appear displaying the error status.

SNAP/RADTRAD Model Development

- Note that multiple root folders are allowed – handy for organizing SNAP/RADTRAD case files.
  - To add a root folder, navigate to Tools->Job Status or click on the Job Status icon ( )and expand Local.
  - Right-click on Local and select Root Folders.
  - Click on New icon (left on Toolbar) and navigate to where you want the root folder (ex. NPP Dose Analysis).
  - The root folder path will be created.
- A couple of points:
  - The root folder directory needs to exist – otherwise you'll get a warning that the directory doesn't exist and the root folder will not be defined.
  - Overlapping paths are not allowed and will generate an error.

SNAP/RADTRAD Model Development



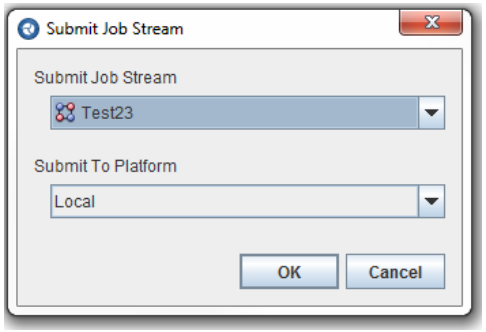


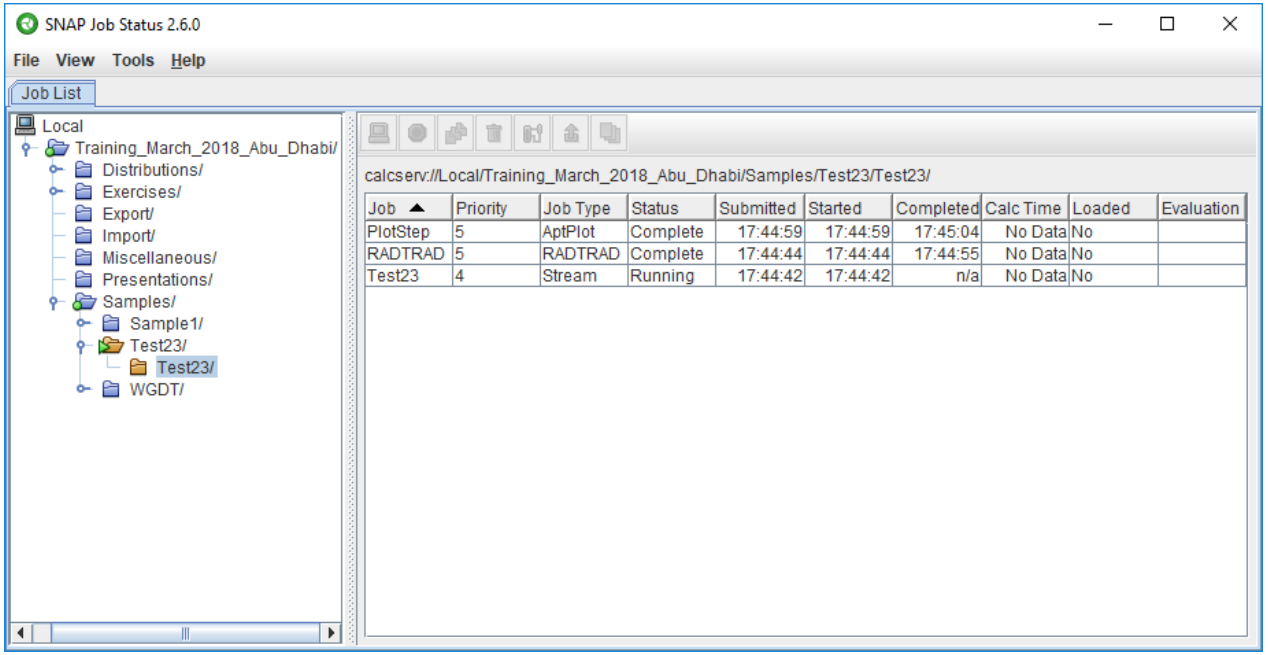
- Before we continue, confirm the link to the analytical code by navigating to

  Tools->Configuration Tool

  and then expand the Applications node by clicking on the icon. Then click on RADTRAD.
- This link is to the RADTRAD analytical code.
- Note that this location is installation-dependent.

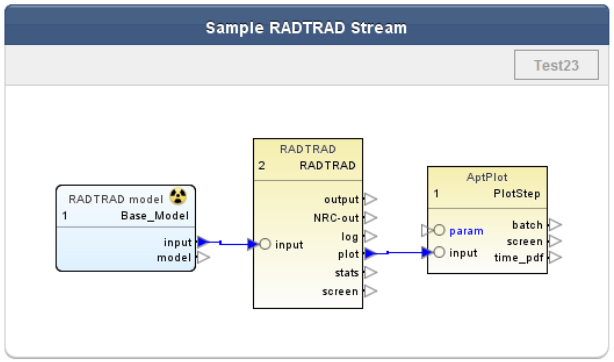
SNAP/RADTRAD Model Development

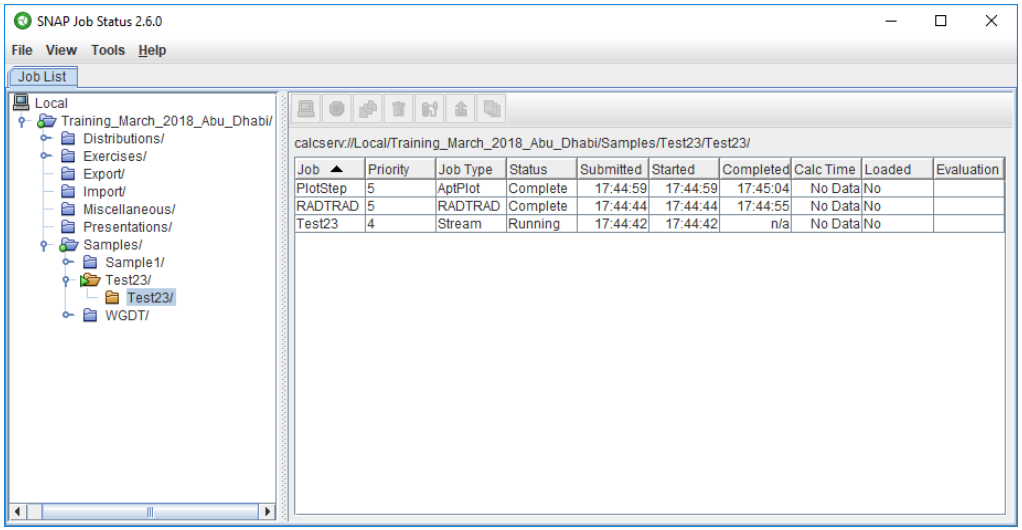


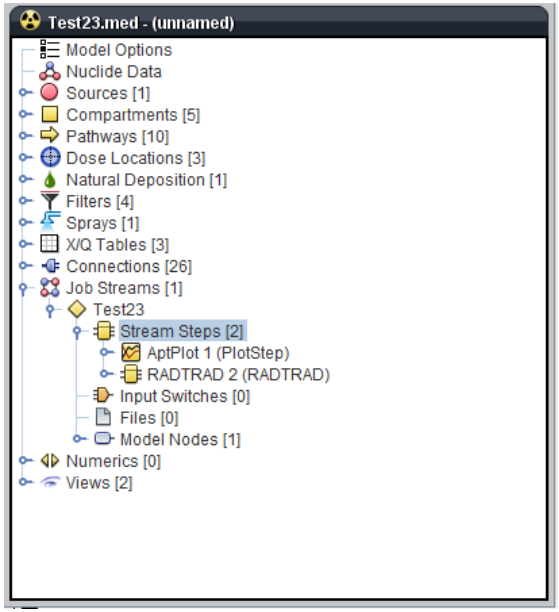


- To run the Test23 case, click on Tools -> Submit Job. A Submit Job Stream window appears.
- Click OK and a confirmatory "Submit Stream" window appears.
- Click OK and the run will start. The SNAP Job Status window will appear. In this case, the run is completed.

SNAP/RADTRAD Model Development







- Note the relationship between the RADTRAD stream, the Navigator Window and the Job Status Window.
  - Two Job Stream steps

SNAP/RADTRAD Model Development

- Output Review – Click on the RADTRAD Job Type in the Job Status Window, then click on the File Viewer () icon and then select Text Files. A list of files will appear. Select the file of interest to open the file in the File Viewer to review the file data (reminiscent of V3.03)
- Key output files are listed below (there are others as well).

Name	Description
radtrad.dfx	dose conversion factors file in xml format (input)
radtrad.nix	nuclide information file in xml format (input)
radtrad.plt	plot file read by AptPlot plotting program (output)
radtrad.psx	plant information file in xml format (input)
radtrad_1.icx, radtrad_2.icx, etc.	initial inventory file for each source (input)
radtrad_1.srx, radtrad_2.icx, etc.	source term file for each source (input)
radtrad.out	RADTRAD output in original output format (output)
radtradNRC.out	RADTRAD output in NRC output format (output)
radtrad.screen	RADTRAD screen output file (output)

SNAP/RADTRAD Output File Description

- radtrad.out – original output format in V3.03/3.10 format. Major sections are:
  - Input echo – provides an edited input summary of plant description (model), scenario (radionuclide source term/DCF) information, compartment/pathway data, X/Q, etc.
  - Breakdown of dose results at various time points generally selected by changes in events (ex. time at which flow rate changes, time at which X/Q changes). Activity balance information also given.
  - I-131 Summary, Cumulative Dose Results, Worst Two-Hour Doses and Final Doses at the end of the file.
  - Contents can be controlled from Model Options -> Output Parameters in the Model Editor. Output units in cgs (Rem/Ci) or SI units (mSv, MBq) available (under Model Options->Output Parameters).

SNAP/RADTRAD Output File Description

- radtradNRC.out – provides time-dependent summary of dose by nuclide -
  - Input echo – provides an edited input summary of plant description (model), scenario (radionuclide source term/DCF) information, compartment/pathway data, X/Q, etc.
  - Output – activity distribution, cumulative and dose difference (delta-dose) for each dose component (inhalation, cloudshine, skin, thyroid, and TEDE). Output units in cgs (Rem/Ci) or SI units (mSv, MBq) available (under Model Options->Output Parameters).
  - I-131 Summary, Cumulative Dose Results, Worst Two-Hour Doses and Final Doses at the end of the file.
  - Contents can be controlled from Model Options -> NRC Output Flags in the Model Editor.
  - Note that this file is designed to be imported into a word processor (page breaks, etc.). Lines/page and output cutoff (so that the file doesn't get too large) can be set in the Model Editor.
- radtrad.screen – summarizes time step information.

SNAP/RADTRAD Model Editor/AptPlot

- Note that context of the job stream step affects the output available for display through the File Viewer.
  - Click on Test23 – only the stream log is available for display.
  - Click on RADTRAD – all files listed on the previous chart are available for display. Time step history is displayed in the window.
- To display a plot, then click on the File Viewer () icon, then click on Plot Files and select "plot – radtrad.plt." AptPlot will open. Alternately, click on the () icon and AptPlot will open.
- In the Select EXTDATA Channels window, scroll down to desired results to be plotted. For example, scroll to "ControlRoom.tede." A plot of the TEDE dose for the control room will appear.
- If you don't want to scroll, type "ControlRoom.tede" in the Filter text box and then click on Control.Room.tede at the top of the data channel window.

SNAP/RADTRAD Model Editor/AptPlot

- Wildcards can be used to identify the results of interest in the Filter text box. Ex:
  - L*P*Z* - isolates the LPZ dose results for all dose categories.
  - L*P*Z*th* - isolates the LPZ dose results for the thyroid dose for all nuclides and the total dose (LowPopulationZone.thyroid).
  - Note that case counts.
- Click on the Clear Sets button to clear the plot.
- To change the units of the x-axis from seconds to hours, navigate to the Time units drop-down menu and pick hours.
- If you accidently close the “Select EXTDATA Channels” window, navigate to Window-> Select EXTDATA Channels to reopen the window.
- Suppose you want to plot the Control Room dose for all dose categories. Available dose categories are whole body, cloudshine, skin, TEDE, and thyroid. Type in the desired result in the Filter window, then pick the result from the Channels window and finally click on the Plot button to add the data plot.

  - C*R*cloudshine – cloudshine dose
  - C*R* - inhalation
  - C*R*skin – skin dose
  - C*R*tede – TEDE dose
  - C*R*thyroid – thyroid dose

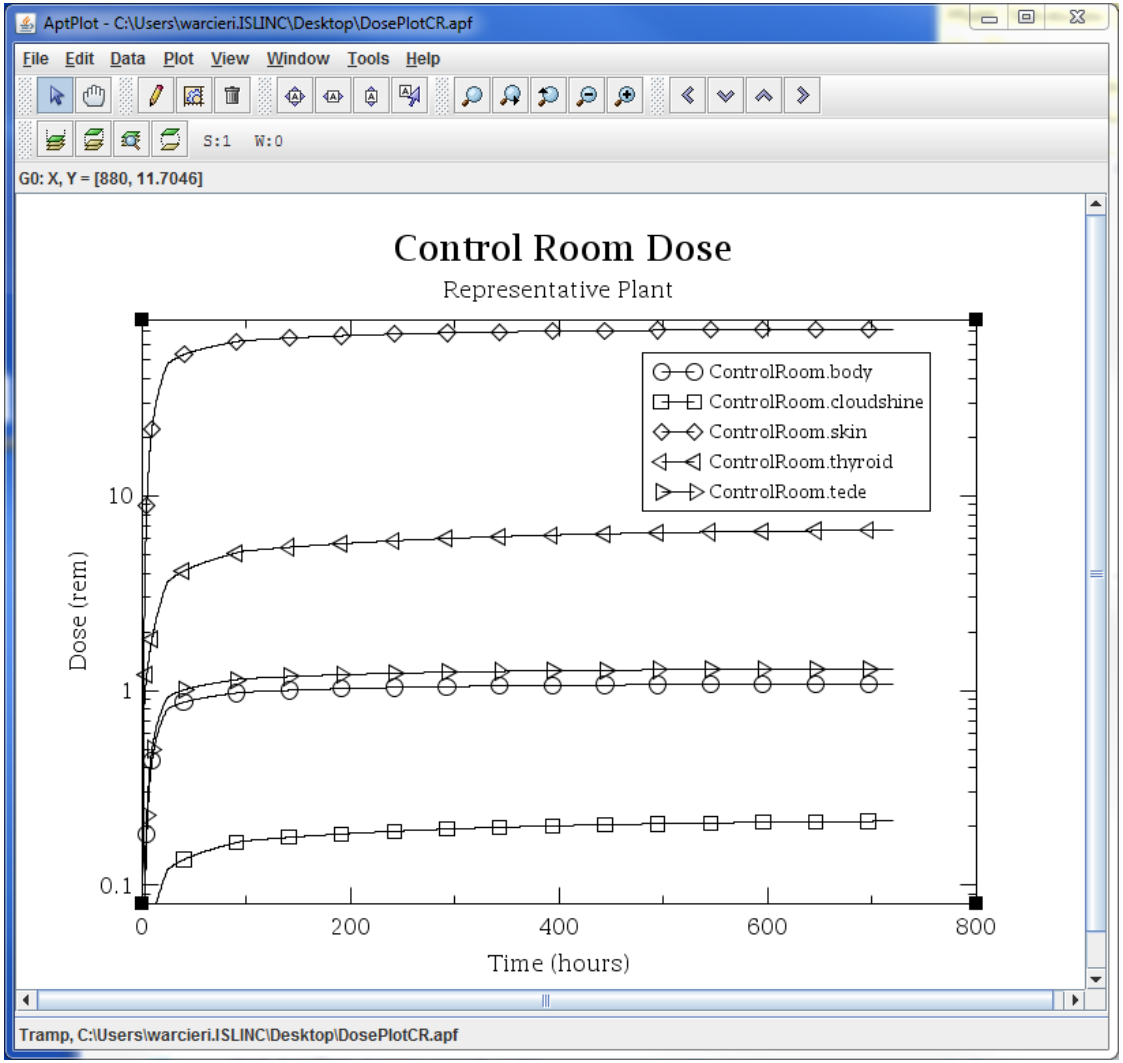
SNAP/RADTRAD Model Editor/AptPlot

- Note that as each data set is added to the plot, AptPlot adds it to the Data sets window (number in brackets are x-y array dimensions).
  - G0.S0[2][1664] – control room cloudshine dose
  - G0.S1[2][1664] – control room inhalation dose
  - etc.
- Double-click on the desired dataset to see the actual data. Note that you can cut and paste the data into a spreadsheet. You can also export the date, but cut and paste works better.
- Suppose you close the Select EXTDATA Channels window. Navigate to Window->Select EXTDATA Channels window to reopen.
- The plotted data is hard to see and distinguish. Let's plot all of the control room dose components as illustrated above and make some changes:
  - Navigate to Plot->Set Appearance to change the appearance of each line.
    - Main tab – select a data set and then go to Line properties and change the color of the line to black. Other line-formatting changes are available. Note that the datasets can be grouped.
    - Main tab – select a data set and then a symbol for each dataset under Symbol Properties (one at a time). Click the Apply button after each selection.

SNAP/RADTRAD Model Editor/AptPlot

- More changes:
  - Navigate to Plot->Set Appearance to change the appearance of each line. Click on the symbols tab and then input a value for Symbol skip for each line – use a value of 100 (need to do them individually). Click Apply after each selection.
  - Change the scale of the y-axis to logarithmic to make plots easier to read. Navigate to Plot->Axis Properties. Change the Edit value from X axis to Y axis, then change the Scale from Normal to Logarithmic. Then click Apply.
  - Legend box is a little big – change the font size by navigating to Plot->Graph appearance.
    - Pick the Legends tab and change the font size from 100 to 75 using the slider. Click on the left or right side of the slider for finer control. Then click Apply.
    - To move the legend box, pick the Leg. Box tab and change the Location to x=0.75 and y=0.81 or other suitable values.
    - Titles and subtitles can be added under the Main tab.

SNAP/RADTRAD Model Editor/AptPlot



SNAP/RADTRAD Model Editor/AptPlot

- To save plot, navigate to File->Save and select a suitable location to save the plot. The plot is saved in AptPlot (apf) format.
- Saved plotfile can be used as a template for plotting other datasets – avoids making many of the formatting settings. Ex. Plot the LPZ dose results for Test23.
  - Open a new AptPlot session from the Model Editor. From the AptPlot window, navigate to the location of the copied .apf file. Note that the control room dose results appear.
  - Clear the sets from the Select EXTDATS Channels window. Switch Time units from seconds to hours.
  - Plot the LPZ dose results as outlined above.
  - Fill in the titles and make other adjustments as desired.
  - Save plot under a new filename.
  - Can also associate the .apf file type to ApTPlot through Windows.
- Many other features are available in AptPlot.

SNAP/RADTRAD Model Editor

- A useful feature is the Model Notebook feature. This feature generates a initial Model Notebook that you can modify.
- To generate an initial Model Notebook, right-click on the “black bar” in the Navigator Window, select Export -> Model Notebook. Click on Export and provide a filename in the File Name textbox. A notebook is generated in .docx (Microsoft Word) or .odt (Open Office document) format
  - An odt formatted file can be read and edited using Microsoft Word.
  - You can append the Test23NRC.out file to the initial notebook to get an editable notebook that you can modify as needed.
- If you prefer, you can select File -> Export -> Model Notebook to generate a model notebook.

SNAP/RADTRAD Model Editor

- RADTRAD Data are built into the Model Editor
  - Dose conversion factors (FGR 11, 12 based on ICRP 30)
  - Radionuclide data (ICRP-38)
  - Core inventory data (RADTRAD 3.03 for PWR, BWR)
  - Release fractions and release timings (Regulatory Guide 1.183)
  - Iodine chemical form fractions (Regulatory Guide 1.183, 1.195)
- Data file export – above data can be exported from SNAP/RADTRAD by selecting File -> Export -> RADTRAD ASCII and specifying a CaseName. CaseName is Test23 in this situation.
- Import of RADTRAD 3.03 models also available. RADTRAD 3.03 imput sample from report SAND2008-6601 (Appendix B).

SNAP/RADTRAD Model Editor

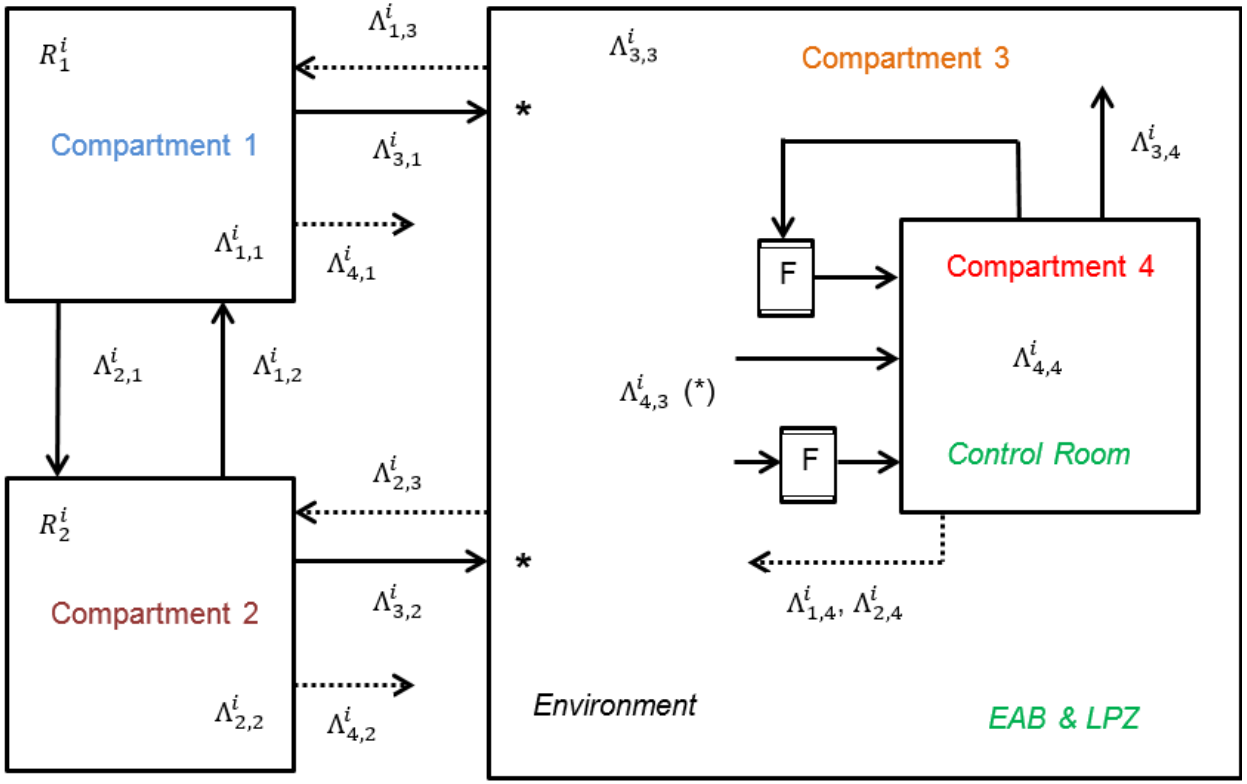
- The following files are exported:

Name	Description
CaseName.psx	Plant information file in ASCII (XML) format. Note that the suffix was added when the export was done.
CaseName.dfx	Dose conversion factors file in ASCII (XML) format.
CaseName.nix	Nuclide data file in ASCII format for each source (x is source number).
CaseName_x.srx	Release fraction file in ASCII format for each source (x is source number).
CaseName_X.icx	Nuclide inventory file in ASCII (XML) format.

RADTRAD Mathematical Models (for RADTRAD-AC)

- RADTRAD utilizes a multi-compartment model with radionuclide release to one or more compartments, flow pathways to account for transfer among compartments, and models for removal within a compartment.
- A key assumption is that the airborne activity in each non-environment compartment is assumed to be uniformly mixed.
- Models for filtration and deposition within a flow pathway can be specified.
- Within a compartment, removal due to decay, natural deposition and sprays can be modeled.
- Daughter product buildup and decay can also be accounted for.

RADTRAD Governing Equations



* Denotes X/Q coupling between release points and dose points (EAB, LPZ) or control room intake.

---- Dotted lines denotes zero flowrate.

Legend:

$\Lambda_{k,j}^i$ – Inter-compartmental transfer from j to k

$\Lambda_{j,j}^i$ – Removal within a compartment j

F – Filter

R_j^i – Source release rate in compartment j

RADTRAD Governing Equations

For, compartment 1, the rate of change in the number of atoms is:

$$\frac{dN_1^i}{dt} = R_1^i - \Lambda_{1,1}^i N_1^i + \Lambda_{1,2}^i N_2^i + \Lambda_{1,3}^i N_3^i + \Lambda_{1,4}^i N_4^i$$

where

R_1^i	= the source release rate of species i in compartment 1 in atoms/s
$\Lambda_{1,1}^i$	= the removal rate of species i within compartment 1 in 1/s
N_1^i	= the inventory of species i in compartment 1 in atoms
$\Lambda_{1,2}^i$	= the transfer rate of species i from compartment 2 to compartment 1 in 1/s
N_2^i	= the inventory of species i in compartment 2 in atoms
$\Lambda_{1,3}^i$	= the transfer rate of species i from compartment 3 to compartment 1 in 1/s
N_3^i	= the inventory of species i in compartment 3 in atoms
$\Lambda_{1,4}^i$	= the transfer rate of species i from compartment 4 to compartment 1 in 1/s
N_4^i	= the inventory of species i in compartment 4 in atoms.

RADTRAD Governing Equations

For compartment 2, a similar equation is used which is:

$$\frac{dN_2^i}{dt} = R_2^i - \Lambda_{2,2}^i N_2^i + \Lambda_{2,1}^i N_1^i + \Lambda_{2,3}^i N_3^i + \Lambda_{2,4}^i N_4^i$$

where

R_2^i	= the source release rate of species i in compartment 2 in atoms/s
$\Lambda_{2,2}^i$	= the removal rate of species i within compartment 2 in 1/s
$\Lambda_{2,1}^i$	= the transfer rate of species i from compartment 1 to compartment 2 in 1/s
$\Lambda_{2,3}^i$	= the transfer rate of species i from compartment 3 to compartment 2 in 1/s
$\Lambda_{2,4}^i$	= the transfer rate of species i from compartment 4 to compartment 2 in 1/s.

RADTRAD Governing Equations

More generally, the rate of change in the number of atoms in the kth compartment in a set of n interconnected compartments is given by

$$\frac{dN_k^i}{dt} = R_k^i - \sum_{j=1}^{n} \lambda_{j,j}^i N_k^i + \sum_{j=1, j\neq k}^{n} \lambda_{k,j}^i N_j^i$$

R_k^i is the source release rate of species i in compartment k in atoms/s

The first summation represents the removal terms from compartment *k* due either to removal within the compartment or transfer to another compartment. The second summation represents transfer from compartment *j* to compartment *k*.

RADTRAD Governing Equations

A matrix formulation can be used to represent the above equations for n compartments as follows:

$$\begin{pmatrix} \dot{N}_1^i \\ \dot{N}_2^i \\ \dot{N}_3^i \\ \vdots \\ \dot{N}_n^i \end{pmatrix} = \begin{pmatrix} R_1^i \\ R_2^i \\ R_3^i \\ \vdots \\ R_n^i \end{pmatrix} + \begin{pmatrix} -\Lambda_{1,1}^i & \Lambda_{1,2}^i & \Lambda_{1,3}^i & \dots & \Lambda_{1,n}^i \\ \Lambda_{2,1}^i & -\Lambda_{2,2}^i & \Lambda_{2,3}^i & \dots & \Lambda_{2,n}^i \\ \Lambda_{3,1}^i & \Lambda_{3,2}^i & \ddots & \dots & \Lambda_{3,n}^i \\ \vdots & \vdots & \vdots & \dots & \vdots \\ \Lambda_{n,1}^i & \Lambda_{n,2}^i & \Lambda_{n,3}^i & \dots & -\Lambda_{n,n}^i \end{pmatrix} \begin{pmatrix} N_1^i \\ N_2^i \\ N_3^i \\ \vdots \\ N_n^i \end{pmatrix}$$

RADTRAD Governing Equations

Off-diagonal terms in the matrix are transfer terms.

- Calculated as f/V where f is the flow rate out of a compartment (vol (or mass) units/time) and V is the compartment volume (vol (or mass) units), yielding units of time^{-1}.
- This ratio is multiplied by the radionuclide inventory in the upstream connecting compartment to provide a source to the connecting downstream compartment.
- Uniform mixing throughout each volume is assumed.

Diagonal terms in the matrix are removal terms.

- Idea is the same in that a removal coefficient expressed in units of time^{-1} is multiplied by the radionuclide inventory to yield a removal rate.

RADTRAD Governing Equations

- The terms included in the diagonal removal coefficients each have units of 1/sec and are:

$$\Lambda^i_{j,j} = \lambda^i_{j,spr} + \lambda^i_{j,dep} + \lambda^i_{j,filter} + \sum_{\substack{k=1 \\ k \neq j}}^{n} \lambda^i_{k,j}$$

$\lambda^i_{j,spr}$ = the spray removal coefficient in 1/s

$\lambda^i_{j,dep}$ = the natural deposition removal rate in 1/s

$\lambda^i_{j,filter}$ = the filtered removal rated within compartment in 1/s

$\lambda^i_{k,j}$ = the removal rate from compartment j toward compartment k in 1/s.

RADTRAD Governing Equations

The removal rate is given by the following equation and includes a few different types of transfer between compartments.

$$\lambda_{k,j}^{i} = \lambda_{k,j,leak}^{i} + \lambda_{k,j,filter}^{i} + \frac{f_{k,j}}{V_j}$$

$\lambda_{k,j,leak}^{i}$ = the transfer via leakage paths in 1/s.
$\lambda_{k,j,filter}^{i}$ = the transfer through a filtered path in 1/s.
$f_{k,j}$ = the flow in m^3/s from j to k through a path with a DF.
V_j = the volume of compartment j in m^3.

RADTRAD Governing Equations

Matrix equation solved in RADTRAD using a matrix exponential based on Lee and Wilson:

- Matrix exponential methods are used to solve systems of linear differential equations of the form $\dot{X} = AX + S$ subject to an initial condition X_0.
- Note that the coefficient matrix is invariant within a time interval. As a result, the initial condition at the start of a given time interval is adjusted based on the quantity of material in each compartment at the end of the previous time interval.

Decay is not explicitly included in the matrix equation.

- Decay is accounted for in RADTRAD by dividing the solution of the differential equations into two parts: (1) radioactive decay and daughter in-growth, and (2) radionuclide transport.
- Used to overcome the limitations of personal computers available at the time the original version of RADTRAD was developed and has been retained to the present time.

RADTRAD Governing Equations

Radioactive decay and daughter production occur within a compartment, so no intercompartmental transfer needs to be considered. The governing equation is:

$$\frac{dN_j^i}{dt} = \sum_{\nu=1}^{n-1} \lambda_\nu \beta_\nu^i N_j^\nu + \lambda_{decay}^i N_j^i$$

β_ν^i = the fraction of nuclide ν that decays to nuclide i (dimensionless).
λ_ν = the decay rate associated with β_ν^i in 1/s.
N_j^ν = the quantity of nuclide ν in compartment j.
λ_{decay}^i = the rate of decay of nuclide i in 1/s.

RADTRAD Governing Equations

Decay and transport calculations are performed alternately in RADTRAD.

- Code begins its integration over a time step by analyzing the effect of radioactive decay and daughter in-growth on the inventory of all compartments.
- Code then calculates the effect of radionuclide transport between compartments during that same time step.
- Process of alternating between radioactive decay and daughter in-growth and radionuclide transport continues until the specified end time is reached.
- Calculations where radioactive decay is not modeled, the solution algorithm is simplified to the single step of calculating radionuclide transport.

RADTRAD Adaptive Time Step

By default RADTRAD uses a predetermined time step size algorithm that starts at 2 seconds and gradually increases to a maximum of 4 hours after about 12.5 hours into the simulation. The time step size can be specified manually as well.

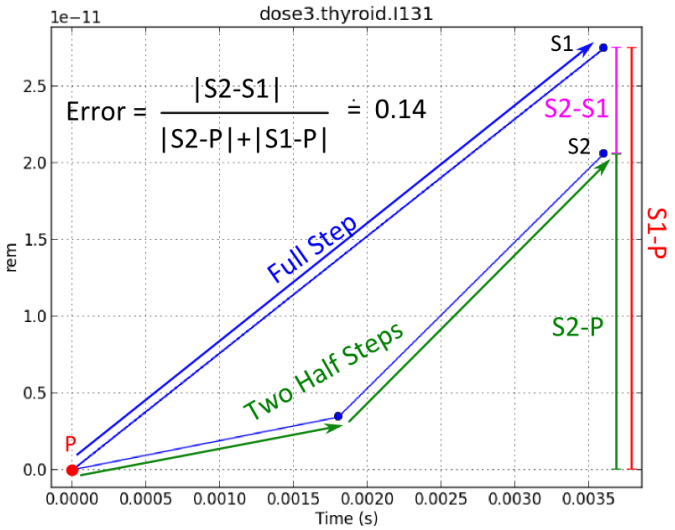
Numerical error is a function of the time step size, and by adjusting the time step size it was found that the default time step size algorithm resulted in notable error for some simulations.

An adaptive time step algorithm was added to RADTRAD in order to control the time step size in order to limit the numerical error.

RADTRAD Adaptive Time Step Error

The adaptive time stepper uses the following algorithm to calculate error over a single time step:

- Starting from solution point P take a full time step to get the time step solution S1.
- Starting again from P take two half time steps to get the time step solution S2.
- Calculate the error by dividing |S2-S1| (the difference in the two solutions) by |S1-P| + |S2-P| (the magnitude of the change in S1 and S2 over the time step).
- The maximum error is 1 and the minimum error is 0.
- To get the percent error in relation to the **average** of |S1-P| and |S2-P|, multiply the error by 200. (The plot shows 28% error)



Adaptive Time Step Algorithm

A simple adaptive time stepping algorithm is used:

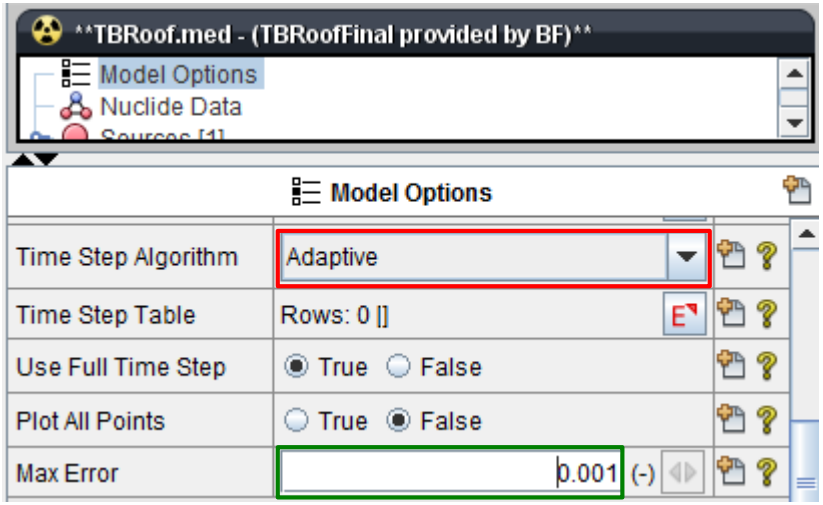
- A **max error** limit is specified for the model. If the error over a time step exceeds the max error, the time step size is cut in half and the time step is repeated.
- If the error is less than **max error/10**, the time step size is doubled for the next time step.

This simple algorithm does not always work and in some cases, more complex logic is used. The adaptive time step algorithm is considered experimental at present since it has had limited use.

Adaptive time step simulations can take significantly longer to complete. On average the adaptive time step logic takes about twice as long to perform a solution step and performs 3 solution steps per time step. For the same number of time steps, it takes 6 times longer on average. In addition, the adaptive time step logic can take many more time steps in order to limit the error. Notably there are some optimizations that are not currently implemented that could significantly improve runtime.

RADTRAD Adaptive Time Step Input

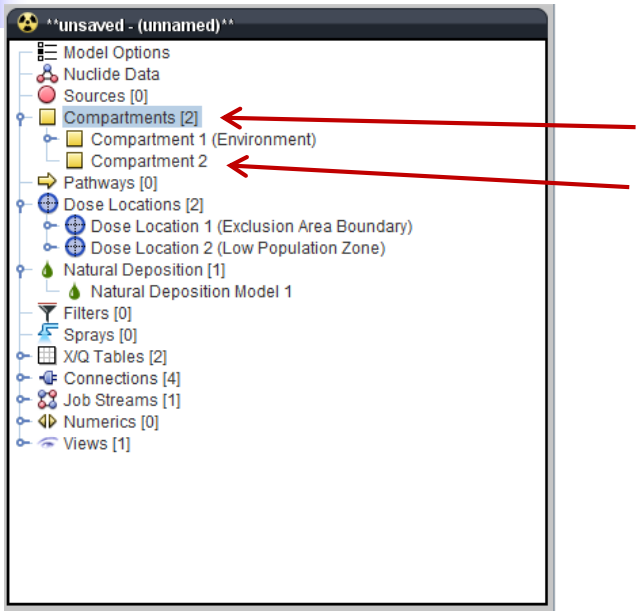
To activate adaptive time stepping, select Model Options. In the properties dialog set Time Step Algorithm to Adaptive. The maximum error is used to control the simulation accuracy. A maximum of between 0.001 and 0.0001 is recommended for most models. A Default with Error Calculation Time Step Algorithm is also available. This uses the default time step algorithm but calculates error to determine if the error is acceptable. An error plot variable is available for examining the error over the simulation.



SNAP/RADTRAD Model Building
4 Node Model Demo

- Start the Model Editor and click on Create a New Model in the Welcome screen. Select RATRAD model in the Select Model Type screen.
  - You should see the basic model nodes in the Navigator Window.
  - If you expand one of the model categories using the ( ) icon, and click on Compartment 1 (Environment), data fields will appear in the Properties Window.
- To build a model, you need to set up an array of compartments, flow pathways, source scenarios, and other components and then specify key parameters in various components in the model.
- For sources, compartments, and pathways that ultimately appear in the View Window, the basic pattern is to expand the node using the ( ) icon, right-click on the component category, and select New. A new model component is created.

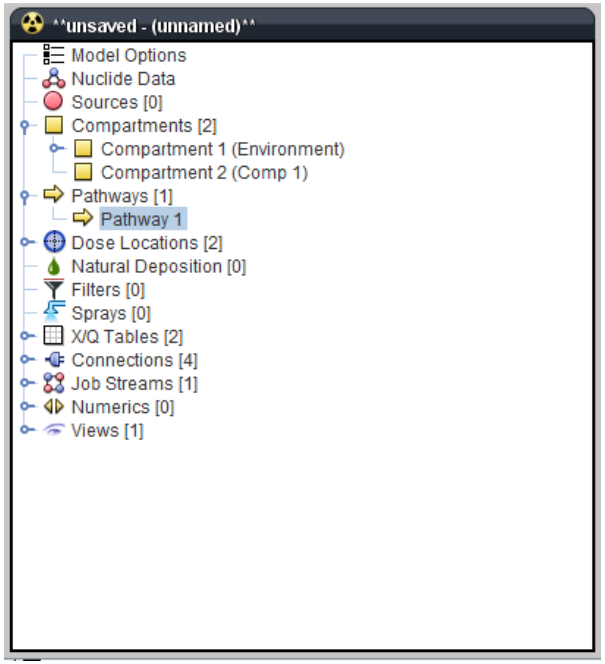
SNAP/RADTRAD Model Building
4 Node Model



- Ex. Create a new compartment by right-clicking on Compartments, and selecting New. A new Compartment component is created.
- Note that the new Compartment is highlighted and the data for that compartment appears in the Properties Window.
- Note that an Environment compartment is automatically included in the model.

- Now, add the new Compartment 2 to the View Window by right-clicking on the new compartment and selecting Add to View -> Default View. Compartment 2 is added to the View Window. Alternately, the Compartment 2 icon can be dragged to the View window.
- The new component is unnamed. In the Name field in the Properties View, type in a name (Ex. Comp 1) and the name will appear in the Component 2 node in the View Window.

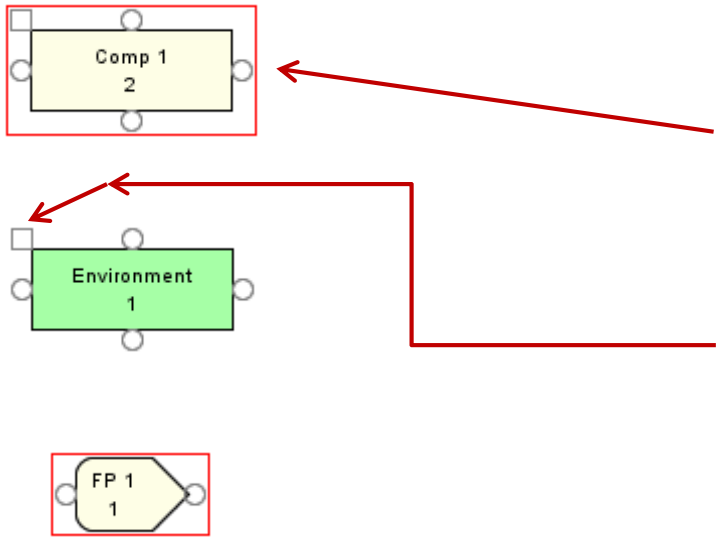
SNAP/RADTRAD Model Building
4 Node Model



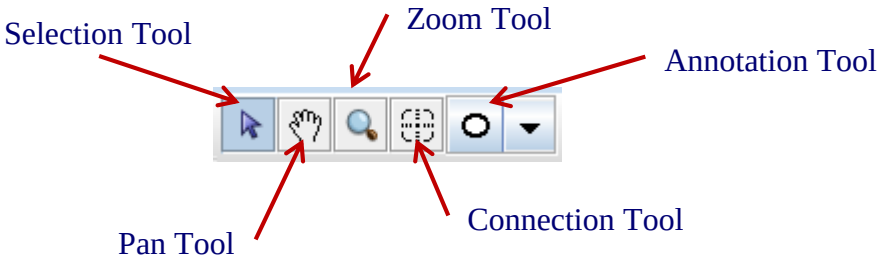
- Add the pre-defined Environment Compartment to the view as was done for Compartment 2.
- Define a flow pathway by right-clicking on Pathways [0] -> New in the Navigator Window. Pathway 1 appears.
- Add Pathway 1 to the View Window (Right-click on Pathway 1 -> Add to View -> Default View).
- Name the flow pathway in the Properties View window (Ex. FP 1).

- Should now have Comp 1, Environment and FP 1 in the View Window.
- The next step is to connect them.

SNAP/RADTRAD Model Building
4 Node Model



- Looking at the icons, you will note flow pathway connection points indicated by the little circles on each edge.
- The square on the upper left corner of each icon is a source connection point.
- The connection tool is used to make connections – activate the connection tool, then move the connection tool pointer to the first connection point, then left-click and drag to the second connection point. Connection should be made.

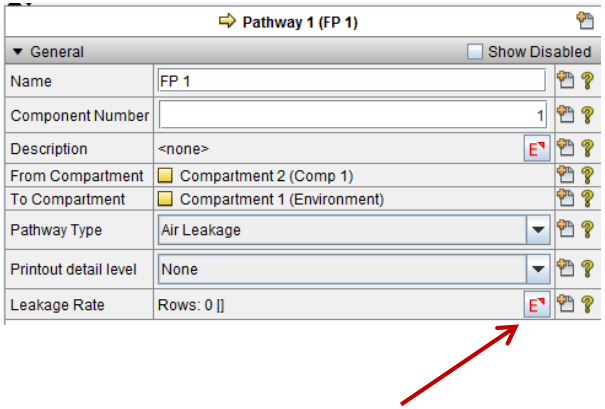


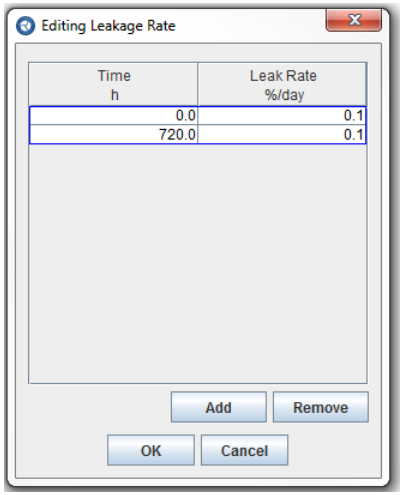
SNAP/RADTRAD Model Building
4 Node Model

- A source component can be added in the same way as the compartment and flow pathway – right-click on Sources [0] -> New, then add to the View. Name the source S1.
- Connect the Source to Compartment 1 using the connect tool – "connecting the squares."
- Use the Selection tool to move the icons within the View Window – left-click and drag.
- Note that the EAB and LPZ are automatically included in the Environment compartment.
- Save the model using "Save As" and a suitable filename (I used sample1a) after the connections are made (usual Windows approach).
- Sometimes users forget to activate the connection tool and can't make connections.
- A Connection Tool video and an Initial Noding video is available from the RAMP website.

SNAP/RADTRAD Model Building

- Once you've complete the initial noding, save file as "sample1a."
- Next step – adding data to the various model components.
  - Start with Comp 1 – set the volume to 2.5 x 10^6 ft^3 (7.079212x10^4 m^3). Note that default units are SI.
    - To switch units to English, right-click on the "black bar" in the Navigator Window, select Engineering Units -> British to change the units.
    - Click on the Comp 1 icon in the View window or on the Navigator window and enter 2.5E6 in the Volume textbox.
    - Note that deposition, filter, and sprays models are not used. We'll use those later.





- For Pathway 1 – expand Pathway node:
  - Change the pathway type from Piping (default) to Air leakage (typically used for containments).
  - For leakage rate specification, click on the icon adjacent to the Leakage Rate row. A data entry table will appear.
  - Click on the Add button and add a leakage rate of 1.0E9 %/day for 0 to 720 hrs (essentially bypassing the compartment). Click OK when completed.

SNAP/RADTRAD Model Building

- Complete X/Q tables for the EAB and LPZ – similar approach as for the leakage from Compartment 1. Units are sec/m^3.

Location	0-2 hr	2-8 hrs	8-24 hrs	1-4 days (24-96 hrs)	4-30 days (96-720 hrs)
EAB	1.40E-4	1.40E-4	1.40E-4	1.40E-4	1.40E-4
LPZ	4.50E-5	2.39E-5	1.29E-5	5.49E-6	1.61E-6

- The final item to be completed is the source specification. For this illustration, we will use the generic PWR core inventory with a power level of 3637 MWth and the alternative source term release fractions from R.G 1.183.
  - Left-click on Model Options in the Navigator Window, locate Plant Power Level and set the plant power level to 3637 MWth.
  - Expand the Sources node and left-click on Source 1 (S1), locate Source Scenarios and left-click on  .
  - In the Edit Inventory Scenarios window, add a new Scenario by clicking on the New () icon under Scenarios in the Edit Inventory Scenarios window that appears. Pick PWR from the Available Total Inventories. Enter PWR-AST in the Scenario Name text box.
  - In the Accident Parameters tab, pick DBA AST under the Accident Type list and pick the PWR button under Defaults Type.

SNAP/RADTRAD Model Building

- The final item …
  - Click on the Adjusted Inventory tab and review the inventories listed.
  - Click on the Release Fractions and Timings tab and review the release fractions used. Note the release durations in hours.
  - Click on the Source Term tab and review the gap and early releases.
  - Change name to PWR Fuel Release in the Scenario Name Textbox.
  - Click on OK.
  - A Model Check is performed at this point to illustrate how errors are identified (Tools->Check Model)
- Complete the Source Scenario input:
  - Source Term Fraction – 1.0
  - Iodine Physical Form – NUREG-1465
  - Note that the aerosol, elemental, and organic fractions are input (greyed out).

- A video illustrating data entry for the 4-node problem is available from the RAMP website.

SNAP/RADTRAD Model Building

- Probably a good idea to resave the model now.
- Check the model using Tools -> Check Model. Look in Messages window to confirm that there are no errors.
- Expand Job Stream node in the Navigator window and click on Simple Stream. Change the Relative Location to Sample1/Results.
- Perform Job Stream check.
- Go to Tools -> Submit Job to submit job.
- Job Status window will appear with the current run status of each step of the job stream.
- Video on Job Execution is available from the RAMP website.

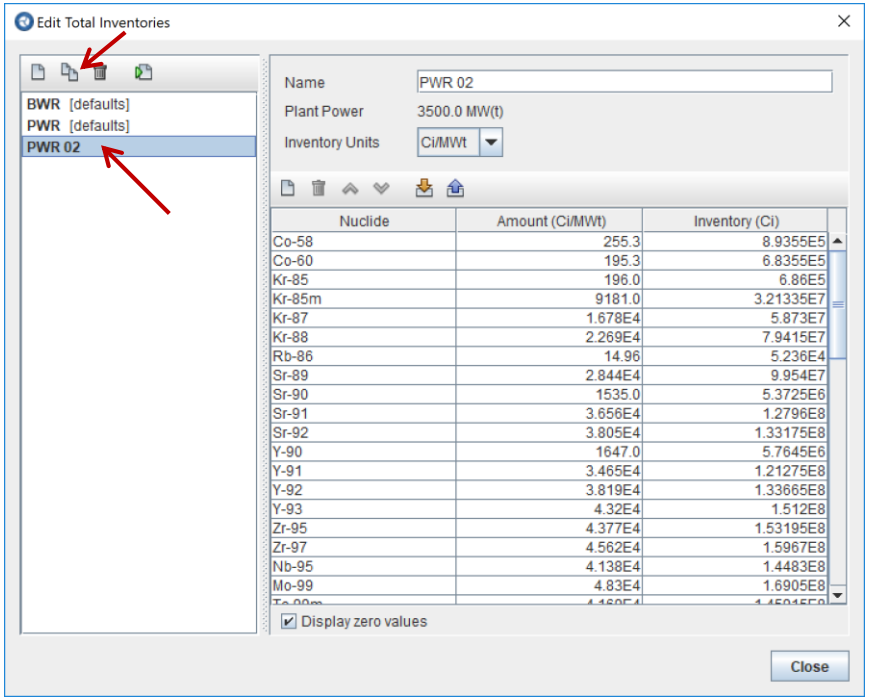
SNAP/RADTRAD Model Building

- If you exit the Job Status window from the Model Editor, you can get it back by clicking on the  icon on the topmost toolbar (I do this all the time!)
- You can also review your output for cases you have run by expanding the Job List navigator in the Job Stream window.
  - Note that you need to navigate to the stream folder to see the results.
  - Clicking on the Base_Job will activate the toolbar and you can select the output you want to examine as before using the File Viewer ().
- If you forget what an icon means, you can lay the mouse cursor on top of the icon and a descriptive text box will appear.

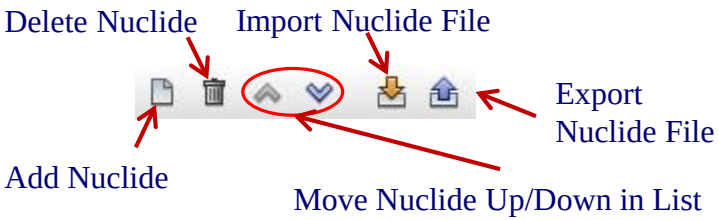
SNAP/RADTRAD Source Term Models

- RADTRAD uses a combination of a radionuclide inventory (generally within the reactor core) and a release fraction model to determine the source term
- Two pre-defined inventory files are available by clicking on Nuclide Data in the Navigator Window, then on the Total Inventories  icon. Available inventory files are displayed.
  - PWR - normalized MACCS sample 3412 MWth PWR core inventory (60 nuclides)
  - BWR - normalized MACCS sample 3578 MWth BWR core inventory (60 nuclides)
- Note that the plant power level under Model Options needs to be specified in order to obtain the total core inventory.
- The PWR and BWR core inventory files are not editable. However, to make changes, click on the Copy () icon. This action will make a copy of the selected inventory file, appending a number after the filename.

SNAP/RADTRAD Source Term Models

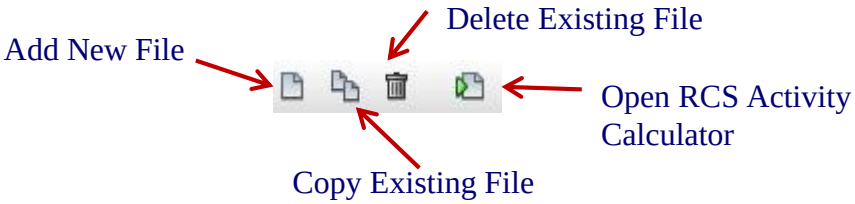


Nuclide Editing Icons

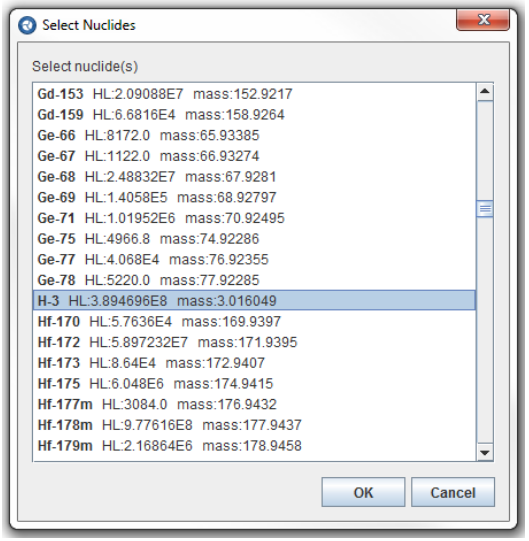


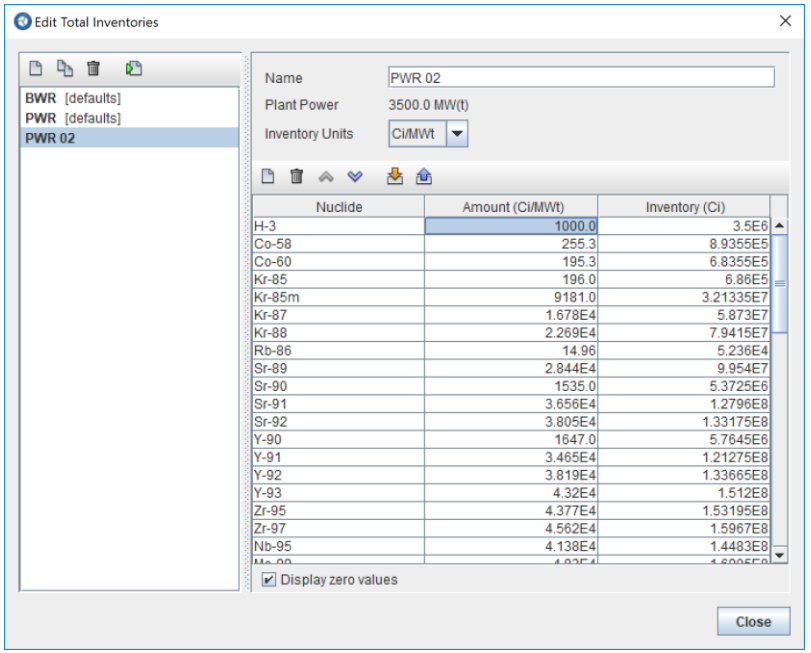
- The user can also add a new file clicking on the Add New File.

File Editing Icons



SNAP/RADTRAD Source Term Models





- Ex. Add H-3 to PWR 2 file.
  - Click on Add Nuclide Icon. The Select Nuclides window will appear.
  - Scroll to H-3, click on H-3 and then click on OK.
  - H-3 will be added to the bottom of the list. Click on the Move Nuclide icon to move H-3 to the top of the list. Alternately, click on the nuclide where you want H-3 inserted and it will be added below that nuclide.
  - Provide value for the amount of H-3 (Ci/MWth).

SNAP/RADTRAD Source Term Models

- Note that there are three inventory units that can be used: Ci/MWth, Ci/cc and Ci/hr.
- Easiest way to build a core inventory file is to either:
  1. Define a new file, then develop the radionuclide inventory using the editing features of SNAP. Note that most SAR documents give core inventories in Ci, so you need to define the core power and then the core inventory. Code will calculate the specific core inventory (Ci/MWth).
  2. Duplicate an existing file and add/delete nuclides as needed, then update inventories.
- Once the inventory file is completed, it can be exported for subsequent use.
- Save your sample problem under a new name so that we can model a waste gas decay tank rupture.

SNAP/RADTRAD Source Term Models

- Use the following radionuclide data (Waste Gas Decay Tank Source Term):

Nuclide	Activity (Ci)	Nuclide	Activity (Ci)
Kr-85m	1.49E+2	Xe-135	1.02E+3
Kr-85	5.52E+3	Xe-138	4.06E+0
Kr-87	3.00E+1	I-130	0.0
Kr-88	1.79E+2	I-131	3.99E-2
Xe-131m	1.07E+3	I-132	2.50E-2
Xe-133m	1.27E+3	I-133	4.28E-2
Xe-133	8.12E+4	I-134	4.96E-3
Xe-135m	5.97E+1	I-135	1.94E-2

Keystrokes can be used to navigate to a particular group of nuclides. Also, cntl-click to select individual nuclides and shift-click to select multiple nuclides can also be done. Also, the release fractions will be changed to user-specified values of 1.0 for NG & I. Use a 2 hour release time for this exercise. A video illustrating specifying the data for the WGDT problem is available from the SNAP website.

SNAP/RADTRAD Source Term Models

- Set the location that you want the results written to in the Job Stream
- Perform the Model Check. Correct any errors.
- Perform the Job Stream Check. Correct any errors.
- Run case by submitting the job.
- When job completes, review the results.
- Results that I got:

	SNAP/RADTRAD (TEDE, rem)	**SNAP/RADTRAD (thyroid, rem)**
EAB (2 hours)	8.11E-2	2.50E-3
LPZ (720 hrs)	2.61E-2	8.05E-4

- These are the results for the Waste Gas Decay Tank Case.

SNAP/RADTRAD Source Term Models

- New release models have been incorporated into SNAP/RADTRAD to model both LOCA and non-LOCA accidents.
- These release models set the release fractions which applied to an inventory file give the source term.
- User-specified release fraction files can be specified.

Accident Type	**Description**
Total Inventory	Uses total inventory in conjunction with user-specified release fractions and timings.
DBA-TID	Design basis (LOCA) accident with TID-14844 release models (RG 1.3, 1.4, instantaneous release).
DBA-AST	Design basis (LOCA) accident with Alternative Source Term (AST) release models based on RG 1.183.
Gap Release	Gap release based either on RG 1.25 (RG 1.3/1.4) or RG 1.183.
REA-CRDA	Rod Ejection Accident or Control Rod Drop Accident – based on RG 1.183.
FHA	Fuel handling accident parameters based on RG 1.183.

SNAP/RADTRAD Release Mechanism Models

- Nuclides are grouped according to their chemical and transport properties in RADTRAD. Grouping is based on NUREG-1465.

No	Group	RG 1.183 Chemical Grouping	Additional Nuclides
1	Noble Gases	Kr, Xe	H (as H-3), Ne, Ar, Rn, N, O
2	Halogens	I	add Br
3	Alkali Metals	Cs, Rb	
4	Tellurium Group	Te, Sb	add Se
5	Barium, Strontium (Alkaline Earth Metals)	Sr, Ba	combine Sr, Ba
6	Noble Metals	Ru, Rh, Mo, Tc, Co	add Pd
7	Cerium Group	Ce, Pu, Np	
8	Lanthanides	La, Zr, Nd, Nb, Pr, Y, Cm, Am	add Eu, Pm, Sm
9	Others		Ac, Ag, Al, As, At, Au, Be, Bi, Bk, C, Ca, Cd, Cf, Cl, Cr, Cu, Dy, Er, Es, F, Fe, Fm, Fr, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, Lu, Md, Mg, Mn, Na, Ni, Os, P, Pa, Pb, Po, Pt, Ra, Re, S, Sc, Si, Sn, Ta, Tb, Th, Ti, Tl, Tm, U, V, W, Yb, Zn
10	Non-Radioactive Aerosols	No change	
Notes: Fl and Cl are gaseous halogens. They are included in the other group since they likely do not behave like iodine.			

- Note that the chemical grouping was revised to permit the use of the ICRP-38 nuclides in the source term calculations.

SNAPRADTRAD Release Mechanisms/Models

Release Fractions for LOCA – NUREG-1465 (Tables 3.12 and 3.13), also Tables 1 and 2 of RG 1.183, and RG 1.3, 1.4.

Chemical Group	Elements	NUREG-1465				TID-14844
		PWR		BWR		(RG 1.3, 1.4)
		Gap Release	Early In-Vessel	Gap Release	Early In-Vessel	
Noble Gases	Xe, Kr	0.05	0.95	0.05	0.95	1.0
Halogens	I, Br	0.05	0.35	0.05	0.25	0.25
Alkali Metals	Cs, Rb	0.05	0.25	0.05	0.20	Note 1
Tellurium Group	Te, Sb, Se	0	0.05	0	0.05	
Barium, Strontium	Ba, Sr	0	0.02	0	0.02	
Noble Metals	Ru, Rh, Pd, Mo, Tc, Co	0	0.0025	0	0.0025	
Cerium Group	Ce, Pu, Np	0	0.0005	0	0.0005	
Lanthanides	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am	0	0.0002	0	0.0002	
Release Duration (hours)		0.5	1.3	0.5	1.5	instantaneous

Note 1: TID-14844 considered a 0.01 release fraction for the solid mixed fission products (See Table IV of TID-14844).
Note 2: RG 1.183 permits a 30 s delay for the onset of the gap release for PWRs and 2 min delay for BWRs

SNAP/RADTRAD Release Mechanisms Models

- Gap Release model incorporated into SNAP/RADTRAD. Two models provided:

	RG 1.25	RG 1.183
I-131	0.12	0.08
Kr-85	0.3	0.1
Other NG	0.1	0.05
Other I	0.1	0.05
Alkali Metals	0.0	0.12

- FHA – fuel handling accident.
  - Basically a drop of a lifted fuel assembly onto the core or spent fuel rack. Models in RADTRAD requires an estimate of the extent of damage, that is the number of assemblies or fuel rods damaged. Peaking factors and iodine DF for the overlying pool needed.
  - Release fractions are the same as above.

SNAP/RADTRAD Release Fraction Models

- Rod Ejection Accident (REA) for a PWR or Control Rod Drop Accident (CRDA) for a BWR.
  - Basically a control rod is ejected causing a power spike and cladding rupture. Some fuel melting is possible.
  - Models in RADTRAD requires an estimate of the extent of damage, that is the fraction of clad breached, fraction of breached fuel that melts, and the peaking factor.
  - Release fractions are listed below (Appendix H of RG 1.183).

	Failed Fuel Release Fraction	Melted Fuel Release to Containment	Melted Fuel Release to Reactor Coolant for Secondary System Release Pathway
Noble Gases	0.1	1.0	1.0
Iodine	0.1	0.25	0.5
Alkali Metals	0.0	0.0	0.0

SNAP/RADTRAD Release Mechanisms/Models

- Iodine exists in three chemical forms: aerosol (particulate), elemental and organic iodine. The actual fractions of each form depends on the accident and analytical assumptions being used.

Accident	**Model**	**Iodine Form**			
		Aerosol	Elemental	Organic	
DBA-LOCA	TID-14844	5	91	4	RG 1.195
DBA-LOCA	RG 1.183	95	4.85	.15	RG 1.183

- Other scenarios assume other fractions, for example 97% elemental and 3% organic for an SGTR (RG 1.183, Appendix F).

SNAP/SNAP/RADTRAD Exercises

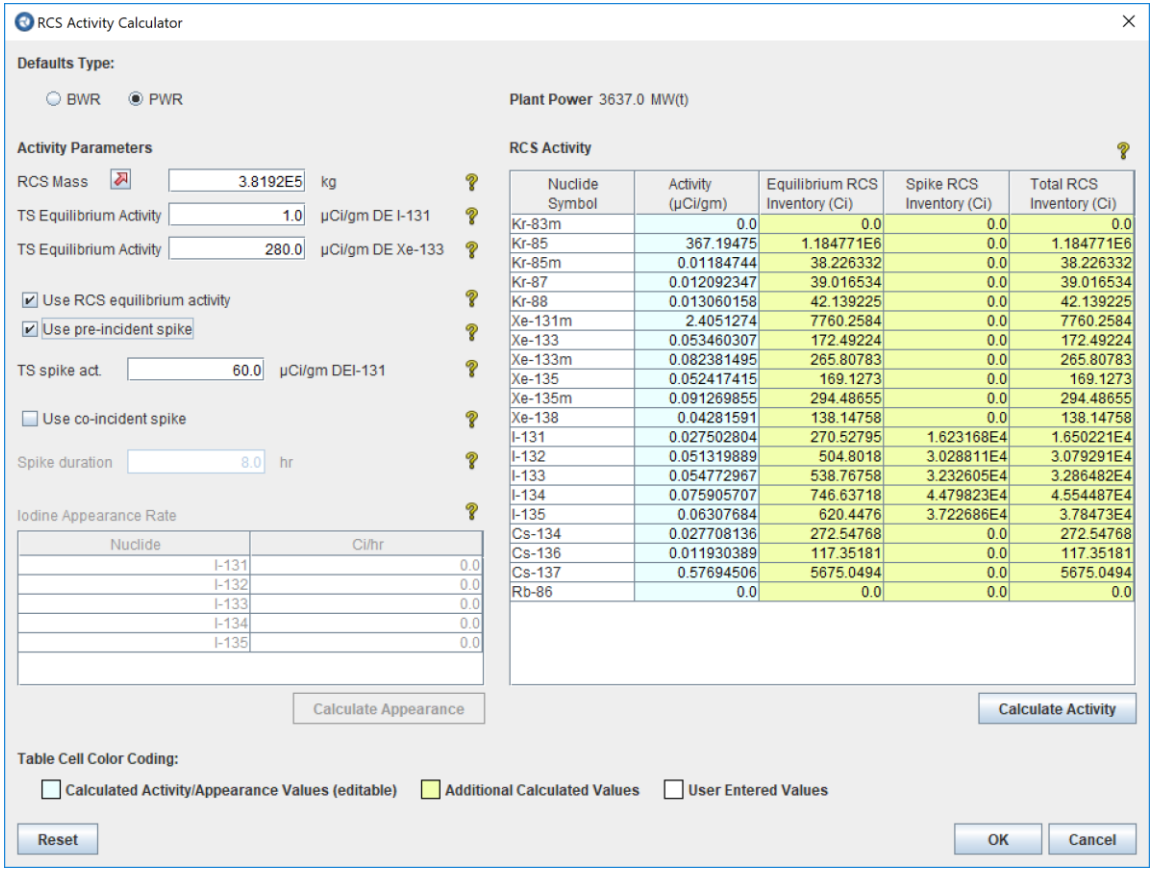
- The first set of exercises are to set up a fuel handling accident (FHA) for a representative PWR plant and determine the EAB and LPZ dose. As noted earlier the FHA is basically a drop of a lifted fuel assembly onto the core or spent fuel rack. Then an normal-mode control room model will be added to the model.
- The rod ejection accident (REA) will be based on the FHA and will be done by changing the source model and adding components to the control room for emergency mode operation.
- Refer to the SNAP/RADTRAD Training Exercises for directions.

SNAP/RADTRAD RCS Activity Calculator

- SNAP/RADTRAD allows user to consider events that involve reactor coolant system (RCS) activity. Two approaches available:
  - User can specify the coolant activity directly and then adjust for pre-incident and co-incident iodine spiking.
  - User can utilize reactor coolant system activities based on the RN Editor formulation, and is similar to GALE code formulation and based on ANSI/ANS 18.1. The original RNEditor was developed by Steve LaVie almost 20 years ago. Steve works for NRC.
- To specify the coolant activity directly, click on Nuclide Data, then click on Total Inventories (), then on the Add RCS Inventory icon (). The window on the next slide appears (may have some number in the various fields – can be cleared by clicking on the Reset Button (lower left)).

SNAP/RADTRAD RCS Activity Calculator

- RCS Activity Calculator – can be calculated by the code or user-specified.
- Can consider various Equilibrium Activities Level based on the Technical Specification values.
- Can also consider pre-incident or coincident iodine spiking.
- Values in this window based on 66,000 lb/hr letdown flow (all other RCS Activity Inputs – PWR set to 0).



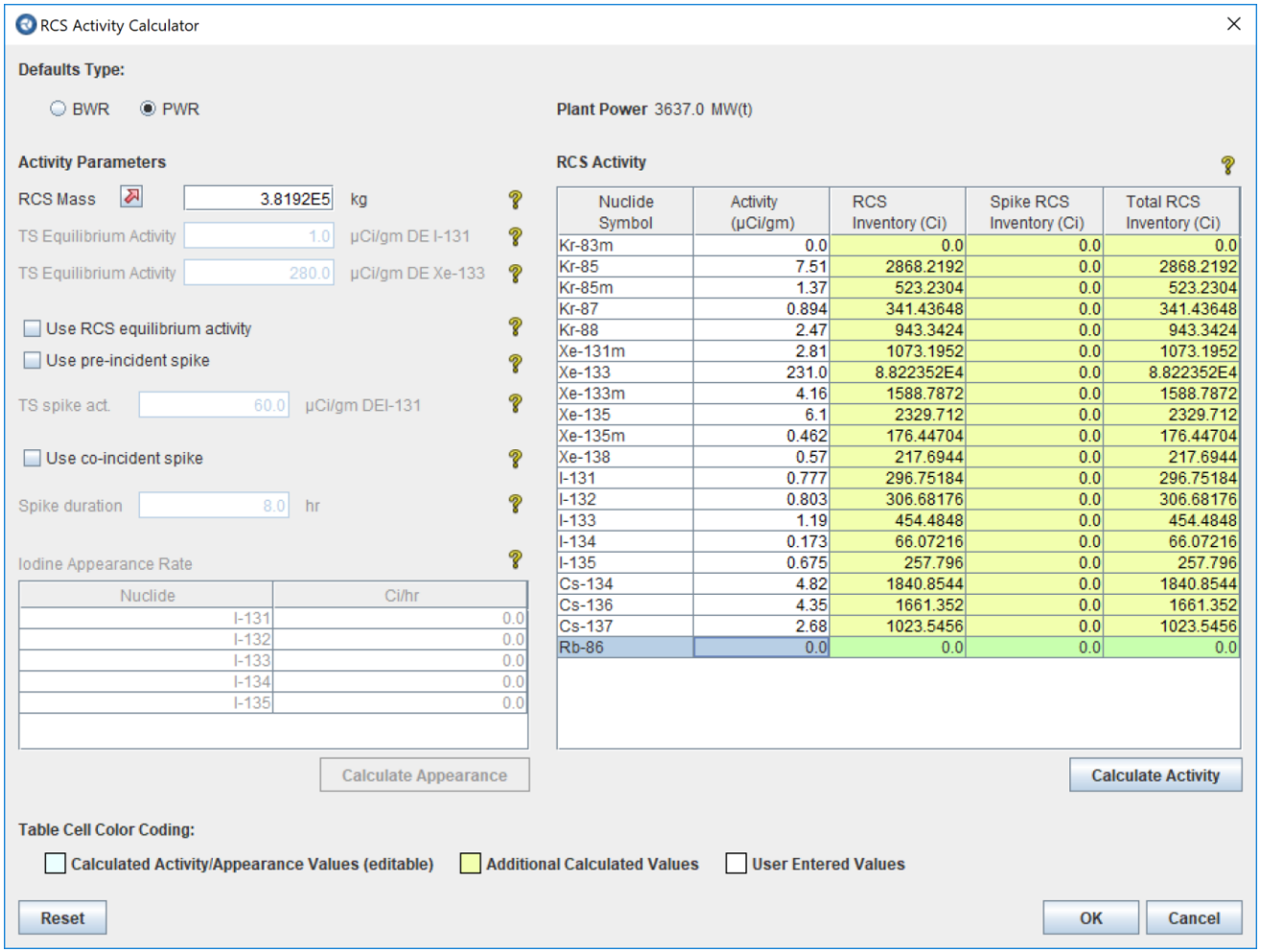
SNAP/RADTRAD RCS Activity Calculator

- Known values for RCS Coolant Activity in µCi/gm can be used to determine the equilibrium concentration. Enter the following parameters in the RCS Activity Calculator screen:
  - Plant Power must be set. Use 3637 MWt for Plant Power Level in Model Options.
  - RCS Mass in grams – use value of 3.819E5 kg as shown.
  - Enter Activity Values listed in the table. Note the RCS Inventory is calculated by SNAP/RADTRAD in Ci.
  - Click on OK – **do not click on Calculate Activities.**

	RCS Conc (uCi/g)
Kr-83m	0.000E+00
Kr-85	7.510E+00
Kr-85m	1.370E+00
Kr-87	8.940E-01
Kr-88	2.470E+00
Xe-131m	2.810E+00
Xe-133	2.310E+02
Xe-133m	4.160E+00
Xe-135	6.100E+00
Xe-135m	4.620E-01
Xe-138	5.700E-01
I-131	7.770E-01
I-132	8.030E-01
I-133	1.190E+00
I-134	1.730E-01
I-135	6.750E-01
Cs-134	4.820E+00
Cs-136	4.350E+00
Cs-137	2.680E+00
Rb-86	0.000E+00

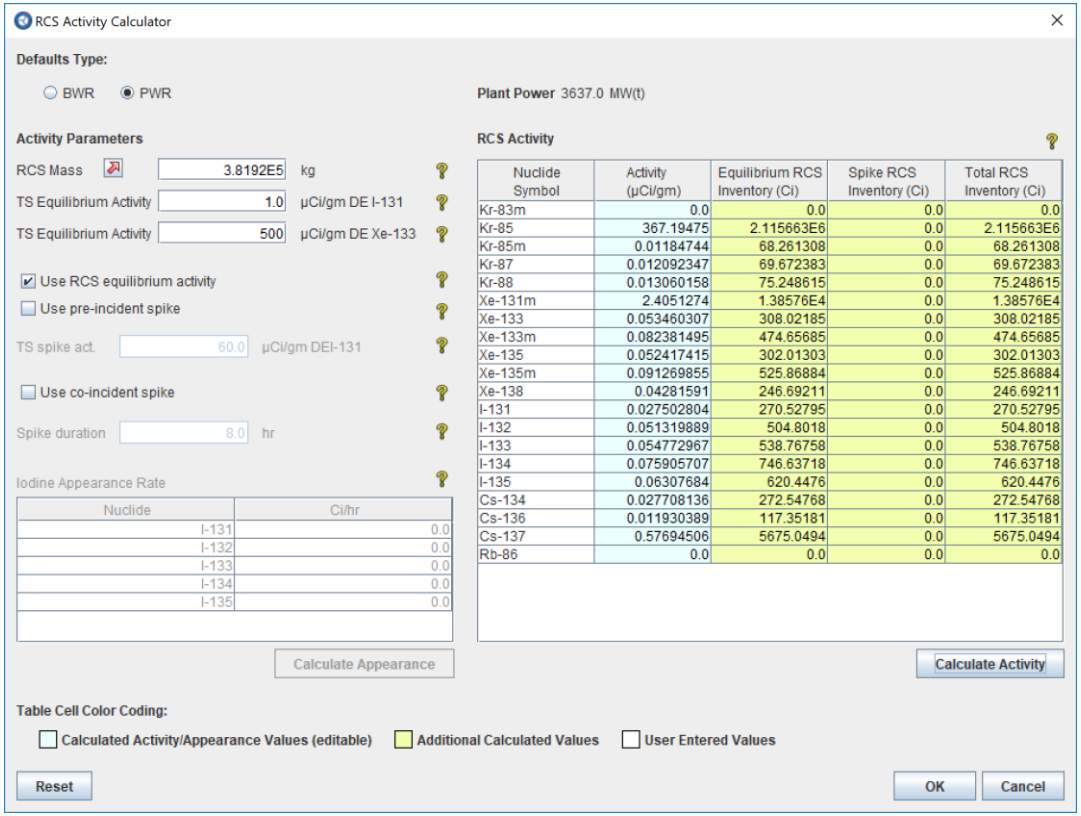
SNAP/RADTRAD RCS Activity Calculator

- RCS Activity Results



SNAP/RADTRAD RCS Activity Calculator

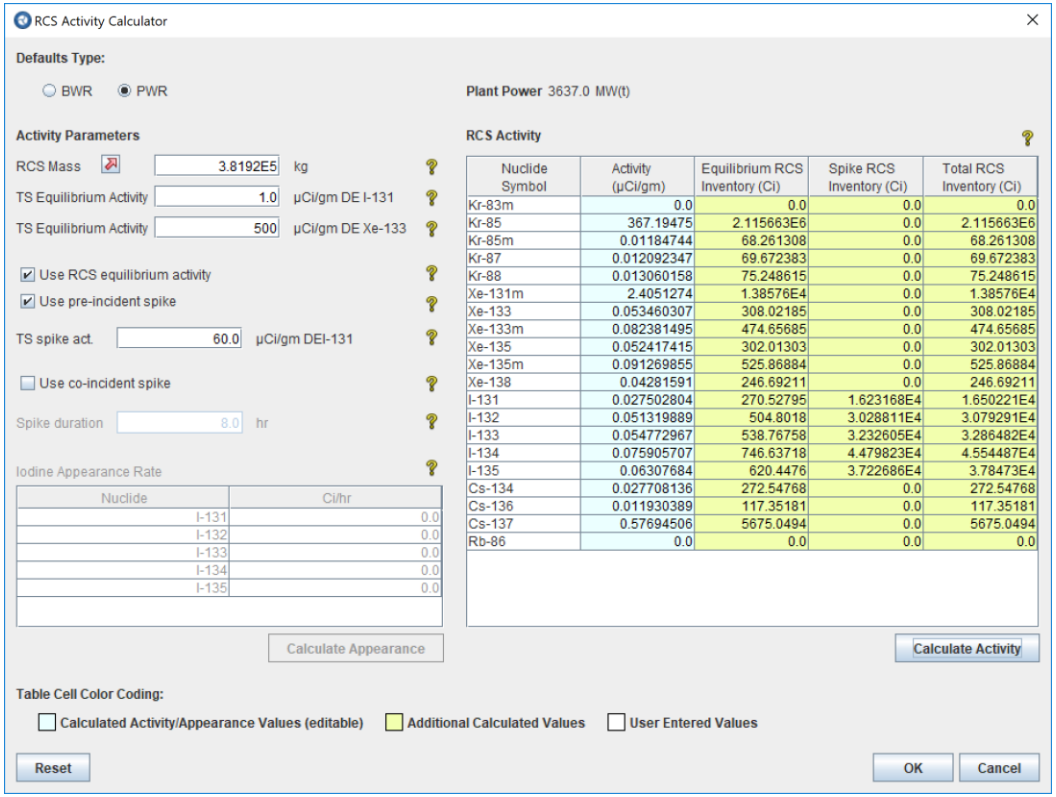
- To calculate the equilibrium nuclide concentration in the coolant, enter the following parameters in the RCS Activity Calculator screen:
  - Set Plant Power Level to 3637 MWth in Model Options (if not set).
  - Use value of 3.8192E5 kg for RCS mass.
  - Check the Use RCS equilibrium activity box.
  - Input values of 1 µCi/gm for DE I-131 and 500 µCi/gm DE Xe-133 for T/S Equilibrium Activity.
  - Click on Calculate Activities and use a value of 66,000 lbm/hr for the letdown flow in the RCS Activity Input Window. Set all other fields to 0. Then click OK.
  - Results in adjacent screenshot should appear.



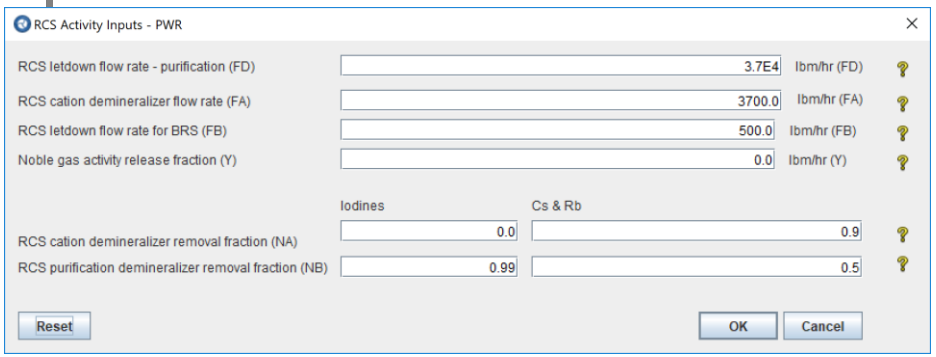
SNAP/RADTRAD RCS Activity

- To add the effect of the pre-incident spike, check the box next to the Use pre-incident spike label. Technical Specification spike activity of 60 µCi/gm is typical.

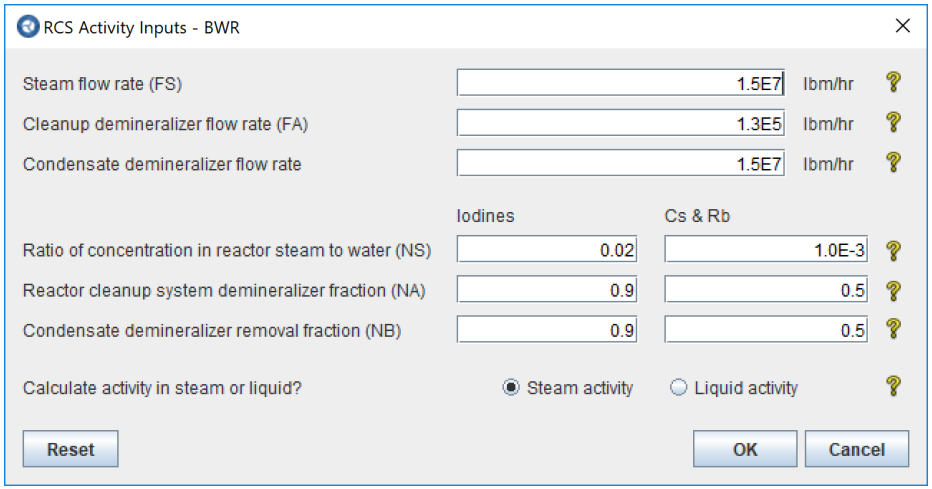
- To add the effect of the co-incident spike, check the box next to the Use co-incident spike label and add the Iodine Appearance Rate as shown here. A spike duration of 8 hours is typical.



SNAP/RADTRAD RCS Activity



- Calculating RCS coolant activity based on ANSI/ANS 18.1 for the PWR requires additional information to determine the effect of letdown and boron recovery system (BRS). Default input shown.

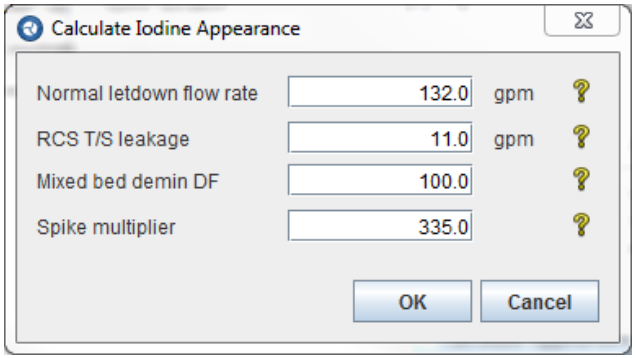


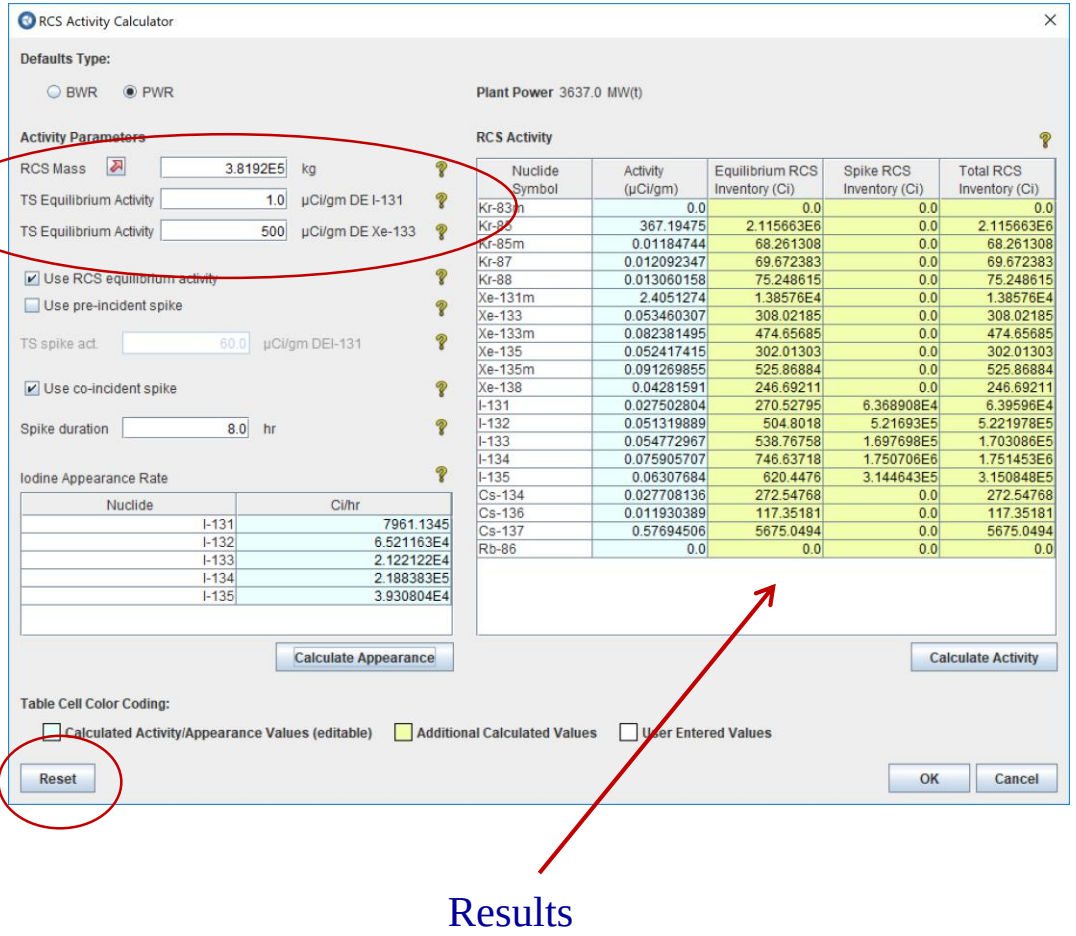
- Calculating RCS coolant activity based on ANSI/ANS 18.1 for the BWR also requires additional information to include the effect of RWCU and condensate demineralizers. Also note that separate calculations are performed for steam and liquid activity. Default input shown.

SNAP/RADTRAD RCS Activity

Co-incident Spike Illustration

- Use the RCS mass and T/S Equilibrium Activities shown. Click on the Calculate Activity button to refresh the equilibrium activity values.
- Check the Use-co-incident spike box and then the Calculate Appearance button. The window shown below appear. Set values as shown. Then click OK.
- Use 66,000 lbm/hr for letdown flow.





Results

SNAP/RADTRAD Exercise

- The next exercise is to model a steam generator tube rupture. A description of the accident is presented in the Exercise writeup.

SNAP/RADTRAD Compartment Removal Models

Natural Deposition

- Two natural deposition models for aerosols in RADTRAD – Powers and Henrys in addition to user defined coefficients. For elemental iodine, user must define removal coefficients.

Henry's Model

- Based upon observation of experiments concerned with aerosol decontamination – sedimentation driven model.
- Coefficients were determined from experimental data from liquid metal reactor tests.
- Time-dependent fall height (ft) and particle density (g/cc) needs to be specified by the user for aerosols. For elemental iodine, removal coefficients are specified in units of 1/hr.

SNAP/RADTRAD Compartment Removal Models

Removal Rate Based on Henry's Natural Deposition Model

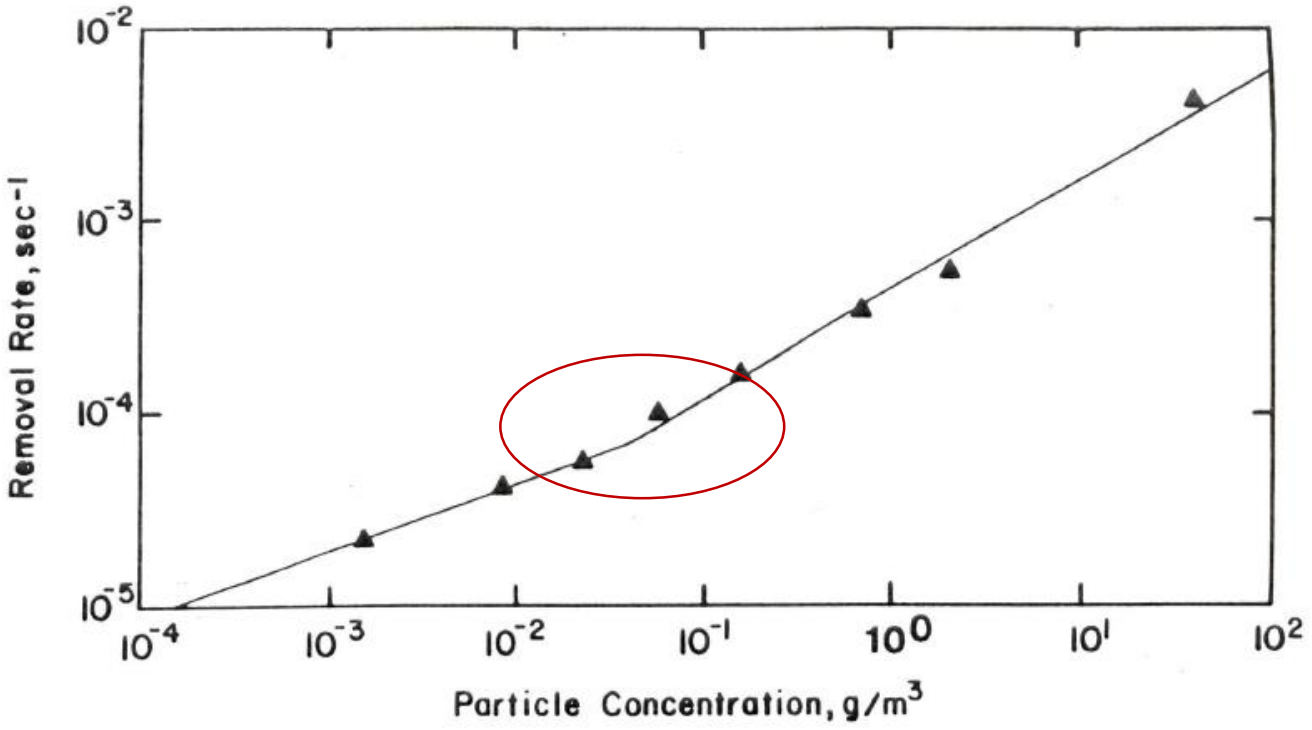


Figure 1 - IDCOR Technical Report 11.7 FAI Aerosol Correlation, March 1985

SNAP/RADTRAD Compartment Removal Models

Power's Aerosol Decontamination Model

- Based on the observation of a self-preserving aerosol size distribution as a key component in predicting aerosol behavior.
- Effects due to turbulence and to the multiple aerosol releases specified in NUREG-1465.
- Uncertainties were accounted for by running a large number of calculations the modified mechanistic model, with specific values for the type of reactor containment, reactor power, and the source term release phase, while varying the values of the uncertain parameters.
- Uncertainty parameters included were the containment pressure during the various release phases, the floor and wall surface areas, the zirconium inventory, the ratio of containment volume to thermal power, and the properties of the concrete. In all, over 20 parameters that were related to the phenomena were varied.

SNAP/RADTRAD Compartment Removal Models

Power's Aerosol Decontamination Model - Input

User specified the Power's Model Accident Type from the following options:

PWR Design Basis Accident
BWR Design Basis Accident
APWR Design Basis Accident

Power's Model Percentile - User selects from the following values:

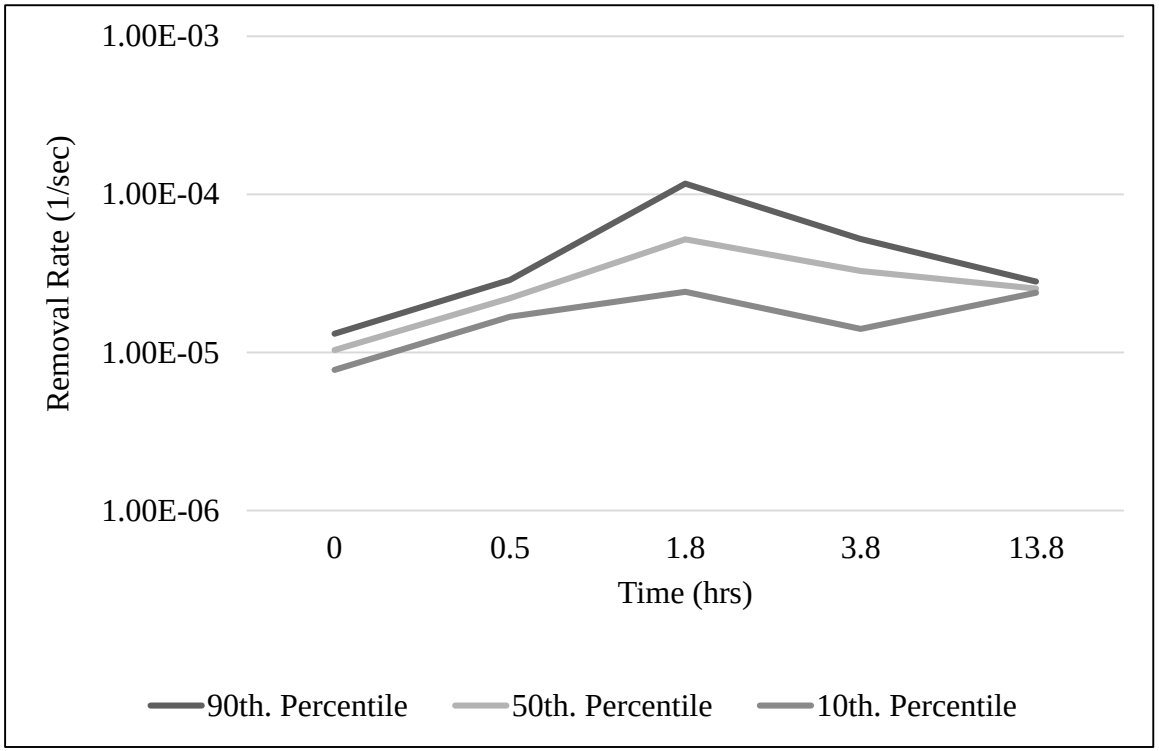
10% **50%** **90%**

User can specify time dependent elemental iodine removal coefficients (units of 1/hr).

See NUREG/CR-6189 for further details on this model.

SNAP/RADTRAD Compartment Removal Models

Removal Rate Based on Power's Natural Deposition Model



SNAP/RADTRAD Compartment Removal Models

Recirculating Filters:

- Recirculating filters can be modeled in a control room (CR) dose compartment.

- Input required is
  - Forced flow rate through the filter (cfm)
  - Filter efficiencies for aerosols, elemental iodine and organic iodine (percent)

Note that an overlying pool model was started in the original version of RADTRAD, but never completed and is disabled.

SNAP/RADTRAD Compartment Removal Models

Sprays:

- RADTRAD has the Power's model for aerosol removal. For elemental and organic iodine, user must define removal coefficients (units of 1/hr).
- User defined coefficients can also be specified for all forms (units of 1/hr).
- SRP 6.5.2, Section III.4 provides other approaches for determining removal.

Power's model for aerosol removal:

- Correlates the removal coefficient for an aerosol to the spray water flux, W (m^3 H_2O/m^2 s) and the fall height of the spray droplets *H* (m). These parameters must be specified by the user.
- Considers uncertainty in the various parameters affecting spray removal.

SNAP/RADTRAD Compartment Removal Models

Power's model for aerosol removal – continued:

- User specifies a percentile.

50th percentile	Best-estimate (median DF)
10th percentile	Lower bound (minimum DF)
90th percentile	Upper bound (maximum DF)

- Typical spray removal rate:

α - fraction of containment sprayed.	8.00E-01
Q - spray water flux (m3·H2O/m2·s)	2.00E-04
m_f - mass fraction of aerosol suspended as a function of time.	5.00E-01
H - droplet fall height (m)	25.908

Removal Rate (1/sec)

10 Pct	50 Pct	90 Pct
1.32E-05	4.49E-05	4.21E-04

Further information on the Power's model can be found in NUREG/CR-5966

SNAP/RADTRAD Flow Pathway Removal Models

Flow Pathways Types –filter pathway, air leakage, generic with non-iodine aerosols:

- Filtered Pathway – in line filter in an HVAC duct.
  - Commonly used in control rooms.
- Air leakage – expressed in %/day. Used to model leakage from containments.
  - Typically ~0.1 %/day for large, dry PWR (listed in SAR, DCD).
- Generic, Generic with non-iodine aerosols
  - Variation on filter pathway.
- Piping – Brockman/Bixler model for aerosol deposition or user-defined DFs.

SNAP/RADTRAD Flow Pathway Removal Models

- Filtered Pathway
  - Time dependent flow rate (cfm) and filter efficiencies (percent) for aerosols and elemental and organic iodine
  - Filter efficiency is related to decontamination factors as

$$DF = \frac{1}{1-\eta}$$

where η is the filter efficiency expressed as a fraction.

- Air Leakage
  - User specifies time-dependent leakage rate in units of percent/day
- Piping – User-specified removal coefficients
  - Input required are flow rate through the pipe (cfm) and decontamination factors for aerosols, elemental iodine and organic iodine.

SNAP/RADTRAD Dose Conversion Factors

- Dose Conversion Factors:
  - Built-in dose conversion factors are based on FGR 11&12. DCF data extracted from the Radiological Toolbox developed by NRC.
  - At one point, ICRP 60 based DCFs were included, but were removed at the request of NRC.
  - User-defined dose conversion factors are permitted.
- Many individual organ doses are listed in FGR 11 and 12. However, in SNAP/RADTRAD, the only DCF values used are:
  - Whole body (Sv per Bq-s-m^{-3}) – from air submersion tabulations (effective) - FGR-12
  - Thyroid (Sv/Bq) – from inhalation tabulations (thyroid) – FGR-11
  - Inhaled Effective (Sv/Bq) – from inhalation tabulations (effective) – FGR 11
  - Skin (Sv per Bq-s-m^{-3}) – from air submersion tabulations (skin) - FGR-12
- TEDE dose is calculated as the sum of the inhaled effective and whole body dose in RADTRAD.

SNAP/RADTRAD Dose Models

EAB and LPZ – immersion dose from each nuclide n:

$$D_{c,n}^{env} = A_n(\chi/Q)\,DCF_{c,n}$$

$D_{c,n}^{env}$ = air immersion (cloudshine) dose due to nuclide *n* in the environment compartment (Sv)

DCF_n = FGR 11 and 12 air immersion (cloudshine) dose conversion factor for nuclide *n* (Sv m^3 / Bq s)

X/Q = user-provided atmospheric dilution factor (s/m^3)

$A_{i,n}$ = integrated release of nuclide n (Bq)

SNAP/RADTRAD Dose Models

The activity is related to the number of atoms of nuclide n as:

$$A_n = \lambda_n N_n$$

where λ_n is the radiological decay constant for nuclide n.

EAB and LPZ – inhalation dose from each nuclide n

$$D_{i,n}^{env} = A_n (X/Q) BR * DCF_n$$

$Di_{i,n}^{env} =$ inhalation dose commitment due to nuclide *n* in the environment compartment (Sv)

$BR =$ user-provided breathing rate (m^3 / s)

$DCF_n =$ user-provided inhalation dose conversion factor for nuclide *n* (Sv/Bq)

SNAP/RADTRAD Dose Models

Control Room Dose Analysis

- Dose computed from the time-integrated concentration of radionuclides in the control room.

$$D_{c,n}^{CR} = \left(\frac{DCF_{c,n}}{G_F} \right) OF \int_t C_n(\tau) d\tau$$

where:

$C_n(\tau)$ is the instantaneous concentration of radionuclide n in the control room compartment.

OF is the control room occupancy factor, which is user defined.

G_F is the Murphy Campe geometric factor, which relates the dose from an infinite cloud to the dose from a cloud of volume V (units of 1/m3).

SNAP/RADTRAD Dose Models

Murphy-Campe factor is given as:

$$G_F = \frac{351.6}{V^{0.338}}$$

Inhalation dose to an individual in the control room is:

$$D_{i,n}^{CR} = BR \cdot OF \cdot DCF \int_t C_n(\tau) d\tau$$

SNAP/RADTRAD Dose Models

X/Q Data - Values required for each location (usually generated in a separate analysis). Set in the X/Q Tables node in the Navigator Window.

Breathing Rates/Occupancy Factors – default values listed below (from RG 1.183 and 1.195).

Offsite Breathing Rates (m^3/s)	
0-8 hours	3.5×10^{-4}
8-24 hours	1.8×10^{-4}
24 – end of accident	2.3×10^{-4}

Control Room Breathing Rates/Occ Factors	
3.5×10^{-4} m^3/s for the duration of the event	
Occupancy Factors	Fraction of time present in CR
0 – 24 hours	1
1 – 4 days	0.6
4 to 30 days	0.4

SNAP/RADTRAD Final Exercise - LOCA

- The final exercise is to model a LOCA. A description of the accident is presented in the Exercise writeup.

Backup Slides

SNAP/RADTRAD Installation

- SNAP - obtained from the Applied Programming Technology website at:
  https://www.snaphome.com/
  https://www.appliedprog.com/

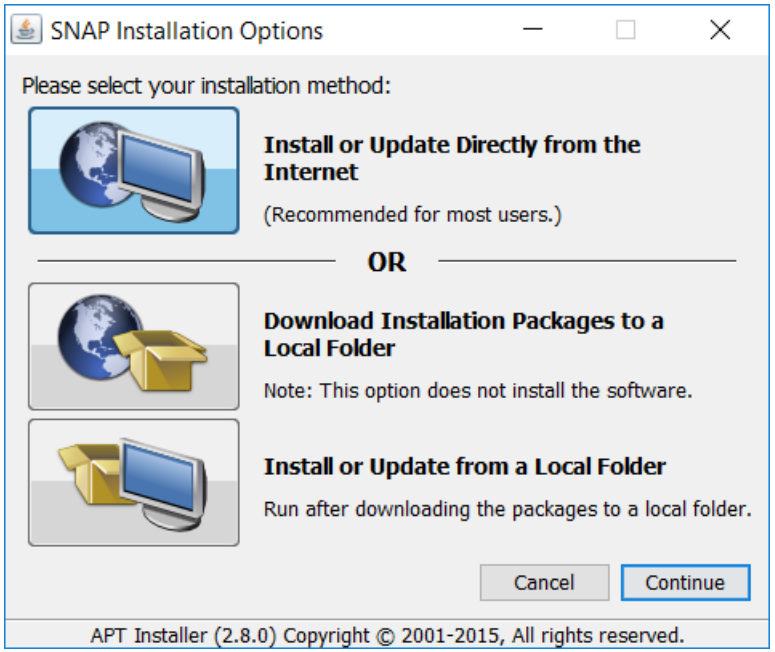
- Files needed to run SNAP/RADTRAD:
  - Java Standard Edition (SE) 7.0 or later. This package is currently available on http://www.oracle.com/technetwork/java/javase/downloads/index.html.
  - SNAP/RADTRAD plugin – distributed with SNAP during the download progress from the APT site.
  - APTPlot – plotting package. See APT website (addresses above).
  - jedit – although not required, jedit adds some user conveniences in SNAP. This package is available from www.jedit.org.

- RADTRAD analytical code packaged separately, available through the RAMP website for registered users.

SNAP/RADTRAD Installation

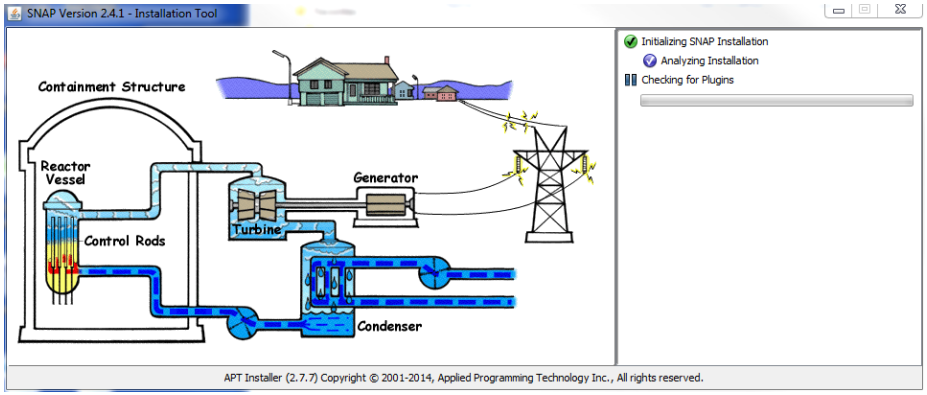
- Installation begins with downloading the snapinstaller.jar file from the APT website to a convenient directory. Once that file is downloaded, click on the SnapInstaller.jar file to start the installation.
- Alternately, you can navigate to the directory where the SnapInstaller.jar file is located and enter:

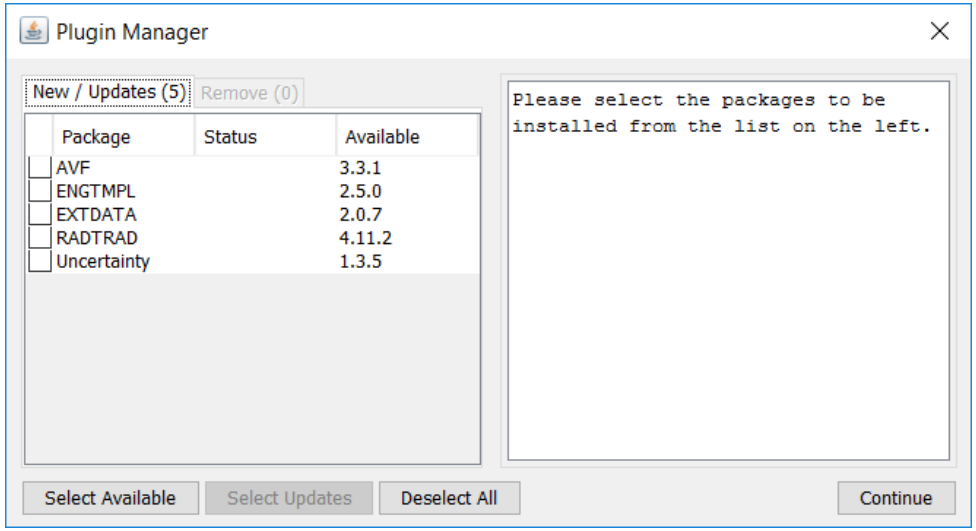
  java –jar SnapInstaller.jar
- There are three installation options available as shown in the adjacent screenshot.
- Installing from the internet is the easiest. I prefer to download the installation packages to a local directory and then perform the installation.



SNAP/RADTRAD Installation

- Initial installer screen analyzes installation and checks for pre-existing plugins.
- Plugin Manager allows the user to select plugins to be installed or updated.
- Select the plugins required and continue. Installation should proceed to completion.
- Plug-ins required for SNAP/RADTRAD are AVF, ENGTMPL, EXTDATA, RADTRAD and Uncertainty.





SNAP/RADTRAD Installation

- The SNAP Installation is written to the /users/*homedir* where *homedir* is the home directory for the login ID being used unless you specified a different location.
  - If you are not sure of where you home directory is, open a command window by going to Start and typing in “command” in the Search textbox. A command prompt window should appear (select “Command Prompt” from menu above if necessary). Then, type in **echo %USERPROFILE%** and your home directory will be displayed.
- The SNAP installer creates two directories: snap and .snap under /users/*homedir*. The code files are written to snap and files needed to use SNAP on a given system are written to .snap.
  - Ex: the location of the root folder on a given computer is written to .snap.

SNAP/RADTRAD Installation

- Once the SNAP/RADTRAD package is installed, the RADTRAD analytical code is installed.
- RADTRAD analytical code files are listed below:

radtrad.jar	castor-xml.jar
castor-codegen.jar	castor-xml-schema.jar
castor-core.jar	commons-logging.jar

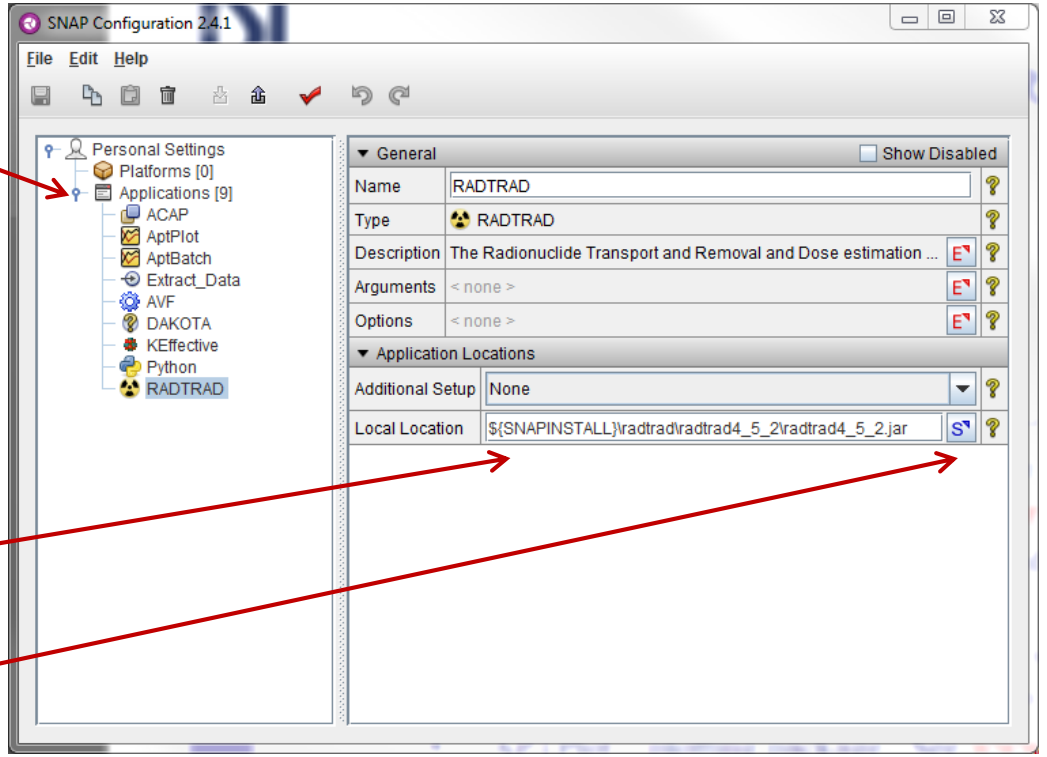
- Basically, the user copies these files to a suitable directory and sets a link to the radtrad.jar file using the SNAP Configuration Tool.
- Most users create a "radtrad" subdirectory in the /users/*homedir*/snap subdirectory and copy the files to that location. Then, the user opens the configuration tool and sets the path to the radtrad.jar file:

  ${SNAPINSTALL}/radtrad/radtrad.jar
- Alternately, the user can copy the files to any location and set the path appropriately in the Configuration Tool.

SNAP/RADTRAD Installation

To start the Configuration Tool, enter
Start->AllPrograms->Snap->Configuration Tool

Click here to show the available applications.



Type the location path here
or
click here to navigate to the radtrad.jar file location (select tool).

AptPlot Installation

- AptPlot Installation – same idea as SNAP.
- Download the AptPlotInstaller.jar file and then either install from the internet or from a local directory.