Fuel Rod Model – Exercise 1

OBJECTIVES

- Become familiar with the LEGACYFRM and DETAILEDFRM NAMELIST options.
- Observe impact of fuel rod modeling options on results.

ACRONYMS

Acronym	Definition
FRM	Fuel Rod Model
MTU	Metric Ton of Uranium
MWD	Mega-Watt Days
PWR	Pressurized Water Reactor

OVERVIEW OF STEPS

1. Run a 100 s base calculation without special fuel rod models
2. Activate new fuel rod models manually
   - New fuel rod models activated with NAMELIST options
   - Increase rod nodalization for improved temperature results
3. Activate the detailed fuel rod model
   - New fuel rod models activated automatically by a single NAMELIST input

STEP 1. RUN A 100 S BASE CALCULATION WITHOUT SPECIAL FUEL ROD MODELS

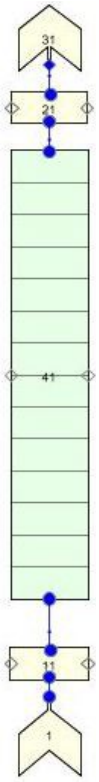
The **Exercise Key** included in the workbook may be useful to help locate the various regions of the SNAP Model Editor that are referred to in this exercise.

A base calculation will be performed to provide a basis for comparison of the fuel rod models.

1. Locate and open the fuel rod model in the SNAP environment:

a. Go to the Day2/Morning/Fuel_Model_Improvements/FRM_Exercise_1 folder and double click on the FRM-Ex1.med file. The SNAP model editor will open with the FRM base model.

b. The FRM base model has a FILL (1) representing the inlet flow condition and a BREAK (31) at the outlet. Two small PIPE segments (11, 21) represent the inlet and outlet piping, and a VESSEL component (41) connected to a heat structure (71). The model layout is shown below.



c. The VESSEL simulates a single hot assembly and uses a square geometry with 17x17 rods divided into 14 axial, 1 X and 1 Y divisions. HTSTR 71 models the average powered rods in the hot assembly. The problem is set up to run a null transient to achieve steady conditions in the fuel rod heat structure. Calculated results are steady before the problem end time is reached at 100 seconds. The key outputs are the fuel rod temperatures.

2. In this exercise, we wish to show differences between the unimproved rod models and those with the updates. The FRM-Exl.med file has the LEGACYFRM NAMELIST variable set to FALSE, which activates some of the improved rod models. We will be changing this setting to deactivate all of the improved rod models.

a. Select the MODEL OPTIONS in the Navigator Window.

b. Verify that the Namelist Option is set to "[1] INOPT Data After Title Cards" in the Properties Window.

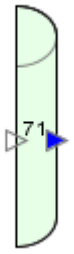
c. Locate the "Namelist Variables" entry in the Properties Window and click on the  to show the Edit Namelist Variables popup window. The NAMELIST variables are divided into seven groups. The filter can be used to help in finding a particular NAMELIST entry.

3. Type legacyfrm in the filter box (you may need to expand the NAMELIST "General" tab). If the checkbox is unchecked, check it, and set the value to "True". This tells the TRACE code to use the basic rod models.

Setting the LEGACYFRM variable to true has changed the required input for the model. The average gap-gas pressure will no longer be calculated by the code (FRGASP is now set to FALSE), and must be input.

4. To set the average gap-gas pressure manually, locate the tabs at the bottom of the View Window, and click on the one labeled "Heat Structures View". In the view

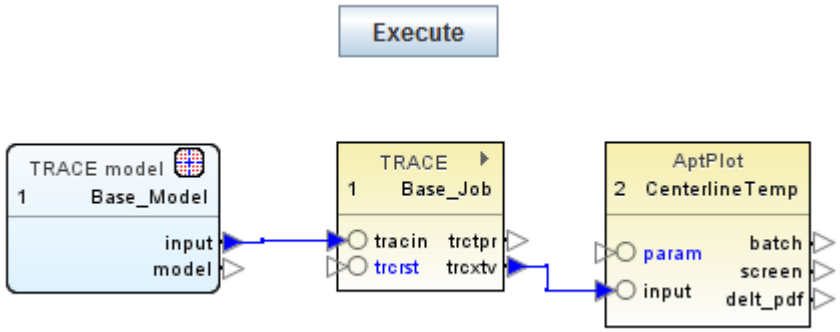
pane, click on the figure representing heat structure 71 (see below). Then do the following:



a. In the Properties Window, locate the "Fuel Properties" section and expand it.

b. Find the entry labeled "Average Gap-Gas Pressure" and type in 2.600713E7.

5. Now we will modify the job stream and run the model. From the tabs at the bottom of the View Window, locate and click on the JOB STREAM tab. This View Window shows the steps that will execute when the model is run.



6. Currently, the SNAP View Window should be unlocked. Verify that the unlocked symbol is showing in the Toolbar. Click on Execute and do the following.

a. In the Properties Window, set the Name field to FRM_Base.

The **Name** field associated with Execute indicates the name used when executing the simulation. If you would like to compare simulations, you can specify a unique Name each time you modify the model before you run the simulation. If you do this, the old simulation will not be overwritten and will be available for comparison.

b. Set the View in Job Status value to Yes.

When you submit a simulation for execution, the Job Status window will open if **View in Job Status** is set to yes. The Job Status window shows you the progress of your simulation and can be very helpful. It is recommended that this be set to "Yes" in general.

7. Click on the TRACE box in the View Window. In the Properties Window do the following:

a. Verify that TRACE is selected for the Application field. This indicates the name of the TRACE application (defined in the Configuration Manager) that will be used to run the simulation.

b. Set the Start Paused field to off.

c. Set the Demultiplex Plot File field to Yes.

Demultiplexing the plot file is not necessary. However, TRACE plot files can be very large, and extracting data for plotting can be slow. Plotting from a demultiplexed (or demuxed) file is typically much faster. Given that the demuxed plot file is both smaller and more efficient for plotting, demultiplexing is recommended.

8. Click on the APTPLOT box in the View Window. In the Properties Window do the following:

a. Locate the "Plot Outputs" entry and click on E to bring up the "Edit Plot Outputs" popup

b. Verify that the name of the output plot is "CenterlineTemp" and that the "Type" is "PDF" and click "Close" to close the window.

If additional output file formats are desired, click the  in the upper left corner of the "Edit Plot Outputs" window to create additional entries. Define each input as described above, selecting the desired "Type" (jpg, tiff, etc.).

c. In the Properties Window, Locate the "Plots" entry and click on  to bring up the "Edit Plot Properties" popup.

d. Click on the g0:graph1 entry, activate the "Title" entry by clicking the checkbox, and give the graph a title (e.g. "Rod Centerline Temperatures").

e. Expand the g0:graph1 entry (left pane of the window), and select s0. Verify that the "Name" of this set is "Rod Centerline Temperature" and that "Dependent Data" is "tsurfi-71A29". The "tsurfi" plot variable is the temperature of the inner rod surface – in this case, it is the centerline temperature of the rod for axial position 29 in heat structure 71. This axial position was selected because it has the highest centerline temperature.

f. Activate the "Legend Entry" by clicking the checkbox. Type "Base" in the box.

9. To execute the job, first lock the View Window by clicking on the  icon located in the left-hand side of the Toolbar. The symbol should change to the locked view symbol  .

10. With the view locked, click  in the View Window to submit the job. A Submit Stream pop-up window should appear. Click the OK button to continue.

11. The SNAP Job Status window will appear and the calculation will start.

12. Once the job completes, check the output plot by clicking on the "Job List" tab in the Job Status window and do the following:

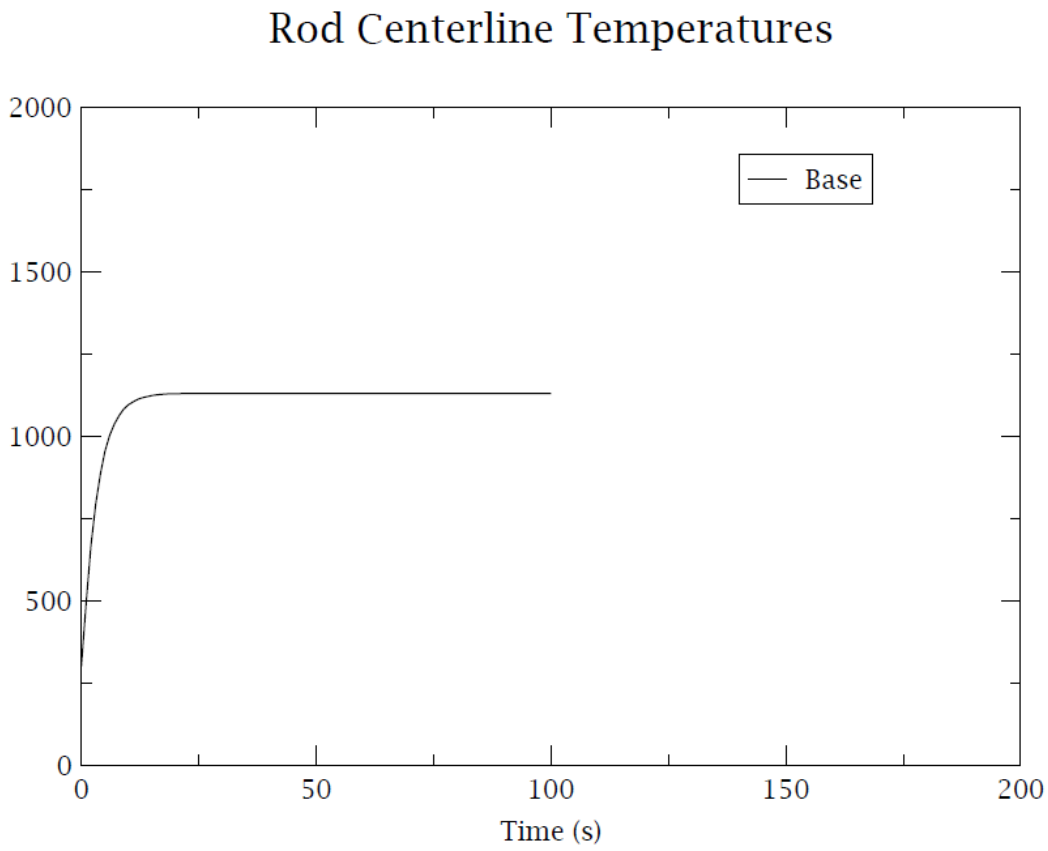
a. Expand the "Local", "Runs" and "TRACE" folders in the tree in the left pane to show the job files that are available.

b. Click on the "FRM_Base" job and observe the listings in the right pane of the window.

c. Click on the listing for "CenterlineTemp" and note the buttons that are activated at the top of the pane.

d. Click on the "View Files" button (), then "PDF Documents" then "CenterlineTemp.pdf" to bring up the figure showing the centerline temperature of the fuel.

e. The generated plot should resemble the figure below.



STEP 2. ACTIVATE NEW FUEL ROD MODELS MANUALLY

This part of the exercise demonstrates the use of the updated rod modeling capabilities by activating each of the models independently. For this step, NAMELIST variable LEGACYFRM is TRUE, which indicates that the new rod models are not activated and the basic fuel rod models are active. We will activate each of the specialized fuel rod models using individual NAMELIST variables.

1. We will be activating each of the improved fuel rod models manually.

a. We must set the NAMELIST variables that will activate some of the detailed rod models. The first is USE_MODNFI_K. Locate this variable using the search box, and set it to "True". USE_MODNFI_K changes the fuel (UO2) correlation to the modified NFI correlation, which includes burnup and gadolinia content. This change requires input to the "gadC" array for the CHAN or HTSTR components.

b. Set NAMELIST CALCSWELLDEN to "False". This flag determines the source of the fuel swelling and densification for each fuel rod. "True" indicates that the TRACE internal models will be used. "False" means that the fuel swelling and densification values will come from user input to the CHAN or HTSTR component.

c. Set CREEPAXIAL to "True". This flag requires values for creepdown for each axial level in every fuel rod HTSTR in the input model. If this flag is not used, or is "False", then only one creepdown value is used for each rod.

d. Set FOXLAYER to "2". This option allows initial oxide layer thickness to vary axially along the rod. TRACE will require an extra array card to specify the initial oxide layer at each axial node for the HTSTR and CHAN components.

The FOXLAYER NAMELIST variable can be set to the following values:
0 – Off, no oxide layer allowed on any fuel rod
1 – On for user-specified components
-1 – Single value applied to all user-specified components
2 – Component arrays give axially varying oxide thickness for individual components

e. Set FRGASP to "True". This flag activates the fuel rod gas pressure model, which requires additional input (describing details about the fuel geometry and gas plenum) for the CHAN and HTSTR components.

f. Set INSIDEOXAPPK to "True". This activates runtime checks to make sure that the inside-surface oxidation calculations conform to Appendix K requirements.

g. Set RADBURN to "1". Indicates that the radial burnup profile will be inferred from the radial power profile. If the radial burnup profile is known, this value can be changed based on the known data (1D or 2D) and additional input will be required.

The RADBURN NAMELIST variable can be set to the following values:
0 – Uniform radial burnup profile in fuel rods
1 – Radial burnup profile obtained from radial power profile
2 – Each rod group has a radial burnup profile that is applied at all axial levels
3 – 2D (axial and radial) burnup profile defined by user for each fuel rod

h. Set SEPARATEROUGH to "True". This indicates that cladding and fuel roughness terms used in the gap conductivity model are supplied as separate values.

i. Set SWELLDENAXIAL to "True". Indicates that TRACE will model the effects of fuel swelling and densification separately at each axial level of all the HTSTR and CHAN components. Axial fuel swelling and densification arrays are required input for all fuel rod heat structures.

2. In order to effectively capture the stored energy and the radial temperature profile in the fuel rod, we need to add some more radial nodes. Beyond those in the base model. Edit heat structure 71 by locating it in the Navigator Window, or right-clicking on pipe 41 in the View Window and selecting "Edit Heat Structures" and "Heat Structure 71 (Average Rod)".

a. In the Property Window, locate "Radial Geometry" and click on  to bring up the "Define Radial Geometry" popup window.

b. The window is divided into three regions. The top region is titled "Mesh Options". Note that the current mesh option is "Standard Mesh". The second region is titled "Material Regions" and shows the material type that is assigned to each of the radial node groups. Note that the rod has mixed oxide fuel at the center, a gas gap, and then Zircaloy cladding. The third region is titled "Radial Intervals", and is used to define the thickness of each node. Note that there are 7 radial intervals.

c. Set the mesh type (located in the upper left corner of the window) to "Finite Element". Recall that this is the recommended approach.

d. It is not necessary in this example to model the cladding with two nodes. Under "Radial Intervals", select the two cladding nodes labeled as "Material 2 (Zircaloy)", and click on "Merge".

e. We need to add some nodes to the fuel region of the HTSTR. Select one of the rows labeled "Material 1 (Mixed Oxide)" and then click the "Split" button and divide it into 5 regions, making a total of 8 fuel regions.

f. Change the thickness of the first 4 fuel nodes to be 6.9331E-4 m. The remaining 4 fuel nodes should be set to 2.87175E-4 m. The gas gap (Material 3) should have a thickness of 7.86E-5 m, and the cladding (Material 2) should have a thickness of 5.715E-4 m.

g. Click on "OK" to save these changes to the fuel rod radial geometry.

3. We will now begin adding the extra input that is required by the updated fuel rod models. We will begin with the oxide layer array. Recall that this array sets an oxide layer thickness for each axial division in the rod heat structure.

   a. Locate "Axial Properties" in the Properties Window and click on the  .

   b. Click on the "Oxide Thickness" entry in the left-side pane to display the array of cell indices, lengths, and Average Rod oxide thickness. This is where you can define the axially-varying oxide thickness, if desired. We will not be defining an axial variation in order to facilitate comparisons with the previous calculation.

   c. Highlight the column labeled "Average Rod" and enter a uniform axial oxide thickness of 3.31942E-5 m.

4. Follow the same process described in 3. above to set the following:

   a. Creepdown to an axially-invariant value of -5.60857E-5 m.

   b. Fuel Swelling to 6.0E-5 m.

   c. Fuel densification to -1.2E-4 m.

   d. Verify that the Gadolinia concentration is set to 0.0.

   e. Close the "Axial Properties" window.

5. The POWER component now requires a radial power shape at 20 locations in the rod (2 for each radial interval defined previously).

   a. Locate and expand the "Power Components [1]" entry in the Navigator Window, and then expand the "Powers [1]" entry. Select POWER component 81 and locate the "Power Shape" section in the Properties Window and expand it.

   b. Locate the "Radial Power Shape" entry and click on the  to show the radial power density array.

c. The following values are to be entered into the table. For convenience, the radial power density is also included in a text file called Radial_Power_Shape.txt in the FRM_Exercise_Part_1 folder. Note that the radial locations are set by the heat structure node definitions and will not need to be modified.

Radial Locations (m)	Radial Power Density (-)
0.0	0.8285
3.46655E-4	0.84224
6.9331E-4	0.84224
1.039965E-3	0.84911
1.38662E-3	0.85598
1.733275E-3	0.867603
2.07993E-3	0.879225
2.426585E-3	0.890848
2.77324E-3	0.90247
2.916828E-3	0.93346
3.060415E-3	0.96445
3.204003E-3	0.99544
3.34759E-3	1.02643
3.491178E-3	1.52358
3.634765E-3	2.02072
3.778352E-3	2.50786
3.92194E-3	2.995
4.00054E-3	0.0
4.28629E-3	0.0
4.57204E-3	0.0

6. We will now run the new model and plot results for comparison to the previous case. From the tabs at the bottom of the View Window, locate and click on the JOB STREAM tab.

7. Verify that the SNAP View Window is unlocked. The unlocked symbol  should be showing on the Toolbar. Click on 

and in the Properties Window, set the Name field to FRM_LegacyTrue.

8. Click on the TRACE box in the View Window. In the Properties Window set the Name field to FRM_Legacy_Job.

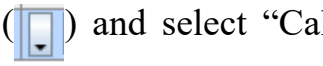
We wish to plot the results from the base calculation against the new results with the updated fuel rod models. In order to do that, the plot file from the base run must be added to the job stream so that it can be included in the plotting step. The next instructions will add the plot file from Step I to the job stream.

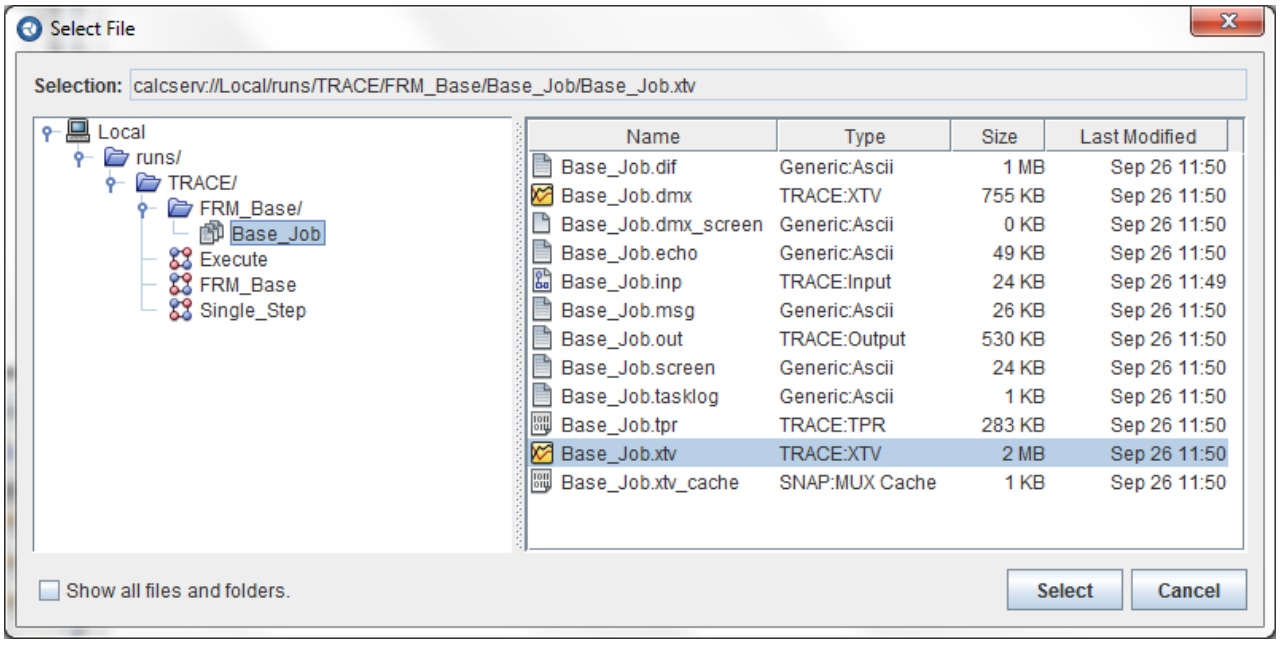
9. In the Navigator Window, expand the "Job Streams [1]" entry and then expand the FRM_LegacyTrue jobstream. Right-click the "Files" entry and select "new". Then do the following:

a. Select "single file" in the popup and click "OK".

b. In the Properties Window, change the "name" to "FRM_Base"

c. Find the "File Type" entry, click on the  and change the type to "TRACE:XTV".

d. Under "File" Click on the down arrow () and select "Calculation Server". This will allow selection of the files from the previous base run, and will bring up the file selection dialog. Navigate in the tree to the "FRM_Base" job that was run in the previous step (see the figure below).



e. Select the "Base_Job" entry in the tree, and then the "Base_Job.xtv" file from the list then click on 

. The input file from the base run is now available for plotting.

f. Drag the entry in the Navigator Window for the External file (FRM_Base) into the View Window so that it can be used in the job stream.

10. Click on the APTPLOT box in the View Window and do the following:

a. Locate "Plot Inputs" in the Properties Window and click on the  to bring up the "Edit Plot Inputs" popup.

b. Add a second input by clicking on the  in the upper left corner.

c. Change the "name" entry to "FRM_Base".

d. Change the "Type" to "TRACE".

e. Click "Close".

f. In the View Window, use the connection tool  to connect the FRM_Base file to the FRM_Base input in the APTPlot box.

11. Click on the APTPLOT box in the View Window and do the following in the Properties Window:

a. Locate the "Plots" entry and click on the  to bring up the "Edit Plot Properties" window.

b. Click on the g0:graph1 entry and verify that the graph Title is "Rod Centerline Temperatures".

c. With the g0:graph1 selected, click on the "add data set" button  in the toolbar. Set "s1" will appear in the tree below g0:graph1.

d. Select set "s1" and change the name to "FRM Base Centerline Temperature".

e. Change "Input" to "FRM_Base"

f. Set “Dependent Data” to “tsurfi-71A29”

g. Activate the “Legend Entry” box by clicking on the checkbox

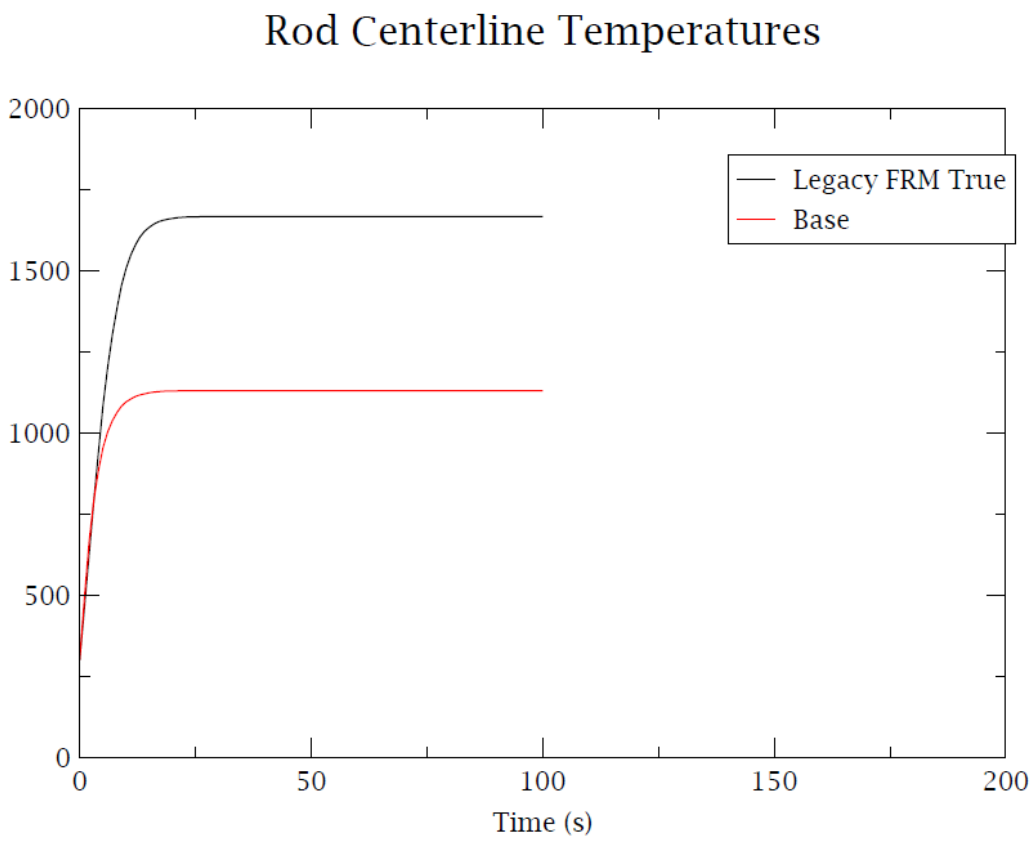
h. Give the data a label of “Base” to indicate that these results are from the base run.

i. Select s0:Rod Centerline Temperature in the tree, and verify that the “Name” entry is “Rod Centerline Temperature” and that the “Dependent Data” is “tsurfi-71A29”

j. Activate the “Legend Entry” by clicking the checkbox, and give this set a legend entry name of “Legacy FRM True”

k. Click “Close”

12. Run the updated jobstream and view the plot that is generated. It should resemble the figure below.



STEP 3. ACTIVATE THE DETAILED FUEL ROD MODEL

We will now show a different approach to setting up the updated fuel rod models. This will use the NAMELIST variable DETAILEDFRM to avoid setting each of the rod model NAMELIST variables separately.

1. We will be changing the setting of NAMELIST variable LEGACYFRM and then set the DETAILEDFRM variable.

a. Open the Edit Namelist Variables window and locate the "LEGACYFRM" entry and deactivate it by un-checking the checkbox.

b. Locate the "DETAILEDFRM" entry, activate it and set it to "True".

Setting DETAILEDFRM to True sets the following NAMELIST variables by default:

1. CALCSWELLDEN = FALSE
2. CREEPAXIAL = TRUE
3. CRUDIN = 1
4. RADHTEMIS = 1
5. FOXLAYER = 2
6. FRGASP = TRUE
7. RADBURN = 3
8. SEPARATEROUGH = TRUE
9. SWELLDENAXIAL = TRUE
10. USE_MODNFI_K = TRUE.

c. The properties set by DETAILEDFRM are identical to those set as part of Step 2. In addition, DETAILEDFRM also sets values for NAMELIST variables CRUDIN, RADHTEMIS, and RADBURN. CRUDIN = 1 indicates that a crud layer will be modeled on the outside surface of all HTSTRs and CHANs, requiring extra input. RADHTEMIS = 1 indicates that the HS material property emissivities will be used for HTSTR surface nodes. RADBURN = 3 allows for a

two-dimensional array of burnup values for each fuel rod. This is more refined than what was done in Step 2. This allows for the radial burnup profile to vary both axially and radially.

2. The changes in NAMELIST RADBURN and CRUDIN require additional array input. RADBURN = 3 requires input for the burn2d array to define the burnup in the radial and axial direction in the rod. Select Heat Structure 71 and locate the "2D Burnup" entry in the Properties Window and under the "Fuel Properties" section and click on the  to bring up the "Edit Initial Burnup" popup.

3. Highlight the columns from "Radial Node 1" out to "Radial Node 17" and type in 5.9918E4 to set the burnup for the fuel nodes at each axial level in MWD/MTU.

4. Highlight the remaining columns (representing the gas gap and the cladding) and set the burnup to 0.0. This is required, since non-fuel materials do not experience burnup. An error will result if non-fuel materials are set to a non-zero burnup.

5. Click "OK" to close the window.

6. Locate the "Axial Properties" entry in the Properties Window under the "General" section and click on the  to bring up the editor for axial properties.

7. Click on "Outside Crud" to bring up the editor for the crud thickness array. Set all the crud thickness values to 0.0. Since Steps 1 and 2 did not use crud, using zero crud thickness will permit a direct comparison to the earlier results.

8. Click on "Close" to close the window.

9. We will now run the new model and plot results for comparison to the previous cases. From the tabs at the bottom of the View Window, locate and click on the JOB STREAM tab.

10. Verify that the SNAP View Window is unlocked. The unlocked symbol  should be showing on the Toolbar. Click on 

and in the Properties Window, set the Name field to FRM_DetailedTrue.

11. Click on the TRACE box in the View Window. In the Properties Window set the Name field to FRM_Detailed_Job.

12. In the Navigator Window, expand the "Job Streams [1]" entry and then expand the FRM_DetailedTrue jobstream. Right-click the "Files" entry and select "new". Then do the following:

a. Select "single file" in the popup.

b. In the Properties Window, change the "name" to "FRM_Legacy"

c. Find the "File Type" entry, click on the  and change the type to "TRACE:XTV".

d. Under "File" Click on the down arrow () and select "Calculation Server". This will allow selection of the files from the previous base run, and will bring up the file selection dialog. Navigate in the tree to the "FRM_LegacyTrue" job that was run in the previous step.

e. Select the "FRM_Legacy_Job" entry in the tree, and then the "FRM_Legacy_Job.xtv" file from the list. The input file from the base run is now available for plotting.

f. Drag the entry for the External file (FRM_Base) from the Navigator Window into the View Window so that it can be used in the job stream.

13. Click on the APTPLOT box in the View Window and do the following:

a. Locate "Plot Inputs" in the Properties Window and click on the  to bring up the "Edit Plot Inputs" popup.

b. Add a second input by clicking on the  in the upper left corner.

c. Change the "name" entry to "FRM_Legacy".

d. Change the "Type" to "TRACE".

e. Click “Close”.

f. In the View Window, use the connection tool  to connect the FRM_Legacy file to the FRM_Legacy input in the APTPlot box.

14. Click on the APTPLOT box in the View Window and locate the “Plots” entry in the Properties Window.

a. Click on the  and expand the g0:graph1 entry in the tree on the left side of the window to show the data sets for the plot.

b. With the g0:graph1 selected, click on the “add data set” button  in the toolbar. Set “s2” will appear in the tree.

c. Select set “s2” and change the name to “FRM Legacy Centerline Temperature”.

d. Change “Input” to “FRM_Legacy”

e. Set “Dependent Data” to “tsurfi-71A29”

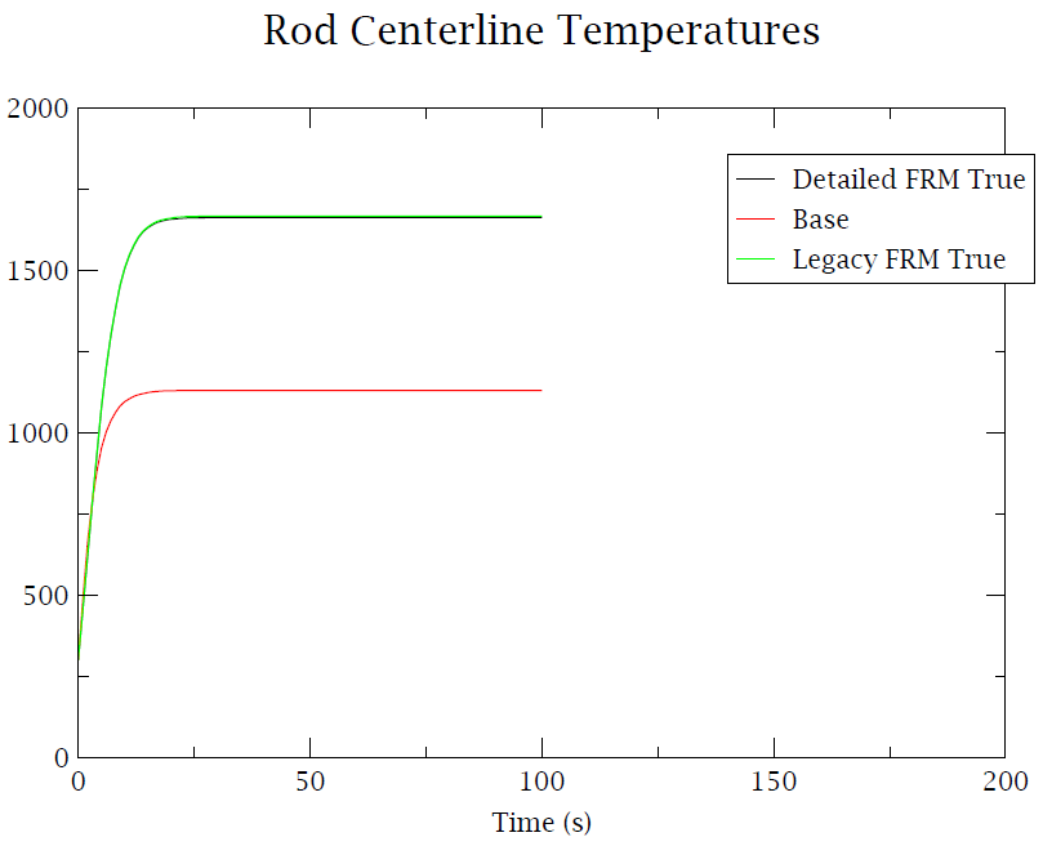
f. Set the “Legend Entry” to “Legacy FRM True”

g. Set the “Legend Entry” for “s0” to “Detailed FRM True”

h. Verify that the other sets are labeled appropriately

i. Click “Close”

15. Run the updated jobstream and view the plot that is generated. It should resemble the figure below.



POINTS TO CONSIDER

- The results of the base case show the rod centerline temperature is approximately 1130 K. The other two cases showed rod centerline temperatures that are significantly higher, around 1664 K.
- The increase in temperature between the cases shows the impact of the improved rod models and the increased radial nodalization of the rods. A key parameter in determining if and when a fuel rod will reach CHF is the amount of energy stored in the rod itself.
- Refining the radial nodalization of the rods improves the calculation of the stored energy, particularly in situations where core burnup is a factor. As the fuel us used, the power profile in the rods tends to flatten out. Toward the end of the life cycle of

the rod, there may be more power generated near the surface than near the middle of the rod. Refining the radial nodalization and including the 2D burnup profile results in better approximations to the amount of energy in the rod, which will result in better predictions of CHF.

- Although centerline temperature is not directly related to how much stored energy exists in a rod, one can infer that higher temperatures will generally indicate that there is more stored energy. The plots generated in this exercise show centerline temperatures for a fuel rod with and without the detailed rod models. It can be seen from the plots and the increase in temperature with more detailed modeling that the stored energy is greater for the detailed models. This means that it is more likely that CHF will be reached for the detailed cases.
- This exercise demonstrates that if the amount of stored energy is important in the analysis, the DETAILEDFRM option should be activated, and sufficient radial nodalization should be used.