Fuel Rod Model – Exercise 2

Objectives

- Demonstrate the impact of the updated Fuel Rod Models on the Peak Cladding Temperature, a key figure of merit for a Large-Break LOCA event.

Acronyms

Acronym	Definition
FRM	Fuel Rod Model
LBLOCA	Large-Break LOCA
LOCA	Loss of Coolant Accident
MTU	Metric Ton of Uranium
MWD	Mega-Watt Days
PCT	Peak Cladding Temperature
PWR	Pressurized Water Reactor

Overview of Steps

1. Run Steady-State calculations with and without the new fuel rod models
2. Import initial conditions to LBLOCA transient models and run the transient
3. Generate a plot to view the effect of the new fuel rod models

STEP 1. RUN STEADY-STATE CALCULATIONS WITH AND WITHOUT THE NEW 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.

One of the key parameters during a LBLOCA is the Peak Centerline Temperature (PCT) of the fuel. The PCT is dependent on the amount of energy stored in the fuel at the start of the LBLOCA. A Steady-State (SS) calculation is needed to set the correct initial fuel temperatures with and without the new fuel rod models. This step will run two SS calculations to provide correct initial temperatures for the LBLOCA analysis.

1. Locate and open the SS model in the SNAP environment:

a. Go to the Day2/Morning/Fuel_Model_Improvements/FRM_Exercise_2 folder and double click on the FRM-Ex2_SS.med file. The SNAP model editor will open with the PWR model.

2. Things to note about the SS model:

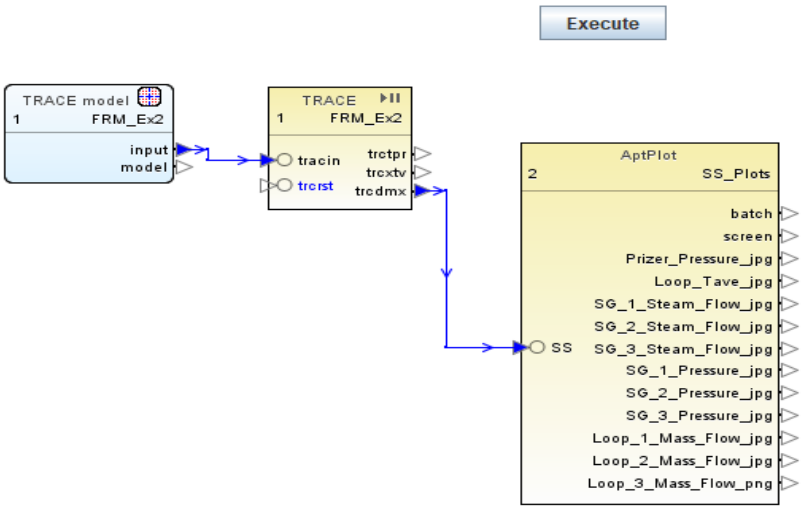
a. The model is of a 3-loop PWR. Note that the initial temperatures of the fuel rods (Heat Structure 41) are all set to 500.0 K.

1. Click on Heat Structure 41 in the Navigator Window
2. In the Properties Window, locate the "Initial Temperature" entry and click on the  to observe the initial temperatures in each node of the heat structure.

b. Verify that the LEGACYFRM NAMELIST variable is unset. This means that LEGACYFRM will have the default value of TRUE. This setting deactivates all of the improved rod models.

3. Run the model to generate initial conditions for the LBLOCA without new fuel rod models

a. 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.



b. 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:

1. In the Properties Window, verify that the Name field is FRM_Ex2_SS_ModelOff and that the View in Job Status value is Yes.

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.

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.

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

1. Verify that the Start Paused field is set to on.
2. Verify that the Demultiplex Plot File field is set 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.

d. To execute the job, first lock the View Window by clicking on the  icon located in the left-hand side of the Toolbar.

e. 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.

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

g. The animation mask will appear as another session in the Model Editor Screen with a popup window that requests to Resume the Calculation. Click on the Yes button. The calculation will now proceed.

h. Observe the key steady-state parameters shown on the "Steady State Plots" tab in the view window.

To save time, while the first steady-state is running, continue to the next section and activate the fuel rod models for the next steady-state calculation.

4. Activate the new fuel rod models.

This step will repeat many of the adjustments that were made in the first FRM example problem to activate the updated rod modeling capabilities one at a time.

a. In the Navigator Window, select the FRM-Ex2_SS.med file. We will now set the NAMELIST variables to activate the updated rod models. The affected variables are: USE_MODNFI_K, CALCSWELLDEN, CREEPAXIAL, FOXLAYER, FRGASP, INSIDEOXAPPK, RADBURN, SEPARATEROUGH, and SWELLDENAXIAL.

b. Unlock the View Window by clicking on the lock ICON  located in the Toolbar on the left-hand side.

c. Open the Edit Namelist Variables popup window.

d. Make the following Namelist variable settings:

1. USE_MODNFI_K to “True”. Recall that 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.**
2. CALCSWELLDEN to “False”. This means that the fuel swelling and densification values will come from user input to the CHAN or HTSTR component.
3. CREEPAXIAL to “True”. Now creepdown must be set for each axial level in every fuel rod HTSTR in the input model.
4. FOXLAYER to “2”. This option allows initial oxide layer thickness to vary axially along the rod. This requires an extra array card to set oxide layer

thickness.

5. FRGASP to "True". This flag activates the fuel rod gas pressure model.
6. INSIDEOXAPPK to "True". This activates runtime checks to make sure that the inside-surface oxidation calculations conform to Appendix K requirements.
7. RADBURN to "1". Indicates that the radial burnup profile will be inferred from the radial power profile.
8. SEPARATEROUGH to "True". This indicates that cladding and fuel roughness terms used in the gap conductivity model are supplied as separate values.
9. 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.

You will recall that the DETAILEDFRM NAMELIST variable sets many of these conditions automatically. It sets a few additional values as well, and it is the automatic setting for CRUDIN that we have decided to avoid for this example. That setting activates the crud input option for all the heat structures in the model. There are many heat structures in addition to those for the fuel rods in the PWR model, and setting crud thickness values for all of them requires more time than is necessary for this demonstration.

5. We will now add 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. Edit heat structure 41 by locating it in the Navigator Window.

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

c. Click on the "Oxide Thickness" entry in the left-side pane. We will not be defining an axial variation in order to facilitate comparisons with the previous

calculation.

d. Highlight both columns (one labeled "Average Rod", the other "Supplemental Rod 1") and enter a uniform axial oxide thickness of 3.31942E-5 m.

6. Follow the same process described in 5. 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. Set the Gadolinia concentration to 0.0. Note that the values for Supplemental Rod 1 will be set to match the Average Rod values.

Note that the Axial Properties window does not "Lock out" the Model Editor. Because of this, it is possible to pull up the Axial Properties window for multiple heat structures at once. When entering values for more than one heat structure, it may be faster to copy and paste values from one heat structure to the additional heat structures, rather than re-typing all the inputs separately. Also recall that by highlighting the entire column, the input need only be typed in once.

e. Close the "Axial Properties" window.

7. Setting SEPARATEROUGH to "True" allows for a separate roughness to be input for the fuel pin and the cladding.

a. In the Properties Window for heat structure 41, locate the "Cladding Roughness" entry and input 1.0E-7.

8. Setting FRGASP to "True" requires additional input to describe the geometry of the gas plenum within the rods.

a. Expand the "Fuel Properties" section in the heat structure 41 Properties Window.

b. Enter the following values for the fuel plenum properties:

Property	Value
Rod Plenum Height	0.188214
Pellet Shoulder Width	1.96E-3
Pellet Dish Depth	3.037E-4
Pellet Height	0.01295
Spring Volume Fraction	0.07736
Sintering Temperature	1872.59
Maximum Density Change	98.82

Note that the fuel plenum properties can be set for multiple heat structures at one time by holding the "Cntrl" key and selecting all the heat structures with the same dimensions from the Navigator Window. Then the plenum values can be set in the Properties Window for all the selected heat structures at once.

9. Run the model to generate initial conditions for the LBLOCA without new fuel rod models

a. Switch to the JOB STREAM tab and verify that the unlocked symbol  is showing in the Toolbar. Click on Execute and do the following:

1. In the Properties Window, modify the Name field to FRM_Ex2_SS_ModelOn.

b. If desired, save the SNAP file with a unique name to preserve the changes made to activate the updated rod models.

1. File Menu → Save As → Change filename to FRM_Ex2_FRMOn_SS.med → save

c. To execute the job, lock the View Window and click Execute to submit the job.

STEP 2. IMPORT INITIAL CONDITIONS TO LBLOCA TRANSIENT MODELS AND RUN THE TRANSIENT

1. Locate and open the LBLOCA model in the SNAP environment:

a. Go to the Day2/Morning/Fuel_Model_Improvements/FRM_Exercise_2 folder and double click on the FRM-Ex2_LBLOCA.med file. The SNAP model editor will open with the PWR model.

2. Things to note about the LBLOCA model:

a. The model was developed from the steady-state model without the new fuel models active. For extra practice, you can attempt to change the SS model into a transient LBLOCA model by making the following changes.

b. The "Model Options" were set to perform a transient calculation.

1. This de-activated the constrained steady-state calculation.

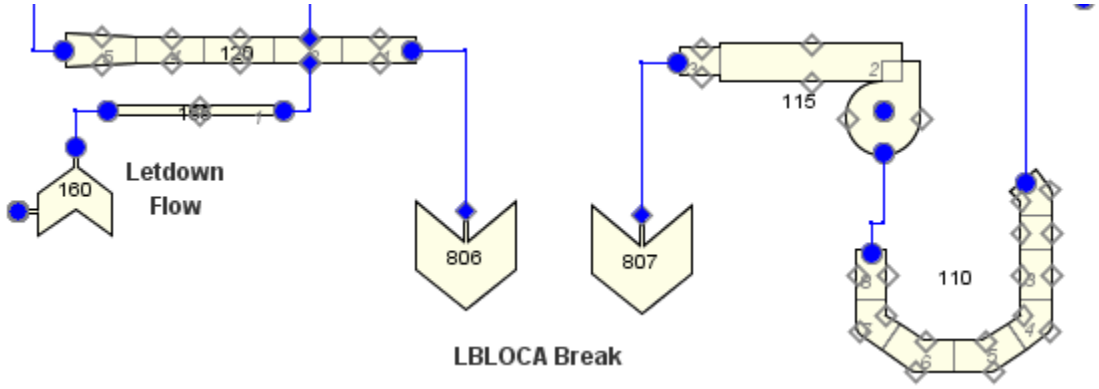
c. The following changes were made to the control system to set the model up for LBLOCA calculations:

1. The gains on control blocks -415, -416, -434, -1162, -2162, -3162, -4340, and -4342 were set to zero. These control blocks are for the pressurizer level and spray control, the SRV and PORV control for each loop, and the steam dump valve controls. Setting the gains on these controllers to zero effectively de-activates these systems.

2. The delays and setpoints for trips 423, 9996, and 9999 were set to zero. These trips are the manual main feedwater trip, the manual RC pump trip, and the manual turbine stop trip. Setting the setpoints to zero initiates trips of these systems at time zero of the transient.

3. Trip signals 160, 220, and 400 (turbine stop trip, RC pump trip, and main feedwater regulating valve trip) were modified to include trip 10 (Reactor trip). This will de-activate these controls when the reactor trips.

d. The connection between the pump in loop 1 (115) and the loop 1 cold leg (120) was removed, and two BREAK components (806 & 807) were added to the model. The breaks were given a large volume (1.0E5 m^3) and a length of 1.0 m. The initial conditions in the breaks were set to complete void, and 373 K. Initial pressure was set to be 1 atmosphere (1.01E5 Pa). See the figure below showing the LBLOCA BREAK components.



e. The timestep data was modified to have two increments:

End Time	Min Step Size	Max Step Size	Heat vs. Fluid Size	Max Conv. Power Difference	Long Edit Interval	Graphics Interval	Restart Interval	Short Edit Interval
15	1.00E-005	0.08	10	1.00E+020	5	0.2	50	25
35	1.00E-004	0.2	10	1.00E+020	50	0.2	50	25

3. Import steady-state conditions from the legacy rod model calculation

a. With the FRM_Ex2_LBLOCA model open, right-click on the black bar in the Navigator Window and select "Manage Initial Conditions".

b. In the window that opens, select "Retrieve"

c. In the "Initial Conditions" window, select "A Local TPR File" by "Retrieve Data From".

Note the second option "A Submitted Run" will allow you to select one of the runs shown in the "Job Status" window. This option retrieves data from the XTV or DMX file. The data retrieved in this way is incomplete; it does not include the temperatures in the heat structures or the initial values of the control blocks. Selecting "A Local TPR File" retrieves the data from the TPR file, which includes the additional heat structure and control block data.

d. Click on the  button to open the "Select TPR File" window. Navigate to the working folder for the results and select the FRM_Ex2_SS_ModelOff folder, then FRM_Ex2 folder, then select the FRM_Ex2.tpr file.

e. Click the "Load Timesteps" button to load the available timesteps from the FRM_Ex2.tpr file.

f. Select the last timestep (it will have a 0.0 timestamp), and then click "OK". The initial conditions will be imported to the model.

g. Check that the initial conditions were imported by opening the initial temperature editor for heat structure 41 and verifying that the temperatures are no longer 500.0 K.

4. The basic fuel rod model LBLOCA model may now be run.

a. Save the SNAP med file with a unique name, if desired.

b. In the Job Stream Window, click on "Execute" and change the Name to FRM_Ex2_LBLOCA_ModelOff.

c. Run the LBLOCA case.

d. Observe the PCT response in the plot labeled "Peak Rod Cladding Temperature" shown on the "Transient Plots" tab in the view window of the animation mask.

e. Note that the temperature rises significantly during the beginning of the transient, and then drops as the core quenches and cools.

5. For enhanced understanding, consider the following questions:

a. Observe the Accumulator, HPSI, and LPSI flows during the transient. At what point do the emergency flows overcome the flow from the break and begin to recover the core?

b. Why does it take so long for the make-up flows to overcome the break loss? What settings in the input model could be adjusted to modify this?

6. Activate the new fuel rod models in the LBLOCA SNAP file by following the same procedure as before (see Items 4 through 8 of Step 1).

7. Import the steady-state results from the updated fuel rod model.

a. Use the same procedure as shown above, though select the FRM_Ex2.tpr file from the FRM_Ex2_SS_ModelOn folder.

8. The new fuel rod model LBLOCA model may now be run.

a. Save the SNAP med file with a unique name, if desired.

b. In the Job Stream Window, click on "Execute" and change the Name to FRM_Ex2_LBLOCA_ModelOn.

c. Run the LBLOCA case.

STEP 3. GENERATE A PLOT TO VIEW THE EFFECT OF THE NEW FUEL ROD MODELS

1. Create a plot of the PCT for the legacy fuel rod case by clicking on the "Job List" tab in the Job Status window and do the following:

Note that these instructions load the plot files into APTPlot one at a time, with the second file replacing the first. This can be inconvenient if you wish to make several comparisons of different variables. In order to keep both plot files loaded into APTPlot at the same time, from within APTPlot, you will need to navigate to the output folder you selected when setting up SNAP, locate the folders for the desired jobs, and select the plot files from those folders. If you would like to do this, and are having difficulty, please ask an instructor for help.

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_Ex2_LBLOCA_ModelOff" job and observe the listings in the right pane of the window.

c. Click on the listing for "FRM_Ex2" and note the buttons that are activated at the top of the pane.

d. Click on the AptPlot icon  to open the output file in the plotting program. The AptPlot window will open, along with the "Read TRACE" plot variable window with the output file loaded.

e. In the left-hand pane of the Read TRACE window locate "power-999". This is the core power component that provides the heat to the fuel rods.

f. Select the trhmax-999 entry, and click on the "Plot" button at the bottom of the window. The plot shows the PCT with respect to time during the LBLOCA transient without the updated fuel rod models. Note that the temperature rises and then decreases as the core quenching process begins.

2. Create a plot of the PCT for the updated fuel rod case by clicking on the "Job List" tab in the Job Status window and do the following:

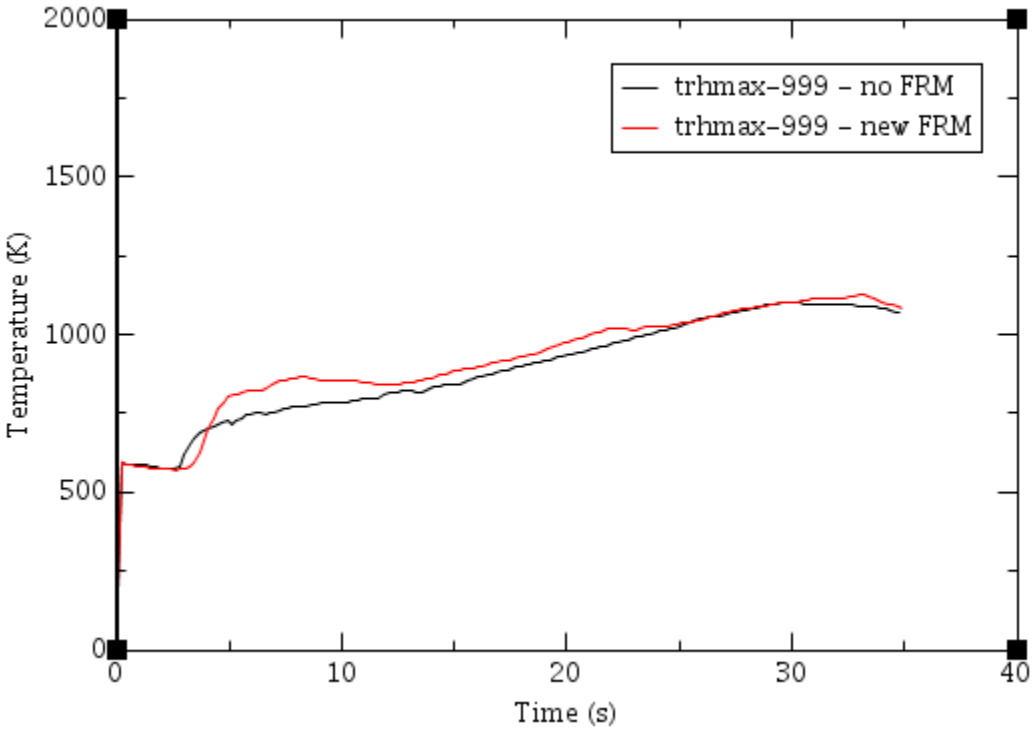
a. Expand the "Local", "Runs" and "TRACE" folders in the tree in the left pane to show the job files that are available.

b. Click on the "FRM_Ex2_LBLOCA_ModelOn" job and observe the listings in the right pane of the window.

c. Click on the listing for "FRM_Ex2" and note the buttons that are activated at the top of the pane.

d. Click on the AptPlot icon  to open the output file in the plotting program. The output plot file will now be opened in AptPlot, replacing the plot file from the legacy case.

e. As before, select the trhmax-999 entry for the "power-999" component, and click on the "Plot" button at the bottom of the window. The plot shows the PCT with respect to time during the LBLOCA transient with the updated fuel rod models. The plot should be similar to the figure below.



POINTS TO CONSIDER

- The results of the FRM case show the initial PCT peaks at approximately 860 K. The case that did not use the improved rod models showed a PCT at the same time of approximately 780 K. The overall peak with the updated FRM is about 1107 K, while the non-FRM case peaks at approximately 1140 K.
- Without the new fuel rod models, the gap between the fuel and the cladding closes. This gives us heat transfer coefficients from fuel to cladding that are much higher than the case with the updated fuel rod models.
- This exercise demonstrates that if the amount of stored energy is important in the analysis, a conservative solution is obtained when the improved fuel rod models are used. The improved fuel rod models can be activated individually or by using the DETAILEDFRM NAMELIST variable.