FLECHT-SEASET Exercise Instructions

The FLECHT-SEASET facility was constructed mainly for PWR core reflood experiments, which included forced and gravity feed and unblocked and blocked bundle tests. A TRACE input model of the FLECHT-SEASET facility simulating Test 32013c, an unblocked-bundle, forced-feed experiment, is used for this exercise.

The main component in the facility was the cylindrical test section which consisted of: a lower plenum, a core region housing a 3.66-m (12-ft) heater rod bundle, an upper plenum, a coolant injection port connected to the lower plenum, and a pressure boundary connected to the top of the upper plenum.

The unblocked experiments used a rod bundle consisting of 177 rods, of which 161 were powered heater rods and 16 were unpowered thimble rods. A cosine axial power profile defined the power distribution within the heater rods.

The unblocked bundle forced-feed tests ranged in flooding rates from 10 to 155 mm/s and in upper plenum pressures from 0.13 to 0.41 MPa.

The nominal boundary conditions for Test 32013c were: a flooding rate of 26.4 mm/s, an inlet liquid temperature of 339 K, an upper plenum pressure of 0.41 MPa, and a total initial bundle power of 805 kW. The bundle power declined during the test period, simulating the behavior of fission product decay heat.

TRACE Model of FLECHT-SEASET

The TRACE base model of the FLECHT-SEASET experimental facility for simulating Test 32013c is summarized here (see the nodalization diagram that follows).

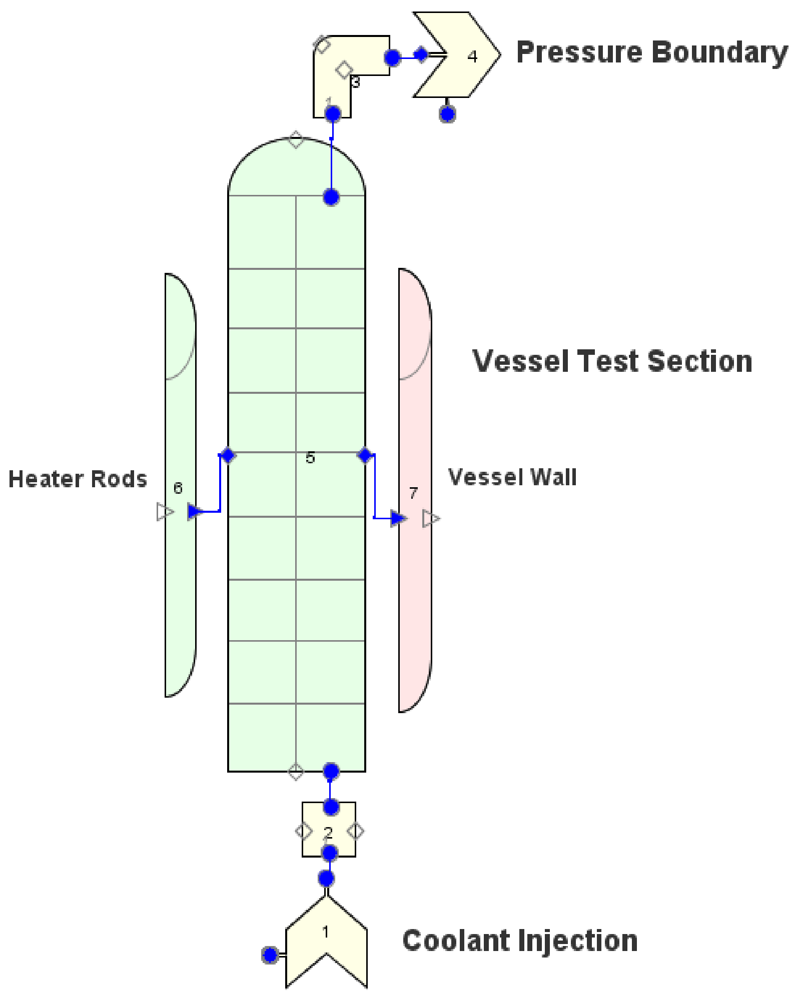
The base model consists of the following components:

1. FILL 1: sets the inlet liquid mass flow rate and fluid temperature.
2. PIPE 2: models the inlet liquid injection line.
3. VESSEL 5: 1-D VESSEL component that represents the lower plenum (level 1), the core region where the heater rods are located (levels 2 through 8) and the

upper plenum (level 9) of the test section.

4. PIPE 3: models the outlet steam discharge line.
5. BREAK 4: sets the outlet pressure boundary condition.
6. HTSTR 6: models the 161 powered heater rods. This heat structure is connected to the core region in the VESSEL component (levels 2 through 8).
7. HTSTR 7: models the metal mass of the test section wall, also connected to the core region fluid cells of the VESSEL component.
8. POWER 8: models the initial power, the decay power versus time and the axial power profile.

The TRACE reflood model options are turned off in the base model.



Objective

This exercise demonstrates the core reflood capabilities of the TRACE code and how to implement these capabilities in a TRACE facility model.

Overview of Steps

1. Open the FLECHT-SEASET Base Model in the SNAP Model Editor.
2. Run the base model and compare calculated results with data.
3. Add additional axial levels in the core region, rerun and compare with data.
4. Activate the VESSEL and HTSTR reflood options, rerun and compare with data.

Step 1. Open the FLECHT-SEASET Base Model in the SNAP Model Editor.

1. Close all Model Editor files that are open.
2. Go to the Day3/Afternoon/Reflood-Heat-Transfer folder and double-click on the file "fs32013c-Step2.med".

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

STEP 2. RUN THE BASE MODEL AND COMPARE CALCULATED RESULTS WITH DATA.

A base calculation will be made and the calculated heater rod surface temperatures will be compared with measured data at selected elevations.

1. Submit and run the FLECHT-SEASET model.

A) Click on the “Job Stream” tab at the bottom of the View Window. A job stream has been set up to run the base model.

B) Lock the View Window by clicking on the padlock located on the left-hand side in the Toolbar.

C) Submit the model for execution by clicking on the fs32013_Step2_Exec” button in the View Window. Click the “OK” in the “Submit Stream” dialog window to submit the job.

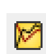
D) The “Job Status” window will appear and the progression of the calculation will be shown. The TRACE calculation ends at 500 s and is followed by the creation of a demultiplexed (dmx) plot file.

2. Compare the TRACE calculated heater rod temperatures with the measured data.

A) When the job has completed, click on the “Job List” tab at the top of the Job Status window. Locate and click on the “fs32013_Step2_Exec” folder 

. and highlight the “fs32013c_Step2 TRACE” job. Click on the yellow plot icon located near the top of the Job Status window.

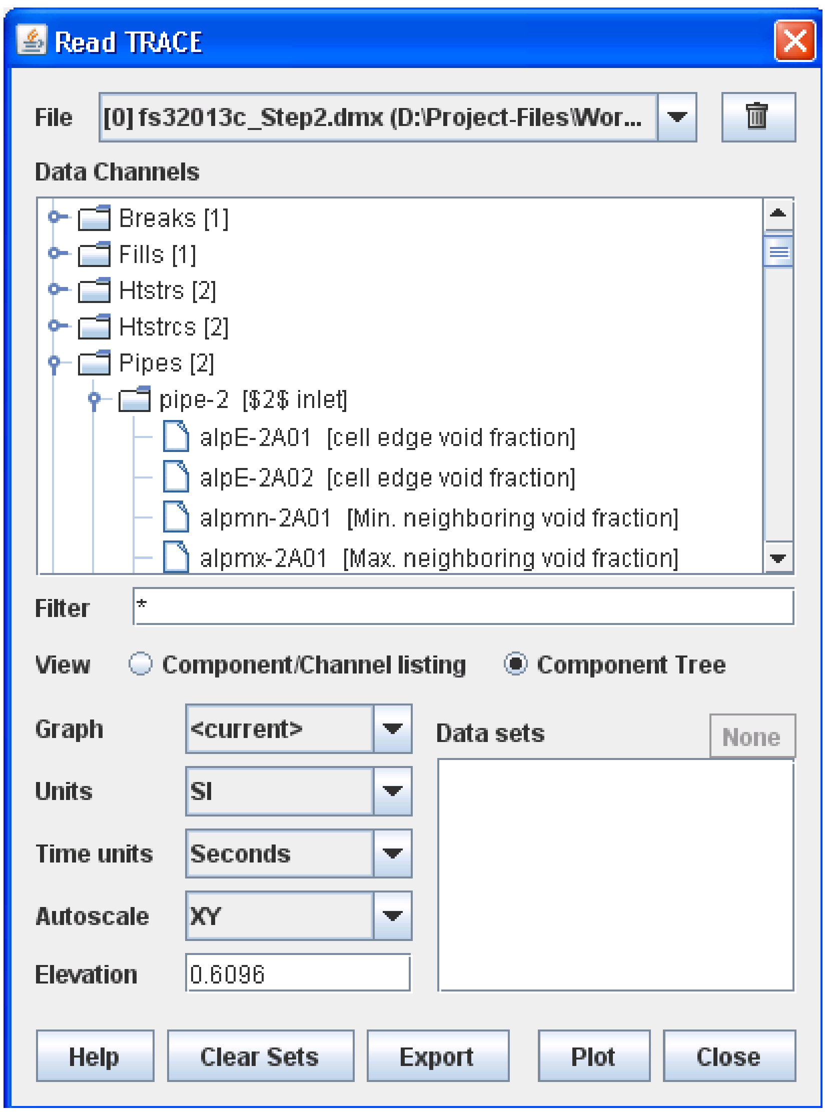
3. In the right-side window click on the “fs32013_Step2” TRACE job.

4. Click on the graphics icon  located in the Job Status View Window Toolbar.

A) An AptPlot window will appear in addition to a “Read TRACE” window.

The Read TRACE window lists the parameters available for plotting. The selected plot parameters are displayed in the AptPlot window.

B) In the "Read TRACE" window click on the "Component Tree" button. Note the organization of the TRACE components available for plotting. Click on the toggle key next to the Pipes [2] folder and note the two Pipe component sub folders. Click on the toggle key next to pipe-2 [2 inlet] and note the calculated pipe variables available to plot.



C) Load in the measured data by clicking on “File” in the Main Toolbar of the AptPlot window and select “Open”.

D) In the “Open” dialog window, navigate to the Day-3/Afternoon/Reflood-Heat-Transfer folder and select “FS32013cTemps.apf” then click the “Open” button. The measured heater rod cladding temperatures at 0.6096, 1.8288 and 3.048 m above the bottom of the test section heated length will be displayed in the AptPlot window.

E) Plot the TRACE calculated heater rod cladding temperatures at the 0.6096, 1.8288 and 3.048 m elevations.

a) In the “Read TRACE” window enter rftn-6A01R07 in the “filter box” and press the enter key on the keyboard.

> This is the calculated heater rod cladding temperature at the bottom of the rod. Note the structure of the number: rftn is the designation for the heat structure temperature, -6 is the heat structure number, A01 is the first axial level of the heat structure and R07 is the radial ring node number. There are 7 radial nodes in heat structure 6 and node 7 is the outside surface.

b) In the “Elevation” box enter 0.6096. This is the elevation from the bottom of the heater rod for which the calculated rod temperature will be plotted.

c) Open (expand) the Htstrcs [2] folder (located in the upper part of the “Read TRACE” window).

d) Open the “htstrc-6 [6 fuel rods]” folder.

e) Click on parameter “rftn-6A01R07 [structure temperature]”.

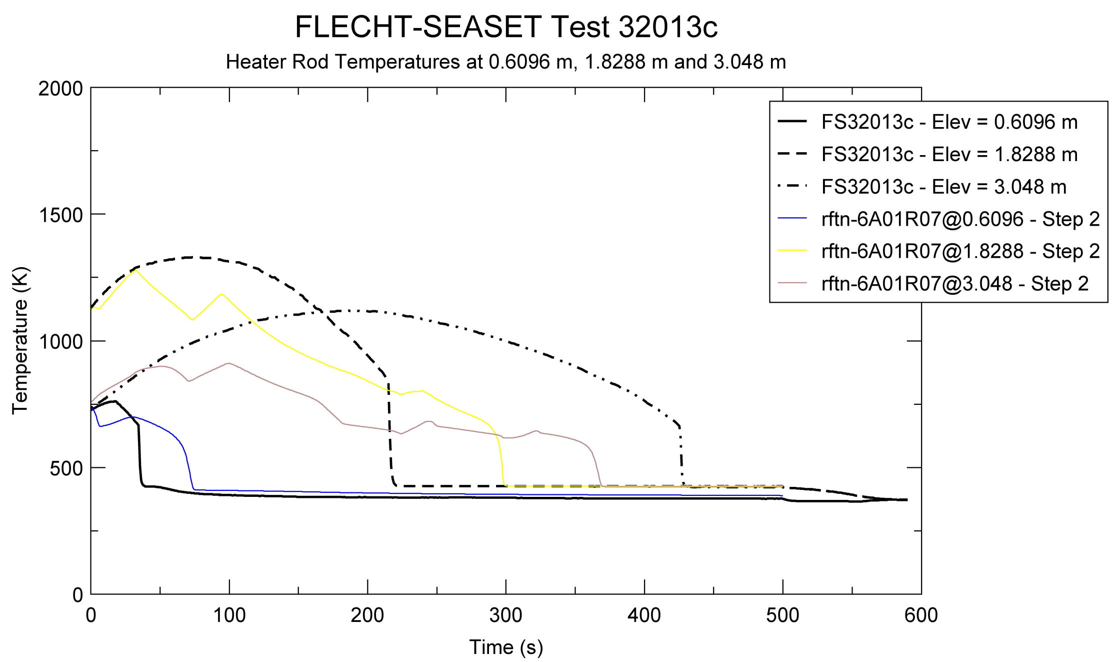
f) Click the “Plot” button at the bottom of the “Read TRACE” window. Note the new curve in the AptPlot window. This is the calculated heater rod cladding temperature at the 0.6096 m elevation.

g) In the “Elevation” box, enter 1.8288 and press the enter key on the keyboard. This is the elevation from the bottom of the heater rod for which the calculated rod temperature will be plotted.

h) Click the "Plot" button at the bottom of the "Read TRACE" window. Note the new curve in the AptPlot window. This is the calculated heater rod cladding temperature at the 1.8288 m elevation.

i) Repeat items g) and h) for the 3.048 m elevation.

F) Your data comparison should be similar to the figure shown below. Note the calculated clad temperatures compared to the measured data. The trends of the clad temperatures are predicted, but the peak temperatures and times to quench are not well represented.



The calculated cladding temperatures are much lower than the data. At the upper elevations the calculated rod temperatures quench much earlier. This behavior is indicative of a rapid propagation of the quench front.

G) Move on the next step, but do not close the AptPlot windows. The measured and calculated data from the above step will be compared to the calculations that follow.

Step 3. Add additional axial levels in the core region, rerun and compare with data.

In the VESSEL core region, the base model has one axial level between each core grid spacer. There are seven axial levels in the core region. Each core level is approximately 20 inches (0.51 m). This step will increase the number of axial levels in the VESSEL core region to include two axial levels between the grid spacers.

TRACE assessments (see TRACE DA Manual) using data from several reflood experiments (FLECHT-SEASET, CCTF, SCTF, etc.) have shown that a coarsely nodalized core region results in a rapid propagation of the quench front, leading to under-prediction of the peak cladding temperature. Sensitivity studies indicate that core cell lengths of about 10 inches result in a better definition of the quench front propagation and thus better prediction of the peak cladding temperature. Grid spacers in the plants and experimental facilities are typically placed at 24 inch intervals in the core region, thus the recommendation for using two axial levels between the core grid spacers.

1. Unlock the model by clicking on the green padlock in the upper left corner of the Model Editor Component Toolbar. In the View Window, right click on the VESSEL component and select "Renodalize Axial Levels".
2. In the "Renodalize Z Axis" popup window, highlight Levels 2 through 8.

VESSEL Levels 2 through 8 model the core region of the FLECHT-SEASET test section.

3. Click the "Split Uniform" button and enter "2" in the "Split each cell into how many cells" box. This operation will split each of the selected levels into two equal spaced levels. Click the OK button.

4. Click the "Next" button at the bottom of the "Renodalize Z Axis" window.

5. Note that the subsequent window compares the original nodalization and the modified nodalization. Click the OK button at the bottom of the window to accept the nodalization changes.

6. A "Renodalization Report" window appears, summarizing the model modifications. Note that the VESSEL nodalization modification also results in modification of the heat structures attached to the VESSEL component. Click the "OK" button.

7. Revise the names of the model and run from "Step2" to "Step3" as follows. Click on the "Job Stream" tab at the bottom of the View Window. Right click on the "TRACE" box (middle box in the View Window) and in the Properties Window change the name of the model from "fs32013c_Step2" to "fs32013c_Step3" and press enter. Right click on the "fs32013_Step2_Exec" button (in the View Window) and in the Properties Window change the name of the run from "fs32013_Step2_Exec" to "fs32013_Step3_Exec".

8. Lock the model by clicking on the red padlock in the upper left corner of the Model Editor Component Toolbar.

9. Run the modified TRACE Step 3 model. Refer to Step 2, Items 1C and 1D above.

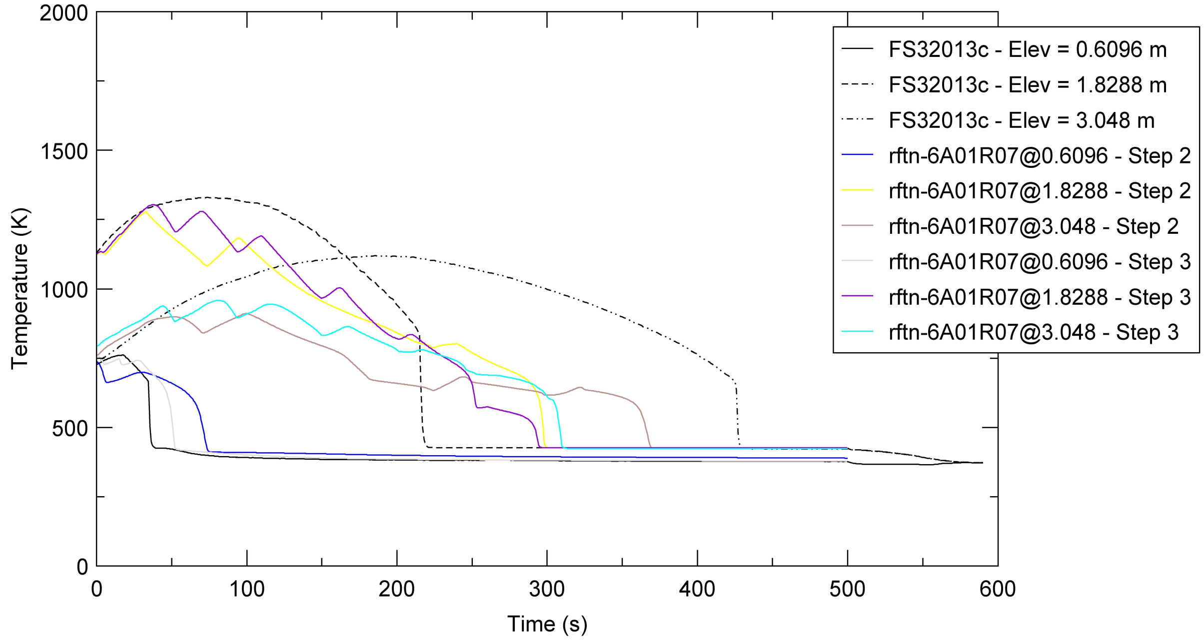
10. Compare the TRACE calculated heater rod temperatures from the Step 3 run to the measured data and to the Step 2 calculation.

A) Plot the calculated rod temperatures at elevations of 0.6096, 1.8288 and 3.048 meters. Refer to Step 2, Item 4E above.

B) Your data comparison should be similar to the figure shown below. Note the changes in the predicted heater rod cladding temperatures compared to the measured data and the calculated temperatures from Step 2. The finer nodalization in the core region of the VESSEL component improved the predicted peak temperature at the lower vessel elevation, but did not have much effect at the middle and upper vessel elevations. The predicted time to quench now compares better with the measured data at the lower and middle vessel elevations but the comparison at the upper vessel elevation is now worse.

FLECHT-SEASET Test 32013c

Heater Rod Temperatures at 0.6096 m, 1.8288 m and 3.048 m



C) Move on to the next step, but do not close the AptPlot windows.

Step 4. Activate the VESSEL and HTSTR reflood options, rerun and compare with data.

This step activates the reflood associated models. The RFLDINPUT input in the VESSEL component is entered, and this allows for input of two special optional parameters of importance for reflood calculations: "funh" and "nhsca".

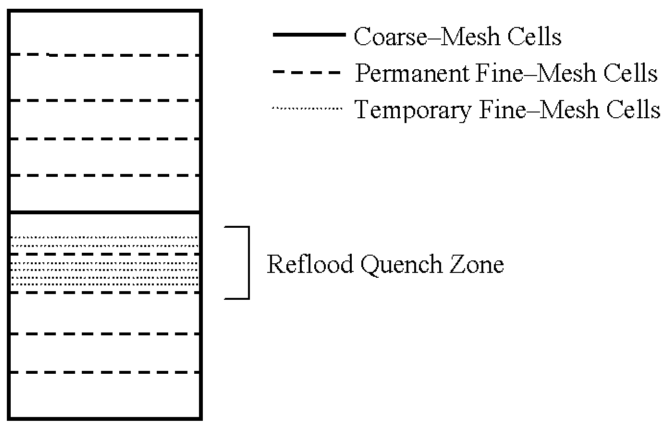
"funh" (the fraction of unheated rod) is the fraction of the reflood HTSTR that is not powered. Since the reflood HTSTR in this model does not have unheated sections, this input is set to 0.0.
"nhsca" defines the powered HTSTR components that are associated with the VESSEL component. In this model, the powered HTSTR is Component 6.

Other reflood associated input is needed for the fine-mesh capability in the HTSTRs. Specifically, HTSTR input parameter FMON is set to TRUE. When FMON is TRUE, the fine-mesh capability is invoked. The activation of FMON requires additional HTSTR inputs: NFAX, NZMAX and DZNHT.

Parameter NFAX defines the number of permanent fine mesh cells which a coarse-mesh cell is divided into at the start of the fine-mesh noding evaluation. Typical input values for NFAX are 3 and 5.

Parameter NZMAX defines the maximum number of additional nodes related to NFAX and the number of reactor-core region axial (cells) levels. Recommended input values for NZMAX range from 100 to 250.

Parameter DZNHT defines the minimum axial spacing below which no additional renoding is added. The recommended input value for DZNHT is 1.0e-03.



Refer to the TRACE V5.0 User's Manual, Volume 2: Modeling Guidelines for additional information.

1. Unlock the model by clicking on the green padlock in the upper left corner of the Model Editor Component Toolbar. Activate the RFLDINPUT option in the VESSEL component and specify the "funh" and "nhsca" inputs.

   A) In the Model Editor click on the VESSEL component in the View Window.

   B) In the Properties Window, click on "True" in the "Use Reflood" box. This causes a "Core Reflood Heating" box to appear higher up in the Properties Window.

C) 'E'xpand the "Core Reflood Heating" box.

D) Click in the Average Heatstructure box, 'S'elect Heat Structure 6, and click OK. This step associates HTSTR 6 as a reflood structure in the VESSEL component.

E) Since there is no unheated fraction in HTSTR 6 (heater rod) then the input for the Unheated Fraction box is 0.0. Click the OK button.

2. Activate the FMON option in HTSTR 6 and HTSTR 7 and specify the inputs for NFAX, DZNHT and NZMAX. The activation of this option will invoke the fine-mesh capability in each of the HTSTRs.

In the experiment, the heater rods were initially powered in order to achieve a desired axial temperature profile before the initiation of coolant injection. During the heat up process, the vessel walls also heated up due to radiation heat transfer from the heater rods. Thus the vessel wall was also initially hot. During the reflood process, the heater rods and vessel wall interact together in the cooling process. Therefore, the fine-mesh option is also activated in the wall heat structure (HTSTR 7) to better define the vessel wall quench front propagation.

A) In the Model Editor View Window, click on HTSTR 6 (fuel rods).

B) In the Properties Window, click on "True" in the "Fine Mesh Reflood" box. This activates the fine-mesh capability (FMON).

C) In the "Maximum Axial Nodes" box change the number to 250 (NZMAX). This is the recommended value for the maximum number of node rows.

D) In the "Minimum Node Distance" box change the number to 1.0e-3 m (DZNHT). This sets the minimum temporary node size the code is allowed to use during the reflood calculation.

E) 'E'xpand the "Axial Nodes/Surface BCs" box and highlight all of the "Axial Cell" boxes (middle column). In the lower part of the window modify the "Fine Mesh Count" number to 3. This sets the number of permanent fine-mesh node rows the coarse HTSTR cells are divided into. Click OK.

F) Repeat Items A through E for HTSTR 7. Although HTSTR 7 is a wall heat structure (non-powered), the wall starts out hot and fine-mesh calculations are used to track the quench front along the vessel wall.

3. Revise the names of the model and run from "Step3" to "Step4" as follows. Click on the "Job Stream" tab at the bottom of the View Window. Right click on the "TRACE" box and in the Properties Window change the name of the model from "fs32013c_Step3" to "fs32013c_Step4" and press enter. Right click on the "fs32013_Step3_Exec" button and in the Properties Window change the name of the run from "fs32013_Step3_Exec" to "fs32013_Step4_Exec".

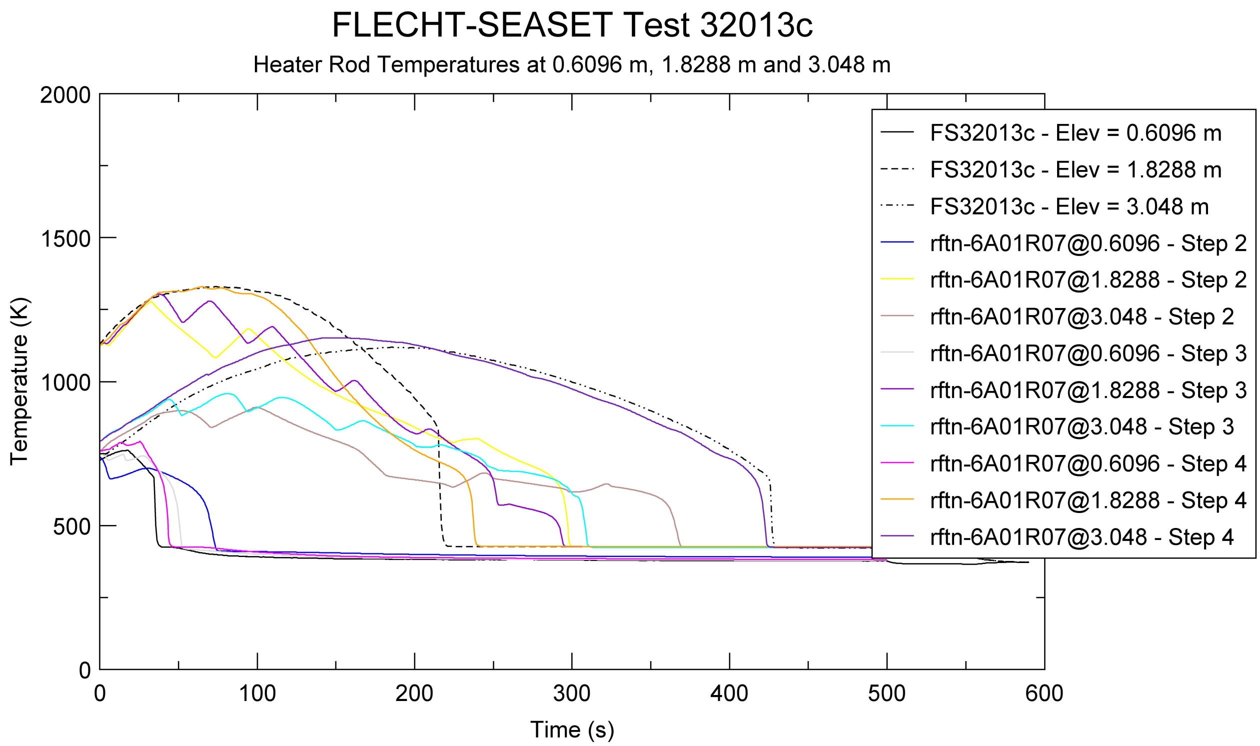
4. Lock the model by clicking on the red padlock in the upper left corner of the Model Editor Component Toolbar.

5. Run the modified TRACE Step 4 model. Refer to Step 2, Items 1C and 1D above

6. Compare the TRACE calculated heater rod temperatures from the Step 3 run to the measured data and to the Step 2 calculation.

A) Plot the calculated rod temperatures at elevations of 0.6096, 1.8288 and 3.048 meters. Refer to Step 2, Item 4E above.

B) Your data comparison should be similar to the figure shown below. Note the changes in the predicted heater rod cladding temperatures compared to the measured data and the calculated temperatures from Step 2 and Step 3. The fine-mesh option used in Step 4 provides for better simulation of the quench front propagation and much improved predictions for the peak cladding temperatures and quench times at all three core elevations.



Conclusions

By utilizing the full reflood heat transfer capabilities in TRACE along with sufficient core region nodalization, the predicted heater rod clad temperatures all along the heated length show good agreement with the experimental data. Similar fuel rod cladding temperature prediction capabilities are expected for commercial power plant simulations.

Optional Exercises

- Add more axial levels in the core region of the VESSEL.
- Modify the HTSTR NZMAX input to more than 250 and/or less than 100. Note the difference in the run time.
- Modify the HTSTR DZNHT by a +/- factor of 10.

In each modification compare the calculated heater rod temperatures to the measured data and note the differences the modifications have on the predicted heater rod temperatures.