Reflood Heat Transfer Modeling

Information Systems Laboratories, Inc.

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Objectives

- Familiarize students with TRACE reflood techniques and how to invoke them

Outline

- Discussion on reflood heat transfer
- Activation of reflood heat transfer models in TRACE
- Reflood heat transfer modeling recommendations and user guidance
- FLECHT-SEASET reflood exercise

Discussion of Reflood Heat Transfer Modeling

- Reflood occurs when the fuel has been uncovered due to a loss of coolant accident.
- When the emergency make-up water begins to re-cover the fuel, this becomes a reflood condition
- What are the expected conditions as the water re-covers the fuel?
- What are the key parameters of interest?
- Based on the modeling limitations, what kind of problems should we expect?
- How could we adjust our model to minimize those problems?

Reflood Heat Transfer Exercise

An exercise is used to demonstrate TRACE reflood heat transfer capabilities and core nodalization effects.

The exercise is based on a TRACE model of the FLECHT-SEASET experimental facility for simulating Test 32013c, an unblocked-bundle forced-feed experiment.

- FLECHT-SEASET was constructed mainly for reflood experiments.
  - Tests included both forced and gravity feed and unblocked and blocked bundle cases.

- The main component in the experimental facility was the cylindrical test section consisting 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
  - A pressure boundary connected to the top of the upper plenum.

Reflood Heat Transfer Modeling

- The unblocked experiments used a heater rod bundle consisting of 177 rods, of which 161 were heater rods and 16 were thimble rods.

- A cosine axial power profile defined the electric power distribution to the heater rods.

- The unblocked bundle forced flow tests ranged in flooding rates from 0.01 mm/s to 0.155 mm/s and in upper plenum pressures from 0.13 MPa to 0.41 MPa.

- Unblocked bundle – forced flow Test 32013c nominal input boundary conditions were:
  - A flooding rate of 0.0264 m/s
  - An inlet liquid temperature of 339 K
  - An upper plenum pressure of 0.41 MPa
  - An initial power of about 805 kW which decayed with time during the experiment

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The TRACE input model for the FLECHT-SEASET test consists of:

- A FILL component that sets the injected liquid mass flow rate and fluid temperature.
- A PIPE component that models the liquid injection line.
- A 1-D VESSEL component modeling the test facility lower plenum (Level 1), core (Levels 2 to 8) and upper plenum (Level 9).
- A PIPE component modeling the steam discharge line.
- A BREAK component that sets the pressure boundary.
- A HTSTR component that models the 161 heater rods.
- A HTSTR component that models the metal mass of the test vessel wall in the core region.
- A POWER component that models the initial power, the decay power as a function of time, and the axial power profile.

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- The exercise will compare measured rod clad temperatures at three different elevations with TRACE-calculated heater rod clad temperatures.
- The first part of the exercise will evaluate the TRACE results without any specialized reflood models
  - The first step is to run the TRACE input model as it is and compare the calculated results with the data.
  - Step two will modify the axial nodalization of the core region in the VESSEL and in the HTSTRs and compare the calculated results with the test data.

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- Refer to the FLECHT-SEASET Exercise Instructions in the Workbook under Day-3 Morning.
- Once you have completed steps 1 and 2, wait to continue the lecture from this point to discuss additional options for reflood modeling available in TRACE

Summarize Reflood Results

- What did you notice when you refined the nodalization in the FLECHT-SEASET model?
- Do you have any concerns about trying to get accurate results using this method?

Discussion of Reflood Heat Transfer Modeling

- TRACE contains a unified heat transfer package that includes models for reflood heat transfer.
- A correctly predicted thermal response from the fuel rods during core reflood requires a numerical technique that can model the rewetting phenomena associated with the quench front motion.
- The leading edge of the rewetting region is characterized by large variations of the fuel rod temperatures and heat fluxes over small axial distances.
- These steep thermal gradients are modeled in TRACE through supplemental rows of conduction nodes, which are inserted in the fuel rod HTSTR model using the fine-mesh rezoning option. Note that the associated hydrodynamic component is not rezoned.

Reflood Heat Transfer Modeling

- Reflood heat transfer is activated in TRACE by setting HTSTR input parameter FMON and VESSEL input parameter RFLDINPUT to non-zero values.
    - FMON – invokes the fine-mesh capability in the HTSTR component. The HTSTR is subdivided into permanent fine-mesh cells as well as temporary fine-mesh cells that follow the quench front as it moves up and down the fuel rod.
    - RFLDINPUT – invokes additional VESSEL input that identifies a heat structure that is associated with the reflood process.

Reflood Heat Transfer Modeling

- When fine-mesh is on (FMON > 0):
  - TRACE adds permanent fine-mesh cells (defined by HTSTR input NFAX) to each of the coarse-mesh cells (NZHTSTR) of the fuel rod heat structure.
  - TRACE dynamically adds and removes additional axial fine-mesh node rows as needed during a calculation. Based on the heat-transfer regime and the HTSTR axial temperature gradient, a temporary fine-mesh node row is added where the temperature gradient is steep and removed where the temperature gradient is not steep.
  - The total number of axial node rows (permanent plus temporary) cannot exceed the input-specified maximum number of axial nodes (NZMAX)
  - A temporary fine-mesh node row will not be added if the fine-mesh node length is less than or equal to the input-specified minimum axial node row height (DZNHT).

Reflood Heat Transfer Modeling

- When RFLDINPUT is on (RFLDINPUT > 0) two additional VESSEL inputs are required:
  - UNHEATFR – Fractions of the HTSTR component fuel element surface that are unheated (i.e., the portions of the fuel rods located above and/or below the elevation span of the fuel pellets).
  - NHSCA – The HTSTR component numbers that define the average power fuel element in each of the VESSEL horizontal-plane mesh-cell columns.
- Since one or more HTSTR may be connected to a hydrodynamic component, these inputs tie together the HTSTRs designated for reflood and the corresponding hydrodynamic components.

Reflood Heat Transfer Modeling Recommendations and User Guidance

- Reflood heat transfer sensitivity studies have provided the following recommendations and user guidance:
  - The recommended user input parameters defining the HTSTR fine-mesh noding are:
    - DZNHT = 1.0e-3 m (minimum temporary node size)
    - NZMAX = 100 to 250 (maximum number of node rows)
  - Typical values for NFAX (number of permanent node rows) are from 3 to 5.
  - In addition to activating the HTSTR fine-mesh option, consideration needs to be given to the hydrodynamic nodalization:
    - The core axial hydro cells and reflood HTSTR cells are typically modeled on a one-to-one basis.
    - Core region flow areas are typically modeled using the bare rod area. The frictional pressure drop effects of area reductions at the grid spacers are modeled using K loss coefficients that have been appropriately adjusted for the difference between the grid spacer and bare rod flow areas.
    - TRACE assessments have shown that core nodalization schemes where there are two axial levels between grid spacers (DX between 0.254 m and 0.3048 m) give good predictions of the fuel/heater rod profile for reflood heat transfer situations.

Reflood Heat Transfer Modeling

- Continue with Step 3 of the reflood exercise
- This part of the exercise will evaluate the TRACE results with the specialized reflood models
  - Complete step three, in which the RFLDINPUT flag in the VESSEL and the HTSTR fine-mesh option are used. The revised calculation results will then be compared with the test data.