Validation of RELAP5-3D Using HE-FUS3 Data

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Outline

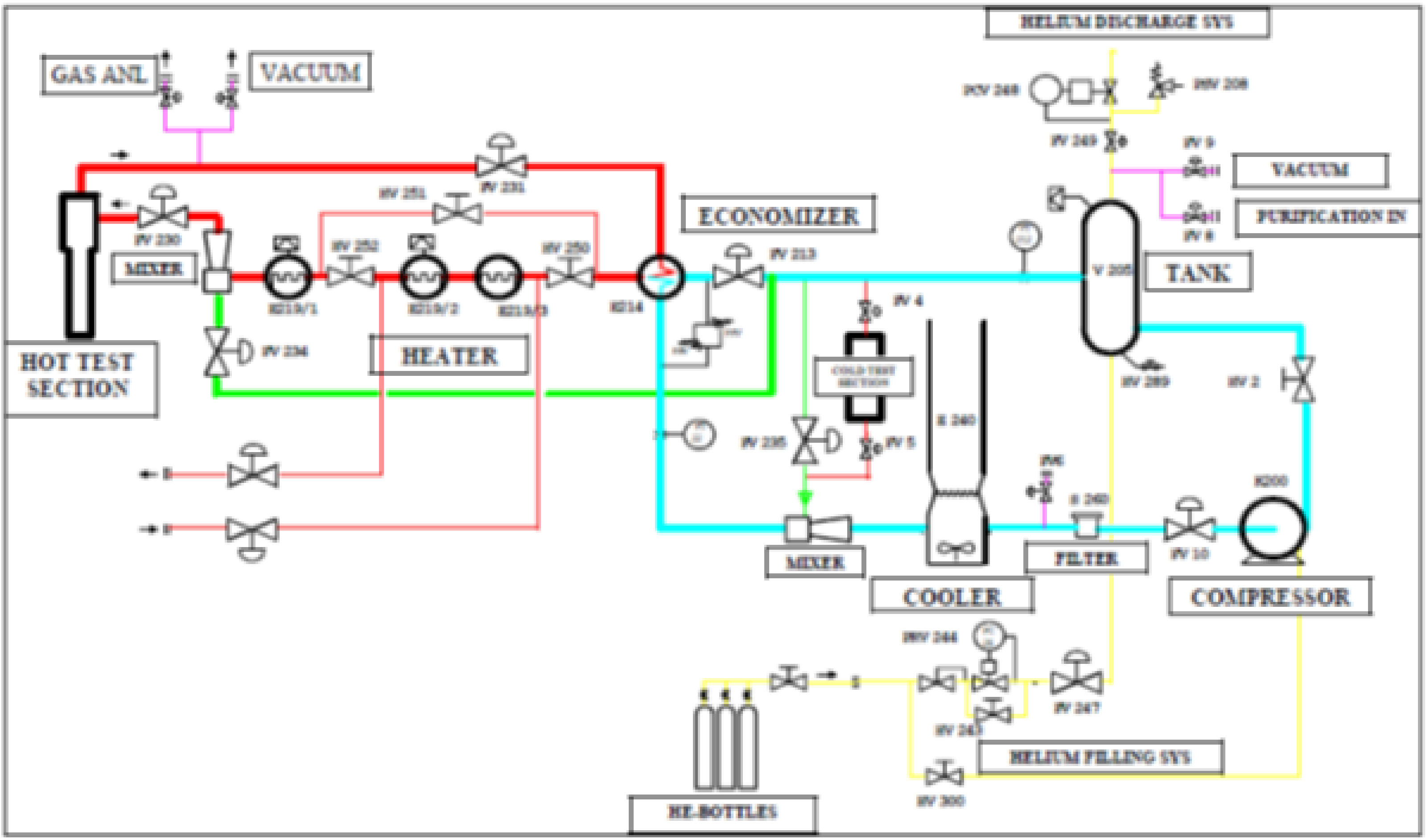
- Introduction
- Description of HE-FUS3 RELAP5-3D model
- Validation results
- Conclusions

Introduction

- HE-FUS3 is a helium-cooled, electrically heated experimental facility designed and constructed at Ente per le Nuove tecnologie, l'Energia e l'Ambiente (ENEA) in Italy in the mid-1990s
- The facility was used to perform experiments to support the validation of thermal-hydraulic system codes for gas-reactor applications
- RELAP5-3D* was validated using data from the HE-FUS3 facility to support high-temperature gas reactor applications

*Davis, C. B., 2018, Validation of RELAP5-3D Using HE-FUS3 Data, INL/EXT-18-46153, August 2018.

Schematic of HE-FUS3*



* Meloni, P. and M. Polidori, 2009, HE-FUS3 Experimental Campaign for the Assessment of Thermal-Hydraulic Codes: Post-Test Analysis, ENEA Report RSE/2009/89

Description of HE-FUS3

- Major components include compressor, economizer, test section, and hot bypass path
- Economizer is a tube in shell heat exchanger
  - Cold fluid flows outside of the tubes
  - Diaphragms are used to promote cross flow and improve the heat transfer
- The hot bypass path is used to control the temperature at the inlet to the test section
- The test section contains an annular downcomer, lower plenum, and core simulator
- Core simulator contains seven simulated fuel rods that are electrically heated
  - Six average rods and one hot rod

Description of HE-FUS3 (cont'd)

- Facility can simulate loss-of-flow and loss-of-coolant accidents
- The facility has 36 instruments that measure temperature, pressure, differential pressure, mass flow rate, valve position, or compressor speed
- The facility also has 27 embedded thermocouples that measure temperature near the surface of the simulated fuel rods
- Measured results are available for seven steady-state tests, two loss-of flow accidents (LOFAs) and two loss-of-coolant accidents (LOCAs)

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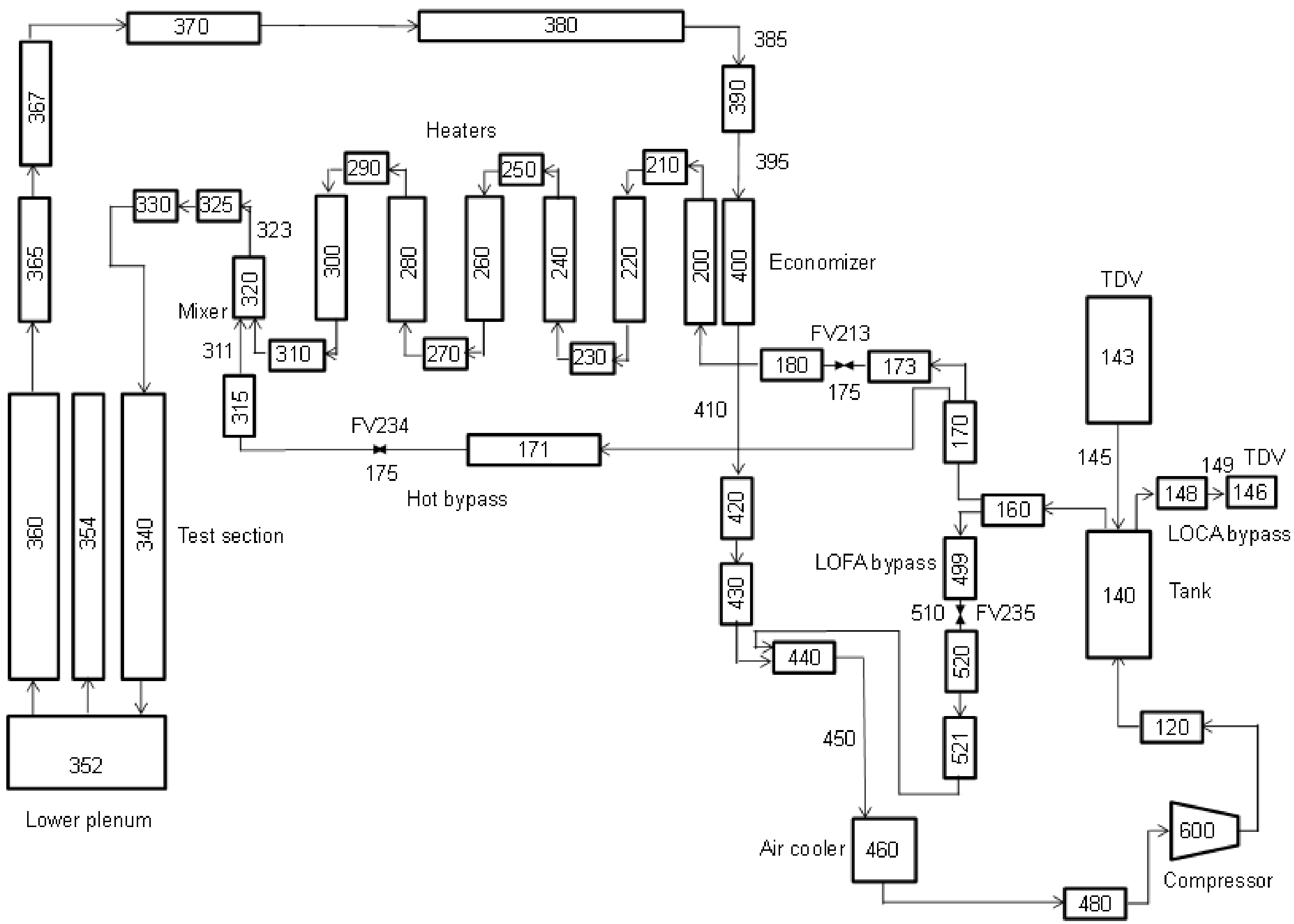
Nodalization of the RELAP5-3D model



Description of RELAP5-3D model

- Model is based on one developed by Meloni and Nitti* (2010)
- Substantial revisions to the original model were made to take advantage of advanced features of RELAP5-3D, incorporate typical INL modeling practices, and adjust various input parameters to match the steady-state data
  - Helium was modeled as a real working fluid
  - The Gnielinski heat-transfer correlation was used on the inside surface of the economizer tubes because it accounts for wall temperature effects and is expected to be more accurate at low Reynolds numbers than Dittus-Boelter
  - The flow area of the shell side of the economizer was adjusted to approximate the actual flow length around the diaphragms and a fouling factor of 0.96 was applied to match measured fluid temperatures

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*Meloni, P., and F. S. Nitti, 2010, Pre-Test Analysis for an Experimental Campaign in the Upgraded HE-FUS3 Loop, ENEA Report RdS/2010/112

Description of RELAP5-3D model (cont'd)

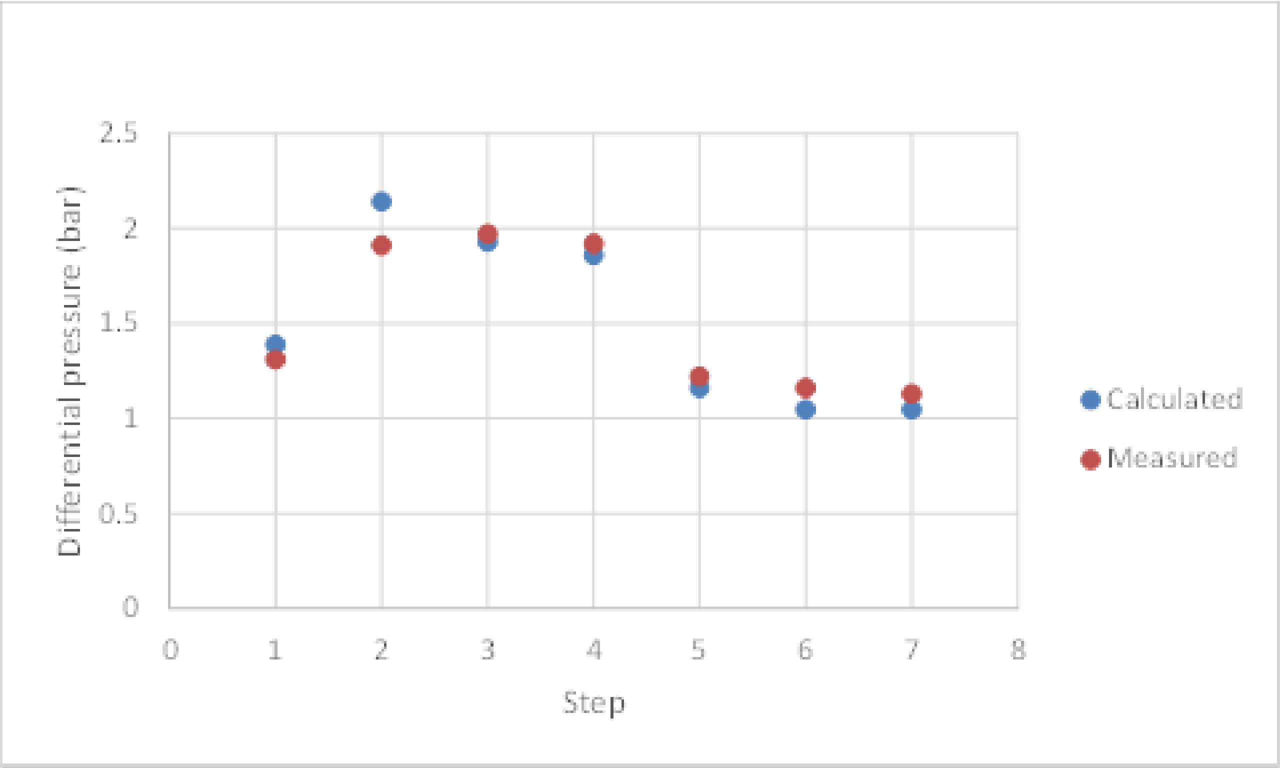
- The helium gap that thermally insulates the downcomer from the core simulator was explicitly modeled and an enclosure model was used to represent radiation across the gap
- The Gnielinski heat-transfer correlation was applied on the outer surface of the simulated fuel rods
- Adjustments were made to the heat loss model to match measured temperatures

• The peaking factor applied to the hot rod was reported to vary between 1.40 and 2.0
  - An average value of 1.70 was applied in the model

Validation results

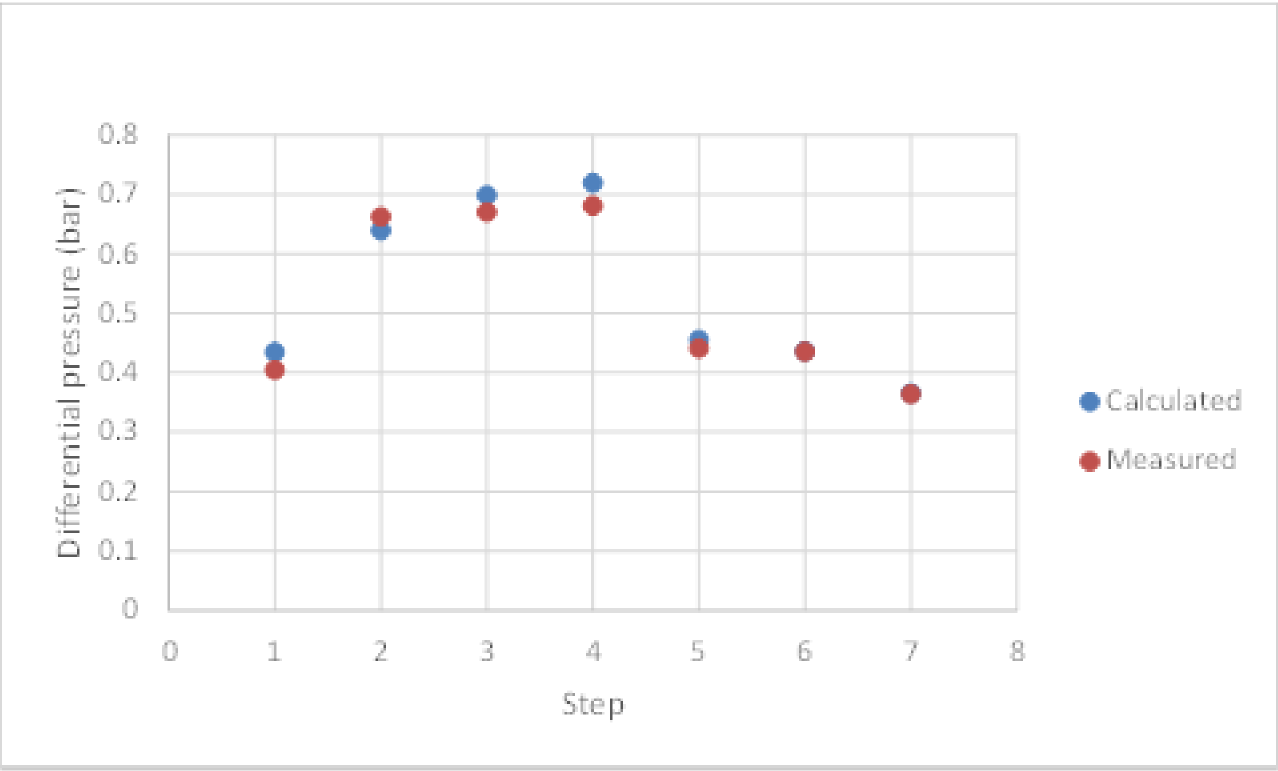
- RELAP5-3D was validated using all seven steady-state tests and one LOFA initiated by a reduction in compressor speed
- Insufficient data were available to characterize the performance of the compressor during the LOFA
  - Therefore, a control system was used to adjust compressor speed to obtain the measured flow rate
  - The validation concentrated on the effect of the change in flow rate on temperatures

Differential pressure across the compressor during the steady-state tests



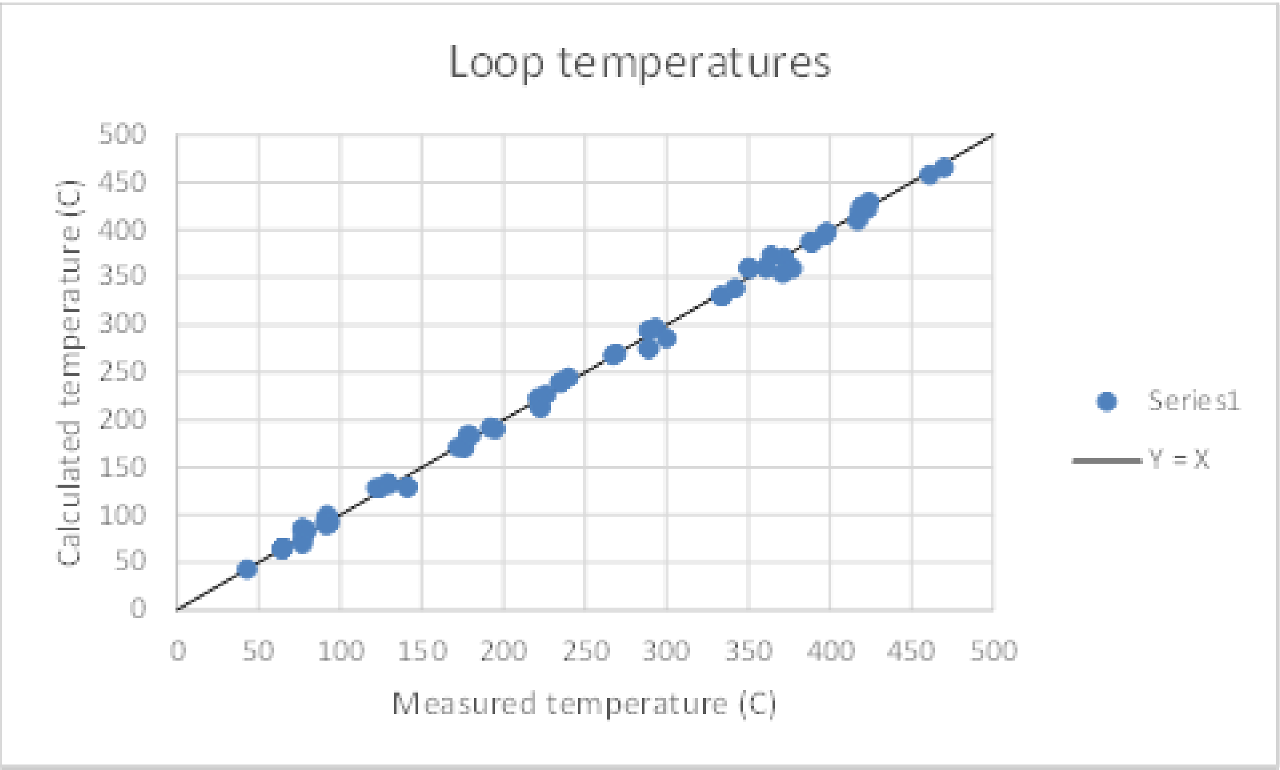
- dP across the compressor is a measure of overall resistance in the loop
- Calculated results were judged to be in reasonable agreement with the measurements

Differential pressure across the test section during the steady-state tests



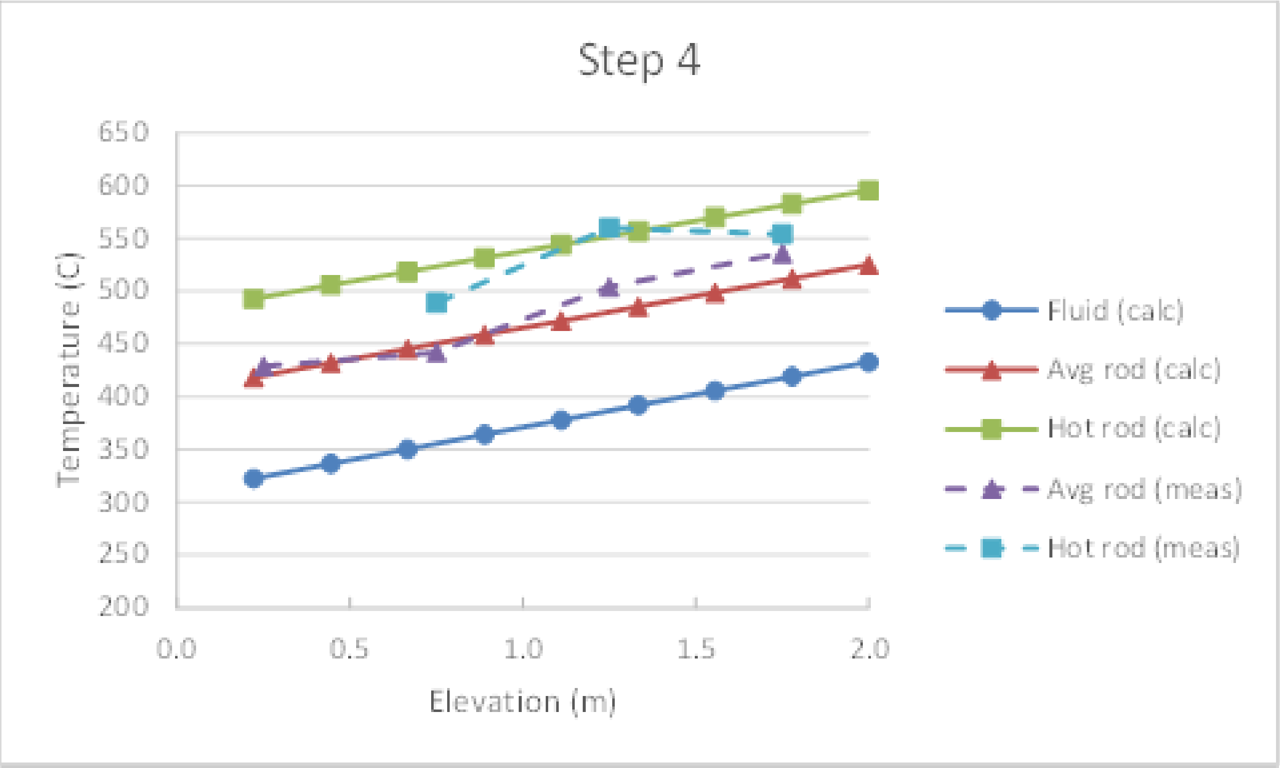
- Only two dP measurements were reported
- The dP across the test section accounted for about 35% of the total, which means that 65% of the losses were not measured
- Additional measurements would be required to characterize the pressure losses well

Fluid temperatures during the steady-state tests



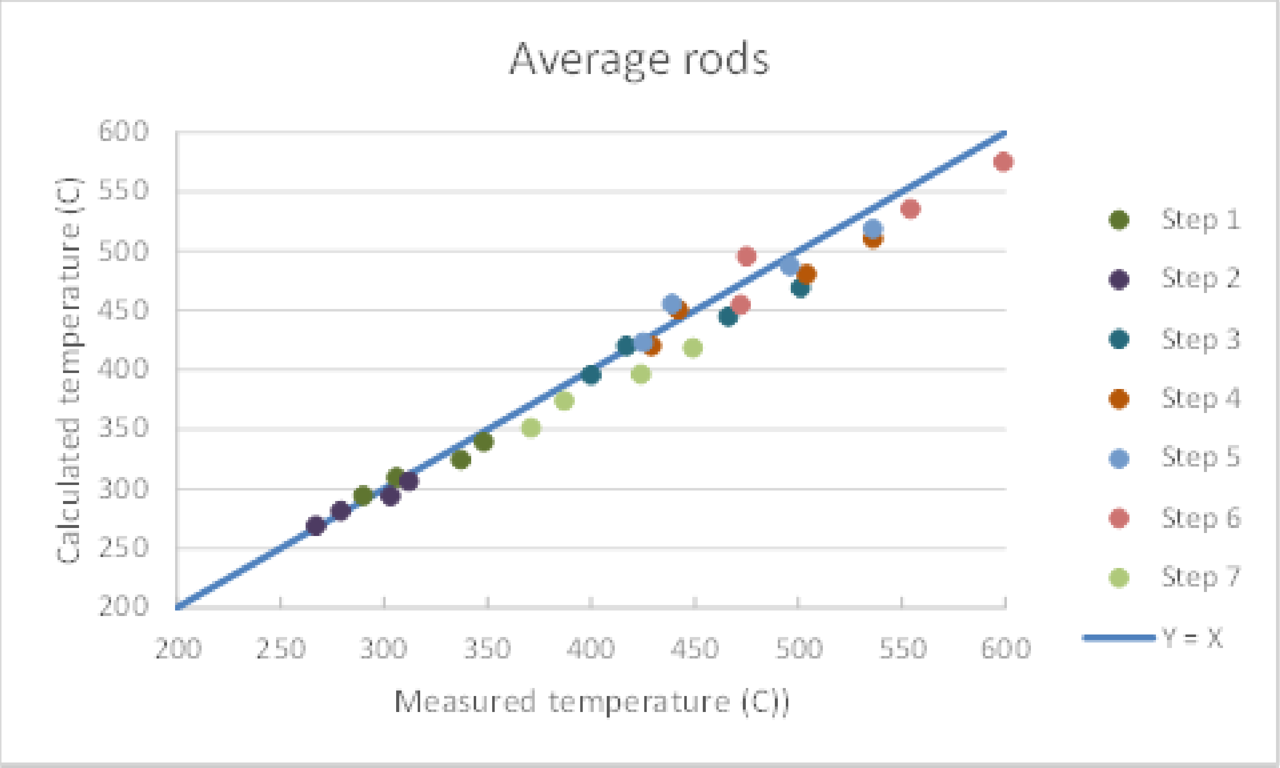
- Average deviation was less than 1°C
- Maximum deviation was 17.4°C
- The calculated and measured temperatures were judged to be in reasonable agreement

Temperatures in the heater rods in Step 4



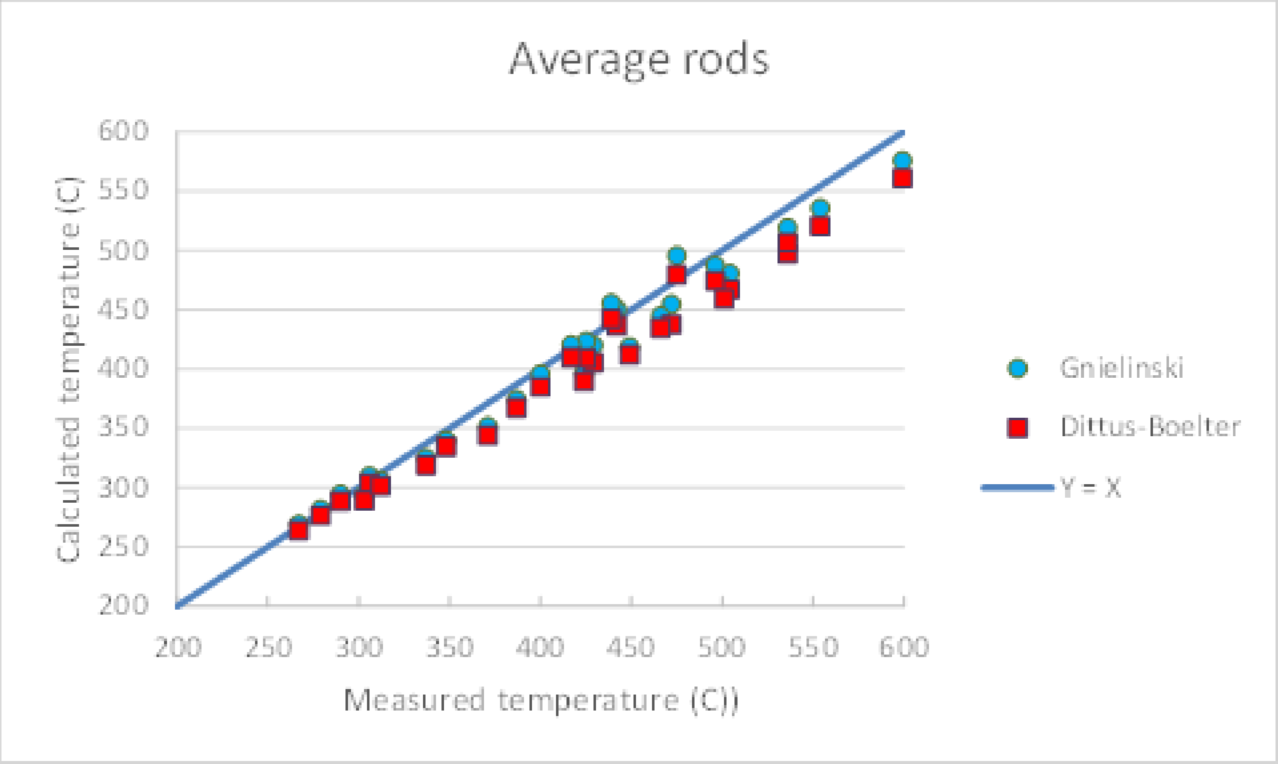
- Calculated temperatures are linear
- Measured temperatures are not as linear
- Measured temperatures in the hot rod sometimes decrease with elevation, which is completely unexpected for a supposedly uniform axial power profile

The overall agreement between calculated and measured heater rod temperatures is reasonably good



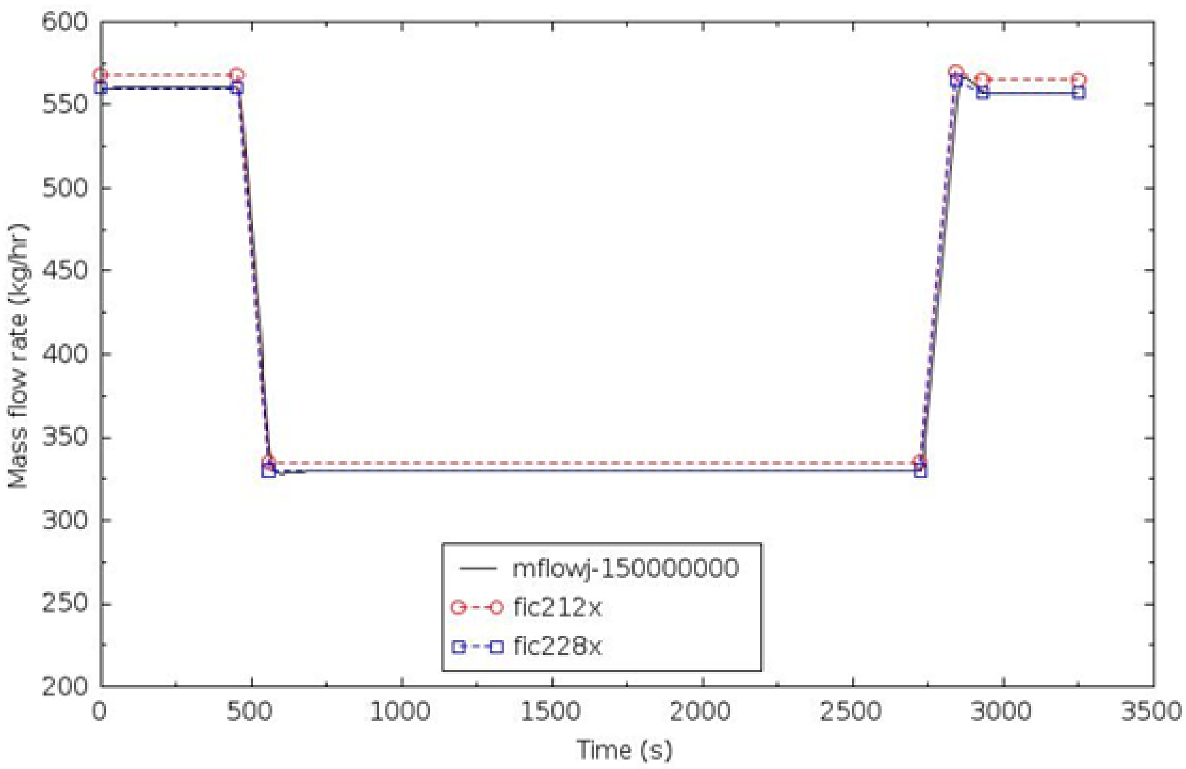
- On average, the calculated temperatures were 9.6°C too low for the average rods and 6.1°C too low for the hot rod

The Gnielinski heat-transfer correlation produced better results than Dittus-Boelter for the heater rods



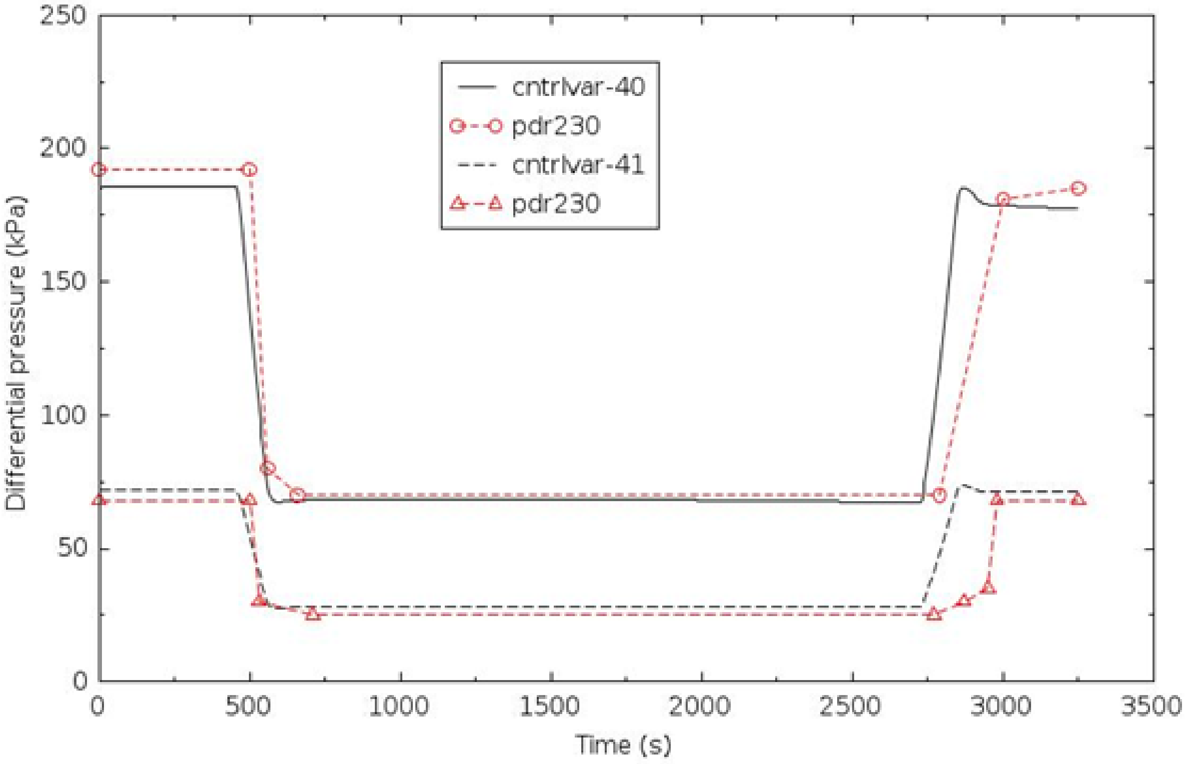
- On average, using Dittus-Boelter reduced the calculated temperatures by 10.1° C for the average rods and 21.5°C for the hot rod

Flow rates during the LOFA



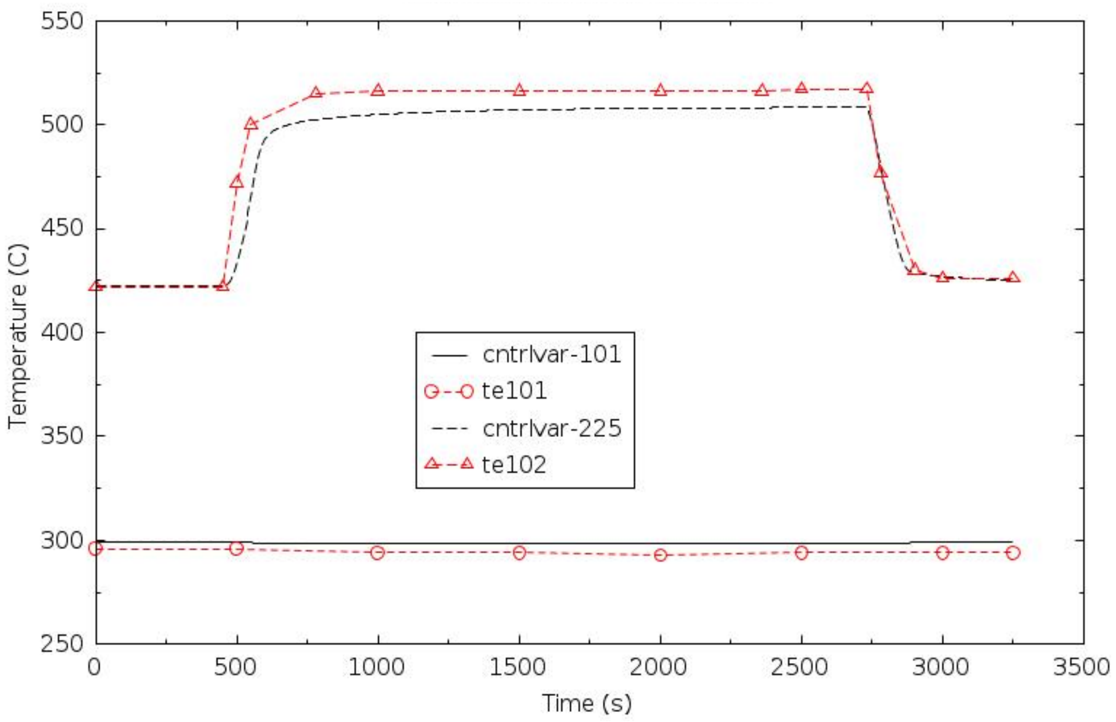
- The flow rate was held constant for about 450 s, then quickly reduced by about 40%, held constant for 2200 s, then quickly increased back to its initial value

Differential pressures during the LOFA



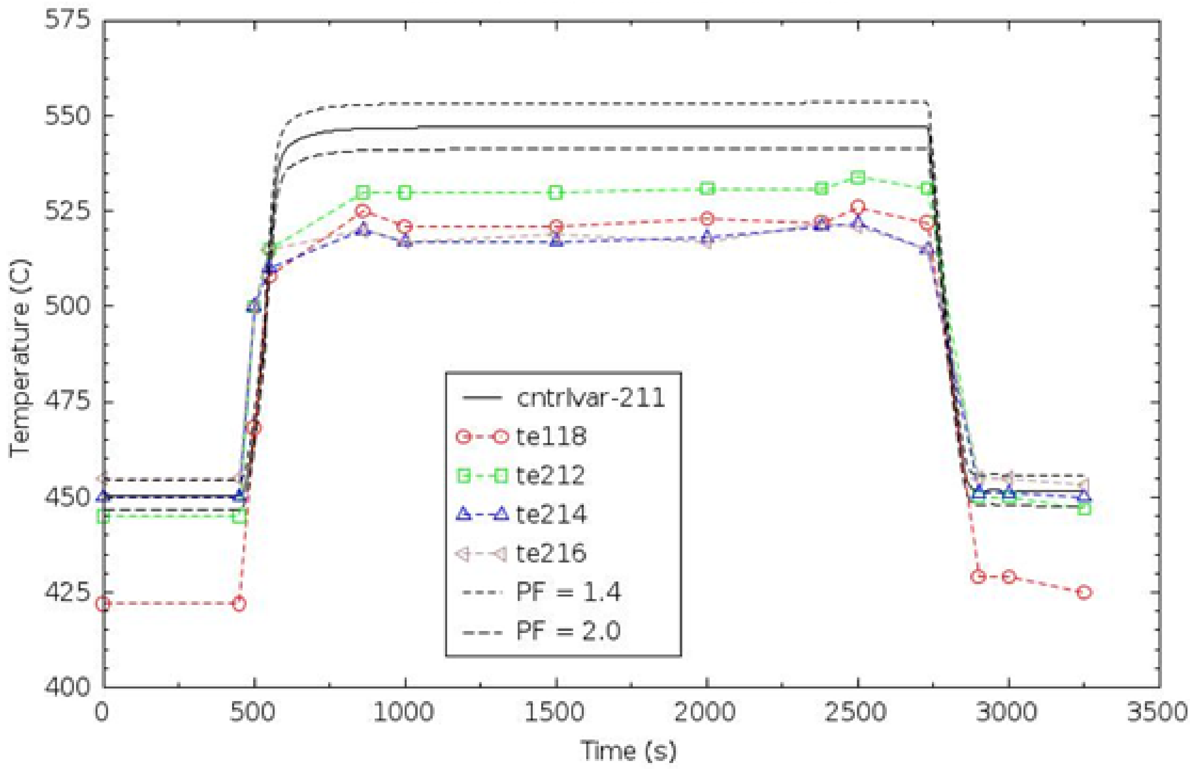
- Calculated results were generally in reasonable agreement with the measurements
- There is a noticeable delay in the response of the measurements around 2700 s

Test section fluid temperatures during the LOFA



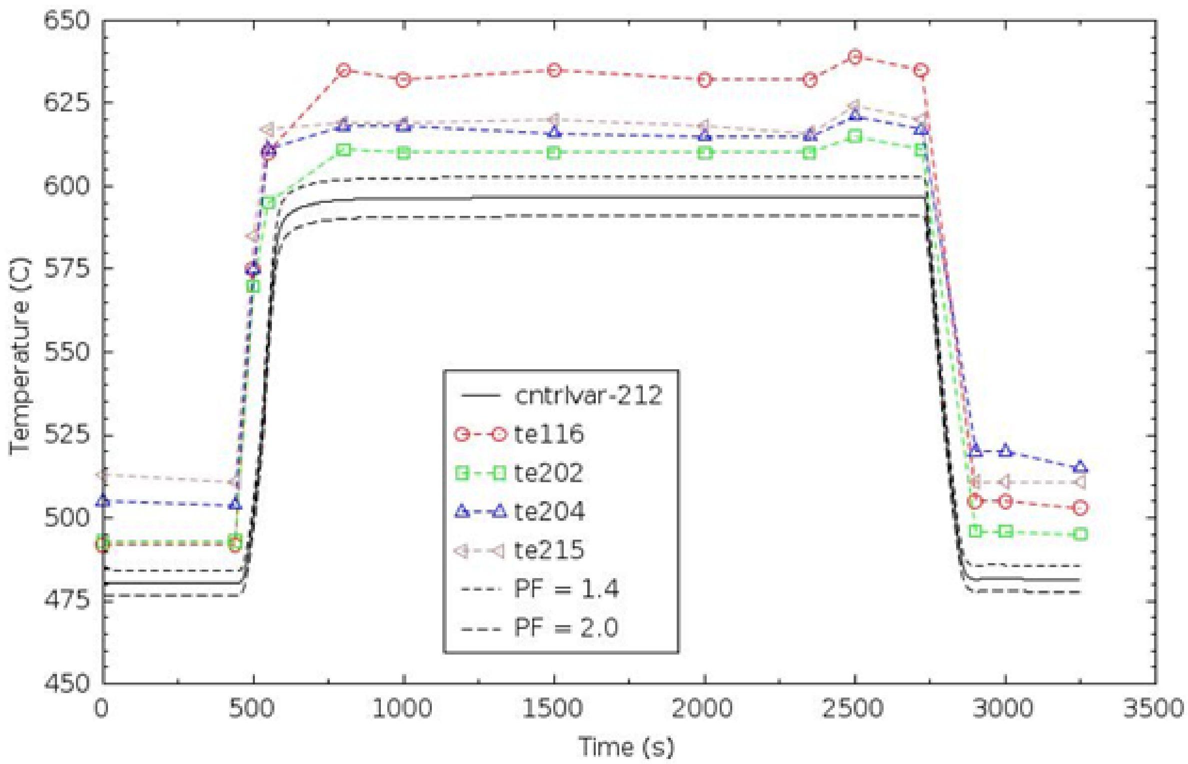
- Inlet temperature was nearly constant because of the action of the hot bypass valve
- Calculated results were judged to be in reasonable agreement with the measurements

Average-rod temperatures at 0.75 m during the LOFA



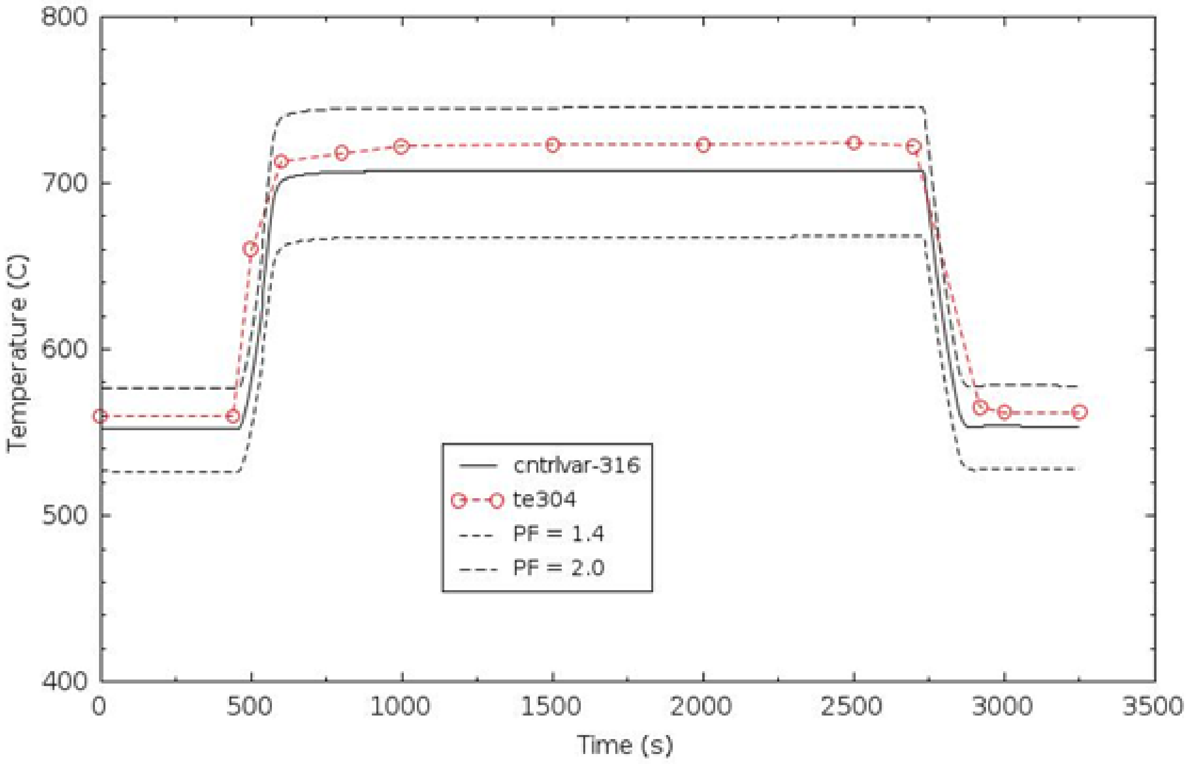
- Comparison between calculated and measured results showed trends similar to those observed at steady state
- Sometimes the calculated results were too high

Average-rod temperatures at 1.25 m during the LOFA



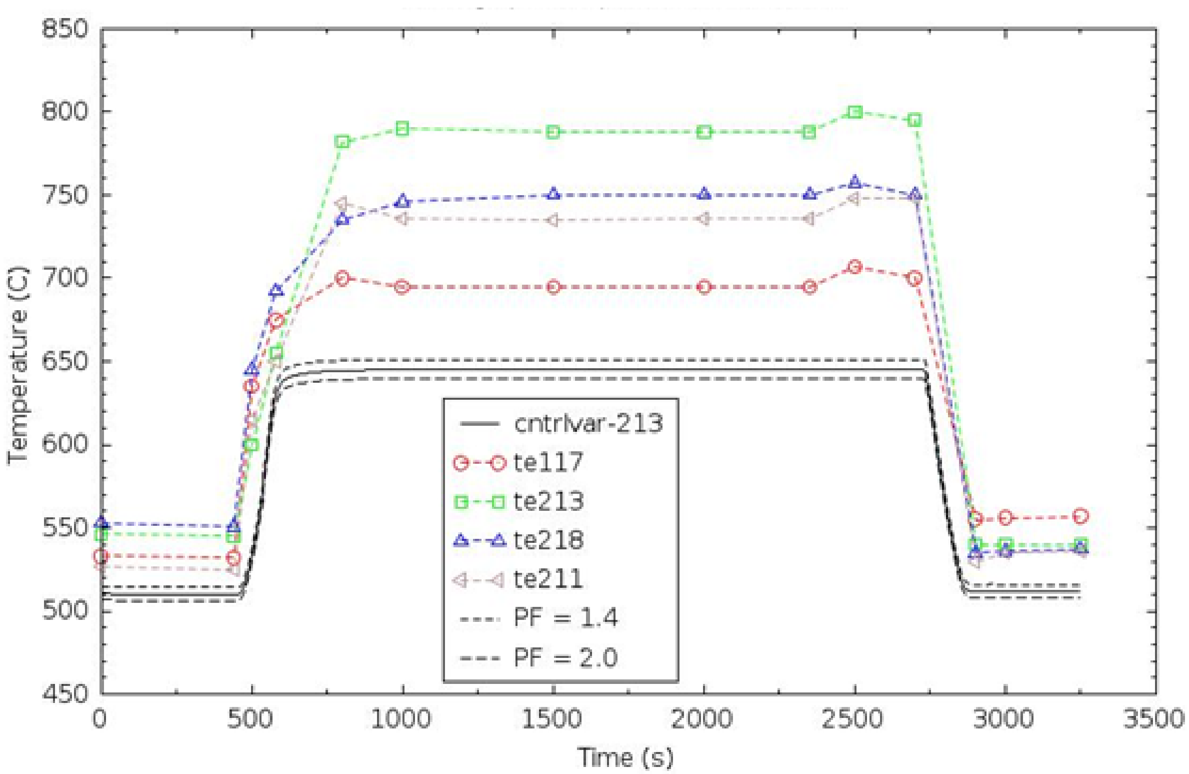
- Sometimes the calculated results were too low
- Calculated quasi-steady temperatures were not very sensitive to the assumed peaking factor in the hot rod

Hot-rod temperatures at 1.25 m during the LOFA



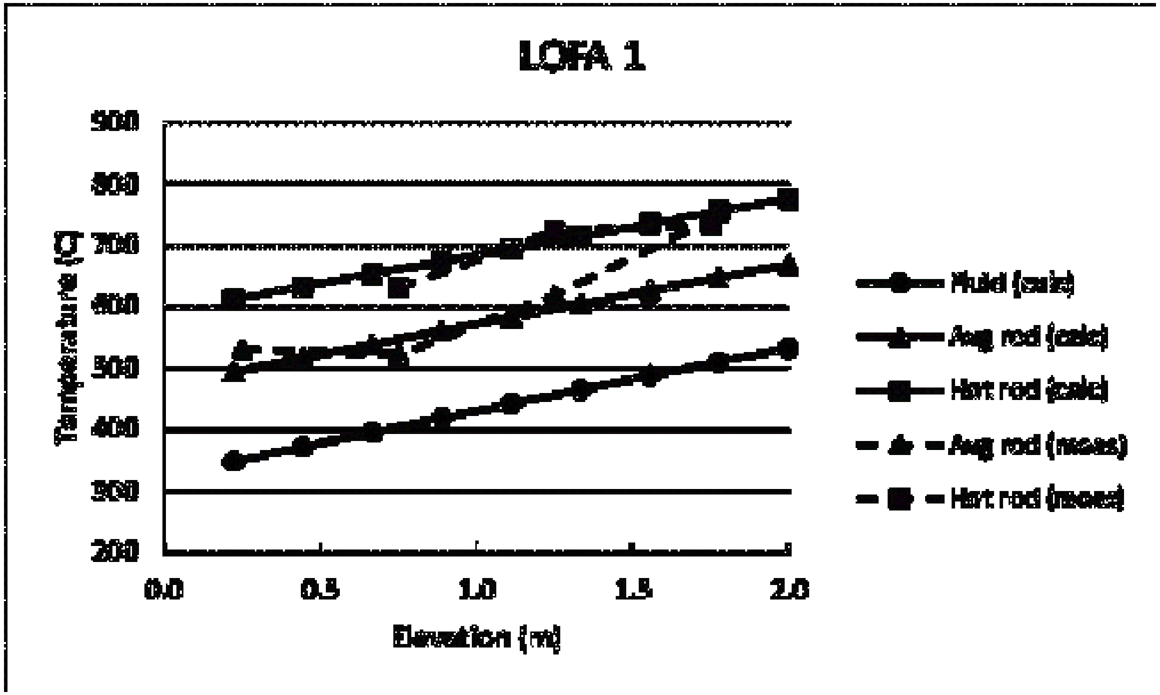
- Hot-rod temperatures were sensitive to the assumed peaking factor

Average-rod temperatures at 1.75 m during the LOFA



- Much worse results at 1.75 m, where the data indicate a severe heat transfer deterioration
- No physical mechanism for heat transfer deterioration could be identified from the literature
- Calculated heat transfer coefficient would have to be reduced by 40% to match these data, but was within 5%, on average, at lower elevations

Quasi-steady axial temperature profile at 2000 s during the LOFA



- Measured temperatures exhibit anomalous and, probably unphysical, behavior at 1.75 m
- The measured average of the average-rod temperatures exceeds the measured temperature of the hot rod

Conclusions

- RELAP5-3D and the HE-FUS3 input model demonstrated a broad capability to represent steady-state and LOFA phenomena associated with gas reactors
- Calculated results were judged to be in generally good agreement with the measurements for the steady-state tests
- The calculated heater-rod temperatures were consistently higher, and in better agreement with the data, when the Gnielinski heat transfer correlation was used rather than Dittus-Boelter
  - The use of Dittus-Boelter reduced the calculated temperatures by 10.1°C for the average rods and by 21.5°C for the hot rod

Conclusions (cont'd)

- The experiments used in the validation are not ideal for several reasons
  - The source of the data was a post-test analysis report, not a data report
    - Not all important information, such as the peaking factor of the hot rod and estimates of measurement uncertainty, were available
  - The facility lacked some important instrumentation, such as a fluid temperature measurement in the lower plenum and differential pressures across important components
  - The heater-rod temperature measurements are not suitable for a rigorous validation of heat transfer correlations because of the lack of a fluid-temperature measurement in the lower plenum and several anomalous behaviors