RELAP5-3D Developmental Assessment Update

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RELAP5 International Users Seminar

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www.inl.gov

Idaho National Laboratory

Developmental Assessment Overview

- Is documented as Volume III of the code manual
  - 2.4.2is version completed in December 2011
  - 4.0.3is version completed in September 2012
- Written from a user's perspective
  - Includes assessment judgments
- Has 53 assessment cases
  - 17 phenomenological problems
  - 27 separate effects experiments
  - 9 integral effects cases (8 experiments)
- Both semi- and nearly-implicit calculations performed for most cases
- Generally uses default code options
- Code manual is expected to be updated with each IRUG version release

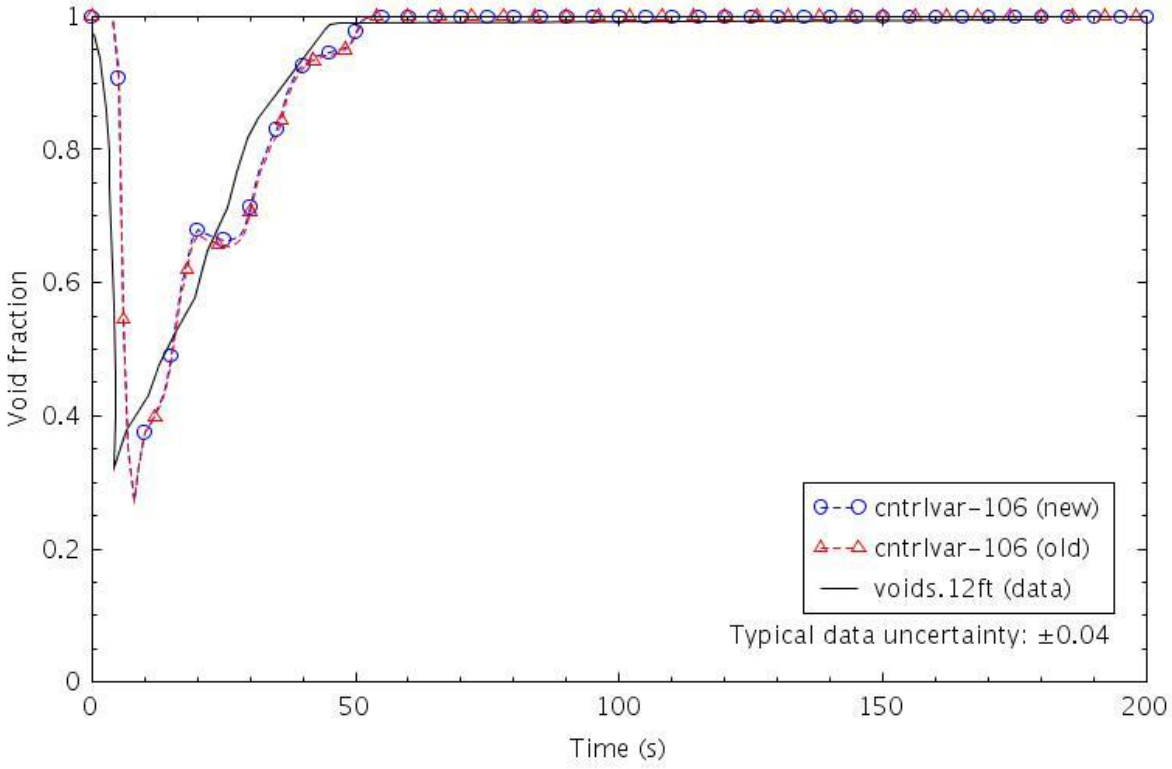
Developmental Assessment Comparison Report

- Compares results from current code version to previous version
- Semi-implicit calculations only
- Identifies which figures in the DA report have changed between versions
  - Noticeable differences
  - Significant differences
- Summarizes assessment judgment changes from Volume III
- Expected to be updated with each IRUG version release
- Report is available, though not on the RELAP5-3D home page

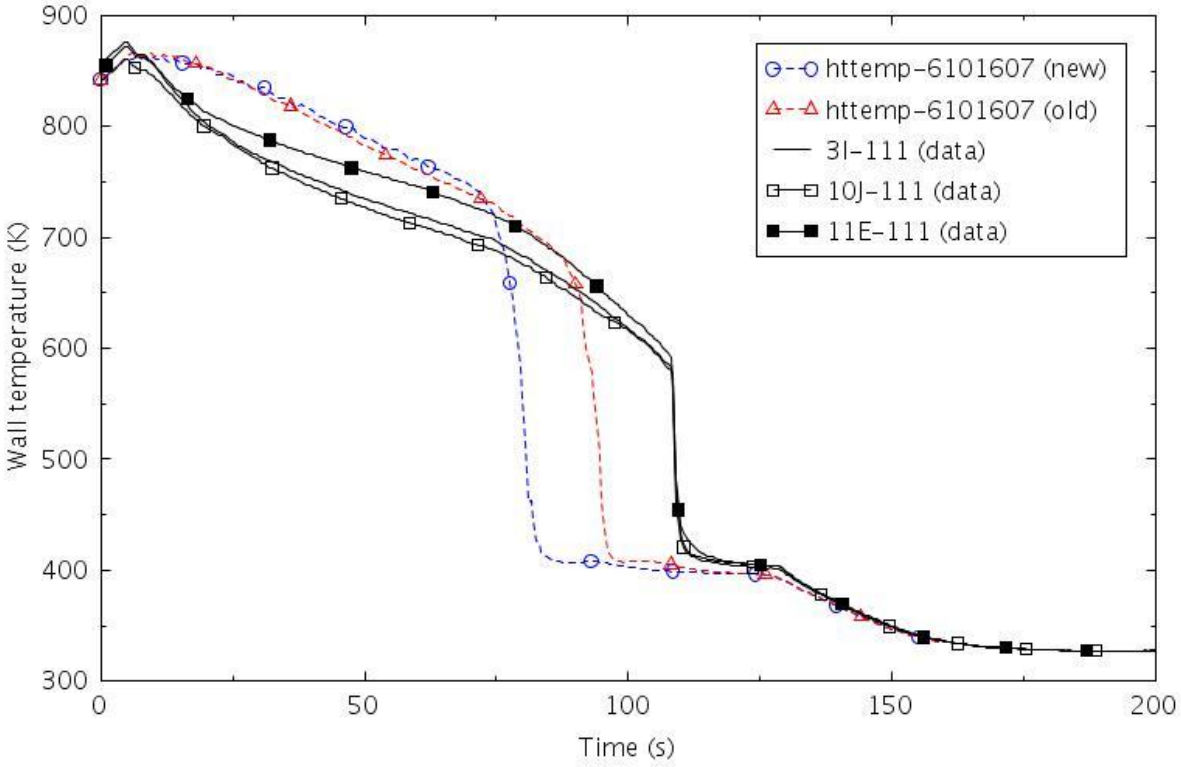
Comparison of Versions 4.0.3is and 2.4.2is

- Large number of changes (6 years between releases)
- 19 significant differences in 9 cases
- 194 noticeable differences in 27 cases
- No differences in 23 cases
- Nine assessment judgments changed in nine cases
  - Four improved
  - Five worsened
- Two calculation run failures (water over steam 3-D, LOFT L2-5 3-D)
- Nearly-implicit results more like semi-implicit than before

What is a noticeable difference?



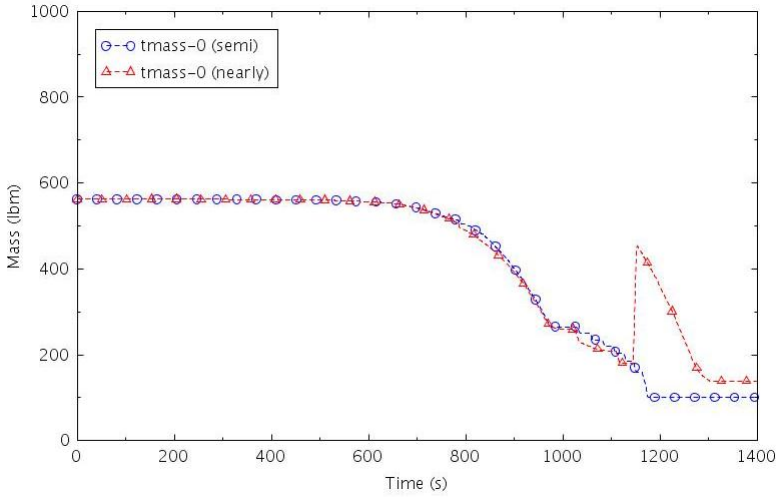
What is a significant difference?



Bubbling Steam Through Liquid (nearly-implicit)

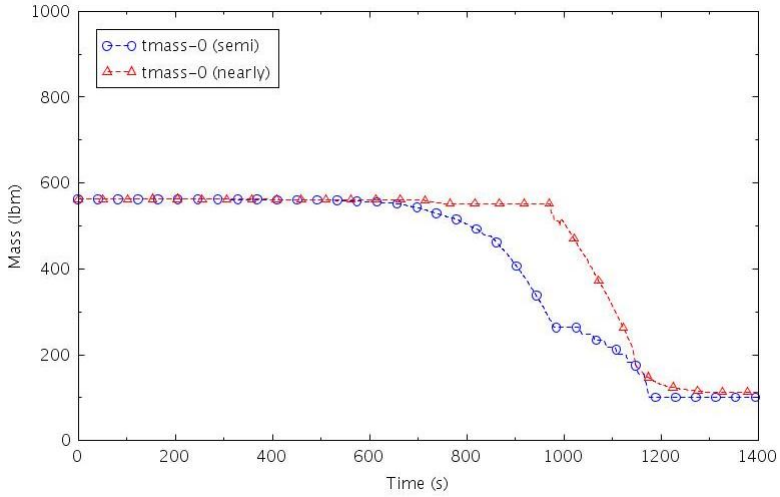
Total System Mass

Version 4.0.3is



Insufficient

Version 2.4.2is

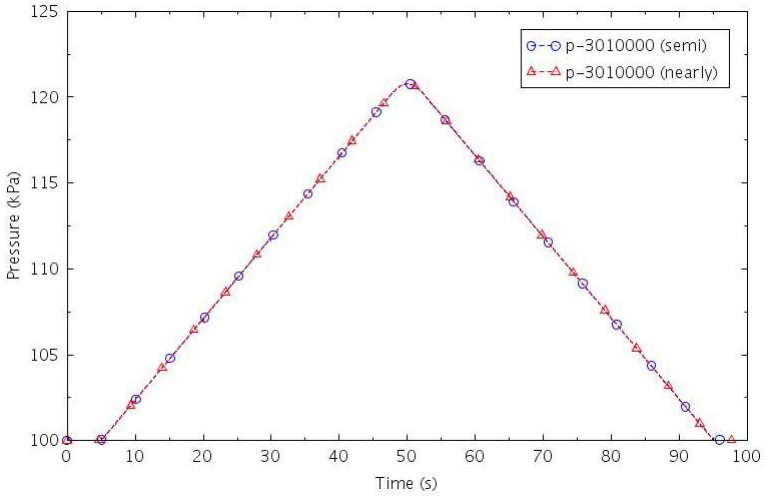


Minimal

Fill-Drain (nearly-implicit)

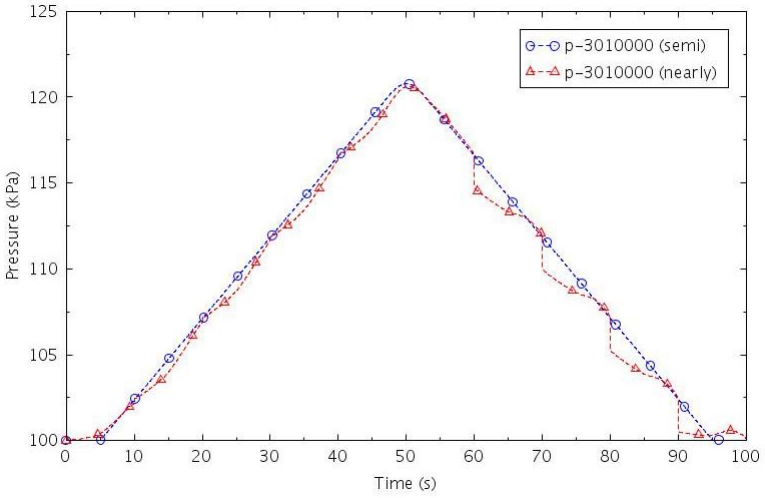
Bottom Volume Pressure

Version 4.0.3is



Excellent

Version 2.4.2is

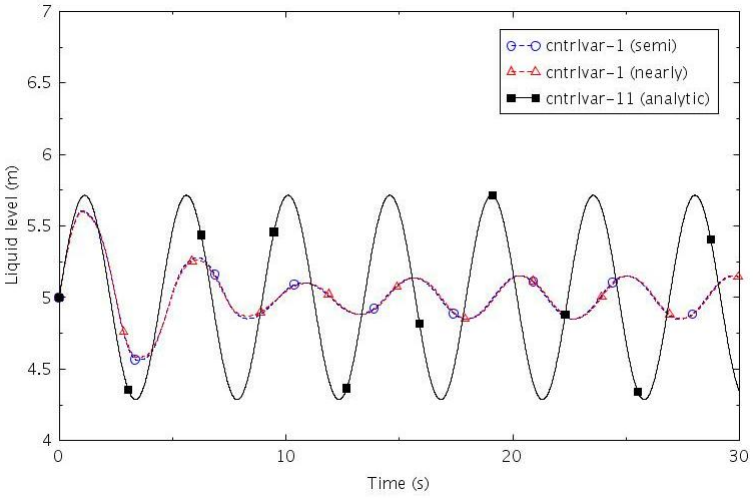


Reasonable

Manometer (no level tracking, nearly-implicit)

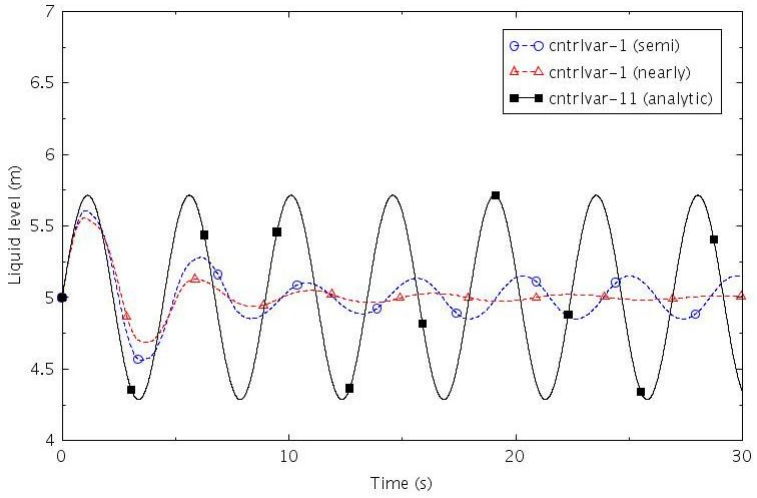
Liquid Level

Version 4.0.3is



Excellent

Version 2.4.2is

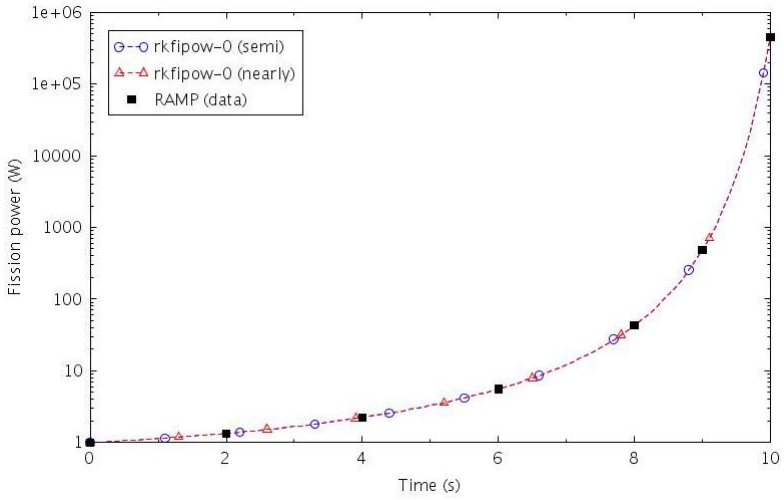


Insufficient

Point Kinetics Ramp (small time step)

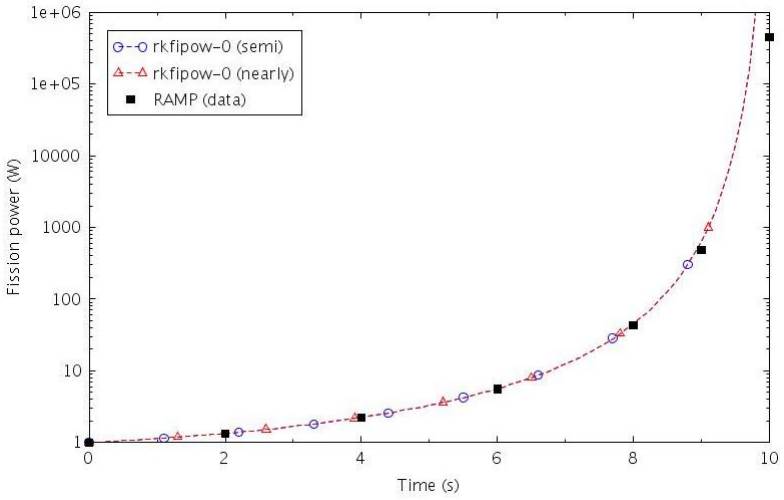
Fission Power

Version 4.0.3is



Excellent

Version 2.4.2is

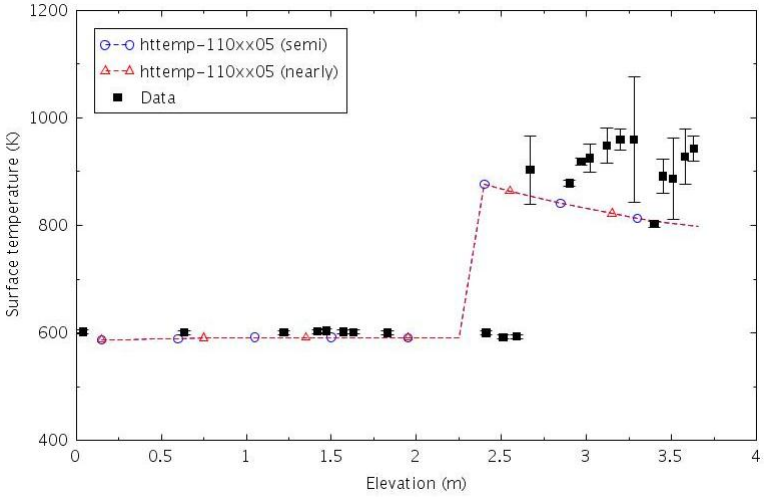


Insufficient

ORNL THTF Test 3.07.9N

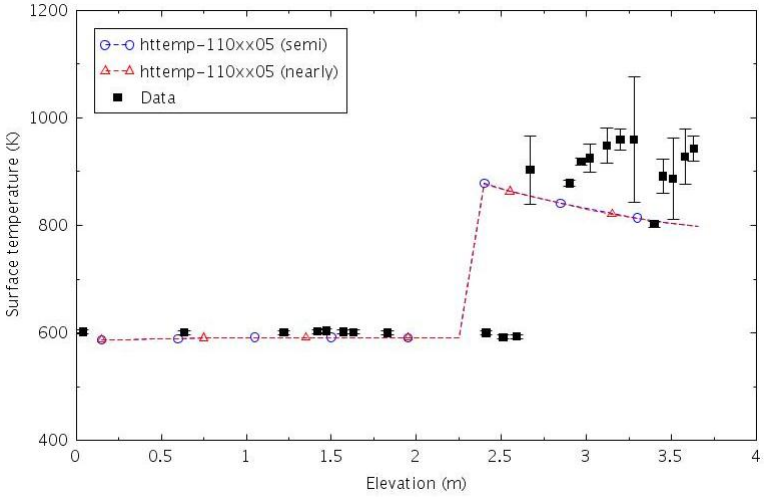
Heater Rod Surface Temperature

Version 4.0.3is



Minimal

Version 2.4.2is

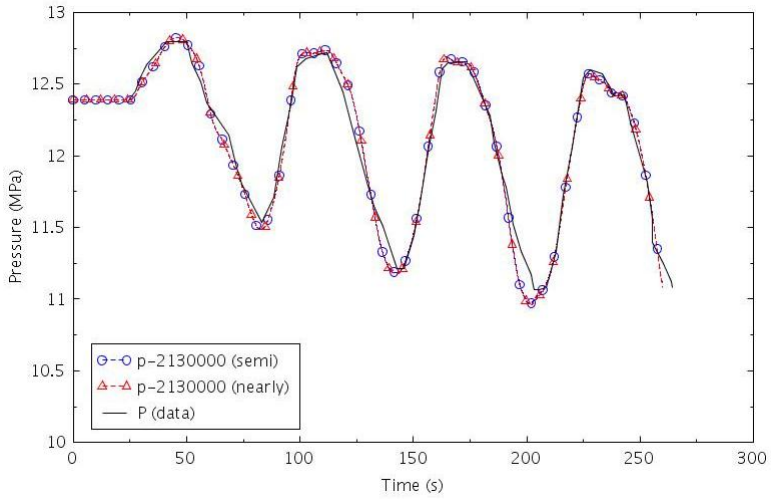


Reasonable

Neptunus Test Y05

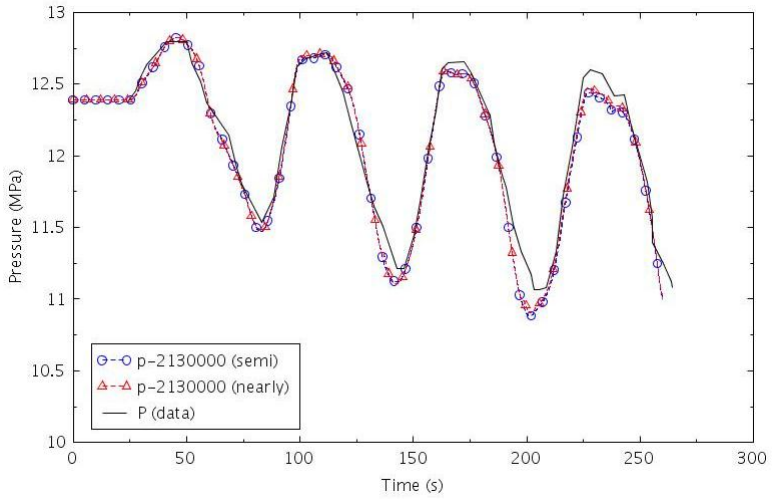
Dome Pressure

Version 4.0.3is



Excellent

Version 2.4.2is

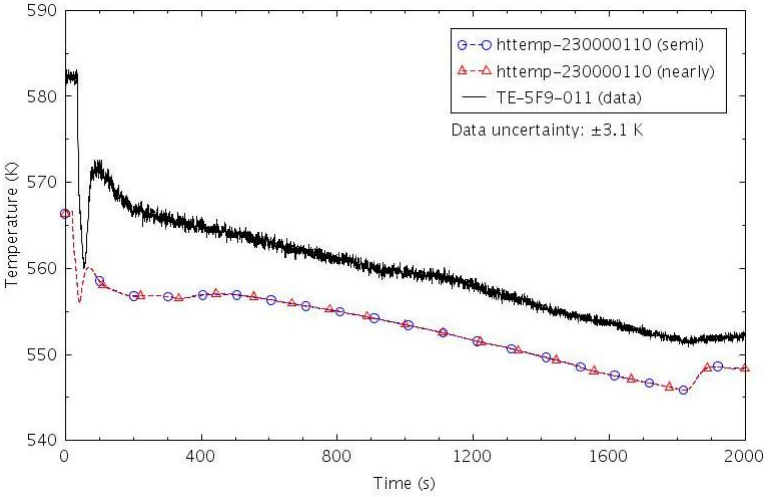


Reasonable

LOFT Experiment L3-7

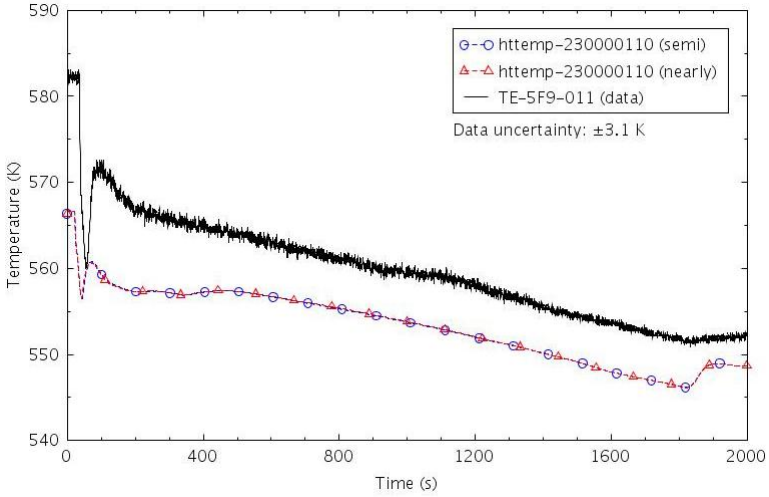
Lower Core Fuel Cladding Surface Temperature

Version 4.0.3is



Minimal

Version 2.4.2is

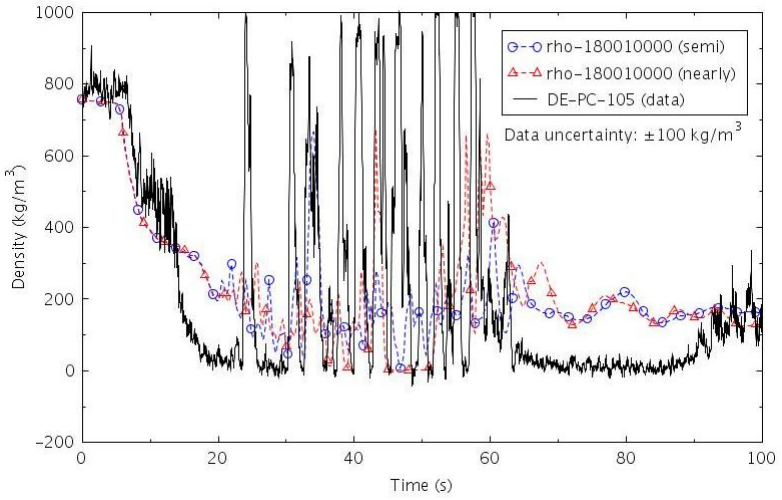


Reasonable

LOFT Experiment L2-5, 1-D (nearly-implicit)

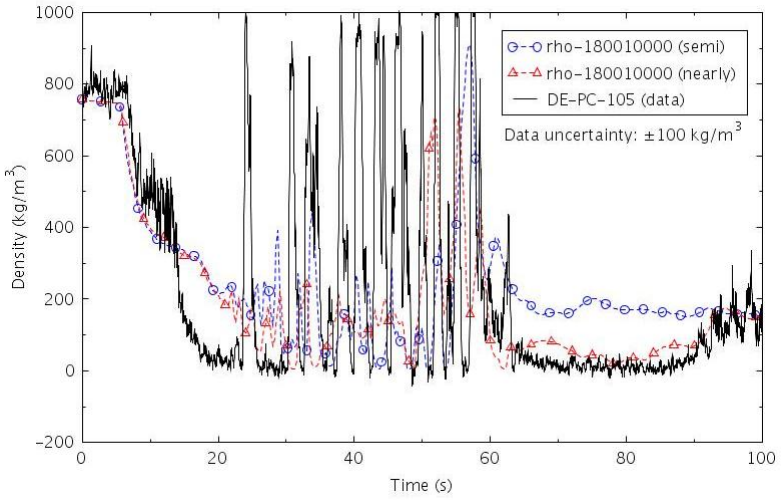
Intact Loop Cold Leg Density

Version 4.0.3is



Minimal

Version 2.4.2is

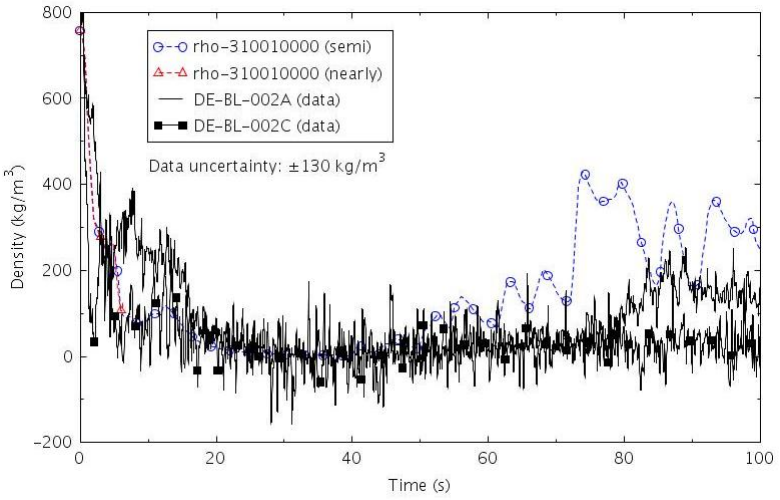


Reasonable

LOFT Experiment L2-5, 3-D

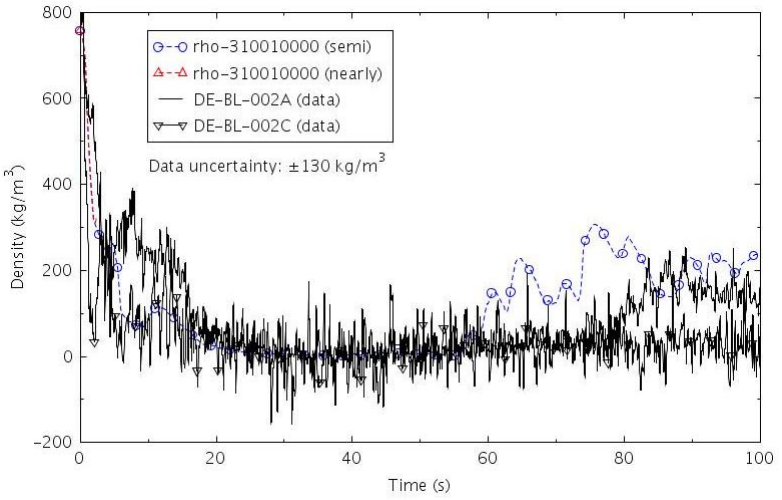
Broken Loop Hot Leg Density

Version 4.0.3is



Minimal

Version 2.4.2is



Reasonable

Current Findings
Version 4.0.3is

Phenomenological Test Cases (1)

Case	Finding
Bubbling steam through liquid	Reasonable/Insufficient
Conduction enclosure steady state	Excellent
Conduction enclosure 1-D transient	Excellent
Conduction enclosure 2-D transient	Excellent
1979 ANS-5.1 decay heat	Excellent
Fill/drain	Excellent
Gravity wave 1-D	Reasonable
Gravity wave 3-D	Reasonable

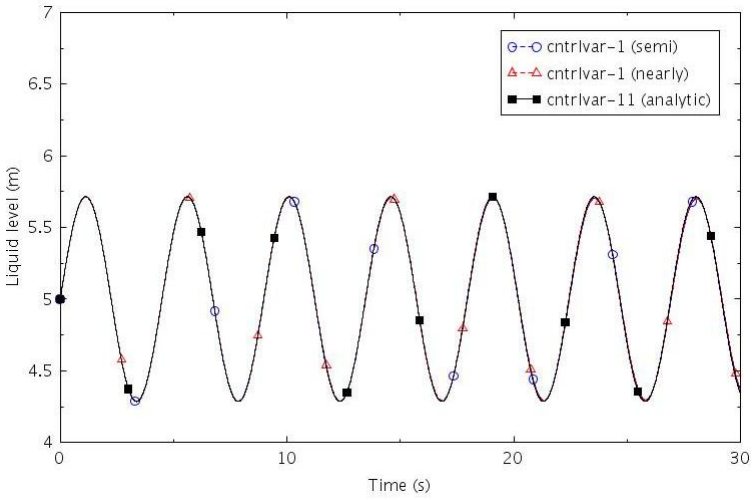
Phenomenological Test Cases (2)

Case	Finding
Manometer	Excellent
Point kinetics ramp	Excellent
Pryor pressure	Reasonable
Pure radial flow	Excellent
Rigid body rotation	Excellent/Minimal
R-theta symmetric flow	Excellent/Minimal
Water faucet	Excellent
Water over steam 1-D	Reasonable
Water over steam 3-D	Reasonable/Insufficient

Manometer Problem

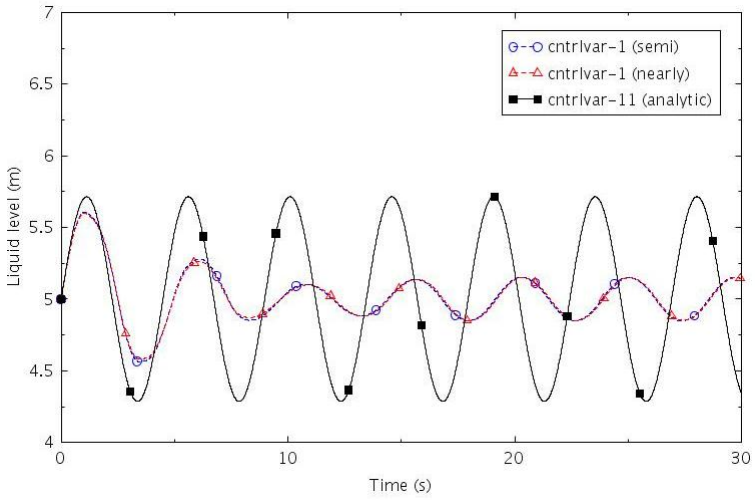
Liquid Level

With mixture level tracking



Excellent

Without mixture level tracking

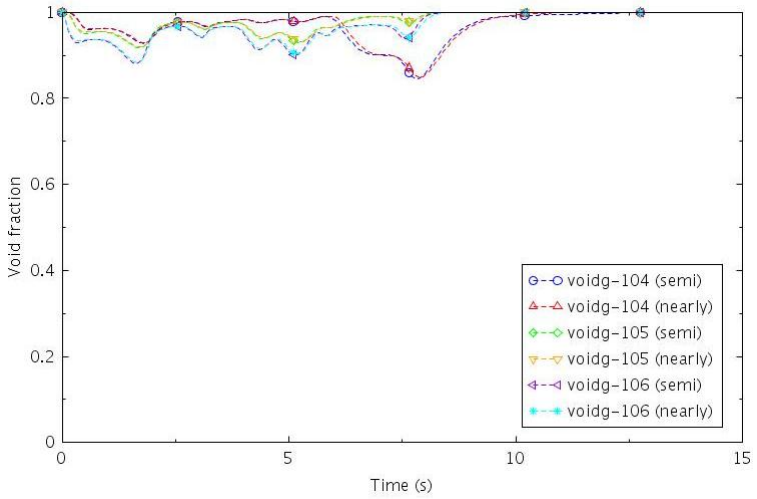


Minimal

Water Over Steam Problem

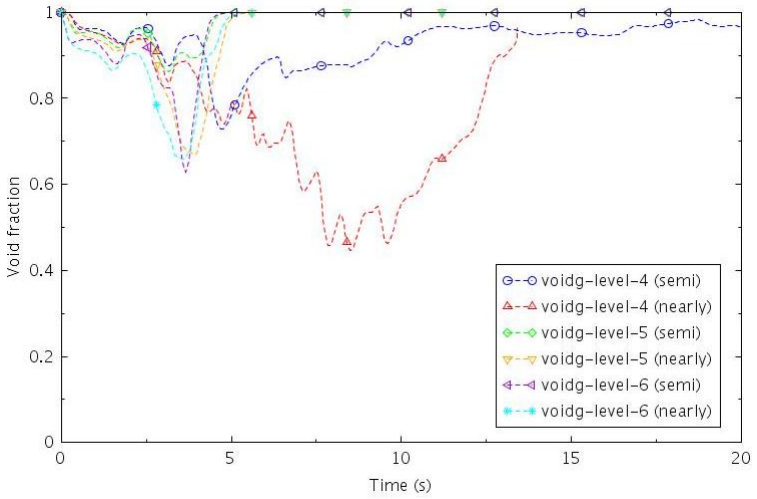
Void Fractions in Volumes 4-6 (of 9)

1-D model



Reasonable

3-D model



Minimal (nearly-implicit)

Separate Effects Test Results (1)

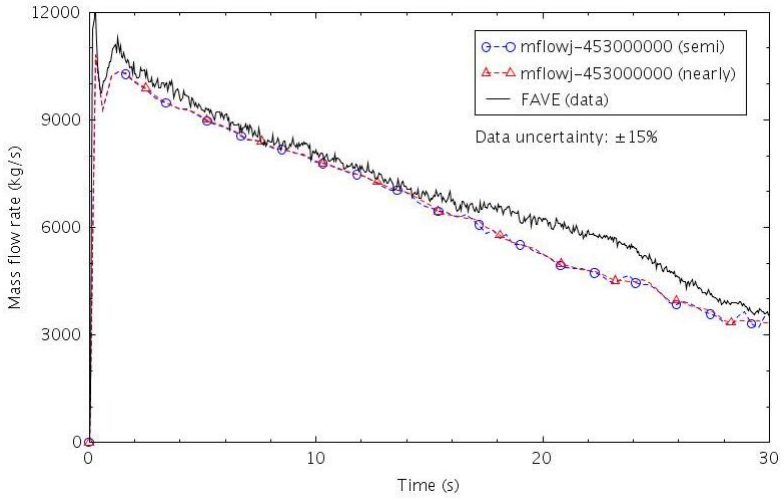
Phenomenon	Finding
Critical flow	Excellent (1) Reasonable (4) Minimal (1)
Two-phase level/void distribution	Excellent (2) Reasonable (2)
Critical heat flux	Reasonable (7)
Reflood	Reasonable (2)
CCFL	Reasonable (2)
Pressurizer behavior	Excellent (1) Reasonable (1)

Separate Effects Test Results (2)

Phenomenon	Finding
Steam generator steady state	Reasonable (1)
Accumulator response	Excellent (1)
Two-phase pump behavior	Reasonable (1)
Jet pump flow	Reasonable (1)
Film boiling heat transfer coefficient	Reasonable (1) Minimal (2)

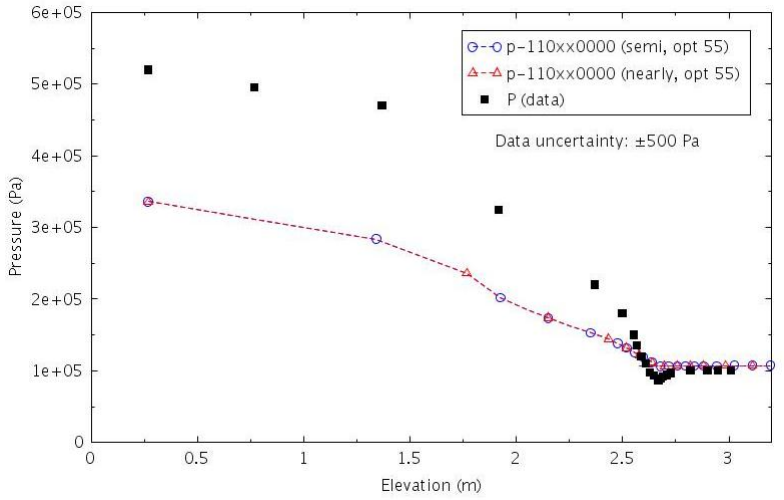
Critical Flow Problems

Marviken CFT-21
Subcooled and saturated
Mass flow rate



Reasonable

Moby-Dick
Two-phase, two-component
Axial pressure distribution

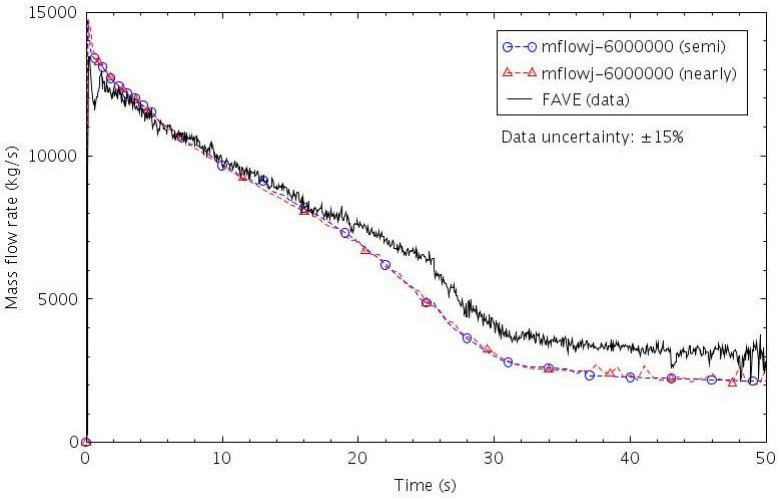


Minimal

Critical Flow Problems

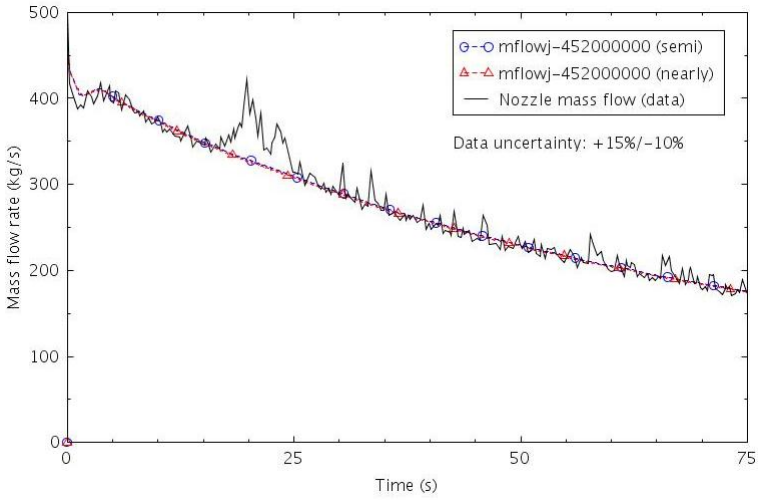
Mass Flow Rate

Marviken CFT-22 (subcooled)



Reasonable

Marviken JIT-11 (saturated vapor)

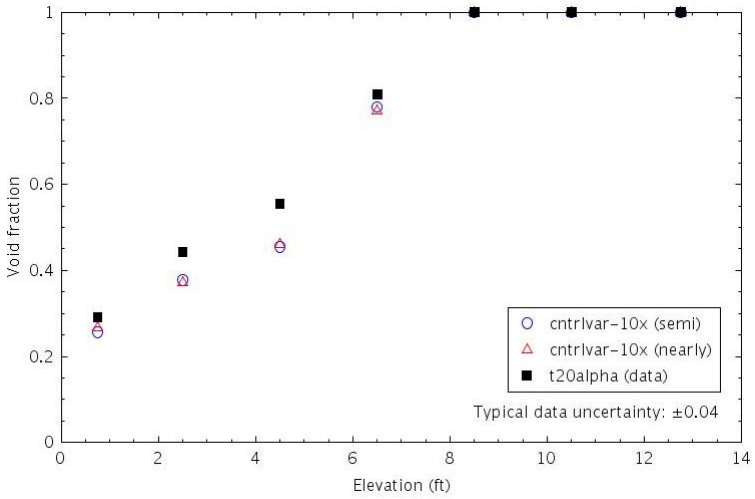


Excellent

Two-Phase Level and Void Distribution

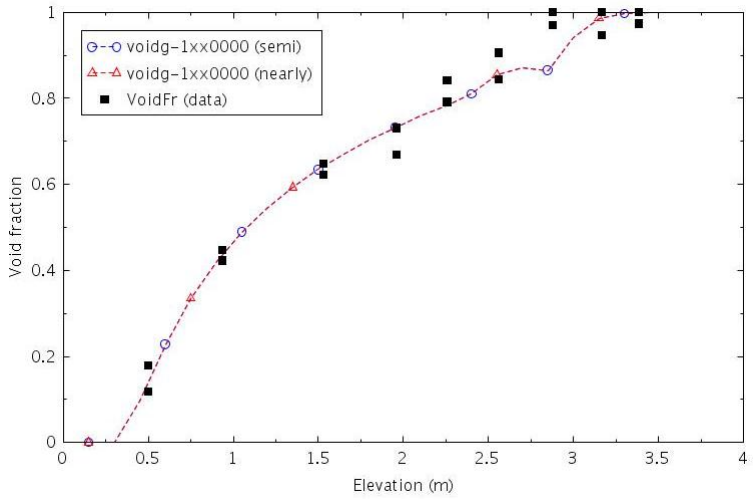
Axial Void Fraction Profile

GE 4-ft. level swell (at 20 s)



Reasonable

ORNL THTF Test 3.09.10I

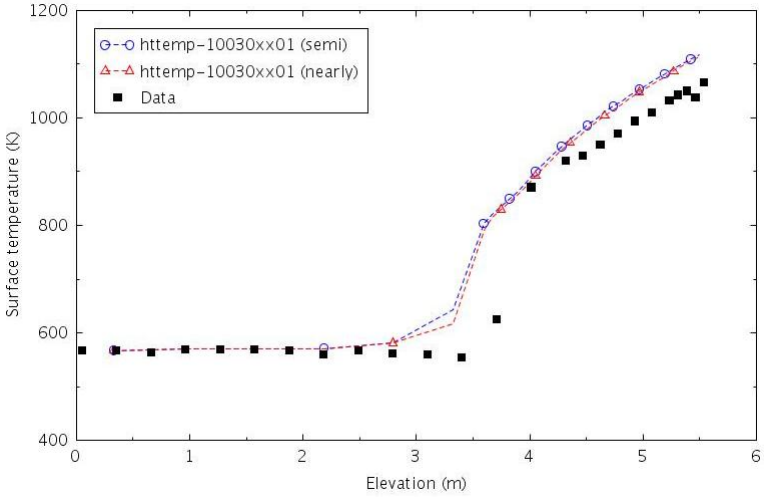


Excellent

Critical Heat Flux

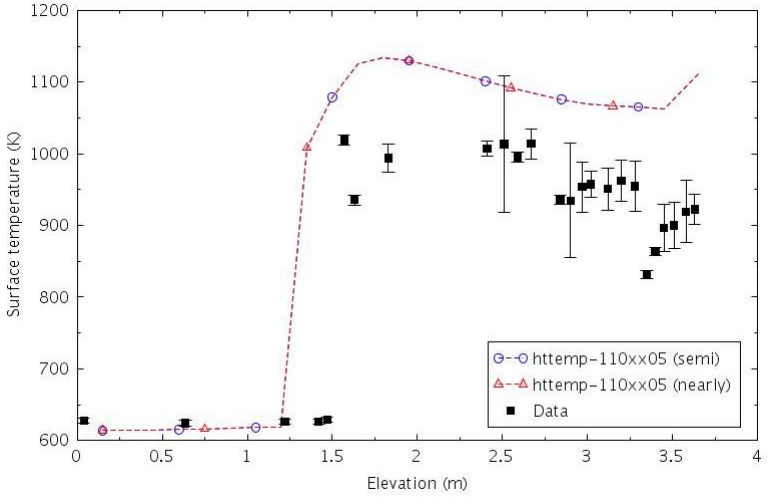
Axial Wall Temperature Distribution

Bennett Test 5358



Reasonable

ORNL THTF Test 3.07.9B

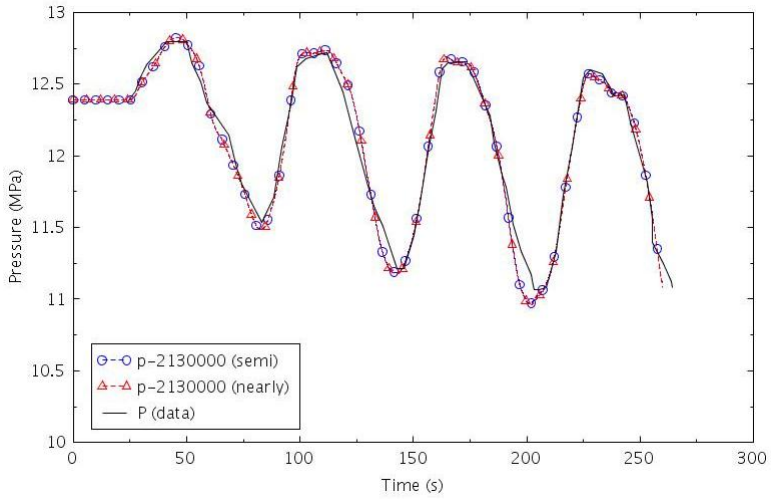


Reasonable/Minimal

Pressurizer Behavior

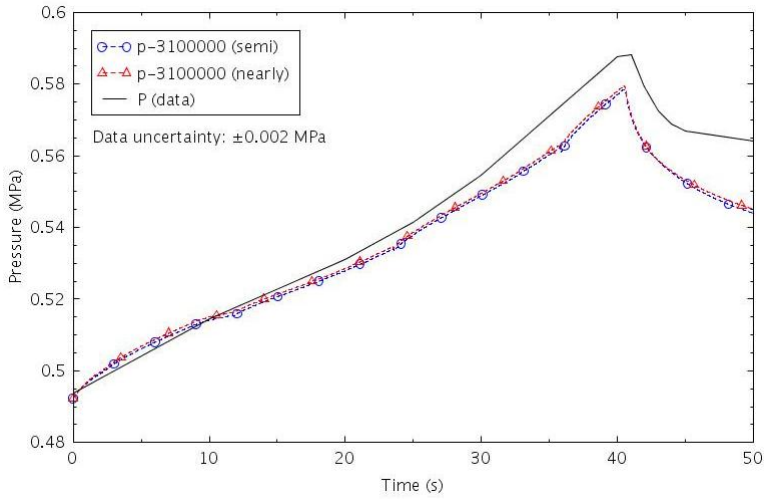
Steam Dome Pressure

Neptunus Test Y05



Excellent

MIT Test ST4



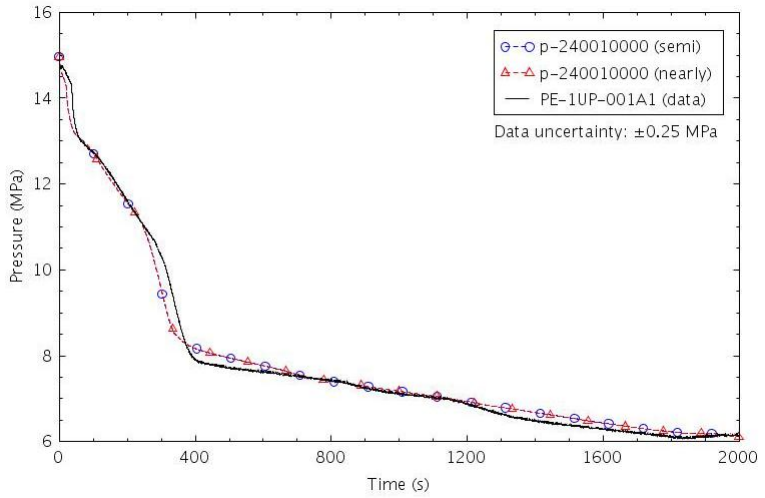
Reasonable

LOFT L3-7 1-in. Cold Leg Break

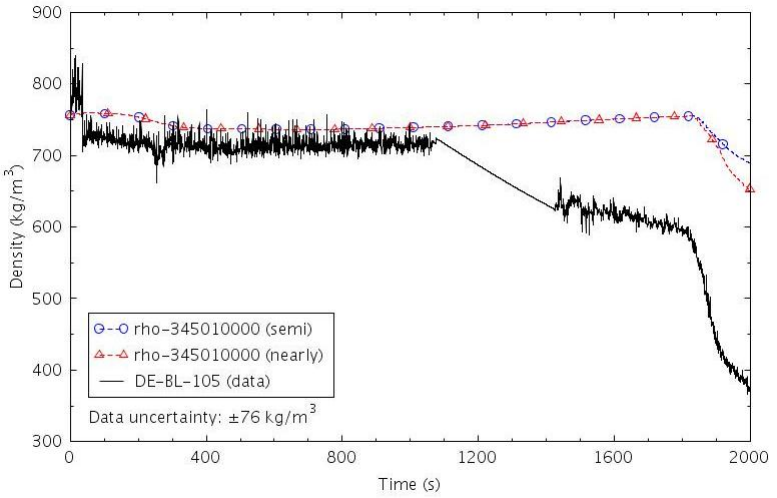
- Most phenomena simulated well
  - Primary coolant system pressure
  - Pressurizer level
  - Temperatures for first 1200 s
  - ECC flow
- Break flow was not well simulated after 400 s
  - Consequent difficulties with cold leg densities, coolant temperatures after 1200 s

LOFT L3-7 SBLOCA

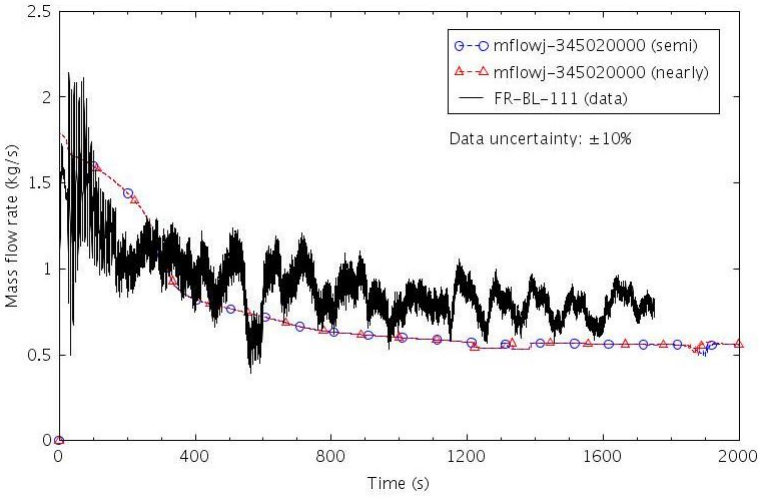
Pressurizer pressure



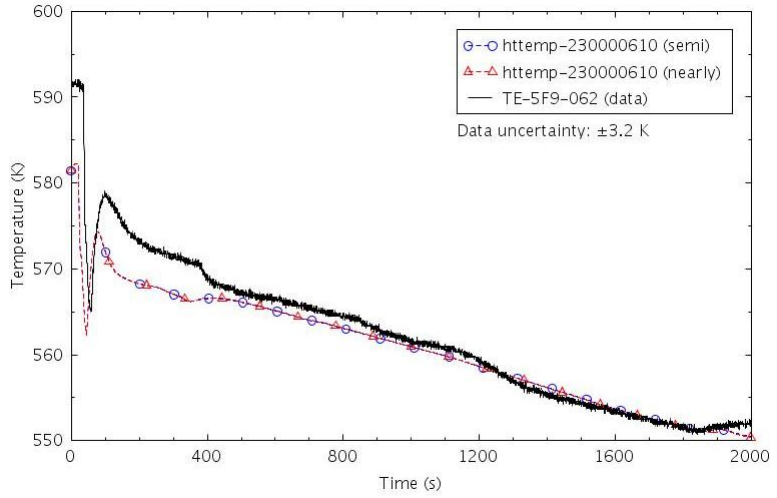
Broken loop cold leg density



Break mass flow rate



Upper core fuel cladding temperature

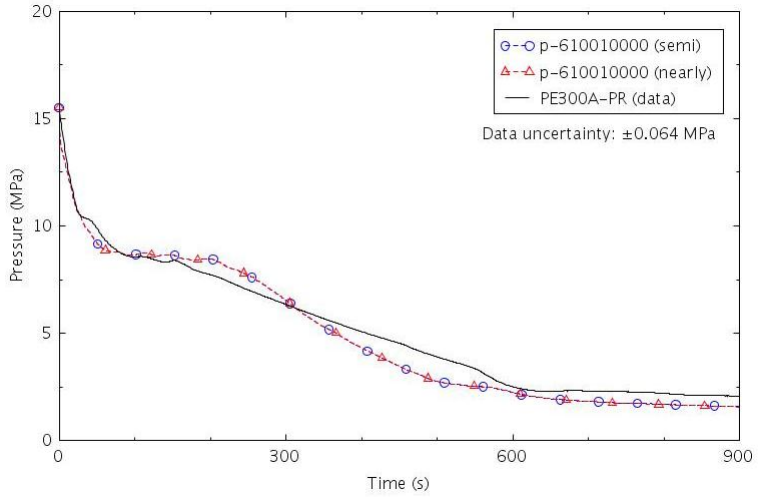


ROSA SB-CL-18 5% Cold Leg Break

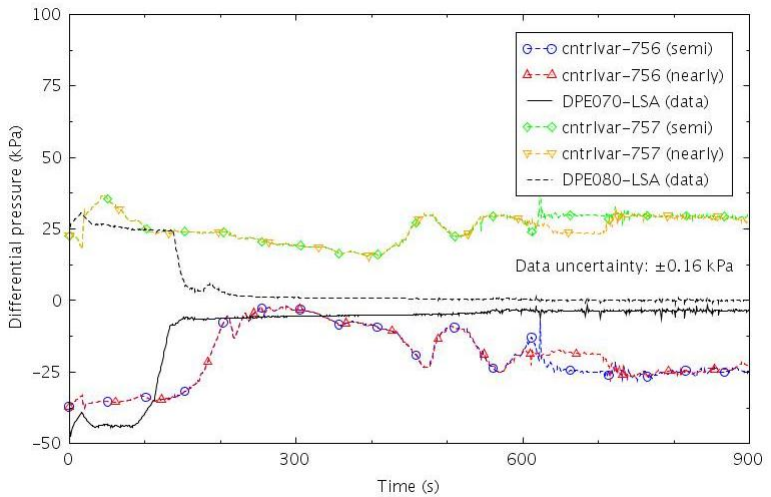
- Most parameters simulated well
  - Primary and secondary system pressures
  - Loop flow rates
  - Accumulator flow rates
  - Lower core temperatures
- Primary problem was not clearing one loop seal
  - Loop densities not well predicted
  - Core level under predicted
  - Length of core uncovering over predicted

ROSA SB-CL-18 SBLOCA

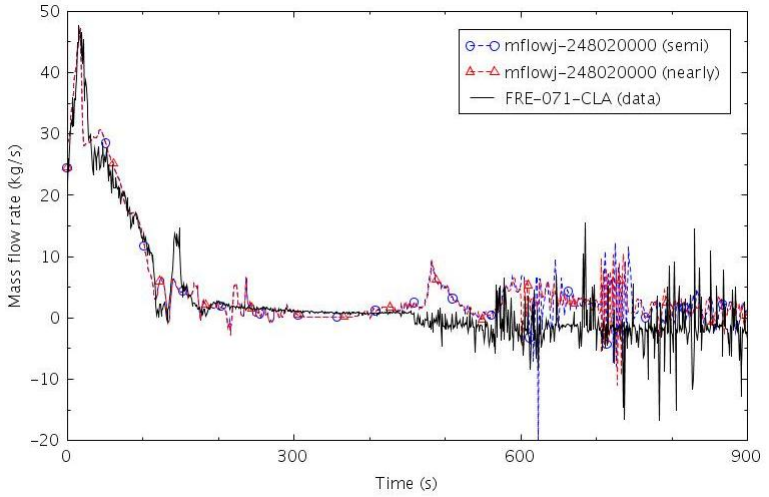
Pressurizer pressure



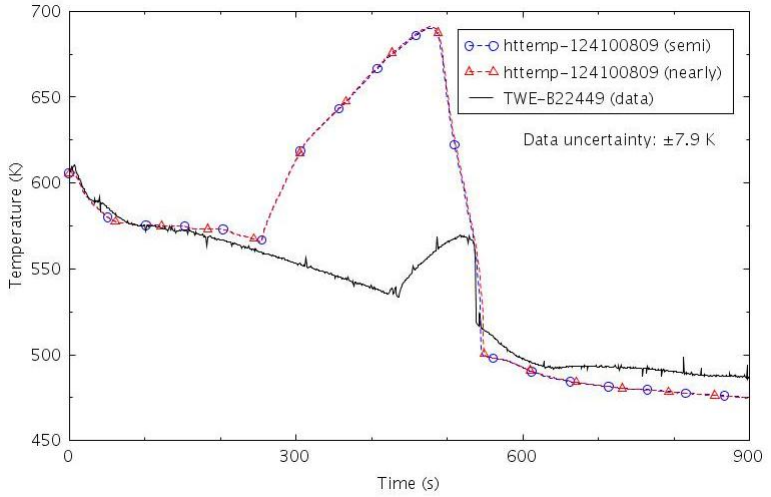
Loop seal A differential pressure



Intact loop cold leg mass flow rate



Upper core heater rod surface temperature

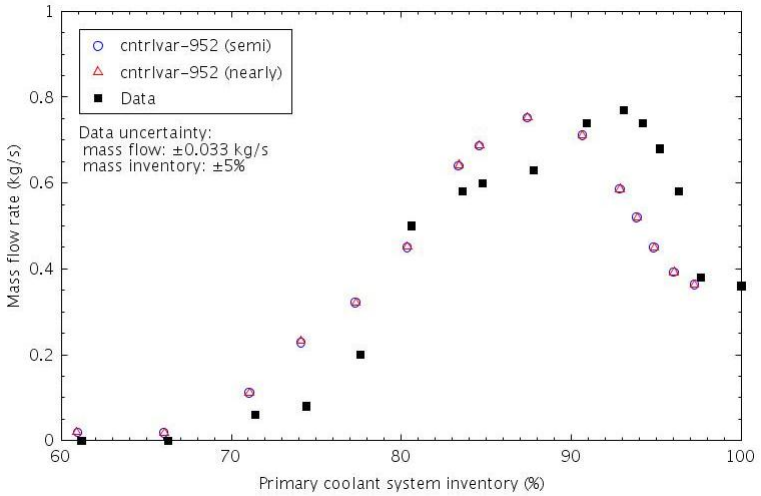


Semiscale Natural Circulation Tests

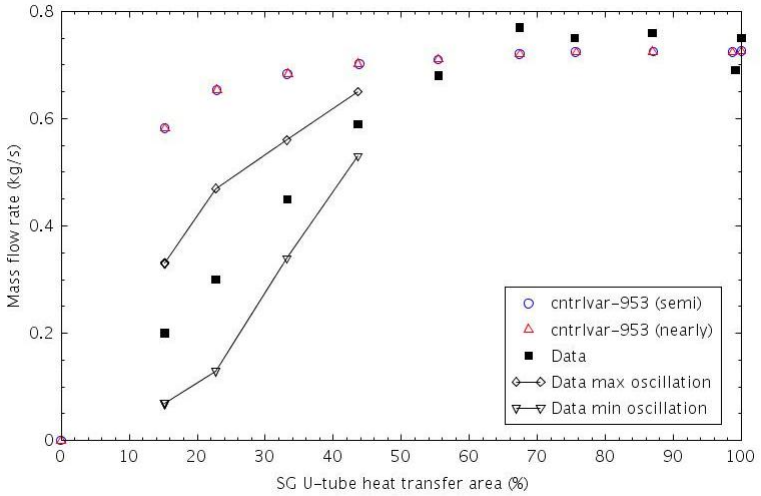
- Single-phase predictions excellent
- Two-phase calculations reasonable at high and intermediate powers, minimal at low power
- Reflux condenser mode predicted reasonably at high power and system inventory less than 67%
- Flow rates well predicted with steam generator heat transfer area >50%, over predicted with lower effective surface areas

Semiscale Natural Circulation Tests

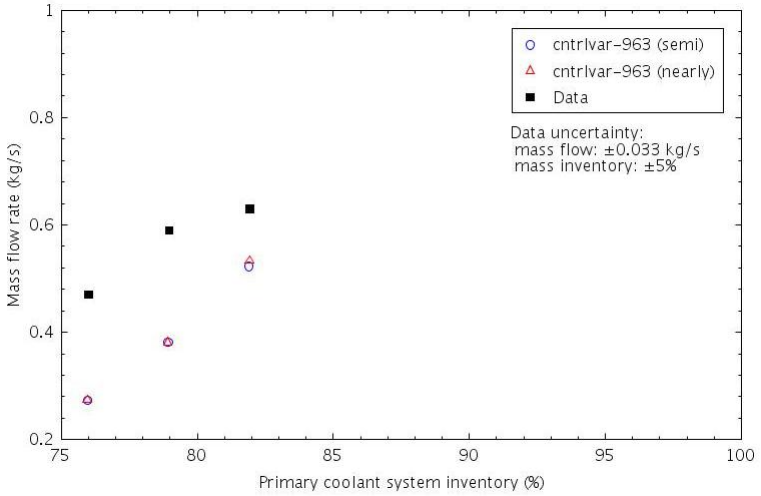
Test S-NC-2 mass flow rate



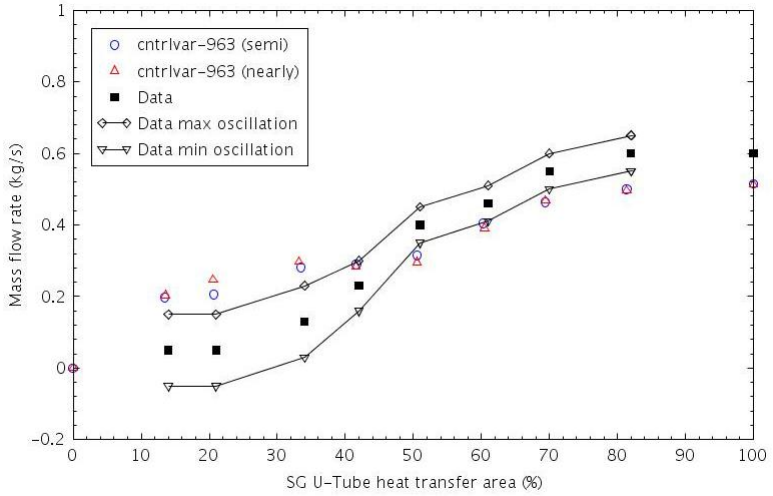
Test S-NC-3 mass flow rate



Test S-NC-10 Part 4 mass flow rate



Test S-NC-10 Part 3 mass flow rate

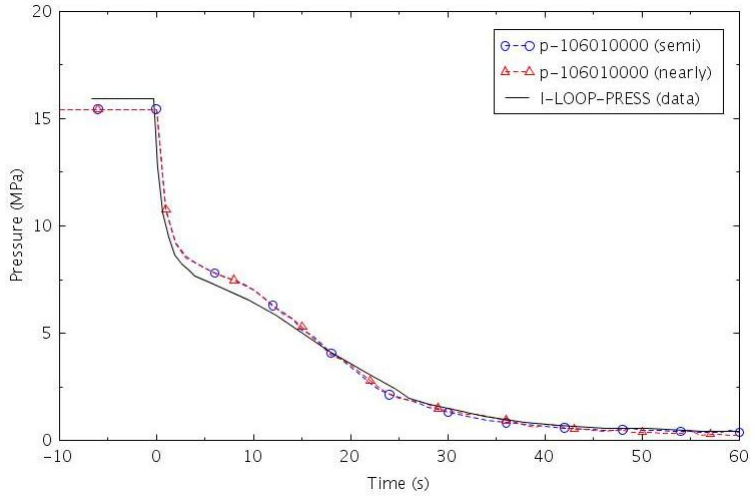


LOBI Test A1-04R LBLOCA

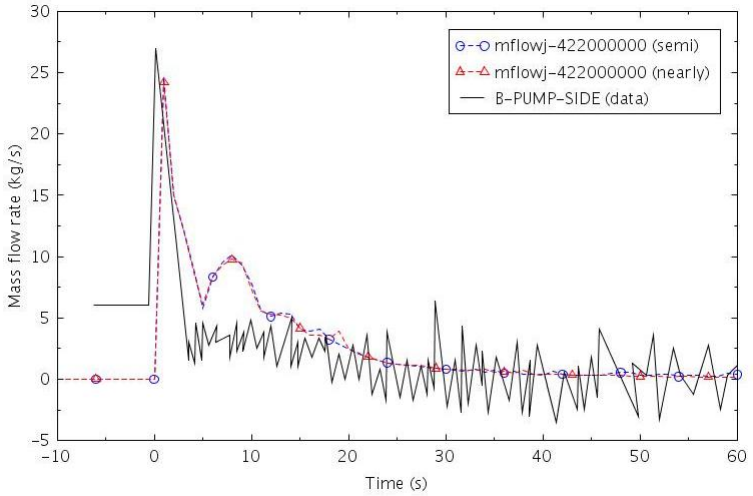
- Excellent agreement for
  - Primary system pressure
  - Core differential pressure
  - Heater rod temperatures in lower core in nucleate boiling region
- Reasonable agreement for
  - Loop mass flow
  - Fluid conditions at the accumulator injection location
  - Heater rod temperatures in lower core
  - Heater rod temperatures in upper core early in transient
- Minimal agreement for heater rod temperatures in upper core in after the initial heatup and rewet

LOBI A1-04R LBLOCA

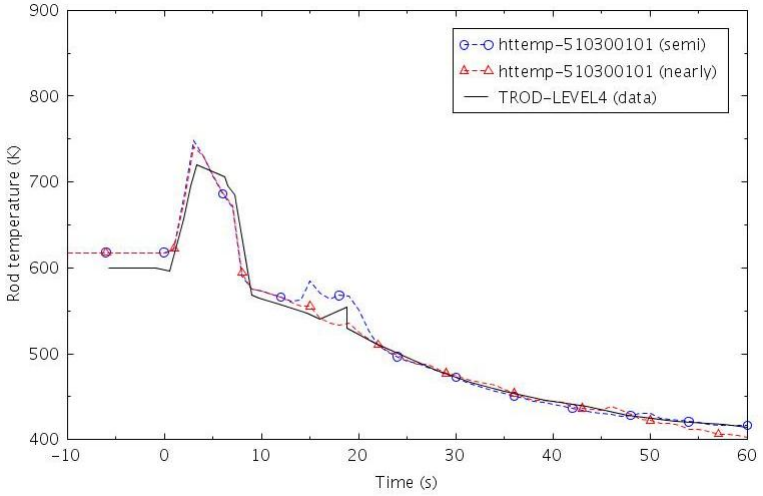
Intact loop pump outlet pressure



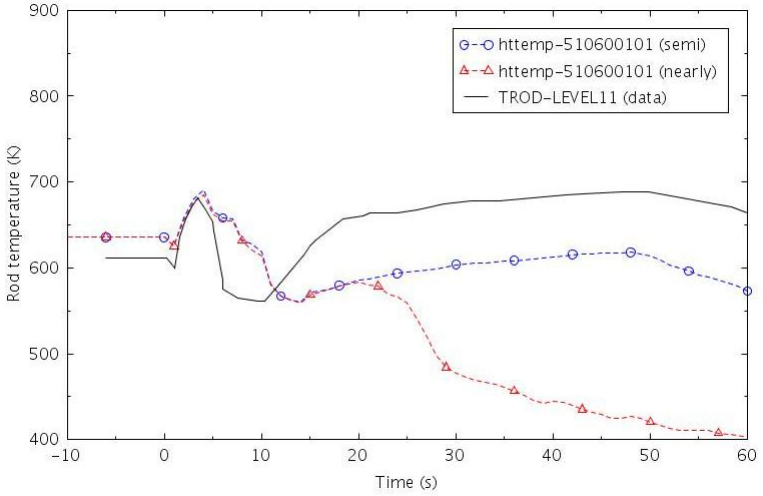
Broken loop pump side mass flow rate



Lower core heater rod temperature



Upper core heater rod temperature

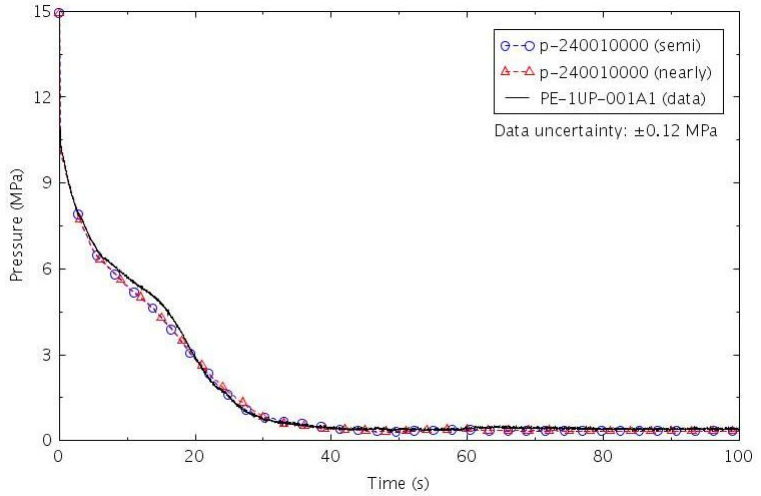


LOFT Experiment L2-5 LBLOCA (1-D)

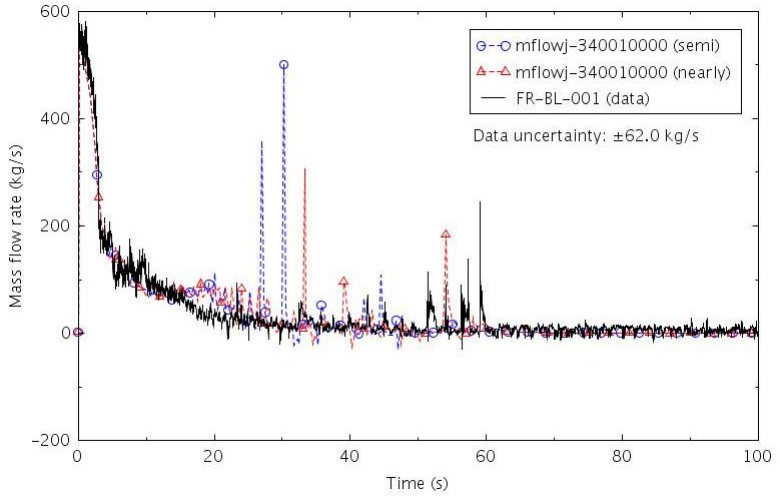
- Acceptable simulations of
  - Primary and secondary system pressures
  - Loop flow rates and broken loop densities
  - Coolant temperatures
  - Fuel rod temperatures
  - ECC flows
  - Bottom-up/top-down quench
- Minimal simulation of intact loop densities (over predicted)

LOFT L2-5 LBLOCA (1-D)

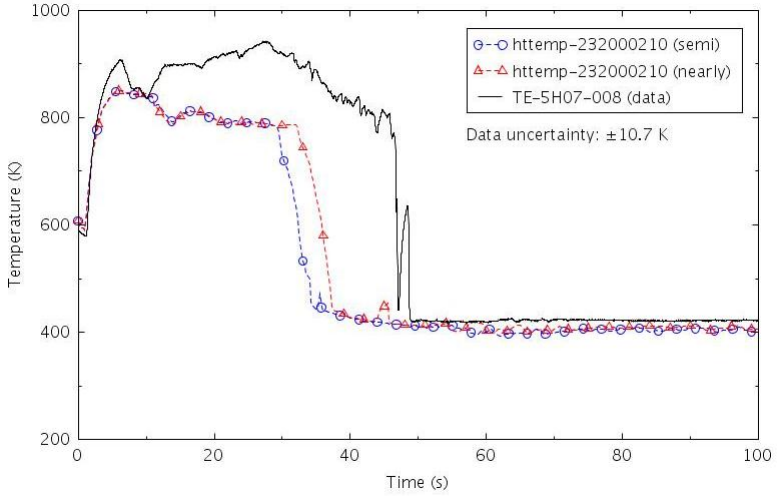
Pressurizer pressure



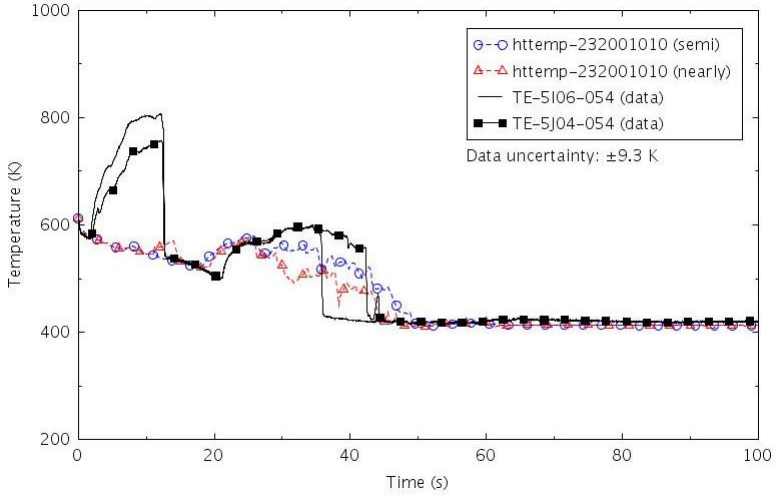
Broken loop cold leg mass flow rate



Lower core fuel cladding temperature



Upper core fuel cladding temperature

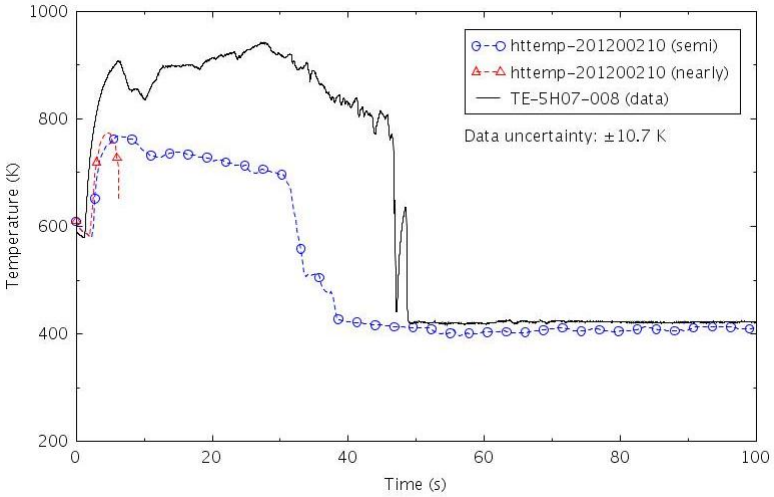


LOFT Experiment L2-5 LBLOCA (3-D)

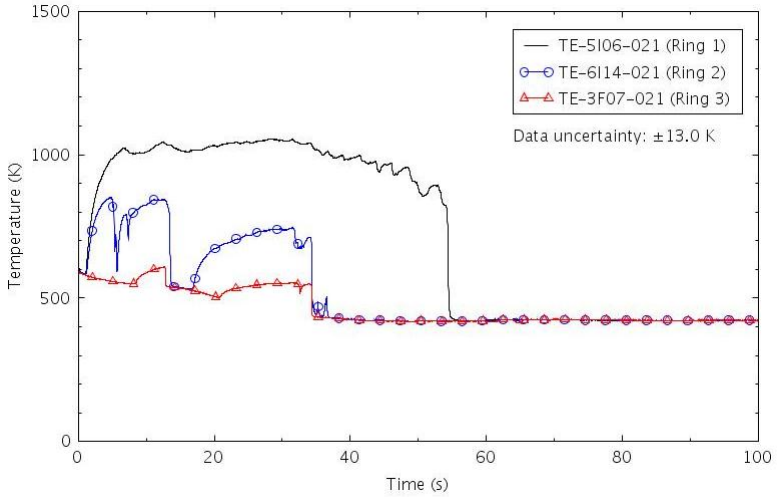
- Most results the same as for the 1-D case
- Nearly-implicit calculation had a water property failure that could not be worked around
- Three-dimensional effects more pronounced in the experiment than in the calculation
  - Radial temperature variations showed correct trends
  - Almost no variation in azimuthal temperatures

LOFT L2-5 LBLOCA (3-D)

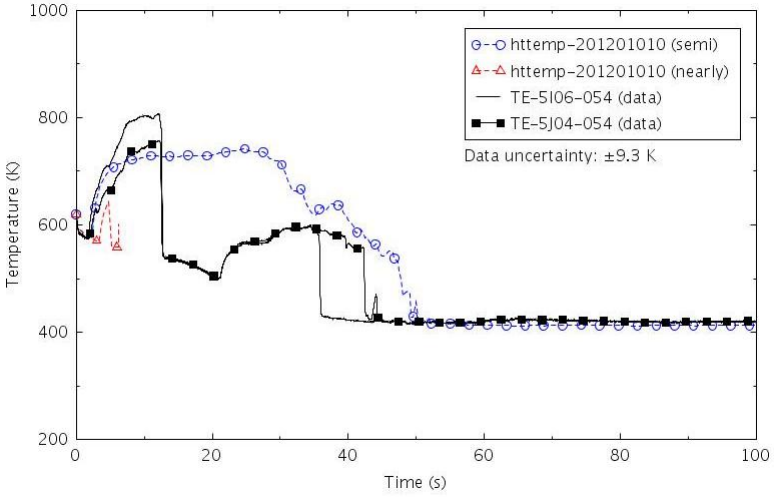
Lower core fuel cladding temperature



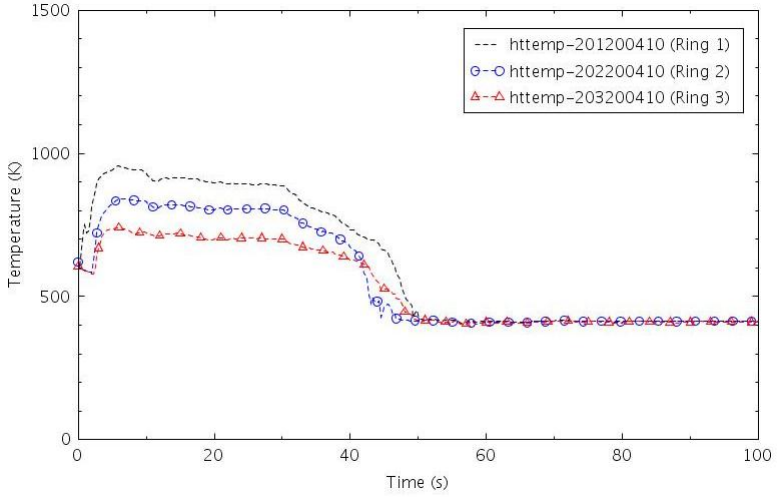
Measured radial fuel cladding temperatures



Upper core fuel cladding temperature



Calculated radial fuel cladding temperatures



Notable Deficiency

- Multi-dimensional hydrodynamic component with the nearly-implicit solution scheme
  - Incorrect pressure distributions with two-dimensional flows
  - Water property failures in water over steam and LOFT L2-5 cases
  - Symptoms known, but root cause undetermined
  - Semi-implicit calculations are fine