FRAMATOME ANP

Quantifying Code Variability for LBLOCA with RELAP5-3D (work in progress)

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Outline

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Introduction/Objective

Variability undermines confidence in calculated results. It makes interpretation of an analysis difficult and masks higher order phenomenological trends.

Computer codes modeling two-phase flow (LOCA codes) contain inherent variability

- Limited first principles understanding of phenomena
- Transient scenarios inherently nonlinear/disjoint
- Numerical techniques may contribute

With LOCA codes, variability refers to uncertainty in cladding temperature predictions (independent of phenomenological uncertainties)

Motivation

The USNRC has produced the Regulatory Guide draft DG-1096, Transient and Accident Analysis Methods. This guide sets a new standard for review of new methodologies designed for thermal-hydraulic analysis of a nuclear power plant.

Emphasis on PIRT requires better understanding of relative influences of particular phenomenon – such influences may be mask by code variability!!!

Experience at Framatome ANP Richland with quantifying PIRT ranking is that Low and Medium ranked phenomenon are difficult to discriminate from the effects of code variability

How should this problem be addressed?

Two options:

- Ignore it
- Quantify, reduce, and iterate

Description of Work

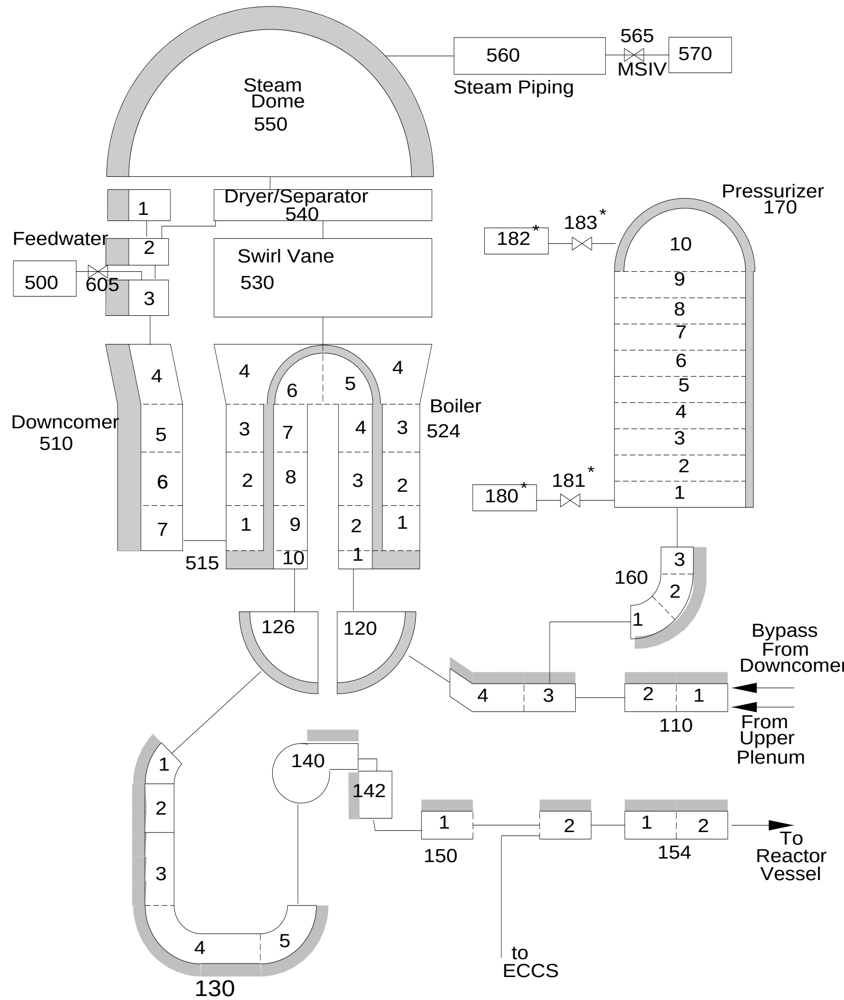
Evolution of this method:

- Appendix K requires a demonstration of time step convergence
- Historically, this is the presentation of 3 or more sample problems varying time step
- Codes tend to show minimal variability for small problems or well controlled problems (e.g., SETs and IETs)
- Plant applications show the biggest variability
- Since DG-1096 and RG-157 emphasize need for “frozen” codes, reduction of variability **must focus on event modeling and plant nodalization**

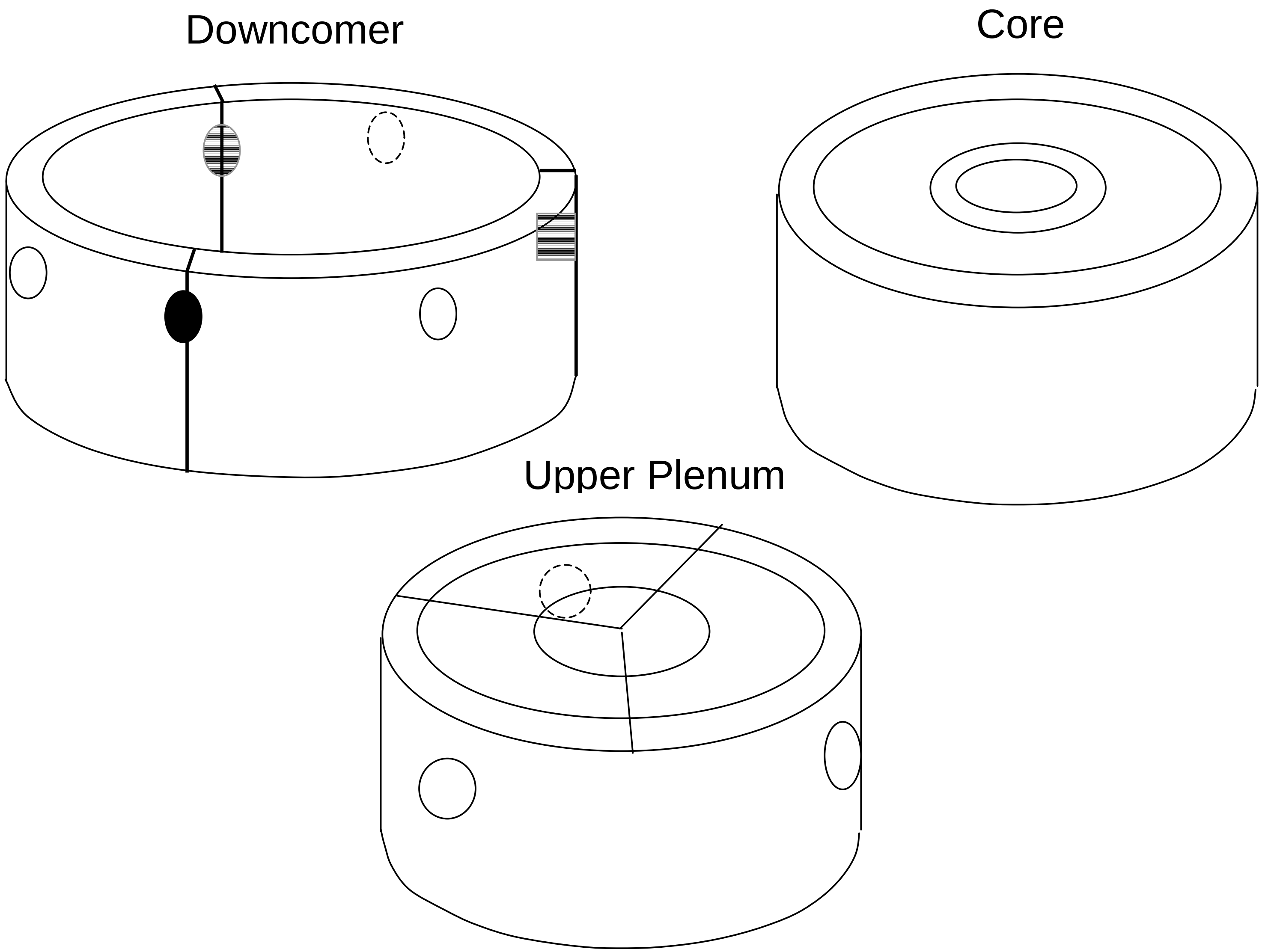
    DG-1096 and RG-157 also require a deep level of assessment with consistent use of nodalization; hence, extensive iteration to reduce variability with nodalization and event modeling is expensive

- To reduce this expense, the variability needs to be quantified and a reasonable goal estabilished to end the iteration of model refinement

Nodalization



Use of 3D Hydrodynamic Model



LBLOCA Description

Event	W 3-loop, sec
Analysis Initiated	0.00
Break Opened (Loop 1 cold leg)	0.00
Safety Injection Signal (high containment pressure)	0.7 to 1.4
Broken Loop Accumulator/ SIT Flow Initiated	1 to 3
Intact Loop Accumulator/ SIT Flow Initiated	10 to 15
End of Bypass/Beginning of Refill	15 to 25
Broken Loop Accumulator/ SIT Empties	25 to 35
Beginning of Reflood	25 to 45
Intact Accumulator/ SIT Empties	32 to 46
PCT Occurred	80 to 135

Calculation Complications

- Big changes from MOD2 to MOD3
  - Translation from S-R5 TWODEE component to R5-3D MULTID
  - Additional heat structures cards
- **3D-to-1D connection Warning**
- Anomalous downcomer flow ("azimuthal sloshing")
- TMDPJUN (representing LPSI) driven by downstream volume pressure unstable
- Underestimation of ECCS bypass (filling of cold leg)

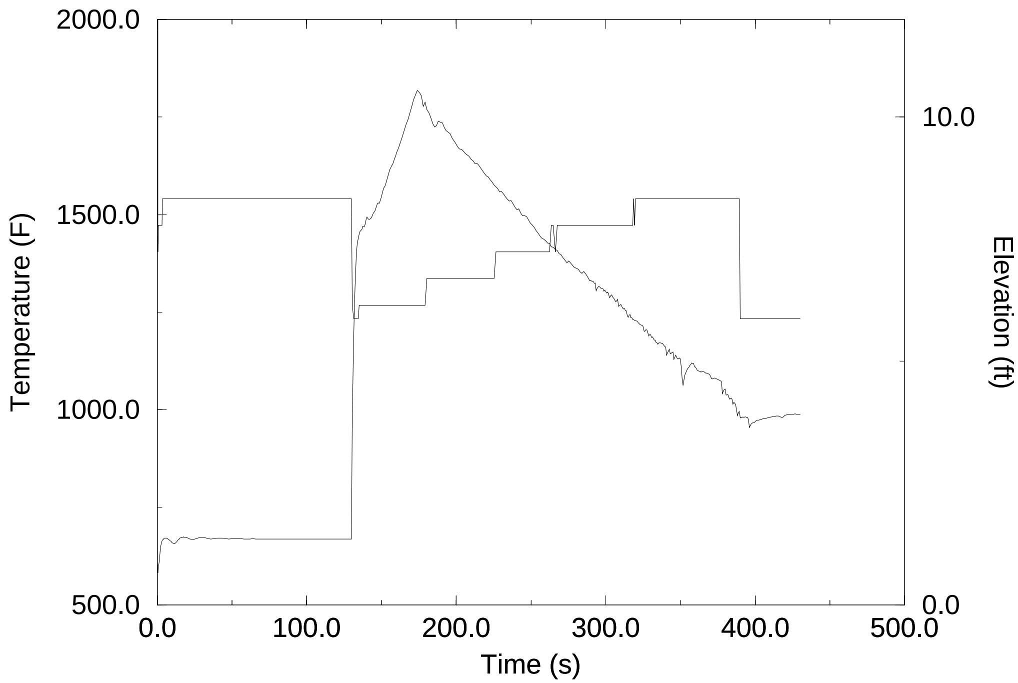
Resolutions/Compromises

- Full 3D upper plenum (removed some warnings, no longer crashed)
- Examined downcomer flow
  - Code failure when mass flows were set to zero at azimuthal junction (resolved by using velocities)
  - “Played with” loss coefficients at azimuthal junctions
  - Examined 3D vs. 1D fluid equations
  - Examined Cartesian vs. Cylindrical
  - Rebuilt RV model “step-by-step”
- Raised pressure in ECCS and lag the pressure reading to stabilize TMDPJUN
- Examined ECCS flow to cold leg:
  - Set “e-flag” on junction from ECCS to CL to 1 (PV term)
  - Homogeneous flow in cold leg
  - Set “v-flag” on CL junctions to 3 (centrally located HS option)

No resolution found for downcomer flow or ECCS bypass

Results

PCT Independent of Location



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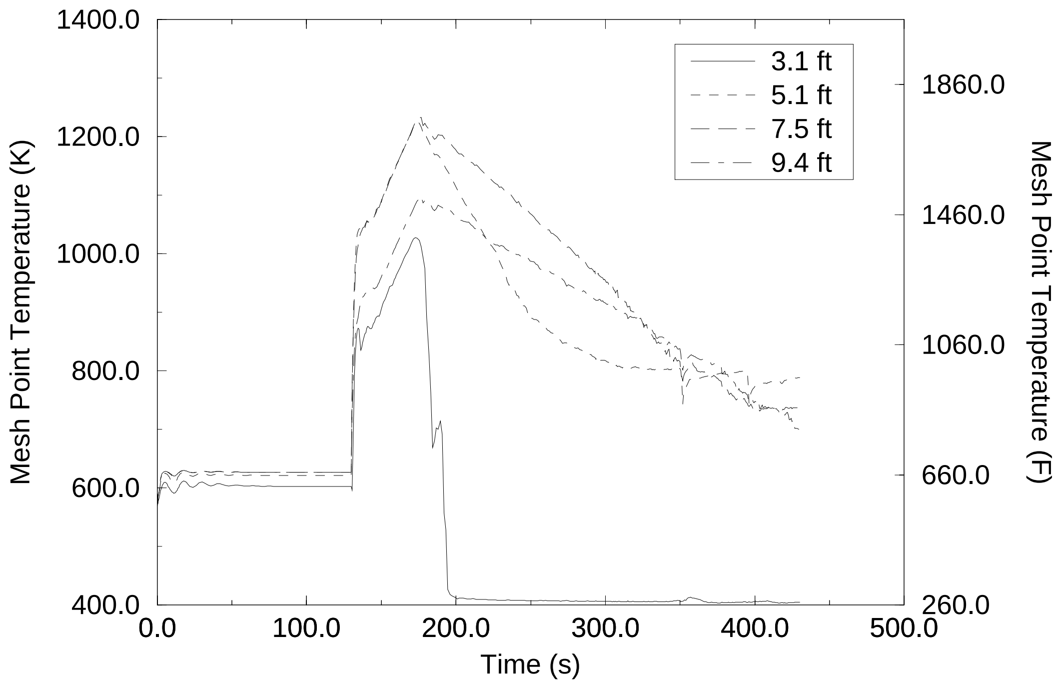
Results

Hot Rod Surface Temperature



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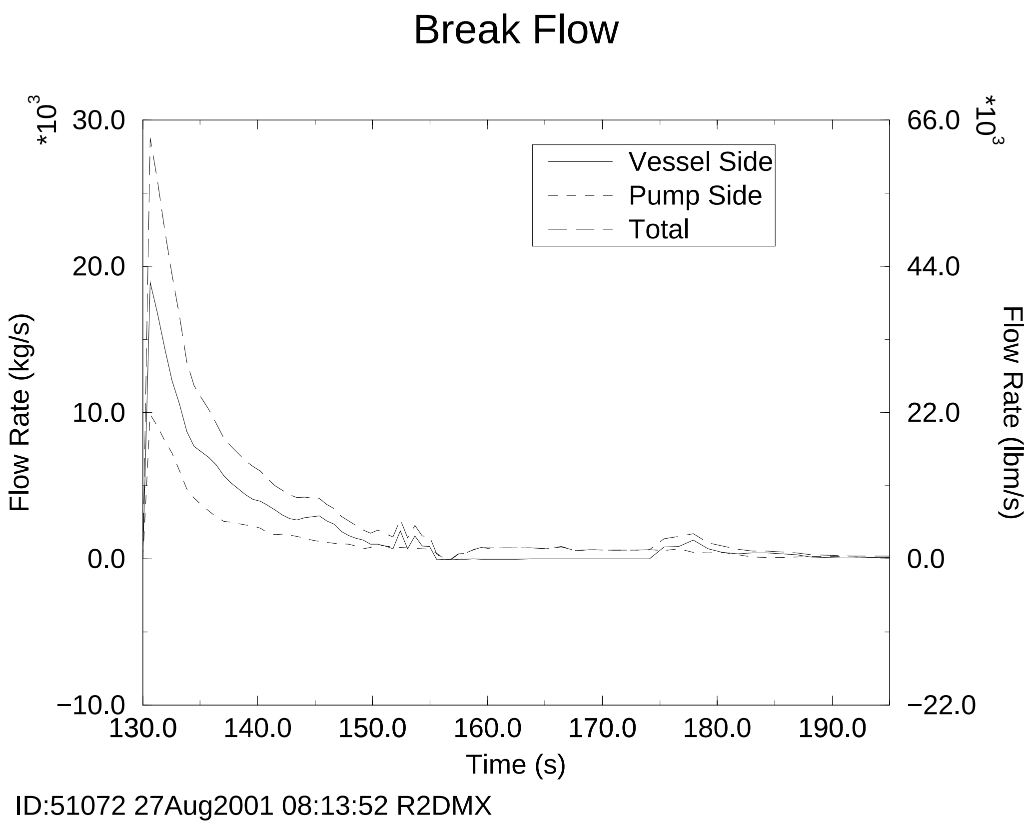
Results



Break Flow
*10^3
30.0
20.0
10.0
0.0
−10.0
66.0
44.0
22.0
0.0
−22.0
*10^3
Flow Rate (kg/s)
Flow Rate (lbm/s)
Vessel Side
Pump Side
Total
130.0
140.0
150.0
160.0
170.0
180.0
190.0
Time (s)
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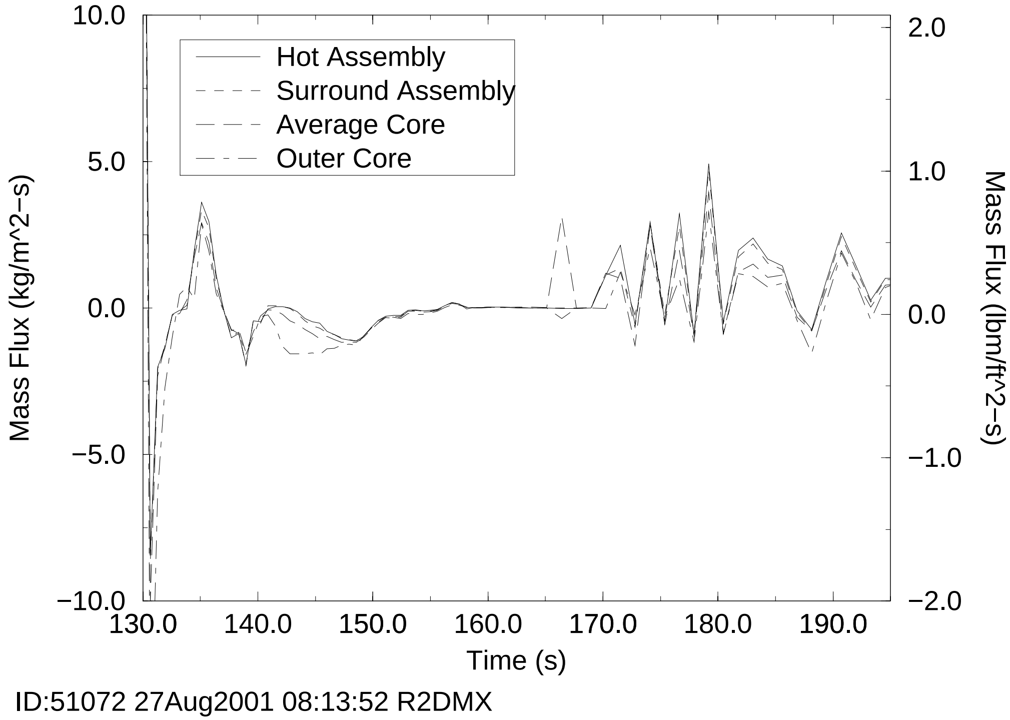
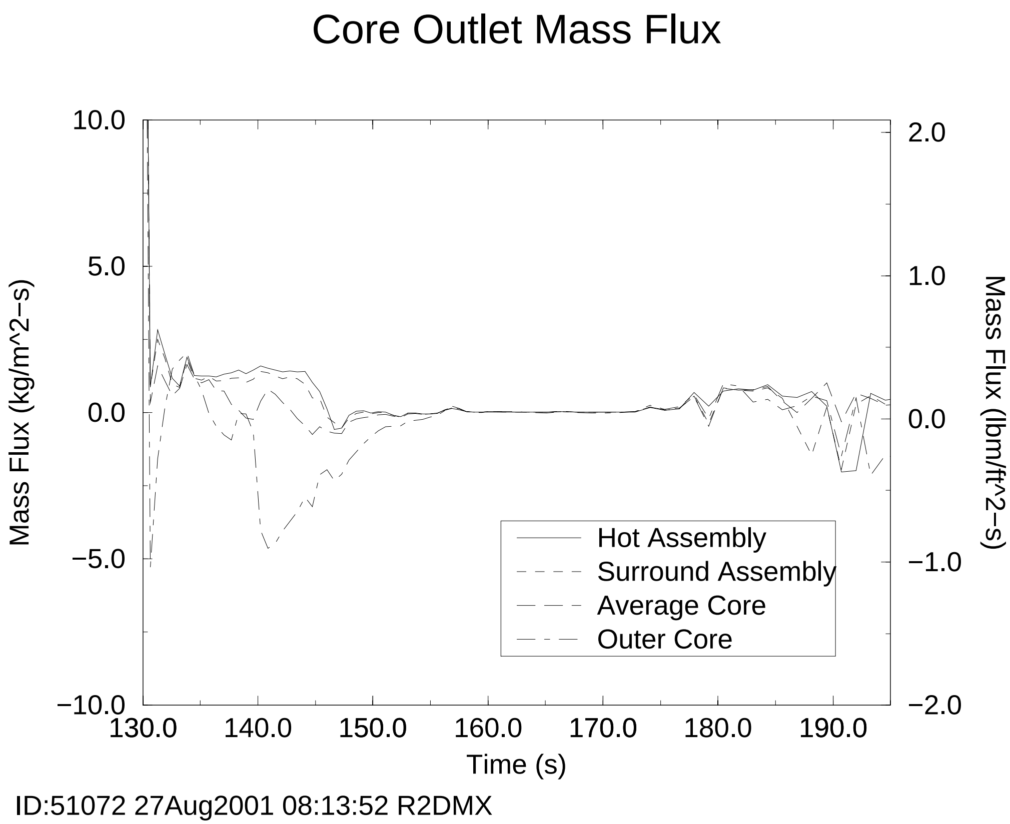
Results

Core Inlet Mass Flux



Results


Core Outlet Mass Flux
10.0
5.0
0.0
−5.0
−10.0
2.0
1.0
0.0
−1.0
−2.0
Mass Flux (kg/m^2−s)
Mass Flux (lbm/ft^2−s)
130.0
140.0
150.0
160.0
170.0
180.0
190.0
Time (s)
Hot Assembly
Surround Assembly
Average Core
Outer Core
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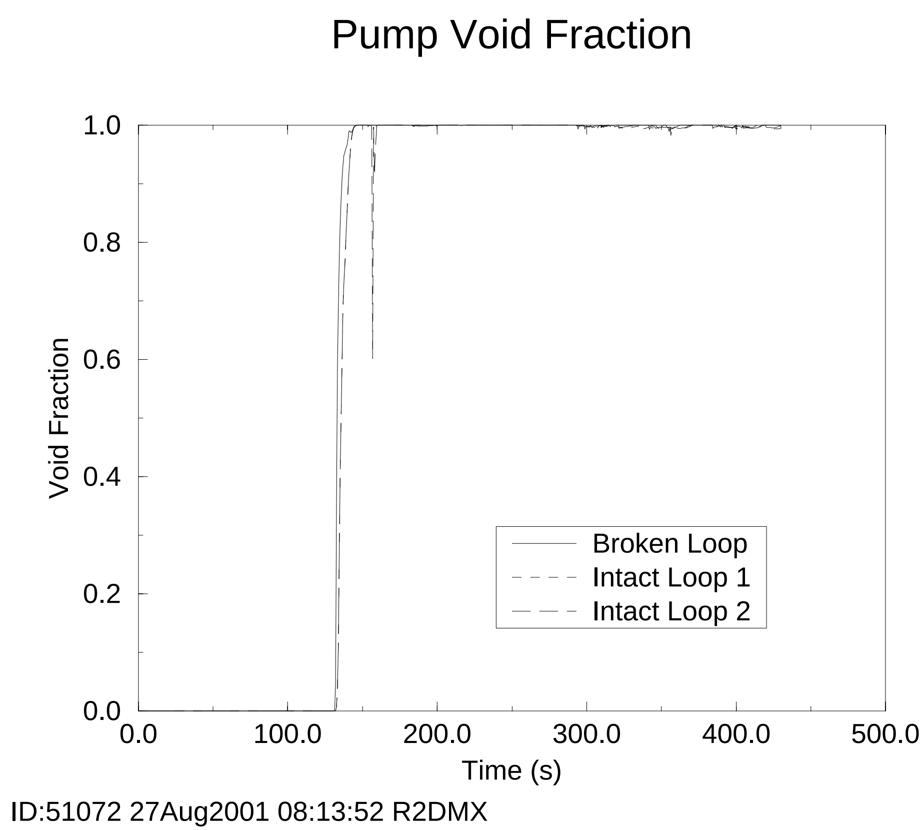
Results



Pump Void Fraction
1.0
0.8
0.6
0.4
0.2
0.0
Void Fraction
0.0
100.0
200.0
300.0
400.0
500.0
Time (s)
Broken Loop
Intact Loop 1
Intact Loop 2
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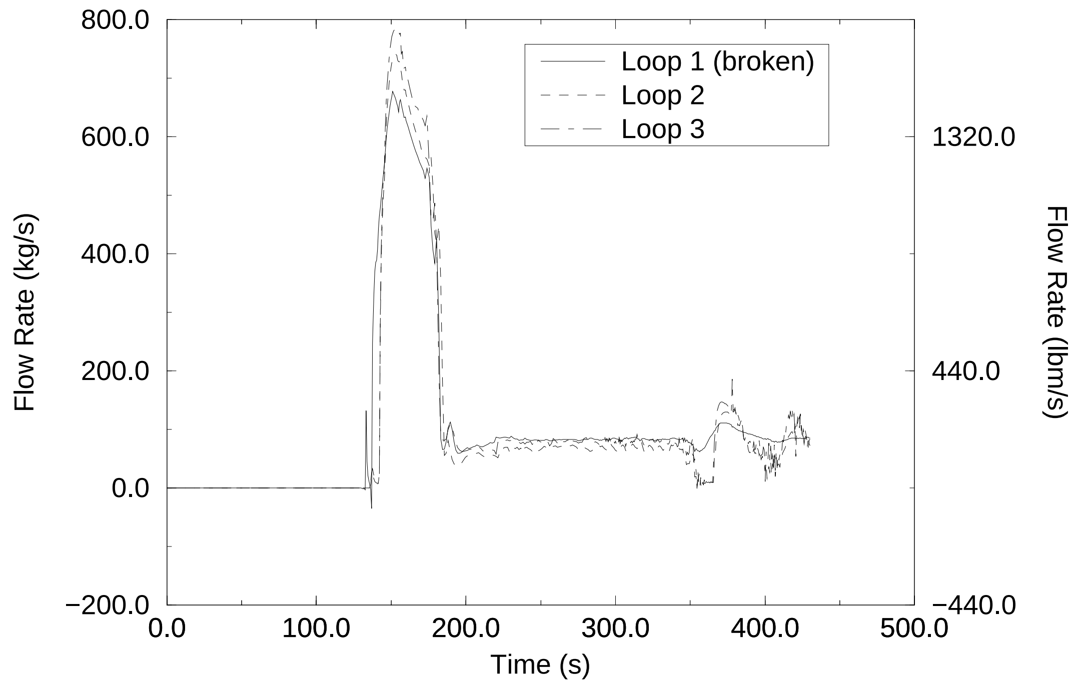
Results

ECCS Flows



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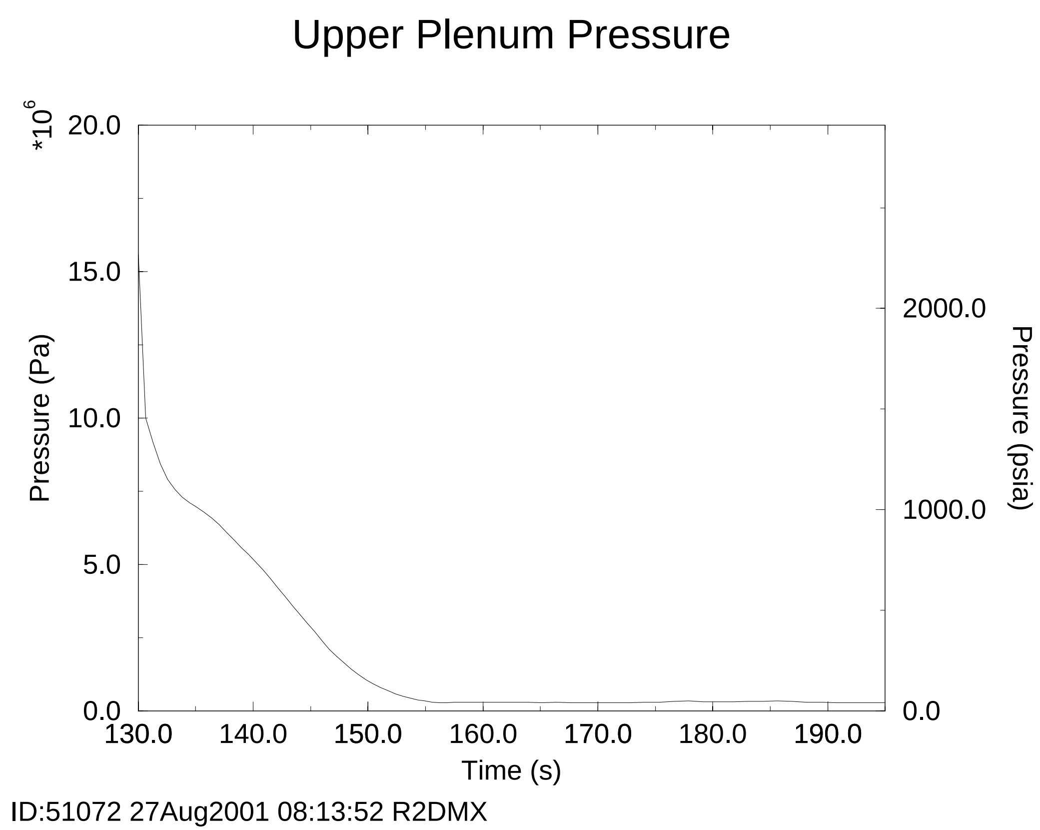
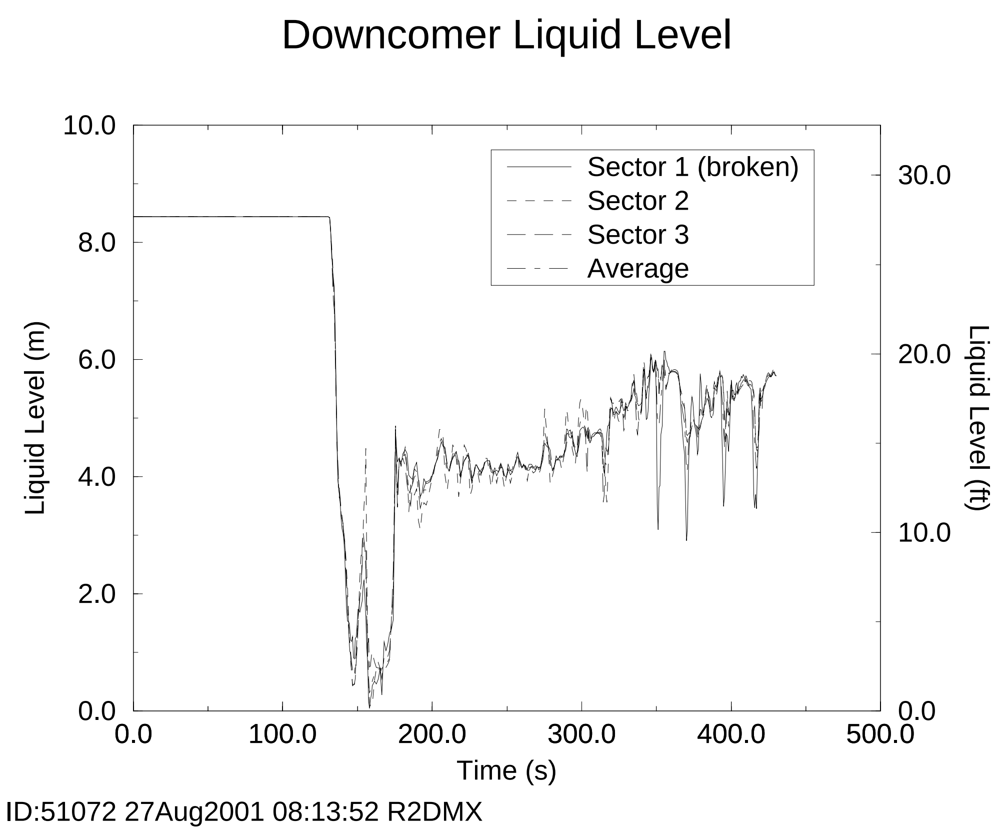
Results


Upper Plenum Pressure
*10^6
20.0
15.0
10.0
5.0
0.0
Pressure (Pa)
2000.0
1000.0
0.0
Pressure (psia)
130.0
140.0
150.0
160.0
170.0
180.0
190.0
Time (s)
ID:51072 27Aug2001 08:13:52 R2DMX

Results


Downcomer Liquid Level
Sector 1 (broken)
Sector 2
Sector 3
Average
Liquid Level (m)
Liquid Level (ft)
Time (s)
10.0
8.0
6.0
4.0
2.0
0.0
30.0
20.0
10.0
0.0
100.0
200.0
300.0
400.0
500.0
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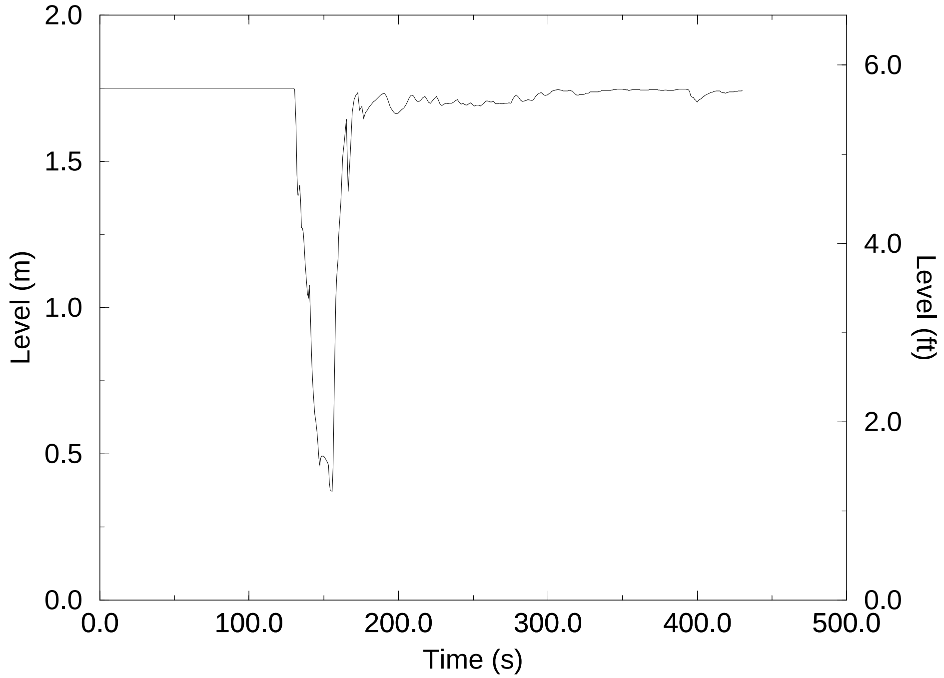
Results

Lower Plenum Liquid Level



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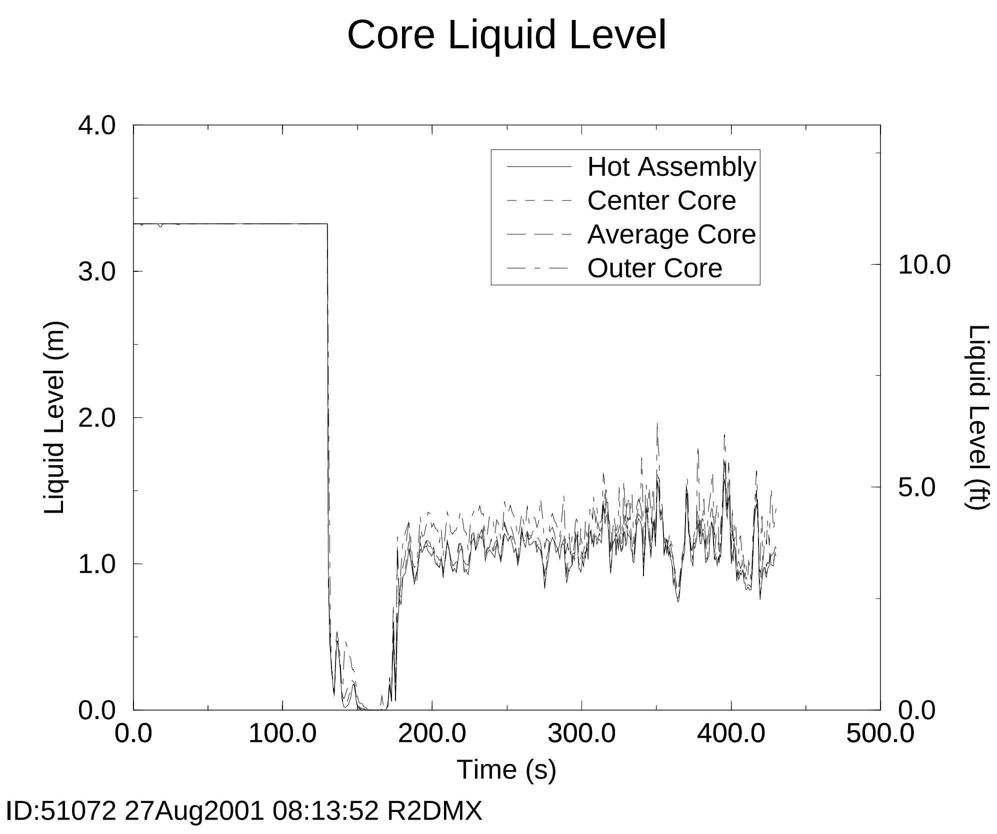
Results



Core Liquid Level
Hot Assembly
Center Core
Average Core
Outer Core
Liquid Level (m)
Liquid Level (ft)
Time (s)
4.0
3.0
2.0
1.0
0.0
10.0
5.0
0.0
0.0
100.0
200.0
300.0
400.0
500.0
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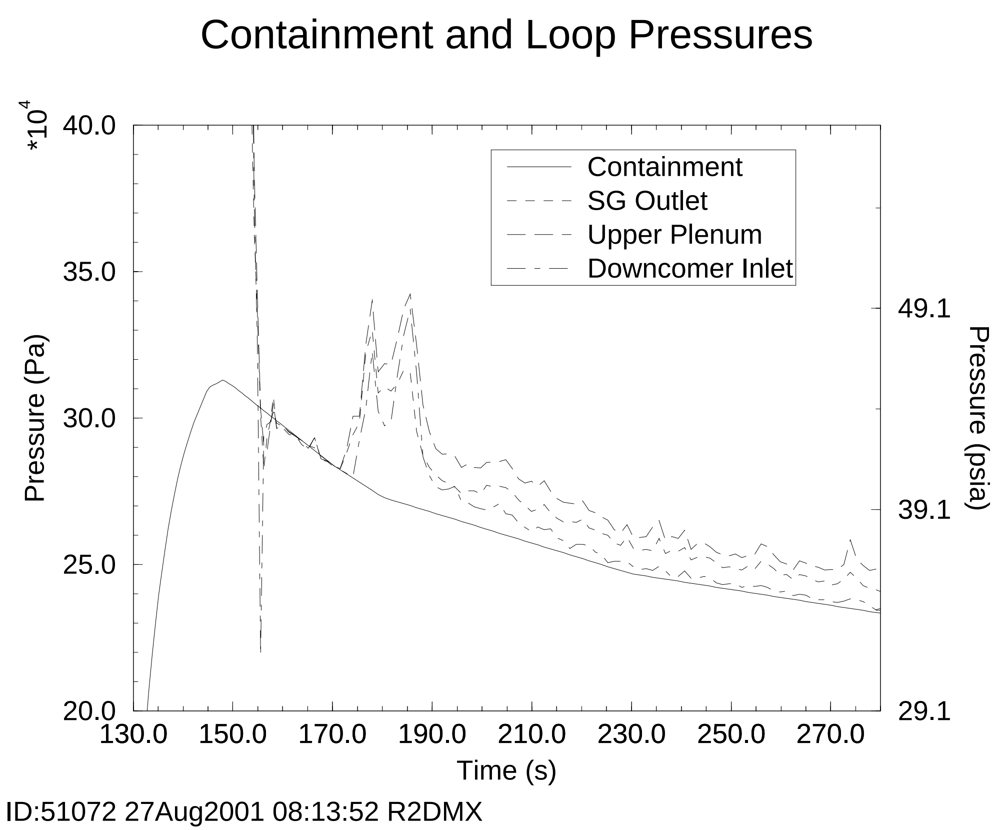
Results



Containment and Loop Pressures
*10^4
40.0
35.0
30.0
25.0
20.0
Pressure (Pa)
Containment
SG Outlet
Upper Plenum
Downcomer Inlet
49.1
39.1
29.1
Pressure (psia)
130.0
150.0
170.0
190.0
210.0
230.0
250.0
270.0
Time (s)
ID:51072 27Aug2001 08:13:52 R2DMX

Statistical Assessment of Variability

A Non-Parameteric Approach

For a series of random samples arranged in ascending (or descending) order, the probability that the fraction of the parent population less than x_k is at least β is given by

$$P\,[F\,(x_k) > \beta\,] = \gamma = \frac{n!}{(k-1)!\cdot(n-k)!} \cdot \int_{\beta}^{1} \xi^{\,k\text{-}1}\,(1 - \xi\,)^{\,n\text{-}k}\, d\,\xi$$

where $F(x_k)$ is the k^th^-sample value, n is the total number of samples and ξ is an abbreviation for the unknown probability distribution function. The probability is called the confidence, γ, and β is called the coverage. For the case in which $k=n$, that is the largest value of all of the samples is used, this relationship reduces to

$$\gamma = 1 - \beta^n$$

This makes the 95/50 limit (γ=0.5/β=0.95) meet the following criterion:

$$(0.95)^n = 0.50$$

hence; n = 13.5 ≡ 14

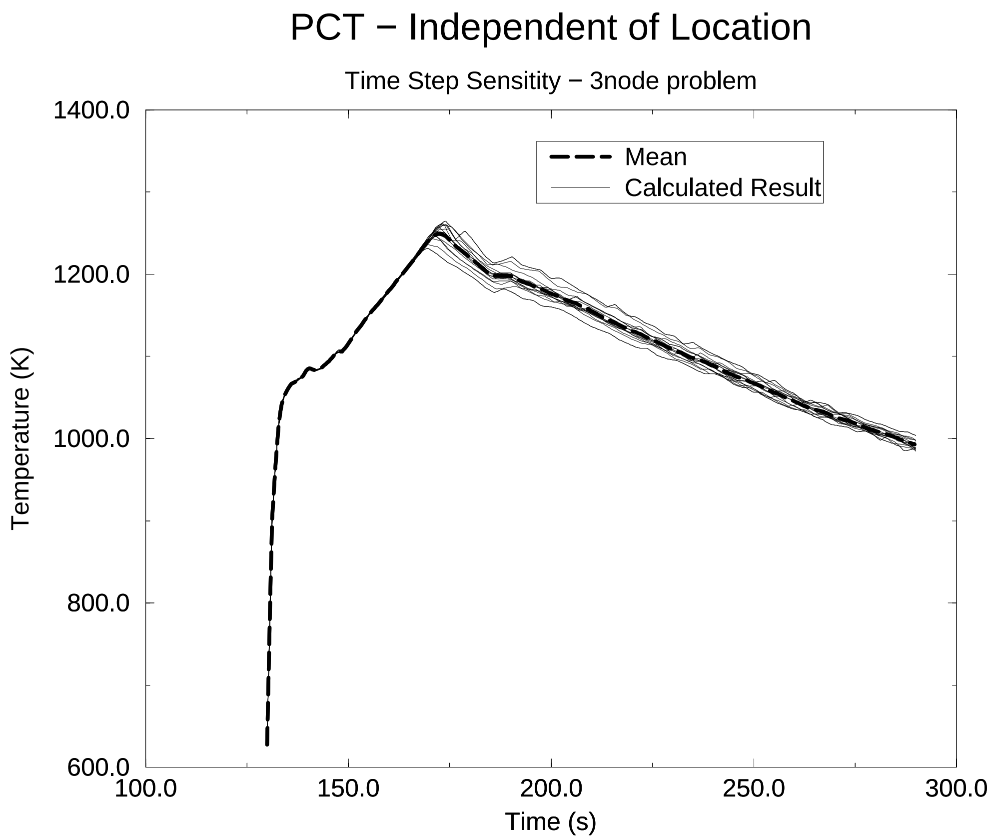
Statistical Assessment of Variability

Quantify 1% error from the difference of mean (50/50) and high (95/95)

$$\frac{\Delta T_{variability}^{2}}{(T_{95/95} - T_{50/50})^{2}} = 0.01$$

This requires that the 95/95 and 50/50 be identified.

Results



PCT − Independent of Location
Time Step Sensitity − 3node problem
Mean
Calculated Result
Temperature (K)
Time (s)
1400.0
1200.0
1000.0
800.0
600.0
100.0
150.0
200.0
250.0
300.0

Conclusions

- LBLOCA model still needs work
- Code fidelity needs to be assess:
  - for steady-state 2D component (axial and azimuthal)
  - ECCS bypass (e.g., UPTF test 8)
  - TMDPJUN problem

- Non-parametric approach capable of quantifying variability which can aid in focusing modeling development and establishing an acceptance criteria