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

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Outline

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- Results
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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 masked 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 established to end the iteration of model refinement.
Use of 3D Hydrodynamic Model

Downcomer

Core

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

![Graph showing mesh point temperature over time with different line styles for 3.1 ft, 5.1 ft, 7.5 ft, and 9.4 ft distances.]
Results

Break Flow

- Vessel Side
- Pump Side
- Total

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Results

Core Inlet Mass Flux

- Hot Assembly
- Surround Assembly
- Average Core
- Outer Core

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Results

Core Outlet Mass Flux

ID:51072 27Aug2001 08:13:52 R2DMX
Results

Pump Void Fraction

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Results

ECCS Flows

- Loop 1 (broken)
- Loop 2
- Loop 3

Flow Rate (kg/s)

Flow Rate (lbm/s)

Time (s)

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Results

Upper Plenum Pressure

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Results

Downcomer Liquid Level

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Lower Plenum Liquid Level

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Results

Core Liquid Level

- Hot Assembly
- Center Core
- Average Core
- Outer Core

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Results

Containment and Loop Pressures

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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 $\beta$ is given by

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

where $F(x_k)$ is the $k^{th}$-sample value, $n$ is the total number of samples and $\xi$ is an abbreviation for the unknown probability distribution function. The probability is called the confidence, $\gamma$, and $\beta$ 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 ($\gamma=0.5/\beta=0.95$) meet the following criterion:

$$(0.95)^n = 0.50$$

hence; $n = 13.5 \approx 14$
Statistical Assessment of Variability

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

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

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

PCT – Independent of Location

Time Step Sensitivity – 3node problem

Temperature (K)

Mean
Calculated Result

Time (s)
Conclusions

- LBLOCA model still needs work
- Code fidelity needs to be assessed:
  - 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