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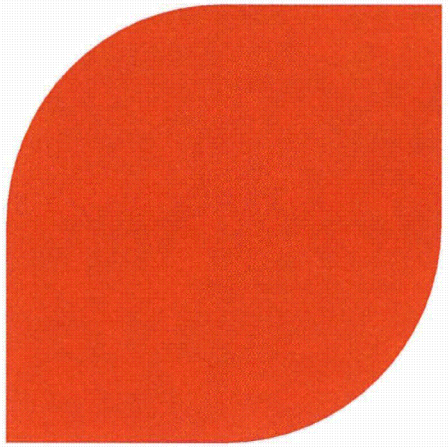

CCTF Test C2-4 Run 62
Uncertainty Analysis

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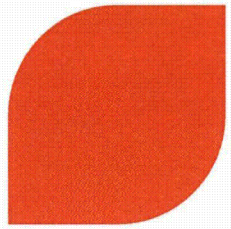
Overview



- Motivation
- Methodology
- Results

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Motivation

- Discussed during the post-submittal meeting w/ NRC on RLBLOCA Rev. 3 - statistical uncertainty evaluation of an IET, specifically CCTF Test C2-4, Run 62

- The purpose is answer the following questions:
  - Are the code calculations a good representation of the experimental results in the sense that they provide a good demonstration of the possible LBLOCA outcomes?
  - Does the S-RELAP5 code retain a conservative bias when predicting the complex phenomena in Integral Effects Tests, such as CCTF Run 62?

Methodology

- Test Data Analysis
- Characterization of test initial and boundary conditions
- Perform a reduced order PIRT
- Execute base run (best-estimate)
- Uncertainty Analysis of CCTF 62

Test Data Analysis

- Identify data available
- Revealed some information is not available or uncertain
  - Lack of direct measurement for steam flow rates I/O SG (difficult to assess steam binding effects)
  - Large uncertainties associated w/ hot leg mass flow rate measurements
  - Large uncertainty in measurement data for liquid carryover
  - Lack of precise geometry description for the containment tank
- Concluded that relevant data is available and adequate for the purpose of the study

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Characterization of test I&B conditions

- Estimated uncertainty ranges for
  - Input parameters
  - Boundary conditions
- Provided as input to the PIRT panel for determination of sampled parameters and their corresponding ranges

Reduced Order PIRT

- **The goal was to identify the model parameters with impact on CCTF Test 62**
- **Started w/ the EMF-2103 Rev. 3 PIRT**
  - **Is the phenomenon listed in the PIRT table important for CCTF Test C2-4 Run 62?**
    - If YES, then it will be included in the reduced order PIRT.
    - If NO, then determine if an alternate/equivalent phenomenon should be considered instead, or exclude it from the reduced order PIRT.
  - **Are there any additional phenomena that are not included in the Revision 3 PIRT that should be considered for the reduced order PIRT?**
  - **How are the identified phenomenological parameters to be ranged in the CCTF UA and quantified for uncertainty evaluation?**

Reduced Order PIRT - selection

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Reduced Order PIRT - Parameters

- Uncertainty Parameters for CCTF Run 62 UA

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Base Run - Model Updates

- CCTF Model has been updated to include:

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Base Case Run (BE)

- Overall hydraulic response show good calculation trends
  - Downcomer Δp
  - Core Δp
- Some response show reasonable to good agreement
  - Break flow rate
  - Upper plenum pressure
  - Broken loop pump Δp
  - Difficult to assess steam binding effect due to lack of measurement data
  - Code calculated cold leg condensation is possibly higher than actually occurring – may impact upper plenum pressure
- Good agreement for high-power rods temperatures
  - Maximum temperatures at all core elevations are at the high end or above the measured data

Base Case Run

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Base Case Run

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Base Case Run

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Base Case Run

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Uncertainty Analysis Results

Uncertainty Analysis Results

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Uncertainty Analysis Results

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Envelope of Calculated and Measured Data at 1.83 m Elevation

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Envelope of Calculated and Measured Data at 2.44 m Elevation

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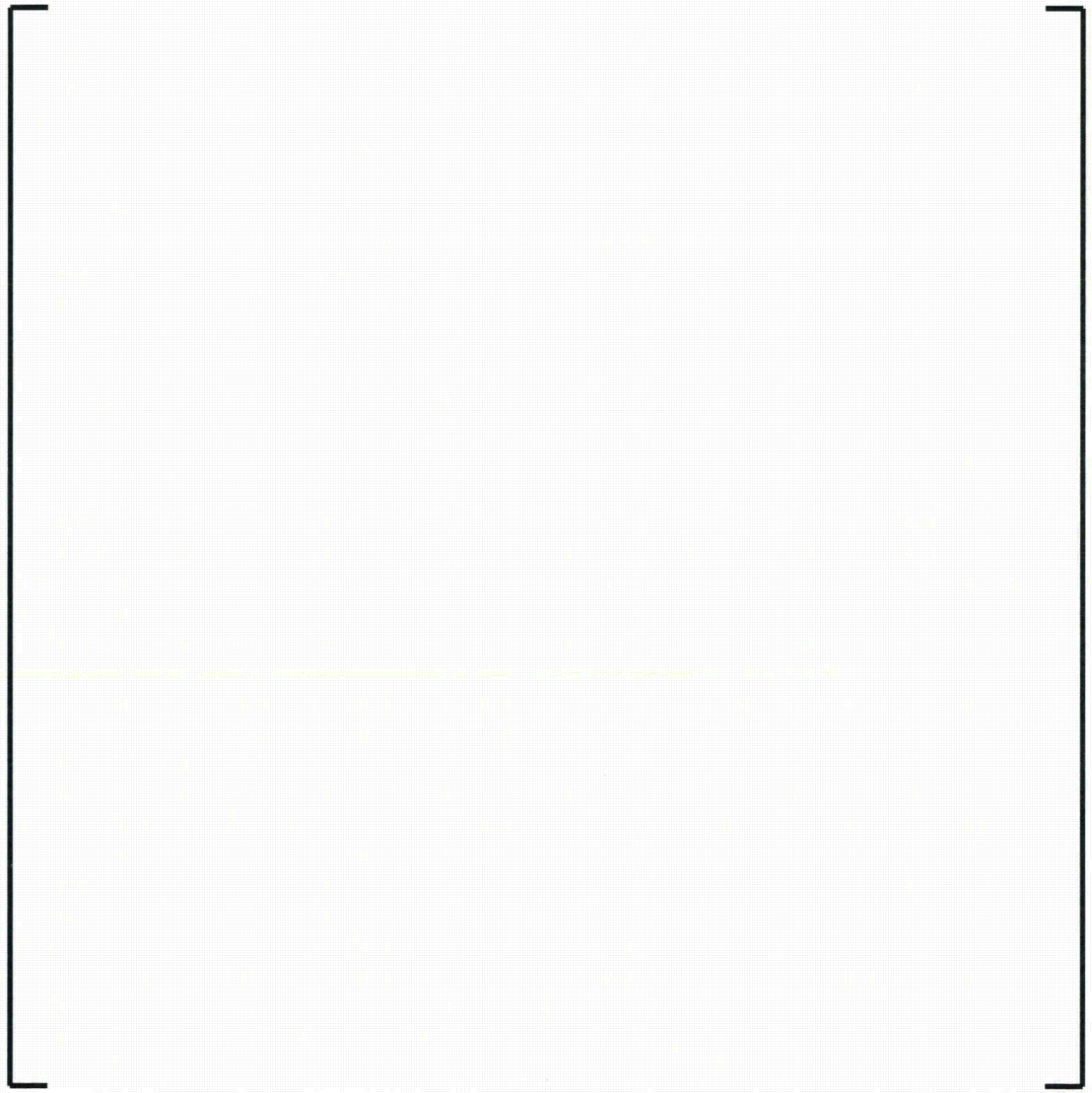
Envelope of Calculated and Measured Data at 3.05 m Elevation



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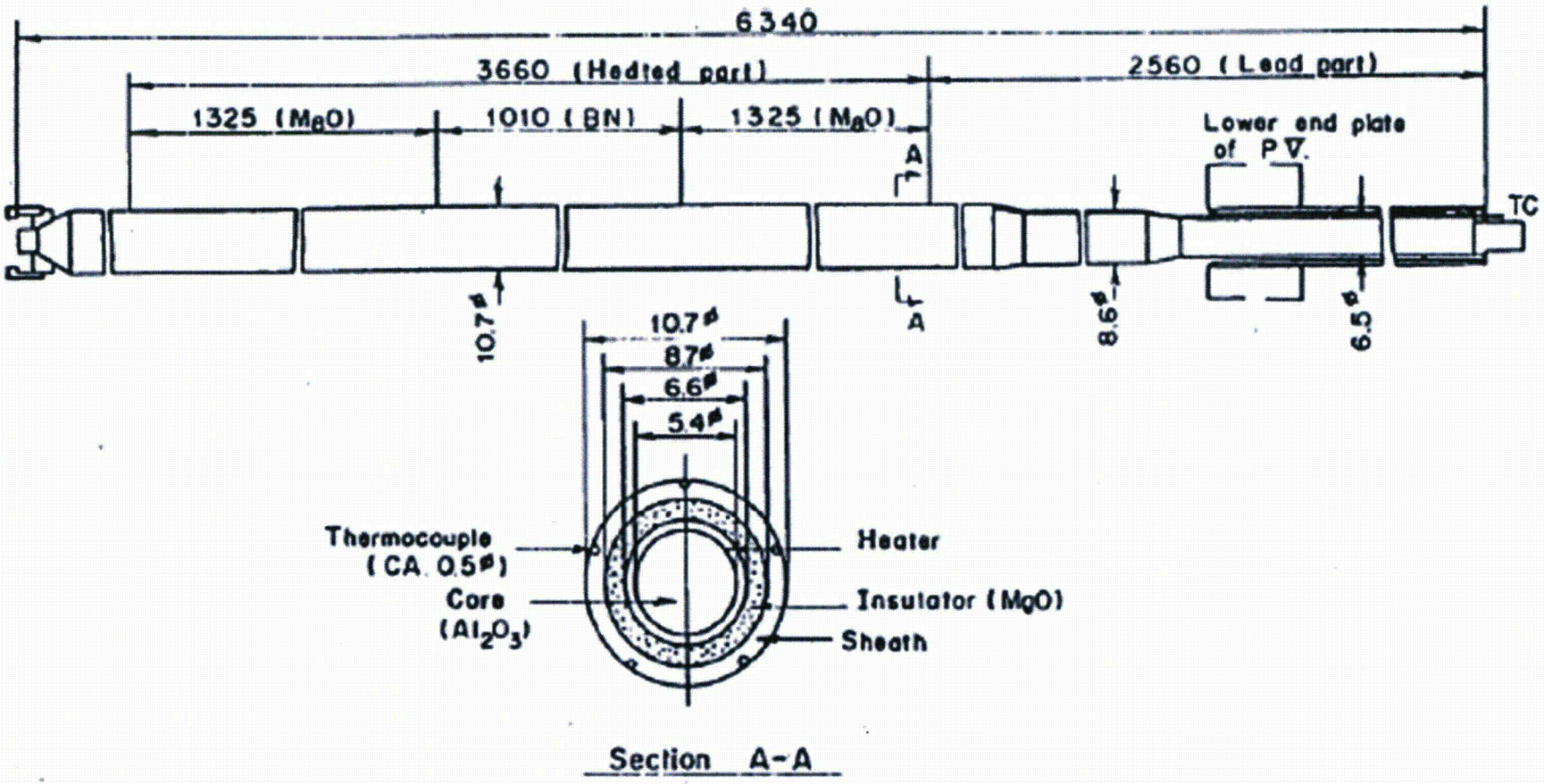
Conclusions

- The study shows that the code calculations are a good representation of the experimental results in the sense that they provide a good demonstration of the possible LBLOCA outcomes.

- The S-RELAP5 code retains a conservative bias when predicting the complex phenomena in Integral Effects Tests, such as CCTF Run 62

CCTF Heater Rod



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Outline of Response on Packing Factor/ Rupture Strain RAI

Bert Dunn

Rockville, Md September 23, 2014

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Packing Factor / Rupture Strain

Packing Factor / Rupture Strain

Packing Factor / Rupture Strain

4.3.B Packing Factor and Burnup

- The possibility of a correlation of packing factor with burnup exists
  - If substantial amounts of fine fragments are present these can fill balloon voids
  - The ruble may then be chunks of the original pellet surrounded by fine fragments
  - Packing of the fine fragments will be limited to 65 to 70 percent but the chunks will be near 100 percent and the average density in the balloon can increase
  - However fine fragments are associated with pulverization of the high burnup structure of the pellet which is only significant near or beyond rod licensing limits
- Thus, there may be a packing factor dependency on burnup but it is only important beyond current licensing limits
- Should these licensing limits be increased it will be appropriate to review the need to apply this dependency

Packing Factor / Rupture Strain

4.3.D Independence of Sampled Parameters

- The statically evaluation applied by AREVA in non-parametric evaluations essentially order statistics is a measure of the probability of given results of a possible LOCA
- Thus it is the events (called cases in the application) of LOCAs that must be independent of each other
- The relationship between parameters or phenomena that interact to produce the results of an event should, be treated realistically including interdependence if present
- In fact, for phenomena that is of importance to the event outcome, the dependence of one phenomena on another even when sampled must be properly reflected for the event result to be a valid possibility

Packing Factor / Rupture Strain

Outline of Response on Zr-4 / ZIRLO, Mixed Core Evaluations RAIs

Bert Dunn

Rockville, Md September 23, 2014

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Zr-4 / ZIRLO Evaluations

3.3.A SRR Treatment for non-M5 clad fuel

- The need to consider non-M5 cladding occurs during mixed core situations
  - Change over to M5 in an AREVA fueled plant (1 possible, Zr-4 to M5)
  - Change of fuel supplier (many possible, ZIRLO to M5)
- Primary approach is to let previous analysis apply for co-resident fuel
  - New AREVA fuel hydraulically similar of channels some flow to co-resident fuel
  - Co-resident fuel cools the same or better than previous analysis indicates
  - Previous analysis is conservative for co-resident fuel
- Conditions of analysis of co-resident fuel reported as plant specific EM

Zr-4 / ZIRLO Evaluations

3.3.A SRR Treatment for non-M5 clad fuel (Continued)

- AREVA fuel less resistive than co-resident AREVA fuel
  - Sensitivity studies performed to show co-resident fuel non-limiting, or
  - Statistical evaluation performed on co-resident fuel
- AREVA fuel less resistive than co-resident Non-AREVA
  - Conservative evaluation technique developed for non-AREVA fuel
  - Sensitivity studies performed to show co-resident fuel non-limiting, or
  - Statistical evaluation performed on co-resident fuel
- Conditions of analysis of co-resident fuel reported as plant specific EMs

Zr-4 / ZIRLO Evaluations

- **3.3.B RODEX-3A in Tables 8.4-1 and 8.5-1**
  - RODEX-3A should not have appeared in either table
    - Tables 8.4-1 and 8.5-1 will be redrafted with only COPERNIC listed as the fuel performance code
    - The inclusion of RODEX-3A in these table was a mistake

Zr-4 / ZIRLO Evaluations

Table 8.4-1: Summary of Evaluated Biases and Uncertainties of Important Code Related PIRT Parameters

Zr-4 / ZIRLO Evaluations

Table 8.5-1 Methodology Treatment of I mportant PIRT Phenomena

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Zr-4 / ZIRLO Evaluations

3.3.C Evaluation of Non-M5 Cladding with RODEX-3A

- RODEX-3A will not be used in the Revision 3 evaluation model

Statistical Approach in EMF-2103, Rev. 3

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Rev. 3 Statistical Approach

- **True multivariate method**
  - **Uses the concept of statistically equivalent blocks – introduced by Tukey [Ref. 1]**
  - **For a univariate sample of size n from a continuous with the order statistics** $X_{(1)} < X_{(2)} < \ldots X_{(n)}$

the equivalent blocks are defined as the intervals

$$(-\infty, X_{(1)}], \ldots (X_{(j-1)}, X_{(j)}], \ldots (X_{(n)}, \infty)$$

This distribution of lengths provides at the same time the distribution of fractions of the population covered by the blocks, i.e.

$$F_X(X_{(1)}), \ldots F_X(X_{(j)}) - F_X(X_{(j-1)}), \ldots, 1 - F_X(X_{(n)})$$

It can be proven that the expected content of the blocks is the same

$$E(C_1) = \ldots E(C_j) = \ldots E(C_{(n+1)}) = \frac{1}{n+1}$$ **[Ref. 2]**

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Rev. 3 Statistical Approach

- The sum of coverages of any k preselected blocks out of n+1 is

$$\Pr\left(\sum_{j=1}^{k} C_j < 1-\gamma\right) = I_{1-\gamma}\left(n-k+1,k\right)$$

or

$$\Pr\left(\sum_{j=1}^{k} C_j \geq \alpha\right) = 1-I_{\alpha}\left(n-k+1,k\right)$$

Rev. 3 Statistical Approach

- Tukey [Ref. 1] extended the construction principle to a multivariate case

[ ]

Bivariate example

RLBLOCA Rev. 3 Example

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Example

- 3 Case Example (numbers are completely arbitrary)

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Example (cont.)

- 3 Case Example (cont.)

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More examples

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Illustration of the results

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References

1. Tukey, J.W., Non-Parametric Estimation II: Statistically Equivalent Blocks and Tolerance Regions – the Continuous Case, Ann. Math. Stat. 18, 529-539
2. Krishnamoorthy, K., Mathew T., Statistical Tolerance Regions – Theory, Applications, and Computation, John Wiley & Sons, 2009