Realistic Large Break LOCA Methodology for Pressurized Water Reactors

October 30, 2001

Realistic Large Break LOCA Methodology for Pressurized Water Reactors

AGENDA	Presenter
Introduction	Holm
Methodology Roadmap	O'Dell
Statistical Approach	Nutt
NPP Nodalization	Martin
Code and Experimental Accuracy	
PIRT Phenomena Treated Statistically	Martin
Evaluation of Code Biases	Jensen
PIRT Phenomena Not Treated Statistically	O'Dell
Sensitivity and Uncertainty Analyses	Martin

Realistic Large Break LOCA Methodology for Pressurized Water Reactors

Topical Report

- EMF-2103(P) Revision 0, “Realistic Large Break LOCA Methodology for Pressurized Water Reactors”

Approved version of this topical report will be referenced in License Actions

Realistic Large Break LOCA Methodology for Pressurized Water Reactors

Supporting Documents

- EMF-2102(P) Revision 0, "S-RELAP5: Code Verification and Validation"
- S-RELAP5 code and sample problems
- Various code documents (8)
  - S-RELAP5
  - RODEX3A
  - ICECON
  - Guidelines

Realistic LBLOCA Methodology Roadmap

Presenter: L. D. O 'Dell

Realistic LBLOCA Methodology Roadmap

Purpose: The Methodology Roadmap will provide an upper level overview of the complete methodology

Objective: The intent is to provide an overall perspective in support of the following presentations

Realistic LBLOCA Methodology Roadmap

Agenda

- Methodology Roadmap
  - Requirements and Capabilities
    - CSAU Element 1, Steps 1 through 6
  - Assessment and Ranging of Parameters
    - CSAU Element 2, Steps 7 through 10
  - Sensitivity and Uncertainty Analysis
    - CSAU Element 3, Steps 11 through 14

Requirements and Code Capabilities (CSAU Element 1)

Specify Scenario (CSAU Step 1)

- Selection of the transient to be analyzed dictates the processes that must be addressed
  - Specified the large break LOCA scenario

Select Plant (CSAU Step 2)

- Selection of plant type influences the dominant phenomena and their interactions
  - Selected W 3- and 4-loop plants and CE plants
  - All three plant types have inverted U-tube steam generators, a pressurizer connected to a hot leg, and ECCS injection into the cold legs
  - Experience with Appendix K LBLOCA analyses indicate that all three plant types behave similarly in the blowdown, refill, and reflood phases of a LBLOCA

Requirements and Code Capabilities (CSAU Element 1)

Identify and Rank Phenomena (CSAU Step 3)

- Develop Process Identification and Ranking Table (PIRT)
  - Performed by experts who are knowledgeable of specified LBLOCA scenario
  - The PIRT identifies and ranks the important phenomena for the specified LBLOCA scenario and plant types
    - The important phases of the LBLOCA scenario are defined
    - The important plant components are identified
    - The important phenomena in each component during each phase are identified
    - The relative importance of each phenomenon during each LOCA phase is identified

Requirements and Code Capabilities (CSAU Element 1)

Identify and Rank Phenomena (CSAU Step 3)

- The PIRT provides the basis for
  - Determining code applicability (does the code model the important phenomena and plant components)
  - Establishing the assessment matrix (identifying test data that contain the appropriate phenomena during each accident phase)
  - Identifying important phenomena to be quantified and ranged for evaluating uncertainties

Requirements and Code Capabilities (CSAU Element 1)

Identify and Rank Phenomena (CSAU Step 3)

- PIRT Development Process
  - Initial PIRT developed from Compendium
    - Average of expert and analytical hierarchy process ranking
  - Initial PIRT reviewed by three independent experts
    - Additional phenomena and ranking changes recommended
  - Final PIRT generated through peer review (Table 3.4 of EMF-2103(P))
    - Framatome ANP personnel
    - External experts (Dr. Hochreiter and M. J. Thurgood)
    - Consistent definitions applied for LBLOCA phases and phenomena

Requirements and Code Capabilities (CSAU Element 1)

Identify and Rank Phenomena (CSAU Step 3)

- LBLOCA Phases
  - Blowdown: Defined as the time period from initiation of the break until flow from the accumulators or safety injection tanks begins
  - Refill: Defined as the time period from end-of-blowdown until the mixture level in the vessel refills the lower plenum and begins to flow into the core
  - Reflood: Defined as the time period from initiation of flow into the bottom of the core until the temperature transient is completed

Requirements and Code Capabilities (CSAU Element 1)

Identify and Rank Phenomena (CSAU Step 3)

- Final PIRT
  - Numerous minor changes to phenomena rankings
  - Single-Phase Natural Convection deleted from PIRT
    - Covered in post CHF heat transfer
  - 3D Flow, Void Distribution and Generation combined into single phenomena
    - Flow and void distribution directly related
  - Accumulator Discharge added to PIRT
    - Discharge rate significant parameter in determining refill and reflood rates
  - Upper Head Component
    - Initial upper head temperature expected to have some impact on blowdown

Requirements and Code Capabilities (CSAU Element 1)

Select Frozen Codes (CSAU Step 4)

- Frozen versions of computer codes used for consistency throughout process
  - Selected frozen versions of RODEX3A and S-RELAP5
    - ICECON containment code included into S-RELAP5
  - RODEX3A code version UJUN00 used in all fuel rod analyses
  - Two versions of S-RELAP5 used in reported analyses, UJUL00 and UMAR01
    - UMAR01 included the addition of the final set of multiplication factors for the uncertainty analysis and corrections to the RODEX3A implementation in S-RELAP5
      - RODEX3A corrections were the result of the RODEX3A implementation verification
    - UJUL00 used for many of the assessments with electrical heater rods
    - UMAR01 used for some of the assessments with electrical heater rods and all analyses with nuclear fuel rods

Requirements and Code Capabilities (CSAU Element 1)

Provide Complete Documentation (CSAU Step 5)

- Documentation supporting the codes must be consistent with the frozen code versions
  - Developed models and correlations document, programmers guide, and user manuals for frozen codes
  - Code verification performed to insured consistency between codes and associated documentation
    - Performed with a combination of Framatome ANP and external personnel
    - Verification consisted of going through the coding to ensure that the models in the documentation were actually in the code and were coded correctly
    - Performed for RODEX3A and S-RELAP5 (including ICECON) models

Requirements and Code Capabilities (CSAU Element 1)

Determine Code Applicability (CSAU Step 6)

- Confirm presence of code models for important phenomena in PIRT
  - Verification performed on S-RELAP5 confirmed presence of documented models
  - Presence of PIRT required conservation and closure equations confirmed in S-RELAP5
  - Code numerics demonstrated through the performance of code sensitivity studies, assessments, and sample problem analysis
  - Code ability to model selected NPP confirmed by comparison of required NPP components and code component modeling capabilities
- S-RELAP5 demonstrated to meet requirements

Assessment and Ranging of Parameters (CSAU Element 2)

Assessment Matrix (CSAU Step 7)

- Select assessment matrix of separate and integral effect tests (SET/IET)
  - Support code evaluation of important PIRT phenomena
    - Defined as those phenomena ranked 5 or higher
  - Provide validation of selected NPP nodalization
  - Support demonstration of code scalability from experimental facilities to NPP
  - Support demonstration that even if compensating errors exist in the code, the code is capable of reliably predicting the selected scenario

Assessment and Ranging of Parameters (CSAU Element 2)

Assessment Matrix (CSAU Step 7)

- PIRT Phenomena
  - Sensitivity analyses were performed for all phenomena ranked 5 or higher
    - Over 250 analyses performed using the input decks for the 3 and 4-loop NPP
    - Sensitivity results classified as high, medium, and low
  - Based on the results of the sensitivity studies
    - Experimental facilities and specific tests were chosen for the important phenomena
    - Required plant data identified

Assessment and Ranging of Parameters (CSAU Element 2)

Assessment Matrix (CSAU Step 7)

- Nodalization
  - Based on the assessment matrix generated from the PIRT, only the SCTF was added to specifically address nodalization
- Scaling Considerations
  - The assessment matrix generated for the PIRT covered a scaling range from 1:1500 to 1:1
  - Counter part LOFT and Semiscale integral effect tests were selected to specifically support scaling

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Assessment and Ranging of Parameters (CSAU Element 2)

Assessment Matrix (CSAU Step 7)

- Compensating Errors
  - Occur if/when an error in one code model is compensated for by an error in another code model
  - May result in the code being able to predict some assessments but not others or produce different results in the assessments and the NPP calculations
  - Addressed by including integral effect and larger scale separate effect tests in the assessment matrix
    - FLECHT, FLECHT-SEASET, SCTF, CCTF, and THTF for core phenomena
    - UPTF for most other NPP components
    - LOFT and Semiscale for integral LBLOCA scenario evaluation

Assessment and Ranging of Parameters (CSAU Element 2)

Final Assessment Matrix

Facility	Tests	Assessment Purpose
THTF Heat Transfer	35	Heat transfer
THTF Level Swell	3	Void distributions
GE Level Swell	1	Void distributions
FRIGG-2	27	Void distributions
Bennett Tube	2	Heat transfer
FLECHT-SEASET and FLECHT	9	Heat transfer, Nodalization, Axial power distributions, Scalability, Upper plenum and hot leg entrainment
PDTF/SMART	4	Spacer effects
Marviken	9	Break flow

Assessment and Ranging of Parameters (CSAU Element 2)

Final Assessment Matrix (continued)

Facility	Tests	Assessment Purpose
W/EPRI 1/3 Scale	9	Cold leg condensation, Interfacial heat transfer
Mini-loop CCFL	3	Upper tie plate CCFL
Multi-dimensional flow	3	Core flow distributions
UPTF	14	ECCS bypass, Steam binding, CCFL, Scalability, Nodalization
CCTF	4	Steam binding, Nodalization, Scalability
SCTF	6	Nodalization
ACHILLES	1	Accumulator nitrogen discharge

Assessment and Ranging of Parameters (CSAU Element 2)

Final Assessment Matrix (continued)

Facility	Tests	Assessment Purpose
LOFT	4	Overall code performance, Nodalization, Scalability, Compensating errors
Semiscale	2	Blowdown heat transfer, Nodalization, Scalability, Compensating errors

15 SET facilities and 130 tests evaluated

2 IET facilities and 6 tests evaluated

Assessment and Ranging of Parameters (CSAU Element 2)

Nodalization (CSAU Step 8)

- Select common nodalization for use in SET, IET, and plant analyses
  - Selected nodalization must
    - Preserve dominant phenomena
    - Minimize code uncertainty
    - Support NPP design characteristics
    - Remain economical
  - Initial nodalization selected based on previous Framatome ANP experience
  - Revised based on plant model studies
  - Further revised based on peer review
  - Final nodalization validated/refined based on performance of SET and IET assessments
    - UPTF, SCTF, CCTF, and FLECHT-SEASET
    - LOFT and Semiscale

Assessment and Ranging of Parameters (CSAU Element 2)

Nodalization (CSAU Step 8)

- Select common nodalization for use in SET, IET, and plant analyses

- Other NPP components addressed in following presentation

Assessment and Ranging of Parameters (CSAU Element 2)

Code and Experiment Accuracy (CSAU Step 9)

- Determine individual parameter uncertainty for identified important PIRT phenomena
  - Uncertainty and biases determined by comparison of code to SET experiments defined in Assessment matrix
  - Impact of code biases demonstrated in the performance of SET and IET with biases applied
    - CCTF tests 54, 62, 67, and 68
    - LOFT tests L2-3, L2-5, LP-02-6, and LP-LB-1
    - Semiscale tests S-06-3 and S-07-1
- Assessment results addressed in following presentations

Assessment and Ranging of Parameters (CSAU Element 2)

Effects of Scale (CSAU Step 10)

- Potential code scaling effects must be quantified for bias and deviation
  - Scale effects address two issues
    - First is the scalability of the tests to a NPP
    - Second is the scalability of the code models from the tests to the NPP
  - Scalability of tests
    - Blowdown
      - Power-to-volume scaling demonstrated applicable for blowdown phase
    - Refill
      - Power-to-volume scaling demonstrated not applicable to refill phase
      - Full scale UPTF tests used to address refill phase
    - Reflood
      - Power-to-volume scaling demonstrated applicable for reflood phase

Assessment and Ranging of Parameters (CSAU Element 2)

Effects of Scale (CSAU Step 10)

- Potential code scaling effects must be quantified for bias and deviation
  - Scalability of Code models
    - Single-phase vapor heat transfer model demonstrated scalable
    - Film boiling heat transfer model demonstrated scalable
    - Core entrainment model demonstrated conservative and scalable
    - Critical flow model demonstrated by application to full scale tests
    - Carry-over to steam generator demonstrated conservative
    - Pump model uses full scale pump data with Semiscale two-phase degradation
    - Cold leg condensation model validated on full scale UPTF test
    - ECCS downcomer bypass demonstrated conservative for full scale UPTF tests
    - Lower plenum sweep-out demonstrated conservative for full scale UPTF tests

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Reactor Input Parameters and State (CSAU Step 11)

- Plant specific variations in input and process parameters are determined based on plant data or analytical studies
  - Analysis must address the Technical Specification limits for those parameters impacting the LBLOCA
  - Plant input and process parameter list developed

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Sensitivity and Uncertainty Analysis (CSAU Element 3)

Reactor Input Parameters and State (CSAU Step 11)

- Plant specific variations in input and process parameters are determined based on plant data or analytical studies
  - Plant input and process parameter list developed

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Reactor Input Parameters and State (CSAU Step 11)

- Plant specific variations in input and process parameters are determined based on plant data or analytical studies
  - Sensitivity studies are performed for the identified NPP parameters to quantify the impact on the LBLOCA
    - Used to assess need for plant data

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Reactor Input Parameters and State (CSAU Step 11)

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Reactor Input Parameters and State (CSAU Step 11)

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Plant Sensitivity Calculations (CSAU Step 12)

- The code's output sensitivity to the plant specific input and process parameter variations is determined from sensitivity studies using the NPP model
  - Those plant specific input and process parameters found to impact the code's results are included in the statistical analysis
- Framatome ANP Approach

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Plant Sensitivity Calculations (CSAU Step 12)

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Plant Sensitivity Calculations (CSAU Step 12)

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Plant Sensitivity Calculations (CSAU Step 12)

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Determine Combined Bias and Uncertainty (CSAU Step 13)

- Methodology Application to 4-Loop Sample Problem
  - RODEX3A input developed for Framatome ANP 17x17 fuel assembly design
  - S-RELAP5 input developed for 4-loop NPP
    - Used input based on several different plants and consequently can only be considered representative of a 4-loop NPP

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Total Uncertainty (CSAU Step 14)

- The statement of total uncertainty for the analysis is given as a statement of probability for the limiting value of the primary safety criteria
- For the 4-loop sample problem the limiting values for the primary safety criteria are:

Criteria	95/95
- PCT	1668 F
- Maximum Nodal Oxidation	1.1 %
- Maximum Core Oxidation	0.02 %

50/50 PCT = 1375 F

Sensitivity and Uncertainty Analysis (CSAU Element 3)

Total Uncertainty (CSAU Step 14)

- The statement of total uncertainty for the analysis is given as a statement of probability for the limiting value of the primary safety criteria.
- A 3-loop licensing analysis with 15x15 fuel has also been performed and the limiting values for the primary safety criteria are:

Criteria	95/95
- PCT	1826 F
- Maximum Nodal Oxidation	1.6 %
- Maximum Core Oxidation	0.06 %

50/50 PCT = 1543 F

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Realistic LBLOCA Methodology Roadmap

Conclusions

- An overview of the complete Framatome ANP Realistic LBLOCA has been provided
- The overview presented the Framatome ANP application of the CSAU methodology elements and steps
- The overview has set the stage for following presentations which will address various components of the methodology in additional detail

Statistical Methods

Presenter: W. T. Nutt

Statistical Methods Overview

Application to LBLOCA

Impact on PIRT and Sensitivities

Statistical Methods - [ ]

Background

- The goal is to show that the upper tolerances of the calculated safety-related values do not exceed the criteria for a LBLOCA
- Statistical methods are used to calculate the upper 95/95 tolerances on PCT, local cladding oxidation and core-wide cladding oxidation
- The probability distributions for the safety-related values are not normal, so non-linear methods of propagating uncertainties are used
  - Response surfaces

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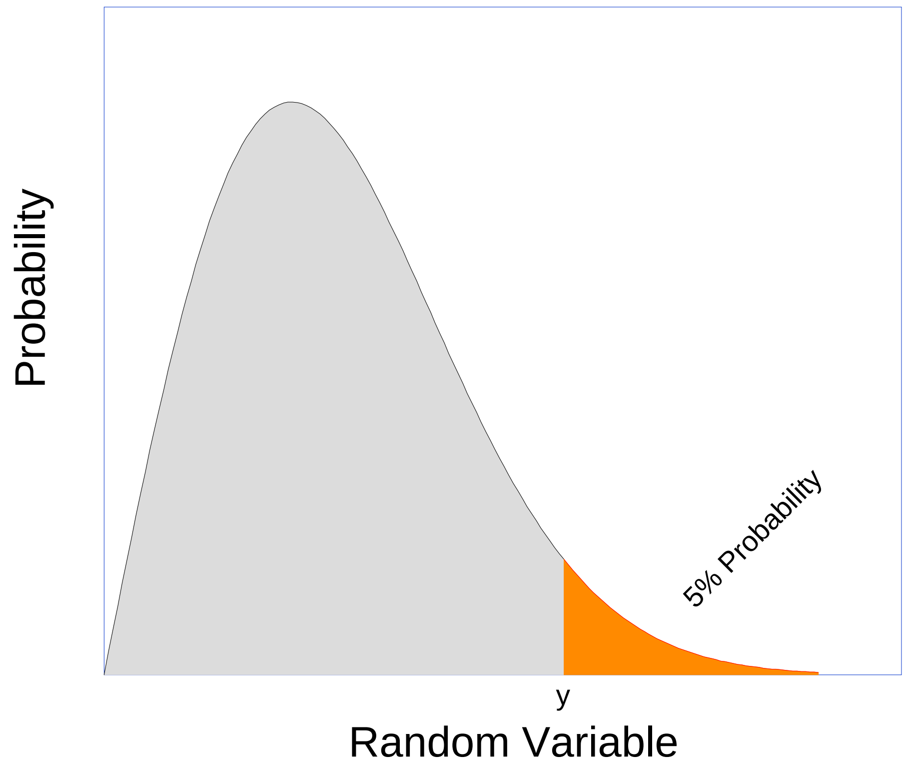
Statistical Methods - [ ]

Statistical Methods - [ ]



Statistical Methods - [ ]

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Statistical Methods - Application to LBLOCA

Response Surface Methods

- These methods were used by the Technical Program Group (TPG) to apply CSAU to LBLOCA
- A series of cases is run using various combinations of the inputs to represent their uncertainty ranges
- The results of all of the runs are fit with a simplified functional form – usually a polynomial with non-linear terms
- The functional form is then used to calculate the probability distributions for the results
- Advantages
    - They give the complete probability distributions for PCT, localized cladding oxidation, core wide cladding oxidation
    - These can be combined with additional uncertainties not considered in the original analysis

Statistical Methods - Application to LBLOCA

Response Surface Methods (continued)

- Weaknesses
  - They are time consuming and severely limited in the number of parameters they can treat
  - The largest errors in the fits are at the extremes of the fit range
    - The tails of the probability distribution have the largest uncertainty
  - To include a large number of variables, subsets are treated independently and multiple response surfaces created and then combined
    - Uncertainties propagated at different conditions
    - Interactions between uncertainties are not considered

Statistical Methods - Application to LBLOCA

Statistical Methods - Impact on PIRT and Sensitivities

Phenomena Identification and Ranking Table (PIRT)

- The PIRT is created to address the unequal influence of different processes and phenomena on the outcome
  - Candidate phenomena selected based on global experience with LBLOCA
  - Ranked by impact on outcome
  - Accurate ranking is very important for response surface methodology
  - The number of phenomena and processes considered statistically is limited (the TPG used 7 parameters)
    - Excluding important phenomena is a significant concern

Statistical Methods - Impact on PIRT and Sensitivities

Phenomena Identification and Ranking Table (PIRT) (continued)

Statistical Methods - Impact on PIRT and Sensitivities

Sensitivities

- Response Surface Method
  - Sensitivity studies are used to quantify the importance of some phenomena for the PIRT
    - NPP sensitivity studies quantify the variations in the safety-related quantities for input variations
  - Sensitivity studies are used to set biases and uncertainties
    - Sensitivity studies on NPP model are used to propagate input uncertainties by generating a multidimensional fit to the PCT and other safety-related quantities

Statistical Methods - Impact on PIRT and Sensitivities

Sensitivities (continued)

Statistical Methods - Impact on PIRT and Sensitivities

Statistical Methods - Impact on PIRT and Sensitivities

Statistical Methods - Impact on PIRT and Sensitivities

Statistical Methods - Impact on PIRT and Sensitivities

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Statistical Methods - Impact on PIRT and Sensitivities

Statistical Methods - Impact on PIRT and Sensitivities

Statistical Methods - Summary

Nuclear Power Plant Nodalization (CSAU Step 8)

Presenter: R. P. Martin

Presentation Summary

Introduction

- Background
- Objectives
- Explanation of strategy

Changes from Past User Experience

- Loop model
- Reactor vessel model
- ECCS model
- Containment model

Introduction

Quotes from "Quantifying Reactor Safety Margins"

*"The plant model must be nodalized **finely enough** to represent both the important phenomena and design characteristics of the NPP but coarsely enough to **remain economical**."*

*"Thus, the preferred path is to establish a **standard NPP nodalization** for the subsequent analysis. This minimizes or removes nodalization, and the freedom to manipulate noding, as a contributor to uncertainty."*

*"Therefore, a nodalization selection procedure defines the **minimum noding needed to capture the important phenomena**."*

*"This procedure starts with analyst experience in **previous code assessment** and application studies and any documented nodalization studies. Next, nodalization studies are performed during the simulation of separate- and integral-effects code data comparisons. Finally, an iterative process using the NPP model is employed to determine sufficiency of the NPP model nodalization."*

Optimize preserving phenomena, minimizing numerical uncertainty, conform to design, minimize computational expense

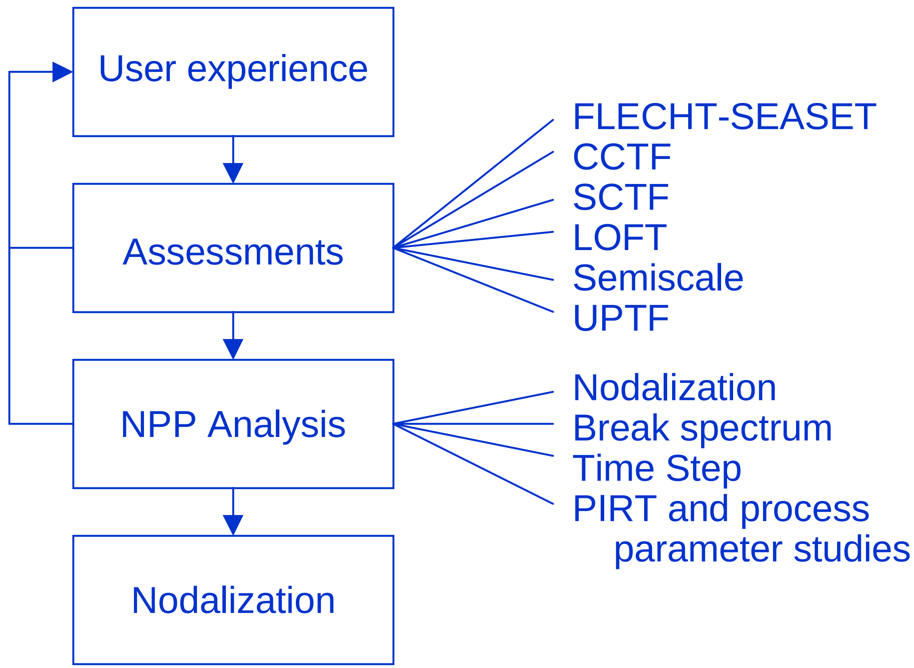
Goal: Satisfactory Nodalization

Necessary Conditions (& method of resolution)

- Discriminate key structure characteristics (drawings)
- Obtain acceptable steady-state agreement with plant (calculations)
- Preserve dominant phenomena (code models & calculations)
- Maintain reasonable computational economics (calculations)
- Maintain scalability (assessments)
- Preserve accuracy, numerical stability, and convergence (calculations)

Issue	Evaluation
Accuracy	Assessment
Stability	Semi-Implicit Numerics
Convergence	Time Step

Nodalization Development



Involved many iterations

Changes from Past User Experience

Loop: (Figure 4.3)

- Crossover Piping & Pump
- Break

Reactor Vessel: (Figure 4.4)

- TWODEE Component
  - Downcomer (Figure 4.5)
  - Core (Figure 4.6-4.7)
  - Upper Plenum (Figure 4.8-4.9)
- 3-Node Lower Plenum (Figure 4.4)
- More bypass detail (Figure 4.6)

ECCS - more detail (Figure 4.10)

Containment - ICECON models

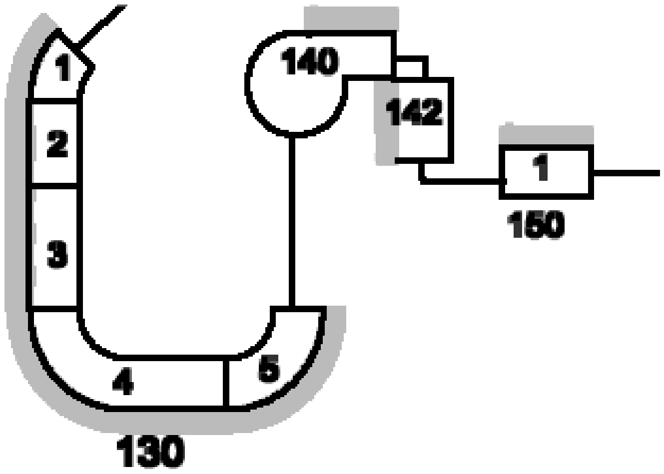
Crossover Piping & Pump

Pump - best-estimate model from plant and vendor data (component model in S-RELAP5)

Adopted small break model guideline for crossover piping and pump discharge (no significant sensitivity on phenomena expected for LBLOCA)

Prediction of loop seal clearing

Resists unphysical backflow into pump



Break Model

Reactor Vessel

Downcomer

Dominant phenomena influence the duration of ECCS bypass (condensation and hot wall effects)

- No sensitivity to increasing axial nodalization (UPTF Test 6)
- ECCS bypass reduced with finer azimuthal nodalization (3-loop plant model)
- However, finer azimuthal nodalization doesn't scale well for smaller tests (i.e., Semiscale)

UPTF Test 6 Countercurrent flow test: steam and ECCS water

Lower Head/Plenum

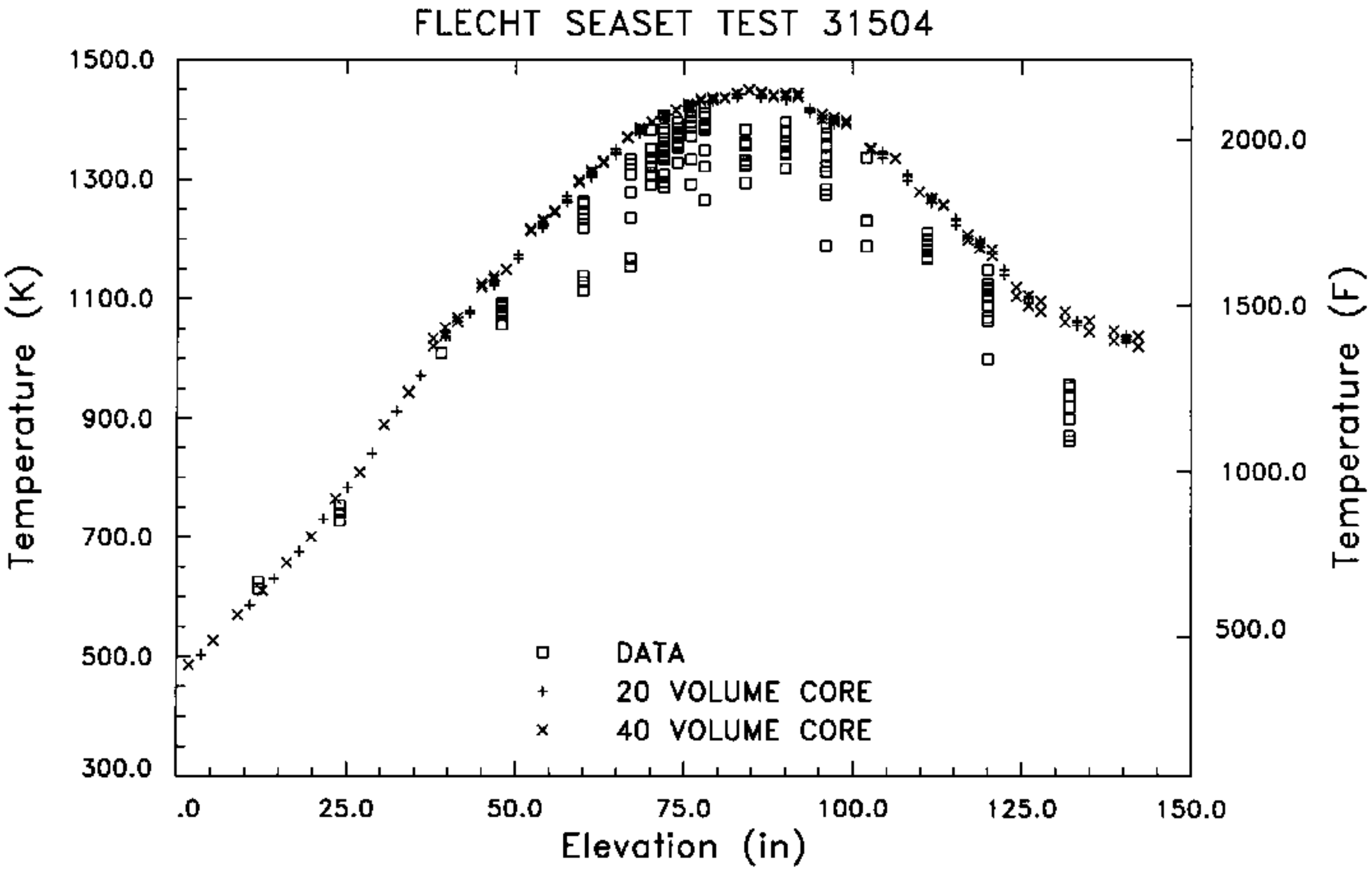
Dominant phenomenon is liquid sweepout

Core, Core Bypass, Fuel

All key phenomena treated statistically except multi-dimensional flow

Core nodalization provides as much detail as computationally tolerable

Core Axial Nodalization



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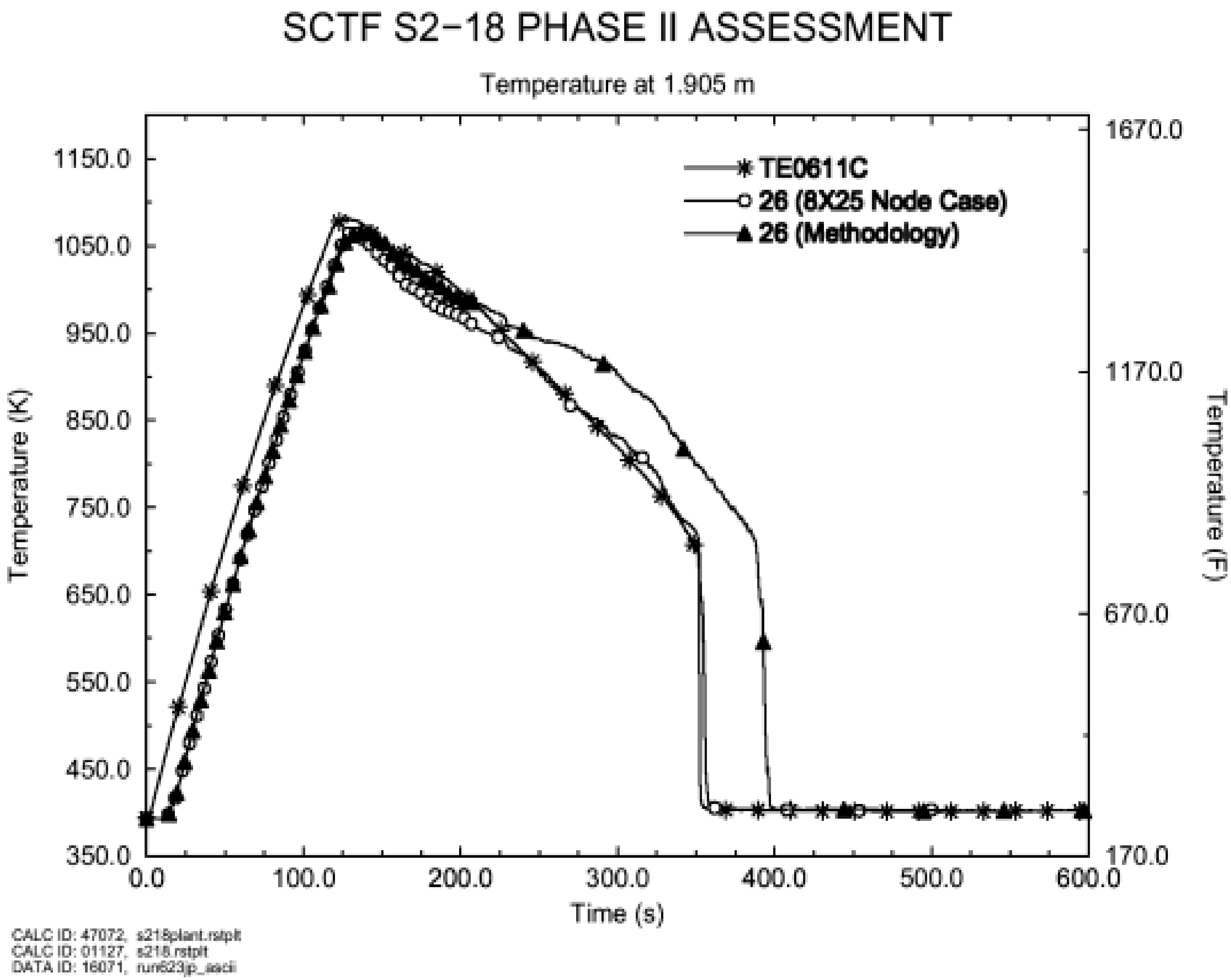
SCTF PCT - Test S2-18

Coarser model allows less cooling resulting from cross flow



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Upper Head/Plenum

Considerable investigation with plant model

ECCS Model

Detailed model used to common LPSI header to capture flow split variations

Accumulator discharge (treated statistically) and non-condensible gas transport (low sensitivity) are dominant phenomena

Containment

ICECON (CONTEMPT) models used to calculate pressure and temperature

Convergence Study

(Appendix C EMF-2103)

Demonstration of solution convergence has been done for S-RELAP5 statistically

- Numerical uncertainty is expected from complexity of the LOCA problem; however, phenomena are preserved and PCT predictions are bounded

PCT variation found to be ±30°F (95/50)

Summary

Objectives

- Explanation of strategy

Changes from past user experience

- Based on capturing or improving the resolution of important phenomena
  - Loop model
  - Reactor vessel model
  - ECCS model
  - Containment model

Convergence study demonstrated numerical stability

PIRT Phenomena Treated Statistically (supporting CSAU Step 9)

Presenter: R. P. Martin

Purpose

To give an overview of the uncertainty analysis for the following PIRT parameters

- Stored Energy
- Oxidation
- Decay Heat
- Critical Heat Flux
- Core Post-CHF Heat Transfer
- Tmin
- Break Flow
- Steam Binding
- Cold Leg Condensation
- Accumulator Discharge
- Reactor Vessel Host Walls
- Containment Pressure

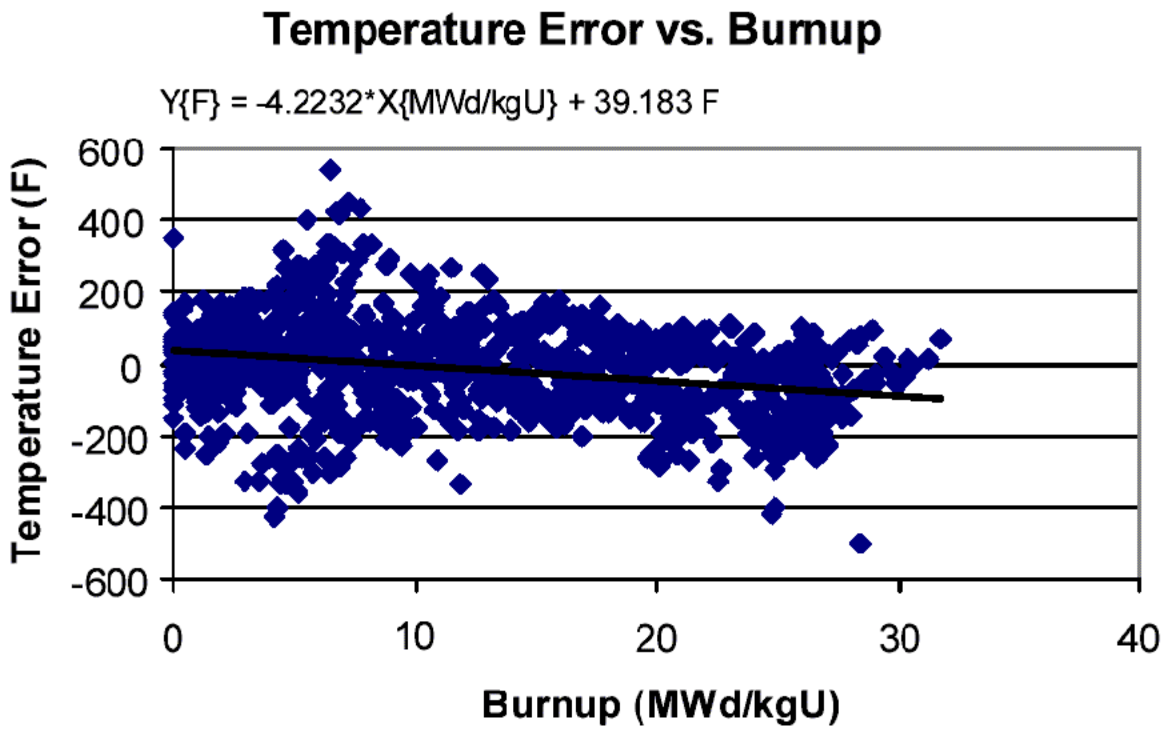
Stored Energy

Calculated with RODEX3A

SER restrictions which are addressed

- Statement of uncertainty
  - Temperature standard deviation = 130°F
- Underprediction of stored energy at <14kW/ft
  - Not important since all T.S. limits >14kW/ft
  - Only applies for burnup <1 GWD/MTU
- Bias as a function of exposure
  - A bias term was developed and applied in the statistical analysis

Stored Energy



Expression for centerline temperature bias vs. burnup derived and applied in RLBLOCA methodology (via multiplier on fuel conductivity)

Oxidation

S-RELAP5 incorporates Cathcart-Pawel model, original documentation includes error analysis:

$$\frac{\delta_\phi^2}{2} = 0.01126\exp(-35890/RT) \equiv \frac{\partial \Delta r_\phi}{\partial t} = \frac{0.000002252}{2\Delta r_\phi}\exp(-18062/T)$$

Assuming a normal distribution results in the following uncertainties

Constant term σ= 18.2%

Exponential term σ= 1.3%

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Decay Heat

1979 ANSI/ANS standard

- Infinite operating time at full power
- All fissions from U-235
  - 200 MeV/fission (conservatively low -> more fission products)
- ANS Standard for treatment of neutron capture in fission products
- Actinide decay included

This model was assessed against a more detailed model and from this, a 1-σ uncertainty of [   ] was derived

Critical Heat Flux

THTF data provided high pressure, steady-state film-boiling data for rod bundles

- Heat transfer coefficients were collected for the 22 tests
- S-RELAP5 calculations simulating the 22 test were made to compare HTC
- Biasi CHF correlation scaled by **[ ]** to improve HTC agreement

RLBLOCA sensitivity to CHF for NPPs was demonstrated to be “low” during sensitivity studies

Core Post-CHF Heat Transfer

Bromley & Dispersed Flow Film Boiling (FB)

- FLECHT, FLECHT-SEASET, and THTF tests used to describe the uncertainty in two multipliers in S-RELAP5

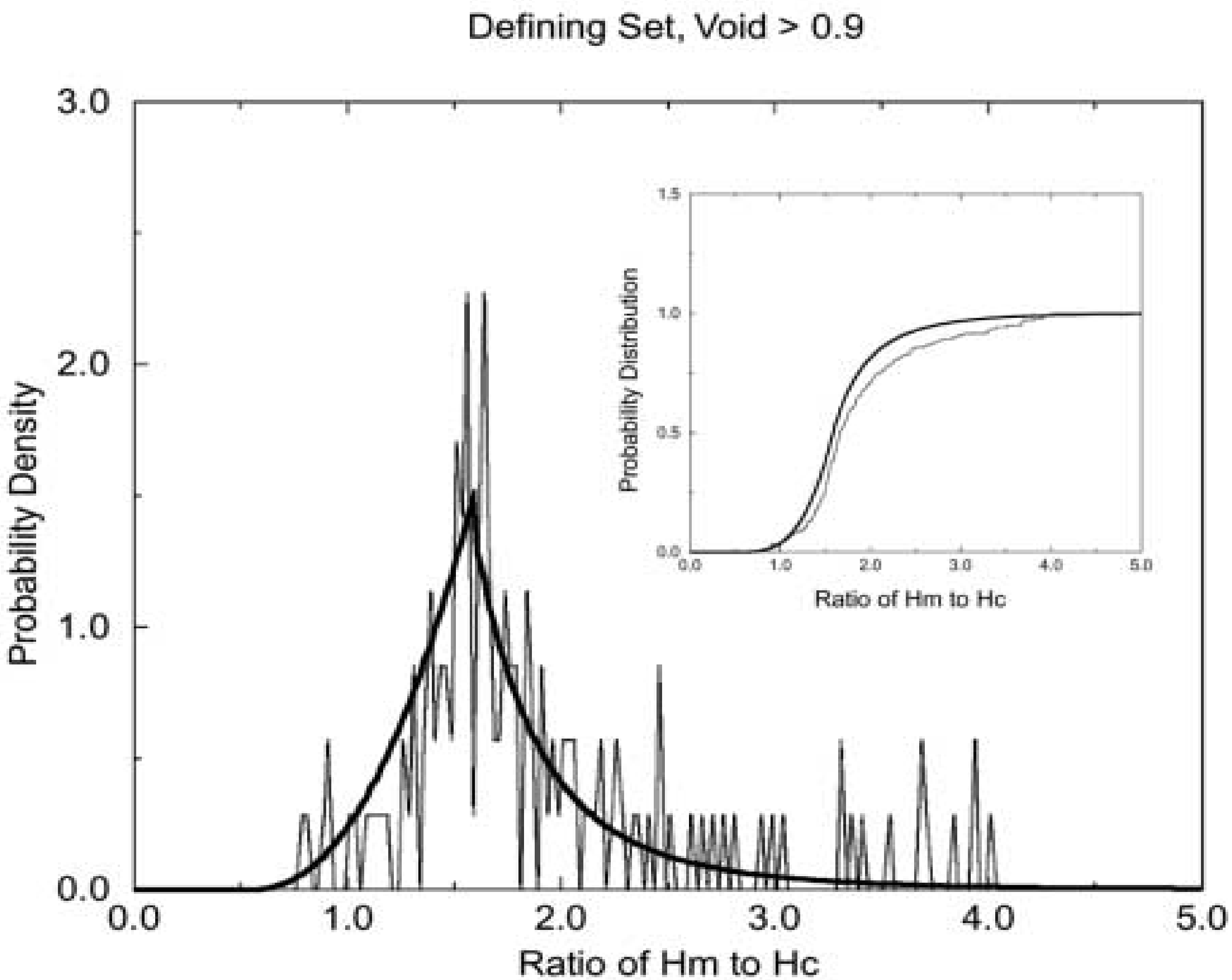
Multiplier Correlation

$$M = \frac{H_{meas}}{H_{calc}}$$

Bromley & dispersed flow uncertainty: M = [1.0, 1.75]

Probability distribution functions have the form (see next slide):

Core Post-CHF Heat Transfer



Tmin

The overall approach:

- Developed a distribution for the quench temperature using the low pressure database
- Demonstrated that the low pressure distribution is conservative with respect to high pressure data and zircaloy material effects
- Assumed that the minimum film boiling temperature is essentially equal to the quench temperature
- Developed a relation between Tmin and the code parameter TMINK
- Combined the distribution for the quench temperature with the relationship between Tmin and TMINK to produce the value and uncertainty distribution for TMINK

Tmin

FLECHT-SEASET Test 31302 bounds all data sets examined:

- 6 other FS tests, G1/G2 tests,THTF, & ROSA/TPTF
- [ ]

Adjustments needed on FS 31302 results for differences between Tmin and TMINK

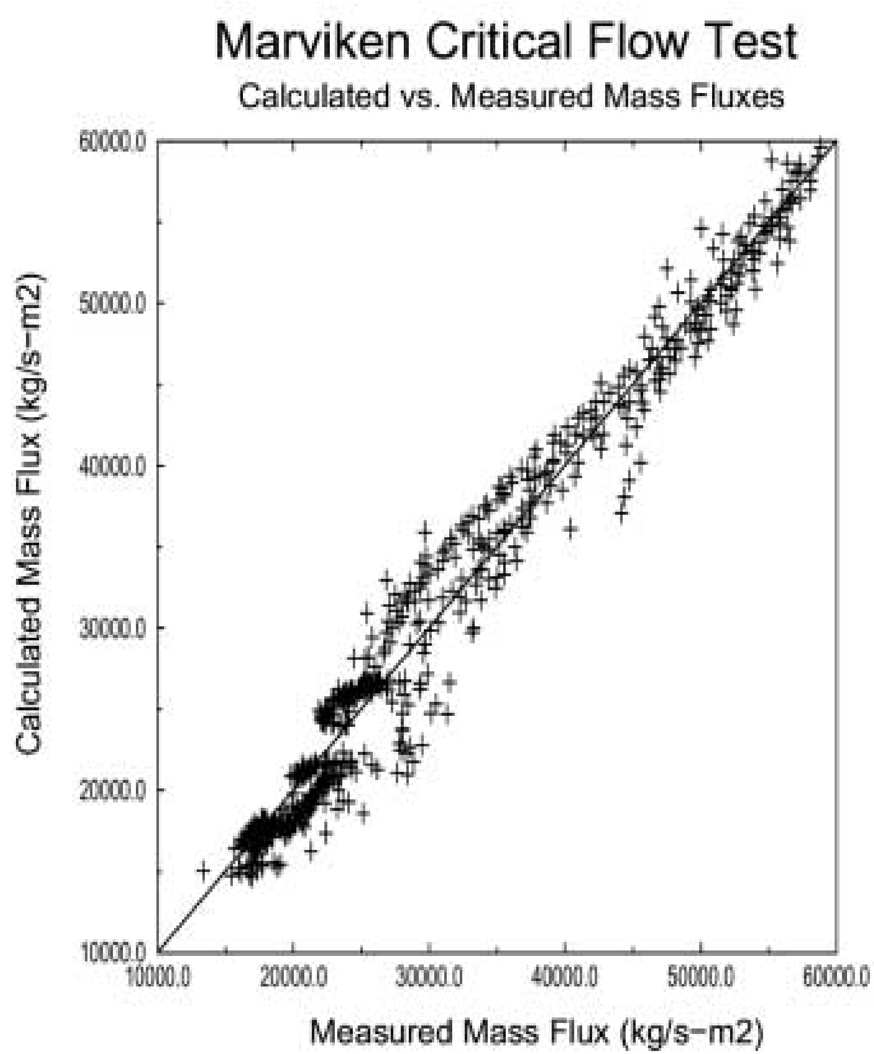
- [ ]

Critical Flow

Critical Flow

- Nine Marviken tests, numbers 2, 6, 8,16, 17, 20, 22, 24 and 25, were selected for the assessments based on the availability of electronic data
- Nozzles of various length-to-diameter ratios are used in the tests

Combined 2ϕ statistics derived:



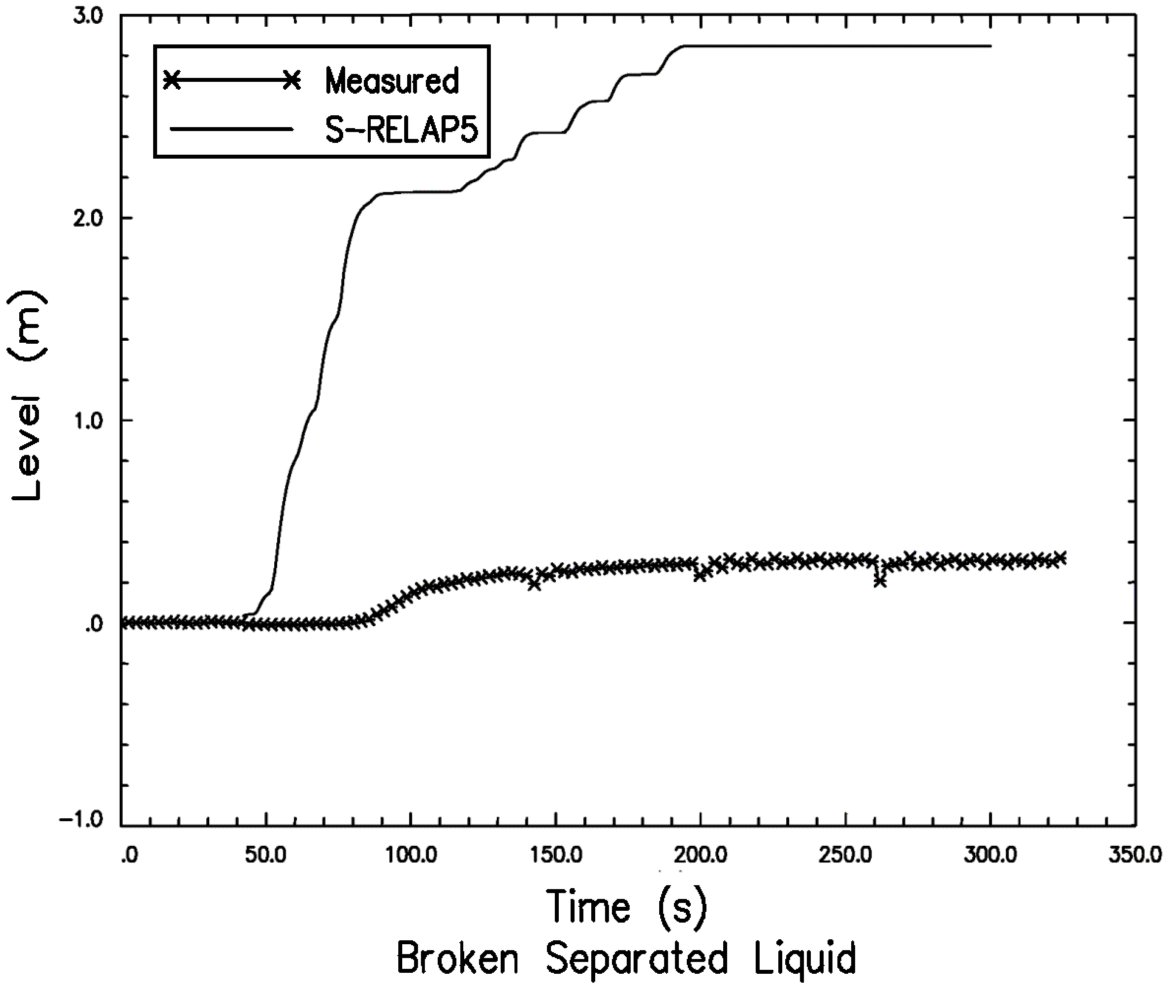
Steam Binding

No explicit parameter; however, the phenomena is dependent on liquid entrainment into the steam generator (and containment pressure)

- FLECHT-SEASET, CCTF, & UPTF used to examine liquid entrainment from core through steam generators
- Comparisons of UP liquid levels in all cases show that S-RELAP5 overpredicts water entrainment from core
- For UPTF & CCTF, liquid entrainment from steam generator was measured by liquid accumulation in a collection tank
- Variations in FIJ from 1-5 in CCTF assessment, **[ ]** aligns well with larger values and gives reasonable predictions of collection tank liquid level (results also show S-RELAP5 predicts more SG flashing)
- Validation of **[ ]** performed on full-scale UPTF Test 10 Run 81

Steam Binding

SGS Collection Tank Liquid Levels from UPTF Test 10 Run 81



Cold Leg Condensation

RLBLOCA multiplier CONMAS created for S-RELAP5

- 19 data points from W/EPRI 1/3 scale condensation experiment used to derive uncertainty

- CONMAS applies to cold Leg and downcomer - (low condensation factors may force the completion of this mixing in the downcomer)

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Accumulator Discharge & RV Hot Wall Effects

Accumulator Discharge dependent on flow resistance and pressure. Plant supplied information and Technical Specifications are used to range this parameter (discussion in a later presentation).

RV hot wall effects related to nucleate boiling inhibiting ECC penetration. The effect of this boiling may be maximized by locking the RV walls into nucleate boiling by raising CHF multiplier to a large value.

- Generally, UPTF tests 6&7 showed S-RELAP5 conservatively predicting ECCS bypass
- A 50/50 probability is assigned to enable this lockout
- The lockout is considered conservative

Containment Pressure

Containment models in S-RELAP5 provide back pressure boundary condition to the RCS

- Best-estimate to conservative assumptions made to model containment sprays and fan coolers
- Pressure ranged indirectly by varying the containment volume from a best-estimate value to the maximum free volume
- Reduced containment pressure is conservative since it will maximize the steam binding effect and the mass lost out the break during blowdown and ECC bypass

Summary

Evaluation of Code Biases

Presenter: S. E. Jensen

Evaluation of Code Biases

Purpose of Bias Evaluation

Definition of Code Biases

Facility and Test Assessments Used to Evaluate Code Biases

For Each Facility

- Summary of code bias effects
- Example results from bias evaluation calculations
- Conclusions based on assessments from each facility

Overall Conclusions Regarding Effects of Code Biases

Evaluation of Code Biases

Purpose of Evaluation

- Purpose of bias evaluation is to evaluate the effects of biases with large scale or integral test assessments
- Integral test assessments include interactions of biases and transition effects
- Code biases determined from separate effects tests evaluations
- When applied to separate effects tests, the biases improve agreement between calculations and measured data
- When biases are applied in integral test assessments, we expect that the evaluations should show improved comparisons with data compared to unbiased results

Evaluation of Code Biases

Code biases are determined in steps 9 & 10 of CSAU procedure

For S-RELAP5 the following code biases were determined

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Evaluation of Code Biases

Facility and test assessments used to evaluate code biases

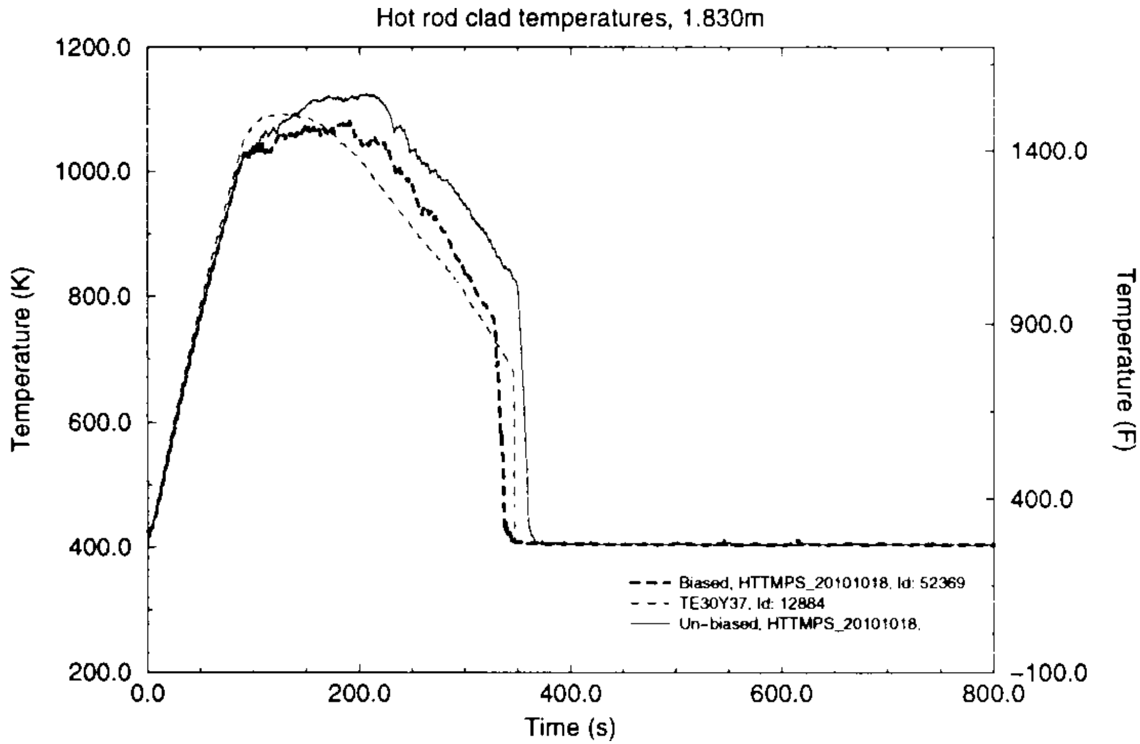
- Cylindrical Core Test Facility (CCTF)
  - Four CCTF test assessments (Tests 54, 62, 67,and 68)
- Loss of Fluid Test Facility (LOFT)
  - Four LOFT test assessments (Tests L2-3, L2-5, LP-02-6, and LP-LB-1)
- Semiscale test Facilities
  - Semiscale Mod 1 facility, Test S-06-3
  - Semiscale Mod 3 facility, Test S-07-1
- Code bias evaluations for all cases are shown in Section 4.3.4 of report EMF-2103

Evaluation of Code Biases - CCTF

Summary of code bias effects - CCTF Tests

- CCTF assessments show that the code calculated the trends of the experimental data for both biased and unbiased calculations
- Both the unbiased and biased calculations tend to overpredict the temperature data at or near the calculated PCT location
- The biased calculation tends to fall between the data and the unbiased results

Example of bias evaluation results for CCTF test 54 are shown



CCTF Test 54 Temperatures at Measured PCT Node

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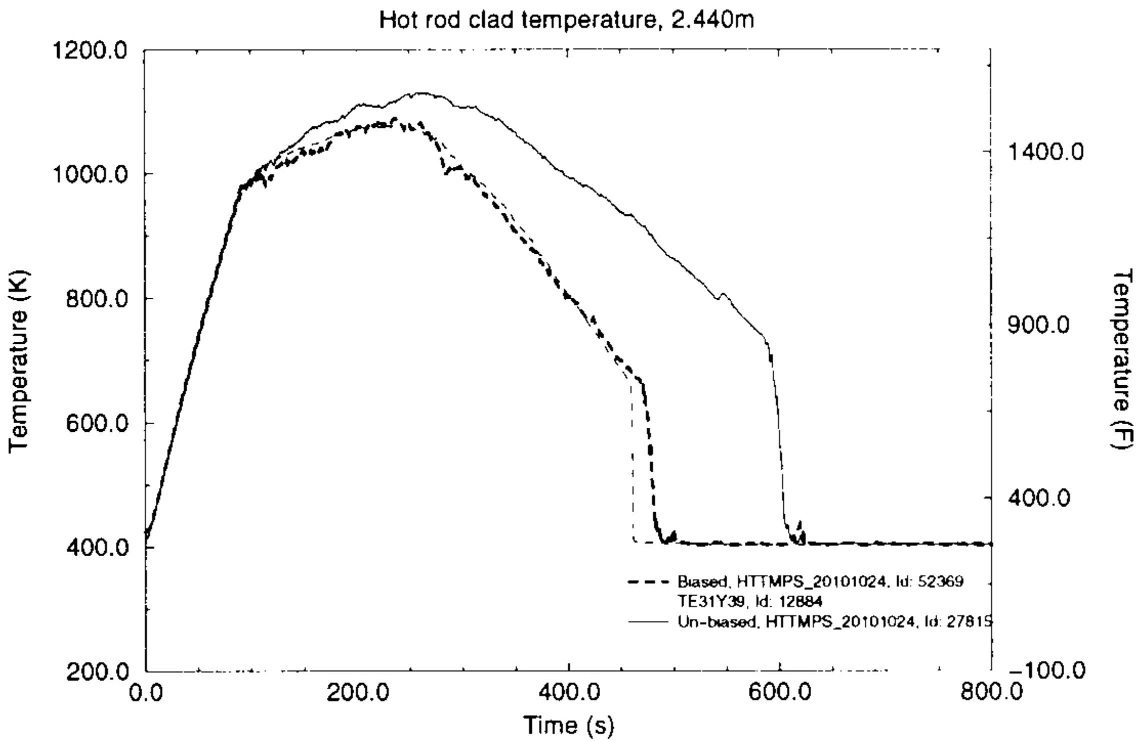
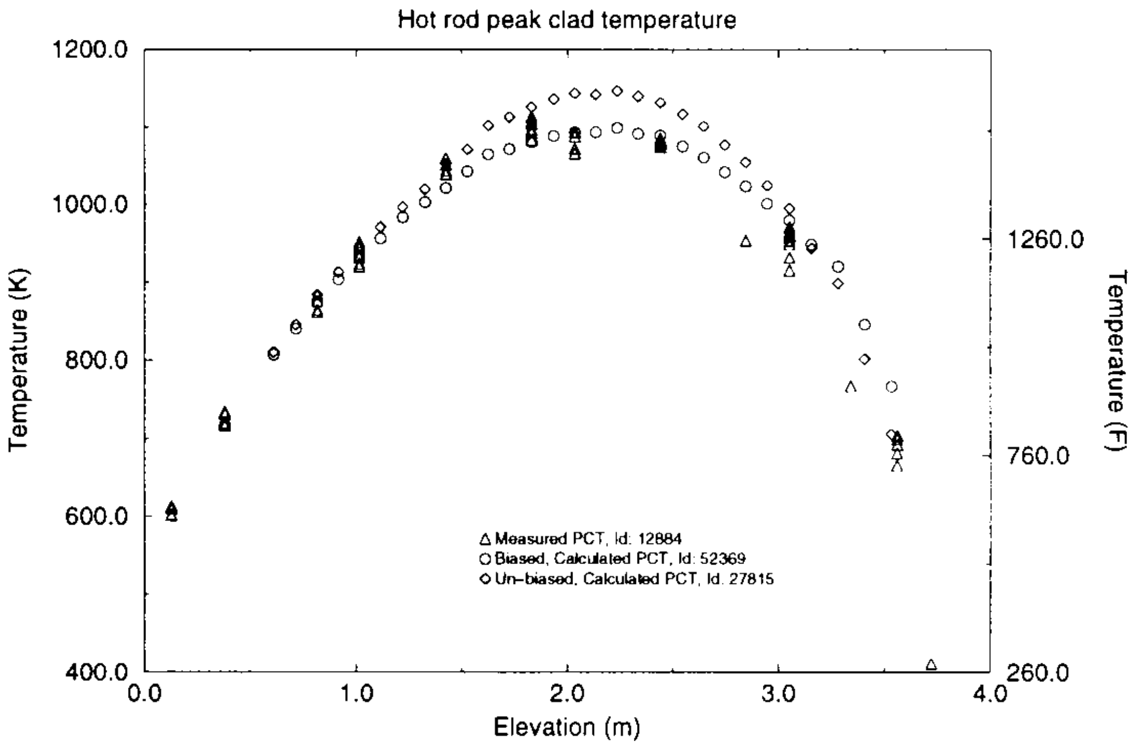


CCTF Test 54 Temperatures Near Calculated PCT Node



CCTF Test 54 PCT Profile

Evaluation of Code Biases - CCTF

Conclusions

- Inclusion of the biases resulted in improved but conservative PCT calculations in three of the four evaluation tests
- In the fourth test, which is a low PCT case, the inclusion of the biases improved the calculation of the general trends and produced a good comparison but slightly lower calculated PCT
- The biases on Tmin and dispersed film boiling were the major contributors to the observed differences between the calculations

Evaluation of Code Biases - LOFT

Summary of code bias effects - LOFT Tests

LOFT Test LP-LB-1

- Except for top-down quenching, the evaluation shows that the code calculated the trends of the experimental data
- Both the unbiased and biased calculations tend to overpredict the data. The biased calculation, however, tends to fall between the data and the unbiased results, and tends to be within the measured uncertainty for ~20% of the data.
- The interphase condensation multiplier had virtually no effect on the transient and no effect on PCT

Evaluation of Code Biases - LOFT

Summary of code bias effects - LOFT Tests

LOFT Test LP-02-6

- The Test LP-02-6 evaluation shows that the calculated peak temperatures overpredict the measured peak temperatures, except in the upper core region
- The biased calculation shows little difference from the unbiased case, although the biased results fall between the measured and unbiased temperatures
- The conclusion from the LP-02-6 assessment is that the code still is conservative, even with the application of the biases

Evaluation of Code Biases - LOFT

Summary of code bias effects - LOFT Tests

LOFT Test L2-5

- The evaluation shows that the unbiased calculated temperatures slightly exceed the measured temperatures
- Biased calculated temperatures are generally within measured data
- PCT for biased calculation is below measured PCT
- Conservatisms shown for LOFT Test L2-5 is less than other LOFT assessments

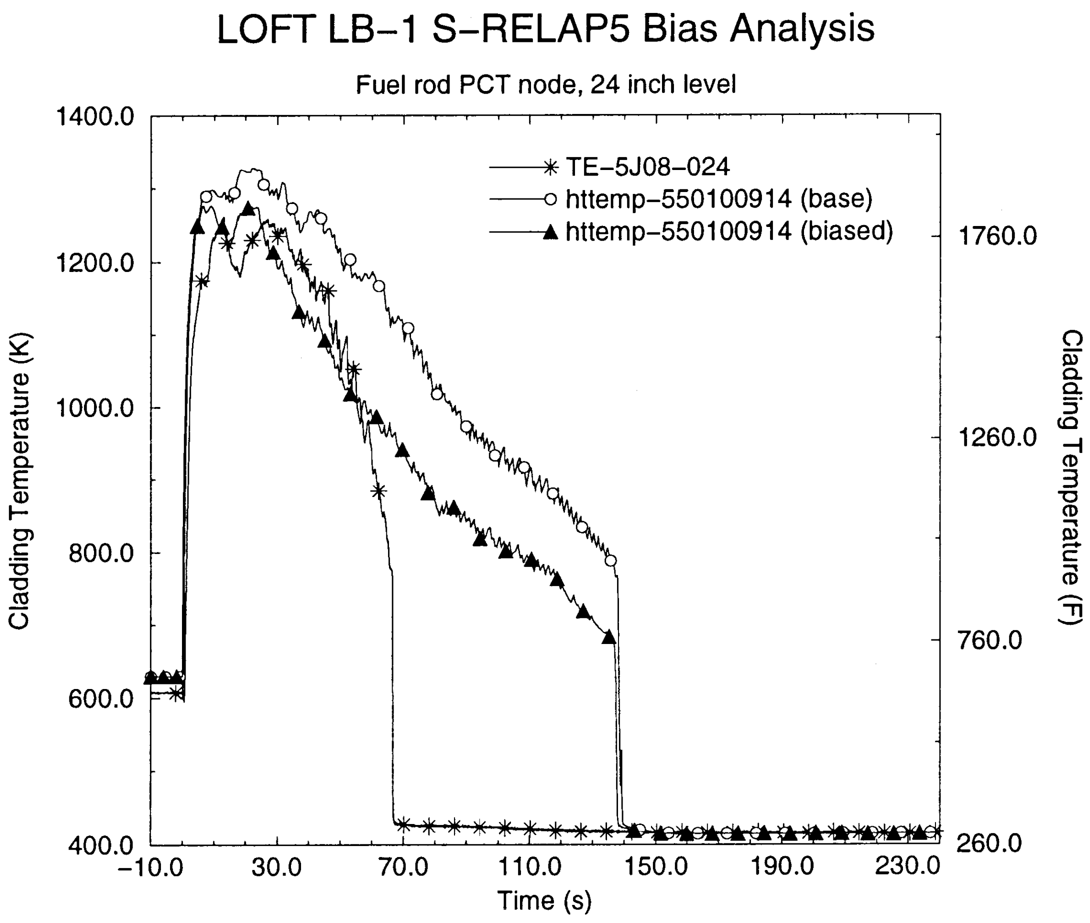
Evaluation of Code Biases - LOFT

Summary of code bias effects - LOFT Tests

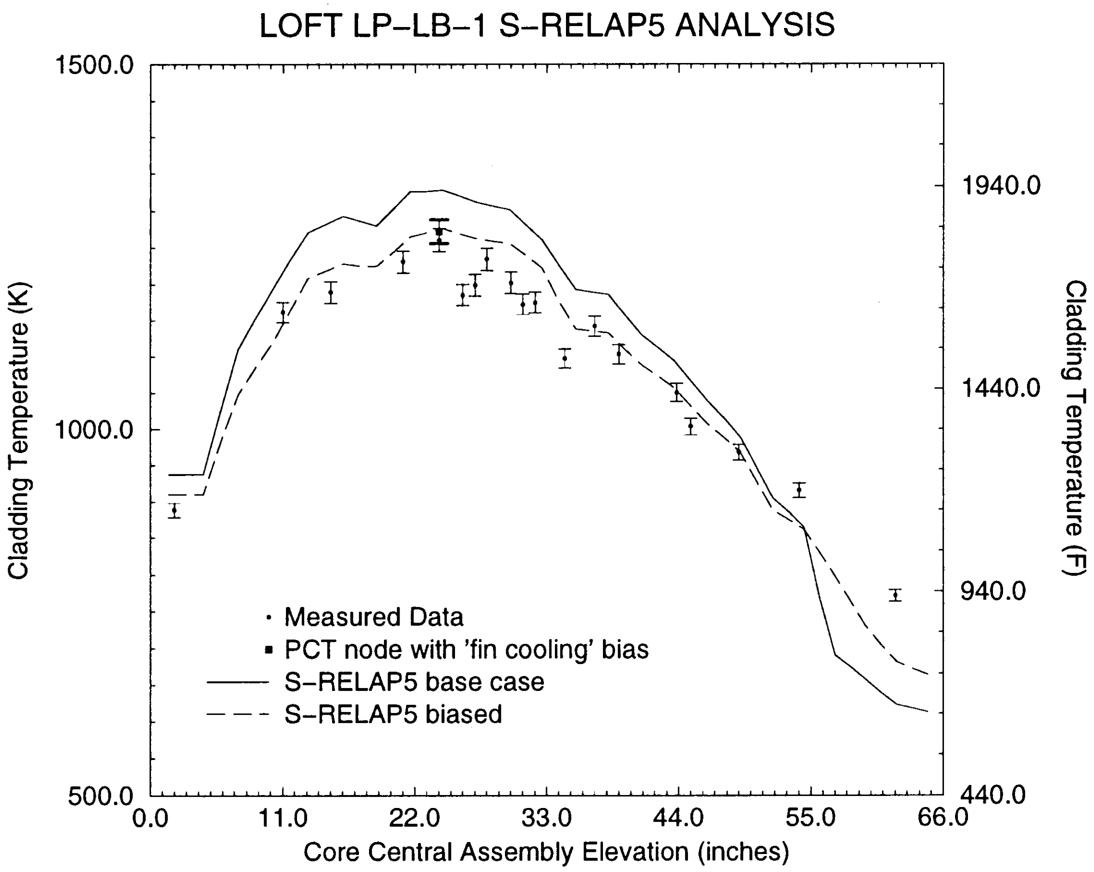
LOFT Test L2-3

- A characteristic of the L2-3 test is total core quench immediately after the blowdown peak temperature occurred. The quenching was caused by the pumps running at 100% speed. The code results do not show the core quenching immediately after the blowdown peak.
- Temperatures from the biased calculation are lower than the temperatures from the unbiased calculation
- Both calculated results overpredict the measured temperatures

Example results are shown for the Test LP-LB-01 evaluation



LOFT LP-LB-1 Temperatures at Measured PCT Node



LOFT LP-LB-1 PCT Profile

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Evaluation of Code Biases - LOFT

Conclusions

- The S-RELAP5 calculated results from the biased calculations agreed better with the data than the unbiased calculation results
- The S-RELAP5 calculated PCT results are still conservatively high compared to the measured data

Evaluation of Code Biases - Semiscale

Summary of code bias effects - Semiscale Tests

Semiscale Test S-06-3

- Test S-06-3 was performed in the Mod 1 facility (40 heated rods, 5.5 ft long)
- Little change between biased and unbiased calculated results
- The comparisons with data were not improved by application of code biases
- The biased temperature results are lower than the unbiased results in the vicinity where the calculated PCT occurs

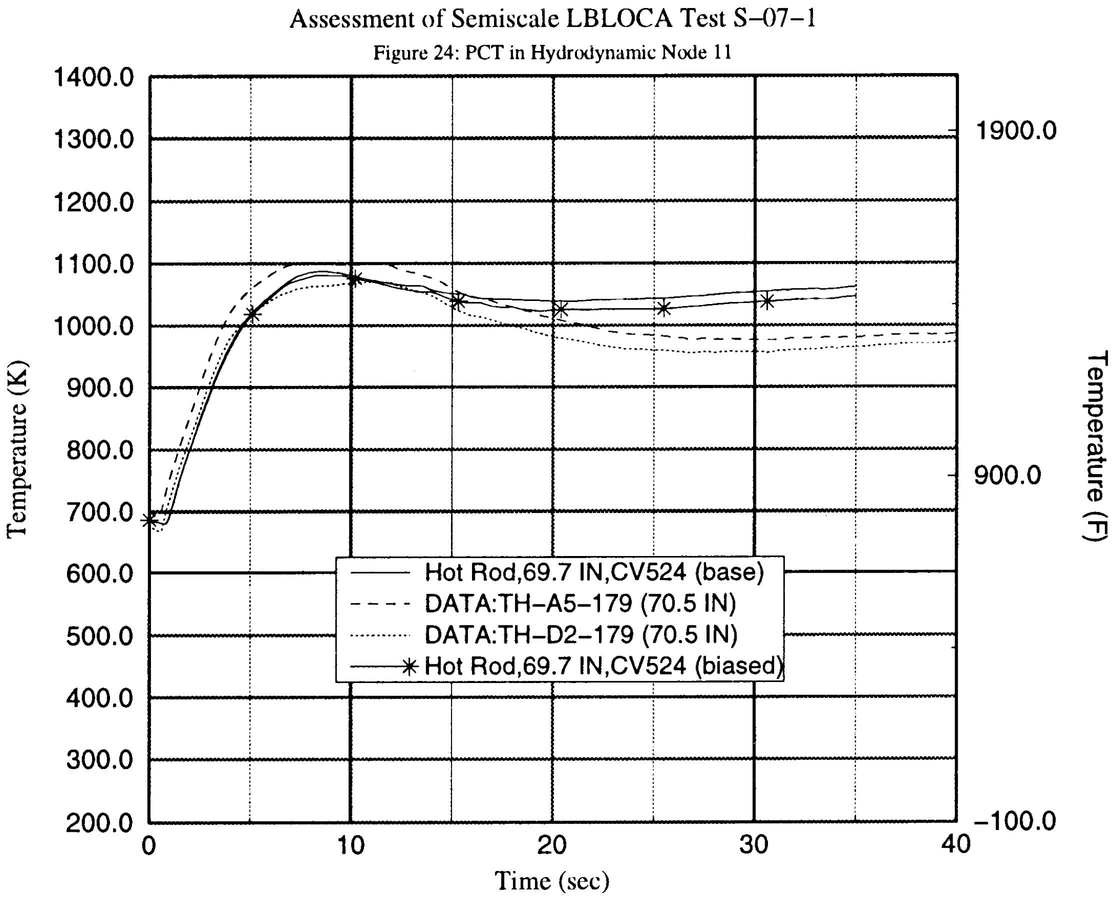
Evaluation of Code Biases - Semiscale

Summary of code bias effects - Semiscale Tests

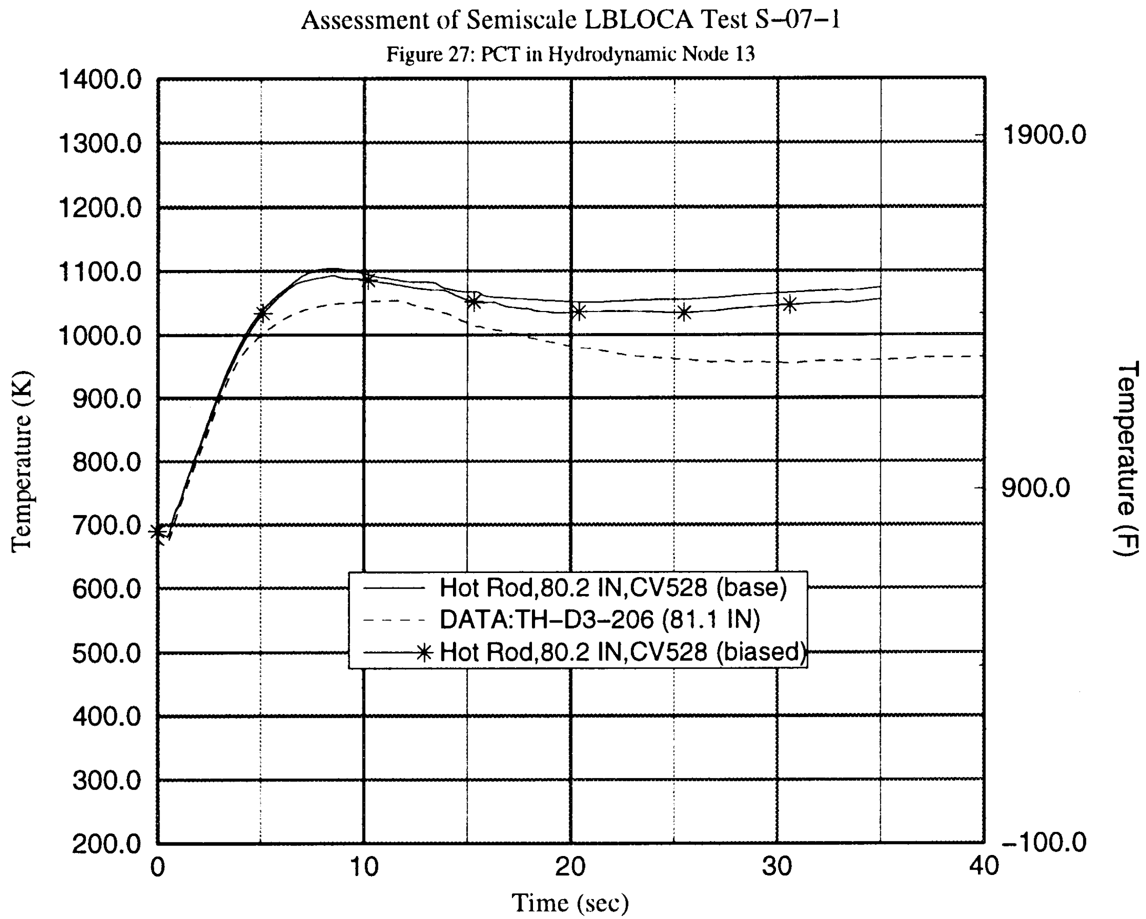
Semiscale Test S-07-1

- Test S-07-1 was performed in the Mod 3 facility (25 heated rods, 12 ft long)
- Test S-07-1 evaluation results are more consistent with expected trends
- Biased temperature results are lower than unbiased results and both calculations are conservatively high compared to measured data

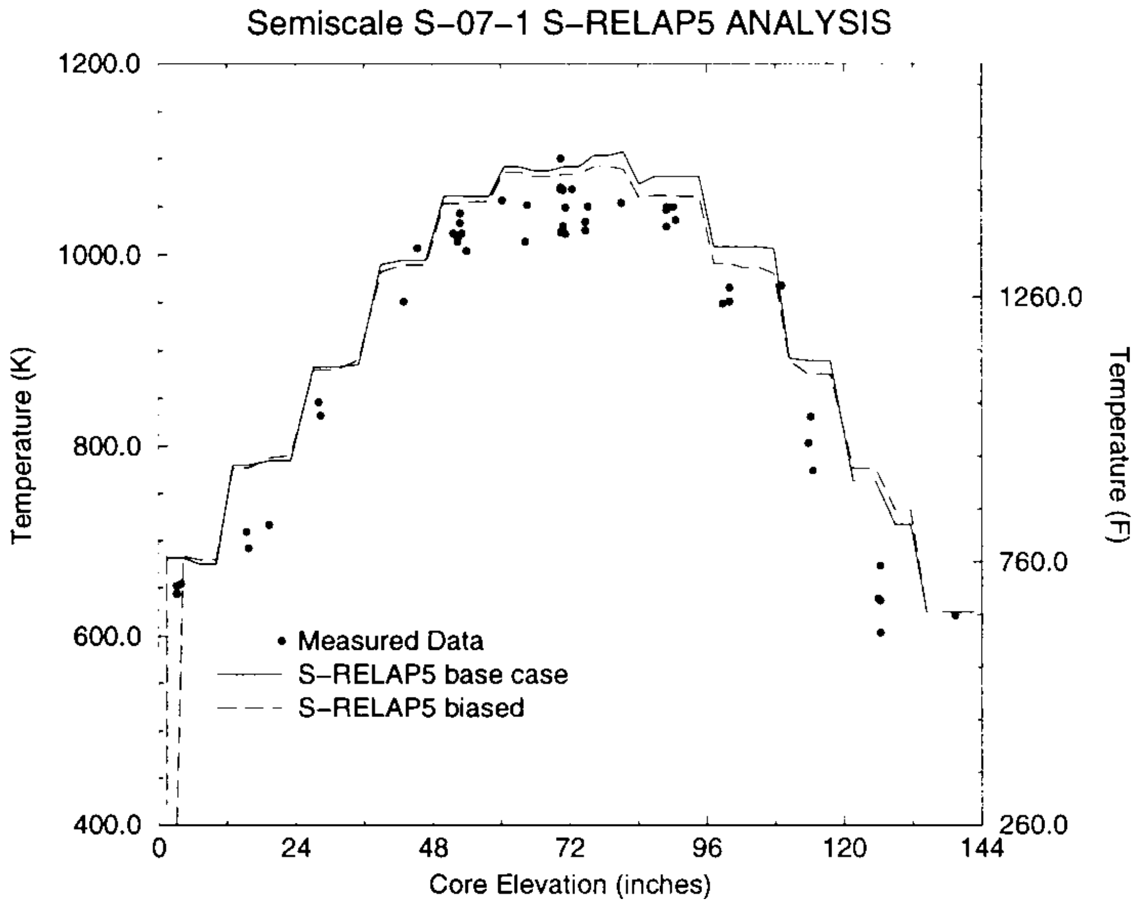
Example results for Test S-07-1 are shown



Semiscale S-07-1 Temperatures at Measured PCT Node



Semiscale S-07-1 Temperatures at Calculated PCT Node



Semiscale S-07-1 PCT Profile

Evaluation of Code Biases - Semiscale

Conclusions

- As expected, for both the Semiscale tests application of the biases reduced the calculated PCT
- For Test S-06-3, the overall comparison to the data was not improved. The temperatures in the lower and upper parts of the rod are further from the data with the application of the biases.
- The results for Test S-07-1, with a 12 ft core, show the PCTs from the biased calculation are lower than the unbiased calculation in the central high power portion of the rod and are in better agreement with the measured data
- The data comparison at the top and bottom of the rod are essentially unchanged between the biased and unbiased calculations. The magnitude of the PCT is in good agreement with the data.

Evaluation of Code Biases

Overall conclusions from bias evaluation

- Overall the evaluation of the model biases showed the expected trends
- The application of the biases resulted in a reduction in the maximum PCT predicted by the code, which is consistent with the observed tendency of the code to overpredict PCT
- In general, the reduction in PCT improved the comparisons between calculation and data, as expected if the developed biases are reasonable
- This indicates that the biases developed from comparison of the code predictions and data for the SET assessments are affecting the IET code predictions consistent with the intent and expectations

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PIRT Phenomena Not Treated Statistically

Presenter: L. D. O 'Dell

Advanced Nuclear Power

Definition of Code and Experimental Accuracy

PIRT Phenomena Not Treated Statistically

Purpose: This presentation will discuss those PIRT phenomena which are not biased or treated statistically in the Realistic LBLOCA methodology

Objective: To provide an understanding of the basis for the unbiased or non-statistical treatment

Definition of Code and Experimental Accuracy

PIRT Phenomena Not Treated Statistically

- Core 3D Flow and Void Distributions
- Core Flow Reversal/Stagnation
- Core Entrainment
- Counter Current Flow Limit (CCFL)
- Two Phase Pump Degradation
- Pump Differential Pressure Loss
- Non-Condensible Transport
- Downcomer Entrainment
- Lower Plenum Sweepout
- Downcomer Level Oscillations

PIRT Phenomena Not Treated Statistically

Core 3D Flow and Void Distributions

- Codes ability to calculate void distributions is demonstrated in comparisons to THTF level swell, GE level swell, and FRIGG-2 tests
  - Agreement with data was good to excellent
- Codes ability to calculate flow distributions is demonstrated in the performance of CCTF, SCTF, and multidimensional flow tests
  - Comparison with data demonstrated that the effect of flow variations in the core are captured by the code and nodalization
- In the NPP analysis the flow and void distributions are driven by the **[ ]**
- In addition, the biases and uncertainties developed for heat transfer include the code prediction of flow and void distribution
- Thus, no specific biases or uncertainties have been included in the methodology for the code prediction of flow and void distributions

PIRT Phenomena Not Treated Statistically

Core Flow Reversal/Stagnation

- The code prediction of core flow reversal and stagnation is considered because the limiting LBLOCA case is generally the one with the longest period of flow stagnation in the core
- However, this is driven by other phenomena and is a result of these phenomena
  - Break size
  - Downcomer bypass
  - Etc.
- Thus, the code prediction of core flow reversal and stagnation is driven by the variations of other phenomena and no individual bias or uncertainty have been developed

PIRT Phenomena Not Treated Statistically

Core Entrainment

- Liquid entrainment in the core is considered because it impacts the amount of liquid that remains in the core to provide cooling and ultimately quench
- Code predicted liquid carry out of the core to the upper plenum was examined in three different test facilities CCTF, UPTF, and FLECHT-SEASET
  - In all three facilities the code over predicted the liquid carry out from the core to the upper plenum
- Based on the demonstrated conservatism, no bias or uncertainty was derived and the conservatism was accepted in the methodology

PIRT Phenomena Not Treated Statistically

Counter Current Flow Limit (CCFL)

- CCFL is considered in the LBLOCA because it limits the amount of top/down flow into the core
- A conservative set of CCFL parameters was selected for use in the Realistic LBLOCA methodology
  - Conservative CCFL parameters were used to over come the lack of information for the SET and IET facilities upper tie plates (UTP)
  - This was deemed necessary to meet the CSAU requirement that the same model be used in the NPP and assessments
- Conservatism demonstrated by comparison to data for Framatome ANP UTP designs and to UPTF data
  - In all comparisons the calculation CCFL parameters were demonstrated to be conservative to the measured data

PIRT Phenomena Not Treated Statistically

Two Phase Pump Degradation

- This phenomenon is considered in the LBLOCA because it reduces the pump performance
- The pump two phase degradation is addressed with conservative input
  - Sensitivity studies were performed for both the 3-loop and 4-loop plant models comparing the results using the CE/EPRI and Semiscale two phase pump degradation models
  - Results of the studies indicated that the Semiscale degradation model produced essentially no impact on the 3-loop NPP and only an 18 F PCT increase in the 4-loop NPP analysis
- Thus, it was decided to conservatively use the Semiscale two-phase pump degradation model and accept the small conservatism in the methodology

PIRT Phenomena Not Treated Statistically

Pump Differential Pressure Loss

- The pump differential pressure loss is considered because it can influence the blowdown rate and liquid loss out the break
- This phenomena is treated in the Realistic LBLOCA methodology strictly as a best estimate
  - The utility supplied NPP pump specific homologous curves are directly input into the code

PIRT Phenomena Not Treated Statistically

Non-condensible Transport

- The transport of non-condensibles is considered in a LBLOCA primarily due to the blowdown of accumulator nitrogen once the accumulator empties
- Non-condensible transport was evaluated through the analysis of the ACHILLES ISP #25
  - Comparison of measured and calculated rod thermocouple temperatures indicated that the code under predicted the cooldown driven by the nitrogen forcing water into the core
  - Thus, the code was demonstrated to conservatively predict the impact of accumulator nitrogen
- Based on the demonstrated conservatism, no bias or uncertainty was derived and the conservatism was accepted in the methodology

PIRT Phenomena Not Treated Statistically

Downcomer Entrainment

- The codes ability to predict downcomer entrainment is considered in a LBLOCA because it impacts the prediction of ECCS water bypass and the filling rate of the lower plenum
- The codes ability to predict downcomer entrainment was assessed using the full scale UPTF Tests 6 and 7
  - The assessment compared the measured and calculated lower plenum fill rate
  - These comparisons clearly showed that the code conservatively under predicted the lower plenum fill rate for all cases
- Based on the demonstrated conservatism, no bias or uncertainty was derived and the conservatism was accepted in the methodology

PIRT Phenomena Not Treated Statistically

Lower Plenum Sweepout

- Lower plenum sweepout is considered in a LBLOCA because if water is swept out of the lower plenum it will go out the break, increasing the time to reach the beginning of reflood and core cooldown
- The codes ability to calculate lower plenum sweepout was also assessed with the full scale UPTF Tests 6 and 7
  - These tests indicated that the code conservatively over predicted the sweepout and resulting loss of water to the break
  - This is shown in the comparison of the measured and calculated lower plenum level
- Based on the demonstrated conservatism, no bias or uncertainty was derived and the conservatism was accepted in the methodology

PIRT Phenomena Not Treated Statistically

Downcomer Level Oscillations

- Downcomer liquid level manometer type oscillations are considered in a LBLOCA because they may drive liquid into the core, increasing the likelihood of early core cooldown and quench
- Downcomer liquid level manometer type oscillations are generally driven by other phenomena and will or will not occur depending upon the variation of those other phenomena
  - In general, manometer type oscillations have not been predicted with the Realistic LBLOCA methodology
  - Undocumented sensitivity studies have shown that manometer type oscillations tend to be damped by the boiling in the downcomer
- Not predicting manometer type oscillations with the methodology is conservative, and therefore acceptable

PIRT Phenomena Not Treated Statistically

Conclusions

- The PIRT phenomena which are neither biased or treated statistically were discussed
- The basis for the methodology treatment of each of these PIRT phenomena was provided

Sensitivity and Uncertainty Analysis (CSAU Steps 11, 12, 13 and 14)

Presenter: R. P. Martin

Purpose (CSAU Step 11)

Demonstrate how important process parameters are identified and treated in the methodology

Outline

- Determining Important Process Parameters
- Quantifying Statistical Quantities
  - General
  - Time-in-cycle
  - Axial and radial power profiles
- Supporting ranges without data

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Introduction

"Uncertainties in NPP simulations may result from uncertainties in the ***plant operating state*** *at the initiation of the transient"*

Framatome ANP contrasts plant process parameters as those that *"characterize the state of operation and are…controllable by plant operators."* - EMF-2103

Why range Time-in-cycle?

"Given the assumed initial conditions, relevant factors such as the actual total power, actual peaking factors, and actual fuel conditions should be calculated in a best- estimate manner." - Regulatory Guide 1.157 states:

"A range of power distribution shapes and peaking factors representing power distributions that may occur over the core lifetime shall be studied."

-Appendix K of 10 CFR 50 states:

Important Process Parameters

However, acceptance criteria variables are insensitive to many parameters and treating parameters unnecessarily over complicates the methodology

Three resources for identifying important process parameters:

- Strong relationship to a dominant PIRT parameter
- Plant technical specification requirement
- Utility request

Identification of Important Process Parameters

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Plant Parameter Uncertainty: General

Ideally: statistical analysis of data

Reality: must incorporate hard constraints (Tech Specs)

Uncertainty Example

Time-in-Cycle & Power Profiles

Axial Power Profiles

Radial Power Profile

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Supporting Ranges without Data

Ranges may be established based on either physical limitations or by analytical studies

Summary

Shown how important process parameters are identified and treated in the methodology

- Quantifying Statistical Quantities
    - General
    - Time-in-cycle
    - Axial and radial power profiles
- Supporting ranges without data

Purpose (CSAU Step 12)

Provide an overview of how RLBLOCA calculations are performed using the **[ ]**

- Flow of the methodology
- Key tasks required for the RLBLOCA Analysis
- Highlight key parameters and where they are initialized

CSAU Step 12

"*NPP calculations are used to determine the* ***code's output sensitivity*** *to various plant operating conditions that arise from uncertainties in the reactor state at the initiation of the transient*"

Framatome ANP definition of "code output sensitivity" is characterized by analysis using **[ ]**

Application of Methodology

RLBLOCA Analysis

Parameter Initialization

Parameter Initialization (continued)

Summary

An overview has been provided of how the RLBLOCA calculations are performed using the non-parametric statistics

- Flow of the methodology
- Key task required for the RLBLOCA Analysis
- Highlight key parameters and where they are initialized
  - Parameter initialization (identified by calculational order and parameter type: PIRT/plant)

Purpose (CSAU Steps 13 and 14)

Provide a preview of the unique aspects of results that would be submitted to the NRC from a Framatome ANP RLBLOCA analysis

- 3-Loop sample problem
- 4-Loop sample problem

Present Acceptance Criteria Summary (w/ Total Uncertainty)

Supported Parameter Ranges

Plant Initial Operating Conditions	
2.1 Reactor Power	
a) Core average linear heat generation rate	*Core power ≤ 102% of 2300 MWt*
b) Peak linear heat generation rate	*≤ 2.62[a] (normalized)*
c) Hot rod average linear heat generation rate	*≤ 1.8[b] (normalized)*
d) Hot assembly linear heat generation rate	*< 1.731[c] (normalized)*
e) Hot assembly burnup	*≤ 62000 MWD/MTU*
f) MTC	*≤ 0 at HFP*
g) HFP boron	*Normal letdown*
2.2 Fluid Conditions	
a) Loop Flow	*97.3 Mlb/hr ≤ M ≤ 113 Mlb/hr*
b) Core Inlet Temperature	*541.6 ≤ T ≤ 553.6 °F[d]*

Results Presentation

Scatter Plots

- 1D plots demonstrating coverage of parameter sampling
- 2D plots presenting key results from the Monte-Carlo RLBLOCA analyses

Report of Acceptance Criteria Results and Total Uncertainty

Sampled Parameters Example

PCT vs. Time of PCT: 3-Loop

PCT vs. Break Size: 3-Loop

Maximum Core Oxidation vs. PCT: 3-Loop

PCT vs. Time of PCT: 4-Loop

PCT vs. Break Size: 4-Loop

Maximum Core Oxidation vs. PCT: 4-Loop

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Acceptance Criteria Summaries (for maximum PCT results)

3-Loop (15x15 fuel)

Case #	28
PCT	
Temperature	*1826 °F*
Time	*117.4 seconds*
Elevation	*9.4 ft*
Metal-Water Reaction	
% Oxidation Maximum	*1.3 %*
% Total Oxidation	*0.041 %*
Total Hydrogen	*0.79 lb*

50/50 PCT = 1543°F

Total Uncertainty: ~283°F

4-Loop (17x17 fuel)

Case #	3
PCT	
Temperature	*1686 °F*
Time	*34 seconds*
Elevation	*9.4 ft*
Metal-Water Reaction	
% Oxidation Maximum	*0.8 %*
% Total Oxidation	*0.022 %*
Total Hydrogen	*0.5 lb*

50/50 PCT = 1375°F

Total Uncertainty: ~311°F

Acceptance Criteria Summaries

Summary of Results for the Limiting Maximum Oxidation Case

Case #	11
PCT	
Temperature	*1826 °F*
Time	*125.4 seconds*
Metal-Water Reaction	
% Oxidation Maximum	*1.6 %*
% Total Oxidation	*0.035 %*
Total Hydrogen	*0.68 lb*

Summary of Results for the Total Oxidation Case

Case #	23
PCT	
Temperature	*1807 °F*
Time	*35.3 seconds*
Metal-Water Reaction	
% Oxidation Maximum	*1.4 %*
% Total Oxidation	*0.060 %*
Total Hydrogen	*1.14 lb*

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Realistic Large Break LOCA Methodology for Pressurized Water Reactors

Advanced Nuclear Power

Schedule

Presenter: J. S. Holm

Realistic Large Break LOCA Methodology for Pressurized Water Reactors

Schedule

Topical Report Submitted	8/01
Presentation to NRC	10/01
First Presentation to ACRS	?
NRC Issues RAIs	?
Framatome Responds to RAIs	?
Final Presentation to ACRS	?
Target Date for NRC Approval	?