FRAMATOME ANP

Realistic Large Break LOCA Methodology

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Realistic Large Break LOCA Methodology

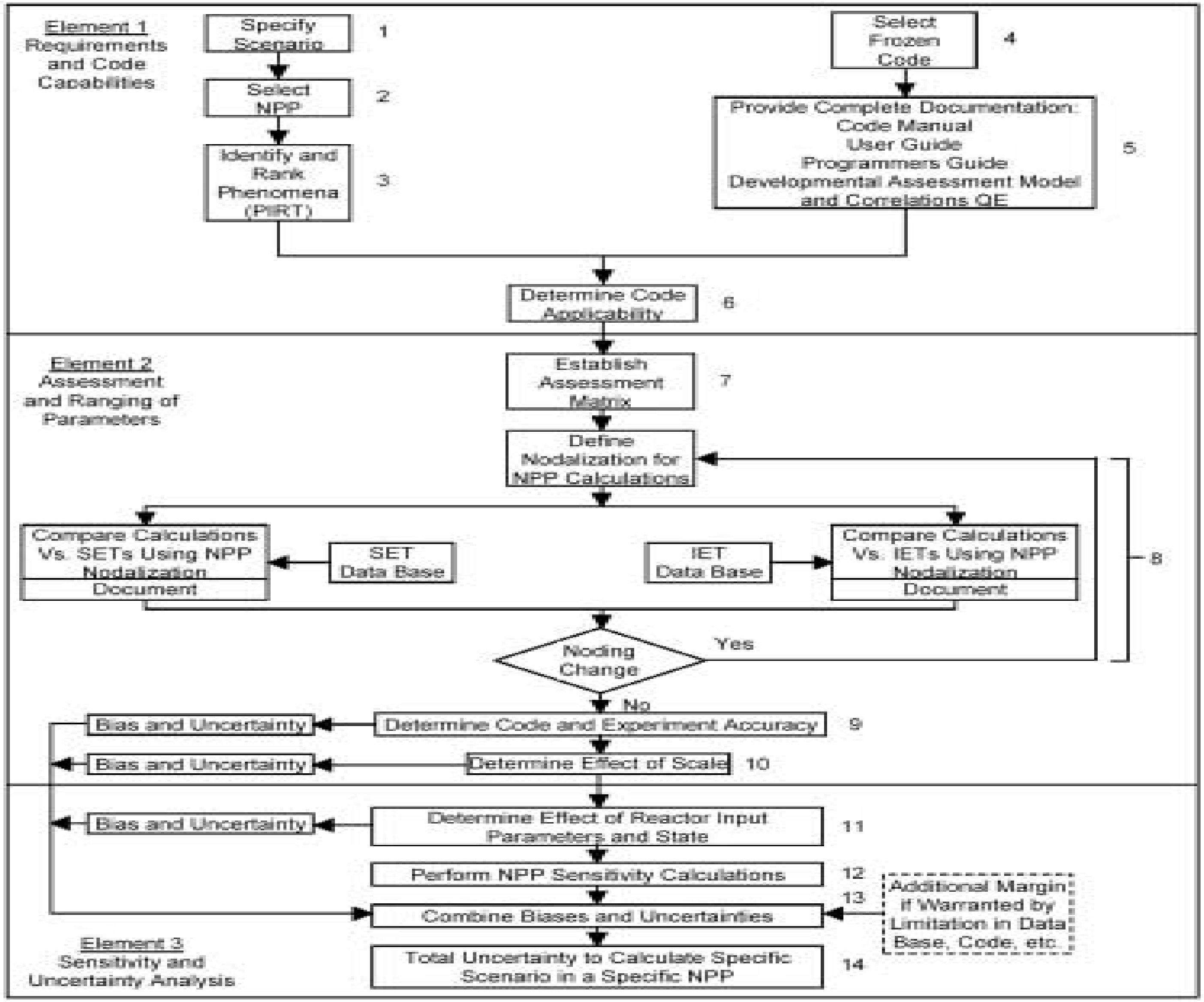
> Outline

- Background
- Methodology Development Overview
- CSAU Compliance
  - Element 1 - Requirements and Code Capabilities
  - Element 2 - Assessment and Ranging of Parameters
  - Element 3 - Sensitivity and Uncertainty Analysis
- Sample Problem Results

Background

- Technical Program Group on Best-Estimate LOCA - mid-1980s
  - End of 2D/3D Program
  - Development of NUREG-1230 - Compendium of ECCS Research
  - NRC commissions TPG to develop a paradigm for performing Best-Estimate LOCA evaluations
    - TPG includes members from the NRC, national labs and academia - no one from industry
    - TPG produces the CSAU methodology documented in NUREG-5249
  - More information at www.nuclearsafetyhistory.com
- Regulatory Guide 1-157 states that there is no regulatory requirement to follow any particular methodology; yet, acknowledges that the CSAU methodology is acceptable

Code Scaling, Applicability, and Uncertainty



CSAU Steps 1-6

> Code Scaling, Applicability, and Uncertainty (CSAU)

- Methodology is for LBLOCA…or W 3- and 4-loop plants and CE 2x4 plants
- Identify Important LBLOCA Phenomena documented in PIRT
- Computer Codes
  - RODEX3A Fuel Rod Code for UO2, COPERNIC for MOX
  - S-RELAP5 System Analysis Code
    - Includes RODEX3A and COPERNIC code models for consistency
    - Includes containment analysis models from the ICECON code
  - Codes demonstrated applicable to fuel designs, plant types and LBLOCA transient
- Codes and Methodology documented
  - Documented with methodology description, S-RELAP5 Models & Correlations, S-RELAP5 V&V, S-RELAP5 Programmers Guide, RLBLOCA guidelines for model development and analysis
- Code Models and Correlations critiqued for applicability to important PIRT phenomena.

Step 7 - Define Assessment Matrix

> Code Scaling, Applicability, and Uncertainty (CSAU)

- Define Assessment Matrix
  - Selected to address
    - Important LOCA phenomena defined in the PIRT
    - Nodalization validation
    - Code/model scaling
    - Verification of no important compensating effects
    - Need for supporting a broad range-of-applicability
  - Final assessment matrix included

15 SET facilities and 130 tests evaluated

2 IET facilities and 6 tests evaluated

Step 8 - Nodalization

> Code Scaling, Applicability, and Uncertainty (CSAU)

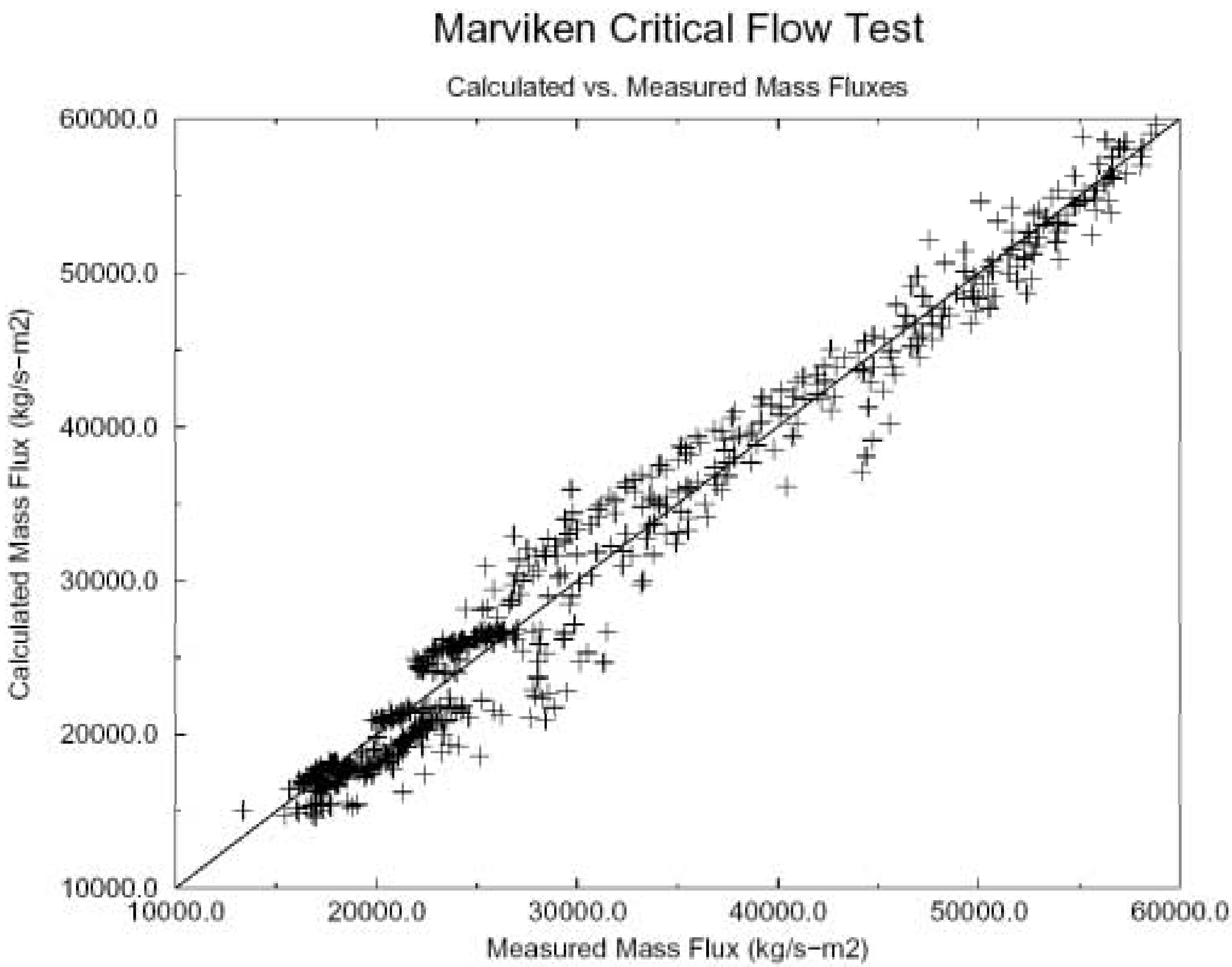
- Nodalization
  - Selected to
    - support NPP design characteristics
    - preserve dominant phenomena
    - minimize code uncertainty
  - Significant nodalization changes
    - 2D downcomer
      - six axial nodes
      - 3/6/4 asmuthal nodes for W3/W4/CE2x4 plants, respectively
    - 2D core
      - approximately 6 inch axial nodes
      - four radial rings
    - 2D upper plenum
      - 3 axial nodes
      - 3 radial rings

Step 9 - Code Accuracy

> Code Scaling, Applicability, and Uncertainty (CSAU)

- Code and Experimental Accuracy
  - All SET and IET modeled and evaluated
  - Results of SET evaluations used to develop uncertainties and distributions for important PIRT phenomena
  - Primary use of IET was to demonstrate the acceptability of the code biases developed from the SET
  - Define range of applicability of important models and correlations
- Statistical Description - Uncertainty is described by
  - Code bias and uncertainty developed for 11 important PIRT phenomena Mean or code bias
  - Probability distribution function
  - Standard deviation or range of uncertainty
- Pedigree of statistics depends on sufficient density and breadth of data within the range-of-applicability

Step 9 - Code Accuracy

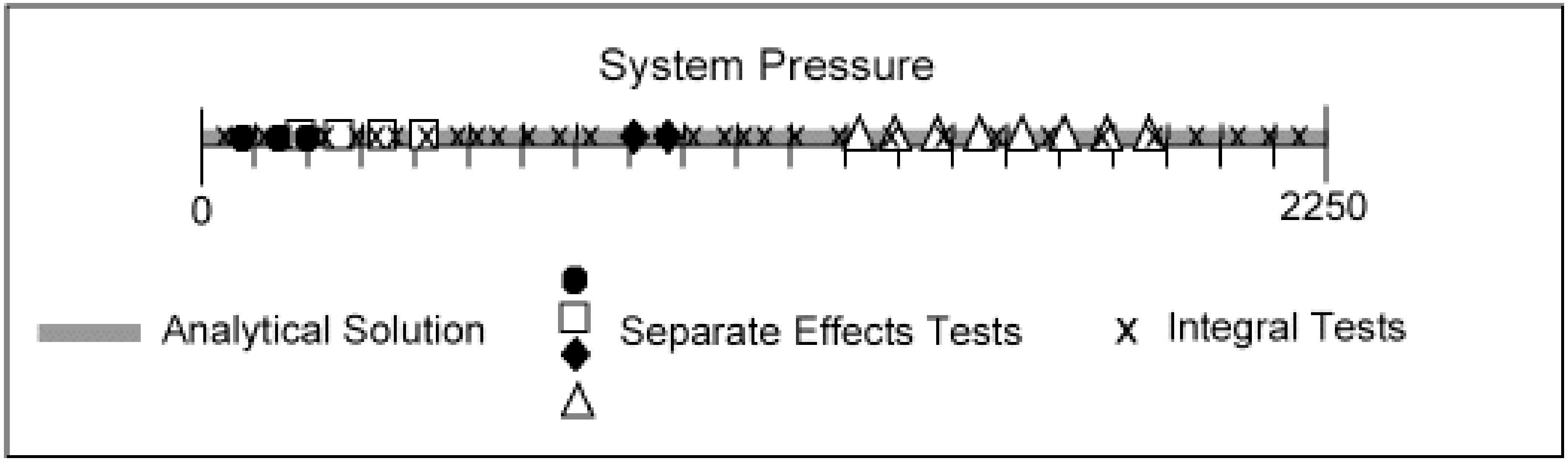


Step 9 - Code Accuracy

> Range-of-applicability:

- “Range-of-Applicability” is subjective, requires technical basis
- Framatome method incorporates
  - Analytical models and correlations
  - Separate-effects assessment
  - Uncertainty analysis
- Validation using integral-effect assessment
- NRC focused only on the “Range-of-Applicability” of Heat transfer correlations (discussed in RAI 2)

Step 9 - Code Accuracy



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Step 9 - Code Accuracy

> PIRT Phenomena Treated Statistically

- Core Post-CHF Heat Transfer (Film Boiling)
- Stored Energy
- Oxidation
- Decay Heat
- Burnup/Power Shapes (Time-In-Cycle)
- Break Flow (Break Size and Flow Split)
- Containment Pressure
- Cold Leg Condensation
- Critical Heat Flux
- T(min)
- Steam Binding
- Reactor Vessel Hot Walls

S-RELAP5 Accuracy Summary

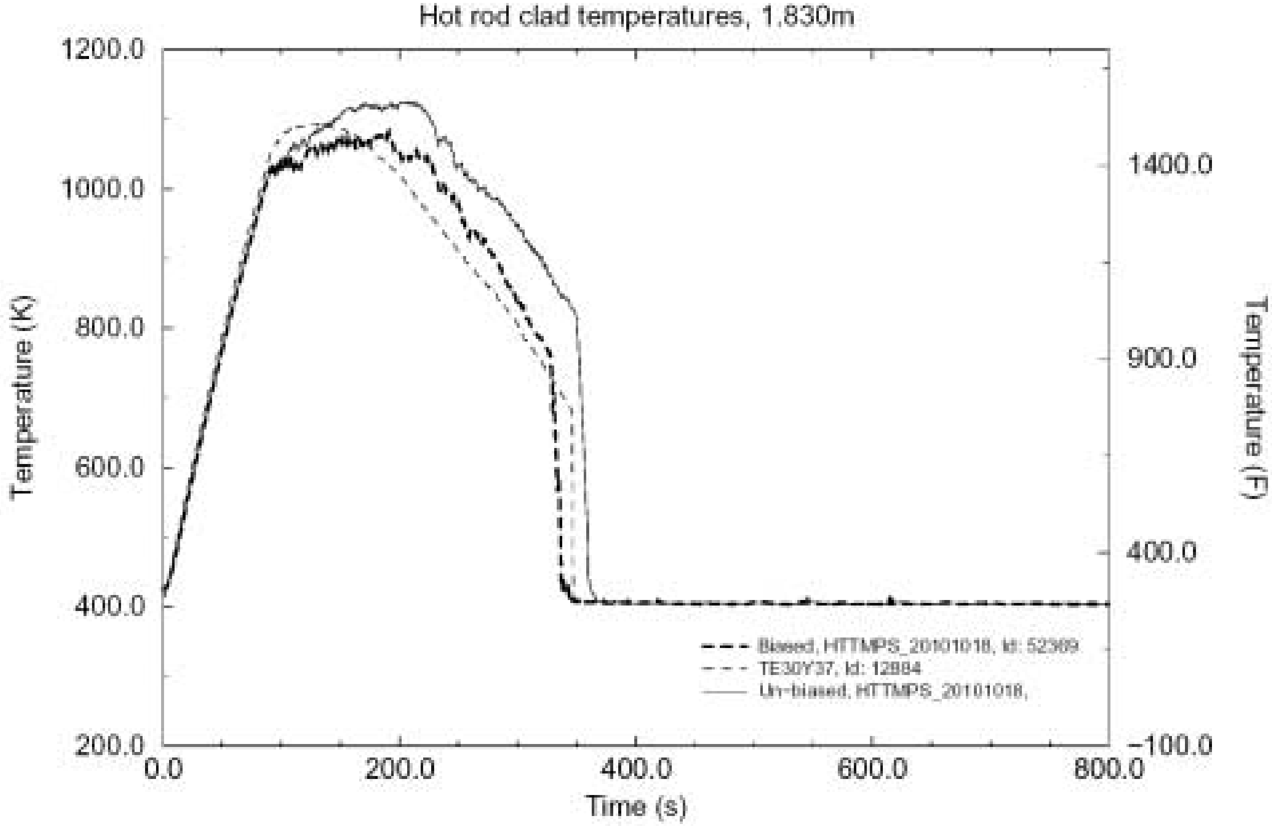
PIRT Parameter	Bias	σ	Min or -2σ	Max or +2σ
Stored energy (centerline temperature)	###	###	###	###
Metal-water reaction constant	1.0	0.182	0.636	1.364
Metal-water reaction exponent	1.0	0.0134	0.9732	1.0268
Decay heat uncertainty	1.0	0.003	0.94	1.06
Biasi CHF,	###	0.0	###	###
Film Boiling HTC,	###	special	###	N/A
Dispersed Film Boiling,	###	special	###	N/A
Tmin,	###	###	###	###
Break Discharge Coefficients,	###	###	###	###
Condensation Interphase HTC,	###	uniform	###	###
Steam Generator Inlet Interphase Friction	###	0.0	###	###
Hot wall (CHF multiplier)	###	binary	###	###
Containment pressure (volume)	###	uniform	min free volume	max free volume

Step 9 - Code Accuracy

> Statistical Validation of Step 9 results

- A subset of CCTF, LOFT, and Semiscale assessments rerun applying code bias
- Results generally showed improved PCT code/data agreement

Example - CCTF



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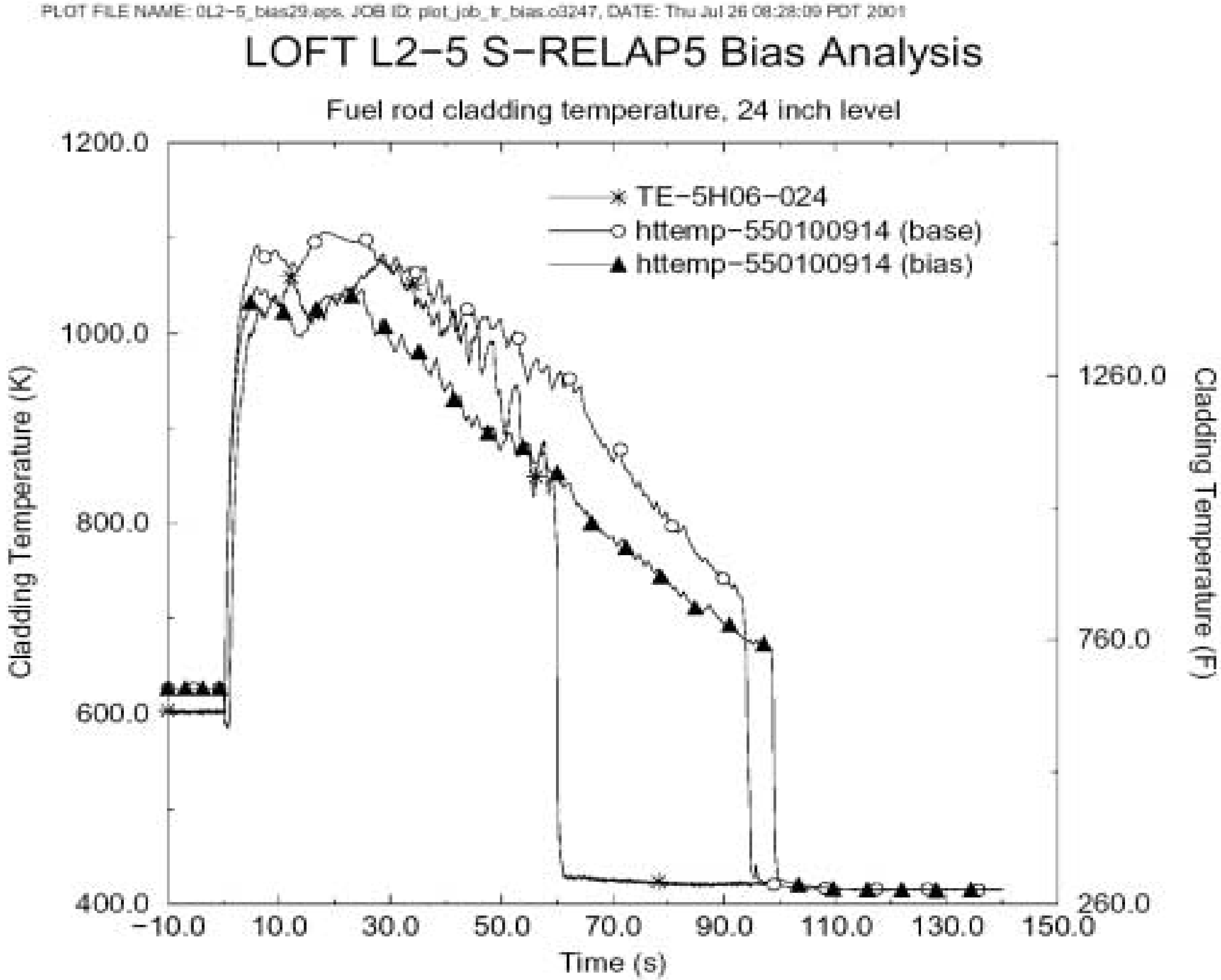
Example - LOFT



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Step 10 - Code Scaling

> Scaling Issue deemphasized largely by arguing
  - Heat transfer tests performed on full-scale fuel assemblies
  - Primary hydraulic phenomena assessed using full-scale UPTF assessment

Step 11 - Reactor Input Parameters

- Analysis must address plant specific variations in operating and process parameters including Technical Specification limits
- For important plant parameters plant data and Tech Specs are used to develop uncertainty distributions
- Sample plant operating and process parameter list
  - Core power distributions total power, $F_{\Delta H}$, F_q, axial shape
  - Reactor coolant system loop flow rates and core inlet temperature
  - Upper head temperature
  - Pressurizer pressure and level
  - Accumulator pressure, volume, and temperature
  - Containment free volume, temperature, fan coolers, and sprays
  - Steam generator feedwater temperature
  - Offsite power availability
  - Diesel start time

Sampled Parameters Summary

PIRT Parameters	Plant Parameters
Heat Transfer	Core Power (%)
Void Distribution	Pressurizer Pressure (psig)
Axial Power Distribution	Pressurizer Level (%)
Entrainment	Accumulator Volume (ft^3)
Spacer Effects	Accumulator Pressure (psig)
Break Flow	Containment/AccumulatorTemperature (°F)
Cold Leg Condensation	Containment Volume ($x10^6$ ft^3)
Interfacial Heat Transfer	Initial Flow Rate (Mlbm/hr)
Upper Tie Plate CCFL	Initial Operating Temperature(°F)
Core Flow Distribution (multidimensional effects)	RWST Temperature (°F)
ECCS Bypass	Offsite Power Availability
Steam Binding	Diesel Start (s)
Accumulator Nitrogen Discharge	

Step 12-14 Convolution of Uncertainties

- Objective
  - Defined in methodology as 95% confidence and 95% coverage
- Methods
  - Parametric - response surface - described & demonstrated in NUREG-5249
  - Nonparametric - Monte Carlo
- Identify 95/95 from largest PCT in the set of calculations
  - Report Total Oxidation from this case
  - Report Maximum Oxidation from this case
- Identify 50/50 from median PCT in the set of calculations to quantify total uncertainty

Nonparametric Statistics

> Does not use a response surface

> Relies on the execution of the code to perform a Monte Carlo analysis

> A defined number of cases are run with the code to determine the 95/95 condition

- 59 cases: highest value calculated is the 95/95
- 93 cases: second highest value calculated is the 95/95
- 124 cases: third highest value calculated is the 95/95
- etc.

> Each case is defined by randomly selecting a value for each PIRT phenomena and plant parameter being treated statistically

Ordered Statistics

> Basic Theory

- Derived from fundamental Bernoulli Trials (combinatorial analysis)
- Assumption of “ordered statistic” provides final form:

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

- For the case in which $k=n$, that is the largest value of all of the samples is used, this relationship reduces to:

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

Define confidence and probability, solve for *n*.

Perform Simulations

> Define cases to be run

- Sampled Parameter Case 1…Case 2…Case 3……Case 59 …… Case N
  (95/95)
  - A
  - B
  - .
  - .
  - .
  - .
  - .
  - .
  - ZZZ
- PCT 1432 F 1853 F 1628 F ……1227 F…… 2138 F

Methodology Demonstration

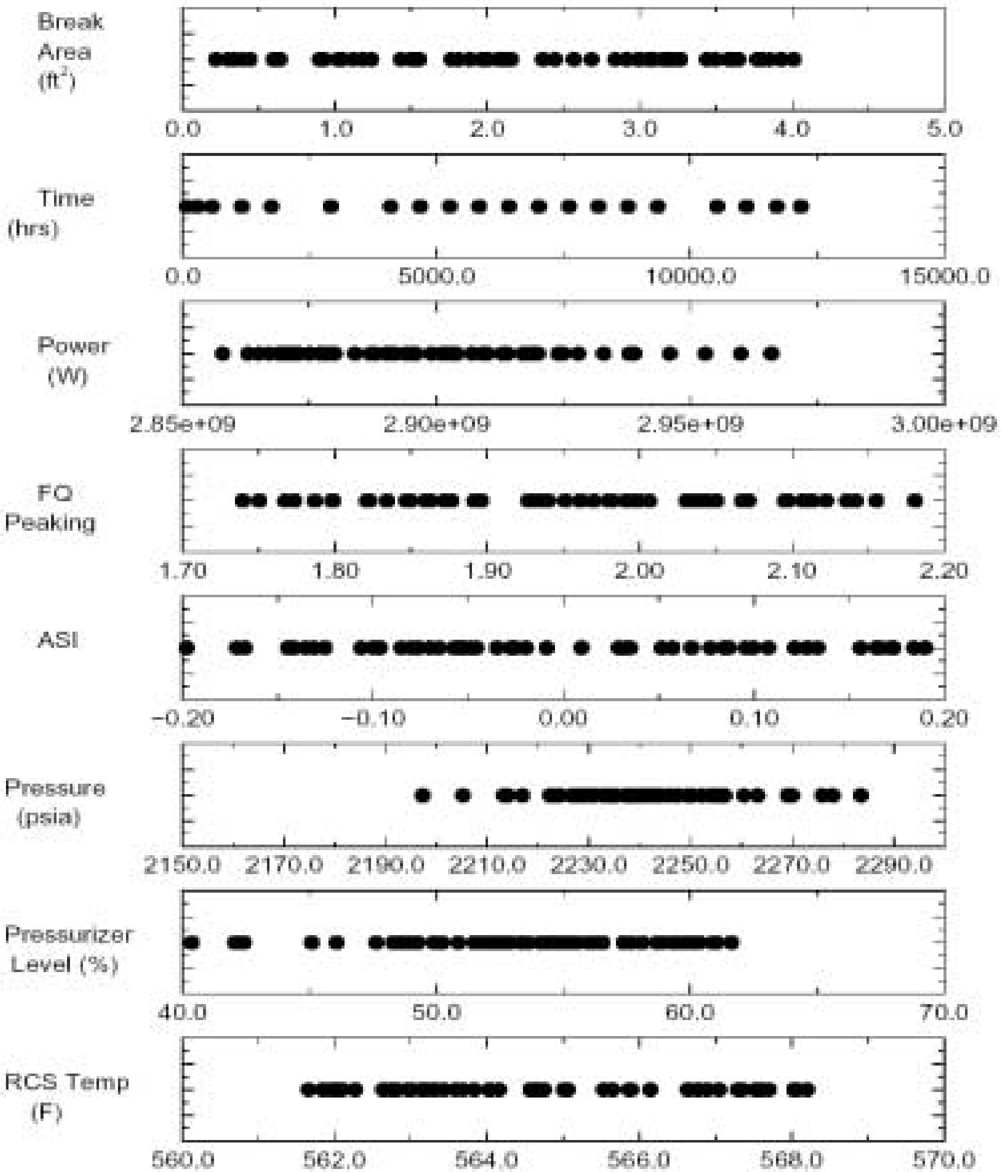
> Methodology Application Process

- Develop base input decks for RODEX3A (or COPERNIC) and S-RELAP5
  - S-RELAP5 input includes input for ICECON containment model
  - Task is automated using plant-specific databases
- Generate time-in-cycle neutronics input data
- Generate plant specific parameter distributions
- Generate modified inputs for a minimum of 59 cases
- Perform calculations for 59 cases
  - Run RODEX3A or COPERNIC to generate initial fuel conditions
  - Run S-RELAP5 steady state
  - Run S-RELAP5 transient calculation
- Analyze results of 59 cases to determine 95/95 peak clad temperature, peak nodal oxidation, and total core oxidation

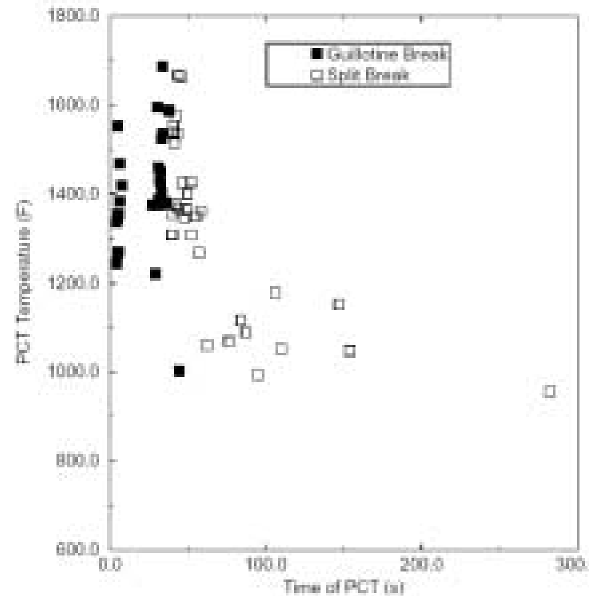
Methodology Demonstration

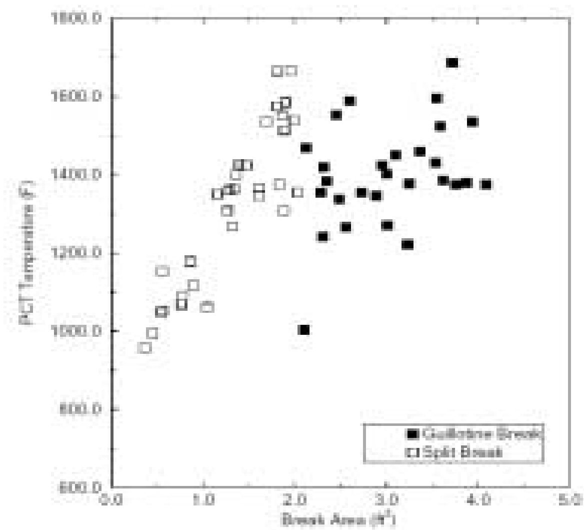
> W 4-loop Sample Problem

- Conditions
  - Power = 3250 MWt
  - $F_{\Delta H}$ = 1.80
  - F_q = 2.62
- 95/95 Results
  - PCT = 1686 F (< 2200 F)
  - Maximum Nodal Oxidation = 1.1% (< 17%)
  - Maximum Core Oxidation = 0.02% (< 1 %)

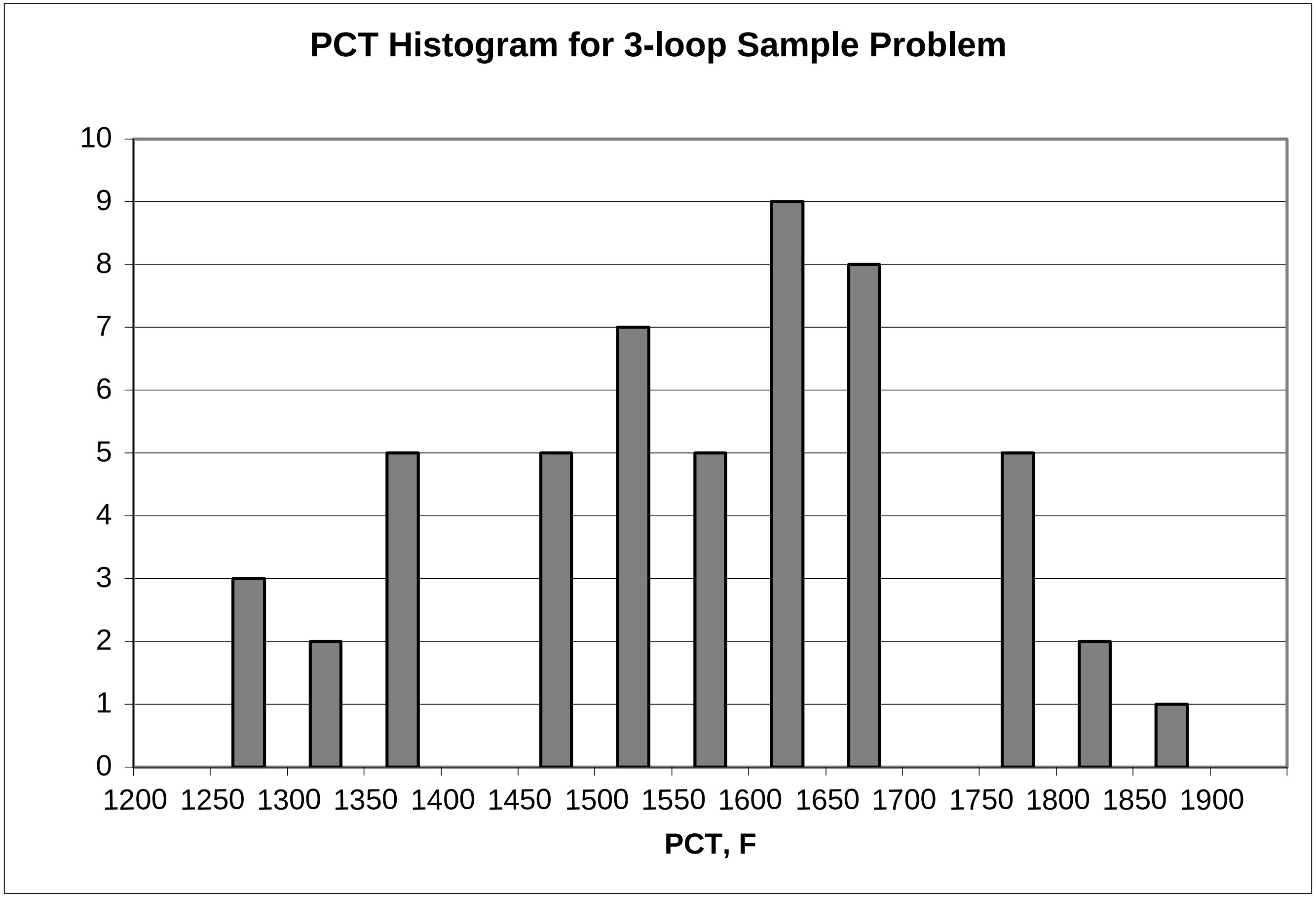


PCT vs Time of PCT





Histogram



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Methodology Development History

> NRC Review Schedule

Original Development	1989-1993
Revision Development	01/98-08/01
Topical Report Submitted	08/01
Presentation to NRC	10/01
First Presentation to ACRS Subcommittee	01/02
NRC Issues Formal RAIs (139 total)	04/02 - 8/02
Framatome Responds to RAIs	05/02 - 10/02
Draft Safety Evaluation Report by NRC	10/02
Final Presentation to ACRS Subcommittee	11/02
ACRS Full Committee Meeting	12/02
NRC Approval	04/09/03