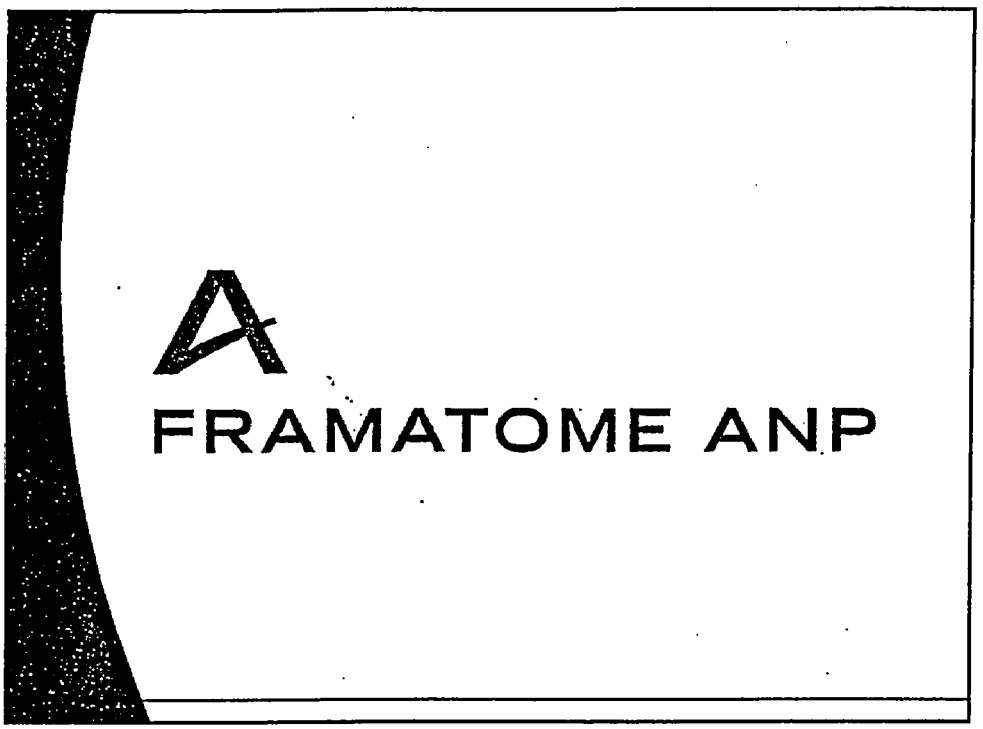


# *Realistic LBLOCA Methodology Roadmap*

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***December 9, 2003***
***Washington, D.C.***

## Realistic LBLOCA Methodology Roadmap

> *Purpose: The Methodology Roadmap provides an upper level overview of the complete methodology*



## 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
    - Initial PIRT developed from Compendium
      - Average of expert and analytical hierarchy process
      - Reviewed by three independent experts who recommended additional phenomena and ranking changes
    - 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)

> 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 in S-RELAP5

> 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



## 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 analyses
  - Code ability to model selected NPP confirmed by comparison of required NPP components and code component modeling capabilities
- S-RELAP5 demonstrated applicable to LBLOCA

## 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
    - 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 44 phenomena ranked 5 or higher
      - Over 250 analyses performed using the 3 and 4-loop NPP models
    - Based on the sensitivity studies evaluation
      - Experimental facilities and specific tests were chosen for the important phenomena
      - Required plant data identified

## Assessment and Ranging of Parameters (CSAU Element 2)



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## 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

## 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 that covered a wide range of PCT's
    - 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 | 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 | 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 | Purpose |
|---|---|---|
| LOFT | 4 | Overall code performance, Nodalization, Scalability, Compensating errors |
| Semiscale | 2 | Blowdown heat transfer, Nodalization, Scalability, Compensating errors |

## Assessment and Ranging of Parameters (CSAU Element 2)

- Final Assessment Matrix
  - 15 SET facilities and 130 tests
  - 2 IET facilities and 6 tests
  - Facility scaling ranged from 1:1500 to 1:1
  - Maximum assessment PCT of 2218 F



## 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

## Assessment and Ranging of Parameters (CSAU Element 2)

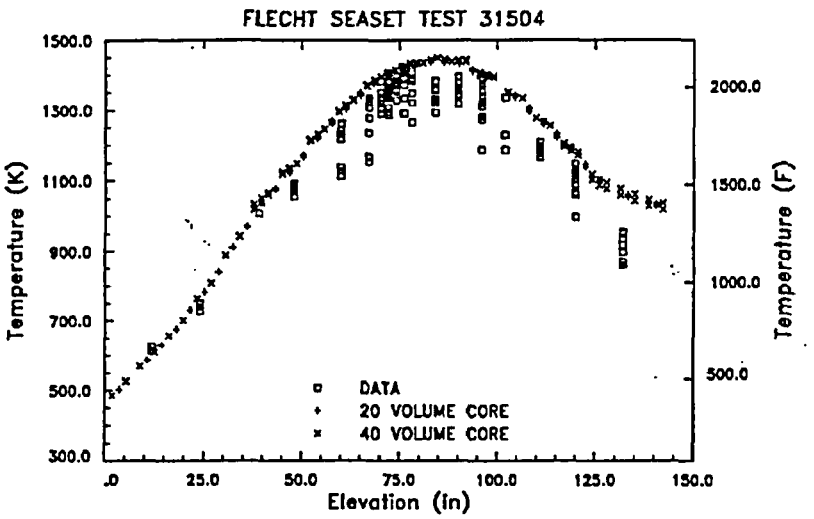
> *Nodalization (CSAU Step 8)*
- *Select common nodalization for use in SET, IET, and plant analyses*
  - *Initial nodalization selected based on previous industry and Framatome ANP experience*
  - *Revised based on initial plant model studies*
  - *Further revised based on peer review*
  - *Final nodalization validated/refined based on performance of SET and IET assessments*
    - *UPTF, SCTF, CCTF, and FLECHT-SEASET*
    - *LOFT and Semiscale*
  - *Key features of the RLBLOCA plant nodalization is the use of 2-dimensional components in the reactor vessel model*
    - *Downcomer*
    - *Core*
    - *Upper plenum*



## Assessment and Ranging of Parameters (CSAU Element 2)

> *Nodalization (CSAU Step 8)*
- *Select common nodalization for use in SET, IET, and plant analyses*

# Core Axial Nodalization Study



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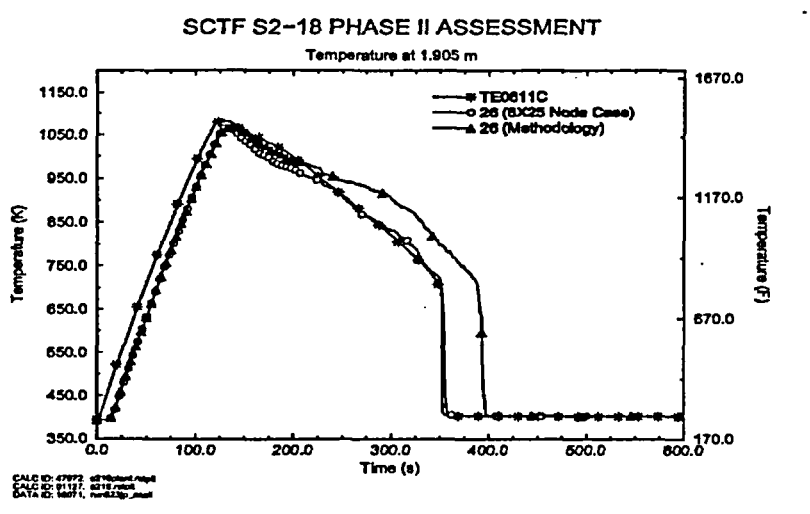
# Core Radial Nodalization Study



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## Assessment and Ranging of Parameters (CSAU Element 2)

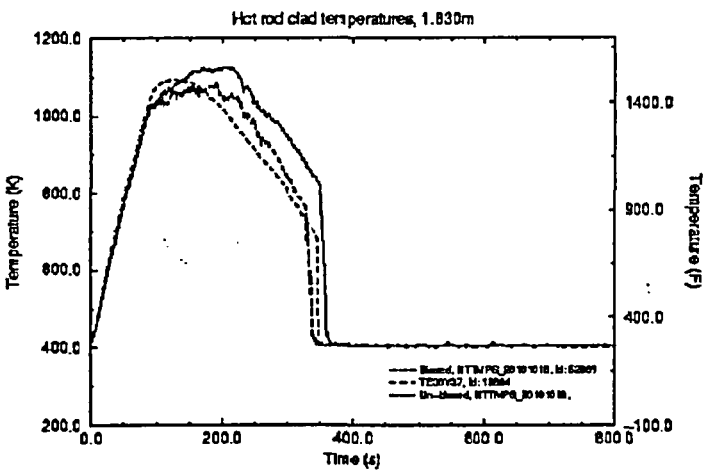
- > Code and Experiment Accuracy (CSAU Step 9)
  - Determine individual parameter uncertainty for identified important PIRT phenomena
    - Code model biases and uncertainties determined by comparison of code to SET experiments defined in Assessment matrix
    - Code model biases confirmed through the performance of independent SET and IET analyses 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



## Dispersed Flow Film Boiling

- > Applied Biases

# CCTF TEST 54 Temperatures at Measured PCT Node



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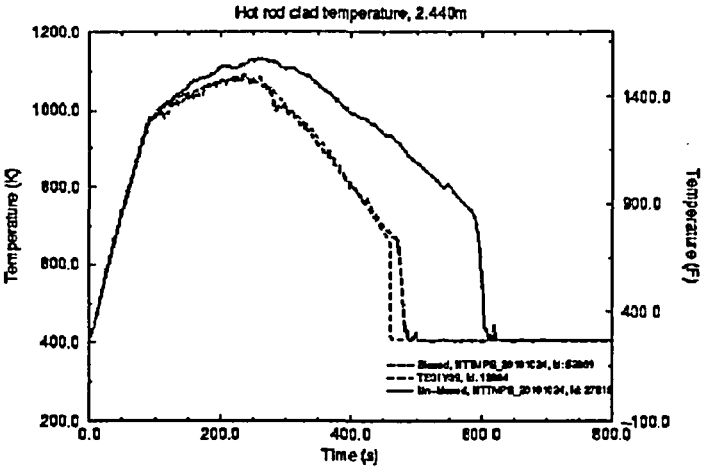
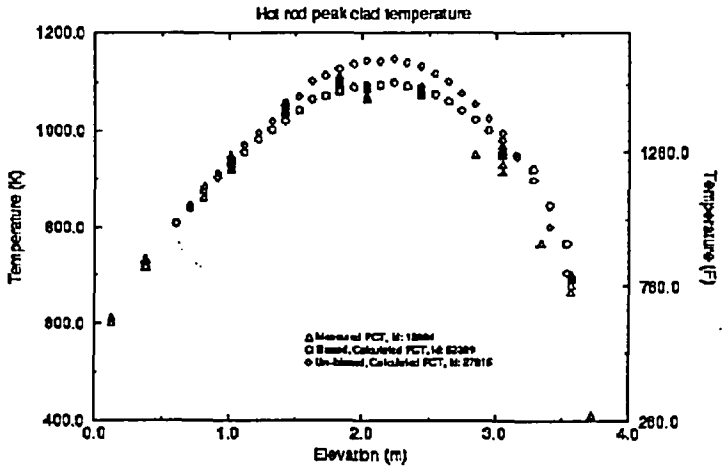
# CCTF TEST 54 Temperatures Near Calculated PCT Node






FRAMATOME ANP

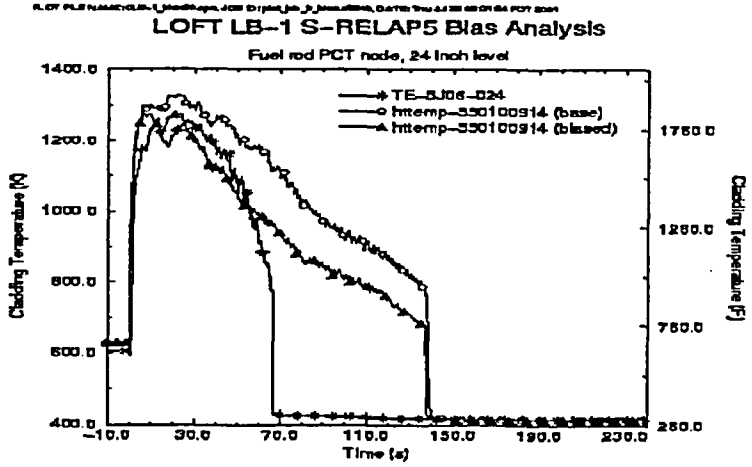
# CCTF TEST 54 PCT Profile






FRAMATOME ANP

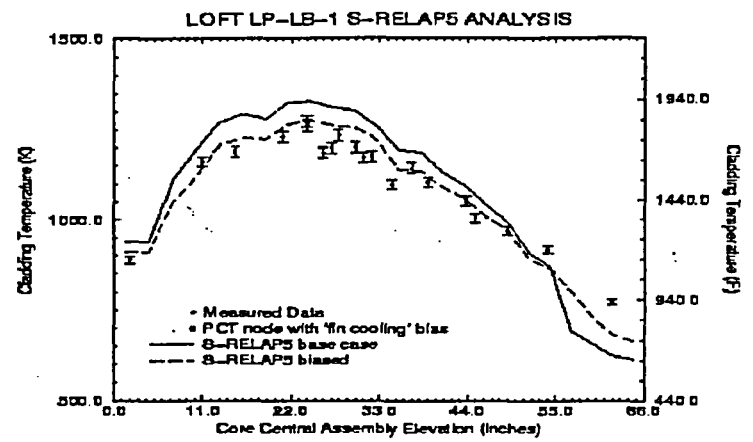
# LOFT LP-LB-1 Temperatures at Measured PCT Node






FRAMATOME ANP

# LOFT LP-LB-1 PCT Profile



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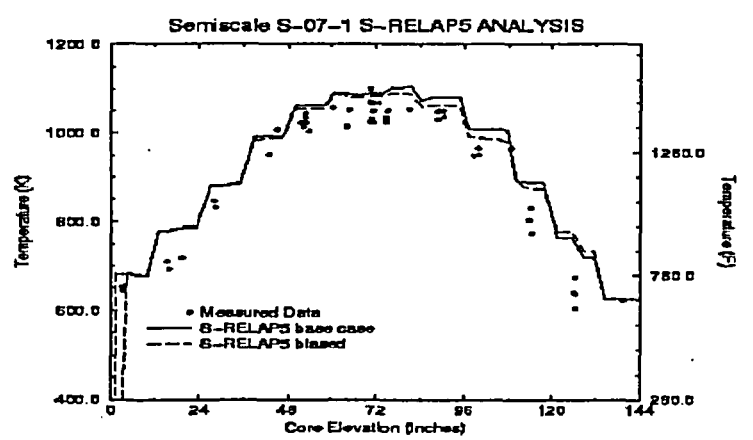
# Semiscale S-07-1 PCT Profile



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## 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 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



## 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 and Uncertainty Analysis (CSAU Element 3)

- > Plant Sensitivity Calculations (CSAU Step 12)
  - The code's PCT sensitivity to the plant specific input and process parameter variations is determined from sensitivity studies using the NPP model
    - Sensitivity studies were performed for the identified NPP parameters to quantify the impact on the LBLOCA

uniform distribution can be used with little impact on margin to limits





## Sensitivity and Uncertainty Analysis (CSAU Element 3)

- > Determine Combined Bias and Uncertainty (CSAU Step 13)
  - Framatome ANP Approach
    - Uses uncertainties developed from assessments as input to analysis
    - Propagates uncertainties through transient using plant model
    - Unlike CSAU Technical Program Group (TPG) approach does not rely on the use of a response surface
    - Instead uses non-parametric statistics
      - Allows statistical treatment of a large number of variables with an acceptable number of calculations
      - Provides 95/95 PCT and associated maximum nodal, and total core oxidation

## Sensitivity and Uncertainty Analysis (CSAU Element 3)

- 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



## Sensitivity and Uncertainty Analysis (CSAU Element 3)

- 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

## Sensitivity and Uncertainty Analysis (CSAU Element 3)

- > Non-Parametric Methods
  - The current methodology uses non-parametric tolerances
  - The acceptance criteria for LBLOCA are expressed as criteria on PCT and on cladding oxidation
  - All one needs to compare to these criteria are tolerances
  - Advantages
    - The number of parameters which can be treated statistically is limited only by the ability of the user to define and implement uncertainties
    - All uncertainties are propagated together and the sensitivities and cross-correlations between them are treated concurrently
      - Uses plant model/code to account for cross-correlations
  - Weaknesses
    - Does not produce probability distributions
    - Tolerance limits are conservatively bounding of the real limits



## Sensitivity and Uncertainty Analysis (CSAU Element 3)

- > Determine Combined Bias and Uncertainty (CSAU Step 13)
  - Non-Parametric Statistics
    - Relies on the execution of a defined number of cases to determine a 95/95 condition
      - 59 cases: highest value calculated is 95/95
      - 93 cases: second highest value calculated is 95/95
      - 124 cases: third highest value calculated is 95/95
      - 153 cases: fourth highest value calculated is 95/95
      - etc.
    - Each case defined by randomly selecting a value for each parameter being treated statistically

## Sensitivity and Uncertainty Analysis (CSAU Element 3)

> *Determine Combined Bias and Uncertainty (CSAU Step 13)*
  - *Define cases to be run*
    - *Parameter Case 1...Case 2.....Case N*
      - » A
      - » B
      - » .
      - » .
      - » .
      - » .
      - » .
      - » .
      - » ZZZ



## Sensitivity and Uncertainty Analysis (CSAU Element 3)

> *Determine Combined Bias and Uncertainty (CSAU Step 13)*

## 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 sample problems the limiting values for the primary safety criteria are:*

| Criteria | 4-loop Case 22 | 3-loop Case 41 |
|---|---|---|
| 95/95 PCT | 1686 F | 1853 F |
| Maximum Nodal Oxidation | 0.8 % | 1.3 % |
| Maximum Core Oxidation | 0.02 % | 0.04 % |
| 50/50 PCT | 1375 F | 1500 F |



## Realistic LBLOCA Methodology Roadmap

> *Conclusions*
- *An overview of the complete Framatome ANP Realistic LBLOCA methodology has been provided*
  - *Demonstrated use of the CSAU methodology elements and steps*
  - *Demonstrated improved statistical treatment*
    - *Non-parametric statistics allowed treatment of a large number of parameter uncertainties, eliminating the need to determine penalties*
    - *Used SET's to remove biases from code models and to determine model uncertainties*
    - *Used IET's to evaluate code model biases on independent data sets*