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Realistic LBLOCA Methodology Roadmap

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Realistic LBLOCA Methodology Roadmap

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

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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

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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

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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

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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

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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

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Assessment and Ranging of Parameters (CSAU Element 2)

11

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Assessment and Ranging of Parameters (CSAU Element 2)

12

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Assessment and Ranging of Parameters (CSAU Element 2)

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

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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

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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

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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

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Assessment and Ranging of Parameters (CSAU Element 2)

> Nodalization (CSAU Step 8)

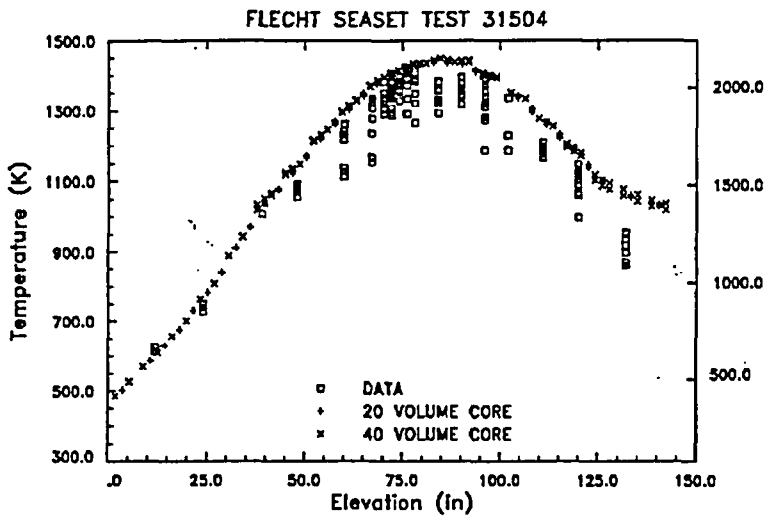
- Select common nodalization for use in SET, IET, and plant analyses
  - Initial nodalization selected based on previous industry and Framatome ANP experience
  - Revised based on initial plant model studies
  - Further revised based on peer review
  - Final nodalization validated/refined based on performance 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)

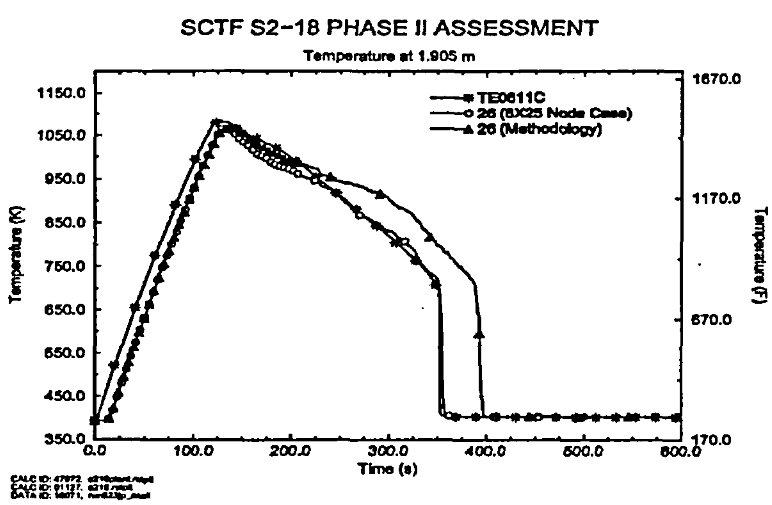
> Nodalization (CSAU Step 8)

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

Core Axial Nodalization Study



Core Radial Nodalization Study



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*

25

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Dispersed Flow Film Boiling

> Applied Biases

26

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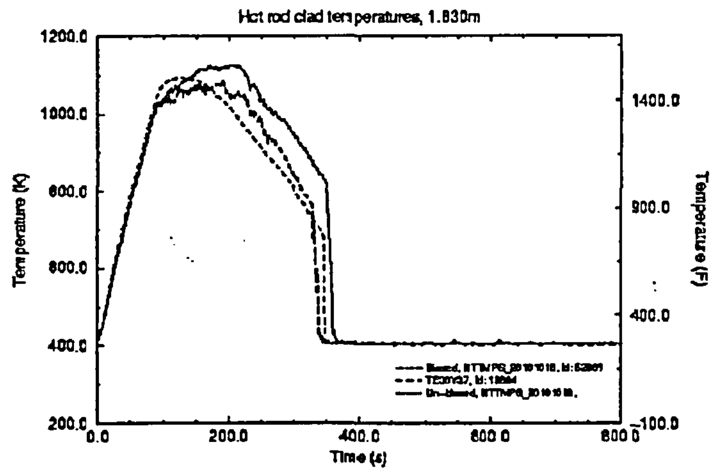
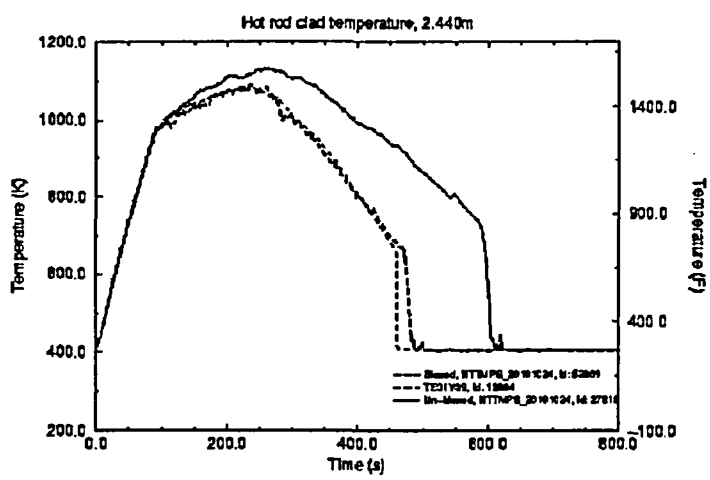
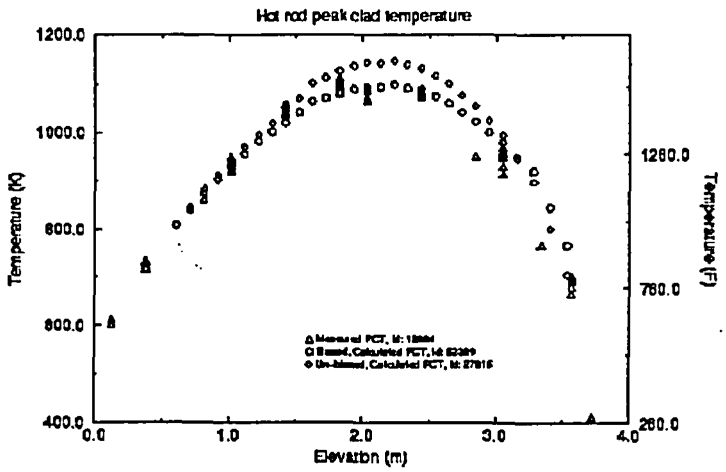
CCTF TEST 54 Temperatures at Measured PCT Node



CCTF TEST 54 Temperatures Near Calculated PCT Node



CCTF TEST 54 PCT Profile



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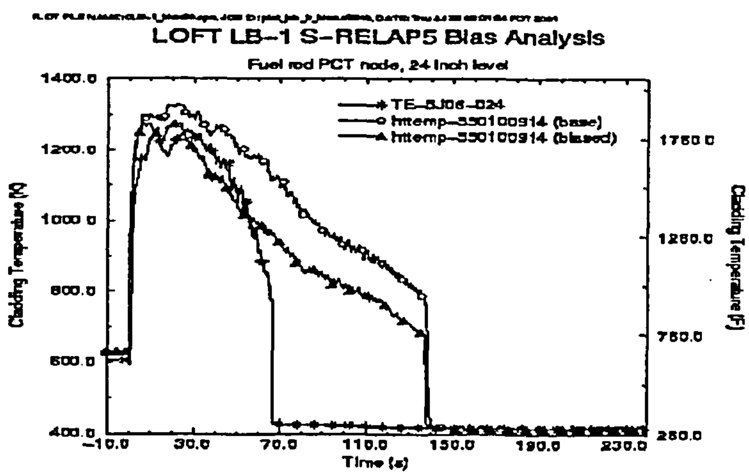
LOFT LP-LB-1 Temperatures at Measured PCT Node



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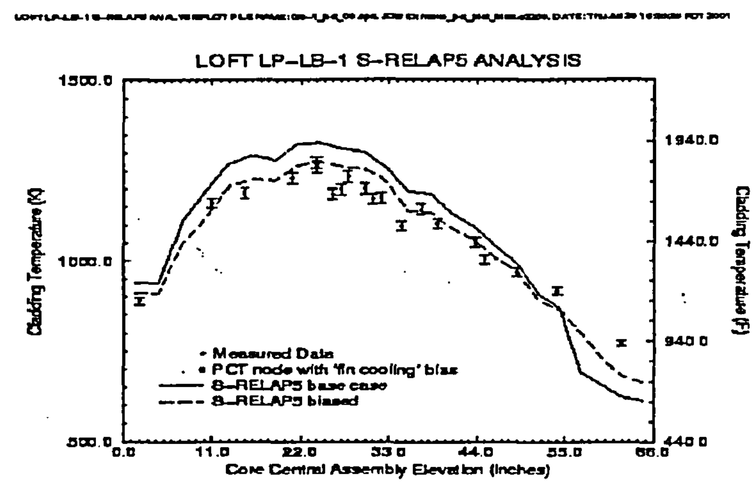
LOFT LP-LB-1 PCT Profile



31

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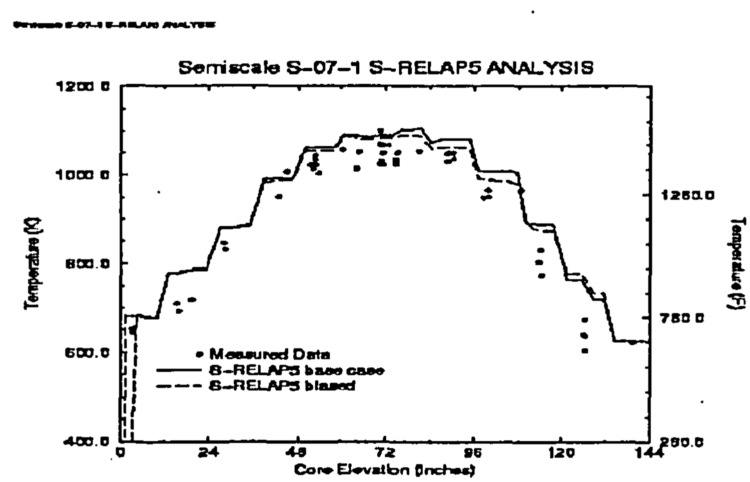
Semiscale S-07-1 PCT Profile



32

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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

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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
  - 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

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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
    - Analysis must address the Technical Specification limits for those parameters impacting the LBLOCA

35

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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

36

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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

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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*

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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

41

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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

42

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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

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Sensitivity and Uncertainty Analysis (CSAU Element 3)

- Determine Combined Bias and Uncertainty (CSAU Step 13)

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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

45

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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

46

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