Westinghouse

A BNFL Group company

Automated Statistical Treatment of Uncertainty Method (ASTRUM)

Overview within CSAU Framework

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August 5, 2003

Current Westinghouse Best-Estimate Large Break LOCA Methodologies

Initially Approved for Westinghouse-Designed 3-/4-Loop Plants with Cold Leg ECCS Injection (WCAP-12945-P-A, approved in 1996)

Later Extended to 2-Loop Plants with Upper Plenum Injection (WCAP-14449-P-A, approved in 1999)

Follow Code Scaling, Applicability and Uncertainty (CSAU) Evaluation Methodology Endorsed by NRC and ACRS

ASTRUM Submitted as WCAP-16009-P

Also Follows CSAU Evaluation Methodology

Uses Same Code as Previously Approved (with Minor Error Corrections per Annual 10 CFR 50.46 Reports)

Uses Same Uncertainty Distributions for Important Physical Phenomena

Revised Method for Combining Uncertainties

- Non-parametric order statistics used
- Response surfaces and superposition correction uncertainty eliminated

CSAU Framework (NUREG/CR-5249)

Element 1, "Requirements and Code Capabilities"

- 6 steps to compare requirements of scenario and plant design with simulation capabilities of the computer code

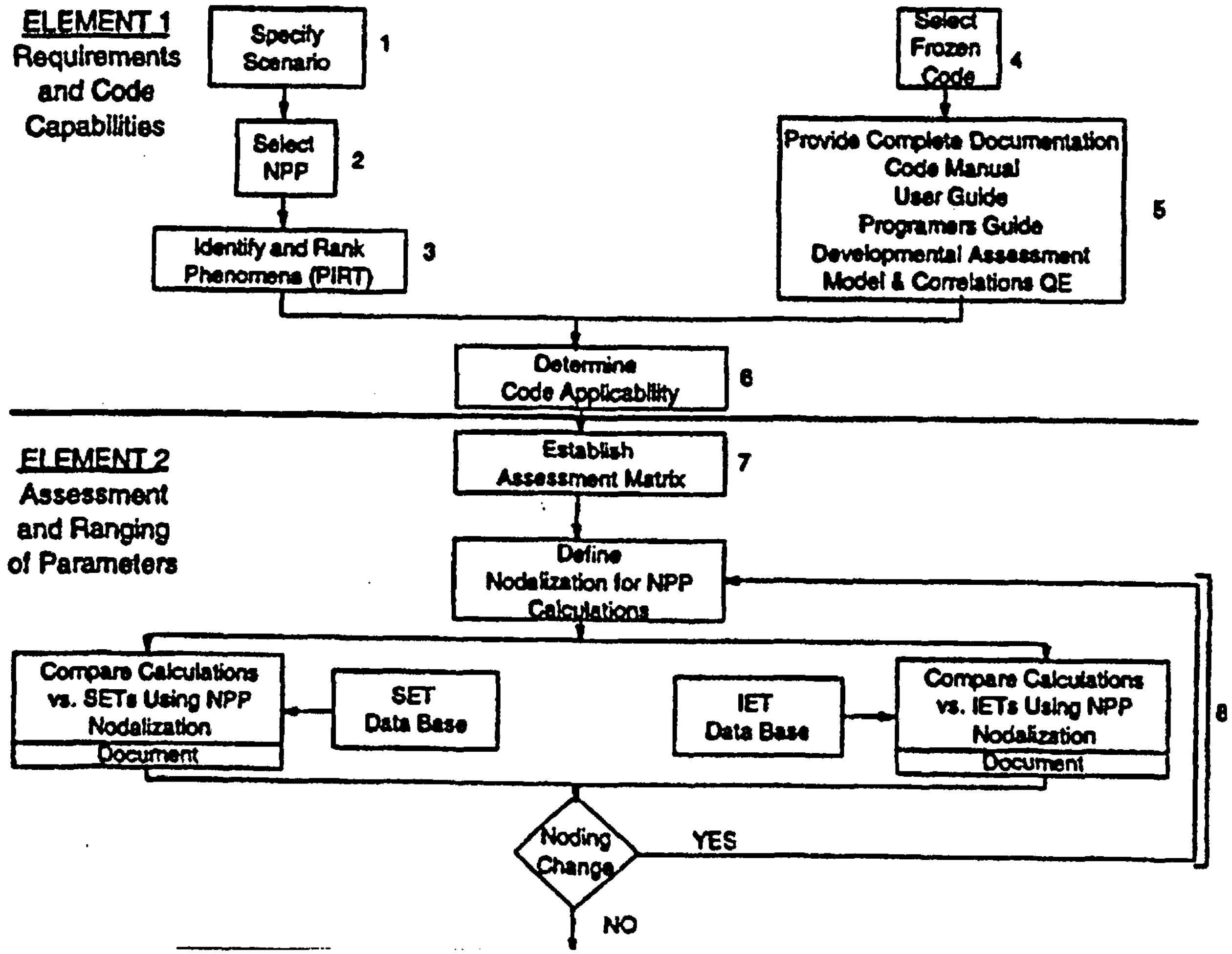
Element 2, "Assessment and Ranging of Parameters"

- 4 steps to quantify code and model accuracy for important physical phenomena

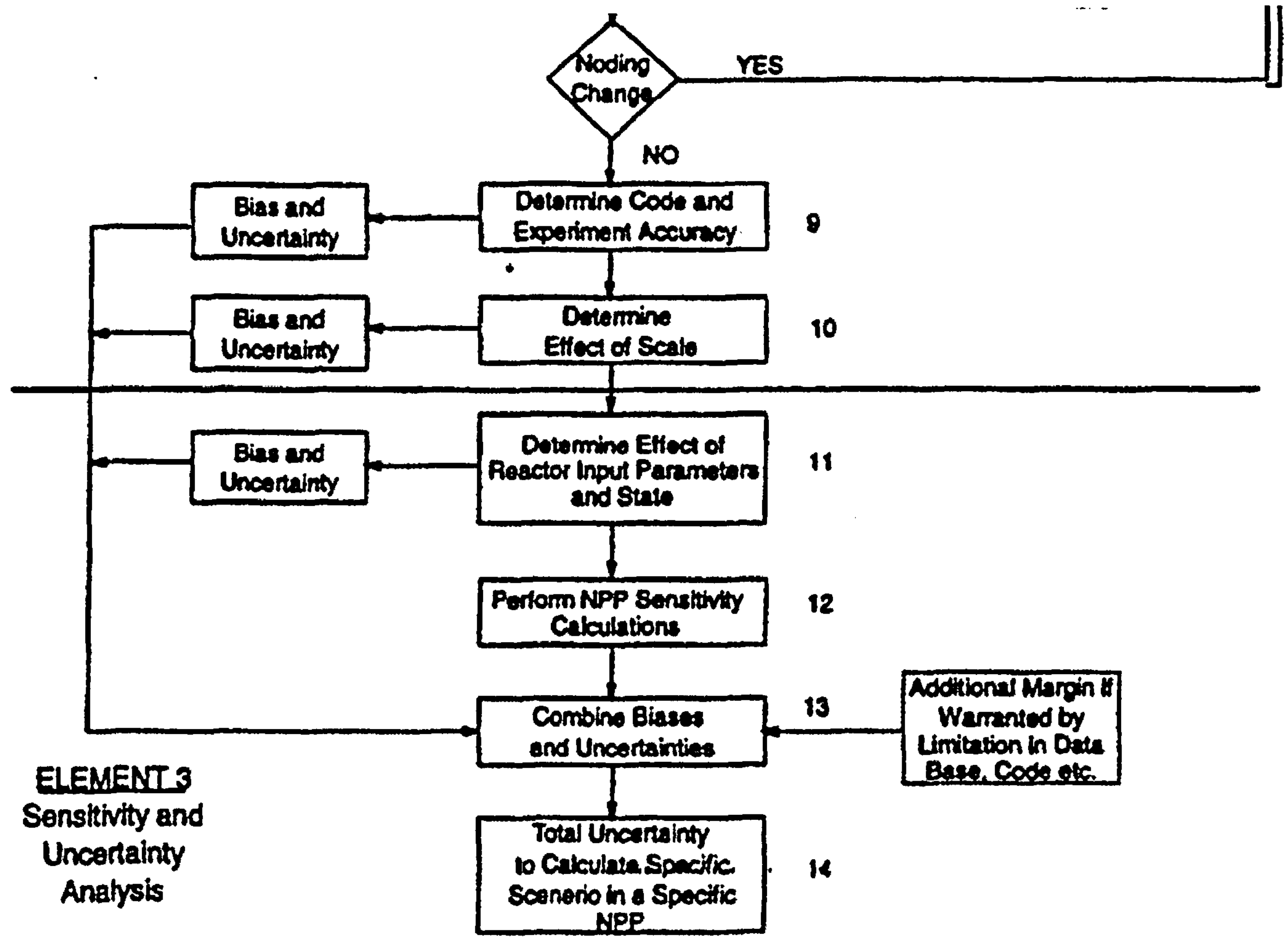
Element 3, "Sensitivity and Uncertainty Analysis"

- 4 steps to quantify plant-specific uncertainty of relevant figure of merit

CSAU Flowchart



CSAU Flowchart (continued)



Requirements and Code Capabilities

Step 1: Scenario Specification

- Large break LOCA in cold leg (limiting location)
- Evolution of transient phenomena dictates PIRT parameters

Step 2: Nuclear Power Plant Selection

- Previously approved Westinghouse-designed PWRs
- Extension to Combustion Engineering-designed PWRs (Appendix A)

Requirements and Code Capabilities (cont'd)

Step 3: Phenomena Identification and Ranking

- Unchanged for previously approved Westinghouse PWR designs
  - Summarized in Table 1-1
- Minor differences identified for CE designs (Appendix A)
  - Existing code assessment matrix adequate to cover those differences

Requirements and Code Capabilities (cont'd)

Step 3 (cont'd)

- Dominant phenomena grouped based on physical processes involved:
  - Critical flow
  - Break path resistance
  - Initial stored energy/fuel rod
  - Core heat transfer
  - Delivery and bypassing of the ECC
  - Steam binding/entrainment
  - Cold leg/downcomer condensation
  - Noncondensable gases/accumulator nitrogen
  - Upper plenum drain distribution (UPI only)

Requirements and Code Capabilities (cont'd)

Step 4: Frozen Code Selection

- WCOBRA/TRAC MOD7A Rev. 6 used for system transient response
  - Based on previously approved WCOBRA/TRAC MOD7A Rev. 1, with error corrections previously reported per 10 CFR 50.46 annual reports
  - Error corrections and code re-validation detailed in Appendix B
    - Re-validation showed no changes in uncertainty distributions required

Requirements and Code Capabilities (cont'd)

Step 4 (cont'd)

- HOTSPOT used for detailed fuel rod model analysis
  - 1-D conduction model
  - Uses boundary conditions from WCOBRA/TRAC
  - Ability to vary local thermal-hydraulic models, including burst and fuel relocation
- COCO (dry) or LOTIC (ice condenser) used for containment pressure transient analysis
- Response surface and Monte Carlo codes used in current methods not needed for ASTRUM

Requirements and Code Capabilities (cont'd)

Step 5: Provide Complete Documentation

- WCAP-16009-P mostly stand-alone, per NRC request
  - Roadmap (Section 1)
  - Models and correlations (Sections 2-10)
  - Uncertainty methodology (Section 11)
  - Sample application (Section 12)
  - Re-validation with WCOBRA/TRAC MOD7A Rev. 6 (Appendix B)
- Some reliance on WCAP-12945-P-A & WCAP-14449-P-A
  - e.g., detailed development of unchanged uncertainty distributions

Requirements and Code Capabilities (cont'd)

Step 6: Code Applicability Determination

- WCOBRA/TRAC previously approved for specified accident scenario and Westinghouse designed plants
- Applicability to CE designs justified in Appendix A

Assessment and Ranging of Parameters

Step 7: Establishment of Assessment Matrix

- Previously selected SET and IET remain appropriate, including extension to CE plants
- Summarized in Tables 1-2 through 1-6

Step 8: Define Nodalization

- Previously defined guidelines remain applicable
  - Section 20 of WCAP-12945-P-A for cold leg injection
  - Section 3 of WCAP-14449-P-A for upper plenum injection

Assessment and Ranging of Parameters (cont'd)

Step 9: Determine Code and Experiment Accuracy

- Biases and uncertainties previously established for highly ranked models and phenomena by comparison with relevant SET
- Resulting global and local model uncertainty distributions summarized in Tables 1-7 and 1-8

Uncertainty Distributions for Global Models

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Uncertainty Distributions for Local Models

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Uncertainty Distributions for Local Models (cont'd)

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Cumulative Distribution Function for Reflood Heat Transfer Multiplier

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Assessment and Ranging of Parameters (cont'd)

Step 10: Determine Effect of Scale

- Previous conclusions for cold leg injection remain valid
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- Previous conclusions for upper plenum injection remain valid
  - Important scaling parameters for UPI well-predicted

Sensitivity and Uncertainty Analysis

Step 11: Determine Effect of Reactor Input Parameters and State

- Uncertainty treatment of plant parameters defined in previous submittals (nominal, bounded, explicitly treated)
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Sensitivity and Uncertainty Analysis (cont'd)

Step 11 (cont'd)

- Same power-related parameters and uncertainty distributions will be considered in uncertainty analysis (Table 1-10)
- Same initial and boundary conditions will be considered in uncertainty analysis (Table 1-11)
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Uncertainty Distributions for Power-Related Parameters

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Initial and Boundary Condition Parameters

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Sensitivity and Uncertainty Analysis (cont'd)

Step 12: Perform NPP Sensitivity Calculations

- Plant-specific confirmatory studies used to select bounding conditions
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Sensitivity and Uncertainty Analysis (cont'd)

Step 12 (cont'd)

- Run matrix generated by randomly sampling from each parameter's uncertainty distribution
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  - Generate 59 cases (optionally 93) to quantify peak cladding temperature at high level of confidence

Sensitivity and Uncertainty Analysis (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

Step 12 (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

Step 12 (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

Step 12 (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

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Sensitivity and Uncertainty Analysis (cont'd)

Step 13: Combine Biases and Uncertainties

- Non-parametric order statistics used to establish 95th percentile peak cladding temperature (PCT) at 95% confidence level
  - Highest PCT for 59 case run matrix
  - Alternatively, second highest for 93 case run matrix

Sensitivity and Uncertainty Analysis (cont'd)

Step 14: Calculate Total Uncertainty

- CSAU has a provision to add margin if warranted (code or data base limitations)
- As with previous methodologies, no such margins required with ASTRUM

Oxidation Analyses

Maximum Local Oxidation

- Calculated for case providing 95/95 PCT
  - Consistent with Regulatory Guide 1.157
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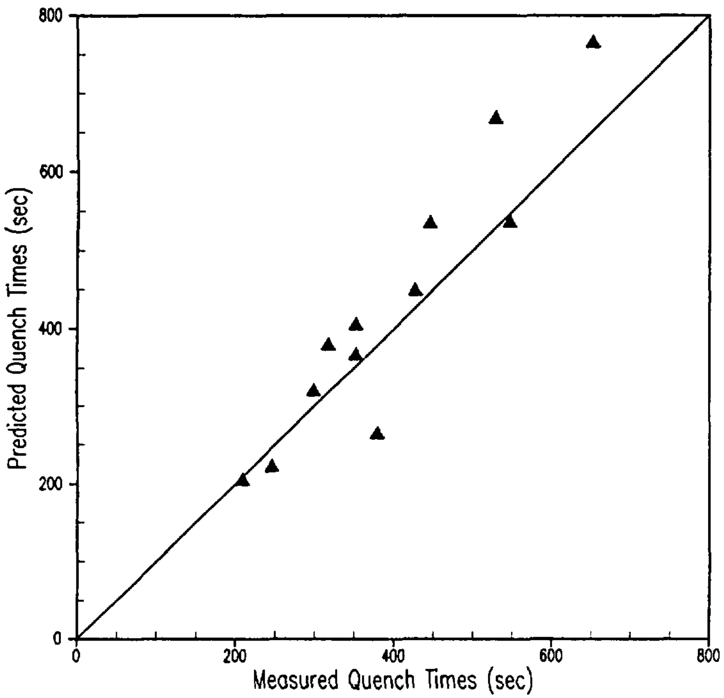
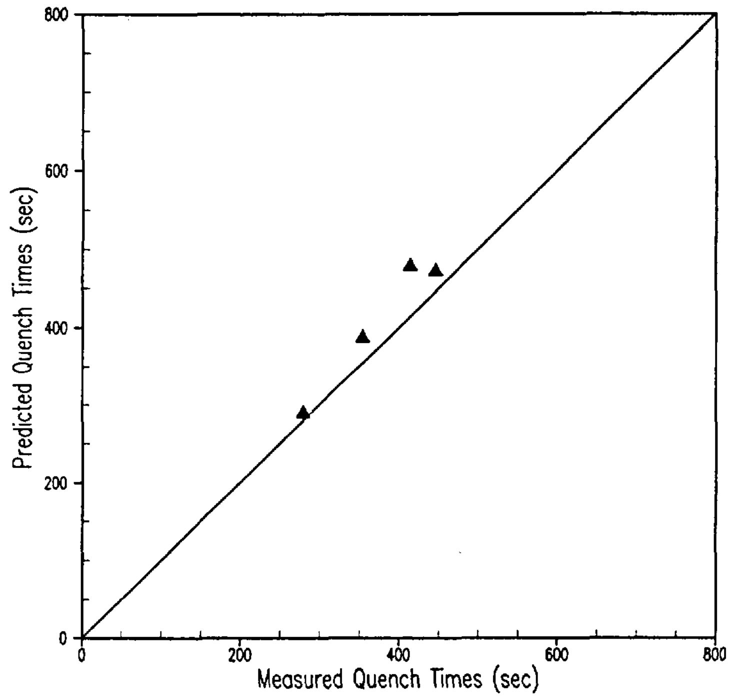
Oxidation Analyses (cont'd)

Quench Time Predictions for Gravity Reflood Tests



CCTF Quench Times
(Runs 62, 63, 64, 67)



SCTF Quench Times
(Run 604)

Oxidation Analyses (cont'd)

Core-Wide Oxidation

- Calculated for case providing 95/95 PCT
  - Consistent with Regulatory Guide 1.157
- Additional WCOBRA/TRAC calculations performed, decreasing hot assembly power in steps
  - Generic or plant-specific rod power census used
  - Oxidation fractions summed to obtain core-wide value

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Example PWR Application

Cesare Frepoli
August 5, 2003

Determination of Reference Transient

Indian Point Unit 2 Used for ASTRUM Demonstration

- Previously used for WCAP-12945-P-A methodology demonstration
- Confirmatory runs identified bounding assumptions
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Confirmatory Run Results

Case	Assumption	Change in PCT from Reference Value
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Analysis Results

95/95 PCT is 1899°F

- Maximum of 59 cases

Corresponding maximum local oxidation is 2%

- Includes burst effects
  - Fuel relocation
  - Double-sided reaction

Core-wide oxidation <<1%

- Hot rod ~ 0.6%

Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Analysis results (cont'd)

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Summary and Conclusions

ASTRUM is an Evolutionary Advancement to Previously Approved Westinghouse Methods

- Codes unaffected by minor error corrections
- Same uncertainty distributions used for important physical phenomena
- Revised method for combining uncertainties eliminates reliance on response surfaces and superposition correction