

**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

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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**

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**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)

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## Element 1, “Requirements and Code Capabilities”

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

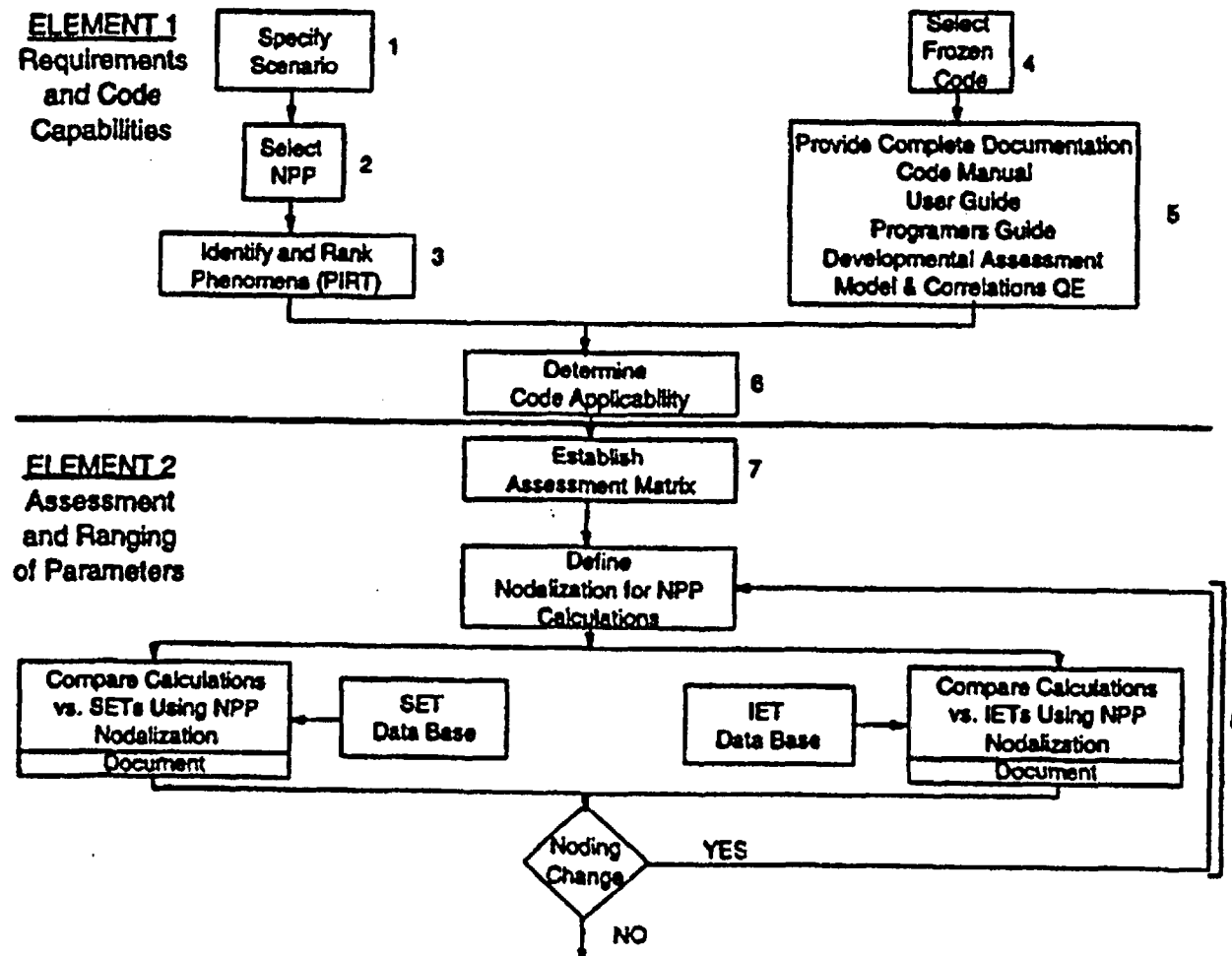
## Element 2, “Assessment and Ranging of Parameters”

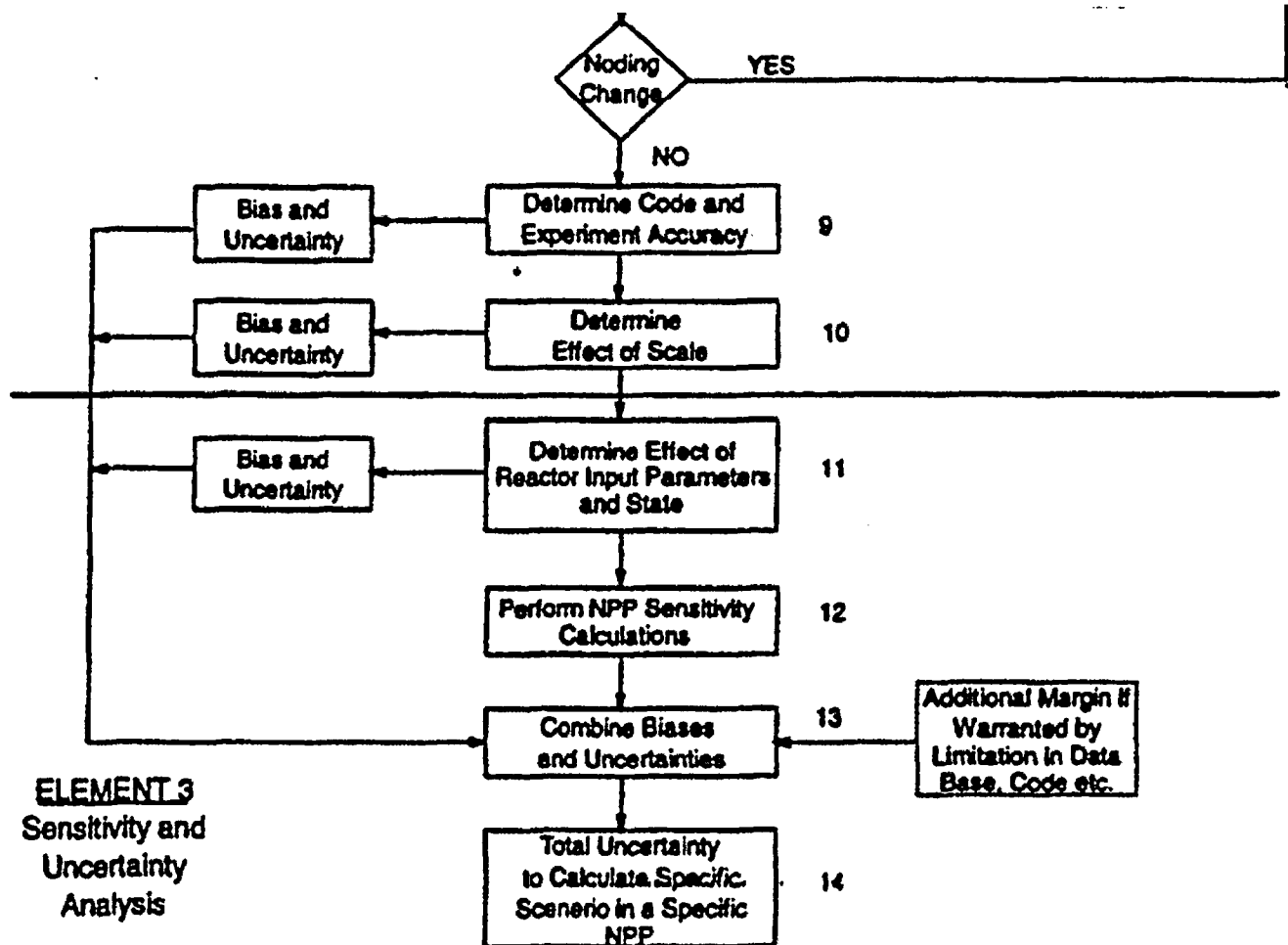
- 4 steps to quantify code and model accuracy for important physical phenomena

## Element 3, “Sensitivity and Uncertainty Analysis”

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

# CSAU Flowchart



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# Requirements and Code Capabilities

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## 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

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## 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

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## 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)

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### 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)

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### 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)

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### 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)

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## 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)

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Step 12 (cont'd)

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# Sensitivity and Uncertainty Analysis (cont'd)

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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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### 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)

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### 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

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## Maximum Local Oxidation

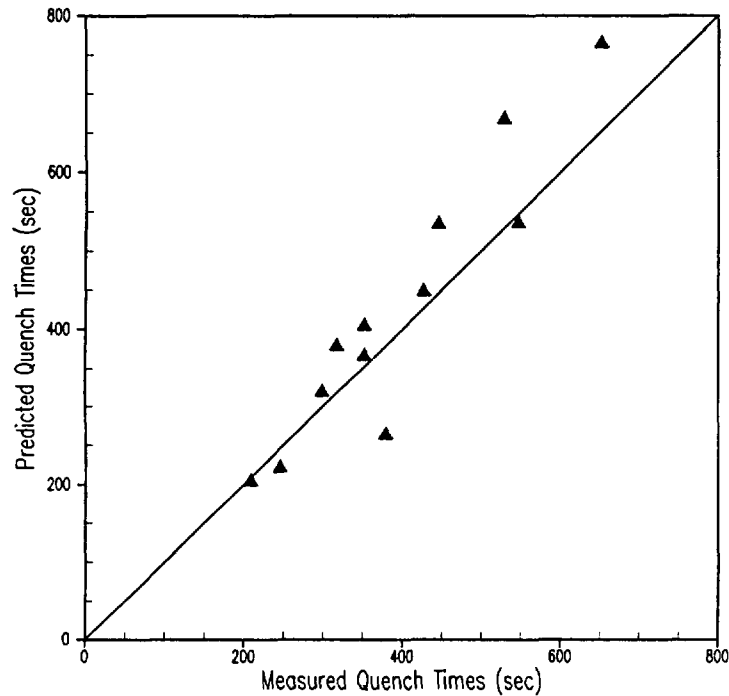
- Calculated for case providing 95/95 PCT
  - Consistent with Regulatory Guide 1.157

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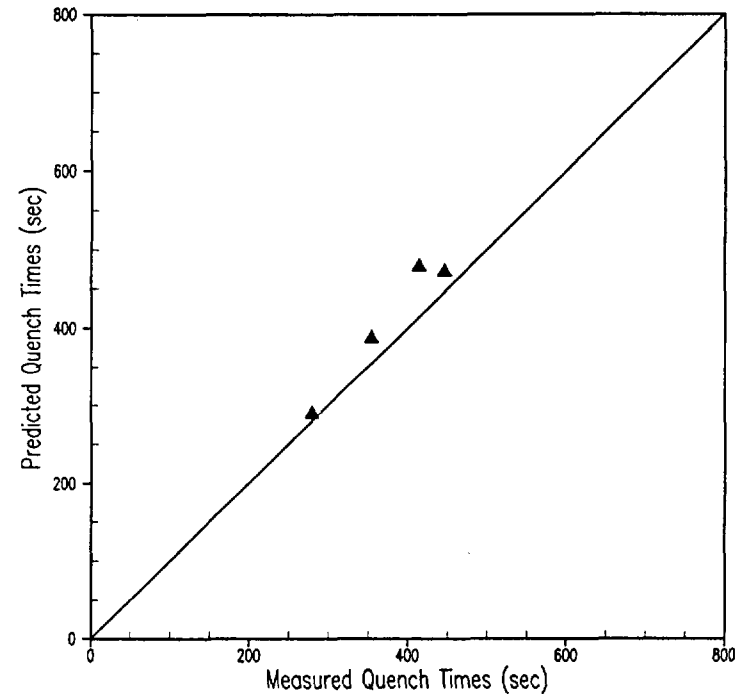
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# Oxidation Analyses (cont'd)

## Quench Time Predictions for Gravity Reflood Tests



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



SCTF Quench Times  
(Run 604)

## Oxidation Analyses (cont'd)

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### 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



# Automated Statistical Treatment of Uncertainty Method (ASTRUM)

## Example PWR Application

Cesare Frepoli  
August 5, 2003

# Determination of Reference Transient

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## 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

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Case	Assumption	Change in PCT from Reference Value
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# Analysis Results

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**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

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### 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