Overview Westinghouse Realistic (Best-Estimate) LOCA Methodology

March 4-5th, 2009

Outline

- PART-1: Overview of the code (WCOBRA/TRAC) and process utilized to assess biases and uncertianties
- PART-2: Overview of the list of uncertainty parameters considered in the analysis
- PART-3: Method used to combine the uncertainties and show compliance with 10 CFR 50.46 criteria

Part 1

WCOBRA/TRAC: Engine of Westinghouse Realistic Large Break LOCA Evaluation Model

Westinghouse Realistic Large Break LOCA Evaluation Model

Year	Development Activity
1983	Obtained COBRA/TRAC (NUREG/CR-3046) for UPI plant appl.
1988	SER on SECY-UPI method (Interim BE method/SECY-83-472)
1988	RG 1.157 “Best Estimate Calculation of ECCS Performance”
1989	CSAU (NUREG/CR-5249)
→1993	Improvements and Error corrections to COBRA/TRAC and Development of WCOBRA/TRAC through > 100 SET/IET test simulations
1993	Submittal of Code Qualification Documents (CQD) to USNRC
1996	SER by USNRC for the BELOCA methodology (1996 CQD Method)
1998	SER for DVI Plant (AP600)
1999	SER for UPI-BELOCA
2004	AP1000, SER for ASTRUM

WCOBRA/TRAC Validation

- PIRT process use to identify important phenomena (consistently with CSAU/EMDAP)
- For large-break LOCA application ~100 simulations/20 facilities (SETs and IETs) were simulated by WCOBRA/TRAC.
- Quantification of model uncertainty performed mainly via SETs.
- IETs and large component tests were used for judging the code's ability to predict system responses.
- Compensating error analyses were performed to investigate the interaction of various models and identify situations where an apparently good prediction is due to offsetting mis-predictions.

WCOBRA/TRAC Validation

- Highly ranked phenomena in LBLOCA discussed here
  - Critical flows ←
  - ECCS bypass and vessel condensation ←
  - Refill/reflood heat transfer in core
  - System response in refill/reflood
  - Entrainment in core/upper plenum and steambinding

Assessment of biases and uncertainties on individual models/processes

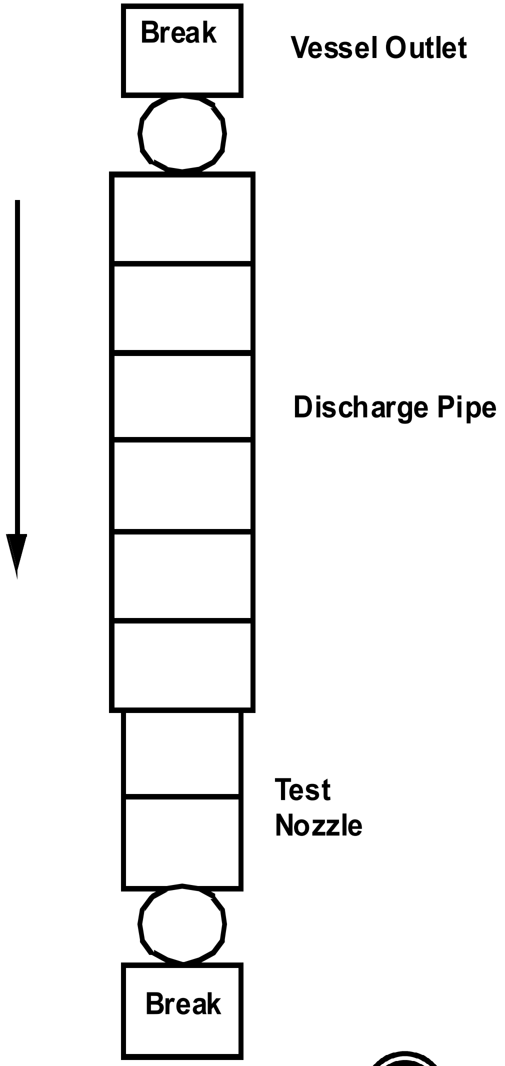
Uncertainty Example #1:

Critical Flow

Critical Flow Model Validation (cont.)

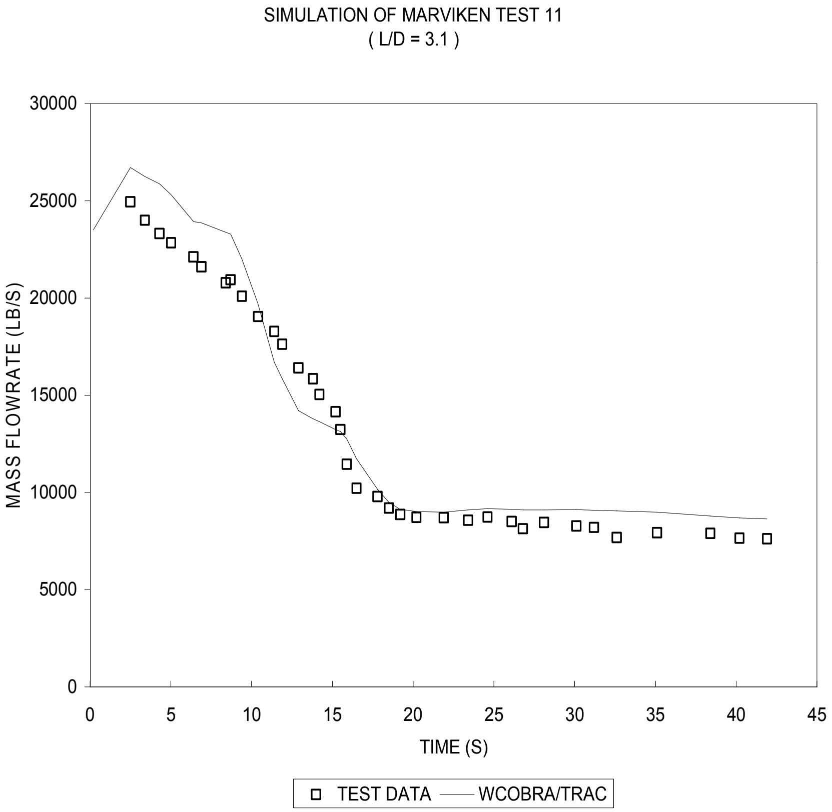
Marviken Model Noding

- Model starts at the point before the acceleration into the discharge pipe, and ends at the throat.
- Similar to the PWR broken pipe modeling which starts at the cold-leg nozzle and ends with the containment pressure boundary.



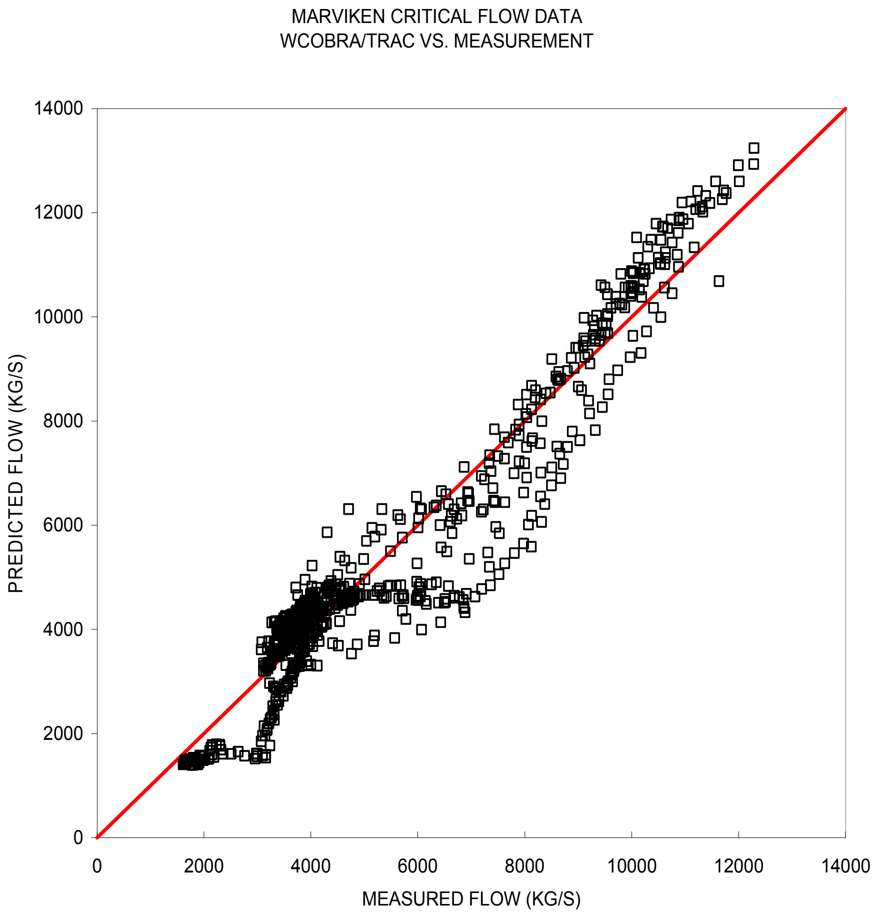
Critical Flow Model Validation (cont.)

Critical Flows/Marviken, LOFT



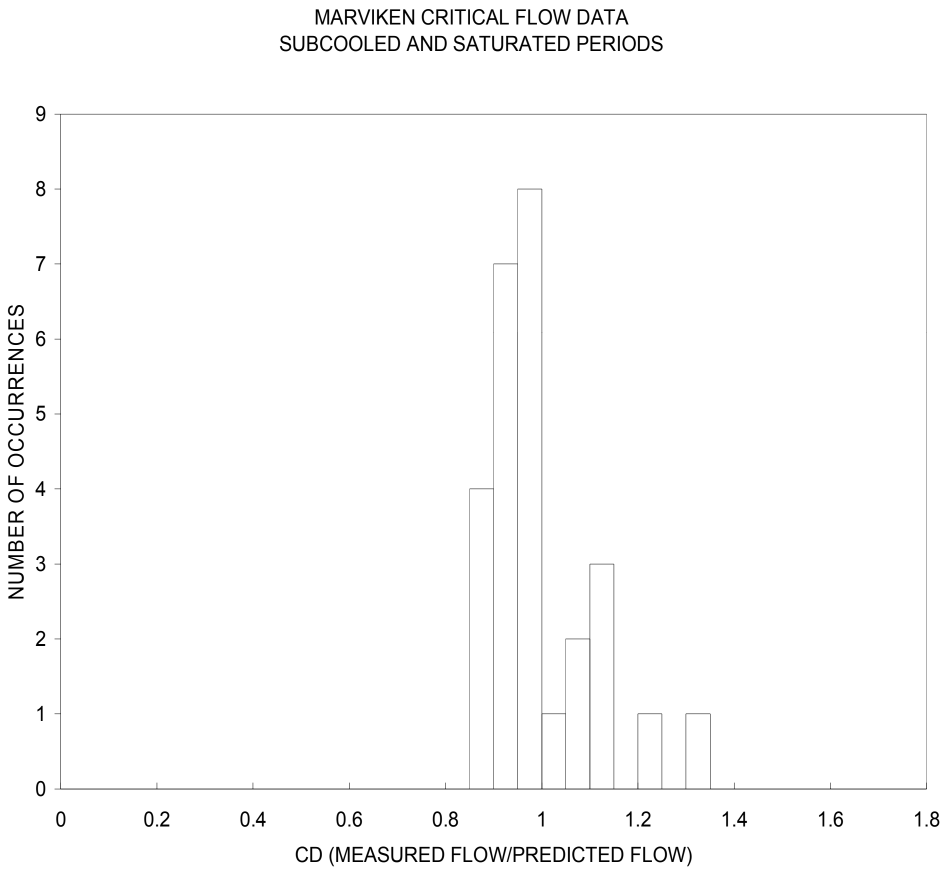
Critical Flow Model Validation (cont.)

Critical Flows/16 Marviken Tests



Critical Flow Model Validation (cont.)

- Histogram of discharge coefficient (CD) from Marviken Test comparisons

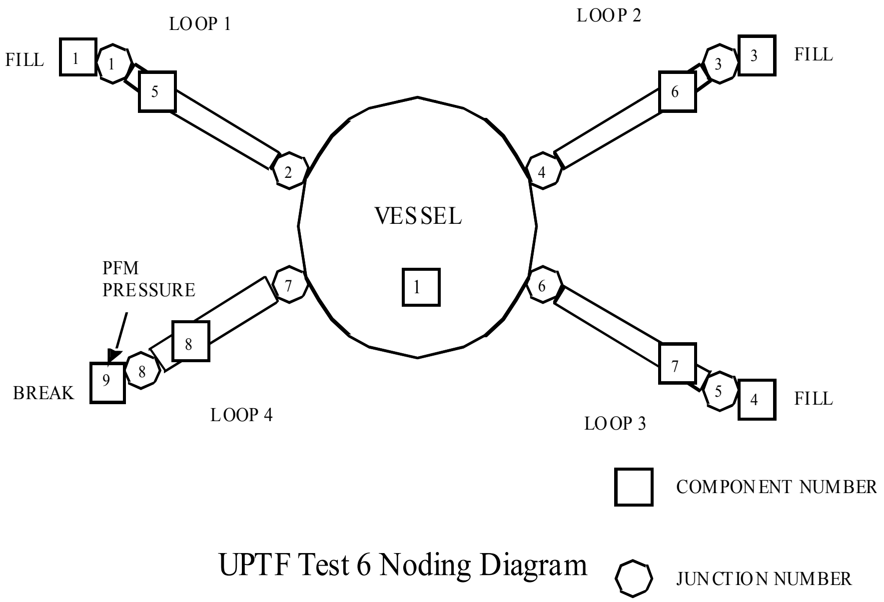


Uncertainty Example #2:

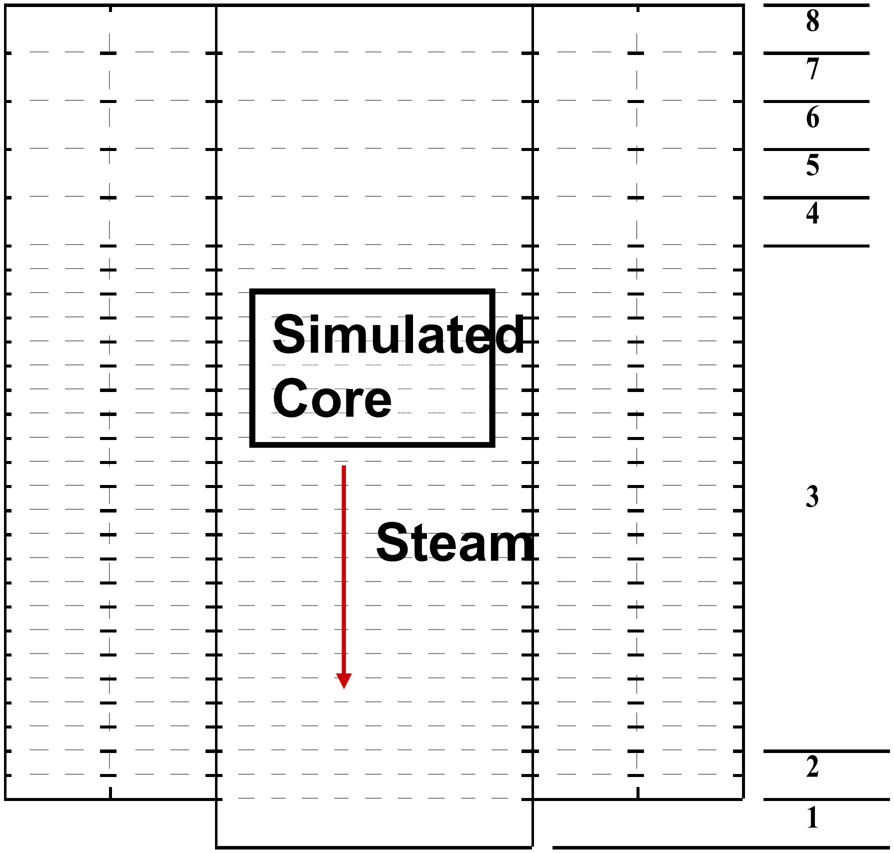
ECCS Bypass and Condensation

Model Validation

UPTF Test 6 Series (5 runs): Noding



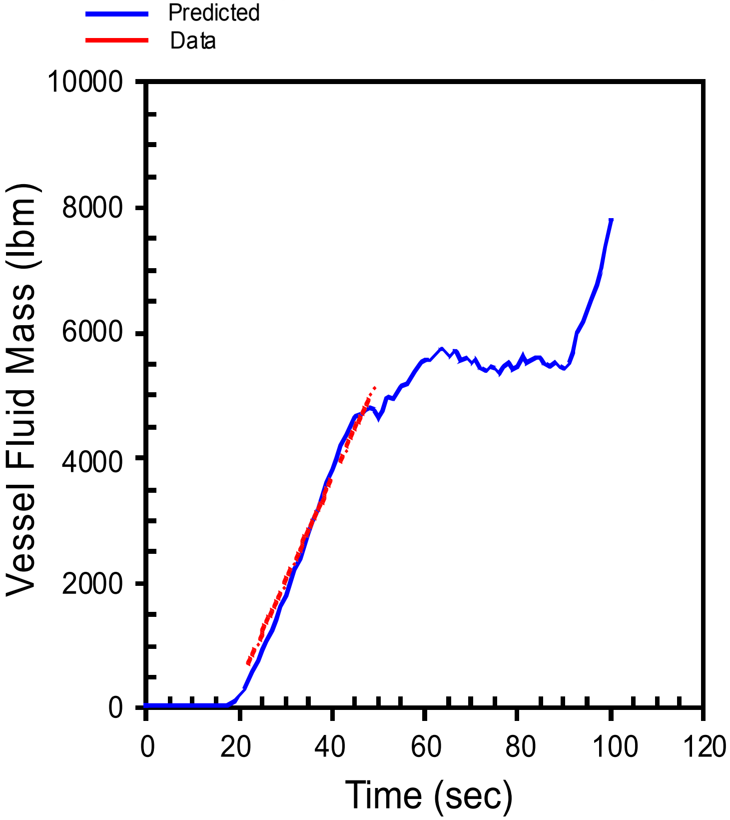
UPTF Test 6 Noding Diagram



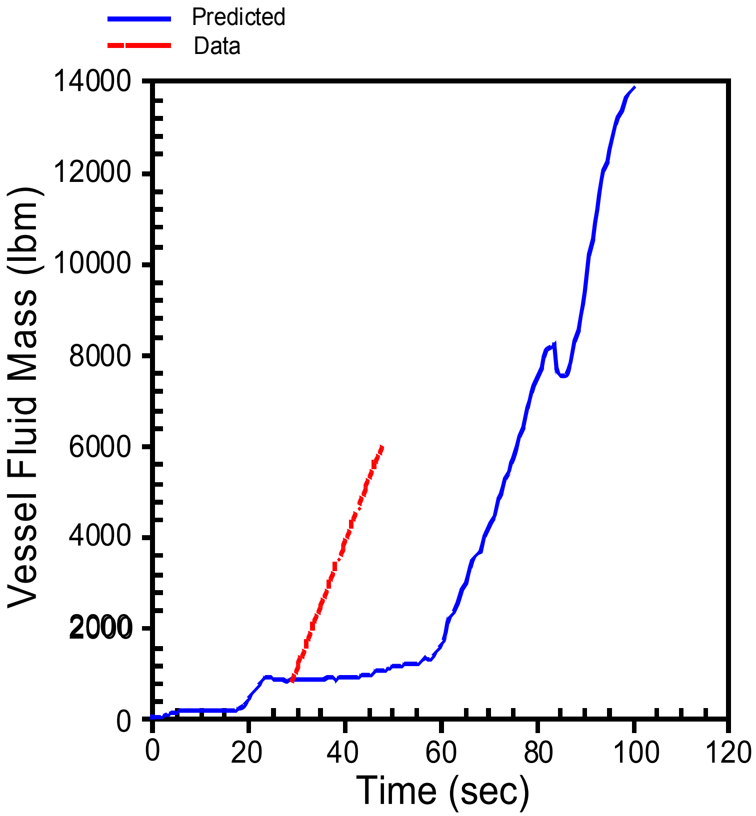
Model Validation (cont.)

UPTF Test 6 Series

Calculated Vessel Mass in UPTF Test 6 Run 136 (Low Steam Flow Test)

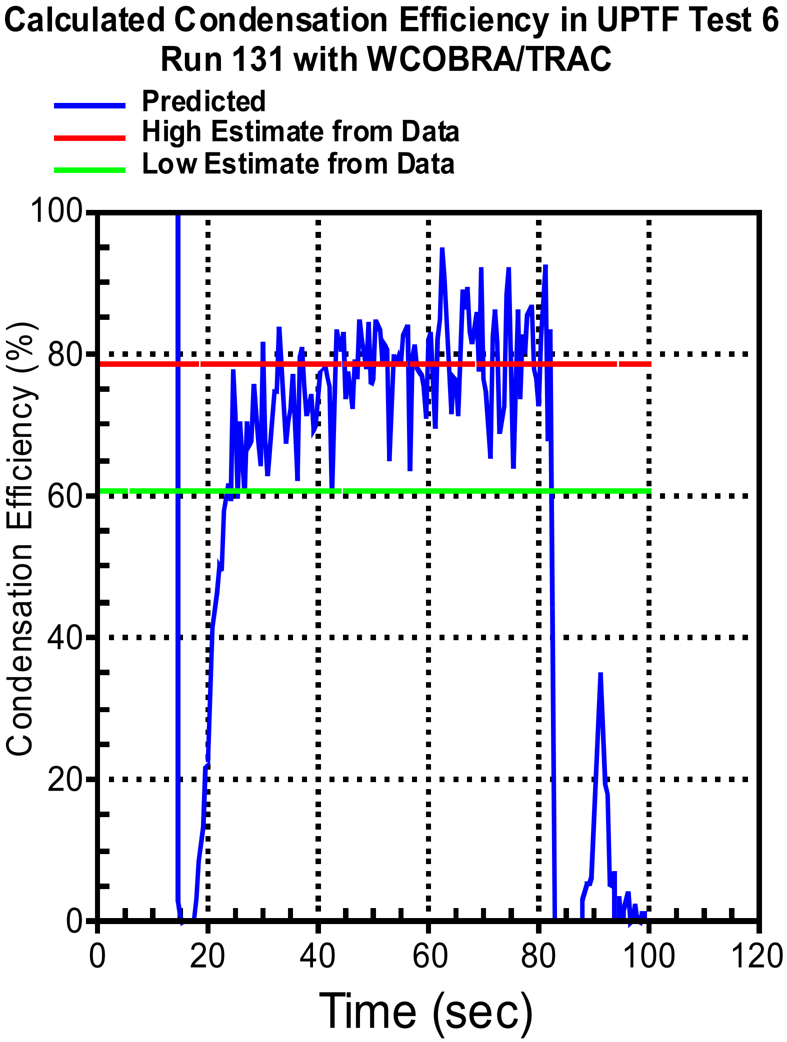


Calculated Vessel Mass in UPTF Test 6 Run 131 (High Steam Flow Test)



Model Validation (cont.)

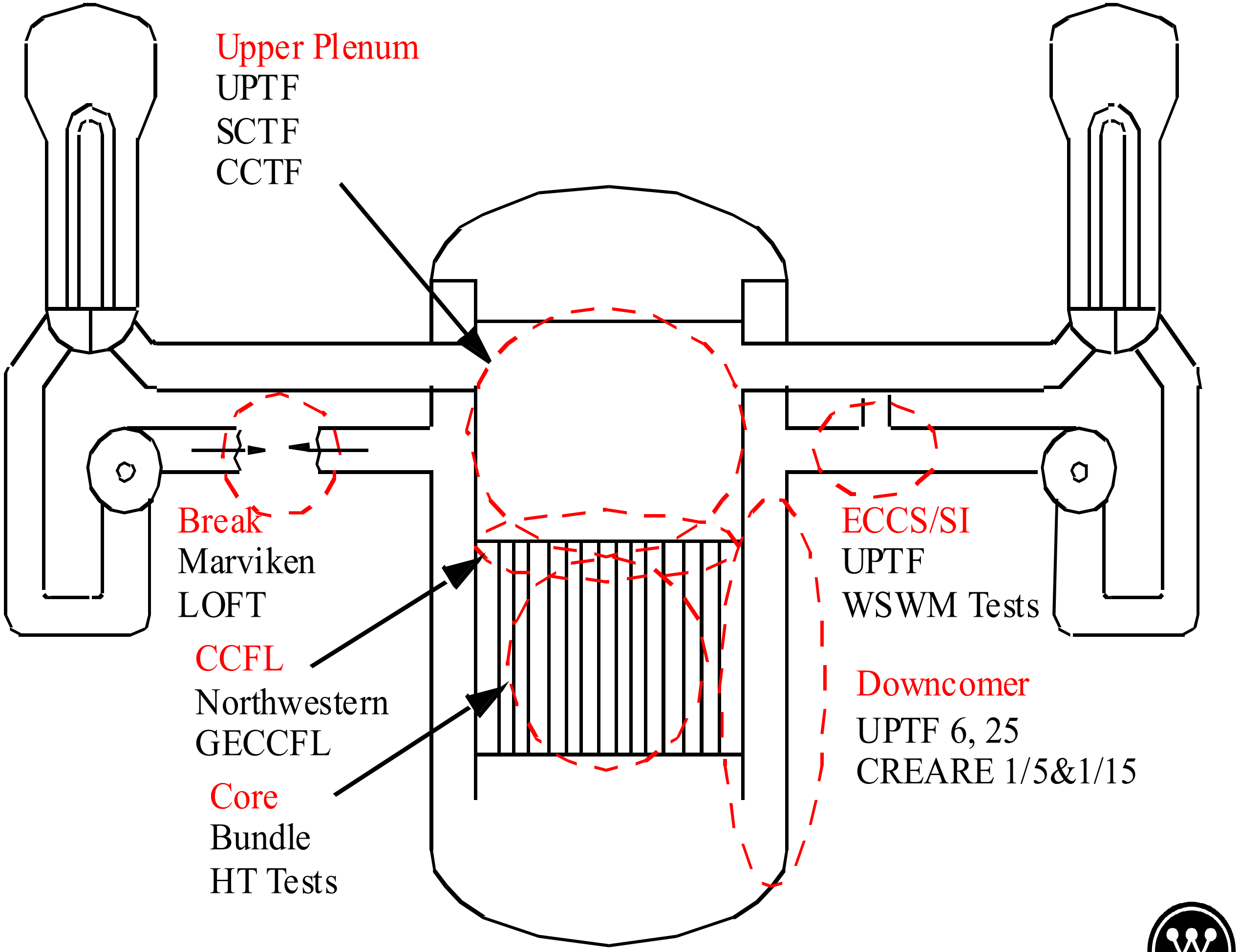
- Vessel condensation
- Two estimates from data using different methods
- WCOBRA/TRAC matched higher estimate, one considered more reliable
- For the PDF assume uniform distribution between low and high estimate (lack on knowledge)



Noding Guidelines Are The Results of the V&V

Model and Noding Scheme Validation

- Models and noding schemes used in PWR were validated.



Upper Plenum
UPTF
SCTF
CCTF

Break
Marviken
LOFT

CCFL
Northwestern
GECCFL

Core
Bundle
HT Tests

ECCS/SI
UPTF
WSWM Tests

Downcomer
UPTF 6, 25
CREARE 1/5&1/15

Part 2

Review Of Biases and Uncertainties

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Introduction

- Input-Driven methodologies require the characterization of the most important uncertainty contributors
- Uncertainty parameters can be grouped as follows:
  - Nominal without uncertainty,
  - Bounded,
  - Nominal with uncertainty

Slide 20

C.F.1 Cesare Frepoli, 3/3/2009

Treatment of Uncertainties – Nominal With Uncertainties

- The Westinghouse methodology includes three main categories of uncertainty contributors to the overall uncertainty assessment:
  1. Thermal-hydraulic model uncertainties
  2. Power-related parameter uncertainties
  3. Initial and boundary condition uncertainties

Treatment of Uncertainties – List of Uncertainty Attributes

Uncertainty Parameters	
Break Type	Total Core Peaking Factor Uncertainties, Hot Rod and Hot Assembly
Split Break Size	Axial Power Shape (P_{BOT}/P_{MID})
Critical Flow	Total Core Power Uncertainty
Broken Cold-Leg Nozzle Resistance	Decay Heat
Broken Loop Pump Resistance	Gamma Redistribution
Downcomer Condensation	Fuel Conductivity Before Burst
Upper Plenum Drain Distribution	Fuel Conductivity After Burst
Time in Cycle	Packing Factor due to Fuel Relocation
RCS Fluid Temperature	Gap Conductance
RCS Pressure	Rod Internal Pressure
Enthalpy Rise Peaking Factor Uncertainties	Cladding Burst Temperature
Accumulator Water Volume	Cladding Burst Strain
Accumulator Pressure	Metal-Water Reaction Rate
Accumulator Water Temperature	Blowdown Heatup HTC Multiplier
Accumulator Line Resistance	Blowdown Cooling HTC Multiplier
Safety Injection Water Temperature	Refill HTC Multiplier
Nominal Total Core Peaking Factor, F_Q	Reflood HTC Multiplier

Part 3

Use of Monte-Carlo Combined With Non-Parametric Statistics to Bound Uncertainty

Background

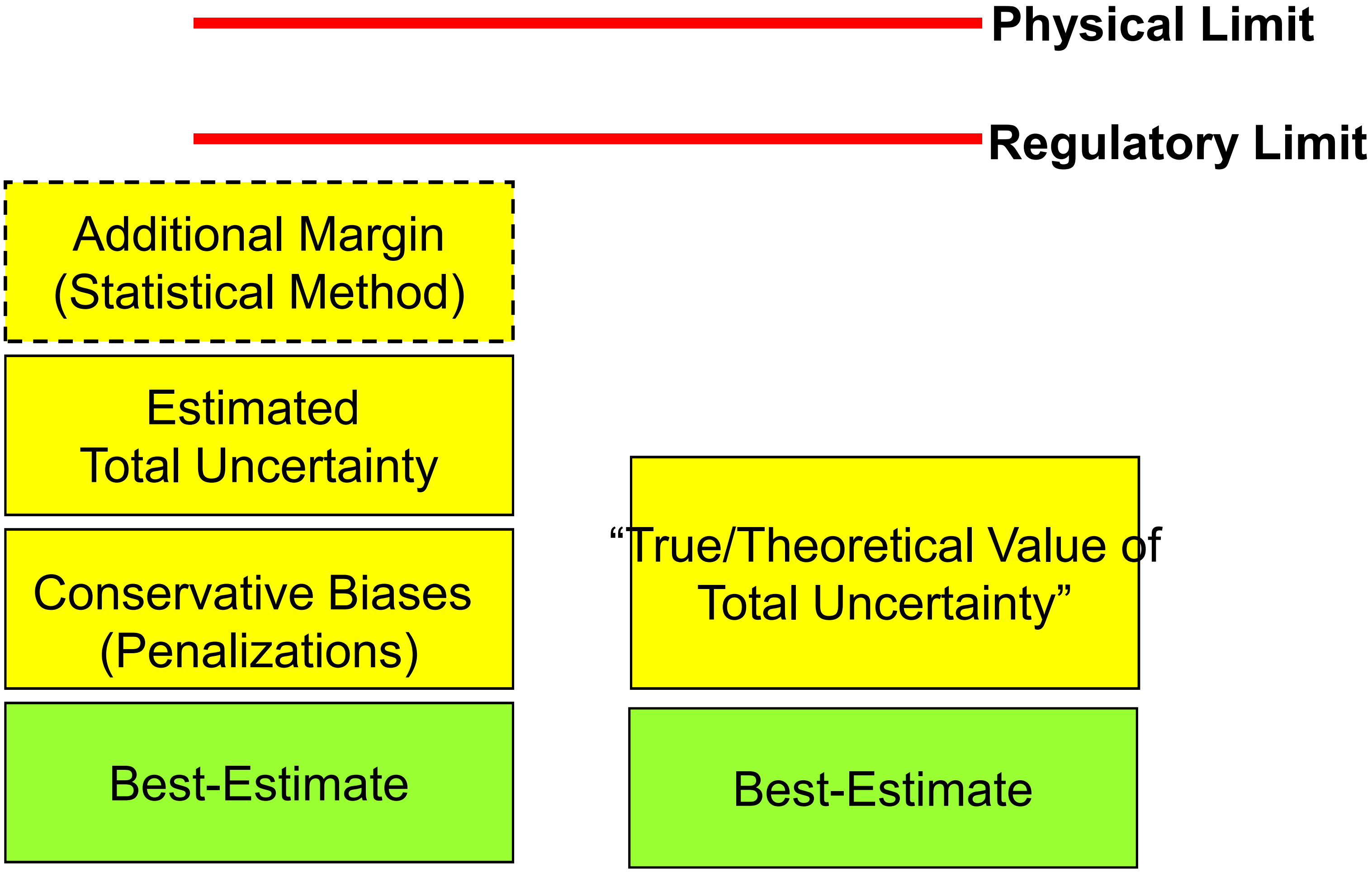
- A realistic analysis of complex systems requires the quantification of the combined effect of the uncertainty contributors to the total uncertainty.
- Decisions on the safety of a design are regulated following simple rules where figure of merits (FOMs) are tested against prescribed safety limits.
- Calculation often requires the analyst to bound the total uncertainty with a given confidence level

LOCA Figures of Merit (FOMs)

10 CFR 50.46 Acceptance Criteria

- Peak clad temperature (PCT) < 2200 F
- Local maximum oxidation (MLO) < 17%
- Core-wide oxidation (CWO) < 1%

10 CFR 50.46 Criteria Compliance



Physical Limit

Regulatory Limit

Additional Margin
(Statistical Method)

Estimated
Total Uncertainty

Conservative Biases
(Penalizations)

Best-Estimate

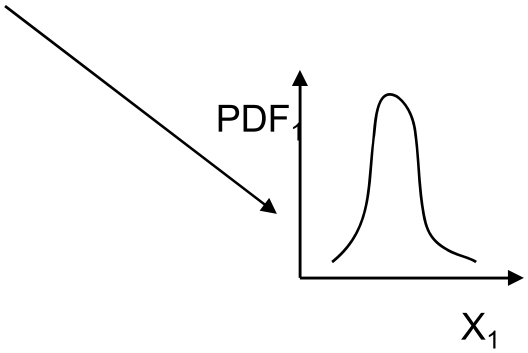
“True/Theoretical Value of
Total Uncertainty”

Best-Estimate

Input Driven Uncertainty Analysis EM Black Box Model

- A computer code represents the link between the input vector **X** (uncertainty parameters) and the output vector **Y** (PCT, LMO, etc.):

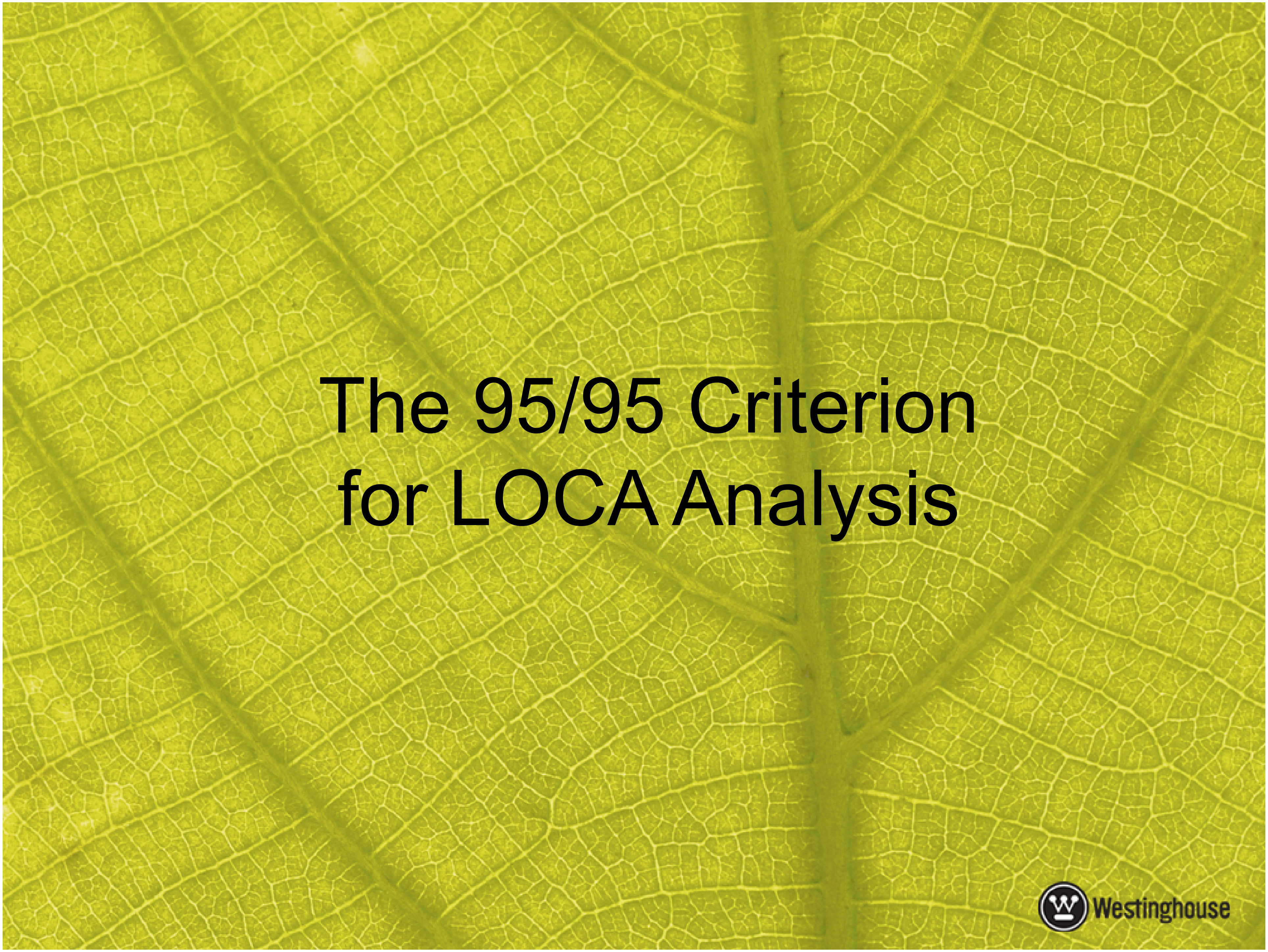
$$\begin{Bmatrix} Y_1 \\ Y_2 \\ \cdot \\ Y_p \end{Bmatrix} = \hat{C}(t) \begin{Bmatrix} X_1 \\ X_2 \\ \cdot \\ X_h \end{Bmatrix}$$



- “**h**” dimension can be different than “**p**”. Typically h>>p.
- “**Y**” is the vector of the figure of merits (output)

Input Driven Uncertainty Analysis
Ideal Solution to the Problem

- Generate a very large sample of the FOMs (PCT, MLO and CWO) population (outputs)
- Obtain probability density function of the output parameters
- Determine the 95th quantile (or required quantile)
- Accept design if upper quantile is below the regulatory limit



The 95/95 Criterion for LOCA Analysis

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95/95 Criterion for LOCA Analysis (cont.)

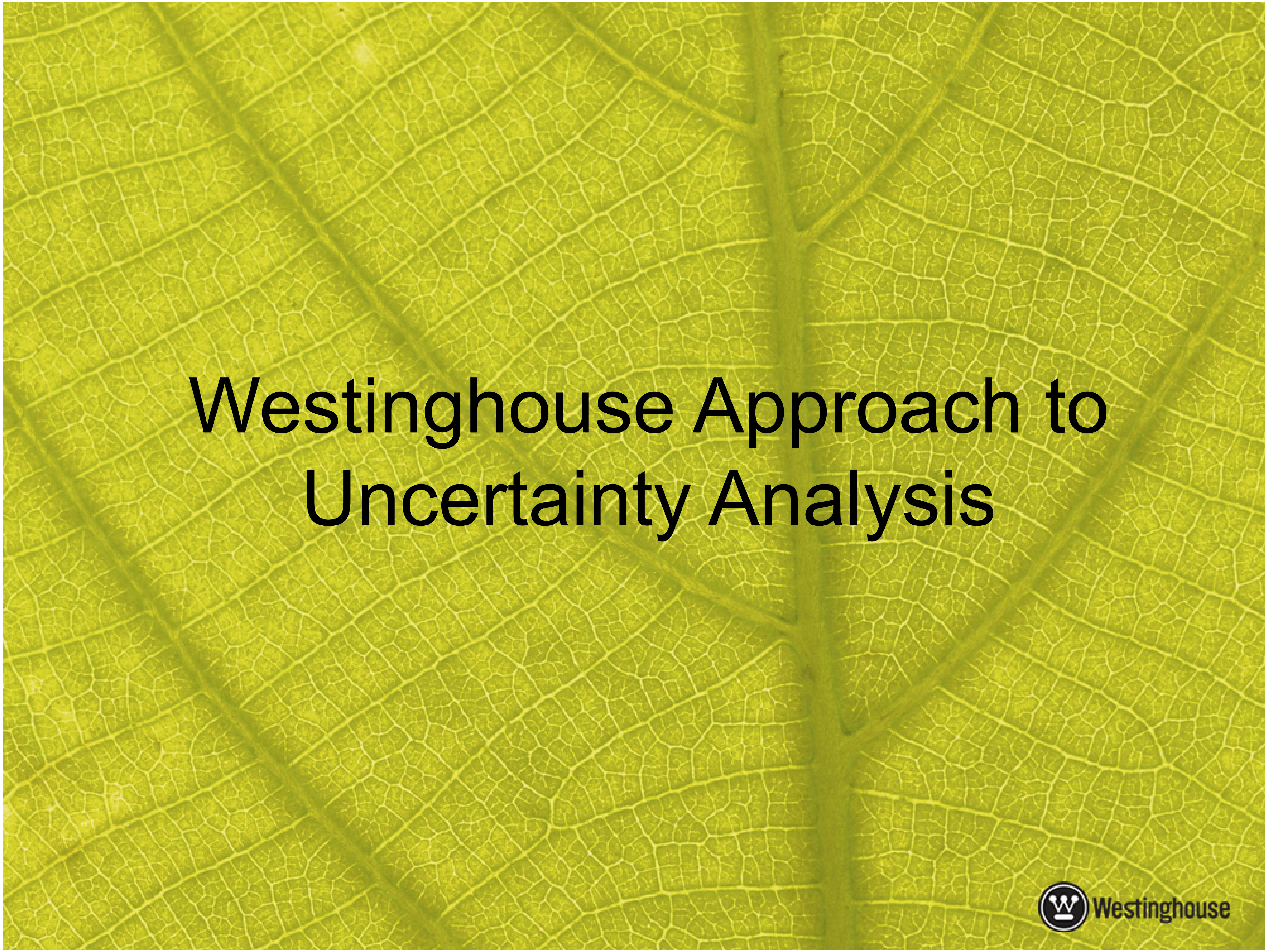
- 10 CFR 50.46 requires that *"[…] uncertainty must be accounted for, so that, when the calculated ECCS cooling performance is compared to the criteria set forth in paragraph (b) of this section,* ***there is a high level of probability*** *that the criteria would not be exceeded.*"
- What is a "high level of probability"?
- Is a 95/95 criterion (95th percentile at 95% confidence) adequate for LOCA analyses? And how is this adequacy justified?

95/95 Criterion for LOCA Analysis (cont.)

- Section 4 of Regulatory Guide 1.157 (Best-Estimate Calculations of Emergency Core Cooling System Performance) provides the NRC position on the “high probability”
  - *“A 95% probability is considered acceptable to the NRC staff […] to show that there is a high probability that the criteria [b.1 to b.3 of 10CFR50.46] will not be exceeded”*
- Basis
  - *“The basis for selecting the 95% is primarily for consistency with standard regulatory practice […]”*
  - The same level applied to SBLOCA is expected to result in a more realistic calculation, improved operator procedures and overall reduced risk

95/95 Criterion for LOCA Analysis (cont.)

- Reg. Guide 1.157 introduces the concept of confidence level as a possible refinement to the uncertainty treatment , but does not expand further on this concept.
- During the review of the Westinghouse best-estimate ASTRUM, the NRC provided further statements to clarify the acceptability of the 95% probability level



Westinghouse Approach to Uncertainty Analysis

ASTRUM relies on Order Statistics

- Order Statistics Analysis is essentially a crude Monte Carlo simulation used with the minimum trial number to “stabilize” the estimator.
- The method is assumption-free with regard to the variate (i.e. PCT, MLO and CWO) distribution

Guba-Makai Formula

- Guba-Makai (2003) generalized the Wilks's Method for cases when p>1 (multivariate). The size of the sample is determined by the following equation:

$$\beta = \sum_{j=0}^{N-p} \frac{N!}{(N-j)!\,j!} \gamma^{j} (1-\gamma)^{N-j}$$

- Where:
  - β = confidence level
  - N = sample size (number of runs)
  - p = number of output variables
  - γ = tolerance interval

Guba-Makai Approach Review

- G-M results reduce to Wilks's when p=1(one variate).
- In particular for β = 0.95 and γ = 0.95, we obtain:
  - p = 1 (i.e. PCT) → **N = 59**
  - p = 3 (i.e. PCT, LMO, CWO) → **N = 124**

PCT = Peak Clad Temperature
LMO = Local Maximum Oxidati
CWO = Core-Wide Oxidation

- G-M approach is based on most generic assumptions:
  - Nothing is known relative to the distribution function of the sample.
  - Nothing is known on the degree of correlation among the sampled variables (PCT, LMO, and CWO)
- G-M general approach results in a requirement of
  - **N=124 runs**.

Summary of the Issues, Consideration for This Forum

Main Issue Encountered During ASTRUM Licensing

- Joint 95/95 Probability Statement
  - Resolved via use of Guba-Makai multi-variate approach to make joint statements on PCT, MLO and CWO
  - Experience to date indicates that, while oxidation and PCT are correlated, different cases can be limiting

No Industry Consensus to Date

Issues to Resolve for Future Applications

- Use of Best-Estimate Plus Uncertainty Treatment for Parameters Controlled by Tech Specs
- Lack of Knowledge of Uncertainty Distributions
- Accounting for Operator Actions When They Would Clearly Occur

Current Examples Exist for First Two

Use of Best-Estimate Plus Uncertainty Treatment for Parameters Controlled by Tech Specs

- Justified for Parameters Tightly Controlled in Normal Operation (e.g., RCS Pressure)

- Justified When Parameter can be Well-Characterized (e.g., Peak Linear Heat Rate)

Lack of Knowledge of Uncertainty Distributions

- Current Practice is to Assume Uniform (“Maximum Entropy”)

- Alternative Approaches Appear Viable (Triangular, Weighted Towards Most Likely, etc.)

Accounting for Operator Actions When They Would Clearly Occur

- Emergency Operating Procedures are Symptom Based
- Example is Operator Trip of RCP During PWR Small Break LOCA
- Accounting for Operator Action is Justifiable
  - Need sound basis for treatment

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