Code Structure Uncertainty Assessment in Thermal-Hydraulics Uncertainty Analysis Method for

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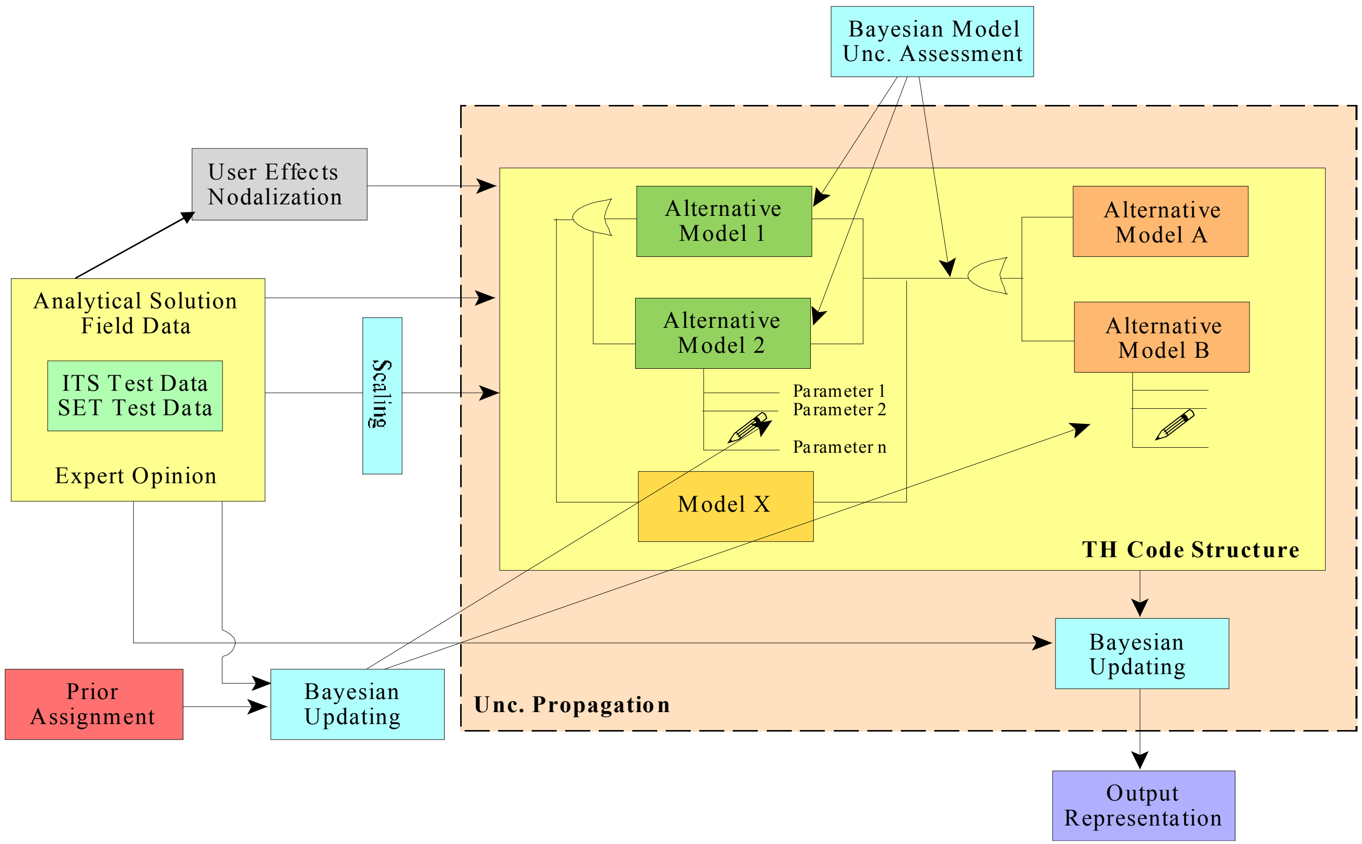
May 20, 2008

Scope of Research

- Performed Under the Collaborative Research Agreement between US NRC and CRR at UMD
- Integrated Methodology for TH Uncertainty Analysis
  - ✓ Implementation of the Best Features from Existing Methodologies
- Use all available information
  - ✓ About Boundary/Initial Conditions
  - ✓ Models, Sub-models, and Corresponding Parameters
  - ✓ Output
- Treat Code Structure Uncertainty (Model Uncertainty)
- Representation/Interpretation of Results

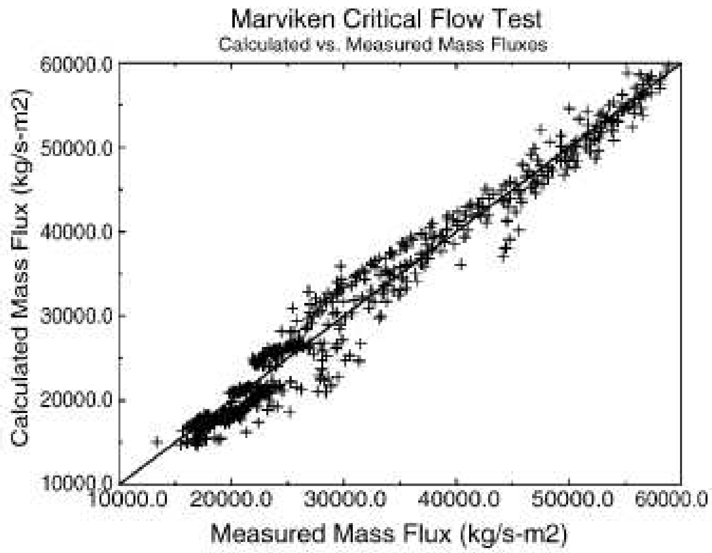
Methodology Overview



Singe Model Uncertainty Treatment

- Use Bayesian Model Uncertainty Approach to account for
  - ✓ Correction Factor
  - ✓ Bias Consideration

$$R_{in} = \frac{\text{Measured Flow Rate}}{\text{Predicted Flow Rate}}$$

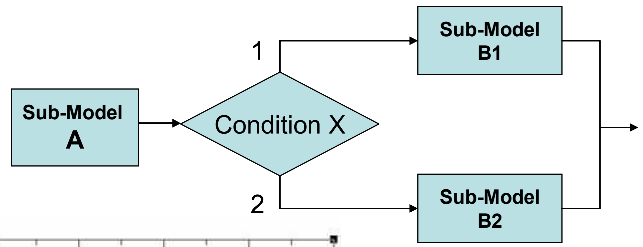


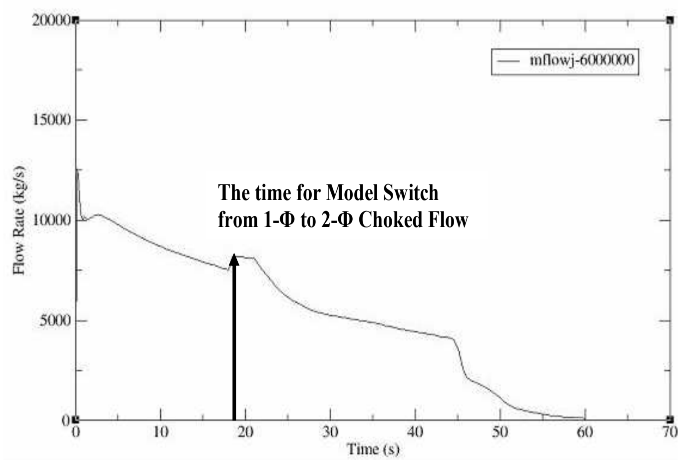
- ✓ E.g., TRAC natural choking model has an average bias of 1.2

Sub-Model Uncertainties (Alternative Models)

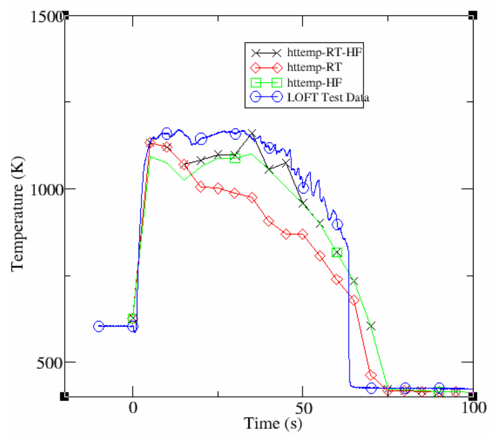
- Dynamic Model Switching
- Use “Recommended” Model
- User Selection Among Provided Models
- Model Mixing

Dynamic Model Switching



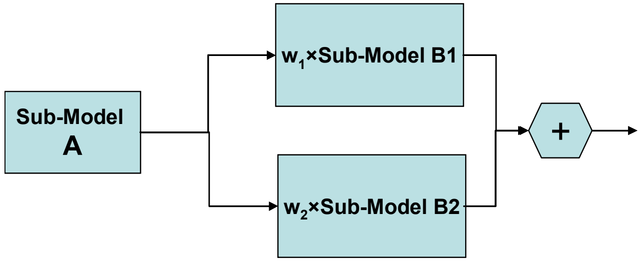


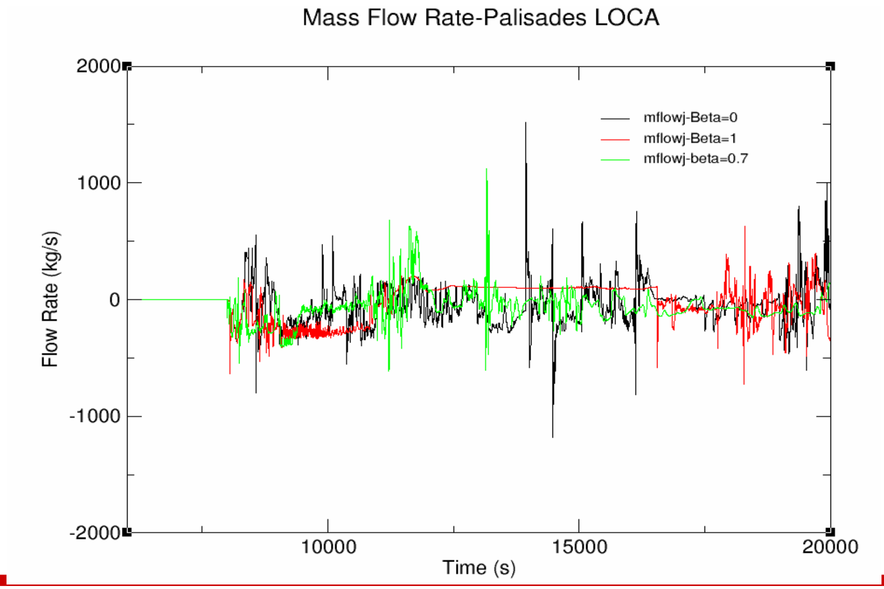
- Model Switch from 1-Φ Choked Flow to 2- Φ Choked Flow-Marviken Blowdown



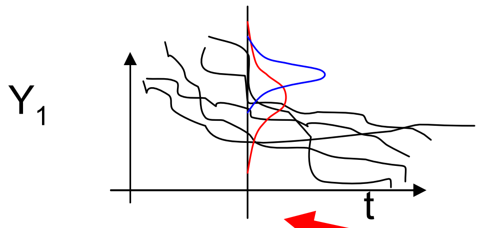
- Model Switch by Code or User for Henry-Fauske and Henry-Trap Choked Flow Model

Model Mixing

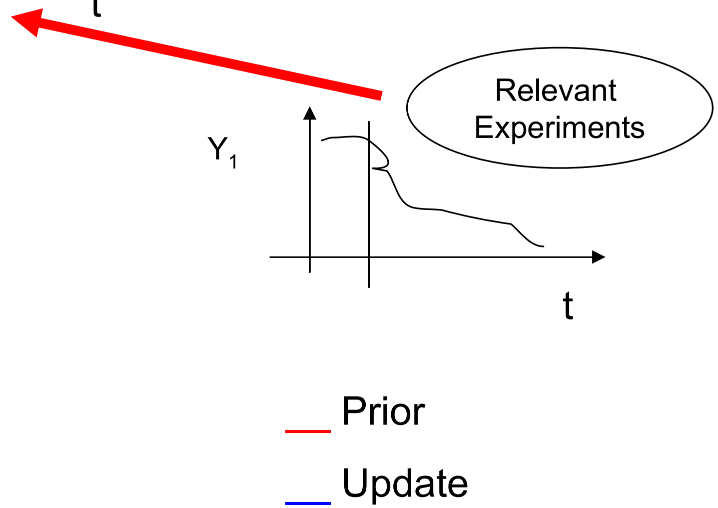




Residual Model Uncertainties : Output Updating



- Data and information about output (usually integral test data) not used for input uncertainty characterization
- Bayesian updating for output is devised to perform updating



Output Updating

- Independent Data Required
  - Data from Integrated Test Facility
- Need likelihood function of the available data
- Approaches
  - Paired Data $(T_1^D, T_2^D, \ldots, T_n^D)$ $(T_1^M, T_2^M, \ldots, T_n^M)$
    - Equal Number of Experimental and Calculation Data
    - Association of Test Data with Code Predictions
  - Non-Paired Data
    - Unequal number of test and code data
    - Assumption of independence between test and code data
- Data can not be precisely paired in case of TH computational codes
  - Many Unknown BIC in Pairing Experiment and Calculation
  - Unequal Sizes of Experiment and Calculation Data
  - Due to Temporal Uncertainty in Magnitude and Timing, it is not Easy to Pair Data Points

Paired vs. Non-Paired Data

- Paired Data
  - ✓ Possibility to construct error distribution explicitly

$$Y_{n+1}^{M} \Rightarrow Y_{n+1}^{M} + \overline{E} + z.S_{E}$$

$$\overline{E} = \frac{1}{n}\sum_{j=1}^{n} E_{j}$$

$$S_{E}^{2} = \frac{1}{n-1}\sum_{j=1}^{n}(E_{j} - \overline{E})^{2}$$

- Independent data
- BVN Distribution for data and code calculation

$$Y_{m+1}^{M} \Rightarrow \overline{Y_{D}} + \frac{S_{D}}{S_{M}}(Y_{m+1}^{M} - \overline{Y_{M}})$$

$$S_{M}^{2} = \frac{1}{m-1}\sum_{j=1}^{m}(Y_{j}^{M} - \overline{Y}^{M})^{2}$$

$$S_{D}^{2} = \frac{1}{n-1}\sum_{j=1}^{n}(Y_{j}^{D} - \overline{Y}^{D})^{2}$$

$$\overline{Y}^{D} = \frac{1}{n}\sum_{j=1}^{n} Y_{j}^{D}$$

$$\overline{Y}^{M} = \frac{1}{m}\sum_{j=1}^{m} Y_{j}^{M}$$

Output Updating-Methodology Steps

Joint Distribution of
Test and Code Data
(e.g., BVN)

↓

Maximize

$Corr\,(T_D, T_M)$

↓

ρ=1

$\sigma_{\mathrm{M|D}} = \sigma_M \sqrt{1-\rho^2} = 0$

↓

$T_M^{New} \mid \mathrm{T_M}, \mu_\mathrm{M}, \sigma_\mathrm{M}, \mu_\mathrm{D}\ \sigma_\mathrm{D} : Degenerate\ \ Distribution$

Mapping One-by-One

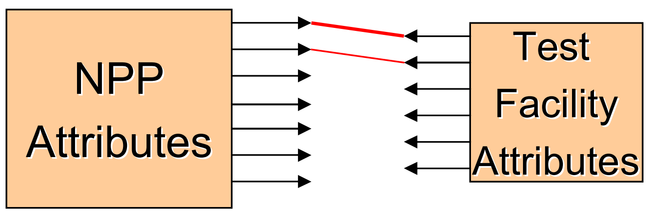
Old to New Model Prediction

↓

$$T_{New}^{M} = \mu_D + \frac{\sigma^2{}_D}{\sigma^2{}_M}(T^M - \mu_M)$$

Mathematical Basis
Data Availability and Applicability

- Availability of Data
  - ✓ Model Estimate from Code Calculation
  - ✓ Experimental data set D such that D={D_1, D_2, …, D_3}
  - ✓ Confidence Factor φ
- Applicability of Data (Attributes of Scenario Facility and Experimental Facilities)
  - ✓ Distortion from Scaling (e.g., π group values)
  - ✓ Location and Size of Break,
  - ✓ Rate of power,
  - ✓ Scaling Ratio of the Facilities,
  - ✓ Involved Safety systems,
  - ✓ Nuclear Core Configuration
  - ✓ Others!



Comparing Attributes

Bayesian Model Uncertainty Framework

$$\pi(T \mid IM, D) = \frac{[L(IM, D \mid T)]^{\varphi} . \pi(T)}{\int_T [L(IM, D \mid T)]^{\varphi} . \pi(T) dT}$$

$0 \leq \varphi \leq 1$

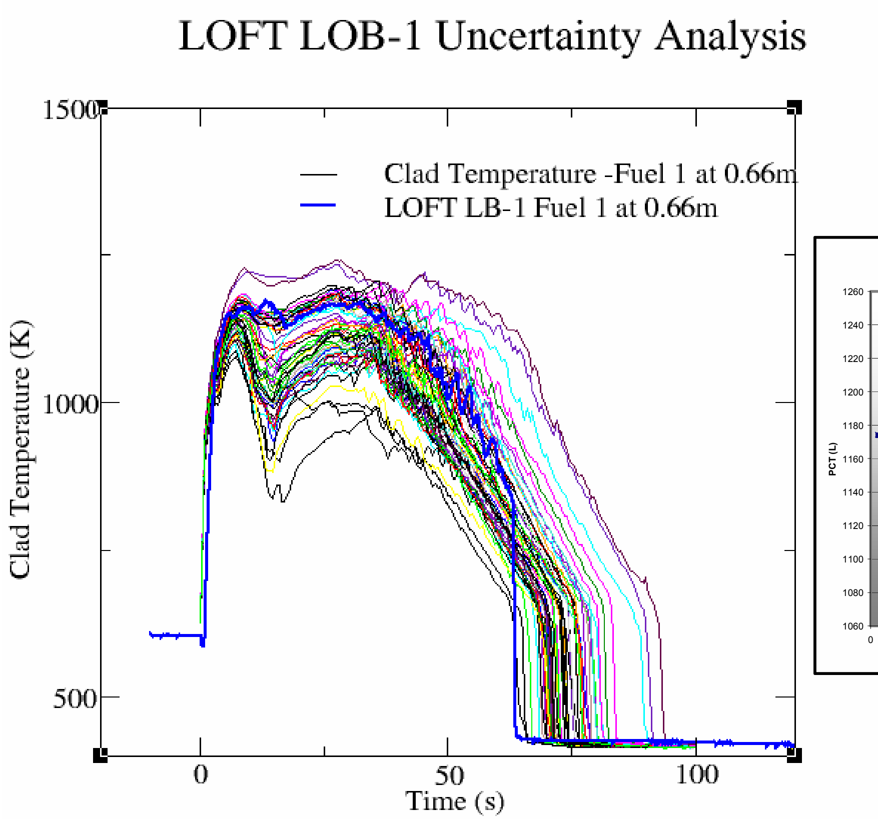
Data Applicability

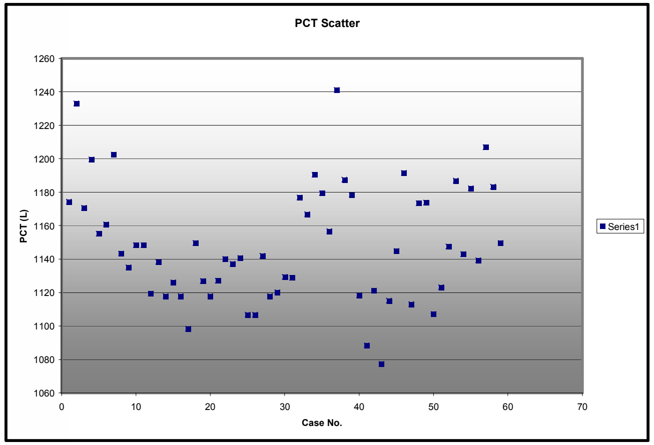
$$0 \le \varphi \le 1$$

Applicability Weight	
Value (φ)	**Statement**
0.00	**Absolutely not Applicable**
0.20	**Strongly not Applicable**
0.40	**Moderately not Applicable**
0.50	**Slightly Applicable**
0.60	**Moderately Applicable**
0.80	**Strongly Applicable**
1.00	**Absolutely Applicable**

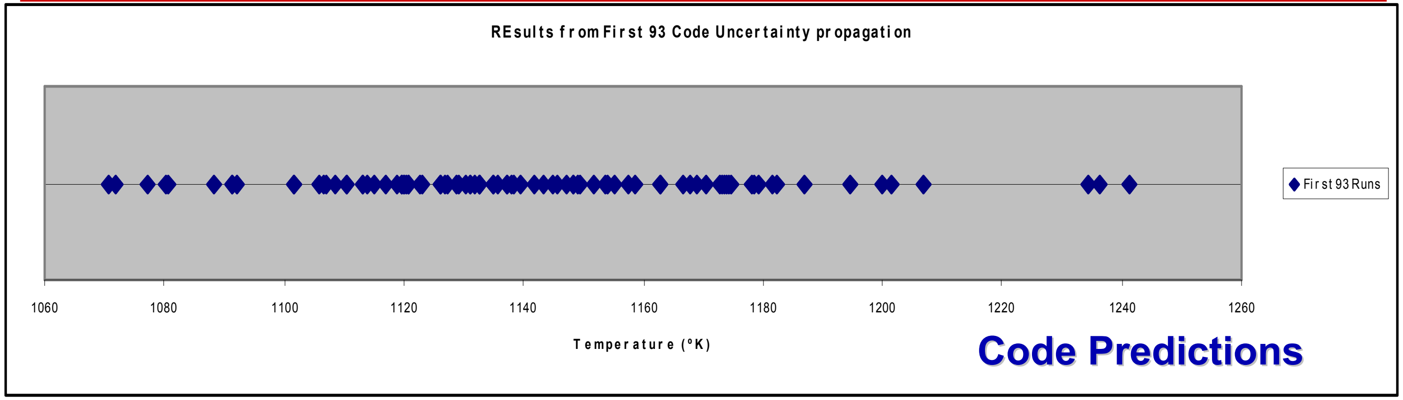
$$\pi(T \mid IM, D) = \frac{[L(IM, D \mid T)]^{\varphi}.\pi(T)}{\int_T [L(IM, D \mid T)]^{\varphi}.\pi(T)dT}$$

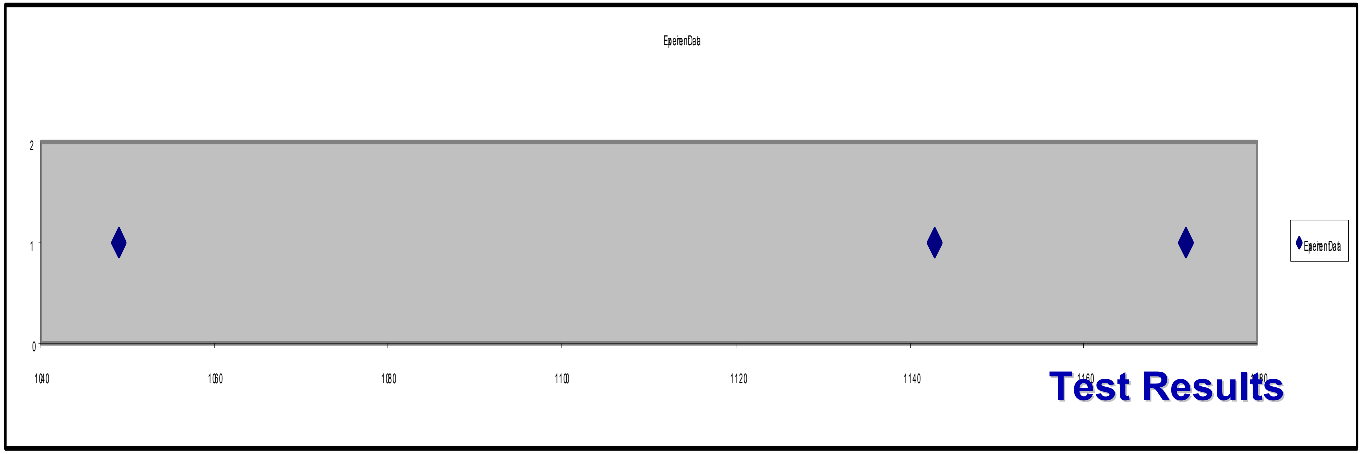
Uncertainty Analysis
LOFT LBLOCA





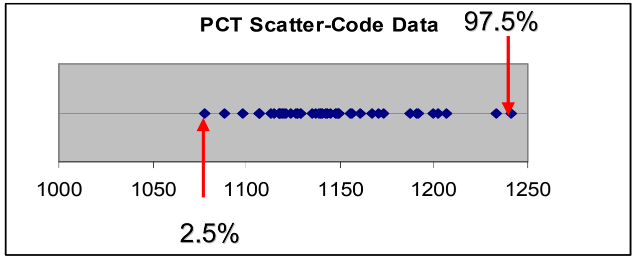
Code/ Test Data for Output Updating





From Input Phase to Out-Put Phase

1.



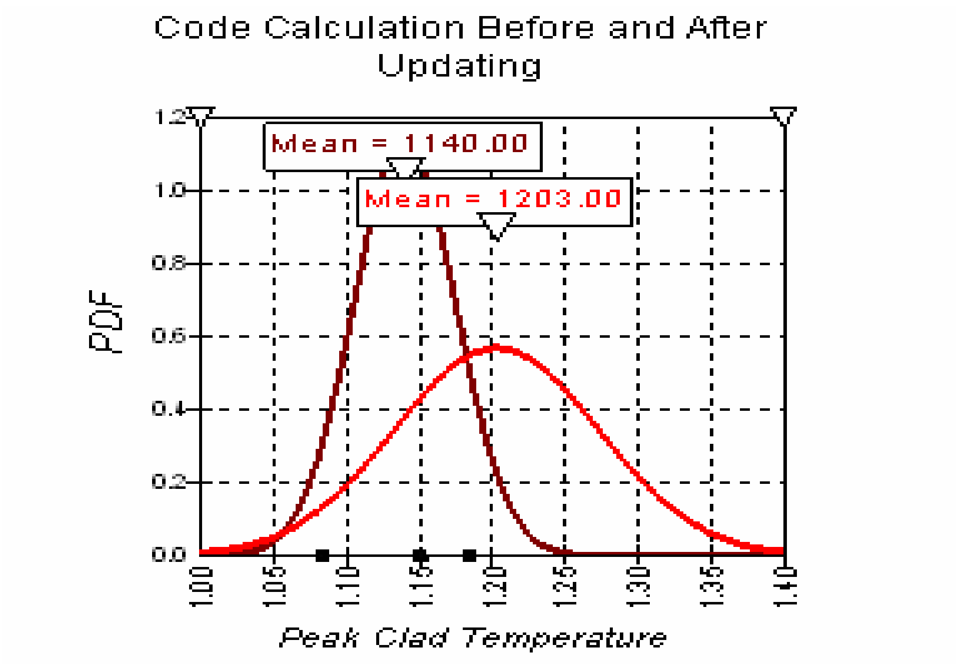
- A distribution shape is assumed for the Data
  - ✓ Best fit to the data
    - e.g., normal or lognormal distribution
  - ✓ Assumed Prior for Distributions Parameters; Wide Ranges
- Update Distribution of Parameters Utilizing Bayesian Theory

2.

$$\pi(\mu,\sigma) = \frac{L(T_1,T_2,\ldots,T_{59})\pi_0(\mu,\sigma)}{\iint_{\mu,\sigma} L(T_1,T_2,\ldots,T_{59})\pi_0(\mu,\sigma)}$$

- Coverage Area of the Distribution from Tolerance Interval is Assigned to Distribution Quantiles
  - ✓ The smallest value to : 2.5% , Largest value to 97.5%
- Distribution Parameters Estimated From Quantiles

LOFT PCT After Update



Node	Mean	SD_DEV	MC Error	2.50%	Median	97.50%
CODE	1203	70.04	0.8462	1061	1199	1336
MEAN	1203	0.09904	0.001448	1200	1200	1200
SD_DEV	70.03	0.1383	0.004049	69.75	70.02	70.3

Concluding Remarks

- TH code structure uncertainty analysis
- Utilization of all available types of data and information
- Different strategy for treating several classes of model (code structure) uncertainty
- A Bayesian solution has been introduced for single model structure uncertainty assessment, while other techniques such as mixing, switching, maximization /minimization, are proposed for alternative models.
- Accounting for User Errors, Numerical Approximations, Unknown and Not Considered Sources of Uncertainties (Screened input and/or Incompleteness)
- Utilization of Partially Relevant Data About Code Output
- Methodology for Paired vs. Non-Paired Data