Statistical Universal Power Reconstruction with Fixed Margin Technical Specifications (SUPR-FMTS) Post-Submittal Meeting

Gayle Elliott
Jesse Klingensmith
Rich Kochendarfer
Dick Deveney

AREVA

Presentation Overview

▶ Introduction	GFE
▶ Background and Objectives	RAK
▶ FMTS Background	RAK
▶ Changes to FMTS	RAK
▶ SUPR	JJK
▶ Concluding Remarks	JJK
▶ Summary and Next Steps	GFE

Introduction

- Discuss the SUPR and the FMTS methodologies and their application to PWR-type reactors
- Obtain timely NRC feedback and interactions to support regulatory review process
- Respond to preliminary NRC feedback to cover:

1. The scope of the review as stated in Section 1.4. The TR addresses the technical issues associated with Super-FMTS, yet requests approval of the FMTS methodology with regard to Westinghouse and CE plants. Figure 1.1 contains insufficient information with regard to a comparison of the performance of FMTS vs. Super-FMTS methodologies.

2. The NRC did not find discussion of the W, CE and B&W measurement systems. The interaction between FMTS and Super-FMTS appears to be central to the request for approval and there are common elements to the methodologies.

Background Discussion

- PWRs presently measure RPD with one of several instrumentation systems
  - Movable Detectors (TIP, etc.)
  - Fixed Incore Detector (FIC)
  - A combination of the two (Aeroballs and FICs)
- Used for monitoring operation of the core with periodic use requirements
- Preserves initial peaking assumptions for all events (LCO limits) by means of monitoring global power
  - Axial Flux Difference (AFD), Quadrant Power Tilt (QPT), Rod Position Limit (RPL)

SUPR-FMTS Objectives

- Support of multiple/diverse core power distribution measurement systems, e.g. TIP, FIC, Aeroball
  - ◇ Kriging, RPD Check, Online Simulator

SUPR

- Preserve safety analysis assumptions through direct monitoring of margin to power peaking limits rather than secondary indicators (AFD, QPT, RI)
  - ◇ FMTS (Fixed Margin Technical Specifications, BAW-10158P-A)

FMTS

- Extension of flux map surveillance intervals in plants with interval measurements (non-continuous, e.g. TIP)
  - ◇ RPD Check, Online Simulator
  - ◇ RPD Check use is optional. Need is determined by uncertainty analysis

SUPR-FMTS

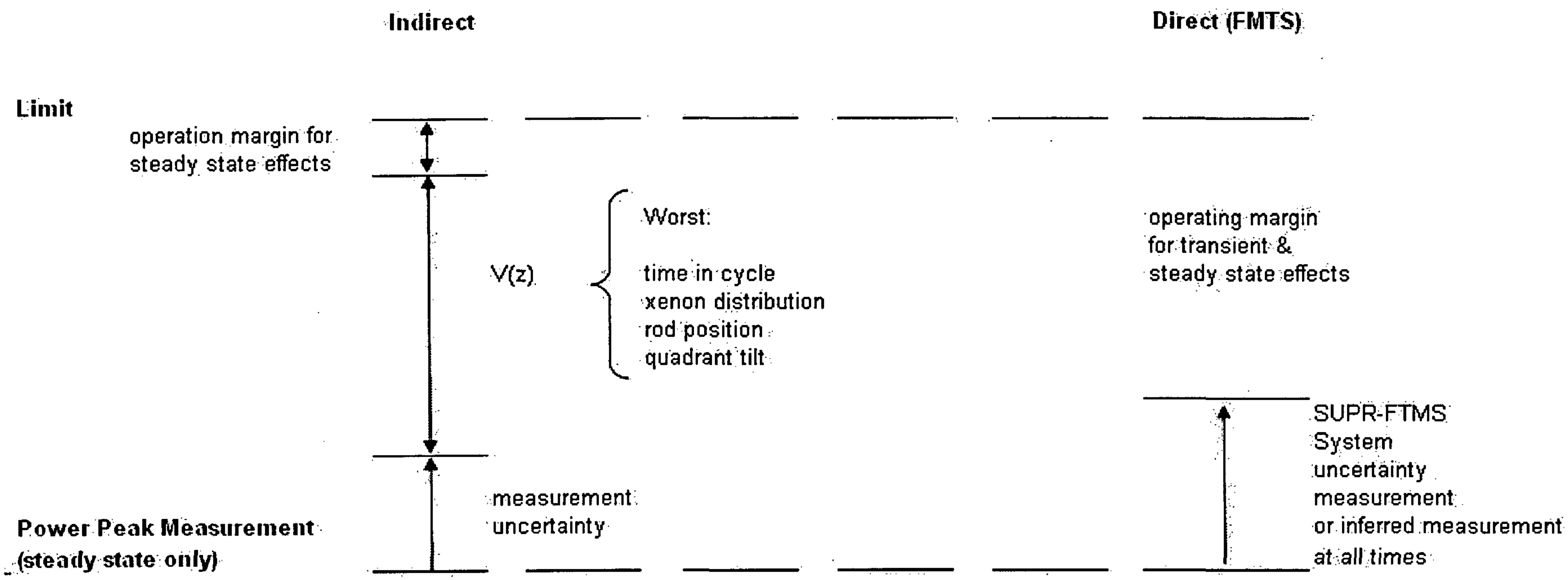
AREVA

FMTS Background

Tech Spec Monitoring Requirements for FMTS

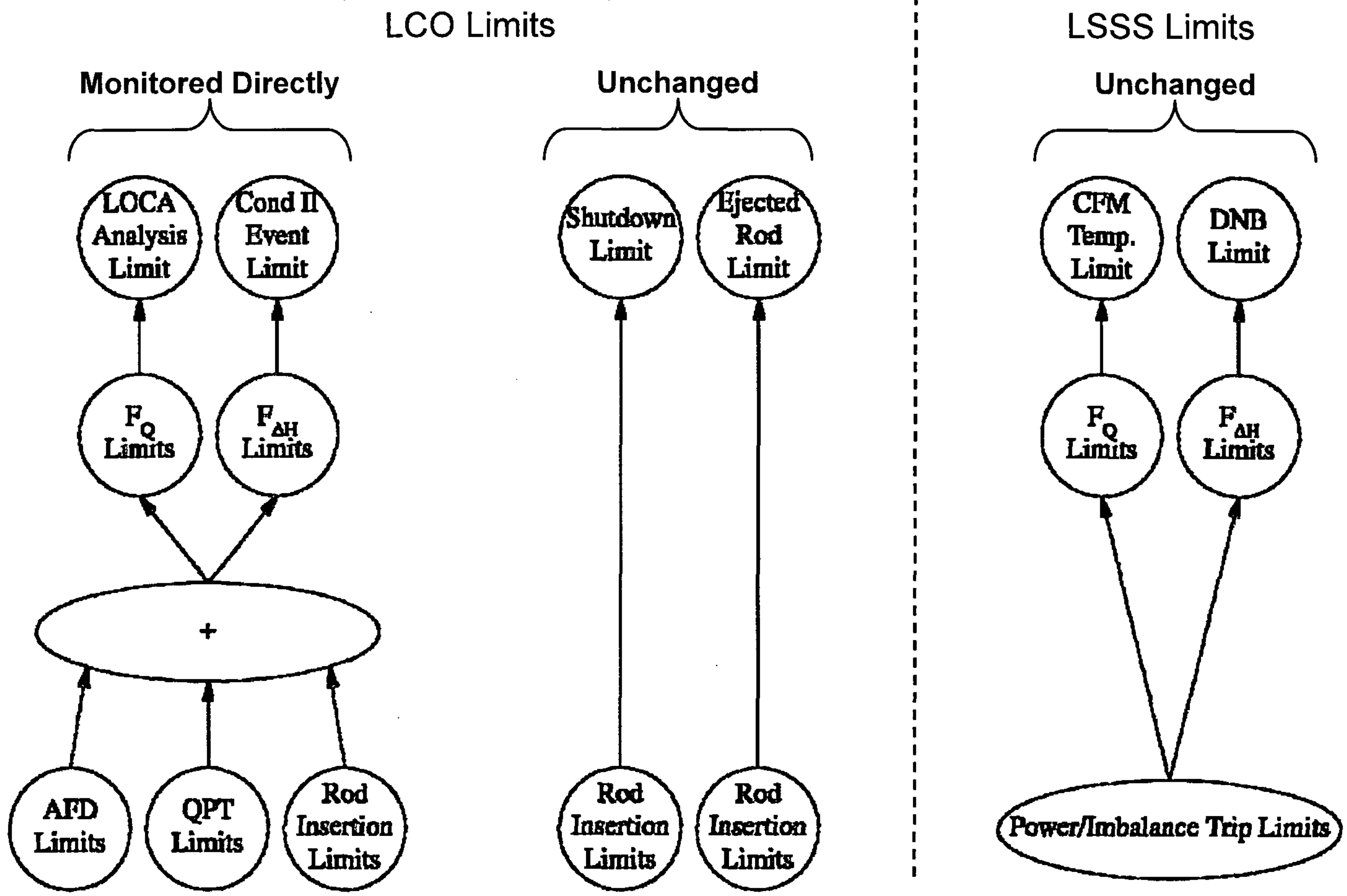
- Monitor Limiting Conditions of Operation (LCO)
  - LCO only -> no change to Limiting Safety System Settings (LSSS)
- Monitor peaking rather than an overly restrictive combination of RPL, AFD, and QPT parameters to preserve peaking limits
- Assure that the core is operating as designed
  - Preserve design basis for LSSS and backup LCO limits
- Define actions when criteria are exceeded as determined by the licensing basis

Peaking Margin for Direct & Indirect Limits



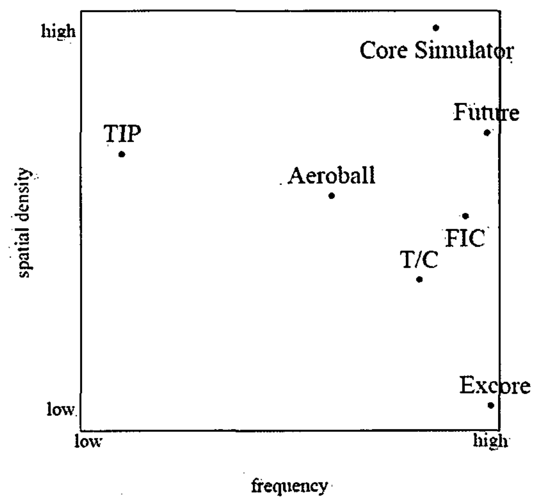
Monitoring Requirements

- FMTS affects some, but not all, LCO



Nuclear Instrumentation (RPD) Systems

- Categorize measurement systems according to:
  - Frequency
  - Data density
  - Directness
- Need to combine all measurements
  - Consider strengths & weaknesses of each measurement system
- Example – TIP v. FIC v. Thermocouple v. Core Simulator



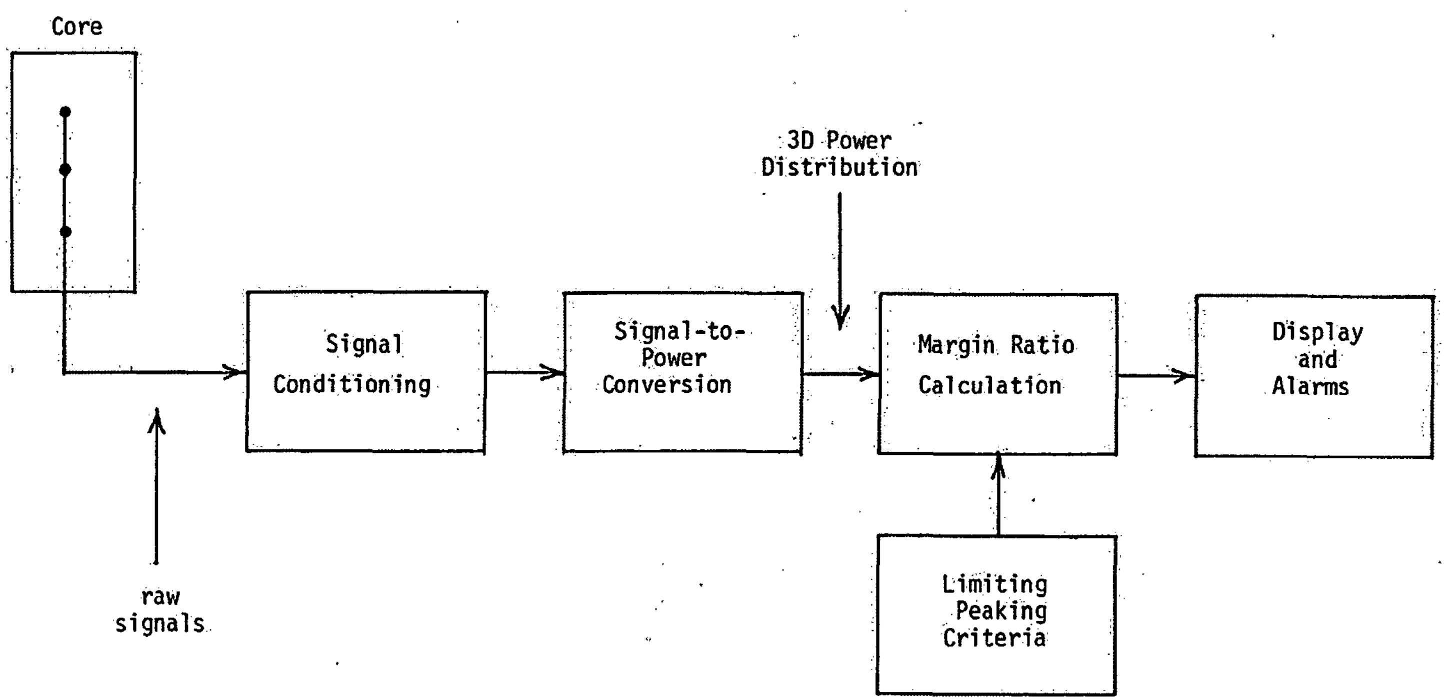
AREVA

FMTS Modifications

AREVA

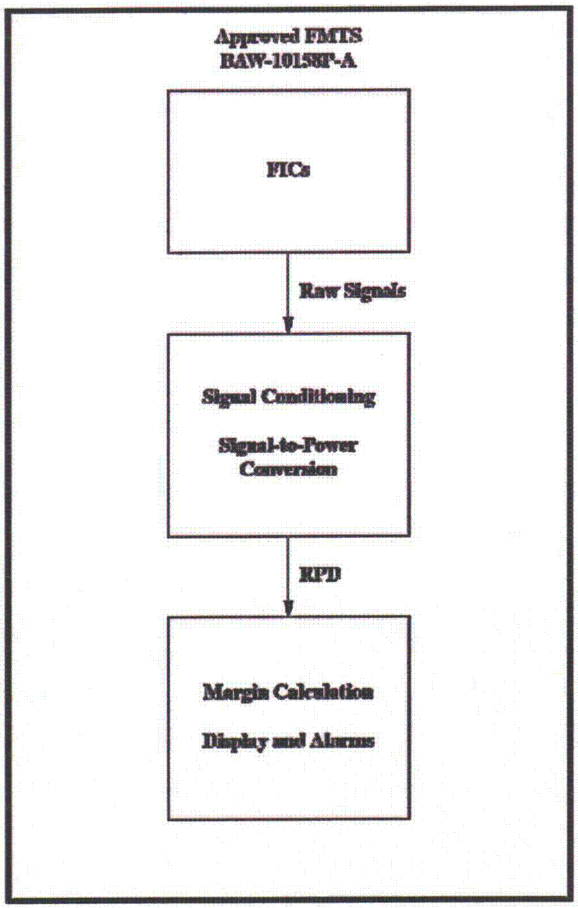
FMTS Flowchart

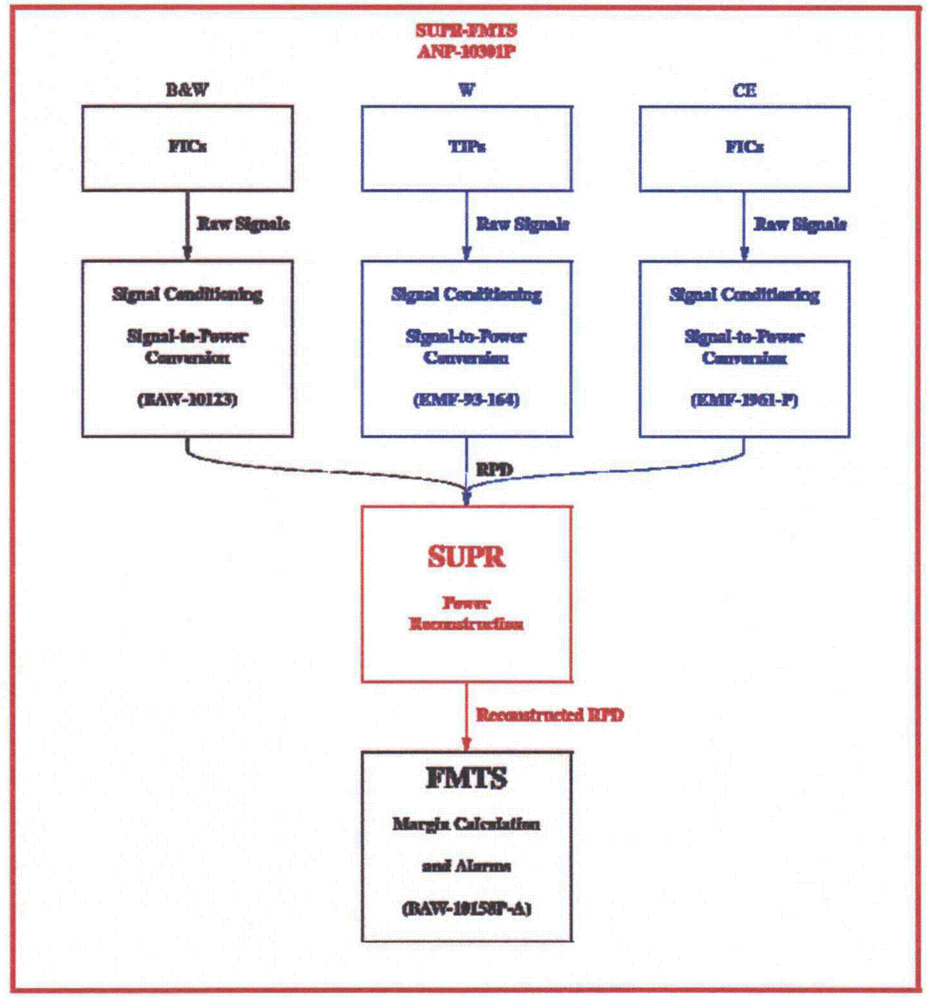
Figure 1.2-1 FMTS Monitoring Procedure



1-5

Comparison of FMTS and SUPR-FMTS





AREVA

Proposed Clarification

1. The scope of the review as stated in Section 1.4. The TR addresses the technical issues associated with Super-FMTS, yet requests approval of the FMTS methodology with regard to Westinghouse and CE plants. Figure 1.1 contains insufficient information with regard to a comparison of the performance of FMTS vs. Super-FMTS methodologies.

2. The NRC did not find discussion of the W, CE and B&W measurement systems. The interaction between FMTS and Super-FMTS appears to be central to the request for approval and there are common elements to the methodologies.

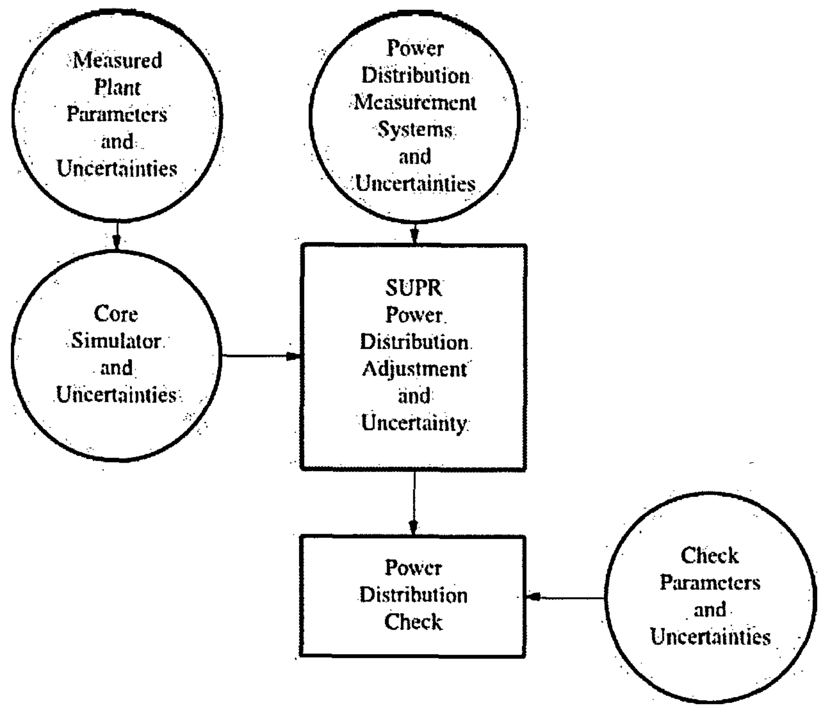
Topical Text, from Section 1.4:

Application of the margin monitoring portion of the FMTS methodology to Westinghouse (*W*), EPR, and Combustion Engineering *(CE)* plants, as well as the previously approved Babcock and Wilcox *(B&W)* plants [6]. This extension is based on the previous approval for Babcock and Wilcox plants, the improvement in both directness and frequency of power distribution monitoring, and the improved quantification of measurement system uncertainty through the use of the Monte Carlo simulation methodology for determining system uncertainty.

AREVA

Characteristic Uncertainty Discussion

- **Quantify Uncertainty in:**
  - ◇ **Measurement systems**
  - ◇ **Plant parameters**
  - ◇ **Reconstruction methods**



AREVA

Determination of Total System Uncertainty

- Sample uncertainties using Monte Carlo simulator
- Calculate the effect of uncertainty during "hard to measure" events
- Quantify the total system uncertainty, [ ]

[ ]

Application to Meet Tech Spec Requirements

SUPR section produces RPD_{meas} and process uncertainty

[ ]

FMTS section compares adjusted RPD to limit criteria with margin calculation

Limits based on available margin

Action required when negative margin condition occurs -> move rods, and/or lower power to restore margin

Monitor operation relative to design to ensure the basis for LSSS & backup LCO limits are preserved.

Tech Spec Implementation

Note: LCO fuel design criteria are

a. During a LOCA, peak cladding temperature must not exceed 2200°F.
b. During a loss of flow accident, there must be at least 95% probability at the 95% confidence level (the 95/95 DNB criterion) that the hot fuel rod in the core does not experience a DNB condition.
c. During an ejected rod accident, the fission energy input to the fuel must not exceed 280 cal/gm.
d. The control rods must be capable of shutting down the reactor with a minimum required SDM with the highest worth control rod stuck fully withdrawn.

Margin Calculations with FMTS

Calculate margin as:

$$M_{i,j,k} = \left(1 - \frac{RPD_{i,j,k} \cdot R_{local} \cdot F_{unc} \cdot F_{OpFlex}}{L_{i,j,k}}\right) \cdot 100$$

Where F_{unc} includes the total system uncertainty and the adjusted process variance.

[ ]

SUPR – Statistical Universal Power Reconstruction

AREVA

Power Reconstruction Methodology (SUPR) Overview

- Reconstruct power with localized kriging models
- Dynamically calculate the process variance of the local model
- When using infrequent power measurements – RPD Check routines are used to:
  - Calculate Assembly Exit Thermocouple and ExCore detector responses
  - Compare calculated to measured responses
  - Impose variance penalties if necessary

The Model Illustrated

[ ]

Background on Kriging Process

- **Kriging**
  - **Named after Danie G. Krig, South African mining engineer who, in 1951, developed empirical models of ore grade distribution based on sampled points**
- **Formalized by Georges Matherton**
  - **Founder (1968) "Centre de Géostatistique et de Morphologic Mathématique" at Paris School of Mines in Fontainbleau**
  - **Considered to be the "father" of spatial statistics**
- **Example applications**
  - **Interpolating grades of ore between measured points**
  - **Intelligent combination of sparse, accurate measurements with plentiful, less accurate measurements (rain gauge and radar measurements of rainfall)**

Interpolation with Kriging Models

- **Form of the statistical model:**

$$y(\mathbf{x}) = g(\mathbf{x}) + \varepsilon(\mathbf{x})$$

where

$g(\mathbf{x})$ **is the trend model**

$\varepsilon(\mathbf{x})$ **is the error, a random deviation from the trend**

- **Assuming an unbiased model and introducing the covariance function, the model becomes:**

$$\hat{y}(\mathbf{x}_0) = g(\mathbf{x}_0) + \mathbf{r}(\mathbf{x}_0)^T \mathbf{R}^{-1}(\mathbf{y} - \mathbf{g})$$

Interpolation with Kriging Models, II

- Expanding the kriging model:

$$\mathbf{r}(\mathbf{x}_0) = \begin{bmatrix} R(\mathbf{x}_0, \mathbf{x}_1) \\ \vdots \\ R(\mathbf{x}_0, \mathbf{x}_N) \end{bmatrix} \qquad \mathbf{R} = \begin{bmatrix} R(\mathbf{x}_1, \mathbf{x}_1) & \cdots & R(\mathbf{x}_N, \mathbf{x}_1) \\ \vdots & & \vdots \\ R(\mathbf{x}_1, \mathbf{x}_N) & \cdots & R(\mathbf{x}_N, \mathbf{x}_N) \end{bmatrix}$$

Variance Calculation

- The kriging variance is:

$$\sigma_k^2(\mathbf{x}_0) = \mathrm{Var}\left[\hat{y}(\mathbf{x}_0) - y(\mathbf{x}_0)\right]$$

- Approximated as:

RPD Check – Calculate Responses

- NOTE: Only used for systems with significant time intervals between measurements
- Generate responses based on reconstructed power
- Assembly exit thermocouple temperatures
  - Calibrate mass flow at measurement time
  - Calculated T_{out} using enthalpy balance
- ExCore detector power signals
  - Adjoint weights correlate power to current
  - Calibrated values convert current to voltage
- Evaluate all responses w.r.t. kriging variance

RPD Check – Compare Responses

RPD Check – Variance Adjustment

[ ]

AREVA

RPD Check – Variance Adjustment

[

]

AREVA

Concluding Remarks

Conclusions

SUPR-FMTS utilizes the present instrumentation systems, their uncertainty analyses, along with the Technical Specifications (with minor modifications) and core monitoring approach.

SUPR provides a method to consistently use diverse core power distribution measurement systems to maintain the applicability of the safety analysis and take advantage of the strengths of each diverse measurement system.

FMTS monitors the core power distribution relative to the Condition II and LOCA peaking limits based on the three-dimensional measured power distribution.

SUPR-FMTS takes advantage of thermocouple and excore detector signals for plants with infrequent measurement systems (TIP) to possibly extend flux mapping intervals.

AREVA

Summary and Next Steps

- Commence formal review and RAI process
- Approval of Statistical Universal Power Reconstruction with Fixed Margin Technical Specifications (SUPR-FMTS) Topical Report

List of Acronyms and Abbreviations

AFD – Axial Flux Difference
COLR – Core Operating Limits Report
ExCore – Excore neutron detector
FIC – Fixed In-Core detector
FMTS – Fixed Margin Technical Specifications
IC-DNB – Initial Condition, Departure from Nucleate Boiling
LCO – Limiting Condition of Operation
LOCA – Loss Of Coolant Accident
LSSS – Limiting Safety System Setting
NRC – Nuclear Regulatory Commission
PWR – Pressurized Water Reactor
QPT – Quadrant Power Tilt
RPL – Rod Position Limit
RPD – Relative Power Density
SUPR - Statistical Universal Power Reconstruction
T/C - Thermocouple
TIP – Traveling In-core Probe
Tech Spec – Technical Specifications