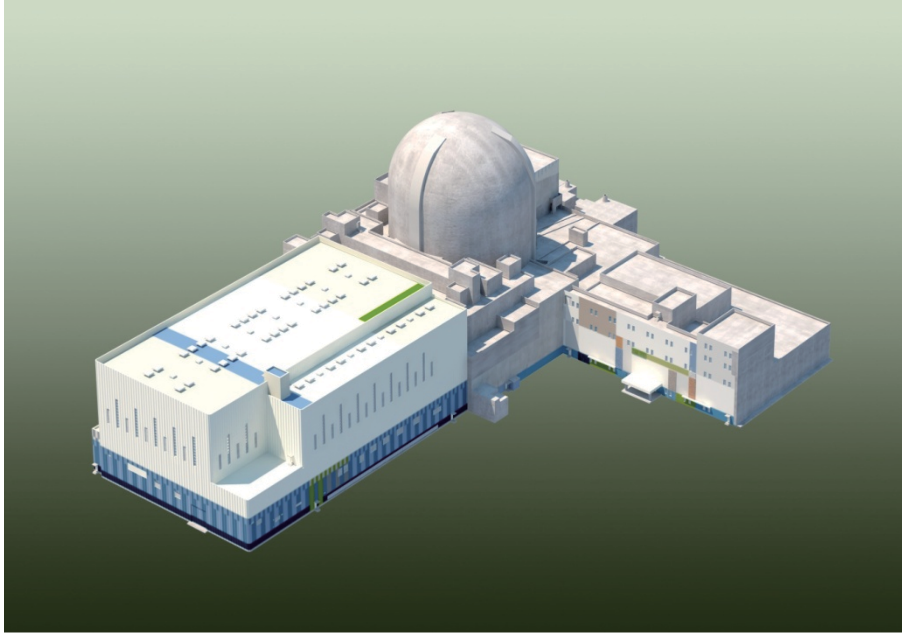
NON-PROPRIETARY

DNBR Limit Determination Methodology for APR1400



KEPCO/KHNP

APRIL 28, 2015

Public Meeting

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- **Introduction**
  - Meeting Topic
  - Background

- **Methodology**
  - Statistical Combination of System Parameters Uncertainties (SCU)

Introduction

Meeting Topic

- **An evaluation of the minimum core wide thermal DNBR limit value**
  - Procedure and result to determine the minimum core wide thermal DNBR limit value for APR1400-specific uncertainty values of the system parameters when combined with the KCE-1 CHF correlation

Background

- **Relevant Regulation**

  - 10 CFR Part 50 Appendix A, GDC 10, “Reactor Design”, requires that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits (SAFDL) are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

  - 10 CFR Part 50 Appendix A, GDC 20, “Protection System Functions,” requires that the reactor coolant system is designed with appropriate margin to assure that SAFDL are not exceeded during normal operations including anticipated operational occurrences.

  - Details :
    - ✓ Standard Review Plan (NUREG-0800, Chapter 4.4)
    - ✓ Regulatory Guide 1.206, C.I.4.4

Background

- **Submission of Documents**

  - APR1400 DCD, December 2014
    - ✓ Preliminary Draft – APR1400 Acceptance Review – Proprietary (#48)

  - Technical Report, "Thermal Design Methodology", APR1400-F-C-NR-12001-NP/P

Revision	Date	Description
1	Nov. 2014	• Detailed combination method of system parameters uncertainties • Additional analysis method for thermal margin evaluation

Public Meeting

Methodology

SCU

- **Kinds of Parameters**
  - System Parameters
    - ✓ Define the physical system under consideration
    - ✓ Modeled using detailed TORC analysis
    - ✓ Examples : core inlet flow distribution, fuel rod pitch, fuel rod clad O.D
  - State Parameters
    - ✓ Define the operational state of the reactor
    - ✓ Modeled using CETOP while the reactor is operational
    - ✓ Examples : system pressure, core inlet temperature, system flow rate

SCU

- **Treatment of Uncertainties**
  - Deterministic Treatment of Uncertainties
    - ✓ Bias design calculations so that all the worst allowance deviations occur simultaneously at the worst place.
    - ✓ In general, easy to implement but excessively conservative.
  - Statistical Treatment of Uncertainties
    - ✓ Takes credit for the small probability of all system parameter deviations occurring in adverse direction at the same time and at the worst location.
    - ✓ Analysis done using best estimate input and models.
    - ✓ In general, more difficult to implement, but removes the excess conservatism associated with the deterministic methods.

SCU

- **Uncertainties Considered in SCU Analysis**
  - Hot assembly inlet flow factor
  - Inlet flow factors adjacent to hot assembly
  - Engineering enthalpy rise factor
  - Fuel rod pitch
  - Fuel rod clad O.D
  - Engineering heat flux factor
  - KCE-1 CHF correlation
  - TORC code uncertainty

SCU

- **Uncertainties of System Parameters**

Parameter	Mean	Standard Deviation	Remark
Hot assembly inlet flow factor	Reference : Section 5.2 and Table 5-1 of APR1400-F-C-NR-12001-P, Rev.1		Distribution of APR1400 Core
Inlet flow factors adjacent to hot assembly			
Engineering enthalpy rise factor			PLUS7 fuel
Fuel rod pitch			
Fuel rod clad O.D			
Engineering heat flux factor			
KCE-1 CHF correlation			
TORC code uncertainty	Reference : Table 3-1 of CEN-356(V)-P-A		Generic uncertainty of subchannel code

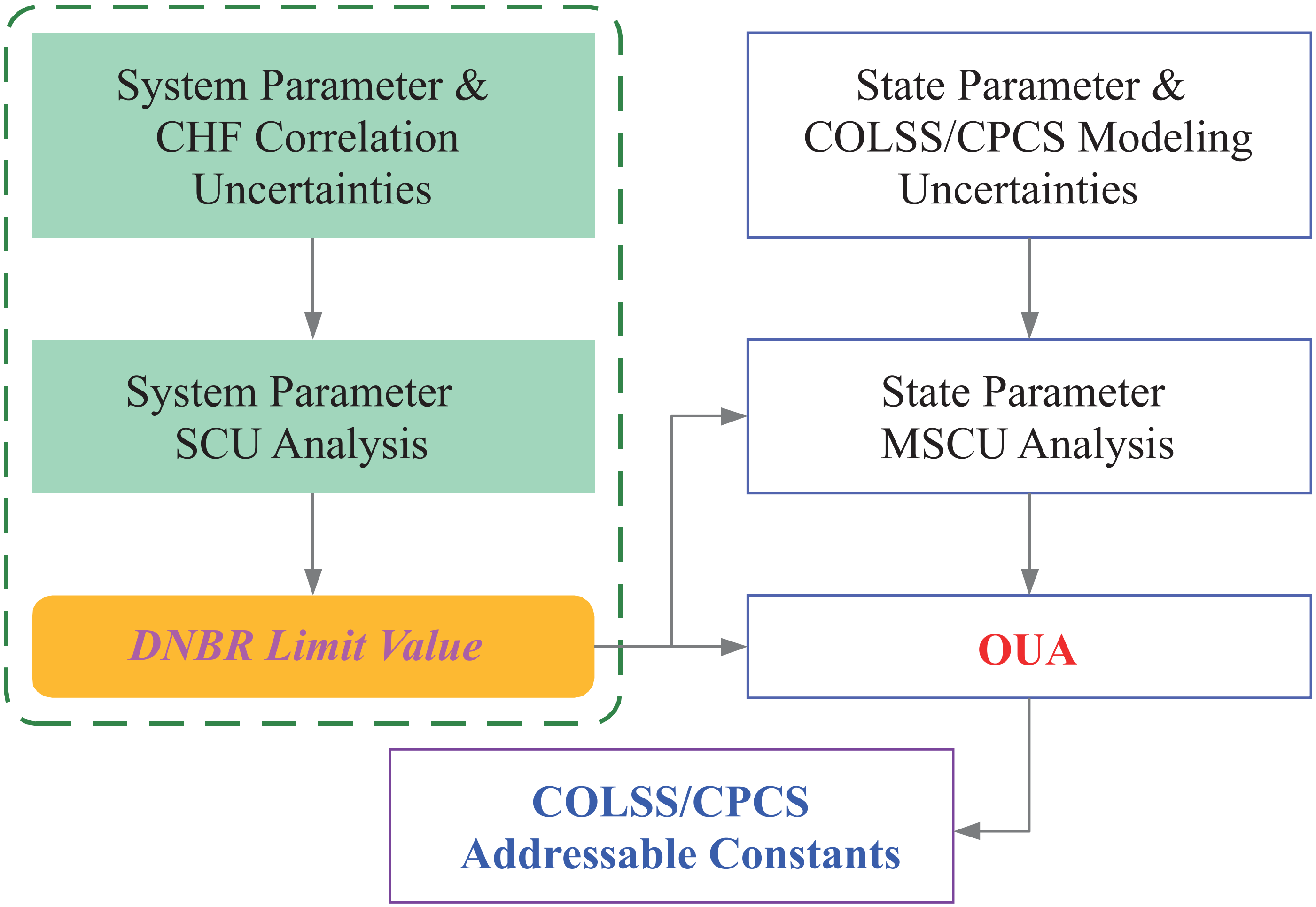
SCU

- **Applicable Operating Range**

Parameter	Narrow Range	Wide Range
Core Inlet Temperature, [^oF]	545 to 563	500 to 595
Pressurizer Pressure, [*psia*]	2175 to 2325	1785 to 2415
Primary System Flow (% of Q_D)	75 to 116	85 to 116
Axial Shape Index	±0.3	±0.6

SCU

- **Design Procedure**


System Parameter & CHF Correlation Uncertainties

System Parameter SCU Analysis

DNBR Limit Value

State Parameter & COLSS/CPCS Modeling Uncertainties

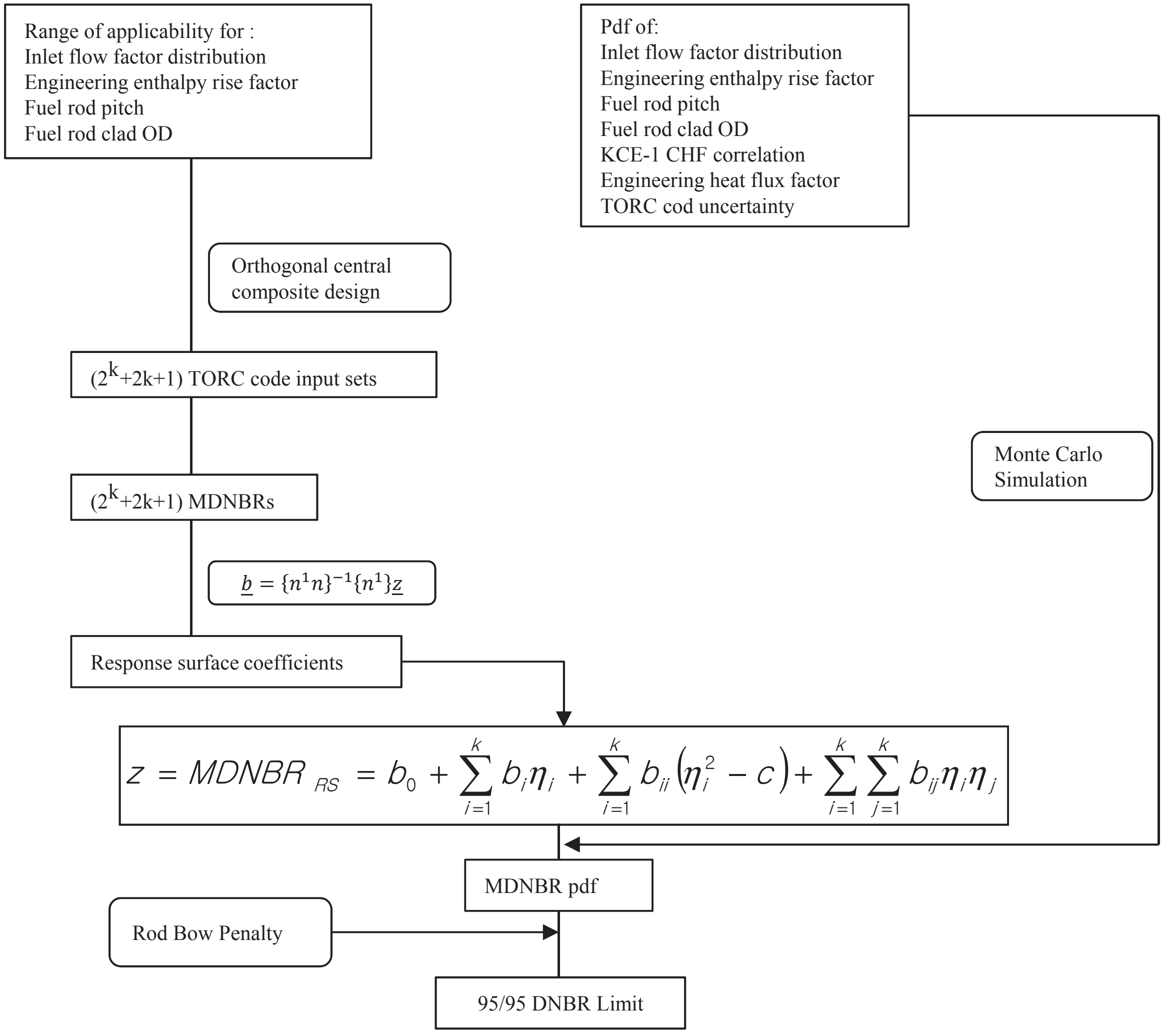
State Parameter MSCU Analysis

OUA

COLSS/CPCS Addressable Constants

SCU

- **Design Procedure**



Range of applicability for :
Inlet flow factor distribution
Engineering enthalpy rise factor
Fuel rod pitch
Fuel rod clad OD

Pdf of:
Inlet flow factor distribution
Engineering enthalpy rise factor
Fuel rod pitch
Fuel rod clad OD
KCE-1 CHF correlation
Engineering heat flux factor
TORC cod uncertainty

Orthogonal central composite design

(2^k+2k+1) TORC code input sets

(2^k+2k+1) MDNBRs

$\underline{b} = \{n^1 n\}^{-1}\{n^1\}\underline{z}$

Response surface coefficients

Monte Carlo Simulation

$$z = MDNBR_{RS} = b_0 + \sum_{i=1}^{k} b_i\eta_i + \sum_{i=1}^{k} b_{ii}\left(\eta_i^2 - c\right) + \sum_{i=1}^{k}\sum_{j=1}^{k} b_{ij}\eta_i\eta_j$$

MDNBR pdf

Rod Bow Penalty

95/95 DNBR Limit

SCU

- **Response Surface Methodology**
  - A functional relationship which involves several independent variable and one dependent variable
  - Created by fitting the constants of an assumed functional relationship to data obtained from “experiments”
  - Used in analytic techniques of a complex or unknown functions

- **Application of Response Surface**
  - A TORC analysis is treated as an “experiments”
  - So, a functional relationship is fitted to the MDNBR results of TORC analysis
  - This response surface is then used in conjunction with Monte Carlo techniques to combine pdf for each of the independent variable into a resultant MDNBR pdf

SCU

- **Monte Carlo Method**
  - Be useful for simulating phenomena with significant uncertainty in inputs with a large number
  - Generate data points to repeat random sampling from a probability distribution

- **Application of Monte Carlo Method**
  - Divide into 40 intervals from normal distribution of each parameter
  - Generate the required number of data points for each interval using the random number generation scheme
  - Random sampling of 20,000 data point within ±5σ from normal distribution
  - Repeat DNBR calculation using data set selected from each parameter
  - Generate the resultant DNBR pdf to combine system parameter pdfs with the KCE-1 CHF correlation pdf
  - Apply the rod bow penalty to the pdf and determine DNBR limit value at 95% confidence level with 95% probability

SCU

- **Generation of DNBR pdf and DNBR Limit**
  - Repetitive calculation for 20,000 randomly selected sets from pdfs of system parameters and the CHF correlation by the following equation;

$$DNBR = DNBR_{CHF} + (DNBR_{RS} - DNBR_{NOM})$$

  - DNBR pdf

Number of calculation	: 20,000
Mean	: 1.059
Standard Deviation	: 0.1255

  - The rod bow penalty is multiplied to DNBR pdf to determine DNBR limit
  - Finally, the DNBR limit was calculated at 95% confidence level with 95% probability by the following equation;

$$DNBR_{Limit} = \mu + 1.645 \cdot \sigma = 1.078 + 1.645 \cdot 0.1277 \approx 1.29$$

Thank you for your attention.