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Preliminary Uncertainty Analysis for SMART Digital Core Protection and Monitoring System

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) developed on-line digital core protection and monitoring systems, called SCOPS and SCOMS as a part of SMART plant protection and monitoring system. SCOPS simplified the protection system by directly connecting the four RSPT signals to each core protection channel and eliminated the control element assembly calculator (CEAC) hardware. SCOMS adopted DPCM3D method in synthesizing core power distribution instead of Fourier expansion method being used in conventional PWRs[1]. The DPCM3D method produces a synthetic 3-D power distribution by coupling a neutronics code and measured in-core detector signals.

The overall uncertainty analysis methodology which is used statistically combining uncertainty components of SMART core protection and monitoring system was developed[2,3]. In this paper, preliminary overall uncertainty factors for SCOPS/SCOMS of SMART initial core were evaluated by applying newly developed uncertainty analysis method.

2. Methods and Results

The overall uncertainty analysis established that the adjusted LPD and DNBR are conservative at a 95/95 probability confidence level throughout the core cycle with respect to actual core conditions. Newly developed statistical combination of uncertainties (SCU) method is applied to the calculation of SCOPS/SCOMS overall uncertainty factors. The probability distribution functions associated with the algorithm and sensor uncertainties are analyzed to obtain the LPD and DNBR overall uncertainty factors based on 95/95 probability/confidence tolerance limit.

2.1 MASTER Neutronics Analysis

MASTER code used as a reactor core simulator generates more than 1000 axial power shapes at each time in life (BOC, MOC, EOC). Axial shapes are prepared by function of power level, CRA configuration and xenon oscillation. MASTER data file includes core parameters representing core condition, such as system pressure, temperature, boron concentration, peaking factors, control rod group position, incore and excore detector signals as well as core axial power (average and 5-hot pin) distributions. MASTER data file is used as basic data in Fq and DNBR calculation.

2.2 FAST T/H Analysis

FAST code was developed to calculate DNBR with fast, which shows conservative results compared with detailed DNBR calculation code. FAST reduces computer time by reducing the number of sub-channels needed in the model and by using a simplified non-iterative scheme called the prediction correction method. Using MASTER provided case sets and a range of the SCOPS/SCOMS operating conditions, GENI code generates stacked case for FAST running. FAST calculates DNB-POL per each case and provides a file to be used in uncertainty analysis of SCOPS/SCOMS. FAST calculates reference DNB-POL per each axial shape.

2.3 Input Uncertainties

The overall uncertainty analysis needs input uncertainties for the input parameters. Individual uncertainties for SMART initial core are assumed and summarized in Table 1 & 2. Since most of uncertainty values are not available (or suitable) for SMART core, YG 3&4 uncertainty data are used[4,5]. But considering the conservatism, 10% additional uncertainty are added to original YG 3&4 data.

2.4 Uncertainty Factors Analysis

SCOPSIM and SCOMSIM code are used to calculate the overall uncertainty factors. These codes are developed in KAERI and similar to CPCSIM and COLSIM currently used in CE-type PWRs. These codes consist of several functional components such as input routines, some parts of SCOPS/SCOMS related with power distribution synthesis and DNBR calculation, statistics routines and a plotting package. The input files required running SCOPSIM/SCOMSIM are as follows:

- MASTER Data File
- FAST Data File
- SCOPS/SCOMS Database
- SCOPS/SCOMS Database Change File
- SCOPSIM/SCOMSIM Input File

As noted in Table 1 & 2, additional uncertainty values are inputted in SCOPSIM and SCOMSIM input files, which are used in calculating BERR1, BERR3 for SCOPS and EPOL2, UNCERT for SCOMS. The uncertainty components are Fxy measurement, POL-derivative, computer processing uncertainties, engineering factor and so on. These uncertainties are combined in a deterministic manner.

Table 3 shows SCOPSIM analysis results. The overall results are similar to those of YG 3&4 cycle 1. Fq uncertainty (BERR3) increases as burnup going on. The reason is expected that SAM and BPPCC used in axial power synthesis are not optimized enough to represent overall core condition. Moreover, values of RSF and planar radial peaking factor and Fxy provided by function of burnup are preliminary values. In conventional PWRs, cubic spline synthesis technique is used in online calculations of the core axial power distributions as like SMART and shows large power distribution errors for the extremely skewed axial shapes due to restrictive function sets and an incorrect SAM value. Especially thus situation is worse at a higher burnup as shown in Table 3.

Table 4 shows SCOMS overall uncertainty factors of SMART initial core. Overall results are similar or more improved to those of YG 3&4 cycle 1. The reason is that SCOMS adopts DPCM3D method in power distribution synthesis and FAST algorithm in DNBR calculation. As mention in above, SCOMS synthesizes 3-dimentional core power distribution. Thus more realistic core condition such as hot pin power distributions as well as core peaking factors is provided in uncertainty analysis. In addition, by adopting FAST algorithm without change, modeling uncertainty between simulator and SCOPS/SCOMS is ruled out basically.

Table 1. Individual Uncertainties for SCOPS Overall Uncertainty Factors Calculation.

Variables	Uncertainty [a]	Distribution
Pressure, psia	-25.3 ~ 25.3	uniform
Temperature, °F	-2.75 ~ 2.75	uniform
Flow rate, % design	0.934 ~ 1.066	uniform
Excore det., % power	1.43	normal
CRA position, % height	5.06	uniform
SAM	0.00	N/A [b]
BPPCC, fraction	0.11	uniform
RSF, fraction	0.0726	uniform
Excore det. dev., fraction	0.0058	normal

a. 10% additional uncertainty applied.
b. statistically treated with SAM pdf file.

Table 2. Individual Uncertainties for SCOMS Overall Uncertainty Factors Calculation.

Variables	Uncertainty [a]		Distribution
	low/mean	high/σ	
Pressure, psia	0.0	8.217	normal
Temperature, °F	0.0	3.168	normal
Flow rate, % design	-5.50	5.50	uniform
CRA pos., % height	1.936	N/A	uniform
Incore det., fraction	0.0374	N/A	normal

a. 10% additional uncertainty applied.

Table 3. SCOPS Overall Uncertainty Factors of SMART Initial Core.

	BOC	MOC	EOC
BERR1	1.064(1.106)	1.065(1.147)	1.066(1.116)
BERR3	1.086(1.143)	1.121(1.207)	1.182(1.122)
Avg. ASI	0.036(0.049)	0.039(0.063)	0.035(0.057)
Hot Pin ASI	0.062(0.047)	0.070(0.089)	0.034(0.080)

a. ( ) value is YG 3&4 uncertainty from Ref. 4.

Table 4. SCOMS Overall Uncertainty Factors of SMART Initial Core.

	BOC	MOC	EOC
UNCERT	1.081(1.128)	1.085(1.186)	1.085(1.130)
EPOL2	0.061(0.101)	0.052(0.095)	0.050(0.091)
Avg. ASI Uncertainty			
Lower	-0.005(-0.017)	-0.005(-0.020)	-0.005(-0.020)
Upper	0.006(0.015)	0.006(0.017)	0.007(0.018)

a. ( ) value is YG 3&4 uncertainty from Ref. 5.

3. Conclusions

The preliminary overall uncertainty analysis was evaluated for the digital core protection and monitoring system of SMART initial core. Newly developed uncertainty analysis method was applied. The overall results are similar or more improved to those of YG 3&4 cycle 1. Even though Fq uncertainty (BERR3) increases at a higher burnup, it is accommodating level. Especially, overall uncertainty factors of SCOMS shows better than those of YG 3&4, because SCOMS adopts DPCM3D method and FAST algorithm in power distribution and DNBR calculation. Thus calculated LPD and DNBR with uncertainty factors will be conservative with a 95/95 probability/confidence level with respect to actual core conditions.

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