Uncertainty Evaluation with Multi-Dimensional Model of LBLOCA in OPR1000 Plant

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1. Introduction

KINS has used KINS-REM (KINS-Realistic Evaluation Methodology) which developed for Best-Estimate (BE) calculation and uncertainty quantification for regulatory audit. This methodology has been improved continuously by numerous studies, such as uncertainty parameters and uncertainty ranges.

In this study, to evaluate the applicability of improved KINS-REM for OPR1000 plant, uncertainty evaluation with multi-dimensional model for confirming multi-dimensional phenomena was conducted with MARS-KS code.

2. Methods and Results

2.1 Multi-Dimensional Modeling

For the assessment of multi-dimensional phenomena for OPR1000 plant, the reactor vessel was modeled as MULTID component of the MARS-KS code [1]. The other parts, such as steam generators, hot legs and cold legs are modeled as 1-Dimensional components.

Figure 1 shows the cross section of reactor vessel. Reactor vessel was modeled to divide into five-rings in the r-direction and six-sectors in the θ-direction. The reactor core is located at the 1st to 3rd ring from the center. The average rods and hot rod which modeled as heat structure were located on each sections (three-rings and six-sectors) in the reactor core.

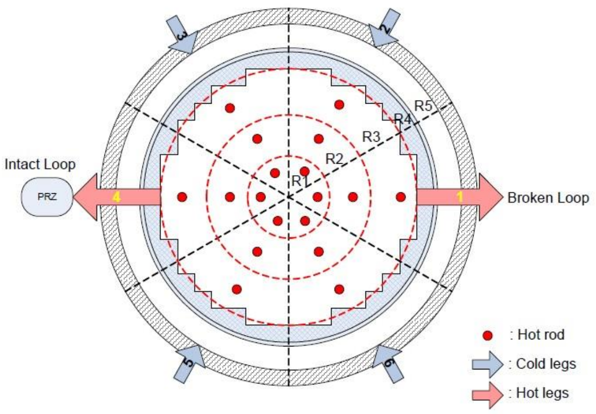

Fig. 1 Cross-section of Reactor Vessel

2.2 Uncertainty Parameters

The 30 uncertainty parameters, including plant operation and physical models based on several previous studies were used for the uncertainty analysis.[2] However, the containment pressure was fixed to a conservative value as a boundary conditions.

Among 29 parameters, the uncertainty of physical model important to the thermal-hydraulic behavior during reflood period were considered through a sensitivity analysis in the previous study [3], and their uncertainty ranges were determined by the statistical uncertainty quantification method.[2]

In order to evaluate the effect on the multi-dimensional phenomena in the reactor vessel, the uncertainty parameters, such as ECC bypass, Core lateral K-factor, Turbulent mixing length and Radial power peaking were considered as shown in Table 1. [4]

Table I: Uncertainty parameters for multi-dimensional model

Models or Uncertainty Parameters	PDF	Ranges	Means
Core power	Normal	0.98 ~1.02	1.0
Fuel thermal conductivity	Uniform	0.847 ~1.153	1.0
Decay heat	Normal	0.934 ~1.066	1.0
Gap conductance (roughness→hg)	Uniform	0.66 ~2.34	1.5
Groeneveld CHF lookup table (AECL)	Normal	0.17 ~1.8	0.985
Dittus-Boelter liquid convection	Normal	0.606 ~1.39	0.998
Dittus-Boelter vapor convection	Normal	0.606 ~1.39	0.998
Chen nucleate boiling	Normal	0.53 ~1.46	0.995
Zuber CHF correlation	Normal	0.38 ~1.62	1.0
Chen transition boiling	Normal	0.54 ~1.46	1.0
Weismann TB correlation	Lognorm al	0.5 ~2.0	1.02
Bromley film boiling	Normal	0.428 ~1.58	1.004

Models or Uncertainty Parameters	PDF	Ranges	Means
QF Bromley correlation	Normal	0.75 ~1.25	1.0
Forslund-Rohsenow FB Correlation (reflood)	Normal	0.5 ~1.5	1.0
Vapor correlation (reflood)	Normal	0.5 ~1.5	1.0
Dry/wet wall criteria(30℃)	Normal	0.568 ~1.269	0.918
Weber number (reflood)	Normal	-0.731 ~1.403	0.336
Droplet interfacial heat transfer	Normal	0.348 ~2.182	1.265
Break CD	Normal	0.729 ~1.165	0.947
RCP 2-phase head multiplier	Uniform	0.0~1.0	0.5
RCP 2-phase torque multiplier	Uniform	0.0~1.0	0.5
SIT actuation pressure (MPa)	Uniform	4.031 ~4.459	4.245
SIT water inventory (㎥)	Uniform	50.69 ~54.57	52.63
SIT water temperature (K)	Uniform	283.2 ~322.0	302.6
RWST temperature (K)	Uniform	277.6 ~322.0	299.8
ECC Bypass (Downcomer K-factor)	Uniform	0.5~1.5	1.0
Core Lateral K-factor	Uniform	0.5~1.5	1.0
Turbulent Mixing Length	Uniform	0.01 ~0.296	0.1
Radial Power Peaking	Uniform	0.8~1.2	1.0

2.3 Calculation results

The uncertainty analysis was conducted for 124 samples generated by random sampling with the 29 uncertainty parameters. To obtain the final PCT (Peak Cladding Temperature) with a 95% confidence level and 95% probability, the 3rd highest PCT value was selected by the 3rd order Wilks' formula.

The maximum PCT shall be the highest cladding temperature of hot rod in the 18 sections. However, the final PCT is expected to occur at the central 1st ring.

The random sampling of the uncertainty parameters and calculations were performed using the Mosaique program [5] with MARS-KS code. Table II and III show the calculation results for blowdown and reflood PCT. In the 124 sampled calculations, the seven cases were failed during reflood period even if the time step control. However, the blowdown PCT showd higher value than reflood PCT for most cases. Thus, the prediction of final PCT are reasonable.

However, the blowdown PCT was showed higher value than reflood PCT mostly. Thus, the prediction of final PCT including failed cases are reasonable.

Figure 2 shows the behavior of peak cladding temperature for 124 sampled calculations. From the calculation results, reflood PCT and blowdown PCT with a 95% confidence level and 95% probability were predicted 1266.8K and 1149.3, respectively. These values do not exceed the acceptance criteria, 1477K.

Table II: Evaluation results (Blowdown PCT)

	Blowdown		
	Case	Time [s]	PCT [K]
-	Base	9.50034	1087
1st	50	9.9	1310.2
2nd	8	8.30107	1295.8
3rd	73	8.70073	1266.8

Table III: Evaluation results (Reflood PCT)

	Reflood		
	Case	Time [s]	PCT [K]
-	Base	137.006	891.84
1st	8	37.5037	1156.1
2nd	81	40.0134	1150.4
3rd	27	35.5036	1149.3

2.4 Sensitivity analysis

The Pearson coefficient calculations with the uncertainty results for each parameter were conducted to determine sensitive uncertainty parameters in the multi-dimensional analysis. Figure 3 shows the analysis results. A parameter with larger absolute value is more sensitive than other parameters.

Thus, it was turned out that the radial power peaking, Groeneveld CHF lookup table, fuel thermal conductivity, gap conductance, break Cd have relatively strong influence to the PCT. These variables are mostly related with plant operation and the fuel material properties. The parameters related with physical model seem to have weak influence for final PCT.

3. Conclusions

In this study, the uncertainty evaluation with multi-dimensional model of OPR1000 plant was conducted for confirming the applicability of improved KINS-REM

The reactor vessel modeled using MULTID component of MARS-KS code, and total 29 uncertainty parameters were considered by 124 sampled calculations.

Through 124 calculations using Mosaique program with MARS-KS code, peak cladding temperature was calculated and final PCT was dertimined by the 3rd order Wilks' formula.

The uncertainty parameters which has strong infulence were investigated by Pearson coefficient analysis. They were mostly related with plant operation and fuel material properties.

Evaluation results through the 124 calculations and sensitivity analysis show that improved KINS-REM could be reasonably applicable for uncertainty evaluation with multi-dimensional model calculations of OPR1000 plants.

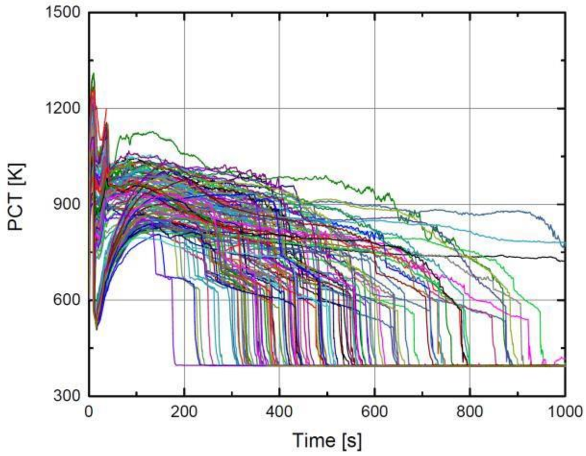

Fig. 2 Peak Cladding Temperature for 124 calculations

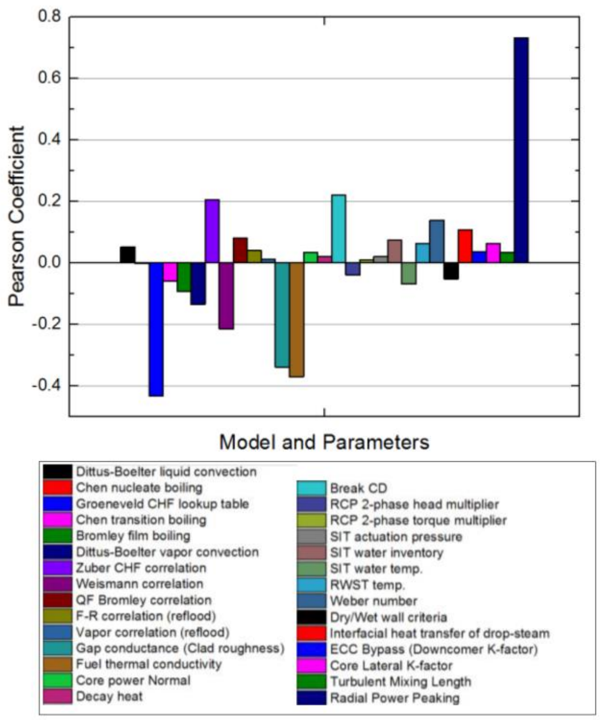

Fig. 3 Sensitivity Analysis

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