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Sensitivity analysis to improve the gap conductance uncertainty for KINS-REM

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1. Introduction

KINS has been using the Best Estimate Plus Uncertainty(BEPU) methodology to analyze the LBLOCA that is the design basis accident of emergency core cooling system(ECCS). KINS-REM(Realistic Evaluation Methodology) is the currently used for LBLOCA analysis methodology and has been improved continuously. One of the important issue of the improvements is the consideration about the uncertainty parameters related to fuel rod behaviors during LBLOCA. Effect of Thermal Conductivity Degradation(TCD)[1] of fuel rod has been studied to be considered in KINS-REM.

For this purpose, the sensitivity analysis has been performed to improve the gap conductance uncertainty parameter in this study. The OPR1000 plant, Hanul unit 3&4, was selected as the reference plant. LBLOCA transient calculations have been performed by MARS-KS.

2. Methods and Results

2.1 Uncertainty Parameters

KINS-REM for LBLOCA analysis methodology has been used by considering a total of 22 uncertainty parameters based on MARS-KS code. Among those uncertainty parameters, 1) gap conductance, 2) fuel thermal conductivity, 3) core power, and 4) decay heat are the uncertainty parameters associated with the fuel rod[2]. Table 1 shows the distribution functions and parameter ranges for the above four uncertainty parameters.

These parameters and the ranges of uncertainty were mainly chosen based on the experimental data of the low burnup fuel. Therefore, the burnup effect was not considered at the existing gap conductance model and the fuel thermal conductivity model which are related directly to the burnup and TCD effect.

Table 1. Four uncertainty parameters considered in KINS-REM

Model/Parameters	Distribution	Range	Mean
Gap conductance (Glad roughness, B)	Uniform	0.4~1.5	0.95
Fuel thermal conductivity	Uniform	0.847~1.153	1.0
Core power	Normal	0.98~1.02	1.0
Decay heat	Normal	0.934~1.066	1.0

2.2 Gap Conductance Model

The gap conductance model, h_g, in MARS-KS is calculated by the equation:

$$h_g = \frac{k_g}{N}\sum_{n=1}^{N}\frac{1}{t_n + 3.2(R_F + R_C) + g_1 + g_2}$$

where

h_g	: conductance through the gas in the gap (W/m^2·K)
N	: total number of a circumferential segment
k_g	: thermal conductivity of gas (W/m·K)
t_n	: width of fuel-cladding gap at the midpoint of the nth circumferential segment (m)
R_F	: surface roughness of fuel (m)
R_C	: surface roughness of cladding (m)
g_1, g_2	: temperature jump distance terms for fuel and cladding

Since the gap conductance model considers the various complex nuclear fuel and cladding behaviors and symptoms as presented in above equation, such as width of fuel-cladding gap (t_n), surface roughness (R_F, R_C), temperature jump distance (g_1, g_2), thermal conductivity of gas (k_g), this implies that a variety of uncertainty may arise therefrom.

Among these variables, up to now, the uncertainty of the gap conductance model has been controlled by adjusting the cladding roughness. According to a previous study[3], the cladding roughness can be obtained in the uncertainty range of the parameter(B) using the following equation:

$$Y\ [\mu m] = -10^{-4} \times X + 7.32 \times B$$

where

Y	: cladding roughness
X	: average linear power density (Hanul unit 3&4 18424.55 W/m)
B	: range of uncertainty parameter (KINS-REM, 0.4~1.5, uniform distribution)

The cladding roughness parameter for the uncertainty of the gap conductance is effective to control the thermal conductivity when fuel and cladding are in contact and also easy to program. Recently, however, uncertainty quantification method has been developed and utilized based on global variables in KINS-REM.

In this study, modification was made such that the global variable, effective gap conductance (h_g) can be controlled directly rather than the gap roughness parameter (B) as the method of uncertainty quantification.

2.3 Sensitivity of Gap Conductance

Sensitivity calculations has been performed to get the multiplication coefficient of the effective gap conductance(h_g) corresponding to the uncertainty range, 0.4~1.5, of the cladding roughness parameter(B).

$$1-\frac{\delta\mathrm{PCT}(B)}{\delta\mathrm{PCT}(\alpha)}\rightarrow 0 \quad \textit{for blowdown, reflood}$$

where α is the multiplication coefficient

The results of sensitivity analysis are shown in Fig. 1 and 2 for peak cladding temperature(PCT) of the hottest cell for LBLOCA. The comparison of h_g and B is based on reflood PCT, blowdown PCT, and blowdown behaviors.

As presented in Fig. 1, multiplication coefficient of h_g, 2.34, is the most consistent value and tendency that the blowdown PCT, reflood PCT, and reflood behaviors at the minimum value of the existing range of uncertainty parameter, B=0.4. At multiplication coefficient of h_g, 0.66, the results show the most similar value of blowdown PCT with B=1.5 as shown in Fig. 2 even though the time delay is shown in reflood conservatively.

Through the sensitivity studies for PCT, it is found that the range of B can be suitably substituted with the direct multiplication coefficient of effective gap conductance (h_g), 0.66~2.34. Fig. 3 and 4 show the PCT variation using previous uncertainty range of gap conductance(cladding roughness, B) and the modified uncertainty range of gap conductance(h_g), respectively.

3. Conclusions

As the method of uncertainty quantification for gap conductance, the controls of the cladding roughness parameter(B) is changed to the controls of the global variable, effective gap conductance(h_g) that is physically reasonable manner.

The sensitivity analysis has been performed on the uncertainty multiplication coefficient of h_g corresponding to the previous uncertainty range of cladding roughness parameter B in PCT calculations of LBLOCA.

Through the comparison and analysis of the PCT values and behavior trends for reflood and blowdown, the range of uncertainty of the multiplication coefficient of the global variable h_g, 2.34~0.66 and mean value 1.5 are reasonable to replace the local variable called the cladding roughness.

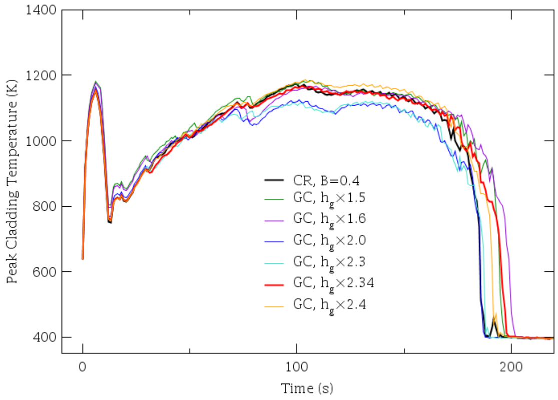

Fig. 1. Comparison of the cladding roughness(CR, B=0.4) and the gap conductance(h_g ×1.5~2.4) for PCT

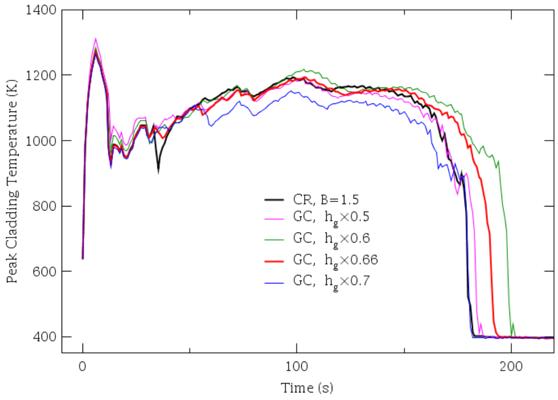

Fig. 2. Comparison of the cladding roughness(CR, B=1.5) and the gap conductance(h_g ×0.5~0.7) for PCT

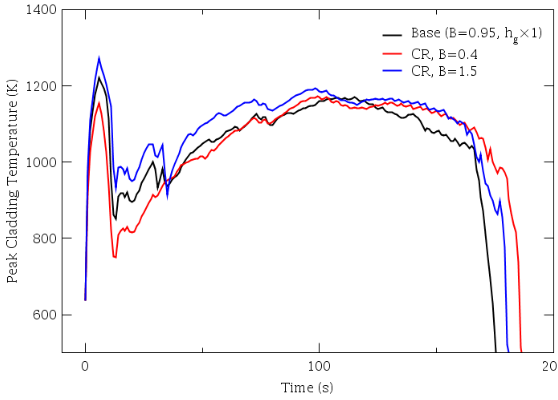

Fig. 3. Uncertainty range of PCT for controlling the local variable called cladding roughness.

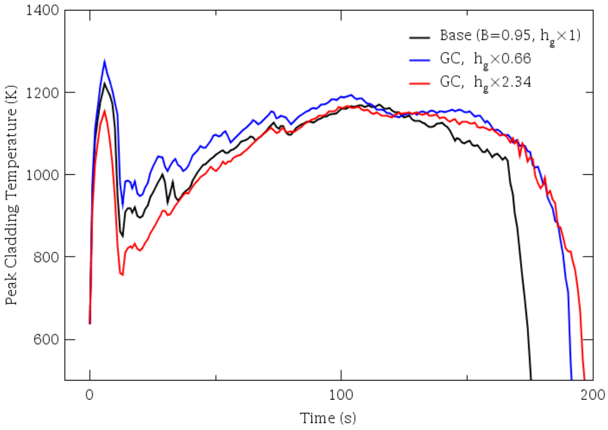

Fig. 4. Uncertainty range of PCT for controlling the global variable called gap conductance.

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