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Evaluation of Gap Conductance Uncertainty for Safety Analysis

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1. Introduction

Currently considered uncertainty parameters of fuel rod in KINS-REM(Relistic Evaluation Methodology) for LOCA analysis are gap conductance, fuel thermal conductivity, core power and decay heat[1]. These parameters and the ranges of uncertainty were mainly chosen based on the experimental data of low burnup fuel. However, authors' previous work indicated that the limiting fuel burnup for LBLOCA analysis should be changed from beginning of life (BOL) to middle of life (MOL) when the thermal conductivity degradation of UO_2 was considered properly[2]. Therefore, in this study, sensitivity studies on gap conductance as a function of fuel burnup have been done, and combined uncertainty of each uncertainty parameter to the conductnce also has been evaluated.

2. Analysis Details

The uncertainty parameter for gap conductance evaluation was chosen based on the gap conductance model in FRAPCON-3.4a code. Fuel-cladding gap conductance model in the code is the sum of three components as follows.

$$h = h_r + h_{gas} + h_{solid}$$

h_r = *conductance due to radiation*
h_{gas} = *conductance due to the gas gap*
h_{solid} = *conductance due to fuel-cladding contact*

Detailed equations and models for each of these components can be found in ref.[3]. Selection of tolerance and bias range is listed in ref.[4]

The simple random sampling (SRS) technique is utilized for the combined uncertainty study. 124 inputs were generated with the uncertainty combinations listed in Table 1.

3. Results

3.1 Sensitivity of Gap Conductance

Table 1 shows the effects of individual uncertainty to the gap conductance within prescribed tolerance and bias ranges. In BOL case, fuel thermal conductivity, cladding inner diameter, pellet outer diameter, fuel pellet radial relocation, fuel thermal expansion, cladding thermal expansion, pellet re-sinter showed a strong impact on the gap conductance. Cladding elastic modulus and cladding corrosion revealed a moderate impact. But, as fuel burnup increased to 30 MWd/kgU, the important uncertainty parameters were changed. Particularly the uncertainties related to the gap width were less significant. Meanwhile, pellet and cladding roughness, fission gas release(FGR) appeared as dominant uncertainty factors. Crud and zirconia thermal conductivity revealed a moderate influence.

3.2 Combined Uncertainty

Fig. 1 shows the combined effect of the uncertainty parameter on the gap conductance change as a function of rod power. In BOL case, at low power region the conductance value increased almost linearly, but it increased rapidly above the certain rod power.

Table 1. Considered uncertainty parameters and their impacts on the gap conductance at the 14.2 kW/ft LHR

	Tolerance or Bias	Δgapcon %	
		BOL	30 MWd/kgU
Model & equation parameter			
Pellet roughness(micron)	±0.5	0.0	39.0
Cladding roughness (micron)	±0.3	0.0	21.6
Cladding surface emissivity	±2σ	< 1	< 1
Fuel emissivity	±2σ	< 1	< 1
Gas conductivity (He)	±2σ	6.7	5.8
Gas conductivity (Xe)	±2σ	0.0	< 1
Gas conductivity (Kr)	±2σ	0.0	< 1
Fuel thermal conductivity	±2σ	125.7	76.1
Cladding thermal conductivity	±2σ	6.7	< 1
Related to the gap width			
Cladding ID(mm)	±0.04	148.6	6.7
Pellet OD(mm)	±0.013	27.0	1.0
Fuel relocation	±2σ	97.0	< 1
Fuel thermal expansion	±2σ	98.7	6.3
Fuel swelling	±2σ	0.0	< 1
Creep of cladding	±2σ	3.4	< 1
Cladding thermal expansion	±2σ	21.7	< 1
Cladding elastic modulus	±2σ	12.3	5.4
Cladding yield stress	±2σ	0.0	3.7
Related to the gas pressure			
Rod fill pressure(MPa)	±0.07	1.6	3.5
FGR	±2σ	0.0	126.3
Cladding axial growth	±2σ	< 1	< 1
Rod plenum length(mm)	±11.4	< 1	1.9
Dish diameter & depth(mm)	±0.5, +0.05	< 1	< 1
Related to the gap temperature			
Pellet density(%)	±0.91	5.0	7.3
Pellet re-sinter density(%)	±0.4	37.8	< 1
Cladding thickness(mm)	±0.04	< 1	1.1
Cladding corrosion	±2σ	19.0	4.1
Crud thermal conductivity	±2σ	< 1	15.1
ZrO2 thermal conductivity	1/0.9~1/5.0	1.2	10.9
Crud thickness, micron	0~30	< 1	7.9

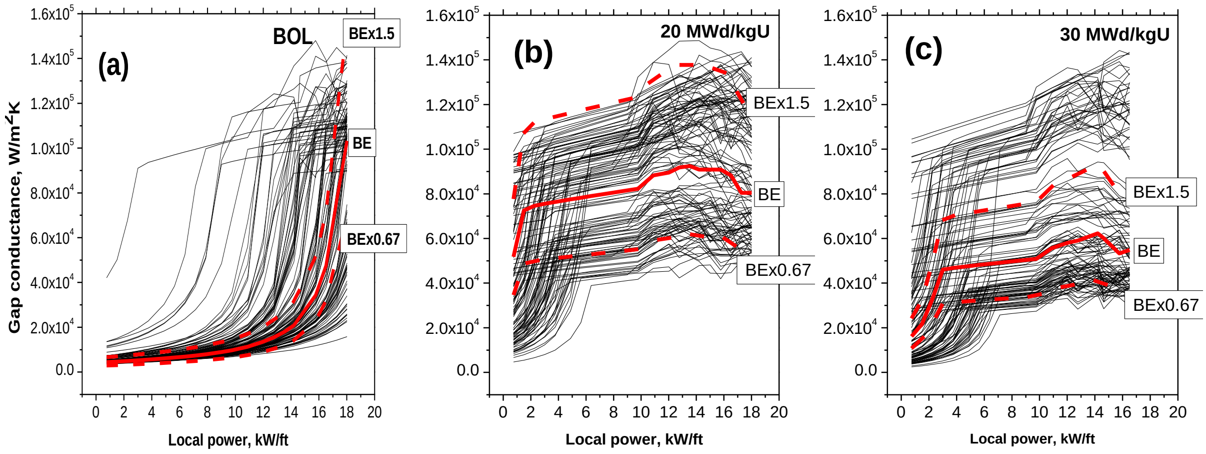

Fig 1. Gap conductance change as a function of local power. Fuel burnup of (a), (b) and (c) is BOL(0.5MWd/kgU), 20 MWd/kgU and 30 MWd/kgU, respectively.

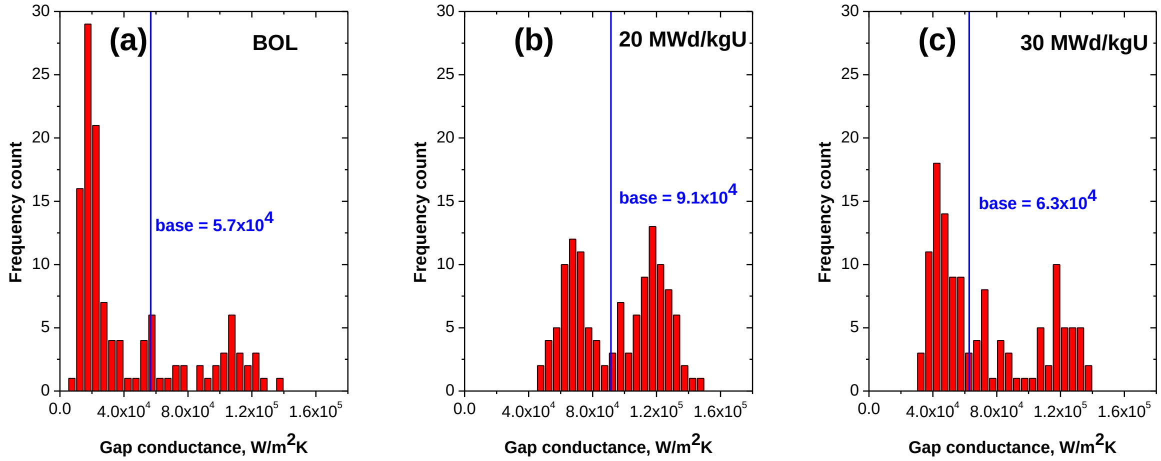

Fig 2. Frequency count of gap conductance at 14.2 kW/ft linear heat rate(LHR). Fuel burnup of (a), (b) and (c) is BOL(0.5MWd/kgU), 20 MWd/kgU and 30 MWd/kgU, respectively.

In case of fuel burnup of 20 and 30 MWd/kgU, rapid increase of the conductance was observed at low power region, and it increased almost linearly. Fig. 1 also shows the best-estimate, lower and upper bound gap conductance curves with respect to power ascension. In the figure the lower and upper bound of gap conductance curve was obtained as a multiplication factor was set 0.67 and 1.5, respectively, because it is utilized in the KINS-REM. From the figure, we could know that the current uncertainty range of gap conductance seems to be insufficient to encompass the 124 SRS gap conductance curves, irrespective of fuel burnup.

Fig. 2 shows the frequency count of gap conductance at the fuel power of 14.2kW/ft. KINS-REM assumes that the sampling probability of gap conductance within the prescribed uncertainty range is normal. However, current analysis results indicate the frequency distribution of gap conductance is neither normal nor uniform, irrespective of fuel burnup.

The ranges of combined uncertainty and frequency distributions of gap conductance are obtained based on the models in FRAPCON-3 with the given uncertainty parameters and tolerance/bias ranges listed in Table 1. Therefore, those are differing from the assumption of KINS-REM that is derived based on experimental data.

REFERENCES

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