Validation of Fuel Performance Uncertainty for RIA Safety Analysis

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1. Introduction

Korea Institute of Nuclear Safety (KINS) has been trying to establish an audit calculation methodology on reactivity-initiated accident (RIA) safety analysis based on a realistic approach [1]. Realistic approach is a well-known methodology for the area of loss-of-coolant accident (LOCA) safety analysis, and it seems to be applicable to the RIA safety analysis also. Realistic approach is composed of the evaluation of best-estimate performance and uncertainty quantification. And the code performance has to be validated based on the experimental results. For the uncertainty quantification, important uncertainty parameters need to be chosen, and combined uncertainty has to be evaluated with an acceptable statistical treatment.

Author previous works have identified as many as uncertainty parameters that can affect the fuel performance during RIA [2]. And important uncertainty parameters to the rod performance such as fuel enthalpy, fission gas release, cladding hoop strain etc. were chosen through the rigorous sensitivity studies. And their validity has been assessed by utilizing the experimental results tested in CABRI and NSRR [3]. Analysis results revealed that several tested rods were not bounded within combined fuel performance uncertainty. These are shown briefly in section 2 in this paper. In the previous study, uncertainty of fuel power was assumed as +/- 5%(2s). But it is reported that the uncertainty of injected energy of CABRI is about +/-11% (2s) [4]. Thereby, in this paper fuel performance was assessed again with extended power uncertainty.

2. Validation with experimental results

Table 1. Selected important uncertainty parameters for covering each fuel performance uncertainty with sufficient levels of assurance [3].

	PFE	FGR_{tran}	PHS
Manu-facturing	- Cladding ID - Pellet OD - Pellet density - Pellet re-sinter density	- Cladding ID - Pellet re-sinter density	- Cladding ID - Cladding thickness - Pellet OD - Pellet density - Pellet re-sinter density - Rod fill pressure - Rod plenum length
Model	- Fuel thermal conductivity - Fuel thermal expansion	- Fuel thermal conductivity - Fuel thermal expansion - FGR_{steady}	- Fuel thermal conductivity - Fuel thermal expansion - Fuel swelling - Fuel relocation - Cladding corrosion - ZrO_2 conductivity - Cladding thermal expansion - Cladding elastic modulus - Cladding yield strength
Power	- Radial power profile - Power (FWHM)	- Radial power profile - Power (FWHM)	- Radial power profile - Power(FWHM)

For the selection of important uncertainty parameters sensitivity study has been carried out by changing fuel burnup, injected energy and full-width half maximum (FWHM) of the given RIA power pulse. Considered fuel burnup was 0.5, 30 and 50 MWd/kgU. Evaluated FWHM was 10 and 20 ms. Radially averaged peak injected energy was 80, 100 and 140 cal/g. FRAPCON-3.5 and FRAPTRAN-1.5 fuel performance code were used. Analysis results revealed that the number of important uncertainty parameters to

Table 2. Information on the tested rods in NSRR and CABRI reactor [5]

Test ID	Burnup (MWd/kgU)	Oxide thickness (μm)	Peak fuel enthalpy (cal/g)	Clad max hoop strain (%)	Transient FGR (%)	Initial test temperature (K)	Test reactor
FK1	45	16	130	0.8	8.2	304.8	NSRR
GK1	42	10	93	2.5	12.8	292.8	
HBO6	49	30	85	1.2	10.4	289.8	
MH3	39	5	67	1.6	4	292.8	
OI2	39	15	108	4.8	10.2	292.8	
TS5	26	6	98	0.	8	297.8	
CIP0-1	75	50~100	93	0.5	15	553.0	CABRI
Na3	54	35~60	123	2.2	13.7	553.0	
Na4	62	60~80	87	0.4	8.3	553.7	
Na5	64	15~25	108	1.1	15.1	553.3	
Na6	35	35	133	2.6	21.3	552.7	
Na9	50	10	197	7.2	33	553.4	

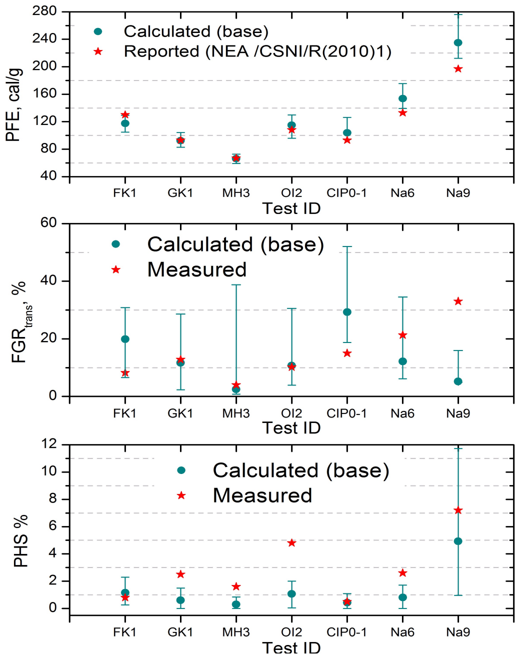

Fig. 1. Calculated and measured fuel performance of (a) peak fuel enthalpy (PFE), (b) transient fission gas release (FGR_{trans}) and (c) maximum plastic hoop strain (PHS). Error bars indicate the third highest and lowest values among 124 runs.

represent the uncertainty of peak fuel enthalpy, peak fuel temperature and fission gas release within a sufficient level of assurance was eight, seven and seven, respectively. And twenty, eighteen and eighteen parameters were identified as the representative parameters for rod internal pressure, plastic hoop strain and peak average cladding temperature, respectively. If these parameters were selected altogether, above 98 % of fuel performance uncertainty coverage can be assured. Table 1 shows the identified uncertainty parameters on the peak fuel enthalpy (PFE), fission gas release (FGR_{trans}) and plastic hoop strain (PHS) of cladding.

The validity of those parameters has been assessed by utilizing the twelve experimental results, which were tested in CABRI and NSRR. Table 2 shows the summarized information on the tested rods. Non-parametric order statistics was used for the combined uncertainty analysis. Analysis results showed that FK1, CIP0-1, Na6 and Na9 rods were not bounded within the analyzed enthalpy uncertainty. CIP0-1 and Na9 test results were not bounded within the transient fission gas release uncertainty. And GK1, MH3, OI2, Na6 were not bounded within plastic hoop strain uncertainty. This implies that the currently considered uncertainty range is not enough to cover the fuel performance sufficiently.

3. Validation with extended power uncertainty

3.1 Analysis methodology

Selected uncertainty parameters, uncertainty ranges, probability density functions were exactly same as the previous work, except for the power uncertainty [3]. The power uncertainty is extended from +/-5% to +/-11%. Seven tested rods in NSRR and CABRI were analyzed again. These are FK1, GK1, MH3, OI2, CIP0-1, Na6, Na9. Non-parametric order statistics was used for uncertainty quantification, and 124 fuel performances were obtained on each tested rod. Detailed information on the analysis methodology can be founded in ref. [3].

3.2 Analysis results

Fig.1 shows the analysis results of PFE, FGR_{trans} and maximum plastic hoop stain. Results showed that CIP0-1, Na6 and Na9 rods were not bounded within the analyzed enthalpy uncertainty. CIP0-1 and Na9 test results were not bounded within the transient fission gas release uncertainty. And GK1, MH3, OI2, Na6 were not bounded within plastic hoop strain uncertainty. This implies that the extended power uncertainty alone is still insufficient to cover the fuel performance uncertainty successfully.

4. Summary

Assessment of fuel performance with extended fuel power uncertainty on tested rods in NSRR and CABRI has been done. Analysis results showed that several tested rods were not bounded still within fuel performance uncertainty.

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