Characterization of Fuel Rod Uncertainty for Safety Analysis

Joosuk Lee and Swengwoong Woo
Korea Institute of Nuclear Safety
62 Gwahak-ro, Yusong-gu, Daejeon, 305-338, Republic of Korea
Tel: +82-42-868-0784, Fax: +82-42-868-0045
Email: jslee2@kins.re.kr

1. Introduction

Authors' previous work indicated that when the conductivity degradation effect was considered properly the limiting fuel burnup for LBLOCA analysis should be changed from beginning of life (BOL) to middle of life (MOL)[1, 2]. And recently issued Information Notice (IN 2011-21) in U.S. NRC states that the thermal conductivity degradation of UO_2 fuel with burnup increase has to be modeled properly in 'best-estimate' emergency core cooling systems (ECCS) evaluation methodology. Furthermore acceptance criteria of ECCS for light water nuclear power reactors are currently being revised in U.S. NRC to reflect the cladding embrittlement of zirconium alloys based on new experimental data. According to the newly proposed criteria it is necessary to analyze the rod performance as a function of fuel burnup. In these circumstances re-screening of uncertainty parameters of fuel rod for LOCA safety analysis is strongly required beacuse those parameters used at KINS-REM were mainly chosen based on the BOL fuel conditions[3]. Current uncertainty parameters used at KINS-REM are gap conductance, fuel thermal conductivity, core power and decay heat. In this study, sensitivity studies have been done to assess what uncertainties will have an impact on the PCT during LBLOCA.

2. Analysis Details

In this paper 32 uncertainty parameters were chosen based on the NUREG/CR-7001(2009), NUREG/CR-7024(2011) and reasonable assumptions. These parameters can be categorized as manufacturing, operational and model that includes mechanical and physical properties of fuel rod [4, 5].

As shown in Table.1, manufacturing uncertainties represent an average value of the tolerances. Model uncertainties were set as $\pm 2\sigma$ (standard deviation), and operational uncertainties, such as the power, decay heat and crud thickness, were made partly based on the reasonable assumptions. FRAPTRAN-1.4 code was utilized with the coupling of FRPACON-3.4a fuel rod performance code. We fixed several coding errors related to the model uncertainties in FRAPCON-3.4a and did additional modeling related to the uncertainties of physical and mechanical property of fuel rod in FRAPCON-3.4a code. Several models in FRAPTRAN-1.4 were also updated to reflect the each uncertainty. In base case, 17x17 fuel assemblies with Zircaloy-4 cladding in Westinghouse 3-Loop plant type were utilized. Thermal-hydraulic boundary conditions such as heat transfer coefficient (HTC), pressure and temperature during LOCA transient were fixed irrespective of fuel burnup.

3. Results

Table 1 shows the effects of individual uncertainty to the PCT change within prescribed tolerance and bias ranges. In BOL case, manufacturing uncertainties such as cladding inner diameter, pellet outer diameter and pellet re-sinter density showed a strong impact on the PCT. Related to the model, thermal conductivity and thermal expansion of UO_2 fuel and cladding specific heat revealed significant impacts. Cladding radial thermal expansion showed moderate influence.

As fuel burnup increased to 30 MWd/kgU, important uncertainty parameters were changed. In general, manufacturing uncertainties were less significant to the PCT, but fuel thermal conductivity, fission gas release and cladding specific heat showed the predominant influence. Meanwhile cladding yield stress and zirconia thermal conductivity revealed a moderate influence. In both cases operational uncertainties such as LCO power, decay heat and crud thickness showed a moderate influence. In this analysis, we assumed that crud was accumulated at a constant rate from the beginning, and the upper bound crud thickness was 30 μm at the fuel burnup of 30MWd/kgU. Upper and lower bound of crud thermal conductivity was also assumed as 1.2972 and 0.4324 W/m-K, respectively. Prescribed upper and lower bound of zirconium oxide thermal conductivity was 2.22 and 0.4 W/m-K, respectively.

4. Summary

Based on the sensitivity studies following results can be drawn.

- In the manufacturing uncertainties, cladding inner diameter, pellet outer diameter and re-sinter density revealed a significant impact on the PCT. In the model uncertainties, fuel thermal conductivity, thermal expansion, fission gas release and cladding specific heat showed

Table 1. Changes of PCT during LBLOCA as a function of uncertainty parameter

				BOL		30 MWd/kgU	
		Base	Tolerance or Bias	|ΔSE| %	|ΔPCT| K	|ΔSE| %	|ΔPCT| K
Manufacturing	1. Cladding ID, mm	8.18	±0.04	16.6	88.4	0.8	7
	2. Cladding thickness, mm	0.61	±0.04	1.2	4	0.8	2.9
	3. Cladding roughness, micron	0.5	±0.3	0.0	< 1.0	0.8	3.2
	4. Pellet OD, mm	8	±0.013	4.4	22.1	0.0	2
	5. Pellet density(TD), %	95	±0.91	1.4	-5.2	2.9	4.8
	6. Pellet Re-sinter density, %	0.9	±0.4	5.2	29.6	1.2	< 1.0
	7. Pellet Roughness, micron	2	±0.5	0.0	< 1.0	1.4	4.5
	8. Pellet Dish Diameter & Depth, mm	4.01, 0.287	±0.5, +0.05	0.0	< 1.0	0.0	< 1.0
	9. Rod Fill Pressure, MPa	2.41	±0.07	0.3	1.3	0.1	2.7
	10. Rod Plenum Length, mm	254	±11.4	0.1	1.3	0.1	1.9
Model	11. Fuel thermal conductivity	0	±2σ	15.9	86.1	35.7	119.1
	12. Fuel Thermal Expansion	0	±2σ	14.7	73	0.0	2.6
	13. FGR	0	±2σ	0.0	0	3.1	28.7
	14. Cladding Corrosion	0	±2σ	0.8	< 1.0	5.3	6
	15. Fuel Swelling	0	±2σ	0.0	0	0.0	1
	16. Creep of cladding	0	±2σ	1.6	2.7	0.0	< 1.0
	17. Cladding Axial Growth	0	±2σ	0.0	0	0.0	< 1.0
	18. Hydrogen pickup	0	±2σ	0.0	0	0.0	0
	19. Cladding thermal conductivity	0	±2σ	1.2	6.5	1.7	5.2
	20_1. Cladding axial thermal expansion	0	±2σ	0.1	< 1.0	0.0	< 1.0
	20_2. Cladding radial thermal expansion	0	±2σ	3.6	18.6	0.0	< 1.0
	21. Cladding elastic modulus	0	±2σ	2.0	9.6	0.2	2.5
	22. Cladding specific heat	0	±2σ	0.0	82.5	0.0	58.7
	23. Cladding yield stress	0	±2σ	0.0	0	0.2	15.2
	24. Crud thermal conductivity, W/m-K	0.8648	0.4324~1.2972	0.1	< 1.0	9.5	3.6
	25. Fuel specific heat capacity	0	±2σ	4.1	4.4	4.1	2.9
	26. Cladding surface emissivity	0	±2σ	0.0	0	0.0	< 1.0
	27. Fuel emissivity	0	±2σ	0.0	0	0.0	< 1.0
	28. Zirconia thermal conductivity, W/m-K	~2	0.4~2.22	0.2	< 1.0	9.9	10.7
	29_1. Gas conductivity (He)	0	±2σ	1.0	5.9	0.2	< 1.0
	29_2. Gas conductivity (Ar, Xe, N_2, H_2, Steam)	0	±2σ	0.0	0	0.0	0
Operational	30. Power(LCO), kW/ft	14.2	±0.284	2.4	12.8	4.4	15.9
	31. Decay heat, %	0	±6.6	0.0	11.9	0.0	8.7
	32. Crud thickness, micron	0	0, 30	0.1	0.4	7.0	8.7

ΔPCT > 20K ΔPCT =10~20K

significant impact. Cladding radial thermal expansion, cladding yield stress and zirconia thermal conductivity showed a moderate influence. Operational uncertainties revealed a moderate impact.

- As the limiting fuel burnup for LOCA analysis changed from BOL to MOL, the important uncertainty parameters which should be taken into account were changed.
- Above analysis results suggest that the validity of uncertainty parameters of fuel rod used for current 'best-estimate' ECCS evaluation methodology should be re-evaluated.

REFERENCES

[1] Joosuk Lee, "Effects of Fuel Thermal Conductivity on the Nuclear Fuel Safety Analysis", *The 8th Symposium on the Nuclear Reactor Safety Analysis, Ramada Plaza Hotel, Cheongju, 2010. 6. (in Korean)*

[2] Joosuk Lee et. al.," Effects of Burnup and Uncertainties on the Fuel Rod Performance during LBLOCA – Based on Statistical Approach", *Proceedings EHPG Meeting 2011, Fuels & Materials*, HRP-374, Vol.1, (2011)

[3] Sweongwoong Woo et. al., "Evaluation for Applicability of MARS Code for KINS-REM and Regulatory Audit Calculation for APR1400 LBLOCA", KINS/AR-893 (2009)

[4] K.J. Geelhood et al., "Predictive Bias and Sensitivity in NRC Fuel Performance Codes", NUREG/CR-7001 (2009)

[5] W.G. Luscher et. al., "Material Property Correlations: Comparison between FRAPCON-3.4, FRAPTRAN 1.4, and MATPRO", NUREG/CR-7022 (2011)