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Effects of Fuel Burnup and Rod Performance on the PCT during LBLOCA

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1. Introduction

Author's previous works indicated that to determine the limiting fuel burnup for LBLOCA analysis, the effects of thermal conductivity degradation of uranium dioxide fuel needed to be considered[1,2]. And authors also identified that the fuel rod performance was strongly affected by the uncertainty parameters of fuel rod related to manufacturing, model and power [3]. These uncertainties are categorized in NUREG/CR-7001(2009). In this study, we assessed preliminarily what uncertainties will have an impact on the PCT as fuel burnup changed, and also assessed the combined effects of uncertainties in terms of a non-parametric order statistics approach.

2. Analysis Details

FRAPTRAN-1.4 code was utilized for LBLOCA analysis with the coupling of FRPACON-3.4a rod performance code. FRAPTRAN received the data from RELAP for its thermal boundary conditions. In the base case, 17x17 fuel assemblies with Zircaloy-4 cladding were considered, and the detailed information of rod dimension, power history and operating conditions can be found in Ref. [4]. Uncertainties of manufacturing, model and power were listed in Table 1. Manufacturing uncertainties represent an average value of the tolerances. Model uncertainties were set as ±2σ (standard deviation). Power uncertainty was set as the deviation of ±2% from the limiting condition for operation(LCO) power density of 14.2 kW/ft.

When considered the conductivity degradation of fuel pellet, the maximum stored energy will be not obtained at the beginning of life (BOL), but at the fuel burnup of 30 MWd/kgU. Thereby, both the BOL and the fuel burnup of 30 MWd/kgU were considered as the initial fuel conditions for LBLOCA analysis. The Westinghouse 3-loop plant was used for simulation of LBLOCA with an assumption of 100 % reactor power and 7 % steam generator tube plugging. Thermal-hydraulic boundary conditions such as HTC, pressure and temperature were assumed to be the same irrespective of fuel burnup. Total 124 inputs were produced with the uncertainty combinations, by the simple random sampling (SRS) technique [5].

3. Results

3.1 PCT change due to individual uncertainty parameter

Table 2 shows the effects of individual uncertainty on the PCT, i.e. impact to the base case, within prescribed tolerance and bias ranges, as listed in Table 1. In a BOL case, manufacturing uncertainties such as cladding inner diameter, pellet outer diameter and pellet re-sinter density showed a strong impact on the PCT changes. Related to the model uncertainties, thermal conductivity and thermal expansion of the fuel pellet also indicated significant impacts on the PCT. However, as fuel burnup increased to 30 MWd/kgU, important uncertainty parameters were changed such that fission gas release (FGR) and fuel thermal conductivity models were the predominant factors to the PCT. While, manufacturing uncertainties except for cladding inner diameter were less significant. In both cases power uncertainty showed a moderate influence.

3.2 Combined uncertainties to the PCT change

Since the fuel burnup considered in the base case was changed from BOL to 30 MWd/kgU, the blowdown PCT increased from 1093.9 K to 1138.6 K. Five different sets of 124 inputs have been produced and PCT was evaluated from each set. Fig.1 shows an example of frequency distribution of PCT evaluated by uncertainty combinations at BOL and 30 MWd/kgU fuel burnup, respectively.

Table 1. Considered fuel rod uncertainties to the rod performance and LBLOCA analysis

		Base	Tolerance or Bias	Probability distribution
Manufacturing	Cladding ID, mm	8.18	±0.04	Normal
	Cladding thickness, mm	0.610	±0.04	Normal
	Cladding roughness, microns	0.5	±0.3	Normal
	Pellet OD, mm	8.0	±0.013	Normal
	Pellet density(TD), %	95	±0.91	Normal
	Pellet re-sinter density, %	0.9	±0.4	Normal
	Pellet roughness, microns	2.0	±0.5	Normal
	Pellet dish diameter & depth, mm	4.01, 0.287	±0.5, +0.05	Normal
	Rod fill pressure, MPa	2.41	±0.07	Normal
	Rod plenum length, mm	254	±11.4	Normal
Model	Fuel thermal conductivity	0	±2σ	Normal
	Fuel thermal expansion	0	±2σ	Normal
	FGR	0	±2σ	Normal
	Cladding corrosion	0	±2σ	Normal
	Fuel swelling	0	±2σ	Normal
	Creep of cladding	0	±2σ	Normal
	Cladding axial growth	0	±2σ	Normal
	H pickup	0	±2σ	Normal
Power	Power(LCO), kW/ft	14.2	±0.284	Normal

Table 2. Sored energy(steady state) and PCT changes depending on the uncertainty parameter.

Fuel burnup		BOL		30 MWd/kgU	
Parameters		Stored energy	PCT	Stored energy	PCT
Tolerance/bias/power (high − low)		Δ %	ΔK	Δ %	ΔK
Manufacturing	Cladding ID	16.2	91.6	-0.7	-7.1
	Cladding thickness	1.1	< -5	0.8	< -5
	Cladding roughness	0.0	0.0	0.8	< 5
	Pellet OD	-4.3	-21.1	-0.0	< 5
	Pellet density(TD)	-1.3	-5.4	-2.8	< -5
	Pellet re-sinter density	5.1	29.7	-1.1	< 5
	Pellet roughness	0.0	0.0	1.4	< 5
	Pellet dish diameter & depth	-0.0	< -5	-0.0	< -5
	Rod fill pressure	0.3	< 5	-0.1	< -5
	Rod plenum length	-0.1	< -5	-0.1	< 5
Model	Fuel thermal conductivity	-13.9	-78.5	-30.4	-101.3
	Fuel thermal expansion	-13.0	-66.0	0.0	< 5
	FGR	0.0	0.0	2.1	-33.4
	Cladding corrosion	0.7	< 5	5.0	5.1
	Fuel swelling	0.0	0.0	-0.0	< -5
	Creep of cladding	-1.4	-6.8	-0.0	< -5
	Cladding axial growth	-0.0	0.0	0.0	< 5
	H pickup	0.0	0.0	0.0	0.0
Power	Power(LCO)	2.3	13	4.2	17.7

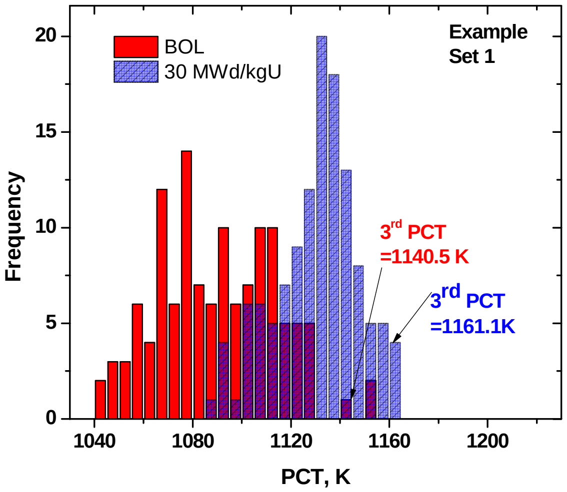

Fig. 1. Frequency distribution of peak cladding temperature during LBLOCA (Example; Set 1).

At BOL fuel, the 3rd PCT among the 124 SRS was 1134.3 K (5 sets average value). Meanwhile, as fuel burnup increased to 30 MWd/kgU, the 3rd highest PCT was 1160.3 K (5 sets average). This is about 26 K higher than the 3rd PCT which was evaluated at BOL fuel.

4. Summary

Based on the burnup and rod performance studies to the PCT during LBLOCA, the following results can be drawn preliminarily.

- Sensitivity studies indicated that as fuel burnup increased from BOL to 30 MWd/kgU, the important uncertainty parameters which should be taken into account were changed in both manufacturing and model.
- At the given thermal-hydraulic boundary conditions, as fuel burnup increased from BOL to 30 MWd/kgU, the PCT increased about 45 K (base case), and the 3rd highest PCT among the 124 SRS also increased about 26 K (5 sets average) as fuel burnup increased.
- Combined uncertainties of fuel rod to the PCT analysis in terms of a non-parametric order statistics were reasonable, but followings should be considered further.
  - Selection of uncertainty parameters and their tolerance/bias ranges
  - Considering the changes of thermal hydraulic boundary conditions during LOCA by a SRS approach

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