Evaluation of the Fuel Burnup Effect for LBLOCA Analysis

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1. Introduction

Most LBLOCA analysis has been performed at the beginning of life (BOL) condition because the internal stored energy is the maximum at BOL. Therefore, the material properties for the fuel and cladding at the BOL condition were used for the steady-state calculation of LBLOCA. The fuel thermal conductivity, fuel pellet size, gas mole fraction, etc. are the important parameters to determine the inner temperature distribution of fuel and have a great effect on the calculation of the initial stored energy.

Recently the safety concerns related to the thermal conductivity degradation of UO_2 fuel and crud buildup appeared [1]. The USNRC issued the Information Notice 2009-23 [2] and pointed out an improper use of conductivity model in the fuel performance codes of utilities approved by NRC before 1999. The thermal conductivity of UO_2 becomes reduced due to the irradiation damage, the buildup of fission products, etc. However, some fuel performance codes of utility did not consider the thermal conductivity degradation with the fuel burnup. Also this effect was not properly taken into account in safety analyses such as LOCA and Non-LOCA.

In this study, the effects of fuel burnup on LBLOCA were evaluated by RELAP5 code [3]. The reference plant chosen for evaluation is the Westinghouse (WH) 3-loop plant and the peak linear heat rate (PLHR) is assumed as 15 kW/ft.

2. Fuel Burnup Effect on LBLOCA

In LBLOCA calculation, the major parameters in the following for the fuel and cladding could be calculated from the fuel performance codes such as FRAPCON-3.4a [4].

- Initial gap internal pressure (Pa)
- Initial oxide thickness on cladding outer surface (m)
- Fuel surface roughness (m)
- Cladding surface roughness (m)
- Radial displacement due to fission gas-induced fuel swelling and densification (m)
- Radial displacement due to cladding creep-down (m)
- Fuel pellet size, gap size, cladding size
- Initial temperature (K)
- Gas mole fraction in gap
- Thermal conductivity of fuel and cladding
- Heat capacity of fuel and cladding

The peak cladding temperature (PCT) is the most important regulatory requirement in LBLOCA. Among the above mentioned parameters, the gap deformation data such as the radial displacement, the geometry data such as fuel size and the thermal properties could influence strongly the PCT. In this study, the effects of the fuel and gap size, the fuel thermal conductivity and the gas mole fraction on LBLOCA were evaluated with increasing the fuel burnup. The fuel at BOL and the fuel burnup of 28 MWd/kgU were considered in LBLOCA calculation. The burnup of 28 MWd/kgU was judged as a limiting condition by considering the power history and the stored energy with burnup.

As shown in Fig. 1, the fuel thermal conductivity calculated by FRAPCON code strongly depends on the fuel burnup and temperature. When the fuel burnup increases up to 60 GWd/MTU, the thermal conductivity decreases significantly up to about 65 percent at room temperature.

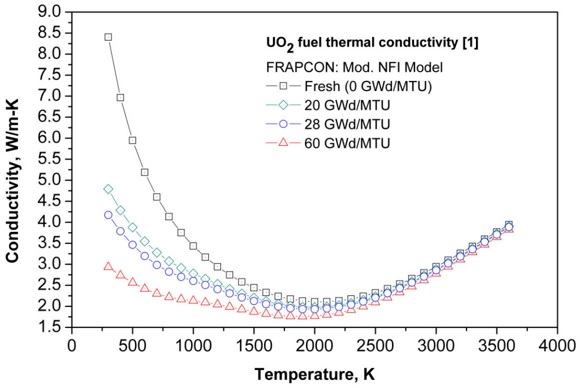

Fig. 1 Fuel Thermal Conductivity with Burnup

As shown in Table I, the sensitivity study for some parameters such as the thermal conductivity on the PCT behaviors during LBLOCA has been performed.

The initial stored energy in the fuel and the steady-state temperature distribution are very important factors at the onset of a postulated LOCA. Therefore, the initial temperature distribution for the transient calculation in RELAP5 was adjusted at all nodes of the hot pin to consider the internal energy at the steady state of the FRAPCON calculation. For example, Fig. 3 shows the steady-state fuel steady-state fuel temperature at about 2.28 m.

Table I. Evaluation Conditions for Sensitivity Analysis

Burnup Condition	Mole Fraction	Fuel Radius (cm)	Thermal conductivity
BOL	He (1.0)	Fuel outer-surface (0.41519) Cladding inner-surface (0.41788) Cladding outer-surface (0.47520)	Fig. 1
28 MWd/kgU	He (0.799) Kr (0.03) Xe (0.171)	Fuel outer-surface (0.41843) Cladding inner-surface (0.41844) Cladding outer-surface (0.47442)	Fig. 1
Case (1) : BOL condition Case (2) : Case (1) + only the internal energy (IE) at 28 MWd/kgU Case (3) : Case (1) + the IE and mole fraction at 28 MWd/kgU Case (4) : Case (1) + the IE and fuel radius at 28 MWd/kgU Case (5) : Case (1) + the IE and fuel conductivity at 28 MWd/kgU Case (6) : Case (1) + the IE and three parpameters at 28 MWd/kgU			

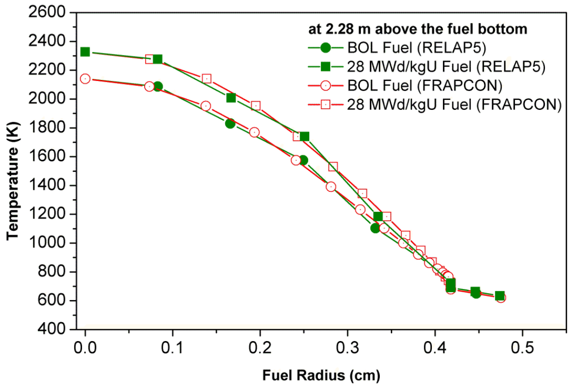

Fig. 2 Steady-state Temperature Distribution for LBLOCA calculation

Fig. 3 shows the cladding temperature at about 2.1 m above the fuel bottom, which is the peak power location. As shown in Fig. 3, the effect of the internal energy in the initial condition was very significant to the blowdown temperature behavior, while the effect of mole fraction and fuel size was less influential on the blowdown temperature during LBLOCA. As expected, the low fuel thermal conductivity makes the cladding temperature to rise. When the effects of three parameters were taken into account altogether in the LBLOCA calculation as in the case (6), the increment of the blowdown PCT becomes around 68 K at 8.8 sec.

As described above, the PLHR was assumed as 15 kW/ft in this study. However, the round value of 14.2 kW/ft PLHR was generally used in the best-estimate calculation of WH 3-loop plant. As the internal energy was taken to be proportional to the PLHR, the increment of the internal energy due to the fuel burnup was about 8.3 % and 11 % for 14.2 kW/ft and 15 kW/ft PLHRs from the FRAPCON results, respectively. Therefore, 68 K PCT rise in Fig. 3 could be reduced if we consider the overestimation of the initial stored energy. The accurate amount of PCT rise could be evaluated by considering the change of all initial conditions according change of all initial conditions according to the fuel burnup. Especially, the fuel thermal conductivity degradation has significant influence over PCT rise during LBLOCA. This PCT increment could become a critical problem for the plant that has a small safety margin to the maximum PCT criteria.

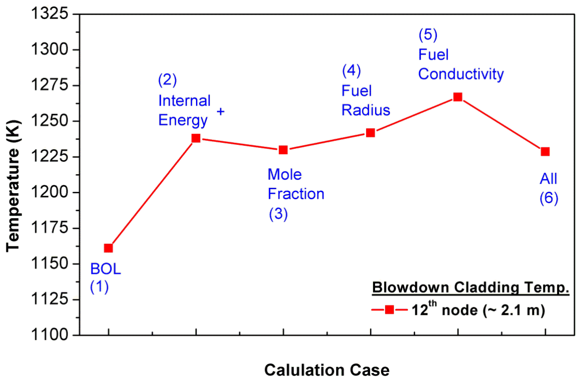

Fig. 3 Blowdown PCT Change during LBLOCA

3. Conclusion

Based on the results of FRAPCON, the effect of the fuel burnup was considered in the LBLOCA analysis and the PCT changes were evaluated changing some parameters. The increment of initial stored energy due to the thermal conductivity degradation resulted in the PCT rise during LBLOCA. From this study, we could identify that it is very important to consider the thermal conductivity degradation due to the fuel burnup in steady-state and transient analysis in LBLOCA and the current limiting fuel burnup (BOL) might be no longer valid as the conservative condition for LBLOCA analysis.

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