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Evaluation of Thermal Conductivity Degradation Effect on an OPR1000 Plant

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1. Introduction

The thermal conductivity of UO_2 fuel is reduced by irradiation damage and the progressive buildup of fission products. U.S.NRC issued the Information Notice 2009-23 and informed the thermal performance codes approved by NRC before 1999 did not deal with Thermal Conductivity Degradation (TCD) effect [1]. U.S.NRC also announced that the realistic ECCS evaluation for 11 Westinghouse plants could result in Peak Cladding Temperatures (PCT) approaching or exceeding the 10 CFR 50.46(b)(1) acceptance criterion [2]. The TCD is a pending issue of Large Break Loss of Coolant Accident (LBLOCA) analysis. With respect to TCD, the penalty of 70 ˚F has been added to the PCT of LBLOCA analysis for operating power plants in Korea. In this study, the TCD effects on LBLOCA were assessed by FRAPCON-3.4a and RELAP5/MOD3.3 codes for an OPR1000 plant.

2. LBLOCA analysis

The OPR1000 plant is 2-loop pressurized water reactor and each loop consists of one hot leg, one steam generator, two reactor coolant pumps and two cold legs. Among OPR1000 plants, Ulchin unit 3&4 was selected as the reference plant.

FRAPCON-3.4a was designed to perform steady-state fuel rod performance calculations. RELAP5/MOD3.3 performed transient analysis during postulated accidents, which was the best-estimate thermal hydraulic system code. FRAPCON-3.4a produced the steady-state condition of fuel pellet and cladding, fuel temperature distribution and gap pressure, etc during LBLOCA. In the calculation, the following parameters were calculated by FRAPCON-3.4a and used for the initial input condition of RELAP5/MOD3.3.

- ✓ Initial gap internal pressure
- ✓ Initial oxide thickness on cladding outer surface
- ✓ Fuel surface roughness
- ✓ Cladding surface roughness
- ✓ Radial displacement due to fission gas-induced fuel swelling and densification
- ✓ Radial displacement due to cladding creepdown
- ✓ Fuel pellet size, gap size, cladding size
- ✓ Initial temperature
- ✓ Gas mole fraction in gap
- ✓ Thermal conductivity of fuel and cladding

In LBLOCA analysis, the input of RELAP5/MOD3.3 has been modified to consider recent change of plant parameters such as the increase of peak linear heat rate (14.3 kw/ft) and the reduced RCS flow (52.36E06 kg/s). And the conservative values obtained by FRAPCON-3.4a were implemented in RELAP5/MOD3.3. The LBLOCA analysis was carried out as varying the fuel burnup from 0.1 to 30 Mwd/kgU. Fuel burnup conditions considered in this calculation were respectively 0.1, 0.5, 5, 10, 20, 28 and 30 MWd/kgU. Fig. 1 shows fuel thermal conductivity. The thermal conductivity was dependent on fuel temperature and burnup. When the fuel burnup was increased up to 30 MWd/kgU, the conductivity decreased significantly to approximately 50% of 0.1 MWd/kgU condition.

Before transient calculation, the initial radial temperature distribution of RELAP5/MOD3.3 was compared with that of FRAPCON-3.4a. As shown in Fig. 2, the steady-state initial temperature distribution at hottest node was very similar between two codes. After confirming all parameters obtained by FRAPCON-3.4a were accurately implemented in RELAP5/MOD3.3, the LBLOCA transient calculation was performed by RELAP5/MOD3.3.

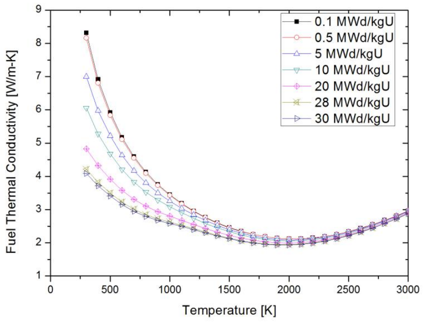

Fig. 1 Fuel thermal conductivity

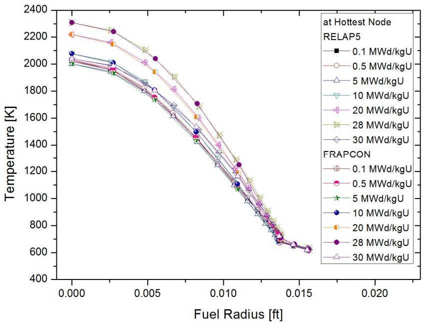

Fig. 2 Steady-state initial temperature distribution

Fig. 3 presents break flow rate of core side in accordance with fuel burnup increase. Plenty of subcooled coolant was released through the broken cold leg. Then, flow regime was changed into two-phase flow due to rapid depressurization and the break flow rate was decreased after all. There was no remarkable different behavior due to fuel burnup increase.

Although general behaviors of break flow rate, depressurization in pressurizer, safety injection flow rate, change of core water level after LBLOCA were similar regardless of fuel burnup, the blowdown PCT was strongly dependent on fuel burnup increase. Fig. 4 shows the cladding temperature distribution. As increasing fuel burnup, the blowdown PCT was also increased. However, the PCT among all fuel burnup was observed in the condition of 28 MWd/kgU not in that of 30 MWd/kgU. Table 1 presents the estimated peak cladding temperatures. When the fuel burnup increased from 0.1 to 28 MWd/kgU, the peak cladding temperature increased form 1086 K to 1192 K. The PCT rise from 0.1 MWd/kgU to 28 MWd/kgU condition was approximately 105 K (189 ˚F). In connection with the PCT rise due to TCD, U.S. NRC has announced that PCT for Westinghouse plant could increase by more than 100 ˚F[2]. Based on the calculation, the PCT rise for Ulchin unit 3&4 estimated to be 189 ˚F, which could be much higher than the expectation.

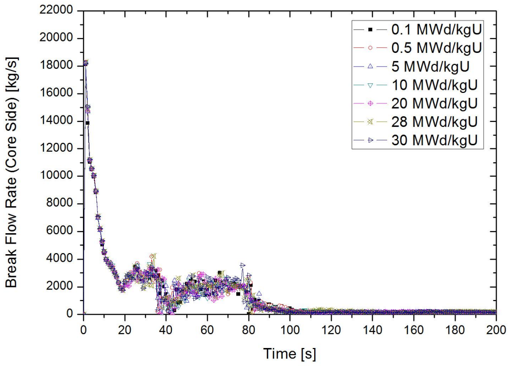

Fig. 3 Break flow rate

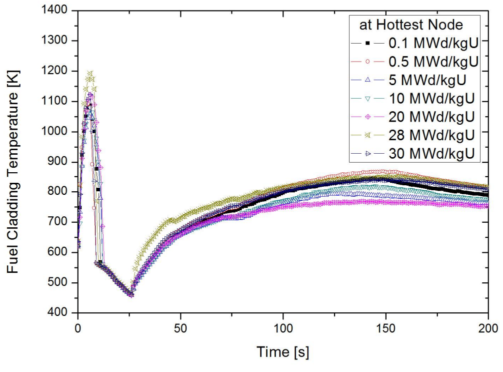

Fig. 4 Cladding temperature distribution

Table 1. Peak cladding temperature

Fuel Burnup Condition	PCT
0.1 Mwd/kgU	1086.7 K
0.5 Mwd/kgU	1092.8 K
5 Mwd/kgU	1060.3 K
10 Mwd/kgU	1078.1 K
20 Mwd/kgU	1122.9 K
28 Mwd/kgU	1192.1 K
30 Mwd/kgU	1122.1 K

3. Conclusion

By use of FRAPCON-3.4a and RELAP5/MOD3.3 codes, the TCD effect on an OPR1000 plant in the LBLOCA has been analyzed for various fuel burnup. The TCD caused by irradiation damage and fission products resulted in the PCT rise during LBLOCA blowdown phase. The results indicated that the PCT rise for Ulchin unit 3&4 was approximately 189 ˚F, which was much higher than the current PCT penalty of 70 ˚F. Based on the analysis, we concluded that it was important to consider the TCD effect on LBLOCA calculation and more detailed analysis of LBLOCA by reflecting the all parameters related to TCD could be needed to find the appropriate temperature for the PCT penalty.

REFERENCES

[1] U.S. NRC Information Notice 2009-23, Nuclear Fuel Thermal Conductivity Degradation, October, 2009.
[2] U.S. NRC Request for Information Letter 12-017, NRC Requests Information From 11 Nuclear Plants Regarding Fuel Performance During Accidents, February, 2012 .