Analysis of IFA-650.5 LOCA test : FFRD analysis by using FRAPTRAN 2.0P1 code

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1. Introduction

The FFRD (Fuel Fragmentation, Relocation and Dispersion) have been considered as important safety issues during LOCA(Loss Of Coolant Accident).

Under LOCA conditions, high burnup fuel pellets can be fractured to very fine fragment due to expanding fission gas bubbles. These fragments may move to ballooned region where relocated fragment cause higher local cladding temperature and aggravate local oxidation.

If the rod bursts, fuel fragments may be ejected into the reactor coolant flow through a rupture region, which can be the interactions of the hot fuel fragments with the coolant during core reflood and lead to coolant channel blockage.

Recently, QT (Quantum Technologies AB) model developed by Jernkvist[1] was implemented as an integral part of FRAPTRAN2.0P1 to predict FFRD phenomenon during LOCA. This model includes axial relocation of fragmented fuel, packing fraction of crumbled fuel and thermal effects of fuel crumbling and axial relocation.

Previous study, an input deck for FRAPCON4.0 code[2], based on Halden IFA-650.5 test which have shown the fuel behavior containing FFRD have been developed to perform LOCA analysis by FRAPTRAN code[3]. In this paper, an input deck development for FRAPTRAN2.0P1 code carry out to perform LOCA analysis for Halden IFA-650.5 test. And then, we simulated the Halden IFA-650.5 test, based on FRAPCON results, with FRAPTRAN2.0P1 including QT model.

2. Description of Halden IFA-650.5 test

Halden IFA-650.5 LOCA test rod was re-fabricated from a segment which was collected between the No. 5 and No 6 spacers of full-length mother rod. This segment had an average burnup of 83.4 MWd/kgU and a length of 480 mm. The LOCA test rod was filled with a gas mixture consisting of 90 vol.% argon and 10 vol.% helium to a pressure of 40 bar at room temperature. Table 1 shows Halden IFA-650.5 test rod data[4].

Three thermocouple was used to measure cladding surface temperature. One of them, TCC1, was located 10 above the fuel stack bottom, and the others, TCC2 and TCC3, were attached 8 cm below the top of the fuel stack.

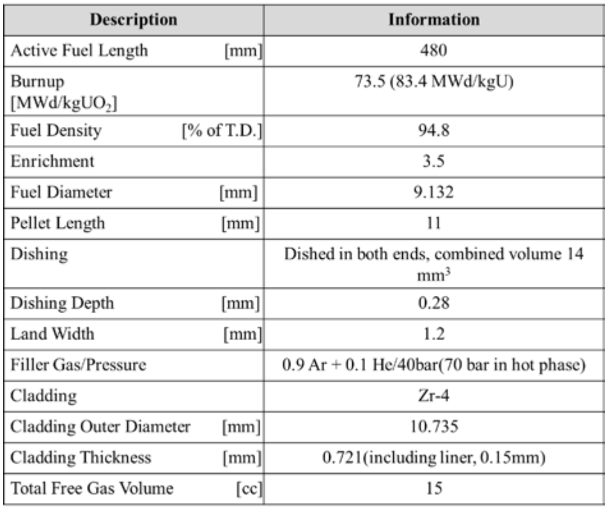
The fuel rod power was kept at an average of about 2.5 kW/m. The axial rod power profile was symmetric and has the largest value in the middle position, which was peak to average power factor during the LOCA test was about 1.05. It maintained a similar shape during the entire test. Figure 1 shows Axial power profile of IFA 650.5 test. The target peak cladding temperature was 1100℃. Cladding burst occurred 178 seconds after blowdown at ~ 750℃.

An input deck for FRAPTRAN2.0P1 was completed by following process.

1. The total length of the test rod was divided into 9 nodes.
2. The rod design parameter such as cladding, pellet was determined by using table 1[4].
3. The axial power distribution was set to the power factor shape in figure 1 with a peak factor of ~1.05.
4. The time dependent thermal-hydraulic boundary conditions was set to measured cladding surface temperature (TCC1 and TCC3) and coolant pressure during LOCA test for calculation the fuel rod behaviour.
5. The input variables of the QT model to predict the FFRD phenomenon are as follows.

- plhgr for calculating fuel fragments size is peak linear heat generation rate during the base irradiation period of the test fuel
- pflarge and pfsmall is 0.69 and 0.72 respectively (proposed by Jernkvist[1])
- crgap for threshold pellet-cladding gap width for fuel fragment axial mobility is 0.0002 m (proposed by Jernkvist[1])

Table I. Halden IFA-650.5 test rod data[4]



Description	Information
Active Fuel Length [mm]	480
Burnup [MWd/kgUO$_2$]	73.5 (83.4 MWd/kgU)
Fuel Density [% of T.D.]	94.8
Enrichment	3.5
Fuel Diameter [mm]	9.132
Pellet Length [mm]	11
Dishing	Dished in both ends, combined volume 14 mm^3
Dishing Depth [mm]	0.28
Land Width [mm]	1.2
Filler Gas/Pressure	0.9 Ar + 0.1 He/40bar(70 bar in hot phase)
Cladding	Zr-4
Cladding Outer Diameter [mm]	10.735
Cladding Thickness [mm]	0.721(including liner, 0.15mm)
Total Free Gas Volume [cc]	15

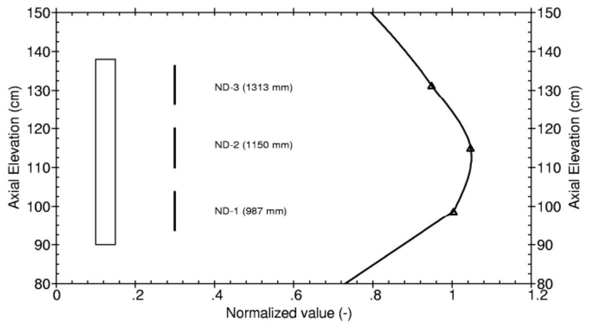


Fig. 1 Axial power profile of IFA 650.5 test[4]

3. Results and Discussion

The Halden IFA650 test was simulated with the FRAPTRAN2.0P1 code containing QT model as the completed input. Also, the effect of the QT model were compared in fuel performance analysis.

Figure 2 shows that comparison of the fuel rod pressure between the experiment and simulation results. The experiment result shows that the pressure decreased slowly after the burst, while the simulated result show that the pressure decreased rapidly. In addition, the burst time also showed a difference in results between experiment and simulation. In the experiment, the burst was occurred at 178 seconds and at 157.5 seconds in FRAPTRAN2.0P1 with QT model. Also, there was a difference in burst time between with or without QT model. The burst time with QT model was about 7 seconds faster than that without QT model.

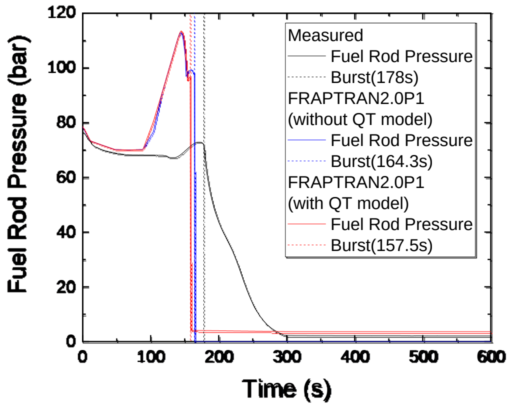


Fig.2 Comparison of fuel rod internal pressure between experiment and FRAPTRAN 2.0P1

The burst position showed a difference in results between experiment and simulation. In the experiment, a burst occurred 7.5 cm above the bottom of the active fuel stack as shown in Figure 3. However, in the code with QT model, a burst occurred at node 3 and its location is 13.3 cm above the bottom the active fuel stack.

Fig. 4 shows a variation of the cladding radius with time and the location where the maximum deformation of the cladding occurs between with and without QT model. In the code without QT model, the maximum ballooning and burst occurred at node 4. Fig.5 shows a difference in axial power without and with QT model. Axial power had little change in the result of the code without QT model, but, a noticeable axial power change was observed in the code with QT model. As a result of QT model, the power increased at node 3 as the fuel was relocated to node 3 where the ballooning occurred, and the power decreased at node 4 due to the fuel relocation.

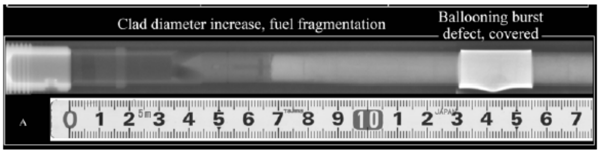


Fig. 3 Neutron radiography of Halden IFA-650.5 LOCA test rod[5]

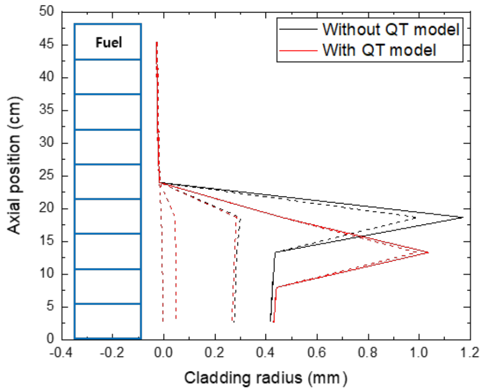


Fig. 4. Comparison of cladding radius between with and without QT model

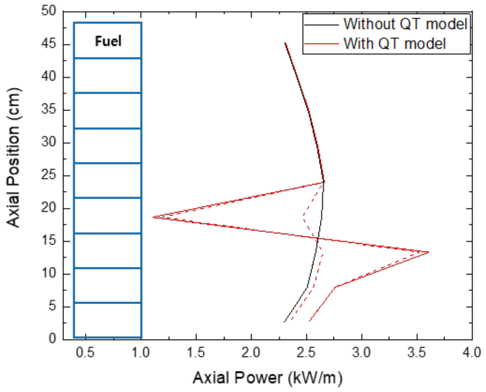


Fig. 5. Comparison of axial power between with and without QT model

In this study, it was not possible to compare the cladding surface temperature variation with or without

QT model. Because FRAPTRAN code dose not calculate the thermal-hydraulic boundary condition and gives it as an input value, the cladding surface temperature has a constant value. This is the limitation of the FRAPTRAN code to simulation the FFRD phenomenon during LOCA.

4. Conclusions

An input deck was developed to simulate Halden IFA-650.5 LOCA test, and fuel performance analysis under LOCA was performed by using FRAPTRAN2.0P1. The analysis result was predicted that the cladding burst time faster than the experiment that, and the burst location occurred above the experiment results. In addition, the axial power variation due to fuel relocation was observed with QT model. However, due to the limitation of FRAPTRAN code, the effect of QT model on cladding surface temperature could not be compared.

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