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Simulation of IFA650.9 Database using FRAPCON/FRAPTRAN for FUMAC program

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1. Introduction

The program of the FUMAC (Fuel Modelling in Accident Conditions) CRP (Coordinated Research Projects) has been started in Nov. 2014 to better understand the phenomenon occurred in the fuel rod in Loss-of-Coolant accident (LOCA), to assess the ability of fuel codes for LOCA, and to compare between the code calculation results generated by participants.

The expectation was that a FUMAC based on modelling severe accidents would tend to comprise four main topic areas: 1) Design basis accidents (DBA); 2) Beyond design basis accidents (BDBA); 3) Fuel code integration; 4) Experimental support. KAERI joined the FUMAC CRP in 2014. We have interested in the simulation of LOCA using FRAPCON/FRAPTRAN and the coupled MARS/FRAPTRANS.

Over the last decade, integral LOCA test on high burnup light water reactor (LWR) fuel rods have been carried out in Halden, Norway, and Studsvik, Sweden [1, 2]. A total of thirteen tests were executed until 2012. They can be grouped as follows:

- Tests using fresh fuel for commissioning and check-out purposes: IFA-650.1/2/8
- Tests using irradiated fuels from commercial nuclear power stations
- PWR fuel : IFA-650.3/4/5/9/10
- BWR fuel : IFA-650.7/12(/13)
- VVER fuel : IFA-650.6/11

In this paper, IFA650.9 database, that was provided in FUMAC CRP, was simulated by FRAPCON_V3.4 and FRAPTRAN_V1.4 which are fuel performance codes developed by NRC [3,4]. Base irradiation of IFA650.9 was simulated by FRAPCON. To simulate the fuel behavior of duplex cladding for IFA650.9 during base irradiation, corrosion model and hydrogen pickup model in FRAPCON were modified. For the LOCA simulation, instead of thermal hydraulic boundaries, the measured cladding temperatures on surface were applied to boundary conditions. The simulation results shows the rupture time and hoop strain of cladding.

2. IFA650.9 Experiment

The mother fuel rod was provided by AREVA and its burnup reached up to 89.9 MWd/kgU. It had been irradiated in the PWR the Swiss NPP Gosgen during seven cycles (average cycle powers 325, 265, 290, 185, 175, 165 and 155 W/cm) and discharged in June 1998. The test segment was cut from a standard PWR fuel rod between spacers 2 and 3. This segment was a sibling rod to the one used for the previous test, IFA650.4. By the refabrication, the length of the fuel stack was ~480 mm and no end pellets were inserted.

The rod was filled with a gas mixture of 95% argon and 5% helium at 40 bars (RT). Argon was chosen to simulate the fission gases, whereas a small amount of helium is required for the leak test of the rod.

For LOCA experiment in Halden Reactor, the fuel rod located in a standard high-pressure flask in the IFA-650 test rig, which was connected to a high-pressure heavy water loop and a blowdown system. The rod was located in the center of the rig and surrounded by an electrical heater inside the flask. The heater is slightly longer than the fuel length, and it is used for simulating the isothermal boundary conditions, heat from the adjacent fuel rods during a LOCA. Cladding temperature is influenced by both rod and heater powers.

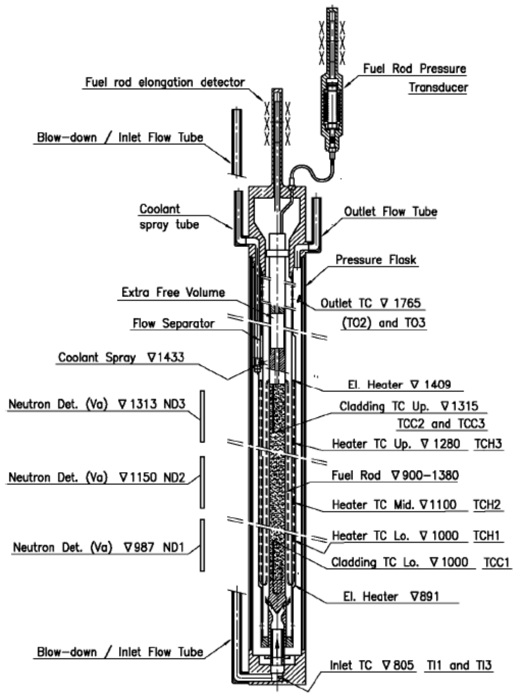

Fig. 1 Schematic of LOCA Test rig

A schematic of the test rig with its instrumentation is shown in Figure 1. One cladding surface thermocouple, TCC1, was located 10cm above the fuel stack bottom, and the other two, TCC2 and TCC3, were attached 6.5cm below the top of the stack. In IFA-650.9, the temperature of the heater was measured by three embedded thermocouples (TCH); TCH1 at the same elevation as TCC1, and TCH2 and TCH3, 4cm below the fuel mid plane and 10cm below the fuel top, respectively [5].

The target peak cladding temperature in the 9th LOCA test was 1100℃. The nuclear heating was set to 25kW/m to achieve this. Due to fuel relocation, the temperature measured with the lower cladding thermocouple approached 1200 ℃, and the test was terminated to avoid even higher temperatures. Cladding failure occurred at about 800℃.

3. Simulation of IFA650.9

3.1 Simulation of Base irradiation

Cladding for IFA-650.9 consists of duplex which enhances oxidation resistance. Even though its burnup reached up to 89.9 MWd/kgU, the measured oxide thickness is around 7 ㎛ and hydrogen content is approximately 30ppm which is remarkably low in comparison to normal cladding. FRAPCON_V3.4 does not include corrosion model and hydrogen pickup model for duplex cladding. Therefore, the corrosion model and hydrogen pickup model in FRAPCON were modified to obtain the measured hydrogen content.

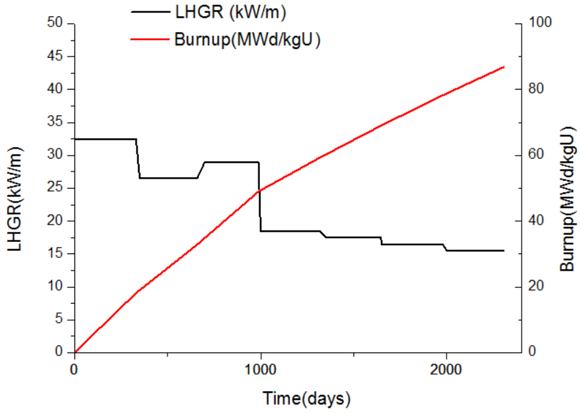

Fig. 2 LHGR and rod average burnup during base irradiation

Figure 2 shows LHGR (Linear Heat Generation Rate) and burnup buildup. As a simulation result, the maximum burnup, oxide thickness and hydrogen content are 86.86MWd/kgU, 7.0 ㎛ the and 33.4ppm, respectively.

3.2 LOCA simulation

Based on the base irradiation results, IFA-650.9 experiment was simulated by FRAPTRAN_V1.4. To remove thermal hydraulic uncertainty for the simulation, the measured surface temperatures are applied to boundary conditions as shown in Figure 3. Simulation time was set as 150 s to predict the burst time and burst strain without fuel relocation model.

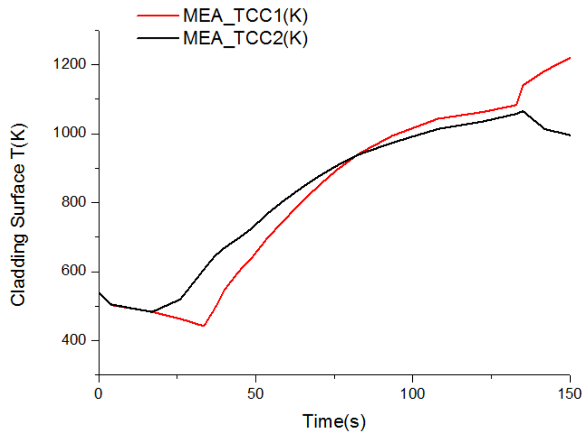

Fig. 3 Measured cladding surface temperatures as boundary conditions

Simulation results predict that the burst time is 112 s, whereas the burst time is 133s in the experiment. In figure 4, comparison of rod internal pressure (RIP) calculated and measured by pressure transducer shows that the maximum calculated RIP is larger than the measured one. According to assessment report of FRAPTRAN, larger RIP can be one of the reasons why the burst time of calculation is earlier than that of measurement [6].

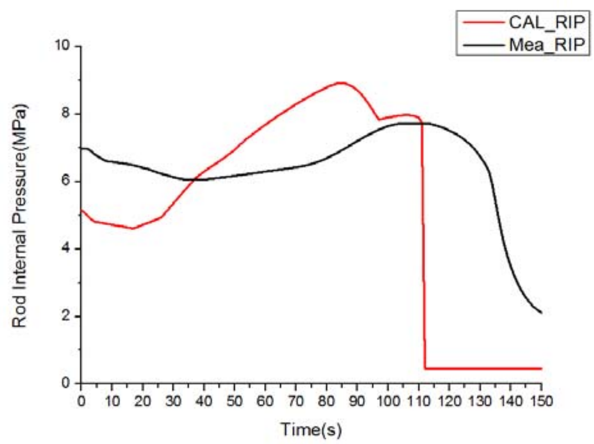

Fig. 4 Comparison between measured RIP and calculated RIP

Figure 5 shows permanent hoop strain profile when the burst occurs. We expect that the diameter profile will be similar to measurement profile in PIE (Post-irradiation Experiment). PIE data are not provided yet from FUMAC because it is blind simulation tests by participants. As further works, we will compare the hoop strain calculated and measured when the raw data are provided.

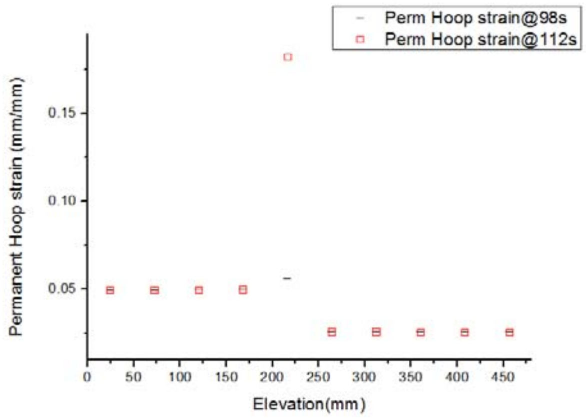

Fig. 5 Calculated permanent hoop strain of cladding at burst

4. Conclusions

The program of the FUMAC CRP has been started to better understand the phenomenon occurred in the fuel rod in LOCA. One of database provided in FUMAC is IFA-650.9, which is integral LOCA experiment in Halden Reactor. To simulate the duplex cladding behavior of IFA-650.9 mother rod, corrosion and hydrogen pickup models in FRAPCON were modified. Based on base irradiation results, LOCA simulation has been simulated by FRAPTRAN. As a result, the calculated burst time is 112 s and maximum hoop strain is 0.1824.

As further works, simulation time will be extended up to 315 s when the reactor scam is carried out. For the extension, the fuel relocation model should be considered or developed because axial fuel relocation in IFA-650.9 experiment was investigated after burst. In addition, the fuel performance code and thermal hydraulic code should be coupled not to set cladding surface temperature as the boundary conditions and to simulate its behavior in right way.

Acknowledgement

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