Analysis of Halden IFA-650.9 LOCA Test by FAMILY Code

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1. Introduction

The validation of FAMILY (**F**RAPTRAN **A**nd **M**ARS-KS **I**ntegrated for Safety Ana**LY**sis) code in which MARS-KS and FRAPTRAN codes are integrated has been performed with available experimental databases. Halden IFA series loss-of-coolant accident (LOCA) tests are useful experiments for the code validation on fuel performance during transient including a variety of deformation considering burnup effect. Prediction of fuel deformation including ballooning and consequent burst is important since it can change the heat transfer characteristics and power profile of fuel due to fuel relocation. In this study, the predictability of FAMILY code on Halden IFA-650.9 LOCA test was evaluated. IFA-650.9 test shows a large deformation of fuel rod including ballooning and resultant burst at high temperature conditions [1]. In addition, the effect of deformation models was assessed.

2. Halden IFA-650.9 LOCA Test

Test rig of Halden IFA-650.9 is shown in Fig. 1. Fuel burnup of Halden IFA-650.9 test was 89.9 MWd/kgU. The thermal power of fuel rod and the electrical heater power simulating adjacent fuel rods were set to 25 kW/m and 15 kW/m, respectively. The height of the fuel rod is 480 mm. A thermocouple TCC1 was located at 100 mm above the lower end of fuel stack and TCC2 and TCC3 were located at 65 mm below the upper end of fuel stack.

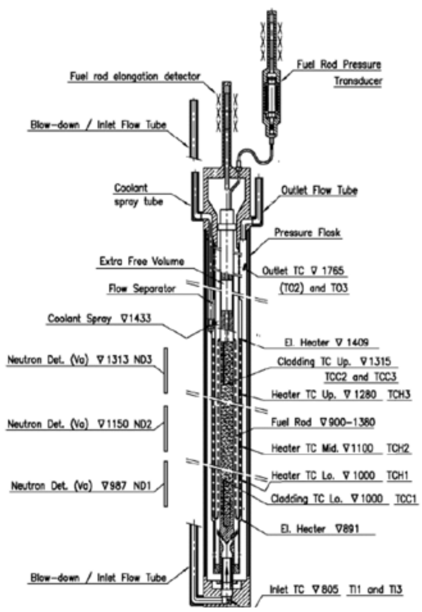

Fig. 1. A schematic of Halden IFA-650.9 test rig

3. FAMILY Code Modeling

FAMILY1.5 code was used for the simulation of Halden IFA-650.9 LOCA test. Fuel performance data including burnup and rod internal pressure history were applied to FRAPTRAN module. The fuel design and initial conditions of IFA-650.9 fuel rod is nearly identicdal to those of IFA-650.4[2]. The nodalization of IFA-650.9 test rig is shown in Fig. 2. The major differences of IFA-650.9 model with respect to the former IFA-650.4 are thermal power of fuel rod and heater, blowdown path, and spray injection characteristics, and so on [2]. Fuel relocation model developed by Quantum Technology(QT) and radiation heat transfer model were used as default modeling options.

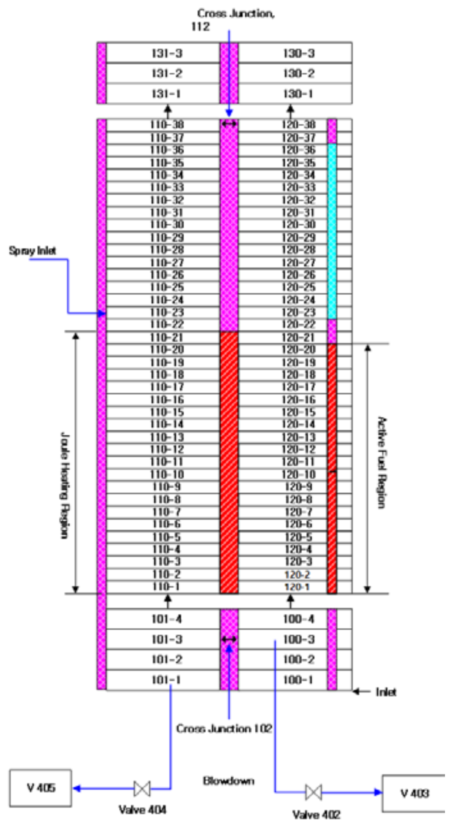

Fig. 2. Nodalization of Halden IFA-650.9 test rig in FAMILY code

The effect of cladding deformation model was evaluated in this study. BALON2 model has been used for predicting high temperature cladding failure. However, it has been known that BALON2 model has limit to calculate realistic deformation as follows [3]:

1) If permanent strain of cladding at a specific node exceeds 0.05, the permanent deformation calculated by BALON2 occurs at the node only.
2) The initial conditions in BALON2 model including bending parameter and time steps can affect the results of hoop strain significantly.

Due to these limitations, high temperature creep model was newly introduced in the FAMLIY code [3]. When the high temperature creep model is used, deformation of cladding may be simulated more realistically [4]. Therefore, the sensitivity of BALON2 and creep model was evaluated.

At steady state calculation, the natural circulation condition in test rig is assumed. Then the trip valve which connects the test rig to blowdown tank is opened for the initiation of coolant blowdown (t =0 sec). The periodic spray injection started at 149 sec and the reactor scrams happened at 315 sec after the blowdown.

4. Results and Discussion

Cladding temperature evolution at TCC1 and TCC2 position are shown in Fig. 3. At TCC1, the predicted temperature increase after the cladding burst was smaller than the measured one. It seems that the primary ballooning was not predicted. This results in lower heat source, and consequently lower cladding temperature. In the experiment, double ballooning was observed. The primary and secondary was observed at the lower region and at the midplane region of fuel stack, as shown in Fig. 4. However, the predicted cladding ballooning occurs at center node in axial direction irrespective of deformation model.

Creep model shows better prediction of cladding temperature at TCC2. This may be related to the better prediction of cladding deformation, also shown in Fig. 4. Although the double ballooning characteristics were not simulated realistically, the temperature evolution seems to be simulated relatively well with the creep model.

Fig. 4 shows the post-test diameter profile of fuel rod in axial direction. In the experiment, the primary and the secondary ballooning occurs at the lower and central region as explained above. However, the ballooning occurs at the central region irrespective of BALON2 and creep model. It is not clear that such a double ballooning characteristics are due to the thermal-hydraulic boundary conditions during LOCA simulation or material characteristics of the cladding. Proper thermal-hydraulic boundary condition with fine axial mesh may predict double ballooning in Halden 650.9[6].

Calculated fuel rod internal pressure behaviors during the transient are compared with experimental data in Fig. 5. The measured burst time is 133 sec after the blowdown initiation. However, the predicted burst time is 105 sec and 121 sec after the blowdown when using BALON2 and creep model, respectively because rod internal pressures are predicted to be higher. Free volume and temperature of plenum could have an influence of the high rod internal pressure in calculation.

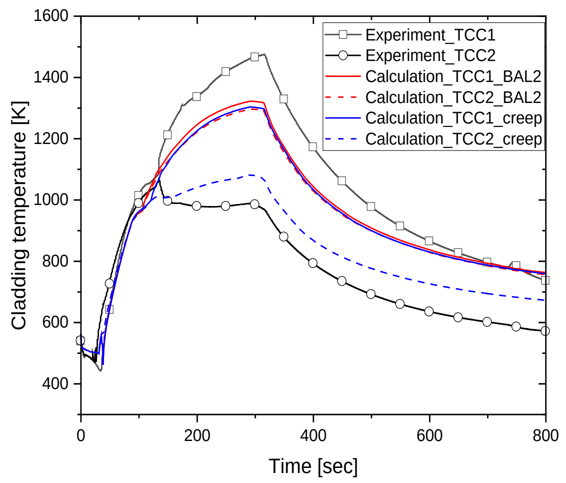

Fig. 3. Fuel cladding temperature

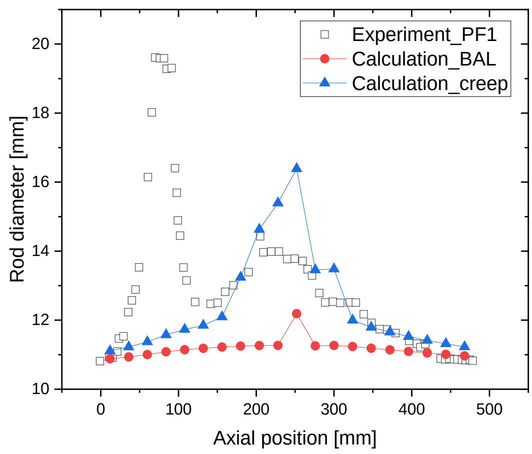

Fig. 4. Fuel rod diameter

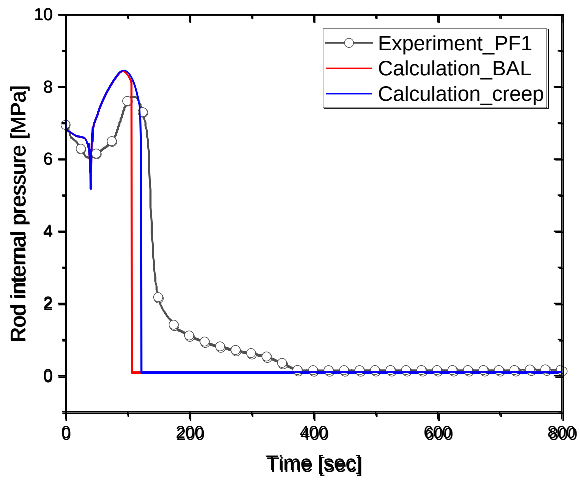

Fig. 5. Fuel rod internal pressure

5. Conclusions

Halden IFA-650.9 LOCA test was analysed by FAMILY code. High temperature creep model was evaluated compared with BALON2 model. Temperature evolution was predicted properly when using the creep model, although the burst location was not simulated exactly. Double ballooning characteristics was not simulated, irrespective of deformation model. Simulation of double ballooning with FAMILY code has to be studied as a further study.

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