Benchmark Calculation on the Halden IFA-650.4 LOCA Test by FRAPTRAN/RELAP5 Code

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1. Introduction

Since May, 2003, LOCA test at Halden has been conducting to examine and verify the validity of safety criteria for LOCA on the high burnup fuel. Meanwhile, benchmark calculations of the test by utilizing thermal-hydraulic codes and transient fuel codes are also being carried out by OECD/NEA member countries. On December, 2007, KINS joined the benchmark calculation. Main purposes of the participation are to improve our understanding on the high burnup fuel behavior under LOCA and also to verify the prediction ability of transient codes (FRAPTRAN/RELAP5) in small scale experiments. This paper briefly introduces the current status of benchmark calculation performed at KINS. Firstly, IFA650.4 LOCA test was selected to the benchmark calculation.

2. Description on the IFA-650.4 LOCA Test

IFA-650.4 test was conducted on April, 2006. The fuel rod had been used in a commercial PWR with fuel burnup of 92MWd/kgU. The peak cladding temperature of 800 °C was achieved, and cladding burst with severe fuel relocation occurred at ~770-780 °C. The main experimental procedure was comprised of following five phases [1].

Phase 1, forced circulation

Steady state operation with the outer loop connected and forced circulation flow. The pressure in the loop was set to ~70 bar. Decrease of LHGR to by decreasing the reactor power. After reaching the correct fuel power level the electrical heater was turned on to the preset value.

Phase 2, natural circulation

Disconnection of the rig from the outer loop. The flow separator enabled natural convection flow in the test section of the rig. Full pressure still existed in the rig. Temperatures in the rig were left to stabilize for a few minutes before blowdown.

Phase 3, blowdown

Valves to the dump tank were opened. The channel pressure decreased to 3-4 bars. The rig was practically emptied of water in some tens of seconds.

Phase 4, heat-up and hold at PCT

The heater power was kept constant until it was (stepwise) switched off ~150 s after the burst. Spray injection was started 230 s after the detection of the burst. The spray was operated periodically. The target cladding temperature of 800 °C was reached and slightly exceeded. The test was ended by a reactor scram at 617 s after the blowdown (281 s after the burst).

Phase 5, cooling

The heater was switched off a few seconds before the scram. One stronger and longer spray pulse was applied after the clad temperature had decreased to ~400 °C.

3. Calculation Method

3.1 Analysis Codes

RELAP5 thermal hydraulic system code [2] and FRAPTRAN fuel code [3] were used for the calculation. FRAPTRAN receives the boundary conditions from RELAP5 such as surface heat transfer coefficients (HTCs) and the local bulk temperature for the calculation of heat transfer and local pressure for the calculation of clad ballooning. However, the feedback from FRAPTRAN to RELAP5 was not carried out in this analysis for simplicity. Fig.1 shows the code interaction between system code and fuel codes.

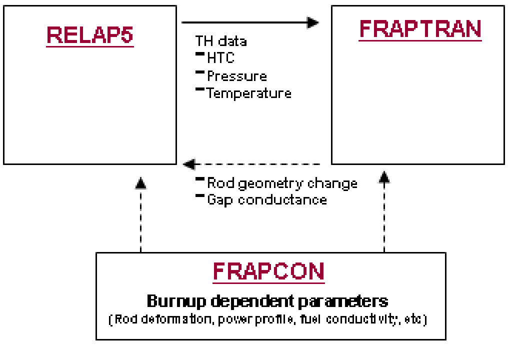

Fig.1. Code interaction diagram between thermal-hydraulic system code, RELAP5, and fuel codes, FRAPCON and FRAPTRAN.

3.2 Analysis Details

FRAPTRAN-1.3 code, developed by USNRC and Pacific Northwest National Laboratory (PNNL) was utilized to assess the evolution of temperature and deformation of fuel rod on the IFA-650.4 LOCA experiment. Rod average power, including the decay heat, was about 10 W/cm, and eleven different axial power profiles are considered during the calculation. Fuel rod was divided into axially 20 equi-spaced lengths. Local heat transfer coefficient, coolant temperature and pressure were obtained from RELAP5 MOD3.3 code analysis results.

4. Results & Discussion

4.1 Cladding Temperature

Fig.2 shows the cladding temperature evolution of IFA-650.4, measured about 400mm above from the bottom of fuel stack (TCC1). FRAPTRAN analysis result indicates an insufficient cooling of cladding at the beginning of blowdown phase, and shows a high rate of heating before cladding burst. Predicted time of cladding burst was also earlier than the measured one. Those incontinences are mainly due to the conservative results of HTCs obtained from RELAP5.

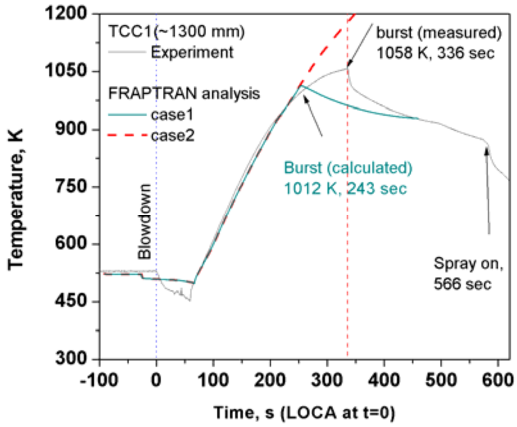

Fig.2. Comparison of cladding temperature evolution between measured and code calculated results during the LOCA.

4.2 Cladding Strain

Fig.3 shows the hoop strain evolution up to the time of cladding burst. FRAPTRAN analysis reveals the much smaller strain along than the measured one after PIE. Predicted axial elevation of cladding burst occurred was slightly upper than the measured position. Cladding ballooning model in FRAPTRAN and axial power profiles used may affect the occurrence of these discrepancies.

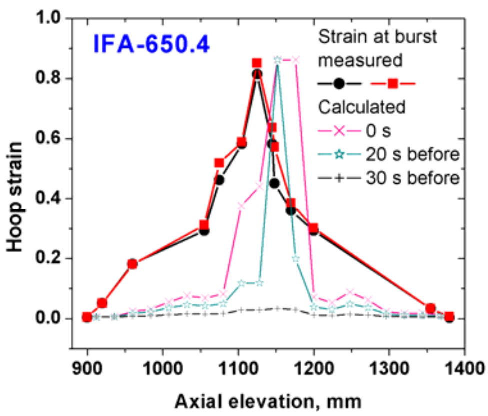

Fig.3. Comparison of a cladding hoop strain between measured and calculated ones along the axial elevation of the fuel rod.

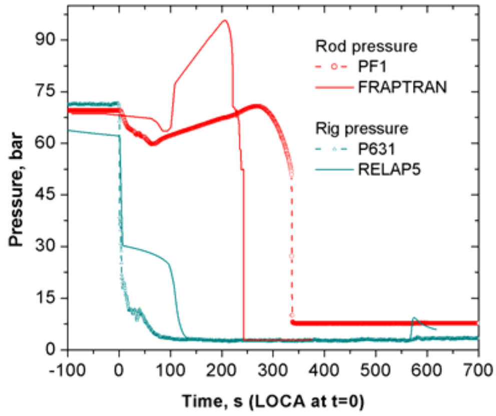

Fig.4. Comparison of fuel rod and rig pressure evolution between measured and code predicted pressure.

4.3 Fuel Rod & Rig Pressure

Fig.4 shows the change of fuel rod and rig pressure before and after LOCA initiation. Before LOCA, predicted rig pressure was lower than the measured one (P631), by about 7~8bar, but it revealed a higher pressure until ~130 sec after LOCA occurred. Predicted rod internal pressure also showed a higher pressure than the measured (PF1) until the cladding burst happened; this may be primary due to the high temperature of the fuel rod during blowdown phase and the uncertainties of the initial rod status after 92MWD/kgU fuel burnup.

5. Summary

Preliminary benchmark calculation on the Halden IFA-650.4 LOCA test by FRAPTRAN/RELAP5 transient codes was performed at KINS.

It showed an insufficient cooling of cladding at the beginning of blowdown and a high rate of heating during the last stage of heat-up. Finally, it resulted in a higher rod internal pressure and an earlier time of cladding burst than the measured ones from the experiment.

Main reason of the discrepancies is attributed to the incomplete results of thermal-hydraulic boundary condition and deformation models. Based on the experience, we are performing more improved modeling works on the Halden 650 LOCA test.

REFERENCES

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