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Validation of Integrated Code of MARS-KS and FRAPTRAN Using Halden IFA-650.5 LOCA Test

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1. Introduction

KINS has performed regulatory researches to propose the acceptance criteria of emergency core cooling system (ECCS) in order to consider the high burnup effect of fuel[1]. For the regulatory audit calculation under proposed rule, it is necessary to develop a system analysis code in which behavior of fuel with high burnup can be properly predicted. In the previous researches, the integrated code was developed[2] in which MARS-KS1.4 code[3] was combined with S-FRAPTRAN module based on FRAPTRAN-2.0 code[4]. In this code, MARS-KS calculates the thermal-hydraulic parameters of system while S-FRAPTRAN module calculates the performance of single fuel rod.

To validate the integrated code, Halden IFA loss-of-coolant accident (LOCA) tests were used since most of the fuels of the Halden IFA tests have shown the fuel behavior including fuel fragmentation, relocation and dispersal (FFRD) related with high burnup condition. In this study, Halden IFA-650.5 LOCA test was analyzed to validate the integratd code as a basis for more validation using Halden IFA series tests in the future since it showed limited relocation and dispersal due to smaller ballooning and burst opening,

2. Description of Halden IFA-650.5 LOCA Test

Fig. 1 and Fig. 2 show the configuration of side view and cross section of the test rig, respectively.

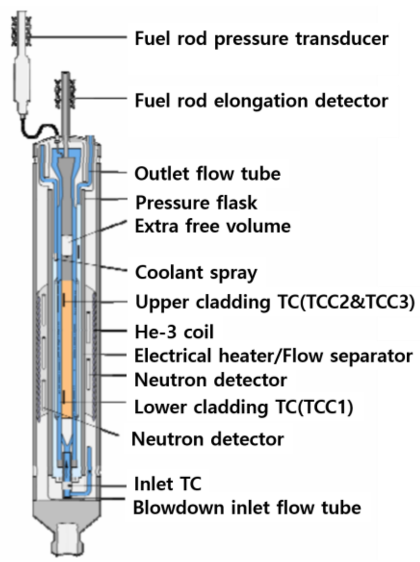

Fig. 1. Side view of Halden IFA-650.5 test rig

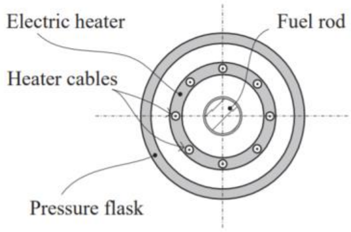

Fig. 2. Cross section of Halden IFA-650.5 test rig

Halden IFA-650.5 LOCA test was conducted in 2006. Table I shows major parameters of Halden IFA-650.5 test[5]. In this test, heavy water was used as coolant. Fuel burnup and target peak cladding temperature (PCT) are 83.4 MWd/kgU and 1,100°C, respectively.

Prior to the test, the thermal power of fuel and electrical heater were adjusted to 22.9 W/cm and 17 W/cm, respectively. Then the circulation loop and the test rig are disconnected each other. Coolant flows upwards through fuel rod and electrical heater, then the coolant flows downwards through the flow path between electrical heater and pressure flask so that it makes a natural circulation. The electrical heater functions not only as a flow separator but also as adjacent fuel rods. When the coolant temperature is stabilized, blowdown valve is opened and the coolant blowdown is initiated.

Table I. Major parameters of Halden IFA-650.5 LOCA test

Parameter	Value
Effective fuel length [mm]	480
Fuel weight [kg UO_2]	0.320
Burnup [MWd/kgUO_2]	73.5 (83.4 MWd/kgU)
Theoretical fuel density %	94.8
Pellet length [mm]	11
Clad oxide thickness [㎛]	mean 65 / max 80
Clad O.D. [mm]	10.735
Clad thickness [mm]	0.721 (including 0.15 mm liner)
Flask I.D./O.D. [mm]	34/40
Electrical heater length [mm]	518
Target PCT [°C]	1,100

3. Modeling of Integrated Code

Integrated code of MARS-KS and FRAPTRAN was used for the analysis. Fig. 3 shows the nodalization of Halden IFA-650.5 test rig of MARS-KS.

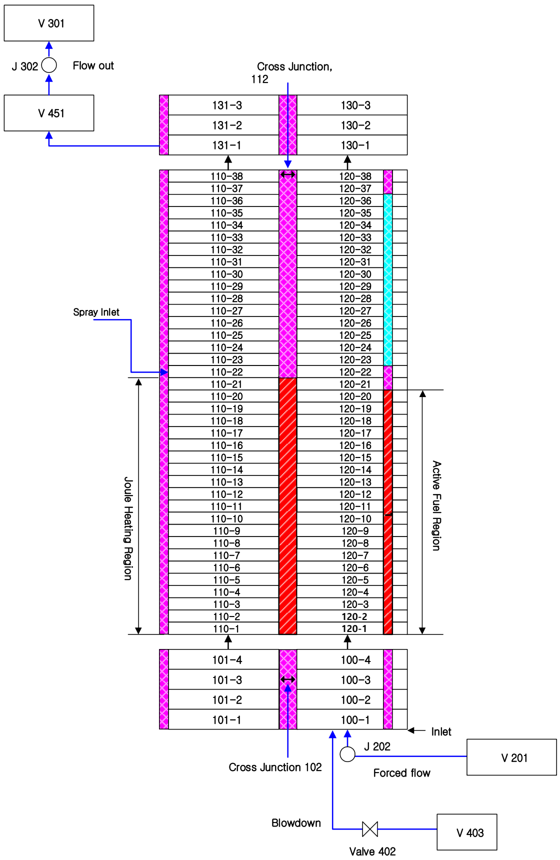

Fig. 3. MARS-KS nodalization of Halden IFA-650.5 test rig

Inlet plenum (PIPE 100) is connected to inner region channel (PIPE 120). Inner region channel consists of 38 volumes totally. Out of 38 volumes, 20 volumes at lower region are attached to fuel rod heat structure (HX 001). When natural circulation is stabilized, coolant flows from PIPE 100 to PIPE 120. At the top of PIPE 120, it is connected to outer region channel (PIPE 110) via cross flow. Outer region channel is also connected to outer-lower channel (PIPE 101) which is connected to inlet plenum (PIPE 100) through cross flow. Therefore, coolant flows through PIPE 100, 120, 110 and 101 in order by natural circulation. 21 volumes at lower region of PIPE 110 are attached to the heat structure model of electrical heater (HX 002). The blowdown valve (Valve 402) is connected to the inlet of PIPE 100. Outside the outer region channel (PIPE 110), HX 003 is applied to model the pressure flask which is a boundary condition to simulate heat transfer to atmosphere. It has been known that radiation heat transfer between fuel and heater has much influence on the cladding temperature in Halden IFA series tests[6][7]. Therefore, radiation heat transfer sets (including HX 001→ HX 002, HX 002→ HX 003, HX 003→ HX 002) were modeled also in this study.

Since high burnup fuel was used in the test, the initial conditions of pre-irradiated fuel rod were calculated by FRAPCON code[8]. The first steady state condition was initialized by only MARS-KS code using heat structure. After the second steady state condition was initialized by coupling MARS-KS with S-FRAPTRAN module in null-transient calculation, transient calculation was conducted.

4. Results and Discussion

Fig. 4 and Fig. 5 show the cladding temperatures of predicted and measured ones. Calculation of cladding temperature was performed by the integrated code and MARS standalone.

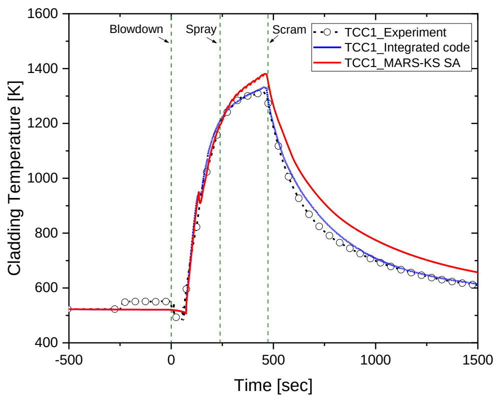

Fig. 4. Comparison of cladding temperatures at TCC1 thermocouple position

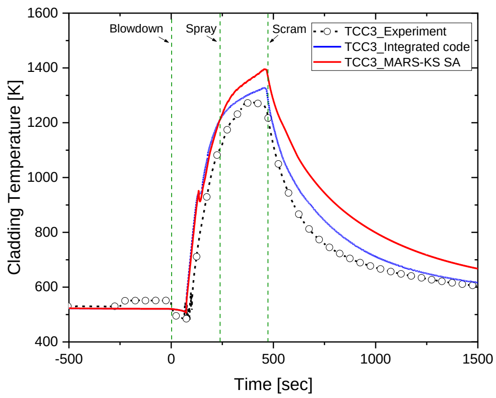

Fig. 5. Comparison of cladding temperatures at TCC3 thermocouple position

When blowdown occurred, cladding temperature maintained or decreased slightly due to continuous blowdown flow. When coolant inventory was emptied, cladding temperature increased rapidly. Then fuel ballooning occurred continuously and fuel rupture occurred at around 750°C. After the fuel rupture, the heat-up rate of cladding decreased since the heat flux of fuel was decreased due to the increased surface area of cladding by ballooning and burst. After spray was initiated at the top of the active fuel region, the fuel cladding temperature reached around 1,050°C which is nearly target temperature. The cladding temperature of integrated code calculation is lower than that of MARS-KS calculation. This may be due to the differences of cladding deformation and also flow blockage area between two codes. Then reactor was scrammed and cladding temperature decreased rapidly.

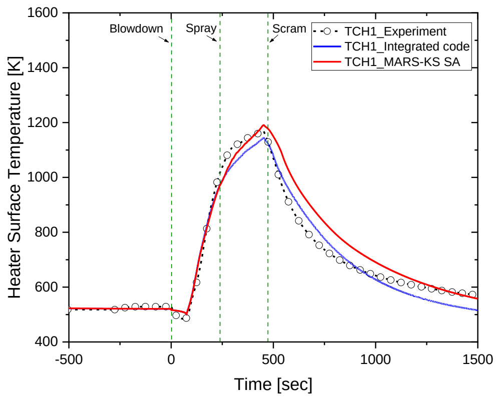

Fig. 6. Comparison of heater temperatures at TCH1 thermocouple position

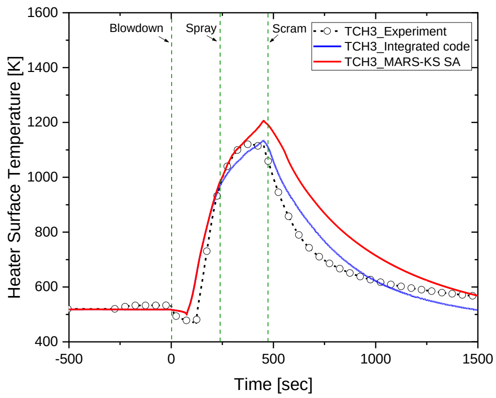

Fig. 7. Comparison of heater temperatures at TCH3 thermocouple position

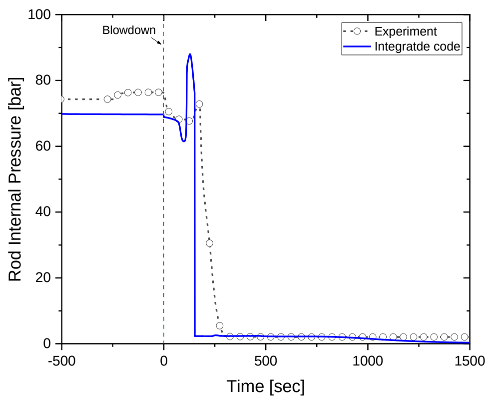

Fig. 8. Comparison of fuel rod internal pressure between integrated code and experiment

The temperature of electrical heater had similar trend with the fuel cladding as shown in Fig. 6 and Fig. 7. Fuel rod internal pressure is presented in Fig. 8. After the fuel was ruptured, the fuel rod internal pressure was predicted to decrease rapidly by integrated code.

The integrated code predicted the temperature of cladding and electrical heater comparatively well especially before reactor scram. And it was discovered that the effect of fuel deformation including fuel relocation was little because the temperature difference between lower (TCC1) and upper thermocouple region (TCC3) was not significant after ballooning and burst. The modeling of radiation heat transfer has induced strong influence on the cladding temperature. Although a view factor depends on a configuration of facing surfaces in a radiation heat transfer modeling, it is not modeled in MARS-KS properly. This limitation in MARS-KS code could affect the assessment capability of MARS-KS/FRAPTRAN.

5. Conclusions

Halden IFA-650.5 LOCA test was analyzed to validate integrated code of MARS-KS and FRAPTRAN. Calculated temperatures of cladding and electrical heater were agreed well with the experimental ones. Radiation heat transfer had a strong influence on the temperature. Other Halden LOCA tests that have strong fuel relocation phenomena will be used for the validation of the integrated code in near future.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J.S. Lee et. al., Research on the ECCS Acceptance Criteria Revision for Domestic PWR Plants, KINS/RR-1848, 2018.

[2] T.W. Kim et. al., Development of Integrated Code in Provision for ECCS Acceptance Criteria Change, KINS/HR-1524, KINS, September 2018.

[3] KINS, MARS-KS Code Manual, Volume II: Input Requirements, KINS/RR-1282, Rev.1, 2018.

[4] K.J. Geelhood et. al., "FRAPTRAN-2.0: A Computer Code for the Transient Analysis of Oxide Fuel Rods", May 2016, PNNL-19400, Vol.1. Rev2

[5] Laura Kekkonen, HWR-839, LOCA Testing at Halden, The PWR Experiment IFA-650.5, January 2007.

[6] T.S. Choi, Code Assessment against IFA-650 LOCA Tests, S06NX08-F-1-TR-041 Rev.0, KEPCO-NF, July 2016.
[7] W.H. Kim et al., Simulation of IFA-650.10 Test Using a Modified Version of RELAP5/MOD3.1, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 27-28, 2016.
[8] K.J. Geelhood et. al., "FRAPCON-4.0: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup", PNNL-19418, Vol.1. Rev.2, September 2015.