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Experimental Study for the Reflood Rate Effect on Emergency Core Cooling During LOCA Using a Thermo-Mechanics and Thermal-Hydraulics Coupled Experimental Facility (ICARUS)

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1. Introduction

The multi-physics coupled safety analysis becomes important because a safety criteria and licensing of nuclear power plant are changing. The design extended condition (DEC) and high burn-up fuel safety issues are has been considered and they require the multi-physics coupled analysis. Several multi-physics coupled safety analysis codes has been developed for this requirement.

Currently, the experimental data to validate the coupled safety code system is not enough. Therefore, multi-physics coupled experiments are required. An experimental facility named ICARUS (Integrated and Coupled Analysis of Reflood Using fuel Simulator) was developed for thermo-mechanics and thermal-hydraulics coupled phenomena during loss of coolant accident (LOCA) at KAERI (Korea Atomic Energy Research Institute) [1-2]. The ICARUS can simulate reflood during LOCA condition under ambient pressure. It has measurement instruments for thermo-mechanical parameters of cladding and thermal-hydraulic parameters in real time.

In this paper, two experimental results are analyzed to recognize the reflood rate effect during a reflood phase. Cladding deformation, cladding surface temperature distribution, quenching front, PCT are compared for two tests.

2. Experimental Facility

Fig. 1 shows a schematic diagram of heater bundle for ICARUS. ICARUS has 1x3 heater bundle. One main heater has installed in cladding as Fig. 1. There is a gap between cladding and main heater. Pressurized helium gas is injected into this gap to simulate inner pressure of fuel rod. Cladding is ballooned or burst by inner pressure when the cladding temperature increases to certain high temperature. Two guide heaters are installed in test section (purple rods on Fig. 1). They make thermal hydraulic boundary conditions for main heater and cladding. The heated length of each heater is 1.0 m. Maximum heater temperature is 1150 °C. Maximum heater power is 3.0 kW/m. Maximum subchannel pressure is 0.3 MP and maximum gap pressure is 12.0 MPa.

Thermocouples are installed to measure temperatures of test section wall, heater surface, cladding surface, and fluid in subchannel. Pressure transmitters are installed to measure the gap pressure, subchannel pressure, differential pressures for water level in subchannel. An IR pyrometer and a laser displacement sensor are applied for cladding temperature and cladding deformation, respectively. They measure temperature and deformation distribution through a visualization window of test section (Fig. 2). The axial cladding expansion is measured by LVDT (linear variable differential transformer) that is installed at the bottom of test section. The detail information is described in a construction report [3].

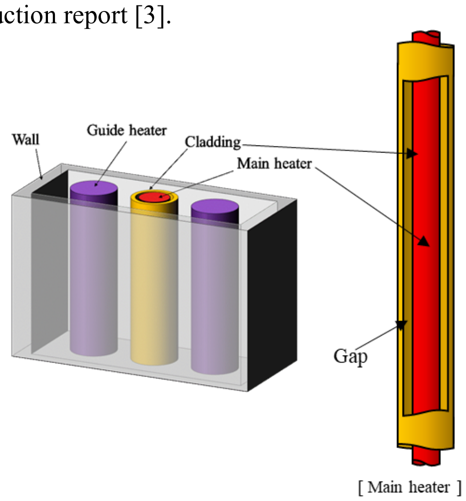

Fig. 1. Schematic diagram of heater bundle for ICARUS

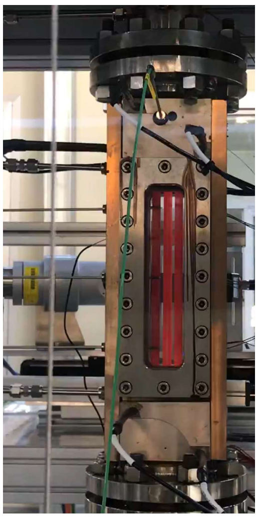

Fig. 2. Visualization window of test section and installed heaters

3. Experimental Results

In this paper, two experiments are compared. The test IDs are “ICARUS-RT-20-03R” and “ICARUS-RT-20-05”. Each data present on graphs as Exp1 and Exp2, respectively. Considering the confidential problem of test data, all of the test results in this paper were normalized by an arbitrary value including the time frame. Fig. 3 ~ Fig. 9 show behavior of major parameters. Each graph has vertical dash-lines. The long dash line means reflood beginning time when the collapsed water level was same as elevation of bottom of heated length. The short dash line means burst time when the gap pressure drop to ambient pressure by cladding burst.

The reflood rate of ICARUS-RT-20-05 is 1.5 times of ICARUS-RT-20-03R. Test time of ICARUS-RT-20-03R was shorter than ICARUS-RT-20-05 because the cladding was burst for ICARUS-RT-20-03R test and test stopped to protect test facility. The reflood beginning time of ICARUS-RT-20-03R later than ICARUS-RT-20-05 though the opening times a valve for reflood water were almost same. The reason is that the test section has lower plenum and reflood water should fill this lower plenum before flows up the subchannel. The difference of filling time made different reflood beginning time. This is similar phenomenon of delay time for ECC water at power plant.

Fig. 3 shows total power for each experiment. The supplied power increased to keep the temperature increasing rate of heaters. This temperature increasing rate is possible to check on Fig. 4 and Fig. 5. The power curves for tests were almost same.

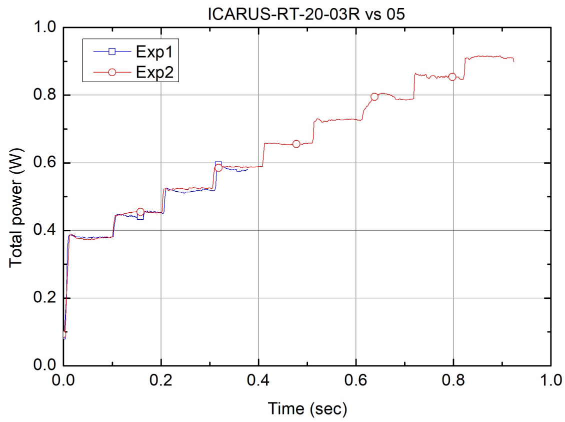

Fig. 3. Total power for each experiment.

Fig. 4 and Fig. 5 show cladding surface temperatures and guide heater surface temperatures. In the case of ICARUS-RT-20-03R, the cladding and heaters cooled by steam that was produced at the quenching front. However, cladding ruptured before the whole cladding was rewetted. In the case of ICARUS-RT-20-05, the cladding and heaters were cooled down and quenched. The cladding burst was not observed because the cladding deformation stopped after the cladding was cool. The quenching time of cladding was faster than guide heaters. The reason of this difference will be analyzed with additional tests. This results means that a critical reflood rate is required to prevent a cladding burst for emergency core cooling

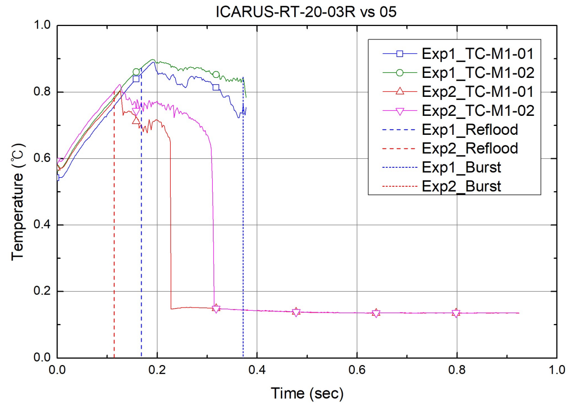

Fig. 4. Guide heater temperature for each experiment.

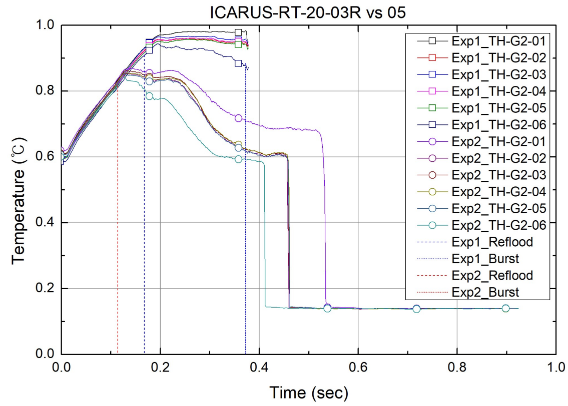

Fig. 5. Guide heater temperature for each experiment.

Fig. 6 shows gap pressures. The gap pressure increased in early phase because the temperature of helium gas in the gap increased. After then, the pressure gradually decreased because the cladding was ballooned and gap volume increased. In the case of ICARUS-RT-20-03R, the gap pressure sharply decreased at the burst. However, the gap pressure was kept for ICARUS-RT-20-05 because the temperature of cladding was constant and cladding deformation stopped during last phase.

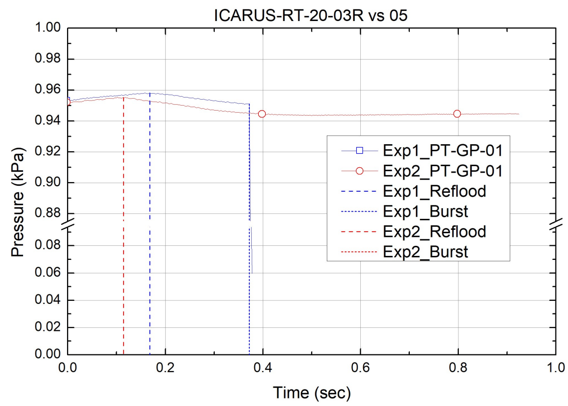

Fig. 6. Gap pressure for each experiment.

Fig. 7 and Fig. 8 show axial distribution of cladding temperature by pyrometer during the tests. The blue color is low temperature, white color is medium temperature, and red color is high temperature on these graphs. Pyrometer cannot work when the liquid covers cladding. So, time axis of graph is shorter than others. After the beginning of transient test (0 sec) temperature increased and cooled down the bottom side first by produced steam and cooled region expanded.

Fig. 9 shows the axial distribution of radial deformation of cladding by laser displacement sensor. Blue color means negative deformation and red color means positive deformation. At early phase, measured result means cladding was shrink. Now, it is not enough to conclude the reason. So, this will be check before conclusion. The maximum deformation was upper part of graph. This is same elevation of burst position. There is not the deformation data for the ICARUS-RT-20-05 test because the laser displacement system had a problem during this test.

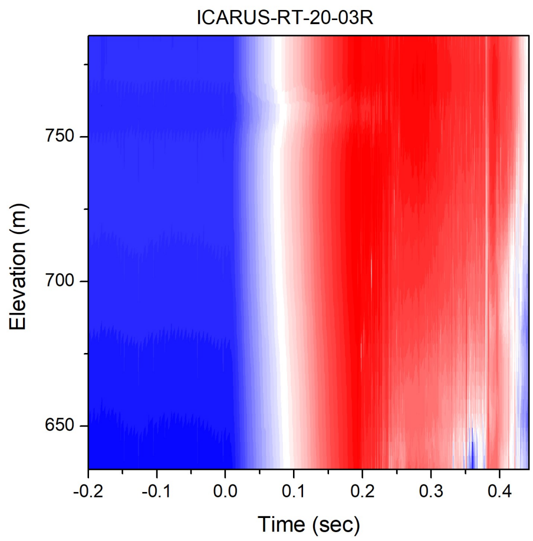

Fig. 7. Axial distribution of cladding temperature by pyrometer for ICARUS-RT-20-03R

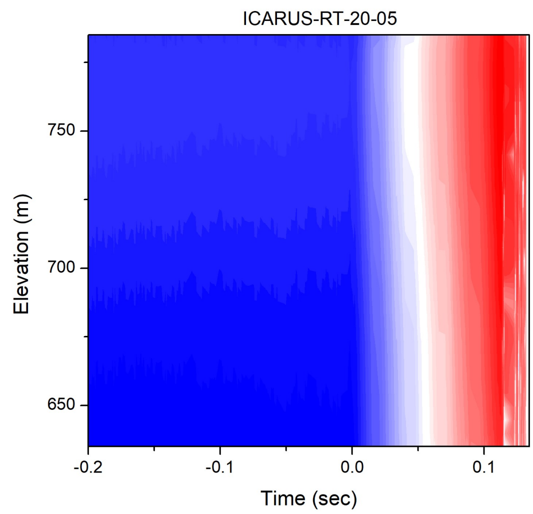

Fig. 8. Axial distribution of cladding temperature by pyrometer for ICARUS-RT-20-05

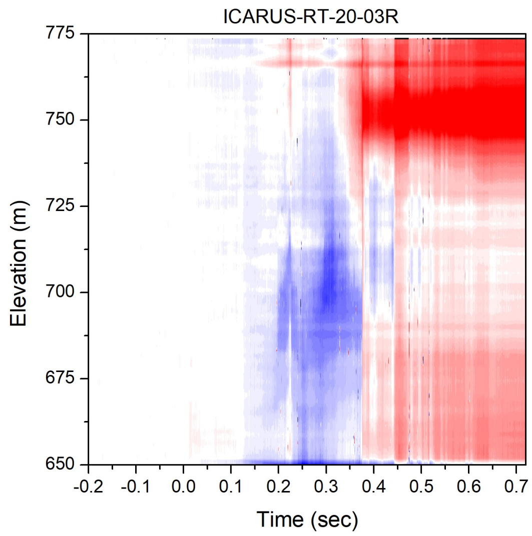

Fig. 9. Axial distribution of radial deformation of cladding by laser displacement sensor for ICARUS-RT-20-03R

4. Conclusions

Two LOCA tests were performed using the ICARUS facility that was developed to simulate a LOCA for analysis the thermo-mechanics and thermal-hydraulics coupled phenomena. A difference of two test is reflood rate and the other conditions were similar. The cladding was burst for the case of slow reflood rate while the cladding was cooled down without burst for the case of fast reflood rate. This means that a critical reflood rate is required to prevent a cladding burst for emergency core cooling.

Additional experiments will be performed to analysis the multi physics coupled phenomena. And this experimental data base will be used to validate the multi physics coupled safety analysis codes.

ACKNOWLEDGMENTS

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