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Analysis of the LOFT L2-5 Experiment Using the 3D Module of the MARS-KS Code

Jun hyeok Kim, Jae Jun Jeong, Bub dong Chung
School of Mechanical Engineering, Pusan National University (PNU)

1. Introduction

The large-break loss of coolant accident (LBLOCA) is one of the design basis accidents of nuclear power plants. The findings from the international 2D/3D program showed the necessity of multi-dimensional analysis [1]. Especially, a multi-dimensional approach is necessary for better understanding of the complex thermal-hydraulic phenomena in a reactor pressure vessel (RPV) during a LBLOCA.

In the past several decades, many LBLOCA experiments were performed to investigate the thermal-hydraulic characteristics during the reflood period and to provide reliable data to help validate the LBLOCA analysis methodology. The Loss-of-fluid-test (LOFT) L2-5 experiment [2] is one of the LBLOCA experiments. The LOFT facility is a 50 MWt pressurized water reactor with instrumentation to measure and provide data on the thermal-hydraulic and nuclear conditions throughout the system [3]. The LOFT L2-5 experiment simulated a 200% break in the cold leg piping with simultaneous loss of offsite power.

In this study, three-dimensional thermal-hydraulic phenomena are analyzed using cladding surface temperature data from the L2-5 experiment using post-processing program, TECPLOT 360. Also, the L2-5 experiment is simulated with both a 1D and a 3D RPV modeling using the system thermal-hydraulic code MARS-KS [4]. The 3D RPV modeling was performed with the “multi-d” component of MARS-KS. The simulation results are compared with experimental data and the results are discussed.

2. Description of LOFT L2-5 experiment

2.1 LOFT system

The LOFT facility is a 50 MWt pressurized water reactor (PWR) with instrumentation to measure and provide data on the thermal-hydraulic and nuclear conditions throughout the system. The volume ratio of 1/60th was used to scale-down a commercial 4-loop PWR. The major components used in the LOFT are the reactor with a nuclear core, primary coolant system, secondary coolant system, blowdown suppression system and emergency core cooling system (ECCS). The primary coolant system consists of an intact loop with an active steam generator, pressurizer, two primary coolant pumps in parallel and a broken loop with steam generator simulator, pump simulator and quick-opening valves to simulate hot or cold leg breaks. The ECCS which provides a core cooling during accident contains two high-pressure injection systems (HPIS), two low-pressure injection systems (LPIS) and two accumulators.

2.2 LOFT L2-5 experiment

Fig.1 shows the LOFT system configuration for Experiment L2-5. The L2-5 experiment was conducted to investigate the system and core thermal response during normal ECC reflood following the double-ended cold leg break transient. For the experiment, the LOFT facility was configured to simulate a double-ended 200% cold leg break. The experiment was initiated from nominal operating conditions by opening the quick-opening blowdown valves in the broken loop hot and cold legs. The reactor scrammed on the low pressure at 0.24 second. Following the reactor scram, the primary coolant pumps were tripped.

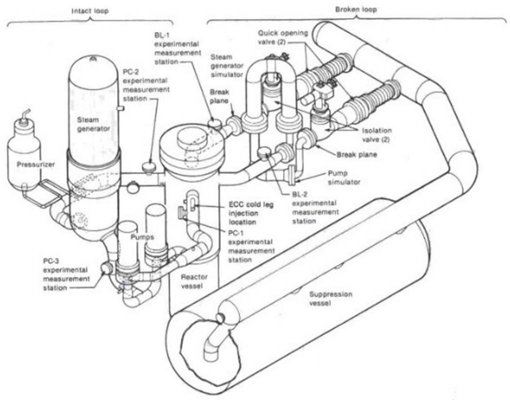


Fig. 1. LOFT system configuration for the L2-5 experiment

3. Analysis of experimental data using TECPLOT 360

The basic philosophy for in-core instrumentation was to instrument the center fuel assembly and about one-half of the peripheral fuel assemblies and to leave the remainder of the core which is adjacent to intact loop un-instrumented. The location and type of instrumentation in the LOFT core are shown in Fig. 2. The RPV instrumentation includes core inlet and outlet coolant temperature; fuel rod cladding and guide tube temperature; core outlet and downcomer momentum flux and velocity; downcomer, lower plenum, core and upper plenum liquid level; and in-core neutron flux measurements.

Among these data, cladding surface temperatures are used to analyze thermal-hydraulic phenomena. There are 164 thermocouples randomly located on six assemblies on the broken loop side. The measured cladding surface temperature was used to visualize thermal responses in the core with TECPLOT 360.

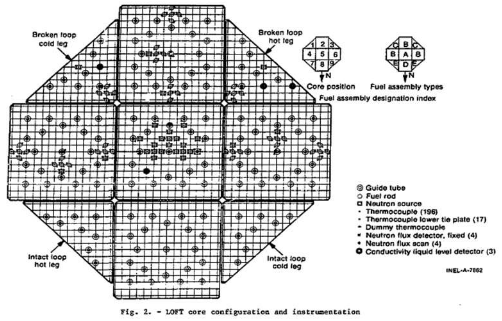


Fig. 2. LOFT core configuration and instrumentation

After LOCA, as shown in Fig. 3, quenching occurs at the upper region in the core, and at the bottom and middle in order. The upper cladding temperature begins to drop after LOCA because the water in the intact loop enters the RPV through the hot leg during blowdown process and the heat generation at the top of the fuel rods is small. Meanwhile, Fig. 4 shows that quenching occurs at the bottom region in the core first during reflood process. This phenomenon is caused by most of the ECC delivery passing through the broken cold leg. Also, the cladding surface temperature near the broken loop cold leg falls earlier than near the broken loop hot leg during reflood process. The reason why the high temperature region appears discontinuously in Fig. 3, 4 is due to the error of interpolation.

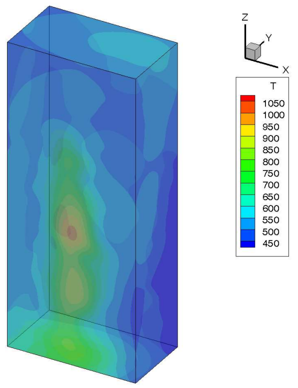


Fig. 3. Temperature distribution at 13 seconds after the large break.

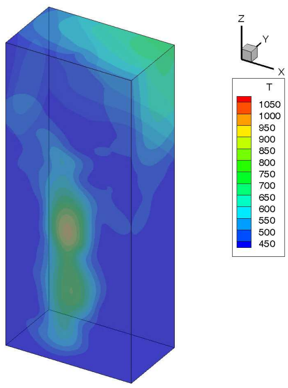


Fig. 4. Temperature distribution at 40 seconds after the large break.

4. Simulation of LOFT L2-5 experiment using MARS-KS 1.5

4.1 Nodalization of LOFT L2-5 experiment

As shown in Fig.5, the input nodalization consists of the intact and broken loops, the steam generator secondary of the intact loop, the pressurizer, the ECCS, and the reactor vessel. Fig. 6 shows the 1D and 3D modelings for the vessel.

The 3D RPV modeling was created with the “multi-d” component of MARS-KS code. The 3D RPV modeling was divided into eight 45° azimuthal sectors and six radial rings. The outermost ring represents the downcomer, and the other rings correspond to the bypass regions and the core regions. The axial nodalization of each component was based on the 1D nodalization, resulting in 2 levels in lower head, 1 level in lower plenum, 9 levels in core, 3 levels in upper plenum and 2 levels in upper head regions.

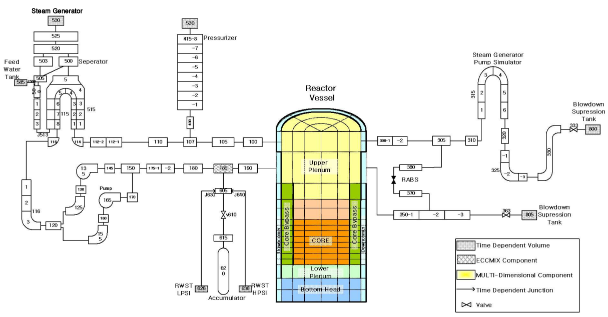
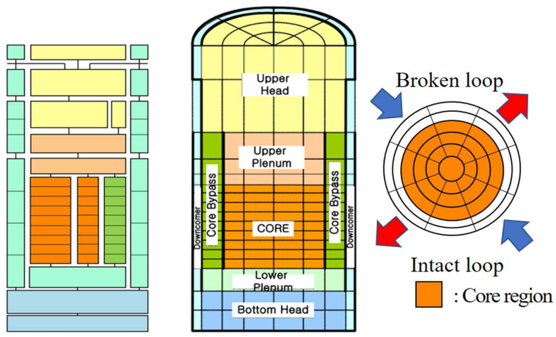


Fig. 5. MARS-KS nodalizations for LOFT



(a) 1D modeling (b) 3D modeling

Fig. 6. 1D and 3D modeling for LOFT reactor vessel

4.2 Simulation Results

Discharge flow rate at the broken loop cold leg and hot leg are compared with measurement data in Fig. 7. The discharge flow rate from the cold leg was well predicted; however, discharge flow rate from the hot leg side was overpredicted before 10 seconds. Fig. 8 shows pressure behavior at pressurizer (PZR) and intact loop hot leg. The calculated primary system pressure was underpredicted after 10 seconds. After that, accumulator injection was initiated earlier by 1.3 seconds as shown in Fig. 9 due to underpredicted pressure. There was no significant difference in discharge flow rate, pressure and accumulator level between 1D and 3D simulation results.

Peak cladding temperatures (PCT) were compared in Fig. 10. Measured PCT was 1048.8 K at 12.3 seconds. PCT of 1D and 3D simulation were 1017.7 K at 9.2 seconds and 1015.1 K at 10.0 seconds, respectively. The calculated PCT by 1D is more consistent with the measured data than result by 3D. Meanwhile, the trend of cladding temperature by 3D has better agreement with experiment than that by 1D. We can confirm that the 3D simulation captures the blowdown quenching occurring at 15 seconds in the experiment, but cannot in 1D simulation. Cladding temperatures of 3D calculation according to level are shown in Fig. 11. In the experiment, as shown in Fig. 3, 4, quenching occurs at the upper region in the core, and at the bottom and middle in order during blowdown process, however, quenching occurs at the bottom region in the core first during reflood process. Cladding temperatures calculated by 3D also show these tendencies.

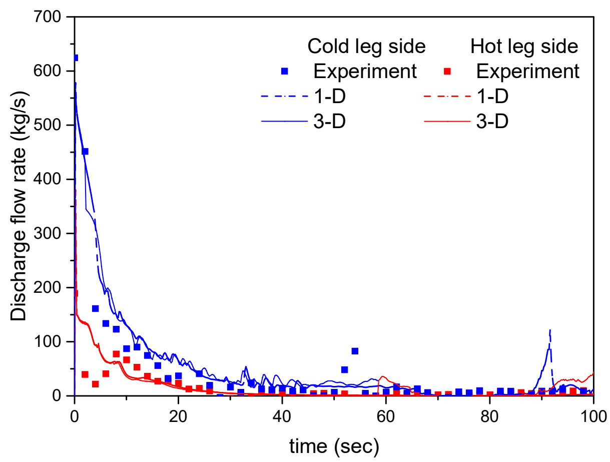


Fig. 7. Comparison of break flow rate

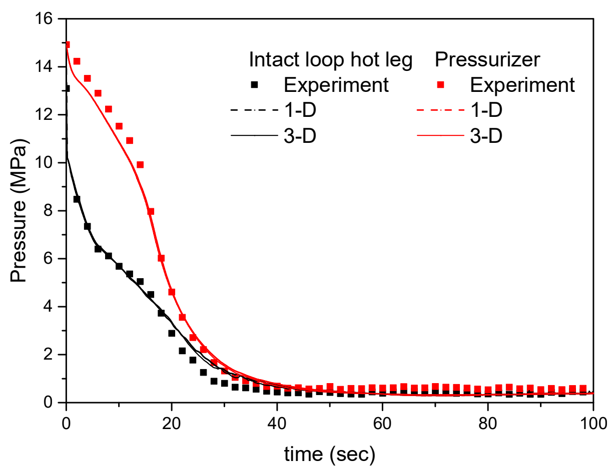


Fig. 8. Pressure behaviors at pressurizer and hot leg

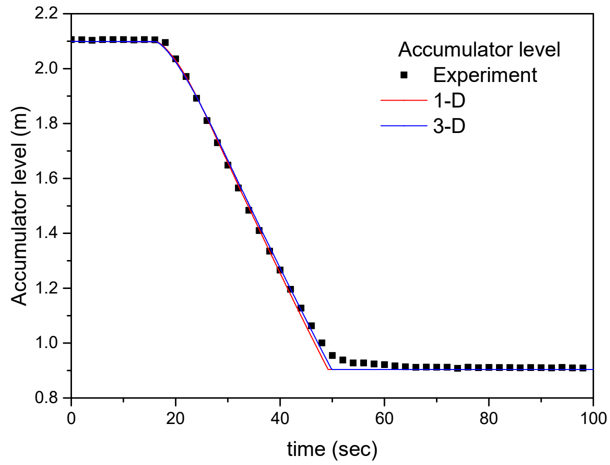


Fig. 9. Comparison of accumulator level

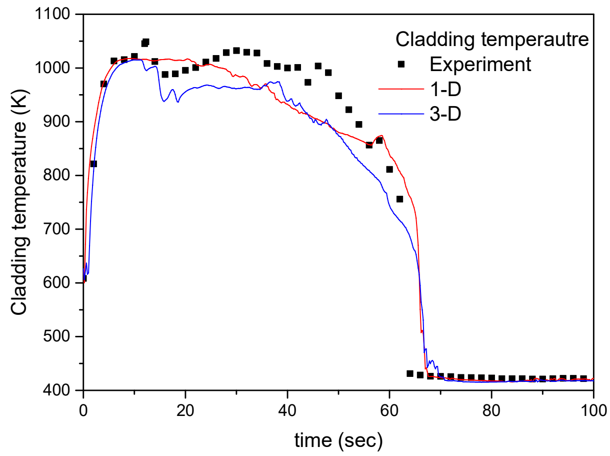


Fig. 10. Comparison of peak cladding temperature

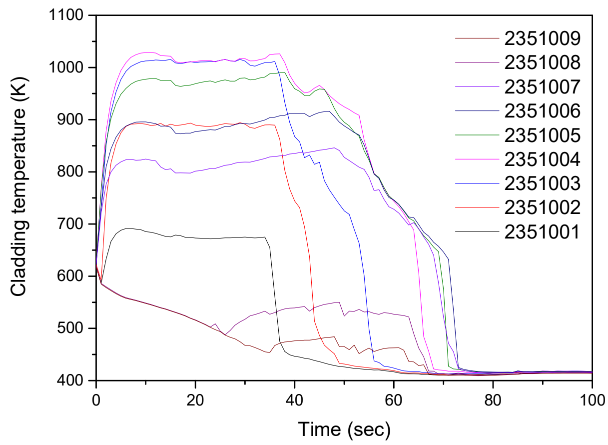


Fig. 11. Cladding temperature according to the axial level

5. Conclusions

In this study, three-dimensional thermal-hydraulic phenomena in the LOFT reactor vessel during the L2-5 experiment are analyzed using a post-processing program, TECPLOT 360. Also, the L2-5 experiment is simulated using the system thermal-hydraulic code, MARS-KS 1.5.

Thermal responses in the core of L2-5 experiment were observed by visualizing measured cladding temperature using TECPLOT 360. Quenching occurs at the upper region in the core, and at the bottom and middle in order. The cladding surface temperature near the broken loop cold leg falls earlier than near the broken loop hot leg during reflood process.

The L2-5 experiment was simulated using the MARS-KS code. Discharge flow rate, primary system pressure, cladding temperature calculated with the 3D RPV modeling were compared with the experiment and the 1D calculation. There was no significant difference in discharge flow rate, pressure and accumulator level between 1D and 3D simulation results. Although the PCT calculated by the 1D model is more consistent with the measured data than the result by the 3D model, the trend of cladding temperature by the 3D model has better agreement with experiment than that by the 1D model. From these results, it can be said that the “multi-d” component of the MARS-KS code has the capability to analyze the thermal response in the core under the LBLOCA well.

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