Analysis of LBLOCA Accident in Research Reactor with Flap Valve installed outside the Reactor Pool

Hyunwoo Lee*, InGuk Kim, Jaeho Bae, Hong Beom Park, Kyungwoo Seo
Korea Atomic Energy Research Institute, 111, Daedeok-daero, Yuseong-gu, Daejeon
**Corresponding author: LHW@kaeri.re.kr*

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1. Introduction

In a research reactor, if the Primary Cooling System (PCS) pump is stopped after the reactor shutdown, the residual heat of the core is removed by using natural convection inside the reactor pool. In order to form a natural convection flow path, a special valve such as a flap valve connected to the PCS is installed in the reactor pool. The flap valve blocks this flow path during normal operation of the PCS pump and opens this flow path when a natural convection flow path is required after the pump is stopped. These special valves and instruments installed in the valve require performance tests and maintenance performed every few years to satisfy their design life.

This valve is submerged in reactor pool and placed in a high radiation dose environment, making it difficult to design and maintain the valve, which is made of non-metallic and electrical products that require temperature, radiation, and waterproof requirements, and the price also increases. To solve this problem, KAERI is in the process of designing a PCS that places the flap valve outside the reactor pool, and a Large Break Loss of Coolant Accident (LBLOCA) analysis was performed on this design to evaluate natural convection.

2. Code Modeling of PCS and Flap Valve

The existing flap valve is installed near the reactor core inside the reactor pool for its functional purpose. To alleviate this extreme environment and achieve the purpose of forming natural convection using reactor pool water in normal operation and all accidents, the new system concept which the PCS is placed on the top of the reactor pool as shown in Figure 1, and the flap valve penetrates the reactor pool wall and is installed in a sealed equipment room. This new concept is a 20MWth upward flow research reactor that aims to minimize pipe length, pump size, etc. to optimize the design of the PCS in consideration of loss of coolant accidents. Figure 2 is a flow diagram of the optimized PCS.

To confirm the validity of this design concept, this study aims to model the optimized PCS, structures inside the reactor pool, the flap valve outside the reactor pool and the flap valve equipment room using RELAP5/MOD3.3 code, and to simulate a LBLOCA in the PCS to check the formation of a natural convection flow path through the flap valve.

Table 1 compares the main design factors of the optimized PCS and the system steady-state analysis results using RELAP5/MOD3.3. The RELAP5/MOD3.3 computer code is a code developed to simulate system transient in the event of an accident that may occur in nuclear reactor.

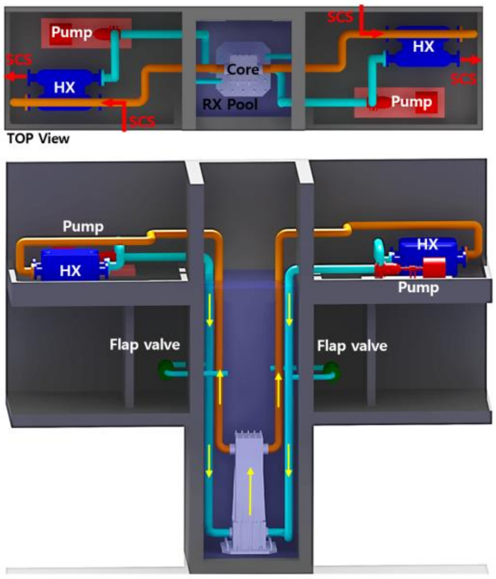

Figure 1. Conceptual Design of Optimized PCS

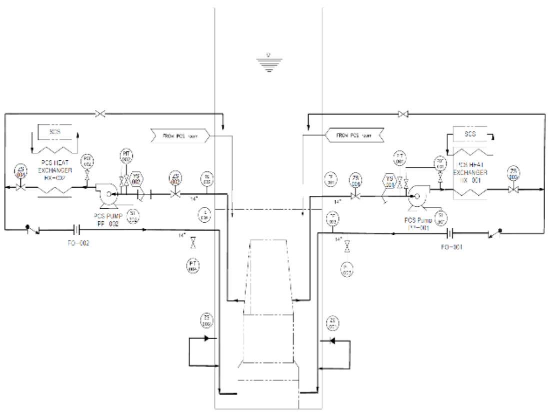

Figure 2. Flow Diagram of the Optimized PCS

3. Accident Scenario

In this analysis, a guillotine break was assumed in the PCS pipe which penetrates the reactor. In the modeled system as shown in Figure 3, the LOCA valve 110 which connected to the reactor inlet pipe (node 650), is opened instantaneously, and the flowrate of the PCS increases to 860kg/s instantaneously as the pressure drop through the piping inside reactor pool and the Reactor Structure Assembly (RSA) decreases. As the high flowrate setpoint of the PCS is exceeded, a reactor stop signal and a PCS pump stop signal are generated, and the reactor power decreases from 1 second after accident. [Figure 4]

Table 1. Steady-state results of the analysis

Variable	Design Value	RELAP	ERROR (%)
HX Primary inlet temp (°C)	40	40.75	1.9
HX Primary outlet temp (°C)	34	33.92	-0.2
HX Secondary inlet temp (°C)	31.5	31.50	0.0
HX Secondary outlet temp (°C)	37.5	38.32	2.2
Heat Transfer per HX (MW)	10	9.97	-0.3
PCS Flow (kg/s)	700.0	701.10	0.2

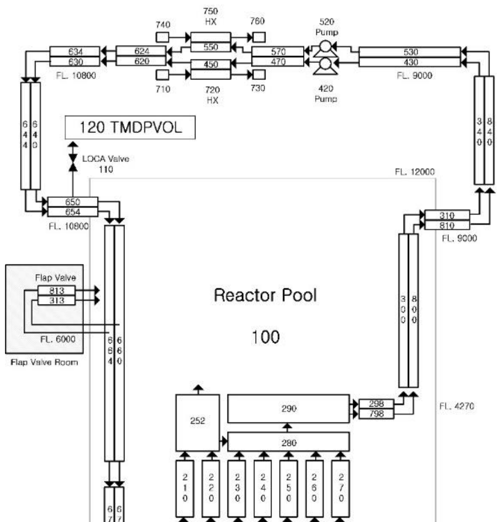

Figure 3. Nodalization of Optimized PCS

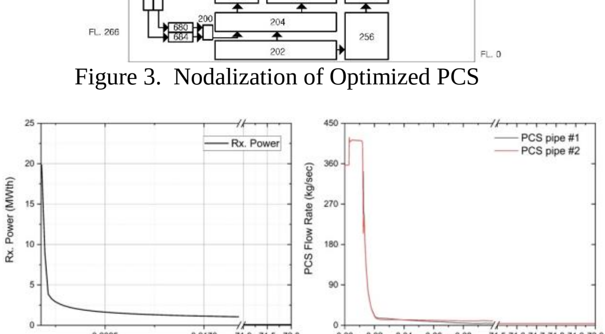

Figure 4. Reactor Power and PCS Flowrate vs Time

The flowrate of the PCS maintains the inertial flowrate due to the influence of the flywheel attached to the pump motor and then gradually decreases. However, the piping of the PCS of the series in which no breakage has occurred maintains a small flowrate due to the density difference of hot pool water passing through the RSA. The amount of pool water leakage through the broken site also increases with the flowrate of the PCS and then gradually decreases. [Figure 4]

4. Analysis of Results

Of the two trains of pipes in the PCS, the flap valve 313 on the side where the break occurred opens immediately as the differential pressure through the flap valve decreases at the same time as the pipe breaks, and air ingression begins through the break point. As the air flows in, the flowrate through flap valve 313 fluctuates greatly and then converges to a flowrate of about 1.6 kg/s. [Figure 5]

The flap valve 813 opens 33.1 seconds after the accident, and the initial flowrate fluctuates, which is consistent with the flowrate through flap valve 313. It can be seen that the reactor pool water introduced through the flap valves 313 and 813 forms a natural convection flow path that passes through the RSA and comes out back to the reactor pool. The flowrate of node 313 fluctuates, the differential pressure of the RSA changes, and the flowrate of node 813 fluctuates together, and then converges to about 1.8kg/s, and the natural convection flowrate through the two flap valves eventually converges to about 3.4kg/s.

Since the flap valve is designed to close at a flowrate of -24 kg/s, both flap valves can remain open and form a stable natural convection flow path.

The water level of the reactor pool decreases rapidly until about 540 seconds after the accident, and the decrease rate is reduced in line with the decrease in the amount of leakage through the piping of the primary cooling system. [Figure 5] 72 hours after the accident, the reactor pool water level remains at 10.91m. It can be seen that it is possible to secure a significantly larger amount of reactor pool water inventory compared to existing research reactors where the PCS piping penetrates near the top of the RSA and the PCS equipment room is located below the reactor pool.

In this modeling, the nuclear fuel loaded in the core was simulated into two types: Spent Nuclear Fuel Assembly (SFA) and Fresh Fuel Assembly (FFA). The minimum CHFR of SFA and FFA reached 6.47 and 5.26 after 1.4 second after the accident, respectively, which were evaluated much higher than the safety limit for general research reactors. [Figure 6] For information, acceptance criteria for minimum CHFR and maximum fuel centerline temperature of the Kijang Research Reactor is 1.5 and 375 °C, respectively.

The maximum fuel centerline temperature was also evaluated at 103.71°C and 110.08°C for SFA and FFA, respectively, with sufficient margin, and the maximum temperature of the reactor pool was evaluated to be approximately 93.94 °C at 72 hours after the accident. [Figure 6]

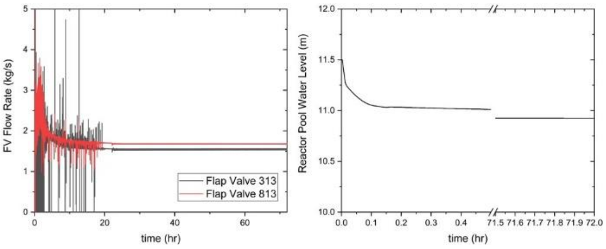

Figure 5. Flap Valve flowrate and Pool Level vs Time

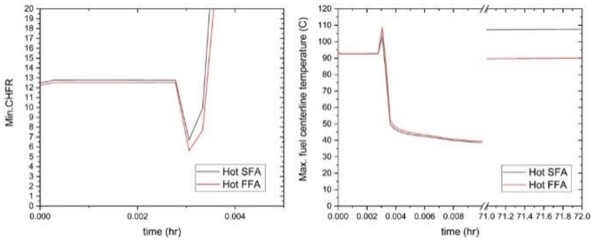

Figure 6. Minimum CHFR and Maximum Fuel Centerline Temperature vs Time

Table 2. Accident scenarios and major events of the analysis

Time after accident (s)	Events
0.02	Flap valve 313 open by low △P across flap valve
0.83	Reactor and PCS Pump trip by High PCS flow rate signal
1.18	Spent fuel centerline temperature reaches peak point (103.71°C)
1.39	Fresh fuel centerline temperature reaches peak point (110.08°C)
1.42	Spent fuel assembly reaches Minimum CHFR (6.47)
1.43	Fresh fuel assembly reaches Minimum CHFR (5.26)
33.10	Flap valve 813 open by low △P across flap valve

5. Conclusions

In this study, the placement of the flap valve outside the reactor pool, which is part of the optimized design of the PCS, was simulated using the RELAP5/MOD3.3 code and the safety evaluation has performed through LBLOCA analysis.

The natural convection flowrate through the flap valve maintains a total of 3.4kg/s, 72 hours after the accident and forms a stable flow path. As a result of confirming safety-related variables such as reactor pool water level and temperature of the reactor pool, minimum CHFR, and maximum fuel center temperature, it was evaluated that sufficient safety margins could be secured.

By placing the flap valve outside the reactor pool, the waterproof and radiation resistance requirements for the flap valve and instruments installed on it are alleviated, and there is no need to drain the reactor pool water for various tests and inspections that are periodically performed. As a result, applying this concept can save a lot of time and resources during construction and operation of the research reactors to be designed in the future.

ACKNOWLEDGEMENTS

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