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Performance Evaluation of Core Cooling Systems for New Research Reactor

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1. Introduction

Unlike commercial power reactors, the downward flow can be adopted in research reactor to improve the reactor utilization. However, when a loss of primary coolant flow such as two primary cooling system (PCS) pumps failure occurs, the core flow direction is changed from a downward inertial flow driven by the PCS pump flywheels to an upward flow by a natural circulation.

During the flow reversal from a downward flow to an upward flow, flow stagnation occurs and it can induce deterioration in heat transfer and threaten the fuel integrity. Therefore, it is important for the downward inertial flow to be kept for a sufficiently long time by using active or passive system.

In this paper, a performance evaluation is carried out on a passive type core cooling system such as a gravity core cooling system (GCCS) and an active type safety residual heat removal system (SRHRS) for a research reactor with 15 MW.

2. Emergency Core Cooling System

The GCCS consists of a vertical gravity core cooling tank (GCCT) and a pipe connected to the reactor outlet plenum as shown in Figure 1. During the PCS pumps are operated, the water level of the GCCT is diminished by the out-surge through the interconnection pipe between the bottom of the GCCT and the reactor outlet plenum due to core flow rate resulting in the pressure decrease of reactor outlet plenum.

After the PCS pumps stop, the decay heat is removed by the flow induced by the inertial force of a flywheel attached to each PCS pump shaft. As the PCS inertial flow by the flywheel decreases slowly, the water level of the GCCT increases by water level difference between reactor pool and GCCT and the core downward flow is maintained.

When the core downward flow decreases due to level equilibrium between the reactor pool and the GCCT, the flap valves installed on the reactor outlet PCS pipes inside the pool are passively opened. The openings of these valves provide flow paths for a natural convection from the reactor pool to the reactor outlet plenum through the flap valves to remove the core decay heat.

On the other hand, the safety pumps of the SRHRS fulfill the function of maintaining downward flow instead of the GCCT for a sufficient time. The SRHRS main inlet pipe line is connected to the reactor outlet PCS pipe. After the PCS pumps stop, the PCS inertia flow by the PCS pump flywheels decreases slowly.

When the PCS flow rate reaches a setpoint, the safety pumps in the SRHRS provide flow paths to the reactor core and maintain the downward flow to remove the core decay heat for the long time.

3. Performance Evaluation

To evaluate the performance of two type core cooling systems for the research reactor with 15 MW, RELAP5/MOD3.3/P4 is used [1].

The reactor core is consisted of four pipe components including fuel assembly and fuel assembly bypass. The reactor pool is modeled as several single-volume and branch components. For the GCCS, GCCT and connecting pipe are modeled as pipe components. The SRHRS is consisted of two safety pumps and several pipe components.

The initiating event for the performance evaluation of core cooling systems is selected to two PCS pumps failure. When an inadvertent stop of the PCS pumps occurs, the reactor is shut down by the trip parameters of the low PCS flow or low core differential pressure.

4. Results and Discussions

Figure 2 shows the normalized core inlet flow rate and core power. After two PCS pumps stop, the downward core flow is maintained for a few minutes by the water level difference between the reactor pool and the GCCT. When the flap valves open and the level between the reactor pool and the GCCT reaches to the equilibrium, the core flow is inversed from a downward to an upward by the natural circulation.

Figures 3 and 4 show the normalized critical heat flux ratio (CHFR) calculated using by Kamigana correlation [2] and coolant temperature profiles at the hot fuel assembly. During the transient, the calculated minimum CHFR satisfies the safety criteria. However, during the flow reversal the coolant temperature at the hot fuel assembly reaches the saturation temperature because of the high decay heat. In addition, there is a small margin for CHFR against the safety criteria at the vicinity of flow reversal.

To enhance the CHFR and sub-cooled margins of coolant temperature at the hot fuel assembly after the flow reversal, the SRHRS is considered in this study. Until the PCS inertial flow is decreased to the certain setpoint due to stopping the PCS pumps, the safety pumps in the SRHRS are operated by an emergency diesel generator (EDG) to maintain the downward flow as shown in figure 2. Until 30 minutes, the decay heat is removed continuously by the forced convection of the safety pumps.

When the safety pumps stop and the flap valves passively open, the decay heat is removed by the natural circulation due to opening the flap valves. During the flow reversal, the sub-cooled margin of the coolant temperature and the CHFR at the hot fuel assembly are higher than using the GCCS as shown in figure 3 and 4.

5. Conclusion

The performance evaluation of a passive and active core cooling system for a research reactor with 15 MW has been carried out by using RELAP5/MOD3.3/P4.

According to the analysis results on the failure of two PCS pumps, it is found that both the passive and active core cooling system have an adequate safety function for the research reactor.

However, the passive core cooling system has not enough the safety margin for the CHFR and coolant temperature at the hot fuel assembly. So the active core cooling system shall be considered to enhance the safety margin for a research reactor with 15 MW.

REFERENCE

[1] RELAP5/MOD3.3, Code Manual Volume V, User's Guideline, NUREG/CR-5535/Rev1, 2001

[2] Kamigana, M., Yamamoto, K., and Sudo, Y., Journal of Nuclear Science and Technology, 35 (12), pp. 943-951, 1998

ACKNOWLEDGEMENT

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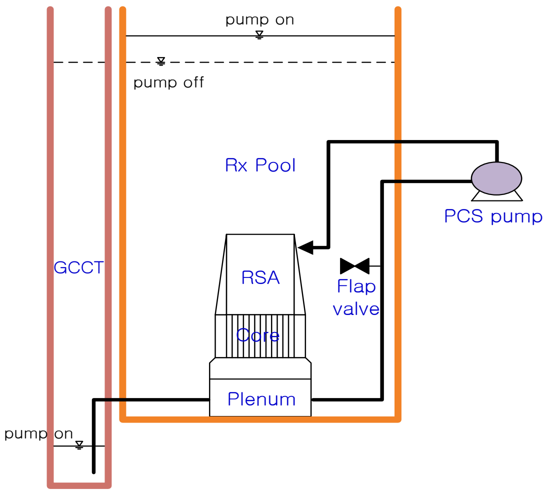

Fig.1. Schematic diagram of GCCS

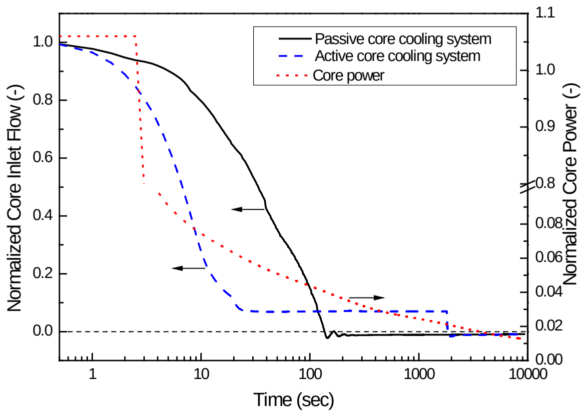

Fig.2. Core inlet flow rate and core power

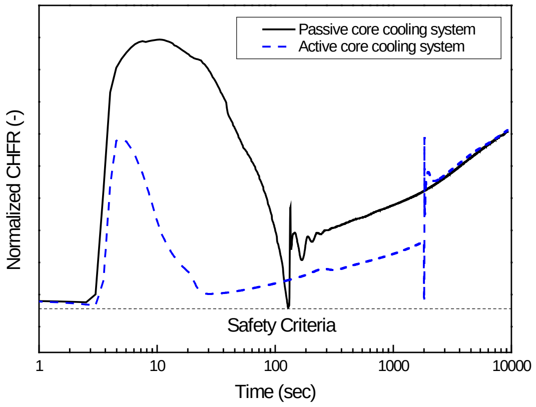

Fig.3 Critical heat flux ratio at the hot fuel assembly

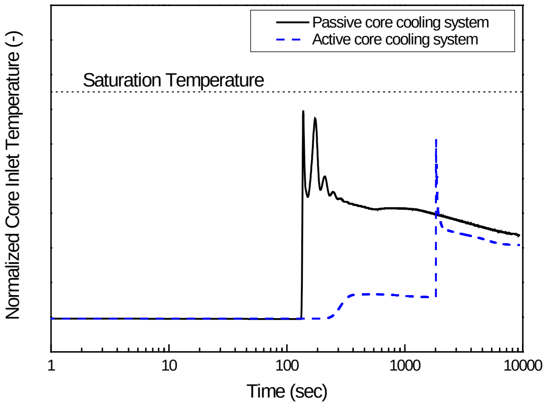

Fig.4. Coolant temperature at the hot fuel assembly