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Analysis of a Passive Emergency Core Cooling System for Research Reactors

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1. Introduction

When a loss of normal forced flow occurs for research reactors with normal downward core flow, the downward flow must be kept for a sufficiently long time to prevent fuel damage during flow reversal from downward flow to upward flow. In usual, research reactors with thermal power lower than 10 MW can accomplish the initial core cooling safely with a downward inertial flow driven by a pump flywheel. After the flow reversal, natural circulation cools down the reactor core. However, the inertial flow is not sufficient for research reactors with thermal power higher than 10 MW. Therefore, the reactors usually have an emergency cooling pump to achieve an appropriate core cooling.

This paper deals with a performance analysis of a passive emergency core cooling system for a research reactor with thermal power of 14 MW and normal downward core flow. The passive emergency core cooling system consists of a vertical tank and a pipe connecting the core outlet plenum and the tank.

2. Passive Emergency Core Cooling System

Figure 1 shows the schematic diagram of the reactor core, reactor pool, and emergency cooling water tank (ECWT) analyzed in this study. The pool water and emergency cooling water levels are 10 m from the reactor pool bottom when primary cooling pumps (PCPs) are off. The pool water level increases and the emergency cooling water level decreases as shown in the figure when the PCPs are running. The pool water level increase depends on the reactor pool area and the ECWT volume, and the decrease of the emergency cooling water level depends on the pressure drop across the reactor core for normal forced flow.

The suction force of the PCPs maintains the lowered emergency cooling water level during normal operation. When the PCPs stop inadvertently or intentionally, the pool water flows into the ECWT through the reactor core by gravitational force. The flow rate depends on the water level difference between the reactor pool and the ECWT as well as the size of the pipe connecting the ECWT and the outlet plenum. The duration time of the downward flow in the core is dependent on the flow rate and the ECWT size. In this study, the cross sectional area of the upper part of the ECWT is assumed four times that of the lower part for an effective emergency core cooling.

3. Analysis Modeling

RELAP5/Mod3.3 is used for this study [1]. The reactor core is modeled as three pipes representing a hot fuel assembly, an average fuel assembly, and a fuel assembly bypass. The reactor pool is modeled as several single-volumes and branches, and the ECWT as a pipe.

The reactor has plate type fuels. The reactor power is 14 MW and the reactor flow rate is 600 kg/s. 105% of the reactor power and 95% of the reactor flow rate are assumed for this analysis. The volume of the ECWT is 15 m^3 and the surface area of the reactor pool is 72 m^2. 95% of the pool surface area is used in this analysis. The size of the pipe connecting the ECWT and the core outlet plenum is 5 inches.

When an inadvertent stop of the PCPs occurs, the reactor is shut down by the trip parameters of the low primary cooling flow and low core differential pressure. In this study, the first reactor trip signal by the low core differential pressure is neglected.

4. Results and Discussions

During the normal operation, the steady state water level of the reactor pool is 10.2 m from the reactor pool bottom and the water level of the ECWT, -2.8 m. When the PCPs are turned off simultaneously, the reactor pool water level decreases gradually while the water level of the ECWT increases rapidly as shown in Figure 2. Finally, they become the water level of 10 m. The water level of the ECWT increases rapidly up to 5 m and after then slowly because of the area change of the ECWT.

Figure 3 shows flow rates at the reactor core, the PCPs, and the piping to the emergency cooling water tank. The rotational velocity of the PCPs’ impellor is modeled to decrease exponentially with the time constant of 3 seconds so that the flow rate at the PCPs steeply decreases to zero right after the PCPs are turned off. At the same time, the emergency cooling water flow increases rapidly up to around 103 kg/s and then decreases slowly to zero as the water level difference between the reactor pool and the ECWT decreases. The core flow decreases rapidly with the flow rate at the PCPs, and decreases more slowly as the emergency cooling water flow increases. And then the core flow shows the similar behavior with the flow rate at the ECWT until the flap valves open at around 72 seconds. The core flow rate becomes lower than the emergency cooling water flow rate due to the flap valve open. After around 300 seconds, the core flow is inversed by buoyancy force.

Figure 4 shows critical heat flux ratio (CHFR) calculated from the RELAP5/Mod3.3 outputs. The CHF correlation proposed by Kamigana [2] is used for the CHFR prediction. The minimum CHFR is predicted around 2.0 at 1.5 seconds right before shutdown rods drop. The CHFR during the flow reversal is calculated about 2.1. After the reversed flow is established, the CHFR steeply increases. Figure 4 shows earlier flow reversal comparing with the reactor core flow in Figure 3. The discrepancy is because the CHFR is calculated at the hot fuel assembly. The flow reversal at the hot fuel assembly occurs in advance before the core average flow is inversed from downward flow to upward flow.

5. Conclusion

A performance analysis of a passive emergency core cooling system for a research reactor with downward core flow and thermal power of 14 MW has been carried out by using RELAP5/Mod3.3. From the analysis on the inadvertent stop of primary cooling pumps, it is found that the passive emergency cooling water system has an adequate safety function for the research reactor investigated in this study.

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

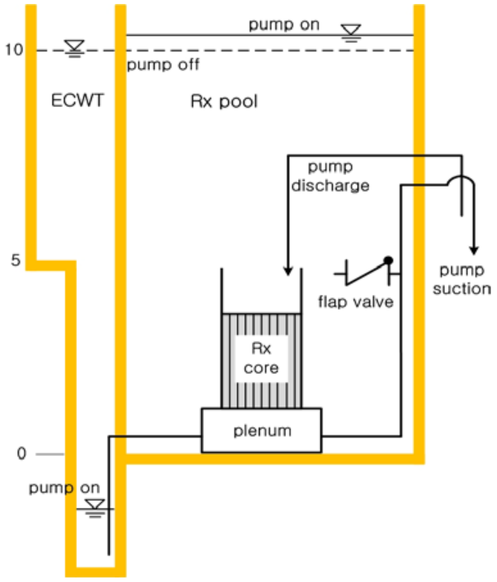

Fig.1. Schematic diagram of the reactor, reactor pool, and ECWT

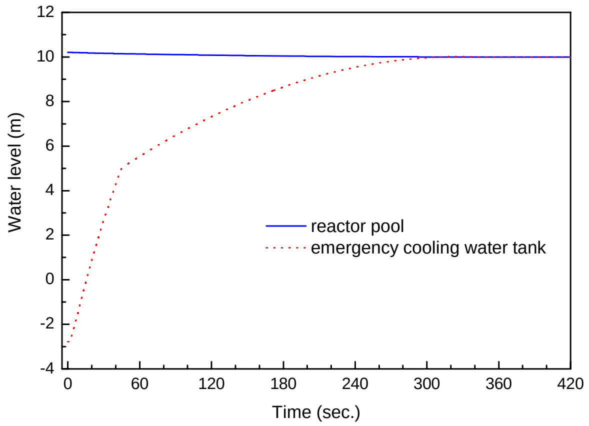

Fig.2. Water levels of the reactor pool and ECWT

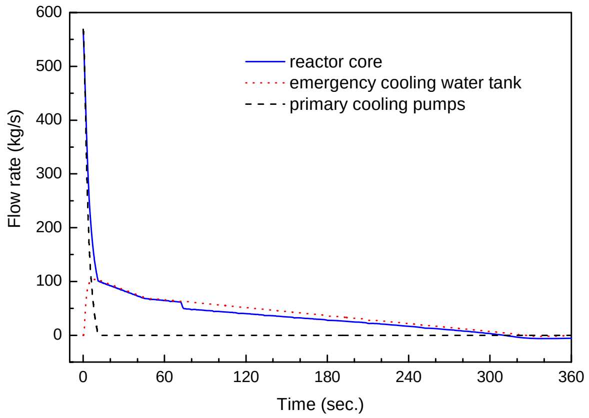

Fig.3. Flow rates at the reactor core, ECWT, and PCPs

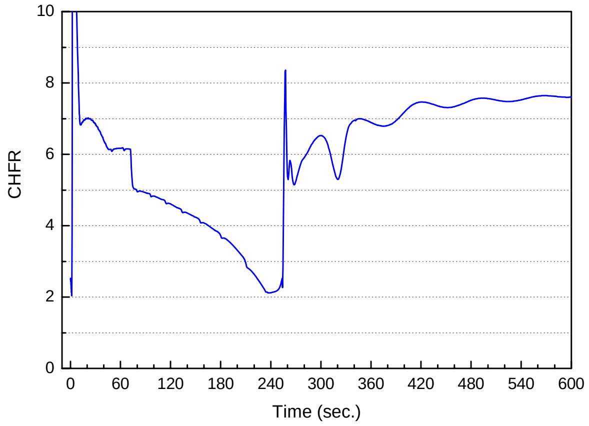

Fig.4. Critical heat flux ratio at the hot fuel assembly