SMART-P PRHRS Performance Analysis

Seong-Wook Lee, Young-Jong Chung, Hee Cheol Kim

Korea Atomic Energy Research Institute, 150 Duckjin-Dong, Yusung-Gu, Daejeon, 305-353, leesw@kaeri.re.kr

1. Introduction

KAERI is developing SMART-P (65MW) which is a pilot plant of the SMART[1] (330MW). The SMART-P is an integral reactor, where the main components such as the main circulation pump (MCP), steam generator (SG), and pressurizer are all located in the reactor vessel. The SMART-P has some passive features such as a self pressurizing pressurizer, passive residual heat removal system (PRHRS) to enhance the simplicity and safety.

The PRHRS in Figure 1 is an important safety system for SMART-P for a long term cooling. They are connected to 4 SG sections and remove the decay heat from the main steam to the Refueling Water Tank (RWT) coolant. One of the main objectives of the PRHRS is to bring out the primary coolant condition to a Shutdown Cooling System (SCS) operation condition (200°C, 2.3MPa) within 36 hours with 2 out of 4 trains of the PRHRS[2].

If both of the MCP and feed water supply system are unavailable and the primary coolant should be cooled down from a normal operation condition to a certain level, a natural circulation of the reactor coolant system and the PRHRS is the only means to the removal of decay heat. This is the natural circulation cooldown operation.

In this paper, the performance of PRHRS is analyzed through the natural circulation cooldown operation.
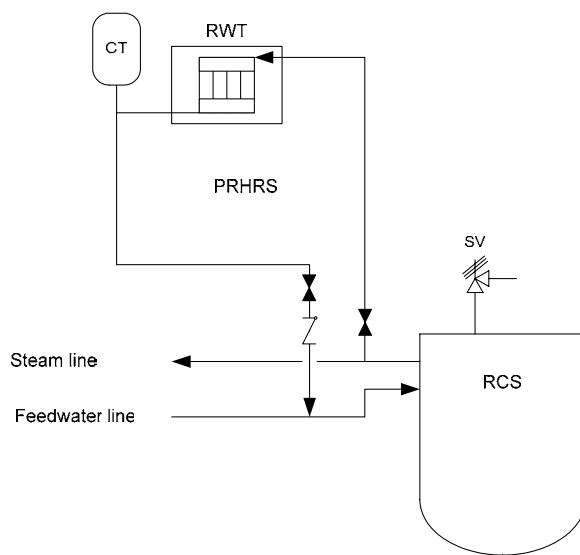

Figure 1. Schematic diagram of the PRHRS of SMART-P

2. Methodology and Results

The method for a performance analysis including some assumptions and the analysis results are presented in this section.

2.1 Analysis Methodology

The performance analysis of the PRHRS is accomplished with the TASS/SMR[3] code, which is a system analysis code for the SMART-P safety and performance analysis. In the code, the core power, heat flux, fluid temperature, pressure and the flow rate are calculated based on the 1-D lumped node-path modeling. Immediately following the loss of offsite power, the primary coolant flow decreases as the MCP coasts down. This results in a reactor trip by the low MCP speed. Then a natural circulation flow is established in the reactor coolant system. The sequence of events is as follows.

1. From the loss of off site power, the power supplied to the MCP is unavailable. Due to the coast down of the MCP speed, the reactor trip signal is generated.
2. The feed water isolation valves and main steam isolation valves are closed by the loss of off site power signal and 2 out of 4 PRHRS isolation valves are assumed to be opened.
3. When the primary coolant temperature reaches 200°C, the operator actuates the Reactor Gas Venting System (RCGVS) to depressurize the primary system for the SCS operation condition.
4. If the system pressure reaches 2.3MPa, the natural circulation cooldown operation by the PRHRS is considered to be completed.

2 out of 4 PRHRS trains are assumed to be inoperable. One train is not opened by a single failure criterion, and the other is to consider a case such as a main steam line break accident.

The decay heat model used in this study is the SMART-P specific fuel model.

In the view of the PRHRS performance, the sensitivity study about the N_2 gas volume change in the Compensation Tank (CT) is accomplished. The N_2 gas volume in the CT is very important for the performance of the PRHRS because the volume affects the PRHRS operation conditions such as the pressure, temperature and flow rate. In this study, 3 cases are analyzed for the N_2 gas volume; Case 1: 0.16m^3, Case 2: 0.1m^3, and Case 3: 0.08m^3[4].
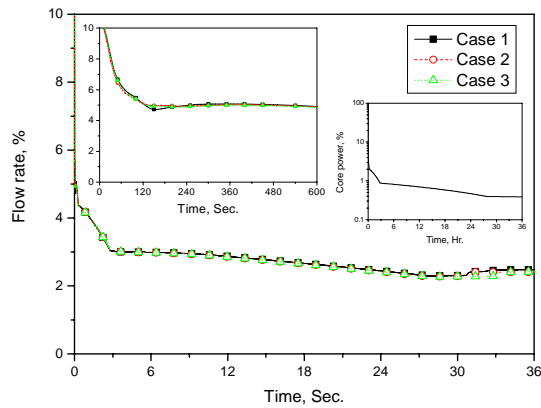
Figure 2. Primary coolant flow rate for natural circulation cooldown operation ; left upper figure: early 10 minutes behavior, right figure : core decay heat level
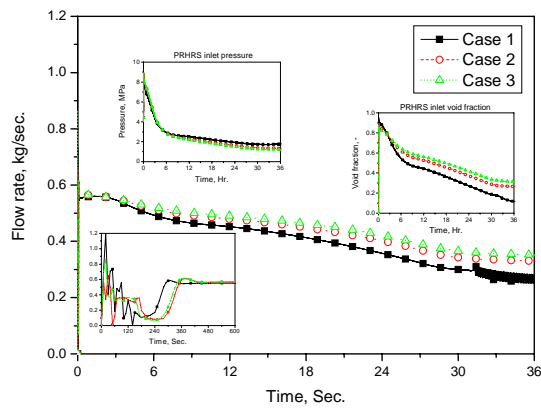

Figure 3. PRHRS flow for natural circulation cooldown operation ; left upper figure: PRHRS pressure, left lower figure: early 10 minutes behavior, right figure : PRHRS void fraction
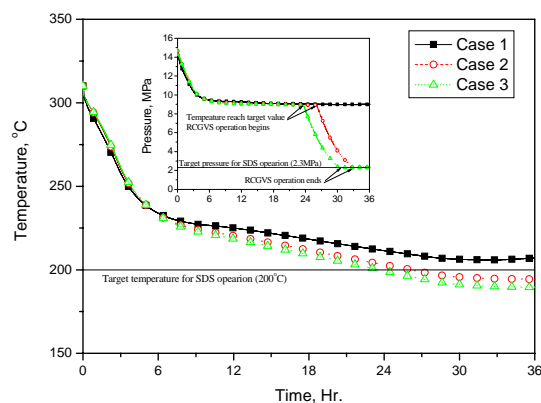

Figure 4. Coolant temperature for natural circulation cooldown operation ; small figure: coolant pressure

2.2 Analysis results

Figure 2 shows the primary coolant natural circulation flows. As the pumps coast down, the flows

decrease rapidly to below 6% of the rated condition. The natural circulation flows are well established within 10 minutes and have a decreasing trend according to the decay heat level for all the cases. Figure 3 shows the flows established in the PRHRS. They show a similar trend to the primary flows but the flow rate is reversely proportional to the N_2 gas volume in the CT. And the flow rate of case 1 shows some oscillating behavior at about 30 hours.

As the N_2 gas volume in the CT decreases, the PRHRS flow rate and steam void fraction increase and the pressure decreases. These conditions enhance the heat removal capability of the PRHRS.

The coolant temperature and pressure are shown in Figure 4. The temperature reaches the target value within 30 hours in case 2 and 3 while the temperature fails to reach it even after 36 hours in case 1. When the coolant temperature reaches the target, the RCGVS begins to actuate to depressurize the primary system to the SDS operation pressure as shown in case 2 and 3.

The natural circulation cooldown operation meets the criteria in case 2 and 3. The N_2 gas volume in the CT is one of the important factors affecting the performance of the PRHRS.

3. Conclusion

The performance analysis for the PRHRS has been accomplished by the TASS/SMR. The analysis case is a "natural circulation cooldown operation"

The SMART-P plant can cooldown to the SDS operation condition from a normal operation condition using a natural circulation in both the primary coolant system and the PRHRS.

According to the sensitivity study results, the N_2 gas volume in the CT is one of the major key parameters for the PRHRS performance.

The results of this study can contribute to the PRHSRS design and optimization.

REFERENCES

[1] SMART-P Basic Design Report, KAERI, KAERI/TR-2142/2002, 2002.
[2] B H Cho, Fluid system design data for SMART-P transient and limiting accident analysis, SMP65-FS-DD012-01 Rev.01, 2004.
[3] H Y Yoon, et. al., TASS/SMR Thermal-hydraulic model description, KAERI/TR-1835/2001, 2001.
[4] Y H Lee, RWT design data response and additional of safety analysis request related with PRHRS design, SMP65-FS-03042, 2004.