Evaluation of the Effectiveness of RCFC Combined with SG External Injection Strategy for Containment Condition Control

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1. Introduction

The Pressurized Water Reactor User Group (PWROG) has developed a PWROG SAMG (Severe Accident Management Guidelines) based on Diagnostic Process Guidelines (DPG), and KHNP is currently developing domestic DPG-based SAMGs reflecting this approach. To establish effective DPG SAMG, it is essential to evaluate the performance of mitigation measures under severe accident conditions and confirm their applicability to domestic PWR plants based on these evaluations, the mitigation measures of the SAMG are determined according to plant specific design characteristics.

DPG SAMG for domestic nuclear power plants consists of seven mitigation strategies developed as measures to mitigate risk factors that may arise during the progression of a severe accident, and to implement the necessary mitigating actions. To validate these strategies, representative accident scenarios were analyzed, and the effectiveness of each mitigation measure was assessed.

To control the containment conditions in high temperature and high-pressure scenarios, the containment strategy (SAG-06) incorporates four mitigation measures. Their effectiveness was evaluated as follows:

1) Containment spray pump
2) High flow mobile pump
3) Reactor containment Fan Cooler (RCFC)
4) Containment venting

In this study, the combined application of RCFC with low pressure mobile pumps for SG secondary side external injection was evaluated as a part of the SAG-06 (containment condition control strategy). The analysis is focused on evaluating the effectiveness of this combined strategy in controlling containment conditions under severe accident conditions.

2. Analysis Methods

2.1 Accident Scenario Selection

The Westinghouse three-loop nuclear power plant is selected for this analysis, with the accident sequence of LOFW (Loss of Feed Water) under high-pressure conditions of containment. In this scenario, RCFC operation was initiated 15 minutes after entry into a severe accident, followed by SG secondary-side external injection two hours after the severe accident entry.

The two cases considered were:

1) Case 1: RCFC operation
2) Case 2: RCFC operation combined with SG secondary-side external injection using low pressure mobile pumps

For the analysis, the EPRI severe accident analysis code MAAP5.06 was used.

2.2 Assumptions for analysis

The assumptions for main equipment and system operations used in this analysis are summarized in Table 1. The other Safety Injection System not listed in that Table 1, were not considered to be operable.

Table 1. Main equipment and system operation assumptions

Equipment & System	Assumptions
Motor-driven Aux Feed System	N/A
Turbine-driven Aux Feed System	N/A
Safety Injection Pumps	N/A
Accumulator	3 Available
Containment Spray System	N/A
Safety Depressurization and Exhaust System (Rapid Depressurization)	2 Available
Reactor Containment Fan Cooler	Available
Mobile Pumps	Available
Passive Autocatalytic Recombiner (PAR) Performance	75%

3. Analysis Results

The major accident progression scenarios analyzed using the MAAP code are presented in Table 2. In both Case 1 and Case 2, since there is no coolant injection into the core and no additional cooling measures are available, the core level gradually decreases. As a result, core uncovery occurs at approximately 0.98 hours after the initiating event, leading to core damage. Subsequently a severe accident is initiated at about 1.23 hours after the initiating event. From 15 minutes after the SAMG entry,

RCFC operation controls the containment pressure and temperature, preventing containment failure.

In Case 2, the SG external injection using a mobile pump was initiated at about 3.23 hours after the accident. In both Case 1 and Case 2, the containment failure was prevented.

Table 2. Event progression of Case 1 and Case 2

EVENT	Case 1	Case 2
	sec (hr)	sec (hr)
LOFW Initiation	0	0
Reactor Scram	30.97 (0.01)	30.97 (0.01)
CORE Uncover	3,522 (0.98)	3,522 (0.98)
SAMG Entry	4,433 (1.23)	4,433 (1.23)
RCFC Operation	5,333 (1.48)	5,333 (1.48)
SG External Injection (using Mobile pumps)	-	11,633 (3.23)
Containment Failure	-	-

Figures 1 and 2 present the containment pressure and temperature for Case 1, which exhibit a rapid initial increase followed by stabilization.

Figures 3 and 4 present the results for Case 2, where RCFC is operated 15 minutes after severe accident entry, and SG secondary-side external injection is implemented at two hours. The containment pressure and temperature are effectively controlled, with Figure 3 showing that containment pressure is maintained at a lower level compared to Case 1.

Figure 5 illustrates the external injection flow rate into the secondary side for Case 2. It shows that after approximately 3.23 hours after the initiating event, the external injection to SGs was performed, with additional injections into SG2 and SG3 after about 40 hours.

Figures 6 and 7 show the RCFC heat removal rate for Case 1 and Case 2. The heat removal rate in Case 2 is lower than that in Case 1, because part of the heat is removed by the SG external injection. The results also indicate that each time a mobile pump is actuated in Case 2, the RCFC heat removal gradually decreases as more of the cooling is shared by the SG injection. The combined strategy therefore achieves more effective containment control.

Figures 8 and 9 present a comparative analysis of Case 1 and Case 2 over the initial 8-hour period including the initiation of the SG external injection at approximately 3.23 hours, showing the containment pressure (Figure 8) and containment temperature (Figure 9). This provides a complementary view of the overall trends shown in Figure 1~4, with the specific purpose of offering a more detailed observation of the rapid variations in the containment during the first 8 hours. The results indicate that, during the injection period, Case 2 demonstrates lower pressure and temperature in containment compared to Case 1, indicating that Case 2 provides overall more effective control of the containment conditions than Case 1.

The results demonstrate that Case 2 provides more effective reduction of containment temperature and pressure, with containment pressure consistently controlled approximately 1 bar lower than in Case 1. Therefore, under this accident sequence, the combined application of RCFC and SG secondary-side external injection proved to be an effective strategy for removing heat and reducing pressure from the containment.

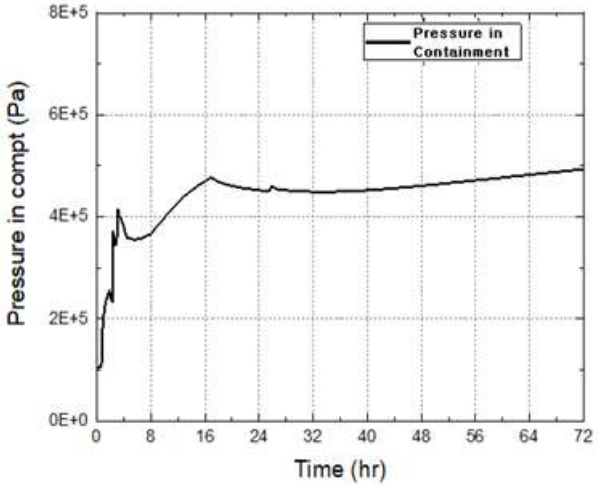

Figure 1. (Case 1) Pressure in containment

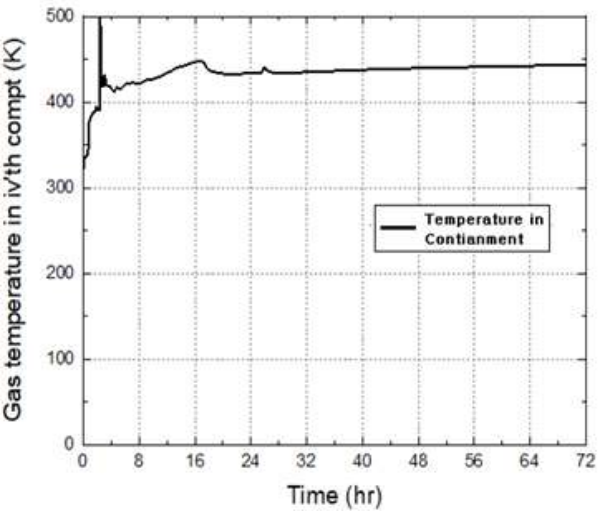

Figure 2. (Case 1) Temperature in containment

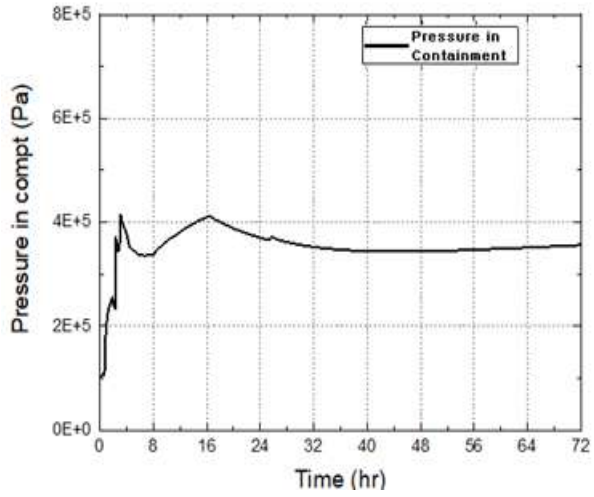

Figure 3. (Case 2) Pressure in containment

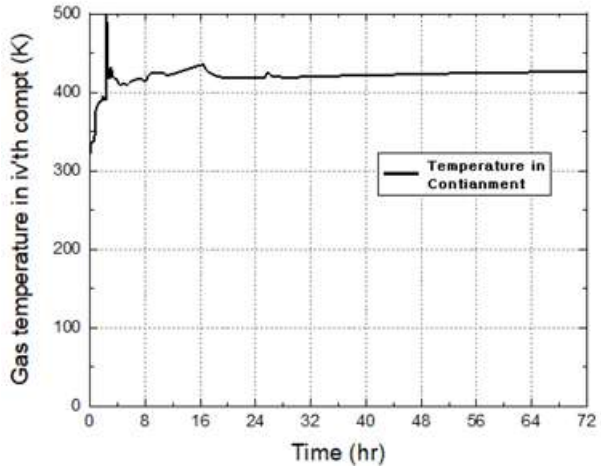

Figure 4. (Case 2) Temperature in containment

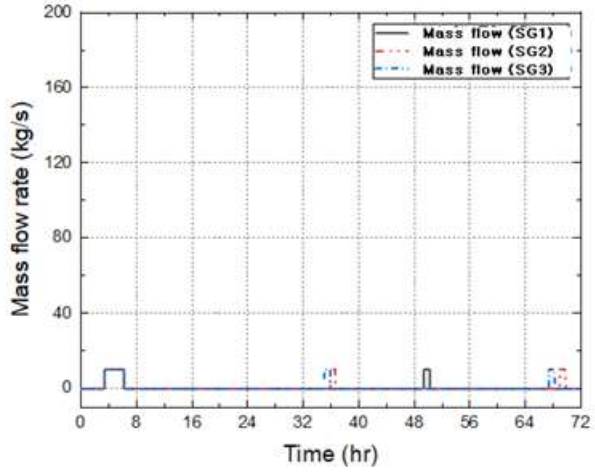

Figure 5. (Case2) Mass flow of mobile pumps

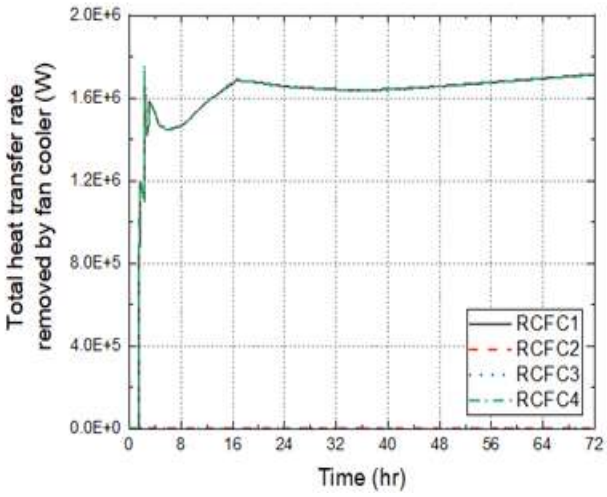

Figure 6. (Case 1) Heat transfer rate removed by RCFC

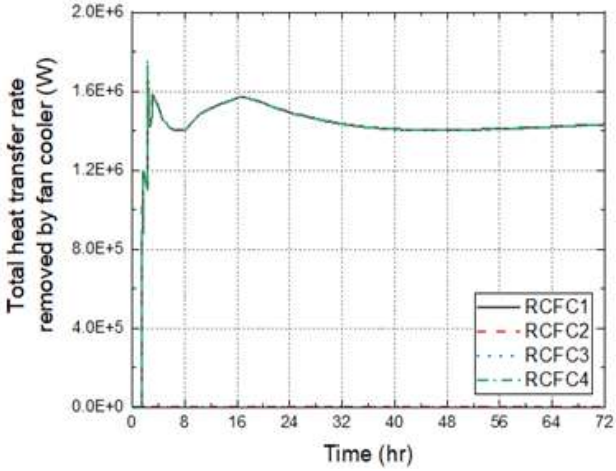

Figure 7. (Case 2) Heat transfer rate removed by RCFC

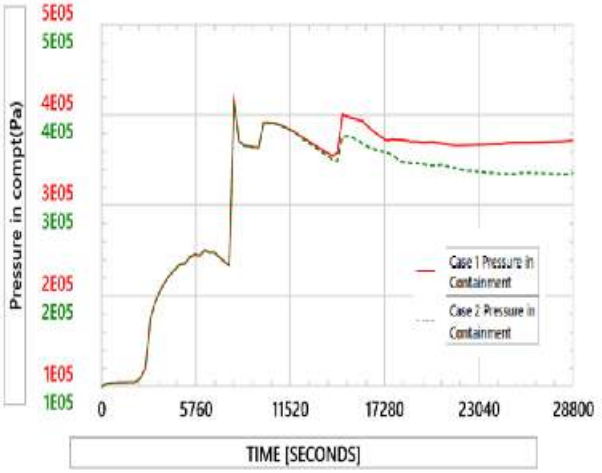

Figure 8. Pressure in containment (~8hr, Case 1&2)

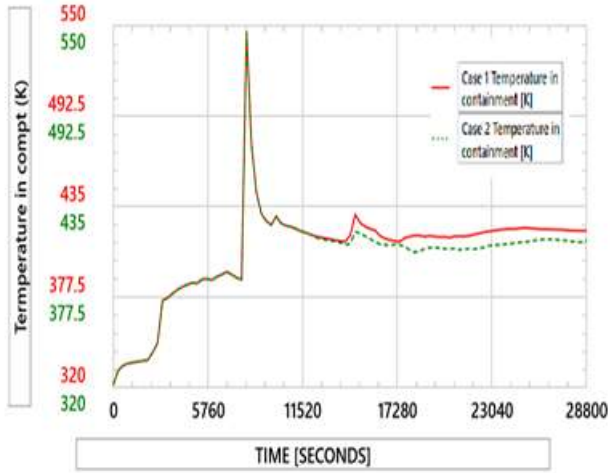

Figure 9. Temperature in containment (~8hr, Case 1&2)

4. Conclusions

In this study, the effectiveness of RCFC operation and SG secondary-side external injection on containment condition control (SAG-06 strategy) was evaluated under severe accident conditions.

The analysis confirmed that the combined strategy provided more effective containment condition control compared to RCFC opeaion alone. The containment heat removal due to the SG secondary-side external injection with the combined strategy of RCFC operation is slightly larger than expected and this effect contributed to maintaining stable presure and temperature, thereby ensuring containment integrity and delaying potential failure. The results showed that simultaneous implementation of RCFC operation and SG secondary-side external injection is an effective measure for controlling containment conditions.

The conclusions derived from this evaluation are expected to support the practical application and selection of mitigation measures, and will serve as reference material for the preparation of SAMG guidelines and technical background documents.

REFERENCES

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