Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Evaluation on the Effectiveness of the Strategies for Depressurizing Reactor Coolant Systems

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***Keywords:* Severe Accident, SAMG, SAG-01, SLOCA, RCS**

1. Introduction

Currently, the Korea Nuclear Power Plant is using the Westinghouse Owner's Group Severe Accident Management Guidelines (WOG SAMG) with a low power shutdown mode. After the Fukushima nuclear accident, Pressurized Water Reactor Owner's Group (PWROG) developed Severe Accident Management Guidelines (SAMG) based on Diagnostic Process Guidelines (DPG)[1] , and KHNP is also researching and developing DPG SAMG for each reactor type. In order to develop DPG SAMG, representative scenarios were selected for each reactor type, mitigation strategies were reviewed, and the effectiveness of the strategies was evaluated [2]. The effectiveness of the severe accident mitigation strategies according to the design characteristics of domestic nuclear power plants is evaluated, and it is reflected in the development of DPG SAMG.

In this paper, several measures for depressurizing the Reactor Coolant Systems (RCS) were analyzed to determine if they could reduce the pressure to the proper pressure for injecting cooling water into the RCS. The effectiveness of these measures was evaluated as means of SAG-01 (Severe Accident Guideline) "Depressurize the RCS".

2. Analysis Methods

2.1 Accident Scenario Selection

The APR1400-type nuclear power plant is selected for this analysis. To evaluate depressurization effect of RCS, Loss of Feed Water (LOFW) were selected among the high-pressure accidents for this study. In order to check the effectiveness of each means after LOFW, it was basically assumed that the fixed equipment would be available at 15 minutes after entering a severe accident, and the mobile equipment would be available at 2 hours after entering a severe accident.

The assumptions for the operations of the main equipment and systems used in the analysis are described in Table 1.

Table 1. Initial Conditions

Equipment & Systems	Assumptions
Aux Feed System	N/A
Safety Injection Pumps	N/A
Safety Injection Tanks	4 Available
Containment Spray Pumps	N/A
Reactor Containment Fan Cooler	N/A
Safety Depressurization and Exhaust System (Rapid Depressurization System)	4 Available
Reactor Cavity Flooding System	N/A
Mobile Pumps	N/A
Passive Autocatalytic Recombiner (PAR) Performance	75%

After the initial event, t, it is supposed that 4 measures to mitigate the accident are available as below.

1) Case 1: Pilot Operated Safety and Relief Valve (POSRV)
2) Case 2: Turbine Bypass Valve
3) Case 3: Main Steam Atmospheric Dump Valve (MSADV)
4) Case 4: Pressurizer Auxiliary Spray

The MAAP5.06, which is the EPRI's Severe Accident Analysis computer code, was used for this analysis.

2.2 Assumptions for analysis

The effectiveness of each measures for LOFW, which is one of the representative high-pressure accidents, is evaluated, in this analysis. The four measures and their use timings to perform the RCS depressurization strategies for LOFW were considered as shown in Table 2.

In the case of Case 1, it was assumed that 4 series of PORSVs would be opened after entering a severe accident 30 minutes later.

In the case of Case 2, as a measure of using the Turbine Bypass Valves, when they are opened, steam passes through the Main Steam lines and is released to the Condenser. It was assumed that it would be used when the level of the Steam Generator (SG) was above 80%, after entering a severe accident 30 minutes later. In order to satisfy 80% of the SG level, it was additionally assumed that a motor-driven Auxiliary Feedwater pump would be available after entering a severe accident 15 minutes later.

Table 2. The Measures and Timing of the Conditions

Case	Measures	Timing of the Conditions
Case 1	POSRV	SA + 30M
Case 2	Turbine Bypass Valve	SA + 30M SG Level > 80%WR
Case 3	MSADV	SA + 30M SG Level > 80%WR
Case 4	Pressurizer Auxiliary Spray	SA + 30M

In the case of Case 3, it was assumed as a measure of using the Main Steam Atmospheric Dump Valves (MSADV). It was assumed that they would be used when the level of the SG was above 80%, after entering a severe accident 30 minutes later. In order to satisfy 80% of the SG level, it was additionally assumed that a motor-driven Auxiliary Feedwater pump would be available and two of MSADV would be opened after entering a severe accident 15 minutes later.

In the case of Case 4, it was assumed that the Pressurizer Auxiliary Spray would be used after entering a severe accident 30 minutes later. At this time, the flow rate of the Pressurizer Auxiliary Spray was simulated at 44gpm, the lowest flow rate.

3. Analysis Results

The major results of accidents analyzed by MAAP code are compared in Table 3.

According to Table 3, in Case 1 and Case 4, RPV Failure was confirmed. In the Case 1, after performing the mitigating action six hours later, the reactor vessel was damaged. In the Case 4, after performing the mitigating action 1 hour later, the reactor vessel was damaged. In the Case 2 and Case 3, after performing the mitigating actions, it didn't cause damage to the reactor vessel.

Table 3. Results of Case1 ~ 4

EVENT	Case 1	Case 2	Case 3	Case 4
	hr	hr	hr	hr
LOFW	0	0	0	0
Reactor Scram	0.00	0.00	0.00	0.00
Core Uncover	0.85	0.88	0.85	0.85
SAMG Entry	1.07	1.08	1.07	1.06
POSRV OPEN	1.57	-	-	-
Motor-Driven AFW on	-	1.33	1.32	-
Turbine Bypass VV OPEN	-	2.49	-	-
MSADV OPEN	-	-	2.16	-
Pressurizer Auxiliary Spray Operation	-	-	-	1.56
Relocation of Core Material to Lower head	6.6	-	-	2.48
RPV Failure	7.86	-	-	2.57

Figure 1 shows the flow rate released through the PORSVs in Case 1. Figure 2. shows that the RCS pressure is reduced to less than 250 psia, which mitigate the potential for HPME, when the PORSVs are opened. Figures 1 and 2 confirm the effectiveness of depressurizing the RCS by opening the POSRV.

Figure 3 shows the flow rate released through the Turbine Bypass Valves in Case 2. Figure 4 shows that the RCS pressure is reduced to less than 250 psia, which mitigate the potential for HPME, when the Turbine Bypass Valve s are opened. Figures 3 and 4 confirm the effectiveness of depressurizing the RCS by opening the Turbine Bypass Valve.

Figure 5 shows the flow rate released through the MSDAVs in Case 3. Figure 6 shows that the RCS pressure is reduced to less than 250 psia, which mitigate the potential for HPME, when the MSADVs are opened. Figures 5 and 6 confirm the effectiveness of the RCS pressure reduction by using the measure of opening the MSADV.

Figure 7 shows the flow rate released through the Pressurizer Auxiliary Spray System in Case 4. Figure 8 shows that the spray did not reduce the RCS pressure until before the RPV Failure.

In the case of Case 4, it was confirmed that the Pressurizer Auxiliary Spray to depressurize the RCS was not effective.

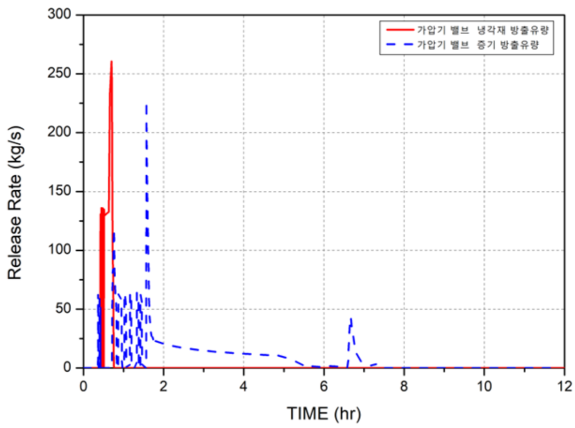

Figure1. (Case 1) Release flow rate of PORSV

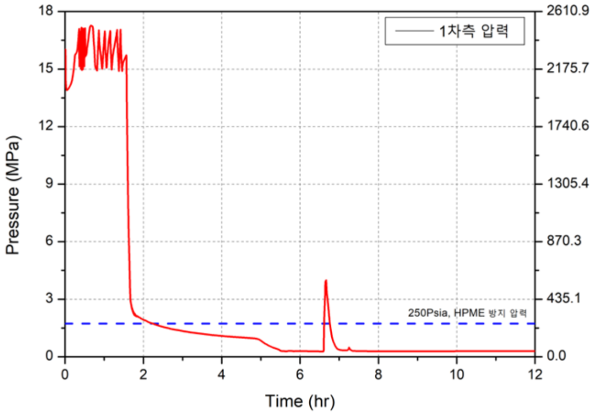

Figure2. (Case 1) Pressure of RCS

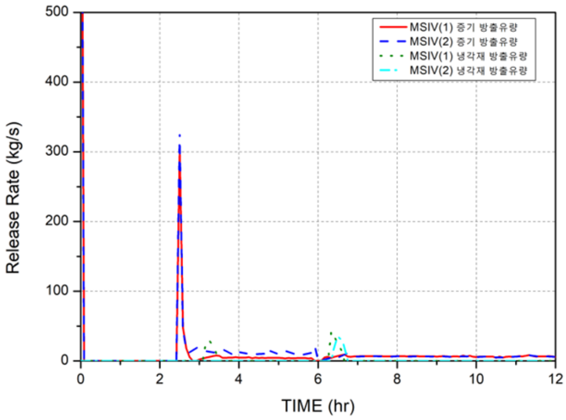

Figure3. (Case 2) Release flow rate of MSIV

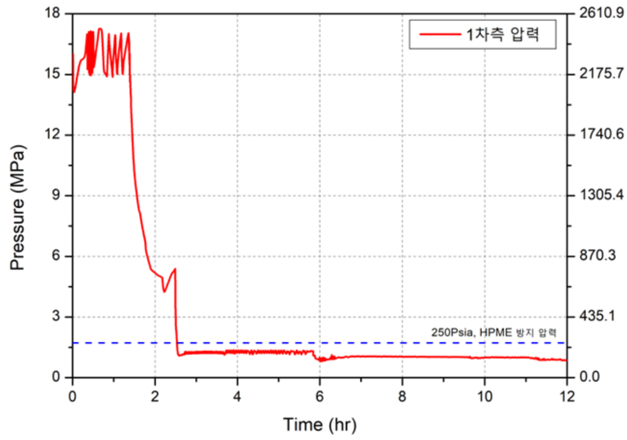

Figure4. (Case 2) Pressure of RCS

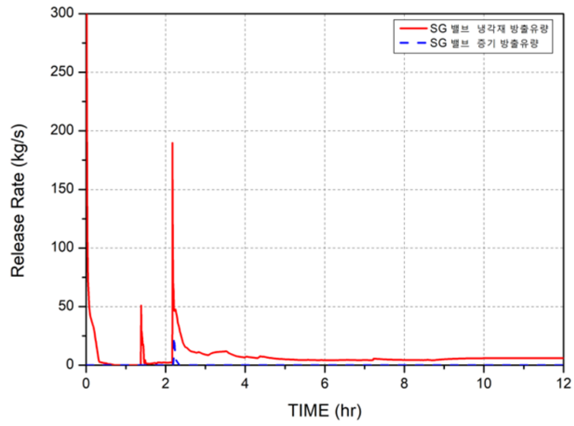

Figure5. (Case 3) Release flow rate of MSADV

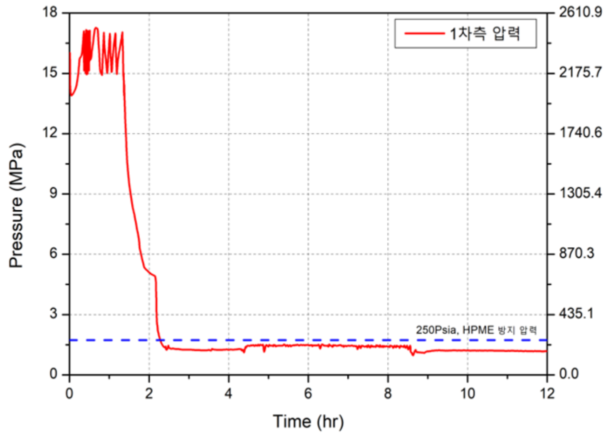

Figure6. (Case3) Pressure of RCS

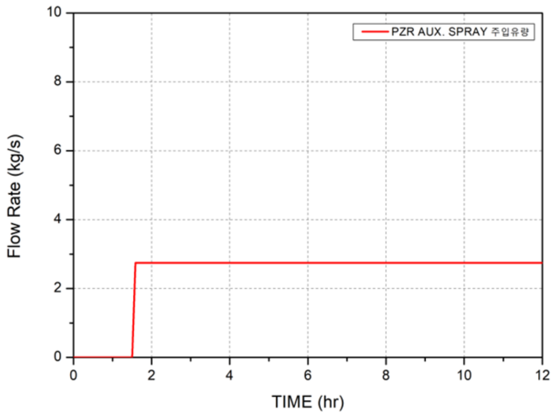

Figure7. (Case 4). Flow rate of Pressurizer Auxiliary Spray System

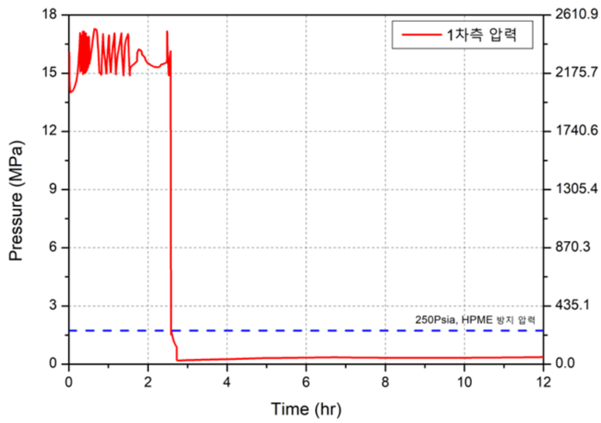

Figure8. (Case4) Pressure of RCS

4. Conclusions

In this paper, the effectiveness of the measures to depressurize the RCS was evaluated as mitigation strategies in the case of LOFW in APR1400 type plants.

In general, the PORSV, Turbine Bypass Valve, and MSADV, which can be used for depressurization of RCS, have been shown to have positive results in depressurization of RCS. However, the Pressurizer Auxiliary Spray, which is basically used to reduce the RCS pressure in the Pressurizer, has no effect on depressurizing the RCS in the event of a high-pressure accident, such as LOFW. After the initial event, most of the steam was already released through the break, so it appears that the Pressurizer Auxiliary Spray didn't reduce the RCS pressure. It will be planned to consider how this measure will be used to the SAG-01 strategy for domestic nuclear power plants.

Through the results of this analysis, it will be reflected in the strategy for SAG-01 when developing DPG SAMG. Like this study, in the development process of the DPG SAMG, the effectiveness of various mitigation strategies to ensure practical response capabilities for the severe accident management strategies will be evaluated continuously.

REFERENCES

[1] PWROG-15015-P Revision 0, "PWROG Severe Accident Management Guidelines", February 2016.
[2]" Report on the Evaluation of the Effectiveness for Severe Accident Mitigation Strategies on DPG-based PWROG SAMG", KEPCO E&C, December 2024