Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Evaluation of the Impact on Containment State Control Strategies by the External Injection of Emergency Cooling Water to Steam Generators

Ji-Eun Oh[a*], Mi-ro Seo[a], Min-gyu Kim[a], Su Won Lee[b], Myeong Kwan Seo[b]
[a]*Korea Hydro & Nuclear Power Co., Ltd., Yuseong-Gu, Daejeon, Korea*
[b]*FNC Technology Co., Ltd.,10 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea*
[*]Corresponding author: k12290641@*khnp.co.kr*

***Keywords :** Severe Accident, SAMG, SAG, LLOCA, Mobile Pump

1. Introduction

In the early 2000s, as a follow-up measure to the Three Mile Island nuclear power plant accident, the Severe Accident Management Guidelines (SAMG), which is a strategy for managing and mitigating severe accidents, was developed and applied to all domestic nuclear power plants in Korea. The current domestic SAMG is an integrated SAMG based on WOG SAMG (1994) including low-power shutdown mode. After the Fukushima nuclear power plant accident, PWROG developed the PWROG SAMG (2016) based on the Diagnostic Process Guidelines (DPG). Accordingly KHNP is also conducting the research for improving domestic nuclear power plant SAMG using DPG-based SAMG.

PWROG SAMG [1] provides the various measures to implement the strategies according to mitigation strategies. These are selected as mitigation measures for domestic SAMG through their effectiveness evaluations for severe accident (SA) mitigation strategies and measures based on the design characteristics of domestic nuclear power plants.

The Steam Generator (SG) feedwater injection strategy is implemented as SAG-01(Severe Accident Guideline) to protect the reactor vessel by removing heat and pressure through the secondary side of the SG in the early stages of an accident, while also providing decontamination effects for nuclear fission products when Steam Generator Tube Rupture (SGTR) occurs [2]. The heat removed from the core through external injection strategy to RCS causes pressurization of the containment. However, the heat removed from the core through external injections strategy to SG is released via the secondary side of the steam generator. Therefore, it is expected that the SG feedwater injection strategy using low-pressure mobile pumps may be advantageous in terms of controlling the state of the containment [3].

This paper has analytically demonstrated that the SG feedwater injection strategy can contribute additional positive effects on the state control of high-temperature, high-pressure containment buildings.

2. Analysis Methods

2.1 Accident Scenario Selection

Westinghouse three-loop nuclear power plant is selected for this analysis. In order to evaluate depressurization effect of containment, Large Loss of Coolant Accident (LLOCA) is selected as the basis scenario for our analysis, which causes significant pressure rise of the containment in the early stages of an accident. After the initiation of SA, it is supposed that any accident mitigation actions were not performed, and 2 hours after the SA initiation, it is supposed that MACST facilities are available as below.

1) Case 1: spray strategy using mobile pump
2) Case 2: spray strategy using mobile pump + external injection strategy to the secondary side of SG

This analysis used EPRI's severe accident analysis computer code, MAAP 5.06.

2.2 Assumptions for analysis

The WH-type nuclear power plant has a prepositioning strategy of MACST facilities for external injection to the primary side. Therefore, actually the mobile equipment should be available at 50 minutes after the accident initiation. However, in this analysis, it is conservatively assumed that they will be deployed two hours after the accident initiation. Two hours after the SA initiation, Case 1 performs only a spray strategy using a mobile pump, while Case 2 performs both spray strategy using a mobile pump and feedwater injection strategy using external injection to SG. The Containment Spray System of the WH-type nuclear power plant doesn't have a heat exchanger, so the heat removal function of the containment is limited by the continuous spray operation. Therefore, an alternative external spray strategy using a mobile pump is required. In this case, the heat and pressure in the containment must be removed without exceeding the maximum flooding level of the containment. The mobile pump is assumed to be started at the containment building design pressure and stopped when the containment pressure reaches 4.1 bar, since continued operation may cause flooding of the containment. The maximum flooding level of the containment was determined as the maximum flooding levels described in WH-type nuclear power plant accident management plan.

The assumptions for main equipment and system operation used in the analysis are shown in Table 1.

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
Initial Opening (Failure)	None
Safety Depressurization and Exhaust System	2 Available
Rapid Depressurization System	N/A
Reactor Cavity Flooding System	N/A
Mobile Pumps	available
Passive Autocatalytic Recombiner (PAR) Performance	75%

Two hours after the SA occurred, external injection of emergency cooling water to the primary side began. Thirty minutes later, external injection of emergency cooling water to the secondary side began, and feedwater was supplied to the SG.
It was assumed that only one of the three SGs was injected with feed water.

3. Analysis Results

The major results of accidents analyzed by MAAP code were compared in Table 2.

Table 2. Results of Case 1 & 2

EVENT	Case 1	Case 2
	hr	hr
LLOCA Initiation	0	0
Reactor Scram	0.00	0.00
CORE Uncover	0.02	0.02
SAMG Entry	0.51	0.51
Relocation of Core Materials to Lower head	1.33	1.33
RPV Failure	1.94	1.94
Basemat Melt Through	1.94	1.94
TSC Activation	2.00	2.00
Mobile Facilities Available	2.51	2.51
SAG-3 Entry	N/A	2.59
SAG-8 Entry	2.59	2.84
Spray After Reaching Containment Design Pressure	18.85	29.15
Reaching Maximum Flooding Level of Containment	-	-
Containment Failure	-	-

Figure 1 shows the spray injection flow rate using a mobile pump in Case 1 and Figure 2 shows the spray injection flow rate using a mobile pump in Case 2. The reactor coolant system (RCS) is cooled by injecting feed water into the SG. The heat energy released from the RCS is then discharged through the secondary side of the SG. This causes a reduction in heat energy which increases the containment pressure. Therefore, in Case 2, the operating cycle of the mobile pump is shown to be significantly reduced.

Figures 3 and 4 compare the pressure fluctuations in the containment. In both Case 1 and Case 2, the area where the containment pressure increases remains within the yellow range on the graph, but the frequency of pressure fluctuations is significantly reduced in Case 2 in conjunction with the spray frequency.

Figure 5 and Figure 6 compare the water levels in the containment. In both cases, it was confirmed that the maximum flooding level of the containment was not reached at 72 hr. However, since the water level inside the containment in Case 2 is relatively lower than in Case 1, it is judged that the containment condition control strategy can be advantageously implemented from a long-term perspective.

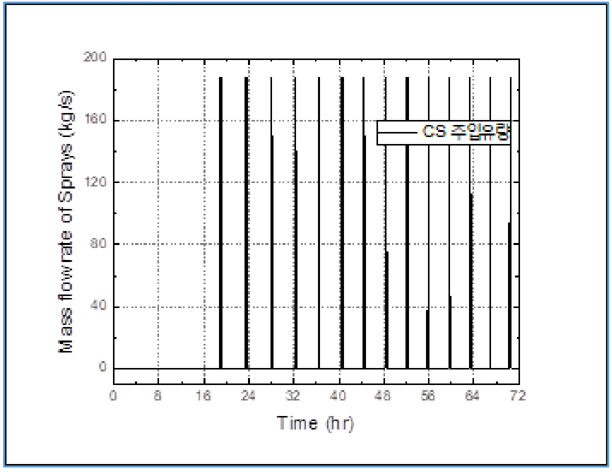

Figure1. Case 1 - Mass flow rate of Sprays (mobile pump)

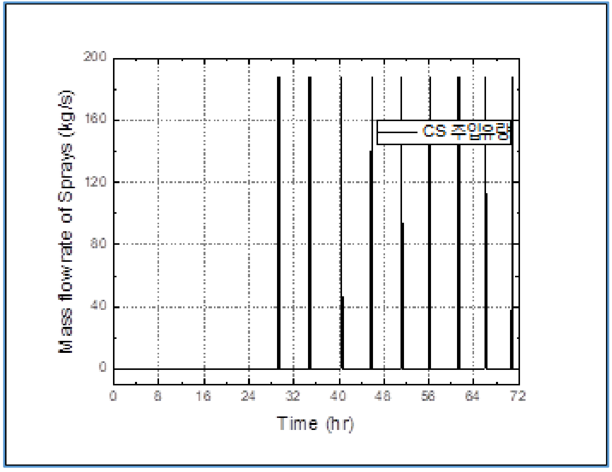

Figure2. Case 2 - Mass flow rate of Sprays (mobile pump)

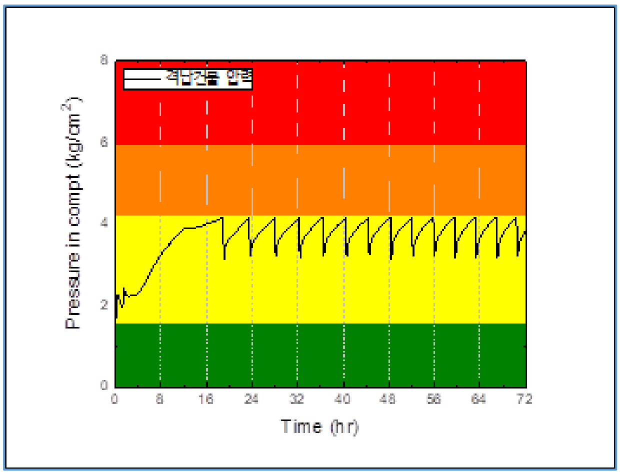

Figure3. Case 1- Pressure in containment

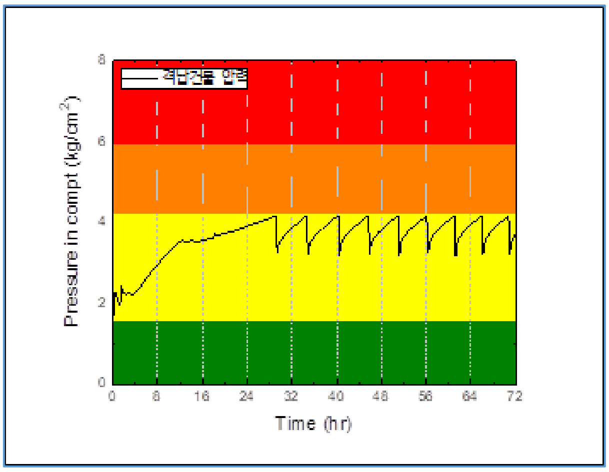

Figure4. Case 2 - Pressure in containment

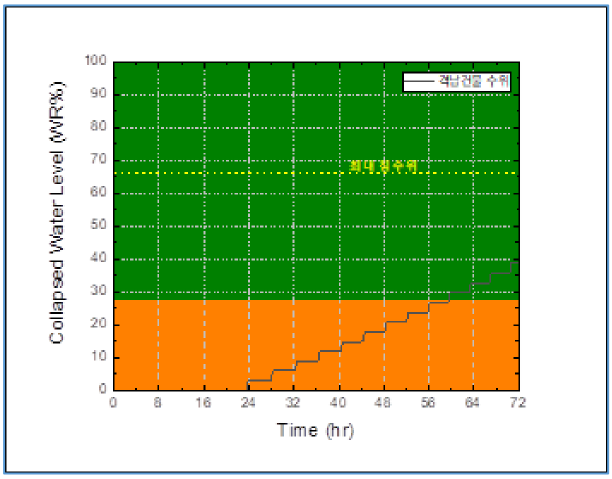

Figure5. Case 1 - Water Level in containment

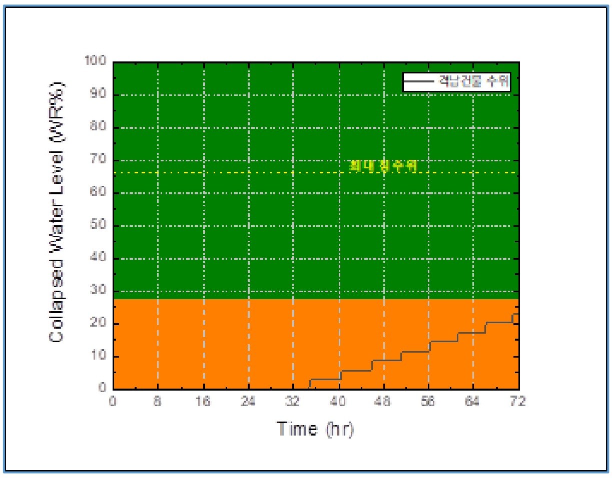

Figure6. Case 2 - Water Level in containment

4. Conclusion

In this paper, a quantitative analysis was performed on the effect of external injection of emergency cooling water into SGs when implementing a containment control strategy.

In general, containment status control is performed by spray or Reactor Containment Fan Cooler (RCFC), but in the event of SBO, an external alternative spray strategy using a mobile pump is known to be the most effective method. However, the spray strategy using external cooling water is limited because it may cause containment flooding. In this case, if external injection of emergency cooling water into the SG using a mobile pump are performed simultaneously, the heat of the reactor can be removed, thereby delaying the increase in containment pressure. It was shown that reduction in the frequency of spray could effectively delay the time until the maximum water level of the containment was reached. In the development process of the DPG SAMG, the effectiveness of mitigation strategies in terms of long-term implementation to ensure practical response capabilities for the SA management strategies will be evaluated continuously.

REFERENCES

[1] PWROG-15015-P Revision 0, "PWROG Severe Accident Management Guidelines", February 2016.

[2] "Westinghouse Owners Group Severe Accident Management Guidance", Westinghouse Electric Co, June 1994.

[3] "Derivation of New Set Points for DPG Based Generic SAMG", FNC, March 2024.