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The Results of Effectiveness Analysis of the Revised Emergency Action in SAMG

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1. Introduction

After the TMI accident, the SAMG (Severe Accident Management Guide) for all domestic NPPs (Nuclear Power Plants) had been developed by the Nuclear Safety Policy Statement and successive Nuclear Power Plant Severe Accident Policy Decision, based on the WOG (Westinghouse Owners Group) SAMG for full power operation mode issued in 1994.

After the Fukushima NPP Accident, the importance of SAMG for LPSD (Low Power and Shutdown) stage and for the SFP (Sent Fuel Pool) was newly issued. So, in Korea, the LPSD SAMG for all domestic NPPs had been developed and integrated in the existing full power mode SAMG by the Post-Fukushima Actions. The current Integrated SAMG had been developed representing the PWROG (Pressurized Water Reactor Owners Group) SAMG issued 2012 that covered the strategies for the severe accidents in LPSD stage and in the SFP.

In 2019, the Accident Management Plan (AMP) for all domestic NPPs had been submitted to the Regulatory body. The main characteristics of AMP is the active prevention measure using the MACST (Multi-barrier Accident Coping Strategies) facilities at the early stage of the accident. The introduction of MACST has also affected the SAMG Emergency Action for the fast mitigation of severe accident progression and the protection of reactor pressure vessel.

2. SAMG Improvement Plans

2.1. The Status of SAMG Improvements

In the previous paper[1] issued in 2022 KNS Autumn Meeting, the SAMG improvement plans of KHNP representing the PWROG SAMG(2016) was introduced. In that paper, the improvement items are classified as the short-term items that should be implemented as soon as possible and the long-term items that will be taken so many years.

The long-term item is represented by the introduction of new SAMG framework based on the PWROG SAMG(2016). The main characteristics of PWROG SAMG(2016) is the DPG (Diagnosis Process Guideline) and Technical Support Guideline (TSG). KHNP has started the project for improving the current Integrated SAMG based on the WOG SAMG (1994) from 2022 to 2025.

2.2. Improvement of Emergency Action

The improvement of emergency action for the guarantee of preferential execution of RCS depressurization, RCS Injection and Cavity flooding is the one of the short-term items to be required by the regulatory body. KHNP had already installed the MACST facilities for injecting the external emergency cooling water to RCS and Steam Generators. So, if there is the proper guidance for the fast response in the emergency actions in SAMG and the prepositioning strategies of MACST facilities such as mobile pump car and mobile generator, there can be the great mitigation effect at the early stage of severe accident progression. Specifically, in the case of low pressure accident such as Large Loss of Coolant Accident that caused the rapid depressurization of RCS, it is known to possible for the fast initiation of RCS injection through the external emergency cooling injection line to protect the reactor vessel integrity.

However, in the case of high pressure accident such as Loss of Feed Water Accident, since the integrity of pressure boundary is maintained, it is expected that the core uncover and melting is delayed. In that case, if the additional coolant is not provided, the core eventually will be melted and the integrity of reactor vessel can be threatened. On the other way, if we try to inject the coolant to RCS, the depressurization by manual operation should have to be executed preferentially. That operation means the initiation of intentional LOCA. And the depressurization caused the loss of RCS inventory, if the successive injection of emergency coolant is not enough, the core cooling is impossible and inevitably the core will be melted. So, the more definite technical analysis should needed for the high pressure accident case.

3. High Pressure Accident Analysis

3.1. The purpose of Analysis and Accident Sequence

In this chapter, we aim to assess the impact of applying revised emergency actions in high-pressure accident like LOFW (Loss of Feed Water) on the progression of severe accident. To achieve this, we performed an analysis by categorizing the scenarios depending on the available timing for the external injection of emergency cooling water. We assessed the possibility of preserving the integrity of reactor vessel and the maximum allowable delay time for mobile equipment deployment condition. Three scenarios are as follows:

1) LOFW_A : Assumed that the external injection of emergency cooling water into primary (RCS) and secondary (SG) systems.
2) LOFW_B : Assumed that the immediate external injection of emergency cooling water into RCS when the required pressure for external injection is reached.
3) LOFW_C : Assumed that the external injection of emergency cooling water into RCS after a 2-hour delay at the time that the required injection pressure being reached.

As explained in Section 2.2, the external injection of emergency cooling water into RCS requires the preferential manual depressurization of RCS. Therefore, we established the timing of external injection based on the point at which the pressure for external injection into RCS is reached. From the previous analysis such as the mitigation capability analysis for Accident Management Plan, it is known if the external injection of emergency cooling water into RCS will be performed within approximately 1.5 hours after the entry of severe accident, the integrity of reactor vessel can be maintained in case of LLOCA. So, we conservatively assumed a 2-hour delay after reaching the required external injection pressure in case of LOFW_C.

3.2. Major Assumption for Accident Analysis

We assumed the following sequential mitigation actions would be implemented with the application of revised SAMG emergency actions:

1) Operation of the 3-way valves
2) RCS pressure verification & rapid depressurization
3) External emergency cooling water injection into the primary and secondary systems (including the request if mobile equipment is unavailable)
4) CFS (Cavity Flooding System) operation
5) Verification of the TSC (Technical Support Center) activation

Furthermore, we assumed that after the initiation of the LOFW, the entire Emergency Core Cooling System is unavailable except for SIT (Safety Injection Tank), and no operator actions are taken until the entry of the severe accident. Therefore, we assumed the unavailability of fixed equipment, including DBA Containment Spray system,

The major assumptions for the scenarios are summarized as shown in Table I.

Table I: Assumed operation time for scenarios

Mitigation Action	Operation time		
	LOFW_A	LOFW_B	LOFW_C
3 way valve	Entry of Severe Accident + 10minute		
POSRV Rapid Depressurization	Entry of Severe Accident + 30minute		
External Emergency Cooling Water Injection	Unavailable	The time at which the pressure for external injection is reached	The time at which the pressure for external injection is reached + 2hour
CFS Operation	Entry of Severe Accident + 30minute		

3.3 Steady-State Analysis

The evaluation of steady-state analysis is important for assessing the suitability of initial inputs and the integrity and consistency of the parameter file. It aims to evaluate the stabilization of key variables such as primary and secondary pressures, as well as water levels, under normal conditions. Additionally, it seeks to evaluate the balance of mass and energy within the primary system and containment. As depicted in the figure 1~4, these key variables are initialized with appropriate values and demonstrate a relatively consistent pattern of behavior. Therefore, it can be confirmed that appropriate initial inputs and well-fitted model have been used.

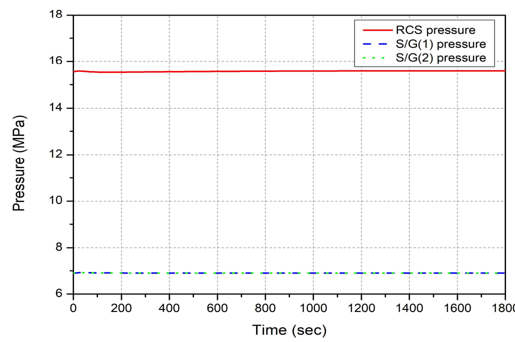

Fig. 1. Steady-State RCS pressure

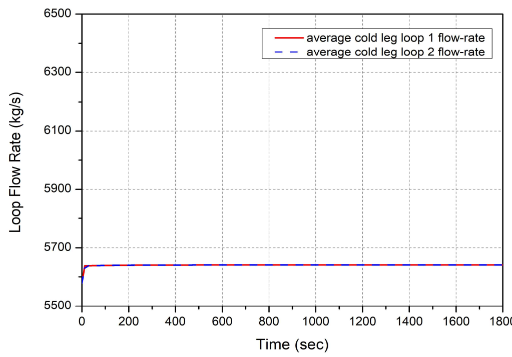

Fig. 2. Steady-State RCS flow rate

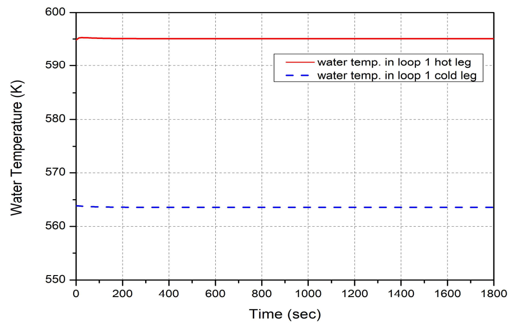

Fig. 3. Steady-State RCS water temperature

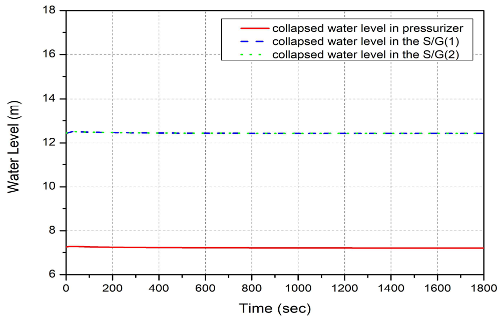

Fig. 4. Steady-State RCS water level

3.4 Analysis Results

From the analysis results, the major event time for each scenarios are summarized in Table II.

Table II: Major Event time of scenarios

Scenario / Event	LOFW_A	LOFW_B	LOFW_C
Entry of Severe Accident	3,276sec (0.91hr)	3,276sec (0.91hr)	3,276sec (0.91hr)
Rapid Depressurization	5,076sec (1.41hr)	5,076sec (1.41hr)	5,076sec (1.41hr)
External Emergency Cooling Water Injection	N/A	7,802sec (2.16hr)	15,003sec (4.16hr)
Relocation	15,604sec (4.33hr)	N/A	N/A
RV Fail	18,210sec (5.05hr)	N/A	N/A
Time to RV Fail after entering a severe accident	14,934sec (4.14hr)	N/A	N/A
Time to RCS Injection after entering a severe accident	N/A	4,526sec (1.25hr)	11,727sec (3.26hr)

According to the results, it was found that 30 minutes after the entry of severe accident, rapid depressurization occurred due to the opening of the POSRV, resulting in an intentional LOCA. As the RCS pressure dropped down, SIT Injection is started at 5,454 seconds (1.5 hours) in every case, LOFW_A, B, C.

In the case of LOFW_A, since the external injection of emergency cooling water into RCS was unavailable, the reactor vessel failed approximately 14,934 seconds (4.14 hours) after severe accident initiation. In Figure 5~8, depressurization of RCS with opening of POSRV and non-recovery of water level of core due to the non-execution of external injection of emergency cooling water into RCS can be observed.

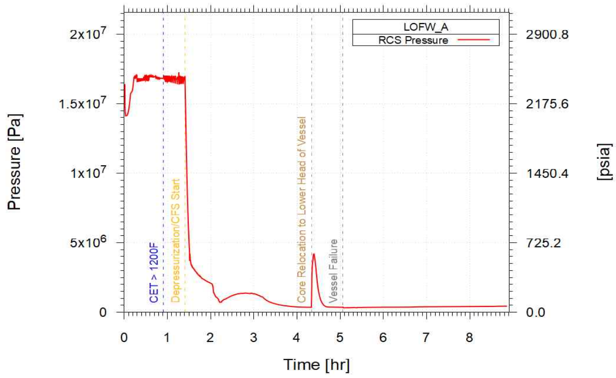

Fig. 5. RCS pressure of LOFW_A

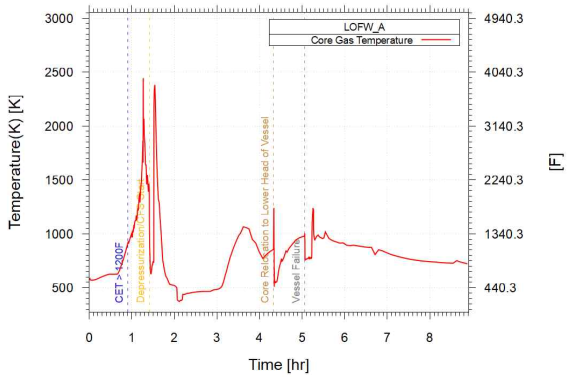

Fig. 6. Core gas temperature of LOFW_A

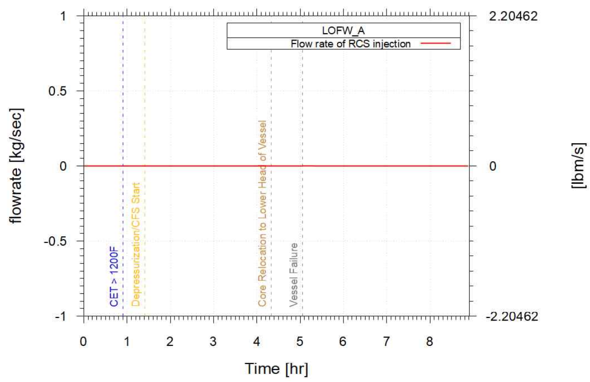

Fig. 7. Flow rate of RCS injection of LOFW_A

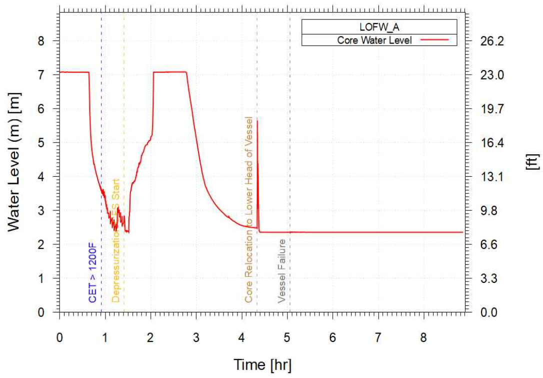

Fig. 8. Core water level of LOFW_A

For the case of LOFW_B, the external injection of emergency cooling water into RCS was initiated immediately upon reaching the external injection pressure of the RCS at 7,802 seconds, the vessel failure can be prevented. As depicted in Figure 9~12, at the moment when RCS pressure reaches the pressure for external injection, immediate external injection is carried out, leading to the recovery of the core level.

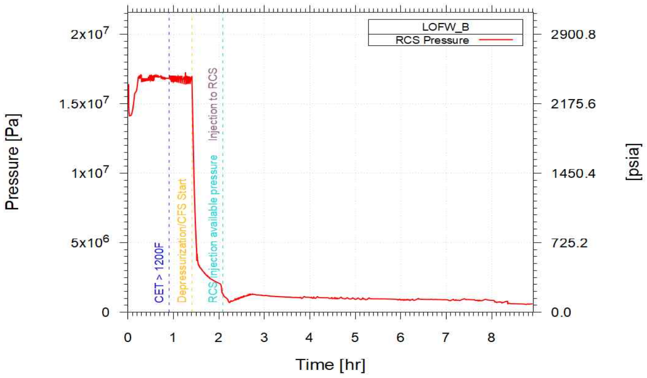

Fig. 9. RCS pressure of LOFW_B

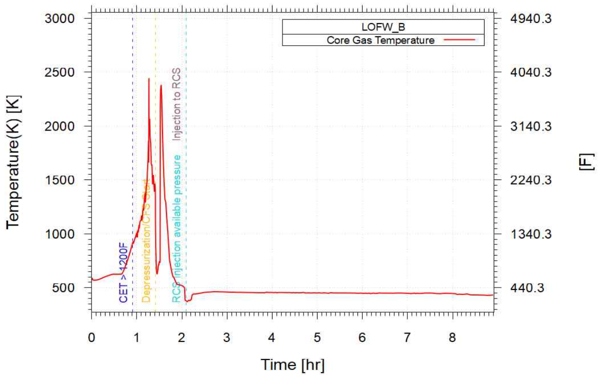

Fig. 10. Core gas temperature of LOFW_B

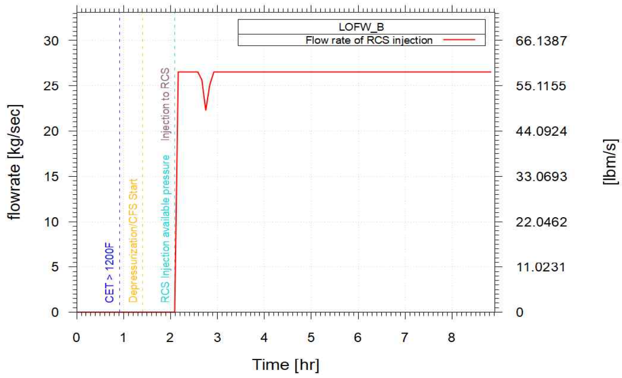

Fig. 11. Flow rate of RCS injection of LOFW_B

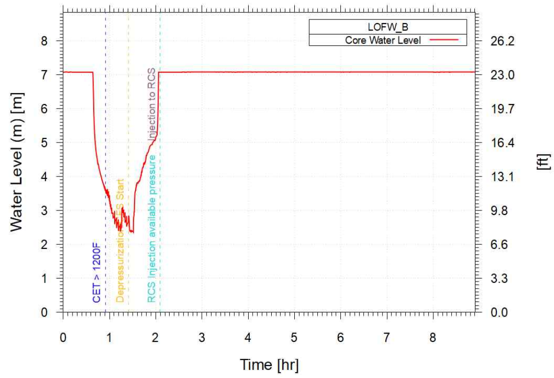

Fig. 12. Core water level of LOFW_B

In the case of LOFW_C, we conservatively assumed that the external injection of emergency cooling water into RCS was initiated with 2-hour delay after reaching the external injection pressure. So, the external injection was initiated at 11,727 seconds (3.26 hours) after entering a severe accident, and the vessel integrity was maintained. As shown in Figure 13~16, the initiation of external injection with 2-hours delay even if the RCS pressure reaches the pressure for external injection, can mitigate the in-vessel condition and protect the vessel integrity.

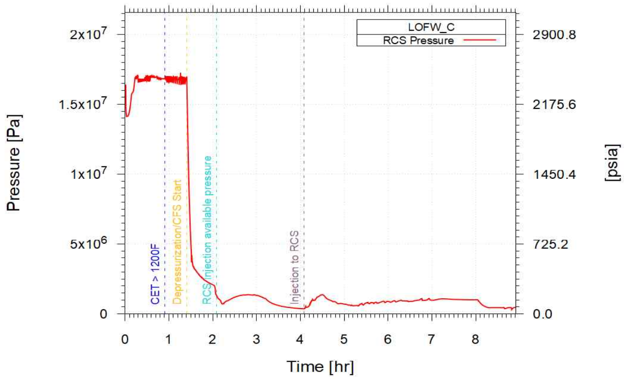

Fig. 13. RCS pressure of LOFW_C

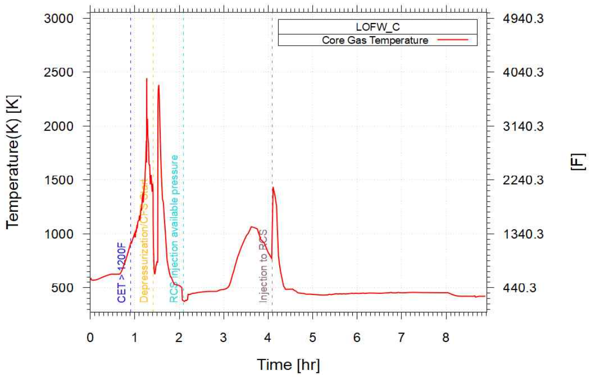

Fig. 14. Core gas temperature of LOFW_C

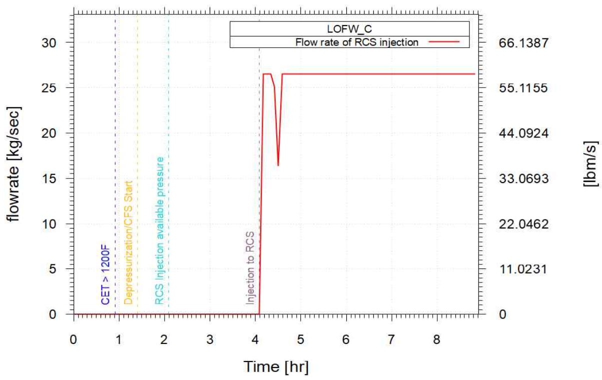

Fig. 15. Flow rate of RCS injection of LOFW_C

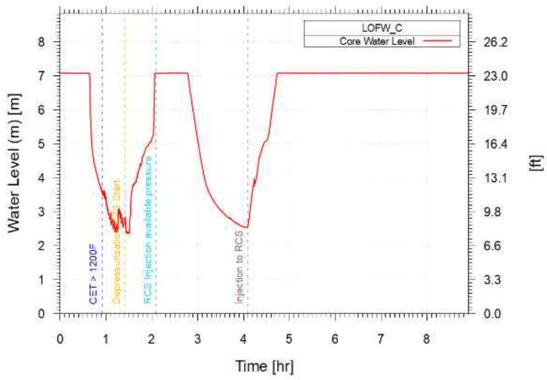

Fig. 16. Core water level of LOFW_C

From the previous analysis for low pressure accident sequence, such as LLOCA, it is known if the external injection of emergency cooling water into RCS will be performed within approximately 1.5 hours after the entry of severe accident, the integrity of reactor vessel can be maintained.

In the case of high pressure accident, such as LOFW, we can find the additional margin about 1.7 hours for the protection of pressure vessel.

4. Conclusion

During the development process of DPG based SAMG in KHNP, so many analyses were planned to be conducted to assess the impact of applying revised emergency actions for the low-pressure and high-pressure accidents scenarios. Also, the sensitivity study for the delayed mobile equipment deployment should be included in order to find the appropriate timing of operator action to protect reactor pressure vessel.

Unlike low-pressure accidents that require the fast mitigation actions, it is found that the timing of RCS injection in high-pressure accidents scenarios have some margins. It was also observed that without external emergency cooling water injection into RCS, vessel failure occurred at approximately 4.14 hours after severe accident initiation. However, with RCS injection initiated at around 3.26 hours after the entry of severe accident, the vessel integrity can be preserved. This analysis results can give the insight for the strategies using the mobile equipment in the early stage of SAMG, such as emergency actions. In the future, the more analysis for the various conditions should be performed including the sensitivity and uncertainty analysis. And, these insights and results should be utilized in the project for developing the new SAMG based on the PWROG SAMG(2016).

REFERENCES

[1] Mi-Ro, Seo, "Evaluation of Key Components for Improvement of Domestic SAMG", KNS Autumn Meeting, 2022