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Preliminary Evaluation of effectiveness of External Injection Strategy during TLOFW

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1. Introduction

An Emergency cooling water External Injection System (EEIS) cools the reactor coolant system (RCS) as an emergency means in case of a severe accident due to various combination of initial events that cause the long term unavailability of the emergency core cooling system (ECCS) and Steam Generator (SG) Main Feed Water System.

The system is designed to ensure that the heat generated from the core is removed to maintain the integrity of the reactor vessel in the case of the primary side and to maintain water level above the upper end of the tube of the steam generator in order to control the release of fission products from Steam Generator.

In order to use EEIS, it is necessary to depressurize the RCS and the secondary side of the SG. In the OPR1000 type nuclear power plant, it is possible to reduce the pressure by using the Safety Depressurization System valves (SDVs) and the Main Steam Atmospheric Dump valve (MSADV).

MAAP 5.03 computer code [1] was used in this evaluation. For Total Loss of Feed Water (TLOFW) scenarios, which are high pressure incidents as with the SBO accidents, preliminary evaluation of the effectiveness of the EEIS strategies has been carried out. Through the evaluation results, various insights on a severe accident management strategies could be derived.

2. Methods and Results

2.1 Computer Code

MAAP 5.03 computer code [1] was used to evaluate the effectiveness of the EEIS. The MAAP code is a computer code that comprehensively simulates the performance of the RCS and the containment. It Includes models for all important phenomena that can occur during severe accident such as core damage, reactor vessel failure, containment overpressure. It also includes models for ESF facilities such as ECCS, Auxiliary Feed Water Systems (AFWS), Containment Spray Systems (CSS), and can simulate severe accident mitigation strategies.

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2.2 Accident scenario

For all scenarios, a failure of the ESF facility except for safety injection tank (SIT) passive injection is assumed. The primary and secondary side inflows set the pressure at which the minimum injection flow rate could be secured. The maximum injection flow rate increased with decreasing RCS pressure, but was limited to the minimum injection flow rate. The injection strategy for the primary and secondary sides was assumed to be 30 minutes after entering the severe accident considering the operator action time. In order to prevent damage to the steam generator tube according to the OPR1000 type SAMG, the amount of feed water was limited to 100 gpm during the initial 10 minutes [2, 3].

In Scenario 1, only EEIS strategy for the RCS is selected and it is simulated that two SDVs were used to depressurize the RCS. In Scenario 2, only EEIS strategy for the secondary side of the SGs is selected and it is simulated that two MSADVs were manually operated as SG's depressurization means. In case of a severe accident where most of the coolant in the RCS is exhausted, the effect of heat removal using the SGs may not be great. Therefore, Scenario 3, which is an accident scenario in which SIT is injected through opening of one SDV, is added. In Scenario 4, it is simulated that only one SG is used using one external injection system. The purpose of EEIS is to recover the core cooling and water level for the RCS and to control the release of radioactive material as well as the decay heat for the secondary side of the SG. Therefore, a severe accident management guidelines (SAMGs) has been developed so that the emergency cooling water can be simultaneously injected into the RCS and the secondary side of the SGs if the injection means is available [3]. In addition, the depressurization of the RCS may not be sufficient at the time of a high pressure accident, so simultaneous injection of the secondary side of the SG may help depressurize the RCS and mitigate accidents. Scenario 5, which is simulated that one SDV is opened, is selected to figure out the effect of the EEIS strategy of secondary side of SGs on decompression of the RCS. Scenario 6 was selected for the accident scenario in which only one SG was injected. Table 2-1 shows detailed description of each scenarios.

2.3 Results

As a result of the evaluation of Scenario 1, the heat removal of the core was successful, the core outlet temperature was reduced below the SAMG termination condition, the reactor core level was restored and the integrity of the reactor vessel was ensured, in the secondary injection scenario, the design goal of recovery of the SGs level was satisfied. However, performance as a primary heat sink was different for different scenarios. In Scenario 2, which does not simulate the opening of the SDV, the SIT is not injected because the primary side decompression is insufficient and the recovery of the core level is also limited. However, it was found that the reactor vessel breach did not occur. In Scenario 3, the SIT coolant was injected by decompressing the RCS using a SDV. As the SIT was injected, the core water level recovered and the core outlet temperature decreased. In Scenario 4, the recovery rate of the SGs is slow, but the core decay heat is appropriately removed, so that the core outlet temperature is reduced to below the SAMG termination condition and the core water level is recovered by the cooling water injection of the SITs. According to the evaluation results, it was confirmed that the injection of the secondary side exerts an influence on the RCS depressurization rate and facilitates the external injection of the primary side. Also, it was evaluated that it is possible to inject the emergency cooling water into the RCS even if the emergency cooling water is injected into only one SG, thereby contributing to ensuring the integrity of the reactor vessel. Therefore, if the means is available, it is advantageous in terms of severe accident management that the RCS and secondary emergency cooling water external injection strategies are simultaneously performed. and It was evaluated that the reactor core can be cooled and recovered even when an emergency cooling water should be injected into only one SG. Table 2-2 shows the severe accident progresses by accident type

3. Conclusions

The EEIS is designed to inject coolant into the RCS and the SG secondary side to ensure the integrity of the reactor vessel and restore and maintain the water level of the SGs. In this analysis, it was confirmed that emergency cooling water can be injected into the RCS and the SG secondary sides by analyzing various accident situations. In addition, if the external injection is successful, the core is cooled and the water level of the core is restored and the reactor vessel integrity is secured. However, it was confirmed that it is effective to mitigate the accident by simultaneously supplying emergency cooling water to the RCS and the SG secondary sides. The results of this evaluation can be used as technical backgrounds of SAMG and other materials for operator training.

Table 2-1: Scenario Descriptions

CONDITION	RCS	SG(S)	SDV	MSADV
Scenario 1	1	-	2	-
Scenario 2	-	2	-	2
Scenario 3	-	2	1	2
Scenario 4	-	1	1	1
Scenario 5	1	2	1	2
Scenario 6	1	1	1	1

Table 2-2: The result of the evaluation

EVENT	S-1	S-2
Reactor Trip	43	43
Core Uncovered	2,866	2,866
SAMG entry	4,471	4,471
SG External water injection	-	6,321
SDV open	6,271	-
RCS External water Injection	8,483	-
SIT Depletion	23,520	45,547
Core recovered	23,534	45,582
SAMG termination condition	22,865	46,574
SG water level recovered	-	32.243
Core Relocation	-	-
RV Fail	-	-

EVENT	S-3	S-4
Reactor Trip	43	43
Core Uncovered	2866	2866
SAMG entry	4,471	4,471
SG External water injection	6,321	6,321
SDV open	6,271	6,271
RCS External water Injection	-	-
SIT Depletion	20,769	-
Core recovered	8,458	8,847
SAMG termination condition	9,768	10,354
SG water level recovered	28,583	63,637
Core Relocation	-	-
RV Fail	-	-

EVENT	S-5	S-6
Reactor Trip	43	43
Core Uncovered	2866	2866
SAMG entry	4,471	4,471
SG External water injection	6,321	6,321
SDV open	6,271	6,271
RCS External water Injection	7,801	8,545
SIT Depletion	14,002	18,325
Core recovered	8,080	8,849
SAMG termination condition	8,833	10,557
SG water level recovered	25,953	38,358
Core Relocation	-	-
RV Fail	-	-

REFERENCES

[1] EPRI, “Modular Accident Analysis Program (MAAP5) Version 5.03 Windows,” Fauske & Associates, Inc, August 2014.
[2] EPRI, "Technical Report, Severe Accident Management Guidance - Technical Basis Report, TR-1025295," dated October 2012
[3] KHNP, “Final Report for Development of LPSD Severe Accident Management Guidelines,” Dec. 2016.