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Sensitivity Analysis for Emergency Cooling Water External Injection Strategy during SBO

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1. Introduction

After the accident at Fukushima nuclear power plant in Japan, a comprehensive safety check on the safety of domestic nuclear facilities was conducted assuming the worst accident scenarios in Korea. As part of measure to enhance the safety of severe accidents, the installation of the emergency cooling water external injection system was included.

The external injection system is designed to inject a minimum flow rate when the RCS pressure is reduced based on the design criterion that the heat generated from the core is removed in order to guarantee the integrity of the reactor vessel in the case of the primary side.

The system is also designed to inject the cooling water into the secondary side of the Steam Generator (SG) to remove the heat generated from the core and to control the release of the fission product through SGs.

In order to use the external injection equipment as described above, it is necessary to depressurize the RCS and the secondary side of the SG. In OPR1000 type nuclear power plant, depressurization is possible by using the safety depressurization system (SDS) valves and the SG atmosphere dump valves (ADV).

In this paper, the analysis was carried out based on the premise that the primary and secondary side external injection facilities are used as the last means in the event of a severe accident in which the core damage has progressed. In addition, the time of access was considered in consideration of the accessibility of mobile equipment due to extreme natural disaster.

2. Methods and Results

2.1 Selection of the Accident Scenario

A station black out (SBO) sequence was performed using OPR1000 MAAP5.03[1] parameter file. For this sequence as a base case, no AFW is modeled, and a loss of AC and DC power is the sequence initiator at time zero. An RCPs seal LOCA on each loop is modeled to occur 45 minutes after the station blackout is initiated, with a leakage area of 0.00004m^2 per loop.

2.2 Analysis of base case

For this scenario, the accident progression is fairly straight forward. Following the SBO initiation, the reactor vessel pressure increases as the primary system and SG water inventories are slowly boiled off over the first hour of the blackout. The combination of the primary system inventory loss through the pressurizer safety valves and out the seal LOCAs eventually leads to core uncover, fuel heat up, hot leg creep rupture, core melt, and eventual core relocation to the lower plenum. Table 1. summarizes these key event timings.

After the SG dry out at 4.639s, the RCS pressure increases to the pressurizer safety valve set-point, and begins oscillating between the pressurizer safety valve dead-band. The RCS remains in this condition until the core uncovers and begins to heat up, leading to the flow of hot gases up through the core and into the hot legs by counter current exchange flow. As a result of prolonged exposure to the hot gases, a “creep rupture” of the hot leg at around 1,2960s. Once the hot leg fails by creep, the RCS depressurizes rapidly and SITs discharge.

After the core becomes uncovered, it starts to heat up. The core support plate fails and the molten fuel slumps into the lower plenum at around 23,004s. The vessel fails shortly thereafter at around 29,160s.

Key Event Description	Result
SG dry out (s)	4,639
Core uncovered (s)	7,852
SAMG entering (s)	9,149
H/L Creep rupture (s)	12,960
Core Relocation (s)	23,004
Vessel Failure (s)	29,160

Table 1. Key Event Summary for SBO case

2.3 Effectiveness of External Injection Strategy

Sensitivity analysis was performed to evaluate effects of the external cooling water injection timing. In case of external injection strategy into the primary system, injection timings were divided into 30,60,90 minutes after entering the severe accident. And it was simulated that two pressure safety depressurization valves were opened manually after a severe accident. The detailed accident progression is shown in table 2.

In case of external injection strategy into the secondary side of the SG, the injection timing was the same as that of the primary system, and it was simulated that a SG ADV opened manually after a severe accident.

Table 3. summarizes the key event timings for these sequences.

Key event description	Case1	Case2	Case3
Injection timing (s)	SA+1,800	SA+3,600	SA+5,400
SDS opening	2	2	2
SG dry out (s)	4,667	4,667	4,667
Core uncovered (s)	7,908	7,908	7,908
Hot leg creep rupture (s)	-	-	12,975
Core relocation (s)	-	-	22,912
Vessel failure (s)	-	-	-

Table 2. Key Event Summary for SBO case with the Primary system External Injection

Key event description	Case4	Case5	Case6
Injection timing (s)	SA+1,800	SA+3,600	SA+5,400
ADV opening	1	1	1
SG dry out (s)	4,667	4,667	4,667
Core uncovered (s)	7,908	7,908	7,908
Hot leg creep rupture (s)	-	13,306	13,284
Core relocation (s)	-	25,666	23,896
Vessel failure (s)	-	35,794	31,548

Table 3. Key Event Summary for SBO case with the Secondary System External Injection

2.3 Result of Analysis

If a primary system external injection is possible within 90 minutes in case of the selected accident scenario, the core heat removal is successful and the core outlet temperature is decreased. The core water level is restored. The integrity of the reactor vessel was intact. However, the relocation of the corium may occur if cooling water is injected 60 minutes after entering severe accident as shown in table 2.

In order to ensure the integrity of the reactor vessel, it was confirmed that the external injection of the emergency cooling water into the SG should start within 30 minutes after a severe accident as shown in table 3. Once the hot leg experiences creep rupture, the combination of the RCS depressurization and inventory loss, the natural circulation of the RCS does not occur when it eventually fails.

3. Conclusions

Emergency Cooling Water External Injection system is designed to meet criteria guaranteeing the integrity of the reactor vessel and restoring and maintaining the water into RCS and the secondary side of the SG by using separate path. According to the results of the analysis, the injection timing after a severe accident was derived through sensitivity analysis. The analysis results for the OPR1000 type nuclear power plant can be used as a technical background for the emergency cooling water external injection strategy and can provide insights for revising and preparing accident management plan.

REFERENCES

[1] EPRI, “Modular Accident Analysis Program (MAAP5) Version 5.03 – Windows,” Fauske & Associates, Inc, August 2014.