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RCS Response Analysis Depending on RCP Seal Leakage for ELAP Event

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1. Introduction

Station Black Out (SBO) is initiated by simultaneous Loss of Offsite Power (LOOP) and operational failure of both Emergency Diesel Generators (EDGs). In such cases, the primary operator action is required to recover Alternative Alternating Current (AAC) power by manually operating an AAC Diesel Generator (AAC DG). If the AAC DG is also unavailable, the plant remains inoperable from all AC power recovery over the long term, and Extended Loss of AC Power (ELAP) occurs.

In the ELAP event, only active systems powered by Direct Current (DC) from batteries and passive systems such as Turbine Driven Auxiliary Feed Water Pumps (TD-AFWPs) could work [1]. In such conditions, the Component Cooling Water System (CCWS) and Charging Pumps (CPs) are not available. CPs provide seal injection water to the Reactor Coolant Pumps (RCPs) to prevent the leakage of coolant through the RCP shaft and cool the seal cartridge. Stoppage of seal injection flow can cause the inflow of coolant into the seal cartridge, which result in exposing the RCP seals at a high temperature. Maintaining the RCP seals at a high temperature will degrade seal materials and increase leak rates. The continuous loss of the Reactor Coolant System (RCS) inventory could bring about core uncovery and damage [2].

This paper presents the RCS response analysis for the ELAP scenario. Comparative case study covers two cases according to the RCP seal leakage. The target scenario follows coping strategies presented in a Stress Test Report for Hanul Unit 3&4 [3].

2. Methods and Results

2.1 ELAP coping strategy

Coping strategies are established to keep the pressure boundaries of the RCS, appropriately cool down the reactor core for avoiding fuel damage, and maintain the integrity of the containment building in the transient conditions with the events of loss of safety functions.

Table 1 shows a series of ELAP coping strategy until completion of connecting a 1 MW mobile generator to cope with total loss of AC power according to the stress test guideline of Nuclear Safety and Security Commission (NSSC) [4].

It is assumed that a RCP seal leakage coincides with loss of all AC power, leading to stoppage of seal injection flow to RCPs. The seal leak rate is assumed to be 25 gpm (1.58 ℓ/s) per one RCP. The RCP seal leaks are completely stopped by activating CPs after recovering AC power by connecting of the 1 MW mobile generator.

2.2 Analysis method

The nodalization diagram of the target system is shown in Fig. 1. The power plant is modeled with 243 fluid cells, 378 faces and 497 heat structures.

Table 1. Sequence of events

Time	Event	Set value
0 sec	Initiating event	SBO
0 sec	Rx trip	
0 sec	RCP trip	
0 sec	Turbine trip	
0 sec	Start of RCP seal leakages	25 gpm/RCP
45 sec	Main Steam Safety Valves (MSSVs) open	SG pressure: 8.618 MPa
10 min	Fail to operate AAC DG	ELAP
27 min	Start of a TD-AFWPs operation	SG level: 23.6 %
30 min	Completing load shedding	
2 hr	Atmospheric Dump Valves (ADVs) open	Cooling rate: 50 °F/hr
8 hr	Completing connection of a 1 MW mobile generator	

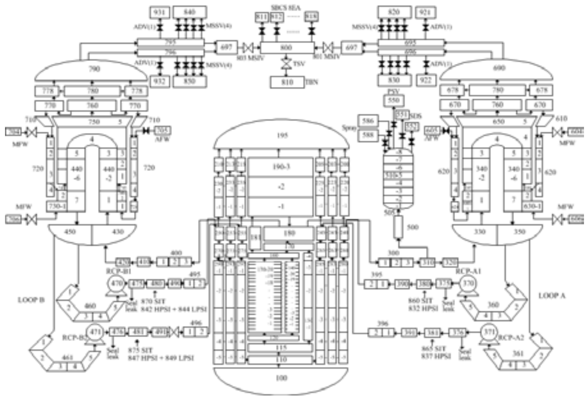

Fig. 1. Nodalization diagram of SPACE code for OPR 1000

We use the SPACE code for analyzing the thermal hydrodynamic behavior of Hanul Unit 3&4 in transient conditions. The SPACE is an advanced thermal hydraulic analysis code capable of analyzing two-fluid and three-field models [5]. The 3.12 version of SPACE code is used in the analysis.

2.3 Analysis results

Two transient cases are analyzed in this study. For Case 1, we consider an initial seal leakage rate of 25 gpm (1.58 ℓ/s) per one RCP. Case 2 assumes that a RCP seal leakage does not occur during the ELAP event.

Fig. 2 and 3 compares pressure and water level changes of the pressurizer, respectively. Transient behavior of two cases shows obvious differences depending on the RCP seal leakage. In Case 1, the pressurizer pressure and water level are rapidly reduced from the beginning of the event due to the continuous loss of the RCS inventory by the seal leakage. The water level of the pressurizer in Case 1 is completely empty within one hour. On the other hand, the pressure and water level of the pressurizer in Case 2 are initially maintained and start to decrease after ADVs open. The water level in the pressurizer is totally exhausted after three hours.

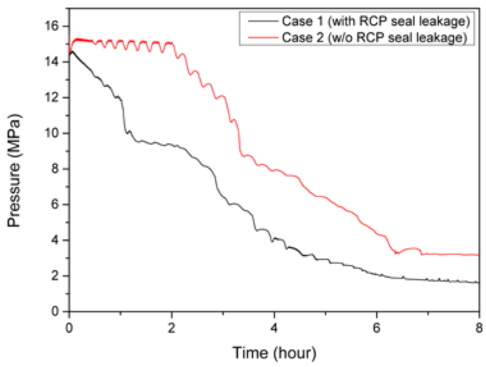

Fig. 2. Pressurizer pressure

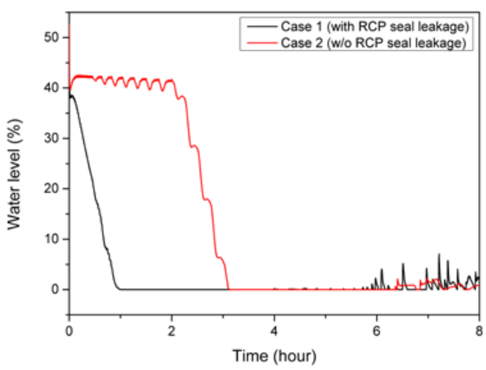

Fig. 3. Pressurizer water level

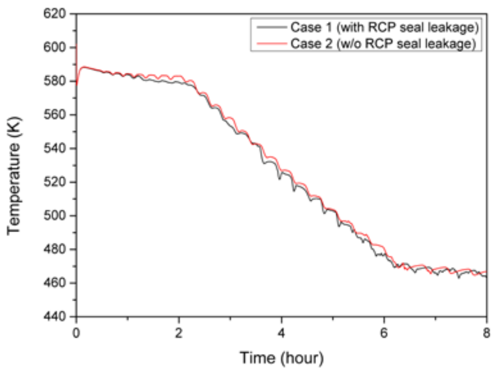

Fig. 4. Hot legs temperature

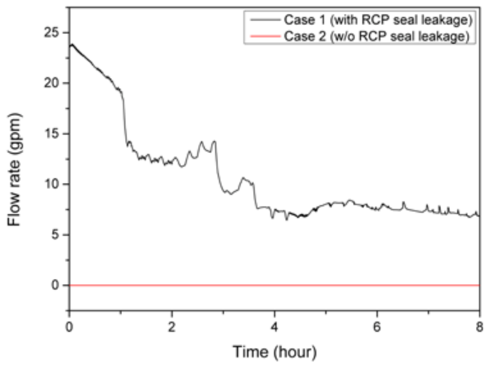

Fig. 5. RCP seal leak rate

Fig. 4 shows temperature changes of hot legs for both cases. The results of Case 1 and Case 2 are similar in overall trend. For the first two hours, hot legs temperature is maintained, but starts to decrease after the plant cooling begins. The cooling rate is 50 ˚F/hr (27.8 ℃/hr) as described in Table 1.

Variations of the RCP seal leak rate for one RCP are shown in Fig. 5. In Case 1, the seal leak rate continues to decrease as pressure of the primary system is reduced. On the contrary, the seal leakage does not occur in Case 2 for the entire duration of the event.

The changes of core collapsed water level for both cases are depicted in Fig. 6. In Case 1, the abrupt drop of the core collapsed water level is observed at the early stage due to rapid depletion of the pressurizer water level. On the other hand, the core collapsed water level of Case 2 starts to decrease two hours later than that of Case 1. In both cases, however, the core collapsed water level does not reach the top of the active core. Thus, core degradation and melting due to the core uncovery do not occur during the event. When the pressurizer pressure decreases to the set point of Safety Injection Tank (SIT) activation, the core collapsed water level starts to recover as shown in Fig. 2 and Fig 6.

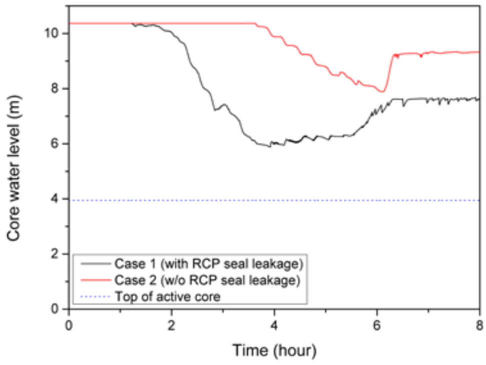

Fig. 6. Core collapsed water level

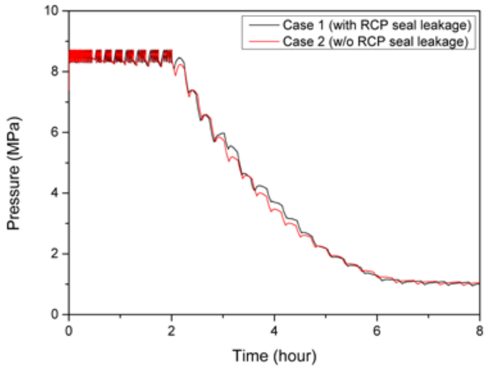

Fig. 7. Steam generator pressure

The pressure behavior of steam generators (SGs) during the event period shows no meaningful differences between two cases as shown in Fig. 7. In both cases, the pressure of SGs is maintained during the first two hours by opening MSSVs and starts to decrease after ADVs open.

3. Conclusions

This study presents the RCS response analysis for Hanul Unit 3&4 in the ELAP event. We particularly paid attention to an effect of the RCP seal leakage causing the continuous loss of the RCS inventory. Two cases depending on consideration of the RCP seal leakage were compared for the case study.

The RCP seal leakage had a great effect on the primary pressure and inventory conditions. The primary pressure rapidly decreased at the beginning of the event when considering the RCP seal leakage. The abrupt drop of the core collapsed water level was also observed from the early stage due to rapid depletion of the pressurizer water level. However, the core uncovery did not occur during the entire event by following coping strategies presented in this paper.

The target leakage rate did not affect the plant cooling strategy using ADVs. The secondary side conditions also presented no meaningful differences between two cases when assuming the leak rate of 25 gpm (1.58 ℓ/s) per one RCP.

Sensitivity studies on the RCS response depending on various seal leakage rates need to be performed for further work.

REFERENCES

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