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Feasibility Study on High-Pressure Mobile Pump as Back-up Strategy for RCS Make-up in ELAP Event

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1. Introduction

The extended loss of AC electric power (ELAP) event has been defined as one of the consequent scenarios initiated by natural disasters. In the accident scenario, the passive accident coping measures play an essential role and the function, operational range and capacity of passive system could be significant factors to the transient and strategy [1]. The component cooling water system (CCWS) and charging pumps (CPs) providing seal injection water to the reactor coolant pumps (RCPs) are also not available. In such conditions, the continuous loss of the inventory could occur in the reactor coolant system (RCS) through RCP seal leakage.

Early cooldown and depressurization of the RCS can minimize the inventory loss through the RCP seals and provide rapid RCS make-up through the injection of borated water from the safety injection tanks (SITs). According to the coping strategy of the ELAP event, RCS cooldown and depressurization are conducted via main steam release to the atmosphere through the main steam safety valves (MSSVs) and/or atmospheric dump valves (ADVs) of the main steam supply system. RCS temperature will decrease to approximately 460 K near by the entry condition of the shutdown cooling system. Available auxiliary feed water pumps (AFWPs) will continuously supply water flow to steam generators (SGs) to make-up for steam release.

Operators will regulate ADVs to control the amount of the steam release and the RCS cooldown rate as necessary. Because all AC power is not available, ADVs should be operated by local manual control during the ELAP event. If the ADV local control is not available, the RCS will not be depressurized and reach the injection pressure of SITs. In such cases, the back-up strategy should be necessary to compensate for RCS inventory loss to avoid core uncovery and damage.

2. MACST strategy

Table 1. MACST Strategy

Phase No.	Coping strategy
Phase 1 (~ 8 hr)	Installed equipment
Phase 2 (8 ~ 72 hr)	MACST facilities supplementing installed equipment
Phase 3 (72 hr ~)	All on/off-site equipment

The multi-barrier accident coping strategy (MACST) has been developed to prevent the severe accident when beyond-design-basis natural disasters occur. There are three phases depending on coping strategies as shown in Table 1.

In Phase 1, the plant copes with the installed equipment, such as DC power and natural circulation cooldown through SG by the available auxiliary feed water pumps up to at least 8 hours.

In Phase 2, a 1 MW mobile generator is connected within at least 8 hours after initiating the event and supplies AC power to the CPs. Since then the seal leakage is stopped by providing the seal injection water to the RCP seals from the CPs. The core level is also gradually recovered.

If the ADV local control and connecting the mobile generator are failed in both Phase 1 and 2, the RCS inventory will continuously decrease and the RCS make-up by SITs and CPs will not be available. Therefore, the back-up strategy for the RCS make-up should be necessary to avoid core uncovery and damage.

The high-pressure mobile pump, with a nominal flow rate of 40 gpm at 1500 psig, will be equipped for primary inventory make-up and boration during Phase 2 in case of a failure of RCS depressurization, SIT injection, and CP operation.

In this study, we examine the feasibility of the MACST strategy using the high-pressure mobile pump with above situations by assuming a failure condition of ADV local control in Phase 1 and connection of the mobile generator in Phase 2. The target plants are Hanbit Units 3&4 and other conditions for the target scenario are adopted from coping strategies presented in a Stress Test [2].

3. Results and Analysis

3.1 Analysis conditions

Table 2 shows a major sequence in Phase 1 and Phase 2 of the ELAP event. We assumed a failure of ADV local control and connection of the mobile generator to create a situation using the high-pressure mobile pump for RCS make-up during Phase 2. It is assumed that the high-pressure mobile pump is successfully connected at 8 hours after initiating the event and starts operation in 15 minutes after the connection.

Table 2. Sequence of events

Phase	Time	Event
Phase 1	0 sec	Initiating event
	0 sec	Rx trip
	0 sec	RCP trip
	0 sec	Turbine trip
	0 sec	Start of RCP seal leakages
	8 sec	Main Steam Safety Valves (MSSVs) open
	10 min	Fail to operate AAC DG
	17 min	Start of AFWPs operation
	30 min	Completing load shedding
	2 hr	Failure of RCS cooldown using ADVs
	8 hr	Completing connection of high-pressure mobile pump
Phase 2	8 hr 15 min	Activating high-pressure mobile pump
	8 hr 30 min	Preparing connection of 3.2 MW mobile generator
	72 hr	Completing connection of 3.2 MW mobile generator

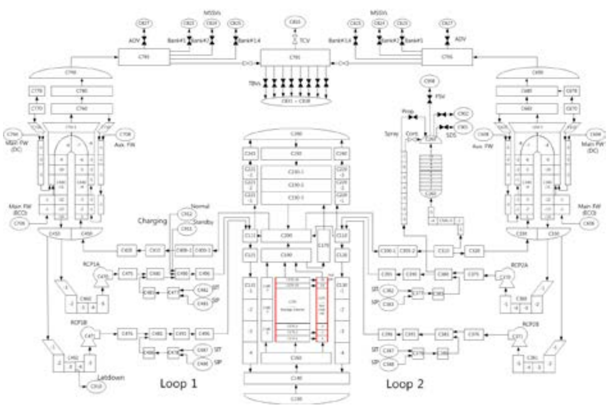

Fig. 1. Nodalization of Hanbit Units 3&4

A RCP seal leakage is assumed to coincide with event initiation caused by stoppage of seal injection flow to RCPs. The initial seal leak rate is assumed to be 25 gpm (1.58 ℓ/s) per one RCP. The transient calculation is performed for 259,200 seconds (72 hours), until the end of Phase 2.

3.2 Analysis method

To analyze the thermal hydrodynamic behavior of the Hanbit Units 3&4, RELAP5 Mod 3.3 is used [3]. The nodalization diagram of the Hanbit Units 3&4 is shown in Fig. 1.

3.3 Transient analysis results

Transient behavior of pressurizer pressure during Phase 1 is shown in Fig 2. The pressurizer pressure decreases from the beginning of the event due to the continuous leakage of the RCS inventory through the RCP seals, and then is maintained between 8.3 ~ 9.0 MPa (1190 ~ 1290 psig) without opening ADVs at the end of Phase 1.

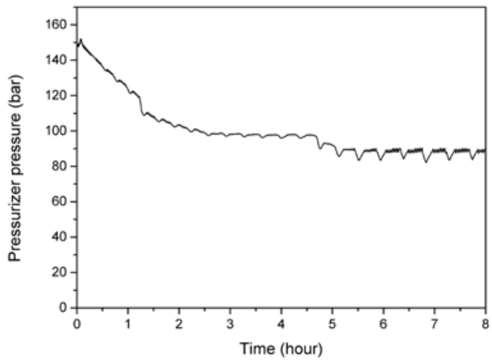

Fig. 2. Pressurizer pressure (Phase 1)

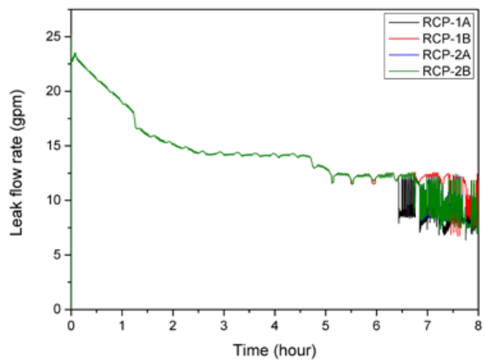

Fig. 3. Flow rate of RCP seal leak (Phase 1)

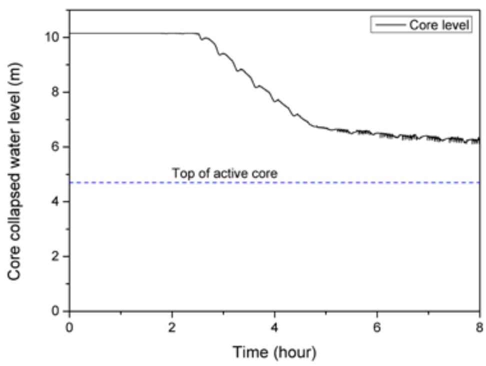

Fig. 4. Core collapsed water level (Phase 1)

The RCP seal leak rate for four RCPs during Phase 1 are shown in Fig. 3. A tendency of the leak rate coincides with transient behavior of pressurizer pressure. The leak rate starts to oscillate between 6 and 12 gpm after 6 hours because the upstream of the RCP seal becomes two phases and the core level is reduced to the cold leg elevation.

The level in the reactor core is shown in Fig. 4. The core collapsed water level starts to decrease from 2.5 hours after initiating the event due to the continuous loss of the RCS inventory. The core uncovery does not occur during Phase 1.

At the end of Phase 1 which is the time of connecting and activating the high-pressure mobile pump, RCS pressure is kept at maximum 9.0 MPa (1290 psig) and RCP seal leak rates show an oscillatory behavior with an average of 10 gpm. These conditions are consistent with the design specifications of the high-pressure mobile pump.

To control reactivity and make up RCS inventory, Phase 2 strategy using MACST facilities should be performed within 8 hours after the event. Fig. 5 shows transient behavior of pressurizer pressure during Phase 1 and Phase 2. In Phase 2, pressurizer pressure is kept at approximately 9.2 MPa (1320 psig) and the high-pressure mobile pump continues to function.

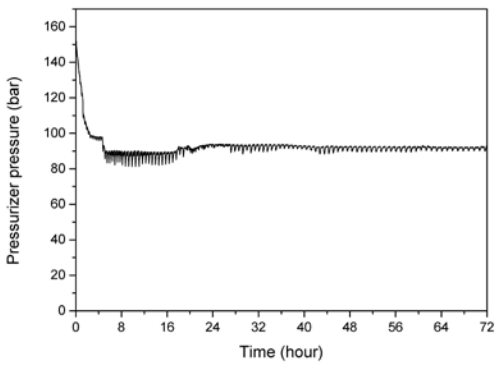

Fig. 5. Pressurizer pressure (Phase 1 and Phase 2)

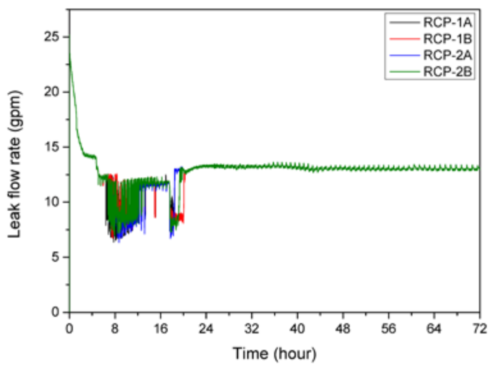

Fig. 6. Flow rate of RCP seal leak (Phase 1 and Phase 2)

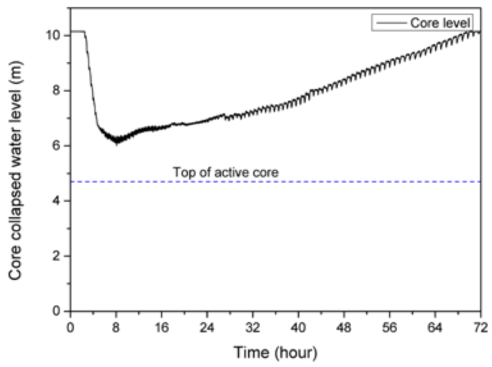

Fig. 7. Core collapsed water level (Phase 1 and Phase 2)

The RCP seal leak rate for each RCP during Phase 1 and Phase 2 are shown in Fig. 6. The oscillation of the flow rate is stopped after the upstream of RCP seal become a single phase and the core level increase above the cold leg elevation.

The core collapsed water level are shown in Fig. 7. Since the charging rate (approximately 2.51 kg/s) for RCS inventory make-up is larger than the rate of inventory loss (approximately 2.37 kg/s) through RCP seals, the inventory of RCS is gradually recovered. When taking into consideration that the initial flow rate of the RCP seal leak is conservatively estimated at 25 gpm, the high-pressure mobile pump can give the entire satisfaction as the back-up strategy for RCS make-up.

3. Conclusions

This study examined the feasibility of the MACST strategy using the high-pressure mobile pump having a capacity of 40 gpm at 1500 psig in the ELAP event. To verify the strategy, we assumed both failure of RCS cooldown and depressurization by ADVs in Phase 1 and a subsequent failure of the 1 MW mobile generator in Phase 2.

It is confirmed that the RCS pressure could be kept at maximum 9.0 MPa (1290 psig) and the seal leak rate for one RCP was approximately 10 gpm at the end of Phase 1 through the simulation with RELAP5 code. It is concluded that these RCS conditions were sufficient to provide RCS make-up and boration using the high-pressure mobile pump in Phase 2 and the core water level could be fully recovered before entering Phase 3.

REFERENCES

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