Feasibility Assessment of Operator's action using HEMS during SBLOCA in APR1400

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1. Introduction

After the Fukushima Daiichi accident, the various passive or inherent safety systems are developed for mitigating the accidents and preventing core meltdown. In South Korea the Advanced Power Reactor Plus (APR+) reactor design was developed and the standard design approval was gained from Korea Institute of Nuclear Safety (KINS) in August 2014. The APR+ adopted a passive auxiliary feedwater system (PAFS) as the secondary cooling system for enhancing the safety of APR+. In order to further improve the safety of nuclear power plants under Fukushima-like accident conditions, a high-pressure emergency system (HEMS) was developed in 2018. The HEMS is a system that provides the core damage delay time by operating in accidents causing the high-pressure condition of the reactor coolant system (RCS). The HEMS is designed for 1500MW advanced nuclear power plant, APR+ and has been confirmed that it can be also utilized to enhance the safety of APR1400 reactor during a station blackout accident (SBO) [1]. According to the probabilistic safety assessment (PSA) results of APR1400 reactor, the main initial events affecting safety were SBO and small break loss of coolant accident (SBLOCA) and the high pressure of the RCS could be caused during the accidents.[2] This study focuses on the feasibility assessment of operator's action using HEMS during SBLOCA to further enhance the safety of APR1400 reactor.

2. Conceptual design of HEMS

The SITs such as accumulators in the commercial nuclear power plant are designed to inject the cooling water into the RCS when the pressure of the RCS reached 4 MPa. If the RCS pressure keeps increasing, the cooling water in the accumulators could not use to cool down the RCS and to mitigate the accident. So the HEMS are developed to provide the cooling water to reactor core on condition of high pressure accidents. A conceptual design of HEMS is given in Fig. 1. [3]

It consists of the 4 hybrid SIT, pressure balance line (PBL) and operation valves. The hybrid SIT is connected between the top of the conventional SIT and the top of the pressurizer (PZR) and is connected the direct vessel injection (DVI) nozzle through check valve. Following the opening of the operation valve, the pressure of the hybrid SIT is equalized with that of the PZR and the coolant in the hybrid SIT is injected into the reactor by the head difference between the hybrid SIT and the RCS. [2]

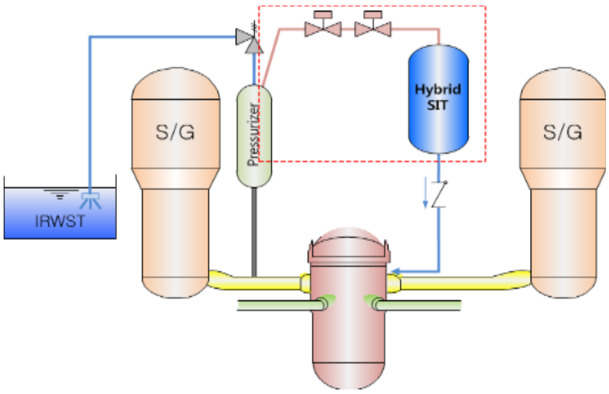

Figure 1. Conceptual design of HEMS

3. Analysis method and results

3.1 Transient scenarios and code model for analysis

For the analysis, the test cases and scenarios are described as follows and derived from the event tree of SBLOCA in APR1400 PSA. If the safety injection system fails after the reactor trip, the operator could cool down the RCS by the aggressive secondary cooldown (ASC). When the auxiliary feedwater is supplied to the SG and the steam from the SG releases via ADVs (atmospheric dump valves) for the ASC, the RCS pressure rapidly decreases to the condition of shutdown cooling and the long-term cooling operation using the shutdown cooling system could prevent the core damage. It was performed to assess the impact of the operator's action using HEMS before the ASC operation when the operation of safety injection system fails during SBLOCA.

a. Break
  - Coldleg break with an inside diameter of 1.97 inch.

b. System conditions and assumptions
  - All safety injection pumps are unavailable.
  - HEMS is available and is operated at the time when the ASC operation is required. (1800sec)

The hybrid SITs' coolant of HEMS is sequentially injected as 4, 3, 2 and 1 order. The hybrid SITs are classified according to the length of their PBL and the hybrid SIT 1 has the longest PBL and the hybrid SIT 4 has the shortest PBL. The hybrid SIT 4, 3, 2 and 1 order is the best order for effective uses of coolant in tanks when hybrid SIT is sequentially injected.

- For sensitive test, an auxiliary feedwater pump is available and starts to operate by the operator within 30 ~ 80 minutes for the ASC after HEMS operation.

The APR1400 reactor with HEMS is modeled by using RELAP5/MOD3.3, the best estimate thermal-hydraulic code as Fig.2. The model is developed in accordance with the design data and system configuration of the APR1400 and the HEMS.[4]

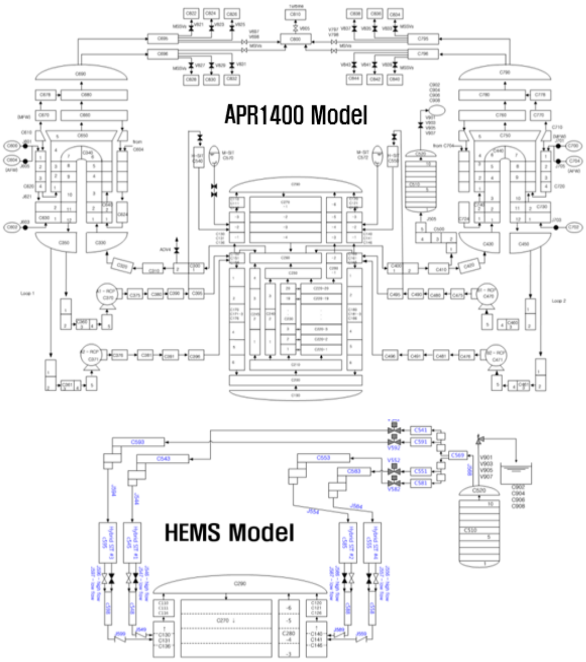

Fig. 2. Noding diagrams of APR1400 and HEMS

3.2 Results

The RELAP calculations are performed for analysis according to the transient scenarios. Figure 3 shows the RCS pressure according to the operator action time for the ASC when the HEMS is operated within 30minutes after SBLOCA.

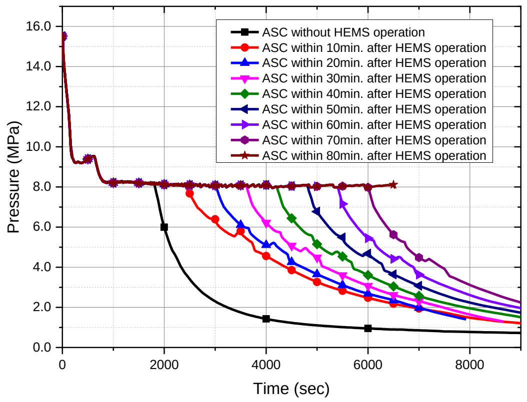

Fig. 3. RCS pressure according to the ASC operation time after the HEMS operation

The core damage are not occurred if the ASC is performed successfully within 70min when the operation of safety injection system fails during SBLOCA. In results, the core damage was delayed by the HEMS operation and the extra operator available time for ASC is helpful to reduce the human error.

3. Conclusions

In this study, the availabilities of the operator's action using the HEMS and the operator available time for the aggressive cooldown are evaluated during SBLOCA when the safety injection systems are unavailable. If the operator use the HEMS before the aggressive cooldown, the operator available time could increase more 70minutes. As the operator available time for aggressive cooldown increased, the human error is decreased and the HEMS could be used to enhance the safety of APR1400 as one of operator's actions to recover the accident.

REFERENCES

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