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Preliminary Performance and Sensitivity Analysis of Hybrid Safety Injection System for Passive emergency core cooling system

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1. Introduction

After Fukushima nuclear power plant accident, it has been suggested various plans to enhance the safety of nuclear power plant. To provide against station blackout (SBO) accident and natural disaster and improve the safety of nuclear plant, it is proposed Hybrid Safety Injection system (Hybrid SIT) for the passive emergency core cooling system (PECCS). The PECCS is considered as the safety system to cool down the reactor coolant system (RCS) without alternating current source such as a safety injection pumps (SIPs), shutdown cooling system (SCS), etc [1]. The performance of Hybrid SIT is confirmed through the preliminary performance testing during SBO accident [2]. This study discusses the applicability of Hybrid SIT and the proper design combinations during small break loss of coolant accident for PECCS conceptual design.

2. Conceptual design of Hybrid SIT

The Hybrid SIT is the passive safety system that connects the top of existing low pressure SIT and the pressurizer. Fig.1 shows an outline of the Hybrid SIT. As the connection valve of SIT and pressurizer is open while transient events, the low pressure SIT is pressured by the high pressure steam of pressurizer and the cooling water of SIT discharged to RCS by differencial head of the RCS and the SIT.

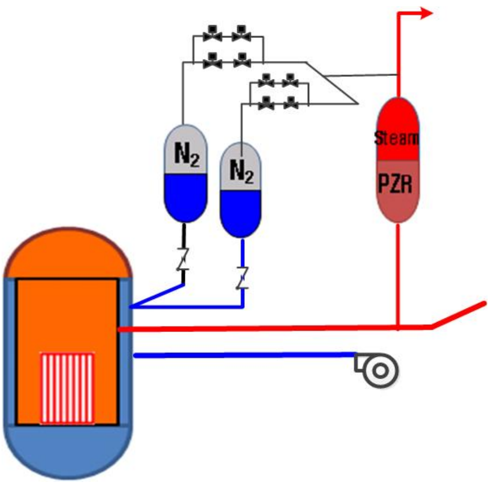


Fig 1. Outline of Hybrid Safety Injection System

3. Performance analysis

3.1 Transient scenarios

For analysis, the sensitivity parameters are selected as Table 1 [3] and assumptions are described as follows:

1. Initial event
   - Small break loss of coolant accident
2. Break
   - Size: $0.01ft^2$, $0.05\ ft^2$
   - Location : coldleg
3. System conditions
   - 4 HPSIs and 2 PAFSs are unavailable.
   - 2 Hybrid SIT and 2 SIT are available.
4. Assumption
   - When primary pressure reaches the pressure of 2bar, the cooldown of RCS is available by using gravity injection of IRWST.
   - Code models reflect the effect of N_2 gas in the SIT after safety injection is completed.
   - ADVs are additional depressurization valves for depressurization to in-containment refueling water storage tank (IRWST) injection pressure and installed 3 valves on top of the pressurizer and 1 valve on the hot leg. They are opened sequentially and not closed after opened.

Table. 1. Sensitivity parameters for analysis

1. ADV #1, #2, #3	▸ Valve Area -#1, #2 : 2.25685e-3 m^2 ,#3: 4.5137e-3 m^2 ▸ Open signal : Consecutive open - #1: 90bar, #2: #1 +70sec, #3: #2+120sec
2. Safety Injection Tank	▸ 2 Hybrid SITs+ 2 Medium Pressure SITs - Operation Pressure of Hybrid SIT : 100bar - Operation Pressure of Medium Pressure SIT : 43bar
3. ADV#4	▸ Open signal : Hybrid SIT low water level ▸ Valve area - c1: 0.04965725 m^2 , c2:0.0993145 m^2 , c3: 0.198629 m^2 , c4: 0.397258 m^2

3.2 RELAP model for Hybrid SIT

For the analysis, Hybrid SIT is modeled by using the best estimate thermal-hydraulic code, RELAP5/MOD3.3. The reference plant for the test model is APR+. Fig. 2 shows the noding diagrams of the APR+ and the Hybrid SIT. The Hybrid SIT model is developed in accordance with the conceptual design for analysis because this system is not developed yet. The Hybrid SIT model is modeled by pipe component instead of accumulator component for connection of SIT and pressurizer. The SIT and pressurizer in this model is connected by 2-inch pipe. A steady-state analysis is successfully performed by using the APR+ conditions.

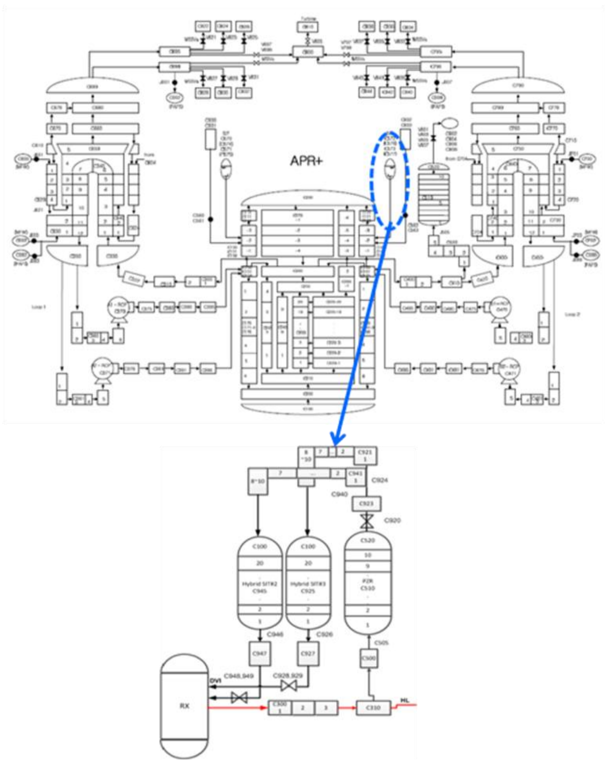
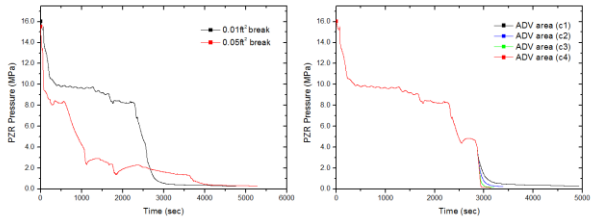


Fig. 2. Noding diagrams of APR+ and Hybrid Safety Injection System

3.3 Results

Analyses were performed for coldleg break of 0.01ft^2 and 0.05 ft^2. Following the SBLOCA transient, the RCS pressure reduces by reactor and reactor coolant pump trip early. At 100 bar of RCS pressure, two Hybrid SITs are actuated and the pressure of Hybrid SIT and pressurize is balanced. The cooling water of SITs is discharged. Figure 3(a) shows that the break case of 0.01ft^2 is that the RCS cooling is delayed rather than the break case of 0.05ft^2 since the discharge flow of coolant from the break is small. To decide the proper design combinations during SBLOCA accident, the additional depressurization cases using the ADVs are performed. ADV #1, #2 and #3 are opened at 90 bar sequentially. The RCS pressure continues to drop. After ADV #4 is opened, the RCS pressure finally reaches the IRWST injection pressure. Figure 3(b) shows the core pressure behavior by the change of ADV #4 open area. According to this result, additional depressurization using ADV #4 needs for the final depressurization to reach the IRWST injection pressure, 2bar. And ADV #4 areas effect on the depressurization rate.



(a) (b)

Fig 4. Core pressure by break size change (a) and by ADV #4 area change (b) (SBLOCA, 0.01ft^2 coldleg break)

3. Conclusions

To provide against SBO accident and natural disaster and enhance the safety of nuclear plant, it is proposed Hybrid SIT. In this study, the applicability of Hybrid SIT and the proper design combinations during SBLOCA accident is assessed for PECCS conceptual design. RELAP calculation results proved that RCS could be cooled down during SBLOCA by additional depressurization using ADVs and by cooling using Hybrid SIT when the PAFSs are unavailable. It is expected that the results can be used for the development of PECCS.

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