The evaluation of the RCS Injection Strategy by an Active Safety Injection Pump during SBLOCA

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1. Introduction

After the Fukushima Daiichi accident, there is an increasing interest in the passive or inherent safety features of nuclear power plants to prevent core damage and to mitigate the accidents caused by severe natural disasters such as earthquakes or tsunamis.

In the Advanced Power Reactor Plus (APR+) reactor design, which is a GEN III+ reactor based on the proven APR1400, has been developed and obtained design approval in August 2014. The APR+ already adopted a passive auxiliary feedwater system (PAFS) for enhancing the safety and the core could be continuously cool down during transient without electricity. Beyond the APR+, a conceptual design of the iPOWER (Innovative Passive Optimized Worldwide Economical Reactor) is currently under development. The iPOWER is an advanced pressurized water reactor (PWR) that incorporates the passive safety features such as the passive emergency cooling system (PECCS) and the passive containment cooling system (PCCS). The accident could be mitigated without operator's action or any electric sources in iPOWER.

But when the PECCS operates for mitigating the accidents, the accident could be expanded to accidents like large break loss of coolant accident (LBLOCA) although small break loss of coolant accident (SBLOCA) occurs because the automatic depressurization valves (ADV) stage 4 in hotleg is opened for final depressurization to reach to IRWST injection pressure. That is, this operation strategy is not desirable for providing defend-in-depth in typical plant operation. Therefore, additional active safety features such as pumps may be used during typical SBLOCA.

This study is focused on the evaluation to suggest operation strategy of safety injection by active safety injection pumps (ASIP) during SBLOCA to avoid ADS-4 actuation and restore safety-related PECCS.

2. Conceptual design of PAFS and PECCS

A conceptual design of the PAFS and the PECCS are given in Figs. 1 and 2. The PAFS replaces the conventional active auxiliary feedwater system (AFWS) and functions as cooling the primary side and removing the decay heat by a natural driving force. It consists of a heat exchanger, a passive condensation cooling water tank, check valves, isolation valves powered by a battery (Class 1E DC), piping, and instrumentation and control systems [1].

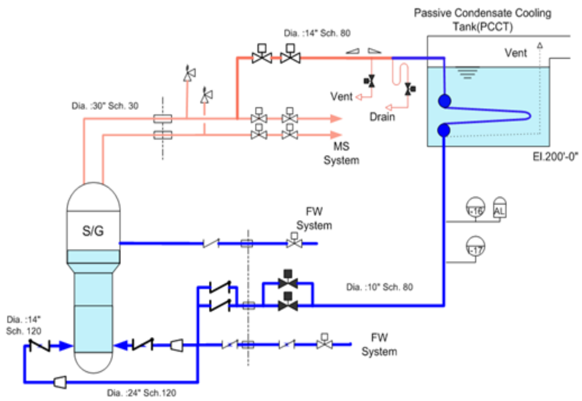

Fig. 1. Conceptual design of PAFS

The Passive emergency cooling system(PECCS) could make up and cool down during unexpected accident like reactor coolant system leaks and ruptures of various sizes and locations. The PECCS provides the safety functions of core residual heat removal, safety injection, and depressurization. It consists of safety injection and depressurization systems to cool down the core continuously without electricity. The PECCS comprises hybrid safety injection tanks (H-SITs), medium-pressure safety injection tanks (M-SITs), and in-containment refueling water storage tanks (IRWSTs) [2].

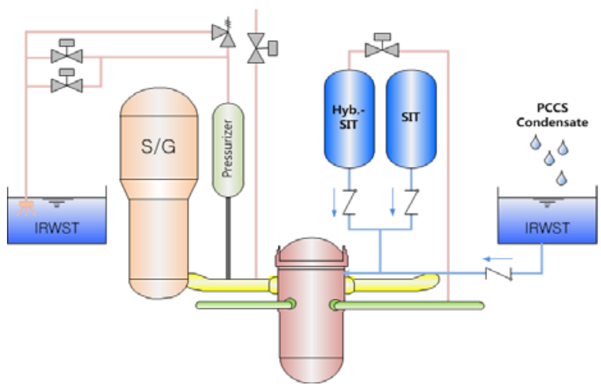

Fig. 2 Conceptual design of PECCS

3. Analysis Model

3.1 Transient scenarios

The reference plant is APR+ with the PECCS because the iPOWER design is under development.

For SBLOCA analysis, the initial event, assumptions and system setpoints are described as follows:

1. Initial event
   - SBLOCA is selected for the analysis of a variety of reactor core heat removal functions and inventory control for transient accidents and break size is 2in in coldleg as the lower limit of SBLOCA range.

2. System conditions

Table.1 Test case according to the available systems

Case	Available system
1	1 PECCS
2	1 PECCS, 1ASIP
3	1 PECCS, 2ASIP
4	1 PECCS, 1 PAFS

3. Assumption
   -The RELAP code calculations were terminated when Reactor coolant system (RCS) pressure reaches to IRWST injection pressure (2 bar)
   -The ASIPs are non-safety pumps and operator actions need for pumps actuation.

4. System setpoints [3]

Table. 2 Operation setpoints of the available systems

System		Setpoints
PECCS	H- SIT	PZR low pressure(100bar) or Low WR SG level (45%) & High hot leg temperature (636˚F)
	M-SIT	40bar
	ADV stage 1	H-SIT low level (40%)
	ADV stage 2	70sec after ADV stage 1
	ADV stage 3	12sec after ADV stage 2
	ADV stage 4	H-SIT low level (20%)
	IRWST	2bar
PAFS		SG low level (25%)
ASIP		Operator action time: 1200,1800(base case), 2400,3000sec

3.2 RELAP model for analysis

For analysis, APR+ is modeled by using RELAP5/MOD3.3, the best estimate thermal-hydraulic code as Fig 3. This model is developed in accordance with the design data and system configuration of the APR+ and the PAFS and the PECCS model. And the design of PECCS may change as ongoing research progresses.

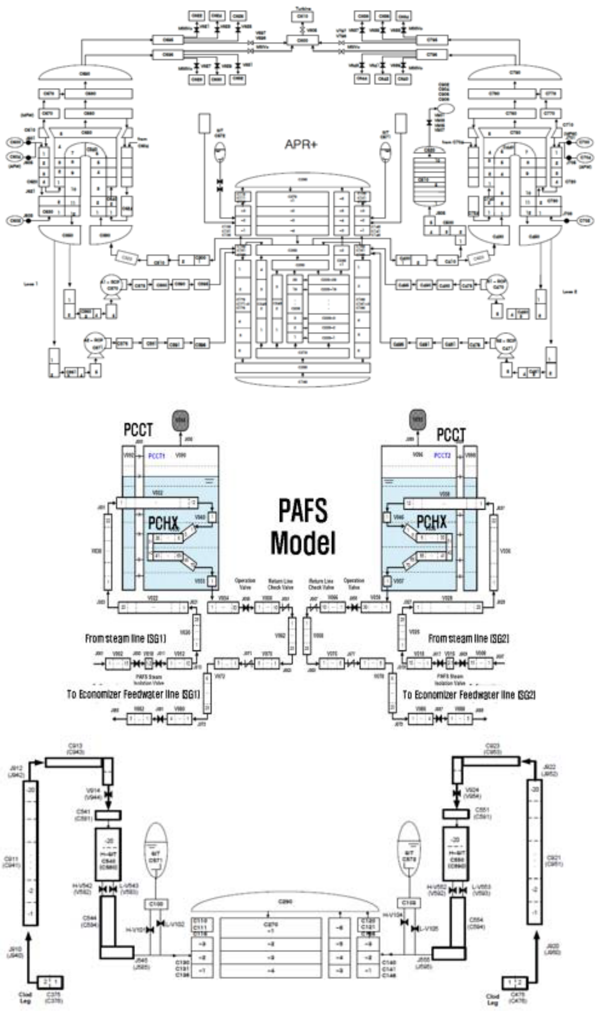

Fig. 3 APR+, PAFS and PECCS nodalization

4. Analysis results

In order to examine the performance of the PECCS and confirm the setpoints of the PECCS, various accidents have been simulated by using RELAP5. In this paper, analysis has been performed to suggest operation strategy of safety injection by active safety pumps to avoid ADS-4 actuation and restore safety-related PECCS.

Fig 4 shows RCS pressure according to the system conditions given in Table. 1. In case 1 and 4, the APR+ with the PECCS is cooled down until the RCS pressure reach to IRWST injection pressure according to the PECCS actuation regardless of the PAFS operation when SBLOCA occurs. The ADV stage 4 are opened for final depressurization and the accident mitigated by expanding to LBLOCA. At this time, if operator could activate ASIP, SBLOCA could be mitigated without ADV stage 4 opening. As the ASIPs are operated, the RCS is makeup and H-SIT level is restored more than set values for ADV stage 4 opening. Also as shown in case 2 and 3, two ASIPs should be operated to avoid ADV stage 4 actuation. At this time, RCS pressure and core level are maintained stably.

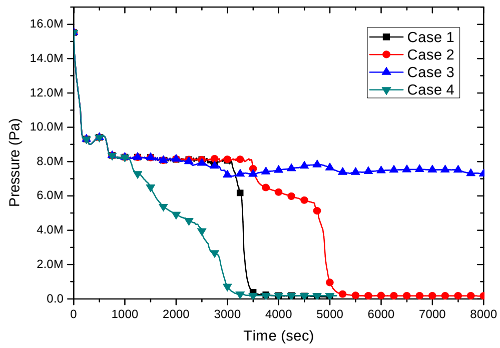

Fig 4. RCS pressure according to ASIP and PAFS

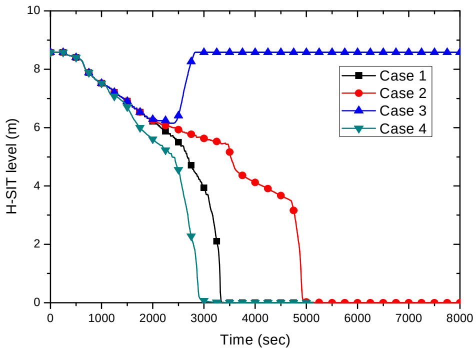

Fig 5. H-SIT level according to ASIP and PAFS

The sensitivity tests for allowable time of ASIP injection analysis were performed. Figs 6 and 7 show that SBLOCA could be mitigated without ADV stage 4 actuation if two ASIPs are operated in 40 min.

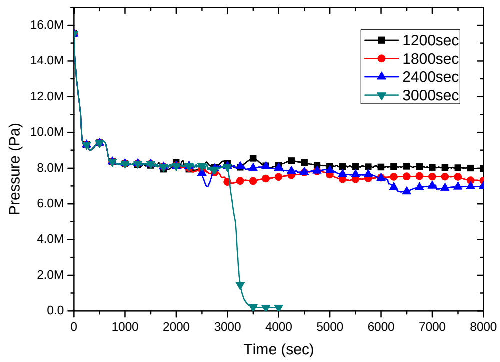

Fig 6. RCS pressure according to ASIP injection time

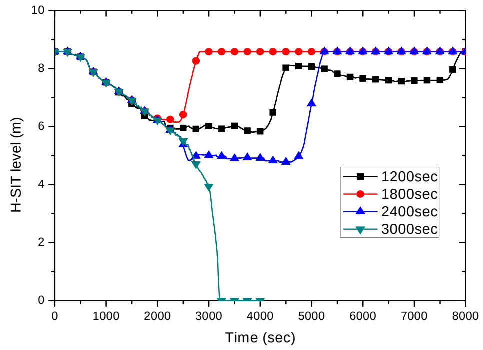

Fig 7. H-SIT level according to ASIP injection time

5. Conclusions

In this study, the results show that safety injection by ASIP is effective for 2inch break SBLOCA to avoid ADS-4 actuation. The core is cooled down until the RCS pressure reach to IRWST injection pressure according to the PECCS actuation regardless of the PAFS operation during SBLOCA. Without ADV stage 4 open, operation methods by using ASIP are suggested. If 2 ASIP could be operated in 40 min during SBLOCA, SBLOCA could be mitigated.

These are limited preliminary test results however they could be used to support the development of the iPOWER operation strategy and applied to the design of non-safety active pump in typical plant operation.

Acknowledgements

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References

[1] Heo S., Kim, H.G. (2016). Passive Safety Concept for Innovative Safety Plan, Korean Society for Energy, 169, April. 2016..

[2] Design change in PAFS and probability improvement, 2013.8, Technical Report, 2013.8

[3] Conceptual design of Passive Emergency Core Cooling System (Final Report), Korea Hydro & Nuclear Power co.,Ltd CRI, Nov, 201

[4] Chung, S. Il, Hong, S. J., Kang, S. H., Kim, H. G., Korea, S., Hydro, K., & Korea, S. (2015). Analysis on Roles for Components of Passive Emergency Core Cooling System, 7–8.