Evaluation of non-condensable gas effect during LBLOCA in an OPR1000 Plant

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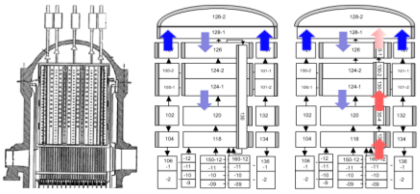
1. Introduction

Gas accumulation in the nuclear power plant may cause diverse safety issues such as water hammer, pump cavitation and inadvertent valve actuation. The Nuclear Regulatory Commission (NRC) has published twenty Information Notices, two Generic Letters, and one NUREG report related to the issue of the gas accumulation [1]. It has been considered that gas accumulation occurred since the beginning of commercial nuclear power plant operation and may occur in the currently operating plants. Gas accumulation in the Emergency Core Cooling System (ECCS) is the condition that did not consider in Accident Analysis of Final Safety Analysis Report or Technical Specification and may finally result in degradation or loss of the safety functions. In this paper, the effect of gas accumulation in the ECCS has been analyzed by modeling non-condensable gas injection during the operation of Safety Injection Tank (SIT) and Low Pressure Safety Injection (LPSI) under the LBLOCA condition.

2. LBLOCA Analysis

2.1 Target Nuclear Power Plant

The Hanul unit 3 and 4 were selected for the target nuclear power plant. The latest licensing contents such as the increase of peak linear heat rate, the reduction of reactor coolant flow rate [2] were reflected in the LBLOCA calculation. Figure 1 shows the modified nodalization for the upper head structure. The modified upper head was constructed by one volume. The CEA guide tube was modeled to be connected to upper head. Figure 2 illustrates the nodalization of Hanul unit 3 and 4.



Reference Model Modified Node

Figure 1. Nodalization of Upper Head

In order to decide the quantity of non-condensable gas injection, a PWROG's position paper was referred [3]. 5 ft^3 at ambient temperature of 68℉ and a system pressure of 400 psia for the high pressure system piping and 5 ft^3 at ambient temperature of 68℉ and a system pressure of 100 psia for the low pressure system piping were assumed in the paper. In this study, the gas of 2.5 ft^3 and 5 ft^3 for high and low pressure condition were considered. For LBLOCA simulation, RELAP5/MOD 3.3 was used.

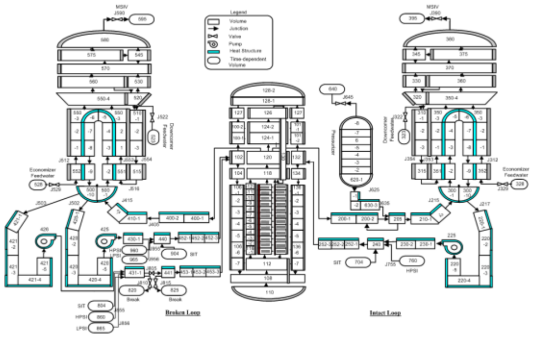


Figure 2. Nodalization for Hanul Unit 3 and 4

2.2 Sensitivity Study for High Pressure Condition

Two different kinds of sensitivity studies were conducted for the high pressure condition. First of all, the quantity of gas injection was evaluated. It was assumed that gas was injected from piping system of an intact loop's SIT (No. 704) as soon as the SIT was actuated. It was simulated that the gas injection continued for 10 seconds. Figure 3 shows the mass flow rate at SIT. As the amount of gas was increased from 2.5 ft^3 to 5 ft^3 the SIT injection was decreased. SIT injection periods for both cases were also reduced for 10 seconds. Figure 4 presents Peak Cladding Temperatures (PCT). Both conditions showed the same blowdown PCTs. It was because SIT's flow rate could not affect the blowdown PCT. The PCT at 5 ft^3 condition was higher than that at 2.5 ft^3 condition because the reduced SIT flow rate resulted in less coolant injection into the reactor core. The reflood PCT at 5 ft^3 condition was 1150 K which was 49K higher than that at no gas condition. The injected gas stayed at the hot assembly channel for a certain period of time and it induced less heat transfer from fuel cladding to core channel. Table 1 summaries the sensitivity result of the gas quantity.

Secondly, the location of gas injection was evaluated. The same amount of gas was injected into both No. 704 and 904's SITs. There were no changes for SIT flow rates and reflood PCTs. It was considered that both of them located in unbroken loops and there were no differences in both SIT flow rate and the transported gas quantity to the reactor core.

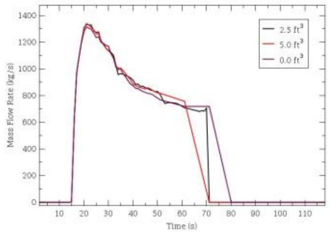


Figure 3. SIT flow rate for gas quantity sensitivity

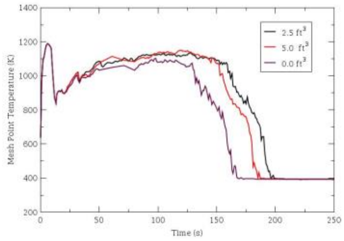


Figure 4. PCT for gas quantity sensitivity

Table 1. Summary of sensitivity for gas quantity

Gas Quantity	Injected Coolant Mass from SIT	Reflood PCT
0 ft^3	53,772 kg	1,101 K
2.5 ft^3	50,544 kg	1,139 K
5 ft^3	48,111 kg	1,150 K

2.3 Sensitivity Study for Low Pressure Condition

The piping system from Refueling Water Tank (RWT) to LPSI pump was composed of a complex piping lines. In this study, the simplified nodalization for LPSI piping was constructed as preserving the length of pipe and minor loss of components. The LPSI piping was constructed of RWT, horizontal and vertical piping and LPSI pump. The LPSI piping was connected to a cold leg piping (No. 440). Figure 5 shows the void fraction in LPSI pump. It was assumed that the gas was accumulated at the horizontal piping which located at the highest point. The void fraction was increased due to the existence of non-condensable gas. Figure 6 presents mass flow rate at LPSI pump. As the amount of gas was increased the flow rate in LPSI pump was decreased due to loss of pump head torque. Figure 7 illustrates the trend of PCTs. Although the amount of the gas injection was increased from 2.5 ft^3 to 5 ft^3 there were moderate PCT changes compared with high pressure conditions. Because LPSI pump injected the coolant at the later period of reflood phase and the amount of the coolant transported by LPSI pump was smaller than that by SIT.

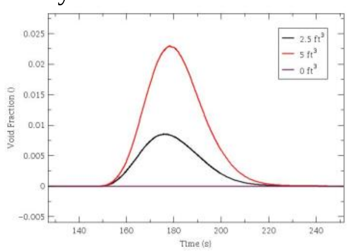


Figure 5. Void fraction in LPSI pump

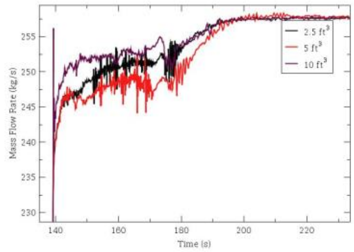


Figure 6. Mass flow rate for LPSI pump

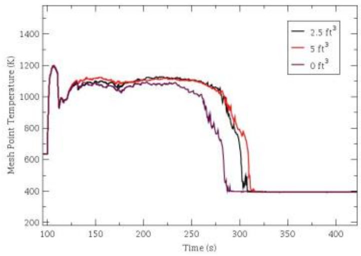


Figure 7. PCT for low pressure condition

3. Conclusions

Gas accumulation in the ECCS has been dealt with one of significant safety issues in the operating nuclear power plants. In order to identify the effect of the non-condensable gas in Hanul unit 3 and 4, the sensitivity studies for gas quantity, location or injection time was conducted for high or low pressure condition. At high pressure condition, the injected gas induced the reduced SIT flow rate and the reduced period of SIT injection. The reflood PCT at 5 ft^3 condition was 1150 K which was 49K higher than that at no gas condition. At low pressure condition, the reduced flow rate and the increased reflood PCT were also identified. However, the PCT deviation due to different gas quantity was not large as much as that at high pressure condition. We concluded that it is necessary to evaluate the effect of the accumulated gas with the consideration of plant-specific conditions such as system pressure, accumulated location, gas quantity and injection time.

REFERENCES

[1] NRC Generic Letter 2008-01, Managing Gas Accumulation in Emergency Cooling, Decay Heat Removal, and Containment Spray Systems, ML072910759, January 11, 2008

[2] Byung-Gil Hu et al., Evaluation for Effect of Upper Head Nodalization and Temperature in OPR1000 Plant, 22nd International Conference Nuclear Energy for New Europe, September 2013

[3] Westinghouse Electric Company LLC, Non-condensable Gas Voids in ECCS Piping; Assessment of Potential Effects on Reactor Coolant System Transients Including Chapter 15 Events, Task 3 of PA-SEE-450, LTR-LIS-08-543, August 19, 2008