Improvement of Modeling Scheme of the Safety Injection Tank with Fluidic Device for Realistic LBLOCA Calculation

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1. Introduction

A special device 'Fluidic Device (FD)' is installed inside a Safety Injection Tank (SIT) in APR 1400 reactor design, which is new and advanced features from the existing nuclear power plants (NPP) [1]. Role of the FD is to obtain an additional safety margin for Large Break loss-of-coolant accident (LBLOCA) by adequately distributing the SIT water in high flow stage and in low flow stage to reduce the bypass of emergency core cooling system (ECCS) water. Confirmation of the performance of the SIT with FD should be based on thermal-hydraulic analysis of LBLOCA and an adequate and physical model simulating the SIT/FD should be used in the LBLOCA calculation. To develop such a physical model on SIT/FD, simulation of the major phenomena including flow distribution of by standpipe and FD should be justified by full scale experiment and/or plant preoperational testing.

Author's previous study [2] indicated that an approximation of SIT/FD phenomena could be obtained by a typical system transient code, MARS-KS [3], and using 'accumulator' component model, however, that additional improvement on modeling scheme of the FD and standpipe flow paths was needed for a reasonable prediction. One problem was a depressurizing behavior after switchover to low flow injection phase. Also a potential to release of nitrogen gas from the SIT to the downstream pipe and then reactor core through flow paths of FD and standpipe has been concerned. The intrusion of noncondensible gas may have an effect on LBLOCA thermal response. Therefore, a more reliable model on SIT/FD has been requested to get a more accurate prediction and a confidence of the evaluation of LBLOCA. The present paper is to discuss an improvement of modeling scheme from the previous study. Compared to the existing modeling, effect of the present modeling scheme on LBLOCA cladding thermal response is discussed.

2. Phenomena and Modeling

2.1 SIT/FD Phenomena

Fig. 1 shows a typical configuration of SIT/FD [4]. Following a LBLOCA, water in SIT starts to inject to reactor coolant system (RCS) when the RCS pressure drops to the pressure of SIT. Water within the SIT pressurized by nitrogen is divided to discharge through a flow path along the standpipe and one along the connecting pipes perforated in FD. Two flow streams are combined at the mixing chamber inside the FD and then discharged out of the SIT. The hydrostatic heads, velocity heads and other head losses along both flow paths to the discharge nozzle are well balanced. Flow rates at each flow path are determined by the geometric shape of the inlets to the mixing chamber and the hydrostatic heads of each path. This hydrostatic heads are also determined by the flow rates after the water level drops down to the top of the standpipe.

From the VAPER experiment conducted by KAERI, it was reported that the water level of standpipe path decreased faster than the level of exterior part and stopped at a certain level, as a result, the flow path through the standpipe was isolated [4]. It implies the flow resistances of two flow paths may change dynamically dependent of the water level. During this process, nitrogen gas may be pulled into the inlet of standpipe due to the depletion of water level and increase of velocity at standpipe. Nitrogen gas also may be transported to the connecting pipes after the stagnation of standpipe flow.

2.2 Modeling Schemes and Improvements

In previous study, a component model 'accumulator' which was built-in MARS-KS code was used in the

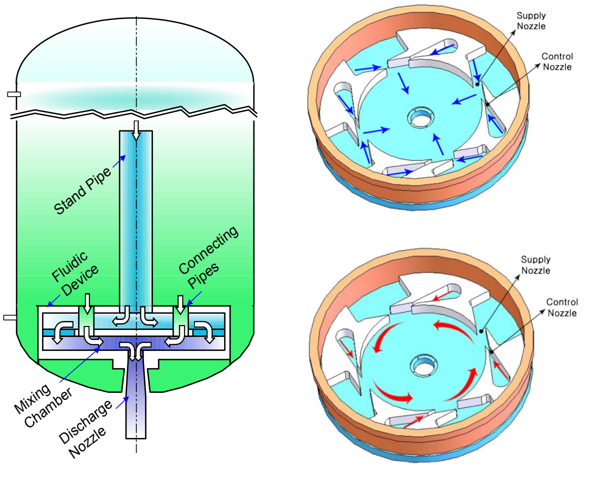

Fig. 1 Configuration of SIT/FD and Mixing Chamber

previous study (case A). Two flow paths were simulated by two valves which opened and closed in switch-overing manner and had different hydraulic resistances to simulate high flow injection phase and low flow one. Another approach was to model the tank, the standpipe, the connecting pipes of FD, and the mixing chamber specifically using 'pipe' component model (case P). Two fixed different hydraulic resistances were applied to two junctions from the standpipe and from the connecting pipe to the mixing chamber, respectively.

The SIT blowdown test [5] of SKN Unit 3 was simulated by two modeling schemes. Result showed that SIT pressure calculated by the case A was higher than the test data during low flow discharge phase while lower pressure calculated by the case P was found for the same period. It was also confirmed the result was due to use of constant hydraulic resistance in both modeling schemes. Regarding the case A, further depressurization was not predicted by isolating the standpipe flow path at the same time of switchover. It implies the standpipe flow path was important role to depressurize SIT. Regarding the case P, an excessive depressurization was due to the continuous release of nitrogen gas through the standpipe flow path having constant resistance for a whole transient. As a result, a significant increase of peak clad temperature (PCT) due to ingestion of noncondensible gas into the reactor core during reflood phase was found at the plant calculation implementing the case P modeling.

To resolve this problem, a scheme incorporating a variable hydraulic resistance at the standpipe flow path based into the case P modeling scheme is proposed in the present study. The Reynolds dependent form loss factor in MARS-KS code could be used for this purpose. However, a difficulty was experienced in implementing the amount of increase of the form loss factor by change of velocity and standpipe water level and isolation of flow path. Alternatively, a scheme to change the area of the junction from the standpipe to the mixing chamber by 'valve' component was adopted, in which additional hydraulic resistance can be imposed automatically (cases P1 and P2). Currently, the valve starts to close at 1 m of standpipe level and completely closed within 6 second. Fig. 2 shows a comparison of the modeling schemes. Also the downstream piping from the SIT nozzle to DVI nozzle including isolation valve was modeled more specifically in the course of improvement.

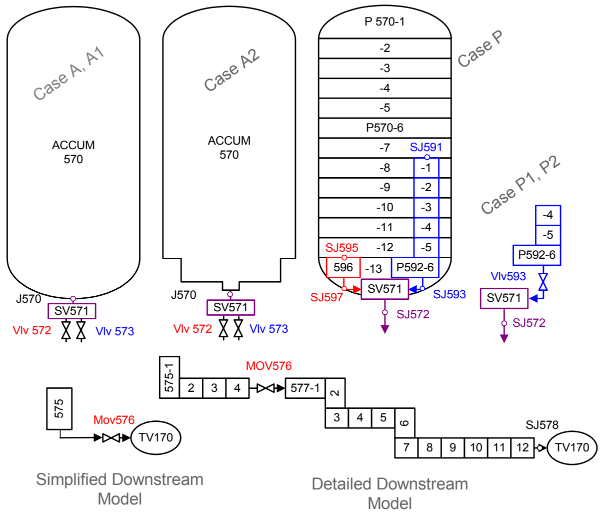

Fig. 2 Comparison of modeling schemes

3. Result and Discussions

3.1 Assessment of SIT Blowdown Test

The SIT blowdown test was conducted at June of 2012 at the SKN Unit 3. The SIT's were pressurized up to 15 kg/cm^2 by nitrogen gas and the water was filled up 85% in terms of wide range level. The motor operated isolation valves connected to each SIT were initially closed and open by initiation of the test. The water in the SIT was discharged to the reactor vessel in which the RV head was removed and was under the atmospheric pressure. During the test, the wide range water level and the pressure of the SIT were measured. The data from the SIT-D were selected for the present study. Calculations to simulate the test were conducted using several modelings based on Case A and Case P as follows.

Table 1 Summary of modeling schemes

Case	Description/Improved	ID
A	accum component	13f
A1	A+ Detailed downstream modeling	ac
A2	A1+ inactive volume excluded	ac5
P	Pipe component	z40
P1	P+ dynamic closing of standpipe path	z5
P2	P1+ detailed downstream modeling	z4

During the simulation, it was found the inventory of the inactive volume submerging the FD structure within SIT should be excluded in sizing the total volume of accumulator component (case A2).

Fig. 3 shows a comparison of the calculated SIT pressures with the measurement. As expected, all cases using 'accumulator' component predicted higher pressure after 70 seconds. For the cases using 'pipe' component, a good approximation was obtained for the cases P1 and P2. Also no significant improvement was found by simplifying the SIT downstream noding. Exclusion of the inactive volume of SIT had an effect to get a closer simulation especially in high flow discharge phase.

Fig 4 shows a comparison of mass flow rate passing Motor Operated Valve (MOV) downstream of SIT with the estimated data from the measured water level. Variation of mass flow rates with variation of the modeling scheme was more sensitive than that of pressure. Also it can be concluded that the scheme using dynamic closing of standpipe flow path is the most realistic one for this problem.

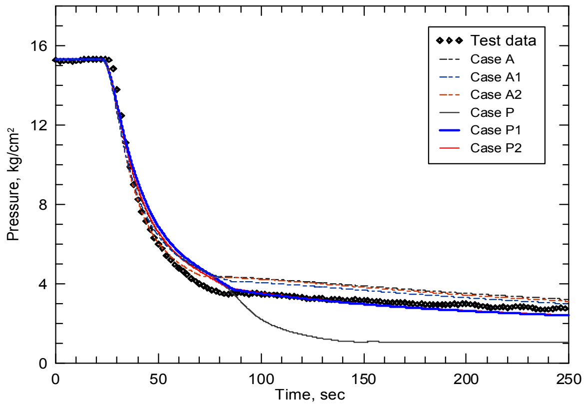

Fig. 3 Comparison of SIT pressures

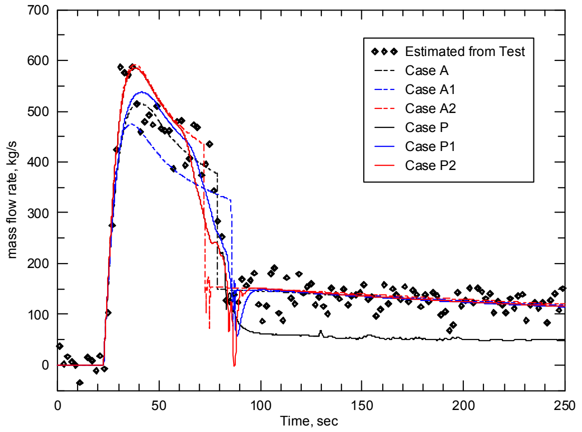

Fig. 4 Comparison of discharge flow rate

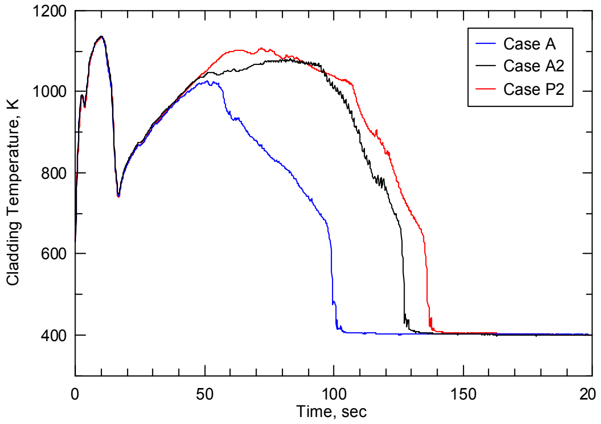

Fig. 5 Comparison of cladding temeperatures

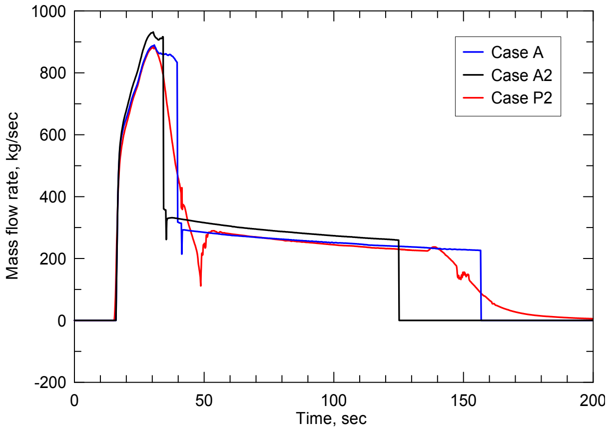

Fig. 6 Comparison of SIT flow rates

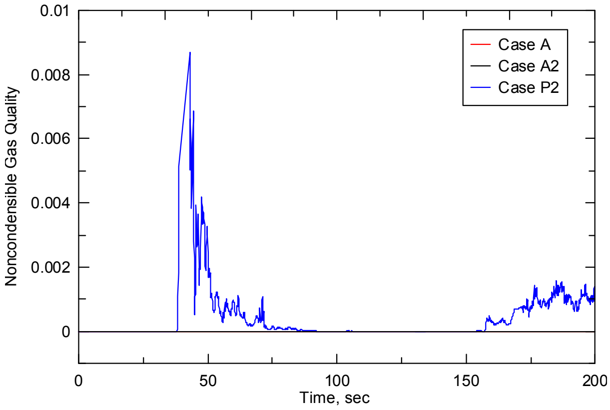

Fig. 7 Comparison of noncondensible gas quality at 14th volume of core hot spot

3.2 Plant Calculation

Using MARS-KS code and the modeling schemes described above, calculations of LBLOCA of SKN Unit 3 were conducted. Sequence of events was the same as the previous study [2], i.e, break at 0 second, reactor trip at 10.72 MPa of RCS pressure, SIP actuation at 10.72 MPa with 40 seconds delay, passive automatic SIT injection at 4.02 MPa, etc. The minimum value of SIT water level at the beginning of accident was assumed.

Fig 5 shows a comparison of the fuel cladding temperatures at hot spot calculated from three cases of modeling (A, A2, P2). Three calculations show an identical behavior before SIT actuation, however, different thermal responses were found after SIT actuation. Difference between Case A and Case A2 is due that the low flow injection phase was shorter (as shown in Fig. 6), which was caused by the exclusion of inactive water volume of SIT. The case P2 shows a highest PCT during reflood phase. The reason for such trend was the reduction of flow rate transition from the high flow stage to the low flow stage. The effect of modeling on PCT was 23 K.

Such an effect may come from the noncondensible gas intrusion to reactor core as shown in Fig. 7. Noncondensible gas was rebuilt after 150 seconds when the SIT was emptied.

4. Conclusions

The present study discussed the modeling scheme of SIT with FD for a realistic simulation of LBLOCA of APR1400. Currently, the SIT blowdown test can be best simulated by the modeling scheme using 'pipe' component with dynamic area reduction. The LBLOCA analysis adopting the modeling scheme showed the PCT increase of 23K when compared to the case of 'accumulator' component model, which was due to the flow rate decrease at transition phase low flow injection and intrusion of nitrogen gas to the core. Accordingly, the effect of SIT/FD modeling scheme should be considered for realistic LBLOCA analysis.

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