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A New SPACE Modeling Method for FD-SIT

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1. Introduction

A Fluidic Device (FD) is installed inside a Safety Injection Tank (SIT) of APR1400 type plant, and its schematic is illustrated in Fig. 1. This is a solely passive device by which the SIT discharge flow rate is controlled depending on the intensity of the vortex flow generated inside the vortex chamber at the bottom of the FD.

A FD separates the single flow path ranging from SIT to discharge nozzle into two flow paths and contributes to the extension of the injection period. At start SIT water level is higher than the top of the stand pipe, and hence the injection takes place through two channels. When SIT water level becomes below the top of the stand pipe, the water flows into 4 control ports resulting in relatively high flow resistance through the control ports. It renders the decrease of the injection flow rate and extends the SIT water injection time.

The SPACE code may model a SIT using the SIT component composed of one CELL and one FACE. In this case, however, fluid movement inside the tank can not be predicted reasonably and the nitrogen gas release is allowed only when the tank becomes empty.

The nitrogen gas released from SITs may have great effects on the core cooling during reflood. The noncondensible gas may not only resist steam condensation in the reactor vessel downcomer but also pressurize the downcomer liquid to the core to enhance the core cooling. Thus predicting the time of nitrogen gas release may be regarded as important in Large Break Loss-Of-Coolant Accident (LBLOCA) analyses.

To predict realistically the nitrogen gas release from SITs, a new SIT modeling method has been developed. In this method, normal hydraulic components such as CELL, FACE, PIPE and BRCH are used instead of the SIT component to simulate the water and gas flow inside the tank. The new method has been validated against the VAPER tests and the pre-operation blowdown tests conducted in Shin-Kori Unit 3.

2. FD-SIT Modeling

2.1 FD-SIT Modeling

Fig. 2 shows the two modeling methods described above. The left one is the old modeling using the SIT component model and the right one is the new modeling using the normal hydraulic components. In the old modeling, the tank is modeled as one volume, and the loss coefficients for high and low flow phases are used as inputs to simulate the flow turn-down.

In the case of new modeling, normal hydraulic components such as BRANCH, CELL, and PIPE are used to realistically model the upper tank dome, the volume above the stand pipe, interior and exterior volumes of the stand pipe, and the FD inside volume. The change of flow resistances from the high flow phase to the low flow phase is simulated with two TRIP VALVs connected to the FD and were set to operate in tune with the water level in the tank.

2.2 Plant Modeling

Plant inputs are basically the same as the inputs described in section 2.1. In plant calculation inputs, the TRIP VALVE to model the flow turn-down is connected to the reactor vessel and the flow is set to be discharged when Reactor Coolant System (RCS) pressure becomes below the SIT pressure set point.

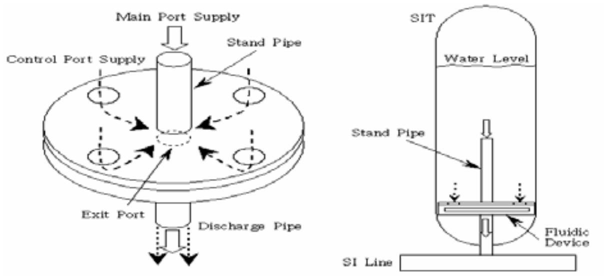
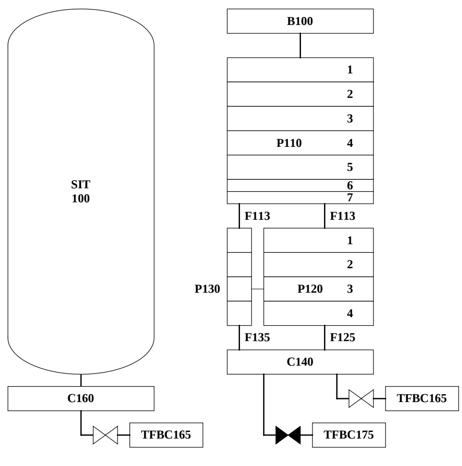


Fig. 1. Schematic Diagram of FD-SIT



a. SIT Component b. PIPE Component
Fig. 2. Nodalization of FD-SIT

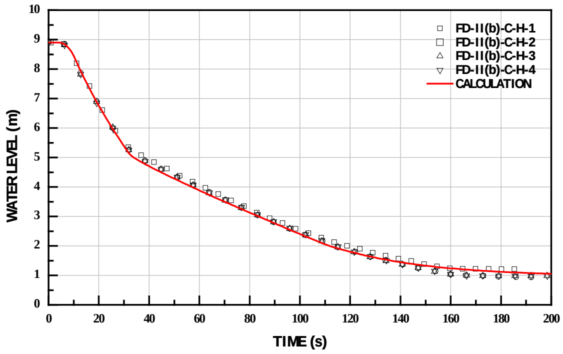


Fig. 3. Calculation Result of VAPER Test - Water Level

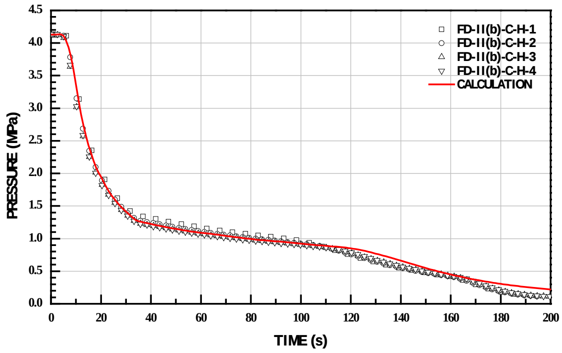


Fig. 4. Calculation Result of VAPER Test - Pressure

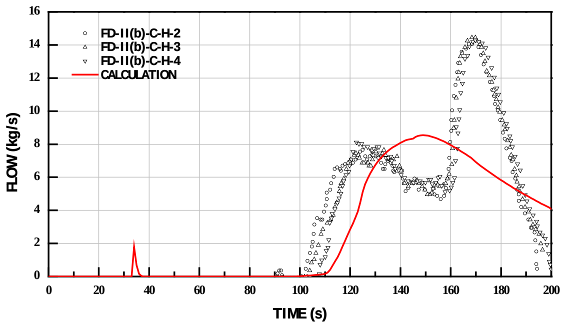


Fig. 5. Calculation Result of VAPER Test - Gas Flow Rate

3. Results and Discussion

3.1 VAPER Test

The VAPER is the facility used to evaluate the performance of the FD and 5 different kinds of tests were conducted there [1]. For the assessment of SIT modeling methods, tests FD-II(b)-C-H-1 ~ FD-II(b)-C-H-4 were selected.

Fig. 3 ~ Fig. 5 shows calculation results of VAPER test using PIPE component model. Fig. 3 presents the predicted water level in the tank which is very similar to the measured data. As seen in Fig. 4 the pressure of upper tank dome was slightly over predicted after ~100 seconds (the time of massive nitrogen gas release), but in general it was predicted quite well. The predicted time of massive nitrogen gas release at ~100 seconds agrees relatively well with the measured data, as illustrated in Fig. 5. Note that the small amount gas release ~30 seconds exits only in the prediction and it is not observed in the test data. However, it should be taken into account that the test data in Fig. 5 is not measured data and it was estimated from the measured gas pressure.

3.2 SIT Blowdown Test

The SIT blowdown test was performed at the Shin-Kori unit 3 [2]. In this paper, high pressure tests were chosen to be evaluated. The inputs used in calculation are identical to those used for VAPER test. Except for the fact that geometry and initial condition of the tank are somewhat different from those of VAPER test.

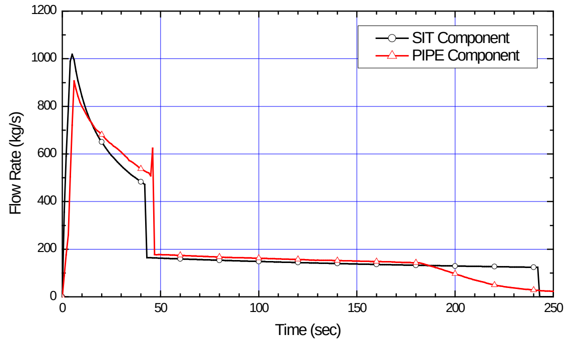


Fig. 6. Comparison of SIT Discharge Flow Rate

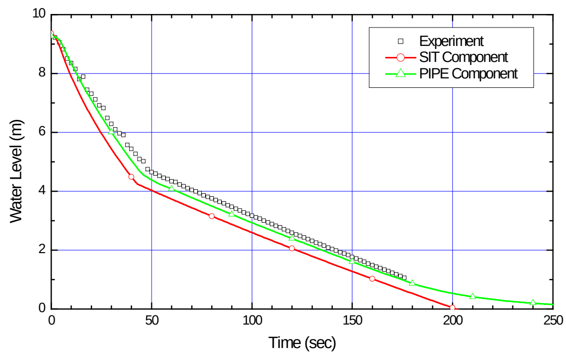


Fig. 7. Comparison of SIT Water Level

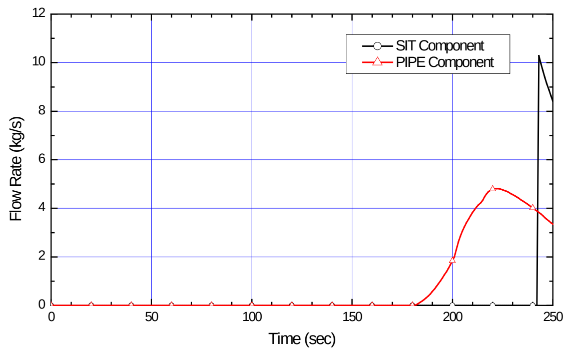


Fig. 8. Comparison of Gas Flow Rate

As shown in Fig. 6, the discharge flow rates depending on modelling method show little discrepancy. Fig. 7 shows the water level of the tank. As judged from the figure, the calculation result using PIPE component model is under predicted compared with measured data but the difference is not significant. On the contrary, SIT component model estimates the whole tank as the cylinder with the consistent cross sections, so it miscalculates the water level of the tank. Fig. 8 represents gas flow rate. The gas release in PIPE component model is observed to occur after about 180 seconds. In comparison, the gas release can not be predicted in SIT component model until SIT is completely depleted.

3.3 LBLOCA Analysis

The Plant inputs are basically the same as the inputs of the SIT blowdown test described in section 4.2. In plant calculation inputs, the TRIP VALVE for the purpose of modelling of turn-down is connected to the reactor vessel and the flow is set to be discharged when RCS pressure becomes below the SIT pressure set point. The break takes place at 0 second. When RCS pressure reaches 10.72 MPa, reactor will trip in 1.15 seconds and safety injection pump start to active in 40 seconds. In the event of RCS pressure being 4.245 MPa, SIT flow injection will start.

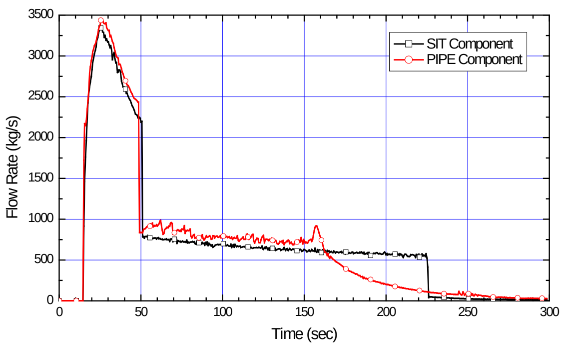


Fig. 9. Comparison of SIT Discharge Flow Rate

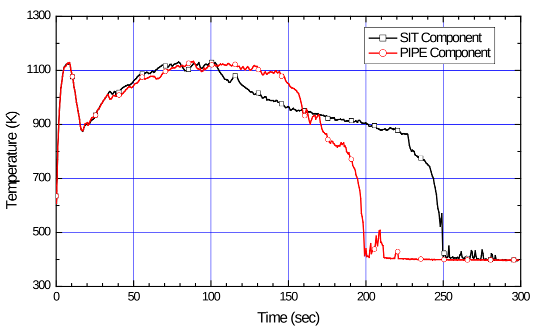


Fig. 10. Comparison of Cladding Temperature at PCT Node

Fig. 9 shows the discharge flow rate of SIT and PIPE component model. As illustrated in the picture, the both models predict the similar behaviors until 150 seconds but show different trends in the latter half. The flow rate of PIPE component model starts to decrease ahead of SIT component model at about 160 seconds with considerably gradual decrease rate which supply the SIT water for relatively long time. On the other hand, SIT component model shows almost constant discharge flow rate during low flow phase. After 150 seconds, the discharge flow rate is relatively higher than that of PIPE component model and SIT is depleted earlier. Such behaviors of two modeling are similar to the calculation results for the SIT blowdown test conducted in Shin-Kori unit 3. Fig. 10 shows the trends of the cladding temperature calculated by SIT and PIPE component model. During the blowdown phase, the trends of the cladding temperature for both model are almost identically. Peak Cladding Temperature (PCT) during reflood phase were 1,131.3 K and 1,133.5 K respectively. Two models are shown similarity, but in PIPE component model, the quenching occurs earlier than that of SIT component model. Relatively high flow rate up to 150 seconds is attributable to this phenomenon.

4. Summary and Conclusions

In this paper, for the purpose of LBLOCA analysis of Shin-Kori units 3&4, SPACE modelling method for SIT with FD was developed. And its applicability and effect has been evaluated.

The SPACE inputs were developed for nitrogen gas release and SIT to be realistically modeled. According to the new SPACE modeling, the VAPER test and the SIT blowdown test conducted in Shin-Kori unit 3 were evaluated to have the applicability of the SPACE modelling confirmed.

Also, LBLOCA analysis for Shin-Kori units 3&4 identified that two SIT modelling methods result in different behaviors, and these bring about discrepancy in PCT and quenching during reflood phase.

REFERENCES

[1] Performance Verification Test for APR1400 Fluidic Device, KAERI/TR-2836-2004, KAERI, 2004.
[2] SKN 3&4 Test Procedure (SIT Test), Rev. 1, 9P-C-441-02, KHNP, 2012.