RELAP5/MOD3.3 Code Calculation for Preoperational Tests of Safety Injection Tanks in SKN unit 3

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1. Introduction

Shin-Kori nuclear power plant (SKN) unit 3 and 4 are now being constructed as a first plant of APR1400. APR1400 has adopted a new design feature, called fluidic device (FD), in safety injection tanks (SITs) to optimize the emergency core cooling (ECC) flow rate.

Before starting the commercial operation, the safety systems have to be tested to ensure their performances of safety functions. The object of preoperational tests for SITs is to confirm whether the performance of SITs satisfies the design requirement which is defined by a design basis accidents analysis. The design requirement can be expressed as pressure loss coefficient, called K-factor, which can convert to discharge flow rate of SITs from a certain pressure condition of SITs.

Preoperational tests of four SITs were performed in March 2012. To evaluate the K-factor, the pressure and water level of SITs are measured. The results of evaluated K-factor are bounded at the lowest value of the design requirement due to measurement uncertainty. Therefore, KHNP expanded the design requirement to embrace the measurement uncertainty. A consistency between the evaluated K-factor and code calculation results has to be verified through code calculation although KINS agrees with validity of expanded requirement.

This paper deals with benchmark calculations of preoperational tests for SITs in SKN unit 3 using RELAP5/MOD3.3 code. Calculation results are compared with measured data and show a consistency between the calculation data and measured data.

2. Governing equation and Calculation Summary

2.1 Governing equation

The momentum equation for frictional, unsteady, incompressible and uniform velocity profile flow can be derived from Euler equations as bellow.

$$\frac{p_1-p_2}{\rho g}+\frac{V_1^2-V_2^2}{2g}+(Z_1-Z_2)-\frac{1}{g}\int\frac{\partial V}{\partial t}\cdot ds=H_{l_T} \quad (1)$$

Where p is pressure, V is flow velocity, Z is elevation, ρ is fluid density and H_{l_T} is total head loss.

$$H_{l_T}=H_l+H_{l_m}=\frac{1}{g}f\frac{L}{D}\frac{V^2}{2}+\frac{1}{g}K\frac{V^2}{2} \quad (2)$$

Where H_l is head loss due to wall friction, H_{l_m} is head loss due to area change, f is friction factor and K is K-factor due to area change.

Total K-factor can be expressed as bellows.

$$K_{tot}=\frac{2gH_{l_T}}{V^2}=f\frac{L}{D}+K \quad (3)$$

$$K_{tot}=f\frac{L}{D}+K=\frac{2g}{V^2}\left[\frac{p_1-p_2}{\rho g}+\frac{V_1^2-V_2^2}{2g}+(Z_1-Z_2)-\frac{1}{g}\int\frac{\partial V}{\partial t}\cdot ds\right] \quad (4)$$

The total K-factor is calculated using measured data. The flow velocity V can be calculated by measured level change. The unsteady term of equation 4 is neglected. Table I shows the evaluated K-factor using measured data.

Table I: Measured K-factor for SKN #3

	Total K-factor	
	High flow	Low flow
SIT A	15.56	103.22
SIT B	17.89	92.74
SIT C	16.58	93.52
SIT D	15.35	87.50

2.2 RELAP5 Calculation Summary

To perform the benchmark calculation for SKN #3, SIT nodalization of KREM is used. Nodalization of SIT consists of ACCUM component, two VALVEs and two TMDPVOLs. One of the VALVEs is modeled for high flow of FD and another VALVE is simulated for low flow of FD. Input of each VALVE is required for a flow energy loss coefficient, which means K-factor. Evaluated K-factors, as shown in Table I, are used in input requirement of VALVEs. Geometrical data and initial conditions such as an initial nitrogen and water volume, height of SIT, area of SIT are set as input requirement of ACCUM component using test data.

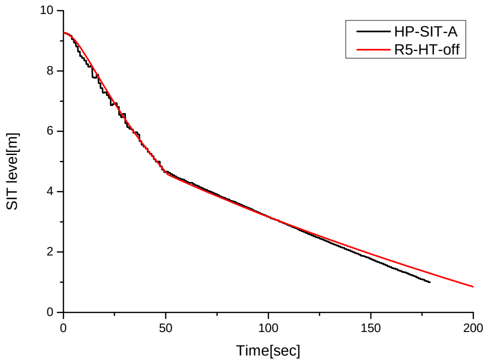

Fig. 1. Comparison of SIT level between test data and RELAP calculation result (SIT A)

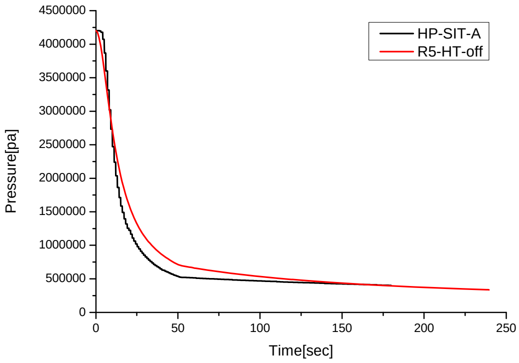

Fig. 2.Comparison of nitrogen pressure between test data and RELAP calculation results (SIT A)

3. Calculation Results and Discussion

From equation 4, velocity can be converted to the discharge mass flow as below.

$$K_{tot} = \frac{1}{\frac{1}{2}\rho V_2^{\,2}}\left[p_1 - \frac{\rho V_2^{\,2}}{2} + gZ_1\right] \qquad (5)$$

Where p_2 is atmospheric pressure, V_1 is level velocity of inner SIT, which can be negligible, Z_2 is zero and unsteady term is negligible.

Using equation 5, velocity can be converted to the mass flow rate as below.

$$K_{tot} = \frac{2\rho A}{W^2}\left[p_1 + gZ_1\right] - 1 \qquad (6)$$

Where W is the discharge flow rate and A is the discharge pipe area.

Although the measured level of SIT has fluctuations due to the measurement uncertainty, the result of RELAP calculation is well agreement with experimental data as shown in Fig. 1. The slope of SIT level means the discharge flow rate. Based on the equation 6, the K-factor is significantly affected by the discharge flow rate. Therefore, the calculation result corresponded with the test data shows a consistency between the test and the RELAP calculation.

Fig. 2 shows the comparison result of nitrogen pressure in the SIT between test data and RELAP calculation. The nitrogen pressure change is governed by discharge flow rate. During the flow discharging, expansion of nitrogen follows polytropic process. Pressure and temperature of nitrogen are drastically decreased by the volume expansion of nitrogen due to discharging of the flow. In RELAP calculation, heat transfer from SIT outer wall to nitrogen is not permitted because the discharging phenomenon is quick enough to neglect the heat transfer. In case of considering the heat transfer between the SIT wall and nitrogen, decreasing pressure of nitrogen is under-predicted because temperature decreasing of nitrogen is prevented by the heat transferring from relatively hot SIT wall.

Nevertheless, there is a difference of pressure tendency between test and calculation. This is because RELAP calculation cannot consider a detail hysteresis of quick opening valve (QOV) at the initiation of discharging. In RELAP input, a simple motor valve is modeled for linear opening characteristics of QOV during 30 second. The detail modeling method is not necessary from the viewpoint of LBLOCA calculation.

3. Conclusions

RELAP5MOD3.3 code calculation is performed to validate the consistency between the measured K-factor of SKN #3 SIT and RELAP calculation. As a result, the level change of SIT, which significantly influences K-factor, is well predicted in RELAP calculation. Modeling for hysteresis characteristics of QOV might be helpful for the accurate prediction of pressure change. Nevertheless, calculation results show a consistency between the calculation data and measured data.

REFERENCES

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[2] U.S. NRC, RELAP5/MOD3.3 Code Manual, U.S. NRC, Vol. I, 2006.