Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Analysis of pressure transients in Safety Injection (SI) piping for the opening cause of SKN 3 Safety Relief Valves

Suk-Ho Lee*, Sang-Gyu Lim and Han-Gon Kim
Advanced Reactors Development Office, Central Research Institute, Korea Hydro & Nuclear Power Company, Ltd., 70, 1312 Beon-gil, Yuseong-daero, Yuseong-gu, Daejeon 305-343, Republic of Korea
*Corresponding author: sukho.lee@khnp.co.kr

1. Introduction

Shin-Kori Nuclear Power Plant 3 (SKN 3) is being prepared for its commercial operation. During pre-operation and tests for that, the damage of Safety Relief Valves (SRVs) located at the exit of Safety Injection Pumps (SIPs) has been observed and issued recently. To resolve this issue, the opening cause of SRVs was examined from system design, piping design and operating condition.

SRV performs the function of thermal relief to protect the over-pressure depending on the temperature increase in the isolated piping. We recognized that the thermal expansion did not result in the opening of SRV because there was not the cause increasing the temperature in piping at that time. In addition, it was examined that there wasn't the external cause increasing the pressure in piping to the set pressure (144.0kg/m^2) of SRV. From operating condition, the possibility of air present in SI piping higher than water level (93 ft) of IRWST was founded. That was considered as main cause because any existing air can augment to the severity of hydraulic transients [1]. To confirm this, mini-flow tests for SIP performance were carried out again through enough air venting in the early of 2015. As shown in table 1, the results following SIPs startup were reasonable. Otherwise, maximum pressure was greater than 142.0 kg/m^2 and the fluctuation of pressure was also greater than 10.0 kg/m^2 in the results of 2014 having the possibility of air present in piping and the damage of SRV.

So, the objective of this paper is to evaluate pressure transients depending upon air present in SI piping as the opening cause of SKN 3 SRVs.

Table 1. The results of mini-flow tests for SIPs

At the exit of SIPs	Jan.~ Feb. 2015	Dec. 2014
Maximum pressure (kg/cm^2)	137.5~138.5	140.1~142.6
Pressure variation (kg/cm^2)	1.2~2.1	9.66~12.0

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2. Method of analysis

2.1 Code applicability

We adopt RELAP5 code to analyze the pressure transient in SI piping following SIP startup. For this, code applicability is preceded by comparing with the related experimental data. Figure 1 shows the diagram of Zhou's experimental apparatus [2]. Zhou's test describes the effects of trapped air on flow transient in pipelines. Test sets initial air fraction in simple pipeline and pressurizes the pressure tank. By opening the valve, system transients and pressure behaviors in pipeline are measured. Figure 2 shows the prediction results. As compared with total 36 test cases, RELAP5 code under-predicts for cases opening the orifice at the end of pipeline but predicts well when d/D (the ratio of orifice and pipeline diameters) is zero. This is similar to the system condition of mini-flow test for SIPs performance. Therefore, RELAP5 code is evaluated to have analysis capability for pressure transients depending upon the air present in SI piping of SKN 3.

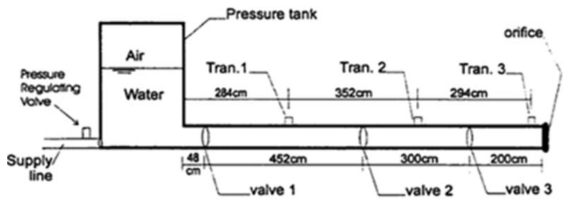

Figure 1. Diagram of Zhou's experimental apparatus

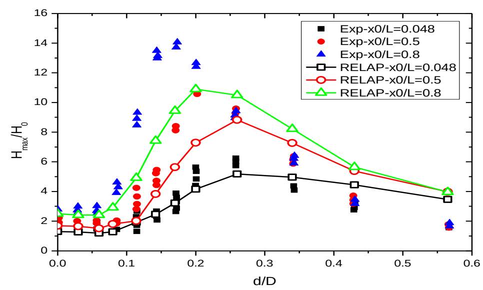

Figure 2. The comparison between test results and RELAP5 prediction

2.2 Analysis conditions and modeling

C-train and B-train of SKN 3 safety systems are used as representative cases for this analysis. Figure 3 shows the nodding diagram of C-train based on ISO drawing which simulates SI piping from SIP to MOV. B-train is also modeled similarly. The elevations of SIP, SRV and MOV in C-train are 56ft, 68ft and 102ft, respectively. The diameters for SI piping and the front piping of SRV are 4 inch and 3/4 inch. Mini-flow line and check valve are located in the rear piping of SIP. Otherwise, B-train is similar to C-train except that the elevation of MOV is 121ft and SRV is located a little lower.

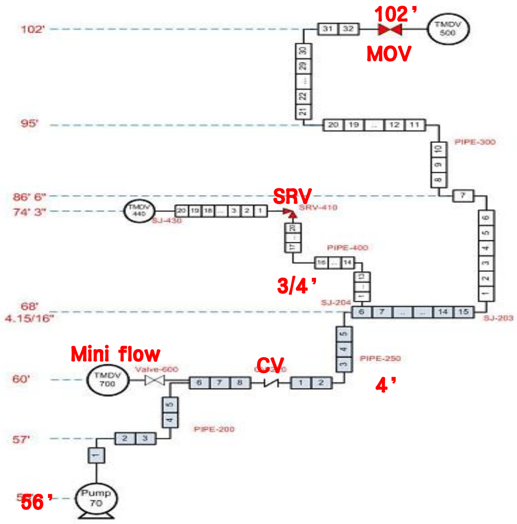

Figure 3. Noding diagram for RELAP5 (C-train)

The nodding has the volume length of 3~5ft and the front pipes of SRV and MOV are coarsely simulated as the volume length of 0.3ft. It is assumed that initial temperature and pressure of fluid are 302.59K and atmospheric pressure. The reach time to the rated speed following SIP startup is simulated as 1.2 seconds which is based on measured data in 2015.

Table 2 shows 4 analysis cases including the opening /closing characteristics of SRV for C-train and B-train, respectively. The opening/closing rate of CV is assumed as 0.1 seconds by considering the measured pressure frequency data. Sensitivity analyses for the amount of air based on Case 2 are carried out as shown in table 3

Table 2. Analysis cases for pressure transient

Case	Fluid in piping		SRV modeling	CV modeling
	SRV piping	SI piping		
Basecase	Air	Water	N/A	N/A
Case 1	Air	Air	N/A	N/A
Case 2	Air	Air	N/A	Applied
Case 3	Air	Air	Applied	Applied

Table 3. Sensitivity cases for the amount of air in piping

	Case	Pipe length (ft)	Case	Pipe length (ft)
C-train	Case 2-1 (a)	40.1	Case 2-1 (d)	18.4
	Case 2-1 (b)	26.9	Case 2-1 (e)	15.3
	Case 2-1 (c)	7.91	Case 2-1 (f)	12.1
B-train	Case 2-2 (a)	99.96	Case 2-2 (d)	14.23
	Case 2-2 (b)	80.98	Case 2-2 (e)	4.9
	Case 2-2 (c)	36.42	-	-

3. Analysis Results

Basecase simulates the mini-flow test of SIP after enough air venting. After the pump startup as shown in figure 4, the pressure of SI piping rises over 1.2 seconds and reaches to the mini-flow condition without the fluctuation of pressure. Basecase matches up with the measured data in figure 5. This means that the fluctuation of pressure inducing the opening of SRV does not happen if air is enough removed in SI piping.

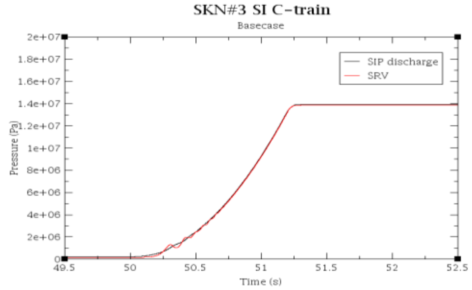

Figure 4. Pressure behaviors for basecase

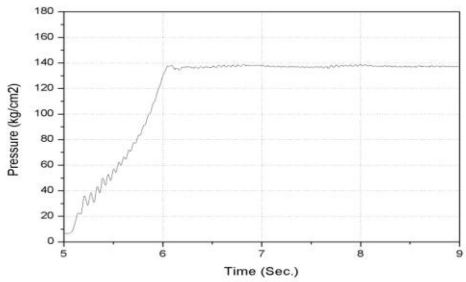

Figure 5. Measured pressure at the exit of SIP in 2015

Case 1 has the same condition with Basecase except for air present in SI piping. Considering that completely drained piping is gravitationally charged with water of IRWST, initially SI piping higher than 93ft is filled with air and its pressure is about 2 bar. Under this condition, the pressure behaviors following SIP startup are shown in figure 6. As comparing with Basecase, the reach time to the maximum pressure is delayed and the peak pressure happens. Although Air plays a role as a buffer for pressure rise initially, the pressure is excessively compressed as time goes on. As the result, the fluctuation of pressure and over-pressure happen in SI piping.

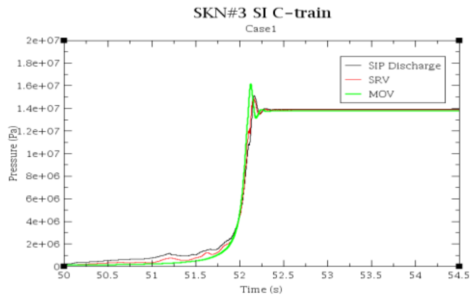

Figure 6. Pressure behaviors for Case 1

Figure 7 shows the results of Case 2 which adds CV modeling on the condition of Case 1. In Basecase and Case 1, the maximum pressure appears at the side of MOV but appears at the side of SRV in Case 2. This is the reason why pressure wave happened by air present in front piping of MOV is transferred to not the mini-flow line but the front piping of SRV due to CV. Also, pressure at the exit of SIP does not fluctuate as shown in figure because the pressure wave is not transferred to the side of SIP due to CV. Therefore, CV in SI piping with air increases the pressure in front piping of SRV and has an effect on the continuous fluctuation.

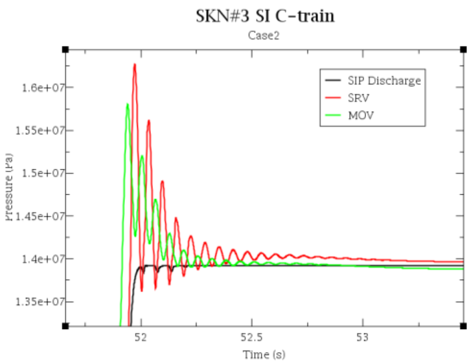

Figure 7. Pressure behaviors for Case 2

Case 3 adds SRV modeling without the blowdown on Case 2. As shown in figure 8, if initial pressure in SI piping exceed the set pressure and SRV is first opened, pressure after that fluctuates rapidly and the opening/closing of SRV are rapidly repeated as well. If blowdown exists, the fluctuation of pressure happens and then is immediately decreased as shown in figure 9. Although pressure fluctuates after initial opening, SRV remains opening because the closing set pressure becomes low by blowdown.

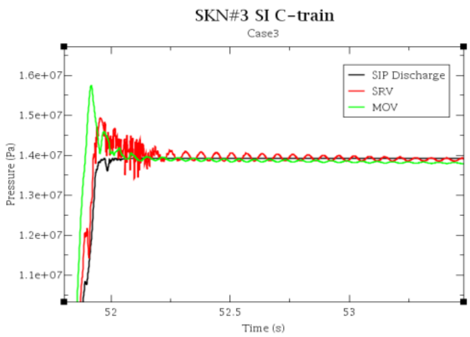

Figure 8. Pressure behaviors for Case 3

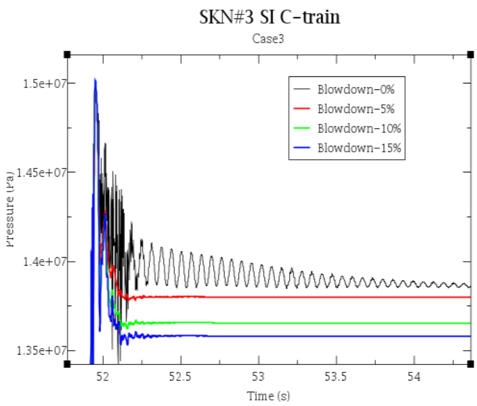

Figure 9. Sensitivities for blowdown (Case 3)

Figure 10 describes the sensitivity results for the amount of air present in SI piping of B-train. As a result, the maximum pressure appears in pipe length of 36.42ft and is decreased if the length of pipe filled with air is longer and shorter than that. In case of C-train, the maximum pressure appears in pipe length of 40.1ft. So, the results show that the optimal amount of air inducing the maximum pressure exists.

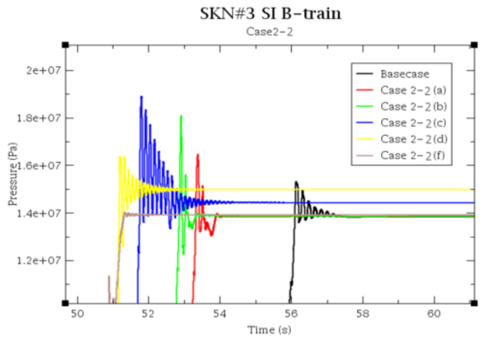

Figure 10. Sensitivities for the amount of air (B-train)

4. Summary and Conclusions

The damage of SRVs located at the exit of SIP has been observed during pre-operation and tests of SKN 3. According to the possibility of air present in SI piping, its effect for pressure transient was evaluated at the same condition using RELAP5 code.

The evaluation results for various cases demonstrate that the compression and expansion of trapped air in piping following SIP startup happen and have an effect on the opening of SRV by inducing the fluctuation of pressure and over-pressure in excess of set pressure. Also, the sensitivity results for the amount of air show that the maximum pressure in SI piping is different depending upon the amount of air and the optimal amount of air inducing the maximum pressure exists. From the evaluation for the blowdown characteristics of SRV, it is assumed that the chattering may be happened if the blowdown period of SRV is not or short.

Nomenclature

d	*orifice diameter [m]*
D	*pipe diameter [m]*
H_{MAX}	*maximum pressure [kg/m^2]*
H_0	*initial pressure [kg/m^2]*
L	*total length of pipeline [m]*
$x0$	*pipe length filled with air [m]*

REFERENCES

1. B. Rupak and R. Jaipal, "Analysis of pressure transients in CCW piping due to pump startup following a safety injection signal", FED-Vol. 221, 1995.
2. F. Zhou, "Effects of trapped air on flow transients in rapidly filling sewers", a thesis for the degree of doctor of philosophy, NLC, 2000.