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RELAP5 code analysis on the overpressure behaviors in SCS piping as the cause of SKN 3 LTOP valve opening

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1. Introduction

Low Temperature Overpressure Protection(LTOP) valve located in Shutdown Cooling System(SCS) was opened in the process of cooling Reactor Cooling System(RCS) to enter MODE 4(99℃< T_{cold} <177℃) during the overhaul of Shin-Kori Nuclear Power Plant 3 (SKN 3) in the early of 2018. The cause of valve opening was examined from system design, piping design, operating conditions and operator interview.

From operating conditions at that time, two things were confirmed. The first was that there were the external causes increasing the pressure in SCS piping close to the opening set-point(38.29 kg/m^{2}A, 3.76MPa) of LTOP valve. The second was that the possibility of vapor present in piping higher than water level of 89ft was founded from the pressure behavior measured at rear of Shutdown Cooling Pump(SCP). Especially, this was considered as main cause of valve opening because any existing air(or vapor) can augment to the severity of hydraulic transients[1].

So, this paper presents the code analysis results for pressure transient behaviors in SCS piping considering the operating conditions at that time.

2. Method and modeling for code analysis

2.1 Used code and its applicability

RELAP5 code is adopted in this paper. This code has been showed its applicability for these similar systems and hydraulic conditions by comparing with the related experimental and plant data. Representatively, RELAP5 well predicted Zhou's test[2] which measured pressure transient behaviors in pipeline having a trapped air and was evaluated to be able to simulate the system having the air/vapor present at the cause analysis on SKN 3 Safety Relief Valve(SRV) opening event[3].

2.2 RELAP5 nodding and analysis conditions

The center of hot leg through SCP is modeled for this analysis. Fig. 1 shows the nodding diagram based on ISO drawing for piping. The elevations of SCP(SV-100), LTOP valve(V-179) and hot leg(TMDV-100) are 59.5ft, 112ft and 117ft, respectively. Two isolation valves(V-653, V-655) are located on 109ft and 103ft. The LTOP valve was opened in the process of the sequential opening of these valves for the inflow of RCS coolant.

Table I summarizes the major factors that affected the pressure rise in front of LTOP valve in operating condition before the event. At that time, two of 4 RCPs were in operation on the loop-2 with the pressurizer, and two of the loop-1 were idle. The opened LTOP valve is installed in SCS Train A which is connected to the hot leg of loop-1. It is analyzed that a pressure imbalance due to RCS single loop operation has occurred. Therefore, the pressure in front of LTOP valve would be about 6.78 kg/cm^2 higher than 31.22 kg/cm^{2}A(RCS indication pressure).

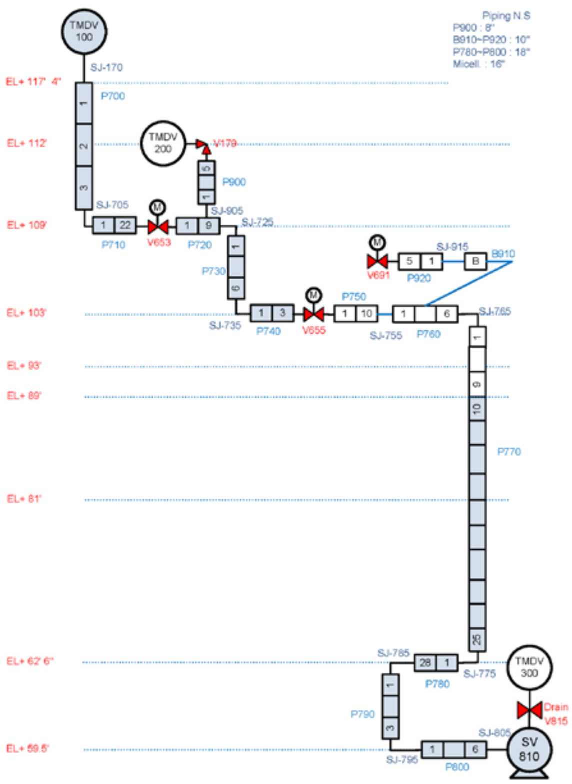

Fig. 1. Nodding diagram for RELAP5

Table I: Factors that affected pressure rise at the LTOP valve

Factors	Values, kg/cm^2 (psi)
Saturation pressure of Pressurizer	0.8 (11.38)
Elevation head between Pressurizer and LTOP valve	1.3 (18.4)
RCS pressure imbalance	4.68 (66.54)
Total	6.78 (96.32)

As a result of checking the measured pressure data, we also recognized that steam was formed in the piping higher than the water level of 89ft due to the leakage of V-655 after opening of V-653 for the inflow of RCS coolant(3.636MPa, 426.15K). In this condition, the LTOP valve was opened at 7 seconds just after opening of V-655 as shown in Fig. 2(0.0 sec. means the opening start time of V-655). Initial conditions are applied based on these measured data.

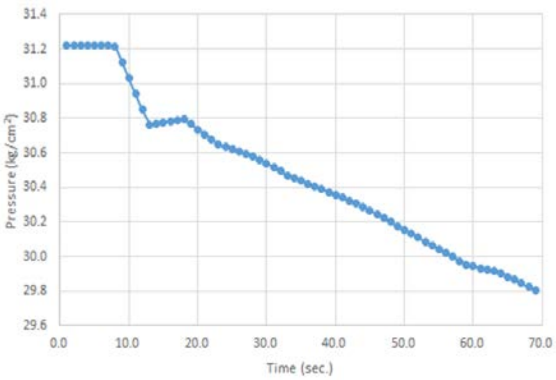

Fig. 2. Measured data for Pressurizer pressure

Fig. 3 shows the opening area ratio of V-655. Due to the absence of the valve characteristic data, we apply the linear opening rate based on the total opening time (68 sec.) of the valve to this analysis.

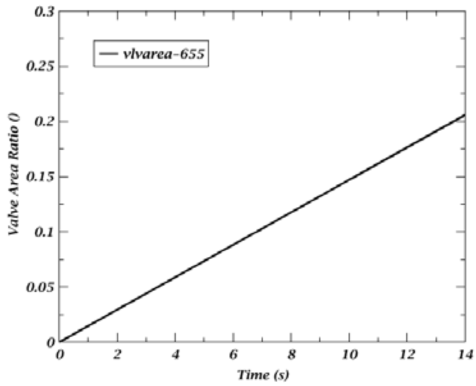

Fig. 3. Valve (V-655) opening rate

3. Analysis results for pressure transient behaviors in SCS piping

The transient analysis start with the opening of the V-655. Fig. 4 shows the results of pressure transient behaviors in piping according to the linear opening of valve. As described above, the LTOP valve was opened at 7 seconds just after opening of V-655. This is estimated from the measured time at which the pressure of the pressurizer decreases and the water level of IRWST increases.

As shown in Fig. 4, it can be seen that the peak pressure in front of the LTOP valve occurred in 6~7 seconds similar to these measured data. Also, it is confirmed that the pressure at that time sufficiently exceeds the opening set-point of the LTOP valve. If the valve is actually simulated, no additional pressure rise due to pressure release would have occurred, but in this analysis the pressure behavior is predicted higher than the opening set-point because the valve is not modeled.

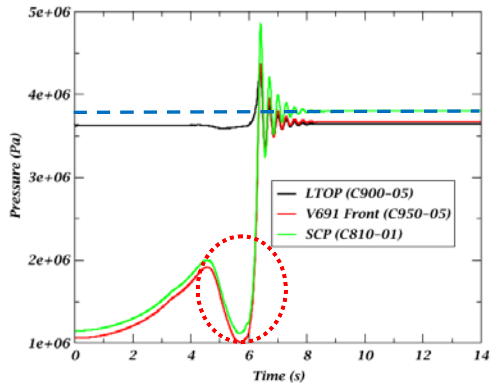

Fig. 4. Pressure behaviors in piping

The pressure drop temporarily occurs during the time interval (1.5sec.) with marked with a red circle in the Fig. 4. This means that the condensation happens after the steam in piping is compressed due to the inflow of RCS coolant. Fig. 5 shows the vapor condensation behaviors in the vertical pipe(P-770). This pressure drop behavior may not be seen in real measurements with intervals of 1.0 seconds. Similarly, the pressure fluctuation in rear of SCP may not be observed in the measured data due to dynamic pressure formation in a relatively short time.

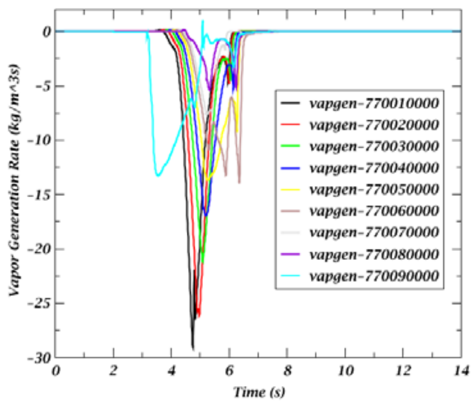

Fig. 5. Vapor condensation behaviors in vertical pipe (P770)

Fig. 6 and 7 show the flow rate behaviors through the isolation valve(V-655) and the branch(SJ-905) to the LTOP valve, respectively. It can be seen that the flow fluctuation happens after the complete condensation of the initially formed steam, and the dynamic pressure wave caused by this flow is propagated to the front of the LTOP valve.

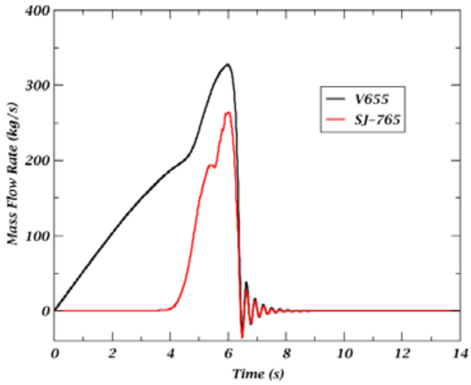

Fig. 6. Mass flow behaviors at isolation valve (V-655) and piping (SJ-765)

As shown in Fig. 6, it can be seen that the water level of the vertical piping(P-770) is completely formed about 6.5 seconds after the valve opening starts, and the back flow happens with the rapid decrease of the flow rate at that time. As a result, this flow transient causes dynamic pressure and pressure fluctuations at the front of the LTOP valve, which results in exceeding its opening set-point.

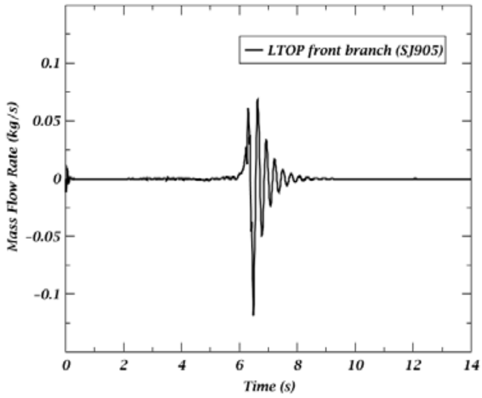

Fig. 7. Mass flow behavior at branch junction (SJ905) to the LTOP valve

4. Summary and Conclusions

The opening of the LTOP valve located in SCS was observed during the overhaul of SKN 3. According to the possibility of steam present in SCS piping at that time, its effect for pressure transient considering the operating conditions is analyzed using RELAP5 code.

The analysis results based on the measured data demonstrate that the compression and condensation of steam present in SCS piping just after the opening of isolation valve(V-655) happen rapidly and have an effect on the opening of the LTOP valve by inducing the fluctuation of pressure and over-pressure in excess of its opening set-point.

REFERENCES

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