An Evaluation on Degree of Conservatism in Pressurizer Level Calculation in Safety Analysis during a Pressurizer Level Control System Malfunction Event

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1. Introduction

Since the current design of Pressurizer Safety Valves (PSVs), installed in OPR1000 Nuclear Power Plants (NPPs), is qualified for only steam release, it should be verified that there is no possibility to release water through the PSVs during the event.

Current method, applied in OPR1000 NPPs, takes a conservative approach on estimating the maximum pressurizer (PZR) level [1], ensuring that the PZR level cannot reach the PSV nozzle. In this study, the maximum PZR level during PSV operation is evaluated with Best-Estimate (BE) methodology on a Pressurizer Level Control System (PLCS) malfunction event by using SPACE computer code [2] in order to investigate the degree of conservatism in the current method.

2. Overview of the PLCS Malfunction Event

While it is in the automatic mode, the PLCS maintains the PZR level by controlling the charging control valve and the letdown orifice isolation valves. If the PZR level controller fails low or the level setpoint fails high, a low level signal can be transmitted to the controller. The controller will maximize the charging flow and minimize the letdown flow.

The High Pressurizer Pressure Trip (HPPT) signal is generated due to the increase of the RCS inventory. If the steam bypass control system is not available after the turbine trip, the RCS temperature and pressure increase until the RCS pressure reaches the PSV opening setpoint. The PZR pressure rapidly decreases after the opening of the PSVs. During the depressurization, the water inside the PZR can flash into steam, causing a further increase of the PZR level.

3. Analysis on Pressurizer Water Level During PLCS Malfunction Event

3.1. Analysis Method

Since BE method is applied in this study, initial conditions and design data used in the analysis are assumed as nominal values.

The nodalization of the OPR1000 NPP for SPACE is shown in Figure 1. A PZR model with fine nodes is developed to investigate the PZR thermal hydraulic behavior during the PSV operation. The PZR model is shown in Figure 2. The model consists of 2 bottom head nodes, 40 PZR cylinder nodes and 8 PZR top head nodes. This detailed nodalization is needed in order to observe the vapor generation inside the PZR during the depressurization. Henry-Fauske/Moody model is used for PSVs and the elevation of the PSV nozzle is considered in the PZR nodalization.

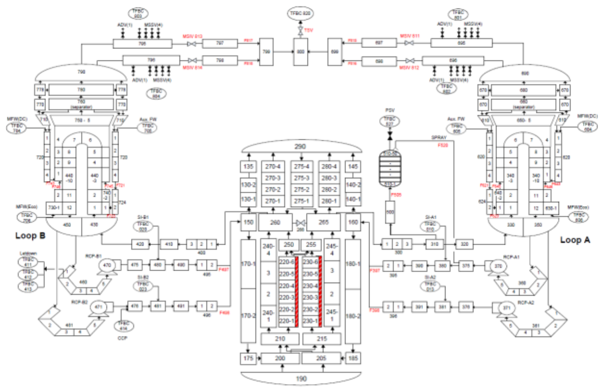

Fig. 1. SPACE nodalization for OPR1000

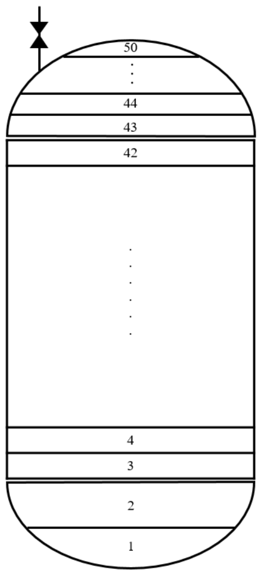

Fig. 2. PZR model

Flashing behavior of the PZR water during the PSV operation can be affected by the characteristics of PSVs. Thus, six cases of the combination with different PSV flowrates and opening setpoints are considered to investigate the effects of PSV characteristics on the flashing of PZR water. Evaluated cases are listed in Table I.

Table I: Evaluated cases considering PSV characteristics

Case	PSV Characteristics	
	Flowrate	Opening Setpoint
1	Max. (630,000 lbm/hr)	Max. (2,540 psia)
2	Max. (630,000 lbm/hr)	Nom. (2,500 psia)
3	Max. (630,000 lbm/hr)	Min. (2,460 psia)
4	Min. (460,000 lbm/hr)	Max. (2,540 psia)
5	Min. (460,000 lbm/hr)	Nom. (2,500 psia)
6	Min. (460,000 lbm/hr)	Min. (2,460 psia)

3.2. Pressurizer Water Volume Evaluation

Figure 3 shows the collapsed water volume after the reactor trip. The results are summarized as Table II. For cases in which the maximum PSV opening setpoint is assumed, the opening of Main Steam Safety Valves (MSSVs) prevents PSVs from opening.

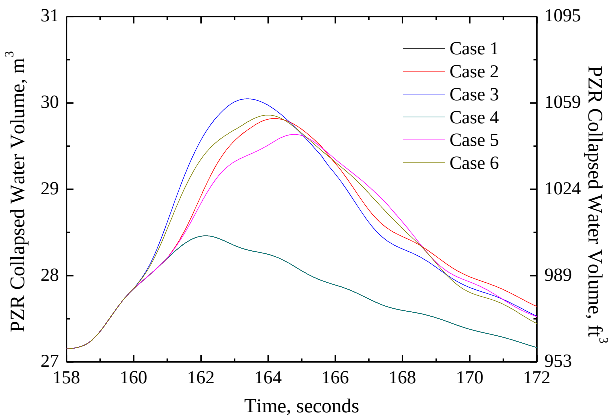

Fig. 3. PZR collapsed water volume

Table II: Results of PZR Collapsed Water Volume

Case	Max. Collapsed Water Volume	PSVs open
1	$28.46m^3$ ($1{,}005.06ft^3$)	N/A
2	$29.82m^3$ ($1{,}053.09ft^3$)	160.98 sec
3	$30.05m^3$ ($1{,}061.21ft^3$)	160.00 sec
4	$28.46m^3$ ($1{,}005.06ft^3$)	N/A
5	$29.64m^3$ ($1{,}046.73ft^3$)	160.98 sec
6	$29.86m^3$ ($1{,}054.50ft^3$)	160.00 sec

Figures 4~7 show the change in vapor volume fraction of PZR nodes, which are filled with water at the time of PSV opening. From the analysis, PZR nodes from node 1 to node 23 are filled with water before PSVs open, as a result of rapid in-surge after the reactor trip. As shown in the figures, the vapor fraction rapidly increases during the depressurization. It is also shown that the vapor volume fraction increase is larger at the upper nodes of the PZR and smaller at the lower ones since the water surged into the PZR during the event have lower enthalpy. Thus, it is expected that the major volume increase by flashing occurs at the upper side of PZR water. However, for conservatism, the flashing is assumed to have occurred uniformly with the largest value of the vapor volume fraction found in Figures 4~7 in the entire volume of PZR water.

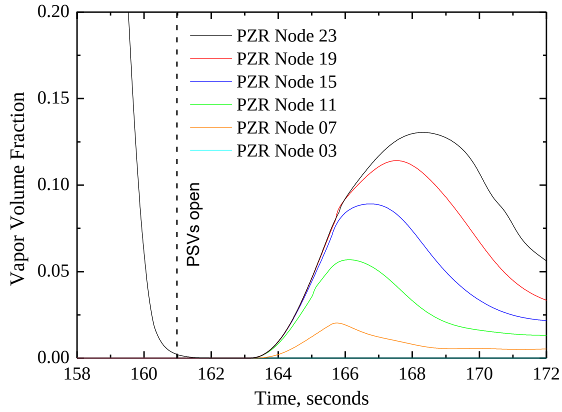

Fig. 4. Vapor volume fraction at PZR nodes (Case 2)

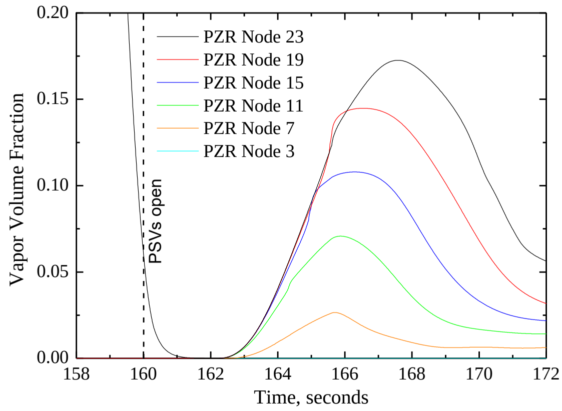

Fig. 5. Vapor volume fraction at PZR nodes (Case 3)

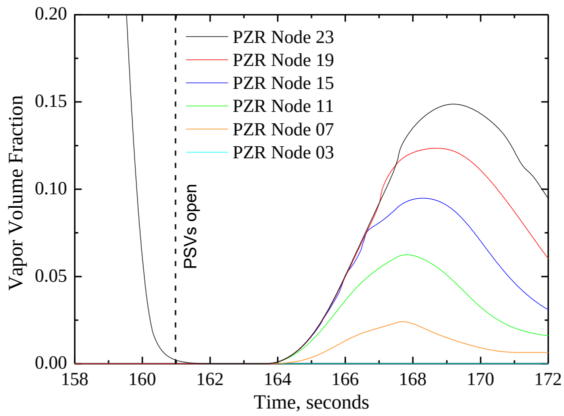

Fig. 6. Vapor volume fraction at PZR nodes (Case 5)

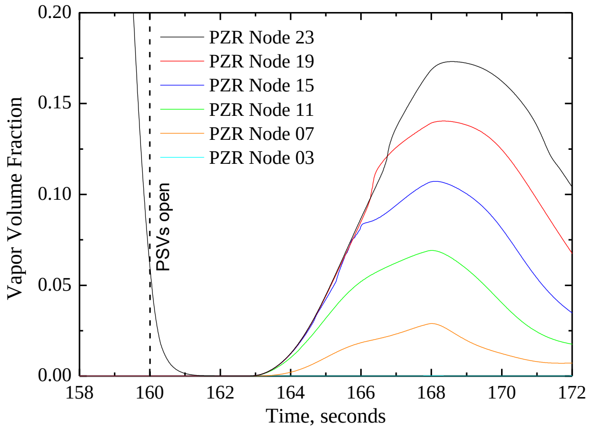

Fig. 7. Vapor volume fraction at PZR nodes (Case 6)

To estimate the maximum PZR water volume, the following procedure is used;

① Find the maximum collapsed water volume during the transient.

② From the PZR nodes which are filled with water at the time of PSV opening, find the maximum value of the vapor volume fraction after PSV opening.

③ The maximum volumetric expansion is estimated based on the maximum vapor volume fraction in ② and the maximum collapsed water volume found in ①.

④ The maximum PZR level is calculated based on the vapor volume calculated in ③ and the maximum collapsed water volume found in ①.

The estimated maximum PZR water volume are summarized as Table III. The results from the analysis show that a volume increase larger than 17.31% cannot occur due to the flashing phenomenon of PZR water during a PLCS malfunction event, which is a significantly smaller value than 43.4% from the conservative estimation [1]. Consequently, through this study, it can be known that the existing method with a conservative PZR level calculation during PLCS malfunction event has a large degree of conservatism.

The main reason for the extreme conservatism in the flashed volume estimation comes from the simplicity of the PZR model in CESEC-III computer code [3] which simulates the PZR as one node with two separated regions. Thus, the excessive conservatism in the current approach is expected to be mitigated if SPACE code is utilized in the licensing of OPR1000 NPPs.

Table III: Evaluation of the maximum PZR water volume

Case	Maximum Collapsed Water Volume	Maximum Vapor Volume Fraction	Maximum Volume Increase by Flashing	Estimated Maximum Water Volume.
1	28.46m^3 (1,005.06ft^3)	N/A	N/A	28.46m^3 (1,005.06ft^3)
2	29.82m^3 (1,053.09ft^3)	13.04%	3.89m^3 (137.37ft^3)	33.71m^3 (1,190.46ft^3)
3	30.05m^3 (1,061.21ft^3)	17.26%	5.19m^3 (183.28ft^3)	35.24m^3 (1,244.49ft^3)
4	28.46m^3 (1,005.06ft^3)	N/A	N/A	28.46m^3 (1,005.06ft^3)
5	29.64m^3 (1,046.73ft^3)	14.88%	4.41m^3 (155.74ft^3)	34.05m^3 (1,202.47ft^3)
6	29.86m^3 (1,054.50ft^3)	17.31%	5.17m^3 (182.58ft^3)	35.03m^3 (1,237.08ft^3)

4. Conclusion

In this study, the maximum PZR level during the PLCS malfunction event is evaluated, considering the flashing phenomenon of the PZR water due to PSV operation. Based on a quantitative evaluation, it can be concluded that the current method [1] of estimating the safety margin regarding PZR level has a substantial amount of conservatism, thus ensuring that there is no possibility for PZR level to reach PSV nozzles. Furthermore, it is expected that the excessive conservatism in the current approach can be mitigated by using SPACE computer code in the future licensing of NPPs.

REFERENCES

[1] S. S. Lee, "A Study on Degree of Conservatism of PZR Inventory during Event Analysis," Transactions of the Korean Nuclear Society Autumn Meeting, 2016.

[2] KHNP, "Topical Report on the SPACE code for Nuclear Power Plant Design," TR-KHNP-0032, March 2017.

[3] CENPD-107, "CESEC Digital Simulation of a Combustion Engineering Nuclear Steam Supply System," April 1974.