Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Analysis on Loss of Condenser Vacuum with a POSRV Failure for APR1400

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Keywords : DEC, loss of condenser vacuum with a POSRV, APR1400, SPACE

1. Introduction

After the Fukushima nuclear accident, Requirements for Design Extension Conditions (DEC) were introduced to provide assurance that the design of the plant is such as to prevent accident conditions that are not considered design basis accidents, or to mitigate their consequences, as far as is reasonably practicable[1]. Multiple failure accidents on safety systems that must be considered were specified according to the Korean Nuclear Safety and Security Commission's Notice No. 2017-34[2]. Under the notice, additional nine mandatory multiple failure accidents shall be considered once those have similar level of occurrences or consequences. Among the potential multiple failure accidents, Loss of Condenser Vacuum (LOCV) with the failure of a single pilot-operated safety relief valve (POSRV) could result in over-pressure of the Reactor Coolant System (RCS) pressure boundary.

According to the Korean Safety Review Guidelines (SRG) for light water reactor nuclear power plants, it is required that the analyses of LOCV event shall independently done for the perspective of primary and secondary system peak pressures, respectively.

This paper presents primary and secondary system peak pressures following LOCV with the failure of a POSRV which could be considered for the additional multiple failure accident. The results are compared with LOCV event that is categorized into the design basis event to find its consequential impact on the integrity of RCS pressure boundary.

2. Analysis Methods

This section describes the BE methodology used for the LOCV with a POSRV failure. The LOCV considered a Design Bases Event (DBE) causing a decrease in heat removal by the secondary system described in Safety Analysis Report (SAR) Chapter 15, has been evaluated with conservative methodology. The LOCV with a POSRV failure, which is one of the DECs caused by multiple failure accident is evaluated using the SPACE (Safety Performance Analysis Code for Nuclear Power Plant) code with the BE methodology using realistic assumptions, initial and boundary conditions to get more accurate analysis results. Therefore, nominal values are used for initial and boundary conditions, and uncertainty analysis is not performed and the single failure or the loss of offsite power is not considered in the analysis.

2.1 Assumption for Acceptance Criteria

There are no specific acceptance criteria for the LOCV with the failure of single POSRV. Therefore, It is assumed that acceptance criteria for the LOCV required by the SRG[3] that the primary and secondary peak pressure should not exceed 110% of the design pressure, respectively.

2.2 Assumptions

Basically, the conservative LOCV analysis considers many assumptions, such as not credit all the NSSS control systems including Pressurizer Pressure Control System (PPCS) and Pressurizer Level Control System (PLCS) to maximize the increase in RCS Pressure. However, for the LOCV with a POSRV failure, it assumed that the PPCS and PLCS can be credited because these are not affected by this event. And the operation of Steam Bypass Control System (SBCS) and Feedwater Control System (FWCS) cannot credited, and the POSRV discharged due to RCS over-pressurization is directed to the In-Containment Refueling Water Storage Tank (IRWST), resulting in no increase with pressure and temperature in the containment.

2.3 Modeling for APR1400 using SPACE code

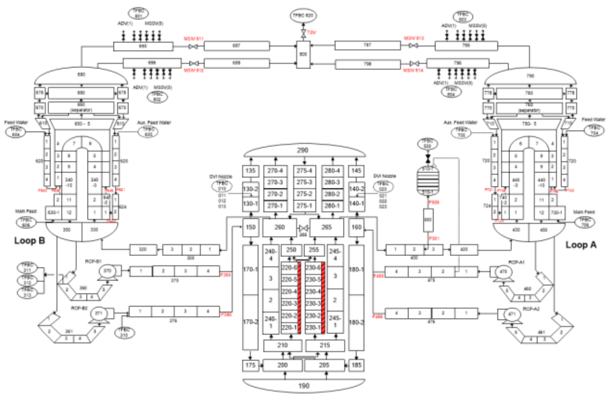

Fig. 1. APR1400 Nodalization using SPACE code

The APR1400 is 2-loop Pressurized Water Reactor (PWR) with a core power of 3,983 MWt, and it has been modeled using the SPACE code. The SPACE code is applied with BE analysis methodology, and the simulated system can be shown in Fig. 1. Table 1 illustrates a comparison between design values and modeled steady-state results.

Table 1. Initial Conditions

Parameter	Design Value	Analysis Value
Core Power(MWt)	3,983	3,983
RCS flow rate(kg/s)	20,991	20,449
Core Inlet Temperature(°C)	323.85	323.68
Pressurizer pressure(psia)	2,250	2,251
Pressurizer Level(%)	50.0	50.0
SG level(%WR)	76.82	76.87

3. Analysis Results

3.1 LOCV with a POSRV failure

Table 2 shows the sequence of events that LOCV with a POSRV failure. This event leads to the interruption of steam flow to the turbine and main feedwater flow to the steam generators, causing a decrease in cooling of the reactor coolant system and an increase in primary side pressure. This situation leads to reactor shutdown due to high pressurizer pressure trip by Plant Protection System (PPS).

Table 2. Seq. of Events for LOCV with a POSRV failure

Event	Time (sec)
LOCV with a POSRV failure - Turbine stop - Main feedwater stop	0.0
Reactor trip by HPPT	4.4
MSSV 1st opening	4.8
POSRV 1st opening RCS peak pressure	6.6
SG Peak Pressure	12.8
Aux. feedwater initiation	286.0
End of simulation	1,800

To limit the pressure increase in the reactor coolant system, the POSRV is opened at once. Assuming the failure of one out of four POSRVs, steam is released using three valves, and the released steam is directed to the IRWST. As the turbine is stopped, the pressure in the main steam system increases, leading to the opening of the Main Steam Safety Valves (MSSV) to limit the pressure in secondary side as shown in Fig. 2. In that case, the steam generator water level decreases, and the auxiliary feedwater is supplied to restore it. In this manner, through the MSSV and auxiliary feedwater system, the secondary side regulates water level, gradually reducing decay heat from the primary side and maintaining SG pressure.

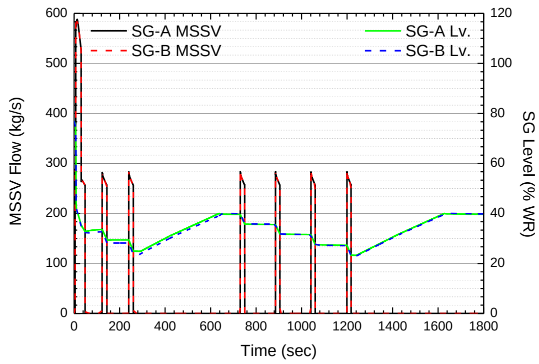

Fig. 2. MSSV Flow and SG Level

3.2 Comparison of Conservative and BE Analysis

Fig. 3 shows the peak pressures of LOCV on the primary side with a conservative methodology and LOCV with a POSRV failure using the BE methodology. From these graphs, it is evident that there is minimal safety margin from the acceptance criteria of 2,750 psia in the case of conservative analysis. However, the peak pressure LOCV with a POSRV failure scenario is bounded by the conservative analysis result with a significant margin to the acceptance criteria.

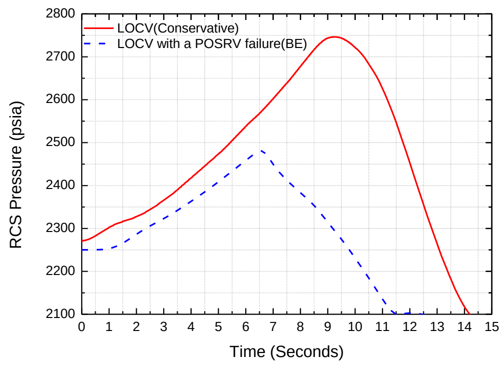

Fig. 3. RCS Pressure

Fig. 4 presents the secondary side pressure for two analyses, the peak pressure occurs during the MSSV opens. Similar to the findings on the primary side, the conservative methodology yields minimal margin to the acceptance criteria of 1,320psia. However, when applying the BE methodology, it is observed that a significant safety margin is maintained, even in the scenario where a POSRV fails to open.

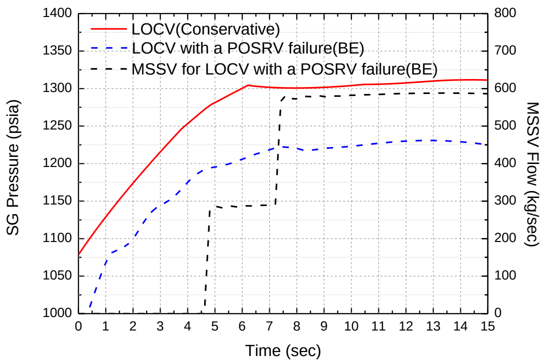

Fig. 4. SG Pressure

Table 3 presents the acceptance criteria and analysis results for the primary and secondary sides. The results for the LOCV with a POSRV failure derived from the DEC show that much more safety margin compared to the conservative analysis.

Table 3. Comparison Conservative and BE Analysis

	RCS Peak Pressure (psia)	SG Peak Pressure (psia)
Acceptance Criteria	2,750	1,320
Conservative Analysis (LOCV)	2,737	1,317
BE Analysis (LOCV with a POSRV fail)	2,483	1,231

4. Conclusions

In this paper, an evaluation was conducted on the LOCV with a POSRV failure, which was selected as a DEC that could result in over-pressurization of the RCS pressure boundary. To assess this scenario, the BE analysis methodology was applied using the SPACE code, and the results showed that both the peak pressure on the primary side and the peak pressure on the secondary side show significant margin to the acceptance criteria. Furthermore, the analysis results indicated that the event was bounded by the conservative LOCV results in Chapter 15 of the FSAR, Therefore, it was concluded that there is no need for quantitative assessment of this scenario as DEC further.

REFERENCES

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[3] Korea Institute of Nuclear safety, Safety Review Guidelines for Light Water Reactor

[4] J.J. Kim, C. E. Park, G. C. Lee, “A Comparative Study on Conservative and Best-estimate Analysis of LOCV for APR1400”, Korean Nuclear Society Autumn Meeting, Goyang, 2019