A Comparative Study on Conservative and Best-estimate Analyses of LOCV for APR1400

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1. Introduction

Loss of Condenser Vacuum (LOCV) is a representative event from the overpressure point of view to ensure primary system integrity. LOCV was analyzed by a conservative methodology and a best-estimate (BE) methodology.

The methodology for non-LOCA safety analysis using SPACE code has been licensed by Korean regulatory body in 2017 [1]. This safety analysis methodology is based on the conservative scheme imposed by regulations. On the contrary, BE methodology is applied to evaluate the multiple failure events in Design Extension Condition (DEC) analyses [2]. According to the qualitative evaluation performed to determine any additional events need to be considered in DEC analyses, LOCV with one POSRV failure event might cause a higher Reactor Coolant System (RCS) peak pressure than that of conservative LOCV safety analysis [3]. However, analysis results of LOCV with one POSRV failure event using BE methodology showed a lower RCS peak pressure by about 90 psia [1,2] as compared to the conservative methodology.

Therefore, this paper presents a comparative study results on conservative and BE analyses of LOCV for APR1400 to find causes of different RCS peak pressure between these analysis methodologies.

2. Comparison of Analysis Methodologies

This section describes the differences between conservative and BE methodologies used for LOCV event analyses. The former is adopted in the non-LOCA safety analysis methodology using SPACE code [1] similar to that presented in Chapter 15.2 of FSAR using CESEC-III code [4]. The latter is used to analyze LOCV with one POSRV failure as a multiple failure event for DEC analysis.

2.1 Common Features between Analysis Methodologies

There are common features between two methodologies such as the computer code and several assumptions on the secondary system for LOCV analysis.

SPACE code version 3.21, which is released in June 2019, is used to simulate the thermal-hydraulic behaviors for both analysis methodologies.

Coincident with LOCV occurrence, it is assumed that turbine trip occurs and main feedwater is cut off simultaneously. Turbine Bypass Valves (TBV) are assumed not to be actuated due to the failure of Steam Bypass Control System (SBCS) caused by LOCV.

2.2 Conservative Methodology for LOCV Analysis

A conservative methodology for LOCV analysis adopts various conservative approaches in initial conditions, assumptions for system behaviors, and setpoints.

Most conservative initial conditions are used to maximize the RCS peak pressure. These include core power, core inlet temperature, RCS flow rate, pressurizer pressure, Steam Generator (SG) level.

Loss of Offsite Power (LOOP) is also assumed to occur after turbine trip. LOOP results in RCP trip and reduces the heat removal of primary system by decreasing RCS flow. The time on which LOOP is conservatively determined to delay the reactor trip as much as possible for a higher RCS peak pressure.

Nuclear kinetics parameters are conservatively applied. Moderator density coefficients are set to zero and Doppler coefficients are most negative ones in order not to decrease core power in early phase of LOCV. The scram rod worth is modeled with the most reactive Control Element Assembly (CEA) stuck out. Decay heat is considered with the weighting factor of 1.2.

None of all the control systems is credited. Feedwater Control System (FWCS) and SBCS are disabled at the beginning of LOCV based on the assumptions. Charging and letdown flows are set to zero since the Pressurizer Level Control System (PLCS) is not credited. The pressurizer spray and heaters are disabled because the Pressurizer Pressure Control System (PPCS) is also not credited.

Conservative reactor trip setpoints of the Reactor Protection System (RPS) are applied to the conservative LOCV analysis. Maximum or minimum analysis setpoints are adopted to model RPS in conservative manner.

Finally, safety valves are conservatively modeled in their setpoints and capacities. POSRVs and Main Steam Safety Valves (MSSVs) are modeled to delay their opening and to minimize their flow rates.

2.3 BE Methodology for DEC LOCV Analysis

A BE methodology is used to simulate LOCV with one POSRV failure event in DEC analyses. The main features of BE methodology consist of nominal values and realistic assumptions.

Nominal values at rated full power plant conditions are applied to initial conditions, moderator density coefficients, Doppler coefficients, RPS trip setpoints, and opening/closing setpoints of safety valves.

For a realistic simulation, LOOP and the most reactive CEA stuck out are not assumed. For the same reason, PLCS and PPCS are credited. Valve areas of POSRVs and MSSVs are modeled to their rated capacities, not to their minimum values.

3. Description of Comparative Study Methodology

APR1400 is a Pressurized Water Reactor (PWR) with 3983 MWt core power. Figure 1 shows the SPACE code nodalization of APR1400 commonly used in conservative and BE methodologies. However, SPACE code input for BE DEC analysis is different from that for conservative analysis in such a way that control systems and related heat structures for primary and secondary systems are included.

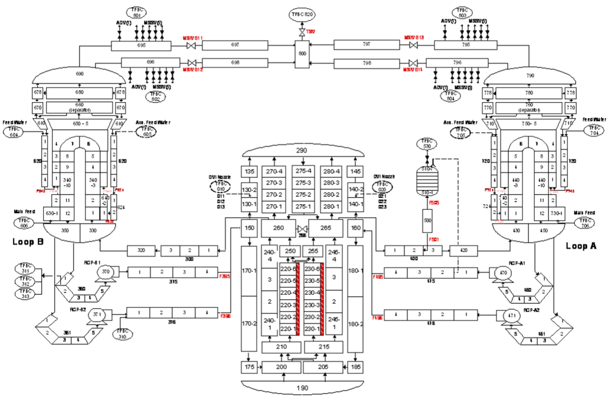

Fig. 1. SPACE Nodalization of APR1400

Table I compares the initial plant conditions for conservative and BE methodologies.

Table I. Initial Conditions for LOCV Analyses

Parameter	Design Value	SPACE Calculation	
		Conservative	BE
Core Power (MWt)	3983	4092	3983
RCS flow rate (lbm/s)	46,277	46,277	46,277
Core Inlet Temperature (°F)	555	550	555
Pressurizer pressure (psia)	2250	2175	2250
Pressurizer level (%)	50.0	21.0	50.0
SG level (%WR)	76.9	65.0	76.9

A comparative study on conservative and BE methodologies is performed by quantifying the impact of each conservative factors on the RCS peak pressure. The selected conservative factors include initial conditions, LOOP, nuclear kinetics parameters, control systems (PPCS and PLCS), reactor trip setpoints and safety valves (POSRV and MSSV).

Based on the SPACE input which is modeled by conservative methodology, each conservative factor is changed to figure out its influence on the RCS peak pressure.

4. Comparative Study Results

Table II summarizes the calculated RCS peak pressure obtained by eliminating each conservative factors from the original conservative case. 'ALL' in Table II means that all conservative factors are changed in order to compare with the original BE analysis. This case is equivalent to 'BE (No POSRV Fail)' in Table III. The RCS peak pressures of 'ALL' and 'BE (No POSRV Fail)' case are 2620.79 and 2622.17 psia, respectively. This slight difference arises from the presence of heat structures in SPACE BE input.

4.1 Minor Conservative Factors

Among the conservative factors, LOOP, reactor trip setpoints and PLCS turned out to have relatively small influence on the RCS peak pressure during LOCV event.

The occurrence of delayed LOOP reduces the RCS flow rate and heat transfer from primary to secondary system. However, heat removal by the secondary system already has been reduced causing RCS heat up before the delayed LOOP because turbine trips at the start of LOCV by the common assumptions described in section 2.1. As a results, the reactor trip can occur by either RCP low speed trip or High Pressurize Pressure (HPP) trip depending on LOOP timing. In the original conservative case analysis, time of LOOP was determined to have HPP trip and RCP low speed trip by LOOP occurring at the same time. Therefore, without delayed LOOP, HPP trip occurred instead as listed in Table II with minor reduction in the RCS peak pressure.

Since, the normal letdown flow is higher than the normal charging flow, a reduced RCS peak pressure would be expected with PLCS in operation. However, the credit of PLCS does not affect the RCS peak pressure because flow rate difference between letdown and charging is small enough to be ignored.

4.2 Major Conservative Factors

The most effective factor on the RCS peak pressure is found in parameters of safety valves. POSRV directly reduces the RCS pressure while MSSV does indirectly by increasing heat removal. Due to the independent mechanisms of the RCS peak pressure reduction between POSRV and MSSV, the sum of individual pressure reductions by POSRV (31.65 psia) and MSSV

(19.03 psia) is nearly same as the combined pressure reduction by POSRV and MSSV (49.10 psia).

The RCS peak pressure occurred during CEA insertion. This means that time versus scram rod worth is a key parameter affecting the RCS peak pressure among nuclear kinetics parameters. As shown in Figures 2 and 3, there is about twice as much difference in core power at the time of the RCS peak pressure between original conservative case and nominal nuclear kinetics case. The RCS peak pressure is lower for nominal case due to an earlier reactor trip and a higher total CEA worth as shown in figures 2 and 3.

Table II. RCS Peak Pressures by Conservative Factor

Conservative Factor		Trip Type	Peak Press. (psia)	Press. Diff. (psia)	Rank
Original Conservative Case (Reference)		**RCP Low***	**2717.46**	**0.0**	**-**
Initial Conditions (Nominal)		HPP**	2686.98	-30.47	4
Delayed LOOP (Not Assumed)		HPP	2712.84	-4.61	8
Nuclear Kinetics (Realistic)		RCP Low	2674.15	-43.31	2
Control Systems (Credited)	PPCS	RCP Low	2696.09	-21.36	6
	PLCS	RCP Low	2716.79	-0.67	9
	PPCS & PLCS	RCP Low	2694.73	-22.73	5
Rx. Trip Setpoint (Nominal)		RCP Low	2716.98	-0.48	10
Safety Valves (Nominal Capacity & Setpoint)	POSRV	RCP Low	2698.43	-31.65	7
	MSSV	RCP Low	2685.81	-19.03	3
	POSRV & MSSV	RCP Low	2668.36	-49.10	1
ALL		**HPP**	**2620.79**	**-96.67**	**-**

* RCP low speed trip
** High Pressurizer Pressure Trip

Table III. RCS Peak Pressures for BE Analyses

BE Case	Trip Type	Peak Press. (psia)	Press. Diff. (psia)
BE (One POSRV Fail)	HPP	2624.70	-92.75
BE (No POSRV Fail)	**HPP**	**2622.17**	**-95.29**

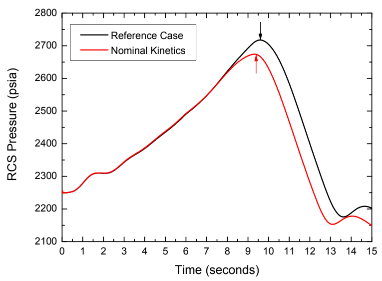

Fig. 2. Time of RCS Peak Pressure

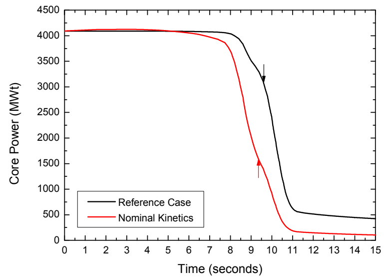

Fig. 3. Core Power at Time of RCS Peak Pressure

Initial conditions and pressurizer spray of PPCS also have influences on the RCS peak pressure as indicated in Table II. Since the nominal pressurizer pressure is higher than that used for the original conservative case as shown in Table I, HPP trip occurred earlier than RCP low speed trip as occurred for the original conservative case causing a lower RCS peak pressure. However, the core power does not decrease sufficiently, an early HPP trip by nominal initial condition may not always reduce the RCS peak pressure effectively as discussed earlier.

5. Conclusions

A comparative study on conservative and BE analysis of LOCV for APR1400 showed that the most important parameter affecting the RCS peak pressure is the conservatism in modeling the safety valves such as POSRV and MSSV.

Pressurizer spray of PPCS reduced the RCS peak pressure as expected. Nuclear kinetics parameters and initial conditions had influence on the RCS peak pressure. However, these cannot always reduce the RCS peak pressure depending on the combination of RCS pressure and core power.

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