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Design Optimization of Overpressurization Protection for ARP1400

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1. Introduction

As compared with the acceptance criteria of Standard Review Plan (SRP), the safety margin of Advanced Power Reactor (APR) 1400 design is insufficient for the Loss of Condenser Vacuum (LOCV) event due to reinforced safety regulation requirement. The purpose of this study is to evaluate the design change to secure the safety margin by analyzing the system peak pressure in case of the LOCV event using the CESEC-III computer code [1]

In this study, the design changes for the Pressurizer (PZR) spray subsystem, PZR surge line and Pressurizer Safety Valve (PSV) & Main Steam Safety Valve (MSSV) are reviewed to reduce system peak pressure during the LOCV event.

2. Methods of Reducing Peak Pressure

Table I: Items of Design Changes

	Current Design	Design Change
PZR Spray	Non-Safety	Safety
Surge Line	① Pipe Size DN[1)] 300 (12 inch)	① Pipe Size DN 350 (14 inch)
	② Flow Area 498 cm^2	② Flow Area 634 cm^2
	③ Bending Radius 1.5 * Nom. Diameter	③ Bending Radius 3.0 * Nom. Diameter
RCS OP[2)] Device	POSRV	PSV
MSSV	① Opening Setpoint 1,174/1,205/1,230 psig ② Opening Area 70% @ $P_{opening\ set}$	① Opening Setpoint 1,174/1,198/1,219 psig ② Opening Area 90% @ $P_{opening\ set}$

1) Diameter Nominal (mm)
2) Overpressurization Protection

2.1 Pressurizer Spray Subsystem

The Reactor Coolant System (RCS) pressure is controlled by using the PZR heaters and PZR spray subsystem to maintain the steam and the water of the PZR in a thermal equilibrium. The PZR spray subsystem consists of the control valves, isolation valves, check valves and pipes connected physically from the outlet of the Reactor Coolant Pumps (RCPs) of Loop 2A and 2B to the PZR spray nozzle. The diaphragm-operated spray valves installed on the two spray lines control the spray flow by the Pressurizer Pressure Control System (PPCS) demand.

In the safety analysis, the non-safety related system is conservatively assumed so that the analysis results are worsened. Thus, if the PZR spray subsystem is redesigned to safety system, as shown in Table I, the spray actuation can be given credit for to reduce the system peak pressure. However, the design change of the PZR spray subsystem to the safety system will give significant impacts on the RCS or Instrumentation and Control (I&C) system.

2.2 Pressurizer Surge Line

The PZR surge line connects the hot leg in the RCS Loop 2 with the PZR and it is designed with the diameter of 12 inch and the elbow bending radius of 18 inch for APR 1400 NPPs.

If the flow resistance in the PZR surge line decreases, the reactor coolant surge into the PZR becomes smooth and the RCS peak pressure will be lower due to the early reactor trip by the High Pressurizer Pressure Trip (HPPT). Relevant design changes are identified in Table I to lower the RCS peak pressure.

2.3 Pressurizer Safety Valves

The PSVs and the Pilot Operated Safety Relief Valves (POSRVs), which are the primary side safety valve, directly release steam to reduce the RCS pressure when the PZR pressure reaches the valve opening setpoint and Table II shows a comparison of PSV and POSRV. The POSRVs are installed on the top of the PZR and each POSRV consists of one main valve, two Spring-Loaded Pilot Valves (SLPVs), double Motor-Operated Pilot Valves (MOPVs) and so on.

As shown in Table I, if POSRVs are replaced with PSVs with pop-open characteristic, the system peak pressure could be lowered. But this case requires a separate Safety Depressurization System (SDS) for rapid depressurization of the RCS.

Table II: Comparison of PSV and POSRV

	PSV	POSRV
Opening Setpoint, psia	2,500	2,470
Minimum Discharge Flow Rate, lbm/hr	2,160,000	2,160,000
Maximum Opening / Closing Time, sec	Pop-Open	0.5 / 0.9
Discharge Permission	Steam	Steam+Water
Uncertainty, % (Design / Analysis)	1.0 / 3.0	0.75 / 2.0
Blowdown, %	18.4	13

2.4 Main Steam Safety Valves

The Main Steam Safety Valves (MSSVs) are installed at the upstream of each main steam isolation valve on the outside of the containment and perform overpressurization protection of the SG secondary side upon transient conditions of the NPP. When the MSSVs open, the steam inside the SG and the main steam line is released to the atmosphere to prevent overpressurization.

If the opening setpoints and characteristic are changed as shown in Table I, the system peak pressure will be further reduced due to more steam release when SG pressure reaches the MSSV opening setpoint.

3. Safety Analysis

3.1 Determination of Limiting Event

The LOCV event has been selected as a limiting one among overpressurization events of FSAR chapter 15 because it has the smallest margin compared with the acceptance criteria specified in the SRP.

The LOCV event is categorized in the 'Decrease in Heat Removal by the Secondary System' events. Upon the LOCV, turbine trip occurs and turbine stop valves and turbine bypass valves are closed to protect the turbine and related system. In this event analysis, instantaneous and complete terminations of steam flow and feedwater flow are assumed conservatively because reducing heat removal capacity of the secondary system increase the RCS and SG pressure rapidly.

3.2 Preliminary Analysis on Design Changes

Table III shows the analysis results following the proposed design changes with regard to the RCS and SG peak pressure for the LOCV event, respectively.

Considering effectiveness of each design change alternative, the decreasing the flow resistance in the PZR surge line and the MSSV opening setpoints are finally selected for optimal design changes because they lead to the highest safety margin. And finally, the sensitivity study is performed by combining these design changes for the LOCV event.

Table III: Peak Pressure and Safety Margin

	Design Change			
	RCS P_{peak}, psia	Margin, psi	SG P_{peak}, psia	Margin, psi
PZR Spray	2,741.89	+8.11	1,318.33	+1.67
Surge Line	2,714.28	+35.72	1,318.82	+1.18
PSV	2,765.07	-15.07	1,319.04	+0.96
MSSV	2,741.55	+8.45	1,282.54	+37.46

3.3 Final analysis on Optimal Design Change

Table IV shows the initial conditions and results for the limiting case of the LOCV event reflecting the design optimization for overpressurization protection with regard to the RCS and SG peak pressure.

The dynamic behavior of the RCS and SG pressure following the LOCV is presented on Figure 1 and Figure 2, respectively. For the LOCV event, the RCS and SG peak pressures for the limiting case reflecting the design optimization for overpressurization protection margin are reduced to 2,718.5 psia and 1,282.6 psia, respectively. The reason why the system peak pressures are higher than the preliminary analysis results is that the initial conditions for the limiting case is changed.

Table IV: Initial Conditions and Results

Parameter	Value	
	RCS	SG
	Optimization	Optimization
Core Power, %	102	102
Core T_{in}, °F	550	563
PZR P, psia	2,175	2,175
PZR Water V, %	50	50
RCS Q, %	95	95
Peak P, psia	2,718.5	1,282.6
Margin, psi	31.5	37.4

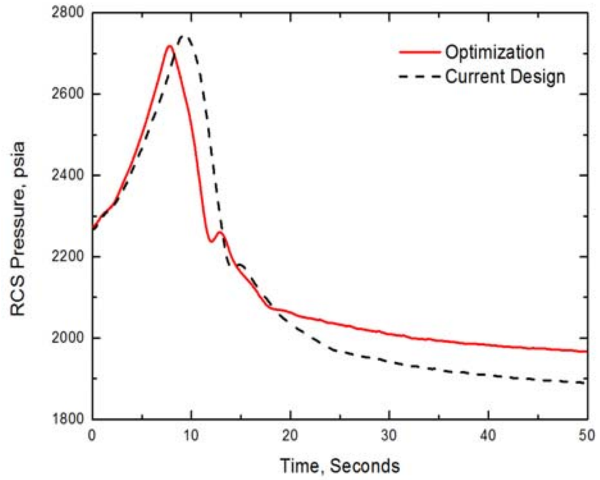

Figure 1 RCS Pressure vs. Time
(with regard to RCS peak pressure)

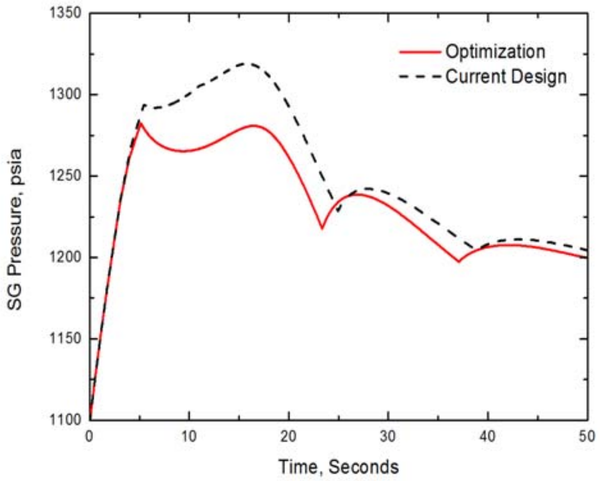

Figure 2 SG Pressure vs. Time
(with regard to SG peak pressure)

4. Summary and Conclusion

The design changes of APR1400 to reduce the system peak pressure are studied and the quantitative analysis on the LOCV are performed event using the CESEC-III computer code. Based on the quantitative evaluation, design changes of the flow resistance in the PZR surge line and the MSSV opening setpoints are assessed to be the most optimal method with regard to the RCS and SG peak pressure, respectively. Therefore, the design optimization is determined as combination of these two and consequently, which gives sufficient margin.

REFERENCES

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