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Preliminary Analysis of a Loss of Condenser Vacuum Accident Using the MARS-KS Code

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1. Introduction

In accordance with revision of NUREG-0800 of USNRC[1], the area of review for loss of condenser vacuum(LOCV) accident has been expanded to analyze both peak pressures of primary and secondary system separately.

Currently, the analysis of LOCV accident, which is caused by malfunction of condenser, has been focused to fuel cladding integrity and peak pressure in the primary system. However, in compliance with the revised NUREG-0800, peak pressure analysis of secondary system would be necessary.

In this paper, accident analysis for LOCV using MARS-KS code were conducted to support the licensing review on transient behavior of secondary system pressure of APR1400 plant.

2. Methods and Assumptions

2.1 Accident scenario of LOCV

The condenser maintained a vacuum pressure to enhance the efficiency of steam and to protect other components such as a turbine. The accident of LOCV is initiated when the condenser has lost the vacuum by unexpected failure.

In the accident analysis of APR1400, turbine and feedwater pump are tripped at the same time of the LOCV and the reactor is tripped by pressurizer high pressure signal or low pump shaft speed signal. The reactor trip with a steam generator low level signal was not credited for conservative calculation in the safety analysis report of APR1400[2].

2.2 Modeling and Nodalization

The MARS-KS code was used to calculate the thermal-hydraulic behavior during the LOCV.

The APR1400 plant was selected to simulate LOCV, as shown in Fig.1. The feature of the modeling is that the main steam safety valves (MSSVs) was modeled with 3 banks which had different opening pressures. And the pressurizer spray line was modeled to consider the effect of the spray on the peak pressure of the secondary system.

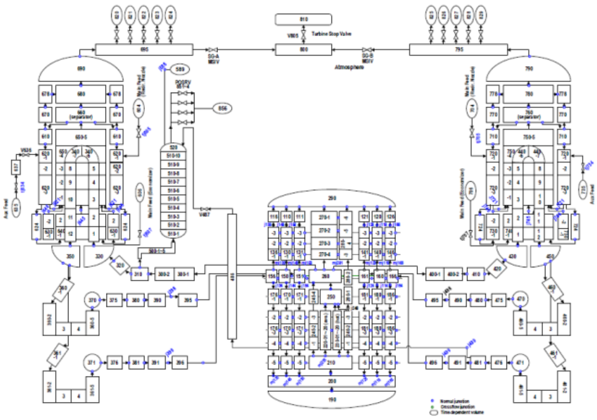

Fig. 1. Nodalization of APR1400 plant

2.3 Loss of offsite power (LOOP)

If the offsite power has been unavailable, reactor coolant pump will be coasted down and the reactor trip signal will be generated by low pump shaft speed. It could be conservative condition with respect to the primary system pressurization because the heat removal by the primary to secondary system is decreased rapidly.

However, in the viewpoint of secondary system, LOOP affects non-conservatively because it may cause earlier reactor trip by low pump shaft speed signal then pressurizer high pressure signal. Thus, the period of forced heat transfer for the primary to secondary system will be shorter than those with LOOP.

Therefore, LOOP should be considered conservatively to the primary or secondary system case by case.

2.4 Pressurizer spray

In this study, the pressurizer spray is assumed as a limiting assumption which may cause the most severe consequence to the secondary system. The flowrate of the spray corresponds that the equivalent flowrate of excessive pressurizer spray flow.

By this assumption, the period of heat transfer to the secondary system will be increased.

2.5 Other assumptions

To perform a conservative calculation, 102% power was assumed and the ANS 73 decay heat model was used with 120% powered by 10CFR50.46 Appendix K. Moderator temperature coefficient which can mitigate the system pressurization was not considered. Control rod insertion and Doppler reactivity was modeled in transient analysis.

3. Results and Discussion

With an occurrence of LOCV accident, turbine and feedwater pumps are tripped at 0.01s. Table I shows the conservative initial condition of transient calculation.

Total 4 cases of calculations are conducted which considered the LOOP or the pressurizer spray. Case 1 is the base case in which the LOOP and single failure was not considered. Case 2 consider LOOP without pressurizer spray and vice versa, Case 3. The Case 4 modeled LOOP and single failure simultaneously.

Table II to V shows the time sequence of events for the LOCV. In those table, the opening pressure of MSSVs and maximum steam generator pressure are the secondary system pressure, and others are the primary system pressure.

Table I: Initial condition

Initial core power, MW_t	4062.66
Core inlet coolant temperature, °F	558.03
Pressurizer of pressurizer, psia	2175.07
Liquid volume of pressurizer, ft^3	486.07
RCS flowrate, 10^6 1bm/hr	153.52
Level of steam generator, %WR	70.72
Pressure of steam generator, psia	1029.78
Temperature of steam generator, °F	548.16

Table II: Sequence of event for case 1

Sequence of event for Case 1	Time [s]	Value [psia]
Loss of condenser vacuum Loss of offsite power	0	-
Pressurizer spray	-	-
1st MSSVs open	6.37	1237.4
2nd MSSVs open	8.08	1269.8
Pressurizer pressure reaches reactor trip analysis setpoint	9.01	2603.5
Reactor trip	9.87	2636.6
3rd MSSVs open	10.04	1295.6
POSRVs open	11.02	2679.8
Maximum RCS pressure	11.17	2682.6
POSRVs close	11.61	2653.5
Maximum SG pressure	14.93	1310.8

After the occurrence of LOCV, the pressure of primary and secondary system are increased rapidly and safety valves of primary and secondary system are opened. In the case 3 and 4, pressurizer spray is actuated at its set point. In the every cases, the primary and secondary system pressures are increased until after few seconds of reactor trip but it didn't exceed the acceptance criteria. The acceptance criteria are 2,750psia for the primary system and 1,320psia for the secondary system.

Table III: Sequence of event for case 2

Sequence of event of Case 2	Time [s]	Value [psia]
Loss of condenser vacuum	0	-
Pressurizer spray	-	-
Low pump speed trip condition reached	0.73	2252.0
Reactor trip	1.19	2269.8
1st MSSVs open	6.72	1235.5
2nd MSSVs open	8.61	1269.2
POSRVs open	9.54	2695.6
Maximum RCS pressure	9.82	2706.1
POSRVs close	10.15	2691.6
3rd MSSVs open	10.79	1295.5
Maximum SG pressure	13.44	1303.0

Table IV: Sequence of event for case 3

Sequence of event of Case 3	Time [s]	Value [psia]
Loss of condenser vacuum	0	-
Pressurizer spray	5.62	2429.3
1st MSSVs open	6.37	1237.3
2nd MSSVs open	8.09	1269.7
3rd MSSVs open	10.06	1295.7
Pressurizer pressure reaches reactor trip analysis setpoint	10.43	2613.4
Reactor trip	11.29	2623.4
Maximum RCS pressure	12.72	2639.8
POSRVs open	13.15	2638.7
POSRVs close	13.78	2589.0
Maximum SG pressure	16.66	1315.6

Table V: Sequence of event for case 4

Sequence of event of Case 4	Time [s]	Value [psia]
Loss of condenser vacuum Loss of offsite power	0	-
Low pump speed trip condition reached	0.73	2252.0
Reactor trip	1.19	2269.8
Pressurizer spray	4.53	2406.1
1st MSSVs open	6.72	1235.5
2nd MSSVs open	8.61	1269.2
POSRVs open	9.61	2691.3
Maximum RCS pressure	9.88	2700.8
POSRVs close	10.20	2685.3
3rd MSSVs open	10.79	1295.6
Maximum SG pressure	13.47	1303.1

Figure 2 shows the system pressure of primary system and Figure 3 shows the system pressure of secondary system. Case 2 shows highest system pressure with respect to the pressure of primary system, which considered LOOP only. Because the reactor coolant pumps are tripped by the LOOP and they cause termination of the forced heat removal by the primary to secondary system. On the other hand, Case 3 shows the most severe consequence in the result of secondary system pressure, which considered the single failure. It is clearly due to the influence of pressurizer spray.

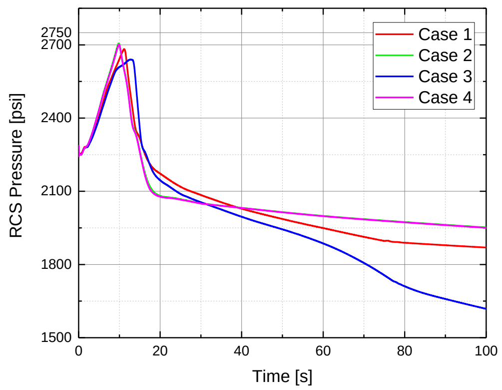

Fig. 2. System pressure of primary system

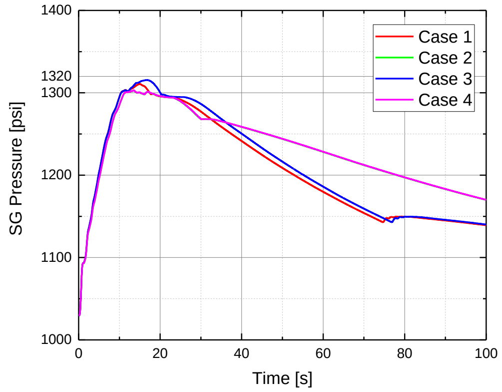

Fig. 3. System pressure of secondary system

4. Conclusions

The accident analysis for the loss of condenser vacuum (LOCV) of APR1400 was conducted with the MARS-KS code to support the review on the pressure behavior of primary and secondary system. Total four cases which have different combination of availability of offsite power and the pressurizer spray are considered.

The analysis result shows that the LOOP is the limiting assumptions with respect to the primary system peak pressure and the pressure spray is the limiting assumptions for the secondary system peak pressure. It means that the delaying of reactor trip signal which is caused by pressurizer spraying increase secondary system pressure.

The preliminary analysis results shows that the initial conditions or assumptions which concludes the severe consequence are different for each viewpoint, and in some cases, it could be confront with each viewpoint.

Therefore, with regard to the each acceptance criteria, figuring out and sensitivity analysis of the initial conditions and assumptions for system pressure would be necessary.

REFERENCES

[1] USNRC, NUREG-0800 Standard review plan, Revision 2, March 2007

[2] KHNP, Final Safety Analysis Report, Shinkori Units 3 and 4, 2008

[3] KAERI, MARS Code Manual, KAERI/TR-2811/2004, , 2009