Analysis of Loss of Condenser Vacuum with One POSRV Open Failure Accident Using SPACE code for APR1400

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1. Introduction

Since the Fukushima nuclear accident, the need for stronger management of nuclear power plants has been raised in Korea.

For the above reasons, KHNP submitted an Accident Management Plan (AMP) for nuclear power plants with enhanced standards in the event of an accident to the regulatory body in 2019. The AMP consists of design based accidents, multiple failure accidents that exceed design basis, severe accidents, and natural disasters that exceed design basis[1]. In 2020, the regulatory body began asking questions about KHNP's AMP submitted in 2019, and KHNP has been responding to the regulatory body's questions to date.

During the question and answer process, the regulatory body asked for an analysis of "Loss of condenser vacuum with one POSRV open failure accident" in addition to the nine accidents for which an AMP must be prepared under the law.

In this paper, we analyzed the "Loss of condenser vacuum with one POSRV open failure accident" for APR1400 requested by the regulatory body to determine whether the accident had a similar level of risk to the nine multiple failure accidents prescribed by law.

2. Methods and Results

2.1 *Major Code Modeling*

The loss of condenser vacuum loss with one POSRV open failure analysis used the SPACE code version 3.0. For this accident, the most important model is heat transfer model from primary system to secondary system. Basically, heat transfer coefficient included in the code is used. Fig 1 is SPACE nodalization.

2.2 *Initial conditions and boundary conditions*

For this accident analysis, important input parameters are initial core power, pressurizer pressure, pressurizer water level, core inlet temperature, RCS mass flow, Steam Generator pressure and steam generator inventory [2]. These initial variables were selected to maximize the pressure of the RCS system. In addition, an important modeling for the analysis of this accident was modeled as one of the four POSRVs mounted on the pressurizer failing to operate normally. In order to model this part, it is assumed that only 3/4 of the flow rate discharged when the POSRV of the pressurizer is operated.

The initial conditions are shown Table I[4].

Table I: Initial Conditions

Parameter	Design Value	SPACE Value
Core Power[MWt]	3,983	3,983
Pzr Pressure[MPa]	15.51	15.51
Pzr water level[%]	50.0	50.0
Core inlet Temp.[F]	563.7	564.5
Core flow[Kg/s]	20,991	20,991
SG Pressure[MPa]	6.89	6.91
SG water level[m]	50.0	50.0

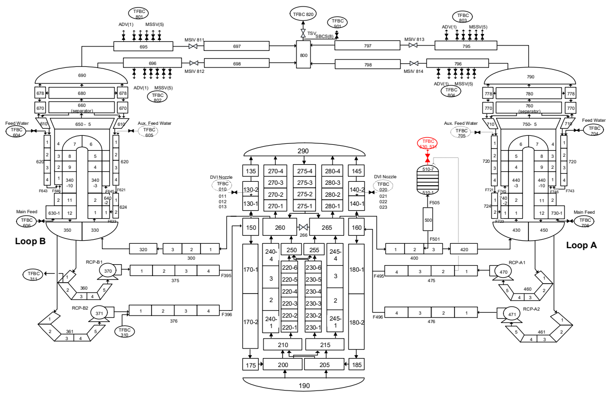

Fig. 1. Nodalization diagram of SPACE code for APR1400.

2.3 *Sequence of Event*

When the vacuum state of the condenser is lost, the main feedwater to the two steam generators trip and the turbine stop occur simultaneously. In addition, since the condenser vacuum is lost, the main steam bypass control system becomes inoperable, and energy removal on the secondary side becomes impossible through the turbine bypass valve after turbine shutdown [3]. The increasing energy of the secondary system increases the pressure of the secondary system enough to open the main steam safety valve. The primary system also fails to remove the energy generated in the core, so the pressure of the RCS increases. In this situation, if the POSRV of the pressurizer is opened, it is possible to prevent the pressure increase of the primary system. However, if one of the four POSRVs does not operate normally, sufficient pressure removal might not be performed.

However, in this analysis, the pressure of the system reaches the POSRV opening setpoint once, but does not consistently exceed the pressure limit of the system.

The sequence of events for the loss of condenser vacuum loss with one POSRV open failure accident are shown Table Ⅱ.

Table II: Sequence of event

Time (s)	Event
0.0	Condenser vacuum loss 1/4 POSRV opening fail Turbine shutdown and SG Main feedwater shutdown
4.51	Pzr high pressure setpoint reach
4.61	MSSV 1st Open
5.36	Reactor Trip
6.41	Pzr Pressure reaches POSRV open setpoint
182.4	MSSV 2nd open
378.0	MSSV 3rd open
1109.2	MSSV 4th open
1360.4	MSSV 5th open
1615.1	MSSV 6th open
1800.0 ~	Operator opens ADV manually after 1800 sec.

2.4 Analysis

The SPACE code is used to analyze the thermal hydraulic behavior of the “Loss of condenser vacuum with one POSRV open failure accident" in transient period. It is assumed that the main feedwater supply to the two steam generators and the turbine shutdown occur simultaneously due to the loss of condenser vacuum. In addition, since the main steam bypass control system is inoperable due to the loss of condenser vacuum, it is impossible to remove energy from the secondary side through the turbine bypass valve after the turbine shutdown.

Figures 2 shows that the core power decreases rapidly after the reactor trip (5.36 sec) after the accident.

In the early stages of the accident, the pressure of the primary system increased rapidly, but figure 3 shows that the increase is not significant by POSRV opening.

The POSRV was opened once by the pressure of the primary system, but the opening time was very short. Since then, the main steam safety valve has been repeatedly opened and closed.

Figures 4 shows that SG pressure. In the event of an accident, the main feedwater supply to the SG is cut off and the steam generator inventory of the steam generator gradually decreases, but auxiliary feedwater supply is supplied to maintain the cooling function of the secondary system.

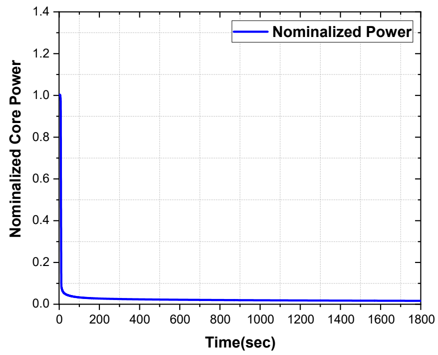

Fig. 2. Nominalized Core Power

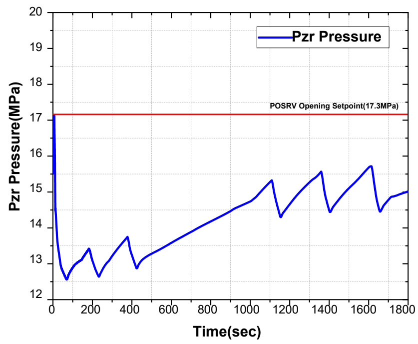

Fig. 3. Pzr Pressure

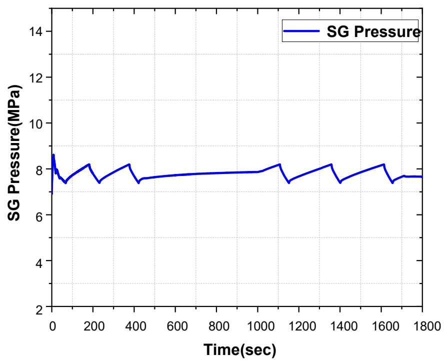

Fig. 4. SG Pressure

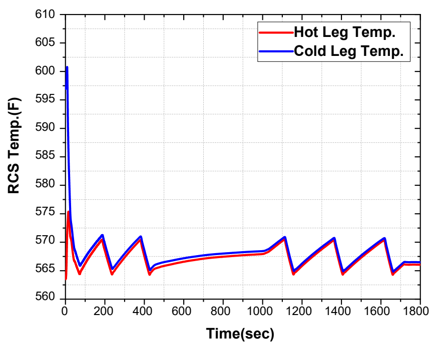

Fig. 5.RCS Temperature

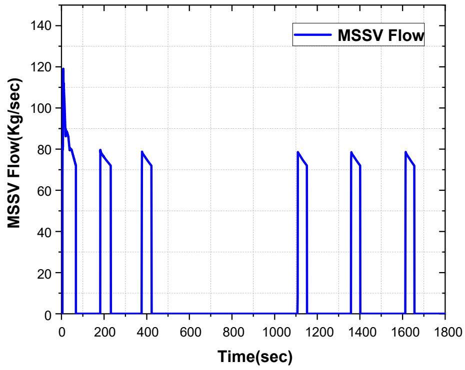

Fig. 6. MSSV Flow

This accident conservatively assumed that there was no operator operation for about 30 minutes. This accident shows the same result as above, but after about 30minitues, the operator opens the ADV and successfully enters the shutdown cooling system operating conditions.

3. Conclusions

This study shows the result of thermal hydraulic behavior on the "Condenser Vacuum Loss with One POSRV Open Failure Accident" using SPACE codes.

This accident analysis was conducted by the regulatory body requesting confirmation of AMP submitted by KHNP during the licensing response process. This multiple failure accident is to see if the integrity of the system is maintained as the secondary side's heat removal capability disappears and one POSRV also fails when the accident occurs.

This analysis showed that even if the vacuum in the condenser is lost and the main feedwater supply is stopped, the pressure in the system can be controlled as long as three of the four POSRVs are functioning normally, even if there is a sudden increase in pressure in system. In addition, even if the main feedwater is interrupted to SG, the temperature of the primary system is controlled because it is supplied through the auxiliary feedwater.

For the above reasons, it can be concluded that this accident did not have the risk at the level of the nine accidents that must be considered under existing law.

REFERENCES

[1] KHNP, Accident Management Plan for Shin-Kori Units 3&4, 2020.
[2] KHNP, SPACE code manual, 2017.
[3] Bum-Soo Youn, Se-Yun Kim, Dong-Hyuk Lee, Analysis of LOCV(Loss Of Condenser Vacuum) for OPR1000 using the SPACE, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 29-30, 2015.
[4] KHNP, DEC Analysis Methodology Report, 2019.06