Analysis of Loss of Condenser Vacuum with one PSV open failure accident using SPACE code for OPR1000

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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.

In 2019, KHNP submitted a nuclear accident management plan(AMP) that strengthened the standards for all nuclear power plants in KOREA to the regulatory body. The AMP consists of design based accidents, multiple failure accidents that exceed design basis, severe accidents, and natural disasters that exceed design basis [1][5]. 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 [5].

During the question and answer process, the regulatory body asked for an analysis of "Loss of condenser vacuum with one PSV 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 PSV open failure accident" for OPR1000 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 PSV open failure analysis used the SPACE 3.2 code version. 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 Gnerator(SG) pressure and SG inventory [2]. Since this is beyond design basis accident, best estimate analysis with nominal design initial conditions were used. In addition, an important modeling for the analysis of this accident was modeled as one of the three PSVs mounted on the pressurizer failing to operate normally. In order to model this part, it is assumed that only 2/3 of the flow rate discharged when the PSV 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]	2,815	2,815
PZR Pressure[MPa]	15.51	15.51
PZR water level[%]	52.6	52.6
Core inlet Temp.[F]	568.98	568.95
Core flow[Kg/s]	15,309	15,309
SG Pressure[MPa]	7.54	7.51
SG water level[m]	79.0	79.0

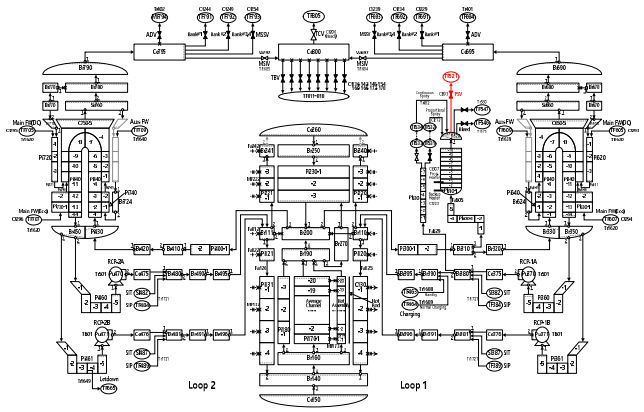

Fig. 1. Nodalization diagram of SPACE code for OPR1000.

2.3 *Sequence of Event*

When the vacuum state of the condenser is lost, the main feedwater to the two SG 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 PSV of the pressurizer is opened, it is possible to prevent the pressure increase of the primary system. However, if one of the three PSVs does not operate normally, sufficient pressure removal might not be performed.

However, in this analysis, the pressure of the system does not reaches the PSV opening setpoint, the pressure

of the system only repeats rising and falling within the setpoint limit.

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

Table II: Sequence of event

Time (s)	Event
0.0	Condenser vacuum loss 1/3 PSV opening fail Turbine shutdown and SG Main feedwater shutdown
6.88	MSSV 1st Open
7.28	PZR high pressure setpoint reach
8.43	Reactor Trip
10.12	PZR Pressure reaches peaking value. (PSV open setpoint not reached)
10.36	MSSV 2nd open
1800.0 ~	Operator opens SGs 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 PSV open failure accident" in transient period. It is assumed that the main feedwater supply to the two SGs 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 [5].

Figures 2 shows that the core power decreases rapidly after the reactor trip (8.43 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 MSSV Bank 1st, 2nd opening.

Figure 3 shows the pressure change of the pressurizer. When a loss of condenser vacuum accident occurs, the main water supply is stopped, and the pressure and temperature on the secondary side of the SG increases rapidly. However, the pressure does not continue to rise as the MSSV repeats opening and closing and the auxiliary water supply operates.

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

Figure 5 shows the temperature of the PCT(Peak Cladding Temperature). It may be seen that the PCT decreases due to the cooling of the primary system by the opening of the MSSV.

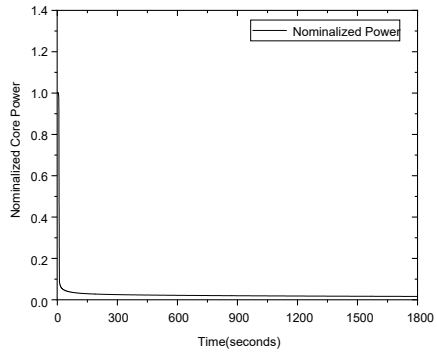

Fig. 2. Nominalized Core Power

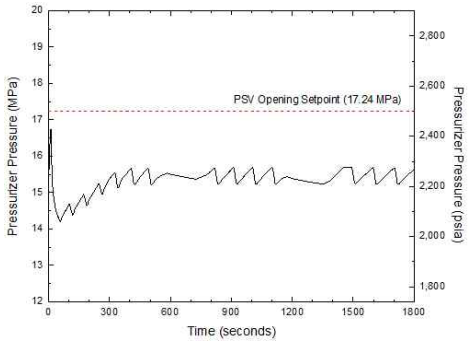

Fig. 3. PZR Pressure

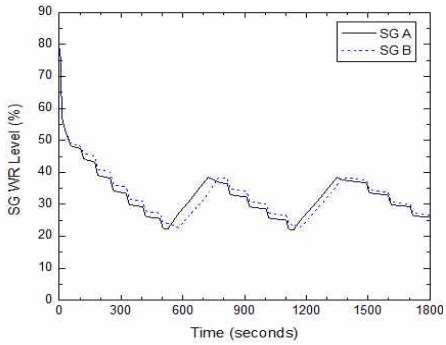

Fig. 4. SG WR Level

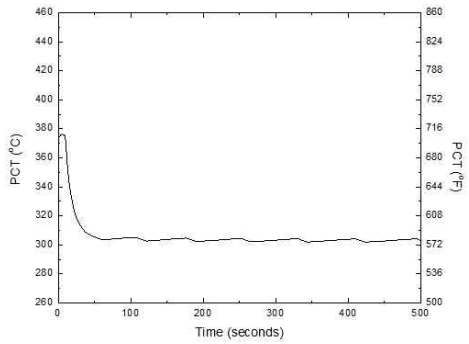

Fig. 5. PCT

This accident conservatively assumed that there was no operator operation for about 30 minutes. 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 PSV Open Failure Accident" using SPACE codes.

This accident analysis was conducted in response to 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 PSV 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 two of the three PSVs 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.

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