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Simulation Analysis on Steam Generator Tube Rupture with Total Failure of High Pressure Safety Injection

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1. Introduction

Steam Generator Tube Rupture (SGTR) is an accident with broken one or more SG tubes. The initial situation is similar to Small Break Loss of Coolant Accident (SBLOCA). However, in the SGTR, it is necessary for the operator to take appropriate actions to prevent leakage to the secondary side and to minimize radiation release to the environment. SGTR takes a small portion of the total Core Damage Frequency (CDF), but it might proceed to a severe accident that affects public health if the core damage occurs. This is because the radioactive material may be released to the outside through the damaged SG by bypassing the containment. In addition, SGTR may result in a complex transient due to various anomalies such as operator actions.[1]

In a safety analysis for SGTR, it is evaluated whether the radioactive material release is within design criteria in the view of Design Based Accidents (DBA). In view of Probabilistic Safety Assessment (PSA), SGTR is evaluated as an initiating event which may lead to the occurrence of core damage. For the purpose of a more realistic PSA, thermal hydraulic behavior is examined for various SGTR sequences including an SGTR with total failure of High Pressure Safety Injection (HPSI) [2]. This paper provides preliminary results from the examination of SGTR sequences.

2. Literature Survey

When an SGTR occurs, the pressure and the level of the pressurizer decreases in the primary side, thereby increasing the charging flow rate. In the secondary side, unbalance occurs in the steam flow rate and the feed water flow rate in the SG due to the leakage flow from Reactor Coolant System (RCS). Alternatively, it can be noticed with high radiation alarms in the secondary side. As leakage to the secondary side continues, the reactor is tripped by low RCS pressure or high Departure from nucleate boiling ratio (DNBR) and Safety Injection Actuation Signal (SIAS) would be generated. Once the accident is diagnosed as an SGTR, operators are directed to isolate the damaged SG and minimize radioactive material release to the environment.[2]

2.1. Research results

In the event trees for SGTR for a Pressurized Water Reactor (PWR) such as the one in NUREG/CR-4674 [3], an SGTR with failed HPSI was generally modeled to result in core damage. However, there were researches such as Han and Yang [2] that raises the possibility that such a situation may not lead to a core damage.

On the other hand, there were studies on SBLOCA which is similar to SGTR situation. Many conventional PSA generally considered SI as success criteria for all break sizes. Recently, Cho et al.[4] concluded that the decay power can be removed by SG, which is normal secondary cooling, without the HPSI at very small break size. Han et al.[5] also found that core damage can be prevented in OPR1000 with operators' timely response in an SBLOCA with total failure of HPSI. The results of these studies indicate that even in absence of HPSI, core damage can be prevented with the operators' timely action of secondary heat removal.

2.2. Operating experience

In the past, there were some cases of SGTR with failure of HPSI. In 1975, the incident at Point Beach-1 caused SGTR at full power and SI did not start. However, steam dump to the condenser was performed to decrease the RCS pressure and temperature, and the pressurizer spray was used to further decrease RCS pressure. The pressure on the primary side then became similar to that of secondary side and the residual heat removal could be operated.

On May 16, 1984, an SGTR occurred during startup in Fort Calhoun, but SI failed to operate. In the situation, RCS was cooled down through intact SG by opening atmospheric dump valves (ADVs).

In 1983, an SGTR also occurred at full power in McGuire. At the time of the accident, the operators manually blocked the SI to prevent unnecessary automatic actuation and cooled down the RCS by dumping steam to the condenser through main steam bypass valves.[6]

3. Simulation Analysis

As a preliminary analysis, SGTR with failure of HPSI is analyzed with Personal Computed Transient Analyzer (PCTRAN) APR1400 which is a transient simulation code for Advanced Power Reactor (APR) 1400. The validity of the transient simulation code can be examined with various benchmark analysis results for normal operation, design basis accidents and severe accidents and their comparisons to those provided in Standard Safety Analysis Report(SSAR) for APR1400.

It was claimed and used as a tool to complement the state-of-the-art codes such as RELAP, MARS, MELCOR or MAAP for analyzing accident phenomena. [7,8]

The scenario is an SGTR where HPSI was completely failed. It is assumed that one of the SG-A tubes is broken, which has a cross section area of 2.54×10^{-4} m^2. Operators are supposed to isolate main steam isolation valves (MSIVs), main feedwater isolation valves (MFIVs), and ADVs in the damaged SG. In the intact SG, auxiliary feedwater flow is adjusted to keep the water level of secondary side. In this scenario, while HPSI is assumed to be unavailable, auxiliary feedwater system is assumed to operate properly.

The collapsed reactor vessel water level and peak cladding temperature (PCT) are monitored to examine the integrity of fuel.

3.1. SGTR without HPSI

In this simulation, reactor trip occurs about 2200 sec after SGTR. Emergency Safety Feature Actuation System (ESFAS) signal occurs at 3200sec, but HPSI is assumed to be unavailable. It is assumed that operators properly isolate the faulted SG according to emergency operating procedures (EOPs).

Fig.1 shows the simulation results for the pressures on the primary and secondary sides. The pressure on the primary side decreases while the pressure on the secondary side increases due to the break of a tube. After a while, these pressures reach equilibrium states. The time-dependent changes of pressurizer level and SG levels are shown in Fig.2, and those of core level and PCT are shown in Fig.3. The pressurizer level decreases due to SGTR, but the core level is maintained. It is also confirmed that the pressurizer level is restored by charging flow. However, the level of the faulted SG gradually increases due to the break flow from the primary side. In the simulation results for about 10 hours, only the initial situation is shown in Fig.3. This is because the phenomena are maintained except for the increase in the level of the faulted SG.

Even if the operators do not perform additional RCS cooldown action by opening ADVs, it is found that the core level and PCT are maintained, and hence core damage does not occur. This phenomenon was also observed in past incidents at Point Beach-1, Fort Calhoun. However, the overfill of SG raises the concern on possible release of radioactive material to the environment.

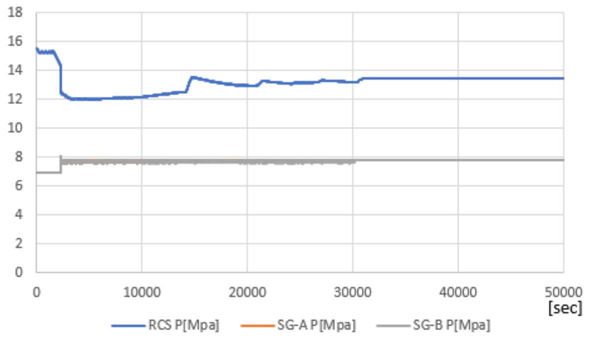

Fig. 1. RCS Pressure, SG Pressure during SGTR without HPSI

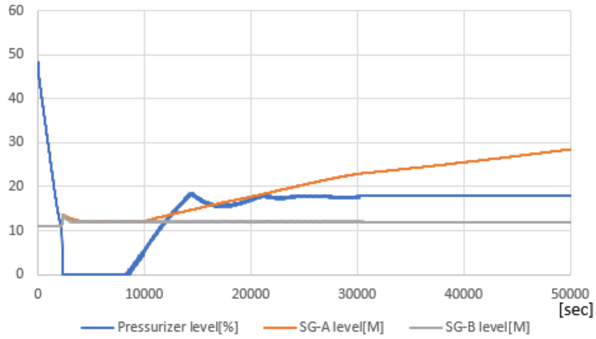

Fig. 2. Pressurizer and SG levels during SGTR without HPSI

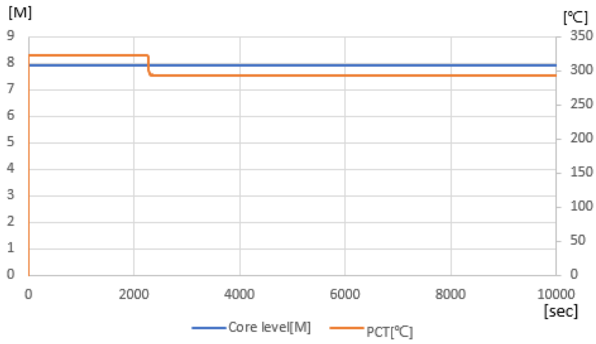

Fig. 3 Core level and PCT during SGTR without HPSI

3.2. SGTR without HPSI and charging flow

SGTR has unique characteristics compared to SBLOCA, even though SGTR can be considered as one type of SBLOCA.

During an SBLOCA, RCS coolant is released from high pressure primary side to the low pressure containment. However, during an SGTR, RCS coolant is released to a SG with pressure about 7MPa which is relatively higher pressure than containment. Also, the leakage of the coolant would be significantly reduced once the balance in pressure between the primary side and the secondary side is established.

For a more conservative analysis, another simulation analysis is performed while ignoring charging flow. Turning off charging pumps (CHPs) has another effect of decreasing the pressure of the primary side.

In this simulation, reactor trip occurs 440sec after SGTR. Thereafter, ESFAS signal is generated at 470sec, but HPSI and CHP are assumed to be unavailable. It is assumed that operators properly isolate the faulted SG according to emergency operating procedures (EOPs).

The simulation results are shown in Fig.4, Fig.5 and Fig.6. Since the phenomena are maintained up to 20 hours of simulation run, only the initial situation of the scenario is presented.

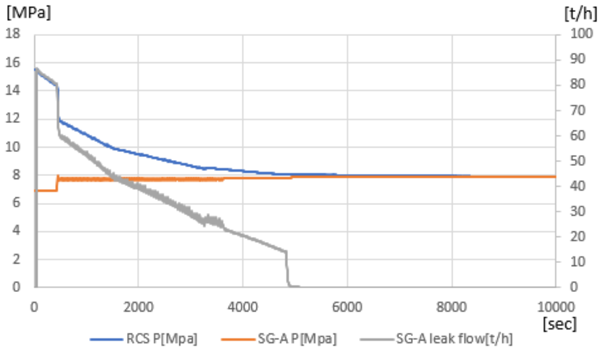

Fig. 4. RCS Pressure, SG-A Pressure, and SG-A tube leak flow during SGTR without HPSI and CHP

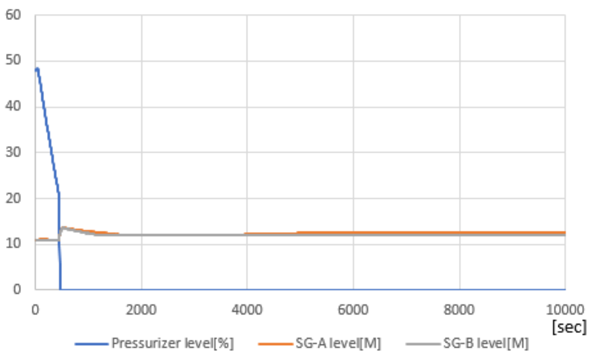

Fig. 5. Pressurizer and SG levels during SGTR without HPSI and CHP

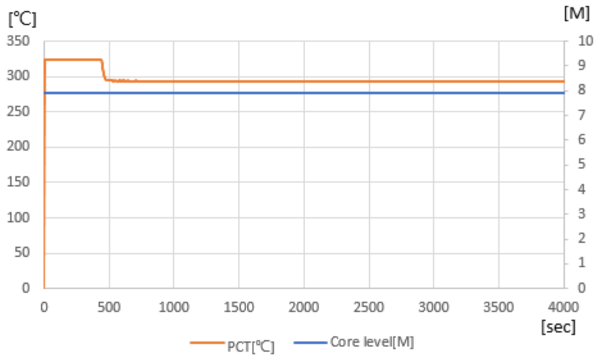

Fig. 6. Core level and PCT during SGTR without HPSI and CHP

By tuning off the CHP, the pressure on the primary side is lowered and equalized with the pressure on the secondary side, and hence there is minimal amount of leakage from the primary side to the secondary side. At that time, the water levels of primary and secondary side are maintained. Accordingly, it is confirmed that the core level and PCT are also maintained.

5. Conclusion

In many conventional PSA, when the HPSI is failed after SGTR or SBLOCA, core damage is assumed without proper operators' actions. However, several studies have been conducted to show that in-depth analysis on such a situation is worth to study. In addition, there exist operating experience on SGTR incidents where HPSI did not work. In this paper, simulation analysis was performed on such a situation and it is found that SGTR with total failure of HPSI does not seem to result in core damage even without operators' action for RCS cooldown and depressurization by opening ADVs. It is also found that SGTR with total failure of HPSI may not result in core damage even when charging flow is not provided to makeup RCS inventory loss.

PSA needs to be performed as realistic as possible. Therefore, a detailed analysis of these scenarios would be worth to be performed to derive more concrete conclusions on whether such a situation would result in core damage or not. More detailed analysis will be performed on the scenarios dealt with in this paper with state-of-the-art thermal-hydraulics codes such as MARS or MELCOR.

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