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Evaluation of Multiple Steam Generator Tubes Rupture for SMART

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1. Introduction

SMART is an advanced integral type of pressurized water reactor with rated thermal power of 365 MW. The Steam Generator (SG) is one of the major components of SMART reactor that transfers the heat generated in the core to the secondary system. Since the SG represents a protective barrier between the reactor coolant system (RCS) and secondary systems, radioactive materials contained in the coolant of the RCS could bypass to the secondary system if one or more SG tubes are ruptured. There are two main concerns regarding the multiple steam generator tube rupture (MSGTR); bypassing the RCS coolant outside the containment and losing the reactor coolant inventory. To ensure the high safety level of the SMART, the MSGTR accident analysis of SMART is performed and the results of the analysis are presented.

2. Description of the SMART

SMART adopts the integral arrangement design concept which contains all the primary components into a single reactor pressure vessel without any pipe connections between those components. The reactor coolant pumps (RCPs) circulate the reactor coolant within the primary system boundaries starting from the pump discharging area, through the SG shell side, flow mixing head assembly (FMHA), the lower plenum , upward through the core and then to the RCPs suction area [1].

In emergency situations, the passive residual heat removal system (PRHRS) can remove the RCS heat using natural circulation while the passive safety injection system (PSIS) compensates any abnormal decrease in the reactor coolant inventory and ensure full coverage of the core. Each system is composed of four mechanically independent trains with a 33% capacity for each train. SMART is capable of reaching the safe shutdown condition within 36 hours and maintain the safe shutdown condition for another 36 hours, without any corrective action by operator or the aid of external AC power during the design basis accidents.

3. Accident and Analysis Methodology

3.1 Description of Accident

SMART adopts once through helical tube SG where the secondary system coolant flows inside 375 tubes receiving the heat from the reactor coolant passing through the SG shell side. Since the high pressure reactor coolant is flowing through the SG shell side, unlike the condition in SG of commercial nuclear power plants, the SG tubes are subjected to high compressive stress and less tensile stress. Therefore, the SGTR accident occurrence in SMART is significantly less than in the commercial nuclear power plants. During the SGTR accident, the fission products can be released to the environment through the PRHRS safety relief valves which open if the secondary system pressure reaches the opening set-point of 17 MPa.

The SGTR accident is classified as a design basis event that requires the use of conservative analysis methods, and the results are presented in chapter 15 of SMART preliminary safety analysis report. The NRC staff claimed that it would be unlikely that more than one SG to break at the same time; however any debris flowed into the SG can initiate multiple SGTR scenarios. In 1982, Ginna nuclear power plant has experienced an SGTR event where one steam generator tube has ruptured and caused the accident. The utility examination followed the accident showed that more than 20 steam generator tubes have been severely damaged, which could be caused by the broken SG loose parts [2].

A suggestion has been raised by the NRC staff to investigate the containment bypass of the primary coolant following to SGTR accident, for the System 80+ design. After that, the multiple SGTR analysis was performed by the ABB-CE to the System 80+ [3]. The design characteristics to minimize the radiological consequence resulting from the MSGTR were evaluated by assuming up to five tubes ruptured in accordance with SECY-93-087 [2].

Since the MSGTR is considered as a beyond design basis event (BDBE), the best estimate analysis methodology and assumptions are proposed by the NRC to be used for this analysis.

3.2 Analysis Methodology

The MSGTR accident of SMART is analyzed using the TASS/SMR-S computer program with the best estimate analysis methods and nominal initial conditions as shown in Table 1. TASS/SMR-S is a thermal hydraulic system analysis code developed for the safety and performance analysis of SMART [4].

The analysis is performed to maximize the pressure increase in the secondary system by assuming the following assumptions:

1. Loss of offsite power (LOOP) is to occur concurrently with the reactor trip, which means the RCPs and feedwater pumps stop, and thus losing the coolant flow in the RCS and secondary system, closing the main steam and feedwater isolation valves immediately which cause an increase in the secondary system pressure.
2. The control systems such as pressurizer level control system and pressurizer pressure control system are in automatic mode.
3. Control systems actuations during the transient are assumed to be at nominal set-point values.
4. The operator action is not considered during the analysis for 72 hours in compliance with the safety analysis requirements for the passive plants.
5. One and up to five tubes break is considered during the analysis.

Table 1: Initial Conditions Used for the Analysis

Parameter	Value
Power level, %	100
RCS pressure, MPa	15.0
Core inlet / outlet coolant temperature,℃	295.5 / 320.9
RCS flow rate, Design %	100
Steam generator pressure, MPa	5.76
PZR level, %	70

3.3 Analysis Results

Figure 1 shows the normalized maximum pressure of the secondary system during the MSGTR accident versus the number of ruptured tubes.

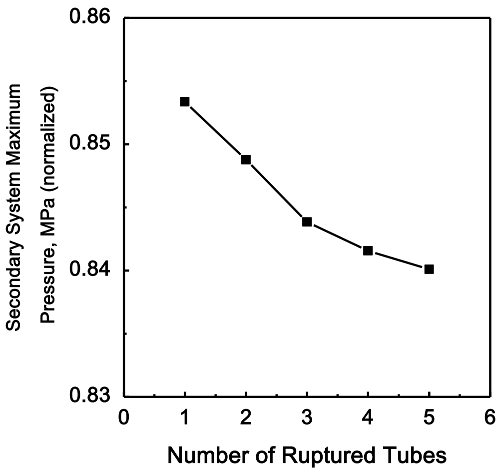

Fig.1. Maximum pressure of the secondary system vs. number of ruptured tubes

It is clearly shown that the pressure increase for the one ruptured tube has more effect in increasing the secondary side pressure than the break of multiple tubes. This is due to the trip time of the reactor in each case as shown in Figure 2. The fewer number of ruptured tubes, the longer time it takes the reactor to trip automatically.

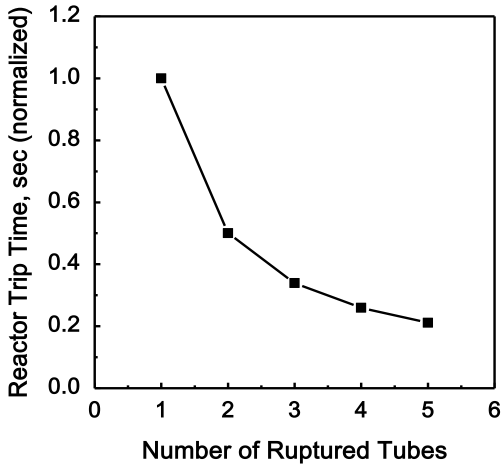

Fig.2. Reactor trip time vs. number of ruptured tubes

The automatic reactor trip by the low PZR level occurs later as the leak flow to the secondary system is smaller as the number of ruptured tube decreases, which allows for the secondary system pressure to build up for a longer time.

The maximum pressures for the various numbers of ruptured tubes cases are well below the PRHRS safety relief valves opening set-point of 17 MPa. For that reason, the fission products bypassed to the secondary system through the ruptured SG tube, will not be released to the environment through the PRHRS safety relief valves during the MSGTR accident, and would be contained within the PRHRS loop throughout the transient.

In regards to the RCS inventory control safety functions, the PSIS is actuated passively after the rector trip. Figure 3 shows the safety injection mass to make up the coolant lost during the accident for one and five steam generator tube ruptured cases (the other three cases data fall in between those two cases). The lost coolant is fully recovered within 40 – 45 minutes for all the cases.

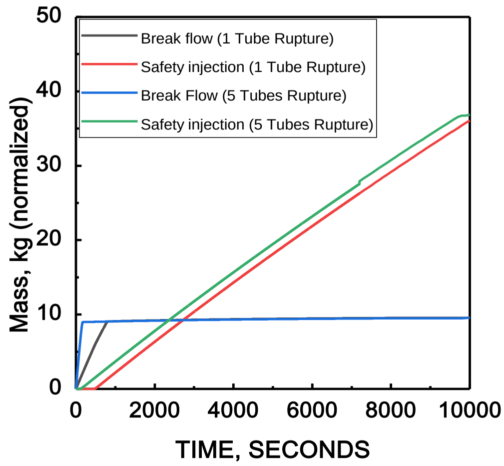

Fig.3. Integrated mass released from and added to the RCS

Due to the safety injection of the PSIS and the natural circulation cooldown by the PRHRS, the RCS temperature decreases monotonically to the safe shutdown condition as shown in Figure 4.

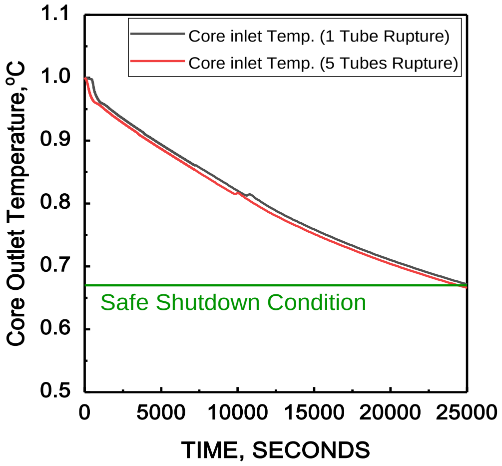

Fig.4. RCS temperature vs. time

4. Conclusions

This analysis has been performed to evaluate the possibility of reactor coolant release outside the containment through the PRHRS safety relief valves during multiple steam generator tube rupture accident.

The reactor coolant bypass possibility is evaluated through the maximum secondary system pressure reached during the accident. For all the five cases considered, one to five tubes rupture cases, the maximum pressure of the secondary system is maintained well below the PRHRS safety relief valves opening set-point. Therefore, there is no possibility of reactor coolant bypass outside the containment through the PRHRS safety relief valves during the MSGTR accident. The RCS was cooled down to the safe shutdown condition after the accident due to the actuation of the passive safety systems.

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