Analysis of Multiple Steam Generator Tube Rupture with Emergency Operating Guidelines for APR1400

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1. Introduction

The Multiple Steam Generator Tube Rupture (MSGTR) is an accident with the possibility of containment bypass via opening of the Main Steam Safety Valves (MSSVs).

APR1400 Final Safety Analysis Report (FSAR) provides the description about relevant systems for mitigation of a steam generator tube rupture event. The design basis of these systems is not typically for the prevention or mitigation of a steam generator tube rupture event, however, their use, whether automatic or manual, decreases the probability of a main steam safety valve from lifting. The objective of the existing MSGTR analysis is to justify that no primary coolant is released to the atmosphere through the MSSVs bypassing the containment during the first 30 minutes after event initiation of the MSGTR without operator actions.

However, the analysis, in this paper, was performed to shutdown cooling system entry condition assuming the operator action according to the Emergency Operating Guidelines (EOGs). Through this, the process of mitigating the MSGTR was verified and the long-term decay heat removal was possible. In addition, it was confirmed that the radiological consequence met the radiological release targets specified in the regulatory guideline 16.4 [1].

2. Analysis Methodology

2.1 Initial Conditions

APR1400 plant is two-loop pressurized water reactor with 3,983 MWt. Table 1 shows the initial conditions for MSGTR analysis and this event is analyzed using RELAP5 /MOD3.3 patch 5 [2].

Table 1. Initial Conditions for MSGTR Analysis

Parameter	Design Value	Analysis Value
Core power, MWt	3,983	3,983
Pressurizer pressure, MPa(a)	15.51	15.52
RCS flow rate, kg/s	20,991	21,055
Core inlet temperature, K	563.7	563.7
Secondary pressure, MPa(a)	7.03	6.99
Secondary steam flow rate, kg/s	2,262	2,252
Pressurizer level, %	50	50
Steam generator level, % NR	50	50

2. Analysis Methodology

2.2 Assumptions

2.2.1 General Assumptions

MSGTR analysis is performed with a Best Estimate (BE) analysis methodology which interprets accidents using realistic assumptions and conditions. Five tube breaks are considered according to the regulatory guidelines [3]. The double-ended breaks of tube in the hot leg side are assumed for this analysis.

2. Analysis Methodology

2.2 Assumptions

2.2.2 Operator Actions

The operator, after reactor trip, performs actions to manage the accident according to EOGs for APR1400 [4].

In order to prevent containment bypass of reactor coolant in the MSGTR case, operators should control to achieve a pressure balance between the primary and secondary sides, and conduct controlled cooldown using the intact steam generator.

It is assumed that Standard Post Trip Action (SPTA) and Diagnostic Action (DA) step are completed within 10 minutes after the reactor trip, and then, operator enters the Optimal Recovery Guidelines (ORGs) of SGTR. The first operator action for mitigation is taken 15 minutes after reactor trip. The operator action time for each procedure is 1 minute. However, it is assumed that different actions can be conducted simultaneously by multiple operators.

3. Analysis Results

The key operator actions and time derived from the MSGTR analysis are as follows:

- Reactor Coolant Pump (RCP) stop: It is assumed that two RCPs per loop are stopped at 10 minutes after reactor trip
- Cooldown of RCS using the Turbine Bypass Valves (TBVs): Cooldown starts from 15 minutes after reactor trip in accordance with Emergency-03 (SGTR recovery guidelines) in the ORGs. The temperature of the RCS is cooled to 280℃ (536°F) using the TBVs to prevent the opening of MSSVs
- SG isolation and pressure control: The operator checks the affected SG isolation at 18 minutes after reactor trip. After 20 minutes, the operator turns off the pressurizer (PZR) heater, opens/ closes the PZR vent valve, and opens PZR auxiliary spray to maintain the pressure balance between the primary and secondary side.
- Affected SG level control: It is assumed that the SG level control starts from 24 minutes after reactor trip by using the main steam isolation bypass valve and the SG blowdown system to prevent the high level of the SG.
- Controlled cooldown of the RCS using the intact-side SG: The controlled cooldown of RCS starts from 30 minutes after the reactor trip by using the SG Atmospheric Dump Valve (ADV) of the intact-side SG.
- Safety injection manual control operation: When the RCS subcooling margin and pressurizer water level reach the conditions for manual control of safe injection, the safety injection is operated manually.

3. Analysis Results

Table 2 shows the event sequence with MSGTR applied with above operator actions.

By taking action to maintain balance of the pressure between the primary and secondary sides, RCS pressure decreases to balance with the SG pressure (Figure 1). Accordingly, the tube break flow rate (Figure 2) decreases and converges to zero. After controlled cooldown, the core temperature decreases to the shutdown cooling system entry condition (Figure 3).

As shown in Figure 4, during the early phase of the MSGTR accident, the large break flow increases the SG inventory. It results in exceeding 100% SG WR level temporarily, but SG inventory does not reach the SG dome. As shown in Figure 5 and 6, neither the MSSV opening nor the core uncover occur during the whole period. Moreover, the fuel cladding temperature meets the relevant acceptance criteria (Figure 7).

Table 2. Event Sequences of MSGTR for APR1400

Time (sec)	Event
0.0	MSGTR Occurs
139.0	Reactor Trip
189.0	Safety Injection Actuated
739.0	Stop two RCPs
1,039.0	RCS Temporary Cooling - By TBV
1,219.0	Isolation of Affected Steam Generator
1,339.0	RCS Depressurization - By PZR Auxiliary Spray
1,579.0	Safety Injection Manual Control
1,939.0	Controlled Cooldown Start - By Intact-Side SG ADVs
4,190.0	Intact-Side Auxiliary Feedwater Actuated
33,070.0	Shutdown Cooling System Entry Condition Reached

3. Analysis Results

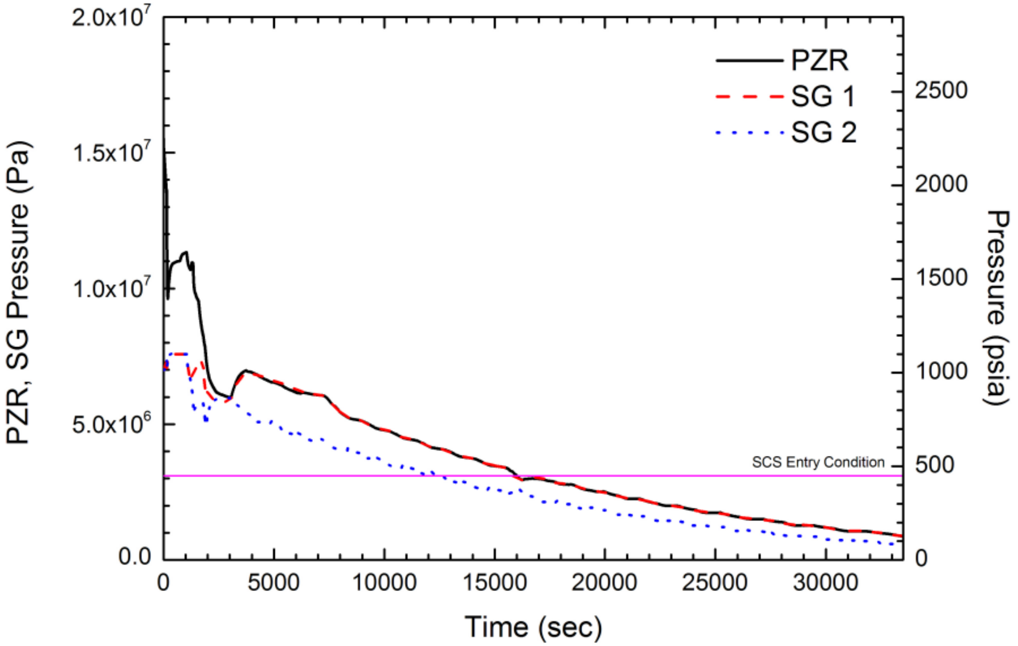

Figure 1. PZR and SG Pressure

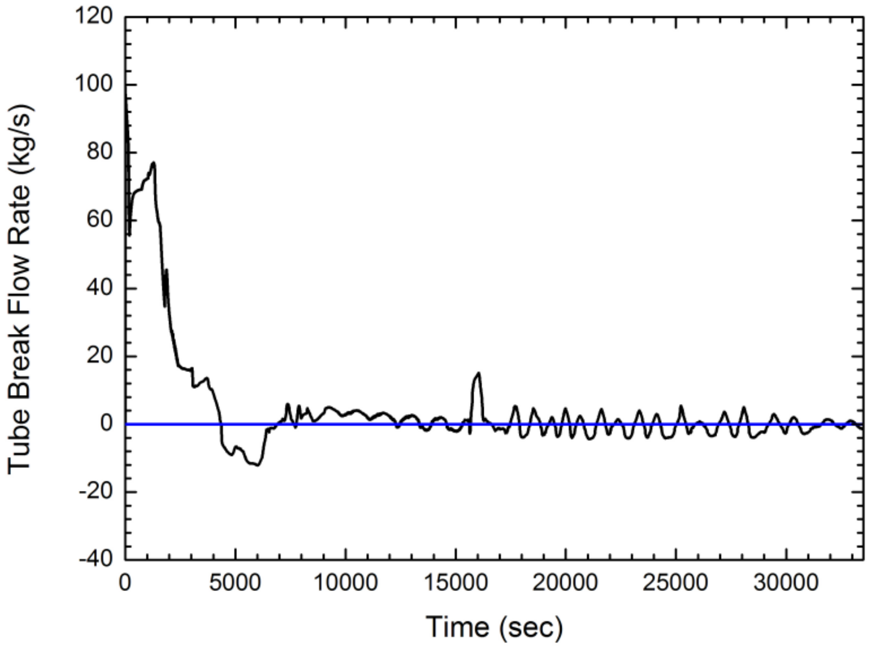

Figure 2. Tube Break Flow

3. Analysis Results

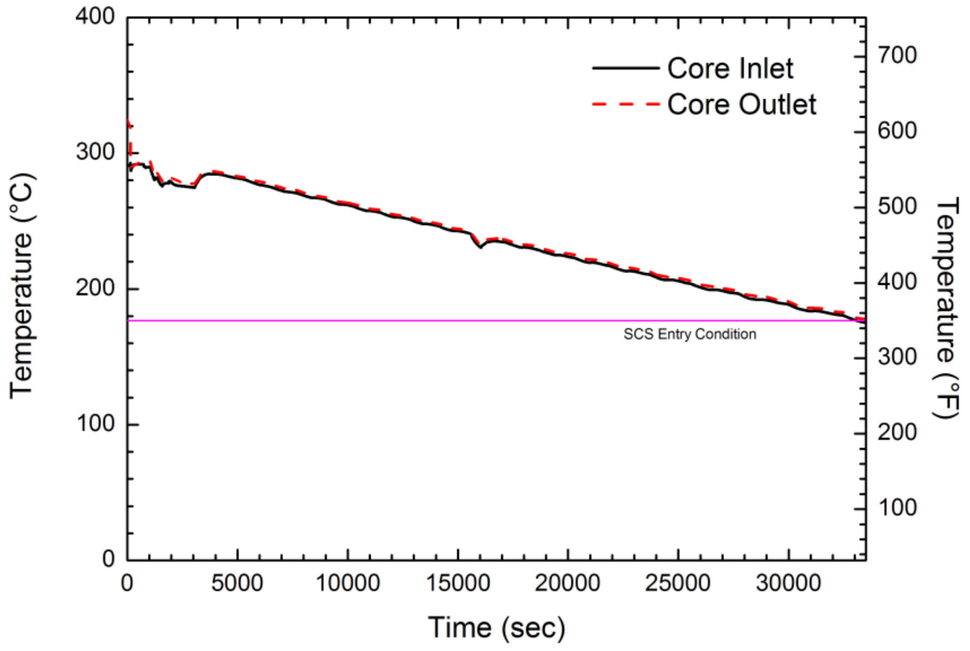

Figure 3. Core Temperature

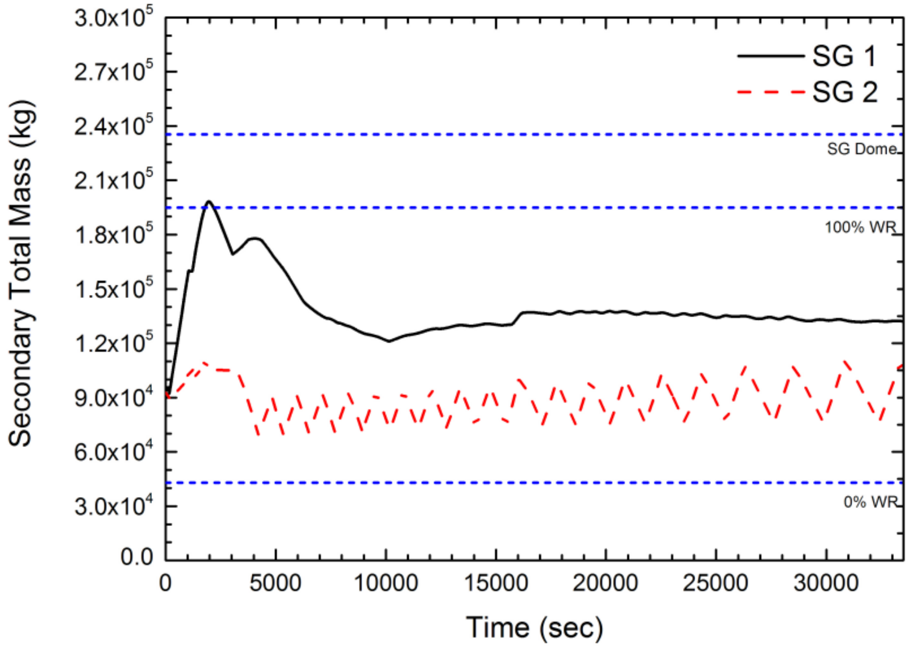

Figure 4. SG Total Mass

3. Analysis Results

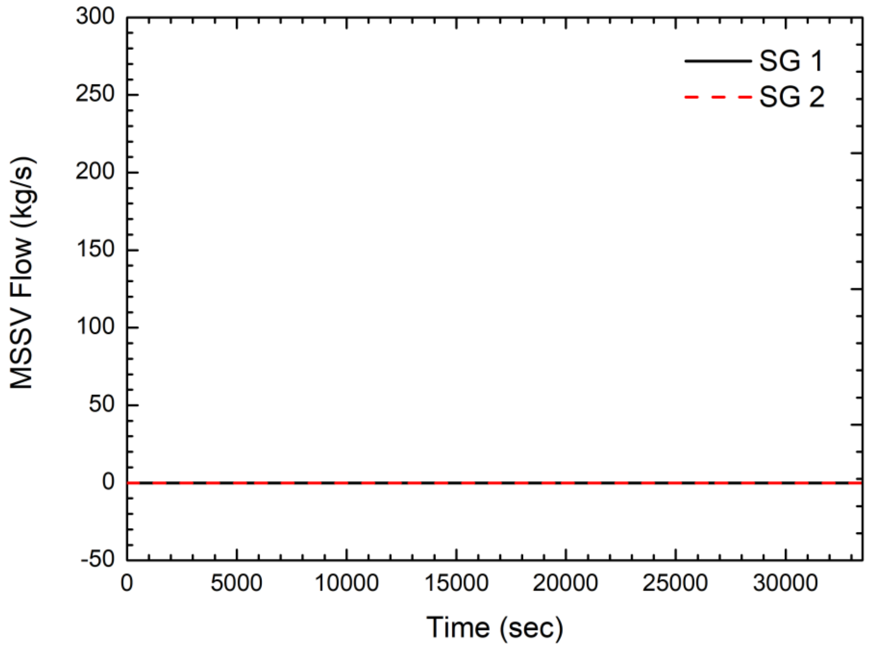

Figure 5. MSSV Mass Flow

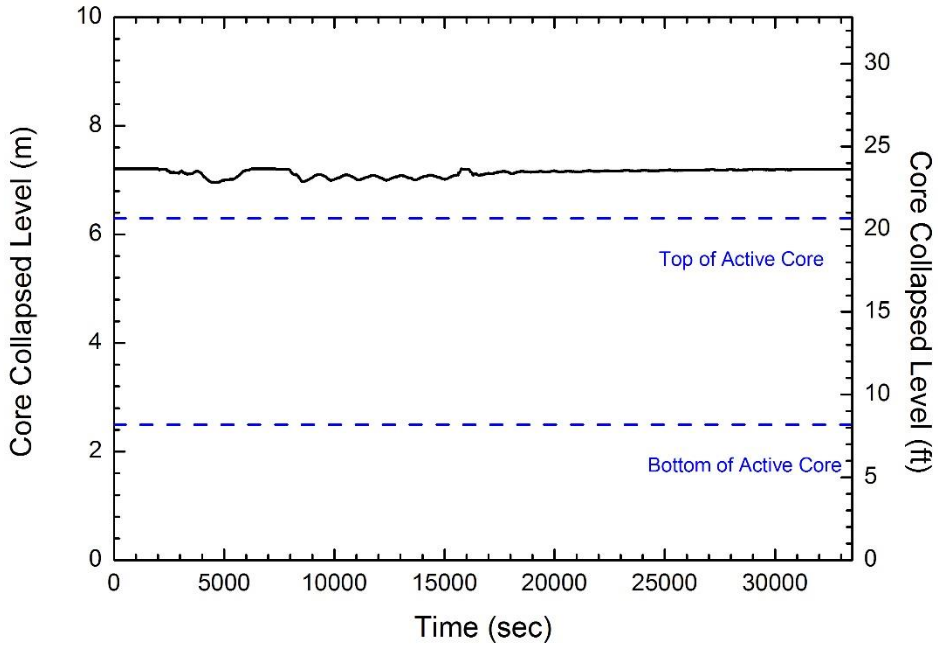

Figure 6. Core Collapsed Level

3. Analysis Results

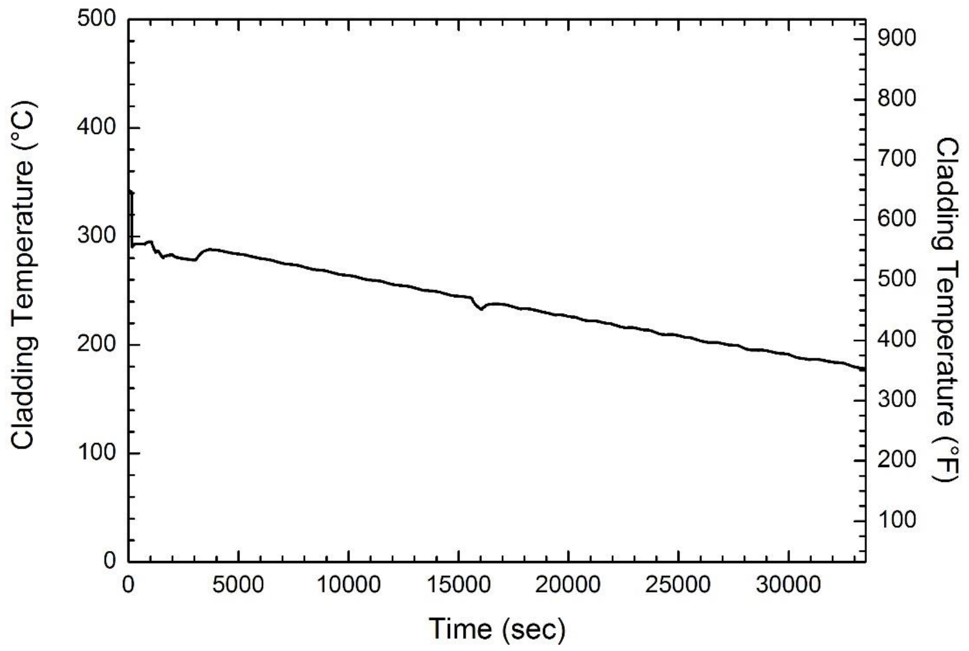

Figure 7. Fuel Cladding Temperature

4. Conclusions

The APR1400 MSGTR analysis in consideration of operator actions of EOG was performed by using RELAP5 code.

The results of the analysis show that the peak cladding temperature is less than the acceptance criteria and the long-term decay heat is removed. Furthermore, the radiological consequence met the radiological release targets specified in the regulatory guideline 16.4 [1].

In conclusion, APR1400 can be led to the safe state with operator actions of EOG during MSGTR accident.

REFERENCES

[1] KINS/RG-N16.04, Rev.0, Regulatory Guideline 16.4, “Accident Consequence Assessment,” 2016.

[2] RELAP5/MOD3.3 Code Manual, ISL, October 2014

[3] KINS/RG-N16.01, Rev.0, Regulatory Guideline 16.1, “Assessment of accidents due to multiple failures,” 2016.

[4] Emergency Operating Guideline for APR1400, 2019.