A Study on SGTR accident management using the MELCOR code

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1. Introduction

Emergency Operation Procedures (EOP) are procedures describing measures taken by equipment, systems, and operators for managing accidents in a nuclear power plant. It requires an operation to mitigate and restore essential safety functions in the event of an accident in which the plant operating variables exceed the reactor protection system or engineering safety facility operating settings. However, in the case of core damage, the operator stops the use of EOP and starts the use of the Severe Accident Management Guideline (SAMG).

The existing EOP is success-oriented, since it is only focused on preventing damage to the core. There is a lack of countermeasures in place following the failure of the operator action. Therefore, a severe accident management plan is needed to systematically manage severe accidents.

According to the Level 1 PSA report of the OPR1000 plant, the most likely major accidents are loss of coolant accident (LOCA) without safety injection, total loss of feedwater (TLOFW), steam generator tube rupture(SGTR), and station blackout (SBO)[1]. Among them, SGTR has the possibility that radioactive fission products of the primary system can be directly released into the atmosphere by bypassing the containment through the steam generator tubes and main steam safety valves(MSSVs). Because SGTR is the largest contributor to large early release frequency (LERF), severe accident mitigation function is strongly required for SGTR.

Due to the flexibility of system simulation, MELCOR[2] has the advantage of being able to expand not only commercial power plants but also next-generation power plants, and even SMRs. Furthermore, detailed thermal-hydraulics fundamental governing equations are utilized. For this reason, this paper used the MELCOR code to analyze the SGTR accident.

In this study, we performed SGTR accident analysis using the MELCOR code for identifying the utility of an accident management plan considering SAMG in the event of severe accidents.

2. SGTR simulation using the MELCOR code

2.1 Steady state calculation

The MELCOR input deck consists of a total of 42 control volumes and 77 flow paths. A safety injection tank (SIT) is connected to each cold leg, and if the pressure of the primary system decreases below 4.3 MPa, the coolant is injected by the pressure difference between the control volume of the cold leg connected to the SIT.

The results of the steady-state calculation are compared to the main design value of the final safety analysis report (FSAR)[3]. Table I shows the results are very close to those of the FSAR.

Table I: Comparison of design value and MELCOR calculation results at steady state.

	FSAR	MELCOR	Error (%)
Core thermal power (MWt)	2,815	2,815	0
RCS pressure (MPa)	15.516	15.5	0.1
Core inlet temperature (K)	568.98	564.85	0.17
Core outlet temperature (K)	600.48	600.3	0.17
Primary flow rate (kg/s)	14944.8	15048.11	0.69
Secondary side pressure (MPa)	7.377	7.36	0.23
Steam flow rate per SG (kg/s)	801.32	809	0.96

2.2 SGTR scenario

Fig. 1. shows an event tree of SGTR accidents. The selected accident scenario is considering the failure of high pressure safety injection (HPSI) and low pressure safety injection (LPSI) due to common cause failures.

This scenario is most likely to lead to severe accidents due to the highest frequency of SGTR accidents and high frequency of core damage.

A break of 0.666-inch diameter(single tube guillotine break) was assumed by adding a flow path connecting the control volume corresponding to the primary side of the steam generator tubes. Table II shows the sequence of the event for the selected accident scenario.

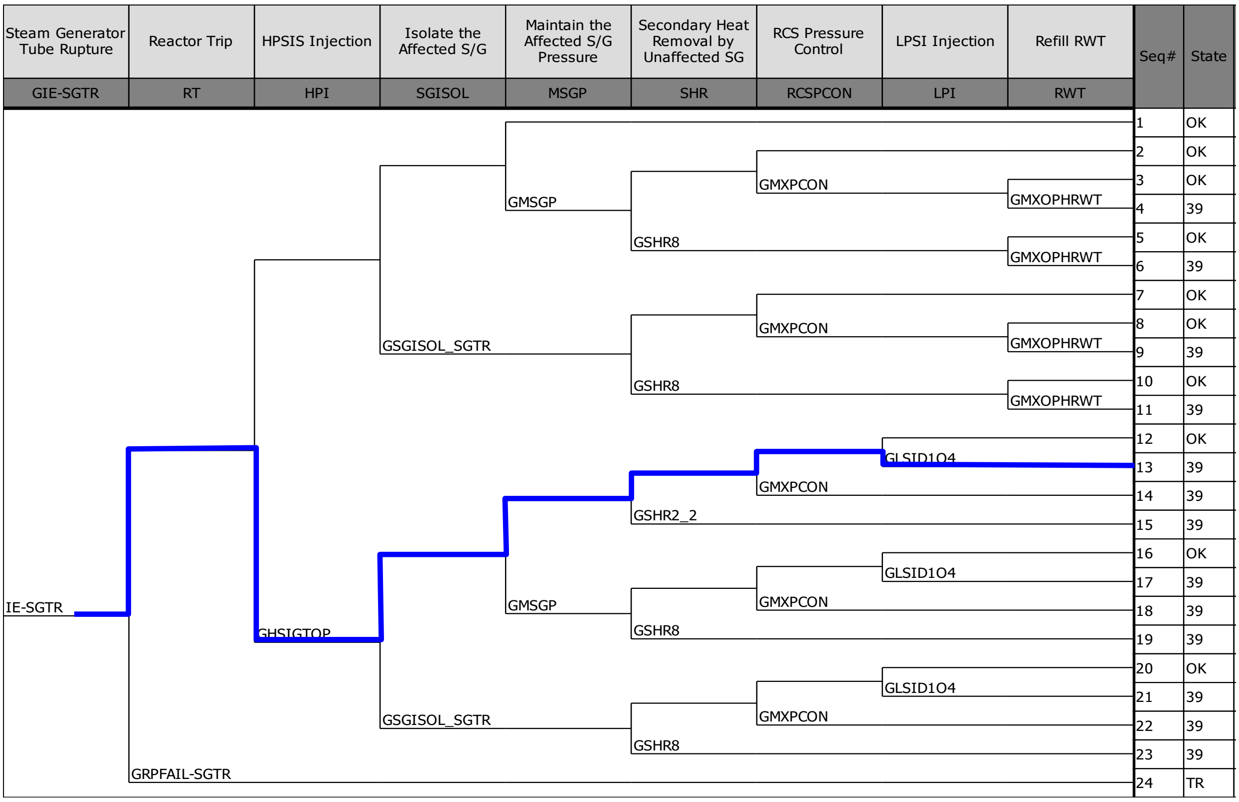

Fig. 1. SGTR Event tree of OPR1000

Table II : Sequences of event

Accident Sequence	Set point	Time (sec)
Accident start		0.0
Reactor trip	Low Pressurizer Pressure Signal	2,679
Main Feed Water (MFW) trip	Reactor trip	2,679
MSIV closure	Reactor trip	2,679
Safety Injection Signal	PRZ Pressure < 122.68 bar	2,679
Reactor Coolant Pump (RCP) trip	Safety Injection Actuation Signal (SIAS)	2,679
MSSV open	SG Pressure > 8.6 MPa	2,685
SG 2 dryout		6,372
SAMG entrance	CET > 923K	11,828
PSV open	Primary Pressure > 17.24 MPa	13,684
Core dryout		13,824
RPV failure		20,245

2.3 SAMG entry condition and mitigation strategy for accidents

If operators fail to control and to make a plant stable state in accordance with EOPs, technical support center (TSC) staff decide to stop the use of EOPs and start the use of SAMG. In the case of the SAMG, the TSC is required to determine and take measures according to the plant conditions and symptoms, so there is no set procedure for each accident scenario unlike the EOP[4].

Seven severe accident guidances (SAGs) defined in the SAMG as shown in Table III will be considered for application from the time when the core exit temperature (CET) exceeds 923K. The plant safety variables corresponding to each strategy are identified, and mitigation strategy measures are taken if the conditions are not satisfied.

Table III: Severe accident mitigation strategies of SAMG.

Strategy No.	Objectives	Equipment
SAG-01	· Establish heat removal source · Coolant inflow after RCS depressurization · Maintain integrity of SG	Auxiliary feed water
SAG-02	· Prevent SG tube creep damage · Establish core cooling	· Safety depressurization valve · Atmospheric dump valve
SAG-03	· Prevent reactor pressure vessel failure · Establish core cooling	· HPSI · LPSI · Spray pump · Charging pump
SAG-04	· Establish core cooling · Prevent reactor pressure vessel failure	· Spray pump · Refueling water tank
SAG-05	· Reduce fission product release	· Spray
SAG-06	· Reduce fission product release · Maintain containment integrity	· Spray ·Containment fan cooler
SAG-07	· Prevent hydrogen explosion	· Hydrogen igniter

2.4 Results of simulation

Fig. 2. shows the system's pressure on accidents without operator action according to the selected accident scenario. When the SGTR occurs at 0 seconds, coolant from the primary system is released to the break due to the relatively high pressure from the primary side.

As a result, the pressure in the primary system is continuously reduced and the reactor is shut down by the pressurizer low pressure signal after 2,679 seconds. After 13684 seconds, the Pressurizer Safety Valve (PSV) is opened and the pressure is reduced accordingly. The secondary system reaches the set point of the MSSV as the MSIV is closed along with the shutdown of the reactor, and maintains the pressure of 8.6 MPa level through repeated opening and closing.

Fig. 3. shows the core collapsed water level and Fig. 4. shows the CET that represents the core cooling. As the core heats up after the steam generator loses its heat removal capability, the CET also rises rapidly. After 11,828 seconds, it can be confirmed that it exceeds the SAMG entry condition of 923 K. After entering SAMG, operator action using applicable mitigation strategies is required. If the safety variable satisfaction requirements for the plant corresponding to each strategy are not met, measures using mitigation strategies may be taken. For example, SAG-01 is a step through the injection of water into a steam generator. If the water level of all steam generators, which is a requirement for satisfying safety variables, does not exceed 63%, measures through auxiliary feed water are required.

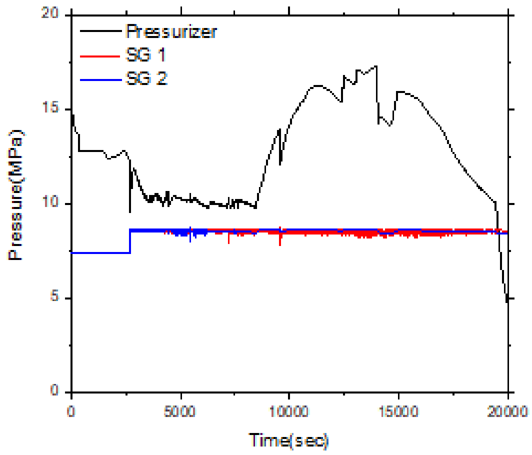

Fig. 2. RCS Pressure.

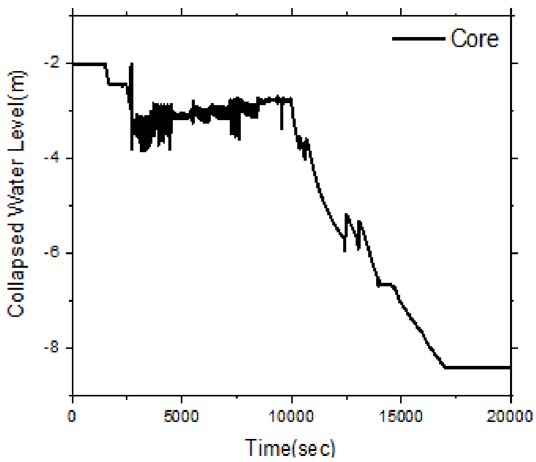

Fig. 3. Collapsed Water level of the core.

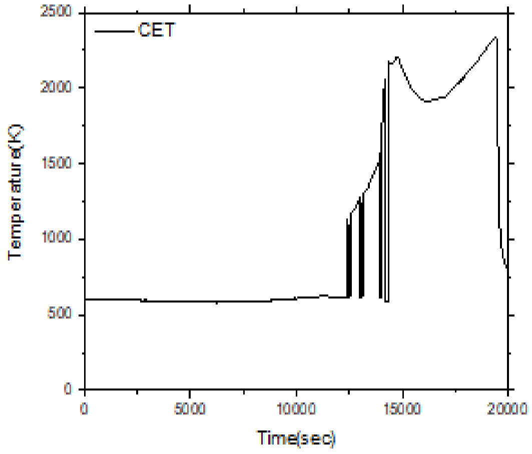

Fig. 4. Core Exit Temperature.

3. Conclusions

Operation Procedure (OP), EOP, and Emergency Planning (EP) alone are insufficient to cope with severe accidents such as reactor vessel damage or hydrogen explosion. In the event of core damage at nuclear power plants, severe accident management should be carried out by SAMG beyond the procedures listed above. Unlike EOP where necessary measures are specifically determined for each accident situation, SAMG is required to mitigate accidents by utilizing available facilities depending on the situation. Therefore, even if accident mitigation is performed using SAMG in the same accident, the number of cases may vary depending on the user's judgment, action time, or facility availability.

For further study, we can analyze accident using SAMG's strategy to mitigate severe accidents. Also, sensitivity and uncertainty analysis studies using MOSAIQUE[5] can be conducted using established mitigation strategy evaluation factors. Also, we can determine the utility of the accident management plan by comparing the SGTR radiation risk before and after the accident management plan is reflected.

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