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An Evaluation of Severe Accident Management Strategy Using PORVs in SGTR Accident

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1. Introduction

When an accident in a nuclear power plant turns into a severe accident, severe accident management strategies presented in the severe accident management guidelines (SAMG) are implemented to control and mitigate the severe accident. Severe accident management (SAM) strategies to control the amount of fission products released through steam generators for a steam generator tube rupture (SGTR) accident, are also included in the SAMG [1]. One of the strategies is to depressurize the primary system using power operated relief valves (PORVs).

In this study, the effectiveness of this SAM strategy was evaluated. MELCOR 2.2 was used to simulate accidents for evaluation of the strategy. Based on the simulation results, the optimal application method of the strategy was derived. Finally, the evaluation whether the safety goal could be achieved through implementation of the strategy was performed.

2. Methods and Results

2.1 Reference System and Accident Scenario

WH600 (Kori Unit 2) was selected as a reference system for applying a SAM strategy. WH600 is an 1,876 MW_{th} pressurized light water reactor with two steam generators [2].

A SGTR was selected as a reference accident scenario. The SGTR is an accident that one or more steam generator tubes are broken and the coolant in the primary system leaks to the secondary system. This accident is considered as one of the most significant accident because the fission products generated in the primary system can be released into the environment directly.

2.2 Reference Severe Accident Management Strategy

A strategy that depressurize primary system through the opening of PORVs in the SGTR accident was evaluated in this study. The function of PORVs is to keep the pressure of pressurizer below the set point by releasing the coolant of the primary system into the containment. They are closed in normal operation [3].

In the SGTR accident, coolant as well as the fission products is leaking through the broken tube between primary system and secondary system as longer there is a pressure difference. Reactor core gets damaged, fission products will leak to the secondary system through the broken tube. Eventually, the fission products will be released out of the containment. The larger the pressure difference between the primary system and secondary system, the greater the leakage of coolant and fission products. Therefore, the amount of fission products leaked to the secondary system can be reduced, if the pressure of the primary system is depressurized by opening of PORVs.

Accident simulations reflecting this strategy were carried out. The event tree of the SGTR accident is shown in figure 1. Based on the probabilistic safety assessment (PSA) model from multi-unit risk research group (MURRG), the frequency of SGTR accounts for 17.64% of total core damage frequency (CDF). Since the SAM strategy needs the PORV, the strategy cannot be applied to scenarios which the PORV is not available: Scenarios that SG-COOL and BLD headings fail on the event tree. In other words, the strategy can be applicated for the SGTR sequences except 9, 16 and 20 sequences. The total frequency of sequences that the strategy could be applicable accounts for 86.01% of SGTR frequency, and 15.17% of total CDF.

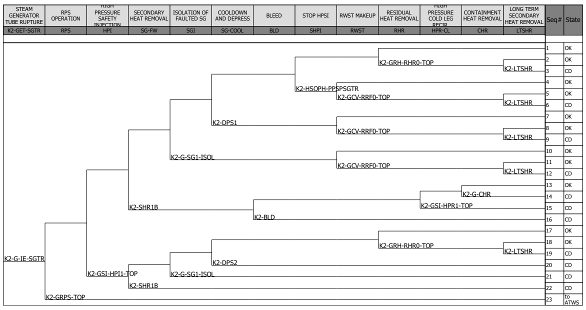

Fig. 1. SGTR event tree of PSA model.

2.3 Accident Simulations and Sensitivity Analysis

The sequence-22 in figure 1 was selected as a base scenario. The SGTR-22 is an accident scenario that high pressure safety injection and secondary heat removal fail. This sequence was expected to show the most conservative result among the SGTR sequences. The isolation of the damaged steam generator was assumed to be succeeded. And all safety systems were assumed to fail, except accumulators. Also, the control of secondary system pressure was assumed to be available only through the main steam safety valves (MSSV).

MELCOR 2.2 was used to simulate accidents [4]. Based on the SGTR-22, sensitivity analyses were performed on release fraction of fission products according to the opening time and the number of opened

PORVs. The entry condition of the SAMG was assumed to be the time when the core exit temperature (CET) exceeds 1200 °F [1]. The time of opening PORVs was divided into 9 cases: from 10 minutes after entering the SAMG condition to 90 minutes. The number of opening PORVs was divided into 2 cases: one or two. Therefore, total of 18 cases were analyzed.

The release fraction of fission products decreased as PORVs opened early. In addition, the release fraction was further reduced when two PORVs were opened than a single PORV was opened. The release fraction was more influenced by the opening time than the number opened PORV. These trends are shown in figure 2 and 3. However, the adverse effect of implementation of the strategy was also confirmed. As the PORV opened, coolant of the primary side leaked into the containment, and the pressure of the containment continuously increased. Assuming the accident was terminated 72 hours after SGTR occurred, the containment pressure exceeded the design pressure in five cases of early opening PORV(s).

In this study, the design leakage was assumed to be occurred when the containment pressure reaches the design pressure (44.8 psig) [3]. Therefore, the calculated release fraction already included the release due the design leakage. However, even the design leakage was considered, the trends of release fraction for each case was not changed. Also, although the containment pressure continued to increase, the pressure did not reach the containment rupture pressure (133.3 psia) until 72 hours after SGTR occurred [3].

That is, even if the design leakage was considered, opening PORVs as quickly as possible was the most effective strategy in reducing fission products release. In case of two PORVs were opened 10 minutes after the SAMG entry, which is an optimal application method of the strategy, the release fraction of Cs and I classes was reduced by 98.72% and 99.46% each, compared to the base case.

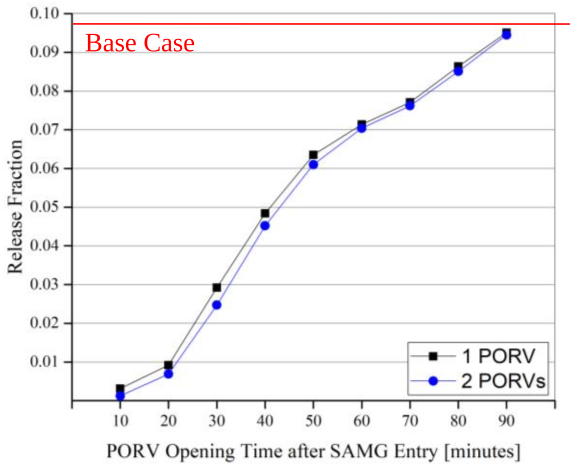

Fig. 2. Release fraction of Cs class at 72 hours after SGTR occurred.

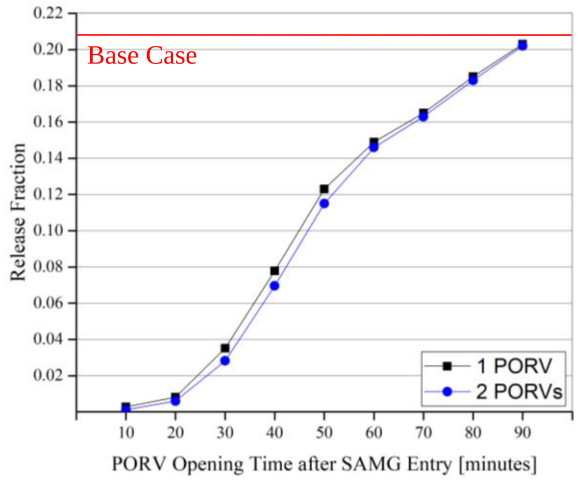

Fig. 3. Release fraction of I class at 72 hours after SGTR occurred.

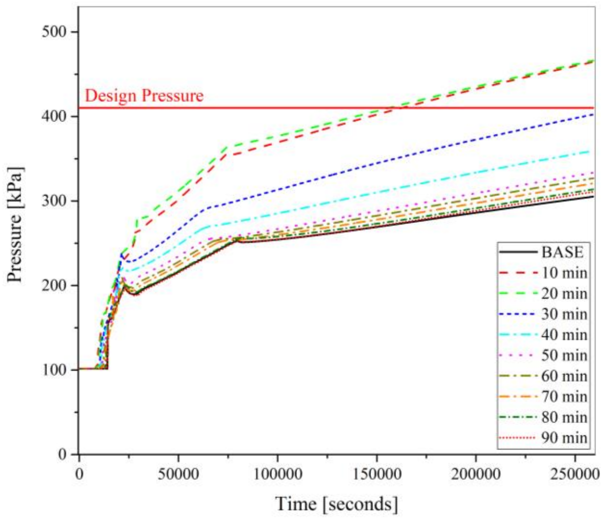

Fig. 4. Containment pressure when a PORV was opened.

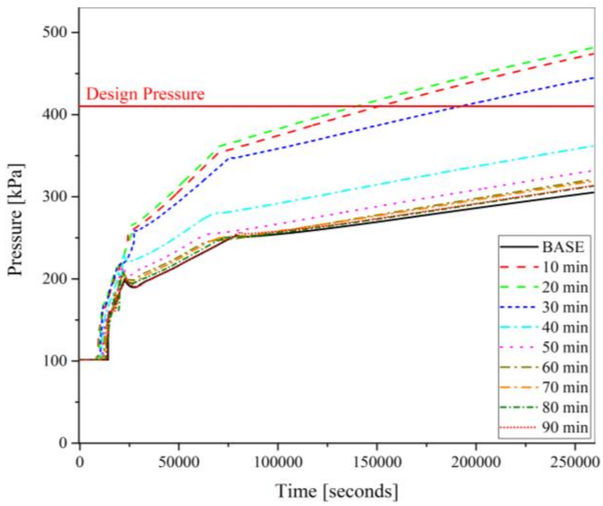

Fig. 5. Containment pressure when two PORVs were opened.

2.4 Limitations of the SAM strategy and Analysis

In Korea, the nuclear safety act revised in 2016 provides the following safety goal for the nuclear power plants: The sum of frequencies of accidents in which the releases of radionuclide Cs-137 exceeds 100 TBq should be less than 1.0E-6/yr [5].

The evaluation whether the safety goal could be achieved through implementation of the strategy was performed. The core inventory of Cs-137 was calculated to be 1.77E+05 TBq using OrigenArp code [6]. The calculation results of the amount of released Cs-137 for each case are shown in table 1. It was confirmed that the safety goal (Cs-137 100 TBq) was not satisfied in all cases including base case even though the release fraction was reduced.

In terms of accident analysis, only the release fraction of fission products and the pressure of containment were analyzed. Also, simulations were performed only for the SGTR-22 which was expected to have the most conservative result. And although the fission products can be released via auxiliary building and turbine building, this phenomenon was not considered.

3. Conclusions

In this study, the SAM strategy using PORVs in the SGTR accident was evaluated. To evaluate the strategy, accident simulations using MELCOR 2.2 were performed. The opening of PORVs increased the pressure of containment, but the release fraction of fission products was reduced. As a result of sensitivity analysis, even if the design leakage was considered, opening PORVs as quickly as possible after the SAMG entry was the most effective strategy. However, it was confirmed that the safety goal was not satisfied even though the release fraction was reduced. Therefore, additional strategies or systems should be considered to satisfy the safety goal.

This study can be used as a basis for the quantitative assessment of the SAM strategy, and improvement of the SAMG. Moreover, this study can also be used to develop a methodology for more realistic multi-unit risk assessment.

Acknowledgements

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Table I: The Amount of Released Cs-137 for Each Case

Cases	Core Inventory of Cs-137 [TBq]	Release Fraction of Cs Class [-]	Released Cs-137[a)] [TBq]
Base	1.77E+05	9.75E-02	1.73E+04
1 PORV, 10 m[b)]		3.12E-03	5.52E+02
1 PORV, 20 m		9.16E-03	1.62E+03
1 PORV, 30 m		2.92E-02	5.17E+03
1 PORV, 40 m		4.84E-02	8.57E+03
1 PORV, 50 m		6.35E-02	1.12E+04
1 PORV, 60 m		7.14E-02	1.26E+04
1 PORV, 70 m		7.71E-02	1.36E+04
1 PORV, 80 m		8.64E-02	1.53E+04
1 PORV, 90 m		9.51E-02	1.68E+04
2 PORV, 10 m		1.25E-03	2.21E+02
2 PORV, 20 m		6.87E-03	1.22E+03
2 PORV, 30 m		2.47E-02	4.37E+03
2 PORV, 40 m		4.52E-02	8.00E+03
2 PORV, 50 m		6.10E-02	1.08E+04
2 PORV, 60 m		7.04E-02	1.25E+04
2 PORV, 70 m		7.62E-02	1.35E+04
2 PORV, 80 m		8.51E-02	1.51E+04
2 PORV, 90 m		9.45E-02	1.67E+04

a) Safety Goal of the Amount of Released Cs-137: 100 TBq
b) A PORV Opened 10 minutes after SAMG Entry