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A Source Terms Evaluation for A SGTR Accident Using the MELCOR Code

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1. Introduction

In Korea, the nuclear safety act revised in 2015 provides the following safety goals for the probabilistic safety assessment (PSA): 1. The early fatality risk and cancer fatality risk of residents near the site arising from accidents at electricity generating reactor facilities must be less than or equal to 0.1% of the total risk or meet the corresponding performance goals. 2. The sum of the frequency of accidents in which the emissions of radionuclide Cs-137 exceeds 100 TBq should be less than 1.0E-6/yr [1]. Prior to the enactment of this act, only the level 1&2 PSAs had been practiced conventionally. However, due to the revision of the act, the risks due to accidents at nuclear power plants should be evaluated comprehensively through the implementation of the level 3 PSA.

Until now, source terms released to the environment during a steam generator tube rupture (SGTR) accident were evaluated very conservatively because the level 3 PSA was not performed. That is, the SGTR core damage sequences have been classified as one source term category (STC) because there is no need to confirm the quantitative safety objectives through the level 3 PSA. However, as it became necessary to confirm whether the safety goal is satisfied through the level 3 PSA, it is necessary to take a more realistic approach than the conservative approach when evaluating source terms for the SGTR accident. In this study, with this realistic approach, source terms were re-evaluated for the SGTR accident.

2. Methods and Results

2.1 Reference System and Accident Scenario

OPR1000 was selected as a reference system for an evaluation of source terms. OPR1000 is a typical Korean reactor type, a 2,815 MW_{th} pressurized light water reactor, with two steam generators (SG-A, SG-B). The main safety systems and valves of OPR1000 considered in this study are as follows: high pressure safety injection system (HPSI), main steam isolation valve (MSIV), atmospheric dump valve (ADV), main steam safety valve (MSSV), and MSIV bypass valve.

The 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 side leaks to the secondary side. This accident is one of the most significant accident because the radionuclides generated in the primary side can be released into the environment directly.

The event tree of the SGTR accident used in this study is shown in figure 1. Source terms were evaluated for core damage sequences in this event tree.

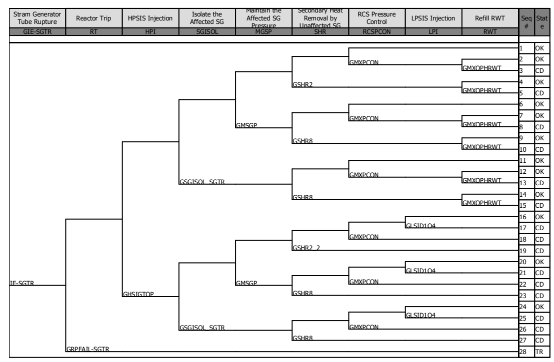

Fig. 1. The event tree of the SGTR accident for a source terms evaluation [2].

2.2 MELCOR Modeling

MELCOR 1.8.6 version was used as a tool to evaluate source terms for SGTR core damage sequences. MELCOR is a fully integrated, engineering-level computer code developed by Sandia National Laboratories for the U.S. Nuclear Regulatory Commission to model the progression of severe accidents in nuclear power plants. A broad spectrum of severe accident phenomena in reactors is treated in MELCOR. MELCOR applications include estimation of severe accident source terms [3].

The descriptions of MELCOR model for the SGTR core damage sequences are summarized in table I. The basic assumptions are as follows. The rupture was assumed to be a complete break of one of the tubes of the SG-A. The break size was assumed to be 0.000449 m^2 with reference to the steam generator tube size of OPR1000 [4]. The main feed water (MFW) supply was assumed to be automatically stopped when a reactor trip occurred. The safety injection tank (SIT) was assumed to automatically inject cooling water when the pressure at the primary side reaches the set point.

The headings of the SGTR event tree are modeled as follows in MELCOR.

- Reactor Trip (RT): The reactor trip failure sequence is transferred to anticipated transient without scram (ATWS) and therefore it was not considered in this study.

- HPSIS Injection (HPI): If the HPSI is success (HPI success branch), it was assumed that all two trains of high pressure safety injection system succeed to inject cooling water into the reactor coolant system (RCS).

- Isolate the Affected SG (SGISOL): After the reactor trip, it was assumed that the operator manually isolates the MSIV of affected SG. The MSIV of unaffected SG was assumed not to be isolated.

- Maintain the Affected SG Pressure (MSGP): After the MSIV-A isolation, the SG-A water level and pressure may continue to increase due to water inflow from the RCS and HPSI operation. According to the reference NPP's emergency operating procedures (EOPs), in this case, the operator opens the MSIV bypass valve (MSIV BV) to prevent opening of the MSSV. If the MSIV bypass valve remains closed, the MSSV will repeat opening and isolation. However, in this study, it was assumed that the MSSV-A is stuck-open after initial opening. This is because the MSSV is likely to stuck-open, but it is difficult to predict when it will stuck-open.

- Secondary Heat Removal by Unaffected SG (SHR): In order to remove the decay heat from the primary side using the secondary side, steam removal from the SG should be performed as well as water injection into the SG. In this study, it was assumed that the auxiliary feed water (AFW) supplies only to the unaffected SG (SG-B). Also, it was assumed that only one of the two ADV-B (ADV-B1) is open to remove the steam. The ADV-B1 was assumed to open 10 minutes after AFW-B start.

- RCS Pressure Control (RCSPCON), LPSI Injection (LPI), and Refill RWT (RWT): In the RCSPCON, LPI, and RWT headings, it was assumed that the headings always fail, because the success branches are sequences that does not cause core damage. That is, sequences-18, 22, and 26 were excluded from the analysis because they were modeled exactly same as sequence-17, 21, and 25 in MELCOR.

2.3 Source Terms Evaluation Results

Source terms for the SGTR core damage sequences were evaluated using MELCOR. Figure 2 to figure 4 show release fractions over time for 72 hours. The release fractions were presented for three classes, Cs, I, and CsI class, of radionuclides that are used as primary variables in level 3 PSA.

The release timing of radionuclides was significantly different according to the success or failure of HPSI and secondary heat removal by unaffected SG (HPI, SHR headings). The start time of release of radionuclides was evaluated to be about 3 hours in case of both failure to supply cooling water into the primary side using HPSI and failure to remove the secondary side heat of unaffected SG. On the other hand, for the sequences in which both headings were success, the start time of release of radionuclides was evaluated to be about 44 hours. When only one of the headings was success, the start time of release of radionuclides was evaluated to be about 30 hours. This is because when the cooling water is injected into the primary side through the HPSI or when the heat of secondary side is remove, the core uncover and melting are delayed.

The total release fraction for 72 hours after the SGTR accident occurred also showed a similar tendency according to the groups classified as above. However, when only one of the two headings (HPI and SHR) was success, the start time of release was similar, but the total release fraction was slightly different. This is because, when the cooling water is injected directly into the primary side using HPSI, the generation of radionuclides due to the core melting is relatively small, unlike the case that only the heat removal using the secondary side succeeds.

Table I: MELCOR model for the SGTR core damage sequences

Headings	Success branch	Failure branch
RT	Auto reactor trip (1,953 sec)	-
HPI	On (2/2)	Off
SGISOL	MSIV-A close at 2,000 sec	All MSIVs remain open
MSGP	MSIV BV-A open at 2,060 sec	All MSIV BVs remain close
SHR	AFW-B(MOP) start at 2,000 sec ADV-B1 open at 2,600 sec	All AFSs not start All ADVs remain close
RCSPCON, LPI, RWT	-	Off (always fail)

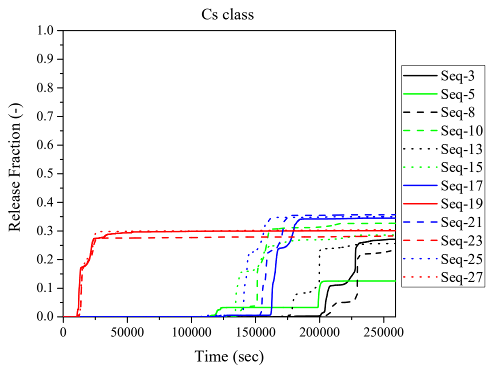

Fig. 2. The release fractions of Cs class radionuclides over time for 72 hours for the SGTR core damage sequences.

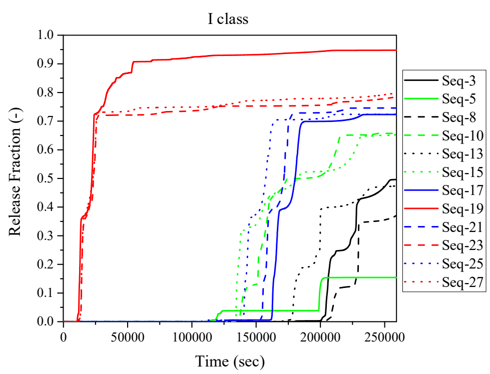

Fig. 3. The release fractions of I class radionuclides over time for 72 hours for the SGTR core damage sequences.

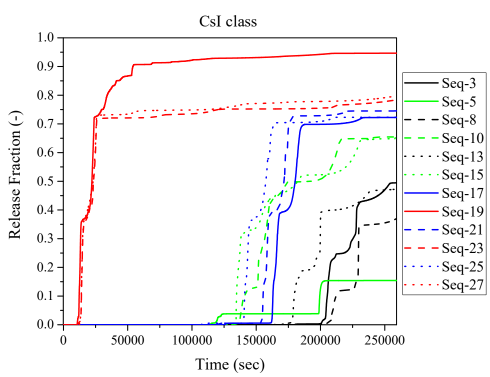

Fig. 4. The release fractions of CsI class radionuclides over time for 72 hours for the SGTR core damage sequences.

In the level 3 PSA considering emergency response, the start time of release of radionuclides could have a significant impact on the risk assessment results. Therefore, STC of the SGTR can be divided into three categories according to the start time of release of radionuclides: SGTR-Early, SGTR- Intermediate, and SGTR-Late (3, 30, and 44 hours). Also, in the sequences with the start time of release of 30 hours, the radionuclides release rate was dramatically increased after 44 hours, so the sequences of the start time of 30 and 44 hours can be grouped into one STC: SGTR-Early and SGTR-Late (3 and 30-44 hours). In terms of total release fractions into the environment, no significant trend was found.

3. Conclusions

Since the amendment of the nuclear safety act, it became necessary to confirm whether the safety goal is satisfied through the level 3 PSA. Until now, the SGTR core damage sequences have been classified as one STC because there is no need to confirm the quantitative safety objectives through the level 3 PSA. Therefore, source terms of the SGTR core damage sequences should be re-evaluated and, if necessary, classified into several STCs. Source terms for the SGTR accident were re-evaluated using MELCOR code. As a result of the evaluation, it was confirmed that the SGTR core damage sequences with similar source term characteristics can be classified into two or three STCs. There was a significant difference in the start time of release of radionuclides into the environment depending on the success of the HPI and SHR headings in the SGTR event tree. This difference can be a key variable in the risk assessment results in the level 3 PSA considering emergency response. This study can be used as a basis for a more realistic comprehensive risk assessment.

Acknowledgements

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REFERENCES

[1] Nuclear Safety and Security Commission (NSSC), Regulation on the criteria of accident management scope and accident management ability evaluation, No. 2016-2, 2016.
[2] Korea Atomic Energy Research Institute (KAERI), Accident Sequence Analysis for at Power Internal Events Level-1 Probabilistic Safety Assessment of OPR, KAERI/TR-6740, 2016.
[3] Gauntt, R. O., et al., MELCOR computer code manuals, Sandia National Laboratories, NUREG/CR 6119, 2005.
[4] KAERI, Materials Data Portal for Nuclear Application, http://mdportal.kaeri.re.kr/d20150027/, 2015.