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Sensitivity Analysis of Multiple Release Locations in Multi-unit Level 3 PSA

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1. Introduction

Level 3 Probabilistic Safety Analysis (PSA) is based on spatiotemporal information on source term release and various physicochemical properties. Temporal information means release start and end time, and spatial information means release point. The difference between the multi-unit Level 3 PSA and the single unit Level 3 PSA is the accident in which multiple source terms are released [1]. In the case of time-dependent information of multi-unit incidents, it can be reflected through the MELMACCS program, which serves as an interface between Methods for Estimation of Leakages and Consequences of Releases (MELCOR) and MELCOR Accident Consequence Code System (MACCS). However, the MACCS code has a limitation that cannot set a number of release points for multi-unit accident.

Since the amount of radioactive material released in a multi-unit accident is greater than that released from each single unit, it will occur more frequently that the radioactive material exceeds the threshold in a multi-unit accident. In addition, since the emergency response at each single unit and the emergency response at multi-unit are different, when a multi-unit accident occurs, the sum of each risk due to the radioactive material released from each single unit is different from the risk caused by a multiple unit accident.

In this study, the weighted release location method (WRL) is developed and applied to the thermal output of the unit where the accident occurred in multi-unit accidents [2-3]. The sensitivity analysis of the off-site consequence according to the release points of the multi-unit accident was performed for 4 cases. The goal is to analyze the sensitivity for the consequence difference according to the release points by changing the proportion of the population that performs emergency response with a value of 0%, 50% and 95% evacuation in the Precaution Action Zone (PAZ) area.

2. Methods

This chapter describes the feature of MACCS code, the reference plants and site, source terms, evacuation level, and the risk result of sensitivity analysis for multiple release points.

2.1 Features of the MACCS Code

All calculations in MACCS, including the transportation and dispersion of radioactive plume segments by the Gaussian plume model, mitigative actions, early and latent health effects risks, and so on, are implemented and saved in the spatial grid elements divided by the specified radius and directions on the polar coordination whose center is a release location. With the most recent update, the ability to reflect multiple source terms whose release time are various was added in MACCS. However, the function to perform the multi-source term calculation considering the positional difference is not provided yet [4-5].

2.2 Reference Plants and Site

In the case of Korea, since the total area is small, more than 6 units are being built on all sites. In this study, the Kori site was selected as a reference site because it has the most units in one site, with 7 units currently in operation and 2 units scheduled to be operated in the future, with a total of 9 units.

As the reference plants, one WH600 type plant (K2), an OPR1000 type plant (S1) and an APR1400 (S3) type plant from Kori site in Korea were selected. The electric and thermal power of the WH600, OPR1000 and APR1400 are 650 MWe, 1882MWth and 1000MWe, 2825MWth, 1400 MWe, 4000MWth respectively.

2.3 Source Term Evaluation

The closest densely populated area to the Kori site is Busan, located in the southwest of the site. In order to calculate the result of the off-site consequence according to the release point, K2 closest to Busan, S3 farthest from Busan, and S1 between K2 and S3 were selected as the multi-unit of accidents.

In this study, the accident scenario for K2 is assumed to be containment-not isolated mode (BYPASS), the accident scenario for S1 is used as late containment failure (LCF), and the accident scenario for S3 is selected to be the steam generator tube rupture (SGTR) based on the frequency importance respectively.

2.4 Comparisons of Consequence Analysis for 4 Cases

In the case of a multi-unit accident, there are multiple release points, but MACCS code has a limitation in that it cannot set multiple release points. In this study, to create an input file for MACCS, the method of weighted average heat output of multiple release points was used using Hanyang Emergency Preparedness Risk Information (HEPRI) [6]. The site data file was obtained by calculating the population within the sector at the heat output weighted average point and the population data of the K2, S1, and S3 using National Statistical Office [7].

In this study, sensitivity analysis was performed on changes in the proportion of the population performing emergency response. The proportion of the population performing emergency response was changed to 95% (best estimation), 50%, and 0%. The emergency response ratio can be set for each group by classifying the population group by distance and characteristics using HEPRI. One of functions to find location and sector population by HEPRI is shown in Figure 1.

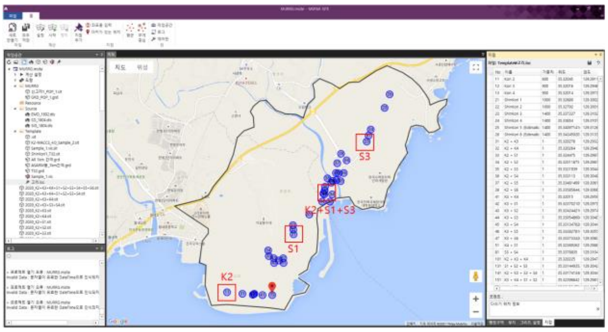

Fig. 1. The example point of weighted release locations obtained from the HEPRI application

Currently, in the event of a nuclear accident, all people living in the PAZ must be evacuated by law. In this study, the proportion of the population performing emergency response was changed by adjusting the proportion of general residents within 5 km of the PAZ, 3 to 5 km and non-evacuation residents.

Cohort 1, 2, and 3 are permanent residents in the PAZ. These cohorts are divided into evacuating and non-evacuating group. The evacuating group is divided into a general evacuation group and a delayed evacuation group. Cohort 4,6 are permanent residents from 5 km to 16 km. These cohorts are divided into voluntary evacuating and non-evacuating group. Cohort 5 are permanent residents over16 km. These cohorts are non-evacuating group. Cohort 7,8 is a population in special facilities. The special facilities include schools, hospitals, nursing homes, welfare centers, and prisons. Cohort 9 is a population temporarily staying in the UPZ. This group includes tourists, shoppers, and workers who do not live in the UPZ.

The proportion of the population performing emergency response was set to the sum of A and B, and the proportion of the population not performing emergency response was set to C. In the proportion of the population performing emergency response, it was assumed that 90% of general evacuation group A and 10% of late evacuation group B. Finally, the sum of A, B and C should be a value of 100%. The fraction of the population used in this study is shown in Table I [8-10].

Table I. Population Ratio of Cohorts

Cohort		Ratio of the Population				NUMEVA
Nu.	Description	0-5km	5-10km	10-16km	>16km	
1	Evacuating Group (0-5km)	A	-	-	-	5km
2	Late Evacuating Group (0-5km)	B	-	-	-	5km
3	Non-Evacuating Group (0-5km)	C	-	-	-	5km
4	Non-Evacuating Group (5-16km)	-	80%		-	10km
5	Non-Evacuating Group (16>km)	-	-	-	100 %	
6	Shadow Evacuating Group (5-10km)	-	20%		-	10km
7	Non-Evacuating Group (0-16km)	N/A				16km
8	Special Facilities (0-16km)	N/A				16km
9	Transient (0-26km)	N/A				26km

3. Results and Discussion

3.1 Early Fatality

The red bar in the Figure 2 shows the population weighted risk for a simultaneous accident of 3 units at the thermal power weighted point. The risk at point K2 is shown in light green, S1 in green, and S3 in dark green. Early Fatality (EF) shows sensitive results depending on the level of emergency response (A: 0%, B: 50%, C: 95%) at 2km and 5km, respectively [3].

The 3 unit simultaneous accident risk to which the WRL method is applied shows that there is almost no difference in the absolute value of EF in the case of 95% emergency response. In Figure 2, when the emergency evacuation with a level of 95% was performed as an input according to the current emergency preparedness procedure, when the WRL method was applied at a radius of 2 km, the EF was about 130% of the mean value of the risk of a simultaneous accident at three nuclear power plant points. And the EF, which applied the WRL method at a radius of 5 km in Figure 3, was found to be conservatively calculated as about 140% of the mean value of the risk of a simultaneous accident at three nuclear power plant points.

As shown in Figures 2 and 3, the calculated risk at the reference nuclear power plant 1 (K2), the reference nuclear power plant 2 (S1), the reference nuclear power plant 3 (S3), and the thermal power weighted point 4 (K2S1S3) was shown to be sensitive. However, in the case of 95% evacuation, which is close to the best estimation, the value of the difference of the population weighted risk showed very small difference in absolute value comparing 4 cases.

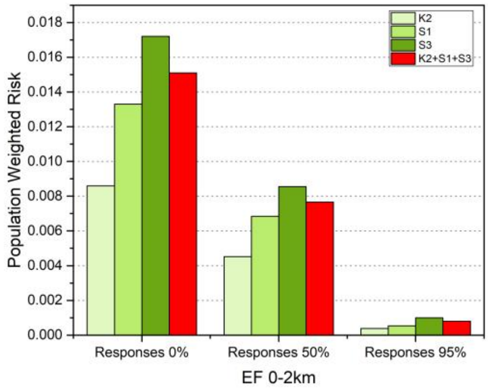

Fig. 2. Population Weighted Risk of Early Fatality (0-2km)

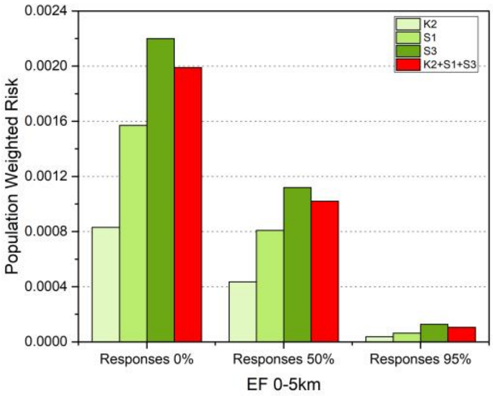

Fig. 3. Population Weighted Risk of Early Fatality (0-2km)

3.2 Late Cancer Fatality

As shown in Table 1, the population weighted risk according to the emergency response level (A, B, C) of the PAZ within a radius of 5 km shows a decreasing trend, but the population weighted risk corresponding to latent cancer fatality is not sensitive. As shown in Figures 4 and 5, the difference in relative risk at the reference nuclear power plant 1 (K2), the reference nuclear power plant 2 (S1), the reference nuclear power plant 3 (S3), and the thermal power weighted point 4 (K2S1S3) was negligible. Therefore, the WRL method presented in this study is a methodology that improved the limitations of multi-location modeling of the current MACCS code and was applied to the sensitivity calculation [2].

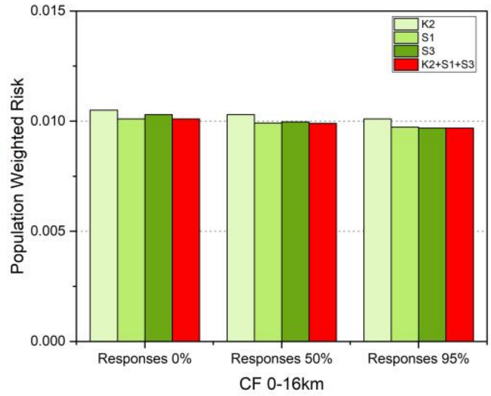

Fig. 4. Population Weighted Risk of Late Cancer Fatality (0-16km)

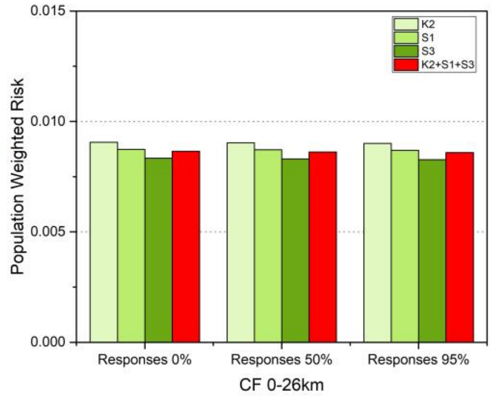

Fig. 5. Population Weighted Risk of Late Cancer Fatality (0-26km)

4. Conclusions

This study shows the results of risk calculation for a simultaneous accident at three nuclear power plants at four emission points according to the level of emergency response using the MACCS code. It was shown that the WRL method applied in this study is a methodology that improves the multi-location limitations of the current MACCS code. The EF was shown to be sensitive to the simultaneous accident release location, but the LF was not sensitive. And according to sensitivity analysis, it was seen that the WRL method proposed in this study is appropriate using the HEPRI in the case of a 95% emergency response close to the actual situation.

The EF risks with respect to release locations were found to be sensitive. However, in the case of 95% evacuation, which is close to the best estimation, the value of the difference of the population weighted risk showed very small difference in absolute value comparing 4 cases.

For further works, it is necessary to improve the function of MACCS code that can consider multi-location for modelling simultaneous accidents for reducing multi-unit consequence analysis.

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