A Sensitivity Study on Population Segmentation Effects in the MACCS Code

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INTRODUCTION

Since the Fukushima nuclear power plant accident occurred, there are gradual social demands for site risk assessment performed by the multi-unit probabilistic safety assessment (MUPSA). Also, the necessity for the level 3 PSA has been increased due to the mandatory submission of the accident management plan which includes the PSA reports in Korea. Therefore, it is required to perform the proper single-unit PSA prior to the multi-unit PSA.

The MACCS recommended by the NRC is widely used to perform the level 3 PSA worldwide. In order to perform the level 3 PSA using the MACCS, spatial and temporal information is required. And, the site file should be provided for spatial information. Population and land fraction information for each sector segmented radially and azimuthally are included in the site file. Therefore, users must segment an evaluation area appropriately in radial and azimuthal directions [1,2].

In this study, sensitivity analyses were performed using the MACCS 3.10 to investigate how much difference occurred in degree of segmentation in radial and azimuthal directions. In addition, the MSPAR-SITE, which systematically calculates the population and land fraction in each sector, has been developed and utilized for this study.

METHODOLOGY

Several cases such as the TABLE I were considered for the sensitivity analyses according to the degree of segmentation. Two cases of 16 and 32 azimuthal segmentations were considered. And, two cases of wide and narrow radial segmentations were considered. Two cases of radial segmentations were showed in the TABLE II. Kori site and OPR1000 in Korea were selected as a reference site and reactor type, respectively.

TABLE I. Several Cases of Sensitivity Analysis

Category	16 Directions	32 Directions
Wide	Case 1	Case 2
Narrow	Case 3	Case 4

TABLE II. Radial Segmentations (unit: km)

Narrow	Wide
0.5, 1, 1.4, 1.8, 2.2, 2.6, 3, 3.4, 3.8, 4.2, 4.6, 5, 6.5, 8, 9.5, 11, 12.5, 14, 15.5, 17, 18.5, 20, 22, 24, 26, 28, 30, 40, 50, 60, 70, 80	0.5, 1.8, 3, 4.2, 5, 6.5, 11, 15.5, 20, 26, 30, 40, 60, 80

Important Inputs of the MACCS

The MACCS consists of three modules (ATMOS, EARLY, and CHRONC) and COMIDA2 which models the dynamic food chain. The CHRONC module and COMIDA2 were not considered. Population and meteorological data of year 2016 were used in this study [3,4]. The values of variables which were dependent on site and reactor type were set as described in the following paragraphs, and other values of variables were cited from the State Of the Art Reactor Consequence Analyses (SOARCA) study [5].

The values of variables for wake effect, release fraction, and release delay in the ATMOS module were referenced from the level 2 PSA report of OPR1000. In this investigation, a reference source term category (STC) was selected as STC 3 which had loss of off-site power accident and early containment leak. The STC 3 has a representative accident sequence which consists of failure of secondary heat removal by auxiliary feed water system, failure of safety depressurization system, failure of safety injection system, and failure of containment spray system [6]. Core inventories were not provided in the level 2 PSA report. Therefore, core inventories of 41,000 MWd/MTU of KSNP reactor type, which had almost the same thermal power as OPR1000, were used [7]. Ground release, one hour of delay time for evacuation notification, and no heat contents were assumed. Also, the duration of release was assumed one hour assuming pop release. The release fraction of the STC 3 is shown in the TABLE III.

TABLE III. Release Fraction of the STC 3 for 72 hours

Noble Gas	Cs Group	Ba Group
9.86×10^{-1}	2.03×10^{-2}	4.12×10^{-4}
I Group	**Te Group**	**Ru Group**
3.54×10^{-2}	1.45×10^{-2}	7.56×10^{-4}
Mo Group	**Ce Group**	**La Group**
5.23×10^{-4}	7.32×10^{-5}	8.70×10^{-6}

Most values of variables in the EARLY module were cited from the SOARCA study. However, emergency response modeling of the SOARCA study considering several cohorts was complicated, and the emergency response modeling was not the main scope of this study. Therefore, emergency response modeling such as sheltering, and evacuation was not considered. Through this, it would be possible to observe only the effects of segmentations by excluding the emergency actions.

A Population Segmentation Computer Program

The preparations of the site input file, which is the MACCS input file, takes a lot of time and effort. There is no officially released program such as SECPOP. Therefore, the MSPAR-SITE creating the site file has been developed in this study.

This program was made using WPF and Javascript-based Google Map APIs. Input data uses the JSON format containing information, which consists of name, population, area, polygon containing the required coordinate layout to draw an area on the map, about each administrative district. A GeoJSON format used by several map-related programs, including this program, is equivalent to JSON.

The program allows for the drawing of a polar grid around a designated accident occurrence area. Separate sectors can be obtained at the intersection of several axes and concentric circles on the grid, and administrative district information can be used for each sector to provide the population per sector. The sector is saved as polygon form which is 'google.Maps.Polygon'.

More specifically, each sector had four vertex points, and the program finds the district where each vertex point belongs. Next, it calculates a population using the following Eq. (1), and the same calculation can be performed on the remaining vertex points and then added together, so the total population of the sector can be calculated.

$$P = \frac{D \cdot A}{4} \quad (1)$$

P: Total population of the sector
D: The population density of the district to which the point belongs
A: The area of the sector

The areas of the different administrative districts that one sector contains are less accurate, since they are not exactly matched off in four divisions. Therefore, to increase the accuracy, a sector requires to be divided into smaller sectors and the each of segments needs to be calculated. This program used the algorithm used to be known as Divided and Conquer method as a method of dividing one sector. If one sector contains different administrative districts, the sector will be divided into four small sectors and the same calculation will be applied. Conversely, if one sector is within just one administrative district, there is no need to have to be separated more and it will calculate the population of the sector at that time [6].

The problem is that when the boundaries of administrative districts are drawn in detail, sectors are divided too many times to increase the process time exponentially.

Therefore, if a sector is divided repeatedly as a specific number of times (depth), by setting the depth of Divided and Conquer method, the population of the sector is calculated directly at that stage, even if the sector contains different administrative districts.

A population calculation result is stored as information in the sector. Also, the sector is numbered by axes and concentric circles on the grid, users can create text files that match the site file form using this number.

This program can configure the number of axes, the interval and the number of concentric circles, and the starting degree of the axis of a first sector, which denotes the left side of the green line in the Fig. 1., to produce information that match the site file form.

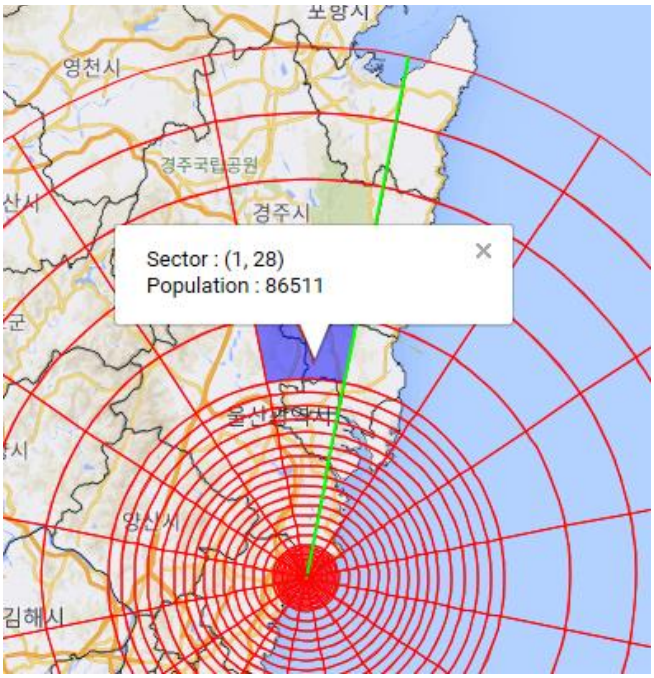

Fig. 1. Segmentation Process of the MSPAR-SITE in a reference site.

RESULTS AND ANALYSIS

Sensitivity analyses for the CASE 1, which is a base case, were performed. The ratios of conditional population weighted risk, which is used as a calculation measure, divided by the result of the CASE 1 are shown as the TABLE IV and the Fig. 2. for each case.

TABLE IV. Results of Comparison with the CASE1 for the CASE 2, 3, and 4

Category	Early Health Effects (0~5 km)	Late Health Effects (0~30 km)
CASE 2 / CASE 1	0.935	1.002
CASE 3 / CASE 1	2.588	1.003
CASE 4 / CASE 1	2.465	1.005

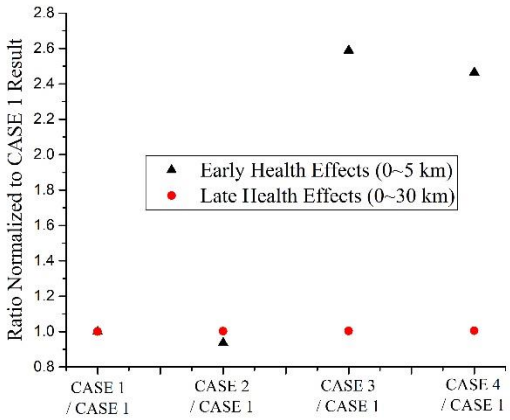

Fig. 2. The Ratios Normalized to the CASE 1.

Comparing early health effects with late those, late those were more affected by the segmentations. Note that only the EARLY module was calculated and the effects of the CHORNC module, which affected the late health effects, were excluded. The evaluation radius of the late health effects was relatively far from the source terms. As the distance from the source term increased, the concentration of radioactive materials decreased sharply. Therefore, the effects of the segmentations were not large for the late health effects. On the other hand, the evaluation radius of the early health effects was close to the source term. Therefore, the effects of the segmentations were large for the early health effects.

The radial segmentations were found to have a larger effect than azimuthal segmentations. Increasing the degree of the azimuthal segmentations had little effect on the early health effects. However, when the degree of the radial segmentations was increased, the early health effects were found to change more than 2 times. This is because the closer the distance from the source term is, the more accurate the calculation result is estimated. Each sector is further segmented to calculate doses, but for a minimum unit sector, an average value is considered in the EARLY module. Therefore, as the near region from the source term was widely segmented, the lower radioactive material concentration was considered to each sector, resulting in optimistic risk results. In addition, because the early health effects were strongly affected by threshold doses, a small dose difference could have a large effect.

To further analyze the effects of the radial segmentations, the results of the ATMOS module were considered. The results of calculating the concentration of radioactive material according to the distance from the source term is shown in the Fig. 3.

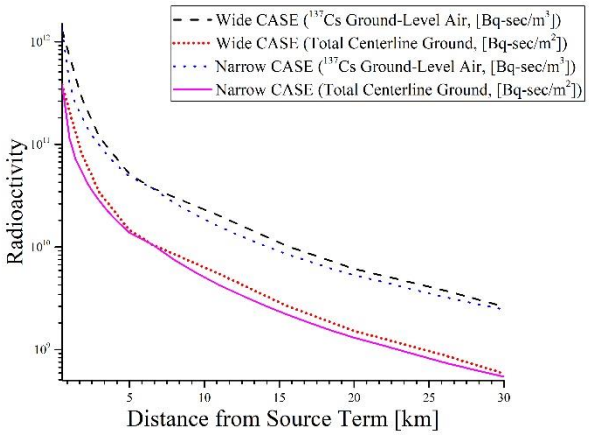

Fig. 3. Radioactivity according to the Distance from the Source Term.

The closer the distance from the source term was, the steeper the concentration changes of radioactive material were observed. Therefore, the narrower the radial segmentations of the near region is, the more realistic dose evaluation becomes possible.

CONCLUSIONS

In this study, sensitivity analyses were performed to observe the radial and azimuthal population segmentation effects. As a result, it was found that the early health effects were more sensitive than the late those. Also, it was found that the radial segmentations had more effects than those of the azimuthal segmentations.

The MSPAR-SITE, which automatically created the site file, was developed to produce the site file systematically. And, the convenience was confirmed through the MSPAR-SITE. Only the ATMOS and EARLY module in the MACCS were executed in this study. Therefore, additional studies considering the CHRONC module and COMIDA2 need to be performed. The MSPAR-SITE will also be updated to allow for more watersheds and smaller administrative areas. Conclusively, the results of this study will contribute to reducing the uncertainty of population segmentation effects in performing the level 3 PSA.

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