Comparison of Two Methods for Dose Distribution Calculation of Multi-unit Site

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1. Introduction

In the risk assessment of multi-unit nuclear power plants (NPPs) in a single site, the realistic dose distribution calculation is a significant issue. So far, probabilistic safety assessment (PSA) analysts have been using the single location method that integrates all NPPs into one virtual NPP and the dose distribution calculation is once performed for the virtual NPP.

This may result in quite different dose distribution from the reality. Besides, dose distribution near the nuclear is drastically overestimated or underestimated. In order to investigate the uncertainty of existing method, the two dose distribution calculation methods are compared in this study. They are center-of-mass (COM) dose calculation method and multiple-location (ML) dose calculation method.

2. Methods

In the COM dose calculation method, concentration of nuclides is calculated on the assumption that all of the NPPs are gathered into center of mass. ML dose calculation method calculates each concentration of nuclides on every location of NPPs.

In this section, the calculation process of COM and ML dose calculations is as follows:

1. (MACCS2 calculation for single NPP) Air and ground concentrations for all of the 60 nuclides on the ground level are calculated from the ATMOS output of MACCS2[1,2].
2. (Discrete nuclide concentrations for single NPP) Discrete values of 18 nuclide concentrations (halogen, noble gases and alkali metals) among 60 nuclides, and σ_y along the wind direction of plume are collected from ATMOS output of MACCS2. They are calculated by Gaussian plume model [1].
3. (Continuous nuclide concentrations for single NPP) Continuous concentration and σ_y along the wind direction are interpolated. Then, continuous concentration at the global location X and Y is calculated from the local coordinate x and y along the wind direction as
$$\chi(x, y, 0) = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} exp\left(-\frac{y^2}{2\sigma_y^2}\right) exp\left(-\frac{H^2}{2\sigma_z^2}\right). \quad (1)$$
Here, σ_y and σ_z are functions of x.
4. (Aggregation of nuclide concentrations for all NPPs) Nuclide concentration at arbitrary point X and Y is a combined value from Eq. 1 for all NPPs. Here, the number of origins for Eq. 1 is equal to the number of NPPs.
5. (Equivalent dose for site risk) Equivalent dose is calculated by multiplying dose coefficient of nuclides by the concentration of nuclides. Dose coefficient is taken from "Hand Book of Dose Coefficient v2.5.4" program by KAERI that is based on ICRP-60[5].

3. Application and Results

3.1 Benchmark problem

As shown in Figure 1, it is supposed that there are 6 virtual nuclear power plants and 8 population locations were marked. As listed in Table 1, 8 representative populations from P1 to P8 are located on the Exclusion Area Boundary (EAB) and Low Population Zone (LPZ). Approximate EAB distance is 560m[3] and LPZ distance is 3km to 5km[4].

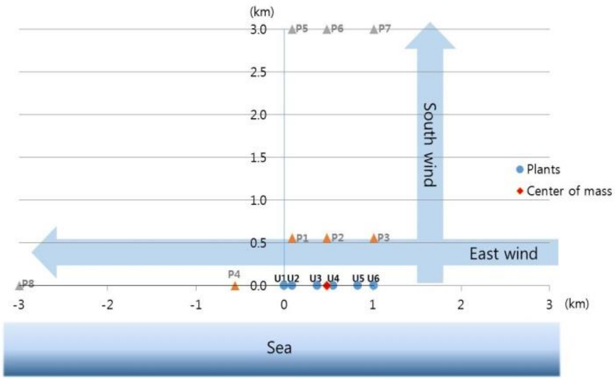

Figure 1. Schematic diagram

Table 1. Population and NPP locations

Location	X(m)	Y(m)
U1	0	0
U2	90	0
U3	370	0
U4	555	0
U5	830	0
U6	1,015	0
P1	90	560
P2	484	560
P3	1,015	560
P4	-560	0
P5	90	3,000
P6	484	3,000
P7	1,015	3,000
P8	-3,000	0

3.2 Calculation results

Although equivalent dose for all organs can be calculated, thyroid equivalent dose is calculated in this study. According to Table 2, and Figures 2 and 3, it is appropriate to use COM dose calculation method when population distribution and NPP units lie on the same line because there are a few differences of thyroid equivalent dose.

Table 2. Thyroid equivalent dose for south wind

Location	COM	ML
P1	0.000	0.000
P2	0.000	0.000
P3	0.000	0.000
P4	0.961	1.000
P5	0.000	0.000
P6	0.000	0.000
P7	0.000	0.000
P8	0.086	0.095

All values are normalized by thyroid equivalent dose at P4.

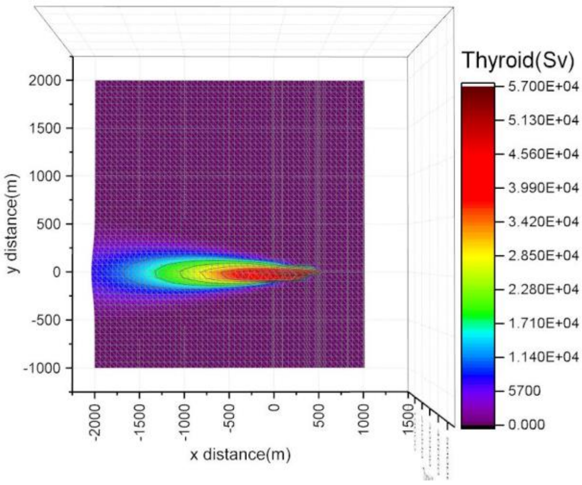

Figure 2. Dose distribution of COM method with east wind

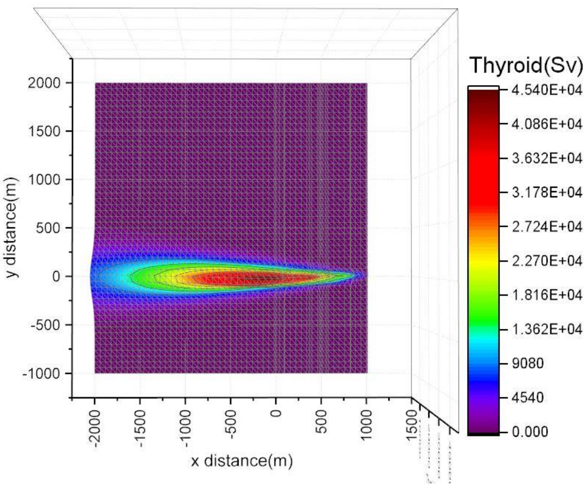

Figure 3. Dose distribution of ML method with east wind

According to Table 3, and Figures 4 and 5, it is inappropriate to use COM dose calculation method when population distribution and NPP units are not collinear. Thyroid equivalent doses at P2 and P6 using COM method are overestimated. However, equivalent doses of the other positions are underestimated.

Table 3. Thyroid equivalent dose for east wind

Location	COM	ML
P1	0.000	0.210
P2	1.000	0.107
P3	0.000	0.171
P4	0.000	0.000
P5	0.024	0.034
P6	0.077	0.037
P7	0.009	0.027
P8	0.000	0.000

All values are normalized by thyroid equivalent dose at P2.

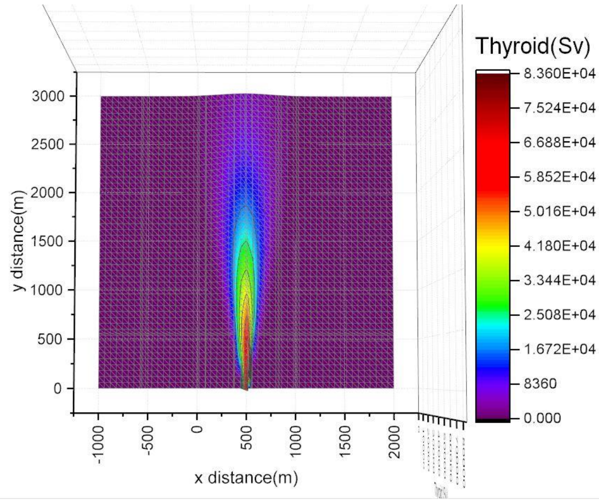

Figure 4. Dose distribution of COM method with south wind

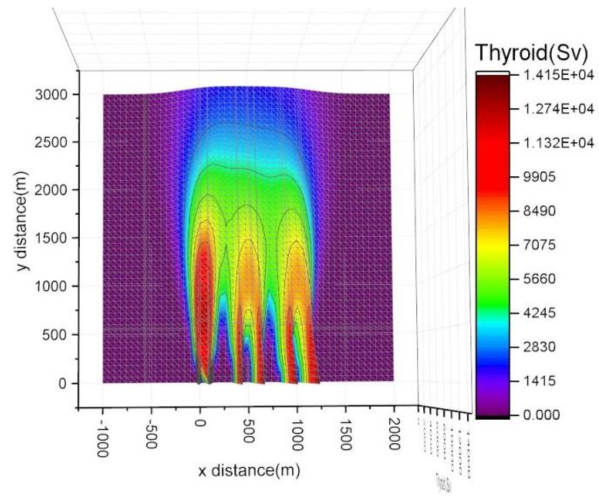

Figure 5. Dose distribution of ML method with south wind

According to Table 2, it is proper to use COM dose calculation method when population distribution and NPP units lie on the same line. However, it is difficult to apply COM dose calculation method to the other cases.

P2 in Table 3, the dose calculated by COM dose calculation method is ten times greater than that of ML dose calculation method, which is drastically overestimated. Likewise, P6 in Table 3, the dose calculated by COM dose calculation method is two times greater than that of ML dose calculation method.

4. Conclusions

In order to investigate the uncertainty of dose calculation methods for multi-unit NPPs in a site, the two dose distribution calculation methods of COM and ML methods are compared in this study. This study is summarized as

1. ML method is recommended for equivalent dose calculation for general population distribution cases.
2. COM method drastically overestimated or underestimated for general population distribution cases. COM method may result in quite different dose distribution from the reality.
3. COM method can be used only for the special case when population distribution and NPP units are collinear.

Acknowledgements

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