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Analysis of tritium dispersion in the atmosphere by using CALPUFF modeling system: Around the Wolseong Nuclear Power Plant Site

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1. Introduction

Radioactive materials from nuclear power plants(NPPs) are released in either liquid or gaseous state. Gaseous radioactive substances affect the human body through breathing and absorption through skin [1]. Gaseous radioactive substances emitted from NPP are mainly tritium, radioactive carbon, and inert gases such as Xenon-133. In particular, since the heavy water reactor type Wolseong NPP emits more tritium than other NPPs, it is important to analyze the radioactive concentration in the atmosphere to evaluate the dose received by nearby residents.

In this study, the dispersion and diffusion of tritium emitted from the Wolseong NPP were evaluated using the CALMET/CALPUFF code system.

2. Methods

Figure 1 shows the CALMET/CALPUFF code system for calculation of dispersion and diffusion of gaseous pollutants. The CALMET code utilizes measured weather data to generate meteorological fields in areas where meteorological observations were not conducted. Based on the results from the CALMET code, the extent of dispersion and diffusion of the emitted pollutants is calculated using the CALPUFF code.

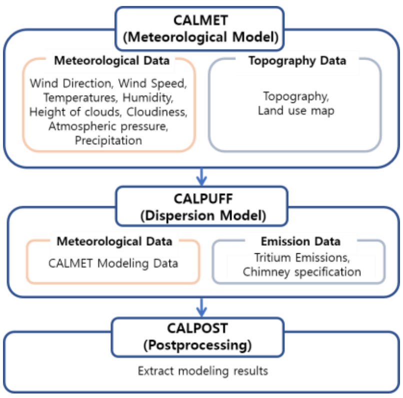

Fig. 1. Atmospheric modeling process: performs in the order of CALMET, CALPUFF, and CALPOST.

Using the CALMET/CALPUFF code system, the dispersion and diffusion of tritium emitted from the Wolseong NPP were simulated for the period of January 2019 to June 2021.

2.1 CALMET

CALMET is a weather processing system that generates detailed meteorological fields for a prediction target area by inputting local meteorological observation data such as temperature, atmospheric pressure, wind speed, wind direction, humidity, and so on. As the input data for CALMET, the meteorological data measured at the regular weather station around Wolseong NPP and weather station located inside the Wolseong NPP were used as ground weather. For high altitude air data, the meteorological observation data of the nearest Pohang High Weather Observatory was used. In addition, data from the Ministry of Environment and data from SRTM1 code[2] were used, respectively, for the land use map and topography required for CALMET calculation.

2.2 CALPUFF & CALPOST

The puff model assumes that the smoke continuously emitted from the chimney is discharged in the form of finely divided smoke masses (puffs). The discharged puff moves and grows along the wind field. The puff model can implement an unsteady state since it can represent the change in the wind field according to time and space as the movement of PUFF. Figure 2 shows the dispersal process of pollutants emitted into the air. CALPUFF is a module that calculates diffusion concentrations using previously performed CALMET data and tritium emissions.

CALPOST is a module that extracts the results of the dispersion calculation. In this process, the degree of dispersion of tritium can be grasped, and the concentration at a desired point can be extracted.

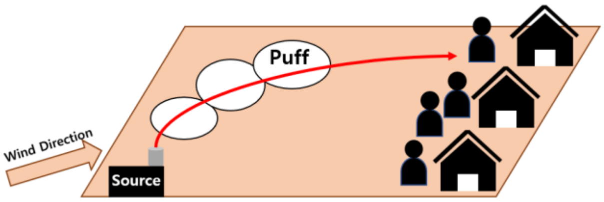

Fig. 2. Dispersion process of pollutants emitted into the atmosphere.

2.3 Modeling Area

A modeling area (10km × 10km) was set around a point inside the Wolseong NPP, and the grid set at 100m intervals. Since the predominant wind direction at Wolseong NPP is northwest wind, gaseous tritium is expected to spread southward. Considering this, the southern region (S1~S6) was selected as the main area of interest, and several locations (N1~N4) in the northern region were chosen for comparison. The information of the tritium diffusion prediction points is shown in Table I and Fig 3, respectively.

Table I: Distance of the prediction points from NPP

Point	Distance (km)	Point	Distance (km)
N1	2.00	S3	2.10
N2	3.75	S4	3.10
N3	4.30	S5	3.75
N4	5.25	S6	5.04
S1	1.05	W1	1.24
S2	1.86		

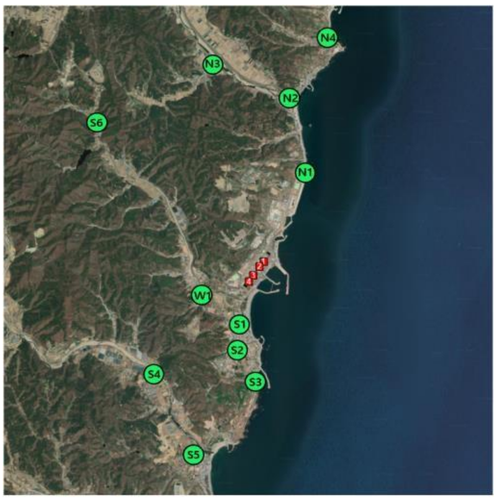

Fig. 3. Tritium influence prediction point in modeling area

3. Results

3.1 Concentration at prediction points

3.1.1 Daily-Average Maximum Concentration

Table II shows the daily-average maximum contribution concentration for the 11 points. The daily-average contribution concentration was highest at point S1 and it was 5.75 Bq/m³ during the entire period, which is considered to be due to its proximity to the NPP. Tritium concentrations were relatively high, mainly along coastal areas. The effect of tritium becomes less as the distance from NPP increases. Figure 4 shows the map of daily-averag maximum contribution concentration.

Table II: Daily-average maximum contribution concentration of tritium by point of interest [Bq/m^3]

Point	2019	2020	2021	All
N1	2.89	3.61	2.90	3.61
N2	1.47	2.86	1.02	2.86
N3	0.81	1.03	0.43	1.03
N4	1.09	1.49	0.67	1.49
S1	5.75	5.07	4.56	5.75
S2	5.63	5.16	5.55	5.63
S3	3.69	3.36	5.27	3.69
S4	1.12	1.17	1.21	1.21
S5	1.84	1.02	1.05	1.84
S6	0.91	1.17	0.82	1.17
W1	2.94	2.29	2.74	2.94

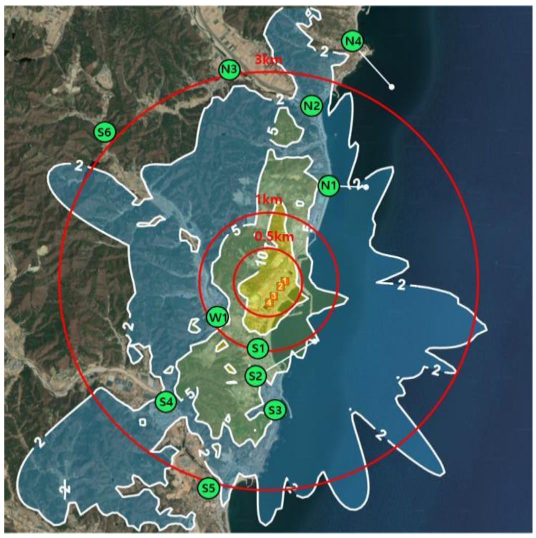

Fig. 4. Daily-average maximum concentration distribution

3.1.2 Annual-Average Maximum Concentration

Table III shows the annual-average and entire-period-average contribution concentration by point of interest. The maximum concentration was 0.51 Bq/m³ at S1 in 2019. Tritium in the atmosphere is mainly diffused in the north-south direction and in the direction of the sea, which is the leeward area of the main wind direction. Figure 5 shows the distribution of tritium in the atmosphere over the entire period (January 2019 ~ June 2021).

Table III: Annual-average maximum contribution concentration of tritium by point of interest [Bq/m^3]

Point	2019	2020	2021	All
N1	0.21	0.26	0.22	0.23
N2	0.12	0.17	0.11	0.14
N3	0.05	0.06	0.05	0.06
N4	0.07	0.09	0.06	0.08
S1	0.51	0.48	0.48	0.51
S2	0.46	0.42	0.36	0.42
S3	0.24	0.29	0.22	0.26
S4	0.10	0.08	0.08	0.09
S5	0.11	0.10	0.09	0.10
S6	0.04	0.04	0.04	0.04
W1	0.20	0.26	0.22	0.23

Fig. 5. Annual average maximum concentration distribution for each region.

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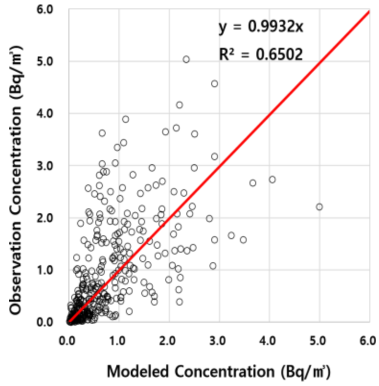
3.2 Correlation analysis

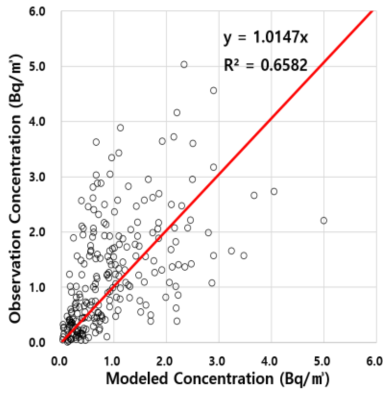
3.2.1 Coefficient of determination

Correlation between simulation results and actual measurements was analyzed. There are four actual measurement points within the Wolseong NPP site and two points outside the site. The two locations outside the site are identical to locations N1 and S2. Tritium measurement was performed regularly twice a month [1], and the reliability was evaluated by comparing the measured data with the model results on the corresponding day.

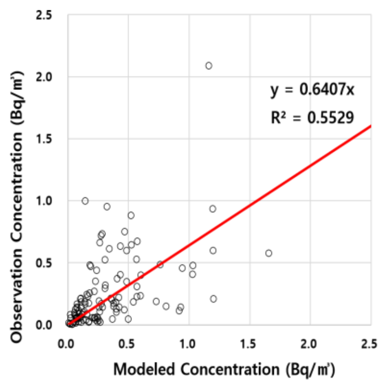
As a result of comparing the correlation using scatter plot, the coefficient of determination(R^2) was analyzed to be 0.650 for whole regions, 0.656 inside the site, and 0.553 outside the site, which is similar to or slightly better than that(0.56) from other research [3] conducted for the area around the NPP located in Tarapur India. The correlation between the measured value and the calculated value is shown in Fig 6(a), Fig 6(b), Fig 6(c).



(a) Whole areas inside and outside the site



(b) Inside the site



(c) N1 and S2 outside the site

Fig 6. Correlation between modeled predicted concentration and measured concentration.

3.2.2 Correlation with the distance from NPP

The relationship between the distance and the direction from NPP and the predicted tritium concentration was analyzed. As seen in Fig 6, the tritium concentration was corelated to the distance from the NPP. In any direction (North, South, and West), the concentration of tritium was higher as it was closer to NPP.

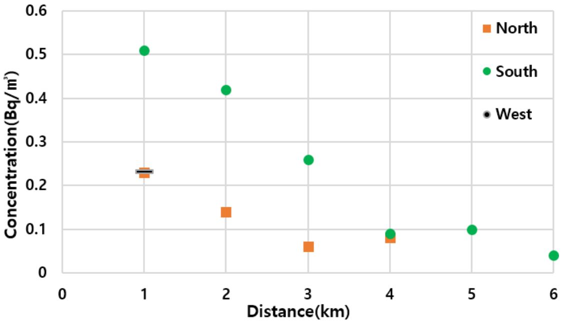


Fig 7. Correlation between distance of prediction point and tritium concentration.

3.3 Dose evaluation

The effective dose received by residents at each point was evaluated using the annual respiratory volume and dose conversion coefficient. For dose evaluation, the absorption rate and dose conversion coefficient presented in ICRP 134 were used. The dose conversion factors used in this study is 2.0E-08 mSv/Bq. At concentrations of C Bq/min in atmosphere, absorption rate through skin is 0.01 C Bq/min and absorption rate through inhalation is 0.02 C Bq/min. The total uptake rate into the human body through tritiated water in the atmosphere is 0.03 C Bq/min[4].

Effective dose values evaluated are given in Table IV. At point S1, where the entire-period-average concentration in the atmosphere is 0.51 Bq/m^3, the result of the evaluation of exposure dose through respiration was 1.61E-04 mSv, which was 0.0161% of the public dose limit of 1 mSv/yr.

Table IV: Dose evaluation result of the maximum concentration value for each point during the entire period

Point	Activity Concentration (Bq/m^3)	Effective Dose (mSv/yr)
N1	0.23	7.25E-05
N2	0.14	4.42E-05
N3	0.06	1.89E-05
N4	0.08	2.52E-05
S1	0.51	1.61E-04
S2	0.42	1.32E-04
S3	0.26	8.20E-05
S4	0.09	2.84E-05
S5	0.10	3.15E-05
S6	0.04	1.26E-05
W1	0.23	5.68E-05

4. Conclusions

Tritium in the atmosphere diffuses mainly in the north-south and seaward directions. In particular, the tritium concentration in air is high in areas mainly located in the south direction. Tritium concentrations were higher as the distance was closer from NPP, and it was corelated to the distance. It is considered that atmospheric modeling can be applied to determine the degree of dispersion of tritium in the atmosphere around Wolseong NPP. In addition, it is necessary to enlarge the tritium analysis point in the atmosphere to further clarify the reliability of the modeling.

The radiological effect on the human body was evaluated using the estimated concentration of tritium by region. It was very low compared to the allowable dose that the public can receive.

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[4] ICRP Publication 134, "Occupational Intakes of Radionuclides: Part 2", Volume 45 No. 3/4 2016.