Contamination Mapping Based on Ambient Dose Equivalent Rate Using a Drone

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***Keywords : Drone, Contamination map, Gamma ray, Ambient dose equivalent rate, G-factor**

1. Introduction

In the event of radioactive contamination resulting from nuclear accidents or acts of terrorism, it is crucial to promptly respond and visualize the contamination by accurately estimating radiation levels and assessing the dose equivalent rate. By obtaining dose rate and constructing a contamination map, the extent of radioactive material dispersion can be determined, facilitating decision support for initial response actions.

The construction of contamination maps necessitates the application of unmanned platforms to minimize individual radiation exposure, in accordance with the as low as reasonably achievable (ALARA) principle [1]. Among unmanned platforms, unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs) are being employed for contamination mapping. UGVs have a high payload capacity, allowing the integration of multiple sensors, and offer advantages in operating time and structural robustness. UAVs can rapidly acquire data over large areas through high-altitude measurements and have the advantage of unrestricted mobility in their flight path.

In this study, the energetic particle sensor for the identification and localization of originating nuclei-gamma (EPSILON-G) was mounted on a drone to obtain energy-specific count rates. Additionally, the G-factor was calculated using Monte Carlo N-Particle eXtended (MCNPX)-Polimi and applied for dose rate estimation. When obtaining dose rates using a drone, measurements are taken at flight altitude; therefore, they must be converted to the ambient dose equivalent rate at 1 meter above ground level. Therefore, hovering was conducted at various altitudes to acquire gamma-ray spectrum, and regression analysis was performed on the altitude-dependent dose rates to estimate the ambient dose equivalent rate at 1 meter above ground level.

2. Materials and Methods

2.1. Unmanned Aerial System

EPSILON-G is a gamma-ray imager independently developed by Jeju National University. It consists of a GAGG(Ce) scintillator, SiPM array, coded-aperture mask, signal processing board, gimbal camera, battery, and cooling fan. An example of the integration of EPSILON-G with a drone is shown in Fig. 1.

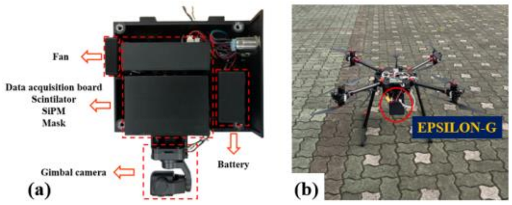

Fig. 1. (a) Components of EPSILON-G integrated with the drone, (b) constructed unmanned aerial system.

2.2. G-factor

To evaluate the ambient dose equivalent rate, the count rate and G-factor are required. The ambient dose equivalent rate can be expressed using the result of Eq. (1) [2].

$$H^*(10) = \int n(E)G(E)dE \tag{1}$$

H(10)* (μSv/hr) represents the ambient dose equivalent rate, *n(E)* (count rate, cps) denotes the energy-specific count rate, and *G(E)* is the G-factor (nSv/hr/cps), which converts the energy-specific count rate into the dose equivalent rate. To obtain the dose rate, this study employed MCNPX-Polimi for calculations. The photon energy range was set from 30 keV to 5 MeV, and energy-specific dose rate conversion factors were obtained.

2.3. Evaluation of the ambient dose equivalent rate

The ambient dose equivalent rate is calculated as shown in Eq. (1). When deriving the dose equivalent rate using the count rate obtained from the drone, the dose rate is evaluated at the drone's flight altitude. Therefore, the count rate and dose equivalent rate at the drone's flight altitude must be converted to the count rate and ambient dose equivalent rate at 1 meter above ground level.

For this purpose, a ^{137}Cs gamma source (34.942 MBq) was deployed, and hovering was performed for 30 to 200 seconds at altitudes of 1, 2, 3, 5, 7, 10 and 15 m.

Subsequently, the obtained dose rates were converted to the ambient dose equivalent rate at 1 meter above ground level through regression analysis, considering air attenuation and the inverse square law. Air attenuation effect was considered as expressed in Eq. (2), and the ambient dose equivalent rate at 1 meter above ground level was derived using Eq. (3).

$$D_{correction} = D_{xm}e^{-\mu(x-1)} \tag{2}$$

$$H^*(10) = AF(H^*(10)_{xm} - BKG) + BKG \tag{3}$$

Here, $D_{correction}$ represents the corrected dose equivalent rate, D_{xm} denotes the dose equivalent rate at x meters altitude, and μ is the attenuation coefficient. Additionally, $H^*(10)_{1m}$ represents the ambient dose equivalent rate at 1 meter above ground level, $H^*(10)_{xm}$ denotes the ambient dose equivalent rate at x meters altitude, *BKG* refers to the background dose equivalent rate, and *AF* is the altitude correction factor applied in the conversion process.

3. Result

The energy range was set from 30 keV to 5 MeV using MCNPX-Polimi, and the G-factor was computed accordingly. The calculation results of the G-factor are presented in Fig. 2, displayed on a logarithmic scale.

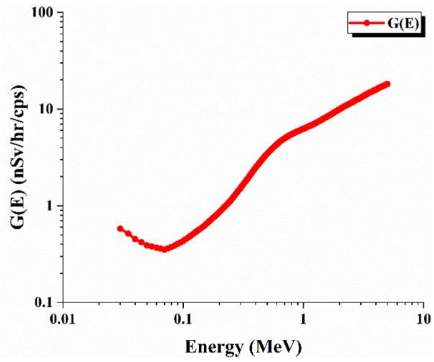

Fig. 2. The G-factor calculated through MCNP simulation for EPSILON-G.

The calculated G-factor was applied to the energy-specific count rates obtained at 1, 2, 3, 5, 7, 10, and 15 m to derive the dose equivalent rate at each altitude. The dose equivalent rates at each altitude were converted to the ambient dose equivalent rate at 1 meter above ground level by applying air attenuation and the inverse square law. The dose equivalent rates at each altitude and the ambient dose equivalent rate at 1 meter above ground level are presented in Fig. 3 and Table I.

Table I: Evaluation results of dose equivalent rates at different altitudes and the ambient dose equivalent rate at 1 meter.

Altitude (m)	$H^*(10)_{xm}$ (μSv/hr)	$H^*(10)_{1m}$ (μSv/hr)	Relative error (%)
1	3.009	3.009	0.000
2	0.967	3.194	6.146
3	0.480	3.134	4.168
5	0.216	2.858	-5.000
7	0.153	2.978	-1.023
10	0.111	3.131	4.054
15	0.085	3.038	0.962

Subsequently, a contamination map was constructed using the drone during a flight at an altitude of 3 m. The latitude, longitude, drone path, and intensity are presented in Fig. 4.

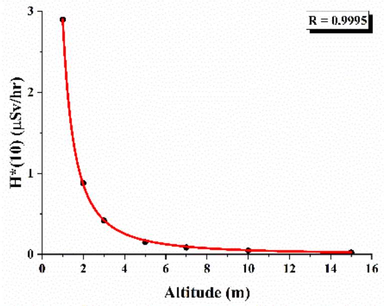

Fig. 3. Regression analysis results of dose equivalent rates at different altitudes.

Fig. 4. The contamination map represented by intensity along the flight path of drone.

4. Conclusion

In this study, a drone was utilized to evaluate the ambient dose equivalent rate and construct a contamination map. To evaluate the dose equivalent rate, the G-factor of the EPSILON-G mounted on the drone was calculated using MCNPX-Polimi simulation. After deploying the gamma source, the drone hovered at different altitudes to obtain the dose equivalent rate at each altitude. The obtained dose rates were then corrected to estimate the ambient dose equivalent rate at 1 meter above ground level.

The dose rate correction results confirmed that the error was approximately ±6%. Using the obtained altitude correction factors, future contamination mapping will be conducted by representing the ambient dose equivalent rate through drone flight path mapping.

Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS) using a financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. RS-2022-KN067110).

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