Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Algorithm for Airborne Radiation Monitoring and Environmental Radiation Survey in Fukushima

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Keywords : environmental radiation survey, airborne radiation monitoring, ground contamination, analysis algorithm

1. Introduction

Airborne radiation monitoring (ARM) facilitates the swift assessment of extensively contaminated regions with minimal personnel, rendering it effective for urgent interventions. Dose distribution maps, created from aerial survey data, prove proficient in visualizing atmospheric dose rates and ground-level radioactive contamination.

However, disparities in altitude can engender notable disparities between contamination information ascertained from airborne and ground-based sources. Therefore, implementing a calibration technique becomes imperative. This study developed an algorithm to predict ground contamination distribution and magnitudes incorporating airborne radiation monitoring data.

2. Key principles and concepts of the algorithm

The fundamental principle of the algorithm developed for analyzing ground contamination distribution is elegantly straightforward. Consider a scenario in which multiple sources of contamination are distributed across a wide area. In such instances, the dose rate in the air results from the cumulative radiation emanating from these multiple sources. As shown in Figure 1, each source contributes to the airborne dose rate with a specific contribution factor (C_i). Equation 1 shows that the airborne dose rate (Airborne_dose$_i$) can be expressed as the sum of contributions from various sources. Consequently, if the contribution of ground contamination to the airborne dose rate is ascertainable, and the airborne dose rate can be represented as the sum of the contributions from ground contamination sources, information regarding ground contamination sources from multiple airborne dose rate measurements can be deduced. Given a sufficient number of aerial survey data points, surpassing the number of contamination sources as shown in the Equation 1, the dose rate on the ground can be calculated.

The algorithm was developed in four main steps:

Step 1) Deriving the contribution of ground contamination to the airborne dose rate: This initial stage entailed establishing a relationship between dose rate and distance.

Step 2) Expressing the airborne dose rate at aerial survey points as the sum of contributions from ground contamination.

Step 3) Deriving solutions for the relationship outlined in Step 2 to analyze ground contamination.

Step 4) Converting ground dose to dose rate at 1m above ground level (1m AGL)

Step 1 involves determining the contribution of ground contamination to the airborne dose rate by establishing a relationship between the distance from the aerial survey point to the contamination source and the dose rate. The theoretical behavior of radiation adheres to the inverse square law with distance from the source. Therefore, the contribution factor for each source, denoted as $C(r) = 1/r^2$, was established.

In Step 2, the dose rate at each aerial survey point was expressed as the sum of the contributions from multiple ground contamination sources. The dose rate at each aerial survey point can be represented using Equation 1 by assuming a contamination distribution divided into grids (see Figure 1).

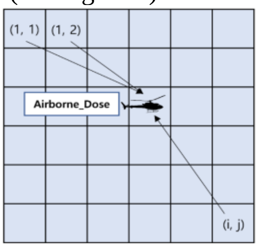

Figure 1. Example of the airborne survey in a contamination area divided into a grid pattern

Equation1

$$Airborne\_Dose_{1,1} = Dose_{1,1} \times C(r_{1,1-1,1}) + Dose_{1,2} \times C(r_{1,1-1,2}) + \cdots + Dose_{i,j} \times C(r_{1,1-i,j})$$

$$Airborne\_Dose_{1,2} = Dose_{1,1} \times C(r_{1,2-1,1}) + Dose_{1,2} \times C(r_{1,2-1,2}) + \cdots + Dose_{i,j} \times C(r_{1,2-i,j})$$

$$\vdots$$

$$\boldsymbol{Airborne\_Dose_{i,j} = Dose_{1,1} \times C(r_{i,j-1,1}) + Dose_{1,2} \times C(r_{i,j-1,2}) + \cdots + Dose_{i,j} \times C(r_{i,j-i,j})}$$

Airborne_Dose$_{i,j}$: Airborne dose rate at the aerial survey location (i, j)
Dose$_{i,j}$: Ground dose rate at ground location (i, j)
C($r_{i,j-m,n}$) : Contribution of ground contamination source (n, m) to the dose rate at aerial survey location (i, j).

As the contamination area expanded and the number of grid cells (i.e., contamination sources) increased, the number of terms in the polynomial and unknowns also increased significantly. Linear algebraic methods were employed to solve the complex polynomials.

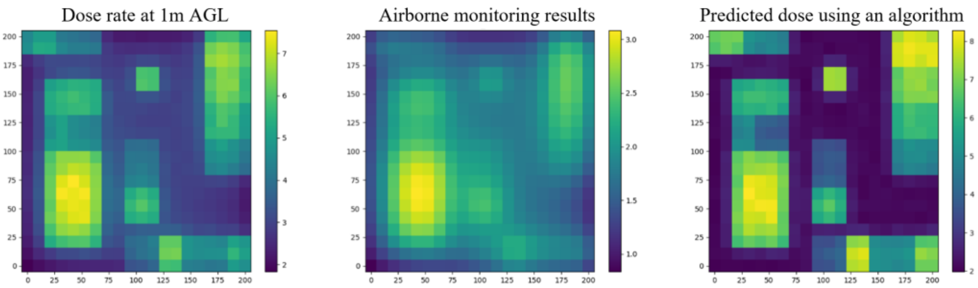

Figure 2. Dose rate at 1m AGL(left), airborne monitoring results(middle), predicted dose rate using an algorithm(right)

Polynomials cited earlier in Equation 1 can be reformulated as a matrix, as shown in Equation 2.

Equation2

$$\begin{bmatrix} C(r_{1,1-1,1}) & \cdots & C(r_{1,1-i,j}) \\ \vdots & \ddots & \vdots \\ C(r_{i,j-1,1}) & \cdots & C(r_{i,j-i,j}) \end{bmatrix} \cdot \begin{bmatrix} Dose_{1,1} \\ \vdots \\ Dose_{i,j} \end{bmatrix} = \begin{bmatrix} Airborne\_Dose_{1,1} \\ \vdots \\ Airborne\_Dose_{i,j} \end{bmatrix}$$

In Step 3, the matrix equation (Equation 2) was solved to deduce the ground dose rates (doses) using the inverse of the first matrix. The matrix equation can be expressed as Equation 3. The solution for the matrix equation was obtained by multiplying the inverse of the first matrix with the vector corresponding to the ground dose rates. This process yielded the ground dose for each location on the grid.

Equation3

$$\begin{bmatrix} Dose_{1,1} \\ \vdots \\ Dose_{i,j} \end{bmatrix} = \begin{bmatrix} C(r_{1,1-1,1}) & \cdots & C(r_{1,1-i,j}) \\ \vdots & \ddots & \vdots \\ C(r_{i,j-1,1}) & \cdots & C(r_{i,j-i,j}) \end{bmatrix}^{-1} \begin{bmatrix} Airborne\_Dose_{1,1} \\ \vdots \\ Airborne\_Dose_{i,j} \end{bmatrix}$$

In step 4, the ground dose is converted to dose rate at 1m AGL. In square surface source with 10m x 10m dimension, 1m AGL dose at the center of the contamination was derived 26% of ground dose(0m AGL) by simulation.

Both contribution factors (C) and airborne dose rate data (Airborne_Dose) were required to derive the ground contamination (Dose). Airborne dose rate data were acquired through measurements during the monitoring process. Contribution factors (C) were required for each contamination source at a single aerial survey point. Given the broad area coverage by aerial surveys, many factors were required. Additionally, the inverse of the large-scale matrix must be obtained to calculate the dose. Therefore, the proposed algorithm was implemented using Python programming language. This selection facilitated the efficient management of numerous contributory factors and the imperative matrix inversion procedure essential for dose computation.

3. Result

The MCNP code was employed to generate data for algorithm validation, encompassing the simulation of various contamination scenarios. Aerial survey data and ground dose rates were obtained via simulations to validate the performance of the algorithm. The contaminated areas were defined with 200 m × 200 m. The surface sources were simulated as rectangular shapes measuring 10 m × 10 m.

Figure 2 represents the dose rate at 1m AGL, airborne dose rate at 10m altitude, and predicted dose rate at 1m AGL using an algorithm.

4. Conclusions

This study developed an algorithm to analyze the distribution of ground-level dose rates from airborne survey data. Subsequent validation through the simulation data confirmed the effective prediction of the dose rates and distribution patterns. The predicted dose-rate distribution patterns accurately matched the real contamination patterns.

The fundamental concept underpinning the algorithm developed in this study is straightforward, accompanied by data preprocessing and application processes that avoid undue intricacies.

The algorithm was validated using simulation data. However, proactive plans are underway to further validate and enhance the performance of the algorithm by obtaining airborne survey data from the Fukushima Daiichi Nuclear Power Plant as shown in figure 3.

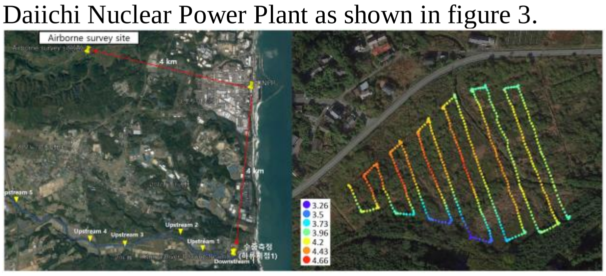

Figure 3. Airborne survey result near the FDNPP

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