The Determination of Depth Distributions of Radioactive Cesium in the Ground Using In Situ Gamma-Ray Spectrometry

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1. Introduction

In general, the depth distribution of deposited nuclides should be first determined to evaluate their radioactivities in the ground. After sampling by the depth in the ground, its analysis can make the depth profile of deposited nuclides. However, this sampling method has some drawbacks about time and cost. To overcome it, in situ measurements with specific algorithms and hardware, which means multiple photopeaks, peak-to-valley, and collimation method, have been using to estimate the depth distribution of nuclides in the ground. However, these approaches have also certain limitations, such as multiple gamma-rays from a nuclide and multiple measurements with and without collimators and lead plates.

In this study, a simple method to estimate the depth distributions of nuclides was developed by calculating the individual dose rate of detected gamma nuclides at 1 m above the ground. The dose rate spectroscopy [1-3] was then used to previously determine the individual dose rate of ^{137}Cs from the measured energy spectrum using a portable HPGe detector. In addition, theoretical individual dose rates of ^{137}Cs at 1 m above the ground were calculated by assuming several depth distributions of ^{137}Cs in the ground. The real depth distribution of ^{137}Cs was determined from the comparison between them. Finally, its radioactivity in the ground was then calculated by applying the dose conversion factor in the unit of nGy/h/Bq/m^2 in the condition of the determined depth distribution.

2. Method and Results

2.1 Depth distribution

As a parameter to determine the exponential depth profile of deposited nuclides in the ground, the parameter β, which means relaxation mass per unit area (g/cm^2), is used as shown in Fig. 1. The relaxation length, λ, means the depth with a relative source intensity of 37 % from the maximum intensity of deposited nuclide. Therefore, a parameter β is the multiplication of the relaxation length and soil density, as assuming the density of soil is constant in the ground. In general, natural radionuclides are assumed to be uniform intensity by the depth, so that they have an infinite value of β. On the other hand, the recent fallout has a zero value of β, because of its distribution only in the surface of the ground. As time passes, the value of a parameter β increases to reflect the exponential depth profile of deposited nuclides.

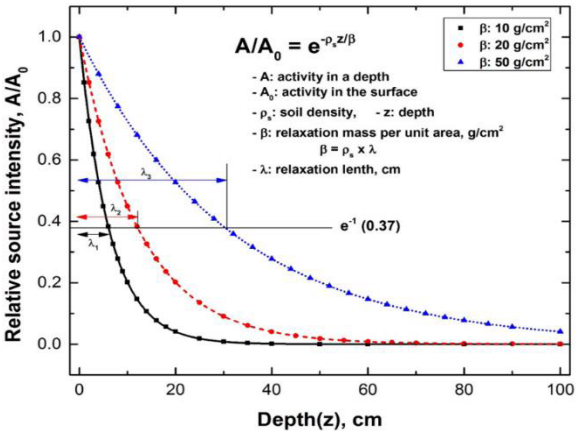

Fig. 1. The exponential depth profile of deposited nuclides.

2.2 Radioactivity and dose rate of deposited nuclides

In general, the radioactivity of deposited nuclides in the ground can be calculated from the measured count rate using in situ gamma-ray spectrometry at general 1 m height from the ground and the in situ calibration factor, as shown in Eq. (1). The dose rate due to the deposited nuclide at 1 m above the ground is then calculated from the dose conversion factor by the nuclide, as shown in Eq. (2). The in situ

calibration factor and dose conversion factor greatly depends on the parameter β, although they can be calculated from the Monte Carlo simulation. Fig. 2 shows an example of in situ calibration factor and dose conversion factor according to the parameter β.

$$A_i = \frac{(n')_E}{\left(\frac{n'}{A_\gamma}\right)_E \times \gamma_E} \quad (1)$$

$$\dot{X}_i = A_i \times d_i \quad (2)$$

where, A_i and $\dot{X}_i$ are the radioactivity in the ground and dose rate at 1 m above the ground of a nuclide, $(n')_E$ and γ_E are the measured count rate of photons with an energy E and its emission probability, $(n'/A_\gamma)_E$ is the in situ calibration factor to convert the net count rate into radioactivity, and d_i is the dose conversion factor from radioactivity in the ground to dose rate at 1 m height.

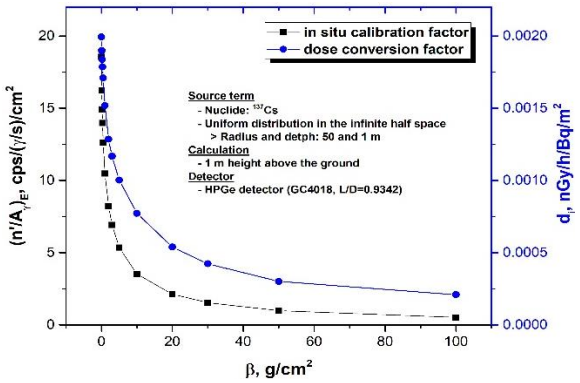

Fig. 2. The calculated in situ calibration factor and dose conversion factor of ^{137}Cs.

2.3 Determination of a parameter β

In this study, the net count rate of ^{137}Cs in the ground was first calculated, which was measured using a portable HPGe detector at 1 m above the ground in Jeju Island. From Eqs. (1) and (2), its radioactivities and dose rates according to the parameter β, as shown in Fig. 3, were calculated by applying values of in situ calibration and dose conversion factors in Fig. 2. Second, the dose rate of ^{137}Cs was then calculated using dose rate spectroscopy, by converting the measured energy spectrum for count rate into one of dose rate. The result was 1.31 nGy/h and compared with ones from Eq. (2). As a result, the parameter β of deposited ^{137}Cs in the ground was determined to be about 6.16 g/cm^2. This means the same value of dose rate of ^{137}Cs was shown at both methods in the case of selecting parameter β of 6.16 g/cm^2. Finally, the radioactivity of ^{137}Cs was analyzed to be about 1382 Bq/m^2 by using the in situ calibration factor in the condition of the determined parameter β.

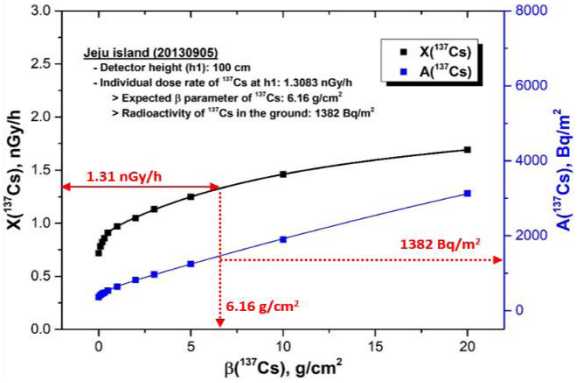

Fig. 3. The calculation of a parameter β and radioactivity of deposited ^{137}Cs.

3. Conclusion

To determine the depth profile of a deposited nuclide in the ground using in situ gamma-ray spectrometry, a simple method was developed by introducing the dose rate spectroscopy. The method was successfully applied to the measured energy spectrum using a portable HPGe detector in Jeju Island.

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