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Feasibility on the spectrometric determination of the individual dose rate for detected gamma nuclides using the dose rate spectroscopy

Young-Yong Ji *, Kun Ho Chung, Wanno Lee, Doo-Won Park, Mun-Ja Kang

Korea Atomic Energy Research Institute, Yuseong, Daejeon 305-353, Republic of Korea

HIGHLIGHTS

- A *G*-factor for converting count rates into the dose rate was calculated.
- The dose rate spectroscopy was introduced by multiplying counts and a *G*-factor.
- The peak-to-total ratio at the dose rate spectroscopy was calculated.
- Individual dose rates for detected gamma nuclides were determined at the dose rate spectroscopy.

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ABSTRACT

A spectrometric determination of the dose rate using a detector is a very useful method to identify the contribution of artificial nuclides. In addition, the individual dose rate for detected gamma nuclides from the radioactive materials as well as the environment can give further information such as the in-situ measurement because of the direct relation between the individual dose rate and the activity of a nuclide. In this study, the calculation method for the individual dose rate for detected gamma nuclides was suggested by introducing the concept of the dose rate spectroscopy and the peak-to-total ratio in the energy spectrum for the dose rate, which means just a form of multiplied counts and the value of a *G*-factor in the spectrum. In addition, the validity of the suggested method for the individual dose rate was experimentally verified through a comparison of the calculation results on the energy spectra for several conditions of the standard source.

1. Introduction

The calculation of the dose rate from the energy spectrum of a detector is a very useful method to identify whether the contribution of the artificial nuclides exists, when compared with a GM counter and an ion chamber. In addition, the radioactivity for materials can be directly estimated from the measured dose rate according to the Dose-to-Curie (DTC) conversion method (IAEA, 2007, Ji et al., 2011). Detectors have adapted a proper method to calculate the dose rate from the counts in the energy spectrum.

There are several methods used to derive the dose rate from the energy spectrum for counts owing to the radiation incident to a detector, such as the peak method and the energy band method (HASL, 1964, HASL, 1972, NCRP, 1976). The peak method can give reasonable results on the individual dose rate for several prominent gamma nuclides with the help of complicated and tedious calibration procedures with several standard sources and an ion chamber. To reduce the problems for sophisticated calibration procedure, the energy band method is generally used to calculate the dose rate from the environment only including K-40, U-238, and Th-232 series, except for the cosmic ray and artificial radiation. Since the total counts in only three energy bands such as the region of interest (ROI) representing the gamma energy of K-40, Bi-214, and Tl-208 are selected in the energy spectrum to calculate the environmental dose rate, the contribution of other nuclides cannot be determined using the energy band method.

The *G*-factor, $G(E)$, method (Cho et al., 1998, Jun et al., 1995, Terada et al., 1980, Tsutsum et al., 1991) used to calculate the dose rate from the energy spectrum is based on the fact that a *G*-factor, which means the dose rate per unit count rate in the detector, can be estimated through the detector response function based on the energy of the incident photons. Since the detector response function according to the energy of the incident photons can be calculated in any range of photon energy and in any kind of detector through a Monte Carlo simulation, the *G*-factor method has more applicability compared with the peak method and energy band methods. The total dose rate owing to environmental radiation as well as artificial gamma radiation can be calculated

* Corresponding author. Tel.: +82 42 868 4958; fax: +82 42 863 1289.
E-mail address: yyji@kaeri.re.kr (Y.-Y. Ji).

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from the measured count rate in the energy spectrum using the *G*-factor.

To make the *G*-factor method more practical, it is necessary to calculate the individual dose rate for each nuclide out of the total dose rate from the *G*-factor, as the individual dose rate for each nuclide is directly related to its activity. Introducing the dose rate spectroscopy as converting the energy spectrum for counts to that for the dose rate by multiplying the *G*-factor to counts by the energy and adopting the concept of a peak-to-total ratio at that spectrum are very effective for calculating the individual dose rate for detected gamma nuclides from the measured energy spectrum. The experimental verification for calculating this individual dose rate for detected gamma nuclides is then performed using a 3″ × 3″ NaI(Tl) detector and the standard source positioned onto a detector. As a result, the validity of the above method to calculate the individual dose rate from the environment as well as the radioactive material can then be experimentally verified through a comparison of the calculation results on the energy spectra for several conditions of the standard source.

2. Material and method

2.1. G-factor

The *G*-factor is a useful parameter to convert the count rate from the measured energy spectrum for incident photons to the detector into the dose rate owing to an energy flux of photons. Since the measured energy spectrum depends on the response function of the detector used for incident photons, the *G*-factor is directly related to it, and can be obtained from a Monte Carlo simulation.

The dose rate, $\dot{X}$, can be expressed using the *G*-factor, G_i, in the unit of μR/h/cps, as shown in (1) as well as from the relation of the dose rate to the incident photon flux, Φ_j, (Attix, 1986) to a detector, as shown in (2). In addition, the energy spectrum, n_i, in the unit of cps can also be calculated by the response function, R_{ij}, of the detector used for the incident photon flux, as shown in (3). As a result, the *G*-factor can be expressed as an inversed response matrix, as shown in (4).

$$\dot{X} = \int n(E)G(E)dE \tag{1}$$

$$\dot{X} = 65.8\left(\frac{\mu_{en}}{\rho}\right)_{air} E_j\phi_j \equiv \left(\frac{\dot{X}}{\phi}\right)_j \phi_j \tag{2}$$

$$n_i = R_{ij}\phi_j \tag{3}$$

$$G_i = \left(\frac{\dot{X}}{\phi}\right)_j R_{ij}^{-1} \tag{4}$$

where, *i* and *j* are the energy of the measured photon and incident photon in the energy spectrum, $(\mu_{en}/\rho)_{air}$ is the mass energy absorption coefficient in dry air (cm^2/g), E_j is the incident photon energy (MeV), and $(X/\Phi)_j$ is the dose rate per unit flux of incident photons with energy E_j, which also means the conversion coefficient of the photon flux into the dose rate.

2.2. Calculation of the G-factor for a 3″ × 3″ NaI(Tl) detector

In general, the detector response function depends on the detector material and geometry, as well as on the incident photon energy and direction. This means the value of the *G*-factor can be different according to the direction of incident photons to the detector even in the same detector material. The *G*-factor for the spectrometer built in a 3″ × 3″ NaI(Tl) detector in a previous study (Ji et al., 2011) was already calculated for parallel incident photons to the detector axis. Using the same method, the *G*-factor for vertical incident photons to the detector axis was calculated, as shown in Fig. 1. A slight difference between the two *G*-factors was shown, especially below 300 keV of the photon energy. However, it can be determined that the variation in the *G*-factor according to the direction of the incident photons will not much affect the dose rate, when multiplying sufficient counts to the value of *G*-factor.

2.3. Dose rate

The dose rate from the energy spectrum of a NaI(Tl) detector was calculated using the *G*-factor. First, the energy spectra were obtained from the environment and the standard sources during a 300-s measurement. Fig. 2 shows the spectrum for only environmental radiation and for environmental radiation and artificial gamma radiation such as Ba-133, Cs-137, and Co-60. The dose rate from the environment was calculated to be 14.04 μR/h from (1). The dose rate in the case of the existence of artificial nuclides in the environment accounted for 30.19 μR/h.

The dose rate from only artificial nuclides is then achieved by subtracting the former value from the latter value, and thus Ba-133, Cs-137, and Co-60 accounted for 16.15 μR/h. This method to calculate the artificial nuclide contribution to the dose rate from the energy spectrum is well known. However, this subtracted value only means the total dose rate for the artificial nuclides, and there is no information on the individual dose rate for each nuclide. Since the individual dose rate for each nuclide is directly related to their activities, it could be a very useful means to infer their activities from some radioactive material facing the detector.

2.4. Dose rate spectroscopy

To directly calculate the individual dose rate from the energy spectrum, it is very effective to convert the energy spectrum for counts to that for the dose rate, as shown in Fig. 3. The energy spectrum for the dose rate is just a form of multiplied counts and the value of a *G*-factor by the energy in the spectrum. Therefore, the integration of its spectrum indicates exactly the dose rate, which consists of environmental and artificial gamma radiation.

The peak-to-total ratio at the energy spectrum for the counts, $P(E)$, is used to calculate the total counts induced from the net peak. There, the total counts mean the detector response including all interactions with incident gamma rays from the nuclide, such as the photoelectric absorption, the Compton scattering, the pair

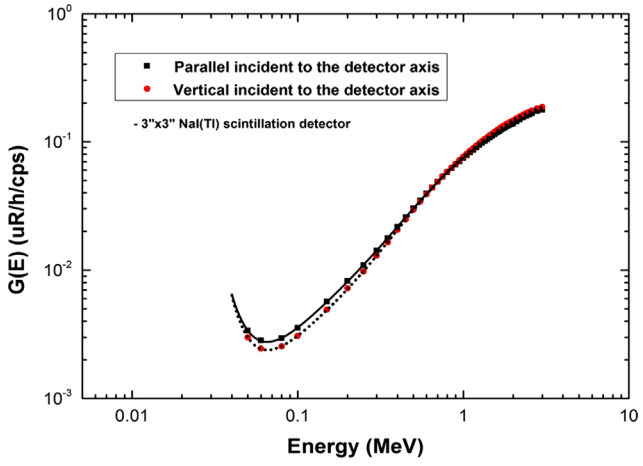

Fig. 1. The *G*-factor of 3″ × 3″ NaI(Tl) detector according to the direction of incident photons.