MONTE CARLO CALCULATION OF ACCURATE NaI(Tl) SCINTILLATION DETECTOR RESPONSE FOR GAMMA RAYS AND DETERMINATION OF SPECTRUM-DOSE CONVERSION FUNCTIONS

Kimiaki SAITO, Shigeru MORIUCHI and Masahiro TSUTSUMI
Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki-ken, Japan

1. INTRODUCTION

Sodium-iodide [NaI(Tl)] scintillation detectors are widely used for the purpose of monitoring or evaluating dose rate from environmental gamma rays. For this purpose, the reliable gamma ray response of energy up to 10 MeV is needed. Although a number of calculations and experiments have been carried out already, they do not give adequately thorough information because of inaccuracy and a lack of tests above 3 MeV.

Here, the accurate response of eight types of NaI(Tl) scintillation detector for gamma rays up to 10 MeV was calculated using a Monte Carlo method. Taking into account the detector housing and scintillation efficiency, the calculated results have been found to agree well with the experimental data.

The operation function for spectrum-dose conversion [G(E) function] was determined from the calculated response. The G(E) function, which derives the gamma dose directly from the observed pulse-height spectrum by a simple procedure, has been found a useful dosimetric method for more than 10 years in Japan(1-3). However, the reliable energy range of the G(E) function application has been limited to under 3 MeV, because of the insufficient detector response data. The present research made it possible to evaluate easily and accurately the dose from gamma rays up to 10 MeV .

2. CALCULATION OF RESPONSE FUNCTIONS

Response functions of NaI(Tl) scintillation detectors for gamma rays were calculated using a developed Monte Carlo program, MARTHA. The authors previously showed that the calculated NaI(Tl) detector response was in good agreement with the experimental data, by taking account of: 1) the detector housing around a NaI(Tl) crystal; 2) the scintillation efficiency of the crystal(4).

Consideration of the detector housing causes a decrease of total absorption peak area, and an increase of Compton continuum level in calculated response. Also, depth of the valley between a total absorption peak and a Compton edge is reduced. Consideration of the scintillation efficiency brings positional changes among a total absorption peak, a Compton edge, and escape peaks. Some calculated response functions are compared with the experimental data in Fig.1.

Using the program, MARTHA, response functions of eight types of NaI(Tl) detector (1"ϕx1", 2"ϕx2", 3"ϕx3", 4"ϕx4", 5"ϕx4" cylindrical detectors and 2"ϕ, 3"ϕ, 5"ϕ spherical detectors) are calculated for gamma rays varying in energy from 40 keV to 10 MeV.

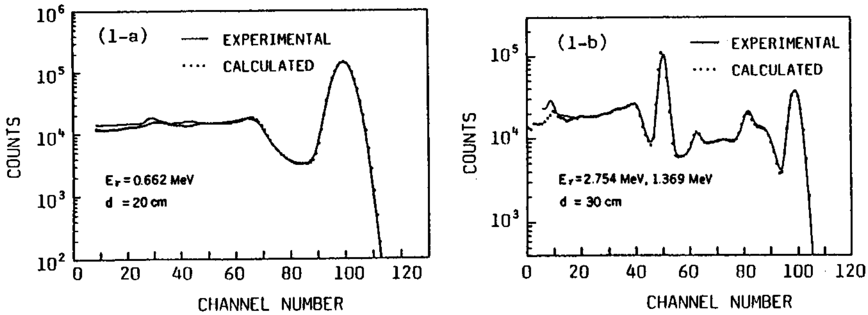

Fig.1. Comparison of calculated and experimental response functions for a 3"φx3" NaI(Tl) detector.

3. DETERMINATION OF G(E) FUNCTIONS

A spectrum-dose conversion function [G(E) function] is defined by the follwing equation,

$$\int_{E_{min}}^{E_{max}} f(E,E_0)G(E)dE = R(E_0), \tag{1}$$

where $f(E,E_0)$ is a pulse-height spectrum per one incident radiation, $R(E_0)$ is dose from a radiation with energy E_0, E_{max} is maximum energy in effective integral range, and E_{min} is minimum energy in effective integral range. Let $F(E) = \sum_j f(E,E_j)$ be the absorbed energy spectrum of a detector for certain gamma ray field, then, the total dose D from the radiation field can be easily given using the following equations,

$$\int_{E_{min}}^{E_{max}} F(E)G(E)dE = \sum_j \int_{E_{min}}^{E_{max}} f(E,E_j)G(E)dE = \sum_j n_j R(E_j) = D, \tag{2}$$

where n_j is the number of radiation with energy E_j.

In order to determine the G(E) functions, the information on $f(E,E_j)$ and $R(E_j)$ are necessary. The calculation of response function, $f(E,E_j)$, was described in sect.2. There are several choices for the value $R(E_j)$, for example, exposure, absorbed dose and dose equivalent can be selected. Here, the output of the G(E) functions is taken to be absorbed dose, and three conditions are simulated in order to estimate the absorbed dose in a human body: 1) the case where radiation equilibrium exists; 2) the case where gamma rays enter a semi-infinite slab of tissue-equivalent material perpendicularly to the surface; 3) the case where gamma rays enter isotropically a 30 cm diameter sphere of tissue-equivalent material(5).

For cases 2) and 3), simulations were carried out using a Monte Carlo calculation, on the assumption that tissue-equivalent material consists of 76.2% O, 10.1% H, 11.1% C and 2.6% N with a density of $1 g/cm^3$(5). For case 1), the absorbed dose can be calculated by a simple equation(6). Fig.2 shows the calculated dose distribution in tissue-equivalent material as a function of tissue depth in case 2). Fig.3 shows the comparison of maximum absorbed dose in tissue-equivalent material among cases 1), 2), and 3).

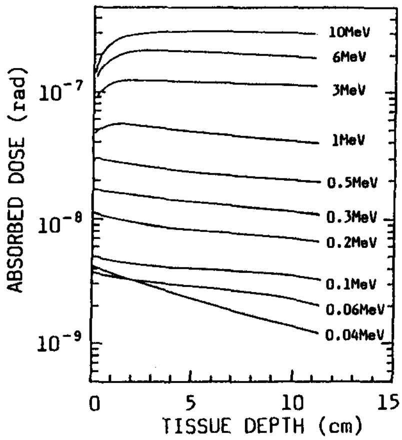

Fig.2. Calculated absorbed dose distribution in a 30 cm sphere of tissue-equivalent material. Intensity of gamma rays is 141.5 photons/cm^2.

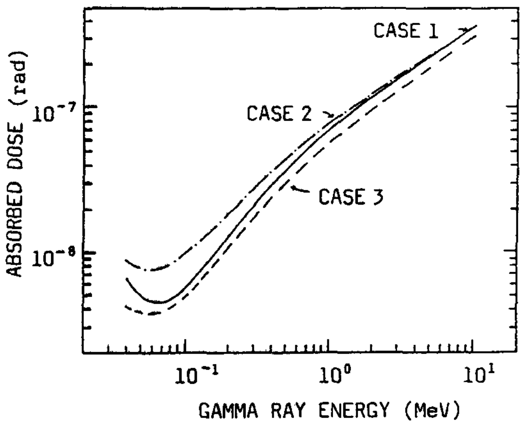

Fig.3. Maximum absorbed dose in tissue-equivalent material for case 1), 2) and 3). Intensity of gamma ray is 141.5 photons/cm^2.

For the derivation of the maximum absorbed dose, the G(E) functions of eight types of NaI(Tl) detector were determined, using polynominal fitting on the calculated results described above(Fig.4). In Fig.5, comparison of G(E) functions for a 3" x3" cylindrical detector was made among cases 1), 2) and 3). Cases 2) and 3) suppose the extreme exposure conditions of a human body to gamma radiations, and a user can select the appropriate one from the three types of G(E) function, according to the usage.

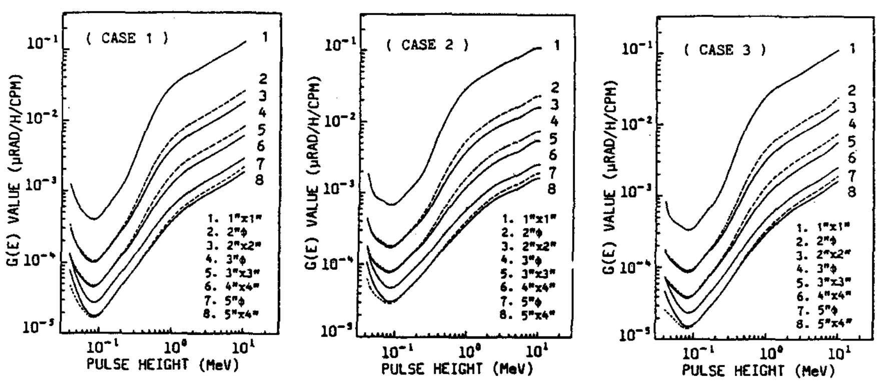

Fig.4. G(E) functions for derivation of maximum absorbed dose in a human body.

4. CONCLUSION

The accurate response functions of eight types of NaI(Tl) detectors, for gamma rays varying in energy from 40 keV to 10 MeV, were calculated making use of the Monte Carlo program, MARTHA. Maximum absorbed dose in a human body was calculated with a Monte Carlo method under three different irradiation conditions. The G(E) functions of eight types of NaI(Tl) detector were determined to derive maximum absorbed dose in a human body under the three different conditions. The dose evaluation using G(E) functions is expected to be applied to more complicated problems.

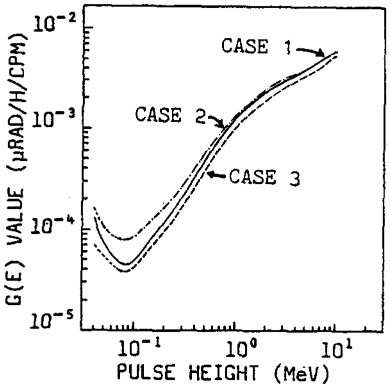

Fig.5. Comparison among three types of G(E) function for a 3"φx3" NaI(Tl) detector.

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