Verification of the modified sum-peak method in ^{134}Cs radioactive source by using Geant4 Monte Carlo simulation

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Radioactivity estimation of ^{134}Cs point source in the modified sum-peak method has been studied by using a Geant4 Monte Carlo simulation. The conversion line spectrum of gamma-rays in Geant4 has been verified in terms of the emission probabilities per disintegration. The simulation has been performed to obtain the gamma-ray spectrum of ^{134}Cs in a high purity germanium detector. The peak counts of 605 keV and 796 keV gamma emissions were chosen to calculate the radioactivity in the modified sum-peak method. The calculated radioactivity was in good agreement with that in the conventional sum-peak method and the decay rate in the simulation.

I. INTRODUCTION

Radioactivity measurement of ^{134}Cs is of concern in environmental monitoring of the Fukushima Nuclear Disaster. Since ^{134}Cs disintegrates through one or more transitions with actual gamma-ray emissions until it reaches to the ground state, the sum-peak method[1] may be applied as an absolute measurement. However, it had known that the soil sampled in Fukushima prefecture after the Fukushima Nuclear Disaster contained multiple radioactive nuclides. Therefore, the sum-peak method cannot be applied for such soil sample, because it requires the total count rate of each nuclide in addition to the peak count rates and the sum-peak count rate. Alternately, the modified sum-peak method[2] had been developed to solve the problem. It can calculate the activity by using solely the peak count rates and the sum-peak count rate.

In this paper, we verified the performance of the modified sum-peak method in the complex decay of ^{134}Cs by using a Geant4 Monte Carlo simulation[3]. The simulation was used to obtain the energy spectrum of ^{134}Cs in a high purity germanium detector (HP-Ge). Firstly, we checked the conversion line spectrum of ^{134}Cs in Geant4 in terms of the relative intensities in percent per disintegration. Secondly, the activity of ^{134}Cs point source was estimated from the energy spectrum in the sum-peak method and the modified sum-peak method, respectively. The activity in the modified sum-peak method was compared with that in the sum-peak method and the decay rate in the simulation.

II. MATERIALS AND METHODS

II.A. Sum-peak method and Modified sum-peak method

The sum-peak method can be applied to nuclides that emit more than one photon per decay. By choosing two gamma-rays in coincidence emitted from a radionuclide, the activity of the source N_0 in the conventional sum-peak method is given by:

$$N_0 = \frac{N_1 N_2}{N_{12}} w(0) + N_t w(0) = R + T, \qquad (1)$$

where N_1 and N_2 are count rates of the full absorption peaks, N_{12} is the sum peak count rate, N_t is the total count rate, and $w(0)$ is the angular correlation. The method does not require any efficiencies such as full absorption peak efficiencies and the total efficiencies.

Because N_0 is constant, T decreases inversely proportional to the square of the source-detector (S-D) distance whereas R increases. Therefore, N_0 can be obtained as the extrapolated value of R at infinite S-D distance. It is rather practical to replace the S-D distance with one of the count rates, N_1, and to apply $N_1 \rightarrow 0$ instead of infinite S-D distance. Hence the formulation of the modified sum-peak method is defined by using a novel solution N_0':

$$N_0' = \frac{N_1 N_2}{N_{12}} w(0) = R \quad (N_1 \rightarrow 0). \qquad (2)$$

II.B. Monte Carlo simulation

The Monte Carlo simulation has been performed by using Geant4 simulation toolkit, version 10.2 patch 02. The physics-list defines the physics processes in the simulation. Our physics-list includes radioactive decay physics of nuclides and electromagnetic interactions of charged particles and photon.

^{134}Cs disintegrates via β^- decay to five excited levels and to the ground state of ^{134}Ba. Gamma emissions following the beta decay in the simulation were checked by using the rdecay01 code in the extended example of Geant4 source code. The probabilities of gamma emissions per disintegration were obtained from the simulation. There were twelve conversion lines in gamma emissions. Those intensities were almost consistent with the reference data[4]. For example, the relative intensities of gamma emissions per disintegration in 605 keV and 796 keV were p_{605} =97.6 % and p_{796} =85.5 %, respectively.

The energy spectrum in a HP-Ge was obtained by modeling GMX-25190, Ortec, which is an n-type coaxial HP-Ge detector. The most of parameters of the detector were taken from the manufacture's datasheet. The diameter and height of the germanium crystal were 55 mm and 50.9 mm, respectively. The detector window enclosing the crystal consists of an aluminized Mylar film (10 um), air layer (3.0 mm) and a beryllium foil (0.5 um). The detector was placed inside the lead shielding box. A point source of ^{134}Cs were placed at a certain point along the axis of the detector. The S-D distance was varied ranging from 0.5 cm to 10 cm. The gamma-ray spectrum was collected from deposited energy in the germanium crystal. The spectra were analyzed with CERN ROOT analysis tool to compute the counts in the full energy peak area. The activity was finally calculated in the sum-peak method and the modified sum-peak method, respectively.

II. RESULTS AND DISCUSSIONS

The partition of the activity R, T, and $(R+T)$ as a function of S-D distance, and the dependence of R and $(R+T)$ on N_1 are shown in Fig. 1. The N_1 was taken from the peak counts of 605 keV. The activity in the modified sum-peak method was determined by fitting those data points with a quadratic function. Here the number of decay in the simulation was normalized to 10^4. The same analysis was repeated in the conventional sum-peak method. The calculated decay rates relative to that in the simulation were 98.11 % and 97.56 % in the conventional sum-peak method and the modified sum-peak method, respectively. However, $N_1(605)$ contained counts from the other transition path that did not coincide with the 796 keV gamma emission, and the result based on the emission rate of the 796 keV gamma-rays. Therefore, we have to multiply the calculated decay rates by a correction factor according to the emission probability, that is defined as:

$$C^{Corr} = (p_{796}/p_{605})/p_{796} = 1/p_{605}. \qquad (3)$$

By applying the correction, the deviations of calculated decay rates from the decay rates in the simulation become +0.5 % and −0.04 % for the conventional sum peak method and the modified sum-peak method, respectively. The systematic uncertainty of these calculations was estimated as 2 %, therefore the results are consistent each other.

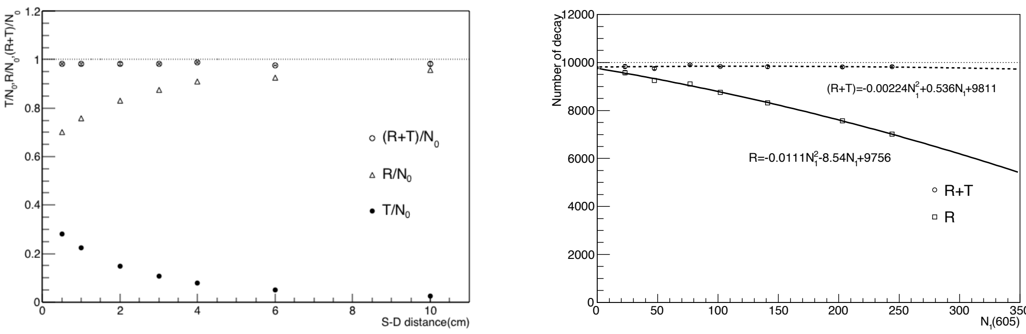

Fig.1. Partition of the activity, R, T, and $(R+T)$ as a function of S-D distance(left), and the dependences on $(R+T)$ and R on N_1 (right) of ^{134}Cs in the simulation

III. CONCLUSIONS

The activity estimation has been performed for ^{134}Cs point source in a HP-Ge detector by using Geant4 Monte Carlo simulation. The calculated activities in the conventional sum-peak method and the modified sum-peak method by choosing 605 keV and 796 keV gamma emissions were in good agreement with the number of decay in the simulation.

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