SIMULATION OF HPGE DETECTOR EFFICIENCIES BY MONTE CARLO METHODS

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ABSTRACT

The HPGe detector, being a gamma nuclide dosimeter, is generally used in the laboratory for monitoring environmental radiation. In order to maintain accuracy of the measurements, it is necessary to do regular maintenance and calibration of the dosimetry criteria for the detector. With diverse samples, the shape and volume of the containers will be different. The various sampling for the same sample might also result in large difference in the density.

Due to the limitation of the present techniques and resources in Taiwan, only important items of efficiency calibration are included in the process of HPGe detector calibration, e.g. energies, densities and sample shapes. Interpolated or extrapolated values are employed when the exact efficiency calibration data are not available. This might cause considerable errors to the sampling measurement value.

In order to reduce measurement errors and reduce experiment times consuming, this paper presents a method to calculate the peak efficiency of the HPGe detector by using the Monte Carlo code EGS4. This code has been performed to compute the gamma-ray spectrum and the influence of absolute peak efficiency with various source volumes. This study compares the theoretical calculation results with experimental data measured from the Radiation Laboratory of the Taiwan Power Company. It shows good agreement for the related cases of different source energy, source volume and source-detector distance.

INTRODUCTION

Monte Carlo methods have been developed to calculate detector counting efficiencies since the 1960’s and many related papers have been published(1-12). The EGS4 electron-gamma-shower Monte Carlo system was designed to simulate the transport problem in the photon energy range of 1 keV to thousand GeV and electron energy range of 10 keV to thousand GeV.

Following publication in 1985, the EGS4 code system(13) has been widely applied to solve various radiation problems by many research institutes. It is especially usefule for calibration of radiation counting instruments and computation of efficiency curves.

This article discusses the peak efficiency of HPGe detector by using the Monte Carlo Code EGS4. This study first measured some simple geometries of known activity radiation sources then repeatedly used the HPGe detector absolute peak efficiencies computed by EGS4 code to compare with measured values to assure the accuracy of geometry simulation. If the detailed detector’s inside geometric structure is known, in theory, any source shape, source detector configuration, detector size, and associated photon interaction can be simulated over the entire energy interval of interest by using the Monte Carlo method. If an unusual shape source is employed, this simulation method will save much effort and time to attain detector peak efficiency. In this article, we will illustrate how to set up up the computing model of the Monte Carlo code

EGS4 and compare this theoretical calculation results with experimental data from the Radiation Laboratory of the Taiwan Power Company.

MATERIALS AND METHODS

This study compared the EGS4 calculation results with experimental data measured by an HPGe detector (coaxial,GI-538) peak efficiency from the Radiation Laboratory of the Taiwan Power Company. Three radionuclide standard sources used are: a Eu-152 point source, a 200 cm^3 cylindrical volume source and a 500 cm^3 cylindrical volume source. The experiment data analyzed by the computer program SPECTRUM-AT. The Eu-152 point source was made on Oct. 4, 1989 and its activity is 0.11 mCi. The 200 cm^3 cylindrical volume source was made on Jan. 14, 1993 and its activity is 0.219 mCi. 500 cm^3 The cylindrical volume source was made on Feb. 2, 1996 and its activity is 0.7728 mCi. The half life of Eu-152 is 13.6 years.

This simulating procedures of EGS4 are described as follows:

(1) geometry model:

The EGS4 simulation refers to the HPGe detector dimension in the Radiation Laboratory of the Taiwan Power Company and is shown schematically in Figure 1. This geometry model is composed of seven cylinders and nine planes, and divided into fifteen regions. Region 10 and region 11 are the detector active volumes and region 15 is the source region. If the radionuclide standard is a point source, region 15 shrinks to zero.

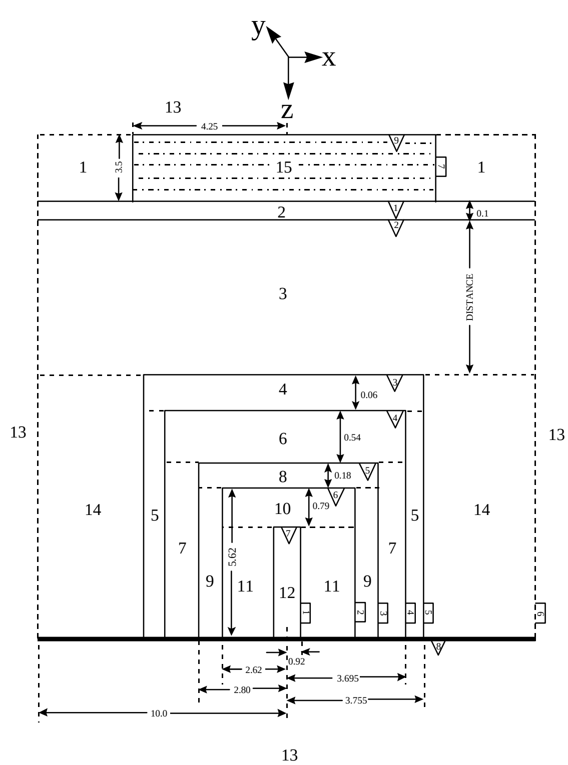

Figure 1 Geometric configuration of the source-detector arrangements for EGS4 simulation.

(2) determination of incident particle classes:

In EGS4 simulation, the definition of photon, electron or positron is determined by the particle's charge. Particle with charge 0 are photons, with charge -1 are electrons and with charge +1 are positrons. This study uses a Eu-152 γ-ray source, thus the incident particles are all photons.

(3) determination of incident particle energy :

Because the detector efficiency is a function of incident photon energy, we have to take the individual photon energy into account. When a Cs-137 radionuclide is used, its single energy is 662 keV. If a Eu-152 source is used, we should choose eleven peak energies: 121.8 keV, 244.7 keV,344.3 keV, 411.1 keV,444.0 keV, 778.9 keV, 867.3 keV, 964.0 keV, 1085.8 keV, 1112.0 keV and 1408.0 keV.

(4) determination of incident particle position :

As shown in Figure 1, the incident particles in the source region (region 15) are in homogeneous distribution. Thus we can choose a incident photon randomly, and its position could be obtained through equation (1):

$$\begin{aligned} q &= x_1 \bullet 2p \\ Xin &= \sqrt{x_2}\, R_7 \bullet \cos q \\ Yin &= \sqrt{x_2}\, R_7 \bullet \sin q \\ Zin &= Z_9 + x_3 \bullet (Z_1 - Z_9) \end{aligned} \qquad (1)$$

where $\xi_{1,2,3}$ are random numbers; R_7 is the source radius; Z_1 is the Z-coordinate of source bottom and Z_9 is the Z-coordinate of source top.

(5) determination of incident particle direction:

Because the source particle emissions are isotropic, angular biasing was used in order to speed up the computation. We count only those source points with the direction that may intersect the detector's active zone. A schematic representation of the subtended solid angle for various source positions is depicted in Figure 2, and the incident direction can be derived as follows :

$$q_{max} = \tan^{-1}\left(\frac{\sqrt{Xin^2 + Yin^2} + R_3}{h}\right)$$

$$\begin{aligned} q &= \cos^{-1}\left[(\cos q_{max} - 1) \bullet x_4 + 1\right] \\ f &= x_5 \bullet 2p \end{aligned} \qquad (2)$$

where $\xi_{4,5}$ are random numbers; R_3 is the detector crystal radius; the azimuthal angle q is from 0 to q_{max} and the polar angle f is from 0 to 2π. The direction cosines can be expressed as :

$$\begin{aligned} a &= \sin q \cos f \\ b &= \sin q \sin f \\ g &= \cos q \end{aligned} \qquad (3)$$

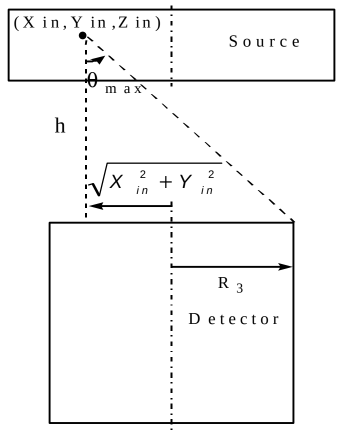

Figure 2 Schematic representation of the proposed mathematical algorithm of the subtended solid angle.

(6) determination of incident region:

The incident region is region 15 in Figure 1.

(7) calling EGS4 subroutine SHOWER:

This process inputs the parameters of incident particle which are mentioned above into the subroutine SHOWER of EGS4 code for tracing the particle transport. SHOWER can trace the sampling particles up of energy below the cutoff energy or outside of the defined region.

(8) collecting the deposited energy in the active zone :

The peak efficiency was obtained by counting the number of full energy interactions in the detector crystal. Because of the use of the angular biasing technique, the weighting factor for each source point must be considered and given by:

$$w = \int_0^{2\pi} d\phi \int_0^{\theta_{max}} \sin\theta d\theta / 4\pi \qquad (4)$$

RESULTS AND DISCUSSION

For a Eu-152 point source at various source-detector distance, the comparison of absolute peak efficiency curves between theoretical and experimental values are listed in Table 1. Figure 3 and Figure 4 present the results of using 200 cm^3 and 500 cm^3 cylindrical volume source, respectively. As shown in Table 1, the differences between EGS4 theoretical values and experimental values are under 10%, and it shows good agreement for the related cases of different source energy, source volume and source-detector distance. For the EGS4 simulation, the percentage standard deviation for each value is 1% or less.

Table 1 Efficiency comparison, theoretical vs. experimental for point source at three source-detector distances.

	5 cm			10 cm			20 cm		
Energy (keV)	Theoretical	Experimental	Errors(%)	Theoretical	Experimental	Errors(%)	Theoretical	Experimental	Errors(%)
121.8	2.37E-2	2.44E-2	-2.87	8.08E-3	8.67E-3	-6.81	2.35E-3	2.60E-3	-9.62
244.7	1.69E-2	1.59E-2	6.29	6.04E-3	5.94E-3	1.68	1.84E-3	1.87E-3	-1.60
344.3	1.22E-2	1.19E-2	2.52	4.43E-3	4.45E-3	-0.45	1.36E-3	1.39E-3	-2.16
411.1	1.02E-2	1.03E-2	-0.97	3.72E-3	3.98E-3	-6.53	1.16E-3	1.24E-3	-6.45
444.0	9.51E-3	9.66E-3	-1.55	3.48E-3	3.74E-3	-6.95	1.07E-3	1.16E-3	-7.76
778.9	5.64E-3	5.59E-3	0.89	2.10E-3	2.13E-3	-1.41	6.55E-4	6.74E-4	-2.82
867.3	5.11E-3	5.01E-3	2.00	1.90E-3	1.92E-3	-1.04	5.99E-4	6.08E-4	-1.48
964.0	4.70E-3	4.51E-3	4.21	1.75E-3	1.74E-3	0.57	5.50E-4	5.52E-4	-0.36
1085.8	4.24E-3	4.04E-3	4.95	1.59E-3	1.57E-3	1.27	5.02E-4	4.98E-4	0.80
1112.0	4.17E-3	3.96E-3	5.30	1.56E-3	1.54E-3	1.30	4.92E-4	4.89E-4	0.61
1408.0	3.34E-3	3.32E-3	0.60	1.27E-3	1.29E-3	-1.55	4.03E-4	4.10E-4	-1.71

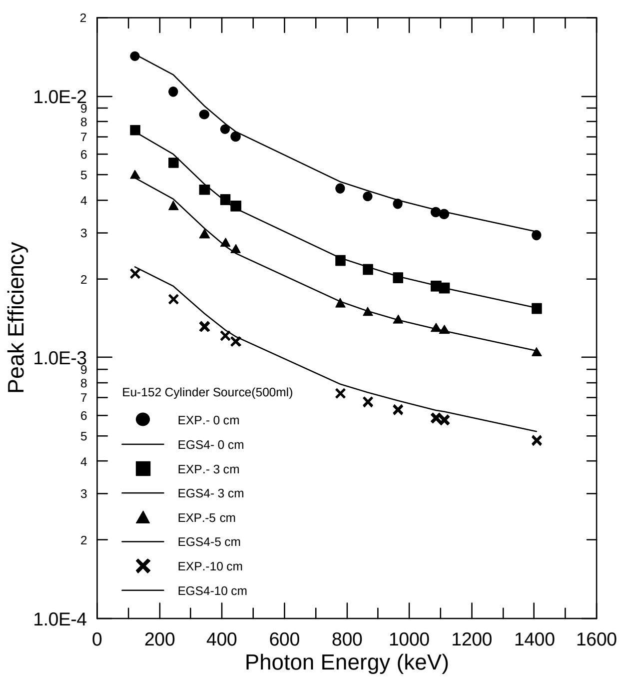

Figure 3 Efficiency comparison, theoretical vs. experimental for 200 cm^3 cylindrical volume source at three source-detector distances.

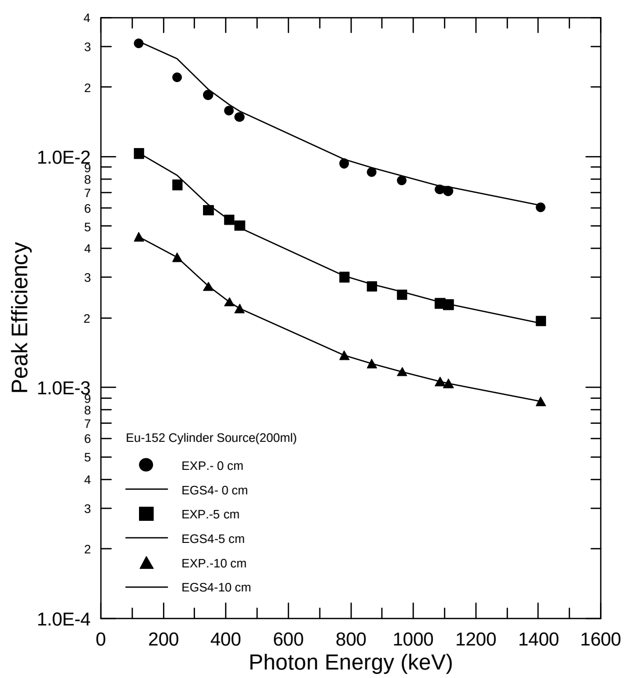

Figure 4 Efficiency comparison, theoretical vs. experimental for 500 cm^3 cylindrical volume source at four source-detector distances.

This study was also made comparisons between EGS4 simulations and actual measured HPGe detector gamma ray pulse height spectrum. Figure 5 and Figure 6 show measured Cs-137 and Co-60 pulse height spectra overlapping a simulation, respectively. In EGS4 simulation, pulse height spectrum counted the number of full energy interactions in the detector, with the peak width broadened to account for Gaussion distribution.

On the basis of this comparison, simulation with the EGS4 code corresponds to measurement if the detector and source configuration can be modeled. The extension of the study to the unusual shape source is to be conducted in the near future.

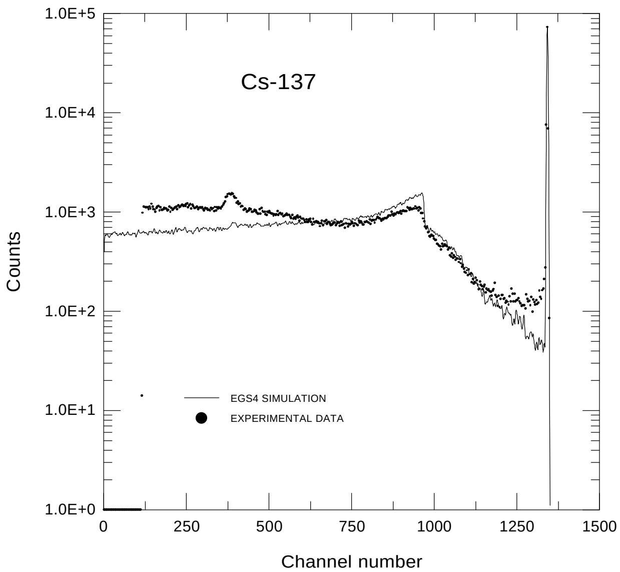

Figure 5 Measured Cs-137 point source pulse height spectrum overlapping a simulation at 10 cm source-detector distances.

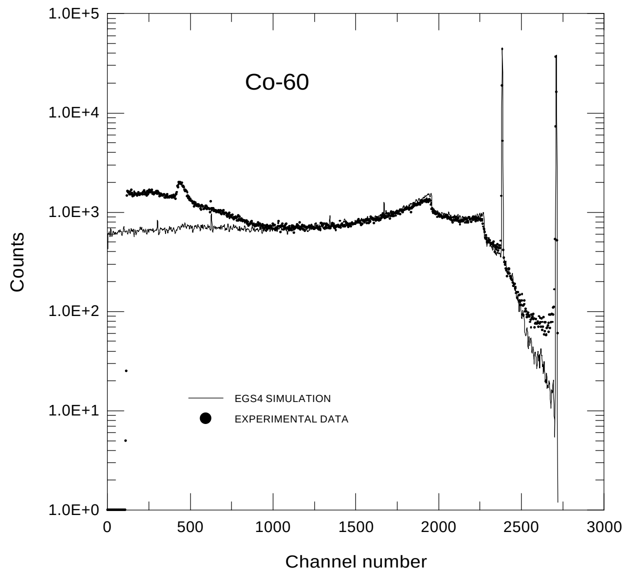

Figure 6 Measured Co-60 point source pulse height spectrum overlapping a simulation at 10 cm source-detector distances.

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KEY WORDS

HPGe Detector, Monte Carlo, gamma, dosimetry, spectrum, absolute peak efficiency.