Kasetsart J. (Nat. Sci.) 41 : 198 - 202 (2007)

Calibration of HPGe Gamma-Ray Planar Detector System for Radioactivity Standards

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ABSTRACT

Quantitative analysis of radioactive materials using efficiency calibration of gamma ray high purity germanium planar detector system has been studied. Seven standard sources including Eu-152, Ba-133, Ag-110, Ho-166, Cs-134, Cs-137 and Co-57 were used for calibrating incident gamma ray energy to memory channels obtained by the new multi-channel analyzer which have been observed in the energy ranges from 25 to 1240 keV. The general equation of efficiency curve with varied source-to-detector distance obtained at high energy range has shown up to 3% of uncertainties, k=2 when compared to low energy range of uncertainties up to 30% at 95% confidence interval when the dead time effect was also mentioned and corrected.

Key words: HPGe, Gamma-spectrometry, efficiency calibration

INTRODUCTION

The high purity germanium (HPGe) spectrometer is used for analysis of environmental sample and determination of radioisotope concentration due to its excellent resolution. This detector has better characteristics and more sensitive to the detection of impurities (Attix, 1986). However, when more precised quantitative results of any level of source activities are needed, the efficiency calibration with varied distance to adjust the flux density is needed. This is so called a general equation of the efficiency along the useful energy ranges of the system (Helmer, 1994).

To solve this problem, firstly, the pulse height scale must be calibrated in terms of gamma ray energy if various peaks in the spectrum are properly identified. In many routine applications, if the gamma rays expected to appear in the spectrum are well identified in advance, the corresponding peaks can readily be identified by inspection. The next approach to solve the calibration problem is to measure all reference radioactive sources to obtain efficiency for each energy over the whole region (Haralamble *et al*., 2004). For efficiency calibration, one can use any source with known nuclide activity and gamma emission probability. But in this case, not only the accuracy of the activity was standardized, but also the uncertainties arising from the emission probability was evaluated with stamped percent dead time. To determine the energy dependence of the detector efficiency, a set of several reference gamma ray sources is needed to cover the energy ranges of interest (IAEA, 1991; Sima *et al*., 2001; Sima and Cazan, 2004).

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In this research a simple and general method for γ-ray efficiency calibration of HPGe detectors was tested and compared with the empirical formula. This could effectively predict the efficiency of a detector at any source-to-detector distance. The method is based on the use of full-energy-peak efficiency, i.e. the ratio of the counts in the full energy peak to the number of the corresponding gamma rays emitted by the source. The combination of sources has been selected to minimize the sum-peak effects but allow the escape peaks due to the configuration of geometry.

MATERIALS AND METHODS

The gamma spectrometer EG&G ORTEC System consists of a p-type HPGe detector (Model GLP-36360/13S, crystal diameter 36 mm) with 0.254 mm Beryllium window thickness. The transistor reset preamplifier was placed inside the detector capsule and the crystal was cooled by liquid nitrogen from the vertical dipstick cryostat (Model SD-GLP-S). The integrated signal processor consists of a pulse height analysis system to transform pulses at any energy, which were collected and stored by a computer-based MCA (DSPEC) into number for all 16,384 memory channels corresponding to energy range when high voltage supply was fixed at -1000 volts. No active background or lead shielding has been used. GammaVision-32 V 3.2 Gamma-Ray Spectroscopy Software, a graphical user interface that was ideal for manipulation and analysis of spectra with a personal computer was used. The 7 reference sources for the experimental calibration were: Eu-152, Ba-133, Ag-110, Ho-166, Cs-134, Cs-137 and Co-57. The test sources for validating the result equations comprised of the following radionuclides: Ce-139, Co-60, Co-57, Cr-51, Cs-134, Cs-137 and Y-88.

An efficiency calibration of the HPGe gamma spectrometry was done using 7 different radionuclides which cover the full energy ranges and fall under three different geometries by fixing the source-to-detector distances to be 26.07, 19.47 and 12.87 cm. The uncertainty of the reference source certificate was about 3-5 %. The full-energy-peak efficiency is defined as

$$\varepsilon\left(E_\gamma\right) = \frac{N_\gamma}{N_s} \cdot f = \frac{N_\gamma}{t_r p A_0} \cdot f \qquad (1)$$

where N_γ is number of counts in the photo-peak, and is number of photons emitted from the source. The other terms describe themselves as A_0, the activity of the source on the reference date, p is branching ratio corresponding to the energy E_γ, f is correction function and t_r denotes the real time taken for each successive measurement.

As mentioned before, in routine analysis, Gamma Vision V3.2 and a distinctive table of calibration parameters are peak energy versus channel relationships, dependence of relative efficiency on peak energy (efficiency curve) and table contains peak shape parameters. The calibration library contains energy and intensity data used for energy-channel and efficiency calibrations. In principle, an automated calibration procedure for establishing the efficiency curve is also possible. Each reference peak can be associated with the closest library line within a given tolerance. In particular for the detector efficiency (ε), the calibration library must contain nuclide activity; fraction of gamma ray decays yielding corresponding to each library peak and relative uncertainty of the stated activity (Sima and Cazan, 2004; Ludington and Helmer, 2000).

RESULTS

Logarithm of the full energy peak efficiency was plotted against logarithm of the gamma ray energy to relate the detection efficiency of the HPGe detector system as a function of energy. The plotted data was split into a low energy

(25-121 keV) region and high energy (121-1240 keV) region, which was fitted by a 3rd order polynomial and power function given by Equation (2) and Equation (3), respectively.

$$\varepsilon\left(E_\gamma\right) = \sum_{i=0}^{3} a_i E^i \quad (2)$$

$$\varepsilon\left(E_\gamma\right) = aE^b \quad (3)$$

where $\varepsilon\,(E_\gamma)$ is efficiency corresponding to the energy , E is the gamma ray energy while a_0- a_3, a and b are the fitted parameters.

The efficiency calibration curves at 3 different source-to-detector distances of 26.07, 19.47 and 12.87 cm are presented in Figure 1. Efficiency curve which normalized source-to-detector distances is shown in Figure 2.

From Equation (1) and results in Figure 1 and Figure 2, correction function (f) obtained by the formula:

$$f = \frac{1}{(S-D)^2} \quad (4)$$

Table 1 showed the curve - fitted parameters of Equation (2) and. Equation (3) with different source-to-detector distances and their corresponding uncertainty at 95% confidence interval. It was found that total uncertainty of the system was 3% at high energy range and 30% at low energy range.

The accuracy of the efficiency calibration has been verified using several sealed-ampoule sources previously used in the intercomparison project at National Standard Radioactivity Laboratory, Office of Atom for Peace (NSRL, OAP). The results compared with the reported values by NSRL are shown in Figure 3.

CONCLUSION

Since natural ageing and radiation damaging processes modify the detector sensitivity with time, each laboratory should have its own calibration sources. In this research, a general and simple direct method for γ-ray efficiency

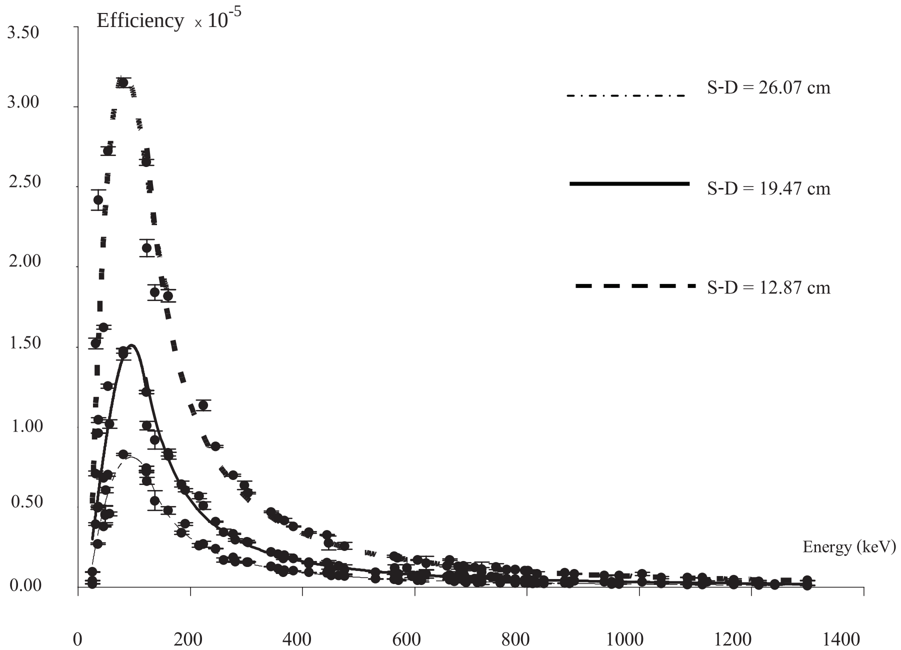

Figure 1 Efficiency as a function of energy (keV).

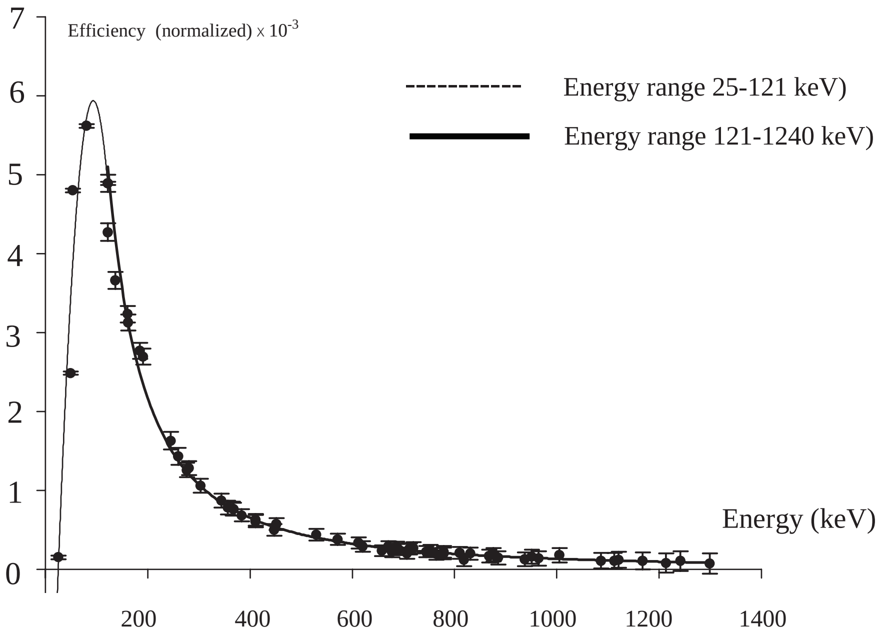

Figure 2 Efficiency curve normalized by different source-to-detector distances.

Table 1 The curve-fitted parameters of equation (2) and equation (3).

S-D (cm)	Parameters							
	a_0	a_1	a_2	a_3	U*	a	b	U*
26.07	-5×10^{-6}	-2×10^{-9}	3×10^{-7}	3×10^{-12}	7.45	0.0365	-1.7684	1.62
19.47	-4×10^{-6}	3×10^{-7}	-8×10^{-10}	-2×10^{-11}	22.90	0.0599	-1.7559	1.98
12.87	-3×10^{-5}	2×10^{-6}	-2×10^{-8}	4×10^{-11}	40.20	0.135	-1.7697	2.23
All S-D	4.8×10^{-3}	3×10^{-4}	-2×10^{-6}	3×10^{-9}	29.69	17.675	-1.7129	2.94

U* is the total uncertainty at 95 % confidence interval.

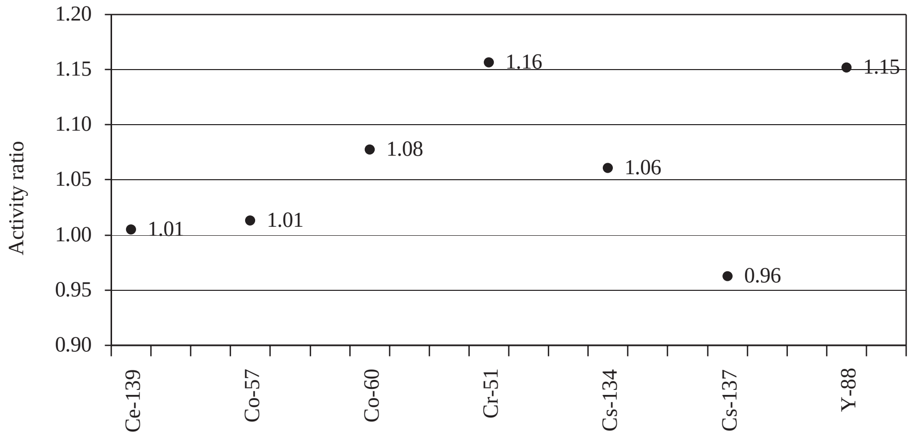

Figure 3 Ratio of measured values and the certified values by the NSRL, OAP.

calibration of HPGe detector system for empirical formula was evaluated. It could effectively predict the efficiency of a detector at any source-to-detector distance. Reference standard sources which cover the energy range are important for efficiency calibration. If the efficiency curve at low energy region is important, selecting proper standard sources as decay gamma ray at low energy range is needed. The statistical error of the efficiency curve can be improved by using longer counting periods if dominant. On the other hand, the point sources are ideal for calibration instead of small voluminous sources.

When the reference volume radioactive source acts as a point source, the emitted photons reach on a detector surface is such that the intensity is inversely proportional to the square of its distance from the source. Radiation spreading out radically covers a bigger and bigger area, proportional to r^2 (Attix, 1986), so its intensity decreases as $1/r^2$. The geometry arrangement should prevent the scattering gamma to be detected by the detector. This calibration method can be used for quantitative analysis of any other radioactive sources.

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