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A Technique of Efficiency Calibration of HPGe Detector

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ABSTRACT

In this work, a technique for the determination of efficiency calibration of hyper-pure germanium detector was obtained using four different concentrations of KCl in Bq/l for different geometrical configurations. The relative intensities of Gamma-rays from ^{226}Ra with its Gamma-Emitting daughters *were used* in addition to the normalizing factor relative to the intensities of gamma-rays photo peaks. The results of this method were compared to standard samples of IAEA-373 and they were found to be in good agreement.

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1. Introduction

The calibration of any detector system refers to the instrument response to a known amount of radioactivity. A source prepared from a calibrated solution must exactly match the form and physical dimensions of the sample to be measured in the system, most often precipitates or electrodeposited samples. The calibration solution should be certified reference material (CRM) or standard reference material (SRM) purchased from a recognized institution such as the National Physical Laboratory (NPL), the Commissariat al'Energie Atomique (CEA) or the National Institute of Standards and Technology (NIST). Since these institutions do not have all the radionuclides of interest at hands at all times, commercial vendors proven to perform accurate measurements through a program of traceability to a national institute do provide a limited range of radionuclide standard solutions. In some cases, appropriate calibrated electrodeposited sources are also available from the institutes and venders.

It must be emphasized that the certified reference solution or source does change with time. These changes may be caused by handling or storage conditions, the decay of the radionuclide or buildup progeny. Most concerns are the handling and storage conditions of radionuclide solution and guidance in this area has been provided by several organizations. Electrodeposited sources are most often subject to damage during handling. In any case, solutions and sources should be replaced or recalibrated on a regular schedule, preferably once a year to eliminate biases in calibration.

Several theoretical efficiency calibration methods are in use today. It is recommended, however, that efficiency calibration is determined experimentally for environmental measurements even though this method is time-consuming. Practical calibration standards must be prepared for each counting configuration from appropriately certified radionuclides. The composition of the standard should approximate as closely as possible, with respect to intensity and attenuation factors, to actual samples to be analyzed. The volume and/or height within each configuration must be the same for standards and sample (ICRU, 1972).

The task of accurate determination of the absolute efficiency of gamma spectrometers is of great importance, especially in the low-level measurements of environmental samples. The usage of different gamma sources for establishing the efficiency curve of detectors leads to wide dispersion, which arises mainly due to specific factors:

(i) *Geometry variation of different sources geometry configuration source-detector.*

(ii) *Uncertainties of the source strength.*

The use of a single standard source with gamma-lines covering wide energy range eliminates the influence of the second factor. The first factor is eliminated by using a right cylindrical hyper-pure germanium (HPGe) detector because of the detector constancy of angular response for energies higher than 200 keV (ICRU, 1972).

2. Materials and Methods

In the present work a hyper-pure germanium detector was used, it is coaxial of vertical configuration and consists of preamplifier, a linear amplifier, an analog - to - digital converter (ADC), and a multi-channel pulse height analyzer. The efficiency curve of HPGe detector was constructed through two stages; both in the energy range from 186 keV to 2450 keV. In stage one the relative efficiency curve of the detector was carried out using ^{226}Ra point source, where the most intensive gamma-ray lines resulting from its decay in equilibrium with its respective progeny have been used (Hossain *et al.*, 2012). In stage two, the average relative efficiency curve for the detector was normalized to an absolute curve for a certain geometrical configuration. Different types of Marinelli type beakers made of plastic adapted to the shape of the shielding and detector in the laboratory with suitable capacities were used, (ORTEC, 2012)

In this study, the normalization was carried out using four different concentrations of KCl for each geometrical configuration (El-Tahawy *et al.*, 1992). The concentrations that had been used were $16g/l$, $32g/l$, $64g/l$, and $128g/l$, which corresponds to 261.8 Bq/l, 532.6 Bq/l, 1047.2 Bq/l, and 2094.4 Bq/l respectively. This work was carried out at the Central Laboratory for Environmental Radiation Measurements of the National Center for Nuclear Safety and Radiation Control (CLERM) of the Atomic Energy Authority of Egypt (AEA).

3. Results and Discussion

The most intensive gamma-ray lines resulting from its decay in equilibrium with its respective progeny have been used. The photo

peak relative efficiency at certain energy was obtained from the formula, (Farouk *et al.*, 1982)

$$\eta_{rel}(E) = \frac{I_d(E)}{I_{rel}(E)} \quad (1)$$

where $\eta_{rel}(E)$ is the relative efficiency at the energy transition E, $I_d(E)$ is the relative intensity measured by the detector for the photo peak with energy E, and I_{rel} is the reference relative intensity of the same photo peak.

The relative efficiency curve for the detector was obtained using 18 different energy values covering the entire energy range needed in most-low level measurements of environmental samples. The source was placed at two different positions, first, when the source placed coaxially at 10 cm distance from the top surface of the detector, and second when the source was placed in the detector side at the same distance. The relative efficiency curve was plotted for both source positions. It was found that the two curves within a good approximation coincide in the energy range between 290 keV and 2450 keV. A slight difference was found at energies less than 290 keV. An average fitting curve was made using both results as shown in Fig. 1. The relative efficiency of the hyper-pure germanium detector corresponding to any photo peak energy could be then obtained using this curve.

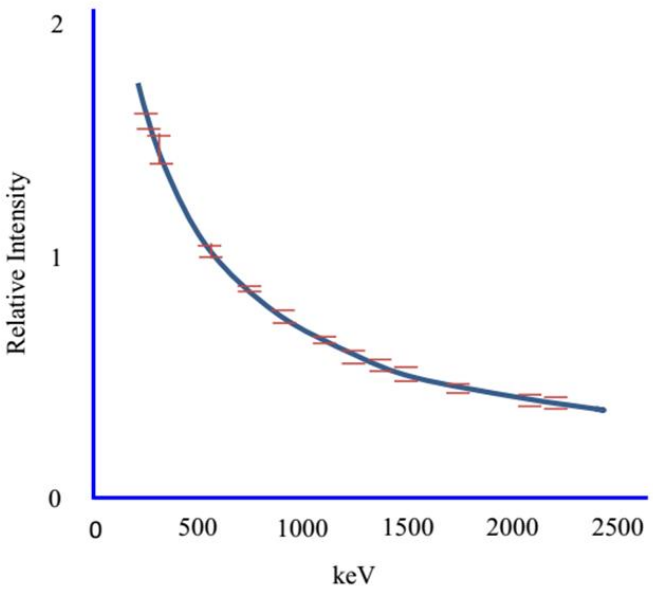

Fig. 1. The relative efficiency curve for standard Ra-226 point source of HPGe detector.

Radioactive potassium-40 exists naturally with the stable potassium-39 and its natural abundance is 0.0117%, (ICRU, 1972). So using natural potassium one can calculate exactly the amount of radioactive nuclei of K-40 in the sample, one also can determine exactly the specific activity of K-40 in any chemical form consisting of natural potassium. Pure KCl is an excellent low-level reference source in many respect, environmental low-level specific activity, wide availability at high purity and relatively simple branching decay. KCl has been used by others (Wollenberg and Smith, 1964, Harb *et al.*, 2008) as low-level standard source for efficiency calibration of gamma-ray spectrometer in measuring large volume of low specific activity materials (ICRU, 1972).

Using these activities, a normalizing factor for each measuring geometry can be determined. The normalizing factor for any radionuclide was calculated relative to the intensities of gamma-ray photo peaks of this radionuclide and that of potassium as well as the percentage of photon per disintegration which is provided by the (IAEA, 1989) see Table 1 (Farouk and Al-Soraya 1982).

Table 1

Sources spectra used for the calculation of the U-238 series, Th-232 series, K-40, and Cs-137

Isotope	$T_{1/2}$	Energy (keV)	Intensity (%)
K-40	$1.28 \times 10^9\ y$	1460	10.50
Cs-137	30.5 y	661.6	85.00
Pb-214	26.8 min	351.9	37.3
Bi-214	19.7 min	609.3	46.3
Bi-214	19.7 min	1120.3	15.0
Bi-214	19.7 min	1764.5	16.0
Ac-228	6.1 hr	338.4	12.0
Tl-208	3.1 min	583.0	30.9
Ac-228	6.1 min	911.1	29.0
Ac-228	6.1 min	968.9	17.0

The normalized factor for the radionuclide (Y) is given by:

$$N.F(Y) = \frac{[R.E(1460keV) \times P.D(K) \times N.F(K)]}{[\,R.E(Y) \times P.D(Y)\,]}$$

where, R. E (1460 keV) is the relative efficiency of K-40, P.D(K) is the percentage of photon per disintegration of K-40, N.F(K) is the normalizing factor of K-40. R.E(Y) is the relative efficiency of the radionuclide (Y) and P.D(Y) is the percentage of photon per disintegration of the radionuclide (Y). This equation can be used only if: {R. E (1460 keV), P.D(K), N.F(K), R.E(Y) and P.D(Y) .} are provided after any environmental sample measurements**.**

The gamma transitions of 351.99 keV (Pb-214) 609.3 keV (Bi-214) 1120.3 keV (Bi2-214) and 1746 keV (Bi-214) were used to represent U-238 series. The gamma transitions of 338.4 keV (Ac-228), 583 keV (Tl-208), and 911 keV (Ac-228) were used to represent Th-232 series. The branching ratio of each peak was taken into account in the activity calculations. The spectrum of these transitions along with energy calibration 1 keV per channel is shown in Figs. 2a & 2b (Cant and Jacquemin, 1990; Daraban *et al.*, 2013).

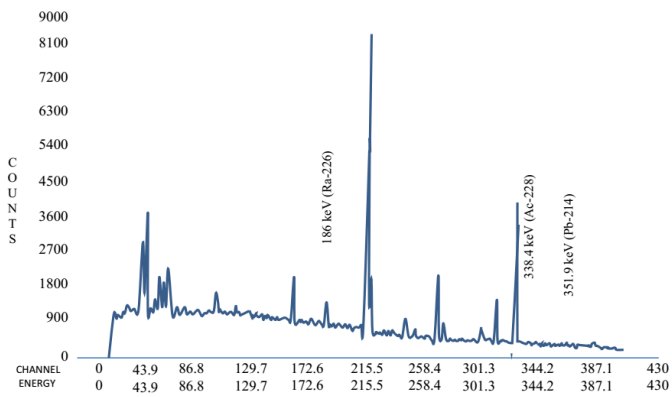

Fig. 2a. Gamma transition of U-238 series, Th-232 series and Ra-226.

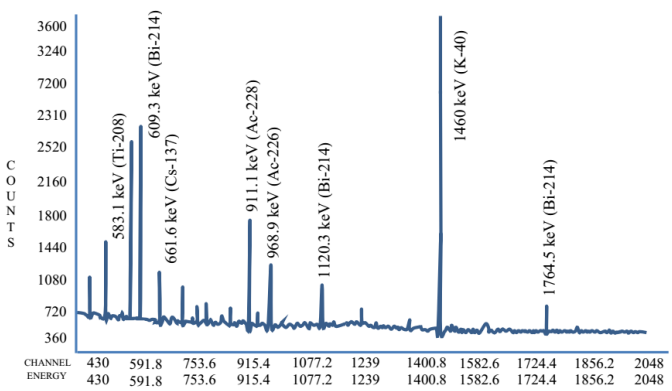

Fig. 2b. Gamma transition of U-238 series, Th-232 series, K-40, and Cs-137

4. Conclusion

This method may be considered as a development in achieving high-quality measurements at low cost, while avoiding the waste of effort and time. However, results of any measurements must be published to allow interested researchers to independently judge the quality and thus validity of the measurements. Such documentation is no longer considered optional but mandatory in many scientific institutions.

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