DEVELOPED A CALIBRATION METHOD IN GAMMA RAY SPECTROMETRY FOR ENVIRONMENTAL SAMPLES

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Abstract: *In gamma ray spectrometry, a rigorous determination of radionuclide concentration for voluminous samples depends mostly on the proper efficiency calibration. The detection efficiency may differ due to sample density, sample measurement geometry, self–absorption and detection system, etc. The aim of this work to evaluate how the efficiencies are varied in different measurement regimes for environmental samples. The efficiency calibration was observed in gamma measurement system (HPGe detectors) with the relative efficiency of 40%. Environmental samples with the density ranging from 0.55 to 1.59 g/cm^3 in 240 cm^3 cylindrical containers were used for efficiency calibration having gamma energy 121 KeV to 1409 KeV. All the secondary reference materials were made by using Eu-152 standard liquid source. The variation of efficiency was found from 63.2% to 76.8% due to the difference in sample matrix and variation due sample position from detector surface was 6% to 40%. Whilst due to variation in sample weight the calculated efficiency values were ranging from 27% to 60%. The evaluated result will be useful to calculate the accurate radionuclide concentration in environmental sample.*

Keywords: *Efficiency Calibration, Gamma Ray Spectrometry, HPGe detector*

1. Introduction

For accurate measurement of radionuclide concentration for voluminous environmental sample, a method called Gamma Spectrometry is widely used. The precision of the result in this method depends on the exactness of detection efficiency. In this type method, efficiency calibration should be done prior to the experiment. Efficiency calibration is the function of energy which provides efficiency value at any energy within a given range. The wider the energy range larger will be the number of radio nuclides whose concentration can be determined. [6, 7] To calculate detection efficiency for various samples, calibration must be done first. During this experiment, efficiency calibration was done for some environmental samples. The accuracy is significant to calculate the activity concentration. However, this detection efficiency is the function of incident gamma ray energy, density, sample composition, detection system, sample size, detectors relative efficiency, sample positioning height.[8]-[10] Some factors have been studied in this work which have influence to the detection efficiency. In this work semiconductor detector known as High Purity Germanium (HPGe) detector of 40% relative efficiency with multi channel analyzer was used. During this work, sample of density 0.91g/cm^3 was contained in cylindrical container of volume 200cm^3. Gamma ray of energy 121 KeV to 1409 KeV was considered to measure efficiency. A calibration standard (Eu-152) was used for preparing the secondary standard sample. Efficiency measurement was done for different sample position height of 2-10 cm and also for different weight of same standard sample.

Some of the previous works shows, there have been a great deal of interest in understanding the influence of the factors during efficiency calibration. ***MAGDALENA et al. (2007)*** studied the change of efficiency due to different parameters like experimental set-up, sample density, different sample position inside the drum. They found the variation from 4% to 20%. Beside this, density can effect on efficiency measurement. ***VUKAŠINOVI et al. (2007)*** studied about the effect of density on counting efficiency of Germanium (Ge) detector. They found, in lower energy range (60-600 KeV), sample density has

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significant influence on Germanium detectors counting efficiency which decreases at higher energies. Moreover, ***AURELIAN LUCA et al. (2012)*** studied the influence of sample volume, geometry and content by using low (high) resolution NAI (HPGe) detector. The absolute full energy peak efficiency of high purity germanium detector (HPGe) detectors was measured between 46.54 and 1836 KeV using the environmental samples matrix standard with both single-photon emitting nuclides mixed standard QCY40 containing ^{210}Pb, ^{241}Am, ^{109}Cd, ^{57}Co, and the second QCY48 containing ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, and ^{60}Co **(S. Harb et al. 2008).** The experimental result showed that efficiency depends on gamma ray energy, geometry, density and characterization of detectors. From the study of ***M. Moshiur Rahman et al. (2014),*** it had been observed that efficiency variation occurs due to various sample matrix, detectors relative efficiency, and detection system. They used powdered milk sample and tried to give an proper radiation control limitation which might be assigned on sample like milk powder in Bangladesh for public eating.[1]-[5] But, none of these studies shows the influence factors of sample positioning height and weight of sample which may affect the result. The purpose of this work is to show the influence of sample position and weight in the measurement of efficiency which can effect largely into activity calculation, and also to prepare reference materials by considering these results for further research work.

2. Materials and Methods

2.1 Materials

For this study, different plastic cylindrical containers of 200cm^3 were used. Environmental sample, Red Lentil, was used which was collected from the local area of Savar, Dhaka, Bangladesh. Some more samples (SS-1, SS-2, SS-3, & SS-4) were used which was collected from same place. For the preparation of secondary standard source Eu-152 solution was used. The properties of Red Lentil were: Weight = 25.58g; Density = 0.91 g/cm^3.

By changing the weight efficiency variation was measured. The sample description is given below.

Table 1 Sample description

Sample ID	Weight (g)	Height (cm)
S-1	52.09	5.7
S-2	40.31	4.8
S-3	38.80	4.5
S-4	49.13	5.2
S-5	49.61	5.3

2.2 Sample Preparation:

After the collection of the samples from the local market, they were collected in polyethylene bag. After that they were cleaned, and taken into a paper and dried it under the sun of temperature 29^{0}C. The dried samples were put into the oven to dry more. Later, samples were turned into powdered form by using mortar. For preparing standard samples, solution of Eu-152 was mixed with the samples and put it into different containers of same geometry and samples weight was measured. All the samples were then collected into cylindrical geometry containers of same volume.

Figure 1: Prepared Sample into sealed container

2.3 Experimental Set-up

The radionuclide was measured by using a high Purity semiconducting Germanium Detector, in short HPGe. It is capable of providing sufficient information about the radionuclide. This type of detector is more effective in detecting impurities as well as has excellent characteristics. Its resolution has 20-30 times better than NaI detector. A detector of 40% relative efficiency was used in this investigation. The detector was supplied by CANBERRA to Atomic Energy Research Establishment (AERE), Savar, Bangladesh.

Table 2 Characteristics of the detector [7]

Characteristics Property	Detector (GC-4010)
Relative efficiency	40%

Geometry & type	Closed coaxial p-type
Volume	172 cm^3
Resolution at 1332 KeV	2 KeV
Crystal diameter	6.2 cm
Crystal length	5.7 cm
Crystal/window distance	5 mm

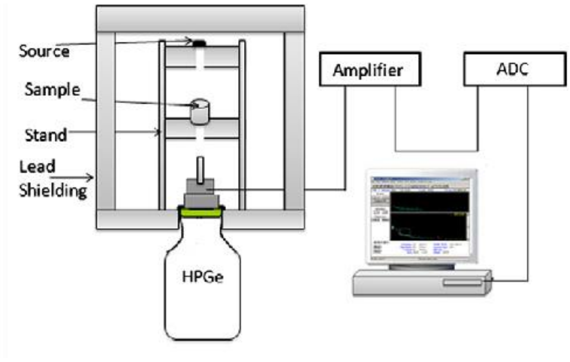

Figure 2: Schematic diagram of experimental set-up.

2.4 Efficiency Calibration Method

The efficiency of semiconductor detector is a function of geometric, intrinsic and sample efficiency. [8] In this investigation, experimental efficiency at energy E can be expressed as:

$$\text{Efficiency (\%)} = \frac{N \times 100}{P(E) \times A} \quad (1)$$

Where, N represents net count rate under the full energy peak corresponding to photon energy E emitted by a radionuclide which has known activity A and emission probability P.

The standard deviation of the net counting rate is,

$$\sigma = \left[\frac{N_s}{T_s^2} + \frac{N_b}{T_b^2}\right]^{1/2} \quad (2)$$

Where, N_s indicates sample counts which is measured in T_s time, and N_b indicates background counts which is measured in T_b. [9]

3. Results and Discussions

Efficiency as a function of energy provides the efficiency value at a certain energy range of radionuclide. Efficiency calibration for the environmental samples was performed with cylindrical geometry containers of same volume. Standard liquid source Eu-152 was used which improves the sensitivity of detection and also enabled the measurement of low-activity environmental samples. Efficiency calibration was carried out for source energy of 121.7, 244.7, 344.3, 411.1, 443.9, 778.9, 963.4, 1085.8, 1112.1, and 1407.9 KeV. All the samples were counted for 10000 seconds. The work was done in three parts. First one was finding the variation of efficiency due to sample matrix, second was variation of efficiency due to sample positioning height, and final one was variation of efficiency due to weight.

3.1 Efficiency variation due to sample matrix

Efficiency variation measurement was done for all the samples and it was carried out by using HPGe detector of 40% relative efficiency detector. For this measurement samples positions was at the end cap of the detector surface. The detection efficiency curve was found as shown in the figure 03

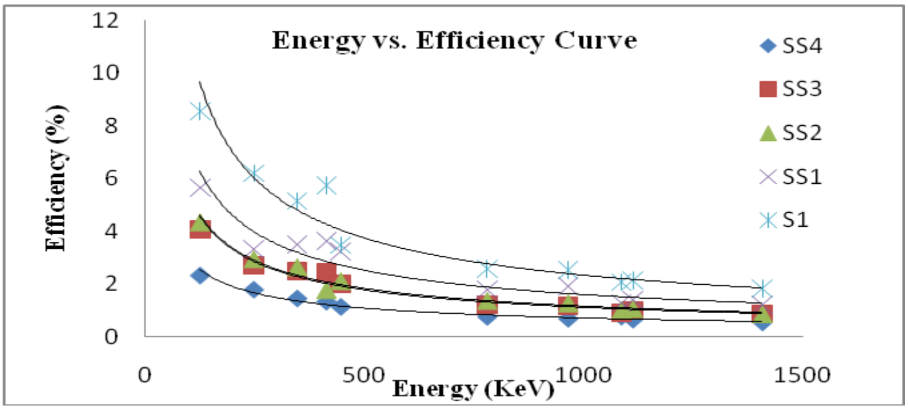

Figure 3: Energy vs. Efficiency curve for samples at the surface of the detector.

From figure 03 it is found that, within energy level of 1408 KeV efficiency decreases very sharply. After that, for higher energies, the variation is not so much prominent. The uniform shape of curves represents the validity of calibration. From this figure it is observed that efficiency value is inversely proportional to energy. Due to the effect of sample matrix, efficiency was found at a range between 10% and 2%. This variation was occurred as count-rate depends on the properties of sample matrices as well as on the container.

3.2 Variation of efficiency due to sample positioning height

Efficiency of a standard sample was measured for various positions to find out the variation percentage. For this experiment, sample S-1 was used and it was sealed in the cylindrical container. The variation was measured for the height 2cm, 4cm, 6cm, 8cm, and 10cm. The detection efficiency curve for sample S-1 was found as shown in the figure 4(a) and 4(b).

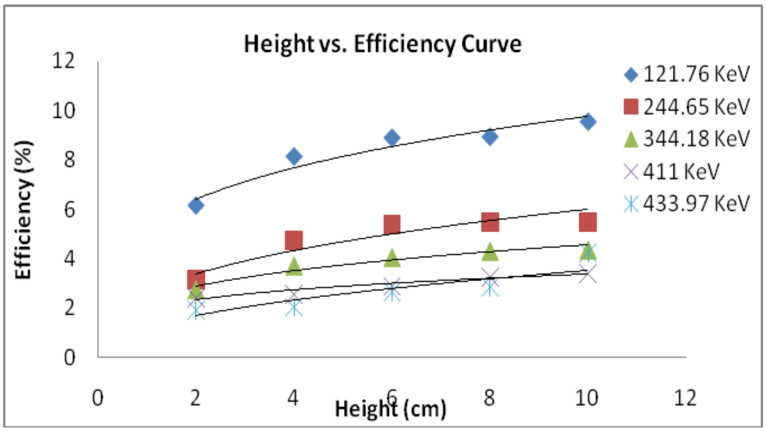

Figure 4 (a): Height vs. Efficiency curve for various position of sample from the detector surface for energy level, 121.76 KeV to 433.97 KeV

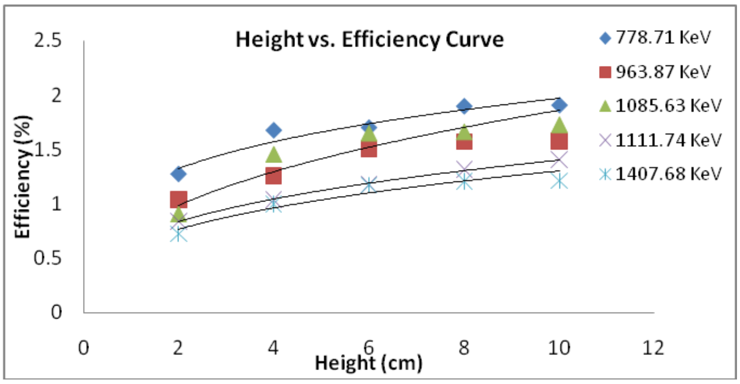

Figure 4 (b): Height vs. Efficiency curve for various position of sample from the detector surface for energy level, 778.71 KeV to 1407.68 KeV

From figure 04 it is observed that efficiency increases as the sample position height increase and also decreases as the gamma ray energy increase. So, appropriate result will not be found if the efficiency calibration was not done with the similar sample positioning height. Thus the count rate will not vary and fitting curve will be found.

3.3 Variation of efficiency due to sample weight

Efficiency measurement was carried out with sample S-2 by changing its weight. During this measurement sample was put in the detector surface so that height cannot affect the data. Samples of various weights, 41.46g, 46.88g, 70.12g, 64.92g and 101.48g, were put into different cylindrical containers of same volume. The counting time was 10000 sec for each sample. The comparison between efficiency and sample weight is shown in the figure 05(a) and 05(b).

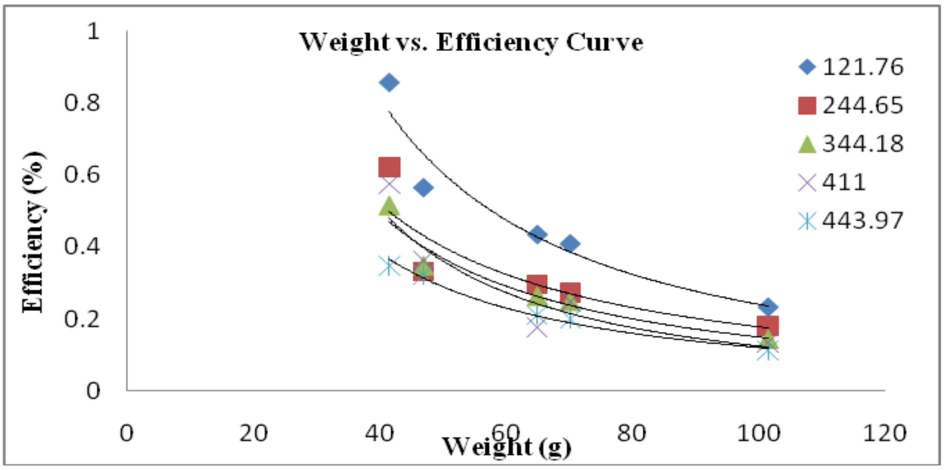

Figure 5(a): Weight vs. Efficiency curve for energy range of 121 KeV to 443 KeV

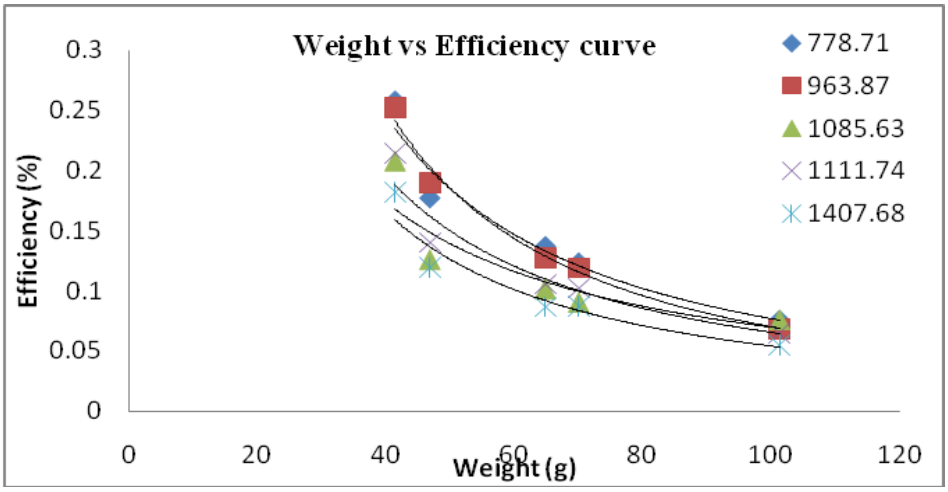

Figure 5(b): Weight vs. Efficiency curve for energy range of 778 KeV to 1408 KeV

From the graphical representation as shown in the figure 05 it has been seen that, as the weight increases efficiency decreases for particular energy range. So, during the experiment weight can be a major factor to interpret the result.

4. Conclusion

For every radionuclide activity measurement, efficiency calibration plays significant role in determining detection efficiency. However, due to some factors proper results of detection efficiency cannot be found. This experiment shows some factors which may affect the result. From the result, it has been seen efficiency varies due to sample matrix, sample positioning height, and sample weight. The uniform shape of curve for energy vs. efficiency illustrates the accuracy of calibration and the curve shows inverse relation between energy and efficiency. By analyzing the results, it is concluded that efficiency calibration must be performed with same geometrical and similar matrix sample. Efficiency of the detector is not universal. It depends on sample matrix, geometry, position of sample. So, similar standards must be used during the calibration. As a consequence, there will be no variation and prepared standard samples may be applied as primary standard sample in further experiment.

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