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Full Energy Peak Efficiency Calibration and Efficiency Transfer to ETNA in Gamma-ray Spectrometry

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Abstract: *Accurate determination of the radionuclide concentration in environmental sample depends directly on the accurate efficiency calibration in gamma ray spectrometry. The detection efficiency may vary due to some factors (density, sample filling height, matrix, measurement geometry, self-absorption, detection system, etc.) for voluminous samples. Some studies has been conducted in this work and presented in here. The efficiency calibration was performed for two HPGe detectors (relative efficiency of 20% and 40%), using samples (STDMS, STDMP, STDMPF, STDMRL, STDB, STDMC, & STDMG) of various densities (0.55 to 1.59 g/cm^3) in cylindrical containers (V=240 cm^3) for the gamma ray energy range of 121 keV to 2614 keV. Secondary reference material was prepared by using the standard reference liquid source ^{152}Eu. From the experimental result it can be seen that efficiency value is inversely proportional to the gamma ray energy. For lower gamma energies of selected nuclide, the efficiency value comparatively higher than the high energies of that nuclide. Efficiency value also varies with filling height of sample. Computer software ETNA was used for the efficiency transfer measurements of three samples (STDMP, STDMPF, & STDMRL) for the configuration of 20% relative efficiency detector. The efficiency value obtained from ETNA was compared with analytical efficiency value. Approximately 2.2% to 15.5% variation was found within the two systems. From the result it can be said that at the initial stage this kind of technical approach is not convenient for the environmental sample measuring laboratory due to the availability of input data for running the ETNA.*

Keywords: *Efficiency Calibration, ETNA, Gamma-Ray Spectrometry, HPGe Detector*

I. INTRODUCTION

For the measurement of radioactive concentration, Gamma Ray Spectrometry with High Purity Germanium (HPGe) detector is widely used. For this method, a detection efficiency curve must be known in advance. [1] The quality of the results of gamma spectrometry measurement depends directly on the accuracy of the detection efficiency. This detection efficiency curve depends on some factors such as sample density, detection system, sample filling height, sample matrix, measurement geometry, self- absorption etc.[2,3,4] Some of these factors dependency on detection efficiency has been studied in this work. For obtaining accurate results in gamma ray spectrometry of voluminous environmental samples by semiconductor Germanium detector, it is essential that this efficiency calibration must be performed with great care because the accuracy of all quantitative results will depend on it. In this work all system settings and adjustments were made prior to determining the efficiencies and maintained. Some points have to consider in determining the efficiency calibration: sample counting configuration (geometry); Calibration method; Calibration sources & analytical efficiency expressions. [5] In this work efficiency calibration was done by using High Purity Germanium detector (HPGe) of two relative efficiencies 20% and 40% by using various samples in cylindrical geometry container of volume 240 cm^3 at the energy range 121 keV to 2614 keV. Efficiency measurements were done for different sample filling heights (1 to 5 cm) of samples STDMC & STDMG.

The resulting efficiencies found by analytical calculation were compared with the predictions of the ETNA software. ETNA stands for Efficiency Transfer for Nuclide Activity measurements. It was developed by the National Laboratory Henri Becquerel (LNHB), Saclay, France for calculating the detector efficiency, and for correcting coincidence summing effects. In this wok, ETNA was used only for calculating detector efficiency. For operating ETNA following information is required-

1. Details about the source
2. Source to detector distance
3. Details about environment
4. Whether an absorber is present or not: if it is, it needs to be described and its distance from the detector window must be indicated.
5. Details about the Detector. [6]

Using this software, detection efficiency was calculated for samples STDMP, STDMPF, & STDMRL for the same detector-source geometry. The detector – source distance was maintained at 5 cm from the detector surface. Finally the result obtained from the prediction of this software was compared with the analytical values for these three samples.

The objective of this work is to see how detection efficiency varies due to sample filling height as well as for the variation of density. This information may be useful to see how the secondary standard samples can be used as reference sample for future research work. Besides, the aim is to see the variation of efficiency for different relative efficiency detector. The most important thing is that to find the variation of efficiency between the analytical value and predicted efficiency value of ETNA.

II. MATERIALS AND METHODS

2.1 MATERIALS:

Varity of environmental samples with different sample ID were used in this study. Name of the samples are- Mosaic Stone, Milk Powder, Pea Flour, Red Lentin, Bricks, Cement, & Granite zet Black and their IDs were STDMS, STDMP, STDMPF, STDMRL, STDB, STDMC, & STDMG respectively. The samples weight and density is given below in the table-

Table-1: Description of the samples

Sample ID	Height (cm)	Weight (g)	Density (g/cm^3)
STDMS	5	246.58	1.59
STDMP		85.64	0.55
STDMPF		108.501	0.698
STDMRL		155.74	1.002
STDB		146.44	0.94
STDMC	1, 2, 3, 4, & 5	30.04, 60.08, 90.12, 120.16 & 150.20	1.063
STDMG	1, 2, 3, 4, & 5	35.04, 70.08, 105.12, 140.16, & 175.21	1.24

2.2 SAMPLE PREPARATION:

All the samples were collected in disposable bags (plastic bag) and marked them by identification ID, date, location, Fresh weight, & collector name. After that all the samples were bought to the laboratory of Health Physics and Radioactive Waste Management Unit, INST, AERE, Savar, Dhaka. Before bringing the samples containers, sample preparation area were cleaned with proper care to avoid contamination. The samples were than cleaned under laboratory temperature (average 30^0c) and relative humidity conditions (average 75%). The samples were dried in the sunlight for about 32 hours to remove added moisture. The dried samples bricks, Pea flour and Red Lentin were then crushed into powder and the particle size was kept at 400 µm. The dried samples weight and density were measured. Standard liquid source Eu-152 was mixed with mosaic stone, milk powder and brick. The standard mosaic stone was then mixed with Cement, Granite zet black, Pea flour, and Red Lentin. After preparing the samples, they were taken into a cylindrical plastic container (radius 3cm × height 8.5cm) of active volume approximately 240 cm^3. The containers were then sealed tightly and wrapped with thick vinyl tapes around their screw necks. After the preparation of samples, weight and density of the sample was measured. By these way samples were prepared for the gamma ray spectrometry reading.

2.3 EXPERIMENTAL SET-UP:

The detection and measurement of radio-nuclides in the samples were carried out using two coaxial cylindrical high purity germanium (HPGe) detectors by gamma ray spectrometry of relative efficiency 20% and 40%. The detectors were supplied by CANBERRA to the Health Physics and Radioactive Waste Management Unit laboratory, AERE, Bangladesh. 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.

Table 2: Characteristics of the detectors

Characteristic Property	Detectors	
	D1 (GC- 4010)	D2 (GC- 2018)
Relative Efficiency	40%	20%
Geometry & Type	Closed coaxial p-type	Closed coaxial p-type
Volume	172 cm^3	93cm^3
Resolution at 1332 keV	2 keV	1.8 keV
Crystal diameter	6.2 cm	4.95 cm
Crystal length	5.7 cm	5.65 cm
Crystal/window distance	5 mm	55 mm

2.4 EFFICIENCY CALCULATION:

The efficiency of semiconductor Ge detectors may be expressed as a product of geometric efficiency, intrinsic efficiency and sample efficiency. [3] In this work, the experimental efficiency at energy E_i for a given set of measuring conditions can be expressed by the formula:

Efficiency (%) = $\frac{N_i \times 100}{P_i(E_i) \times A_n}$ (1)

Where, N_i is the net count rate under the full energy peak (i.e. of a spectrum of radiation, the part of the spectral response curve corresponding to the total absorption in a detecting material of the energy of the detected radiation) corresponding to E_i energy photons emitted by a radionuclide with a known activity A_n and emission probability P_i.

The error in the measurements was expressed in terms of standard deviation (± σ). 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 is the sample counts measured in time T_s, and N_b is the background counts measured in time T_b. [4]

III. RESULTS AND DISCUSSIONS

The efficiency calibration of different environmental sample was done by using cylindrical containers of same volume. The efficiency calibration of the 20% and 40% relative efficiency detector was performed by the standard point source Na-22, Co-60, Cs-137 and Ba-133 using identical container used for the measurement of the sample.

3.1 EFFICIENCY CALIBRATION:

The efficiency calibration for all the samples (STDMS, STDMP, STDMPF, STDMRL, & STDB) was carried out for the energies ranging from 121 keV to 2614 keV. Counting time for all the samples was 10000 seconds. The efficiency calibration was done for two different position of the detector (at the surface of the detector and at 5cm distance from the detector surface). The detection efficiency curves for the samples at different positions are given in below-

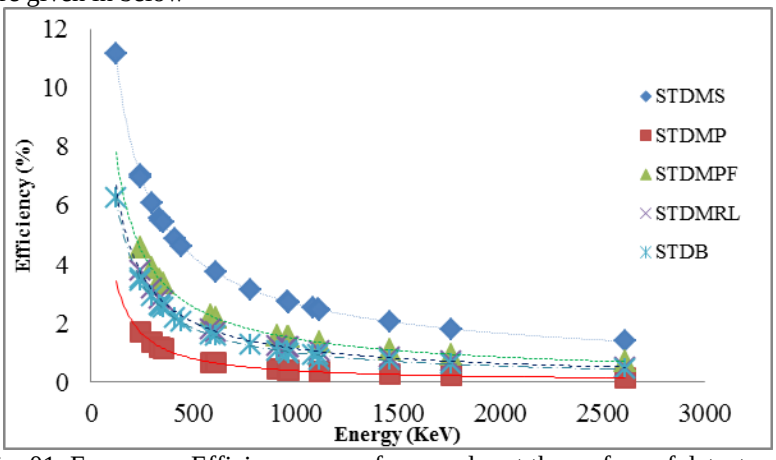

Fig. 01: Energy vs. Efficiency curve for samples at the surface of detector 1.

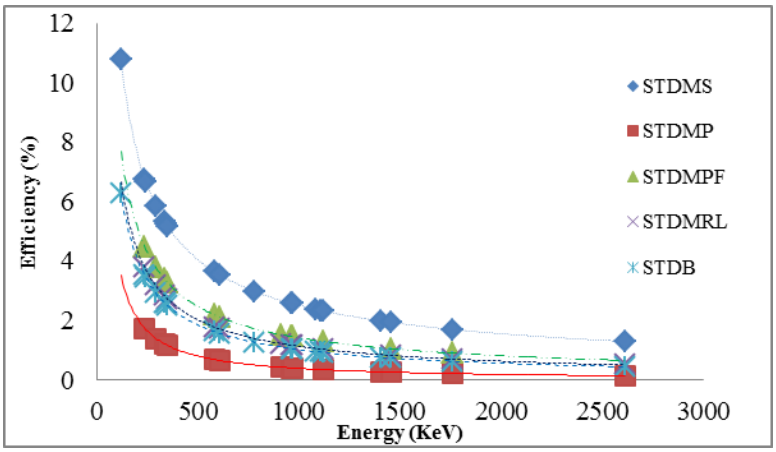

Fig. 02: Energy vs. Efficiency curve for samples at 5cm distance from the Detector 1 surface.

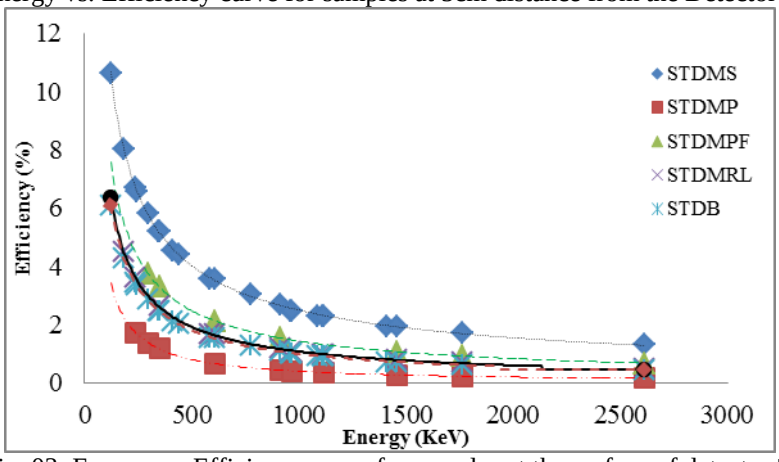

Fig. 03: Energy vs. Efficiency curve for samples at the surface of detector 2.

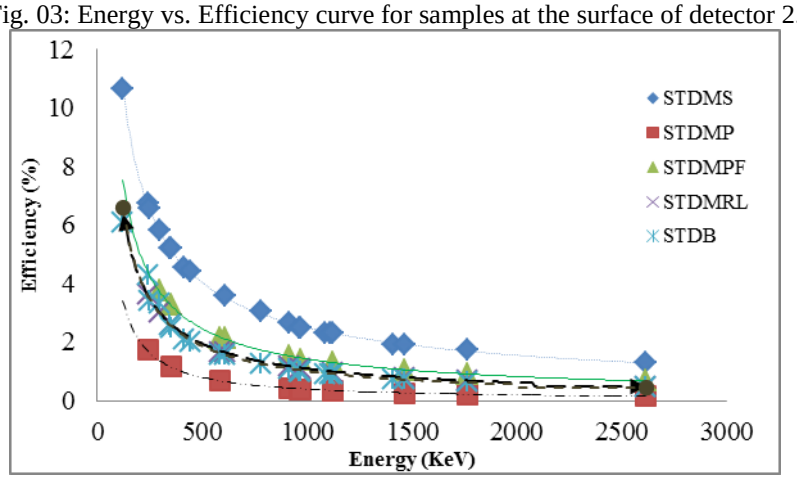

Fig. 04: Energy vs. Efficiency curve for samples at 5cm distance from the Detector 2 surface.

The efficiency calculation for the samples STDMS, STDMP, STDMPF, STDMRL and STDB was done for both 20% and 40% relative efficiency detectors. From the figure 01 to 04 it is seen that there is a sharp decrease in the efficiency values up to an energy level. After this, for higher energies variation is not so much prominent. By analyzing the efficiency values it is seen that efficiency value does not greatly vary for the difference in the sample measuring height for same detector. This is happened for both 20% and 40% relative efficiency detectors. From the figure 01 & 03 it is seen that the variation for different detection system of sample STDMS is from 1.59% to 16.21%, STDMP is 0.89% to 1.8%, STDMPF is 2.35% to 4.81%, STDMRL is 4.06% to 9.32% and STDB is 1.05% to 14.83%, when all the sample position is at the surface of the detectors. From figure 02 & 04 it is seen that the variation for STDMS is from 1.20% to 15.07%, for STDMP is 0.68% to 3.30%, for STDMPF is 0.8% to 3.70%, for STDMRL is 4.06% to 9.40% and for STDB is 1.70% to 17.62% when all the sample position is at 5cm distance from the detectors surface. From these variations it is confirmed that there is small variation in efficiency value for different detection system. So, efficiency measurement should be performed for same detection system and same sample position.

3.2 VARIATION OF DETECTION EFFICIENCY DUE TO SAMPLE FILLING HEIGHT:

The efficiency variation was measured for the sample STDMPF & STDMRL for sample filling height of 1 to 5 cm. This measurement was performed in the detector 1. The resulting height vs. efficiency curves are as follows-

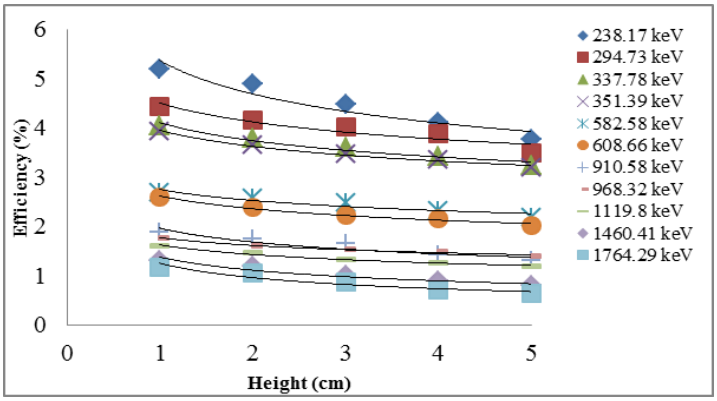

Fig. 05: Height vs. Efficiency curve for sample STDMC

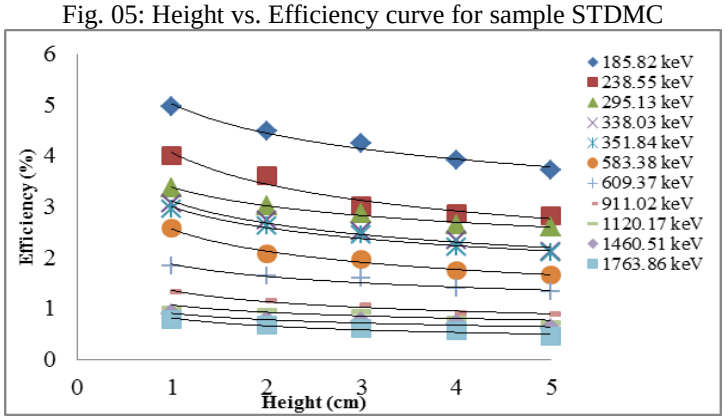

Fig. 06: Height vs. Efficiency curve for sample STDMG

From these curves it can be said that, efficiency varies with the sample filling height. It is seen that efficiency value decreases with the increase of height or with the quantity of samples and for lower energies the rate of decrease is high than higher energy. So, measuring sample filling height should be similar to that of calibration source height.

3.3 COMPARISON OF ANALYTICAL EFFICIENCY VALUE TO THE PREDICTED VALUE BY ETNA:

The efficiency for point source was estimated by using the efficiency transfer method. In this method efficiency measurement is computed by the product of the transfer factor and the measured efficiency for a reference measurement. The transfer factor is computed by simplified procedures as the ratio between the computed efficiency for the given measurement and efficiency for reference measurement. By giving proper information about the reference material and some others required information, efficiency value found by ETNA for detector 2 is shown in graph below-

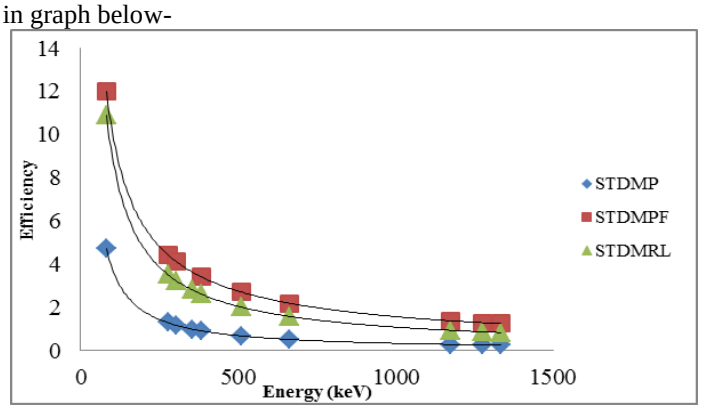

Fig. 07: Energy vs. Efficiency curve for samples STDMP, STDMPF, & STDMRL measured by ETNA

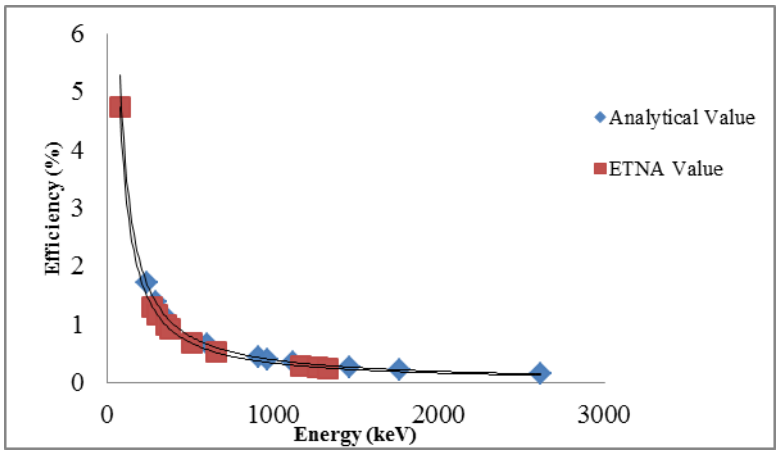

Fig. 08: Comparison between analytical and ETNA efficiency value for sample STDMP.

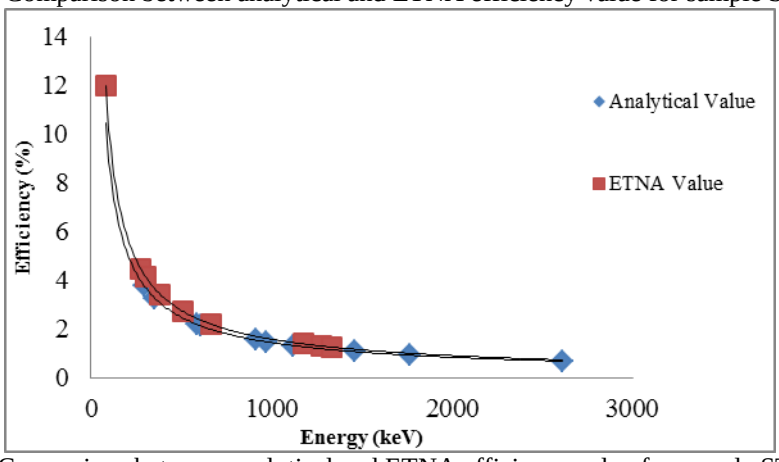

Fig. 09: Comparison between analytical and ETNA efficiency value for sample STDMPF.

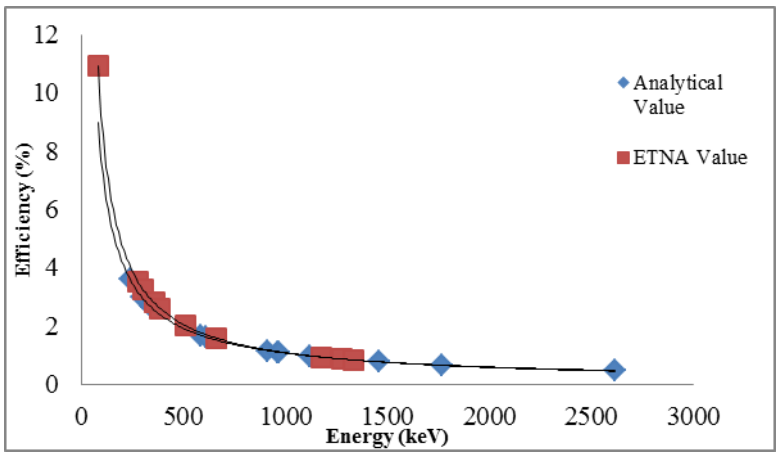

Fig. 10: Comparison between analytical and ETNA efficiency value for sample STDMRL.

There is variation between analytical and measured efficiency value by ETNA as shown in figures 08 to 10. The variation for STDMP is from 5.1% to 15.64%, for STDMPF is from 7.75% to 12.5% and for STDMRL is from 0.9% to 17.5%. If the analytical value is taken as standard than ETNA value is wrong and vice-versa. The results acquired from the procedure of ETNA measurement is marginally affected by the uncertainty of the detector data, which is a major source of uncertainty in direct computation. So, by giving proper information required for the measurement of efficiency, ETNA can give accurate result as output whether analytical efficiency value can be affected by different factors which may makes the result incorrect.

IV. Conclusion

The accurate determination of radionuclide concentration depends directly on efficiency calibration in gamma ray spectrometry. Proper efficiency calibration can give proper result of detection efficiency. As efficiency varies with different detection system, sample filling height, sample position etc. as studied in this

work; calibration should be performed with great care and also with the similar standards at the beginning of gamma spectrometry as of the samples. From the result it is clear that efficiency transfer gives the best results in the case when the measurement of interest is similar with the reference measurement. These results should be taken into consideration while measuring the efficiency of environmental samples in gamma ray spectrometry.

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