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Using the experimental method for the computation of the efficiency in various measurement geometries for a reference point source geometry with NaI(Tl) Detectors

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Abstract:

The quality of the results of gamma spectrometry measurement depends directly on the accuracy of the detection efficiency in the specific configuration of concern. In the present work, measurement conditions .In gamma-ray spectroscopy using Scintillation detectors, one usually needs to know the full-energy peak efficiency for any specific source-detector we will describe the experimental method employed to calibrate Scintillation detectors at the laboratory of Dr.Younis. S. Selim of Radiation Physics-Faculty of Science - Alexandria University, where the detectors are calibrated for measuring point sources are placed in succession at constant distance from the considered detector to optimize the detection. Experimental efficiency calibration is restricted to several measurement geometries and cannot be applied directly to all measurement configurations. An alternative possibility of being able to compute the efficiencies is thus highly desirable. The purpose of this work is to Calibration The NaI(Tl) scintillation detector practically by using radioactive point sources in the development of axial dimensions from the surface of detector and with varying photon energies .

Keywords**:** Gamma peak efficiency, efficiency calibration, full -energy peak efficiency.

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INTRODUCTION

Point sources efficiency measurements and the construction of the corresponding calibration curve are usually carried out in gamma-ray spectrometry with the purpose of either subsequent measurement of point sources of unknown activity in the same geometry or in order to facilitate the computation of the extended-source efficiency. The use of point sources is standard in the determination of the gamma-ray efficiency for detectors. (1)

The experimental method is applied for the computation of the efficiency of The NaI (Tl) scintillation detector for a point source located at several distances from the detector.

In this work, an analytical expression for the so-called full-energy peak efficiency ε(E) of the detector is defined as the quotient of the number of detected photons in a peak N_{det} , and the total number of emitted photons in the same peak N_{emit} , both per unit time interval. (2)

This efficiency which is a dimensionless fraction is related to a specific source – detector geometry and a particular peak analysis procedure. (3)

MATERIALS AND METHODS

The calibration process was done by using (PTB) point sources, measured these sources placed in different geometries. In this work, different point sources are considered, such as (^{241}Am, ^{133}Ba, ^{137}Cs, ^{152}Eu and ^{60}Co), all of the sources have the same geometric dimensions, reference date: 2009-06-01(12H00), these sources served as calibration solutions for systems used to measure full-energy peak efficiency at different distances from the detector. The certificates give the sources activities and their uncertainties for (PTB) sources are listed in table 1.The data sheet states values of half lives, photon energies and photon emission probabilities per decay for the all radionuclides used in the calibration process are listed in table 2. The axis of the sources was perpendicular to the detector axis. In order to keep the center of the sources on the detector axis, the sources were fixed on Plexiglas holders producing negligible attenuation (4)

All of the spectra for all point sources have been collected using Scintillation Detector with crystal size (3in×3in.) with a high resolution 7.5%.The details of the Model 802 Scintillation detector with the most common crystal sizes listed in table 3. Resolution is specified at the 662 keV peak of ^{137}Cs. Table 4 shows the measuring times for different energy peaks. The sources are placed at locations 20,25,30,35,40,45 and 50 cm along the vertical axis plane e.g. (θ=0°) as shown in (Fig.1).

Table 1: (PTB) point sources activities and their uncertainties.

PTB Nuclide	Activity(KBq)	Reference date 12H00	Uncertainty %(K=2σ)
^{241}Am	259.0	1-6-2009	2.6
^{133}Ba	275.3	1-6-2009	2.8
^{137}Cs	385.0	1-6-2009	4.0
^{152}Eu	290.0	1-6-2009	4.0
^{60}Co	212.1	1-6-2009	1.5

Table 2: Half-lives, photon energies and photon emission probabilities per decay for the all radionuclides used in this work.

Nuclide	Energy(KeV)	Emission probability %	Half life (day)
^{241}Am	59.52	35.3	1.58E+05
^{133}Ba	80.99	35	3.85E+03
	356.01	61.9	3.85E+03
^{152}Eu	121.78	28.2	4.97E+03
	244.7	7	4.97E+03
	344.27	26	4.97E+03
	778.9	13	4.97E+03
	964	14	4.97E+03
	1407.92	21	4.97E+03
^{137}Cs	661.64	86	1.10E+04
^{60}Co	1173.23	99.9	1.93E+03
	1332.51	99.982	1.93E+03

Table 3: The Model 802 Scintillation Detectors with the most common crystal sizes.

Model	Crystal Size mm (in.)	Resolution	Well Dimensions mm (in.) D	L
802-3x3	76 x 76 (3 x 3)	7.5%	N.A.	N.A.

Table 4: The measuring times for different energy peaks along the vertical axis (the inclination angle θ=0°).

Nuclide IPL	Energy (keV)	Height 20 cm	Height 25 cm	Height 30 cm	Height 35 cm	Height 40 cm	Height 45cm	Height 50 cm
		Tmeas (s)	Tmeas (s)	Tmeas (s)	Tmeas (s)	Tmeas (s)	Tmeas (s)	Tmeas (s)
^{241}Am	59.53	645.3	952.2	1415.2	1818.1	2261.3	2748.7	2329.6
^{133}Ba	80.99	223	291.1	402.4	551.1	680.1	845.2	1033.7
^{152}Eu	121.78 244.7 344.27 778.9 964 1407.92	8721.3	5815	7870.5	10042.7	14481	14628.2	19219.2
^{137}Cs	661.66	432.1	619.7	821.8	987.5	1258.4	1555	3559.9
^{60}Co	1173.23 1332.51	1153	1691.3	2365.3	3069.7	3767	4952.5	5992.3

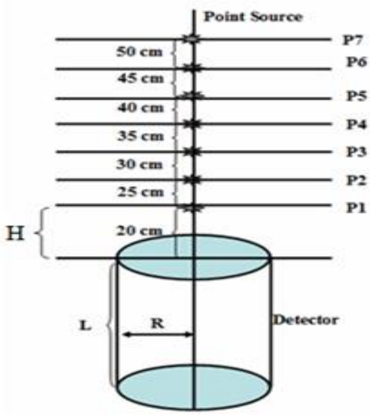


Fig.1: axial motion from the detector.

Results and Discussion

The full-energy peak efficiency values are measured as a function of the photon energy for The NaI (Tl) scintillation detector determined by the following equation:

$$\varepsilon(E) = \frac{N(E)}{T \cdot A_S \cdot P(E)} \prod C_i \tag{1}$$

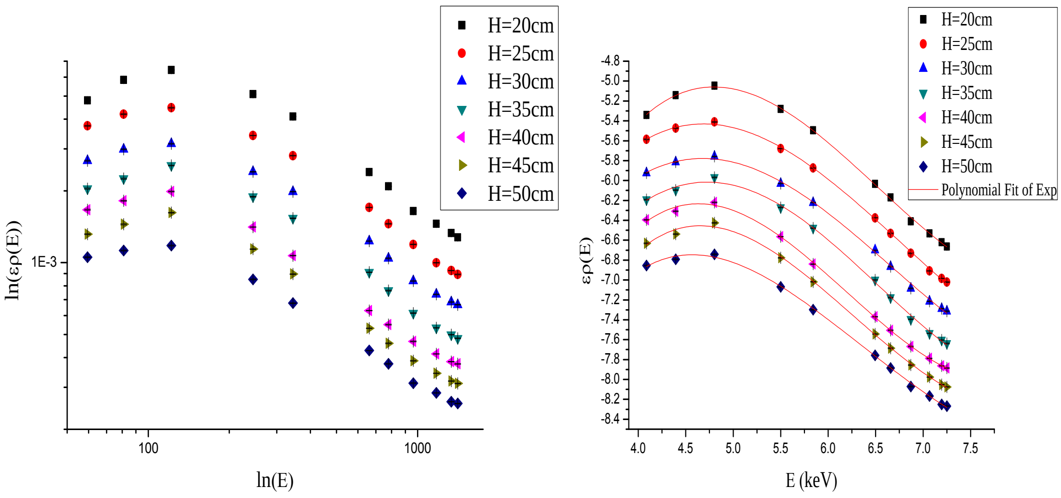
Where, N(E), is the number of counts in the full-energy peak which can be obtained using Genie 2000 software, T is the measuring time (in second), P(E), is the photon emission probability at energy, E, A_S, is the radionuclide activity and, C_i, are the correction factors due to dead time, radionuclide decay and coincidence summing corrections. The calibration source decay correction Cd can be obtained from the decay constant λ and the interval ΔT between the reference time and the run time. [4]

$$C_d = e^{\lambda \cdot \Delta T} \tag{2}$$

The statistical uncertainties of the net peak areas were smaller than 0.1 % since the acquisition time was long enough to get number of counts at least 10,000 counts. The uncertainty in the full-energy peak efficiency, σ_ε, was given by:

$$\sigma_\varepsilon = \varepsilon \cdot \sqrt{\left(\frac{\partial \varepsilon}{\partial A}\right)^2 \cdot \sigma_A{}^2 + \left(\frac{\partial \varepsilon}{\partial P}\right)^2 \cdot \sigma_P{}^2 + \left(\frac{\partial \varepsilon}{\partial N}\right)^2 \cdot \sigma_N{}^2} \tag{3}$$

where, σ_A, σ_P, and, σ_N, are the uncertainties associated with the quantities, A_S, P(E), and, N(E), respectively, assuming that the only correction made is due to the source activity decay.



(a) (b)

Fig.2: (a) represents the variation of efficiency with the energy at different heights from the detector center. (b) Polynomial fit to the experimental efficiency with various gamma-ray energies.

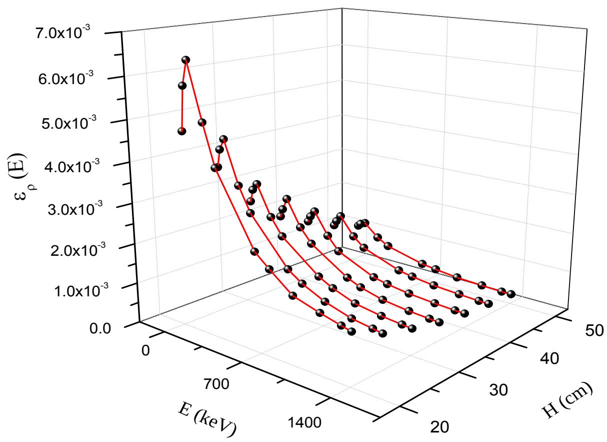


Fig.3 represents three dimensional presentation of the variation of efficiency as a function of energy at different heights as (θ=0°).

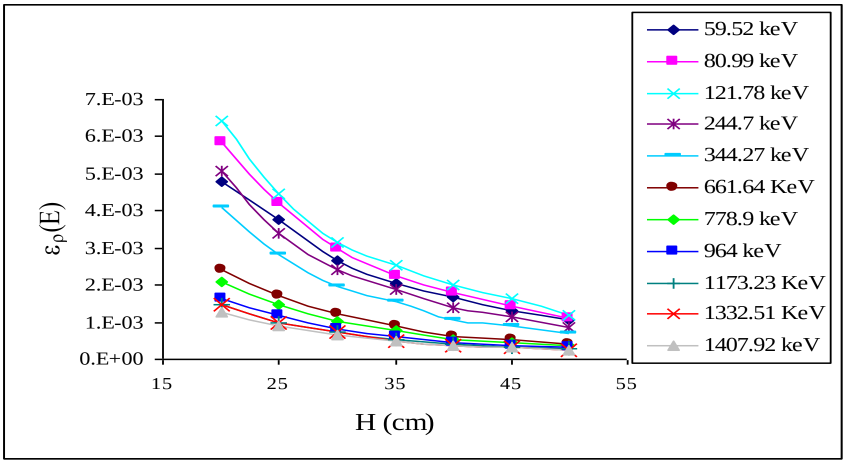


Fig.4 represents the variation of efficiency with the height, at (θ=0°) for different energies.

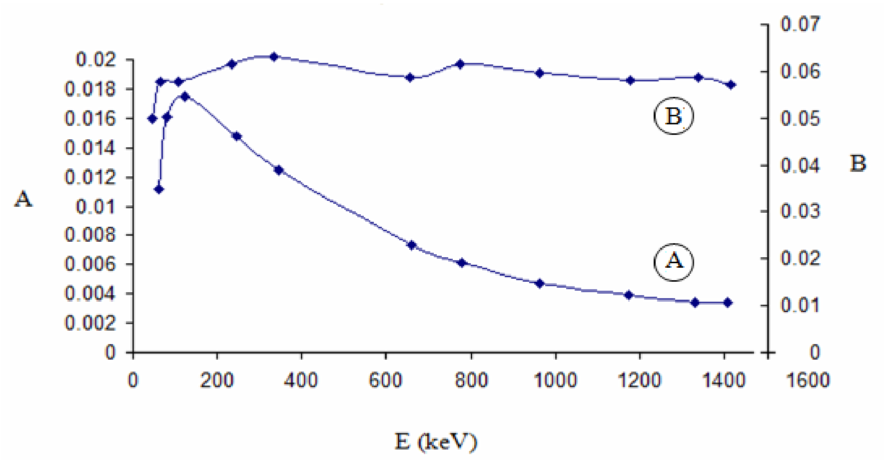


Fig.5: represents the variation of constant values (A and B) with the photon of energy, at (θ=0°) from the detector.

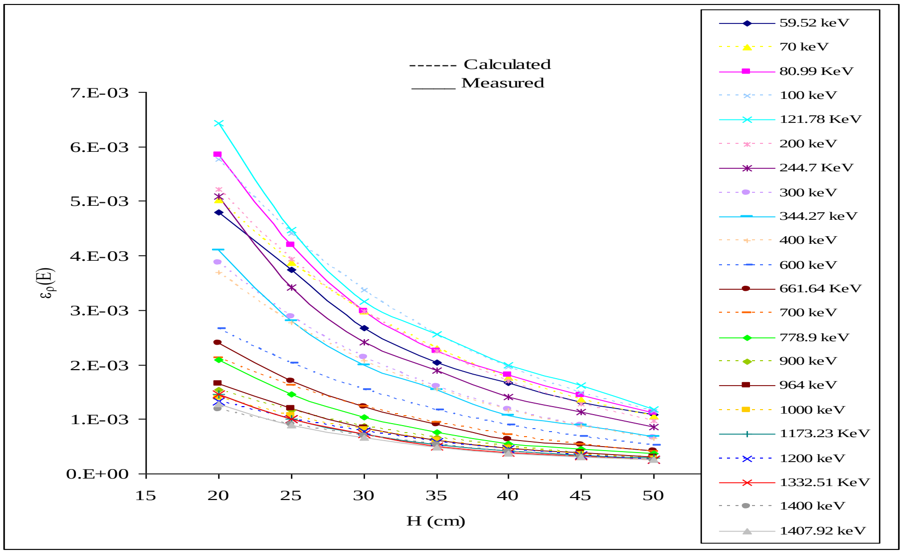


Fig.6: represents the variation of measured and calculated efficiency with the height, at (θ=0°) from the detector.

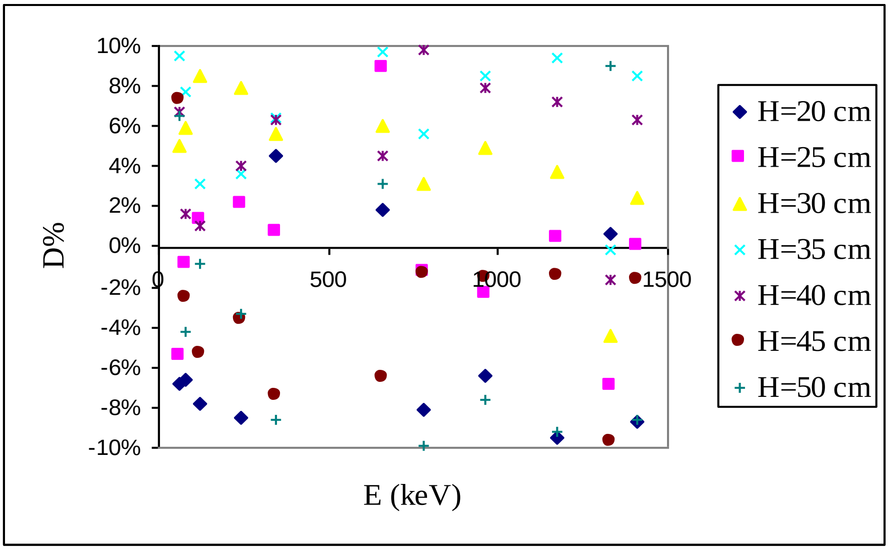


Fig.7: represents the variation of deviation with the energy at different heights (H) along the vertical axis.The deviation shows a maximum at about 650 keV and decreases to show a minimum at about 1300 keV.

In Figs. 2–3, the full energy peak efficiency (ε_p) increases gradually as a function of energy to reach a maximum at E=120 keV and then decreases gradually to be very small at the high energy peak. In Fig.4 the full-energy peak efficiency (ε_p) for low and medium energy (59.52 to 661.64 keV) decreases remarkably as the height increases, but in the high energy (778.9 to 1407.92 keV) the full-energy peak efficiency (ε_p) decreases slowly with increasing height, according to these data one an empirical formula.

$$\varepsilon_p = A(E)e^{-B(E)H} \tag{4}$$

Where: (ε_p) is the experimentally measured efficiency, (A) and (B) are constants for a particular energy and certain angle (θ), (H) is the height, as show in table5.

Table 5: Values of the constant (A) and (B) according to the source energy and (θ=0°).

E (keV)	A ($\times10^{-3}$)	B ($\times10^{-3}$)
59.53	11.2	46
80.99	16.1	54.1
121.78	17.5	54.1
244.7	14.8	57.8
344.27	12.5	59.4
661.66	7.3	54.8
778.9	6.1	57.8
964	4.7	55.8
1173.23	3.9	54.3
1332.51	4.2	57.8
1407.92	3.4	53.5

In fig.5 the values of the constant (A) is remarkably change with the energy of gamma photons while the constant (B) is slightly changes with (B).where one are easily calculated the values of efficiency (ε_p) at any height (H) for a particular energy.The discrepancies between the calculated and the measured full-energy peak efficiency values are given by the following equation:

$$D\% = \frac{\varepsilon_{cal} - \varepsilon_{meas}}{\varepsilon_{meas}} \times 100 \tag{5}$$

Conclusion

From the measurement of efficiency and results that we obtained, we conclude the following: The full-energy peak efficiency is energy dependent and varying from energy region to another. At low energies, the full-energy peak efficiency increases with energy to some point (about 81keV) because in the dominant interaction in the detector material is the photoelectric effect. Whereas, in the energy range from 100 keV up to 1000 keV the Compton scattering takes place with high probability and some of the gamma rays are scattered and escape from the detector without detection, therefore, not all the photon energies contribute to the full-energy peak, so the full-energy peak efficiency decreases gradually. At very high gamma ray energy ($E > 1.022$ MeV), pair production is competing with Compton scattering when the probability of pair production increases with increasing energy, although the single and double escape peaks should be taken into account at high energy. In addition, the attenuation from the detector window, detector geometry and source -detector distance also is an issue and affect the efficiency. Efficiency (ε_p) of the detector as function of energy at the different height between the source and the detector along the vertical axis ($\theta=0°$) decreases exponentially by increasing height and photon energy. The best position of the point source to get high detector efficiency and high accuracy is at vertical height (h=20cm) where ($\theta=0°$). On the other hand we found that the low detector efficiency at (h=50cm). Finally this work can estimate the full-energy peak efficiency for NaI(Tl) detector with crystal size (3×3in.) with a high resolution 7.5% at any energy and any certain position.

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