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Solution of the Standard Source Lack in Quantitative Radioactive Samples Analysis

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Abstract. Determination of detector efficiency is very important for a wide range of activation analysis applications. The presence of a standard source has the same shape of the sample is the main problem in quantitative analysis. In this work, a new theoretical method used to calculate the full energy peak efficiency (FEPE) which depends on the efficiency transfer principle and the direct mathematical method. Different geometries of cylindrical sources were used for the calibration process of two different scintillation detectors.It was found that, the theoretical and the experimental (FEPE) values are in a good agreement.

Keywords:*Scintillation Detectors, Efficiency Transfer, Direct Mathematical Method, Full Energy Peak Efficiency, QuantitativeAnalysis.*

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INTRODUCTION

Detector efficiency is very important in various scientific and industrial fields, especially in the field of Quantitative analysis. To determine the full energy peak efficiency FEPE of a certain sample we must have a standard source of the same geometry of the sample under investigation. This problem can be solved by using the efficiency transfer principle to avoid time consumption resulting from experimental work. Using the efficiency transfer principle the detector efficiency for various geometrical conditions isderivedfromtheknown efficiency for reference source-detector geometry. The efficiency transfer method is particularlyuseful due to its insensitivity to the inaccuracy of theinput data, e.g. to the uncertainty of the detector characterization[1,2].

Many laboratories use the cylindrical shape vial in Quantitative analysis process, and the full energy peak efficiency for cylindrical sources$\varepsilon(E, Cyl)$Can be obtained as the following equation depending on the efficiency transfer principle.

$$\varepsilon\left(E,Cyl\right)=\varepsilon\left(E,Ref\right)\frac{\Omega_{eff}(Cyl)}{\Omega_{eff}(Ref)} \quad (1)$$

Where the $\varepsilon(E, Ref)$ is the reference efficiency of the valid standard source of any dimensions,$\Omega_{eff}(Ref)$, is its effective solid angle. And$\Omega_{eff}(Cyl)$, is the effective solid angle of the cylindrical source sample. M. Abd-Elzaher et al. [3] used point source efficiency as a reference efficiency to calculate the FEPE.

The effective solid angle subtended by the source and the active surface of the detector, must include absorbing factors, taking into account the attenuation effects in the materials between the source and the active part of the crystal, [4].

Mathematical Treatment

Effective solid angle for cylindrical source geometry is calculated by using Selim and Abbas direct mathematical method. They used the spherical coordinate system to derive the direct analytical elliptic integrals to calculate different detector efficiencies [5-7] for any source-detector configuration.

The effective solid angle (Ω_{eff}) subtended by the detector at the source point is introduced in [3] as:

$$\Omega_{eff}=\int_{\theta}\int_{\varphi} f_{att}.\sin\theta d\varphi d\theta \quad (2)$$

Wheref_{att} is the factor that determines the photon attenuation by all absorbers between source and detector, it is expressed as:

$$f_{att}=e^{-\sum_i \mu_i\delta_i} \quad (3)$$

Whereμ_i is the attenuation coefficient of the i^{th} absorber for a gamma-ray photon with energy E_γ and δ_i is the average gamma photon path length through the i^{th} absorber.

Volumetric source can be treated as group of point sources which are uniformly distributed; each point source has an effective solid angle $\Omega_{eff(Point)}$ as: [8]

$$\Omega_{eff(Cyl)}=\frac{\int_V f_{att}.\,\Omega_{eff(Point)}\,dV}{V} \quad (4)$$

For an arbitrary element of volume dV at lateral distance ρ from the detector axis that makes an angle α with the detector's major axis, with hsource to detector separation, this element of volume can be expressed as:

$$dV=\rho d\rho d\alpha dh \quad (5)$$

The effective solid angle of a cylindrical detector in case of a cylindrical source of radius S and height H can be expressed as: [9]

$$\Omega_{\text{eff(Cyl)}} = \frac{\int_{h_o}^{H+h_o} \int_{0}^{2\pi} \int_{0}^{S} f_{att} \cdot S_f \cdot \Omega_{\text{eff(Point)}} \cdot \rho d\rho d\alpha dh}{\pi S^2 H} \quad (6)$$

In volumetric source, not all the emitted photons from the source exit from it, but part of them is absorbed in the source itself, which affects the effective solid angle calculations. The factor concerning this effect is called the self-absorption factor Sf which is given by: [8]

$$S_f = e^{-\mu_s \cdot d_s} \quad (7)$$

Where μ_s is the source attenuation coefficient and d_s is the distance traveled by the emitted photon inside the source.

Experimental setup

The experimental work was held at Younis. S. Selim laboratory for Radiation Physics, Faculty of Science, Alexandria University. This laboratory uses several coaxial NaI (Tl) scintillation detectors. Two NaI (Tl) scintillation detectors are used (2*2 in) and (3*3 in) detectors.The details of these detectors of model number 802 are obtained from CANBERRA company website. D1 and D2 represent the (2*2 in) and (3*3 in) NaI (Tl) scintillation detector respectively.

Sources used for calibration process are 25, 200, 300, and 400 ml ^{152}Eu solution of known activity. The details of the prepared sources are tabulated in Table (1). Vials used in preparation process specifications are tabulated in Table (2) and vials dimensions clarified in Figure (1)

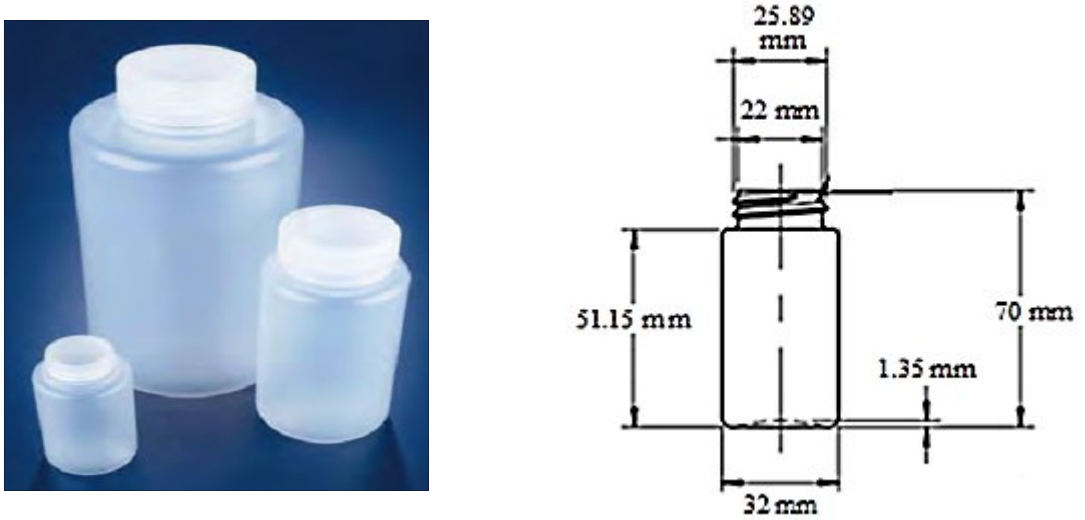

FIGURE 1.(a) SciLab ware (Azlon) 25 ml Jar Dimensions.

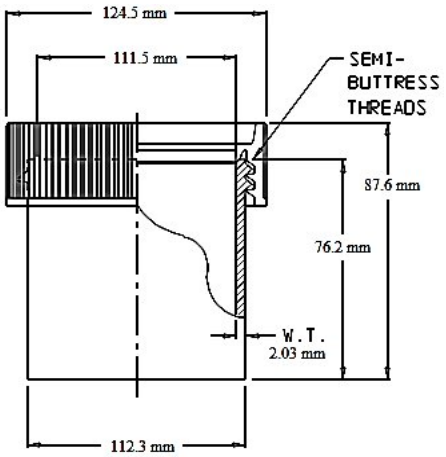

FIGURE 2.(b) Nalgene 500 ml Jar Dimensions.

FIGURE 3. Vials used in preparation process Dimensions.

The volumetric sources were measured on a Plexiglas cover placed directly on the detector end-cap. These measurements were done using two cylindrical detectors (D1 and D2). The source was placed on the detector end-cap with the center of the source centered on the end-cap. The angular correlation effects can be neglected for the low source-to-detector distance. [10]

The spectrum acquired with winTMCA32 software is made by ICx Technologies. It was analyzed with Genie 2000 data acquisition and analysis software.

The 25 ml 152Eu source experimental full energy peak efficiency values that tabulated in Table (3) is used as a reference efficiency curve to calculate the FEPE of the 200, 300, 400 ml sources for both D1 and D2.

Results and Discussions

The used detectors were calibrated by measuring the low activity cylindrical sources, previously described. The theoretical FEPE can be obtained as given in equation (1).

The percentage error between measured and calculated efficiencies is given by:

$$\Delta\% = \frac{\varepsilon_{Cal} - \varepsilon_{meas}}{\varepsilon_{meas}} \times 100 \tag{8}$$

Where$\varepsilon_{cal}$and ε_{meas} are the calculated and experimentally measured efficiencies, respectively.

The measured efficiency values as a function of the photon energy ε(E) for NaI Scintillation detectors were calculated by:

$$\varepsilon(E) = \frac{N(E)}{T \cdot A_S \cdot P(E)} \prod C_i \tag{9}$$

where N(E) is the number of counts in the full-energy peak, T is the measuring time, 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 and radionuclide decay.

The decay correction C_d for the calibration source from the reference time to the run time was given by:

$$C_d = e^{\lambda \cdot \Delta T} \tag{10}$$

Where λ is the decay constant and ΔT is the time interval over which the source decays corresponding to the run time.

Theoretical and experimental FEPE values and Discrepancy percentage (Δ%) between them for all calibration sources and detectors are listed in Table (4).

Figures (2-3) show that the efficiency is increasing by decreasing the source volume. The self-attenuation effect increased by increasing the carrier solution as we know when the attenuation factors increase then the number of photons reach the detector decrease so the efficiency decreased. Moreover, the efficiency is increased with increasing the detector's volume, where the crystal should be long enough to have reasonable efficiency for the highest energy gamma-rays of interest. This is due to the change in solid angle and increasing the chance of various interactions ofphoton with the detector material as a result of increasing the pass length in the crystal of larger volume.

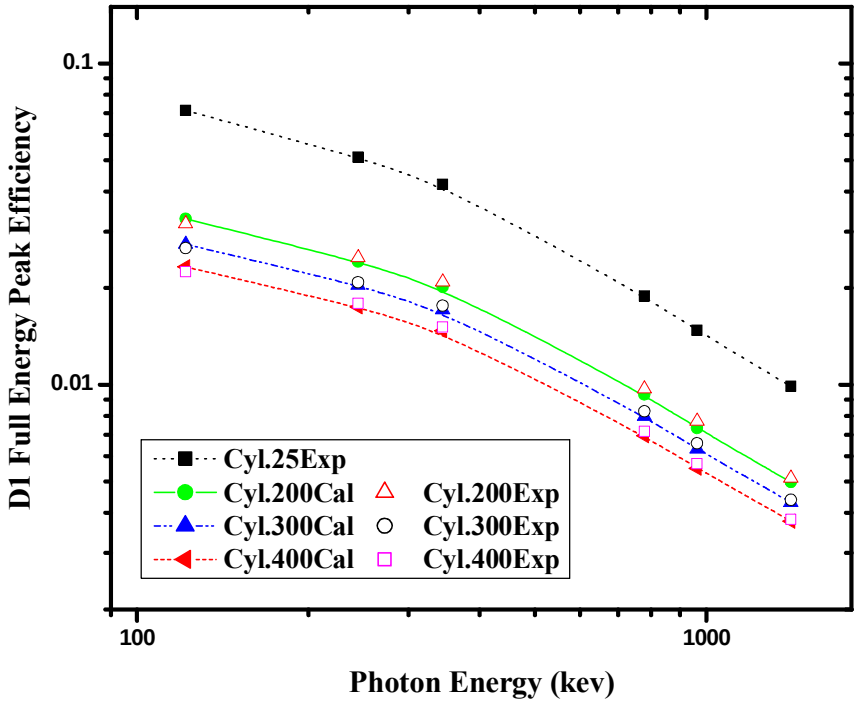

FIGURE 2. Calculated Efficiency Results for Conversion From 25 ml Source to 200, 300, 400 ml Sources Using Detector (D1).

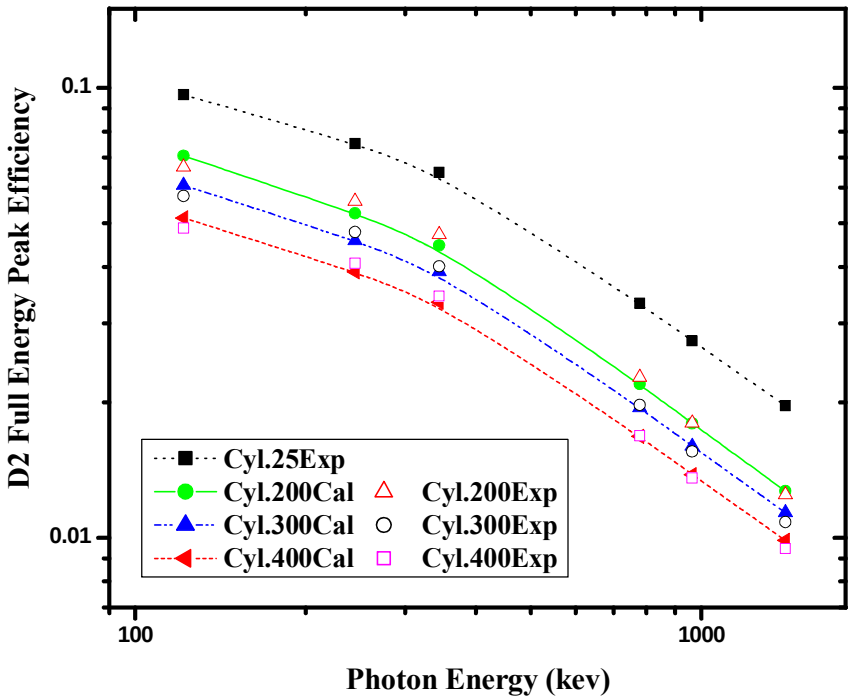

FIGURE 3. Calculated Efficiency Results for Conversion From 25 ml Source to 200, 300, 400 ml Sources Using Detector (D2).

The efficiency of the detectors is high at low source energies (absorption coefficient is very high) and decreases as the energy increases (fall off in the absorption coefficient). This is due to the fact that the photoelectric is dominant around 100 keV, which means in other words that it is higher for the bigger detector than the smaller one and it is higher for lower source energy than higher source energy. This is because of the dominance of the photoelectric at lower source energies.

Conclusion

In the present work, a new theoretical method used to calculate the full energy peak efficiency which depends on the efficiency transfer principle and the direct mathematical method. Only by knowing the effective solid angle for sample under investigation one can determine its FEPE depending on one of mentioned reference efficiencythen the activity of it can easily determined,or by putting the sample under investigation in a vial like that described in this work.The theoretical and the experimental (FEPE) values are in a good agreement.

TABLE 2. Vials Used In Preparation Process Specifications.

Item	25 ml Jar	500 ml Jar
Manufacturer	SciLab ware (Azlon)	Nalgene Lab ware
Catalog Number	BWP0030PN	NG-2118 (16)
Closure Material	Polypropylene	Polypropylene
Jar Material		
Capacity	30 ml	500 ml
Weight with Closure	9.51 gm	130 gm
Source Volume	25 ml	200, 300, and 400 ml

TABLE 1. Prepared Sources Details.

Volume	Nuclide	Activity (KBq)	Reference Date 00:00 Hr	Uncertainty (KBq)
25 ml 200 ml 300 ml 400 ml	^{152}Eu	5	1.Jan 2010	±4.0

TABLE 3. Reference Experimental Full Energy Peak Efficiency Values

Energy	D1 (2*2 in)	D2 (3*3 in)
	Cyl 25ml Exp	Cyl 25ml Exp
121.78	7.136E-02	9.666E-02
244.69	5.111E-02	7.513E-02
344.28	4.210E-02	6.487E-02
778.9	1.888E-02	3.320E-02
964.13	1.476E-02	2.737E-02
1408.01	9.904E-03	1.966E-02

TABLE 4. Theoretical and Experimental FEPE Values and Discrepancy Percentage (Δ%)

Energy	D1 (2*2 in)		Δ%	D2 (3*3 in)		Δ%
	Cyl 200ml Cal	Cyl 200ml Exp		Cyl 200ml Cal	Cyl 200ml Exp	
121.78	3.287E-02	3.168E-02	3.623%	7.060E-02	6.676E-02	5.445%
244.69	2.420E-02	2.488E-02	-2.836%	5.261E-02	5.599E-02	-6.426%
344.28	2.018E-02	2.090E-02	-3.550%	4.462E-02	4.720E-02	-5.790%
778.9	9.319E-03	9.719E-03	-4.293%	2.197E-02	2.276E-02	-3.572%
964.13	7.333E-03	7.710E-03	-5.140%	1.795E-02	1.798E-02	-0.170%
1408.01	4.977E-03	5.118E-03	-2.845%	1.271E-02	1.248E-02	1.845%
Energy	**D1 (2*2 in)**		**Δ%**	**D2 (3*3 in)**		**Δ%**
	Cyl 300ml Cal	**Cyl 300ml Exp**		**Cyl 300ml Cal**	**Cyl 300ml Exp**	
121.78	2.743E-02	2.663E-02	2.915%	6.077E-02	5.745E-02	5.460%
244.69	2.040E-02	2.083E-02	-2.114%	4.579E-02	4.782E-02	-4.435%
344.28	1.710E-02	1.763E-02	-3.082%	3.905E-02	4.009E-02	-2.662%
778.9	7.992E-03	8.270E-03	-3.479%	1.948E-02	1.973E-02	-1.294%
964.13	6.307E-03	6.580E-03	-4.343%	1.597E-02	1.555E-02	2.593%
1408.01	4.301E-03	4.382E-03	-1.884%	1.137E-02	1.083E-02	4.740%
Energy	**D1 (2*2 in)**		**Δ%**	**D2 (3*3 in)**		**Δ%**
	Cyl 400ml Cal	**Cyl 400ml Exp**		**Cyl 400ml Cal**	**Cyl 400ml Exp**	
121.78	2.331E-02	2.247E-02	3.600%	5.136E-02	4.880E-02	4.978%
244.69	1.748E-02	1.792E-02	-2.478%	3.899E-02	4.075E-02	-4.508%
344.28	1.473E-02	1.514E-02	-2.819%	3.339E-02	3.442E-02	-3.082%
778.9	6.951E-03	7.156E-03	-2.950%	1.681E-02	1.686E-02	-0.328%
964.13	5.498E-03	5.688E-03	-3.445%	1.380E-02	1.359E-02	1.527%
1408.01	3.765E-03	3.819E-03	-1.449%	9.861E-03	9.465E-03	4.014%

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