Romanian Reports in Physics, Vol. 62, No. 1, P. 57–64, 2010

TRANSFER OF DETECTOR EFFICIENCY CALIBRATION FROM A POINT SOURCE TO OTHER GEOMETRIES USING ETNA SOFTWARE*

DANIELA RADU[1], DORU STANGA[1], OCTAVIAN SIMA[2]

1"Horia Hulubei" National Institute of Physics and Nuclear Engineering, Bucharest, Romania
E-mail: radu.daniela@yahoo.co.uk
[2]University of Bucharest, Department of Atomic and Nuclear Physics, Bucharest, Romania
E-mail: osima@olimp.fiz.infim.ro

(Received October 10, 2008)

Abstract. The quality of the results of gamma spectrometry measurement depends directly on the accuracy of the detection efficiency in the specific measurement conditions. Traditionally, measurements are performed in gamma-ray spectrometry by the so-called relative method, according to which a standard sample is first used for calibration; the standard sample should match the measured one in all the important characteristics, such as its size, chemical composition and density. The preparation of the standard is costly and time consuming, especially if the laboratory is required to measure samples with different geometries. 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 examine the applicability of the efficiency transfer method for the computation of the efficiency in various measurement geometries on the basis of the measured efficiency for reference point source geometry. For this, the ETNA (Efficiency Transfer for Nuclide Activity measurements) code is used. In this study the transfer method was applied for the computation of the efficiency of a high purity germanium (HPGe) detector for a point source placed at several distances and in addition for volume sources of different compositions and densities on the basis of the reference efficiency measured for a point source located at 10 cm distance from the detector. The experimental efficiency curves were compared with the prediction of the ETNA software.

Key words: Gamma-ray spectrometry, efficiency calibration, coincidence summing.

1. 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, usually in connection with the efficiency transfer

* Paper presented at the National Conference of Physics, September 10–13, 2008, Bucharest – Măgurele, Romania.

method [1]. The use of point sources is standard in the determination of the gamma-ray efficiency for detectors.

The purpose of this work is to examine the applicability of the efficiency transfer method for the computation of the efficiency in various measurement geometries on the basis of the measured efficiency for a reference point source geometry using ETNA software. The transfer method is applied for the computation of the efficiency of a high purity germanium (HPGe) detector for a point source located at several distances and in addition for volume sources of different compositions and densities on the basis of the reference efficiency measured for a point source located at 100 mm distance from the detector.

The code validity has been checked by F. Piton et al. [2] by comparison with experimental efficiencies determined for an HPGe detector with standard point sources at 20, 50, 100 and 200 mm.

2. EXPERIMENTAL CALIBRATION

The gamma spectrometry system used consisted of a high purity germanium detector model GMX50P4, transplantable in Pop Top technology, with dimensions: 64.6 mm diameter, 75.0 mm length, 0.50 mm beryllium absorber layer and a Digital Portable Multichannel Analyzer type DigiDART. The detector has an energy resolution of 2.2 keV at 1.33 MeV (^{60}Co) and 800 eV at 5.9 keV (^{55}Fe), 58:1 peak to Compton ratio (^{60}Co), 50 % relative efficiency at 1.33 MeV (^{60}Co) and works at –3300 V.

In the first step the detector efficiencies were determined experimentally, as a function of gamma-ray energies [3] using ^{241}Am, ^{152}Eu, ^{137}Cs, ^{134}Cs and ^{60}Co point sources located at 20, 50, 100, 150 and 200 mm from the face of the detector. The activity of the sources was in the range from 10^3 Bq to 10^4 Bq.

The experimental values of the efficiencies are represented in Fig. 1. It is seen that the experimental efficiencies $\varepsilon(E)$ do not present a smooth variation with the energy E.

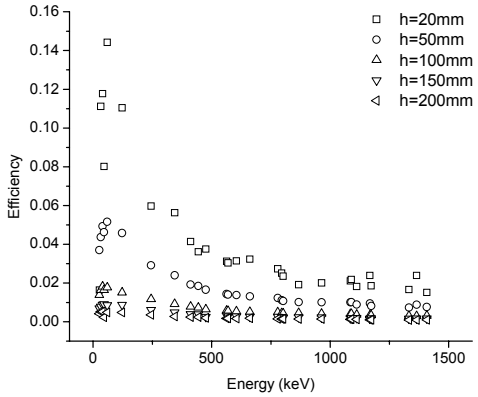

Fig. 1 – The experimental values of the detection efficiency for point sources.

Cylindrical sources, containing ^{134}Cs gel matrix (density ρ=1.0 g/cm3) with the diameter *D*=74 mm and height *H*=32 mm, and ^{137}Cs soil matrix (ρ=1.4 g/cm3), with the diameter *D*=74 mm and height *H*=33 mm were also measured, at 0 and 20 mm from the face of the detector. The reference activities and the uncertainties (1σ) of the cylindrical sources were of (1916±48) Bq for ^{134}Cs source and (1190±41.5) Bq for ^{137}Cs source. The counting dead time for these sources was in general controlled to be less than 3%, and consequently corrected during the counting.

3. COINCIDENCE SUMMING CORRECTIONS

The origin of the deviation of the efficiency data displayed in Fig. 1 from smooth curves as a function of energy is the presence of important coincidence summing effects in the case of ^{152}Eu, ^{60}Co and ^{134}Cs sources. In view of removing the effects of coincidence summing, specific corrections were applied to the experimental efficiencies for these nuclides in order to obtain a generally useful efficiency curve. A realistic evaluation of the coincidence summing effects is a difficult task, especially in the case of nuclides with complex decay schemes. Succinctly, some nuclides emit multiple gamma rays or X-rays when they decay to the ground state. If these gamma rays and X-rays are emitted essentially at the same time, it is possible that multiple photons will be detected at the same time in the detector, giving rise to a single signal in the spectrum as if a single photon would have been detected. This is known as “Cascade” or “True Coincidence” summing. The most common example of this is ^{60}Co, where the 1173.23 and 1332.51 keV gamma rays are emitted in cascade and can sum up to produce the 2505.74 keV gamma ray peak. This True Coincidence Summing has two effects, one is the decrease of the of the count rate in the spectrum, including losses from peaks, by replacing several signals with a single signal, the other is the creation of the extra peaks in the spectrum or the increase of the count rate in existing peaks due to summation of individual photons. Both of these can cause the spectrum analysis to give erroneous results.

The best method available to correct these effects is the Monte Carlo method. In this work in order to evaluate the coincidence summing corrections we applied a dedicated software called GESPECOR.

GESPECOR [4] is a Monte Carlo simulation code specifically developed for the computation of efficiency, of matrix effects [5, 6] and of coincidence summing effects [7, 8] in gamma-ray spectrometry with HPGe detectors. The GESPECOR software is a realistic simulation program that can describe in detail the physics processes and the measurement arrangement; it also incorporates efficient algorithms and variance reduction techniques and furthermore it has a user-friendly interface.

In this work the Monte Carlo computation used as input detector data the values included in the detector specifications sheets. No adjustment of the detector model parameters was undertaken; the values were taken straight from the manufacturer's data. The computed correction factors were subsequently used to obtain improved values of the peak efficiencies.

The values obtained for the peak efficiencies for the point source measurements are represented in Fig. 2.

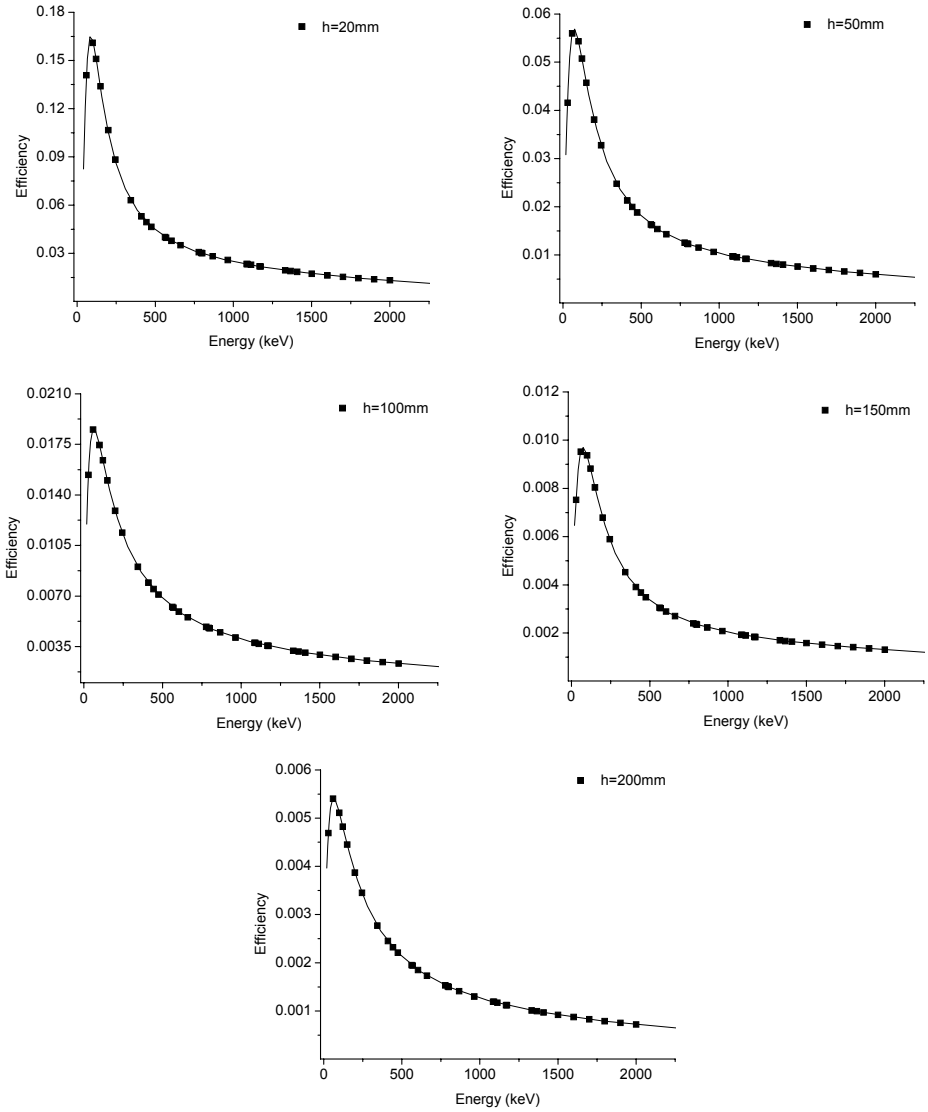

Fig. 2 – The detection efficiency for point sources measured at 20, 50, 100, 150 and 200 mm from the face of the detector, corrected for the effects of coincidence summing.

In Table 1 the computed values of the coincidence summing correction factors are presented. In the case of cylindrical sources the corrections were necessary only for ^{134}Cs.

Table 1

The coincidence summing correction factors for the sources measured

Energy	Point sources					Cylindrical sources	
(keV)	20mm	50mm	100mm	150mm	200mm	*h*=0mm	*h*=20mm
121.78	0.748	0.894	0.960	0.980	0.988		
244.70	0.660	0.855	0.947	0.974	0.984		
344.28	0.912	0.959	0.983	0.991	0.995		
411.12	0.794	0.902	0.963	0.981	0.989		
443.96	0.693	0.870	0.952	0.976	0.985		
475.34	0.793	0.900	0.960	0.979	0.987	0.775	0.887
563.23	0.777	0.892	0.956	0.977	0.986	0.755	0.878
569.32	0.780	0.893	0.957	0.978	0.986	0.759	0.880
604.69	0.859	0.934	0.973	0.986	0.992	0.845	0.924
778.90	0.869	0.940	0.978	0.989	0.993		
795.84	0.859	0.934	0.974	0.986	0.992	0.846	0.926
801.93	0.793	0.901	0.959	0.979	0.988	0.775	0.888
867.38	0.625	0.839	0.943	0.972	0.984		
964.08	0.728	0.893	0.964	0.982	0.989		
1085.84	0.933	0.978	0.993	0.997	0.998		
1089.74	0.889	0.947	0.981	0.990	0.994		
1112.08	0.756	0.908	0.971	0.986	0.992		
1167.92	1.198	1.076	1.027	1.014	1.009	1.155	1.090
1173.23	0.901	0.955	0.980	0.990	0.994		
1332.51	0.898	0.953	0.980	0.989	0.993		
1365.16	1.330	1.130	1.048	1.024	1.015	1.282	1.161
1408.01	0.745	0.904	0.968	0.984	0.991		

The efficiency for the point sources obtained in this way for the reference measurement geometry (100 mm distance from the source to the detector) can be used to evaluate the efficiency for other measurement geometries. The results are presented in the next section.

4. EFFICIENCY TRANSFER

This step dealt with the transfer of the efficiency from the reference point source geometry, *h*=100 mm, to other point source geometries (distances from the detector end cap equal to 20, 50, 150 and 200 mm) using ETNA software. The transfer method was applied also for the computation of the efficiency for cylindrical samples with different matrices. ETNA (an acronym standing for

Efficiency Transfer for Nuclide Activity) [2, 9] is a calculation facility that offers a practical and convenient solution to several problems encountered in gamma-spectrometry laboratories. It can be used to calculate the efficiency of the detector under measurement conditions different from those of calibration, and to correct for coincidence summing effects. Its application improves the accuracy of the results of quantitative gamma-spectrometry analysis, and avoids time-consuming measurement sequences [9].

The transfer efficiency is computed for discreet values of the fitted efficiency data from the 100 mm source to detector distance to derive new efficiencies values for the four other distances. The detector efficiency was measured for the same locations of the point sources and also for cylindrical sources with various matrices. The experimental efficiency curves were compared with the prediction of the ETNA software.

The ratios of the computed to the experimental values (corrected for coincidence summing) for point sources are presented in Table 2. The efficiency transfer has also been applied to cylindrical source with gel (1.0 g/cm^3) matrix; the ratios of the computed to experimental values for this source are presented in the same table.

Table 2

Efficiency transfer results. Ratio of ETNA computed to experimental values

Radio-nuclide	Energy (keV)	Point sources				Cylindrical source	
		20mm	50mm	150mm	200mm	0mm	20mm
^{241}Am	59.54	0.990	0.996	0.960	0.953		
^{152}Eu	121.78	0.959	0.940	0.936	0.983		
	244.70	0.995	0.997	1.000	0.999		
	344.28	1.046	1.013	1.009	0.994		
	411.12	1.029	1.011	1.025	0.994		
	443.97	1.038	1.010	1.020	0.993		
	778.90	1.041	1.026	1.006	0.997		
	867.38	1.049	1.031	1.031	0.998		
	964.08	1.047	1.028	1.003	0.998		
	1085.84	1.049	1.023	1.006	0.999		
	1089.74	1.050	1.023	1.009	0.996		
	1112.08	1.049	1.022	1.003	0.998		
	1408.01	1.024	1.014	0.973	1.011		
^{134}Cs	475.34	1.032	1.006	1.033	0.992	1.019	0.949
	563.23	1.039	1.019	1.031	0.993	1.018	1.016
	569.32	1.040	1.013	1.030	0.991	1.055	1.035
	604.69	1.036	1.020	1,016	0.995	1.093	1.025
	795.84	1.043	1.027	1.032	0.994	1.096	1.035
	801.93	1.044	1.027	1.032	0.995	1.092	1.003
	1167.92	1.056	1.004	1.012	1.005	0.954	0.987
	1365.16	1.052	1.005	0.977	1.008	0.975	0.997
^{137}Cs	661.66	1.032	1.020	1.014	0.995		
^{60}Co	1173.24	1.054	1.020	1.014	1.001		
	1332.50	1.066	1.011	0.989	1.010		

For the cylindrical source with soil matrix (1.4 g/cm^3), containing ^{137}Cs, the ratio between the ETNA value and the experimental value of the efficiency was 1.038 for h=0 mm and 0.966 for h=20 mm.

Table 3 presents the efficiency transfer ratios calculated by ETNA software for the present experiment. In the same table the values reported by M.-C. Lepy et al. [10] for the distances equal to 50 and 150 mm are included for comparison with our results.

Table 3

Efficiency transfer ratios (present work and ref [10]) calculated by ETNA for different energies, from 100 mm source to detector reference distance to other distances

Radio-nuclide	Energy (keV)	Source to detector distance (mm)						
		20	50		100	150		200
				[10]			[10]	
^{241}Am	59.54	8.845	3.122		1	0.478		0.277
^{137}Cs	661.66	7.218	2.755	2.820	1	0.511	0.509	0.310
^{134}Cs	475.34	7.364	2.783		1	0.508		0.307
	563.23	7.288	2.768	2.830	1	0.510	0.508	0.308
	569.32	7.283	2.768	2.830	1	0.510	0.508	0.308
	604.66	7.257	2.762	2.826	1	0.511	0.509	0.309
	795.84	7.139	2.739	2.810	1	0.513	0.511	0.311
	801.93	7.136	2.739	2.809	1	0.513	0.511	0.312
	1167.92	6.982	2.708		1	0.516		0.315
	1365.16	6.925	2.697		1	0.518		0.316
^{60}Co	1173.23	6.980	2.708	2.789	1	0.516	0.513	0.315
	1332.51	6.934	2.698	2.783	1	0.517	0.514	0.316
^{152}Eu	121.78	8.392	2.991	3.056	1	0.485	0.486	0.285
	244.70	7.674	2.841	2.894	1	0.501	0.501	0.300
	344.28	7.537	2.817	2.869	1	0.505	0.504	0.303
	411.12	7.436	2.797		1	0.507		0.305
	443.96	7.399	2.790		1	0.508		0.306
	778.90	7.148	2.741	2.811	1	0.513	0.510	0.311
	867.38	7.103	2.732		1	0.514		0.312
	964.08	7.063	2.724		1	0.515		0.313
	1085.84	7.008	2.713		1	0.516		0.314
	1089.74	7.007	2.713		1	0.516		0.314
	1112.08	6.998	2.711		1	0.516		0.314
	1408.01	6.914	2.694	2.780	1	0.518	0.514	0.316

5. CONCLUSIONS

In specific applications, samples with large volumes are often characterized by gamma-ray spectrometry. For such samples the experimental calibration is quite difficult: appropriate calibration sources are scarce, difficult to produce and expensive. In many cases of volume source measurement the actual sample differs

slightly from the geometry of the reference measurement. For example, the sources are places in identical containers, but the filling height is not exactly the same, or the density is different. Computational methods are therefore needed. In this work the applicability of the efficiency transfer method for the computation of the efficiency in various measurement geometries on the basis of the measured efficiency for a reference point source geometry was examined. The coincidence summing effects were evaluated using GESPECOR software and were used to correct the experimental values of the efficiencies. The analytical values of the efficiencies and the measured values, corrected for coincidence summing effects, are in reasonable agreement for point and cylindrical sources. Therefore this method can be useful in routine laboratory work, because the computation of the efficiency can save time and avoid tedious experimental calibration for different samples geometries.

REFERENCES

1. L. Moens, J. Donder, X. Lin, F. De Corte, A. De Wispelaere, A. Simonits, J. Hoste, *Calculation of the absolute peak efficiency of gamma-ray detectors for different counting geometries*, Nuclear Instrument and Methods, **187**, 451–472 (1981).
2. F. Piton, M.-C. Lepy, M.-M. Be, J. Plagnard, *Efficiency transfer and coincidence summing corrections for gamma-ray spectrometry*, Applied Radiation and Isotopes, **52**, 791–795 (2000).
3. K. DEBERTIN, R. G. HELMER, *Gamma- and X-ray Spectrometry with Semiconductor Detectors*, North-Holland, Amsterdam, 1998.
4. O. SIMA, D. ARNOLD, C. DOVLETE, *GESPECOR – A versatile tool in gamma ray spectrometry*, Journal of Radioanalytical and Nuclear Chemistry, **248**, 359–364 (2001).
5. O. SIMA, C. DOVLETE, *Matrix effects in the activity measurement of environmental samples - Implementation of specific corrections in a gamma-ray spectrometry analysis program*, Applied Radiation and Isotopes, **48**, 59–69 (1997).
6. O. SIMA, I. L. CAZAN, L. DINESCU, D. ARNOLD, *Efficiency calibration of high volume samples using the GESPECOR software*, Applied Radiation and Isotopes, **61**, 123–127 (2004).
7. O. SIMA, D. ARNOLD, *Transfer of the efficiency calibration of Germanium gamma-ray detectors using the GESPECOR software*, Applied Radiation and Isotopes, **56**, 71–75 (2002).
8. O. SIMA, D. ARNOLD, *Accurate computation of coincidence summing corrections in low level gamma-ray spectrometry*, Applied Radiation and Isotopes, **53**, *1–2*, 51–56 (2000).
9. M.-C. LEPY, M.-M. BE, F. PITON, *ETNA (Efficiency Transfer for Nuclide activity measurement): Software for efficiency transfer and coincidence summing corrections in gamma-ray spectrometry*, Note Technique LNHB 01/09/A, 2004.
10. M.-C. Lepy, P. Brun, C. Collin, J. Plagnard, *Experimental validation of coincidence summing corrections computed by the ETNA software*, Applied Radiation and Isotopes, **64**, 1340–1345 (2006).