Journal of Radioanalytical and Nuclear Chemistry, Articles, Vol. 125, No. 1 (1988) 3–10

EFFICIENCY CALIBRATION AND SUMMATION EFFECTS IN GAMMA-RAY SPECTROMETRY

H. N. ERTEN,* Ş. AKSOYOĞLU** H. GÖKTÜRK**

**Chemistry Department, Bilkent University, Bilkent, Ankara (Turkey)*
***Chemistry Department, Middle East Technical University, Ankara (Turkey)*

(Received September 16, 1987)

Precise, absolute γ-ray efficiences (ϵ_γ) and total efficiences (ϵ_T), have been measured at various distances from the detector, using a set of standards. The observed linear variation of ϵ_γ and ϵ_T as well as $\epsilon_\gamma/\epsilon_T$ with E_γ and $1/\sqrt{d}$ provides a simple means of interpolation and extrapolation. Experimental coincidence summation effects were determined for various nuclides and compared with calculated values. The results are found to be in good agreement with each other.

Introduction

The accuracy of many gamma-spectrometric measurements is not as high as it should be. Some of the likely sources of errors include geometry effects, dead-time effects and coincidence summing effects. The errors can be minimized if the samples and the standards are of the same size, shape, material and density. They should be placed at the same positions relative to the detector. If a radionuclide being measured has a decay scheme involving cascading transitions the areas of the individual γ-lines can be seriously distorted because of true coincidence summing effects. Furthermore, these summation effects become increasingly significant as one places the samples closer to the detector. Random coincidence summing becomes important only at relatively high activities and does not depend on the decay scheme. Previous work on efficiency calibration and summation effects in γ-ray spectrometry are given in References 1–9. To illustrate the calculation of true coincidence summing, let us consider a species with a decay scheme similar to that shown in Fig. 1. The photopeak γ_1 will contain too many counts because of photopeak-photopeak coincidences of γ_2 and γ_3. The photopeaks γ_2 and γ_3 will both contain too few counts because of coincidences between the two. Neglecting angular correlations, these effects are given quantitatively by the following equations

$$FE_1 = \frac{f_2 \cdot \epsilon\gamma_2 \cdot f_3 \cdot \epsilon\gamma_3}{f_1 \cdot \epsilon\gamma_1}, \qquad (1)$$

Elsevier Sequoia S. A., Lausanne
Akadémiai Kiadó, Budapest

$$FL_2 = f_3 \cdot \epsilon_{T3}, \tag{2}$$

$$FL_3 = f_2 \cdot \epsilon_{T2} \tag{3}$$

where FE_1 – fractional excess of photopeak γ_1,
FL_1 – fractional loss of photopeak γ_1,
$\epsilon\gamma_1$ – absolute photopeak efficiency of photopeak γ_1,
$\epsilon\gamma_1$ – absolute total efficiency of photopeak γ_1,
f_1 – fractional emission factors of unconverted γ_1 photons.

For an arbitrarily complex decay scheme general forms of the equations given above may be derived considering direct and indirect cascades. Various publications[4-7] may be consulted for such calculations.

As is seen in the equations given above, summation effect calculations involve both photopeak efficiency $\epsilon\gamma$, as well as tottal efficiency ϵ_T values. In this work ex-

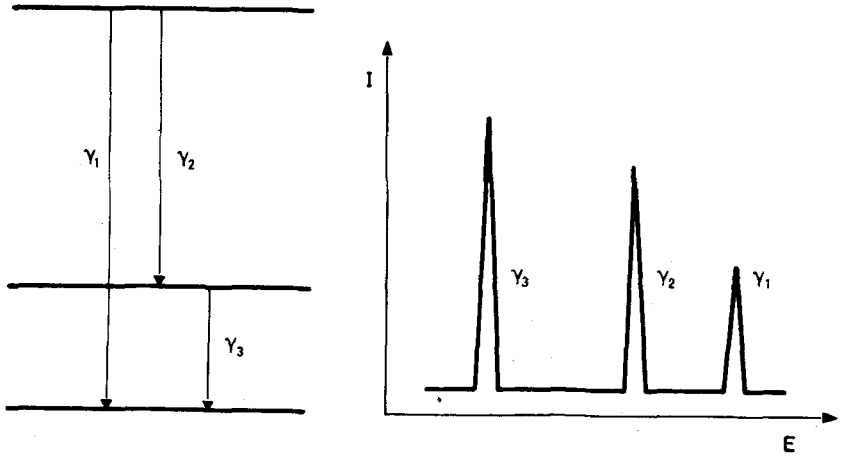

Fig. 1. Energy levels and gamma-ray photopeaks considered in summation effect calculations

perimental $\epsilon\gamma$ and ϵ_T values were determined at various distances from the detector. Simple ways of interpolation and extrapolation are suggested. Experimental coincidence summation effects were determined for some nuclides and compared with calculated values.

Experimental

The detector employed in the measurements was a coaxial cylindrical Ge(Li) detector with an active volume of 35 cm^3. It was used in conjunction with a 4096-channel analyzer. The energy resolution of the 1332 keV peak of ^{60}Co was 2.5 keV.

Table 1
Standard nuclides used in the studies

Standard	Half-life	Gamma-energy, keV	Absolute intensity	Reference
^{241}Am	458 y	59.5	35.3	10
^{57}Co	271.6 d	122.1	85.5	11
		136.4		
^{133}Ba	10.7 y	276.3	7.1	12
		302.7	18.3	
		355.8	62.3	
		383.7	8.9	
^{137}Cs	30 y	661.6	85.0	11
^{54}Mn	312.5 d	834.8	99.98	11
^{22}Na	2.6 y	1274.5	99.97	11
^{60}Co	5.263 y	1173.2	99.87	11
		1332.5	99.98	
^{88}Y	107 d	898.0	94.6	8
		1836	99.47	
^{152}Eu	13 y	40	46.0	10
		45.4	9.0	
		244.7	7.2	
		344.2	31.4	
		411.0	2.5	
		443.0	3.3	
		778.0	15.2	
		867.4	5.1	
		964.0	17.3	
		1085.0	10.0	
		1112.0	16.4	
		1407.9	24.3	
^{182}Ta	115 d	67.7	51.0	10
		100.1	11.9	
		222.0	7.98	
		1121.2	37.0	
		1221.3	28.9	

Efficiency measurements were made using a set of radioactive standards given in Table 1. All of the standards used were point sources with a diameter of about 0.1 mm. The sources were counted at various source-to-detector distances ranging from 0.65 to 34.3 cm. In all measurements dead time corrections were below 10%. For total efficiency measurements single line standard sources are needed. The single-line sources ^{241}Am, ^{54}Mn, ^{137}Cs as well as the double-line sources ^{57}Co, ^{60}Co and ^{88}Y were used. For this purpose ^{57}Co may be taken as emitting one γ-ray of a mean

energy of 129 keV; ^{60}Co as emitting two γ-rays of a mean energy of 1253 keV per decay. In the case of ^{88}Y, which has two γ-lines at 898 keV and at 1836 keV the contribution of the 898 keV line can be subtracted from the total count rate in order to get the total efficiency for the 1836 keV γ-ray.

Experimental summing effects were determined for the nuclides ^{60}Co, ^{88}Y, ^{134}Te and ^{152}Eu by counting them at close and at far distances from the detector. In the case of ^{134}Te, it was produced in reactor irradiation, chemically separated and divided into two halves. To one of the sources, ^{137}Cs reference was added. This source was counted at various distances from the detector. The second half of the source was counted simultaneously with the first at a fixed position of 12 cm from a second detector. The latter measurements were used to correct for the decay of ^{134}Te (41.8 m) during the measurements. From the areas of various γ-lines, after correction for differences in distances using the reference ^{137}Cs, experimental summing effects were determined.

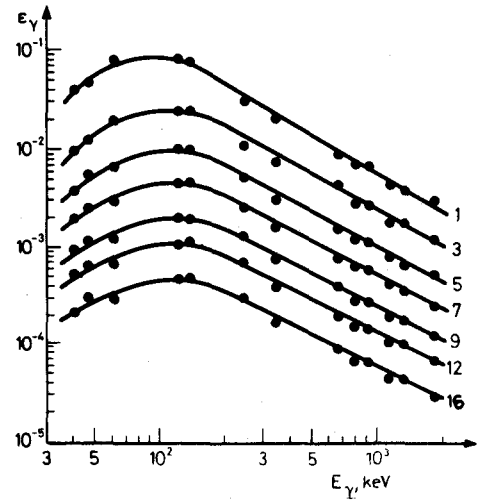

Fig. 2. Gamma-ray efficiency ε_γ, variation as a function of gamma-ray energy, E_γ. The numbers represent various positions from the detector:

Position	Distance from detector, cm
1	0.65
3	3.25
5	6.30
7	10.1
9	15.7
12	22.0
16	34.3

Results and discusion

The results of efficiency measurements are given in Figs 2 and 3. Figure 2 shows the variation of the photopeak efficiency $\epsilon\gamma$ and Fig. 3 shows the total efficiency ϵ_T variation, at seven different distances from the detector. It is seen that above about 100 keV the variation of both $\epsilon\gamma$ and ϵ_T as a function of energy is approximately linear at all distances when plotted on a log-log scale.

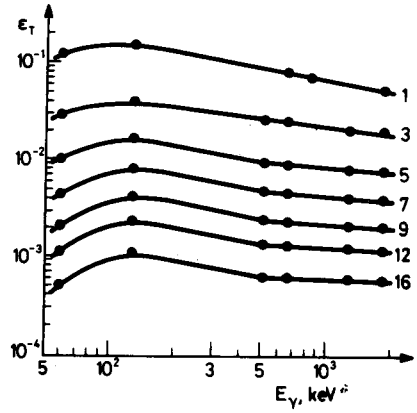

Fig. 3. Total efficiency ϵ_T variation as a function of gamma-ray energy E_γ. The numbers represent various positions from the detector. The corresponding distances (in cm) are as given in the caption of Fig. 2

Figure 4 shows the variation of $\epsilon\gamma$ and ϵ_T values as a function of distance from the detector for various energy γ-rays. Except for positions very near the detector, $\epsilon\gamma$ and ϵ_T change linearly with $1/\sqrt{d}$, where d is the distance from the detector. Furthermore, it was observed that the ratio $\epsilon_\gamma/\epsilon_T$ changes smoothly and approximately linearly with E_γ as shown in Fig. 5. On the other hand, $\epsilon_\gamma/\epsilon_T$ did not vary much with distance from the detector for a particular E_γ energy. Each point shown in Fig. 5 represents the average of values measured at sixteen different distances from the detector. The errors given are the standard deviations of these average values.

Often in γ-ray spectroscopy one measures several γ-lines at various distances from the detector. These measurements necessitate the knowledge of ϵ_γ and ϵ_T values. A simple and reliable method of interpolation and/or extrapolation of such efficiency values will be of outmost importance. The linear variation of ϵ_γ and ϵ_T as well as $\epsilon_\gamma/\epsilon_T$ with E_γ and $1/\sqrt{d}$ as pointed above provides such a simple means of estimation of these values.

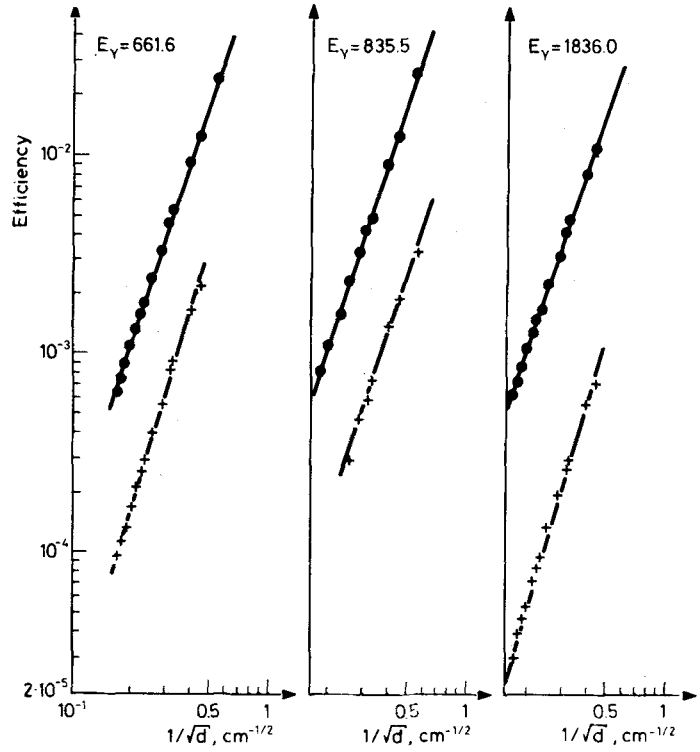

Fig. 4. Variation of ϵ_γ and ϵ_T values as a function of distance from the detector for various energy γ-rays. Points represent ϵ_T and crosses ϵ_γ values

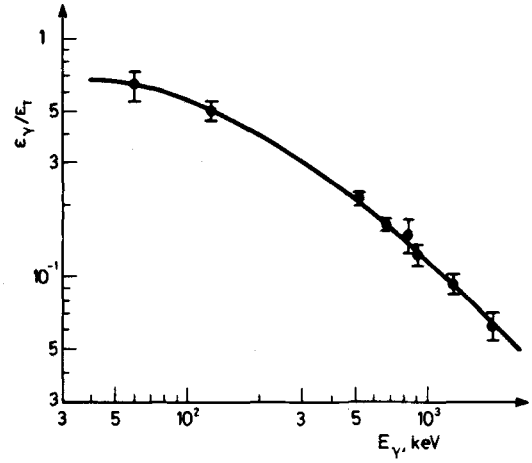

Fig. 5. Variation of $\epsilon_\gamma/\epsilon_T$ ratio with γ-ray energy. Each point represents average $\epsilon_\gamma/\epsilon_T$ values for sixteen different positions from the detector. The errors shown are the standard deviations of the average values

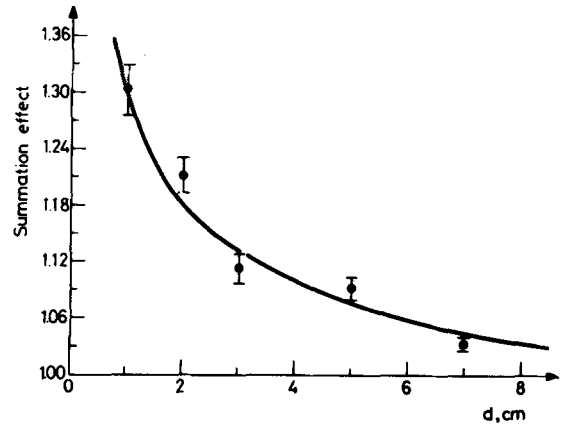

Fig. 6. Results of summation effect studies in ^{134}Te as illustrated for the 211 keV γ-ray. The curve represents calculated values and the points are experimentally determined values. The ordinate gives the summation correction factors

Table 2
Experimental and calculated summation effects for some nuclides

Nuclide	Gamma-energy, keV	Distance to detector, cm	Summation correction factor	
			Experimental	Calculated
^{60}Co	1173.2	1.2	1.057	1.067
^{88}Y	1836.0	1.2	1.027	1.056
^{152}Eu	121.8	1.2	1.079	1.086
	244.7	1.2	1.121	1.157
	344.3	1.2	1.045	1.058
	411.0	1.2	1.134	1.163
	443.0	1.2	1.094	1.135
	778.9	1.2	1.105	1.116
	867.4	1.2	1.182	1.232
	964.0	1.2	1.072	1.096
	1085.0	1.2	1.019	1.984
	1112.0	1.2	1.060	1.084
^{134}Te	211.0	1.0	1.33	1.29
	211.0	2.0	1.23	1.18
	211.0	3.0	1.11	1.13
	211.0	5.0	1.09	1.08
	211.0	7.0	1.03	1.04

The results of summation effect measurements are given in Table 2. The experimental values are seen to be in good agreement with the calculated values using Eqs (1)–(3).

The results of ^{134}Te measurements are illustrated in Fig. 6 for 211 keV γ-rays. The curve represents calculated summation effects and the points are experimentally determined values.

*

The ^{134}Te measurements were made at the Institute of Nuclear Chemistry, Mainz University, Federal Republic of Germany. One of us (HNE) thanks Prof. H. O. DENSCHLAG for his kind hospitality and the Alexander von Humboldt-Stiftung for a fellowship.

References

1. G. AUBIN, J. BARRETTE, M. BARRETTE, S. MONARO, Nucl. Instr. Methods, 76 (1969) 93.
2. R. GRIFFITHS, Nucl. Instr. Methods, 91 (1971) 377.
3. L. A. McNELLES, J. L. CAMPBELL, Nucl. Instr. Methods, 109 (1973) 241.
4. G. J. McCALLUM, G. E. COOTE, Nucl. Instr. Methods, 130 (1975) 189.
5. D. S. ANDREEV, K. I. EROKHINA, V. S. ZVONOV, I. Kh. LEMBERG, Izv. Akad. Nauk. SSR, Ser. Fiz., 37 (1975) 1609.
6. K. DEBERTIN, U. SCHÖTZIG, Nucl. Instr. Methods, 140 (1973) 337.
7. R. J. GEHRKE, R. G. HELMER, R. C. GREENWOOD, Nucl. Instr. Methods, 147 (1977) 405.
8. K. DEBERTIN, U. SCHÖTZIG, Kerntechnik. 19 (1977) 420.
9. K. DEBERTIN, Nucl. Instr. Methods, 158 (1979) 479.
10. G. ERDTMANN, W. SOYKA, The Gamma-Lines of Radionuclides, KFA, Jül-100 3-AC, 1974.
11. Calibration References of the "Laboratory for Measurement of Ionizing Radiation" C. E. N. Sacley, France.
12. V. SHÖTZIG, K. DEBERTIN, J. Appl. Radiation Isotopes, 28 (1977) 503.