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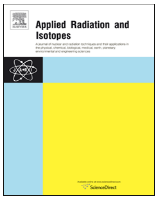

# Experimental assessment of the coincidence summing corrections in gamma-ray spectrometry of bulk samples

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## HIGHLIGHTS

- TCS-dependence on the source-to-detector distance $d$ is linearized for point source.
- A representative distance $d_V$ is evaluated in the case of volume-source TCS-effect.
- TCS-correction for volume source is evaluated on the basis of TCS-linear dependence.
- The representative distance $d_V$ is like the volume-source effective thickness $d_{eff}$.
- Parameters $d_V$ and $d_{eff}$ are related to average solid angle subtended by the detector.

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## ABSTRACT

This work presents an experimental approach for estimation of the true coincidence-summing (TCS) correction for volume sources on the basis of TCS dependence on the source-to-detector distance. Firstly, it is shown that the TCS dependence on the source-to-detector distance can be linearized for point source geometry. If this linear dependence is established then TCS correction for an arbitrary source-to-detector distance can be obtained. In the case of a volume source a representative parameter $d_V$ can be formulated as the distance at which the point-source summing effect is the same as the one for the volume-source. Then if the TCS dependence on the source-to-detector distance is established for the point-source case and the volume-source $d_V$-value is known, the TCS correction corresponding to the volume-source measuring geometry can be estimated. Experimental method and results are presented in the work too.

## 1. Introduction

An important correction applied in “close” measuring gamma-ray spectrometry is the correction for the effect of true coincidence summing (TCS).

The true coincidence summing effect is observed when two (or more) simultaneously emitted gamma-rays from a same nucleus are simultaneously detected within the resolving time of the gamma spectrometer system. The magnitude of the process depends on the detector efficiency (including source-detector measuring geometry) and on the decay-scheme parameters. TCS usually results in lower full-energy peak areas. In order to compensate the loss of counts the adequate correction is needed. Different ways (mathematical and/or experimental) to evaluate this correction were described in the basic textbooks (Debertin and Helmer, 1988; Gilmore and Hemingway, 1995), international standards (IEC 6 1452, 1995) as well as in a series of valuables works starting with (Andreev et al., 1973; Debertin and Schötzig, 1979). Mathematical precise evaluation of TCS-correction requires availability of complete data for decay scheme, internal conversion coefficients, full-energy peak (FEP) efficiency and total efficiency. Different ways and approaches for estimation of FEP and total efficiency can be applied (Blaauw and Gelsema, 2003; De Felice et al., 2000; Lépy, 2007; Piton et al., 2000; Sima and Arnold, 2000; Vidmar and Korun, 2006). Monte Carlo simulations are widely used especially for extended sources (Decombaz et al.,1992; Garcia-Torano et al., 2005; Vidmar et al., 2007). Specific codes (CSCOR, ETNA, GESPECOR, KORSUM, TRUECOINC) were developed for TCS-correction estimation (Lépy et al.,2010). Experimental data are used mostly for FEP efficiency estimation and/or for validation of analytical and Monte Carlo calculations.

Irrespective of mode for TCS-correction estimation, the obtained correction value is unique – it is valid only for the given detector, measuring geometry, sample properties and for the respective gamma-line of the respective nuclide. In this sense, each laboratory in its turn has to evaluate TCS-corrections applicable to the given

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measuring conditions. But we have to draw attention to the fact that some laboratories have no appropriate software available and it impedes the TCS-correction estimation particularly for nuclides with complex decay scheme and/or for extended sources. In that case the “pure” experimental contrivance may be useful.

In this paper we report on an experimental approach to estimate TCS correction coefficients for volume sources on the basis of TCS dependence on the source-to-detector distance.

## 2. Method

It is well known that the number of TCS events strongly depends on the measuring geometry – the closer the source to the detector is, the greater the TCS probability will be.

Let us assume that $n$ is the full-energy count rate in the presence of a coincidence-summing effect, $n_t$ – the full-energy count rate in the absence of a coincidence-summing effect, $n_c$ – the loss of the full-energy count rate owing to the coincidence-summing effect and $C_c$ – the TCS correction coefficient. Then the following relations are valid: $n = n_t - n_c$ and $n_t = nC_c$, which leads to: $\frac{n_t}{n_c} = \frac{C_c}{C_c - 1}$. Bearing in mind that for point source measuring geometry $n_t$ depends on the source-to-detector distance $d$ as $\sim 1/\mathrm{d}^2$ and $n_c$ depends on $d$ as $\sim 1/d^4$, we can assume that $\frac{n_t}{n_c}$ (as well as $\frac{C_c}{C_c-1}$) will depend on the source-to-detector distance as $\sim d^2$. Then $\sqrt{\frac{C_c}{C_c-1}} \sim d$, i.e. we can assume that for point source measuring geometry the following dependence is valid:

$$\sqrt{\frac{C_c}{C_c - 1}} = ad + b \tag{1}$$

where $a$ and $b$ are the linear function parameters. If $C_c$-values (experimentally or mathematically evaluated) are available for minimum two $d$-values, the dependence (1) can be established and $C_c$-values for an arbitrary source-to-detector distance can be obtained.

To demonstrate the dependence (1) here we use data from (Lépy et al., 2006), where the values of the coincidence summing corrections $C_c$ are computed by the ETNA software and experimentally validated for different source-to-detector distance $d$. Using ETNA-computed $C_c$-values from (Lépy et al., 2006) the respective $\sqrt{\frac{C_c}{C_c-1}}$-values were calculated. In Fig. 1 the calculated $\sqrt{\frac{C_c}{C_c-1}}$-values are presented vs the $d$-values for some gamma-rays emitted from some radionuclides. Data for $d = 1$, 3, 5, 8 and 10 cm were utilized. (The results for $d = 15$ cm were neglected because of their great uncertainties). It can be seen from Fig. 1 that dependence (1) describes well the $C_c$-data from (Lépy et al., 2006).

The straight lines in Fig. 1 are fitted through five points covering distances from 1 to 10 cm. Furthermore, it is easy to ascertain (using the same $C_c$-data according to (Lépy et al., 2006)) that if the dependence (1) is established by means of only two points close to the detector ($d = 1$ and 3 cm) then for the remote source positions ($d = 5$, 8, 10, 15 cm) the calculated through the fit $C_c$-values deviate from the real (ETNA-computed) $C_c$-values less than 1%.

Although the above presented examples concern the case when the coincidence-summing effect leads to loss of the full-energy count rate (i.e. the case when $C_c > 1$), it can be assumed that the method will be workable also in the case when $C_c < 1$. It can be shown that in the case when the coincidence-summing effect leads to increase of the full-energy count rate the term linear in the source-to-detector distance $d$ will be $\sqrt{\frac{C_c}{1-C_c}}$. The last is illustrated in Fig. 2 where the calculated $\sqrt{\frac{C_c}{1-C_c}}$-values are presented vs the $d$-values for 1365 keV gamma-line emitted from $^{134}$Cs. Again ETNA-computed $C_c$-values from (Lépy et al., 2006) were utilized.

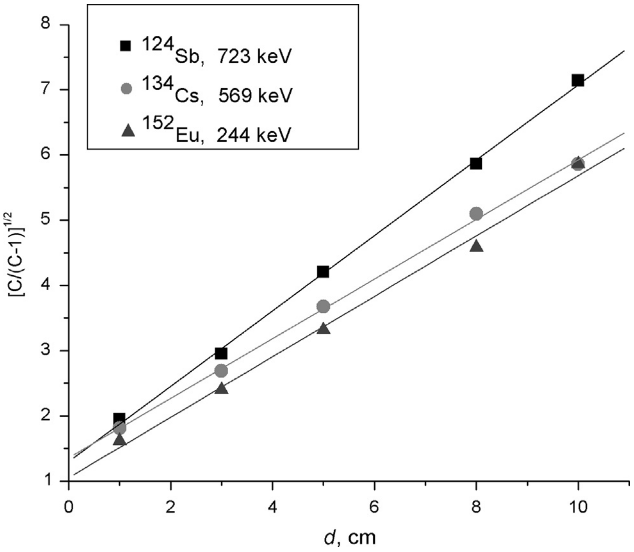

**Fig. 1.** TCS-effect vs source-to-detector distance $d$ for some gamma-rays emitted from some radionuclides. ETNA-computed $C_c$-values from (Lépy et al., 2006) were utilized. The solid lines were obtained by fitting a linear function (1) by means of the method of least squares.

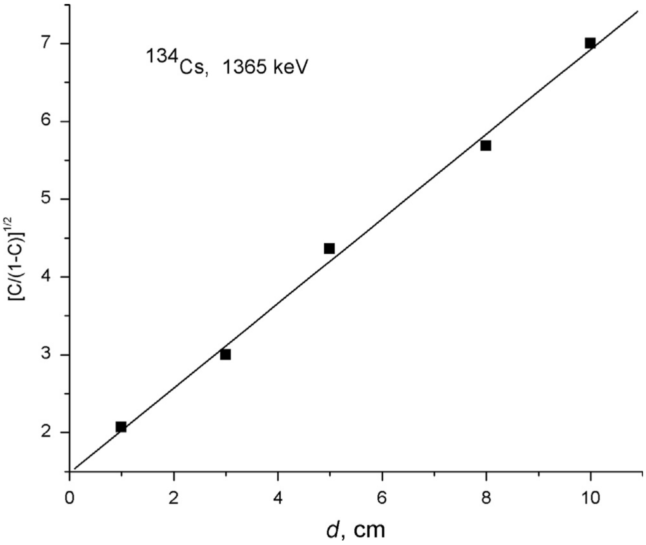

**Fig. 2.** TCS-effect vs source-to-detector distance $d$ for the case when $C_c < 1$. ETNA-computed $C_c$-values from (Lépy et al., 2006) were utilized. The solid line is obtained by means of the method of least squares.

Unfortunately, the above approach is inapplicable to the case of volume sources. The summing effect for volume-source measuring geometry will depend on each individual volume element and its distance from the detector. But we can introduce an effective distance $d_V$ (a representative parameter of the particular volume-source measuring geometry) as the distance at which the point-source summing effect is the same as the one for the volume-source. Then if the dependence (1) (i.e. the $a$- and $b$-values) is established for the point-source case and the volume-source $d_V$-value is known, the $C_c$-values corresponding to the volume-source measuring geometry can be estimated. In the general case the volume-source $d_V$-value is unknown, but we can evaluate it using some easy to access experimental data – for instance, the volume sources spectra intended for system's calibration. In this sense, here and below we will assume that some “coincidence” radionuclides ($i$) are “easy to access”, i.e., radionuclides which are