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Simple method for absolute activity measurement of ^{60}Co source

Istvan Bikit *, Tomas Nemes, Dusan Mrda

Department of Physics, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovica 4, 21000 Novi Sad, Serbia

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ABSTRACT

The activity of ^{60}Co source was measured using the full absorption, sum and random coincidence (pile-up) peaks and the total spectrum area. It is shown that if the true and random coincidences in the single detector are treated correctly, no additional data are needed for absolute source strength measurement. With the source on the detector end-cap (when the angular correlation effects are negligible), this simple method yields absolute activity values deviating from the reference activity by about 1%.

1. Introduction

The multi-detector source strength measurement by coincidence counting has been, for a long time, accepted as a unique absolute calibration method [1]. However the absolute source strength measurements by a single detector based on the coincidence summing are much less recognized.

The sum-peak method was introduced in a series of papers by Brinkman et al. [2–5]. They canceled out the problem of angular correlation between the two gamma rays emitted in cascade by placing the point source of ^{60}Co on the top of the detector crystal.

Moving the source further away from the detector, accurate activity measurements by the sum-peak method require angular correlation corrections. Using the Monte Carlo method, Kim and collaborators [6] theoretically calculated angular correlation corrections, which were later successfully applied for activity measurements of point sources of ^{60}Co also by Kim et al. [7]. They obtained spectra of point sources of ^{60}Co at different distances from the HPGe detector end-cap. For each distance, they vary the shaping time of an amplifier and calculate activities. Extrapolating the linear function of activities vs. shaping time of the amplifier for each source and distance from detector to zero shaping time, they achieved excellent accuracy (less than 2% deviation from the reference activity), keeping the total count rate below $15\times10^3\,\mathrm{s}^{-1}$.

Activity measurements for extended sources of ^{60}Co by the sum-peak method are freshly reported by Vidmar et al. [8]. They used Monte Carlo calculations to account for the effects of the special variation of the efficiency across the sample volume and for angular correlations between the emitted gamma rays. In the sources they used, total count rates were less than $1.5\times10^3\,\mathrm{s}^{-1}$, and the determined activities agreed with their reference values within 1%.

All the methods listed above use additional data besides spectral intensity. In the present paper it is shown that by exact treatment of chance coincidence and pile-up events, the source activity can be absolutely measured from the data in the single spectrum, when angular correlation effects are negligible.

2. Summing effects in the ^{60}Co spectrum

The decay scheme of ^{60}Co is very simple (Fig. 1). There are two intensive gamma rays at energies 1173 and 1332 keV, which are in 99.85% of all decays emitted in the cascade. The probability for the cross-over gamma ray emission with the energy of 2505 keV is negligible.

For the decay scheme of ^{60}Co, the net peak area equations (originally developed by Brinkman and Aten [5]) can be written as follows:

$$N_1 = At\varepsilon_1(1-\varepsilon_{T2}w)L_\tau \tag{2.1}$$

$$N_2 = At\varepsilon_2(1-\varepsilon_{T1}w)L_\tau \tag{2.2}$$

where N_1 and N_2 are net peak areas of the full absorption peaks, A is the activity of ^{60}Co, ε_1 and ε_2 are the full absorption peak efficiencies, ε_{T1} and ε_{T2} are the total efficiencies, subscripts 1 and 2 denote the gamma rays at 1173 and 1332 keV, respectively, and t is the time of measurement. The angular correlation factor w is the same for any combination of detections of the two gamma rays, which is verified by Kim et al. [6]. L_τ is the correction factor for

* Corresponding author. Tel.: +381 21 459 368; fax: +381 21 459 367.
E-mail address: bikit@im.ns.ac.yu (I. Bikit).

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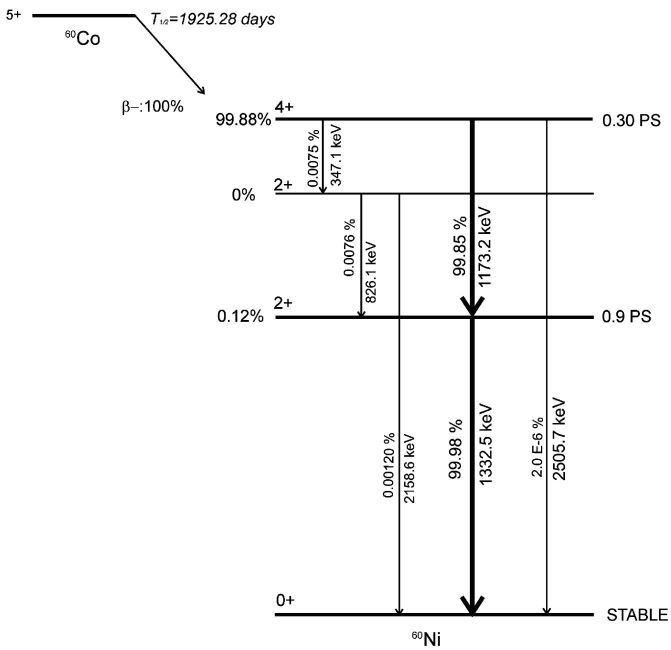

Fig. 1. Decay scheme of ^{60}Co. Probability for emitting gamma rays of energies 1173 and 1332 keV in cascade is 0.9985, while direct emission of gamma ray 2505 keV is 2.0×10^{-8}. Other gamma transitions have probability less than 10^{-5}.

losses from full energy peaks due to finite time resolution of the system. The sum-peak net area is

$$N_{\Sigma} = At\varepsilon_1\varepsilon_2 w L_{\tau} + N_C \tag{2.3}$$

where N_C is the number of counts due to chance coincidence events of two totally absorbed gamma rays of energies 1173 and 1332 keV. Neglecting losses due to finite time resolution of the system, the total spectrum area can be expressed as

$$N_T = At(\varepsilon_{T1} + \varepsilon_{T2} - \varepsilon_{T1}\varepsilon_{T2}w). \tag{2.4}$$

Hence from Eqs. (2.1)–(2.4), the activity A is given by

$$A = \frac{1}{t}\left[\frac{N_1 N_2}{(N_{\Sigma} - N_C)L_{\tau}} + N_T\right]w. \tag{2.5}$$

3. Chance coincidences and losses from full energy peaks in the spectrum of ^{60}Co

The rate of chance coincidences in the two-detector experiment, where DET 1 registers only energy 1 in the cascade and DET 2 only energy 2 in the cascade, is given by

$$R_C = 2\tau R_1 R_2, \tag{3.1}$$

where R_1 and R_2 are the detector count rates while 2τ is the resolving time of the coincidence circuit. In the single-detector experiment, 2τ is the effective time in which the detection system cannot resolve two events due to chance coincidence or pulse pile-up. This will lead to count losses from full energy peaks that will appear in the spectral continuum. The gain in the sum-peak due to coincidence events from totally absorbed gamma rays of energies 1173 and 1332 keV and losses from peaks due to chance coincidence events can be described making use of 2τ as the time resolution of the spectrometer system.

If the two gamma rays, emitted from different nuclei, are totally absorbed in the detector within the time interval 2τ, in the spectrum will also appear peaks due to chance coincidences only. So beside the sum peak (N_{Σ}), in the ^{60}Co spectrum, 2×1173 and 2×1332 keV peaks are present (Fig. 2).

These random coincidence peak areas can be related to the effective resolving time 2τ by the relations

$$N_{C1} = 2\tau A^2 t(\varepsilon_1(1 - \varepsilon_{T2}w))^2 \tag{3.2}$$

and

$$N_{C2} = 2\tau A^2 t(\varepsilon_2(1 - \varepsilon_{T1}w))^2. \tag{3.3}$$

In the above Eqs. (3.2) and (3.3), losses from counts due to third-order chance coincidences are assumed to be negligible.

The chance coincidence summing probability in a single detector is different for the 1173–1173, 1332–1332 and 1173–1332 events (Fig. 3.). If the 1173 keV gamma ray from one nucleus is emitted, it can be summed only with the 1173 keV gamma ray from another nucleus to give the (2×1173 keV) peak with the probability proportional to N_{C1}. It is the same case with the (2×1332 keV) random sum peak. However, the random sum peak at the energy 2505 keV may originate from the combinations 1173+1332 and 1332+1173, thus having two times higher probability than the previous ones.

Therefore chance coincidence counts in the sum peak, neglecting a third-order chance coincidence losses, can be written as follows:

$$N_C = 4\tau A^2 t\varepsilon_1\varepsilon_2(1 - \varepsilon_{T1}w)(1 - \varepsilon_{T2}w). \tag{3.4}$$

Making use of Eqs. (3.2), (3.3) and (3.4), the chance coincidence contribution to the sum peak can be expressed as

$$N_C = 2\sqrt{N_{C1}N_{C2}}. \tag{3.5}$$

Due to finite time resolution (2τ) of the detection system, some counts will be lost from the full energy and true coincidence peaks and collected in other parts of the spectrum. The correction factor for these losses is connected with 2τ by the relation

$$L_{\tau} = 1 - 2\tau A(\varepsilon_{T1} + \varepsilon_{T2} - \varepsilon_{T1}\varepsilon_{T2}w) \tag{3.6}$$

which gives, taking the total counts from Eq. (2.4),

$$L_{\tau} = 1 - \frac{2\tau N_T}{t}. \tag{3.7}$$

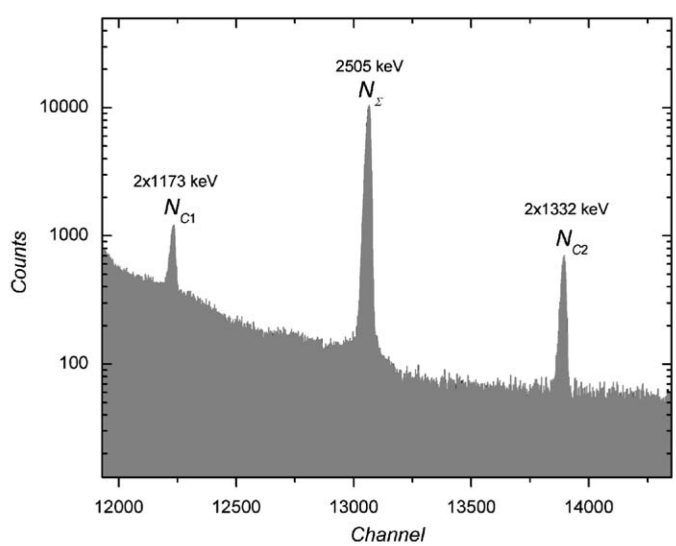

Fig. 2. Spectrum from point source of ^{60}Co (reference activity: 246.1 kBq) placed on the HPGe detector end-cap used in this study. The time of measurement was 600 s live time. Besides the sum-peak at energy 2505 keV there are peaks appearing due to chance coincidences. The counts above 2664 keV are caused by multiple pile-up and random coincidence events.