Experimental Validation of True Coincidence Summing Correction Factors for ^{60}Co and ^{152}Eu Using EFFTRAN in Point Source Geometry

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INTRODUCTION

- Gamma-ray spectrometry is widely used for the qualitative and quantitative analysis of radionuclides in environmental, industrial, and nuclear applications. True coincidence summing (TCS) is one of the most significant sources of error in gamma-ray spectrometry, particularly in close-geometry measurements involving cascade-emitting radionuclides. TCS results in either summing losses or summing peaks in the measured spectrum due to the simultaneous detection of cascade gamma rays emitted during the same nuclear decay. Consequently, the measured peak intensities deviate from their true values, leading to significant errors in activity determination and efficiency calibration.
- In this study, TCS correction factors for point-source geometry were evaluated for ^{152}Eu and ^{60}Co using both experimental method and the EFFTRAN code.

MATERIALS

- Gamma-ray measurements were carried out using a p-type coaxial HPGe detector at the Low-Level Radioactivity Measurements Laboratory of the Energy Institute, Istanbul Technical University. The detector has a relative efficiency of 40% and an energy resolution of 1.8 keV for the 1332 keV gamma ray of ^{60}Co.
- Standard gamma-emitting point sources (^{241}Am, ^{57}Co, ^{137}Cs, ^{54}Mn, and ^{65}Zn) were used to establish a TCS-free efficiency calibration, while ^{60}Co and ^{152}Eu point sources were used to evaluate the effects of true coincidence summing (TCS).

Figure 1. The HPGe detector and radioactive point sources used in the measurements.

METHODOLOGY

1. The experimental efficiency values were determined for ^{241}Am, ^{57}Co, ^{137}Cs, ^{54}Mn, and ^{65}Zn point sources at a source-to-detector distance of 10 cm:

$$\varepsilon = \frac{\frac{N_p}{t_m}}{A \times I_\gamma}$$

where ε is the efficiency, N_p is the net counts measured in the full-energy peak, A is the activity of the radionuclide, t_m is the measurement (live) timei and I_γ (%) is the gamma emission probability.

*TCS correction is not required for single-energy point sources. Since the TCS correction factors obtained for ^{57}Co were approximately equal to 1, ^{57}Co was used in establishing the experimental efficiency calibration curve.

2. The experimental efficiency data were fitted using a logarithmic function [$\boldsymbol{\varepsilon = A + B * ln(E) + C * ln(E)^2 + D * ln(E)^3}$] to obtain a continuous efficiency curve.

Table 1. Experimental and fitted efficiency values.

Nuclide	Energy (keV)	$\varepsilon_{exp} \pm u(\varepsilon_{exp})$%	ε_{fitted}	Difference (%)
Am-241	59.5	0.0125 ± 0.22	0.0125	-0.11
Co-57	122.1	0.0131± 0.85	0.0133	1.39
Co-57	136.5	0.0130 ± 1.01	0.0128	-0.96
Cs-137	661.7	0.0039 ± 0.32	0.0040	1.06
Mn-54	834.8	0.0033 ± 0.68	0.0033	0.54
Zn-65	1115.5	0.0026 ± 0.99	0.0026	2.79

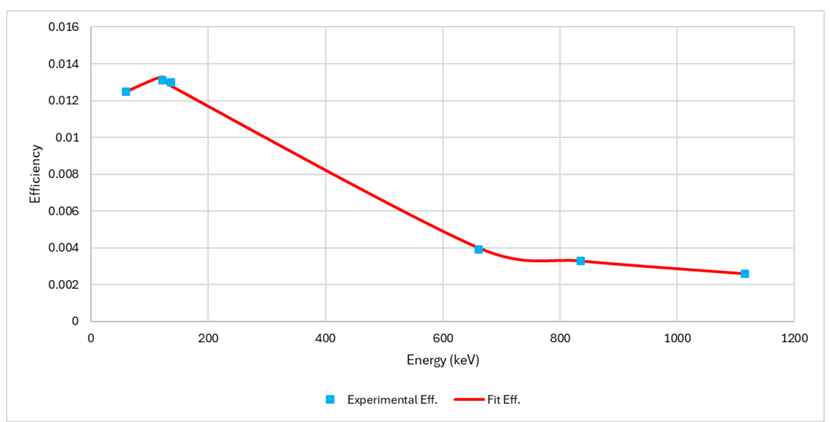

Figure 2. Experimental and fitted efficiency curves.

3. TCS-effected efficiencies of (ε_{exp}) were calculated from the measured spectra of ^{152}Eu and ^{60}Co. TCS-free efficiency values (ε_{fit}) for ^{152}Eu and ^{60}Co were derived from the fitted curve shown in Figure 2.

Table 2. Efficiency values for ^{152}Eu and ^{60}Co.

Nuclide	Energy (keV)	$\varepsilon_{exp} \pm u(\varepsilon_{exp})$%	ε_{fit}	Difference (%)
Eu-152	121.8	0.0129 ± 3.01	0.0133	3.51
Eu-152	244.7	0.0086 ± 3.05	0.0092	7.20
Eu-152	344.3	0.0066 ± 3.01	0.0070	6.34
Eu-152	411.1	0.0057 ± 3.17	0.0060	5.72
Eu-152	444.0	0.0059 ± 3.12	0.0056	-3.87
Eu-152	778.9	0.0034 ± 3.03	0.0035	1.80
Eu-152	867.4	0.0031± 3.16	0.0032	3.78
Eu-152	964.1	0.0029 ± 3.03	0.0029	1.64
Eu-152	1085.8	0.0026 ± 3.06	0.0027	4.40
Eu-152	1112.1	0.0026 ± 3.04	0.0026	2.37
Eu-152	1408.0	0.0025 ± 3.01	0.0025	7.13
Co-60	1173.2	0.0023 ± 3.01	0.0024	0.21
Co-60	1332.5	0.0021 ± 3.03	0.0023	1.31

METHODOLOGY

4. In the first method, the experimental TCS correction factors for ^{152}Eu and ^{60}Co were calculated using the following equation together with the ε_{exp} and ε_{fit} values from Table 2.

$$TCS = \frac{\varepsilon_{fit}}{\varepsilon_{exp}}$$

5. In the second method, the TCS correction factors were calculated using the EFFTRAN code based on the detector specifications provided by the manufacturer and the experimental conditions.

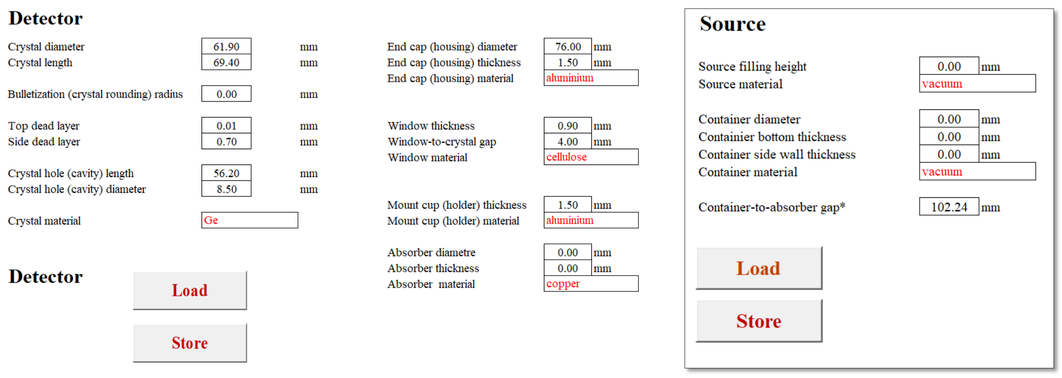

Figure 3. Detector and source geometry and structural parameters used in the EFFTRAN calculations.

RESULTS

- TCS correction factors obtained experimentally and calculated using the EFFTRAN code were presented in Table 3.
- The comparison of the experimental and EFFTRAN results demonstrated good agreement, with deviations varying between 0.1% and 7.4% over the investigated gamma-ray energy range.

Table 3. Comparison of TCS factors.

Nuclide	Energy (keV)	TCS correction factors determined experimentally	TCS correction factors calculated by EFFTRAN	% Difference
Eu-152	121.8	1.036	1.027	0.91
Eu-152	244.7	1.078	1.043	3.21
Eu-152	344.3	1.068	1.010	5.40
Eu-152	411.1	1.061	1.022	3.65
Eu-152	444.0	0.963	1.034	-7.40
Eu-152	778.9	1.018	1.013	0.52
Eu-152	867.4	1.039	1.042	-0.26
Eu-152	964.1	1.017	1.028	-1.12
Eu-152	1085.8	1.046	1.004	4.02
Eu-152	1112.1	1.024	1.023	0.13
Eu-152	1408.0	1.077	1.025	4.80
Co-60	1173.2	1.002	1.011	-0.89
Co-60	1332.5	1.013	1.011	0.22

- The largest deviation was observed for the 444.0 keV gamma line of ^{152}Eu (−7.4%). This difference may originate from limitations in the detector model employed in the EFFTRAN calculations. As detailed detector characterization using the Monte Carlo (MC) method has not yet been carried out, parameters such as the effective detector dimensions and dead-layer thickness remain uncertain. Consequently, these uncertainties may influence the calculated efficiencies and TCS correction factors.

CONCLUSION

- In this study, true coincidence summing (TCS) correction factors for ^{152}Eu and ^{60}Co were determined both experimentally and using the EFFTRAN code. Good agreement was observed between the experimental and computational results, despite the absence of detailed detector characterization. This agreement demonstrates the validity and applicability of the proposed experimental approach for determining TCS correction factors.
- The proposed method offers a practical, rapid, and straightforward alternative for calculating TCS correction factors when detailed detector modeling is either unavailable or unnecessary.
- The present study forms part of an ongoing project focused on HPGe detector characterization. Monte Carlo (MC)-based detector characterization studies are currently in progress to further improve the accuracy and reliability of TCS calculations.

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ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under Project No. 124F493, titled “Characterization of a High-Purity Germanium Detector Using Experimental and Monte Carlo Simulation Methods and Its Application to Radioactivity Measurements.” The authors gratefully acknowledge the financial support provided by TÜBİTAK.