



Simulation based study on activity of gamma sources for different source to detector separation in scintillation detector

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Abstract: In cascade gamma-ray decays, coincident gamma photons may deposit their energies simultaneously within the active volume of a detector, resulting in the formation of a composite gamma spectrum. Such coincidence events give rise to sum peaks that appear in addition to the individual photo-peaks. These sum peaks provide a quantitative basis for absolute activity determination of radioactive sources. The modified sum-peak method offers a precise and reliable approach for performing these measurements. In the present study, this method has been employed to conduct both experimental measurements and Monte Carlo simulations of the total count rate under the full energy spectrum, as well as the peak count rates corresponding to individual gamma lines, using a 2"×2" NaI(Tl) scintillation detector. Double gamma-emitting radionuclides such as Co-60, Nb-94, Sc-46, and Na-24 were investigated. The formalism was validated using a ⁶⁰Co source, where the modified sum-peak method proved highly effective in determining the source activity. The measured activity was in good agreement with the results obtained from GEANT4 simulations. *Key words:* Modified sum-peak method, Activity, GEANT4

INTRODUCTION

The radioactivity of a sample is commonly determined through relative measurements [1]. The activity of gamma-emitting sources is generally obtained from a calibration curve of photopeak efficiency as a function of gamma-ray energy. However, when a sample contains more than one radionuclide, the determination of activity becomes more complex. In recent years, a modified sum-peak method has been introduced to determine the absolute activity of gamma sources. For radionuclides such as ⁶⁰Co, ¹³⁷Cs, and ²⁴Na, the activity is typically derived from the calibration plot of full-energy peak efficiency versus gamma-ray energy for a fixed geometry. When a source emits cascade gamma rays, the coincident photons may be absorbed simultaneously within the active volume of the detector, resulting in a gamma spectrum that includes both photo-peaks and sum peaks. The appearance of sum peaks provides the basis for the sum-peak method, which offers a practical means to determine the absolute activity of gamma-emitting radionuclides. The method, first proposed by Brinkman *et al.* [2–4], is generally less accurate than the conventional $4\pi\beta\text{-}\gamma$ coincidence technique [5,6], but remains a

valuable alternative for many applications. In the present work, both experimental measurements and Monte Carlo simulations have been performed to determine the total count rate over the entire spectrum as well as the individual photopeak count rates using a 2"×2" NaI(Tl) scintillation detector. Double-gamma-emitting sources such as ^{60}Co , ^{94}Nb , ^{46}Sc , and ^{24}Na were employed under various source–detector configurations to investigate and validate the modified sum-peak methodology.

METHODOLOGY

The basic formula for the activity measurement is given by equation [i] the modified formula in given in equation [ii]

$$N=[R+N_t]*W(0) \quad [i]$$

$$R=A_1A_2/A_{12}$$

$$R=[A_1A_2/A_{12}]*W(0) \quad [ii]$$

A_1 - Count rate under the first photo peak

A_2 -Count rate under the second photo peak

A_{12} = Count rate under the sum peak

N_t – Total count rate under the whole spectrum

$W(0)$ - angular correlation between the gamma rays

In the conventional sum-peak method [7–8], determining the total count rate N_t over the entire spectrum is required. However, because the equation involves total count rate, therefore the method cannot be applied to samples containing multiple radionuclides. The advantages of this method are: (i) it depends only on directly measured quantities such as A_1 , A_2 and A_{12} (ii) it does not require any complex setup, as a single gamma spectrometer is sufficient; and (iii) it can be used for point, surface, and volume sources.

Later, Ogata *et al.* [7–9] modified the original expression slightly, as given in Eq. [i]. The significant advantage of this modified method is that the total count rate can be ignored when calculating the absolute activity.

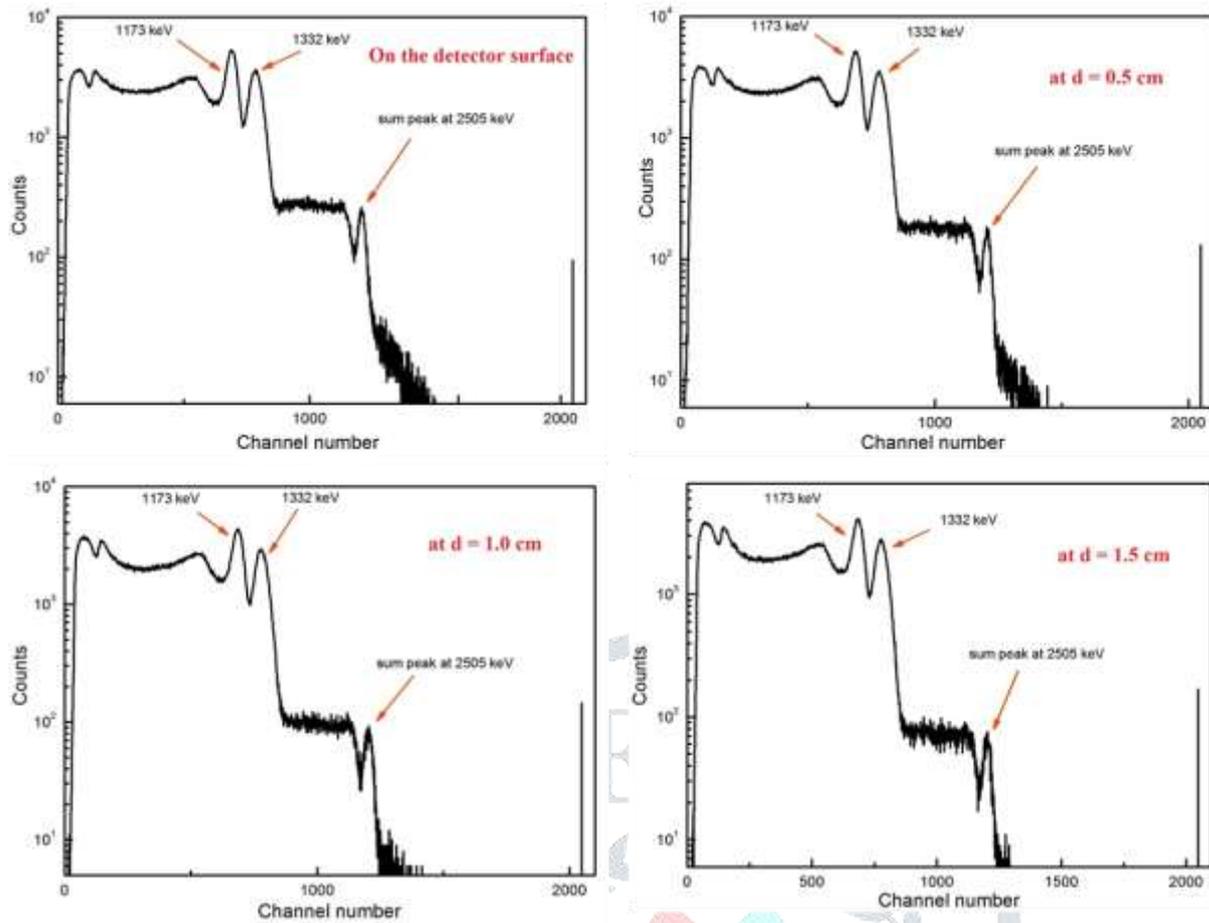


Fig.1. Measured energy spectrum of ⁶⁰Co at different source to detector separation.

Source	d (cm)	Conventional sum-peak method (mCi)	Modified sum-peak method (mCi)
²⁴ Na	0.0	30.14(0.16)	22.15(0.22)
	4.0	25.30(0.18)	18.68(0.35)
	6.0	30.46(0.30)	26.35(0.35)
	8.0	39.06(0.30)	37.15(0.40)
	10.0	35.93(0.22)	34.61(0.30)
⁹⁴ Nb	0.0	28.63(0.20)	22.26(0.19)
	4.0	28.23(0.15)	24.81(0.15)
	6.0	32.14(0.26)	29.97(0.31)
	8.0	34.36(0.30)	32.88(0.40)
	10.0	26.34(0.25)	25.27(0.22)
⁴⁶ Sc	0.0	30.01(0.22)	24.23(0.21)

	4.0	33.38(0.21)	30.28(0.15)
	6.0	35.05(0.20)	33.10(0.19)
	8.0	36.46(0.12)	35.15(0.15)
	10.0	30.18(0.20)	29.54(0.18)

Table-1. Activity of different gamma sources at different source-detection separations for different methods.

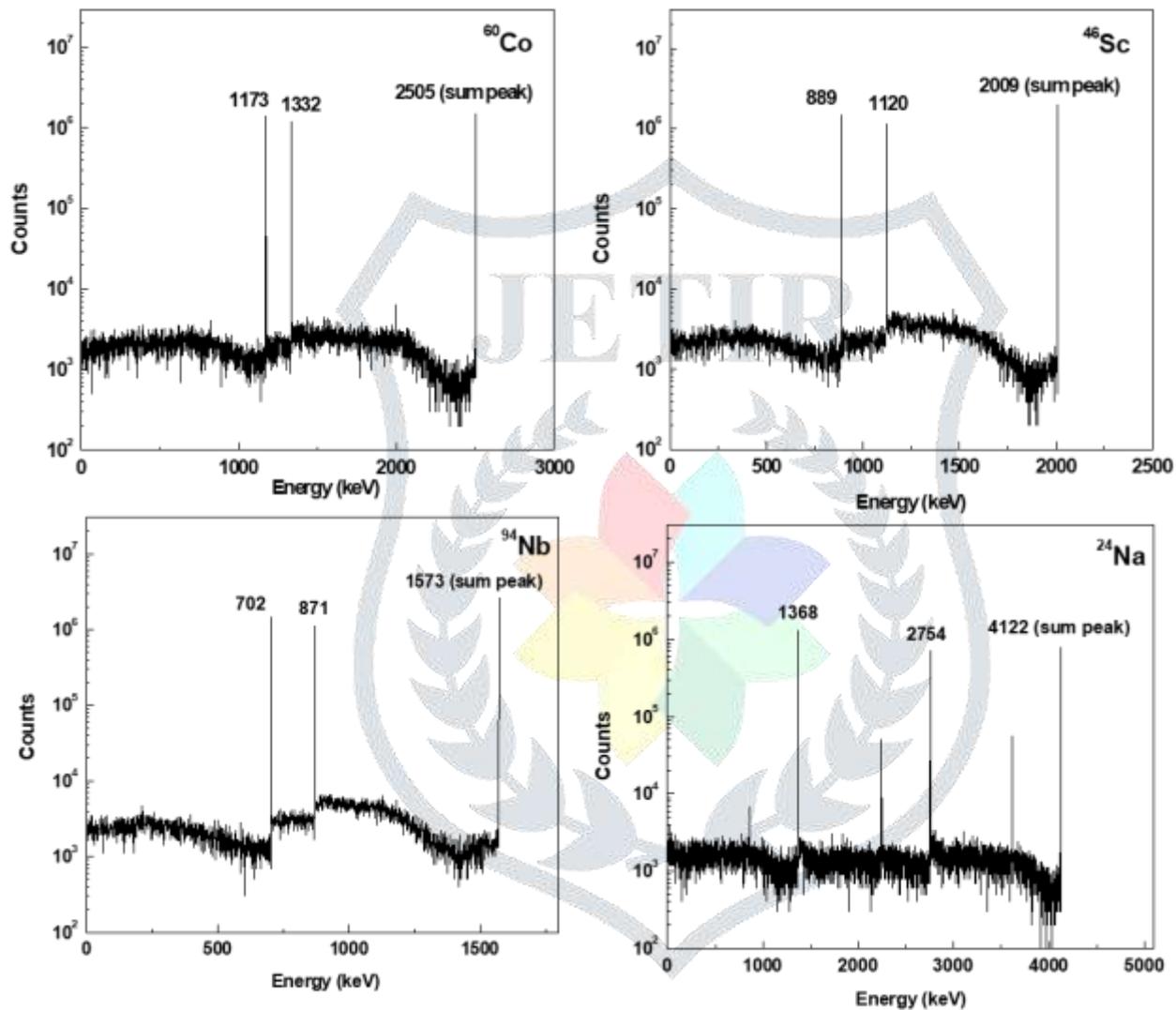


Fig.2. Simulated Energy spectrum of different gamma sources using 2"×2" NaI(Tl) detector.

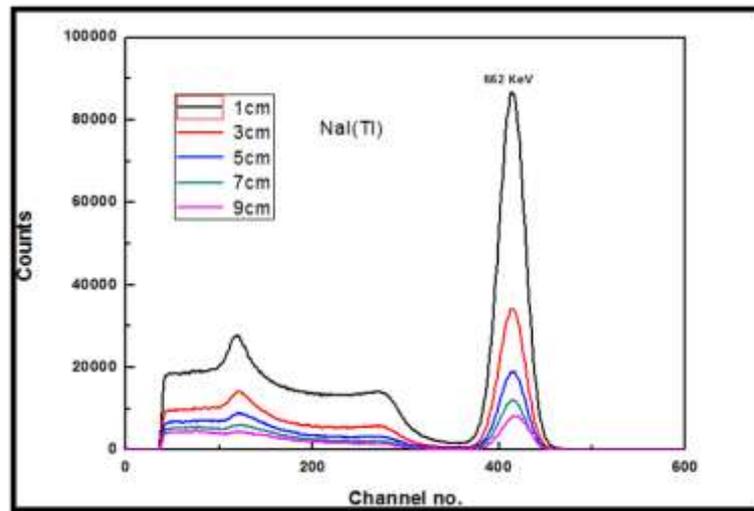


Fig.4. ^{137}Cs energy spectrum recorded using NaI(Tl) detector for different source-detector separations

Distance (cm)	Activity (in μCi) with NaI(Tl) detector	
	Experimental	Simulated
1	2.6 (0.09)	3.0 (0.13)
3	2.4 (0.11)	2.9 (0.15)
5	2.6 (0.09)	2.8 (0.19)
7	2.5 (0.09)	3.0 (0.22)
9	2-6 (0.11)	2.7 (0.21)

Table-2. Measured activity using absolute method for ^{137}Cs

Detector	Activity in Conventional Sum-peak method (μCi)		Activity in Modified Sum-peak method (μCi)	
	Simulated	Measured	Simulated	Measured
0mm	17.0(0.11)	16.8(0.03)	11.7(0.12)	10.0(0.04)
5mm	17.6(0.10)	16.5(0.04)	13.8(0.11)	12.7(0.05)
10mm	17.6(0.12)	18.1(0.05)	13.4(0.12)	15.0(0.07)
15mm	15.3(0.11)	15.4(0.07)	15.0(0.11)	14.9(0.08)

Table-3. Simulated and measured activity of ^{60}Co using 2"×2" NaI(Tl) detector.

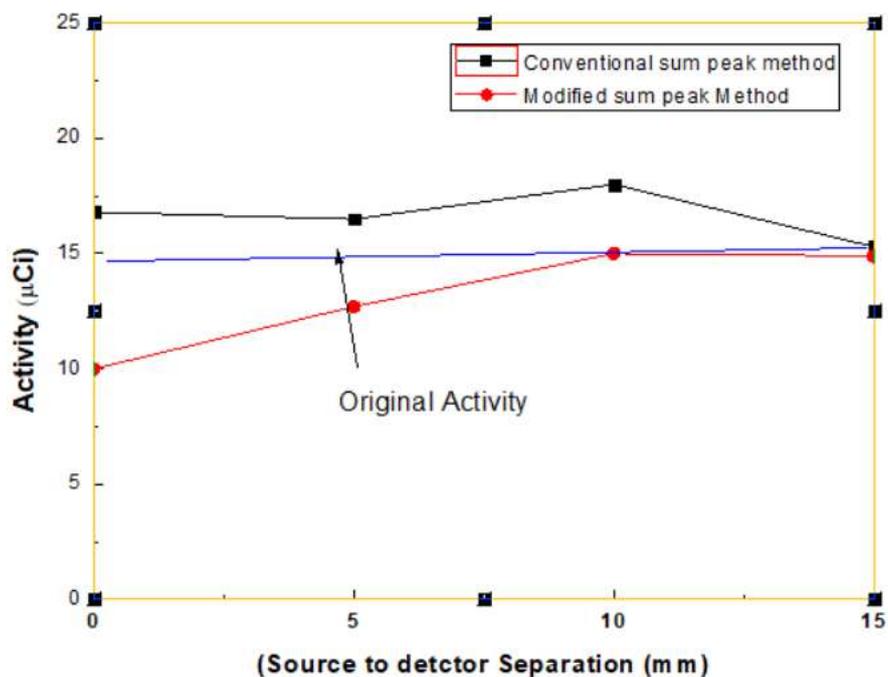


Fig.4. Absolute Activity with different methods and compared with original activity.

RESULTS AND DISCUSSION

The modified sum-peak method was employed to perform both experimental measurements and Monte Carlo simulations for determining the total count rate across the full spectrum and the count rates under individual photo-peaks of the scintillation detector. Gamma-ray sources ^{60}Co , ^{94}Nb , ^{46}Sc , and ^{24}Na were used in the study. The experimental data were validated using detailed GEANT4 [10] simulations, showing excellent agreement between measurement and simulation. Simulated spectra were generated based on the number of events calculated from the calibrated source activity and the measurement duration, employing the low-energy electromagnetic (EM) physics model in GEANT4. The simulated spectra for various radioactive sources are shown in Fig. 1, and the absolute activities obtained using both the conventional and modified sum-peak methods are summarized in Table 1.

A representative simulated energy spectrum for the source–detector setup is illustrated in Fig. 2. The measured and simulated efficiencies for the ^{137}Cs source are presented in Table 2, while Table 3 shows the absolute activity of the ^{60}Co source determined using both experimental and simulated approaches. To validate the results obtained from the GEANT4 simulation, efficiency measurements were also performed using a monochromatic gamma source, ^{137}Cs . The corresponding recorded energy spectrum is shown in Fig. 3, and the measured results are summarized in Table 2. Figure 4 compares the activities measured by both methods with the reference values provided by the source manufacturer. It is observed that, at larger source-to-detector distances, the absolute activities derived from both methods approach the reference activity. This is because, at greater distances, the emitted gamma rays are more collimated toward the detector face, resulting in reduced

losses. In contrast, at shorter distances, the isotropic emission of gamma rays increases photon losses, leading to fewer detected photons and hence lower measured activity. From the summarized results, it is evident that the measured and simulated activities obtained using both methods are in very good agreement.

In summary, the findings confirm that the modified sum-peak method provides a dependable and effective means for determining absolute activity. A notable advantage of this approach is that it avoids the necessity of accounting for total counts, thus streamlining the measurement process. Future studies are intended to explore the applicability of this method to various types of scintillation detectors.

Acknowledgement: The whole work is supported by RDS lab IIT Roorkee, Department of Physics.

The author acknowledges the support received from the Lab.

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