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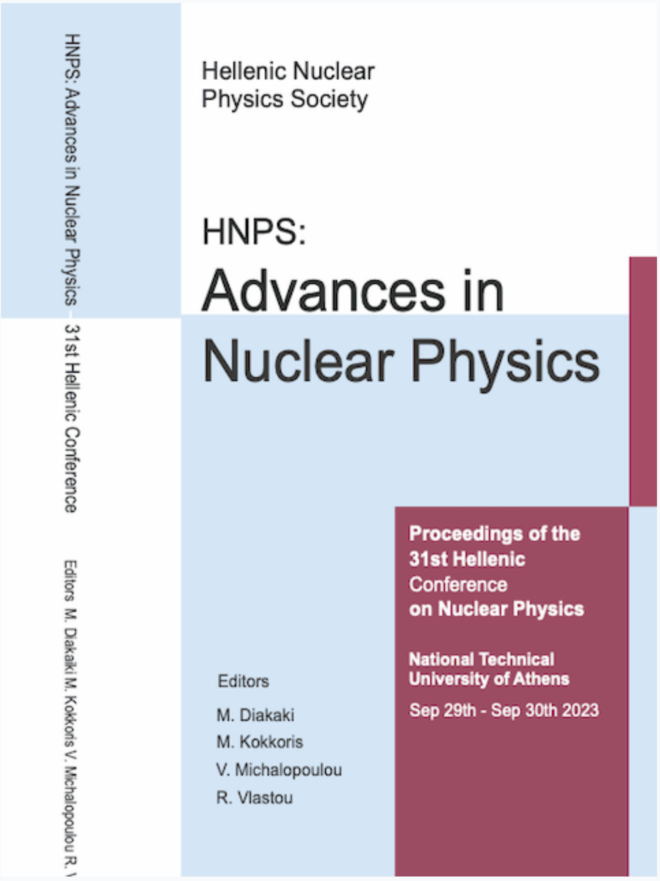

A comparative study of γ-ray spectrometers in various applications

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A comparative study of γ-ray spectrometers in various applications

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Abstract The present work concentrates on the detailed study of various types of γ-radiation spectrometers used mainly for applications. More specifically, various experiments were carried out to characterize and compare two (2) different high-purity germanium (HPGe) detectors, one (1) NaI scintillation detector, three (3) CdZnTe (CZT) detectors with standard calibration sources (^{152}Eu, ^{137}Cs and ^{22}Na). In the context of the present work, the main focus was on the efficiency and the energy resolution of the detectors, but also on the angular response and operation of the CZT.

Keywords γ-spectroscopy, detection efficiency, energy resolution, nuclear applications

INTRODUCTION

One of the most crucial steps when measuring radiation is the characterization of the detectors employed in research [1,2]. The present work focuses on the characterization and intercomparison of a group of γ-ray spectrometers of different features and properties, currently being in the pool of nuclear instrumentation at the Environmental Radioactivity Laboratory of NKUA, which are used in various applications [3], including the activities in the aquatic environment in the framework of the EU H2020 project RAMONES [4].

EXPERIMENTAL DETAILS

In the present study, six different detectors were studied including two HPGe detectors, 40% (*TIGER*) and 22% (*GEROS*), respectively; one 3"x3" NaI; and three CZT, one with active crystal volume 4 cm^3 and two with 1 cm^3. For the detailed characterization of these detectors, three standard point calibration sources were used: ^{152}Eu, ^{22}Na, ^{137}Cs.

Firstly, to construct the Full Energy Peak Efficiency (FEPE) and the energy resolution (FWHM) curves, ^{152}Eu and ^{22}Na sources were placed 13 cm away from each detector. The measurement time of each study varied depending of the detector and the source.

The HPGe absolute efficiencies were modeled using the following equation [5]:

$$y = A_1 \cdot lnE + B_1 \cdot \frac{lnE}{E} + C_1 \cdot \frac{(lnE)^2}{E} + D_1 \cdot \frac{(lnE)^4}{E} + F_1 \cdot \frac{(lnE)^5}{E} \tag{1}$$

The CZT and NaI absolute efficiences were modeled using the following equation:

$$y = \frac{1}{A_2 \cdot E^{B_2} + C_2 \cdot E^{D_2}} \tag{2}$$

The FWHM of all detectors were modeled using the following equation:

$$y = A_3 + B_3\sqrt{E + C_3 \cdot E^2} \tag{3}$$

where *E* is the photon energy. All other coefficients in Eqs. (1)-(3) are parameters to be deduced from fits to the data.

In addition, the angular response and quality of operation of both 1 cm^3 CZT detectors in a

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combinatory mode were studied using different configurations. The detectors were placed in a stationary crosswise arrangement, and an additional setup in which one CZT had a fixed position, while the other CZT was allowed to move to different angles in relation to the fixed ^{137}Cs source (see a sketch in Fig. 1). The two setups were considered useful to investigate the effect of internal crystal geometry of the CZT crystal on the overall efficiency and angular response of the detectors.

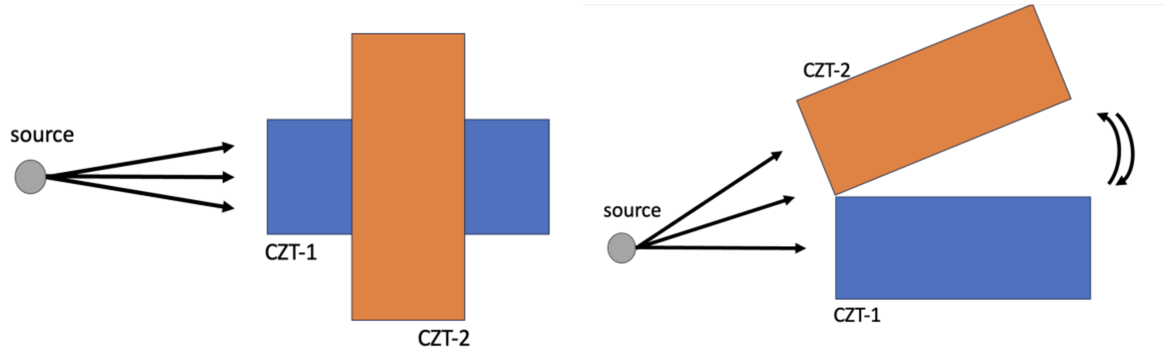

Figure 1. *Two configurations studied for the angular response of a system of two 1 cm^3 CZT detectors. In both configurations, CZT-1 was kept at a fixed position.*

RESULTS AND DISCUSSION

A well established convention is that relative efficiencies of γ-ray detectors have a common reference to a 3”x3” NaI(Tl) scintillator [6]. The efficiencies of all detectors studied in the present work are depicted in Fig. 2. This figure seems to suggest that the detectors have slightly higher relative efficiency than the nominal ones.

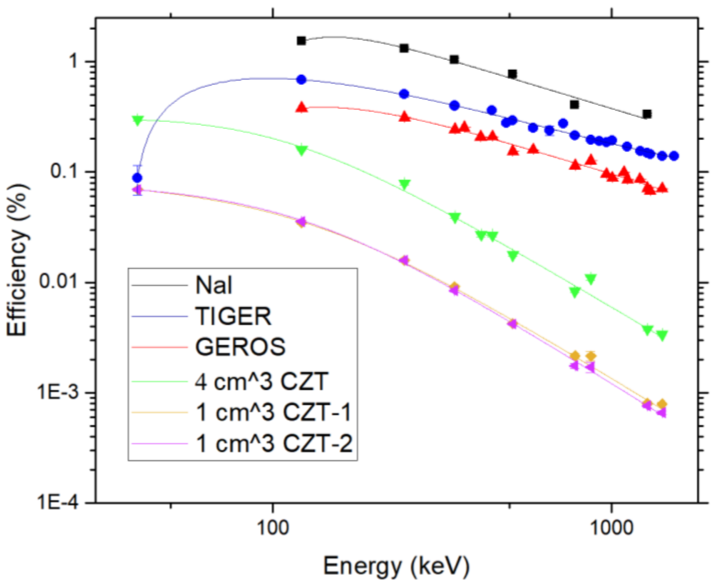

Figure 2. *Efficiency curves (FEPE) of all detectors in logarithmic scale*

The HPGe detectors remain the best ones regarding the energy resolution, as expected. The aged *GEROS* has worse energy resolution than *TIGER*, see Fig. 3. Overall, the respective plot puts in relative efficiency scale the group of detectors used in the present study. For the 22% HPGe detector, the current measurements agree very well with the published data in [2].

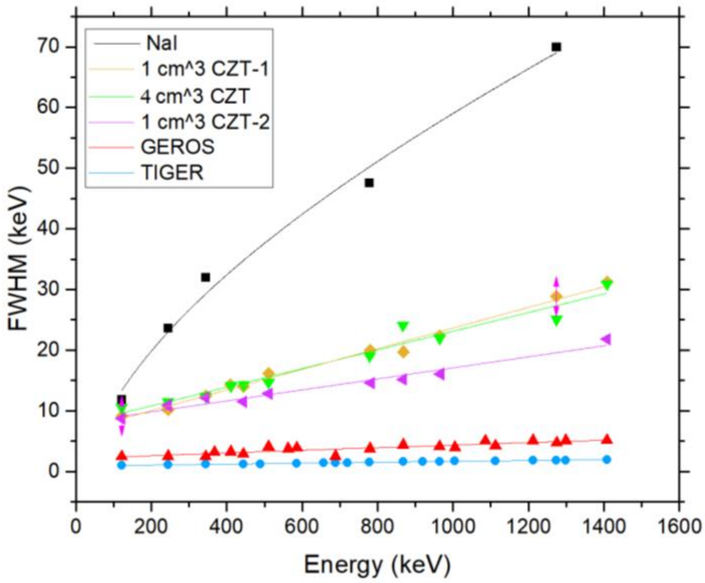

Figure 3. *FWHM vs. energy of all detectors used in the present study*

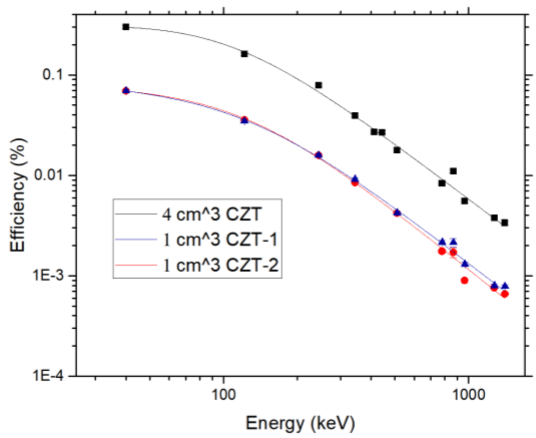

Figure 4. *Efficiency curves (FEPE) of CZT detectors in logarithmic scale*

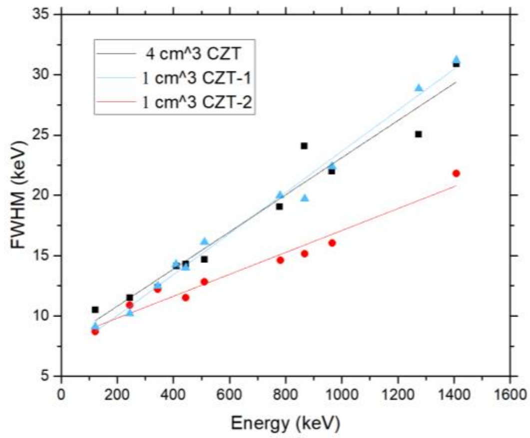

Figure 5. *FWHM vs. energy of CZT detectors used in the present study*

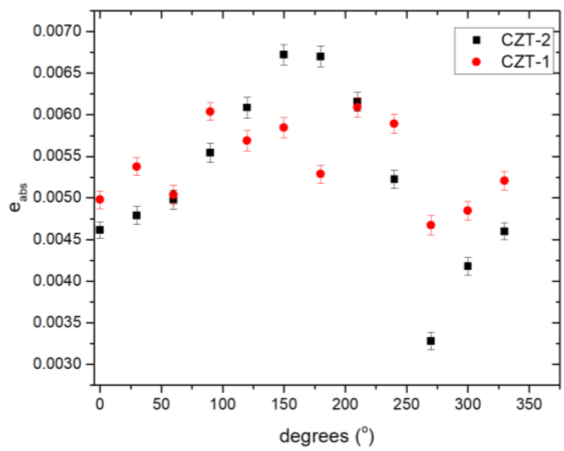

Figure 6. *Efficiency of both 1 cm^3 CZT in the crosswise setup*

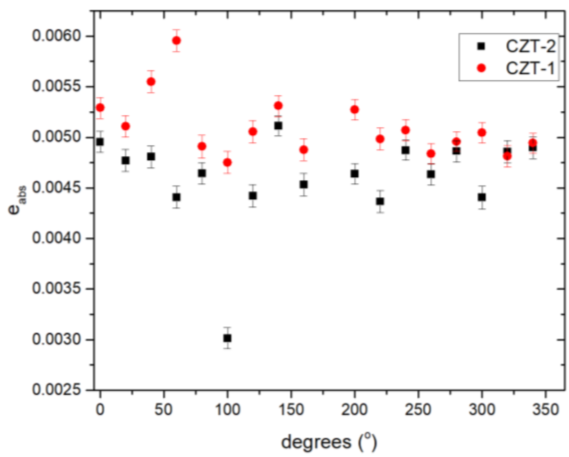

Figure 7. *Efficiency of both 1 cm^3 CZT in the angular setup*

The 4 cm^3 CZT was found to have ≈3.5 times better efficiency than the 1 cm^3 CZTs (Fig. 4), but slightly lower energy resolution. In addition, CZT-1 shows worse energy resolution than CZT-2, see Fig. 5. This response was measured during the first characterization of the instruments after acquisition. A possible explanation could be the difference in volumes of the crystals and/or composition during original manufacturing. The fact that 1 cm^3 CZT-1 and 4 cm^3 CZT exhibit similar energy resolution is purely incidental. In both angular setups (Figs. 6 and 7), the detectors are working supplementary to each other and are able to suffiently detect gamma-ray radiation in every direction.

CONCLUSIONS

All studied detectors exhibit good operational characteristics in the detection of γ-radiation, making them suitable for various radiation applications. Particularly for marine applications, considering the harsh conditions of the aquatic environment, the two stationary HPGe detectors can be exploited as validation and benchmarking spectrometers, also due to their superior energy resolution. The bulky NaI(Tl) detector has the best efficiency, but show poor energy resolution in γ-ray detection and falls behind in the comparison of the more portable CZT detectors.

Acknowledgments

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References

[1] I. Akkurt et al., Sci. Tech. Nucl. Article no. 186798, (2014); doi: 10.1155/2014/186798
[2] V. Lagaki et al., JINST 18, T05001 (2023); doi:10.1088/1748-0221/18/05/T05001
[3] J. Wang et al., Cardiovasc. Diagn. Ther. 11, 56 (2021); doi: 10.21037/cdt-20-728
[4] The RAMONES project, url: https://www.ramones-project.eu
[5] K. Debertin, The effect of correlations in the efficiency calibration of germanium detectors. Elsevier (1984)
[6] G. Gilmore, Practical gamma-ray spectrometry, Wiley (2008)