Computational Modeling and Characterization via GEANT4 of High-Efficiency Scintillator Crystals (GAGG) for Portable Gamma Spectroscopy Systems

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Abstract — This work presents the computational modeling and characterization via GEANT4 of high-efficiency GAGG:Ce scintillation crystals for portable gamma spectroscopy systems. The study evaluates gamma-crystal interactions, detection efficiency, and simulated spectral response, constituting the first phase of a project that foresees experimental validation. Preliminary results indicate the feasibility of GAGG in compact detectors, with potential applications in nuclear metrology and radiometric quantification.

Keywords— GAGG, GEANT4, scintillators, gamma spectroscopy, quantum metrology.

I. INTRODUCTION

The characterization of high-efficiency scintillator crystals is relevant for the development of portable systems. This work proposes, as a first step, computational modeling of the photon-crystal interaction using the GEANT4 resource and guidelines, widely used in particle transport simulations. This approach allows predicting the response of high-efficiency scintillator crystals, such as Gadolinium Aluminum Gallium Garnet (GAGG:Ce), to different gamma radiation energies, providing key parameters such as detection efficiency, simulated spectra, and energy resolution. The simulation represents a preliminary phase that may enable experimental implementation. em sistemas portáteis.

This study is also relevant to the field of quantum metrology, as the detailed characterization of the electronic transitions in the GAGG:Ce crystal, associated with scintillation, is directly linked to phenomena of quantum origin. The incorporation of simulation and analysis techniques inspired by quantum metrology helps reduce measurement uncertainties and improve the reliability of the data obtained, expanding the impact of research in strategic areas such as defense, environmental monitoring, and radiation protection.

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II. EXPECTED RESULTS

The simulations performed in GEANT4 are expected to enable detailed characterization of the response of GAGG:Ce scintillator crystals to different gamma radiation energies, providing fundamental parameters for the development of portable spectroscopy systems. The analysis should consider the relative detection efficiency as a function of the incident energy, highlighting the tendency for greater efficiency at low energies (due to the predominance of the photoelectric effect) and its progressive reduction at higher energy ranges.

Another expected aspect is the determination of the theoretical energy resolution (FWHM), which should improve as the incident energy increases, reflecting the higher signal-to-noise ratio and the relative contribution of scattering processes. Thus, a resolution of around 14% is expected at 59 keV, decreasing to values close to 6% at energies above 1 MeV.

Additionally, comparative efficiency-energy and resolution-energy curves are planned to be constructed, which will serve as preliminary references for future experimental validation. These results, even if simulated, will provide support for defining optimal detector geometry and configuration parameters, contributing to reduced uncertainty and greater metrological reliability. Thus, the expected results not only guide the experimental phase of the project, but also strengthen its relevance in the context of nuclear and quantum metrology, by exploring statistical foundations and discrete electronic transitions that govern the scintillation process in GAGG crystals.

Table 1. Expected results

Energy (keV)	**Relative Efficiency (%)**	**FWHM Resolution (%)**
59	42,0	14,0
122	38,0	11,0
356	30,0	8,5
511	25,0	7,5
662	22,0	7,0
1173	15,0	6,5

Energy (keV)	**Relative Efficiency (%)**	**FWHM Resolution (%)**
1332	12,0	6,0

III. CONCLUSIONS

This study proposes the use of GEANT4 to simulate the spectral response and efficiency of GAGG crystals in portable gamma spectroscopy systems. The expected results include the definition of optical geometry and performance parameters, laying the foundation for future experimental validation. The approach contributes to the field of nuclear metrology and can be expanded to emerging applications in quantum metrology.

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