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A portable γ spectroscopy detector for didactic applications

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Summary. — A γ spectroscopy standard system is normally based on inorganic scintillators or on HPGe detectors. The electronic chain consists of a set of NIM modules necessary for the acquisition and processing of the analog signal. The structural characteristics and the complexity of the traditional system make it unsuitable for field measurements and for experiments in high schools. This contribution will describe a compact and portable setup based on a CsI:Tl scintillating crystal readout by a photomultiplier tube, and will demonstrate that the performance of a commercial DAQ board is comparable with that of the standard electronic chain, using a NaI:Tl detector in both measures. The limited power consumption, the low cost and the small size make it a versatile and suitable alternative for educational activities both for the nuclear physics lab of the Physics Bachelor's degree and for dedicated activities in high schools.

1. – Introduction

Since the discovery of natural radioactivity in 1896 by Antoine Henri Becquerel, the extensive use of radioactive sources in the medical, industrial, energy and war fields has led to the need to develop measurement techniques aimed at safeguarding the population and natural ecosystems [1]. In this context, γ spectroscopy is a technique commonly used

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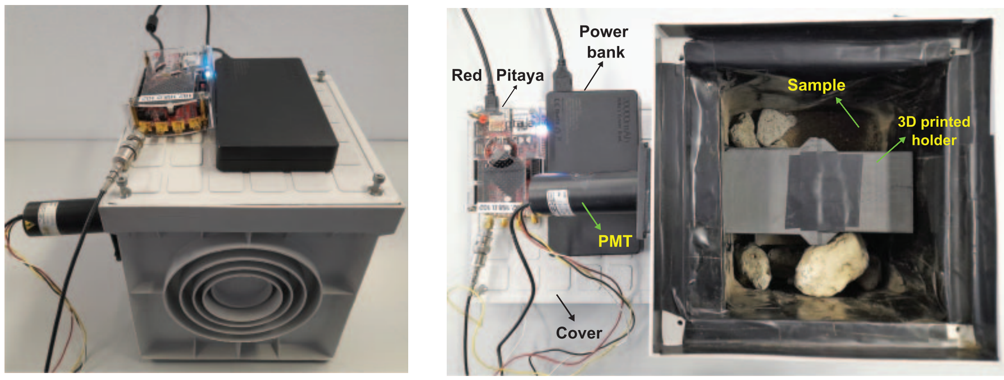

Fig. 1. – Left: the box with the detector inside, the *Red Pitaya STEMlab 125-14* and the power bank (20000 mA/h) on the top. Right: the inner part of the box. From left to right: the *Red Pitaya STEMlab 125-14* and the power bank placed on the lid of the box that contains the environmental sample and the 3D case with the photomultiplier tube and the CsI:Tl crystal.

by the authorities responsible for radiation protection or in university laboratories [2]. It allows characterizing the radioisotopic composition and estimating the specific activity of an environmental matrix, starting from the measurement of the photoelectric peaks in the energy spectrum. The γ spectroscopy experimental setup is typically based on inorganic crystals such as NaI:Tl or $LaBr_3$:Ce, coupled to photomultiplier tubes or, in more advanced applications, semiconductors cooled to cryogenic temperatures, such as the HPGe detectors. As far as the readout chain is concerned, the analog output signal from the first pre-amplification stage is amplified and shaped by an amplifier-shaper NIM module, and sampled by a multi-channel analyser. The high cost([1]), non-portability and the complexity make these systems unsuitable for educational applications in high schools or for field measurements.

This contribution aims to present the feasibility of an alternative portable gamma spectroscopy setup and the validation of its performance compared to the one of a traditional system.

2. – The experimental setup

The portable system (fig. 1) consists of a $20 \times 20 \times 20\,\text{cm}^3$ box, which works as the environmental solid sample case, in the same way as a *Marinelli beaker* [3]. Inside the case there is a 3D printed holder for the detector, which is a $3 \times 3 \times 10\,\text{cm}^3$ slightly hygroscopic CsI:Tl [4] non-radioactive scintillating crystal, coupled to a *Sens-Tech P30CW5* [5] photomultiplier tube with a 2.5 cm diameter and 16 cm long, which operates at +5 V. The readout system is based on a small size ($14 \times 10 \times 4.5\,\text{cm}^3$) and low weight (0.4 kg) *Red Pitaya STEMlab 125-14* [6] connected to a power bank, containing:

- a *Dual-Core ARM Cortex-A9 MPCore* processor and a *Xilinx Zynq 7010* FPGA;
- a connection via Ethernet (1 Gbit) or Wi-Fi;

([1]) With equal scintillator and PMT, the cost of the standard electronic chain is around 3500 €, which is approximately seven times higher than that of the *Red Pitaya STEMlab 125-14*.

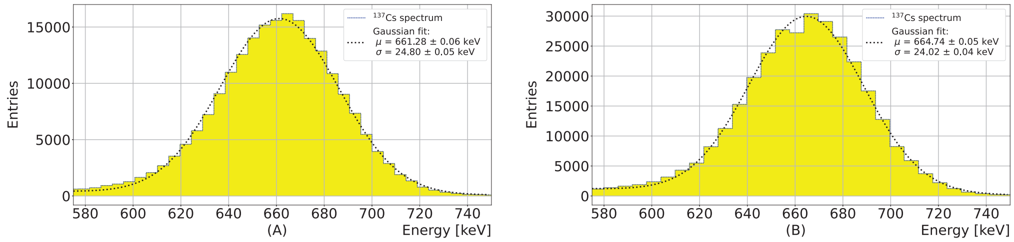

Fig. 2. – 662 keV photoelectric peak of a ^{137}Cs source, acquired with a Saint Gobain NaI:Tl, used to measure the energy resolution with the portable system (A) and with the standard one (B).

- a 512 MB (that can be upgraded to 4 GB) RAM with a 32 GB system memory hosted on a Micro SD card;
- two DC coupled analog inputs, sampled at 125 MHz by a 14 bit ADC with a range of $\pm$ 1 V or $\pm$ 20 V and a 60 MHz bandwidth.

The board is in practice a set of two digitizers that are controlled via software by the ABCD [7] framework, which is a Data AcQuisition structure accessible from a web browser.

3. – The system performance

The performance of the portable system has been measured in terms of energy resolution(2) and linearity(3) [8], comparing them with the ones obtained with a traditional setup. A Saint-Gobain $2'' \times 2''$ NaI:Tl inorganic scintillator coupled to a photomultiplier tube has been used. The standard system consists of:

- a CAEN HV power supply (Mod. N126) for the photomultiplier tube supply;
- a custom discriminator board to generate the trigger and the ADC gate;
- an ORTEC (472A) spectroscopy amplifier;
- a CAEN (Mod. V785N) 12 bit ADC;
- an SBS VME bus for the data transmission to the PC.

The peak used to compute the energy resolution is the 662 keV photoelectric peak of a ^{137}Cs source (fig. 2); the peak has been fitted with a gaussian function with mean μ and standard deviation σ.

With reference to the parameters shown in fig. 2, the energy resolution value obtained with the portable system (A) is 8.81% $\pm$ 0.22%, which is compatible with the one (8.49% $\pm$ 0.18%) measured with the standard one (B).

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(2) The energy resolution is defined as $\frac{\Delta E}{E}$, where ΔE is the FWHM of the Gaussian fitting curve and E its mean value.
(3) The linearity is defined as $\frac{E_m - E_r}{E_r} \cdot 100$, where E_m are the measured energy values and E_r the reference ones [9].

The linearity has been characterized in a range between 241 keV and 1764 keV with a ^{226}Ra, a ^{137}Cs and a ^{60}Co source: for each measured photoelectric peak, the linearity values are better than 1%.

4. – Conclusions and future updates

The feasibility of a portable and low-consumption spectroscopic system, based on a cheap electronic board for the signal acquisition and processing, has been demonstrated. The measurements provided an energy resolution comparable with the one obtained with a traditional setup and a linearity better than 1% in the 241–1764 keV range.

Two are the possible improvements foreseen for the setup: the use of a non-hygroscopic and non-radioactive inorganic scintillator (such as GAGG:Ce [10]) and the development of a 3D printed sample holder, that is easily reproducible in Monte Carlo simulations.

Lastly, this system has been designed to be easily used in schools with low specific activity and low cost natural or artificial radioactive sources, such as tuff or thoriated welding rods.

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