Id.: CR51

ASSESSMENT OF THE DETECTION CAPABILITIES OF A MINIATURIZED ELECTRONIC CIRCUIT DESIGNED FOR NUCLEAR INSTRUMENTATION INTEGRATED INTO UNMANNED AERIAL VEHICLES

Joana B. Soares[1], Ary M. Azevedo[1], William H. S. Profeta[1], Fábio Lacerda[2], Wallace V. Nunes[1]

[1] Instituto Militar de Engenharia - Praça Gen. Tibúrcio, 80 - Urca, Rio de Janeiro - RJ, 22290-270.
[2] Instituto de Engenharia Nuclear (IEN) - Cidade Universitária, R. Hélio de Almeida, 75 - Ilha do Fundão - RJ, 21941-614.

joana.batista@ime.eb.br

Keywords: Nuclear Instrumentation; Detection; Drone.

ABSTRACT

In the event of radioactive material accidents, the speed and accuracy in obtaining information are crucial for making assertive decisions that minimize risks to human health and the environment. The complex nature of these events, often characterized by hard-to-reach areas and challenging conditions, demands effective tools for mapping and accurately detecting the source and extent of contamination. Drones equipped with appropriate sensors are a promising alternative to address the challenges of radioactive material detection in disaster scenarios. Their mobility, flexibility, and ability to reach hard-to-reach areas make them valuable tools for collecting accurate data and generating detailed maps of radioactive contamination. However, flight autonomy is one of the main challenges for using this equipment in radioactive material detection. The limited load capacity imposes restrictions on the weight and size of sensors, directly impacting detection sensitivity and resolution. Therefore, this work aimed to evaluate the detection capacity of a miniaturized electronic circuit developed for pre-amplification and amplification of a detection system with a 1" NaI(Tl) scintillator. The main objective is to verify the circuit's feasibility for detection at different distances, without compromising the flight autonomy of drones, paving the way for applications in real-world radioactive material disaster scenarios. The carefully designed experiment used a non-collimated Cs-137 source with an activity of approximately 69 µCi and consisted of acquiring energy spectra at four predetermined distances. With this, the study investigated the most appropriate distance for identifying radioactive elements through spectroscopy and conducted a comparative study between data acquisition time and these spectra. The miniaturization of the electronic circuit was a fundamental aspect for the feasibility of the application in drones. The reduced weight and size of the circuit ensure uncompromised flight autonomy of drones, allowing for long-duration missions in disaster-affected areas. Thus, the results obtained in this work aim to contribute significantly to the improvement of tools and techniques used in responding to radioactive material accidents, envisioning greater safety for the population and the environment.

1. INTRODUCTION

The widespread use of radioactive and nuclear materials, crucial for fields like medicine and energy, poses significant risks in case of accidents. The need for swift and effective responses to such incidents, minimizing risks to health and the environment, has elevated radiological and nuclear defense to a priority.

Drones, capable of accessing remote areas and gathering data rapidly, have emerged as valuable tools for detecting radioactive materials in emergencies. By forming swarms, drones can cover vast areas in a short time. This research aims to develop a compact nuclear detection system for drones, combining expertise in ionizing radiation, nuclear detection, and electronics. This study aims to evaluate the capability of a compact radiation detection system to detect and identify radioactive sources through energy spectrum analysis. Experiments were performed at the Institute of Nuclear Engineering.

2. METHODS

Initially, to establish a baseline for the analysis of the results, an experiment was conducted to determine a reference point. This allowed for a comparative analysis at the end of the experiment. To achieve this, an experimental study was carried out using commercially available reference modules, widely recognized in the field, to acquire radiation spectra. The comparison between the data obtained from these modules and the data generated by the developed electronics made it possible to validate the performance of the proposed system, establishing a reference parameter for future analyses.

The variation in distance between the radioactive source and the detector significantly influences radiological detection, especially in drone applications. Changes in distance modify the solid angle under which the source is viewed by the detector, directly impacting the amount of incident radiation.

This study employed, in addition to a custom-designed electronic circuit, the following equipment: a 1-inch NaI(Tl) scintillation detector coupled to a photomultiplier tube, a portable multichannel analyzer from Amptek (model MCA 8000D), and the DPPMCA software (Digital Pulse Processor Multi-Channel Analyzer) for digital pulse processing. The equipment selection was based on portability and lightweight criteria. Both present compact dimensions and reduced weight, with the multichannel analyzer being an exemplary case, weighing only 165g.

A sealed Cesium-137 source with an activity of 55.6 µCi at the time of the experiment served as the radioactive source.

To investigate this relationship, experiments were conducted using the radioactive source previously described. Maintaining a fixed acquisition time of 60 seconds, the distance between the source and the detector was varied, resulting in different solid angles, as illustrated in Figure 1.

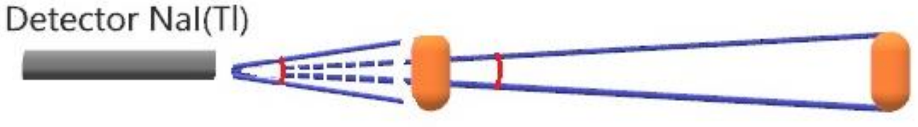

Fig. 1. Detection Solid Angle

In order to assess the influence of source-detector distance on spectral resolution and counting efficiency, four spectra were acquired under different geometries. The radioactive source was positioned in four distinct positions: in direct contact with the detector window, and at distances of 1, 2, and 3 meters from the detector, as illustrated in Fig. 2. This variation in distance allowed for the analysis of the impact of radiation attenuation by air and the detector system geometry on the characteristics of the obtained spectra.

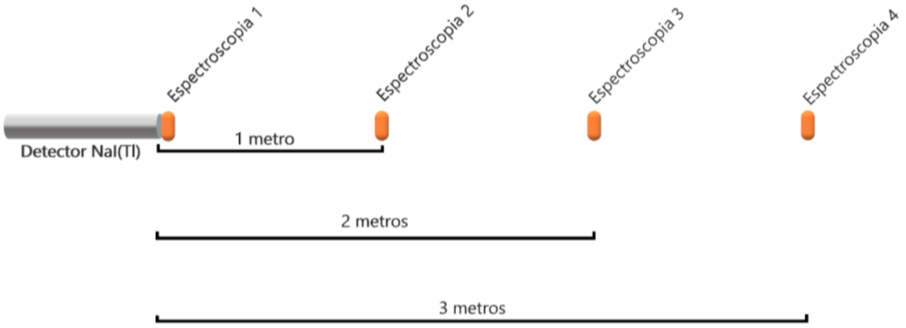

Fig. 2. Schematic diagram of the experimental setup for spectra acquisition

3. RESULTS

A background spectrum was acquired (Fig. 3) under conditions free from intentional radioactive sources to characterize the system's inherent background radiation. This spectrum was used to subtract the background component from subsequent sample spectra, resulting in net spectra with improved signal-to-noise ratios.

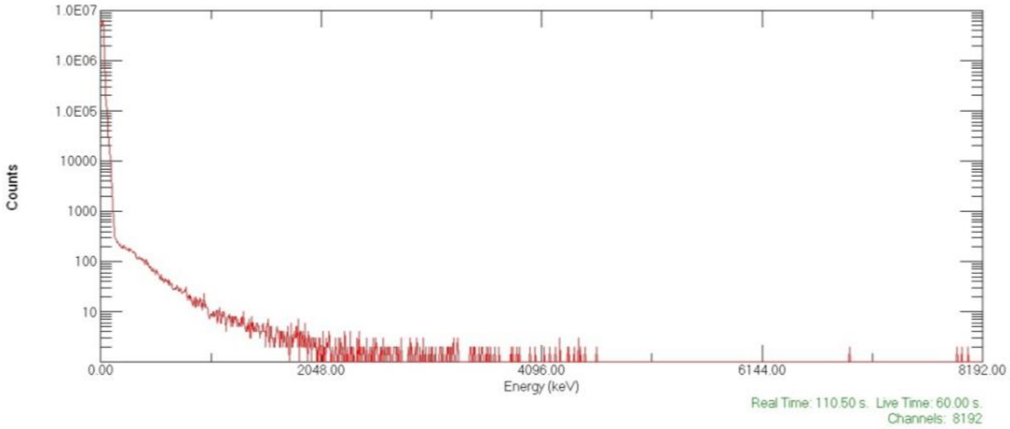

Fig.3. Background Radiation Energy Spectrum

3.1 Reference Spectrum

The reference energy spectrum of Cs-137, obtained under the described experimental conditions, exhibited the characteristic photopeak of this radionuclide, as illustrated in Fig. 4. The dead time of the detection system, calculated from the real and live times, was 52.56 seconds. It is important to note that these results were obtained using a preamplifier with a capacitance of 100 pF and an amplifier with a gain of 10.78 and a shaping time constant of 0.5 µs.

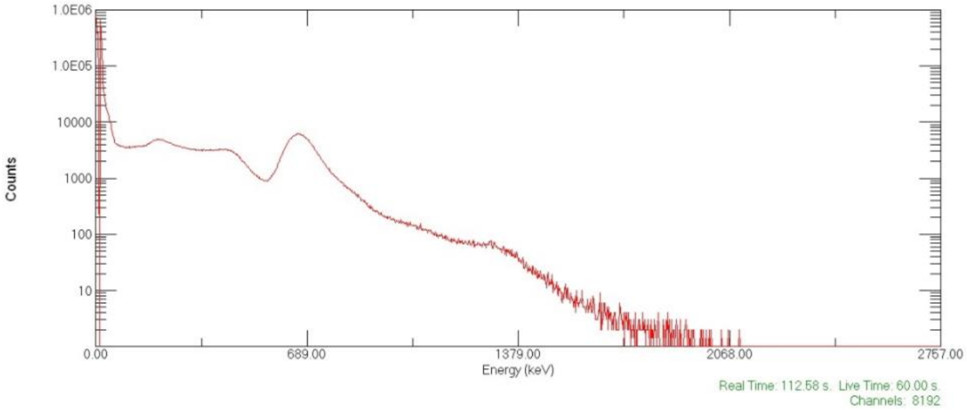

Fig. 4. Reference Energy Spectrum of Cs-137

3.2 Spectroscopies

All the energy spectra presented below were properly calibrated in energy.

With the radioactive source in direct contact with the detector, the net spectrum illustrated in Fig. 5 was obtained. This spectrum presents the characteristic photopeak of Cs-137, with a dead time of 10 seconds and a full width at half maximum (FWHM) smaller than that of the reference spectrum. The smaller FWHM indicates a better energy resolution in this configuration.

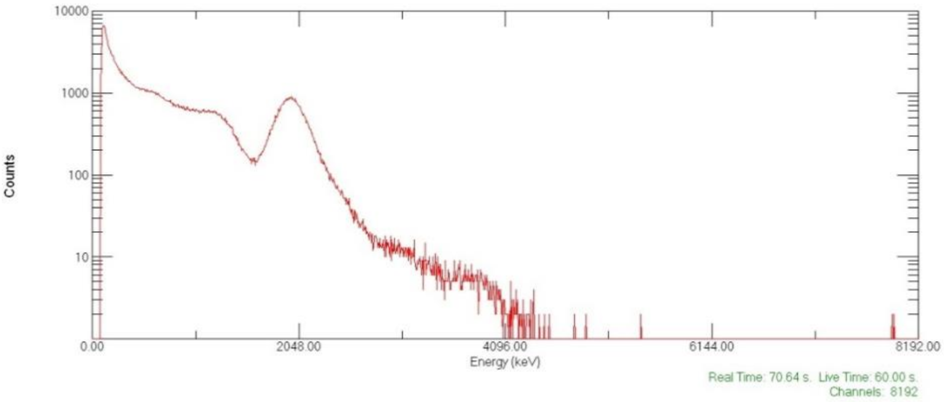

Fig. 5. Cs-137 Energy Spectrum with Proposed Circuit

In the second spectroscopy measurement, with the source positioned one meter from the detector, a significant decrease in the 662 keV count rate was observed. Consequently, the area of the Cs-137 photopeak decreased substantially, as depicted in Fig. 6. The system's dead time increased to 40 seconds in this configuration. Despite the reduced count rate, the characteristic Cs-137 photopeak remains discernible.

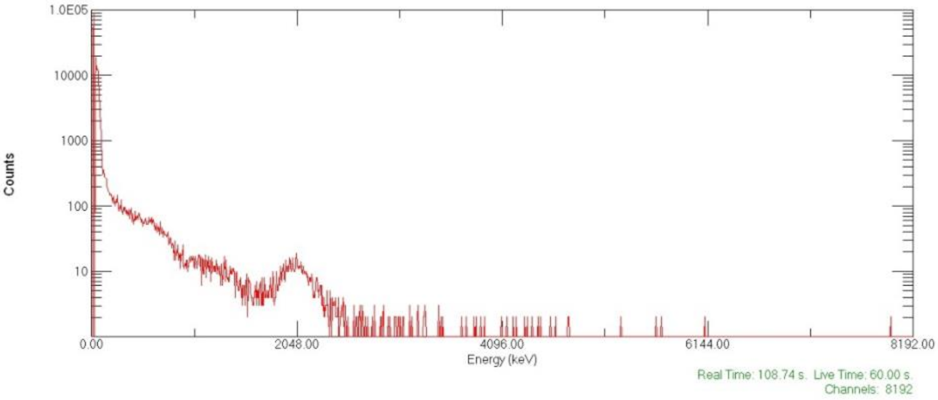

Fig. 6. Spectroscopy 2: NaI(Tl) Net Spectrum at 1-meter Distance from Cs-137

In the configuration where the Cs-137 source was positioned two meters away from the detector, the resulting spectrum did not exhibit a photopeak with considerable intensity. The decrease in count rate, due to the inverse square law, made photopeak detection challenging. By increasing the distance to three meters, as illustrated in Fig. 8, the photopeak became indistinguishable from the background noise, even after one minute of acquisition. These results demonstrate that the efficiency of the detection system is limited to distances below one meter. To mitigate this effect, a significant increase in acquisition time or the use of a detector with higher intrinsic efficiency would be necessary. The detector's dead time, which stabilized around 50 seconds for the longest distances, indicates that the system reached a counting limit, corroborating the need for optimizations in the experimental conditions.

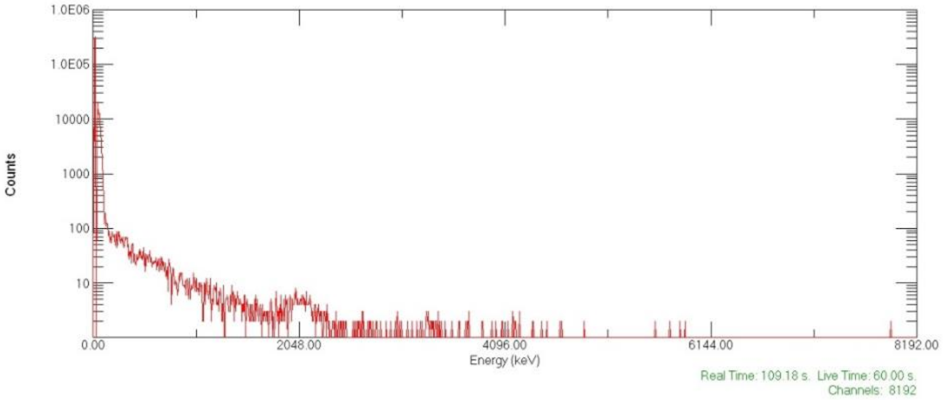

Fig. 7. Spectroscopy 3: NaI(Tl) Net Spectrum at 2-meter Distance from Cs-137

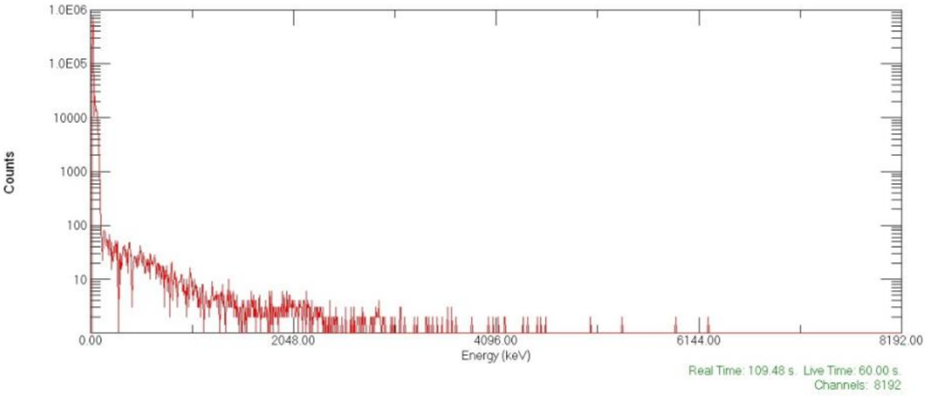

Fig. 8. Spectroscopy 4: NaI(Tl) Net Spectrum at 3-meter Distance from Cs-137

4. CONCLUSIONS

To further investigate the system's behavior, an additional spectrum was acquired with a 5-minute acquisition time, keeping the other experimental conditions of the fourth spectroscopy constant. Despite the substantial increase in counting time, the Cs-137 photopeak remained with low intensity and poor resolution, suggesting that, for distances greater than one meter, acquisition times on the order of tens of minutes would be required to obtain spectra with acceptable quality. This is likely due to the combination of factors such as the inverse square law and the intrinsic efficiency of the detector.

The results obtained with the developed electronic circuit, on the other hand, demonstrated excellent agreement with the reference spectra, particularly at distances less than 1m, indicating that the electronic system is operating as designed. The limitations observed at larger distances warrant further investigation. It is important to note that the radioactive source used had an activity on the order of µCi. Hence, an experiment utilizing a source with higher activity is the next step in this study.

ACKNOWLEDGMENT

This work was developed by a group of the first semester of the Master's Degree in Nuclear Engineering at the Military Institute of Engineering (IME), with the help of professors and employees of the Institute of Nuclear Engineering (IEN).

The group of students who participated in the preparation of the work especially thank the professionals of the Nuclear Measurement Equipment from IEN, who dedicated part of their time adding knowledge through explanations in the field and making the elaboration of this work possible.

This work was supported by the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - PDPG-CONSOLIDACAO-3-4.

BIBLIOGRAPHIC REFERENCE

[1] L. Tahuata *et al.*, Radioproteção e Dosimetria: Fundamentos, 9ª rev., Rio de Janeiro, IRD/CNEN (2013).

[2] N. Tsoulfanidis e S. Landsberg, Measurement and Detection of Radiation, 3ª ed, CRC Press (2010).

[3] G. F. Knoll, Radiation Detection and Measurement, 4ªed, Wiley (2010).

[4] Instrumentação Nuclear, IEN (2020).

[5] J.B. Soares, Instrumentação Nuclear Embarcada em Drones de Detecção de Radiação, IME (2024).

[6] A. Liland, Societal Consequences of Nuclear Accidents, Springer (2015).

[7] F. H. Attix, Introduction to Radiological Physics and Radiation Dosimetry, Wiley-VCH (2004).