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Use of the Grubbs test to study the homogeneity of a NaI(Tl) detector

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ABSTRACT

The NaI(Tl) detector is one of the most used in gamma-ray spectrometry because it presents high counting efficiency for gamma-rays in a wide range of energy. The crystal can have a lower efficiency that can be indicated by the effects of its aging by several factors such as: the reaction of sodium iodide with magnesium oxide, absorption of water vapor by crystal, and problems related to photomultiplier. In an experiment, several measures can be taken and when a doubt exists between one of the measured values it is possible to use a statistical test. Grubbs test is designed to verify the presence of extreme values in sample observations. This paper presents a methodology that aims to evaluate the homogeneity of a NaI(Tl) scintillation detector using the Grubbs test to validated the crystal homogeneity. The study pre-established five different locations in frontal area of detector where measurements were performed using a ^{137}Cs standard source in order to calculate the standard deviation.

Keywords: **photopeak counts, NaI(Tl) detectors, homogeneity of detector**

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1. INTRODUCTION

NaI(Tl) detectors is one of the most used materials in gamma-ray spectrometry and the important features of these detectors are the energy spectrum response function and the efficiency curve, including full energy peak efficiency and total efficiency [1]. The accurate full energy peak efficiency (FEPE) calibration curve of NaI(Tl) detectors is required for most of the radioactive monitoring applications [2-4]. The crystal can have a lower efficiency which can be indicated by the effects of its aging by several factors such as: the reaction of sodium iodide with magnesium oxide, absorption of water vapor by the crystal, problems related to the photomultiplier [5]. It can also evaluate the physical structure of the crystal, for example by falling, which can cause a crack in it.

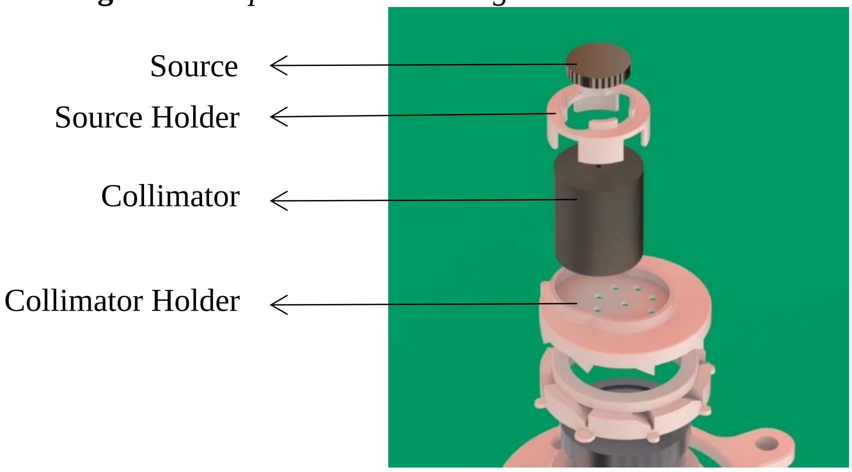
According to previous research, a detection efficiency study was performed for a detector with real dimensions of 3.175 × 1.905 cm, diameter and length, respectively, and it was found that the values obtained were not compatible with the values simulated by MCNPX code [6]. It has been assumed, then, that there was a problem in the crystal that caused the loss of efficiency. Therefore, this paper aims to study the homogeneity of a NaI(Tl) detector using ^{137}Cs source with 539.612 kBq activity and the Grubbs test.

2. MATERIALS AND METHODS

2.1 3D holder and measurements

A scan was perfomed on the crystal to check the homogeneity of the NaI(Tl) crystal. The detector source distance took some aspects into consideration. The development of the source-collimator-holder system considered the holder of source on the top of the collimator. The collimator holder was in direct contact with the detector. These distances were used to facilitate alignment between source-detector, and considered the thickness of the lead collimator for transmission about 97% of 662 keV gamma-rays. In addition, the acquisition dead time was chosen to be below 3% and to obtain low counting statistics. For this, a source-detector system was developed with 5 cm distance between the source and the detector. A holder was 3D printed to ensure alignment between the source, the opening of the collimator with the face of the detector and the analyzed regions of the crystal detector. The holder allows the source to be accommodated with the face of the collimator allowing an alignment with the points that were predetermined on the face of the detector as shown in Figure 1, where the project and development of the holder was carried out by the Serviço de Instrumentação (SEINS) of Instituto de Engenharia Nuclear (IEN).

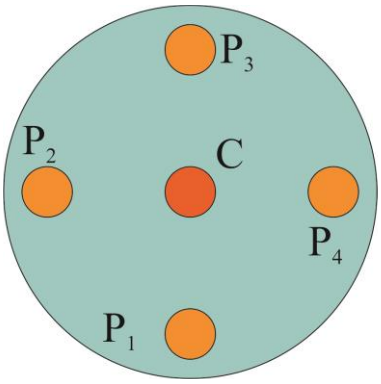
Figure 1: *3D printed holder designed to accommodate the collimator and the source.*



In order to ensure that the opening of the lead collimator was aligned with the area of interest of the detector, a holder coupled to the face of the detector was developed to make a 45 degree rotation. A cylindrical lead collimator with a length of 4.410 cm, a diameter of 3.665 cm and an opening of 0.399 cm was positioned on the holder to be more accurately position the center of the collimator with the center of the detector and the five points defined on the face of the detector.

Homogeneity was validated using Grubbs test and the measurements of the photopeak of the crystal was performed three times in the center and in the four regions equidistant from the center with 0.813 cm from the center of the detector in the horizontal and vertical direction as shown in Figure 2. For each detector region it was made measurements of 300 seconds.

Figure 2: *Distribution of predetermined points on the face of the detector.*



2.2 Grubbs tests

Grubbs test is one of the methods used to evaluate whether or not a given value within a group of values is considered outlined or not. This test is designed to verify the presence of extreme values in sample observations. Extreme values can be considered as manifestations of the random variability inherent in the data, or only an error in the calculation during data collection and even an annotation precipitated by the operator [7].

In Grubbs test, it is used the follow statistic:

$$Z = \frac{x_i - \bar{x}}{\sigma} \tag{1}$$

Where:

x_i: is a sample observation;

$\bar{x}$: is the sample mean;

σ: is the standard deviation.

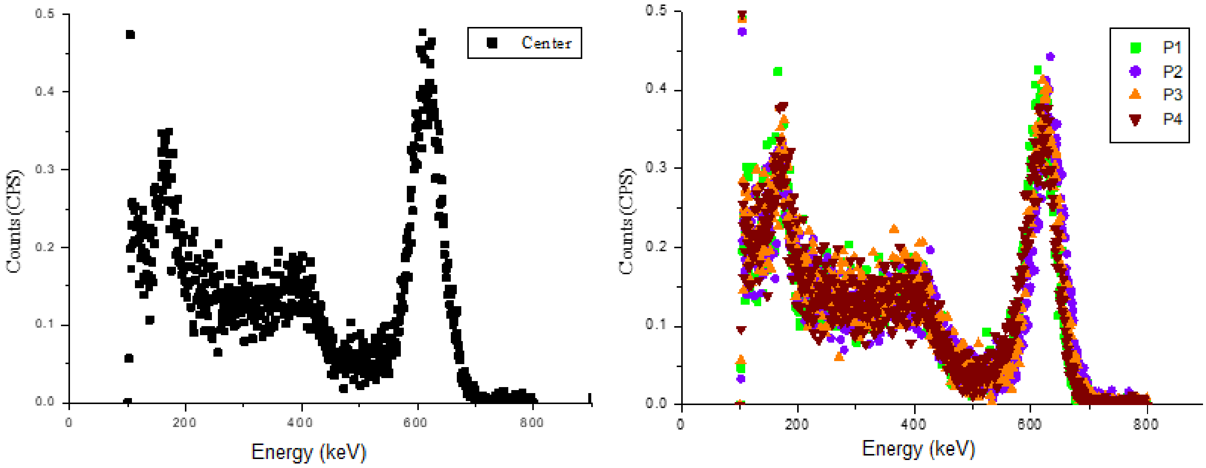
The calculated value of Z is compared with a critical table value (N) for a given level of significance. If Z is greater than N, it is measured as an outlier.

3. RESULTS AND DISCUSSION

A Spectrum for each predetermined point of the frontal area of the crystal were obtained with the pulse height distributions (PHD), which were obtained from each measurement of ^{137}Cs source. Figure 3a shows the spectrum of the center of the crystal and Figure 3b shows the spectrum of each predetermined point of the crystal for the ^{137}Cs source.

The central point was separated from the others for Grubbs test because it has a greater count of photons compared to the others. This can occur due to the escape of photons at the regions away from the center (points) of the detector, which in the central measurement of the detector is more difficult to happen.

Figure 3: *Spectra obtained for the points: a) center point; b) P1, P2, P3 and P4 points.*



It was possible to calculate the photopeak area for predetermined points from both spectrum. Three counts were performed for each predetermined point to guarantee good counting statistics. The average of the measured points was equal to 18048.53, with a standard deviation of 1489.10, and this information was used to perform Grubbs test. In order to analyze the homogeneity of the crystal, Grubbs test was used for a significance level of 0.5%, to perform the test with five measurements. The critical table value is equal to 1.764. The test result can be seen in Table 1.

Table 1: Result achieved for points P1, P2, P3, P4 and Center.

Point	Photopeak Area	Z	Status for 0.005
P1	17390.67	0.05956	ok
P2	17502	1.05428	ok
P3	17410.67	0.23826	ok

P4	17232.67	1.3521	ok
Center	20706.67	1.78506	outlier

The center point is an outlier for a significance interval of up to 10%, which can be explained by escape probability of light photons, that is, for an effective test the compared points must be equidistant from the center of the crystal.

4. CONCLUSION

The main purpose of this research is to perform an evaluation the homogeneity of a NaI(Tl) detector using Grubbs test. A 3D printed holder system was developed in order to ensure alignment between source, opening of the collimator with the face of the detector and analyzed regions of the crystal detector. Compared with other measurements, the center of the crystal has the highest photopeak counts, as it was possible to observe experimentally, showing the region that has the highest photon absorption during radiation interaction with the crystal. This is because scattered photons are more likely to escape at the edges of the crystal. Through the Grubbs test, it was possible to consider that the measurements made at points P1, P2, P3, P4 are within the confidence interval of 0.5% for the critical values of each point. With this, it was also possible to consider, statistically through the Grubbs test, that the NaI(Tl) crystal is homogeneous. However, the center point was considered an outlier due to its higher count, which is explained by the escape of the photons. Therefore, in order to ensure a better evaluation of the crystal, the design and development of a new holder system that allows measurements laterally to the detector is in progress. In addition, it is necessary to use other sources with different energies and to increase the number of investigated regions to make new measurements.

REFERENCES

1. CHUONG H.D.; HUNG N.Q.; MY LE N.T., NGUYEN V.H.; THANH T.T.; Validation of gamma scanning method for optimizing NaI(Tl) detector model in Monte Carlo simulation. **Applied Radiation and Isotopes**, V. 149, p. 1-8, 2019.

2. GRUJIC S.; ĐORĐEVIC I.; MILOSEVIC M.; KOZMIDIS-LUBURIC U.; Monte Carlo simulation of GM probe and NaI detector efficiency for surface activity measurements. **Radiation Measurements**, V. 58, p. 45-51, 2013.
3. HUNG N.Q.; CHUONG H.D.; VUONG L.Q.; THANH T.T.; TAO C.V. Intercomparison NaI(Tl) and HPGe spectrometry to studies of natural radioactivity on geological samples. **Journal of Environmental Radioactivity**, V. 164, p. 197-201, 2016.
4. THANH T.T.; TRANG H.T.K.; CHUONG H.D.; NGUYEN V.H.; TRAN L.B.; TAM H.D.; TAO C.V. A prototype of radioactive waste drum monitor by non-destructive assays using gamma spectrometry. **Applied Radiation and Isotopes,** V. 109, p. 544-546, 2016.
5. GRINEV B.V.; NIKULINA R.A.; BERSHININA S.P.; VINOGRAD E.L. Investigation of the aging of scintillation detectors. **Scientific Planning Department**, V. 70, p. 50-51, 1991.
6. RAMOS L.L.; SALGADO C.M. Estudo do volume sensível efetivo de detectores de NaI(Tl) utilizando o código MCNP-X. **INTERNATIONAL NUCLEAR ATLANTIC CONFERENCE – INAC**, São Paulo, Brazil, October 4-9, 2015.
7. GRUBBS F. E.. Procedures for detecting outlying observations in samples. **Technometrics**, Maryland, United States of America, 1969.