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Characterization of the CsI(Tl) Crystalline Scintillating Detector Produced at IPEN

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ABSTRACT

Cesium iodide crystal activated with thallium (CsI(Tl)) is used as radiation sensor because of its favorable characteristics as scintillator, when excited by gamma radiation. This crystal has good mechanical strength and it is relatively little hygroscopic. In the present work, the CsI(Tl) crystal was grown in the Nuclear Energy Research Institute (IPEN/CNEN/SP) by Brigdman technique, in two different formats: (a) cylindric (∅ 20.1 mm x ↑ 11.9 mm) and (b) parallelepiped (□12.3 mm x ↑ 19.5 mm). The scintillator spectrometry was studied through five gamma radiation sources: ^{99m}Tc (140 keV), ^{133}Ba (355 keV) ^{22}Na (511 keV) and ^{137}Cs (662 keV). The crystals were coupled to a photomultiplier tube using 0.5 McStokes viscosity silicone grease as the optical interface. All electronics for signal measurements were developed at IPEN. Luminescence property of the CsI(Tl) crystal was excited by the radiation from a ^{137}Cs source. The energy resolution of the crystalline detector was determined by the FWHM parameter, corresponding to the photopeak width at half of its height.

Keywords: **Scintillator Detector, Crystal, Response Function .**

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1. INTRODUCTION

Cesium iodide crystals (CsI) have high stopping power for the gamma rays due to their high density and atomic number. These properties elect this material as a good gamma ray detector [1-3]. The CsI crystals are mechanically stable because of the absence of cleavage plane and have better chemical stability when compared to sodium iodide (NaI) crystals because of its less hygroscopic nature [4]. Doping the crystal with thallium (Tl) or sodium (Na) produces impurity levels in the energy gap between the steady state and excitation levels [5]. When doped with Tl it has favorable scintillating properties for use with PIN-type photodiodes and when doped with Na makes its use more appropriate for alkaline photomultipliers (PMT). When the CsI crystal is doped with Tl, its excitation from one valence energy level to another higher valence level, on its return to the ground state, it will emit a photon of 565 nm corresponding to a green light photon. When doped with Na, it will emit a 410 nm near UV photon [6].

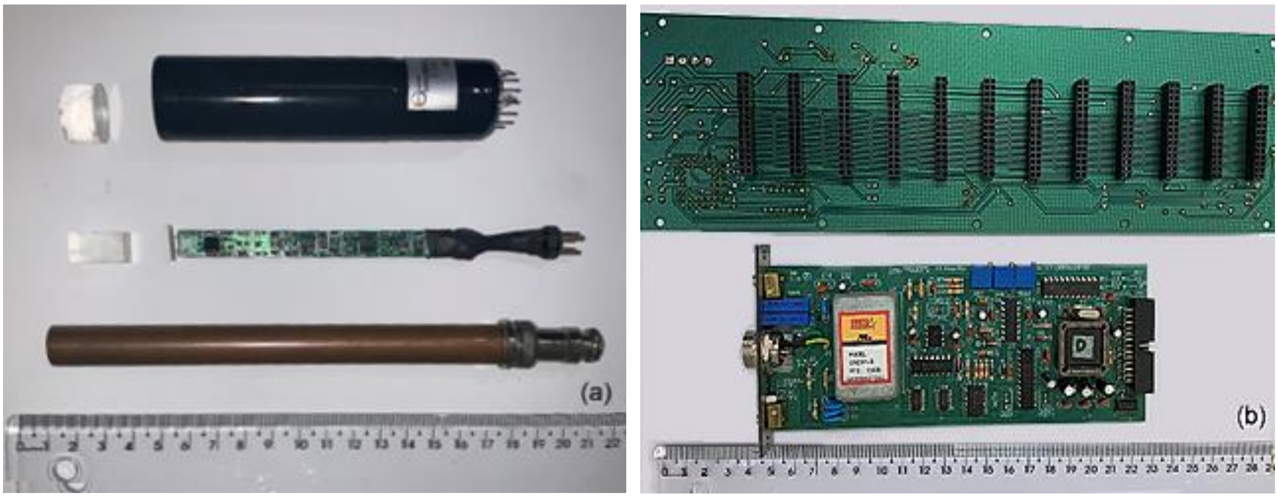
The development and availability in the market of silicon photodiodes with low capacitance and large area of sensitivity have stimulated the designs of the CsI(Tl) detector crystals, by replacing the photomultipliers with the photodiodes because they are small sizes and work with bias voltage of a few tens of volts in contrast to hundreds of volts of the photomultipliers [4]. Cesium Iodide Crystal activated with Thallium (CsI(Tl)), when compared to Sodium Iodide activated with Thallium (NaI(Tl)), presents some more favorable properties.

In this work, we chose the inorganic scintillator CsI(Tl) for its characteristic of withstanding mechanical shocks, sudden changes in temperature and for having greater efficiency to detect gamma radiation [5]. Its versatility in applications, such as in medicine, X-ray detection for mammography [7], in security, identification of hidden explosives [8], detectors for air dose rate measurement in contaminated environments [9], motivating us to apply the CsI(Tl), in the near future, to use it in a tomography device to evaluate the thyroid. An important advantage of CsI(Tl) is that it can be coupled to photodiodes that operate with reverse voltages of approximately 10 to 40 volts and therefore do not subject patients to deadly high voltage hazards, as they could occur with photomultipliers that operate approximately between 700 to 1800 volts [10,11,14].

2. MATERIAL AND METHODS

The cesium iodate crystals dopped with 10^{-3} M of thallium were produced at IPEN/CNEN/SP by Bridgman method [12]. The crystals of CsI(Tl) used in this work, shown in Figure 1, were cut into the following formats: (a) parallelepiped with dimensions of (□12.3 mm x ↑19.5 mm) (parallel squared face and thickness) and (b) a cylinder with dimensions of (∅20.1 mm x ↑11.9 mm) (circular face and thickness). The crystals were polished and coupled directly to the bi-alkaline photomultiplier (ET Enterprise, Model 9924SB, England), using 0.5 McStokes viscosity silicone grease (Dow Corning) as the optical interface. The CsI(Tl) was collimated with lead of 5 cm thick with a septum of 5 mm diameter. The electronic modules were used to treat the signals from the photomultiplier. Electronics developed at IPEN were used as showed in Figure 1.

Figure 1- *(a) CsI(Tl) crystals with the photomultiplier and the photodiode. (b) Electronic developed at IPEN.*



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The gamma spectrum is used to know the detector energetic resolution. This parameter for gamma radiation of ^{99m}Tc (140 keV), ^{137}Cs (662 keV), ^{22}Na (511 keV) and ^{133}Ba (355 keV) sources to both crystals are showed in Figure 2 were the resolution was estimated by the scattering of the photopeak expressed by the FWHM parameter divided by the corresponding energy [5,14]. The luminescence emission spectrum was determined by means of the different wavelength light produced by a ^{137}Cs source measured with a monochromator (JASCL, model FP550A, Japan), filtered with resolution of 20 nm. In this measurement the crystals were coupled to the photomultiplier and excited by a ^{99m}Tc, ^{22}Na,^{133}Ba and ^{137}Cs source positioned at a distance of 40 cm from the detector as shown in Figure 3. The response to gamma radiation was performed using the crystals machined, polished and directly coupled to the bi-alkaline photomultiplier using silicone grease (Dow Corning) of 0.5 McStokes viscosity as optical interface. Gamma radiation sources were used, with energies in the range from 140, 355, 511 and 662 keV. The bias voltage of the photomultiplier was 800 V. The accumulation time in the counting process was 600 s which was a time considered adequate for obtaining experimental results with good precision. The background radiation was measured in same manner without the radioactive sources.

Figure 2: *CsI(Tl) crystals containing 10^{-3} Molar of Tl. Parallelepiped crystal (a) and cylinder (b).*

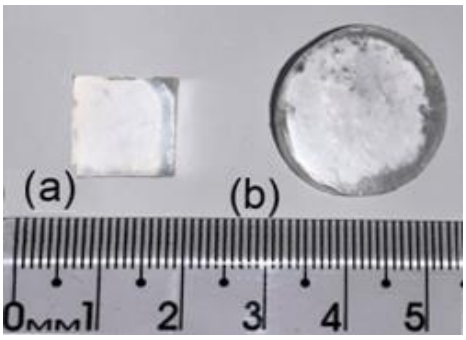

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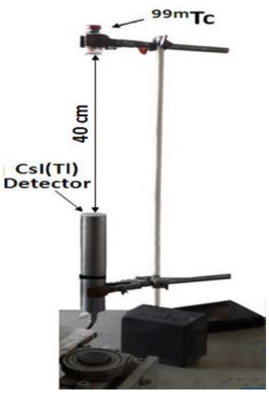
Figure 3: *Experimental scheme to estimate the energy resolution parameter for a ^{99m}Tc source.*



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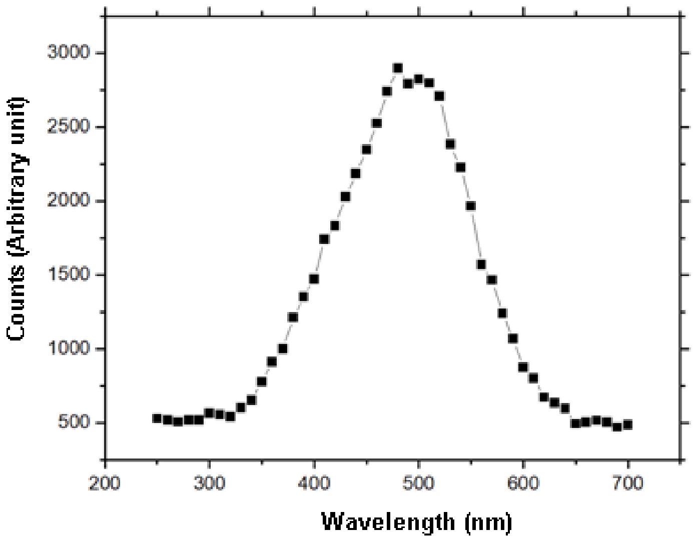
3. RESULTS AND DISCUSSION

3.1- CsI(Tl) Luminescence emission.

The determination of the emission spectrum of the grown crystal at IPEN was achieved by adjusting a wavelength in the monochromator and measuring the pulse counts of a ^{137}Cs source. The monochromator is calibrated to scan the wavelength range from 250 nm to 700 nm in steps of 10 nm. The experimental luminescence spectrum of the cylinder CsI(Tl) crystal is shown in Figure 3. The peak intensity at approximately 520 nm is attributed to the crystal. Similar spectrum was obtained for the parallelepiped crystal**,** shown in Figure 2 (a).

Figure 4: *Luminescence spectrum of CsI(Tl) as a function of the wavelength.*



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Knowing the maximum luminescence intensity wavelength of the scintillating crystals is essential when selecting the most suitable photosensor for mounting radiation detectors, that is, the photosensor should have the region of maximum sensitivity as close as possible to the center of the emission band of the crystal. Therefore, each scintillating crystal has its own characteristics regarding the photons of light emitted and every photosensor is more efficient for a certain wavelength range of the incident photon. The peak of maximum fluorescence of CsI(Tl) produced in IPEN was approximately at 520 nm as showed in Figure 4. This finding confirms the appropriateness of using the PIN-type photodiode to be used as a sensor for the light generated in the CsI(Tl) crystal by gamma or X ray radiation [13,15].

3.2- Energy resolution obtained by a detector coupled to photomultiplier

The gamma spectrometries for the detectors (a) parallelepiped and (b) cylindrical, shown in Figure 2, are presented in figures 5 to 8. The of Energy Resolution parameter was calculated from figures 5 to 8 [5]. For the dimensioned crystals showed in Figure 2, the energetic resolutions are showed in Table 1.

Table 1: Energy resolution of the CsI(Tl) crystals developed in this paper.

Source	**Main Photopeak (keV)**	**Energy Resolution (%)**	
		Parallelepiped Crystal	**Cylindric Crystal**
^{199m}Tc	140	21.0	20.0
^{133}Ba	355	13.4	13.9
^{22}Na	511	9.9	13.7
^{137}Cs	662	7.0	7.5

Particularly for ^{140m}Tc the energetic resolution was 21% for parallelepiped crystal and 20% for the cylinder detector. In the literature [5], the energy resolution for CsI(Tl) is described as being 15%. The difference observed here may be probably due to the small sizes of the faces of the crystals (12.3 mm and 20.1 mm), compared to the 25 mm face of the photomultiplier used. It can be suggested that, if the crystal faces were the same as the sensitive surface of the photomultiplier, the resolutions found (Table 1) would be closer to the values described in the literature. The energy spectrum for the both crystals with source of the ^{99m}Tc is demonstrated in Figure 5.

The energy resolutions obtained for the cylindrical and parallelepiped crystal shown in Table 1 are in accordance with the results obtained in the literature [5]. As shown in these four figures, spectra with defined energies can be observed, clearly distinguishing the photopeaks of each energy from the sources used. The sources used were calibrated November 1, 1997. Figure 6 shows the spectrum of ^{133}Ba that has the characteristic energy at 355 keV, while Figure 7 shows the energy spectrum at 662 keV, from ^{137}Cs. The same may be stated for the photopeak of the 511 energy from the ^{22}Na, shown in Figure 8.

Background radiation was collected for cylindrical and parallelepiped crystals, in Figures 5,6,7,8. As it can be seen from these figures, there was no significant interference from background radiation and electronic noise in the spectrum measurements.

Figure 5: *Gamma energy spectrum of the ^{99m}Tc obtained with the Csl(Tl) using the detector coupled to the photomultiplier and the electronics developed at IPEN.*

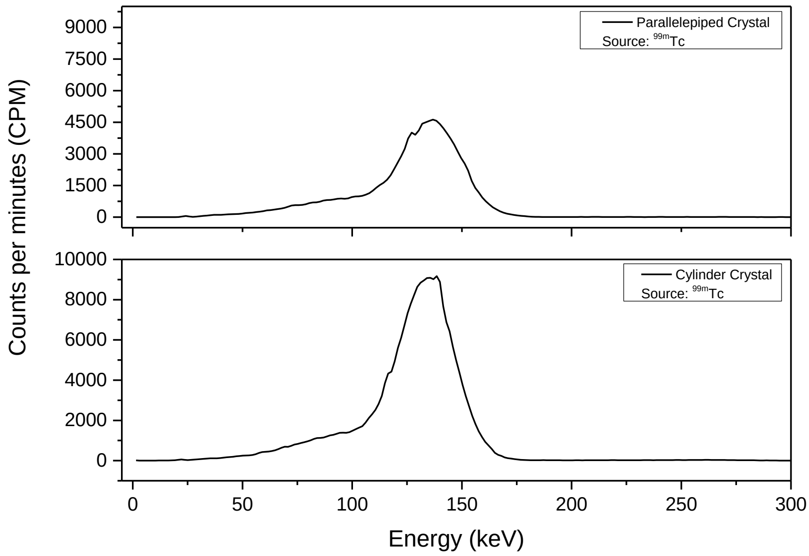

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Figure 6: *Gamma energy spectrum of the ^{133}Ba obtained with the Csl(Tl) Molar using the detector coupled to the photomultiplier and the electronics developed at IPEN.*

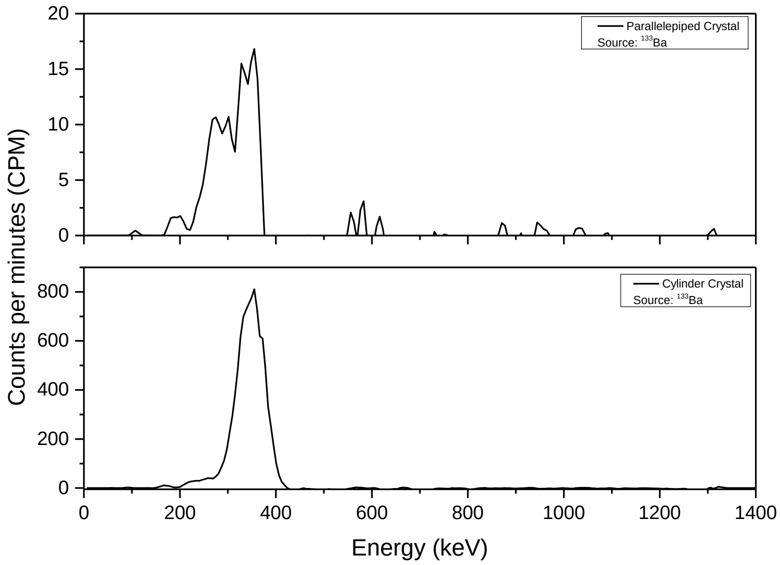

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Figure 7*: Gama energy spectrum of the 137Cs obtained with the Csl(Tl) using the detector coupled to the photomultiplier and the electronics developed at IPEN***.**

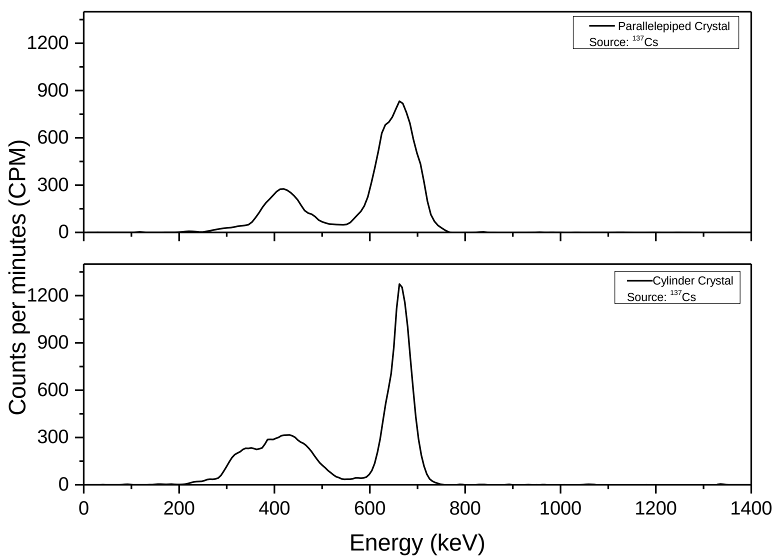

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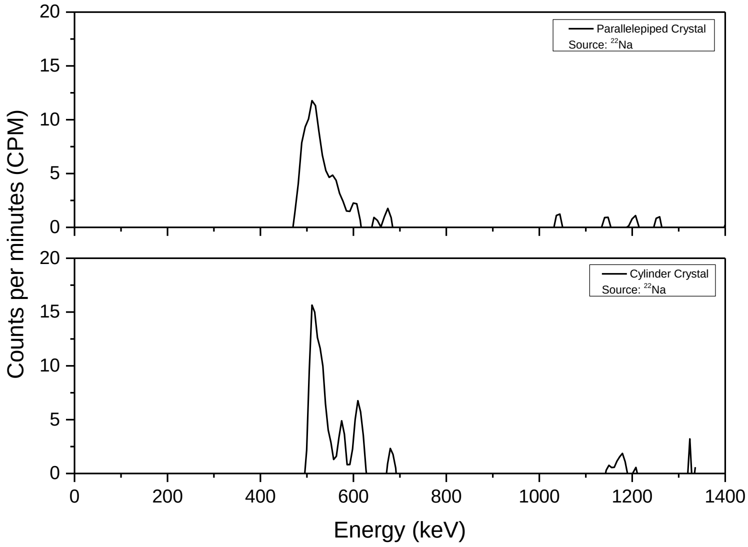
Figure 8: *Gamma energy spectrum of the 22Na obtained with the CsI(Tl) using the detector coupled to the photomultiplier and the electronics developed at IPEN.*



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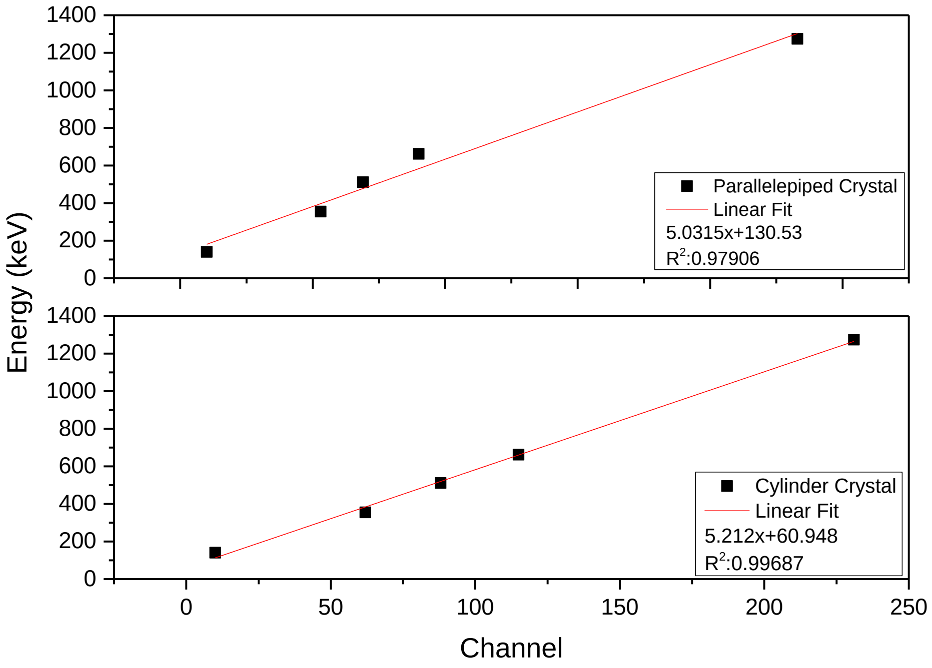
For a detection system to be used for spectrometry purposes, it is essential that the position of the peak is linear with respect to the incident radiation energy. Through the main photopeaks of the gamma emitters identified in the spectra of Figures 5 to 8, the calibration curves was constructed as shown in Figure 9, which presented the linearity of the detection system. Figure 9 shows the linear correlation between the energies of the sources used and the number of channels. As it can be observed, a good correlation was found between the different energies of gamma radiation sources (^{99m}Tc, ^{241}Ba, ^{137}Cs and ^{22}Na) and the number of channels. The quality of the linear adjustment showed R^2= 0.97906 to parallelepiped crystal and R^2=0.99687 to cylinder crystal, whose value can be considered satisfactory

Figure 9: *Linearity Curve between energies 140 keV to 1274 keV and the channel of radiation source*



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4. CONCLUSION

The results demonstrated that the laboratory-harvested cesium iodide crystal of IPEN proved to be sensitive to the detection of gamma radiation. The emission of luminescence showed a suitable curve, with a peak at 560 nm. The comparison of FWHM (full width at half the maximum) between crystals of different sizes is close to that described in the literature. Spectra with defined energies and good linearity in the correlation between the energies of the sources and the number of channels were obtained with the use of the CsI(Tl) radiation detector, for energies (355 keV) from the ^{133}Ba source, (662 keV) from ^{137}Cs and (511 and 1275keV) from ^{22}Na. The spectra show in Figures 5-8 are similar to those described in the literature for CsI(Tl) detector.

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