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Development and Characterization of CsI (Tl) Crystal for use as a Radiation Detector

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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 not hygroscopic. In the present work the CsI(Tl) crystal was growed in the Nuclear Energy Research Institute (IPEN/CNEN/SP) by Brigdman technique in different sizes. The scintillator response was studied through gamma radiation from ^{99m}Tc source with the energy of 140 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. Measurements of luminescence and gamma spectrometry of a ^{99m}Tc source were performed. The energy resolution of the crystals was determined by the spectrum photopeak considering its full width at half maximum (FWHM).

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 good gamma ray detection. 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 [1]. Cesium iodide crystal activated with thallium (CsI (Tl)) is used as a radiation sensor due to its favorable characteristics as scintillator [2]. Cesium iodide is an inorganic crystal which has scintillator proprieties. Its scintillation is due to the electrons excitation from the valence energy level to an excited level and its return to the steady state emiting a visible light or near to UV. Doping the crystal with thallium or sodium produces impurity levels in the energy gap between the steady state and excitation levels. The CsI (Tl) crystal has good mechanical strength, is few hygroscopic and the light emission spectrum matches with the sensitivity region of the PIN photodiodes [3,4]. The cesium iodide crystal (CsI(Tl)) can be coupled to the PIN photodiode due to the better overlapping of the luminescence spectrum as a function of the quantum efficiency of photodiodes [5,6]. 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 [5,7,8]. Cesium Iodide Crystal activated with Thallium (CsI(Tl)) when compared to Sodium Iodide activated with Thallium (NaI(Tl)) presents some more favorable properties. The CsI(Tl) has a density of 4.51 g/cm^3 against the 3.67 g/cm^3 of the NaI(Tl) and its weighted atomic number is higher than the NaI(Tl), so its efficiency for the gamma detection is higher especially when using the PIN type photodiode. At room temperature, the quantum conversion efficiency of gamma or X ray incident photons to visible light photons at the CsI(Tl) is 54 photons/keV. The CsI(Tl) has a signal decay constant of approximately one μs [1]. The emission spectrum of the CsI(Tl) extends in the range of 420 to 600 nm, with the maximum luminescence wavelength being 540 nm corresponding to the green color. This material is less hygroscopic than NaI(Tl), but deteriorates if exposed to water or high humidity. Its mechanical hardness is smaller and has more malleability than the NaI(Tl). It has (i) better resistance to severe mechanical shocks, (ii) acceleration and (iii) vibration, as well as (iv) higher gradients and sudden changes in temperature.

2. EXPERIMENTAL PROCEDURE

The cesium iodate crystals activated with 10^{-3} M of thallium was produced at IPEN/CNEN/SP by Bridgman method [10]. 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 electronic modules were used to treat the signals from the photomultiplier. 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 face and thickness) and (b) cylinder with dimensions of ∅20.1 mm x ↕11.9 mm (circular face and thickness). It was utilized an electronic developed at IPEN. The energy resolution of the CsI(Tl) crystals was estimated by the FWHM parameter, i.e. the ratio of the photopeak width at it half height. The crystals were coupled to the photomultiplier and exciteted by a ^{99m}Tc source (energy of 140 keV) with activity of 5.55×10^7 Bq (1.5 mCi) positioned at a distance of 40 cm from the detector (Figure 2). The luminescence emission spectrum was determined by means the different wavelength light produced by a ^{137}Cs source measured with a monochromator (JASCL, model FP550A, Japan) filtered with resolution of 20 nm.

Figure 1- Grown crystals of CsI(Tl) size (a) □12.3 x ↕19.5 (parallel face and thickness) and (b) cylinder with dimensions of ∅20.1 x ↕11.9 (circular face and thickness). All dimensions are in milimeters.

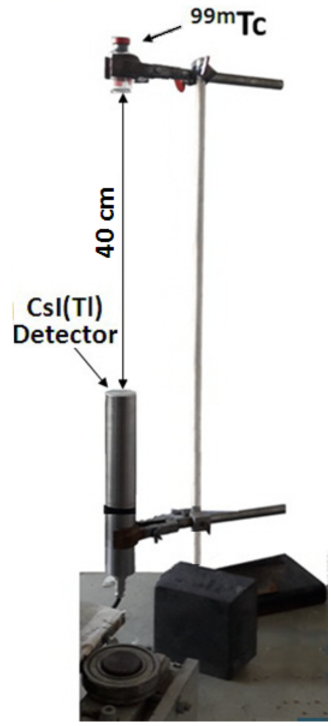

Figure 2- Experimental scheme to determine the FWHM parameter for a ^{99m}Tc source.

3. RESULTS

3.1- CsI(Tl) Luminescence emission

The determination of the emission spectrum of the grown crystal at IPEN was carrying out 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 intensity of the peak around 500 nm is attributed to the presence of thallium ions in the crystal. Similar spectrum was obtained for the □ crystal.

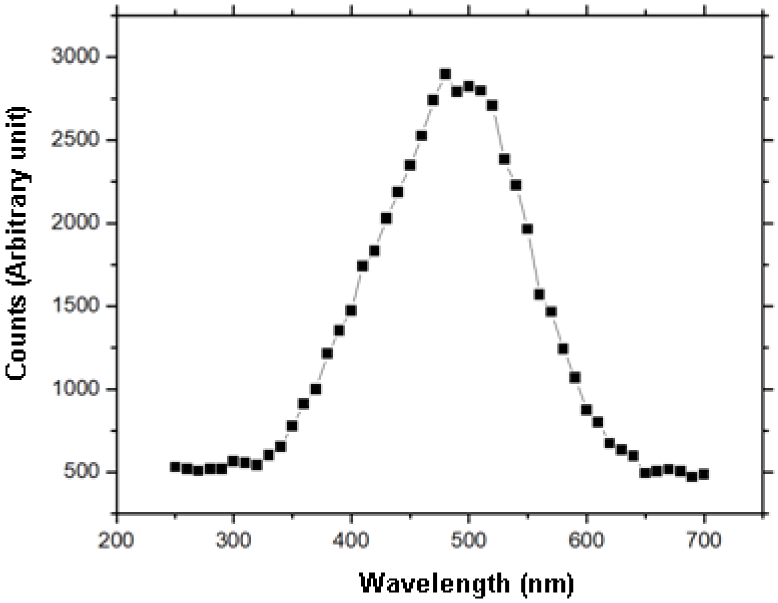

Figure 3- Spectrum luminescence of CsI (Tl at 10^{-3} M) as a function of the wavelength.

3.2- CsI(Tl) energy resolution obtained by detector coupled to photomultiplier

The gamma spectrometries for the detectors (a) □ 12.3 x ↕19.5 e (b) ∅ 20.1 x ↕11.9 shown in Figure 1 are presented in figures 4 and 5, respectively. ^{99m}Tc is a gamma emitter with an approximate energy of 140 keV. The gamma spectrum is used to know the detector energetic resolution. The calculation of the full width to half maximum (FWHM) parameter showed calculated from figures 4 and 5. For dimensioned crystals showed in Figure 1 (a) the energetic resolution FWHM was 23% and for (b) detector the FWHM was 20%. In the literature [11] the FWHM for CsI(Tl) is described as being 15%. The difference observed here is probably due to the small sizes of the faces of the crystals (12.3 mm (a) and 20.1 mm (b)) compared to the 25 mm face of the photomultiplier used ET Enterprise, Model 9924SB. It is suggested that if the photomultiplier or photodiode faces were 12.5 mm and 25 mm, then the resolutions found here would be similar to the values described in the literature.

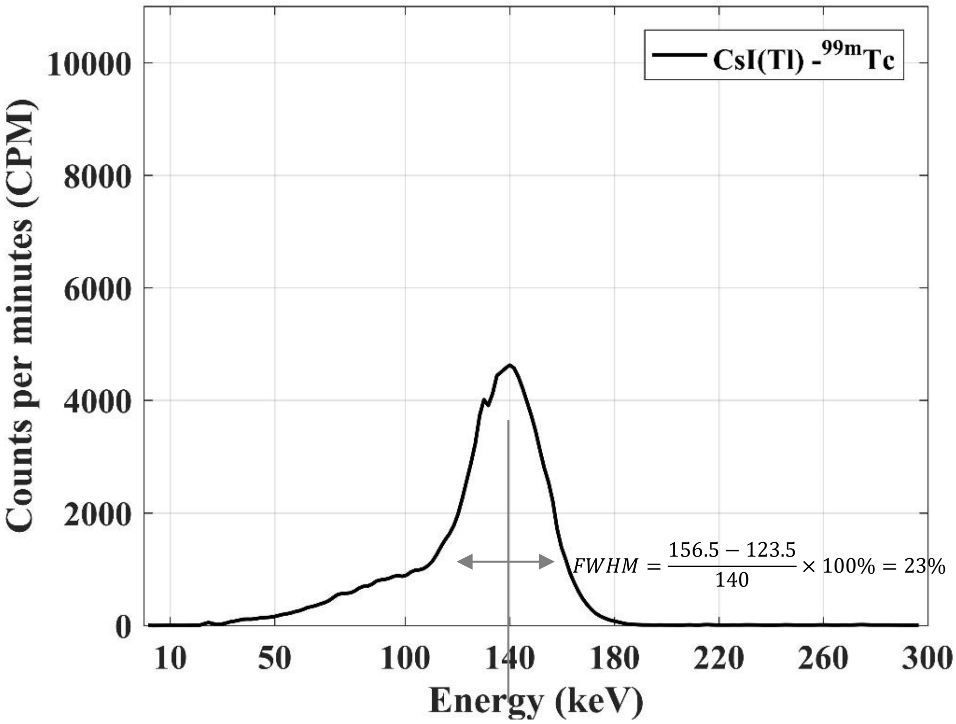

Figure 3- Gamma spectrometry obtained for the ^{99m}Tc radiation with the crystal of CsI(Tl) (a) □ 12.3 x ↕19.5(parallel face and thickness) coupled to the photomultiplier and electronic by IPEN

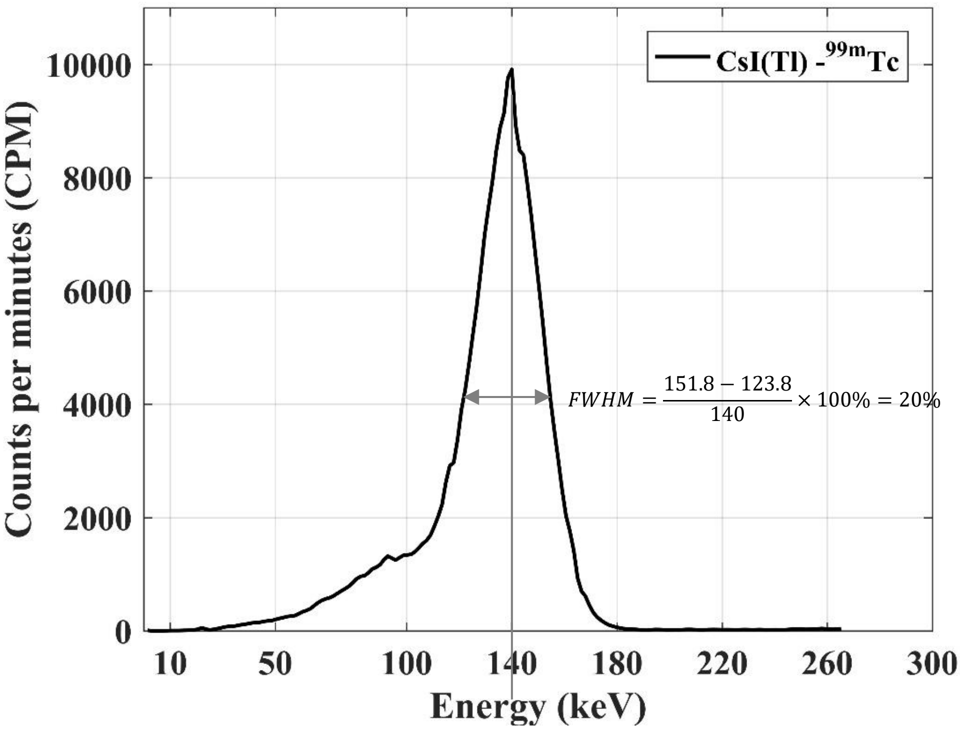

Figure 4- Gamma spectrometry obtained for the ^{99m}Tc radiation with the crystal of CsI(Tl) (b) ∅20.1 x ↕11.9 (circular face and thickness) coupled to the photomultiplier and electronic by IPEN

4. CONCLUSIONS

The experiments 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 approximately 500 nm. The comparison of FWHM (full width to half the maximum) between crystals of different sizes is close to that described in the literature.

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REFERENCES

1. N. Balamurugana, A. Arulchakkaravarthib, S. Selvakumarc, M. Lenina, Rakesh Kumard, S. Muralithard, K. Sivajic, P. Ramasamya, "Growth and characterization of undoped and thallium doped cesium iodide single crystals," *Journal of Crystal Growth*, **Vol.286**, pp. 294-299 (2006).
2. H. Grassmann, E. Lorenz, G. H. Moser, Properties of CsI(Tl)- "Renaissance of an old scintillation material," *Nuclear Instrument. Methods Physics Research*, **Vol.228**, pp.323-326 (1985).
3. J. Pursley, "Determination of Thallium Doping in Cesium Iodide Scintillator Crystals," NSCL, Michigan State University, East Lansing, MI 48824 (2001).
4. W. G. Gong, D. Y. Kim, G. Poggi, Z. Chen, K. C. Gelbke, G. W. Lynch, R. M. Maier, T. Murakami, B. M. Tsang and M. H. Xu, "Resolution tests of Csl(Tl) scintillators readout by PIN diodes," *Nuclear Instrument. Methods Physics Research*, **Vol. A268**, pp. 190-199 (1988).
5. S. Gunji, N. Hanada, T. Koshino, T. Kamae, S. Miyasaki, T. Takahashi, T. Tamura, T. Yamagami, H. Murakami, K. Mori, H. Tanaka, K. Yamamoto, "Use of a large area photodiode in CsI(Tl) scintillation counters," *Nuclear Instrument. Methods Physics Research*, **Vol. A295**, pp. 400-404 (1990).
6. M. M. Hamada, T. Hashimoto, F. Shiraishi, "Performance of CsI(Tl) crystal coupled to photodiode," In: *Sixth workshop on radiation detectors and their uses*, Japan, January 29-30, pp. 55-57 (1991).
7. M. M. Hamada, C. H. Mesquita, R. P. Rela, T. Hashimoto, F. Shiraishi, "Estudo do desempenho da combinação do cristal de CsI(Tl) com fotodiodo tipo PIN," In: *Congresso geral de Energia Nuclear*, Associação Brasileira de Energia Nuclear. Rio de Janeiro, July 5-9, **Vol.2**, pp. 611- 614 (1992).
8. P. Kreutz, A. Kuhmichel, C. Pinkenburg, J. Pochodzalla, Y. Z. Guo, S. H. Lynen, Trautmann, "Photodiode readout and pulse analysis of CsI(Tl) scintillator signals," *Nuclear Instrument. Methods Physics Research*, **Vol. A260**, pp. 120-123 (1987).
9. Blanco et. Al. "Desenvolvimento de um dispositivo para obtenção de monocristais de ligas à base de cobre," *Quim. Nova*, **Vol. 26**, N° 5, 757-762 (2003).
10. M. C. C. Pereira, T. M. Filho, V. M. Lopes, J. R. Berreta, J. P. N. Cárdenas, "Scintillation Response of CsI:Tl Crystal under neutron, gama, alpha particles and

beta excitations," In: *International Nuclear Atlantic Conference - INAC* São Paulo, SP, Brazil, October 4-9 (2015).