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Development of Neutron Detector Using Li-Doped CsI Scintillator Crystal

Berretta J R[1], Pereira, M C C[2], Filho, T M[3], Mesquita C H[4]

[1]*jrretta@ipen.br*
[2]*macoper@ipen.br*
[3]*chmesquita@usp.br*
[4]*tufic.madi@gmail.com*

1.Introduction

The detection of radiation and the measurement of its properties are requirements for the development of all areas of nuclear technology and its applications. Among its applications, the following stand out: scientific research, medical application, reactor operation, the area of radiological protection and industrial applications. Neutron detection is not trivial, given the lack of charge of these particles and the peculiarity of their interactions with matter. Another difficulty in detecting neutrons is that it is always accompanied by radiation of other natures, which makes it difficult to electronically discriminate the impulses generated by the neutrons from those generated by other radiations. In this work, CsI-based crystals were studied for application as neutron detectors. Many authors use CsI-based crystals using various elements as dopants such as Br, Pb, Tl and Li [1, 2, 3]. In this work, Li is used as a dopant, evaluating the neutron detection response to different concentrations of dopants (between 10^{-1}M to 10^{-4}M). The reaction of the neutron with Li is given as: $n+{}^{6}Li \rightarrow {}^{3}H(2{,}75\ MeV) + {}^{4}He(2{,}05\ MeV)$ with σ= 520 *b*[4]. CsI crystals have a low hygroscope, low production cost, ease of handling, and Li has a low cross section for interactions with gamma radiation, feature that allows the construction of detectors with a configuration of good sensitivity to neutron detection and low sensitivity to gamma radiation.[2].

2.Methodology

High purity CsI salt was used and Li was added in form of the lithium iodine (LiI) at varying concentrations and subjected to oven growth using the Bridgman method[5, 6].

The crystals were cut 20 mm in diameter and 14 mm in thickness. Then, thecrystals were polished and coated with teflon tape less than the face facing the photo multiplier in order to reflec the generated photons towards the photomultiplier. A thin layer of silicone grease was used as optical coupling between the photomultiplier and the CsI:Li crystal. This entire set was coated with a black cover to prevent any light penetration and in turn a 1 mm cadmium layer was placed enclosing the set, crystal and photomultiplier, in order to prevent thermal neutrons that did not directly impact the crystal from being detected. The 21-pin photomultiplier was connected to: a high voltage source, a preamplifier, a signal amplifier and finally a multichannel analyzer. An oscilloscope helped in the adjustments and monitoring of the electronic signals, and the spectra obtained were recorded on a microcomputer.

The set was subjected to neutron incidence from an AmBe source of 100 mCi activity with neutron flux of $2{,}5 \times 10^{5} ns^{-1}$[7]. Measurements were made using a paraffin block positioned between the neutron source and the crystal in order to thermalize the fast neutrons and thus increase the system's detection efficiency. The counts with the neutron source were made at a distance150 mm between the CsI:Li crystal and the neutron source. Measurements were also taken with a 20 mm and 40 mm thick paraffin moderator block positioned against the CsI:Li crystal with150 mm distances. The experimental arrangement and the assembly scheme are shown in Fig. 1 and Fig. 2.

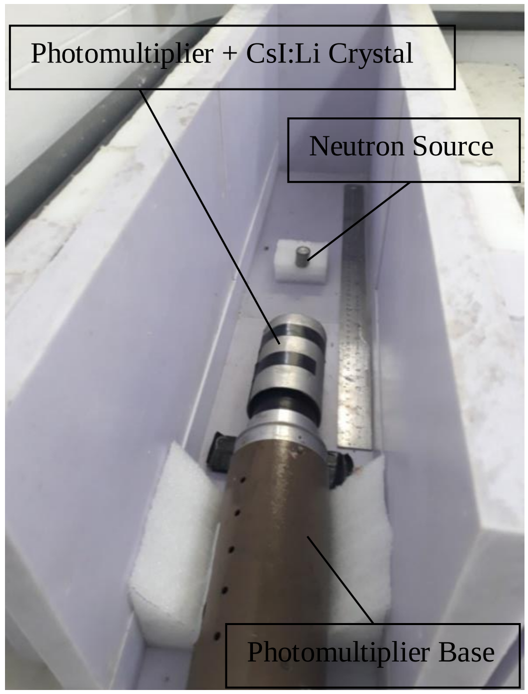

Figure 1: Experimental setup. CsI:Li crystal photomultiplier and neutron source

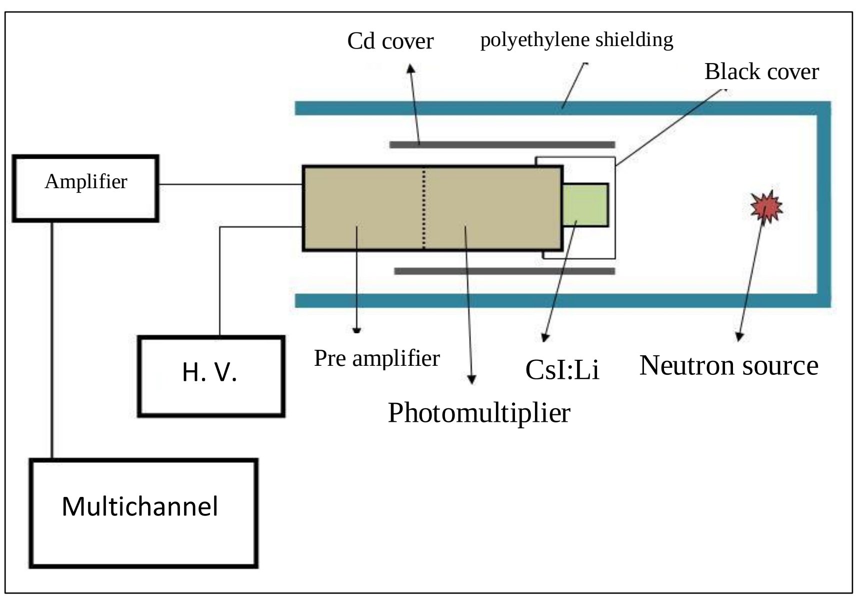

Figure 2: Assembly scheme.

The spectra obtained were compared in relation to the concentration of the dopant and in relation to the response to the presence of a moderator between the source and the crystal.

3. Results and Discussion

The crystals were exposed to a neutron source of AmBe positioned 150 mm away which has a neutron emission energy spectrum ranging from 1 Mev to 12 Mev.
The spectra obtained using Li-doped CsI crystals at concentrations ranging from 10^{-1}M to10^{-4}M are shown in the Fig. 3.

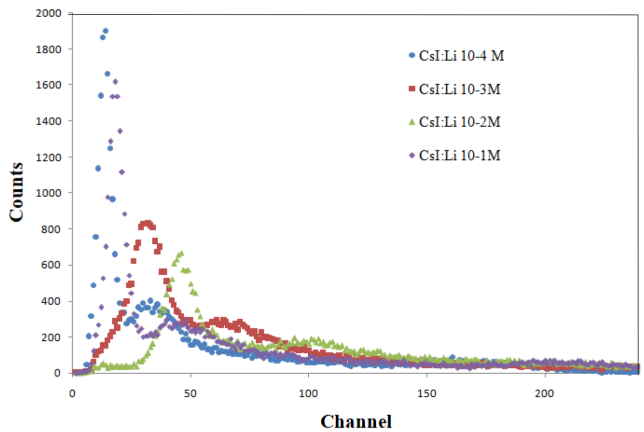

Figure 3: Neutron count for 10^{-1}M to 10^{-4}M CsI:Li crystal.

The relationship between moderator thickness and counts observed in the CsI:Li 10^{-3} M crystal is shown in Fig. 4.

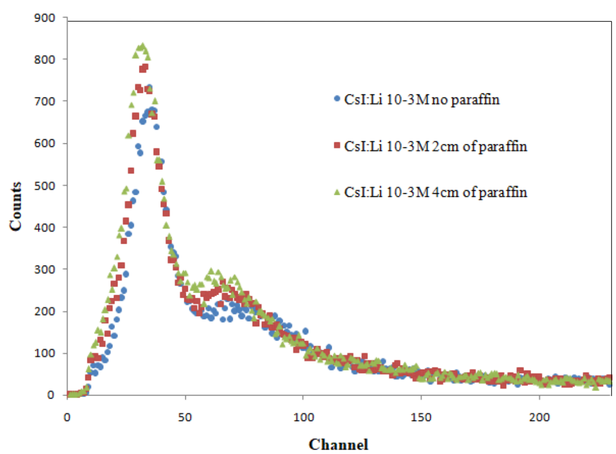

Figure 4: Neutron counts with various moderator thicknesses.

Observing the spectra of Fig. 3, the CsI:Li crystal of 10^{-1} M and the concentration of 10^{-4} M have a peak count in the first channels of the spectrum but with a lower volume of counts. The concentration crystals of 10^{-2} M and 10^{-3} M showed better performance in the detection of neutrons, despite having a less accentuated peak, but the level of counts of the crystal concentration of 10^{-3} M showed an efficiency of about 20% higher than the crystal with a higher concentration of Li 10^{-1} M.
The improvement in neutron detection as a function of the amount of dopant can be attributed to a set of factors such as the ability of the lithium element to interact with the neutrons incident on the crystal due to its high cross section for thermal neutrons and the ability to deposit all the energy of the neutron interaction

with lithium in the crystal, while the interaction of gamma radiation deposits a smaller amount of energy. However, this improvement is compromised by the worsening in crystal transparency with the greater amount of dopant in the crystal.

The CsI:Li 10^{-1}M crystal had the lowest volume of counts, despite having the highest amount of the doping element lithium. This behavior can be explained by the deterioration of light transmittance with the increase in the amount of Li dopant. The reaction of Li with the neutron has a good cross section for thermal neutrons and the experimental results demonstrate this relationship with increased detection with the use of paraffin as a moderator, (Fig. 4). The best thickness used was 40 mm of paraffin we can observe in Fig. 3.

4. Conclusions

The best Li dopant concentration for the CsI crystal in this experiment was determined to be 10^{-3}M.

The crystal was grown using natural Li as a dopant which has only 7.5% ^{6}Li, this demonstrates the feasibility of using this type of crystal as a neutron detector since using Li enriched in ^{6}Li will greatly increase its efficiency.

The use of Li as an added dopant during CsI crystal growth showed good sensitivity for both, fast neutrons and thermal neutrons, making the CsI:Li crystal a promising detector for reactor dosimetry applications as well as in experiments involving high neutrons energy.

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