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# Determination of the optimized thickness of a CsI:Li crystal to be used as a scintillator detector for neutrons using the Monte Carlo technique.

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## 1. Introduction

Scintillation materials have historically been one of the first techniques applied to the detection of ionizing radiation. The operating principle of these devices is based on the absorption of incident radiation and the subsequent re-emission of this energy in the form of electromagnetic radiation at lower frequencies. This process occurs at wavelengths compatible with the region of maximum photonic efficiency of the coupled photosensor.[1] In order to maximize the probability of photon emission in the visible spectrum region during the de-excitation mechanism, controlled additions of small concentrations of impurities (dopants) are promoted to the crystalline matrix during its growth.[2]

In the case of the Li-doped CsI crystal (CsI:Li), Li plays the role of dopant and as a converter for neutron detection. Li found in nature has a mixture of two stable isotopes: $^{6}$Li with an abundance of 7,5% and $^{7}$Li with an abundance of 92,5%. The neutron reaction with Li is given as: n + $^{6}$Li $\rightarrow$ $^{3}$H (2,75 MeV) + $^{4}$He (2,05 MeV) with capture cross-section $\sigma$= 940 *b*. The capture cross-section for $^{7}$Li can be considered negligible for this work $\approx 10^{-1}$*b.* [3] [4]

Obtaining isotopically enriched $^{6}$Li on the world market has certain difficulties, as $^{6}$Li is used in the manufacture of nuclear weapons, in addition to being an input for which there are not many suppliers in the world. For these reasons, the present work proposed to use the Monte Carlo technique to simulate and determine the thickness of the CsI:Li crystal to be used as a detector for the best response to neutron detection.

## 2. Methodology

The Monte Carlo method is an important tool for simulating the interaction of radiation with matter, whether neutrons, protons, electrons, or photons, or a combination thereof. In the simulation, the code considers the sequence of individual probabilistic events that make up a process. These probability distributions are statistically sampled to describe the total phenomenon.[5]

The technique was used to calculate the reaction rate of the thermal neutron with the $^{6}$Li of the scintillator along the thickness of the crystal and thus evaluate the best crystal thickness with a concentration of $10^{-3}$ M of $^{6}$Li for neutron detection.

Before using MCNP, it is necessary to create a model, which is the description of physical reality in an input file, the INPUT, where all the information of the experiment is provided so that the program can simulate the problem.

The Vised graphical interface, which works with MCNP-6, was used to generate Figures 1 and 2.

The modeling considered that the detector/photomultiplier assembly is positioned between walls of

borated polyethylene on all sides, forming a shield for neutrons. It was also considered to have a cadmium layer surrounding the photomultiplier/crystal assembly, except for its face, in order to prevent neutrons that might be scattered on the walls of the assembly or in the paraffin from entering the crystal from the side. The neutron source was modeled according to the manufacturer's drawings and construction materials. A paraffin moderator was considered to exist between the AmBe neutron source and the scintillator crystal.

Two cases were simulated using the Monte Carlo technique, namely:

1. Simulation performed with an AmBe neutron source positioned at a distance of 150 mm. The crystal dimensions were 26 mm in diameter and 14 mm in thickness. The crystal was coated with a layer of cadmium, except on its faces. Figures 1 and 2 show the experimental setup. Figures 3 and 4 show the distribution of neutron flux in the vicinity of the detector and inside it. The crystal used for this simulation was CsI:Li with natural Li and a concentration of $10^{-3}$ M.
2. Study of the range of neutrons within the CsI:Li crystal with a concentration of $10^{-3}$ M of Li enriched in 6Li. The dimensions of the CsI:Li crystal in this simulation were 26 mm in diameter and 50 mm in length.

Figures 5 and 6 show the crystal divided into 5 mm slices. The neutron source was considered to have an exclusively thermal neutron energy spectrum and was positioned at the crystal/air interface.

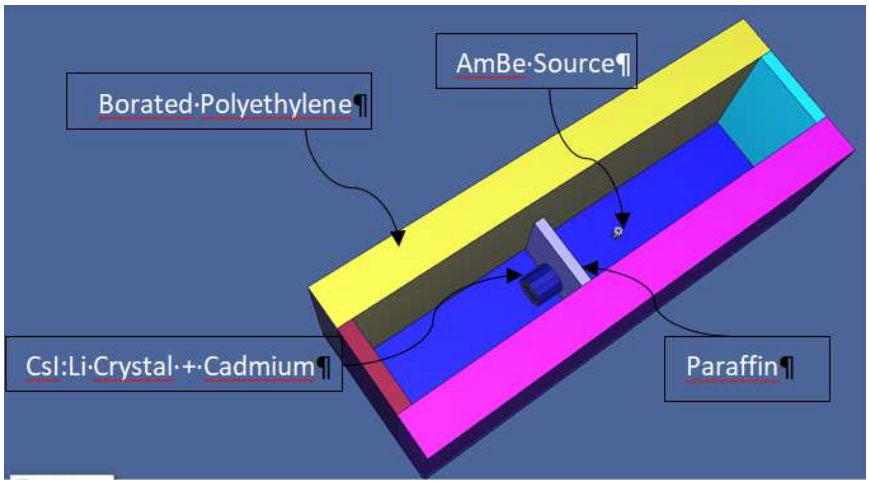


Figure 1 - Experiment modeling – 3D view.

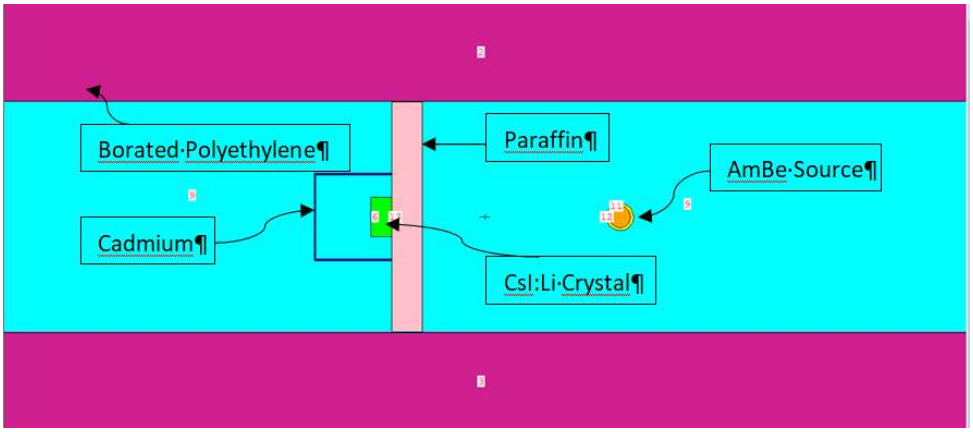


Figure 2 - Experiment modeling – Top view.

## 3. Results and Discussion

Figures 3 and 4 show a decrease in neutron flux of around 50% between the incident and emerging flux from the crystal, indicating interaction with the lithium dopant in the crystal.
Figure 5 shows the behavior of the neutron flux from the source to the crystal doped with $10^{-3}$ M enriched lithium. Note that some of the incident neutrons are reflected, and the fraction that penetrates the CsI:Li crystal reacts with the lithium nuclei. A reduction in neutron flux of the order of $10^{3}$ is observed up to the fourth slice, i.e., 20 mm crystal thickness. From the fourth slice to the tenth, the neutron flux is insignificant. Figure 6 shows the same situation, but with a more focused view of the crystal reactions.

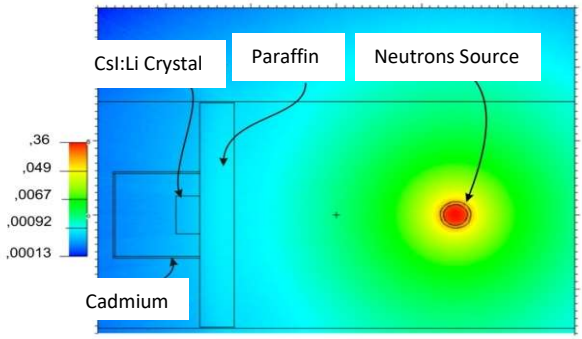


Figure 3 - Neutron flux Case 1 CsI:Li $10^{-3}$ M crystal – top view. Relative scale.

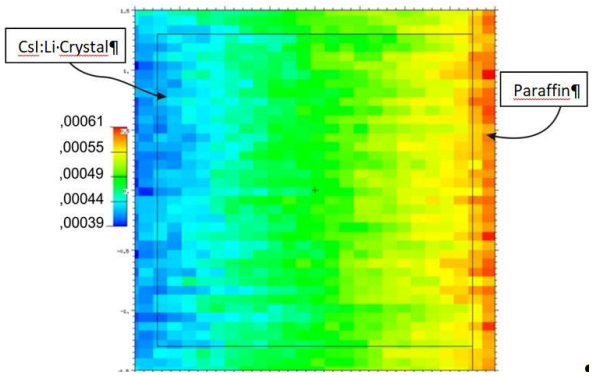


Figure 4 - Neutron flux Case 1 CsI:Li $10^{-3}$ M crystal – crystal detail. Relative scale.

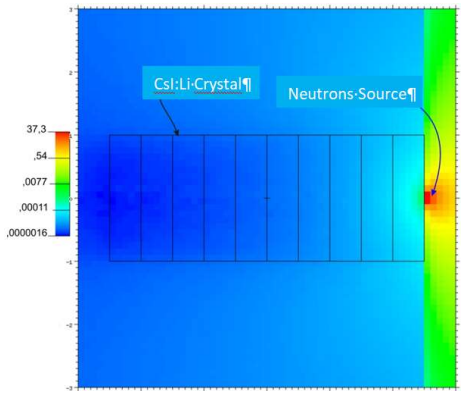


Figure 5 - Neutron flux Case 2 CsI:Li crystal $10^{-3}$ M Li enriched – top view. Relative scale.

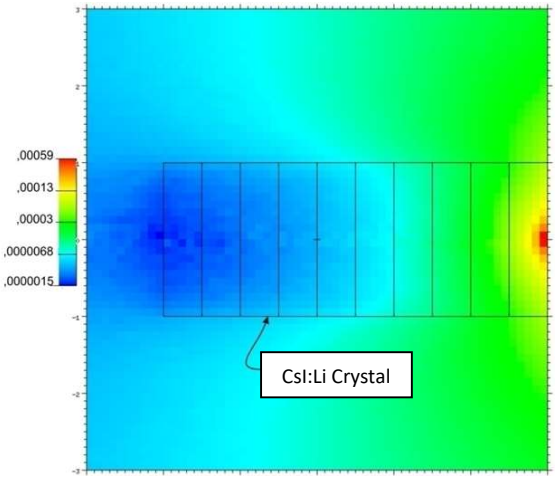


Figure 6 - Neutron flux Case 2 CsI:Li $10^{-3}$ M crystal and enriched Li – Detail. Relative scale.

## 4. Conclusions

In the simulation, the crystal with the best experimental response for neutron detection was chosen, in this case the CsI:Li crystal with a Li concentration of $10^{-3}$ M. This crystal showed an increase in detection sensitivity of 25,62 % compared to the pure reference crystal (CsI). (Reference: Berretta thesis)

The neutron deposit energy simulations in the CsI:Li crystal performed by the MCNP-6 program showed that it is not necessary to work with large crystals, as the CsI:Li crystals showed great sensitivity to neutron detection. Thus, a crystal thickness of 20 mm was sufficient for efficient neutron detection.

The improvement in neutron detection with the increase in Li dopant was attributed to the ability of the Li dopant element to absorb the incident neutron due to the high cross-section for thermal neutrons.

Studies should be conducted to improve the optical properties of crystals with Li concentrations above $10^{-3}$ M and with the use of enriched Li, which would greatly improve the sensitivity of neutron detection.

## References

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