# SIMULATION OF THE THERMAL NEUTRON SEMICONDUCTOR DETECTOR RESPONSE USING MCNPX CODE

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## 1. Introduction

Development of thermal neutron semiconductor detectors with satisfying spectroscopic performances is becoming an increasing importance especially due to progress in neutron radiography imaging. Semiconductor materials like GaAs, Si or SiC can be utilized for neutron detection when externally coated by a neutron reactive layer. In our recent papers, design and spectroscopic properties of fast neutron detectors based on GaAs, Si and SiC have been investigated. The effect of HDPE layer converting neutrons to detectable charged particles (protons) on a detector performance has been evaluated via measurements and also simulations [1]. In this contribution we have focused our interest on SiC detectors of thermal neutrons. Simple thermal neutron detectors are a combination of a planar diode with a layer of an appropriate neutron converter, the most commonly $^{6}LiF$. These devices have limited detection efficiency of a few percent which depends among other factors also on the thickness of the conversion layer [2, 3]. The goal of this work was to simulate the transport of thermal neutrons through the detector conversion layer in order to assess the detector efficiency and to inspect the effect of converter thickness on detector response. A self-consistent Monte Carlo based MCNPX (Monte Carlo N-Particle eXtended) code has been used for this purpose.

## 2. SiC detectors of thermal neutrons

SiC detectors cannot be used for thermal neutron detection directly. It is necessary that a material, which converts thermal neutrons to charged particles, so called converter, is present. There are many options for choice of conversion layer material. Although $^{10}B$ has a very high thermal neutron cross-section of $\sigma$ = 3838 b, it would produce a high sensitivity only in limited range of measurement due to short range of reaction products (0.84 MeV for $^{7}Li$ and 1.47 MeV for $^{4}He$). The most popularly the $^{6}LiF$ is used as converter due to still high thermal neutron absorption cross-section ($\sigma$ = 942 b at a neutron energy of 0.0253 eV), relatively high energies of reaction products and acceptable chemical properties (unlike e.g. highly reactive Li or chemically unstable LiH).

The neutron capture reaction on $^{6}Li$ results in alpha and triton particle production as follows:

$$^{6}Li + n \rightarrow \alpha\ (2.05\ MeV) + {}^{3}H\ (2.73\ MeV) \qquad Q = 4.78\ MeV$$

The reaction products from the thermal neutron capture are released in opposite directions, as illustrated in Fig. 1, and therefore, the simple planar detector can register either alpha or triton particle, but never both.

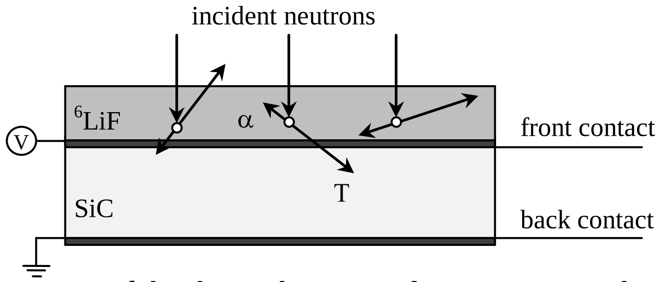


Fig.1: *Illustration of the thermal neutron detection principle.*

Assuming that the total detection efficiency of a detector is for charged incident particles close to 100 %, the detection efficiency of a detector is consistent with integral conversion efficiency, i.e. the ratio of the integral flux density of charged reaction products (alpha particles plus tritons in this case) entering the active region of a detector to the integral flux density of neutrons entering the $^6$LiF layer. For front irradiation (i.e. the conversion layer is placed between a source of radiation and a detector), the detection efficiency is increasing with conversion layer thickness, levels off at a certain thickness as a result of the finite range of reaction products and after reaching its maximum value starts to decrease due to thermal neutron absorption by the $^6$Li in the conversion layer. This behaviour was simulated using MCNPX code in order to disclose the optimal thickness of the conversion layer and will be discussed further.

## 3. Calculation details

MCNPX is a widely spread calculation code based on Monte Carlo algorithms used to simulate interaction of radiation with matter. It contains high-quality physics and has access to the most up-to-date cross-section data. In our calculations, the version 2.7.0 [4] released in April 2011 has been used. The code enables to follow the transport of the neutrons and also products from neutron interactions like alpha particles and tritons, whereby the nuclear data tables along the model physics are employed.

The detector has been modeled as a cylinder of a diameter of 4.5 mm having a thickness of 55 μm corresponding to the applied reverse bias of ca -300 V in a real experiment. $^6$LiF conversion layer was placed on the top of a detector, i.e. between the source and the front detector contact (front irradiation). A point source collimated into a cone at a perpendicular distance of 1 cm to the detection structure has been used to model the source of thermal neutrons. The outside medium was air.

As first, we have calculated using the SRIM code [5] the ranges of 2.05 MeV alpha particles and 2.73 MeV tritons in $^6$LiF layer, which are 6.05 μm and 33 μm, respectively. According to those values it can be expected that a layer thicker than 33 μm will not increase the detection efficiency. The specific value of $^6$LiF thickness yielding the maximum detection efficiency has been calculated using MCNPX code as a ratio of the charged reaction products flux on the back side of the $^6$LiF film (alpha particles + tritons) to the neutron flux on the top side of the conversion layer (i.e. F1 tallies in the MCNPX code).

In further, we have simulated a detector response to thermal neutrons of a SiC detector covered by a $^6$LiF layer of different thicknesses. The F8 tally has been employed to evaluate the detector response. F8 tally is the pulse height tally which provides the energy distribution of pulses created in a cell that models the physical detector. It has to be noted, that MCNPX code has the ability to transport heavy charged particles only from the model physics. The use of physics models below 20 MeV is, however, rather limited and therefore, the calculated results might have limited accuracy as concerned alpha particles and tritons transport.

## 4. Results

The theoretical detection efficiency calculated using MCNPX as described above is plotted against $^6$LiF reactive film thickness in Fig. 2. The curve shows expected tendency and reaches its maximum of about 4.8 % for a $^6$LiF thickness of ca 25 μm. The further decrease in efficiency is due to neutron absorption in a region too far away for the reaction products to reach the active volume of a detector. Therefore, the optimum value is a bit shorter as compared to the 2.73 MeV-triton range in the film calculated using the SRIM program. The optimal $^6$LiF thickness as well as the maximum value of the efficiency are in a good agreement with results reported in [2] and [3], i.e. 4.48 % and 4.3 %, respectively.

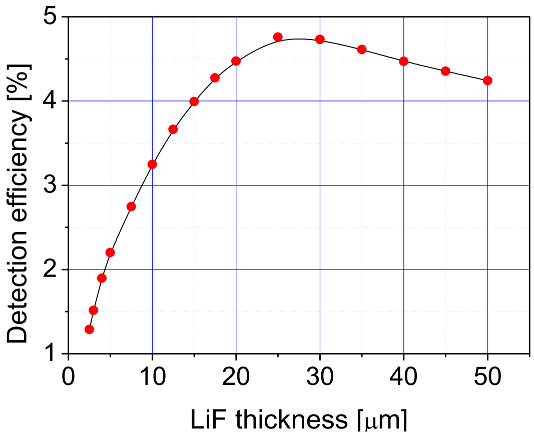


Fig.2: *Detection efficiency of $^6$LiF layer as a function of its thickness.*

The detector response and its dependency on $^6$LiF conversion layer thickness has been simulated using F8 pulse height tally, which provides the number of pulses depositing energy within the specified energy bins. The F8 tallies of the individual contributing charged particles - tritons and alpha particles, are plotted in Fig. 3a and 3b, respectively. The total F8 tally from both reaction products representing a response of a SiC detector with an active volume thickness of 55 μm (corresponds to an applied reverse bias of -300 V) is shown in Fig. 3c.

In Fig. 3a, the response from tritons shows an expected sharp edge at the energy of about 2.5 MeV and is getting broader with increasing $^6$LiF thickness. That means, for thicker conversion layer, the tritons produced immediately after entering the $^6$LiF layer pass a longer distance and consequently, have higher energy losses and enter the detector active volume with lower energies. The height of the edge at the end of the response is gradually falling with increasing $^6$LiF thickness due to thermal neutron absorption followed by decreased flux density of reaction products born close to the $^6$LiF-detector interface. The responses from alpha particles display an analogical behaviour, qualitatively deviating from triton response only due to considerably shorter range of ca 6 μm. Quantitatively lower height of the response is due to greater mass of alpha particles, which deposits the carried energy in less interaction steps as compared to lighter tritons. The total responses of the SiC detector shown in Fig. 3c disclose a predominant contribution from tritons for thicker conversion layers. The edge from alpha particle energy deposition can be easily recognised for all converter thicknesses. The total response height apparently tends to decrease for $^6$LiF thicknesses higher than its optimal value (the line corresponding to 40 μm thick $^6$LiF layer in Fig. 3c).

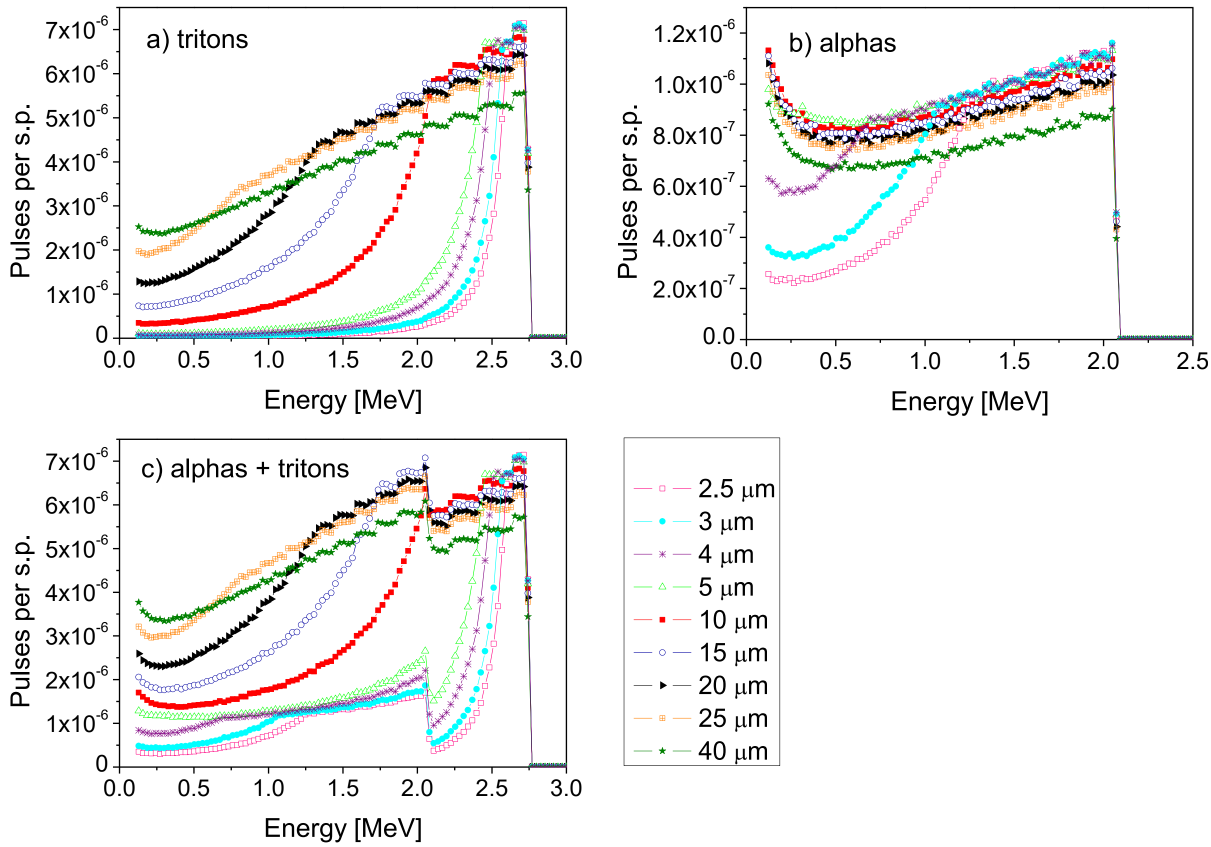


Fig.3: *Contribution to the SiC detector response from tritons (f8:t), a), and from alpha particles (f8:a), b), and the total SiC detector response (f8:t + f8:a), c), all of them plotted for different $^{6}$LiF layer thicknesses.*

## 5. Conclusion

We have utilised the MCNPX code to evaluate the optimal thickness of $^{6}$LiF reactive film and to simulate the response of SiC detector disposed of $^{6}$LiF layer of different thicknesses. The optimal thickness of the conversion layer has been found at 25 μm. The relatively low value of the corresponding detection efficiency (4.8 %) can be slightly enhanced when irradiated from the back. In this case, the region with highest reaction rate lies close to the detector and only the detector material can interfere with registered neutrons. Other possibility to increase the detection efficiency is creating a 3D microstructure of dips, trenches or pores in the detector and filling it with a neutron converter [2].

The detector response results showed that with increasing converter thickness, the pulse height tally is getting broader due to prevailing contribution from tritons. From the $^{6}$LiF layer thickness corresponding to its optimal value, the maximum of the detector response starts to decrease and for higher thicknesses the pulse height curve tends to level off toward its low energy tail. The results from simulation have been successfully compared with detector responses obtained by measurement for two different $^{6}$LiF thicknesses and will be presented in [6].

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