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Simulated Spectral Responses of Thin Planar-Type Radiation Detectors by Tracking Primary Electrons from the Gamma-ray Interaction

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1. Introduction

State of the art Monte Carlo codes, as GEANT [1] or MCNP [2], are extensively used to model and calculate the response of detectors in different radiation scenarios, such as medical or space applications, nuclear security or radiation protection, among others. After validation of the Monte Carlo model, the results of such simulations often serve as guidelines for radiation protection practices, detectors' design or facilities shielding. As these codes use models and/or libraries to transport radiation through matter, it may happen that the calculated response of a detector changes with the used method. A particular aspect to take into account is how the energy deposited in a material is treated. When simulating a spectral response from a radiation detector measuring gamma rays, the pulse height (F8) tally of the MCNP code is often used, or the energy deposited in the detector is calculated from the energy lost by each incident gamma ray due to the interactions within the material. However, in reality, the energy deposition to a radiation detector is indeed caused by the kinetic energy transferred by primary electrons which are generated by the gamma ray interactions and further create information carriers to create the detector signal. This means that frequently the simulated energy deposited spectra in a medium is obtained by assuming that all the energy is deposited by the incident particle in the point of interaction, without taking into account the electrons transport. This approximation is only valid if the medium has a large enough volume so it encloses the path length of the primary electrons and the diffusion areas of the secondary electrons, meaning that these electrons deposit all its energy within the volume [3]. However, if the detector is thinner than the path length or diffusion areas of these electrons, these will escape and the incident energy is only partially deposited in the medium. This affects the simulated spectra, namely the x-ray escape peaks, Compton continuum, photopeak area and peak-to-Compton ratio.

It is therefore necessary to include the proper electron transportation when simulating thin films, so the electron escape is taken into account.

Previous studies have simulated the spectral response of nanocrystals assembly based radiation detectors and assessed the spectral response variation with the thickness of the detector [3, 4]. One of these studies does not include the particle tracks of the primary electrons into de calculations while the other is a very complete study performed with PENELOPE and MCNP5.

The goal of this study is to simulate and transport the response of a thin film silicon detector by having and not having the primary electrons track into account. Because this type of detectors is widely used in different field applications, it is crucial to understand how the code options influence the final results, to assure that these are correct and in agreement with experimental results. This knowledge is also essential for micro-dosimetry, as one needs to precisely calculate the radiation deposited in a specific volume.

2. Methods

In this work, simulated spectra obtained for a thin planar-type detector by tracking primary electrons with those obtained with conventional methods are compared. First, the spectra using MCNP6 was calculated by changing the thickness of the detector and the cutoff energy of the electron transport. The modeled detector is a 0.5 cm radius cylindrical silicon detector with its thickness set as 50 μm, 100 μm and 500 μm and it was irradiated by a 662 keV gamma point source, located 25 cm away from the detector. The energy cutoff for electrons was set as 30 eV, 160 eV and 1 keV. The simulations were carried out having and not having into account the electron transport. In MCNP6, the pulse height tally F8 was used to obtain the energy deposition spectra by the primary recoil electrons in the detector volume. The ENDF / B-VI library was used with MCNP6.

In addition to the simulated spectra, the total efficiency, full energy peak efficiency, peak to Compton ratio and multiple Compton event ratio were calculated. The total efficiency was obtained by dividing the total counts by the total number of simulated photons. The full energy peak efficiency was obtained by dividing the number of photopeak counts by the number of simulated photons. By dividing the photopeak counts by the average counts of the Compton continuum, one obtains the peak to Compton ratio. Finally, the multiple Compton event ratio was obtained by dividing the counts between the Compton edge and the photopeak by the number of simulated photons. By calculating these parameter, one can compare the different obtained spectra and understand what the impact of the electron transport on the energy deposition in the detector is.

3. Results

3.1. Considering electron transport simulation

Figure 1 to Figure 3 show the simulated spectra simulated with MCNP6 for a detector thickness of 50 µm, 100 µm and 500 µm for an electron energy cutoff of 30 eV, 160 eV and 1 keV.

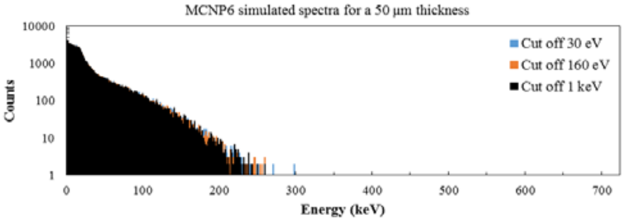


Fig. 1. MCNP6 simulated spectra for a 50 µm thickness, considering the transport of electrons, for different electron cutoff energies.

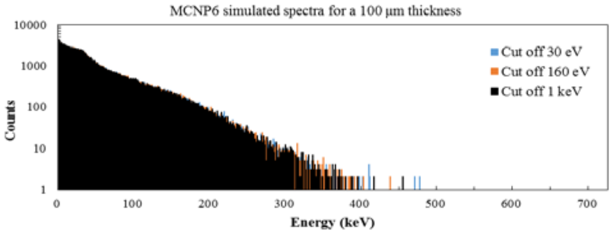


Fig. 2. MCNP6 simulated spectra for a 100 µm thickness, considering the transport of electrons, for different electron cutoff energies.

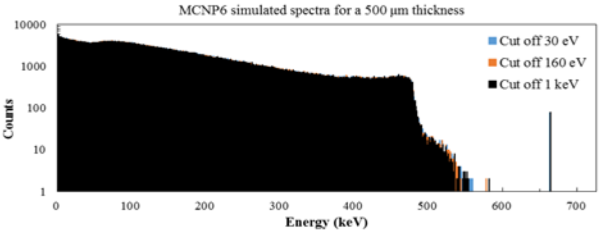


Fig. 3. MCNP6 simulated spectra for a 500 µm thickness, considering the transport of electrons, for different electron cutoff energies.

It can be observed that with increasing detector thickness, the maximum detected energy also increases, as less radiation escapes the detector and therefore more electrons deposit their energy within the detector. For a 500 µm detector thickness, a full spectrum is obtained, meaning that it includes a continuum up to the Compton edge at 478 keV and a photopeak at 662 keV, showing that this thickness encloses the path length of the primary and secondary electrons. Lowering the electron energy cutoff does not have a significant influence for any of the detector thicknesses.

3.2. Considering electron transport vs. not considering electron transport

Figure 4 shows the spectra obtained with MCNP6 when considering the electron transport and when not considering it, for a 500 µm detector thickness. While both spectra show the Compton continuum, Compton edge and the photopeak, the spectrum obtained not considering electron transport recorded more counts from around 210 keV and lower counts for values below 210 keV. This happens because when not transporting electrons, the code assumes that the energy of the created electrons is deposited in that point, and high energy electrons do not escape the detector. On the other hand, when transporting electrons, electrons escape the detector and only deposit part of their energy in it, thus producing a spectrum with higher counts in the lower energy range. However, the total efficiency of both spectra must be similar, as the higher counts in the lower energy range (considering electron transport) correspond to the higher counts in the higher energy range (not considering electron transport). The efficiency values are present in Table 1.

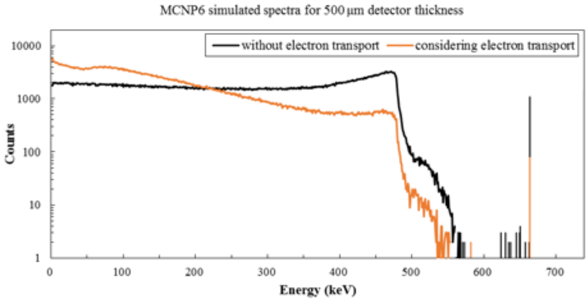
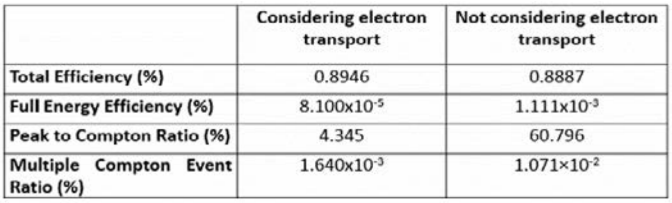


Fig. 4. MCNP6 simulated spectra for a 500 µm detector thickness, taking into account the transport of electrons and not taking into account.

The full efficiency peak is higher when not taking the transport of electrons as the electrons deposit their full energy inside the detector's volume, which also leads to a higher peak to Compton ratio.

Table I: Values of the total efficiency, full energy peak efficiency, peak to Compton ratio and multiple Compton event ratio of the spectra obtained with MCNP6, with and without having into consideration the electron transport.



	Considering electron transport	Not considering electron transport
Total Efficiency (%)	0.8946	0.8887
Full Energy Efficiency (%)	8.100×10^{-5}	1.111×10^{-3}
Peak to Compton Ratio (%)	4.345	60.796
Multiple Compton Event Ratio (%)	1.640×10^{-3}	1.071×10^{-2}

6. Conclusions

In this work, the comparison between the results of the response of a Si thin film detector to a 662 keV gamma source obtained with MCNP6 for different detector thicknesses and electron cutoff energies, as well as having and not having into account the electron transport. Results show that when having into account the electron transport, the MCNP6 simulations only show a full spectrum for a detector thickness of 500 μm. When not taking into consideration the transport of electrons the code produces a full spectrum, independently of the thickness of the detector. In all cases, the variation of the electron energy cutoff did not produce significant variations of the simulated spectra. When performing a Monte Carlo study, not assuming the electron transport generally leads to a drastic reduction of the computing time. Therefore, if one knows that the thickness of the simulated detector is large enough to enclose all the primary electrons and the diffusion areas of the secondary electrons, then one can use this approximation to simulate the response of the detector.

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