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Comparison of Simulated Responses Derived from Silicon Detectors Depending on the Consideration of Primary Electron Tracks

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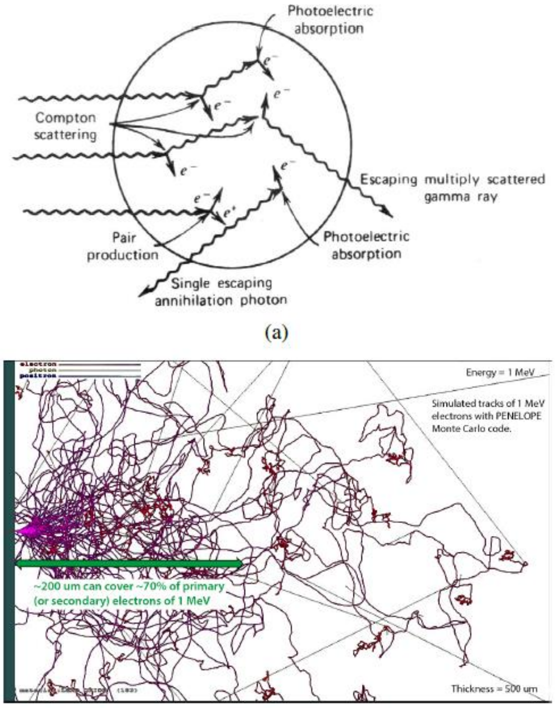
1. Introduction

In the modeling and the response simulation of the radiation detectors, one simply considers the energy deposited by the incident radiation to the detection medium, as a result of the radiation interaction, for the detector response calculation such as simulated energy spectra, assuming that the energy transferred to the medium is always fully absorbed in the medium [1]. However, we have previously shown the alteration of the simulated spectral response from radiation detectors when the active detector volume is not as large as the penetration length, or diffusion areas of the primary and secondary electrons, i.e. the solid lines of electron path illustrated in Fig. 1a is not confined within the detector volume anymore [2]. For thin-film-based detectors, such as nanostructure material based radiation detectors [3]-[5], it is important to include the incomplete charge carrier creation due to the primary electron escaping in the simulation of the spectral response and detection efficiency [6]. If the effect due to the partial energy deposition from the primary electrons, thus limited charge creation by the initial energy deposition because of the electrons escaped from the active region is considered, the simulated spectra will reflect the effect accordingly.

According to a simple simulation using PENELOPE 2011 Code (Fig. 1b), a Detector thickness of 200 μm can only embrace 70% of the recoiled electron tracks within the region. Considering the spatial distribution of the radiation interaction within the detector volume, one can estimate that any detectors which is less than 400-500 m thickness, in general, is subject to the effect of the incomplete charge creation by the energy deposition, in which case the electron path is not fully confined as illustrated in Fig. 2.

In this paper we will study how overall features in the simulated spectra, such as X-ray escape peaks, Compton continuum, the photopeak area and the peak-to-Compton ratio will be affected when the primary electron tracks are considered in a normal PIN-type silicon detectors. We used both PENELOPE and MCNP5 codes to calculate the electron particle tracks with the kinetic energy value down to the lower energy limit of each code (50 eV for PENELOPE and 1 keV for MCNP5) including variance reduction methods for the sake of extensive computing time. We performed additional simulations to calculate the energy deposited by each electron track, to estimate the total net energy deposition per each gamma-ray event in the detector. We then compared the result with the previous simulation results obtained from the MCNP simulation, which only considers the energy deposited by the initial interactions of the incident radiation.



(a)

(b)

Fig. 1. (a) Illustration of gamma-ray interactions in the detection medium [2]. (b) Monte Carlo simulation of 1 MeV electron particle tracks in a PbS slab via PENELOPE code. Primary and secondary electrons created by gamma-ray interactions can travel up to a few hundred micrometers.

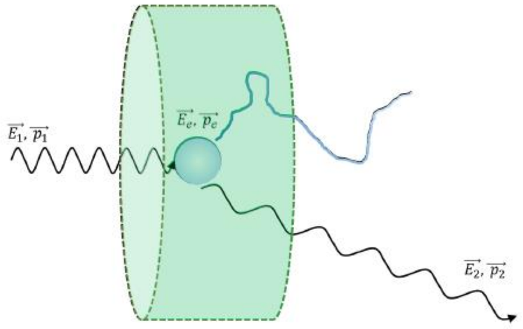


Fig. 2. Illustration of a recoil electron track created by the Compton scattering event in a thin wafer-type detector. The recoil electron can escape from the detection volume instead of transferring all of its energy to the detector.

2. Methods and Results

Monte Carlo simulations were performed using the MCNP5 and PENELOPE code systems as a schematic shown in Fig. 3. We first used MCNP5 to simulate photon events in the detector volume including PTRAC option. The location, direction vector, interaction type and energy deposition of each event history were obtained from the PTRAC data file, and the energy spectra were obtained using F8 pulse height tally. Based on the direction vectors of two event histories for each simulated particle, the new direction vector of the recoil electron was calculated from the energy and the linear momentum conservation relationship. The second stage of the Monte Carlo simulation was performed for each electron that was created at the interaction location and started its history with the given direction and the energy transferred from the photon event.

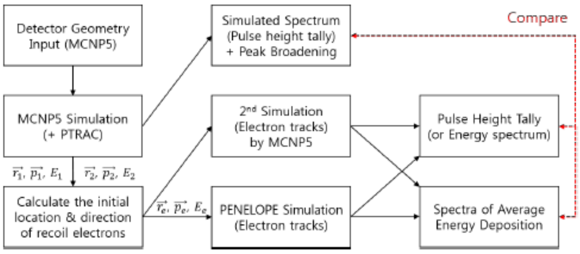


Fig. 3. A schematic diagram of the simulation structure.

We created three detector geometry inputs for silicon detectors of which thicknesses are 500, 100, and 20 m, to study the thickness effect on the difference between simulated spectra when primary electron track was considered and not considered. Each detector consists of the main detector volume in silicon with 300 nm gold layer on the front side of the detector, which is a typical thickness of the gold electrode used for silicon detectors. The direction biasing method, one of the variance reduction techniques in the Monte Carlo simulation theory, was utilized to save the computation time, as the photons which were not initially incident on the detector volume would hardly make any influence on the simulation when there is no surrounding materials assumed. Simulated spectra for a ^{137}Cs standard source were obtained by simulating 10^7 particles of 662 keV photons incident on the silicon detectors of 500, 100, and 20 m thickness.

Each detector simulation created 90441, 18648, and 4065 event histories for 500, 100, and 20 m cases, respectively, and the intrinsic total efficiency of each silicon detector was calculated to be 0.9, 0.19, and 0.04%. For every particle event, additional simulations for the primary electrons were performed with both MCNP5 and PENELOPE codes. The lower energy boundary of the simulation were set to 1 keV and 50 eV for MCNP5 and PENELOPE calculations, respectively, both of which are the lowest limit of each code can calculate. Pulse height tally and average energy deposition by the primary electron track were obtained to create energy spectra that are realistically deposited in the main detector volume. Meanwhile, the pulse height tally result obtained from the photon event was processed with the Gaussian peak broadening algorithm that only considers the statistical fluctuation in the charge creation process by the energy deposition, of which the detail is given in [6].

Each spectrum showed different shapes in the energy distribution; spectra resulted from the additional PENELOPE simulation appeared to be substantially different from the MCNP5 pulse height tally spectra, as examples shown in Fig. 4. More detailed results of the simulation comparing: (a) simple pulse height tally of MCNP5 from the photon event, (b) sum of energy deposition spectra simulated by the PENELOPE code for each primary electron, and (c) collection of average energy deposition from the primary electrons to the detector volume calculated by the additional simulation (PENELOPE and MCNP5) will be presented at the conference.

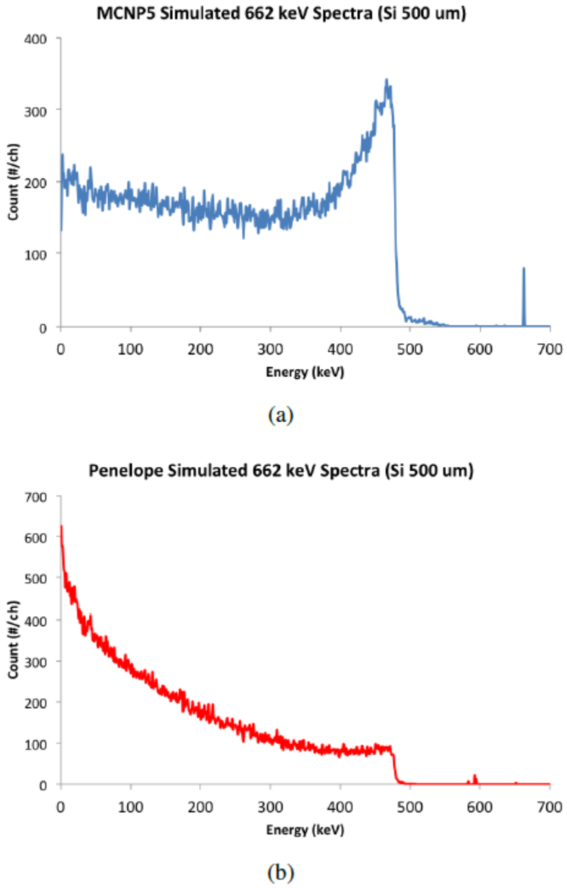


Fig. 4. Simulated spectra of ^{137}Cs gamma-ray source on a 500 μm-thick silicon detector using: a) simple pulse height tally from the photon event in MCNP5 simulation, and b) sum of energy deposition spectra calculated by the additional PENELOPE simulations.

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