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Simulation of alpha patricles detection efficiency for polycarbonate detector using Geant4 toolkit

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Abstract

In the present work, the detection efficiency of alpha particles of an ^{241}Am source (alpha energy = 5.486 MeV) for the ploycarbonate (PC) detector is calculated using Geant4 simulation toolkit. This simulation is based on the PC detector with 250 µm thickness under electrochemical (ECE) process and collimated alpha particles. Assuming a brass collimator with different lengths in air, various alpha energies ranged from 0.2 to 2.5 MeV are modeled. Also the bulk etching layer of 6 µm related to a given ECE process reported in the literature as well as a threshold stopping power of 240 keV µm^{-1} for foming the ECE tracks are given to Geant4 as the input data. The detection efficiency is determined as the ratio of registered tracks to the number of alpha particles reaching the PC detector surface. To validate the simulation, the results are compared with the experimental data reported in the literature corresponding to the above ECE conditions. It is found that the both results agree well within a maximum variation of 10%. Moreover, the Geant4 program used in this work can be applied to the other solid state nuclear track detectors (SSNTDs).

Keywords: Geant4 simulation, Alpha particles, Detection efficiency, Polycarbonate

Introduction

PC detector is a common SSNTD for detecting alpha particles using specified etching processes [1]. Alpha spectrometry has been carried out with these detectors [2]. In addition, using a specified calibration procedure, radon concentration in an environment can be determined by the PC for which detection efficiency relates the track density to total exposure [3]. Since experimental measurements with SSNTDs including PC can be time-consuming, costly and may not be feasible in some circumstances, it is worth to simulate their detection efficiency. For example, simulation of a radon SSNTD is carried out with a Monte Carlo software in 2001 [4]. Also, in 2014, response of SSNTDs in carbon beams is calculated using Geant4 [5]. In the present work, a Geant4 program [6] is developed for determining the detection efficiency of the PC detectors.

Materials and Methods

The geometry simulated here is adapted with the experimental setup reported by Taheri and Toudeshki [7] and Hosseini Pooye et al [2] which is still being utilized in National Radiation Protection Department (NRPD) in AEOI, Tehran, Iran. As schematically shown in Fig. 1, alpha particles of an ^{241}Am source with 5.486 MeV energy and activity of 7.2 × 10^{4} alpha per minute are collimated in a cylindrical brass tube with 0.5 cm diameter filled with air. Irradiation time is set such that about 4000 alpha particle reach the detector. The air density is corrected regarding the Tehran height from the sea level (1800 m) to be 9.65 × 10^{-4} g cm^{-3}. Different lengths of the tube (i.e., the air collumn) provides different alpha energies reaching the PC that can be derived from the National Institute of Standard and Technology (NIST) data library [8]. These alpha particles possess energy spectra with mean energies presented in Table 1. Further, etching process used in Ref. [5] includes the PEW etchant with normal ECE condition (32 kV cm^{-1}, 3 h, 25 ºC, 2 kHz and 1.7 mA) for which an etching rate of 2 µm h^{-1} leads to removing a thickness of t_{etch} = 6 µm (etching layer).

In Geant4 a PC detector with a dimension of 2.5 × 2.5 cm^{2} and a thickness of 250 µm is simulated on the top of the collimator. The low energy electromagnetic Livermore Physics with 1.0 µm cutoff is used for modeling the interactions of alpha particles. To determine the detection efficiency, first the number of alpha particles impinging on the unit area of the film is calculated by counting those depositing some energy in the PC. Then, for computing the number of tracks per unit area (track density), an algorithm is written in Geant4. A threshold LET required for producing the tracks equal to L_{th} = 240 keV µm^{-1} is considered [7].

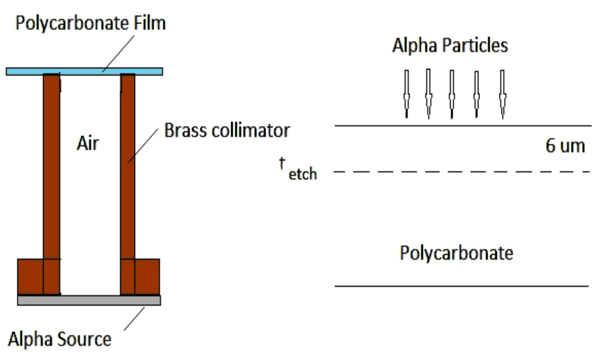

Fig.1. Schematice view of the geometry simulated in Geant4.

Table 1. Height of air collumn and alpha energies.

Air Collumn (mm)	Alpha Energy (MeV)
47	0.205
46	0.381
45	0.58
44	0.78
43	0.96
40	1.496
36	2.03
33	2.45

Since Geant4 cannot calculate LET directly, the kinetic energy K_{th} = 0.3 MeV [8] corresponding to L_{th} is given to the algorithm. For any alpha particle passing through the detector, the kinetic energy is calculated step-by-step. When this energy becomes eqaul to K_{th}, the traversed path length is recorded the particle "vertical range", R_{th}. Based on the model given by Doi, et al. [9], if R_{th} lies witihin t_{etch}, the track can be formed in the ECE process. Finally, the detection efficiency is calculated by Eq. (1):

$$D.E. = n\,N^{-1} \quad (1)$$

in which N is the number of incident alpha particle per unit area of the PC and n is the track density. The number of alpha particles emitted from the source is chosen such that N = 4000 particles reach the detector.

Results and discussion

In order to validate the simulation results, the calculated detection efficiencies with one standard deviation are compared with the experimental data reported [7] in Fig. 2. As can be observed, the simulations agree with the experimental data within a maximum descrepancy of 10%. The efficiency is maximum between 0.5 and 1.5 MeV, because for all alpha particles R_{th} lies within the etching layer. Also, the efficiency decreases for the energies larger than 1.5 MeV. The reason is that the incident alpha particles have energy spectra and by increasing the energy R_{th} lies outside the etching layer as a result of incresing the range.

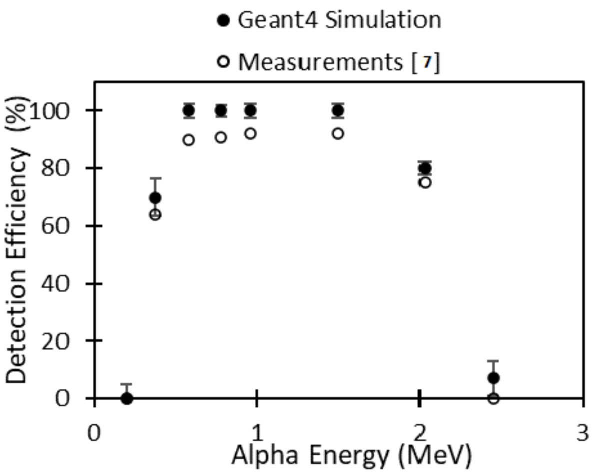

Fig.2. Detection efficiency of polycarbonate film vs. alpha energy. Error bars show one standard deviation of the data.

Further, for the energies smaller than 0.5 MeV the detection efficiency decreases too. In practice, after putting the PC in the etching solution, it takes a few minutes to set the ECE parameters [7]. During this time, the soultion removes about 0.5 µm from the surface. Therefore, for some alpha particles R_{th} lies inside this layer in which the superficial tracks are removed before being shaped by the ECE process. This bulk etching is included in the simulations.

Eventually, the difference between the simulation and experiment may refer to other complex chemical phenomena not included in the simulations.

Conclusions

In this work the detection efficiency of alpha particles ranged from 0.2 to 2.5 MeV in the PC detector is simulated by Geant4 toolkit. Including the basic factors required for forming the tracks such as the etching layer (depending on the ECE), vertical range and the threshold LET in the simulations, the detection efficiency is satisfactorily predicted within a 10% difference compared with the experimental data. Therefore, this Geant4 program can be applied to the other SSNTDs which is a topic for future investigations.

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