Journal of Nuclear Research and Applications

Research Paper
Vol. 2, No. 3, 2022, P 19-22

Cited in: https://jonra.nstri.ir
Received: 3 April 2022, Accepted: 25 April 2022

Calculation of alpha particles detection efficiency for polycarbonate detector using Geant4 toolkit

A. Moslehi[1*], S. Baradaran[2], M. Taheri[3]

[1]*Radiation Applications Research School, Nuclear Science and Technology Research Institute, P.O. Box 14155-1339, Tehran, Iran*
[2]*Nuclear Science and Technology Research Institute, P.O. Box 14155-1339, Tehran, Iran*
[3]*Iran Nuclear Regulatory Authority, National Radiation Protection Department, P.O. Box 14155-1339, Tehran, Iran*

ABSTRACT
In the present work, alpha particles detection efficiency of polycarbonate detector (PC) is calculated using Geant4 simulation toolkit. A PC detector with 250 µm thickness and dimension of 2.5 × 2.5 cm^2 is considered. Assuming the passage of alpha particles of an ^{241}Am source through brass collimators with different lengths, various alpha energies ranging from 0.2 to 2.5 MeV are modeled. Also, an etching layer of 6 µm related to a given electrochemical etching process as well as a threshold stopping power of 240 keV μm^{-1} required for forming the tracks are used as the input data. The detection efficiency is determined as the ratio of registered tracks per unit area 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. It is found that the both results agree well within a maximum variation of 10%.

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

I. Introductions

Solid-state nuclear track detectors (SSNTDs) are common passive detectors usually made of polymeric materials for measuring charged particles and neutrons [1]. Interaction of each primary or secondary charged particle in these detectors generates microscopic latent track damage. Suppose LET of charged particle exceeds a threshold value which is a characteristic of the detector material. In that case, the latent track can grow and become observable after appropriate chemical or electrochemical etching processes. In the etching process, the detector is put in a given solution where a thickness of its surface is removed under definite environmental conditions. The number of tracks represent a measure of the personal or ambient dose depending on the measuring purposes.

Polycarbonate (PC) is a SSNTD utilized for detecting alpha particles applying the electrochemical etching (ECE) process [2]. Also, it can be used for alpha particle spectrometry [3]. In addition, using a specified calibration procedure, radon concentration in an environment can be determined by the PC. In this case detection efficiency relates the track density (number of tracks per unit area) to total exposure [4].

In order to better understand the physical mechanisms involved in detecting the charged

**Corresponding Author name:* A. Moslehi
E-mail address: ammoslehi@aeoi.org.ir

particles with SSNTDs, Monte Carlo simulations are beneficial. There are few studies in this field. For example, Sima carried out simulation of a radon SSNTD with a Monte Carlo software in 2001 [5]. More recently, Sefl calculated the response of PMMA as a SSNTD in carbon beams using Geant4 in 2014 [6].

In the most of simulation studies on the SSNTDs, the focus is on the geometry of track formation and its relation with the etching parameters (e.g., etching rate). Alternatively, in the present work, we seek a simple simulation model without concentrating on the track geometry to determine the detection efficiency of the PC detectors to alpha particles. Geant4 toolkit [7] is applied for this purpose.

II. Materials and methods

The setup simulated here is adapted with the measurements carried out by Taheri and Toudeshki [8] and Hosseini Pooya et al. [3] 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. Different lengths of the tube (i.e., the air column) provide different alpha energies reaching the PC. These alpha particles possess energy spectra with mean energies presented in Table 1. The mean energy of these particles can be derived from the National Institute of Standard and Technology (NIST) data library [9]. In practice, the fluence and energy of alpha particles have been controlled by a surface barrier detector connected to a proper electronic setup [8]. Also, irradiation time is set such that about 4000 alpha particle per cm^2 reach the detector surface. Further, the etching process, including the PEW etchant with normal ECE conditions (3 kV cm^{-1}, 3 h, 25 °C, 2 kHz and 1.7 mA), has been used [8] for which an etching rate of 2 μm h^{-1} leads to removing a thickness of $t_{etch} \approx 6$ μm (etching layer). It is found that the threshold LET for producing the tracks in the PC is $L_{th} \approx 240$ keV μm^{-1} [8].

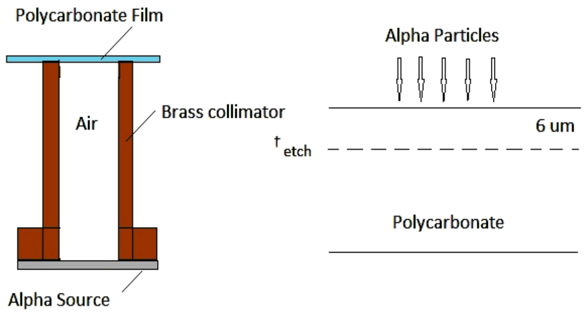

Fig.1. Schematic view of the geometry simulated in Geant4.

Table 1. Heights of the air column and mean alpha energies.

Air Column (mm)	Mean Energy (MeV)
47	0.21
46	0.38
45	0.58
44	0.78
43	0.96
40	1.50
36	2.03
33	2.45

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 air density is corrected regarding the Tehran height from sea level (1800 m) by applying the barometric formula [10] to be 9.65×10^{-4} g cm^{-3}. The low energy electromagnetic Livermore Physics model with a 1.0 μm cutoff is used to model alpha particles' interactions with all materials in the simulation. It should be mentioned that since Geant4 cannot calculate LET directly, the kinetic energy $K_{th} = 0.3$ MeV [9] corresponding to L_{th} is used. To determine the detection efficiency, the steps below are followed:

1. The number of alpha particles impinging on the unit area of the film, N, is calculated by counting those depositing some energy in the PC.
2. For any alpha particle passing through the detector, the kinetic energy is calculated step by step.
3. When the kinetic energy lies within the interval ($K_{th} \pm 1$ keV), the traversed path length in the

normal direction to the PC is recorded as the particle “vertical range”, R_{th}.

4. (Based on the model given by Doi et al. [11]), a track is counted for any alpha particle if R_{th} is placed within t_{etch}. The total number of tracks is *n*.
5. Finally, the detection efficiency is calculated by Eq. (1):

$$D, E, = \frac{n}{N} \tag{1}$$

To adapt to the measurements [8], for any alpha energy, the number of alpha particles emitted from the source is chosen such that about 4000 particles reach the detector surface.

III. Results and Discussions

To validate the simulation results, the detection efficiencies calculated with one standard deviation (68% confidence level) are compared with the experimental data [8] 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 energies larger than 1.5 MeV. The reason is that by increasing the range of alpha particles, for some of them in their energy spectra, R_{th} lies outside the etching layer,and their tracks cannot be counted. Further, the detection efficiency decreases again for the energies smaller than 0.5 MeV. Because in practice, after putting the PC in the etching solution, it takes a few minutes to set the ECE conditions mentioned before [8]. During this time, the solution removes about 0.5 µm from the surface called the bulk etching. Therefore, for some alpha particles, R_{th} lies inside this layer in which the so-called superficial latent tracks are removed before being shaped by the ECE process. The thickness of bulk etching is included in the simulations.

Eventually, the difference observed between the simulation and experiment in the range of 0.5, and 1.5 MeV refers to the etching time. The ECE conditions mentioned previously are optimum for the PC detector, and it is found that after three h etching, only about 90% of the tracks can be detected. Applying additional times for recording the latent tracks remaining leads to piercing the PC sheet by the etchant solution. Therefore, unlike the simulation where all the possible tracks can be counted, in practice is not possible to achieve 100% efficiency.

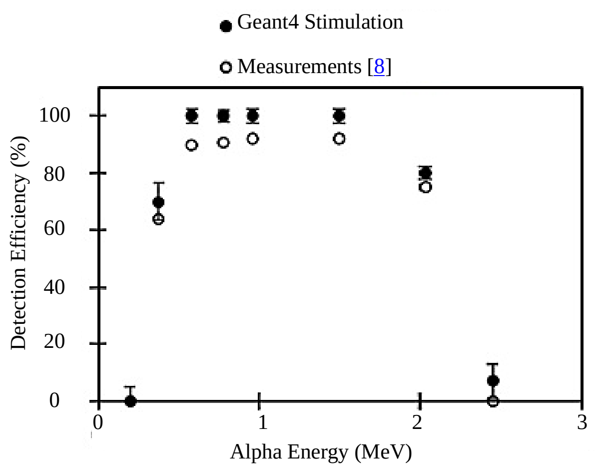

Fig.2. Detection efficiency of polycarbonate detector vs. alpha energy. Error bars show one standard deviation of the data.

IV. Conclusions

The detection efficiency of alpha particles ranging from 0.2 to 2.5 MeV in the PC detector is simulated by the Geant4 toolkit. Including the essential 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 determined by a 10% difference compared with the experimental data. It can be called a *calibrated simulation* because the input parameters such as etching thickness and the threshold LET are found experimentally. Nevertheless, this Geant4 simulation can be applied to the other SSNTDs that could be a topic for future investigations.

References

1. R. L. Fleischer, b. P. Price, R. M. Walker, *nuclear Tracks in solids: Principles and applications*, University of California Press, (1975).
2. G. Espinosa, R. B. Gammage, J. I. Golzarri, V. M. Castanoc, *Studies on the interaction of alpha particles with polycarbonate materials*. Int. J. Pol. Mat. Pol. Biomat. 40, 87-95 (1998).
3. S. M. Hosseini Pooya. H. Afarideh, M. Taheri, M. R. Kardan, *Passive α-particle spectrometry by polycarbonate SSNTD using new etching conditions*. Rad. Phys. Chem 77, 949-953 (2008).
4. D. Pressyanov, J. Buyesse, A. Poffijn, G. Meesen, A. Van Deynse, *Polycarbonate: a long-termhighly sensitive radon monitor*. Nucl. Instrum. Meth. A. 447, 619-621 (2000).
5. Sima, *Monte Carlo simulation of radon SSNT detectors*. Rad. Meas. 34, 181-186 (2001).
6. M. Sefl, *Calculation of solid-state track etched detector response in 290 and 400 MeV/n carbon ion beams using Geant4. Diploma Thesis*, Czech Technical University in Prague (2014).
7. A. Agostinelli, J. Allison, K. Amako, J. Apostolakis, H, Araujo, et al., *Geant4-a simulation toolkit*. Nucl. Instrum. Meth. A. 506, 250-303 (2003).
8. M. Taheri, S. Hosseini Toudeshki, *Characteristic studies for fast detection of a wide energy range of alpha particles in polycarbonate detectors*. Rad. Meas. 40, 307-310 (2005).
9. https://physics.nist.gov/PhysRefData/Star/Astar
10. J. V. Iribarnei, W. L. Godson, *Atmospheric thermodynamics*, Springer, (1981).
11. M. Doi, K. Fujimoto, S. Kobayashi, *Etch pit formation model during chemical and electrochemical etching in polycarbonate foil*. Rad. Prot. dosim. 37, 5-12 (1991).

How to cite this article

A. Moslehi, S. Baradaran, M. Taheri, Calculation of alpha particles detection efficiency for polycarbonate detector using Geant4 toolkit, *Journal of Nuclear Science and Applications*, Vol. **2,** No. **3, (2022),** P **19-22, Url: https://jonra.nstri.ir/article_1412.html, DOI**: 10.24200/jon.2022.1022