A computer program called Neutron_CR-39.F90 for neutron simulation through a PADC detector and its detection was described and developed. In this work the neutron Am–Be source was considered for simulation. It was shown that the most intensive secondary particles, created in neutron interactions with the detector, are protons. The programming steps are outlined with detailed description of neutron simulation, determination of latent tracks of created protons, as well as, their development after detector etching in the same and opposite direction of particle motion. The outputs of the code are parameters of created protons (coordinates of starting and stopping points, direction angles of particles, initial and deposited energies) and number of visible tracks per incident neutron.

A computer program is prepared to simulate neutron’s interactions in a PADC by the Monte Carlo method using the Neutron data library ENDF/B-VII [B. Milenkovic, D. Nikezic, N. Stevanovic, Radiat. Meas. 45 (2010) 1338]. The parameters of the emitted secondary particles (emission angle, initial energy, deposited energy and starting and stopping coordinates) were stored in an enclosed file. The subroutine for calculation of track profiles by a finite difference method for particles emitted in the same and opposite direction as etchant progression. The outputs of the code are parameters of secondary particles (coordinates of starting and stopping points, direction angles of particles, initial and deposited energies) and number of visible tracks per incident neutron.
1. Introduction

Solid state nuclear track detectors (SSNTDs) have been successfully applied in neutron and ion particle detection [1–3]. One of the most widely used SSNTDs is made of polyallyldiglycol carbonate (PADC), generally known by its trade mark CR-39. A review on SSNTDs can be found in Ref. [1].

Being electrically neutral, the neutrons do not cause ionizations in the detector, and consequently no tracks are produced directly by them in the PADC. Due to the elastic and nonelastic interaction of neutrons with the atoms of PADC, recoil nuclei and secondary particles are created producing latent intrinsic tracks. Neutron interaction with H atom is only elastic, H(n,n) where proton is recoiled. Creation of proton in neutron interactions with C and O atoms is possible for neutron energies higher than emitted from Am–Be source. Creation of alpha particles from C and O atoms is possible, but with low probability. The most intensive reaction of neutron from Am–Be source is H(n,n) where recoiled proton created latent track. Others having much smaller cross sections are neglected in this work [4].

The latent track becomes visible as a particle track through the etching, which can be seen under an optical microscope. Created particles are emitted in different directions and their latent tracks are oriented randomly within the detector. Some tracks will be etched from the point where the particle was created in the direction of the particle motion – this is direct etching. Other tracks will be etched from the point where the particle was stopped, or from where it exited from the detector, in opposite direction of particle movement – this is etching in reverse direction. There are a lot of these tracks and they need to be treated specifically as has been done in this work.

By the analyzing of visible proton tracks in the detector, neutron efficiency can be determined. The developed program enables the determination of the energy and angular distributions of recoiled protons and a calculation of their energies. The data for the created protons have been stored in the files.

In this paper the methodology for neutron detection by PADC detector was described. A program code for neutron simulation through PADC detector and its detection were developed. Subroutines for neutron simulation, track development in the same and opposite directions were presented separately.

2. Programming steps

2.1. Geometry

The interaction of the neutrons emitted by an Am–Be source with a PADC detector is simulated in this paper. The sheet PADC detector was irradiated using an Am–Be neutron source of a cylindrical shape with the same axis as the detector. The position of the detector and the source with their dimensions are presented in Fig. 1.

The energy of the neutron was sampled from a spectrum of the Am–Be source which can be found in Ref. [5]. The neutron energy in that spectrum is up to 11 MeV with a maximum of about 2 MeV. It is taken that neutrons are emitted from the source, randomly distributed on the surface, neglecting the interaction within the source itself and in the air space between the source and the detector. Sampling of the neutron from Am–Be source was described in detail in [4].

2.2. Cross sections

The PADC detector (chemical formula C12H18O7) consists of hydrogen, oxygen and carbon. The data for cross sections of these atoms were taken from the well-established Neutron data library ENDF/B-VII [6]. If the total cross sections of these atoms are denoted as \( \sigma_{\text{H}}, \sigma_{\text{C}} \) and \( \sigma_{\text{O}} \), the total cross section of a molecule \( \sigma_{\text{tot}} \) is given by \( \sigma_{\text{tot}} = (18\sigma_{\text{H}} + 12\sigma_{\text{C}} + 7\sigma_{\text{O}}) \), which were introduced in Ref. [4]. The total cross sections of the atom include elastic and nonelastic interactions, \( n(p) \), \( (n,\alpha) \), \( (n,t) \) and \( (n,d) \). These values were used as functions of neutron energy from 1 keV up to 11 MeV, with a step of 1 keV and sorted in input data enclosed files.

2.3. Sampling of interaction type and target

The neutron simulation was performed by the Monte Carlo method. The simulation starts with the homogeneous sampling of the emission point of the neutron in the source at \((x_0, y_0, z_0)\), its initial energy \(E_0\), initial direction of neutron in source determined with cosines \( (p_{x0}, p_{y0}, p_{z0}) \) was sampled isotropic according to well-known formula given for example by Lux and Koblinger [7].

If the sampled direction did not cut the detector top surface, sampling was repeated. When the sampled neutron struck the detector surface at the point \((x_0 = 0, y_0, z_0)\), a further step was the sampling of these atoms, H, C or O which could be struck. The three ratios were defined as \( A = 18\sigma_{\text{H}}/\sigma_{\text{tot}} \), \( B = 12\sigma_{\text{C}}/\sigma_{\text{tot}} \).
\[ C = 7\sigma_0/\sigma_{tot} \]. The standard method of discrete event sampling was applied to "choose" an atom as follows. The random number generator was invoked to get one random number \( \gamma \); if \( \gamma < A \), the atom was chosen as H; if \( A < \gamma < (A + B) \), the atom was C; and if \( (A + B) < \gamma < 1 \), the atom was O.

The new coordinates of the interaction point within the detector, \((x_i, y_i, z_i)\), were calculated based on the known mean free path \( \lambda \) and new sampled direction \((p_x, p_y, p_z)\) as

\[
\begin{align*}
x_i &= x_0 + \lambda \cdot p_x \\
y_i &= y_0 + \lambda \cdot p_y \\
z_i &= z_0 + \lambda \cdot p_z
\end{align*}
\] (1)

The neutron path was further simulated until the neutron was outside of the detector or the secondary particle had been created.

### 2.4. Determination of the free path

The mean free path, \( \lambda \), which the neutron travels before the interaction with some nucleus in the detector is given as

\[
\lambda = -\frac{1}{\sigma \cdot N} \ln(1 - u) = -\frac{1}{\Sigma} \ln(1 - u)
\] (2)

where \( u \) is a random number distributed uniformly on \((0, 1)\), \( \sigma \) is the total microscopic cross section and \( N \) is the density of the nuclei in the detector material. Lux and Koblinger [7] have shown that \( \Sigma \) is the total macroscopic cross section which is calculated as follows

\[
\Sigma = \rho \cdot N_A \sum_{i=1}^{n=3} \frac{w_i}{M_i} \sum_{j=1}^{m=4} \sigma_{ij}^w
\] (3)

where \( \rho \) is the density of the material, \( N_A \) is the Avogadro number, \( M_i \) is the molar mass of the i-th component, \( w_i \) is the weight fraction and \( \sigma_{ij}^w \) is a partial microscopic cross section of the j-th type of interaction with the i-th element.

### 2.5. Neutron interaction within PADC

Due to the detector composition, elastic and inelastic scattering of neutrons is possible. Nonelastic processes, like \((n, p)\), \((n, \alpha)\), \((n, t)\), \((n, d)\), include nuclear reaction with the creation of some particles: proton, alpha particle, tritium and deuterium, respectively. All these interactions were considered in this work, but it was shown that the number of created protons is 0.0483 from incident neutron, while the number of created alpha particle is only 0.000354. In other words, probability for alpha particles creation is less than 0.7% in respect to all secondary particles and could be neglected [2,4,8].

The effective removed layer is equal to

\[ RL_1 \]

\[
\begin{align*}
RL_1 &= X_1 - X_1' \\
X_1 &= \text{coordinate of proton creation}.
\end{align*}
\]

The condition for track formation is \( V \sin \theta > 1 \), equivalent to condition for critical angle used in [10]. If \( R_L < X_1 \) the visible track will not be formed.

The shape of the track obtained after the etching depends on: incident particle energy, incident angle, etching time and etch rates ratio \( V \). The coordinates of the track wall can be obtained from Eq. (6)

### 3. Calculation of track walls

The protons are created in different directions and their latent tracks are oriented randomly within the detector. Some tracks will be etched from the point where the particle was created in the direction of the particle motion – this is direct etching. Other tracks will be etched from the point where the particle was stopped, or from where it exited from the detector, in an opposite direction to the particle movement – this is the etching in a reverse direction. In this section a calculation of the track walls etched in the same and opposite directions will be described by using Newton’s method.

#### 3.1. Direct etching

The geometry of track development and some important parameters for direct etching are shown in Fig. 2. A proton with energy \( E \) is emitted in the detector under the angle \( \alpha \) in respect to the detector \( X \)-axis. Due to the interaction of a particle with detector molecules, the damage region, i.e. latent track is formed along its path. The distance that a particle passes within the detector material is the particle range, denoted with \( RL \). The etching solution progresses along the particle path in the same direction as the particle which was created in the detector at the point \((0, 0)\) of the \( xoY \) system and stops in the detector at point \( P \) after the distance \( RL \). The etch rates ratio is distance \( RL = MP = R - (x + y) \).

Two coordinate systems are shown in Fig. 2. The first one, \( XOY \), has a \( Y \)-axis along the detector surface and a normal \( X \)-axis on it. The second system, \( xoY \), is rotated for the angle \( \alpha \) in respect to the \( XOY \) system so that the \( x \)-axis is along the particle path. The total removed layer is equal to \( RL = V_0 T \), where \( T \) is the etching time. The effective removed layer is equal to \( h = R_L - X_1 \), where \( X_1 \) is the coordinate of proton creation. The condition for track formation is \( V \sin \theta > 1 \), equivalent to condition for critical angle used in [10]. If \( R_L < X_1 \) the visible track will not be formed.
3.2. Calculation of track wall by the finite difference method

The coordinates of the track wall are described by Eq. (6) in the $xOy$ coordinate system, where the $x$-axis is along the latent track. If the track is not over-etched, the initial condition is defined as $y(l) = 0$. $L$ is the penetration depth of the solution, i.e. the distance that the etchant passes along the particle track, found from the equation

$$T = \int_{0}^{L} \frac{1}{V_b R(x)} \, dx$$

where $T$ is the time of etching. To determine $L$ from Eq. (7) the iteration procedure should be applied, because the unknown variable is the upper integration limit, while the time of etching, $T$, is known.

For over-etched tracks the initial condition of calculation was $x = R$, $y = 0$. A track profile was obtained at the moment when the etching solution just attained the endpoint of the particle in the detector. In this case the remaining etching time, $t'$, and the residual removed thickness $d_t = V_b \cdot t'$ have to be determined. Then the track wall should be shifted parallel to itself according to the equations [12]

$$x = x + d_t \sin \delta$$
$$y = y + d_t \cos \delta$$

where $\delta$ is the local developing angle, defined as $\delta = \arcsin \frac{1}{V}$. The track profile obtained at the moment when the etching solution just attained the endpoint of the particle in the detector is $R = L + d_t$. The angle between the particle trajectory and the etch front is $\alpha$. The origin is located at point $P$. The coordinate system $xOy$ is the same as above.

Calculations of particle range. Several computer codes exist for the calculation of stopping power and for the range of charged particles in different stopping media. One of the most frequently used is SRIM (Stopping and Range of Ions in Matter) code and may be downloaded from the web page http://www.srim.org [13]. The chemical formula of the CR-39 detector is $C_{12}H_{18}O_7$ and the density is $\rho = 1.32$ g cm$^{-3}$. SRIM code was used to calculate the stopping power and ranges of protons for the CR-39. Based on data obtained by SRIM, the ranges of particles were fitted as a function of incident energy with the following formula

$$R = a_0 + \sum_{i=1}^{4} a_i \cdot E^i$$

The $E$ is energy in MeV, and the fitting constants are $a_0 = 0$, $a_1 = 10.99$, $a_2 = -6.45$, $a_3 = 30.30$, $a_4 = -15.42$ if $E \leq 1$ MeV and $a_0 = -1.09$, $a_1 = 10.89$, $a_2 = 9.92$, $a_3 = -0.20$, $a_4 = -0.005$ if $E > 1$ MeV.

3.3. Calculation of track wall by the finite difference method

The argument of the function $V$ in Eq. (6) is the residual range, $R' = R - (x + yy')$ (see Fig. 2). Consequently, Eq. (6) has the form

$$y' = \frac{1}{\sqrt{V^2(R - (x + yy'))} - 1}$$

Eq. (10) is not analytically solvable for the most commonly used $V$ functions. It was done numerically by the finite difference method (FDM) [11]. In that way, Eq. (10) becomes

$$y(x - Ax) = y(x) - Ax - \frac{1}{\sqrt{V^2(R - x - y(x))} - 1}$$

The idea is to calculate the value of the function $y(x - Ax)$ at point $x - Ax$, if its value $y(x)$ is known at point $x$. To apply such a recursive procedure, coordinates of at least one point on the track wall should be known.

Eq. (11) was calculated using Newton's method. Two different cases were considered: (i) tracks with a sharp tip (not an over-etched track) and (ii) over-etched tracks. For tracks which are not over-etched the only point with known coordinates is the track tip, where $y(l) = 0$. $L$ is the penetration depth defined above and calculated by the integration of reciprocal function $V$. The point $(l, 0)$ was used as the starting point in the calculation. Eq. (6) was solved iteratively where the $x$-coordinate was varied from $x = l$ to $x = 0$, with the step $Ax = -0.01$ mm.

For an over-etched track it is necessary to calculate the thickness, $d_t$, etched after the solution attains the ending point of the particle trajectory. Thus the distance that the etchant penetrates in the detector is $L = R + d_t$. The point $(l, 0)$ was taken as the starting one in the solving of Eq. (10) for an over-etched track. Other points were obtained by the parallel movement of the points which represent the track profile obtained at $L = R$ for the distance $d_t$.

3.3. Etching in an opposite direction (reverse etching)

Some particles are emitted under such an angle that the etching of their tracks will progress in a reverse direction to their motion. For these tracks, the previously described mathematical model is not fully valid. The development of tracks etched reversely is described in [14] and experimentally was confirmed in [15]. This model is briefly described here.

Fig. 3 represents track development in the case of reverse etching. The particle is created in the detector at point $A$ and its direction is opposite in respect to the direction of the etching. Two cases exist here: (i) the energy of the particle is large enough so that it exits from the detector at point $O$. Point $P$ is ending point of particle assuming that the detector is infinitely thick; (ii) particle energy is smaller, the range is shorter and it is stopped within the detector body (not shown in Fig. 4). The angle between the particle path and the detector axis is $\alpha$. The origin is located at point $P$. The coordinate system $xOy$ is the same as above.

Particles which are stopped outside the detector are treated in the following way: here we have assumed that the detector is infinitely thick. Such an assumption was necessary to determine the residual range and $V$ function at the point where the particle escaped from the detector.

The choice of the coordinate system. The choice of the coordinate system in the two above mentioned cases is shown in Fig. 4.

Fig. 4A examines the case when the particle is stopped within the detector material and the origin is located at the stopping point, where $L_{\text{start}} = 0$. In this case the track will start to develop after the etching removes a layer of the detector with the thickness $d_t$. The case when the particle passes through the detector and stops outside is presented in Fig. 4B. The origin of the coordinate system $xOy$ is out of the detector, at the virtual point where the particle would stop under the assumption that the detector is
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Fig. 3. The particle is created in the detector material at point A and is stopped at point P (assuming infinite detector thickness). Etching progresses from the exit point (0, 0) towards the starting point in the opposite direction to the particle movement (reversed etching). The coordinate origin is placed in the point where the particle would be stopped. The positive part of the x-axis is in the direction of solution progression. The residual range is equal to \( R' = PM = x' + y'y' \).

Fig. 4. Coordinate systems x0y0. (A) Particle was stopped within the detector at point (0, 0), where \( L_{\text{start}} = 0 \); (B) Particle was stopped out of the detector material at point (0, 0) at a distance of \( L_{\text{start}} \) from the detector surface along the x-axis.

ininitely thick. The ending point of the particle path is at the distance \( L_{\text{start}} \) from the detector surface, where

\[
L_{\text{start}} = R - \frac{X_1}{\sin(\theta)} \quad (12)
\]

In this case \( d = 0 \) and the removed layer, \( h \), is equal to the total removed layer.

The equation of the track wall keeps the same form as in the case of direct etching [13]. As it was mentioned above, the argument of the function \( V \) is the residual range, i.e. the distance between the point where the particle was stopped and the etchant. This distance, \( PM \), presented in Fig. 3 is equal to \( x + y'y' \). Due to this reason, Eq. (6) keeps its form

\[
y' = -\frac{1}{\sqrt{V^2(x + y'y') - 1}} \quad (13)
\]

It can be seen that both equations (10) and (13) for direct and reversed etching have the same form, but a different argument in \( V \) function.

By using the finite difference method, Eq. (13) is transformed into the form

\[
y(x + \Delta x) = y(x) + \Delta x \frac{-1}{\sqrt{V^2(x + y(x), y(x + \Delta x)) - 1}} \quad (14)
\]

The boundary condition for this equation is \( y(L) = 0 \) and the following condition is applied

\[
t = \int_{L_{\text{start}}}^{L} \frac{1}{V_t(x)} \, dx \quad (15)
\]

to find the point with coordinates \((L, 0)\) which the solution attained during the etching time, \( t \). This point is taken as the initial condition in calculation \( y(L) = 0 \) if the track is not over-etched. If the track is over-etched the starting point is \( y(R) = 0 \) as explained above.

4. Program description

The program Neutron_CR-39.F90 was written in Fortran 90 code. This program enables neutron simulation through CR-39 detectors and the calculation of proton track profiles after detector etching. At the start of the program execution the user defines the following input parameters: the number of simulations; detector dimensions; source dimensions and the distance between the source and the detector. The program Neutron_CR-39.F90 contains subroutine Neutron.f90 for neutron simulation and subroutines Trackfdmsame.f90 and Trackfdmback.f90 for the calculation of created track profiles after detector etching in the same and reverse direction, respectively.

5. Subroutine for neutron simulation

After defining the input parameters, the subroutine Neutron.f90 which simulates neutrons through the detector is started. The simulation of neutrons in a CR-39 detector was described in [4]. The subroutine Neutron.f90 performs the following steps: neutron sampling in the source; determination of the neutron free path; sampling of an atom in the detector which interacts with the neutron; sampling of the interaction type (elastic or nonelastic). As a result, the data file PROTONS_AmBe.DAT is created. In that file the following data for the created protons will be stored: the angle, \( \alpha \); position and the initial and deposited energies.

5.1. Subroutine TRACKFDMSAME.F90

When neutron simulation is performed the user inputs the value for the removed layer \( R_L \) in micrometers. Then the subroutine Trackfdmsame.f90 will be automatically started for the calculation of track profiles etched in the same direction. It must be noted that both sides of the CR-39 detector can be etched simultaneously. This subroutine Trackfdmsame.f90 analyzes data from the PROTONS_AmBe.DAT file and determines which created latent track will be etched from the top or bottom side of the detector. Etching in the same direction will be performed for the protons latent tracks: (i) created with angle \( \alpha < \pi/2 \), etched from the top side and (ii) created with angle \( \alpha > \pi/2 \), etched from the bottom side.

The following task of the subroutine is to calculate the range in the detector material of a proton with known incident energy by using Eq. (9). When the particle range is calculated then
the code determines whether the track can be formed. It will be done if $V \sin \theta > 1$ and $R_L > X_1$. The $V$ function for a proton in PADC as a function on the residual range $R'$ is taken from Hermisdorf [16]:

$$V = 1 + \frac{3.4}{(R' + 1)} \cdot \ln\left( R' + 1 \right) \cdot \left( 1 - e^{-R'/0.4} \right) + \frac{R'}{1500}$$

and $V$ is coded in the function subroutine $V.F90$ with a dummy parameter which simulates the residual range. Then the coordinates of the points in the track wall are calculated according to Eq. (11) by Newton’s iteration method.

5.2. Subroutine TRACKFDMBACK.F90

The subroutine Trackfdmback.f90 is started after execution of Trackfdmsame.f90. From the file PROTIONS_AmBe.DAT the proton tracks etched in a reverse direction will be analyzed. The reverse etched tracks will come from the latent tracks: (i) created with angle $\alpha < \pi / 2$, etched from the bottom side and (ii) created with angle $\alpha > \pi / 2$, etched from the top side. The range of the particle is calculated according to Eq. (9).

The next step is to determine whether the particle will stop within the detector or exit from it. The decision is made based on particle range, incident angle and $X_1$. If the particle is not stopped in the detector it is necessary to determine $L_{start}$ which is the lower integration limit in Eq. (15). $L_{start}$ represents the distance between the stopping point and the detector along the $x$-axis. Its determination is described in the following section.

5.2.1. Determination of $L_{start}$

If the particle was stopped in the detector, $L_{start} = 0$ (Fig. 4A). To reach the track in this case it is necessary to etch the detector and remove the layer of thickness $d$. After that the development of the track may be started. The total removed layer during the whole etching procedure is equal to $R_L = d + h$, where $h$ is the thickness of the layer removed after the point where the particle was stopped. For the calculation of the track wall coordinates the parameter $h$ is needed and can be determined as

$$h = R_L - \left( X_1 - R \cdot \sin(\theta) \right)$$

If the particle was stopped out of the detector, then from Fig. 4B, $L_{start}$ is calculated as

$$L_{start} = R - \frac{X_1}{\sin(\theta)}$$

In this case $d = 0$ and the removed layer, $h$, is equal to the total removed layer ($h = R_L$).

5.2.2. Determination of whether a latent track becomes visible or not

To make a latent track visible, two conditions must be satisfied.

The first condition is that the etching solution must attain the latent track for the particle which was stopped within the detector. In a mathematical form, this condition is read as $R_L > d$ (see Fig. 4A).

The second condition has already been mentioned above, i.e. $V(x) \sin \theta > V_p$.

The following part of the program examines whether the track will become visible or not. A loop examines condition $V(x) \sin \theta > 1$ along the particle trajectory. If this condition is not satisfied at any point along the latent track, it will not become visible, the program terminates and prints the message, “track will not be created”.

5.2.3. Examination of whether the track is over-etched

The track is over-etched if the etching solution has passed along the whole particle path and has etched further after point $P$ (Fig. 2) for direct or point $A$ (Fig. 3) for reverse etching. The relation

$$t_D = \int_{L_{start}}^{R} \frac{1}{V(x)} \, dx$$

is used to determine whether the track was over-etched or not. $t_D$ is the time needed that the etching solution attains point $P$ (direct etching) or up to the starting point $A$ of the particle (reverse etching). If the etching time is larger than $t_D$ the track is over-etched, otherwise it is not over-etched. Subroutine VINTEGRAL.F90 given below, calculates $t_D$.

5.2.4. Calculation of track profile

The track wall coordinates, by using Eq. (14) were calculated with Track_wall.f90 subroutine. The starting point in this calculation is the ending point where the etching solution attains, for not over-etched tracks $(L, 0)$, or point $(R, 0)$ for over-etched track. Eq. (14) was calculated by Newton’s iteration method.

6. Results

Input data should be defined by user before program execution. Data can be input from a file named “input.dat”. For example, if input parameters are:

(i) detector dimensions hight, $h_d = 3 \text{ cm}$; width, $w_d = 3 \text{ cm}$; thickness, $t_d = 0.05 \text{ cm}$,
(ii) source dimensions $r_s = 1.1 \text{ cm}$, $h_s = 2 \text{ cm}$,
(iii) distance between detector and source $d = 0.3 \text{ cm}$,
(iv) removed layer of the detector after etching $R_L = 6 \text{ μm}$,

the following output will be printed in file “Results.dat”:

$Ed = 68843.66 \text{ keV/visible tracks}$

$N_n = 0.00095 \text{ visible tracks/neutron}$

The outputs of the program are:

(i) the file Protons Am-Be.dat which contains data of recoiled protons as: recoiled angle $\alpha$, in respect to the $X$-axis; coordinates $X$ of starting and stopping point; initial and deposited energies of protons,
(ii) deposited energy of recoiled protons per number of visible tracks, $E_d \text{ (keV/track)}$,
(iii) number of visible tracks per number of incident neutrons, $N_n \text{ (tracks/n)}$.

The values of $E_d$ and $N_n$ are printed into the file “Results.dat” which is created in the same directory where .exe file was saved.

7. Conclusion

The computer code Neutron_CR-39.F90, written in Fortran 90, was developed in this paper. It contains three subroutines. First, Neutron.f90 which simulates neutron through CR-39 detector and store parameters of secondary particles in output file. Second, Trackfdmsame.f90 which calculates profiles of tracks emitted in the same direction as etchant progression. Third, subroutine Trackfdmback.f90 which calculates profiles of tracks emitted in opposite direction than etchant progression.
In this paper, determination of parameters of tracks etched in opposite directions was explained. Using these parameters the efficiency of CR-39 for the neutron detection was estimated. Our code takes into account the tracks etched in opposite as well as in the same direction and it is different in comparison to other group [15, 17–19]. Our results were not comparable with other authors. For example, in [18] Monte Carlo method was used for mono-energetic neutrons interacting with H, C and O. However, chemical etching was assumed only in forward direction and track formation efficiency was calculated. In [17] electro-chemical etching was assumed and irradiation of a neutron dosimeter by neutron spectra from Am–Be and Cf sources. Hersmdorf et al. [15,19] used PE-converter, chemical etching in forward direction and calculated the fluence response in number of tracks per unit neutron fluence.

Parameters of secondary particles and number of visible tracks are outputs of the code. It enables calculation of neutron detection efficiency for different input parameters and may be used for further analyses.

Acknowledgement

The authors would like to thank the Serbian Ministry of Science and Technological Development who supported this work through the project No. 171021.

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