Abstract

A solid state track detector, SSNTD, has been used to determine the neutron capture cross-section for paraffin wax. 200 μm CR-39 detectors (1cm*1cm) are distributed at different height of paraffin wax, which are irradiated using a 38 mCi Am-Be neutron source. It was found the neutron capture cross-section is (σ_c=0.624 ±6.5 %), the number of neutron collisions leads to the thermal thermal energy stage is about 21 Collisions at depth reached to 26 cm. From these results one can conclude that this material at limited dimension is more applicable, as a shielding material with neutron sources, in slowing down neutrons from the fast energy energy stage and can define the neutron energy at a certain depth of the wax material.

Keywords: neutron capture cross-section measurement, paraffin wax, diffusion lenght, number of neutron collision.

1.1 Introduction

Solid state nuclear track detectors (SSNTDs) have been successfully applied in neutron and ion particle detection. This method represents one of the most widely technique that is used polyallyldiglycol carbonate (PADEC) [1], generally known by its trade as CR-39. Being electrically neutral, the neutrons do not cause ionization in the detector, and consequently no tracks are produced directly from them in the PADEC neutron interaction with H atom is only the elastic H (n, n), where the proton is recoiled. Produce proton, from neutron interaction with C and O atoms, is possible for neutron energies higher than emitted from Am-Be source. Produce alpha particles from C and O atoms has also been possible, but with low probability. The interaction of the neutrons emitted by an Am-Be source a PADC detector is simulated inside the paraffin wax.

The idea of moderating materials should have the following nuclear properties, large scattering cross-section, small absorption cross-section and large energy loss per collision [2]. Neutron attenuation is accomplished mainly through elastic and inelastic scattering reactions which reduced the neutron energy until they can be absorbed (capture) by shielding materials. The neutron capture cross section is larger only for thermal neutron energies. Therefore, the neutrons slowing down by scattering are important before capture [3]. As shown in Fig (2) the fast neutron flux of five moderate materials decreases with thickness [4].

In this case of thermal neutron, the flux is decreased rapidly with increasing thickness in light water, paraffin and polyethylene. But with the increasing thickness of the moderator a large number of the thermal neutron is absorbed. Also, during the neutron moderation process gamma ray yields will produce from paraffin and polyethylene, these are getting the maximum and can be reduced subsequently to the increasing the thickness, approximately toward 22cm. Graphite and heavy water are not substantially generated γ-rays as shown in Fig (3).

In Fig (4) shows the source of Am-Be and CR39 in moderator...
1.2 Theoretical and Experimental Method

As shown in figure (4) a sketch of the experimental setup used in the present work, where the neutron source, is an Am-Be plane source, is positioned vertically with the paraffin wax, slab shape, of dimension $52 \times 10 \times 4$ cm$^3$. The CR39 detectors have been placed in the wax for different distances.

Due to the interaction of neutrons with nuclear species of wax, different collisions have been induced through the neutron trajectories, which caused slowing down neutrons along the path of interactions. From attenuation of neutrons with wax a neutron capture cross-section measurements can be made so easy using the following equation:

$$A = A_0 e^{-\Sigma r}$$  \hspace{1cm} (1)

where, $A$ is the activity of neutrons measure, $A_0$ number of neutron incidents from the source, $\Sigma$ is the macroscopic cross-section to be determined from the experiment and $r$ is the distance from the source.

As shown in figure (5) the experimental behavior of the $(\ln (A/A_0) r^2)$ against $r^2$, where the neutron macroscopic cross-section can be measured through analyzed this behavior. The number of measured neutrons, that attenuated in the wax and detected by CR39 detector, can be determined by [5]:

$$Y = n * \left[1 - \exp (-N * \sigma _E * t)\right] \approx \frac{\sigma _t}{\sigma _E}$$  \hspace{1cm} (2)

where $Y$ is the number of neutrons measured by CR39 detector, $N$ is the atomic mass density of the wax, $t$ is the distance from the source, $\sigma _E$ is the neutron elastic scattering cross section at energy (E), $\sigma _t$ is the total cross-section of the neutron with wax material. As shown in figure (6) a sample of the paraffin wax with CR-39 detectors (A) and picture for some neutron tracks on the detector (B).

The logarithmic average energy decrement, $\xi$, and the number of collisions, $N$, can be determined by:

$$N = \frac{\ln(E_{high}/E_{low})}{\xi}$$  \hspace{1cm} (3)

where $\xi$ is the logarithmic average energy decrement[6],

$$\xi = \frac{\frac{\sigma _E - \sigma _t}{\sigma _E} + \frac{\sigma _E - \sigma _t}{\sigma _E}}{\ln(E_{high}/E_{low})}$$

Fig (5) The relationship between $\ln (A/A_0) r^2$ and $r^2$

Fig(6) The sample of the paraffin wax with CR-39 detectors (A) and picture for some neutron tracks on detector (B)
The attenuation range of the neutron in the paraffin wax can be calculated using,
\[ A = 1/(N_i(\sigma_{abs}+\sigma_{sc})) \]  
(4)
where \( N_i \) is the number of atoms per volume, \( \sigma \) is the absorption and scattering microscopic cross-section respectively[7].

From calculation the mean distance of the neutron between the point originates from the source to the point at which absorbed can measured experimentally. Hence, the mean square distance, \( r^2 \), is:
\[ r^2 = \frac{(1/E_i - 1/E_0)v^2}{\Sigma_s} = 6L^2 \]  
(5)
Where \( L \) is the diffusion length of the neutrons in wax material.

Another nuclear parameter is the slowing down time for neutron in wax material which can determined by the logarithm of the energy \( dE \) in time \( dt \) [5],
\[ t = \frac{\sqrt{2mE_0}}{\xi E_s} \left( \frac{1}{\sqrt{E_0}} - \frac{1}{\sqrt{E}} \right) \]  
(6)
where \( E_0 \) equal to 0.025eV, \( E_0 \) is 4.8*10^6 eV, \( \Sigma_s \) macroscopic cross-section to scattering.

All parameters ( \( \xi, L, \sigma_s, \Sigma_s, \Sigma_t, \) and \( t \)) are listed in table (1) and compared the results with the theory.

**Table (1)** Experimental measurements and theoretical calculations of some parameters for paraffin wax material (\( \text{C}_{20} \text{H}_{30+} \)) irradiated with neutron flux using Am-Be source.

<table>
<thead>
<tr>
<th>Nuclear parameter</th>
<th>Type of calculation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density g/cm³</td>
<td>………..</td>
<td>0.89</td>
</tr>
<tr>
<td>( \xi )</td>
<td>Exp.</td>
<td>0.95±3.8%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>0.913</td>
</tr>
<tr>
<td>L(cm)</td>
<td>Exp.</td>
<td>11.72±3.1%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>11.35</td>
</tr>
<tr>
<td>( \sigma_s ) (barn)</td>
<td>Exp.</td>
<td>0.62±6.5%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>0.665</td>
</tr>
<tr>
<td>( \sigma_t ) (barn)</td>
<td>Exp.</td>
<td>43.37±3.7%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>45.0</td>
</tr>
<tr>
<td>( \Sigma_s ) (cm⁻¹)</td>
<td>Exp.</td>
<td>0.00080±6.2%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>0.00085</td>
</tr>
<tr>
<td>( \Sigma_t ) (cm⁻¹)</td>
<td>Exp.</td>
<td>0.0556±3.7%</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>0.0577</td>
</tr>
<tr>
<td>( \Sigma_n ) (cm⁻¹)</td>
<td>Exp.</td>
<td>0.534</td>
</tr>
<tr>
<td></td>
<td>Th.</td>
<td>………..</td>
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<tr>
<td>( t_s ) (µ sec)</td>
<td>Exp.</td>
<td>0.0172</td>
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<td></td>
<td>Th.</td>
<td>………..</td>
</tr>
<tr>
<td>( L ) (cm)</td>
<td>Exp.</td>
<td>17.71±3.6%</td>
</tr>
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<td></td>
<td>Th.</td>
<td>17.07</td>
</tr>
</tbody>
</table>

1.3 Conclusion

In the present work the SSNTDs technique has been used to measure the neutron capture cross-section for the paraffin wax. The technique, performance includes preparation of the sample slab dimension 52.10*10*4 cm³ with the appropriate size of the CR39 (1×1×0.1 cm) and irradiated with Am-Be neutron source. The measurement has been calculated for cross-section according to (eq1) which shows total neutron cross-section (\( \Sigma_t = 46.11±1% \) barn). While, the neutron capture cross-section is about (\( \sigma_c = 0.624 ± 6.5 \% \)) according to (eq2) which in turn showed very closed result compared with \( \sigma_c = 0.665 \text{ barn} \) [8]. The number of neutron collisions with paraffin wax leads to the thermal energy stage is about 21 Collisions at depth reached to 26 cm and the slowing down time reached to 0.0172µsec. From these results one can conclude that this material at limited dimension is more applicable, as a shielding with neutron sources, in slowing down neutrons from the fast energy stage.
Reference


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