Measurements of flux and dose distributions of neutrons in graphite matrices using LR-115 nuclear track detector

Y S Selim, A F Hafez and M M Abdel-Meguid

Department of Physics, Faculty of Science, Alexandria University,
21511 Alexandria, Egypt

Abstract : Attenuation of fission neutrons has been studied in graphite blocks of different dimensions. Fast, epithermal and thermal neutron fluxes were measured at different depths inside graphite blocks. The fast neutron group was measured using bare LR-115 cellulose nitrate nuclear track detector, while fast, epithermal and thermal neutron groups were obtained using LR-115 type B detector. But, the fast and epithermal neutron groups were detected using LR-115 type B detector which was shielded against thermal neutron flux by two 1 mm thick Cd-foils. Moreover, the build up factors of the three neutron groups and the fast neutron absorbed dose rate distribution inside the graphite medium were calculated as well.

1. Introduction

As is well known, the measurement of the neutron flux distribution in some media is very important in many fields such as radiation protection dosimetry, neutron therapy, shielding studies and nuclear reactors construction.

The study of flux and absorbed dose distributions of neutrons in graphite is of great importance, since graphite is often used as a reflector, moderator, or shield component of the fast neutrons in fusion and fission reactors [1,2].

The application of solid state nuclear track detectors (SSNTDs) to neutron dosimetry is increasing mainly due to their high degree of reproducibility, long-term stability, insensitivity to beta and gamma rays, low cost and the ease to handle [3].

One of the most appropriate SSNTDs for dosimetric applications is cellulose nitrate LR-115 type II (Kodak-Pathé, France) nuclear track detector.

This detector can be used in two modes, either as a bare detector, or with an external converter. In the case of a bare detector exposed to fast neutrons, the neutrons can undergo elastic collision and (n, α) reactions with C, N and O nuclei constituting the detector material. In the second mode, the detector is covered with (n, α) converter for the detection of thermal and epithermal neutrons, the most suitable (n, α) converter is the lithium tetraborate $(Li_2B_4O_7)$, for which the (n, α) cross section is very large (3840 barns for ^{10}B and 950 barns for ^6Li) [4]. The alpha particles and the recoil nuclei resulting from these reactions leave etchable tracks in LR-115 detector. If the tracks are completely etched through the sensitive cellulose nitrate layer, the tracks appear as bright holes [5–7].

Some Measurements on flux and depth dose distributions of neutrons inside water phantom using SSNTDs have been done. For example, using CR-39 polymeric nuclear track detector and $D-T$ neutron source [8]. Sayed and Adnan [9] also used LR-115 type II cellulose nitrate nuclear track detector to measure fast neutron depth-dose distribution inside water phantom from Am-Be neutron source.

The aim of the present work is to measure the flux distribution of fast, epithermal and thermal neutrons in blocks of graphite of different dimensions. The detector used in this investigation was LR-115 nuclear track detector.

2. Experimental methods

The investigations were carried out using ^{252}Cf neutron source of average energy 2.16 MeV. The detector used was cellulose nitrate sheet, LR-115 type II $(C_6H_8O_9N_2)$ with density of 1.52 g cm^{-3} and 12–13 µm thick on 100 µm polyester base. The detectors used were obtained by cutting the cellulose nitrate sheets into pieces of size 1.5 × 1.5 cm. These detectors were classified into three groups. The first, was the bare group detectors which were used to detect only the fast neutrons. In this case the track holes of α-particles that are produced through the ^{14}N (n, α) ^{11}B reaction whose Q-value is –0.16 MeV only can be formed and observed in the LR-115 detector because the threshold neutron energies for ^{12}C (n, α) ^9Be and ^{16}O (n, α) ^{12}C are greater than the energy of the ^{252}Cf neutron source. The second group of detectors was coated with $Li_2B_4O_7$ as (n, α) converter (LR-115 type B) to detect the fluxes of the fast, epithermal and thermal neutrons, while the third group was LR-115 type B detectors too, but was shielded for thermal neutron flux by two 1 mm thick Cd-foils. By this way, all neutrons below a cut-off energy, E_{cd}, of about 0.5 eV are absorbed while all neutrons above this energy pass the cadmium foil without appreciable capture.

The medium under investigation was consisting of 100–200 graphite blocks, each block of dimensions 5 × 5 × 1 cm. This medium was considered to be composed mainly of carbon of density 1.6 g cm^{-3}. The graphite blocks were arranged in different parallel rectangular shapes of dimensions A × B × C cm.

The assemblies of the three detector groups were placed axially within the graphite blocks. The first assembly of detectors was put in front of the neutron source at a distance of about 0.5 cm. Due to the low neutrons yield ($\sim 10^4$ n.sec^{-1}) from the closed ^{252}Cf source the experimental arrangement was left for different exposure times lasted from 10 to 20 days. This experimental arrangement was located 1 m above the floor in the center of an irradiation room of dimensions 8 m × 5 m × 4 m in order to avoid the contribution of neutrons scattered from the floor and surroundings.

After irradiation, the detectors were removed and cleaned with running water and then dried. The LR-115 detectors were etched chemically in 2.5 M NaOH solution at 60°C for two hours to give an average residual thickness of cellulose nitrate red layer of about 5–6 µm. After etching, the detectors were washed in distilled water and treated with B solution (50 cm^3 distilled water + 50 cm^3 ethyl alcohol) then washed by distilled water again and dried. The detectors were scanned and the track density was evaluated using an optical microscope with magnification 500x.

The neutron flux ϕ was calculated through the relation :

$$\phi = \frac{\rho}{S.t},$$ (1)

where ρ is the net track density (track-holes/cm^2), t is the exposure time in seconds and S is the neutron sensitivity (tracks/neutron). This sensitivity was found to depend on the neutron energy and the residual thickness of LR-115 detector. For ^{252}Cf neutron source, the value of S was calculated by us and found to be $(2.2 \pm 0.7) \times 10^{-7}$ tracks/neutron according to the equation given by Medvecky [10]. This value of S was found in good agreement with the experimental results obtained by Sawamura and Yamazaki [11]. Whereas for thermal and epithermal neutrons the values of the neutron sensitivity S were $(4.5 \pm 1) \times 10^{-5}$ and $(1 \pm 0.3) \times 10^{-7}$ tracks/neutron, respectively as reported by Pàlfalvi [12].

It was observed that, within a bad geometry medium, the flux of neutrons of a certain energy E and at a certain depth r is somewhat higher than that expected from the exponential absorption law, *i.e.* an excess of neutrons is built up at this depth. Thus, the expected neutron flux at a depth r inside the medium can be given by Selim *et al* [13] :

$$\phi(E,r) = B(E,r). \quad \phi_0(E)\exp(-r/\lambda),$$ (2)

where $\phi_0(E)$ is the initial flux of neutrons at energy E, λ is the relaxation length and $B(E, r)$ is the build up factor.

The fast neutron absorbed dose rate (Gys^{-1}) was calculated using the formula [14] :

$$D = 1.6 \times 10^{-13} \phi EN\sigma f,$$ (3)

where ϕ is the measured neutron flux, $E = 2.16$ MeV is the average neutron energy of ^{252}Cf neutron source [15], $N = 5 \times 10^{25}$ nuclei/kg for ^{12}C, $\sigma = 1.7$ barn is the total cross section of ^{12}C, and $f = 0.142$ ($f = 2A/(A + 1)^2$, where A is the atomic mass of the nucleus that received the energy transferred) is the fraction average energy transfer to scattered nuclei [14].

3. Results

Figure 1 shows the variation of the measured fast neutron flux with depth in rectangular graphite blocks of different dimensions.
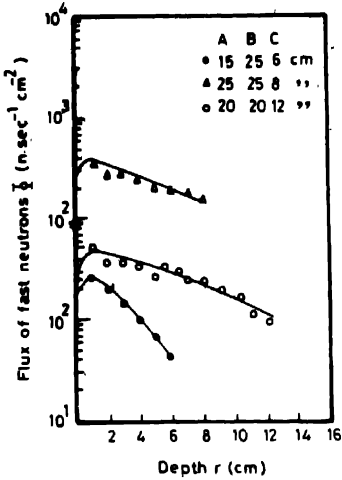

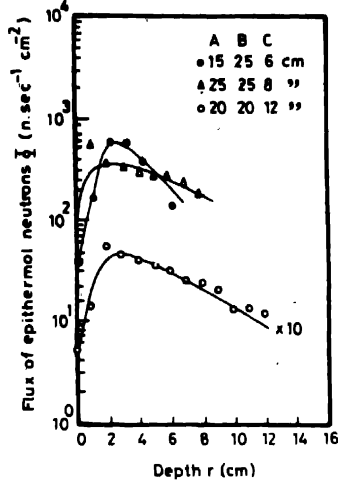**Figure 1.** The variation of fast neutron flux with the depth in graphite blocks of different dimensions.

Figure 2. The variation of epithermal neutron flux with the depth in graphite blocks of different dimensions.

The thermal and epithermal neutron flux distributions determined by the LR-115 detectors at various depths in the considered medium are represented in Figures 2 and 3.
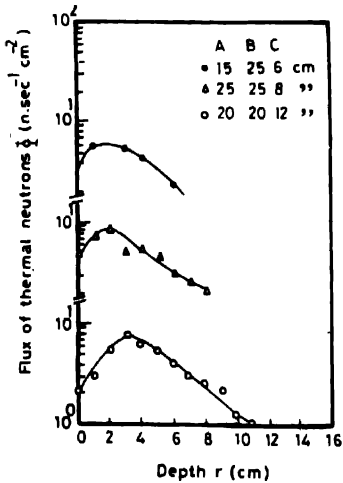

Figure 3. The variation of thermal neutron flux with the depth inside graphite blocks of different dimensions.
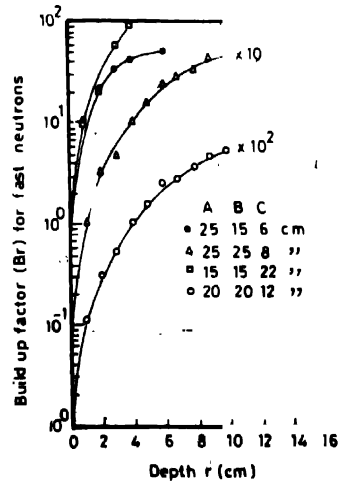
Figure 4. Measured build-up factors of fast neutron in different arrangements of graphite blocks.

Based on eq. (1) the build up factors for fast, epithermal and thermal neutrons were determined from the ratio of the measured neutron flux to the theoretical neutron flux *i.e.* in the absence of the build up factor. In this work, we calculated the values of the relaxation lengths and were found to be 7.76, 2.76 and 2.94 cm for fast, thermal and epithermal neutrons, respectively [16].

Figure 4, shows the variation of the build up factor as a function of the depth inside the graphite blocks for fast neutron.
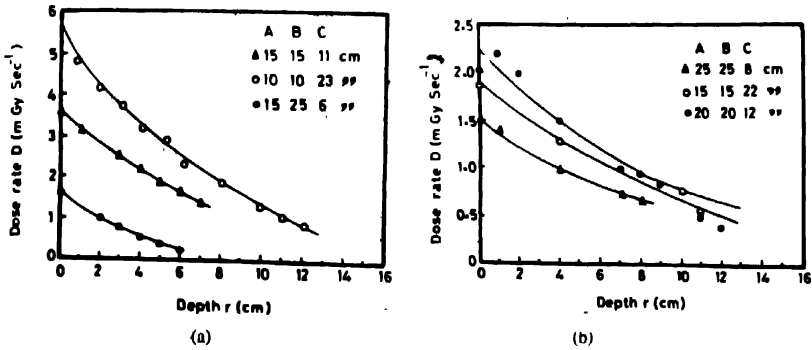
Figures 5(a, b). The variation of fast neutron dose rate as a function of the depth inside the graphite blocks.

Figures 5(a,b) represent the variation of fast neutron dose rate, as calculated from eq. (3) with depth in the medium under study.

4. Discussion

LR-115 cellulose nitrate nuclear track detector was used to measure fast, epithermal and thermal neutron flux distributions from ^{252}Cf source in graphite blocks. The influence of the medium size on the distribution of the three neutron energy groups were carried out as well.

It is clear from Figure 1 that the fast neutron flux in the different arrangements of the graphite blocks decreases with increasing the depth inside the attenuation medium. On the other hand, the flux distribution of thermal and epithermal neutrons in the graphite matrices show maximum values around 3 cm inside the graphite blocks as shown in Figures 2 and 3. This means that the neutrons are accumulated in this domain. So the measurements enabled us to study an important factor known as the build up factor. In Figure 4 it was noticed that the build up factor increases with depths in the medium under study, then it may exhibit a saturation that depends on the dimensions of the medium, its constituents, the leakage of the neutrons and their energy.

The results obtained in this article also enabled us to calculate the distribution of the fast neutron dose rate in different blocks of graphite as represented in Figures 5(a,b). These results are in good agreement with previous published data [12,17–19].

References

[1]   J R L Lamarsh *Introduction to Nuclear Engineering* (New York : Addison-Wesley Publishing Company) (1975)

[2]   A E Profio *Radiation Shielding and Dosimetry* (New York : John Wiley & Inc.) (1979)

[3]   S A Durrani and R K Bull *Solid State Nuclear Track Detection, Principles, Methods and Application* (Oxford : Pergamon Press) (1987)

[4]   G Dajko and G Somogyi *Techniques of Radiation Dosimetry Solid State Nuclear Track Dosimetry Chapter 11* (New Delhi : Wiley Eastern Limited) (1985)

[5]   Y Cheng, J Lin, B Zhang, L Zheng and R Lu *Nucl. Instrum. Meth.* B52 68 (1990)

[6]   A Dragu *Nucl. Tracks Radiat. Meas.* 19 461 (1990)

[7]   A F Hafez and G I Khalil *Nucl. Instrum. Meth.* B94 107 (1994)

[8]   S E El-Chennawi *PhD Thesis* (Faculty of Science, Alexandria University, Egypt) (1989)

[9]   A M Sayed and N R Adnan *2nd National Conference on Pure and Applied Biophysics Sciences and 1st Egyptian British Radiation Protection Symposium.* (Cairo, Egypt) (1985)

[10] L Medveczky *Acta Physica Academiae Scientarum Hungaricae* 52 357 (1982)

[11] T Sawamura and H Yamazaki *Nucl. Tracks.* 5 271 (1981)

[12] J Pàlfalvi *Nucl. Tracks* 9 47 (1984)

[13] Y S Selim, A M El-Khatib, W M Abou-Taleb and M A Fawzy *The Arabian J. Sci Engg.* 8 377 (1983)

[14] H Cember *Introduction to Health Physics* (Oxford, U.K. : Pergamon) (1985)

[15] F H Fröhner *Nucl. Sci. Engg.* 106 345 (1990)

[16] D Ecullen and P K Mclaughlin *International Atomic Energy Agency (IAEA) NDs Vienna* (1985)

[17] R A Rashed and M A Ibrahim *Egypt. J. Phys.* 12 135 (1981)

[18] A M El-Khatib, A Abdel-Naby, A F Hafez and M A Kotb *J. Medical Res. Inst. Egypt* 13 133 (1992)

[19] W A Kansouh *PhD Thesis* (Faculty of Science, Ain Shams University, Egypt) (1996)