A STUDY OF BACKSCATTERED NEUTRON DOSES IN WATER USING CR-39 DETECTORS

A.A. Abou El-Khier, M.Adel Fawzy, A.M.El-khatib* and S.E.El-Chennawi
Physics Department, Faculty of Science, Alexandria University,
Alexandria, Egypt.

ABSTRACT

Backscattered neutrons produced from a D-T neutron generator with energy 14.5 MeV were investigated as a function of water layer thickness. The plastic track detector CR-39 which is designed as a dosimeter was used to measure the fast, intermediate and thermal neutrons. The sensitivity of the detector for the energy regions of interest is determined. Also the does equivalent rates due to backscattered neutrons at the surface of phantom were measured.

KEY WORDS

Neutron dosimeter, plastic track detector CR-39, backscattering coefficient, dose equivalent rate.

INTRODUCTION

The experimental investigation of neutron reflections from water leads to important results in protecting persons against neutrons. The subject of neutron backscattering has an important interest, but a few such investigations are available [1-4]. When a water layer is exposed to neutrons, a fraction of the incident *neutrons is reflected from the layer and contribute to* the surface does. The qualitative characteristics of the reflection effect which is the so called backscattering coefficient (albedo), η is given by

$$\eta = \frac{\phi_b - \phi_i}{\phi_i}$$

where ϕ_i represents the incident neutrons from the source and ϕ_b represents the reflected neutrons from the medium over a certain energy region. This factor (η) depends on the nature , dimensions of the reflecting medium, the surroundings, and energy spectrum of the neutron source.

In order to determine the backscattering coefficient η from water, the experiment was carried out at first with an empty phantom and then repeated systematically by filling the phantom with a layer water of thickness 2.5, 5,10 and 15 cm.

Plastic track detector is a promising dosimeter to measure the neutron doses [5-8]. The aim of this work is to study the backscattered neutrons from water at different locations on its surface, by using CR-39 plastic detector as a personal dosimeter.

EXPERIMENTAL PROCEDURES

The measurements were carried out by using a D-T/D-D neutron generator of 120 kV accelerating voltage, Philips manufacture PW 5310. The neutron yield was continuously monitored by means of activated copper foil. Making use of the yield of ^{63}Cu(n,2n) ^{62}Cu reaction and special factor given by the manufactures and checked routinly by the authors, the neutron yield was determined in each run. Normalization and correction in the flux have been taken into consideration [9].

A phantom made of plexiglass dimensions (30X30X20) cm^3 was used. According to the design of the phantom, it was easy to vary the water thickness in layers of about 2.5 cm (Figure (1-a)).

---

* Faculty of Medicine, Jeddah,King Abdel-Aziz University, Kingdom of Saudia Arabia.

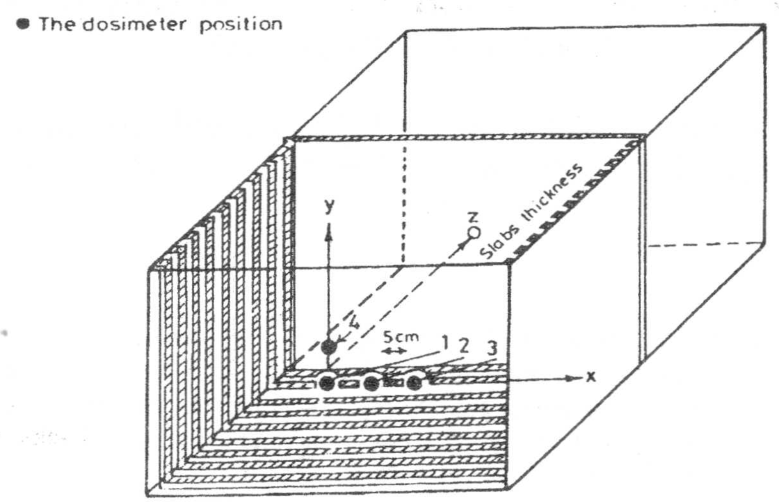

Figure 1-a. Arrangement of the dosimeters on the phantom surface where the distance between each dosimeters is 5 cm, and Z represents the water layer thickness.

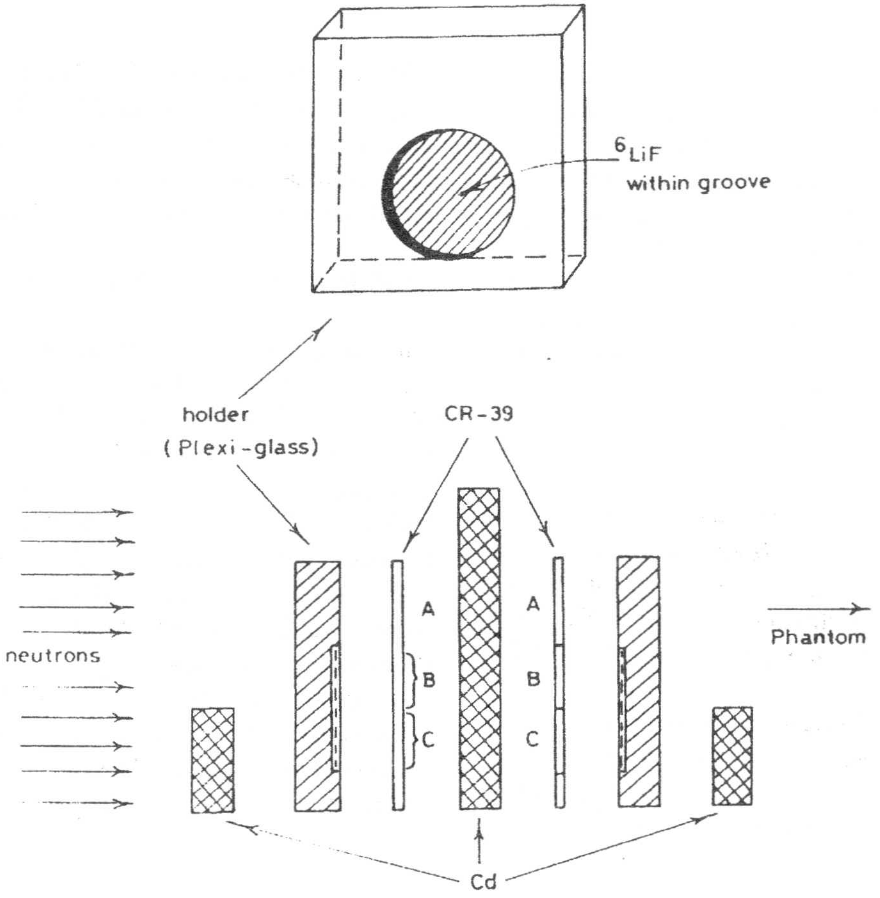

Figure 1-b. Schematic diagram of the neutron dosimeter design.

CR-39 "Super grade" PM-355 having a thickness ≈ 250 μm was obtained from Pershore Mouldings Ltd. U.K.

The neutron dosimeter designed from a combination of ^{6}LiF, Cd foil and CR-39 plastic. Schematical representation is shown in (Figure (1-b)). By means of such a dosimeter one can easily separate and measure the tracks densities produced by thermal-, intermediate- and fast-neutrons. Thermal energy region was considered from the Cd cutoff (0.5 eV) down to (0.025 eV).

The dosimeters were mounted on the surface of the phantom at locations 1,2,3 and 4 as shown in (Figure (1-a)). After that, the phantom was irradiated for a suitable time. CR-39 was chemically etched in 6.25 M NaOH at 70°C for 6 hours, and examined by an optical microscope with an amplification about 600 X .One of the eyepieces is fitted with a square grid to attain a high accuracy in the track counting.

RESULTS AND DISCUSSION

The registered tracks in CR-39 are produced due to the interaction of that fast neutrons with the constituents of plastic detector material (H,C,O) which occur in both the removal layer (≈ 8μm) during chemical etching and the remaining bulk material. These layers are effectivelly intrinsic radiators. It was found that the track density is approximately independent on the water thickness while it is remarkably varied from one location to another on the surface.

In order to get the neutron fluence one should know the registration efficiency which is an important problem in any quantitative analysis. For that purpose Cu, Al and In foils were irradiated simultaneously several times under the same conditions. The fast neutron fluence was determined and consequently the registeration efficiency of CR-39 over the fast neutron region was found to be 4.5 X 10^{-5} track/neutrons.

Thermal and intermediate neutrons are not able to create charged particles to produce tracks in CR-39 detector through the interaction with its constituents. Therefore, the detection of thermal and intermediate neutrons by CR-39 requires an alphagenic convertes such as ^{6}LiF placed in contact with the detector.

This converter has a circular shape of diameter 10 mm and thickness 20 mg/cm^2 which is greater than the maximum range of the alpha-particle in ^{6}LiF.The converter is embeded inside a circular groove in a plexiglass plate as a holder. The emitted α-particles due to the ^{6}Li (n,α) ^{3}H reaction which cross the converter to the detector will have an energy spectrum ranging from O to E_{max}(= 2.04 MeV) which is independent of the neutron energy in the thermal and intermediate regions.

The track density have been measured for thermal and intermediate neutron fluence on the surface of the phantom at a different locations for the empty phantom as well as filled with different water slab thicknesses . Consequently, the backscattering coefficient η could be determined and graphically represented in Figure (2-a, 2-b). A theoreticall fitting of the experimentall data could be accomplished through the derivation of Fick's law and applying the one velocity diffusion theory [10]. Considering one dimensional neutron propagation inside a finite slab of thickness C, using polar coordinates and expanding the flux inside the slab in the form of a Taylor's series, assumed to vary slowly with position, the neutron current density which flows backwards through a unit area [10], will be

$$J_{\bar{z}} = \frac{\Sigma_s}{4\pi} \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} \int_{r=0}^{c} e^{-\Sigma_t r} \left[\varphi_0 + \left(\frac{\partial \varphi}{\partial z} \right)_0 r \cos\theta \right]$$
$$X \cos\theta \sin\theta \; dr \, d\theta \, d\phi$$

which when evaluted gives:

$$J_{\bar{z}} = \frac{\Sigma_s \varphi_0}{4\Sigma_t}(1 - e^{-\Sigma_t c}) + \frac{\Sigma_s}{6\Sigma_t^2}[1 - (1 + C\Sigma_t)e^{-\Sigma_t c}] X \left(\frac{\partial \varphi}{\partial z} \right)_0$$

For thickness less than a mean free path,

$$J_{\bar{z}} \propto \left(\frac{\Sigma_s \varphi_0}{4\Sigma_t} + \frac{\Sigma_s \left(\frac{\partial \varphi}{\partial z} \right)_0}{6\Sigma_t^2} \right) (1 - e^{-\Sigma_t C})$$

Accroding to the difinition [10], $J_{\bar{z}}$ defines the part of the neutron flux emitted backward when an incident flux φ_0 is falling inwards.

Therefore,

$$\frac{\varphi}{\varphi_0} \propto A(1 - e^{-BC})$$

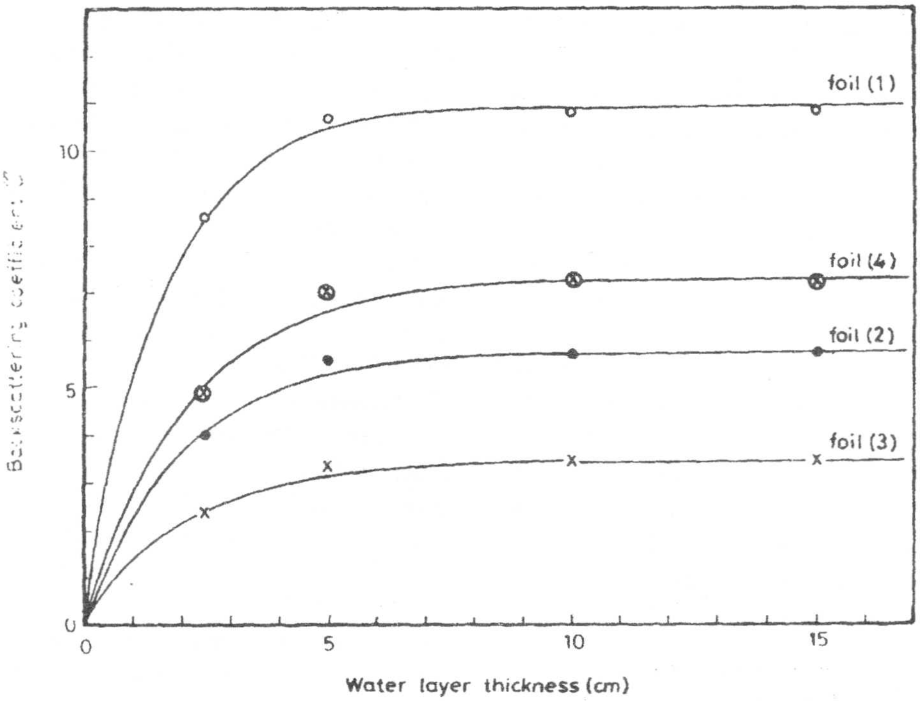

Figure 2-a. thermal neutron flux.

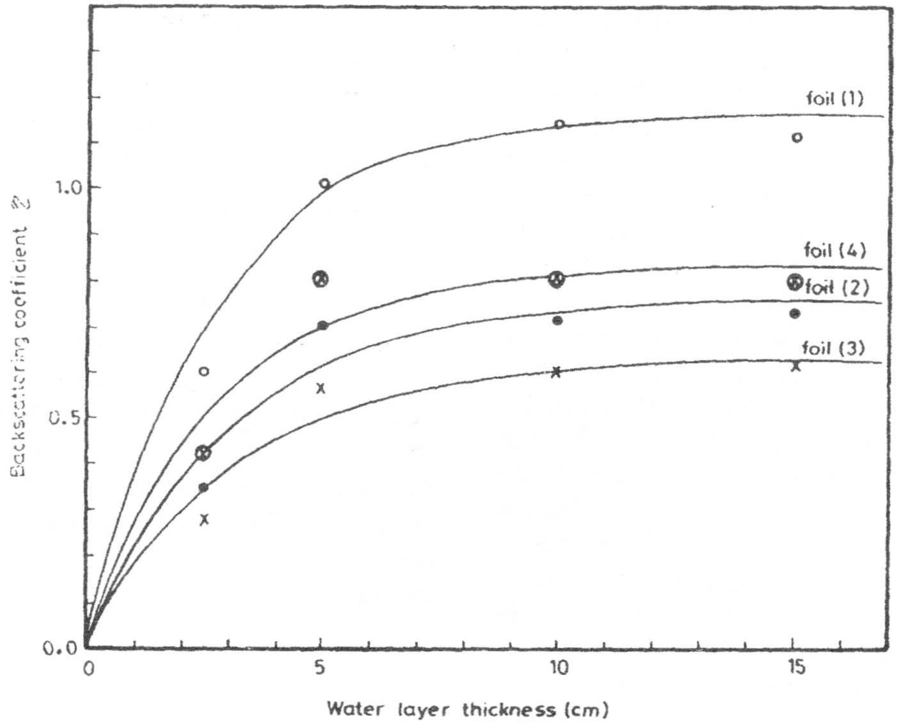

Figure 2-b. intermediate neutron flux.

Backscattering coefficient (η) of neutron flux on the surface of the phantom at different locations as a function of water layer thickness, foil (1) - (0,0,0), foil (2) - (5,0,0), foil (3) - (10,0,0), foil (4) - (0,5,0).

which is to be considered. A and B are constants of the medium; A is depending on the atomic mass of the medium and on the energy of the detected neutrons, while B is depending on the total macroscopic cross section (Σ_t). Making use of the obtained experimental data the valeus of A and B can be deduced. There values are represented in Table (1).

Table 1.

Foil locations	Thermal region		Intermediate region	
	A	B	A	B
1- (0,0,0)	10.93	0.63	1.17	0.37
2- (5,0,0)	5.79	0.50	0.76	0.33
3- (10,0,0)	3.47	0.48	0.64	0.31
4- (0,5,0)	7.37	0.47	0.83	0.36

The general behaviour of the curves is that all of them having the same trend, i.e saturation occurs at a layer thickness of 5 cm. In addition to that the , the values of η decreases as the dosimeter moves on the surface of the phantom far from the direct incident beam. The values of η for thermal neutrons are greater about 10 times with respect to the intermediate neutrons.

The relation between the track densities ρ on the surface of CR-39 in close contact with a thick ^{6}LiF disk and the neutron fluence F incident on the surface [11] is:

$$\rho = \xi F$$

where ξ is the registiration efficiency. The calculated values of ξ for thermal and intermediate neutrons were found to be 6.7 X 10^{-3} and 3.4 X 10^{-4} track/neutron respectively.

From the track density and registration efficiency of CR-39, the neutron fluences were determined for the thermal, intermediate and fast energy regions.

In order to determine the dose equivalent response of CR-39 detector for the three energy regions, the ICRP [12] conversion factors have been considered. The following equation gives the total doses equivalent (DE) during the period of exposure:

$$DE = f_f \rho_f + f_i \rho_i + f_{th} \rho_{th}$$

where f_f , f_i and f_{th} are the reciprocal of dosimetric responce CR-39 in the fast, intermediate and thermal regions respectively.

Accordingly, the dosimetric response values of CR-39 are 1.10 X 10^2, 2.82 X 10^4 and 5.83 X 10^5 (track.cm^{-2}/ mSv) respectively. Figure (3) reproduces the variation of the total dose equivalent rate as a function of the water slab thickness at different locations on the surface of the phantom.

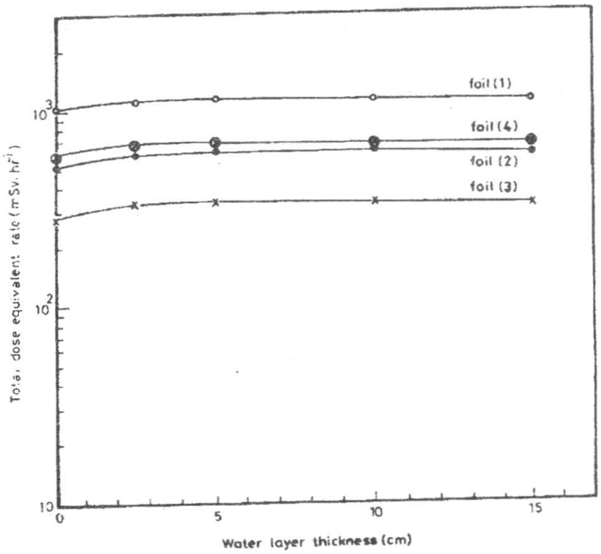

Figure 3. Variation of total dose equivalent rate on the phantom surface as a function of water layer thickness (locations given in Figure 2).

CONCLUSION

This work lead to conclude that, the backscattered intermediate and thermal neutrons from the water have a contribution in the total dose of the order of 10% . Therefore, their biological effectiveness should be considered.

ACKNOWLEDGEMENT

Our cordial thanks to Professor **Younis S.Selim** for helpful discussions and continuous guidance.

REFERENCES

[1] Matiullah and N. Ahmad, Nucl. Instr. and Meth. B 43, 581, 1989.

[2] D.T. Bartlett, J.D. Steels and D.R. Stubberfield, Nucl. Tracks 12, 654, 1986

[3] R. Hollnagell, R. Jahr and B.R.L. Siebert, Radiat. Protect. Dosim. 20, 25, 1987.

[4] E. Piesch, J. Jasiak and M. Urban, Nucl. Tracks 8, 323, 1984.

[5] C.S. Sims, H.W. Dickson, Radiat.Protect. Dosim. 10, 331, 1985.

[6] Y. Eisen, Y. Shamia, E. Ovadia, Z. Karpinovitch, S. Fearmann and T. Schlesinger, Health. Phys. 41, 349, 1981.

[7] J.S. Durham, T.E. Blue, B.W. Wehring, M.H. Ragheb and J.W. Blue, Nucl.Instr.and Meth. B 36, 319, 1989.

[8] M.A. Gomaa and S.A. Kasim, Nucl.Instr. and Meth. 176, 579, 1980.

[9] M.A. Fawzy, A.M. El-Khatib, W. Abou-Taleb and S.S.Yassin, Isotopenpraxis, 23 1 pp. 25, 1987.

[10] J.R. Lamarsh, *Introduction To Nuclear Reactor Theory*, Addison-Wesley Publishing Company, 1972.

[11] S.A. Durrani and P.K. Bull, solid state Nuclear Track Detection, Principles, Methods and Applications *pergamon Press, Oxford*, 147. 1987.

[12] International "Data for Protection Against Ionization Radiation From External Sources, Supplement to ICRP Publication 15" Adopted by the commission in April 1971, ICRP *Publication 21, Pergamon Press Oxford* 1973.