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TRANSMITTED NEUTRON DOSE MEASUREMENTS IN WATER USING PLASTIC TRACK DETECTORS

By

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ABSTRACT

A personnel neutron dosimeter designed from track detector CR-39 to separate and detect the thermal, intermediate and fast neutrons has been used. The transmitted neutron flux from a D+T compact neutron generator within slabs of water with different thicknesses has been investigated. In addition to that, the corresponding dose equivalent rates have been estimated. It has been concluded that, the predominant dose equivalent rates are due mainly to the fast neutrons.

INTRODUCTION

Shielding against neutrons is more difficult than either against charged particles or photons. If a source emits fast neutrons, the first step is to provide a material that will thermalize neutrons. Such materials are water, wax, or paraffin. For the design of an efficient shield and collimator system for the application of neutrons in radiotherapy, various aspects must be considered such as:

a) The dose to normal tissues outside the beam must be reduced to a sufficiently low level, and

b) The shield thickness should be kept to a minimum because of the limited yields of neutrons from presently neutron generators.

The introduction of the controlled thermonuclear reactor, for example, has attracted more attention to the higher energy neutrons. The feasibilty of fusion-fission hybrid concepts and the media surrounding a D+T source of 14 MeV neutrons have brought more interest to the study of the interaction of these neutrons with different materials. In addition, the develop- ment of the neutron dosimetry technique necessitated shifting towards the higher energy region. All these facts made the investigation of 14 MeV neutrons worthwhile. The availability of the D+T neutron source and the use of the satisfactory techniques such as the foil activation and the solid state nuclear track detectors (SSNTD) made it possible to determine transmitted neutron-flux and - dose equivalent rates within any block of material.

The development of a SSNTD CR-39 as a neutron dosimeter either for neutron therapy[1] or as personnel dosimeter[2-5] become the subject of many experimental and theoretical works.

Neutron measurements by SSNTD are carried out either directly in case of fast neutrons by the registration of the recoil particles due to neutron scattering with the plastic constituents[6] (H, C and O), or indirectly in case of thermal and intermediate neutrons by using converters rich with Li or B to produce α particles through the (n,α) reaction, leave also a damage trial[7].

The neutron energy dependence of the registiration efficiency of SSNTD was studied in details either theoretically or experimentally[8]. There are some parameters which play an impor- tant role in the improvement of the efficiency of the CR-39 detector, such as the type of etching (chemical or electrochemical) as well as its conditions, the manufacture of the detector, and the use of convertors. A number of experiments[9,10,11] were carried out to study the effect of the above mentioned parameters on the efficiency of the CR-39.

The aim of this work is to measure the transmitted neutron doses in slabs of water with different thicknesses using a personnel neutron dosimeter designed to separate and detect the thermal, intermediate and fast neutrons.

EXPERIMENTAL PROCEDURES

The measurements were carried out by using a D+T compact neutron generator. The fast neutron yield was continuously monitored by means of an activated copper foil.

Making use of the yield of $^{63}Cu(n,2n)^{62}Cu$ reaction and special factor given by the manufacturer 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[12,13].

CR-39 plastic detector, "Super grade" PM-355 having a thickness ≈ 250 μm and supplied by Pershore Mouldings Ltd. U. K.", was used. Thermal and intermediate neutrons are not able to create charged particles to produce tracks in CR-39 detector through the interac- tion with its constituents. Therefore, the detection of thermal and intermediate neutrons by CR-39 requires an alphagenic converters 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 $^{6}Li(n,\alpha)\ ^{3}H$ reaction which cross the converter to the detector will have an energy spectrum ranging from 0 up to E_{max} (= 2.04 MeV) which is independent of the neutron energy in the thermal and intermediate regions. Figure 1 gives the details of the used neutron dosimeter which facilitate the determination of the neutron doses in the three energy regions A (fast and intermediate), B (all regions) and C (fast region) with a sufficient accuracy. By means of such a dosimeter one can easily measure the track densities produced by thermal-, intermediate- and fast-neutrons. Thermal energy region was considered to be extended from the Cd cutoff (0.5 eV) down to (0.025 eV).

A water phantom in a plexiglass container with 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 (fig. 2). The experiment was carried out first with an empty phantom, then it is repeated systematically by filling the phantom with water to have a different water slabs thickness from 2.5 up to 15 cm. The dosimeter was mounted on the center of the back surface of the phantom (fig. 2).

After, each irradiation run for a suitable time, the CR-39 plastic detector was chemically etched in 6.25 N NaOH at 70° for 6 hours, and examined by an optical microscope to measure the track densities corresponding to the different energy regions.

RESULTS AND DISCUSSION

The registered tracks in CR-39 are produced due to the interaction of the fast neutrons with the constituents of the plastic detector material (H, C and O) which occur in both the removed layer ($\approx$ 8 μm) during chemical etching and the remaining bulk material. These layers are effectivelly intrinsic radiators. 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, a Cu foil as well as the dosimeter were placed in contact with the neutron source and irradiated simultaneously several times under the same conditions. The fast neutron flux and the corresponding track densities were measured and consequently the registration efficiency of CR-39 over the fast neutron region was deduced and it is found to be 4.5×10^{-5} track. n^{-1}.

The track density have been measured for thermal and intermediate neutron fluence transmitted through the water slab (with different thicknesses) and reach the center of its back surface. 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[14] (for thermal and intermediate energy regions only) is :

$$\rho = \xi \cdot F$$

where ξ is the registiration efficiency.
The calculated values of ξ for thermal and intermediate neutrons were found to be 6.7×10^{-3} and 3.4×10^{-4} track n^{-1} respectively. Accordingly, the neutron fluence for the two energy regions was estimated .

Figure 3 reproduces the variation of the registered track densities in accordance with the water slab thickness. It is clear from this figure, that the rate of registration of neutrons in the thermal and intermediate energy regions is higher than in the fast energy region.

The dose equivalent response of CR-39 detector in the different energy regions could be determined by making use of certain Flux-to-Dose rate conversion factors[15]. The variation in the estimated dose equivalent rates in the different energy regions is depicted in figure 4 and it indicates that the doses due to the transmitted thermal and intermediate neutrons can be neglected with respect to those due the fast netrons.

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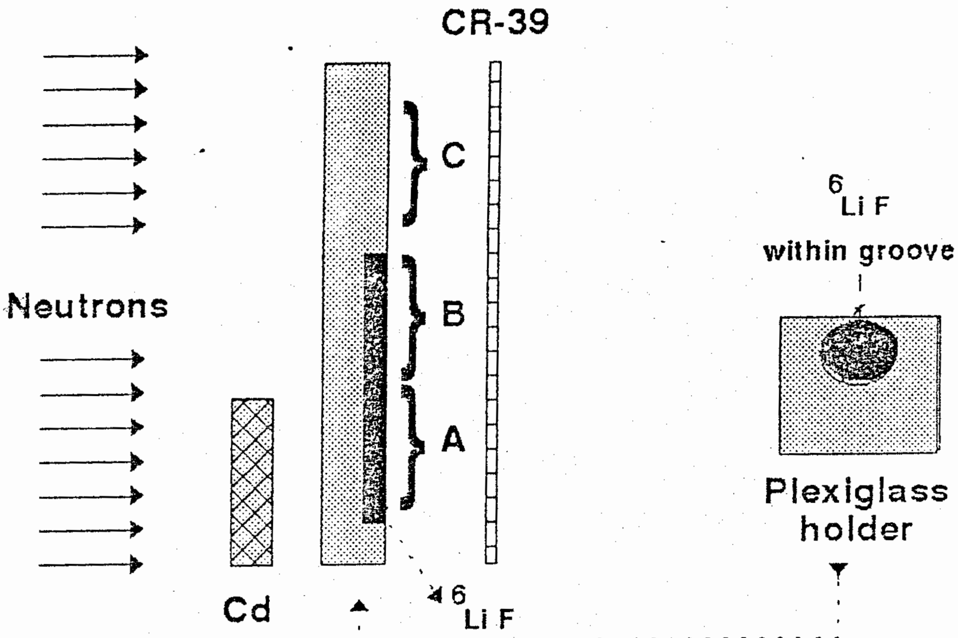
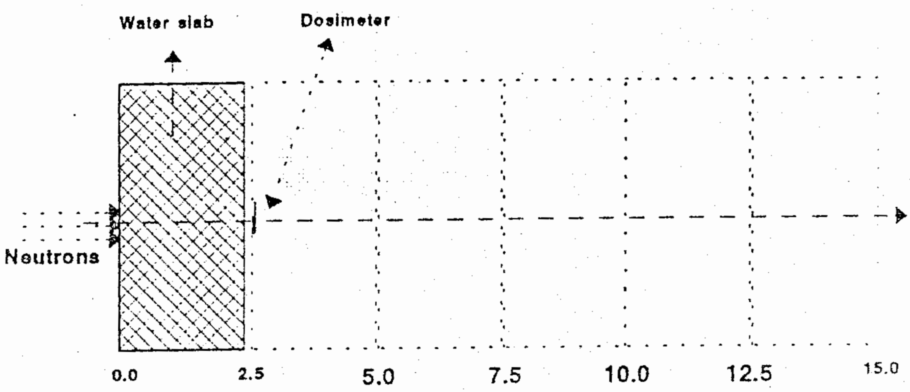


Fig. 1: Schematic diagram of the used neutron dosimeter.



The phantom

Fig. 2: Arrangement of the neutron source and the dosimeter on the water slabs surface.

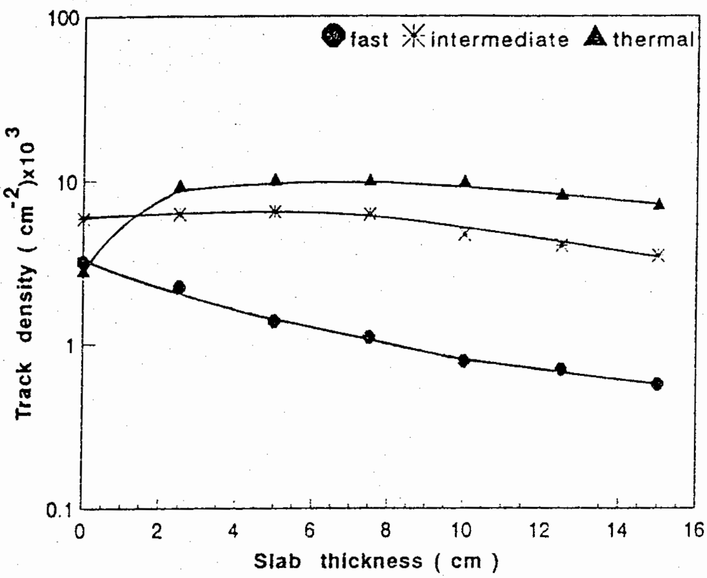


Fig. 3: Variation of the track densities as a function of the water slab thickness.

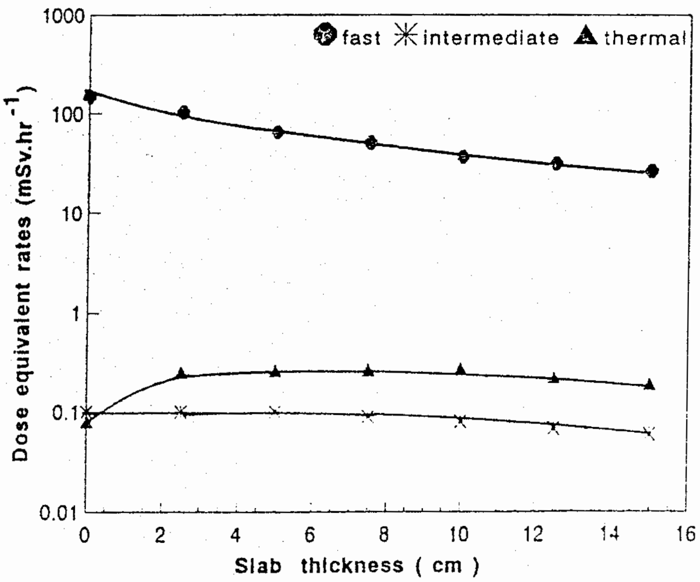


Fig. 4: Variation of the neutrons dose equivalent rates as a function of the water slab thickness.

قياس جرعات النيوترونات النافذة من الماء باستخدام كواشف الأثر البلاستيكية

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تم إستخدام مقياس شخصى للجرعات النيوترونية مصمم من كاشف الأثر البلاستيكى س ر - ٣٩ ، وذلك للكشف والتفريق بين كل مجموعة من النيوترونات الحرارية والمتوسطة والسريعة . ولقد تم دراسة السيل النيوترونى النافذ خلال شرائح من الماء ذات سمك متغير ، والناتج من مولد مضموم (د + ت) .

بالأضافة الى ذلك ، فقد استنتجت معدلات الجرعات المكافئة والمناظرة من كل مجموعة من الطاقات التى درست ولوحظ أن النيوترونات السريعة لها التأثير السائد على معدل الجرعات المكافئة .