DEVELOPMENT OF NEUTRON DOSIMETERS FOR FAST AND EPITHERMAL NEUTRONS

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In recent years great effort has been devoted to the development of personnel neutron dosimeters. Attempts to replace the NTA film, which has several shortcomings, by polycarbonate foils have been successful (1-3) in the high energy region above 1 MeV. The polycarbonate foil dosimeters are based on the elastic interaction of the incident neutrons with the carbon and oxygen nuclei of the polycarbonate molecule. The damage sites are revealed by the electrochemical etching (ECE) technique (4,5). Albedo dosimeters composed of ^{6}LiF and ^{7}LiF thermoluminescent chips, are used in several laboratories (6) for the epithermal region, above the Cd cutoff. These dosimeters are strongly energy dependent and sensitive to γ fields. Quite recently a new type of plastic, CR-39, has been developed (7,8) and has been found to be useful in the detection of low energy neutrons down to 200 keV. This sensitivity is based on damage sites produced in the plastic by recoil protons. It creates new possibilities for the production of neutron dosimeters which are very sensitive in the energy range of 200 keV to 14 MeV. However, the energy dose dependence of these dosimeters must be investigated carefully since it might decrease dramatically at lower energies.

DESCRIPTION OF DOSIMETER

The study presented here is an attempt to obtain , in one dosimeter, sensitivity to the energy region from 1 eV up to 14 MeV. The dosimeter is composed of three separate parts as shown in Fig. 1. The first two parts are a ^{10}B miniature spectrometer for the energy region 1 eV to 30 keV and a ^{10}B albedo detector for determining the dose in the energy range 30 keV to 1 MeV; both are in contact with a polycarbonate foil (or CR-39 plastic). The third part is a plastic detector, which is either a bare polycarbonate foil or CR-39 material covered with a thin polyethylene proton radiator for the high energy region 1-14 MeV.

The ^{10}B miniature spectrometer

The ^{10}B spectrometer (9) consists of three ^{10}B layers of the following thicknesses: 60, 360 and 1,500 mg/cm^2. The layers are 6 mm diam cylinders, prepared by pressing ^{10}B powder (enriched to 92%). The thinnest layer is attached to a 1 mm thick Al disk in order to obtain rigidity. The three layers are mounted on the

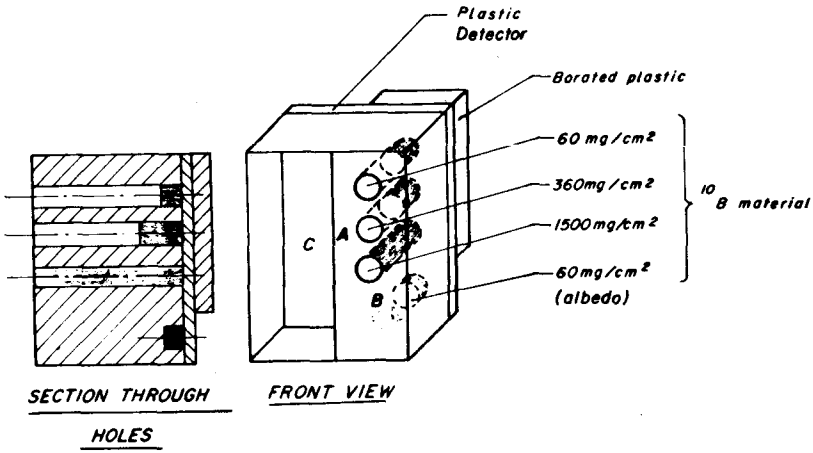

Fig. 1. The combined dosimeter for the 1 keV to 14 MeV energy region. A - ^{10}B spectrometer; B - ^{10}B albedo detector; C - bare plastic detector, made of either polycarbonate foil or CR-39 material with a polyethylene radiator.

plastic detector. The whole assembly is covered on all sides except the front by Cd and borated plastic.

All three layers are thicker than the maximum range of the emitted α (or ^{7}Li) particles. Therefore, the number of particles reaching the plastic detector depends on the number of neutrons which are not absorbed and reach the narrow region (∿1 mg/cm^2) in contact with the detector and on the $^{10}B(n,\alpha)^{7}Li$ reaction and energy loss in this narrow region. The dependence of the number of α particles in each ^{10}B layer on energy was described by us in a previous publication (9). At low energies α particles emerge mainly from the thinnest layer, but at high energies they emerge equally well from the three layers. It was found that, up to 30 keV, there exists a linear combination D of the number of α particles emerging from each layer, which is proportional to the dose and almost independent of energy. D is given by:

$$D = K\ (N_1 + 4N_2 + 36N_3) \qquad (1)$$

where N_1, N_2 and N_3 are the number of α particles from the respective layers.

The following assumptions were made in calculating the number of α particles and the coefficients of the above linear combination:

1) The neutrons are incident normal to the surface of the layers.
2) The neutrons are not moderated in the ^{10}B layers.
3) All α particles emerging from the ^{10}B layers which have energies greater than 0.2 MeV produce damage sites in the plastic detector.

4) The $^{10}B(n,\alpha)^{7}Li$ cross section is isotopic in the center-of-mass system.

The albedo ^{10}B detector

It is suggested that, in the energy range between 30 keV and 1 MeV, the ^{10}B spectrometer described above should be used in conjunction with an albedo type dosimeter consisting of a 60 mg/cm^2 ^{10}B layer in contact with the plastic detector and unshielded toward the body. The number of α particles, N_4 , emerging from this ^{10}B layer due to the interaction of thermal neutrons backscattered from the body, was calculated using the results of Alsmiller and Barish (10). N_4 is greater than N_i (i=1- 3) in the energy range mentioned above and the ratio $R = N_4 / \sum_{i=1}^{3} N_i$ can be used to determine the effective energy between 30 keV and 1 MeV. The dose can then be determined.

EXPERIMENTAL RESULTS

^{10}B spectrometer

Calibration experiments were performed on a ^{10}B spectrometer in which the ^{10}B layers were mounted on cellulose nitrate of the LR-115 type. The spectrometer was calibrated with 24 keV monoenergetic neutrons from a ^{124}Sb-Be source, polyenergetic neutrons from a ^{252}Cf source, and ^{252}Cf neutrons moderated through 5 and 10 cm thick cylinders of H_2O and D_2O. The efficiencies of the ^{10}B layers are given in Table 1.

TABLE 1. Efficiencies of the ^{10}B spectrometer for different neutron spectra and the ratio of response of the thinnest to the thickest ^{10}B layers. N_i is given in (α/cm^2)/100mRem

Source/Moderator	N_1	N_2	N_3	N_1/N_3
^{124}Sb-Be	4020	3560	2370	1.7
^{124}Sb-Be/5 cm H_2O	7500	4380	2080	3.6
^{252}Cf	58	58	58	1
^{252}Cf/5 cm H_2O	310	270	170	1.8
^{252}Cf/10 cm H_2O	830	500	190	4.4
^{252}Cf/10 cm D_2O	530	420	240	2.2
^{252}Cf/5 cm H_2O + 10 cm D_2O	910	480	260	3.5

The proportional factor K given in Eq. 1 was extracted using the results of the ^{124}Sb-Be irradiation and found to be equal to $\sim$0.1 mRem/(α/mm^2). The ratio of the number of α particles emerging

from the thinnest layer to those emerging from the thickest layer changes with the energy of the incident neutrons. The largest ratio was obtained using moderators composed of 5 cm H_2O combined with 10 cm D_2O or 10 cm H_2O. Good agreement was obtained between the experimental results and our theoretical calculations for the ^{124}Sb-Be source. Two dimensional transport calculations are now in progress for the other types of irradiations listed in Table 1.

Bare polycarbonate

The polycarbonate material, 370μm thick, was calibrated using monoenergetic neutrons of $^{7}Li(p,n)$, D(D,n) and T(D,n) reactions and polyenergetic neutrons of ^{252}Cf and ^{239}Pu-Be sources. The efficiencies for ^{252}Cf neutrons and for neutrons above 3 MeV were found to be (32±4) and (60±6) pits/(4 cm^2 - 100 mRem), respectively. The average background is (6±2) pits/4 cm^2.

DISCUSSION

The combination of the ^{10}B spectrometer, the albedo ^{10}B layer and the polycarbonate (or CR-39) foil for fast neutrons may make it possible to determine the dose in the entire energy range between 1 eV and 14 MeV. The plastic foils will be electrochemically etched to reveal the damage sites. The response of the ^{10}B albedo detector and that of CR-39 to different α-particle energies are now being studied.

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