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STUDIES ON NEUTRON DETECTION WITH SOLID STATE NUCLEAR TRACK DETECTORS

Marília Cesar KHOURI, Eudice Correia VILELA e Cleber de ANDRADE

SÃO PAULO

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Marilia Cesar KHOURI, Eudice Correia VILELA e Cleber de ANDRADE

INIS Categories and Descriptors

E41.00

DIELECTRIC TRACK DETECTORS
NEUTRON DETECTION
THERMAL NEUTRONS
ALPHA PARTICLES
FAST NEUTRONS

STUDIES ON NEUTRON DETECTION WITH SOLID STATE
NUCLEAR TRACK DETECTORS

Marília Cesar KHOURI, Eudice Correia VILELA e
Cleber de ANDRADE

Comissão Nacional de Energia Nuclear/SP
Instituto de Pesquisas Energéticas e Nucleares
Caixa Postal 11049 - Pinheiros
05422-970 - São Paulo - SP - Brasil

ABSTRACT

Thermal and fast neutron detection were studied. Thermal neutrons were detected using alpha sensitive plastics to register the products of nuclear reations taking place in boron and/or lithium converters. Fast neutrons produce recoil tracks within the detector, in this case CR-39 and Makrofol E were used. The etching conditions were determined, chemical and electrochemical etching processes were used for thermal and fast neutron detectors, respectively.

ESTUDOS SOBRE DETECÇÃO DE NEUTRONS COM DETECTORES SÓLIDOS DE TRAÇOS NUCLEARES

Marília Cesar KHOURI, Eudice Correia VILELA e
Cleber de ANDR..DE

Comissão Nacional de Energia Nuclear/SP
Instituto de Pesquisas Energéticas e Nucleares
Caixa Postal 11049 - Pinheiros
05422-970 - São Paulo - SP - Brasil

RESUMO

Neste trabalho estudou-se a detecção de neutrons térmicos e rápidos. Neutrons térmicos foram detectados usando plásticos sensíveis a partículas alfa, de modo a registrar os produtos de reações nucleares em conversores de boro e/ou lítio. Neutrons rápidos produzem traços de recuo dentro do detector, neste caso foram usados os detectores CR-39 e Makrofol E. As condições de revelação foram determinadas, sendo utilizados os processos químico e eletroquímico para detectores de neutrons térmicos e rápidos, respectivamente.

1. INTRODUCTION

Neutron monitoring around nuclear installations is important, as well as gamma ray monitoring, for radiation protection. In the surroundings of reactors and accelerators neutrons have a wide energy range, from thermal to fast neutrons, and are also accompanied by gamma rays. Solid state nuclear track detectors (SSNTDs) are in use for neutron fluence measurements as well as for dosimetric measurements in some laboratories [1-3]. For neutron monitoring in mixed fields the plastic track detectors are much more effective than film badge or thermoluminescent dosimeters since the track detector is insensitive to gamma rays. In general, fast neutrons are always accompanied by thermal neutrons resulting from wall reflections, environmental scattering and moderation. The first part of our work is concentrated upon fast neutron detection, using CR-39 and Makrofol E, and the second part is related to thermal neutron detection with cellulose nitrate, Makrofol E and CR-39, using (n,α) converters.

2. EXPERIMENTAL PART

2.1- Fast Neutron Detection

Our experiments on fast neutron detection were performed with CR-39 produced by Pershore Mouldings Ltd., UK, nominal thickness 500μm, and with 200μm thick Makrofol E produced by Bayer, Germany. Samples of the detectors wrapped in aluminium foil, 20μm thick, in order to protect the surfaces, were irradiated in air at 2.5 meters from the ground, in the central position of a special neutron irradiation room (14m x 12m x 4m). A ^{252}Cf (En-2.1 MeV) and an AmBe source (En=4.3 MeV) were used.

The irradiated CR-39 detectors were processed by a combination of chemical and electrochemical etching. Only

the rear surface of the plastic was etched because the response is improved by this procedure, the detector material itself behaving as a radiator. The samples were chemically pre-etched in 5N NaOH at 70°C for one hour and then electrochemically etched in 5N NaOH at room temperature (22-26°C), 30kVcm^{-1}(rms), 2kHz for 13 hours. These conditions were determined based in Bartlett et al [4] results but with some differences. In that work it was used a chemical etch in 5N NaOH at 70°C for one hour followed by an electrochemical etch in the same solution at 30°C with an applied field strength of between 20 and 22kVcm^{-1}(rms), 2kHz, for 16 hours and a 3 hours post etch at 30°C in the same solution. We verified that the post etch does not change the detector response, only enlarges the track diameter, and using a larger field strength we obtained suitable track diameters. Samples irradiated with ^{252}Cf neutrons were processed during different etching times, the corresponding results are presented in Fig.1.

Makrofol E samples were electrochemically etched in PEW solution (15% KOH, 40% ethilic alcohol, 45% water), 40kVcm^{-1}(rms), 2kHz, for two hours at room temperature. These conditions were studied elsewhere [5] and were determined based on signal to background ratio as it can be seen in figures 2 and 3. Figure 3a shows the dependence of track density on etching time for irradiated and non-irradiated Makrofol detectors. The etching time used was obtained by signal/background ratio shown in figure 3b.

The CR-39 electrochemically etched spots were projected on a screen using a slide projector and then counted, Makrofol E tracks were counted using a Reichert screen microscope with magnification of 140X.

2.2- Thermal Neutron Detection

Any track detector sensitive to alpha particle can be used to detect thermal neutrons via (n,α) reations. A radiator containing lithium and/or boron placed aginst the various plastics were the detectors employed in this work (Table 1).

Thermal neutron irradiations were carried out with thermalized neutrons from a ^{252}Cf source. The ^{252}Cf source was placed in the central position of a paraffin cylinder. The thermal neutron flux in the irradiation position has been measured by gold foil activation method and the result obtained was $(6.4 \pm 0.2)10^4$ n/cm^2/s.

After exposure the plastic samples were chemically etched in suitable conditions in order to obtain about 10μm track diameters and a good signal to background ratio (Table 2).

The tracks were counted by eye in a Leitz microscope with a magnification of 100 times.

3. RESULTS AND DISCUSSION

We obtained linear responses to about 10^6 tracks cm^{-2} for the etching conditions used with fast neutron detectors and about $1.5 \ 10^5$ tracks cm^{-2}, with chemical etching, in the case of thermal neutron detection. These results show that linearity is a function of the etching procedure. The measurable fluence upper limit is determined by overlapping tracks due to the difficulty on counting or to changes in the track shape. The lower limit is determined by two background standard deviation. The background values listed were measured within a batch and in future must be determined for each batch received. A significant problem, as shown several authors, is the non-uniformity of the detection material. We have noticed variations in the background and in the sensitivity due to different batches and even to different foils of the same

batch.

The sensitivity or number of tracks registered per neutron, for ^{252}Cf (En=2.1 MeV) and AmBe (En=4.3 MeV) neutrons, of each detector type is presented in Table 3 and thermal neutron sensitivity results are listed in Table 4.

We used the relationship between fluence and ambient dose equivalent reported by Harvey [6] to convert fluences into doses. Table 5 shows the background and measuring range for thermal neutron detection. In spite of the high values of background the lower limit values are rather small, but the high thermal neutron response of the detectors limits the dose range of interest. The dose range for fast neutron detector was calculated for ^{252}Cf neutrons, Table 6 shows the results. As we can see, the CR-39 detection dose range for fast neutron is from 30μSv to 70mSv, which is proper for personnel dosimetry.

ACKNOWLEDGEMENT

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Table 1- Materials used for thermal neutron detection

Type	Manufacturer	Converter
LR 115 type 2B	Kodak Pathé	$Li_2 B_4 O_7$
CN 85 B	Kodak Pathé	$Li_2 B_4 O_7$
LR 115 type 2	Kodak Pathé	BN
CN 85	Kodak Pathé	BN
Makrofol E	Bayer	BN
CR 39	Pershore Mou... .ng	BN

Table 2- Optimum etching conditions used in thermal neutron detection

Detector	Etchant,Concentration,Temperature	Etching Time
LR 115	NaOH-2.5N - 60°C	125 min
CN 85	NaOH-2.5N - 60°C	130 min
Makrofol E	KOH 15%,H_2O 45%,C_2H_5OH 40% - 70°C	50 min
CR 39	NaOH 6.25N 70°C	360 min

Table 3- Fast neutron detection sensitivities

Detector	Sensitivities			
	$^{252}Cf(\bar{E} = 2.1$ MeV$)$		AmBe$(\bar{E}=4.3$ MeV$)$	
	t/n	$t.mSv^{-1}cm^{-2}$	t/n	$t.mSv^{-1}cm^{-2}$
CR 39	$(5.1\pm0.6)10^{-5}$	132 ± 16	$(3.5\pm0.5)10^{-5}$	85 ± 11
Makrofol E	$(4.1\pm0.6)10^{-6}$	10 ± 1	$(4.5\pm0.6)10^{-6}$	11 ± 1

Table 4- Thermal neutron detectors sensitivities

Detector	Sensitivities t/n	$t.\mu Sv^{-1}cm^{-2}$
LR 115 B	$(8.5 \pm 0.9)10^{-4}$	101 ± 10
LR 115 (BN)	$(2.5 \pm 0.3)10^{-3}$	298 ± 36
CN 85 B	$(4.0 \pm 0.4)10^{-4}$	48 ± 5
CN 85 (BN)	$(2.9 \pm 0.3)10^{-3}$	346 ± 36
Makrofol E (BN)	$(1.9 \pm 0.2)10^{-3}$	226 ± 24
CR 39 (BN)	$(1.6 \pm 0.1)10^{-3}$	191 ± 11

Table 5- Background and measuring range for thermal neutron detection

Detector	BG $t.cm^{-2}$	Lower Limit $n.cm^{-2}$	μSv	Upper Limit $n.cm^{-2}$	mSv
LR 115 B	1492 ± 39	$9.2x10^{4}$	0.8	$1.8x10^{8}$	1.5
LR 115 (BN)	1552 ± 28	$2.2x10^{5}$	1.9	$6.0x10^{7}$	0.5
CN 85 B	1578 ± 40	$2.2x10^{5}$	1.9	$3.8x10^{8}$	3.2
CN 85 (BN)	1790 ± 30	$2.1x10^{4}$	0.2	$5.2x10^{7}$	0.4
Makrofol E(BN)	277 ± 32	$3.4x10^{4}$	0.3	$7.9x10^{7}$	0.6
CR 39 (BN)	314 ± 23	$2.9x10^{4}$	0.2	$2.2x10^{8}$	0.8

Table 5- Background and measuring range for fast neutron detection

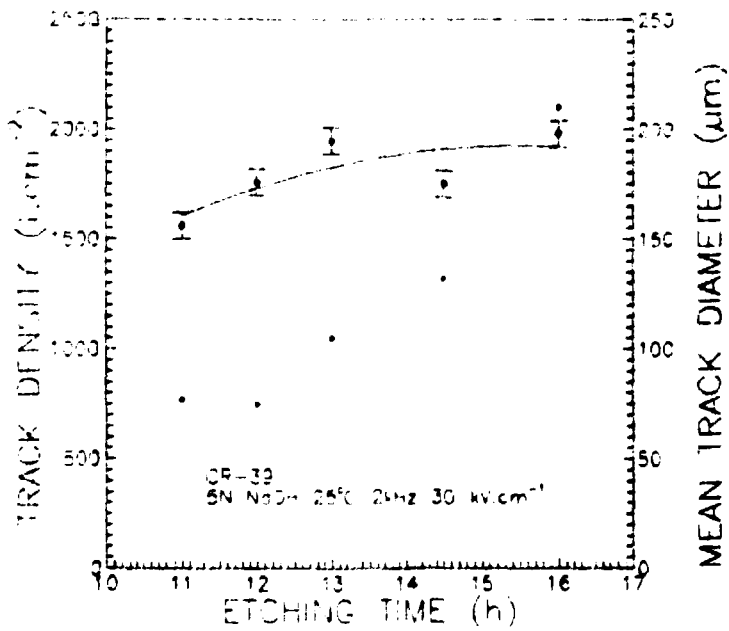| Detector	BG $t.cm^{2}$	Lower Limit $n.cm^{-2}$	μSv	Upper Limit $n.cm^{-2}$	mSv
CR 39	18 ± 2	$7.8x10^{4}$	30	$2.0x10^{8}$	80
Makrofol E	130 ± 10	$4.9x10^{6}$	1900	$2.4x10^{9}$	900

Fig. 1- Track density (.) and mean track diameter (*) vs.
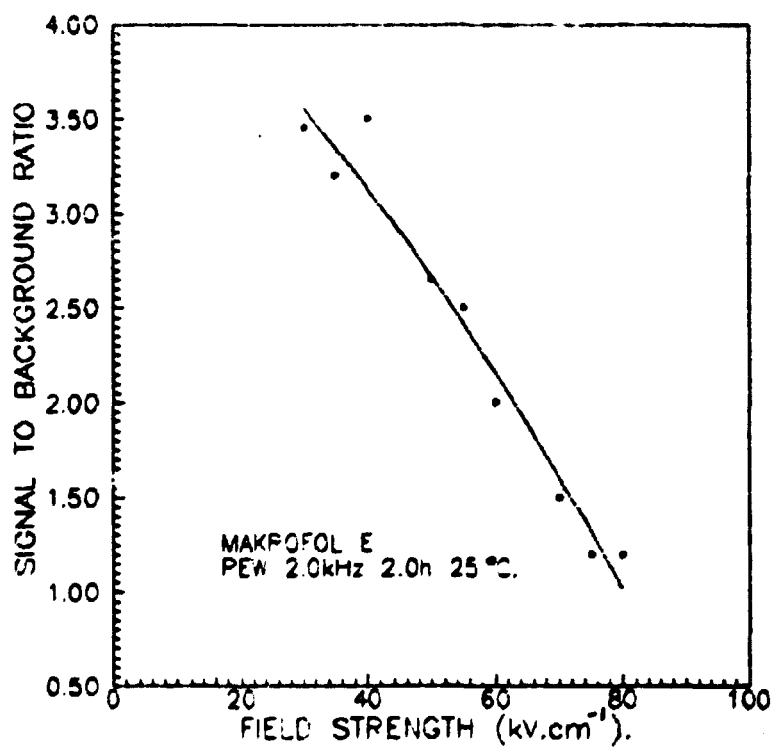etching time for CR-39 electrochemical etching.

Fig. 2- Signal to background ratio, for Makrofol E response,
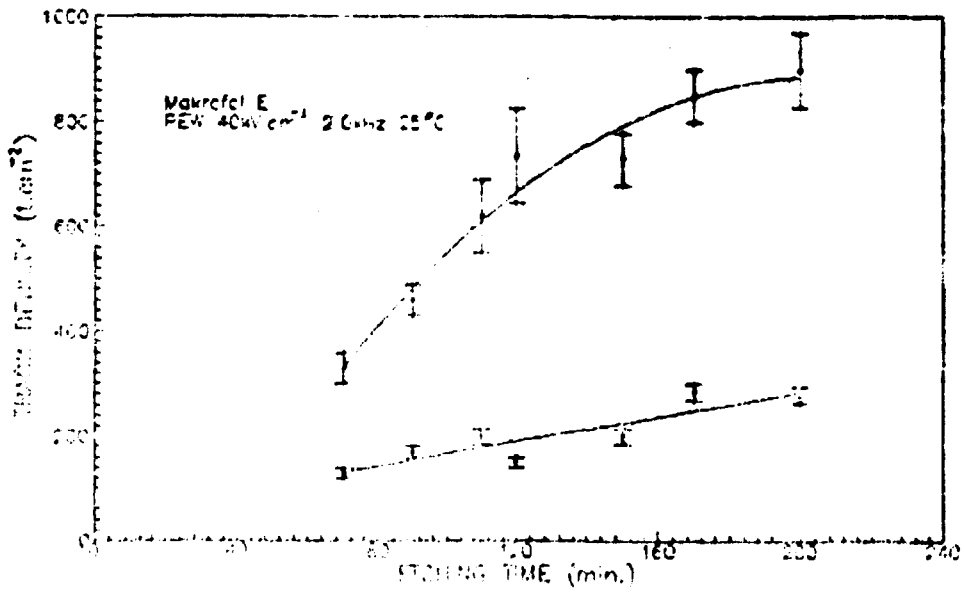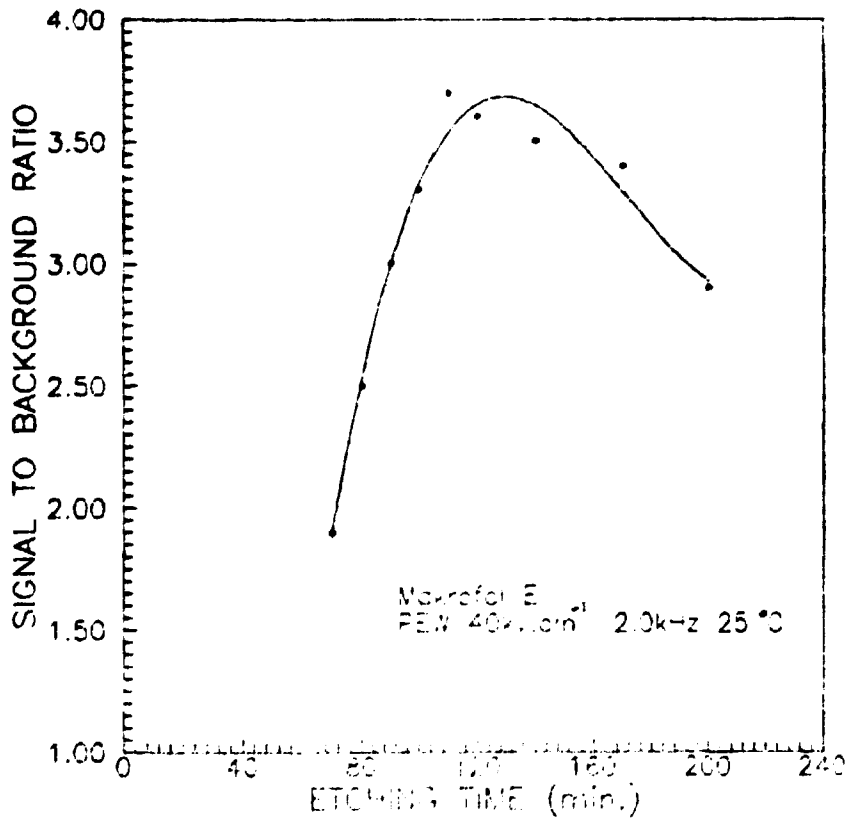as a function of the field strength.

Fig. 3a- Track density (upper curve) and background vari
ation as a function of etching time for Makrofol E.

Fig. 3b- Signal to background ratio as a function of etching
time for Makrofol E.