

BR 9533200

ISSN 0101-3084



**CNEN/SP**

---

***ipen*** Instituto de Pesquisas  
Energéticas e Nucleares

GOVERNO DO BRASIL

STUDIES ON NEUTRON DETECTION WITH SOLID STATE  
NUCLEAR TRACK DETECTORS

Marília Cesar KHOURI, Eudice Correia VILELA e Cleber de ANDRADE

IPEN-Pub-386

MARÇO/1993

SÃO PAULO

**STUDIES ON NEUTRON DETECTION WITH SOLID STATE  
NUCLEAR TRACK DETECTORS**

**Márcia Cesar KHOURI, Eudice Correia VILELA e Cleber de ANDRADE**

**DEPARTAMENTO DE FÍSICA E QUÍMICA NUCLEARES**

**CNEN/SP  
INSTITUTO DE PESQUISAS ENERGÉTICAS E NUCLEARES  
SÃO PAULO - BRASIL**

**Série PUBLICAÇÃO IPEN**

**INIS Categories and Descriptors**

**E41.00**

**DIELECTRIC TRACK DETECTORS  
NEUTRON DETECTION  
THERMAL NEUTRONS  
ALPHA PARTICLES  
FAST NEUTRONS**

---

**IPEN-Doc-4593**

**Aprovado para publicação em 16/11/92.**

**Note: A redação, ortografia, conceitos e revisão final são de responsabilidade do(s) autor(es).**

**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 reactions 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 nêutrons térmicos e rápidos. Nêutrons 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. Nêutrons 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 nêutrons 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, $\alpha$ ) 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 500 $\mu$ m, and with 200 $\mu$ m thick Makrofol E produced by Bayer, Germany. Samples of the detectors wrapped in aluminium foil, 20 $\mu$ m 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  $^{252}\text{Cf}$  ( $E_n=2.1$  MeV) and an AmBe source ( $E_n=4.3$  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<sup>-1</sup>(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<sup>-1</sup>(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 <sup>252</sup>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<sup>-1</sup>(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  $(n,\alpha)$  reactions. A radiator containing lithium and/or boron placed against the various plastics were the detectors employed in this work (Table 1).

Thermal neutron irradiations were carried out with thermalized neutrons from a  $^{252}\text{Cf}$  source. The  $^{252}\text{Cf}$  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<sup>2</sup>/s.

After exposure the plastic samples were chemically etched in suitable conditions in order to obtain about 10 $\mu\text{m}$  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  $10^4$  tracks cm<sup>-2</sup> for the etching conditions used with fast neutron detectors and about  $1.5 \cdot 10^5$  tracks cm<sup>-2</sup>, 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  $^{252}\text{Cf}$  ( $E_n=2.1$  MeV) and  $\text{AmBe}$  ( $E_n=4.3$  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  $^{252}\text{Cf}$  neutrons, Table 6 shows the results. As we can see, the CR-39 detection dose range for fast neutron is from  $30\mu\text{Sv}$  to  $70\text{mSv}$ , which is proper for personnel dosimetry.

#### ACKNOWLEDGEMENT

The authors wish to thank Dra. Marilia Texeira da Cruz and M.Sc. Luciano Fratini from Physics Institute, Universidade de São Paulo, for making the fast neutron irradiations possible.

## REFERENCES

1. PIESCH, E.; AL-NAJJAR, S.A.; NINOMIYA, K. Neutron dosimetry with CR-39 track detectors using electrochemical etching: recent improvements, dosimetric characteristics and aspects of routine applications. *Radiat. Prot. Dosim.*, 27(4):215-230, 1989.
2. MATTIULLAH; DURRANI, S.A.; KHAN, G.A. A practical fast-neutron dosimeter based on electrochemically etched CR-39 detector with angle-independent response. *Nucl. Instr. and Meth.*, B34:499-504, 1988.
3. LEMBO, L. Personal neutron dosimetry using track detectors. *Nucl. Tracks Radiat. Meas.* 15(1-4):473-88, 1988.
4. BARTLETT, D.T.; STEELE, J.D.; STUBBE FIELD, D.R. Development of a single element neutron personal dosimeter for thermal, epithermal and fast neutrons. *Nucl. Tracks*, 12(1-4):645-8, 1986.
5. VILELA, E.C. *Fast neutrons detection using solid state nuclear track detectors*. São Paulo, 1991. (Master Thesis, Instituto de Pesquisas Energéticas e Nucleares, Univ. São Paulo).
6. HARVEY, J.R. & MILL, A.J. A proposed procedure for standardising the relationship between ambient dose and neutron fluence. *Radiat. Prot. Dosim.* 12:141-3, 1985

Table 1- Materials used for thermal neutron detection

| Type           | Manufacturer      | Converter                         |
|----------------|-------------------|-----------------------------------|
| LR 115 type 2B | Kodak Pathé       | $\text{Li}_2\text{B}_4\text{O}_7$ |
| CN 85 B        | Kodak Pathé       | $\text{Li}_2\text{B}_4\text{O}_7$ |
| LR 115 type 2  | Kodak Pathé       | BN                                |
| CN 85          | Kodak Pathé       | BN                                |
| Makrofol E     | Bayer             | BN                                |
| CR 39          | Pershore Moulding | 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 <sub>2</sub> O 45%, C <sub>2</sub> H <sub>5</sub> OH 40% - 70°C | 50 min       |
| CR 39      | NaOH 6.25N 70°C  | 360 min      |

Table 3- Fast neutron detection sensitivities

| Detector   | Sensitivities                                 |                                      |   |                                      |
|------------|---|--------------------------------------|---|--------------------------------------|
|            | $^{252}\text{Cf} (\bar{E} = 2.1 \text{ MeV})$ |                                      | $\text{AmBe} (\bar{E} = 4.3 \text{ MeV})$ |                                      |
|            | t/n   | t.mSv <sup>-1</sup> cm <sup>-2</sup> | t/n                                       | t.mSv <sup>-1</sup> cm <sup>-2</sup> |
| CR 39      | $(5.1 \pm 0.6) 10^{-5}$                       | 132 ± 16                             | $(3.5 \pm 0.5) 10^{-5}$                   | 85 ± 11                              |
| Makrofol E | $(4.1 \pm 0.6) 10^{-6}$                       | 10 ± 1                               | $(4.5 \pm 0.6) 10^{-6}$                   | 11 ± 1                               |

Table 4- Thermal neutron detectors sensitivities

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

Table 5- Background and measuring range for thermal neutron detection

| Detector        | BG<br>t.cm <sup>-2</sup> | Lower Limit        |                | Upper Limit        |     |
|-----------------|--------------------------|--------------------|----------------|--------------------|-----|
|                 |                          | n.cm <sup>-2</sup> | $\mu\text{Sv}$ | n.cm <sup>-2</sup> | mSv |
| LR 115 B        | $1492 \pm 39$            | $9.2 \times 10^4$  | 0.8            | $1.8 \times 10^8$  | 1.5 |
| LR 115 (BN)     | $1552 \pm 28$            | $2.2 \times 10^5$  | 1.9            | $6.0 \times 10^7$  | 0.5 |
| CN 85 B         | $1578 \pm 40$            | $2.2 \times 10^5$  | 1.9            | $3.8 \times 10^8$  | 3.2 |
| CN 85 (BN)      | $1790 \pm 30$            | $2.1 \times 10^4$  | 0.2            | $5.2 \times 10^7$  | 0.4 |
| Makrofol E (BN) | $277 \pm 32$             | $3.4 \times 10^4$  | 0.3            | $7.9 \times 10^7$  | 0.6 |
| CR 39 (BN)      | $314 \pm 23$             | $2.9 \times 10^4$  | 0.2            | $2.2 \times 10^8$  | 0.8 |

Table 5- Background and measuring range for fast neutron detection

| Detector   | BG<br>t.cm <sup>2</sup> | Lower Limit        |                | Upper Limit        |     |
|------------|-------------------------|--------------------|----------------|--------------------|-----|
|            |                         | n.cm <sup>-2</sup> | $\mu\text{Sv}$ | n.cm <sup>-2</sup> | mSv |
| CR 39      | $18 \pm 2$              | $7.8 \times 10^4$  | 30             | $2.0 \times 10^8$  | 80  |
| Makrofol F | $130 \pm 10$            | $4.9 \times 10^6$  | 1900           | $2.4 \times 10^9$  | 900 |

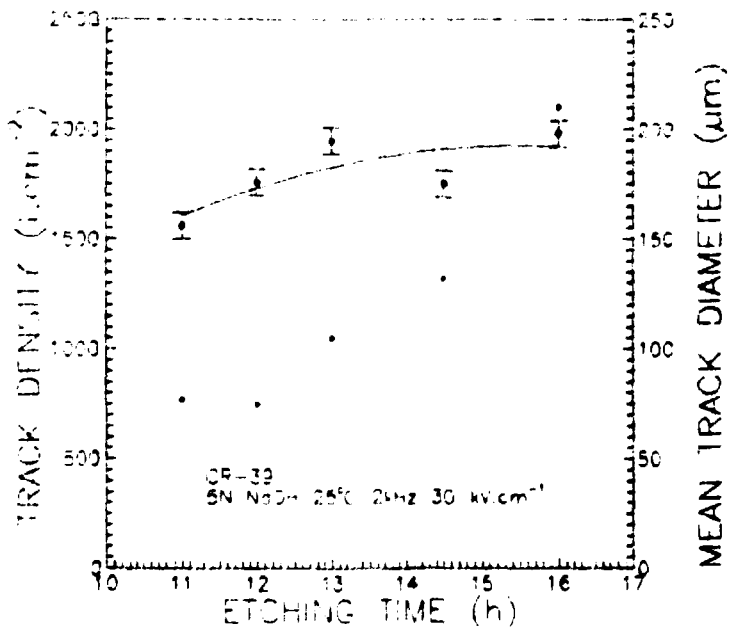


Fig. 1- Track density (.) and mean track diameter (\*) vs. etching time for CR-39 electrochemical etching.

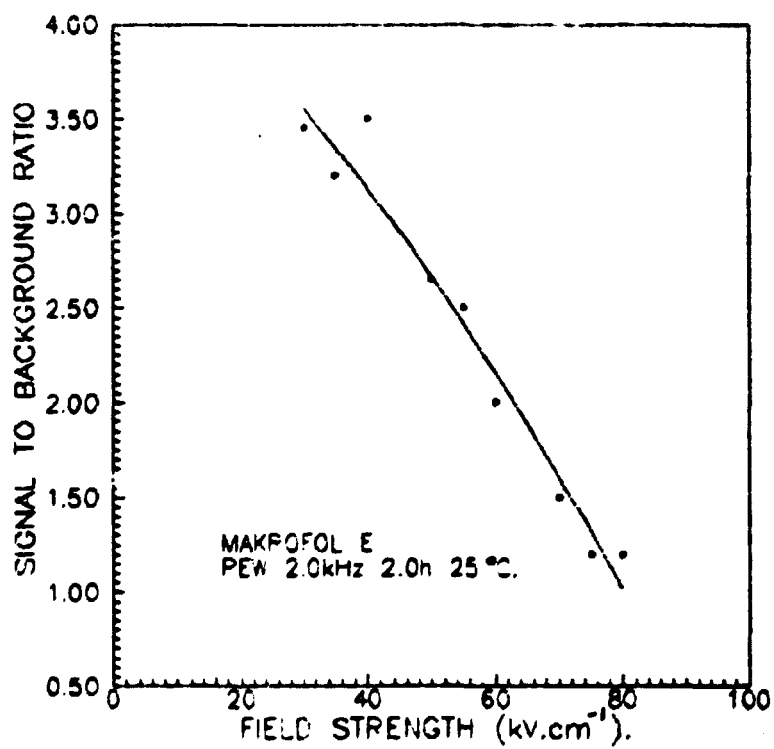


Fig. 2- Signal to background ratio, for Makrofol E response, as a function of the field strength.

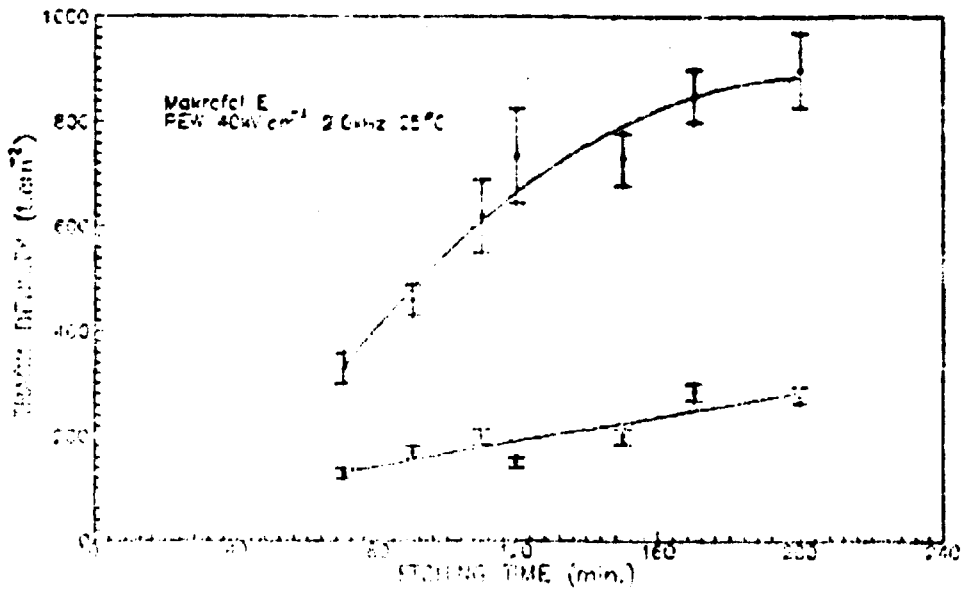
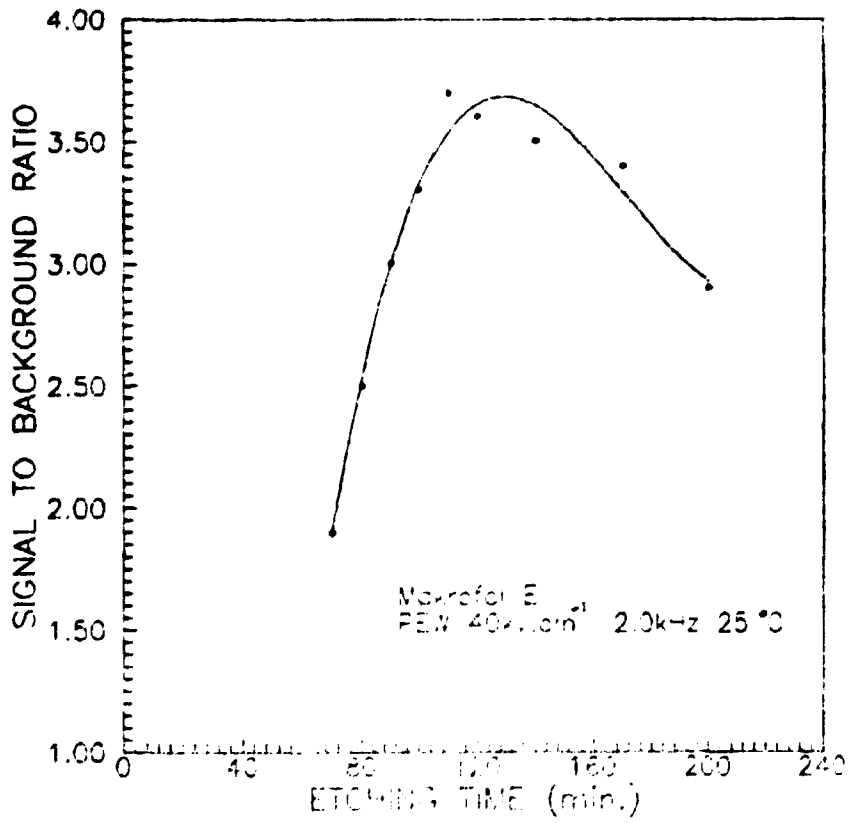


Fig. 3a- Track density (upper curve) and background variation as a function of etching time for Makrofol E.



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