Nuclear Instruments and Methods in Physics Research A311 (1992) 558–562
North-Holland

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

A new technique for thermal neutron detection using pyroelectric ceramics

S.B. Crestana [1] and S. Mascarenhas [2]
Instituto de Física e Química de São Carlos, IFQSC-USP, CP 369, 13560, São Carlos (SP), Brazil

L.P. Geraldo
Instituto de Pesquisas Energéticas e Nucleares, IPEN-CNEN/SP, CP 11049, Pinheiros, 05499, São Paulo (SP), Brazil

A. De Carvalho
Universidade Estadual de São Paulo, CP 31, Ilha Solteira (SP), Brazil

Received 9 August 1991

In this article a new technique for thermal neutron detection using pyroelectric ceramics is described. The detector system is basically constituted of a PZT (lead zirconate titanate) ceramic attached to an uranium disk. The energy released in the uranium fission gives rise to an electrical signal in the detector which is amplified by a lock-in system. The neutron beam impinging on the uranium disk was modulated with a cadmium chopper. Thermal neutron fluxes within the interval of 10^3 to 10^6 n/cm^2 s have been detected using a U_3O_8 pellet with 20% enrichment in ^{235}U.

1. Introduction

PZT (lead zirconate titanate) ceramics have been successfully used for photothermal detection by several authors [1–3]. The pyroelectric effect presented by these material allows the detection of thermal fluxes of low intensities at room temperatures [4].

More recently, besides crystals and ceramics, thin films such as polyvinylidene difluoride (PVF_2) have also been used as photopyroelectric detectors [5,6].

A pyroelectric detector is basically constituted of a thin layer of pyroelectric ceramic with the electrodes normally oriented with relation to its polarization vector. Thus, it is a thermal transducer as well as a capacitive element. The pyroelectric effect is basically a spontaneous induction of polarization due to a change of temperature in the ceramic. On the other hand, a change of polarization is equivalent to a source of voltage V_0 in series with the ceramic capacitance C as

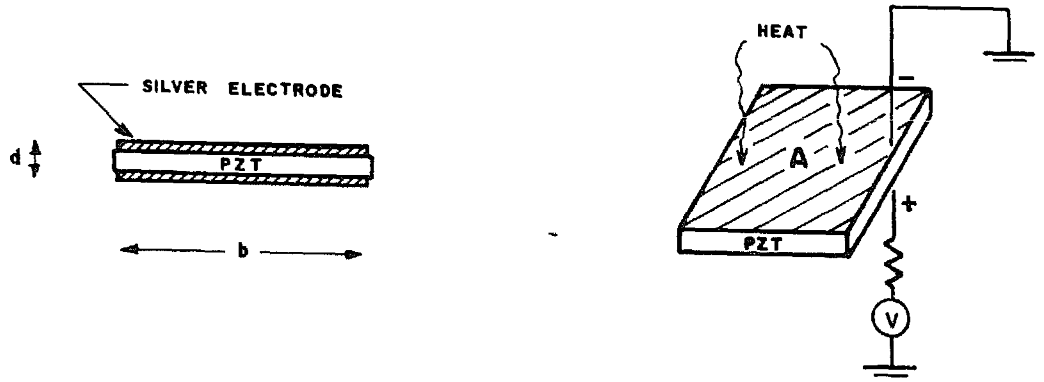

Fig 1 Electrical configuration of pyroelectric detectors with area A, side b, thickness d and capacitance C.

---

[1] Present address: COPESP/IPEN, CP 11253, 05593, São Paulo (SP), Brazil.

[2] Present address: EMBRAPA, NPDIA, CP 741, 13560, São Carlos (SP), Brazil.

is sketched in fig. 1. The signal V_0 is very low (μV) and in order to separate it from the background, produced mainly by temperature, acoustic and Johnson noise, the measurements have to be performed in a synchronous form. A phase modulation technique employing a lock-in amplifier and a chopper system is usually employed.

A change in the power level of the radiation incident on the ceramic produces a change of temperature ΔT, and a charge difference of magnitude Q appears across the ceramic electrodes [7] with

$$Q = PA\Delta T, \tag{1}$$

where A is the area of one electrode, and P is the pyroelectric coefficient in C/m^2 K.

If the PZT ceramic is connected to a high impedance load [7], for example a lock-in amplifier, it acts as a voltage source V, with

$$V = (P/\rho c_p \omega C d) W, \tag{2}$$

where the symbols are

ρ – density of the pyroelectric material,
c_p – specific heat of the ceramic,
ω – modulation frequency,
C – capacitance of the ceramic,
d – electrode spacing, and
W – modulated power.

According to eq. (2), the technique provides maximum sensitivity for input power modulated at low frequencies.

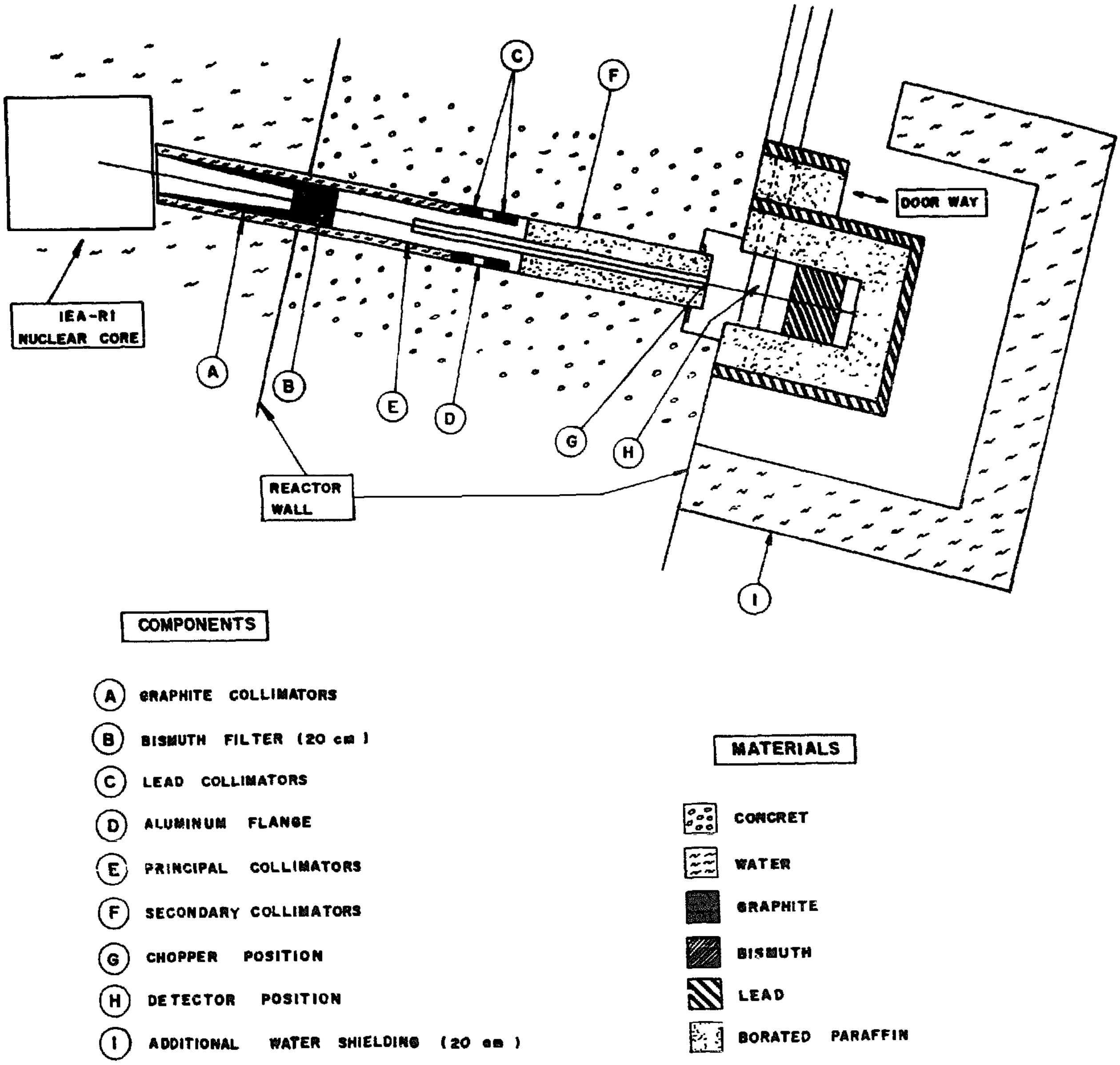

Fig 2 Experimental arrangement for neutron beam collimation at the IEA-R1 reactor.

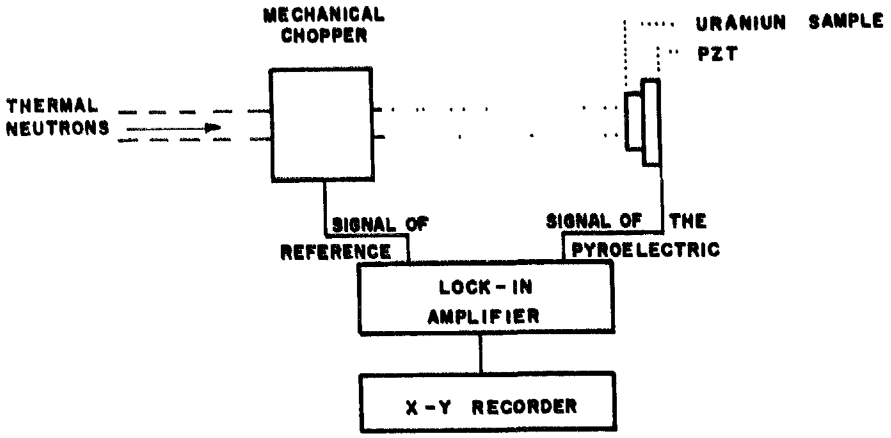

Fig. 3. Diagram of the neutron detector system.

This type of detector system has already been used for X-ray [8,9], γ-ray [10] and ion beam [7] flux measurements. In this present article a similar device was used to detect thermal neutrons via the (n, f) reaction in ^{235}U. An uranium pellet attached to the PZT ceramic produced the modulated power which is related to the thermal neutron flux by the following relationship [11-13]:

$$W = \Phi \sigma N . E \tag{3}$$

where,

Φ - thermal neutron flux,
σ - fission cross section for ^{235}U,
N - number of ^{235}U nuclei, and
E - energy released in one fission event.

2. Experimental procedures

The irradiations have been carried out at a beam tube (BH-8) of the IEA-R1, 2 MW pool type research reactor. The experimental arrangement used for neutron beam collimation is presented in fig. 2. The thermal neutron flux and the cadmium ratio at the position H have been measured by the activation technique with gold foils and the results obtained were 8.5×10^5 n/cm^2 s and 150 respectively.

At the end of the collimation assembly (position G) there is a cadmium stopper which allows to interrupt the thermal neutron beam when it is necessary. A mechanical chopper installed in front of this beam stopper has the function of modulating the neutron beam. This chopper has been built with cadmium foil of 1 mm thickness. It is driven by a small motor which has the rotation frequency controlled by a Variac placed outside of the shielding shown in fig. 2. The chopper rotation is monitored by a photodiode system which sends a square wave as a reference signal to the lock-in amplifier.

The detector system is positioned in front of the chopper by means of a small cart which is moved on an aluminium support through a pulley system. The cart basis has been built with a special plastic cushion in order to isolate the detector against mechanical vibrations.

Our detector is constituted of a square PZT$_4$ ceramic 2 cm long and 3 mm thick (Edon-Western Corp.) attached to a uranium (U_3O_8) pellet with 14 mm diameter and 2 mm thickness. A good coupling between ceramic and uranium has been obtained by using an Apiezon-L type grease. The silver electrodes of the pyroelectric detector were connected to a lock-in amplifier through coaxial cables as is sketched in fig. 3.

3. Results and discussion

The detector response for a thermal neutron flux of about 8.5×10^5 n/cm^2 s has been studied employing

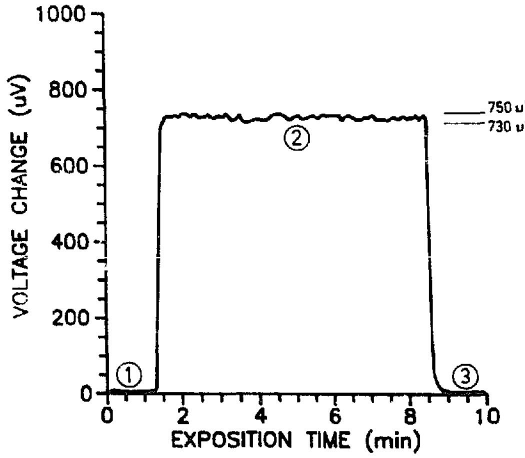

Fig 4. The pyroelectric detector response as a function of exposition time. (1) and (3) detector background signal, (2) with neutron flux = 8.5×10^5 n/cm^2 s, modulation frequency = 3.0 Hz.

an uranium (U_3O_8) pellet converter of 1.694 g with 20% enrichment in ^{235}U isotope. As can be seen in fig. 4 the signal generated by the detector was 740 ± 10 μV for a modulation frequency of 3 Hz. On the other hand, with the thermal neutron flux interrupted by the cadmium stopper, the detector background signal was only 2 μV at the same modulation frequency. These results show that, for monitoration of thermal neutron fluxes with intensities $\geq 10^6$ n/cm^2 s, converters of natural uranium could be adequately used. According to the signal fluctuation (± 10 μV) obtained in this experiment, one can say that with the present detector system, a variation of only $\approx 1.5\%$ in thermal neutron fluxes would be observed.

Fig. 4 shows the detector signal recorded during approximately 10 min of observation. Measurements performed during all the reactor operation period (≈ 8 h) did not show any significant variation of the detector response for a constant neutron flux, when the PZT ceramic produced by Edo-Western Corp. was used. However, for PZT ceramics from other manufacturers a slow and continuous decay of the signal has been observed in some cases during the neutron exposition.

The detector response for different thermal neutron fluxes has been experimentally studied and the results are shown in fig. 5. Neutron fluxes of several intensities were obtained using foils (200 μm thickness) of Makrofol-E ($C_{16}H_{14}O_3$, $\rho = 1.21$ g/cm^3) to attenuate the neutron beam before impinging on the detector system. Measurements of neutron fluxes have been performed with gold foils for two particular situations, one without attenuation and the other with 3 mm thickness of Makrofol-E. The results obtained were 8.5×10^5 and 4.2×10^5 n/cm^2 s respectively which are in excellent agreement with the experimental data presented in fig. 5. One can also observe in this figure that the detector response for different thickness of Makrofol-E follows the expression:

$$\Phi = \Phi_0 e^{-\mu x} \tag{4}$$

as expected from the theoretical model predictions [14] In this equation, Φ is the neutron flux observed after the neutron beam has passed through a thickness of a material with an absorption coefficient μ and Φ_0 is the neutron flux incident.

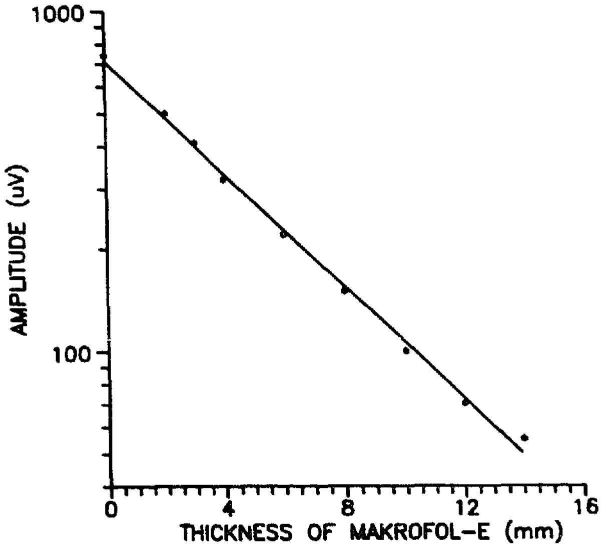

Fig 5 Pyroelectric signal amplitude as a function of Makrofol-E thickness Detector made with U(20%), at a modulation frequency of 3.0 Hz

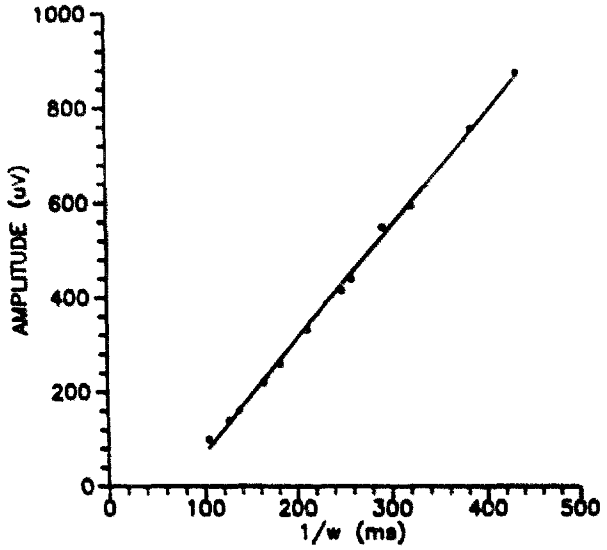

Fig 6 Pyroelectric signal amplitude as a function of inverse of the chopper modulation frequency

Measurements have also been made using different modulation frequencies and the results obtained are shown in fig. 6. As can be seen in this figure, the experimental data points are in excellent agreement with the theoretical predictions expressed by eq. (2). According to this equation and theoretical model proposed by Liu and Donald [4], and Rosencwaig [3], the signal generated by a pyroelectric detector should be inversely proportional to the modulation frequency of the chopper.

4. Conclusions

The detector system developed in this work has shown to be convenient and adequate for monitoring thermal neutron fluxes within the interval of 10^3 to 10^6 n/cm^2 s. Much higher neutron fluxes can be measured by changing the modulation frequency, using a converter of natural uranium or by means of beam attenuation with appropriate materials.

This technique of thermal neutron detection may also be an important tool for other areas of the nuclear technology, such as: measurements of ^{235}U enrichment in uranium samples, measurements of the energy released in nuclear fission, study of thermal parameters of nuclear fuels, for example thermal diffusivity, etc. Besides fission other nuclear reactions may eventually be also studied with the present technique.

Acknowledgements

The authors are indebted to CNPQ, EMBRAPA, CNEN and COPESP for financial support of this research. They also wish to thank Dr. R. Pugliesi and Dr. A. Mirage from IPEN and Dr. M.H. de Paula from MS University for many helpful discussions.

References

[1] A. Mandelis and M.M. Zver, J. Appl. Phys. 57 (1985) 4421.
[2] W. Jackson and N.M. Amer, J. Appl. Phys. 51 (1980) 3343.
[3] A. Rosencwaig, Photoacoustics and Photoacoustics Spectroscopy (Wiley, New York, 1980).
[4] S.T. Liu and D. Long, Proc. IEEE 66 (1978) p. 14.
[5] H. Coufal, Appl. Phys. Lett. 44 (1984) 59.
[6] A. Mandelis, Chem. Phys. Lett. 108 (1984) 388.
[7] M.W. Geis, K.A. Smith and R.D. Rundel, J. Phys. E8 (1975) 1011.
[8] M.H. de Paula, A.A. de Carvalho, S. Mascarenhas and R.L. Zimmermand, Med. Phys. 11 (1984) 866.
[9] S. Mascarenhas, H. Vargas and C.L. Cezar, Med. Phys. 11 (1984) 73.
[10] R.Ya. Strakovskaya, L.S. Kemenshgsrii and G.A. Dimoglo, Exp. Tech. 19 (1976) 1317.
[11] L.P. Geraldo, M.F. Cesar, O.Y. Mafra and E.M. Tanaka, J. Rad. Chem. 49 (1979) 115.
[12] L.P. Geraldo, L.A. Vinhas and M.T.F. Cesar, Nucl. Sci. Eng. 89 (1985) 150.
[13] R. Vandenbosch and J.R. Huizenga, Nuclear Fission (Academic Press, New York, 1973). p. 329.
[14] P. Morrison and B.T. Feld, The Neutron – Experimental Nuclear Physics V II (Wiley, New York, 1953) p. 279.