SIMPLIFIED PROTON RECOIL "TELESCOPE" FOR REACTOR BEAM FAST NEUTRON SPECTROMETRY

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SUMÁRIO

O trabalho descreve um "telescópio" simplificado de recuo de protons, de resolução relativamente boa e eficiência suficientemente alta para medidas em feixes de reatores com fluxos da ordem de 10^6 n/cm^2/seg. A boa resolução é conseguida com o uso de radiadores finos de polietileno e pequeno ângulo sólido de detecção. A discriminação contra a radiação de fundo, usualmente provida por medidas em coincidência, é neste caso parcialmente conseguida por uma disposição adequada dos vários componentes da câmara de recuo. As principais características da câmara são: a) tamanho grande, para evitar espalhamento pelas paredes; b) detetor de protons cintilador de CsI(Tl), localizado fora do feixe do reator; c) operação em vácuo; d) colimador de protons e blindagem do detetor feitos com material de alto número atômico.

Na faixa de energias que vai de 2 a 12 Mev, a eficiência de detecção varia de 10^{-5} a 10^{-7} e a resolução intrín

seca da câmara é da ordem de 8%.

Espectros dos neutrons de fissão do U^{235}, transmitidos através de vários materiais, foram obtidos num dos canais experimentais do reator de piscina do I.E.A., operando a uma potência de 2 Mw. Os resultados obtidos concordam com previsões teóricas, dados sôbre secções de choque, e determinações experimentais realizadas em outros reatores de piscina.

RÉSUMÉ

Un télescope simplifié à recul de protons a été développé dans notre laboratoire; cet appareil présente une résolution rélativement bonne, avec une efficience suffisamment élévée pour effectuer des mesures avec le flux d'un réacteur de l'ordre de 10^6 neutrons/cm^2/sec. Une bonne résolution est atteinte par l'emploi de fins radiateurs à polyethylène, dans un petit angle solide de détection. On réussit à la discrimination contre le bruit de fond, que est habituellement faite par des mesures de coincidence, en ayant projecté convénablement les différents composants de la chambre à recul. Les principales caractéristiques de la chambre sont: a) grandes dimensions afin d'eviter diffusion sur les murs; b) détecteur de protons (un scintillateur à CsI (Tl)) localisé hors du faisceau du réacteur; c) opération en vide; d) collimateur de protons et blindage du détecteur construits avec un matériau de haut numéro atomique.

Dans la bande d'énergies de 2 à 12 Mev, l'efficience de détection varie de 10^5 à 10^{-7} et la résolution intrinsèque est de l'ordre de 8%.

Des spectres de neutrons de fission du U^{235}, transmis à travers de différents matériaux, ont été obtenus à l'un des canaux expérimentaux du réacteur type piscine de l'I.E.A. en opérant à la puissance de 2 Mw. Les résultats obtenus sont en accord avec les prévisions théoriques, avec les valeurs des sections efficaces, et avec les déterminations expérimentales réalisées dans d'autres réacteurs type piscine.

SUMMARY

A simplified proton recoil "telescope" was developed which presents relatively good resolution with an efficiency high enough for measurements in reactor beams whose fluxes are of the order of $10^6 n/cm^2/sec$. Good resolution is achieved by the use of thin polyethylene radiators and small detection solid angle. Background discrimination, usually provided by coincidence measurements, is here attained by a careful design of the recoil chamber. The principal features of the chamber are: a) large size, in order to avoid wall scattering; b) proton detector, a CsI (Tl) scintillator, located out of the reactor beam; c) operation in vacuum, providing a free path for the recoil protons from radiator to detector; d) detector collimator and shield made with high Z material.

At neutron energies ranging from 2 to 12 Mev the detection efficiency varies from 10^{-5} to 10^{-7} and the chamber intrinsic resolution is of the order of 8%.

Spectra of fission neutrons from U^{235}, transmitted through various materials, were obtained at the "Instituto de

Energia Atômica" swimming pool reactor operating at a power of 2 Mw. The results are in close agreement with theoretical predictions, cross section data, and experimental determinations performed in similar reactors.

INTRODUCTION

A proton recoil telescope consists essentially of a thin polyethylene radiator followed by one or two proportional counters and a scintillation detector in which recoil protons lose almost all their energies. Only pulses from the scintillation detector in coincidence with similar events in all proportional counters are recorded. The operation of such telescopes and the electronic equipment involved are quite cumbersome. A simplified version, where the proportional counters were eliminated, designed for the measurement of monoenergetic neutron yields have been described in the literature(1). This instrument has a relatively high efficiency but a poor energy resolution due to the wide angle of detection. For the measurement of continuous fast neutron spectra in high intensity collimated reactor beams we have developed a lower efficiency simplified telescope with a small solid angle of detection and, therefore, presenting a better energy resolution.

DESCRIPTION OF APPARATUS

A polyethylene radiator, a CsI(Tl) thin crystal and, eventually, an aluminum absorber are located inside a cylindrical vacuum chamber 30 cm high and 40 cm in diameter. The angle between the direction of the incident beam and the line from the center of the radiator to the center of the detector is equal to 20º. With a reasonable collimation, the scintillation detector is not affected by the transmitted beam. The chamber is provided with thin aluminum windows for the entrance and exit of the incident beam. A proton collimator consisting of spaced perforated lead disks, 1mm thick, minimizes charge particle background. Gamma radiation is attenuated by a bismuth filter located inside the reactor collimator and by a lead shield around the detector. The contribution of gamma-ray pulses to the background is important for proton energies below ~ 2.5 Mev for a 0.45mm thick crystal, and below ~ 6 Mev for a 0.93 mm thick crystal. The reactor thermal neutron flux is reduced by a cadmium filter. Proton scattering and undesirable energy losses in the air of the chamber are minimized by operation in a vacuum better than 3mm.Hg. Wall scattering is avoided by a good collimation and by the large size of the chamber.

The response of CsI(Tl) to charged particles have been studied by several experimenters (2), as well as the energy loss in very thin crystals (3). For the measurements presented in this paper we used either a 0.45 mm or a 0.93 mm thick crystal, mounted directly on a Dumond 6292 photomultiplier with silicone grease. Polyethylene foils 1.65 mg/cm^2, 2.11 mg/cm^2 and 23.15 mg/cm^2 were used as radiators. All data were collected in a 256-channel pulse high analyser. The counting system was calibrated with alpha particles from Po^{210}, Bi^{212} and Po^{212}. From these data and from the known relative response of CsI(Tl) to alphas and protons of various energies a proton calibration curve can be constructed.

Neutron spectra can be deduced from proton energy distributions through the relation $E_p=E_n \cos^2\theta$, where θ is the scattering angle in the laboratory system of coordinates.

The average solid angle of detection is equal to 2.24×10^{-4} steradian. With this solid angle, the chamber efficiency at a given neutron energy can be evaluated by the expression.

$$\epsilon(E) = 8.94 \times 10^{19} \quad \sigma_{n,p}(E)\, t,$$

where $\sigma_{n,p}(E)$ is the hydrogen n-p scattering cross section in cm^2 for neutrons of energy E, and t is thickness of the polyethylene foil in cm. For thin radiators the efficiency varies from 10^{-7} to 10^{-5}.

The intrinsic resolution that depends essentially on the radiator thickness and on uncertainties of the scattering angle is of the order of 8%.The overall resolution is somewhat poorer due mainly to crystal and photomultiplier contributions.

MEASUREMENTS AND RESULTS

Fast neutron spectra were measured at the exit of a beam-hole at the IEAR-1 5 Mw swimming reactor (4). Fast neutrons leaking through beam-holes of pool reactors were found to have a fission-like spectrum. Nevertheless, the presense of water and other materials and the collimation of the beam introduce distortions in the fission spectrum when measured outside the reactor shield (5). Such distortions are also predicted in theoretical studies related to a fission point source in water (6).

Measurements were performed with two reactor core configurations, one with and the other one without a graphite reflector. The proton recoil chamber was situated in front of the beam-port nº 7 (fig. 1). The collimator consists of two aluminum concentric pipes, the space between them being filled with concrete at the reactor shield and with water at the pool. In 2/3 of its total length (3.30 m), measured from the core, the hole has a diameter of 2 inches and in the last 1/3 this diameter is reduced to 1cm by a polyesther plus boron secondary collimator, as shown in fig. 1.

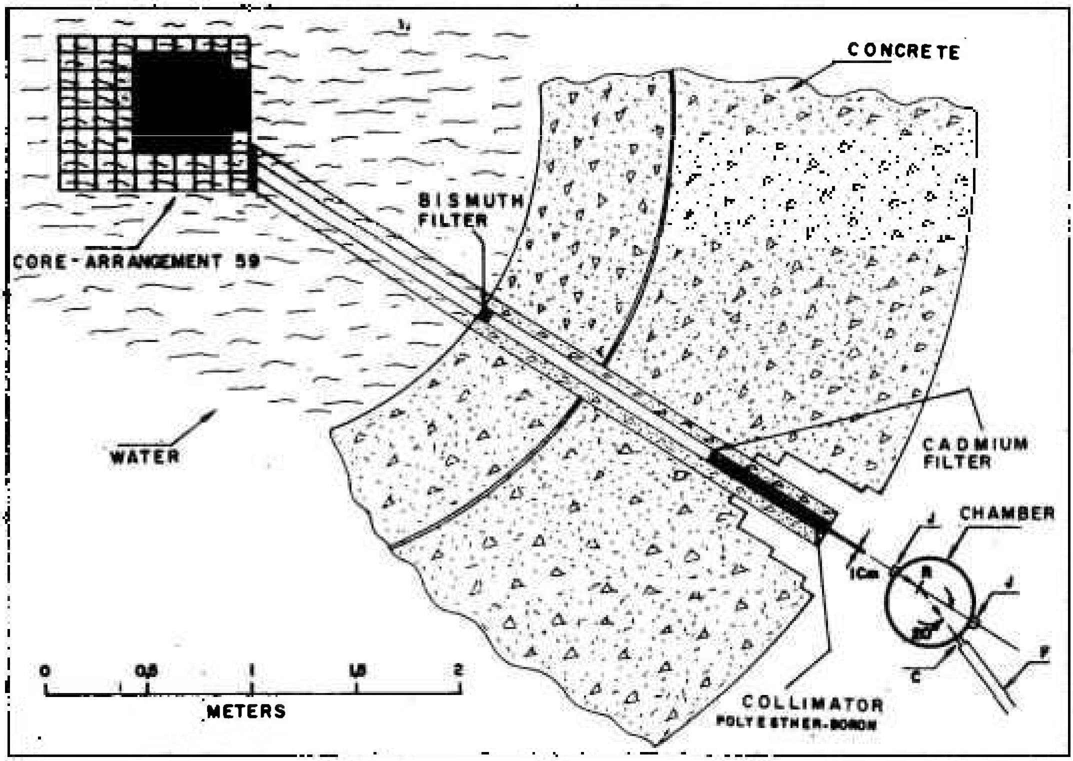


FIGURE 1

Experimental arrangement at beam-hole nº 7 for the measurement of fast neutron spectra.

J= thin aluminum windows, R= polyethylene radiator, C= CsI(Tl) crystal, F= photomultiplier and pre-amplifier.

Without the graphite reflector, the fission neutrons traverse about 12 cm of water in the pool, 7.5 cm of bismuth, 1 cm of aluminum and 0.255 cm of cadmium before reaching the chamber polyethylene radiator. With the graphite reflector, about 11 cm of water is replaced by carbon. Figures 2 and 3 show the results obtained with the two different core arrangements. The valley at about 3.7 Mev presented in curve of fig. 2 is probably due to the broad peaks of the oxygen and bismuth total cross sections for neutrons at this energy. The hydrogen cross section tends to lower the fission spectrum as one goes in the sense of decreasing neutron energies. The fluctuations suggested by the curve of fig. 3 are probably caused by graphite and bismuth.

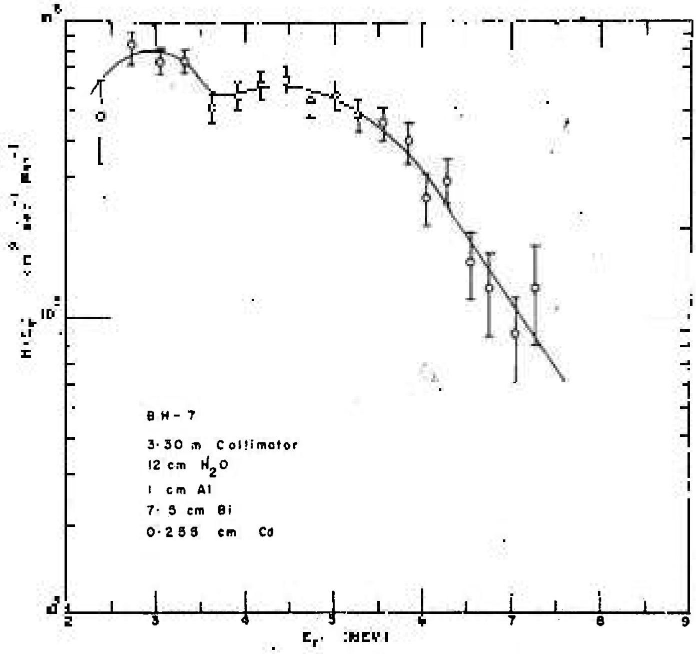
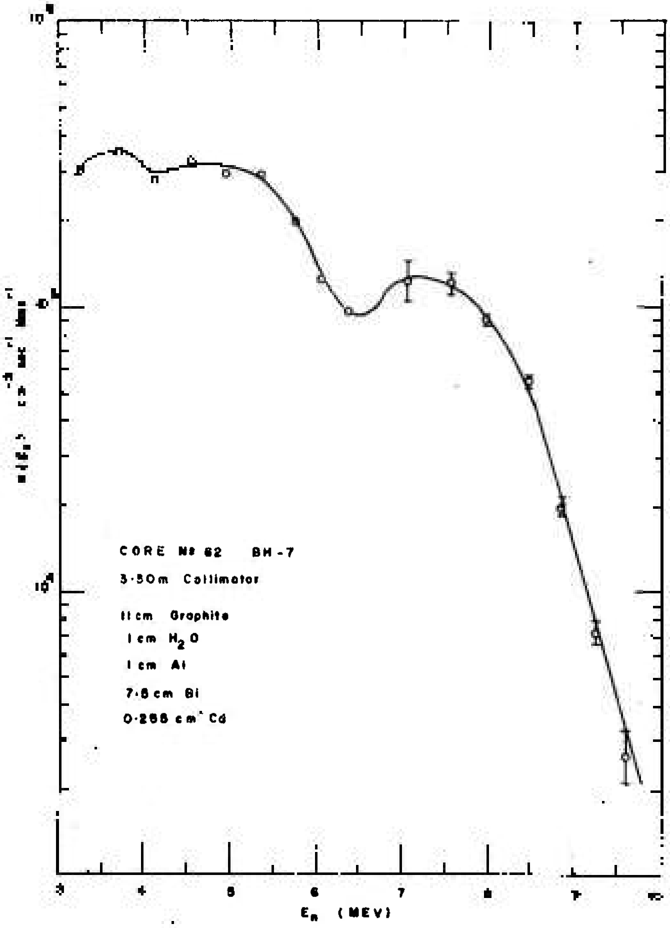


FIGURE 2

Fast neutron spectrum measured at the exit of beam-hole nº 7. Reactor core without a graphite reflector.



<u>FIGURA 3</u>

Fast neutron spectrum measured at the exit of beam--hole nº 7. Reactor core with graphite reflector.

CONCLUSION

The instrument developed for reactor fast neutron measurements here described is a simple device that can be improved by the utilization, for instance, of pulse shape gamma--ray discrimination in CsI(Tl) or by the replacement of the scintillation detector by a semiconductor surface barrier detector. A versatile version can be built with provision for changing both angle of detection and radiator-detector distance.

R E F E R E N C E S

(1) S.J. Bame, E. Haddad, J.E. Perry Jr., and R.K. Smith, "Measurement of monoenergetic neutron yields with a simplified telescope", Rev. Sci. Instr.29,652N (1958).

(2) a- S.Bashkin, R.R. Carlson, R.A. Douglas, and J. A. Jacobs, "Response of CsI(Tl) crystal to energetic particles", Phys.Rev., 109, 434, (1958).

b- R.A. Peck, H.P. Eubank, and J. Lowe, "Response of CsI(Tl) to p,d and alpha particles", Rev. Sci. Instr., 30,703 (1959).

c- A.R. Quinton, C.E. Anderson, and W.J. Knox,"Fluorescent response of CsI crystals to heavy ions", Phys.Rev.,115, 886 (1959).

d J. Fleury, P. Perrin, M. Boge et J. Laugier, "Spectrometre alpha a scintilation avec ICs(Tl)", Le Journal de Physique et le radium, Tome 21, Mai 1960, pg. 480.

(3) D.C. Worth, and G.R. Haste, "Experimental calibration of scintillation pulse heights of thin CsI crystals", Rev. Sci. Instr., 31, 169 (1960).

(4) a- M.D. de Souza Santos and P.S. Toledo, "The Brazilian Research Reactor", Proceedings of the 2nd International Conference on the Peaceful uses of Atomic Energy, U.N. vol.10, pg. 259 (1958).

b- A. Penteado Fº and M.D. de Souza Santos, "Operational Experience and Utilizations of the Brazilian 5 Mw Swimming Pool Reactor", Symposium on the Programing and Utilization of Research Reactors, Vienna, 1961 ; Public.IEA nº 44.

(5) a- R.G. Cockran and K.M. Henry, "Fast-Neutron Spectra of the BSF", AECD-3720 (1953).

b- R.G. Cockran and K.M. Henry, "Fast-Neutron spectrum of the LITR", AECD-3721 (1953).

(6) R. Aronson, J. Certaine, H. Goldstein, and S. Preiser, "Penetration of Neutrons from a Point Isotropic Fission Source in water", NYO-6267 (1954).

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