ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Padova

INFN/BE-81/3
15 Gennaio 1981

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A RECOIL-PROTON FAST NEUTRON COUNTER TELESCOPE.

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SUMMARY.

A proton-recoil neutron counter telescope is described composed of a solid state silicon transmission detector and a NE 102 A plastic scintillator, measuring the energy loss, the energy of the recoil protons and the time-of-flight between the two detectors. The counter exposed to monoenergetic neutron beams of energy from 6 to 20 MeV, presents a low background and a moderate energy resolution. Its absolute efficiency is calculated up to 50 MeV.

1. - INTRODUCTION.

The proton-recoil neutron counter telescope is composed of a hydrogenated radiator followed by two or more counters which operate in coincidence and detect the recoil protons generated on the radiator by a collimated neutron beam and which are emitted within a narrow cone. The use of the coincidence technique is necessary in order to reduce the background[(1)].

The importance of the instrument is due to the fact that its detection efficiency is easily and precisely calculable from the geometry of the counter, the mass and composition of the radiator and the backward differential neutron-proton scattering cross section, which is now known, up to 50 MeV, with a precision varying from 0.5 % below 10 MeV, to 1-2 % at higher energies[(2-5)].

Important improvements in the reliability of the counter have recently been obtained through the better knowledge of the n-p cross section the use of thin solid state transmission detectors and the progress of the fast electronics which permits, in particular, time-of-flight measurements with precision greater than one nanosecond.

The telescope here described has been devised to be used with neutrons of some tens MeV energy, obtainable with tandem accelerators. The instrument, similar to one made at Wisconsin[6], has been tested with monoenergetic neutrons having energies between 6 and 20 MeV, and its detection efficiency was calculated up to 50 MeV.

2. - THE COUNTER.

The counter, represented in Fig. 1, is made of a polyethylene $(CH_2)_n$ radiator about 0.1 mm thick and having a diameter of 0.9 cm, followed by a silicon solid state transmission detector having an area of 1.5 cm^2 and a thickness of 0.2 mm, and by a plastic NE 102 A scintillator, at a distance of 15 cm from the radiator, having a diameter of 3 cm and a thickness sufficient to stop the recoil protons (6 mm for 30 MeV protons), optically coupled with a 56 AVP photomultiplier.

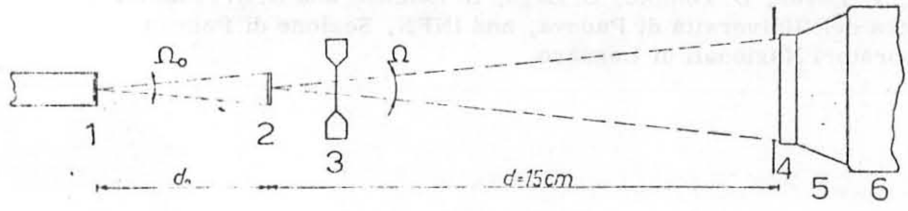

FIG. 1 - Neutron counter telescope. 1 : Neutron source ; 2 : Polyethylene radiator ; 3 : Silicon solid state transmission detector ; 4 : Diaphragm and plastic scintillator NE 102 A ; 5 : Light pipe ; 6 : Photomultiplier 56 AVP.

On the counter axis and in front of the transmission counter, by means of a sample-changer wheel, it is possible to place polyethylene radiators of different thickness, a graphite radiator having mass and thickness near to those of the polyethylene radiators ; a tantalum disc 0.2 mm thick equal to those supporting the polyethylene and graphite radiators, and an α particle source to calibrate the transmission counter.

The counter and the radiator-changer wheel are contained in a steel box, evacuated by a rotary pump, which presents an entrance window closed by a 0.2 mm steel plate.

3. - ELECTRONICS.

A block diagram of the electronics is represented in Fig. 2. The preamplifier of the solid state detector and the base of the photomultiplier each transmits a fast signal and a linear signal

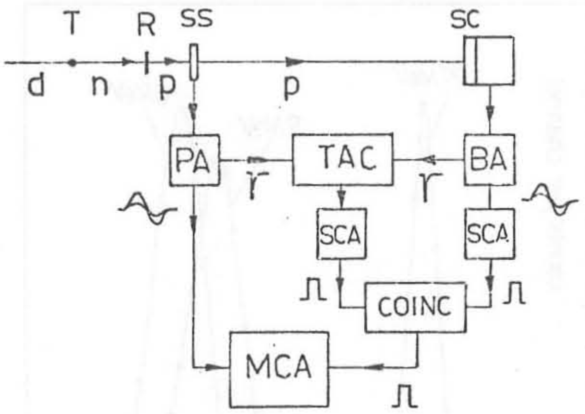

FIG. 2 - Block diagram of the electronics PA : preamplifier ; BA : photomultiplier base ; TAC : time-amplitude converter ; SCA: single channel analyzer ; COINC : coincidence circuit ; MCA : multichannel analyzer.

proportional respectively to the energy loss ΔE and to the energy E of the recoil protons.

The two fast signals trigger a time-to-pulse-height converter, followed by a single channel analyzer, acting as fast coincidence circuit with a resolution of about 5 nanoseconds for the particles crossing both the detectors. The background low energy input pulses are suppressed by threshold levels.

The ΔE linear signals from the transmission counter are analyzed by a multichannel analyzer gated by the coincidence pulses.

In usual conditions, with neutrons from 5 to 20 MeV, and with a counting frequency of coincidence pulses of the order of 10 per second, the frequency of the single pulses of the ΔE counter is some hundreds per second and that of the plastic scintillator of the order of 10^4-10^5 per second.

The background, determined by removing the radiator from the beam (see the next section), is about 1 %. It has been found that the reduction of the background to such a low value is mostly due to the fast coincidence obtained by the time-to-pulse-height converter.

The dead time of the system was mainly due to the time-to-pulse-height converter, and was 0.4 % with a frequency of start signals from ΔE counter of 10^3 per second.

4. - PERFORMANCE OF THE COUNTER WITH 6 TO 20 MeV MONOENERGETIC NEUTRONS.

The counter performances have been investigated by means of 6 to 20 MeV neutron beams, obtained from reactions (d, d) and (d, t) induced by CN Van de Graaff and 400 keV accelerators at Legnaro.

The counter was located aligned with the incident deuteron beam and with the polyethylene radiator a few cm distant from the neutron source.

Some spectra of the pulse height of the ΔE signals taken with and without the coincidence with the pulses from the scintillator are shown in Figs. 3 and 4.

The energy resolution of the counter is made of three components : the energy spread of the incident neutrons, the energy loss of the recoil protons crossing the radiator and the energy variation associated with the n-p scattering angle θ , proportional to $\sin^2\theta$.

It is usual to choose, as a compromise between the counting frequency and the energy resolution, a radiator thickness corresponding to an energy loss equal to 5-10 % of the recoil proton energy, or equal to the energy spread of the neutron beam when this is greater.

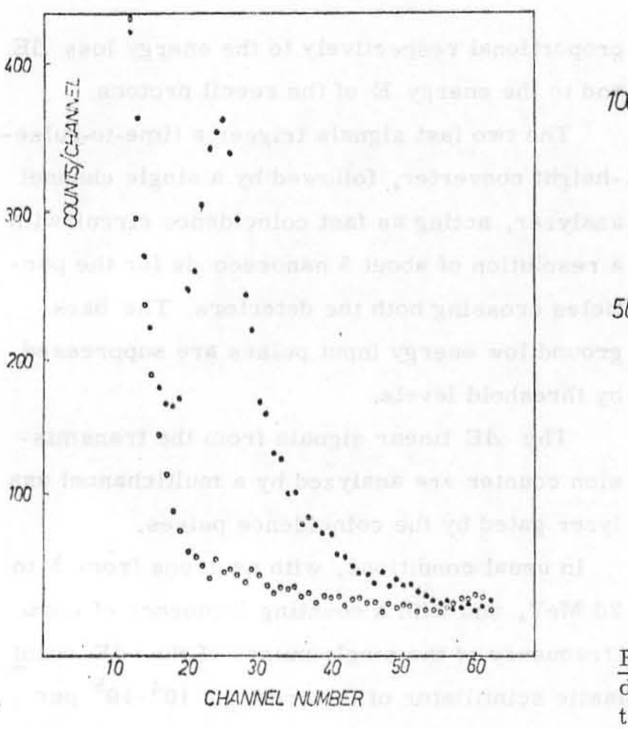

FIG. 3 - Spectra of ΔE pulses, for 20 MeV neutrons, without coincidence, with and without the polyethylene radiator.

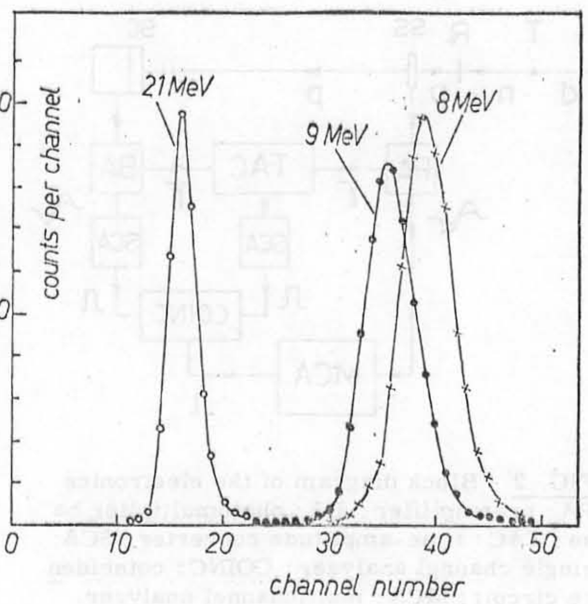

FIG. 4 - Spectra of ΔE pulses in fast coincidence with the scintillator pulses and without the coincidence with E linear pulses for the indicated neutron energies, and with radiators of 10 mg/cm^2 (8 MeV) and 20 mg/cm^2 (9 and 21 MeV).

The specific energy loss $\Delta E/\Delta t$ of protons in polyethylene is represented in Fig. 5.

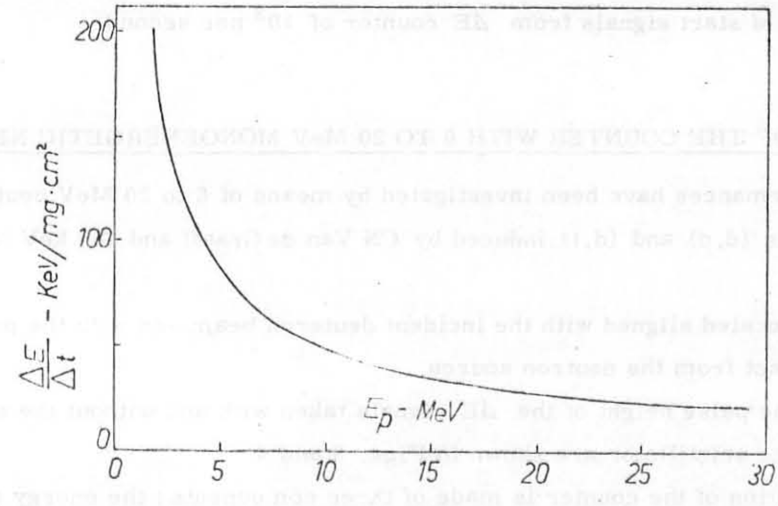

FIG. 5 - Specific energy loss $\Delta E/\Delta t$ of protons in polyethylene as a function of the proton energy E_p.

An indication of the energy resolution of the telescope under actual conditions is given in Fig. 4.

The solid state intrinsic resolution worsens owing to the radiation damage. It has beenfound that the radiation damage is appreciable but still not prohibitive, after an exposure of about a hundred hours to 8 MeV neutron fluxes of the order of 10^7 neutrons per cm^2 and second. Correspondingly an increase in the reverse current of a factor two was observed.

The background, determined by removing the polyethylene radiator from the neutron beam, was 1 % at 9 MeV with a radiator 13 mg/cm^2 thick and 2 % at 20 MeV with a radiator 27 mg/cm^2 thick.

The background due to the carbon present in the polyethylene, measured by substituting the polyethylene with a graphite radiator having the same number of carbon nuclei, was found inappreciable.

5. - DETECTION EFFICIENCY.

The telescope is usually employed as represented in Fig. 1 to measure the intensity I (neutrons per second and steradian) of the neutrons of energy E emitted within the solid angle Ω_o, by a neutron source which may be considered a point if the target is solid and a segment if gaseous.

The counting frequency F in these conditions, if the apertures of the solid angles Ω_o and Ω_1 are small, is

$$F = I\, 4\sigma_{np}(180^o)\, n\, \Omega_o\, \Omega_1 \qquad (1)$$

where σ_{np} is the differential n-p scattering cross section in the center of mass system at 180°, n the number of protons per cm^2 present in the radiator, and Ω_1 the acceptance solid angle of the recoil protons.

The detection efficiency ε, defined as the ratio F/I (counts per neutron and steradian), is therefore:

$$\varepsilon = 4\sigma_{np}(180^o)\, n\, \Omega_o\, \Omega_1 . \qquad (2)$$

The uncertainty of ε is essentially that of σ_{np} which is now known with an error of 0.5 % below 10 MeV and of 1-2 % up to about 50 MeV(2-5).

The errors of n, Ω_o and Ω_1, may easily be rendered negligible.

When the angles are not small the efficiency of formula (2) must be corrected. Tabulation of the correction factor, for neutron energies between 2 and 30 MeV and for several values of the geometrical parameters of the counter, are given in Ref. (1).

Equations which permit an easy calculation of the efficiency also taking into account the relativistic correction are given in Ref. (7).

Fig. 6 represents the efficiency ε as a function of the neutron energy, in the following rather typical conditions, $\Omega_o = \Omega_1 = 3 \times 10^{-2}$ sr, n such to give rise to an energy loss of the recoil protons in the polyethylene radiator of 5 % of the incident neutron energy.

The same figure also represents the thickness t of the polyethylene radiator corresponding to the 5 % energy loss.

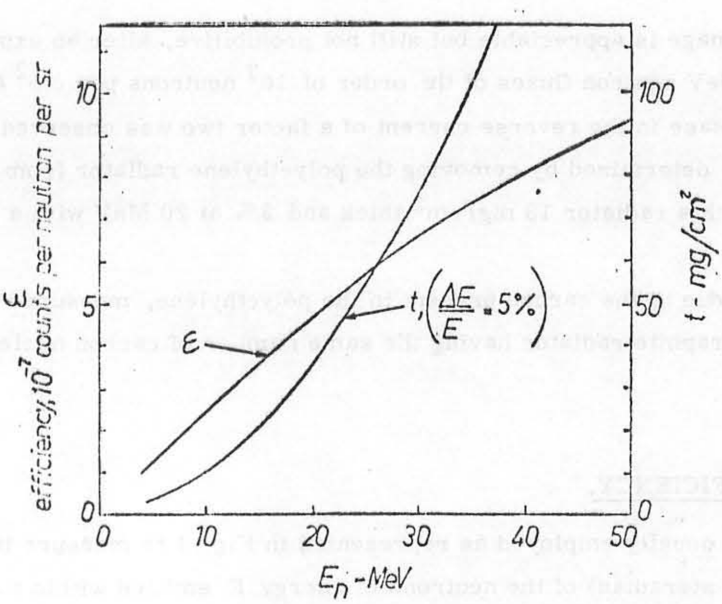

FIG. 6 - Efficiency ε of the telescope with the geometry described in the text, and radiator thickness t corresponding to $\Delta E/E = 5\%$ (see text), as a function of the neutron energy E_n.

With the above considered geometry the geometrical correction factor of ε of formula is practically negligible at 10 MeV and about 1 % at 30 MeV.

6. - CONCLUSIONS.

The recoil proton neutron counter telescope here described was made to measure cross sections of neutrons producing reactions, as for example (d, d), (d, t), (p, t) with energy from a few to some tens of MeV.

The forward intensity of such reactions, with thin deuterium or tritium gaseous targets (at about one atmosphere, few cm thick), and incident ion currents of the order of 1 μA, are of the order of 10^7-10^8 neutrons per second and steradian(8). The corresponding counting frequency with the counter about 10 cm from the neutron source and radiator thickness corresponding to an energy resolution of around 5 %, are of the order of a few to a few tens of counts per second. Statistical errors of the order of a percent per point are therefore obtainable in counting times of the order of one hour or less.

The absolute efficiency of the telescope may easily be calculated with an accuracy of 1-2 % up to about 30 MeV.

The very low experimental background obtainable with a relatively simple counting electronics (1-2 % up to 20 MeV) should insure small systematic errors.

An application of the instruments to a measurement of the absolute forward cross section of the reaction $^2H(d,n)^3He$ for E_d = 3 to 6 MeV (E_n between 7 and 10 MeV), is described in Ref. (9).

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