KERNFORSCHUNGSZENTRUM

KARLSRUHE

June 1970

KFK 1226
IAEA-CN-26/9

Institut für Angewandte Kernphysik

Absolute Neutron Flux Determination

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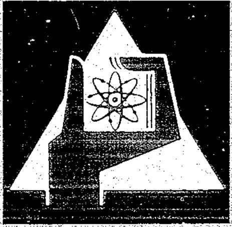

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* Paper presented at the Second International Conference on Nuclear Data for Reactors, Helsinki, June 15 - 19, 1970.

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ABSTRACT

A proton recoil counter with a solid radiator and a solid state detector for absolute measurements of neutron beam fluxes above ~ 250 keV is described. The geometry is such that only protons emerging within a narrow cone around the forward direction are detected. Thus only relatively high-energy protons reach the detector and background correction is facilitated. A specially developped Monte Carlo program is used to normalize the spectra. The counter is fast enough (~ 18 nsec time resolution) for many time of flight applications.

ZUSAMMENFASSUNG

Für die Absolutmessung von Neutronenflüssen oberhalb ~ 250 keV wird ein Protonenrückstoßdetektor mit einer festen Streuprobe und einem Halbleiterzähler beschrieben. Die Geometrie wurde so gewählt, daß nur solche Rückstoßprotonen den Detektor treffen, die unter kleinen Winkeln gegen die Einfallsrichtung der Neutronen aus der Streuprobe austreten. Da so nur Protonen mit relativ hoher Energie nachgewiesen werden, kann leichter gegen niederenergetischen Untergrund diskriminiert werden. Für die Normalisierung der Spektren wurde ein eigenes Monte Carlo Programm entwickelt. Mit ungefähr 18 nsec Zeitauflösung ist der Detektor für viele Flugzeitexperimente geeignet.

ABSOLUTE NEUTRON FLUX DETERMINATION

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1. INTRODUCTION

For neutron energies higher than about 100 keV any partial neutron cross section measurement of good accuracy has to refer to the hydrogen (n,p) scattering cross section. This is the only standard cross section with an accuracy better than 3 % in this energy region, well established by experimental as well as by theoretical work [1] .

Therefore many efforts were made to design proton recoil counters for neutron flux measurements. In general one can distinguish between counters with solid radiator and counters filled with gas containing hydrogen [2,3] . The use of a solid radiator (for example a thin layer of stearic acid) has the advantages that the detector geometry is well defined even in a divergent neutron flux and that it is possible to determine the background by covering the radiator. The disadvantage of such a system is its small efficiency: Since the solid radiator has to be so thin that practically all protons can escape from it the efficiency is about three orders of magnitude lower than for a gas-filled counter.

The recoil protons from a solid radiator can be detected in a proportional counter or with a solid-state detector. The proportional counter has a good efficiency - the protons are detected in 2π-geometry - but it is sensitive to γ-rays. The γ-flash of an accelerator causes a background which masks the lower part of the step-like recoil proton spectrum. Because the proportional counter is too slow for time-of-flight-discrimination of the γ-ray background, one always has to extrapolate the spectrum to zero pulse height in order to find the full count rate. This extrapolated portion of the pulse-height distribution and thus the uncertainty of the number of recoil protons gets larger with decreasing energy. Additional uncertainties arise from the amount of protons absorbed in the radiator. These difficulties remain when the proportional counter is replaced by a solid state detector located close to the surface of the radiator as in Ref. [4] .

The uncertainty due to extrapolation of the recoil proton spectrum can be avoided with a solid state detector positioned at a certain distance from the radiator. Then only forward-peaked protons are detected. The minimum proton energy $E_{p\ min} = E_n \cos^2 \theta_{max}$ is defined by the maximum scattering angle θ_{max} between the radiator and the detector. Thus, it is not at all necessary to extrapolate the spectra to zero pulse height. Furthermore, all recoil protons impinging on the solid state detector have enough energy to be detected. No recoil protons are lost by absorption in the radiator or in the detector window. The penalty for the improvement in background discrimination is a further reduction of the efficiency. Nevertheless, this solution is valuable for neutron energies below about 1 MeV, where other recoil detector systems fail because of background problems.

2. EXPERIMENTAL ARRANGEMENT

2.1 The Proton Recoil Counter

In its first form, this detector was suggested by E. Pfletschinger. The principle was to measure the entire spectrum of recoil protons. When the spectrum is integrated for the calculation of the detector efficiency, it is not necessary to make corrections for an extrapolated part of the spectrum. Fig. 1a shows the counter. The materials used were bronze for the walls and brass for the lid and the flanges. During operation, the counter is evacuated to about 0.1 Torr. It was designed as light-weight as possible to keep the amount of scattered neutrons small. A coolant baffle filled with liquid nitrogen prevents oil vapors from contaminating the counter. Storage and handling of the counter is always done in Argon atmosphere.

The solid state detector and the radiator are mounted on the lid. Therefore deformations due to the air pressure outside the counter cannot change the solid angle between them.

2.2 The Solid State Detector

An ion-implanted silicon detector was used as the proton detector [5] . Its surface was metallized with 20 $\mu g/cm^2$ gold and the thickness of the insensitive region, measured by a collimated beam of alpha particles impinging under different angles, was about 20 $\mu g/cm^2$

silicon under experimental conditions. The detector had an energy resolution of about 2 % and a sensitive area, defined by a mask with an aperture, of 1.76 cm^2. During measurements the detector can be covered with a 0.1 mm thick bronze sheet during every second cycle of an automatic sample changer. The distance between the aperture of the detector and the bronze sheet was 1.0 cm. The background spectrum measured with the detector covered can be stored in the memory of an on-line computer under exactly the same conditions as the recoil proton spectrum.

2.3 Radiator

The radiators were made by the CBNM/Euratom in Geel [6] . Stearic acid ($C_{18}H_{36}O_2$) was evaporated at a constant temperature of 240° C onto a 1 mm thick sheet of stainless steel. The polish of the backing is better than 1 μm, which was measured with an optical method. Evaporation times from one to several hours were used, depending on the layer thickness. Stearic acid was chosen because of the large hydrogen content of about 12 %, the high purity of this material and its resistance against air moisture.

The diameter of the layer was 4 cm and the thickness varied between 60 μg/cm^2 and 180 μg/cm^2, corresponding to 0.6 and 2.2 mg of stearic acid. The total mass was determined by weighing the samples with a vacuum balance before and after evaporation. The uncertainty is estimated to be $\pm$ 10 μg and is caused by the error of the balance. After storage in air as well as in Argon over long time periods (several months) no change in the weight of the samples greater than $\pm$ 10 μg was found.

A second method to determine the hydrogen content of the radiators is a quantitative chemical analysis which is supposed to be accurate to about 1 %. Such an analysis is being prepared.

2.4 Neutron Source

Neutrons were produced with the Karlsruhe 3 MV pulsed Van de Graaff accelerator via the ^{7}Li(p,n)^{7}Be reaction. The pulse width was 1 nsec and the repetition rate $10^6 \frac{1}{sec}$. The neutron energy was determined with a Li-glass detector at a distance of 1.80 m and with a time resolution $< 2 \frac{nsec}{m}$. Normally the ^{7}Li-targets were 30 to 70 keV thick. Ta-backings for the ^{7}Li-targets and a shielding of 2 cm Pb reduced the γ-flash of the accelerator.

2.5 Electronics

Fig. 1b shows a block diagram of the electronics. The pulses from a charge-sensitive preamplifier located close to the silicon detector are shaped and amplified by a spectroscopy amplifier. The width of the output pulses was 250 nsec. Time determination is achieved with a zero-crossing trigger, the time resolution depending on the pulse height, e.g. 18 nsec at 500 keV. The time-of-flight-spectrum produced in a first analog-to-digital converter (ADC1 in Fig. 1b) contained 256 channels. By the computer program they were compressed to 64 channels in such a way, that the important part of the spectrum with the recoil protons is preserved with the original resolution. The two resulting 64 x 64 channel matrixes (for covered and uncovered silicon detector) contain pulse height spectra versus time of flight.

For data transmission from the buffer memory to the computer it is necessary that there are two coincident signals, one from every ADC.

3. MONTE CARLO PROGRAM

For the calculation of the efficiency and for the simulation of pulse-height spectra of the proton recoil counter a Monte Carlo program was written. Similar to that of Bame et al.[7] , the neutrons from a point source hit the (circular) radiator sheet, producing recoil protons. The laboratory scattering angles are sampled from the appropriate distributions, then the energy and the direction of the knock-on proton can be determined for a given neutron energy and direction. This is done for different places and depths in the radiator. To save computer time, angle sampling for each interaction is restricted to a cone containing the solid state detector. The geometry factors of the efficiency M, determined with about 10^5 hits of the solid state detector agreed within the statistical uncertainties with the values of Bame et al. [7] . Energy losses in the radiator and in the entrance window of the solid state detector are calculated from known energy-range and dE/dx relationships [8,9,10,11] .

4. RESULTS AND DISCUSSION

First experiments without any radiator material confirmed that there was no difference in the spectra measured with the detector uncovered or covered by the 0.1 mm thick bronze sheet. Fig. 2a shows a spectrum taken with the radiator in place. Also shown is the background. The spectrum is due to neutrons with energies of (550 ± 20) keV from a pulsed 3 MV Van de Graaff accelerator. It demonstrates that measurements can be done with good discrimination against background. In Fig. 2b the experimental results at three neutron energies are plotted together with the theoretical curves. The agreement is satisfactory. Absolute fission cross section measurements with this detector are in progress.

ACKNOWLEDGEMENT

The authors wishes to thank E. Pfletschinger for the initiation of, and Prof. Beckurts for his support and permanent interest in, this work. We appreciate the careful preparation of the radiator foils by H.L. Eschbach and E.W. Kruidhof as well as the good work of the van de Graaff operators.

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FIGURE CAPTIONS

Fig. 1a	Schematic view of the proton recoil counter
Fig. 1b	Block diagram of the electronics
Fig. 2a	Spectrum with covered and uncovered solid state detector
Fig. 2b	Experimental and calculated spectra at three energies

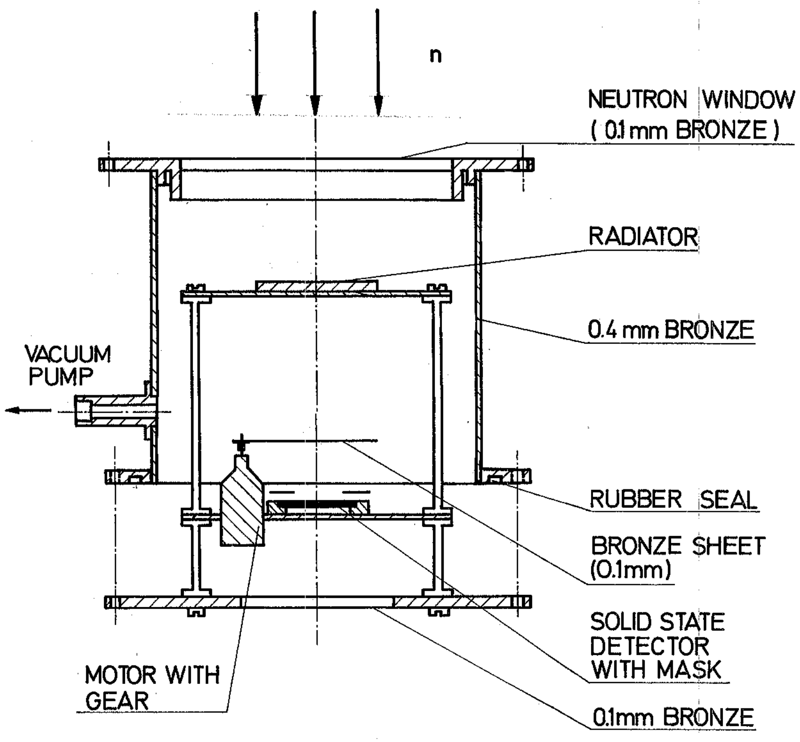
n
NEUTRON WINDOW
(0.1 mm BRONZE)
RADIATOR
0.4 mm BRONZE
VACUUM
PUMP
RUBBER SEAL
BRONZE SHEET
(0.1mm)
SOLID STATE
DETECTOR
WITH MASK
MOTOR WITH
GEAR
0.1mm BRONZE

FIG. 1a

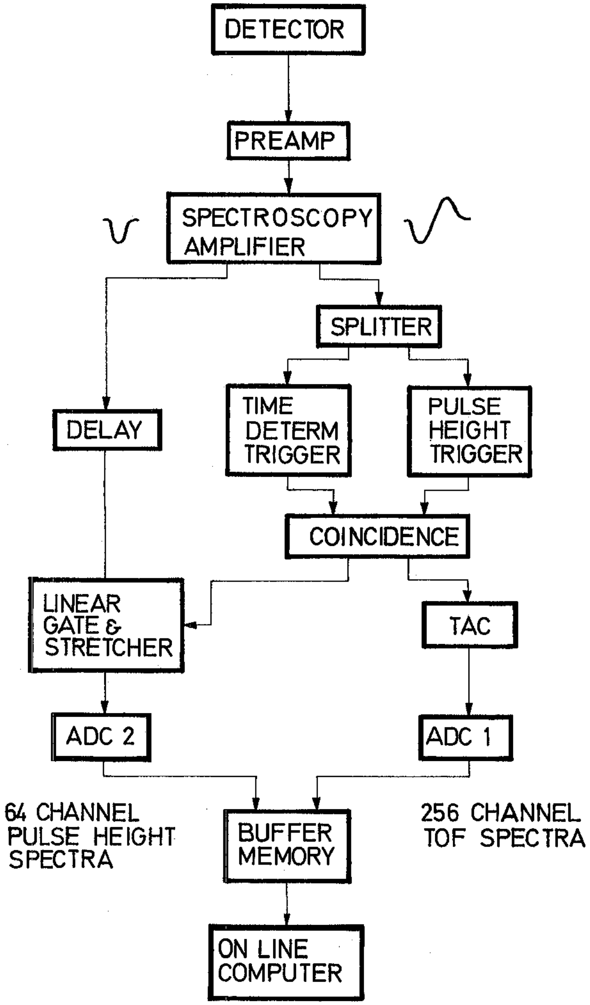
DETECTOR
PREAMP
SPECTROSCOPY
AMPLIFIER
SPLITTER
DELAY
TIME
DETERM
TRIGGER
PULSE
HEIGHT
TRIGGER
COINCIDENCE
LINEAR
GATE &
STRETCHER
TAC
ADC 2
ADC 1
64 CHANNEL
PULSE HEIGHT
SPECTRA
BUFFER
MEMORY
256 CHANNEL
TOF SPECTRA
ON LINE
COMPUTER

FIG.1b

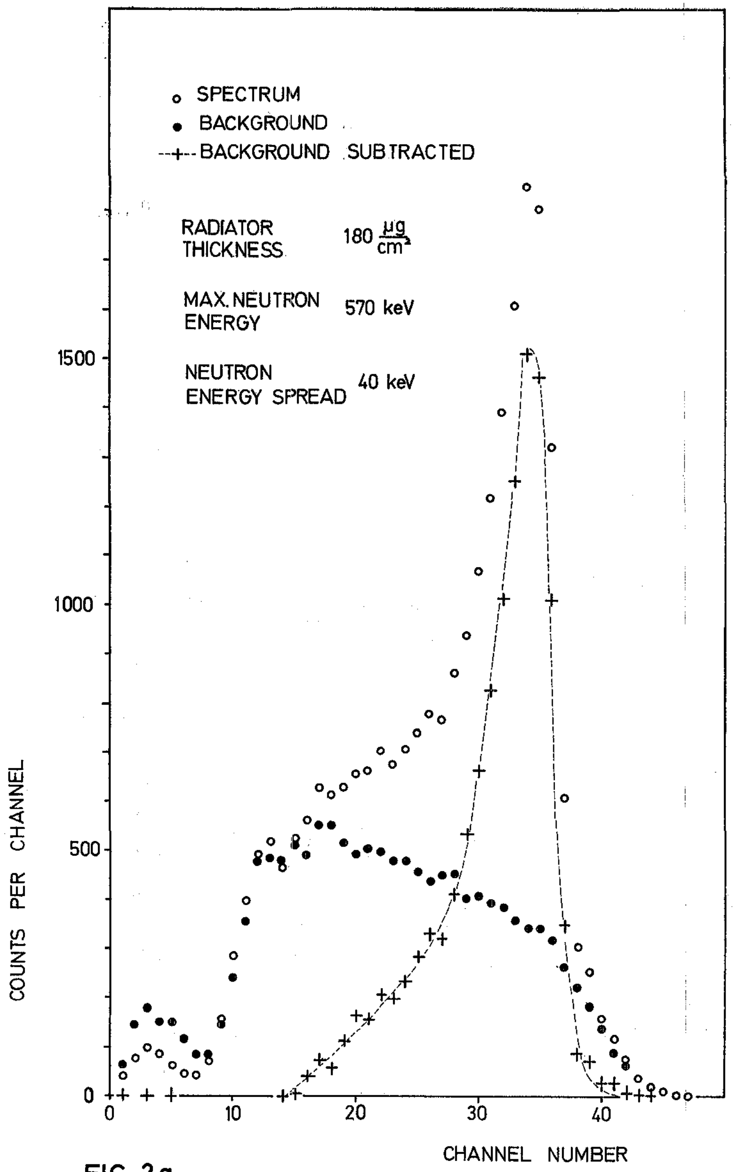
○ SPECTRUM
● BACKGROUND
--+-- BACKGROUND SUBTRACTED
RADIATOR THICKNESS 180 $\frac{\mu g}{cm^2}$
MAX. NEUTRON ENERGY 570 keV
NEUTRON ENERGY SPREAD 40 keV
COUNTS PER CHANNEL
1500
1000
500
0
0
10
20
30
40
CHANNEL NUMBER

FIG. 2a

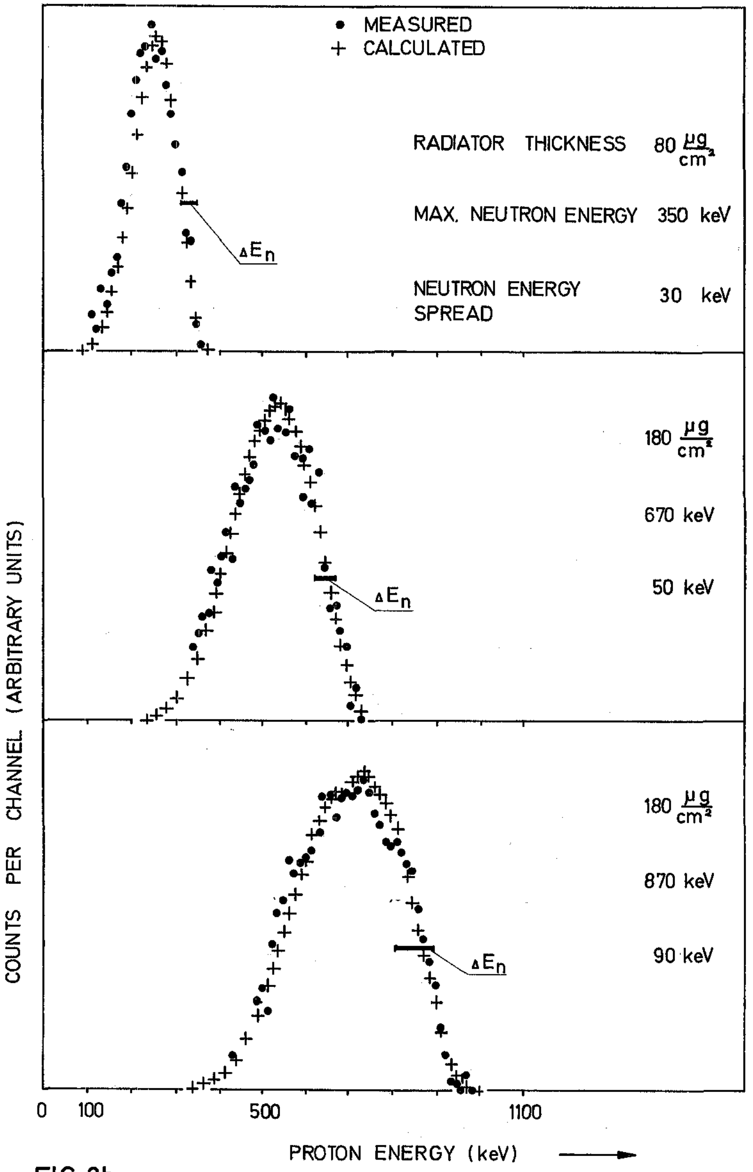
● MEASURED
+ CALCULATED
RADIATOR THICKNESS 80 $\frac{\mu g}{cm^2}$
MAX. NEUTRON ENERGY 350 keV
NEUTRON ENERGY SPREAD 30 keV
ΔE_n
180 $\frac{\mu g}{cm^2}$
670 keV
50 keV
ΔE_n
180 $\frac{\mu g}{cm^2}$
870 keV
90 keV
ΔE_n
COUNTS PER CHANNEL (ARBITRARY UNITS)
0
100
500
1100
PROTON ENERGY (keV) ⟶

FIG. 2b