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DETECTION EFFICIENCY OF PLASTIC SCINTILLATION COUNTERS FOR NEUTRONS IN THE ENERGY RANGE 20–130 MeV

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Measurements on plastic scintillation counters of 28.6 cm thickness and 30 cm dia. have been made with neutrons of energies 20–130 MeV. The detection efficiency has been measured in detail for different parts of the counter and integrated to give the overall efficiency as a function of energy.

The results are compared with calculations based on the work of Kurz and are found to be consistent with them.

1. Introduction

A knowledge of the absolute detection efficiency of hydrocarbon scintillators is often necessary when they are used for detecting neutrons in high energy physics experiments. At neutron energies up to 10 MeV and for scintillator dimensions of a few cm the efficiencies can be reliably determined from the systematics of single neutron-hydrogen collisions[1]) provided the bias level is sufficiently well known.

Above 10 MeV, calculations must also take into account neutron-carbon interactions and the rescattering contributions in detectors whose dimensions are of the order of magnitude of the mean-free-path for neutron interactions. Up to 14 MeV, calculations show fairly good agreement with experiment[2,3]). For higher energies the shortage of information on the neutron-carbon interactions makes the calculations difficult and less reliable.

However, Kurz[4]) has developed a FORTRAN programme which uses all the available cross-section data to calculate the detection efficiency for cylinders of plastic scintillator in the neutron energy range 1–300 MeV. The calculations have an uncertainty estimated to be ± 10%, but the agreement shown with the measurements of Wiegand et al.[5]) is compatible with the experimental error.

We report here measurements of the efficiency of six detectors used in a study of the reaction

$$\pi^- + p \rightarrow n + \pi + \pi,$$

on Nimrod at the Rutherford Laboratory. The measurements were designed to show the variation in neutron response over the face of a particular counter and that from counter to counter. Also they were to be used as a comparison with the calculations using the Kurz programme.

The detectors, hereafter called the Nimrod counters, were used in a time-of-flight system which selected and

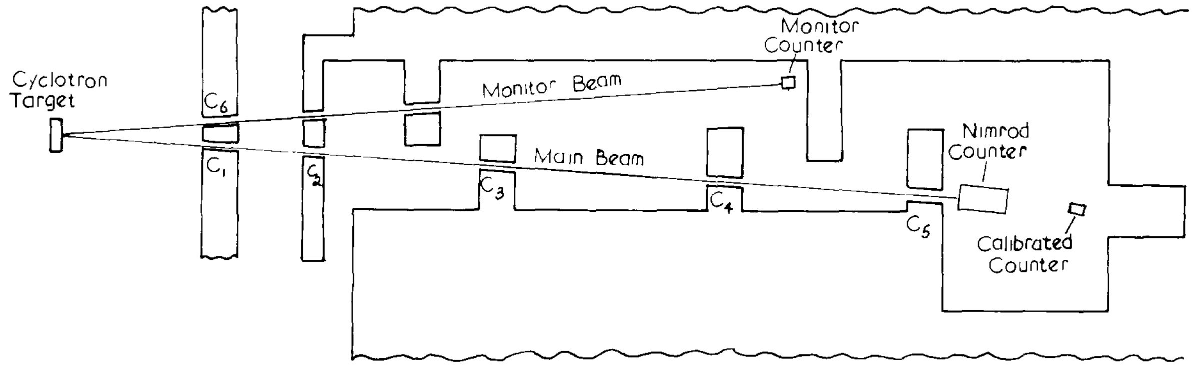

Fig. 1. Geometrical layout of beams and counters.

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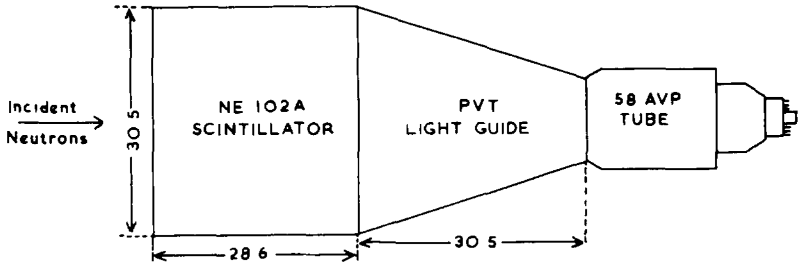

Fig 2 Simplified diagram of a Nimrod counter All distances in cm

measured neutron energies in the range 20–200 MeV. To find the detection efficiencies in this energy range, the neutron-time-of-flight spectrometer on the Harwell synchrocyclotron was used The method involved the comparison, as a function of energy, of the total number of neutrons detected in a Nimrod counter, with those detected in a calibrated counter, whose neutron detection efficiency had been measured independently[6])

For a particular neutron energy E the measured efficiency ε_E is given by

$$\varepsilon_E = (N_E/n_E)S_E,$$

where N_E is the number of neutrons detected in the Nimrod counter, n_E is the number detected in the calibrated standard counter and S_E is the detection efficiency of the standard counter The measurements were made over the neutron energy range 20–130 MeV and the detection efficiencies found were compared with the values computed from the Kurz programme.

2. Experimental details

The spectrometer has been described in detail elsewhere[7]), so it will suffice to say that the neutrons are produced by deflecting the proton bunch in the synchrocyclotron onto an aluminium target, in a single turn. The protons, which have an energy of 143 MeV, are stopped in the target and produce neutrons with energies up to 137 MeV. The neutrons emerging from the target are collimated to form two beams as shown in fig 1 The main beam is defined by collimators C_1 and C_5 to be one cm^2 at the counter, which is 26 m from the target. The second beam is the monitor beam and is defined by the collimator C_6 and the monitor counter itself The number of charged particles in the beams is negligible

A diagram of a Nimrod counter is given in fig 2 I consists of a cylinder of NE 102A plastic scintillato optically coupled to a solid polyvinyl-toluene ligh guide and viewed by a single 58 AVP photomultiplier The assembly is mounted in an aluminium and mild steel container and the neutrons incident at the front pass through a 25 μm aluminium window

The timing electronics is shown schematically in fig 3. A "start" timing pulse is provided by the deflection system and triggers a time-to-amplitude converter (time sorter) "Stop" pulses come from eithe the Nimrod or standard counter and are split two ways into a fast-slow system to improve timing ac

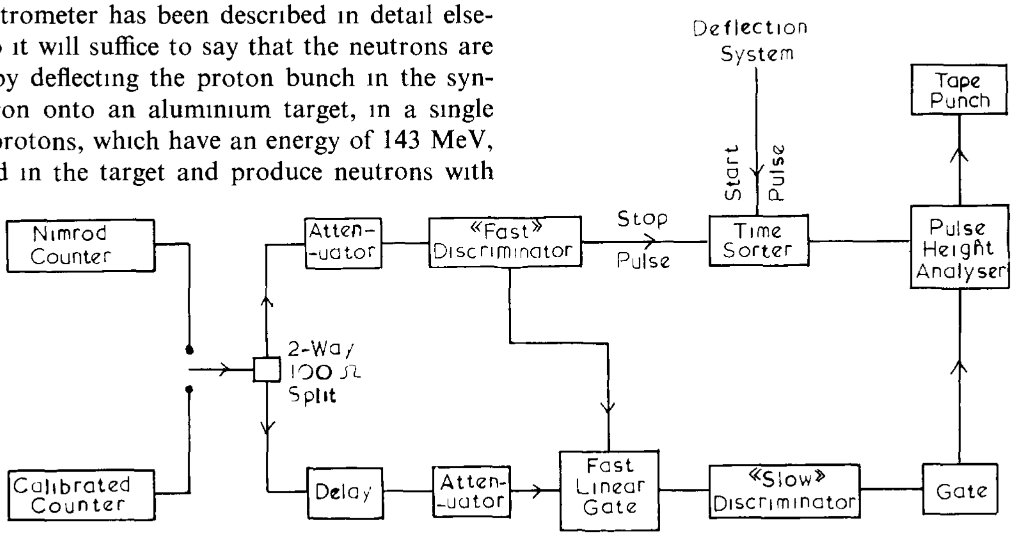

Fig 3 Schematic diagram of the timing electronics

curacy. In order to avoid pile-up on the "slow" side, the "fast" discriminator opens a linear gate to allow only the "slow" pulse corresponding to the timed "fast" pulse to trigger the "slow" discriminator. The output from this discriminator gates the time sorter output onto one of two 256 channel displays in the pulse height analyser; one corresponds to poorly-timed events below the "slow" discriminator threshold, the other to well-timed events. The bias level in this experiment is set by the "slow" discriminator threshold.

The Nimrod counters were mounted one at a time on a table which could be moved remotely so that the beam could fire into a number of selected positions across the counter face. It could also be moved completely away from the collimator so that the beam could enter the calibrated counter.

3. Efficiency measurements

The procedure for determining the efficiency at a particular position on a Nimrod counter was simply to measure, as a function of energy, the number of neutrons detected per unit monitor count compared with the standard counter. From measurements at several different positions, the average detection efficiency was found by integration over its sensitive area.

Before making any measurements, the bias levels on the counters had to be set at a reproducible level. The bias levels of the monitor and calibrated counters were set using a ^{137}Cs source[6]), but this was not applicable in the case of the Nimrod counters because of the relatively high background levels expected in the main experiment. An alternative method was devised in which the cosmic ray peak of the counter was used as a calibration point. Then, knowing that the output pulse height of the counter is a linear function of the energy deposited in the scintillator and to what value the cosmic ray peak corresponds (these were both determined in a separate experiment), the pulse height analyser can be calibrated as a function of particle energy. The bias can be set at any channel of the analyser and its value known. The bias level of the Nimrod counters for these measurements was set at 2.5 MeV equivalent electron energy or approximately 6 MeV proton energy[8,9]).

The measurements took the form of short runs at each position. The centre of a Nimrod counter served as a reference point to check stability several times during the course of investigation of a particular counter. Generally, one run in six was made using the calibrated counter. The counter gains and biases were checked at intervals.

The investigation of each counter took the form of a scan across a diameter, giving particular regard to points near the perimeter, since the efficiency at large radii contributes most to the average efficiency of the counter.

Investigations were made into the contribution to the efficiency from beam entering the aluminium and steel of the container. The efficiency for detecting neutrons scattered from the container when the beam is $1\frac{1}{2}$ cm from the edge of the scintillator is 0.05 while at 3 cm the efficiency is 0.015.

Background effects contributed from 1% to 3% to the detection efficiency at any one point and were measured by blocking up the collimator.

4. Analysis and results

Dead time corrections[6]) and normalization factors were applied to the experimental results which were then grouped into energy bands 5 MeV wide in the energy range 20 to 130 MeV.

The detection efficiency ε as a function of neutron

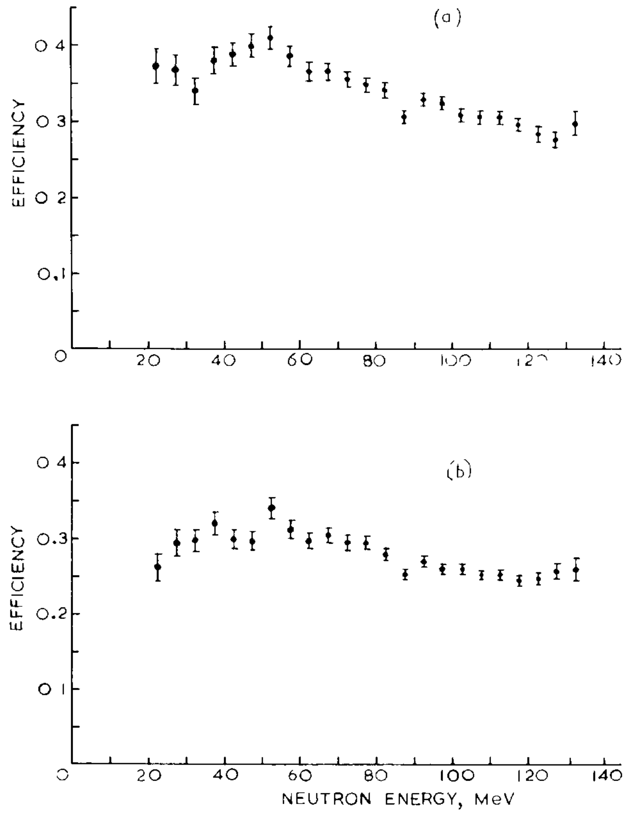

Fig. 4. Detection efficiencies vs energy for a point at the centre of the counter (a), 14 cm from the centre (b). The bias is at 6 MeV proton energy.

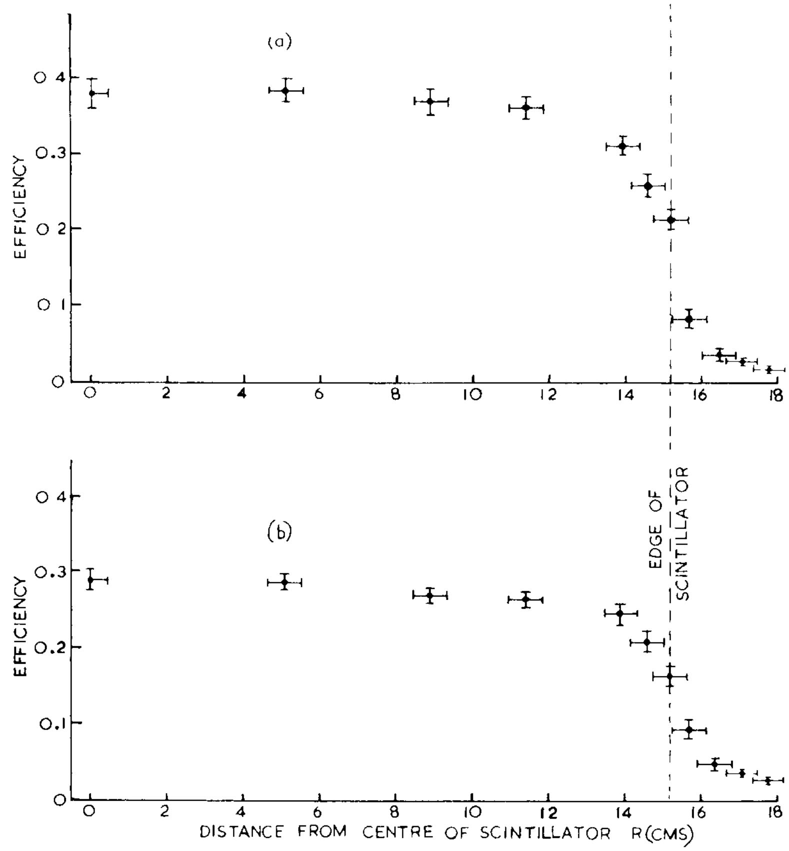

Fig 5 Detection efficiencies vs radial position for 40 MeV neutrons (a), 120 MeV neutrons (b) The contribution outside the scintillator limits is due to the container The horizontal error-bars indicate the beam width

energy E for a given position x on a Nimrod counter i was then computed by using the expression

$$\varepsilon^i(E,x) = [\{N^i(E,x)-B^i(E,x)\}/\{n^i(E)-b^i(E)\}]s(E),$$

where $N^i(E,x)$ and $n^i(E)$ are the normalized spectra for the Nimrod and standard counters respectively $B^i(E,x)$ and $b^i(E)$ are the corresponding background spectra $s(E)$ is the efficiency of the standard counter.

Typical efficiencies as a function of energy for two radial positions on the scintillator face are shown in fig 4. The efficiency as a function of radial position for 40 and 120 MeV neutrons is shown in fig 5. In both figures the vertical errors are statistical The horizontal error-bars indicate the beam width Outside the scintillator limits, the contributions to the efficiency are due to neutron interactions in the aluminium and steel of the container

The overall detection efficiency was calculated by weighting the measured efficiencies according to radial positions and then integrating graphically over the face of the detector Corrections were made for beam width and the contribution from the metal in the container The average of the calculated values from the six Nimrod counters for each of twelve neutron energies is given in table 1 All six counters give similar values within the experimental errors

TABLE 1

Average neutron energy (MeV)	Efficiency
22.5	0.296 ± 0.014
27.5	0.314 ± 0.015
32.5	0.341 ± 0.007
40	0.354 ± 0.016
50	0.360 ± 0.015
60	0.357 ± 0.012
70	0.336 ± 0.010
80	0.318 ± 0.010
90	0.298 ± 0.009
100	0.294 ± 0.009
110	0.286 ± 0.009
120	0.280 ± 0.011

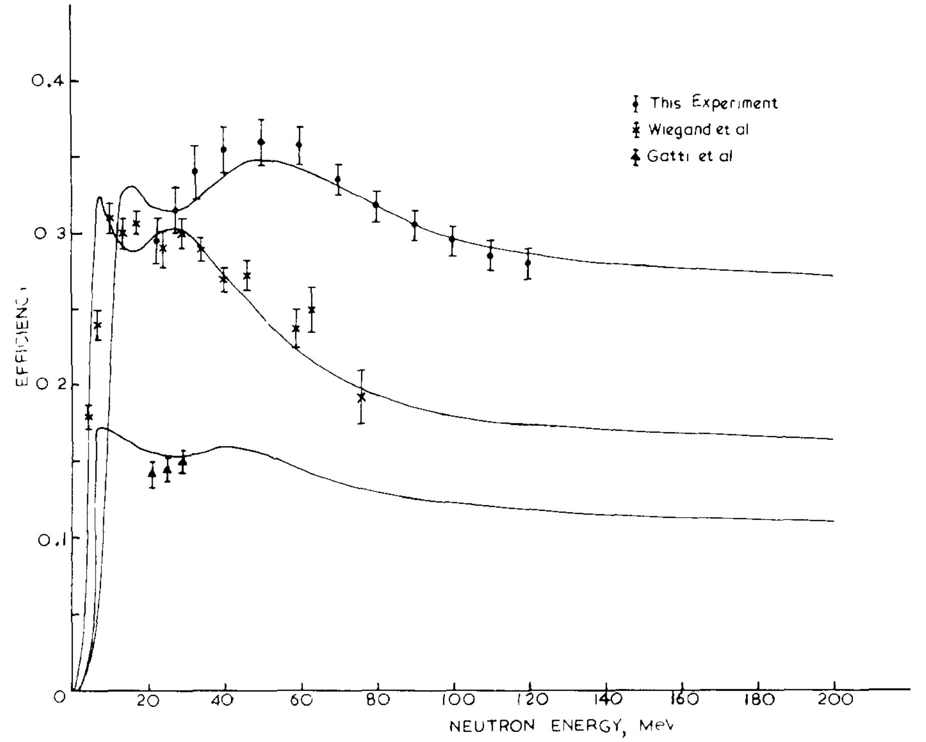

Fig 6 Neutron detection efficiency vs neutron energy The points ● refer to the present experiment with a 28 6 cm thick plastic scintillator and a bias of 6 MeV proton energy The points △ are for a 10 cm thick plastic scintillator and bias of 6 MeV proton energy [Gatti et al [10]] The points × are for a 15 cm thick plastic scintillator and bias of 4 MeV proton energy [Wiegand et al [5]] The solid lines corresponding to each set of data are calculated using the method of Kurz

The statistical errors are very much reduced on integration and are typically less than 1% The main errors arise from the uncertainty in knowing exactly how the efficiency approaches zero at the periphery of the scintillator. Estimates of the sensitivity of the overall efficiency to variations at the periphery were made by noting the effect of several parameters The total error was estimated to be ±5% at 22 5 MeV falling to ±3% at 80 MeV and rising to ±4% at 120 MeV

5. Discussion

The detection efficiencies tabulated in table 1 are plotted as a function of neutron energy in fig 6 The solid line associated with this set of data corresponds to the calculated efficiencies using the method given by Kurz The calculations are in agreement with the measured efficiencies especially at the higher neutron energies

For comparison we have also plotted on fig 6 the efficiencies of the counters of Wiegand et al [5]) and Gatti et al [10]) together with the calculated efficiencies corresponding to each counter The Wiegand counter measurements are in good agreement with the calculations and those from the Gatti counter are not inconsistent

After the initial variations near the cut-off imposed by the bias, the efficiency of the counters varies slowly with neutron energy and above about 100 MeV is almost independent of it In this energy region the efficiency is approximately 1%/cm of scintillator thickness The three counters have different geometries and the Wiegand counter has a lower bias so that the conclusions are that above 100 MeV neutron energy, the efficiency depends principally on the scintillator thickness, but not significantly on the other dimensions and is insensitive to small changes in bias

The effect of bias on the Nimrod counters was calculated for energies up to 200 MeV and is shown in fig 7 For biases higher than 6 MeV proton energy, the efficiency is a smooth function of neutron energy and above 100 MeV is affected little by relatively large bias changes Measurements at different biases made on the Nimrod counters, although not as complete as the measurements at 6 MeV bias, do confirm the trend of the calculations

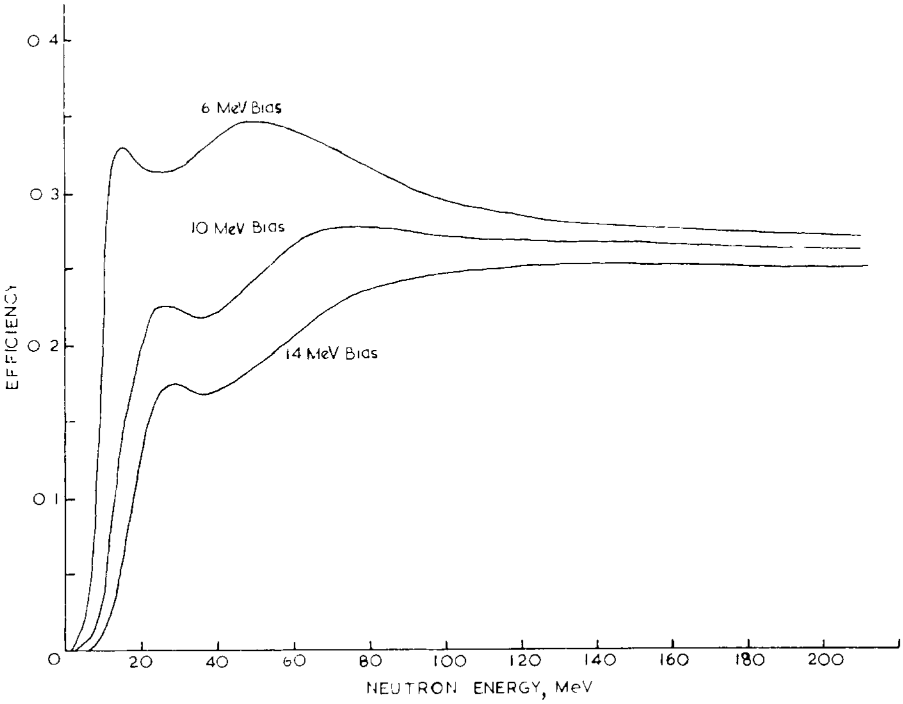

Fig 7 The calculated detection efficiency of the Nimrod counter as a function of neutron energy for different bias levels

Because our work here has shown the reliability of Kurz's calculations, we have used the results of his programme to extrapolate our experimental results into the region 130–200 MeV and use these in the analysis of the Nimrod experiment. In this experiment we detect neutrons of energies up to 200 MeV with a bias set at 12 5 MeV proton energy

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