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A MEASUREMENT OF THE AVERAGE NUMBER OF PROMPT NEUTRONS EMITTED IN FISSION AT HIGH ENERGY

by

I. JOHNSTONE

HARWELL, BERKS.
1956

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ABSTRACT

A coincidence gate method has been used to determine $\bar{\nu}$., the average number of neutrons emitted in fission, induced by neutrons at 2.5 and 14.1 MeV energy. Absolute values have been obtained by relating the measurements to the known spontaneous fission neutron rate of natural uranium. (Littler (1)). Some results are given for the fast fission of U^{233}, U^{235}, U^{238}, Th^{232} and Pu^{239}, and for spontaneous fission of Pu^{240}.

A.E.R.E. Harwell

20th March 1956

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CONTENTS

1. INTRODUCTION

Much experimental work has been carried out on the evaluation of $\bar{\nu}$ for thermal fission (Mummery and Story (2) Sanders (3)). The aim of the experiment to be described is to determine the change in $\bar{\nu}$ with variation in incident neutron energy by inducing fission with neutrons at 2.5 and 14.1 MeV energy.

The measurements were made in each case, relative to the number of neutrons emitted by a spontaneous fission source, previously calibrated to within ± 5.5%.

2. METHOD

The experiment involved the counting of "prompt" fission neutrons detected within ~ 500 μ secs. of a fission event. The general arrangement of the apparatus is shown in Figure 1. The deuteron beam from a 500 KeV Cockcroft-Walton accelerator was allowed to fall on a zirconium tritide, of heavy sodium hydroxide target. The fast neutrons emitted were collimated into a 1" diameter beam, using water and concrete to slow down and capture the unwanted neutrons. This beam then passed axially through a fission ionisation chamber placed in a channel through the centre of a neutron detector. Any neutron detected within a predetermined time after a fission pulse, was counted by means of a coincidence gating circuit. To establish the efficiency of the neutron detector, it was then necessary to use it to measure the rate of neutron emission from a previously calibrated neutron source, placed in the position normally occupied by the fission chamber. Since the neutron production rate due to spontaneous fission of natural uranium has been measured (Littler (1)), a known mass of natural uranium can be used as a calibrated source of fission neutrons. A sphere of radius 3 cms. was used to calibrate the neutron detector an allowance being made for the effect of fast fission.

3. APPARATUS

3.1 Fission Ionisation Chamber

A multiple parallel plate type of chamber was used and is illustrated in Figure 1. All parts of the chamber traversed by the neutron beam were made of the thinnest material possible to avoid scattering neutrons into the boron detector and thereby increasing the neutron background. Since very fast pulses were not required and ease of foil changing was of great importance, the gas filling was of hydrogen at atmospheric pressure flowing continuously through the chamber. Build-up of pulses from natural alpha-activity limited the amount of fissile material which could be used in the chamber.

As the experimental counting rates were small (2-20counts/min) it was essential that no spurious pulses from the fission chamber or its associated electronics operated the gating circuits. Of the amplifiers available a type 1008 was found to be most satisfactory, and a battery pack was used to supply + 500 volts H.T. for the chamber, via a filter unit. Frequent checks were made during runs to see that no fission counts were recorded while the deuteron beam was off the target.

3.2 Boron Neutron Detector (Figure I)

The detector consists of six 1" diameter x 12" long proportional counters filled with BF_3 enriched to 95% B^{10} content at a pressure of ~ 70 cms of mercury. These counters are embedded in an 18" x 18" cylinder of paraffin wax, with a 3" diameter hole down the axis to admit the fission chamber. This paraffin wax cylinder is totally enclosed in 0.010" thick cadmium to reduce background due to thermal neutrons. Fast neutrons incident on the paraffin wax are slowed down and a small fraction (~ 4%) are captured by the B^{10} present in the counters giving alpha-particle pulses. The six proportional counters are connected in parallel and were found to give a satisfactory discriminator bias curve at a H.T. voltage of 2.2 KV.

3.3 Electronics

In spite of the provision of 2 metres of shielding material between the neutron source and the boron detector, random concidences between fission events and background neutrons sometimes accounted for one fifth of the total concidence rate. This random coincidence rate was monitored throughout the experiment by feeding all neutron pulses, after discrimination, into two identical coincidence gates in parallel. The input into the "random coincidence gate" was delayed by ~ 1 milli.second (which greatly exceeds the average neutron life-time in the paraffin wax - boron assembly of the neutron detector.) Thus, random coincidences were counted by both gating circuits but true coincidences by one only.

Additional scalers recorded the number of times that the gating circuits operated (fission rate) and the total number of neutron pulses.

4. EXPERIMENTAL PROCEDURE

(a) With H.T. set off, neutrons from a Ra-Be source were used to take discriminator bias runs on both fission and neutron detectors

(b) With the fission discriminator bias set at the chosen working point, it was ensured that no spurious fission pulses were observed during a 5 - minute count.

(c) With the H.T. set on, neutrons, fissions and true and random coincidences were recorede simultaneously until ~ 1,000 true coincidences had been observed.

(d) At least once every three hours, the H.T. set was turned off and the fission background check repeated.

(e) Once per day during a run and at the end of each run, the discriminator bias for the neutron detector was checked to ensure that no alteration in the calibration had taken place.

To check that the apparatus was working reliably it was used to measure the values of $\overline{\nu}$ for thermal fission of U^{235} and Pu^{239}, which are relatively well known. In both cases the results agreed with the values recommended by Mummery and Story (2), within the limits of experimental accuracy.

As a further check, in the later stages of the experiment the apparatus was used to measure $\overline{\nu}$ for the spontaneous fission of Pu^{240} for 2 days of each week.

5. RESULTS

Isotope	Incident Neutron (Energy (KeV)	ν Prompt	Total Error (%)	Statistical Error (%)
Th^{232}	14.1	3.55 0.28	7.9	5.8
U^{233}	14.1	3.86 ± 0.28	7.1	4.6
U^{235}	2.5	2.64 ± 0.19	7.1	4.5
U^{235}	14.1	4.52 ± 0.32	7.1	4.5
U^{238}	2.5	2.35 ± 0.18	7.6	5.1
U^{238}	14.1	4.13 ± 0.25	6.0	2.5
Pu^{239}	14.1	4.85 ± 0.50	10.4	8.8
Pu^{240}	Spontaneous	2.21 ± 0.13	5.8	1.7

6. DISCUSSION OF ERRORS

6.1 Incident Neutron Energy Spectrum

The following checks were made to ensure that the fission events investigated were induced by neutrons of known energy.

(a) The energy spectra of the fast neutrons in the collimated neutron beams were measured using photographic plates (Fig.3).

In each case, more than 89% of the proton tracks examined, resulted from collisions with neutrons of the primary energy (i.e. 2.5 or 14.1 KeV). The remaining tracks are thought to be due to neutrons degraded in energy by inelastic scattering or to protons produced by ((n.p.) reactions in the photographic plate or its associated vacuum chamber (Fig.4). Assuming reasonable values for the cross section involved such processes could more than account for the ~ 11% of unidentified tracks.

(b) The thermal neutron flux at the fission chamber position was measured using photographic plates loaded with lithium. One half of each plate was irradiated in a calibrated thermal neutron flux from the B.E.P.O. and the other half placed in the fission chamber position for a known time with the H.T. set in operation. The number of tracks observed in the second half of each plate was not greater than the number expected from cosmic ray background. This indicated that the thermal flux passing through the fission chamber was less than 5×10^{-3} neutron/cm^2/sec.

(c) Epicadmium Neutrons Before reaching the fission chamber the neutron beam passed through 0.005" of cadmium. A boron disc one cm. in thickness was found to reduce the fission counting rate by 40% compared with a calculated effect of 10% for fast neutrons. This indicated that epicadmium neutrons were present in the original beam and that a boron filter would be necessary to prevent such neutrons causing fission in the chamber.

A further check on the residual spectrum was made by the addition of a second similar filter, which caused an alteration of ~ 10% in agreement with the calculated value for fast neutrons. The second filter was therefore omitted during counting runs.

6.2 Gate length calibration

The coincidence gate length was measured using a calibrated cathode-ray oscilloscope which was compared in turn with a crystal controlled oscillator. Since an error of 2% in the value of τ used results in an error of $\approx \frac{1}{2}$% in $\bar{\nu}$, any errors from this source are small.

6.3 Counting "dead time" due to delay circuit.

Any neutron pulse reaching the coincidence unit within one delay time t of a previous pulse would not be counted. It can be shown (4) that the counting efficiency E is given by $E = \frac{1}{(1+\mu t)}$ where μ is the average number of neutron pulses/second. Since the neutron rate was monitored continuously throughout the experiment an accurate correction for this effect could be made.

6.4 Neutron Detector Energy ~~Reparse~~ Response

In the design of the boron neutron detector, reference was made to the results of an experiment carried out at the A.W.R.E., Aldermaston (7) to determine the optimum radius of the BF_3 counter ring in a paraffin wax cylinder with a central hole, for minimum change of sensitivity with neutron energy.

It was found that neutron sources such as Sb-γ-Be (1.67 MeV) and Ra-α-Be (Most probable energy; 5 MeV. Maximum energy ~ 12 MeV) placed in the centre of the assembly, gave energy sensitivities varying by ~ 10% with 14 cms of paraffin wax between the source and the ring of counters. The same thickness was used in the neutron detector for the present work.

The use of fission neutrons to calibrate the detector eliminates the necessity of knowing its energy response for the determination of $\bar{\nu}$ at thermal energies. When using incident neutrons of high energy, however, some of the neutrons detected may result from nuclear evaporation prior to fission. For these neutrons a Maxwellian distribution of energies may be expected. (Graves and Rosen (5)). However a Maxwellian distribution of neutron velocities corresponding to 14 MeV of incident neutron energy is is similar to the experimentally determined energy distribution of fission neutrons. (Watt (5) Fig.4) and therefore should be detected with similar efficiency.

6.5 Neutrons detected after closing of coincidence gate

The average neutron life-time T in the paraffin wax boron assembly of the neutron detector is ~ 150 μ secs. If the coincidence gate is closed ~ $\frac{1}{2}$ millisecond after a fission event a small fraction (~ 6%) of the prompt fission neutrons will not be detected.

The coincidence counting rate was measured for various gate lengths and the resultant curve (Fig.6) used to extrapolate the data obtained to infinite gate length.

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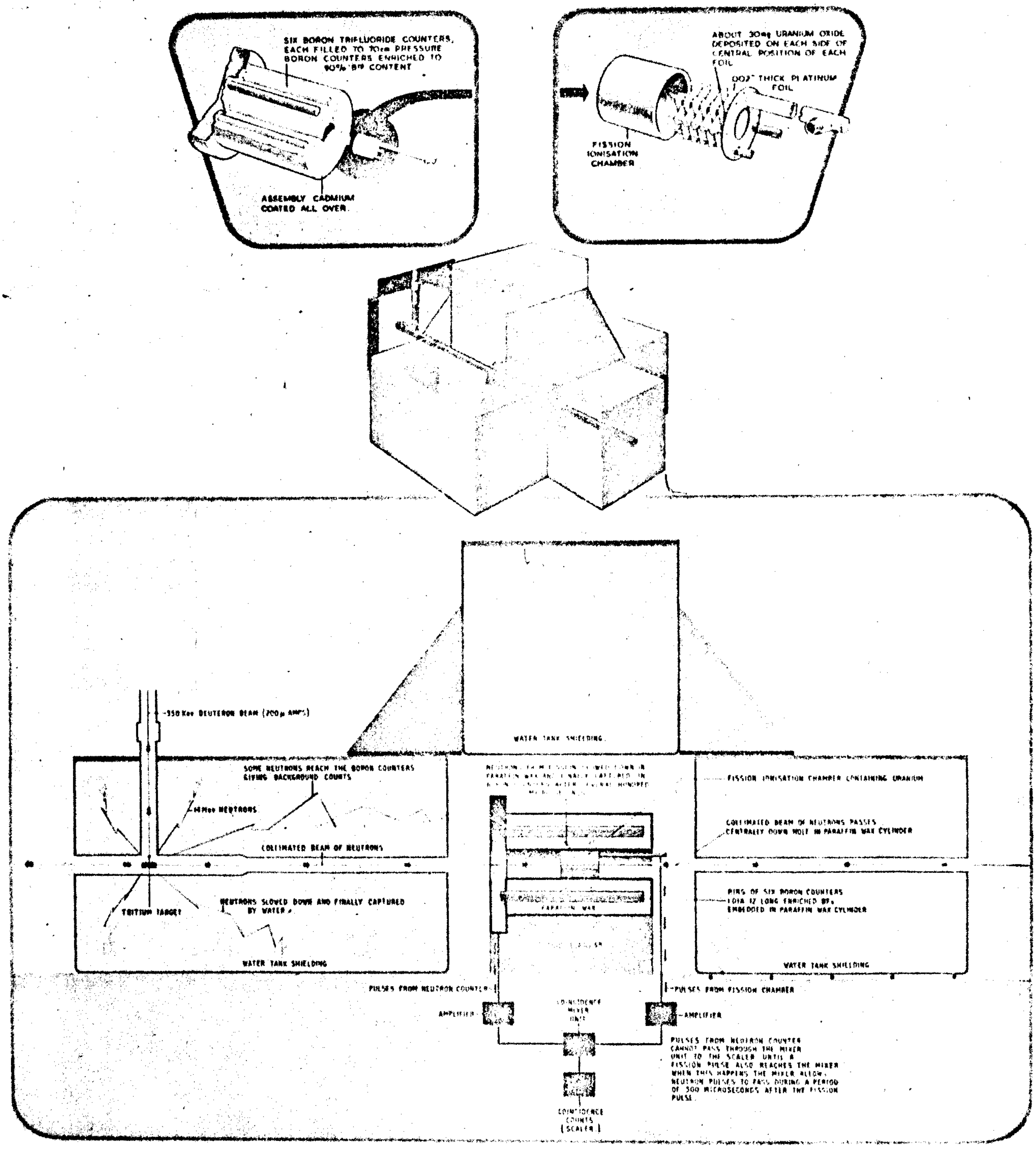
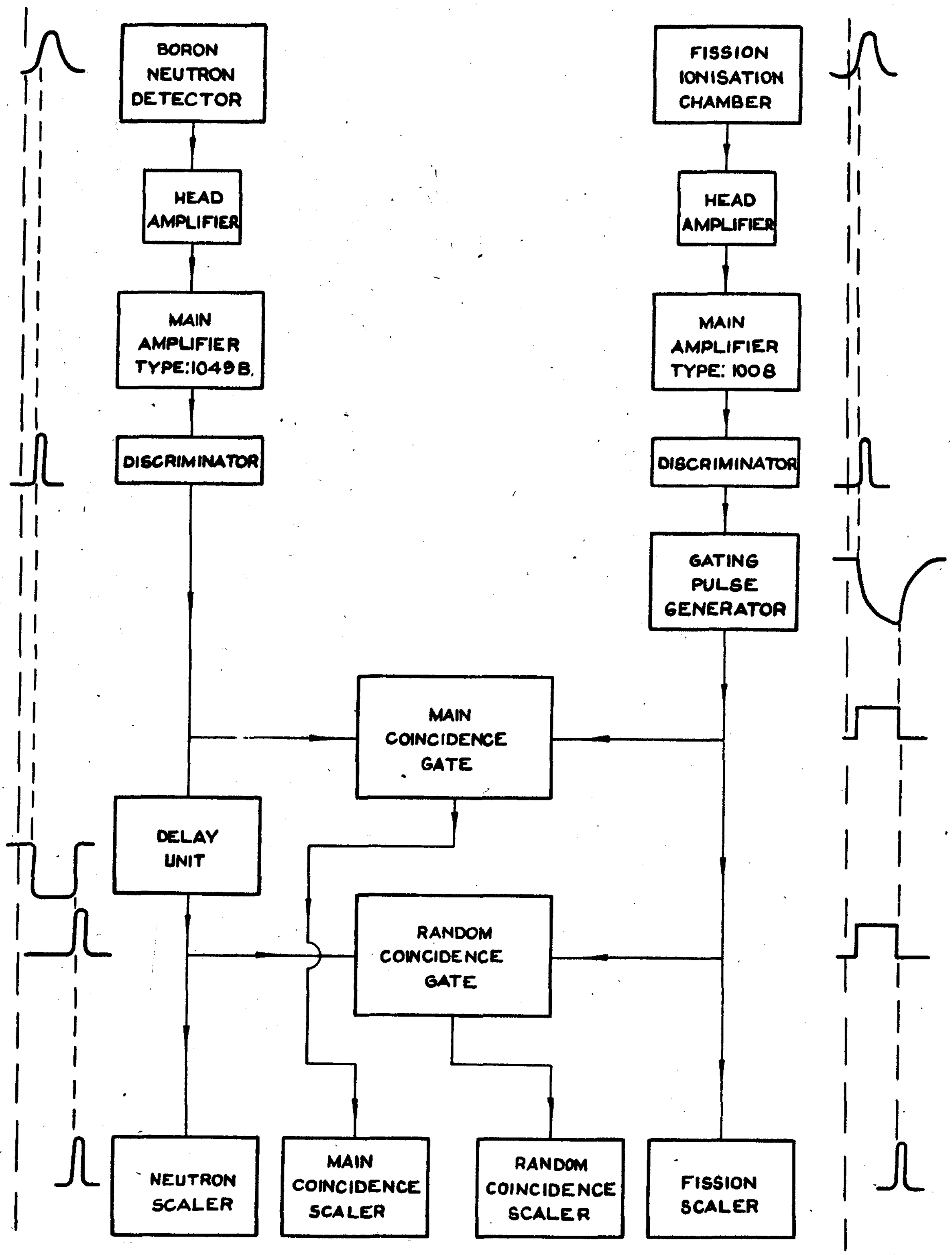
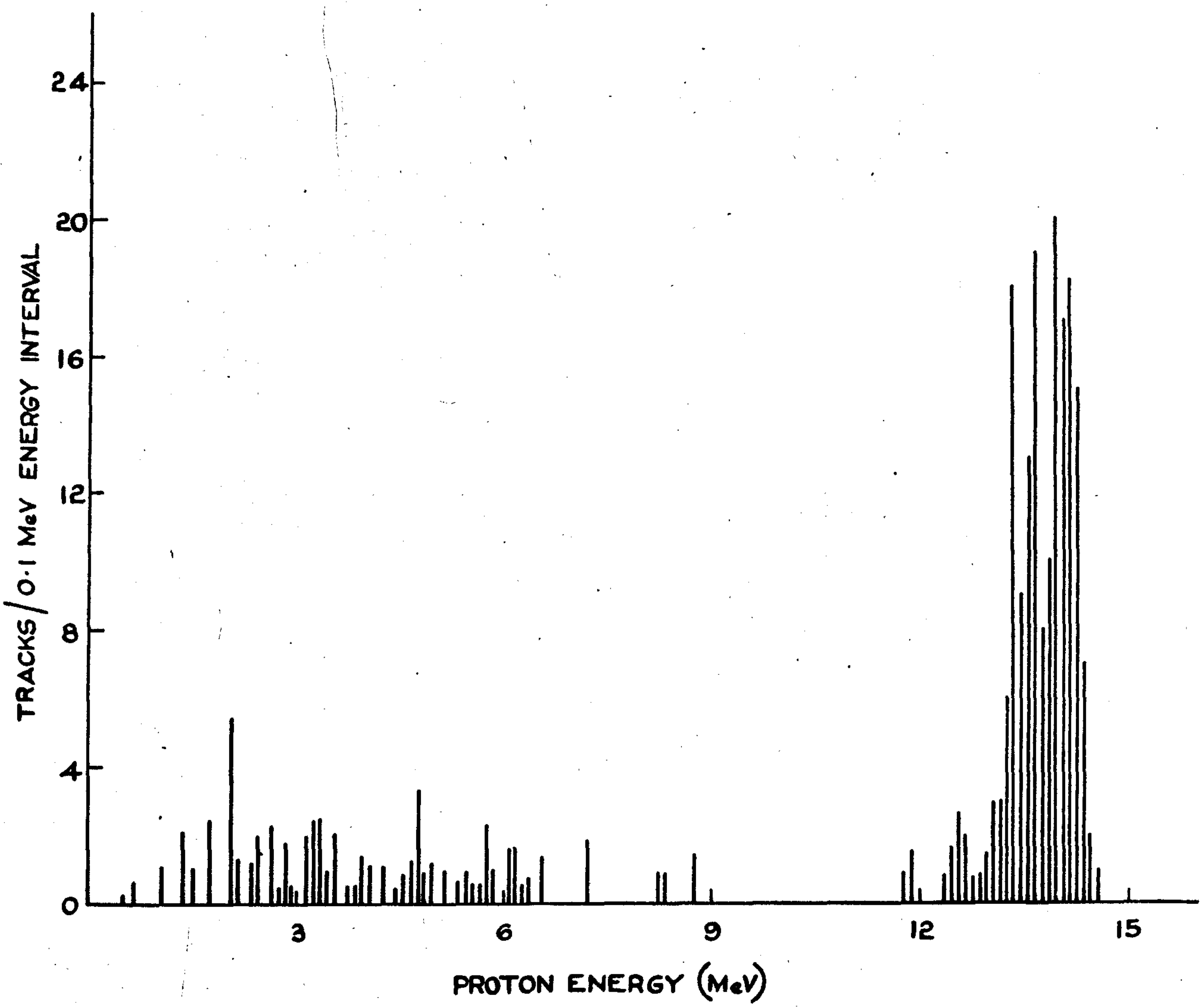


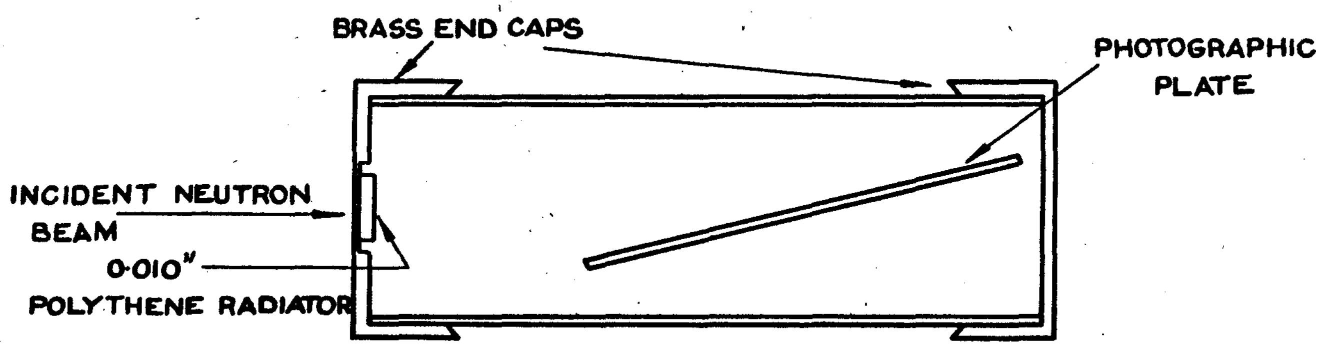
FIG. 1 General Diagram of apparatus.



A.E.R.E. NP/R.1912. FIG.2. ELECTRONICS BLOCK DIAGRAM.



A.E.R.E. NP/R.1912. FIG.3. INCIDENT NEUTRON SPECTRUM.



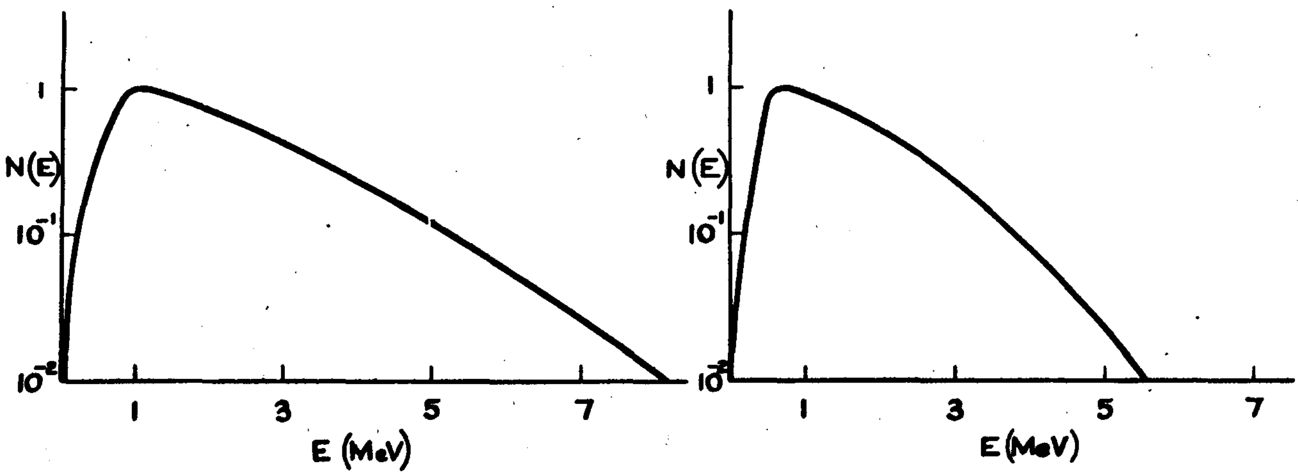
A.E.R.E. NP/R.1912. FIG. 4. PHOTOGRAPHIC PLATE VACUUM CHAMBER.

(a) FISSION NEUTRONS.

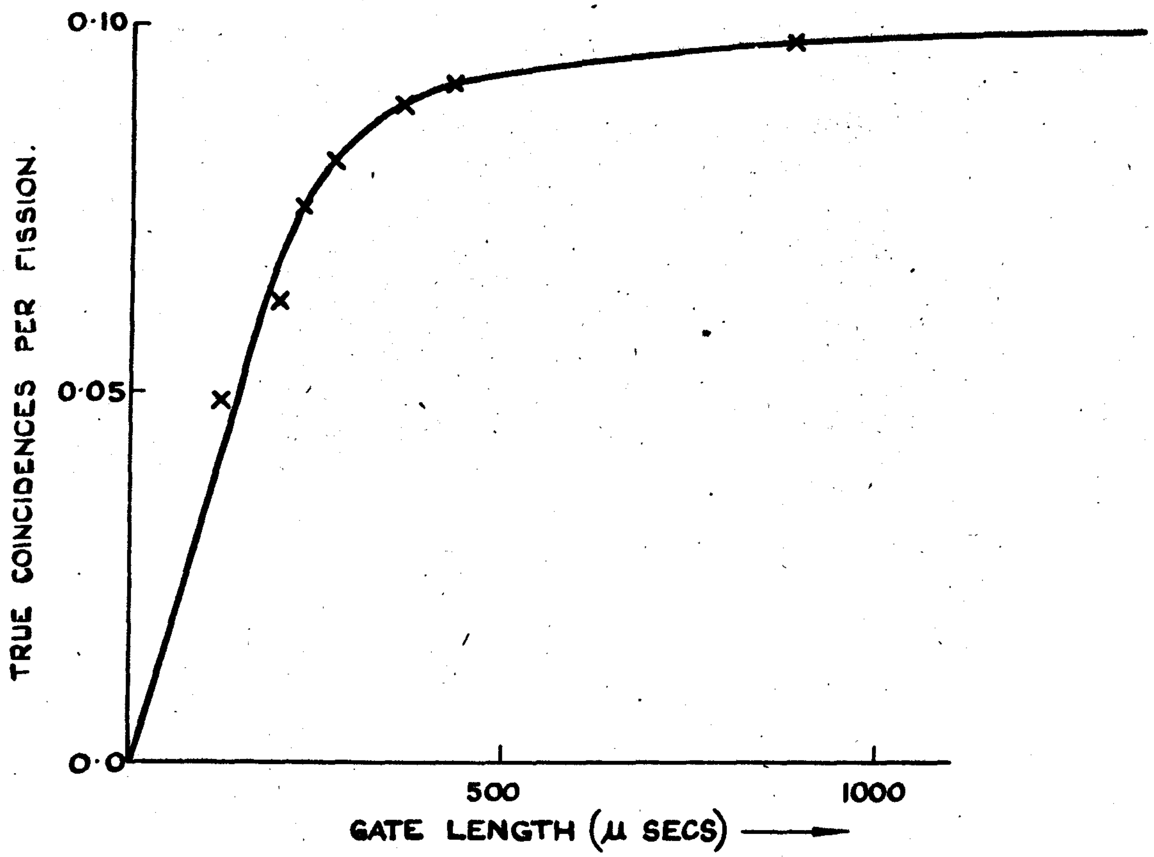
$$N(E) = e^{-E} \sinh (2E)^{\frac{1}{2}}$$

(b) 'EVAPORATED' NEUTRONS.

$$N(E) = E\, e^{-E/KT}$$



A.E.R.E. NP/R.1912. FIG. 5. NEUTRON DETECTOR ENERGY SENSITIVITY.



A.E.R.E. NP/R.1912. FIG.6. VARIATION IN COUNTING EFFICIENCY WITH GATE LENGTH.