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The study of prompt neutron spectra of fast neutron induced fission of U-238

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MEASUREMENT OF THE PROMT NEUTRON SPECTRUM OF ^{238}U FISSION

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ABSTRACT

The prompt neutron spectrum of ^{238}U fission induced by 12 MeV neutrons was measured using a multi-segment fission chamber and a two-arm TOF speotrometer. The flight time of the incident neutrons was event by event recorded. Use of coincidence between the fission fragments and neutrons enabled the fission neutrons to be distinguished from other secondary ones. The events induced by 12 MeV neutrons were software-selected by gating the 12 MeV peak of incident neutron TOF spectrum.

The measured spectrum can be roughly described by the Maxwellian distribution with T equal to 1.46 ± 0.04 MeV.

1. Introduction

The knowledge of the neutron spectrum of ^{238}U fission and its dependence on incident neutron energy is of great importance for designing fast neutron devices such as fast breeder reactor and fusion-fission hybrid reactor. It is also interesting for study of fission mechanism. There are no experimental data in the incident energy range 8 to 13 MeV because of lack of monoenergetic neutron source. In the case of incident energy greater than 6 MeV, second chance fission (n, n'f) might occur which perhaps has an observable influence on fission neutron spectrum. The present measurement at En = 12 MeV should be helpful to verify the theoretical models.

2. Experimental Arrangement

The measurement has been carried out at HI-13 Tandem Van de Graff Accelerator Laboratory of CIAE. The experimental arrangement is shown in Fig. 1. The primary neutrons of 12 MeV with breakup neutrons were produced at 0° direction via the D(d,n) reaction. A pulsed deuteron beam of 9.4 MeV, with a pulse width of 1.0 ns, a repetition rate of 4 MHz and average beam current of 1.3 mA impinged on a gas cell filled with 4.3 atm. deuterium gas.

The natural uranium has been both-side electro-deposited on the 0.2 mm thick plates of stainless steel with deposition thickness of about o.5 mg/cm^2. The 103 plates in all were loaded into a parallel-plate ionization chamber in spacing of 1.5 mm. The total amount of the deposited natural uranium was about 5 g. The chamber operated in multi-segment mode and filled with pure methane at 4.3 atm. The distance between centres of the gas cell and the chamber was 64 cm.

The fission neutrons were detected by two well shielded liquid scintillators of 25 cm in diameter by 5 cm thick. The detectors were placed at $\pm 100^\circ$ to the incident neutron beam. Time of flight technique was used with flight path of 2.5 m for both detectors.

A small liquid scintillator located at 0° and 3.1 m downstream of the gas cell served as a monitor of incident neutron TOF spectrum. The measured spectrum is shown in Fig. 2.

Use of coincidence between the signals from fission fragments and those from neutron detectors enabled the fission neutrons to be distinguished from other secondary ones. The timing output of fission chamber and pick-off signal of pulsed beam were fed into a TAC to measure the incident neutron TOF spectrum. Events induced by 12 MeV neutrons were finally selected by using coincidence between software-gated peak of the 12 MeV neutrons and the TOF spectrum of secondary neutrons detected with neutron detectors, while events from breakup neutrons were rejected.

As mentioned above, the background was suppressed in a great measure, a small amount of it, however, still leaked in via random coincidence. Such a random coincidence TOF spectrum was measured by the following means. The timing output of fission chamber was delayed for some integer cycles of pulsed beam and then fed into the same TAC used to measure fission neutron TOF spectrum. The TOF spectrum obtained in this operation reproduced fairly the random coincidence in the same cycle. Fig. 3(A) shows the measured TOF spectra, the real plus random and the random alone. Actually both of them were measured simultaneously and routed into different areas of computer memory. As can be seen from the figure, a peak of elastic scattering neutrons leaked in and distorted the fission neutron spectrum. The peak disappeared after subtracting the random coincidence, as shown in Fig. 3(B).

The schematic diagram of electronics is shown in Fig. 4. The 103 plates were grouped into eight electro-separated chambers in order to reduce the pile up of inter-plate capacitances and make rise time of fission fragment pulses fast. Each chamber was connected to individual preamplifier, fast filter amplifier and constant fraction discriminator. The eight timing outputs were mixed together for enabling eight singles of TOF spectrum to be measured in a single ADC, while these outputs were fed into an input register of computer interface to distinguish which chamber the fission event belongs to.

Two biases at Ep = 0.65 and 1.65 MeV were set for each neutron detector by electronics and software respectively. The higher was aimed at upgrading the ratio of effect to background in higher energy region of spectra. Moreover, the pulse shape discrimination of neutrons from gamma rays was used for eliminating gamma ray background. The efficiency response of neutron detectors was determined by combining Monte-Carlo calculation in standard code NEFF4 with experimental calibration using a low-mass ^{252}Cf ionization chamber. The chamber was made of

0.14 mm thick stainless steel with total weight of 1.65 gram and filled with flowing methane, as shown in Fig. 5. ^{252}Cf was deposited on a stainless steel foil of 24 mm in diameter and 0.09 mm in thickness by self-transfer. The separation of the source from the collecting electrode was 2 mm. The rise time of fission fragment pulses was 6 ns, while a detection efficiency of 99% to the fragments was achieved at a source strength of 3000 fission events/s. The chamber has not only good time resolution but also excellent alpha-suppression and discrimination of fragments from alpha-particles. Up to 3×10^6 counts over the fission neutron spectrum was accumulated for the low bias. A standard neutron spectrum of ^{252}Cf spontaneous fission has been recommended by Boldman. The comparison between Boldman's spectrum and the spectra measured for calibration yields two relative efficiency curves corresponding to the low and high biases respectively, as shown in Fig. 6. The calculated curves are consistent with the normalized experimental points within the experimental errors for a wide energy range less than 10 MeV.

3. Result and Discussion

The measured neutron spectra of ^{238}U fission at two biases connected with each other spontaneously. The available energy range in the present experiment is 0.9 to 10.5 MeV.

The spectrum can be roughly described by the Maxwellian distribution. The optimum fitting yields

$$T = 1.46 \pm 0.04 \text{ MeV} \quad \text{or} \quad \bar{E} = \frac{3}{2}T = 2.19 \pm 0.06 \text{ MeV}$$

as shown in Fig. 7. The error refers to statistic uncertainty and that from determination of detection efficiency. The theoretical calculation predicts that the average energy increases slowly as incident neutron energy goes up. The present measurement in comparison to previous data at different incident energies shows such a tendency, as can be seen from Fig. 8.

In principle, there might appear two Maxwellian components in the present measurement corresponding to (n,f) and (n, n'f) reactions respectively because the post-fission neutrons were emitted from fragments having different excitation energies. Unfortunately the two components can not be clearly separated, since accuracy of our data is not good enough. The fitting Maxwellian temperature here is thus a weighted average of two components. The theoretical calculation of spectrum based on standard nuclear evaporation model will be presented later on.

The authors would like to thank International Atomic Energy Agency for the support under the contract F4. CPR. 5188.

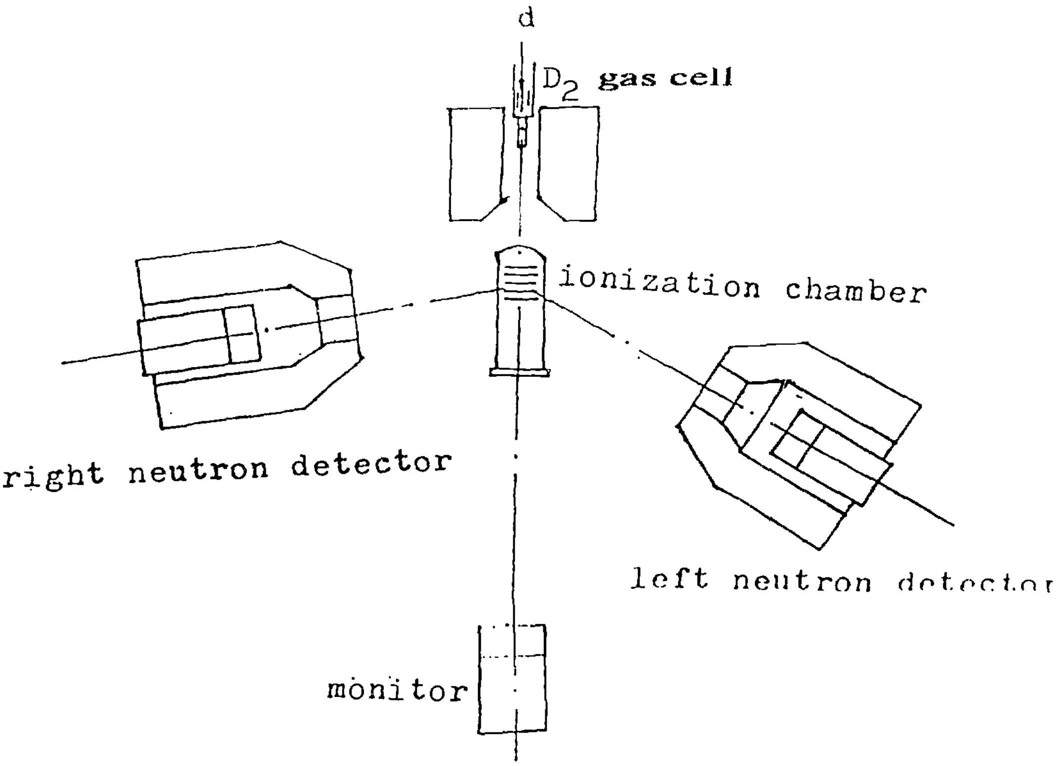


Fig. 1 The experimental set up

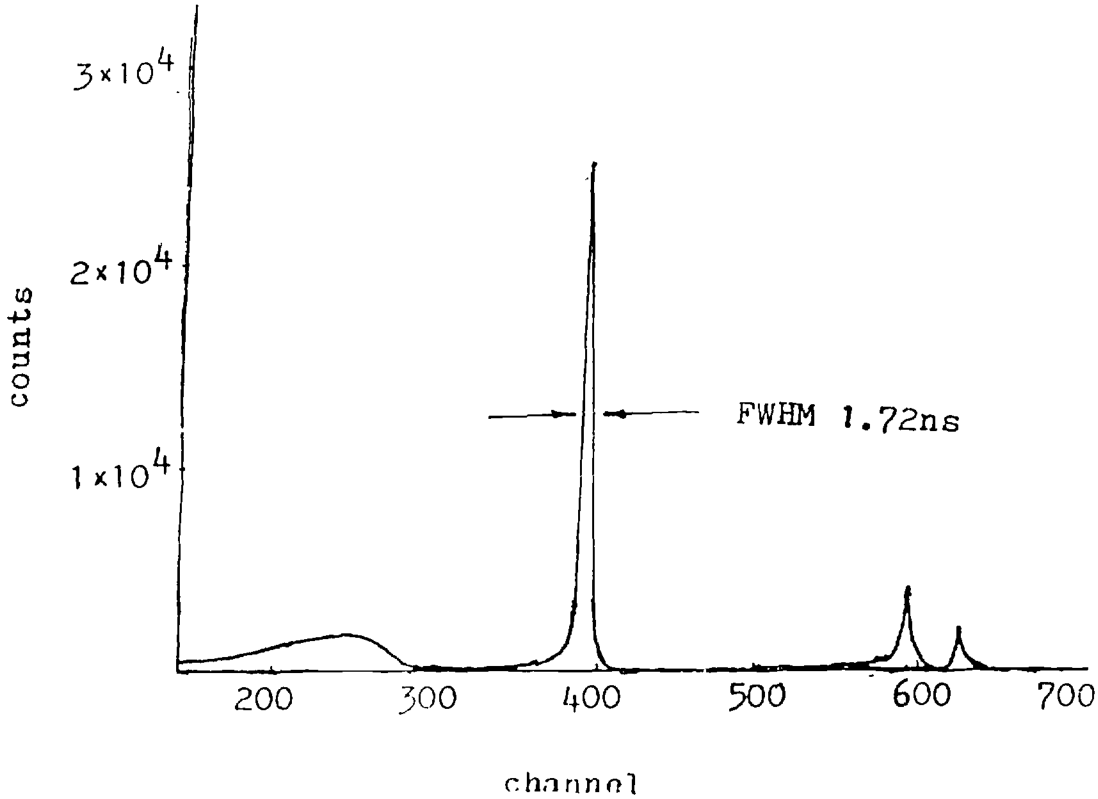


Fig.2 Primary neutron TOF spectrum
measured by 0° monitor

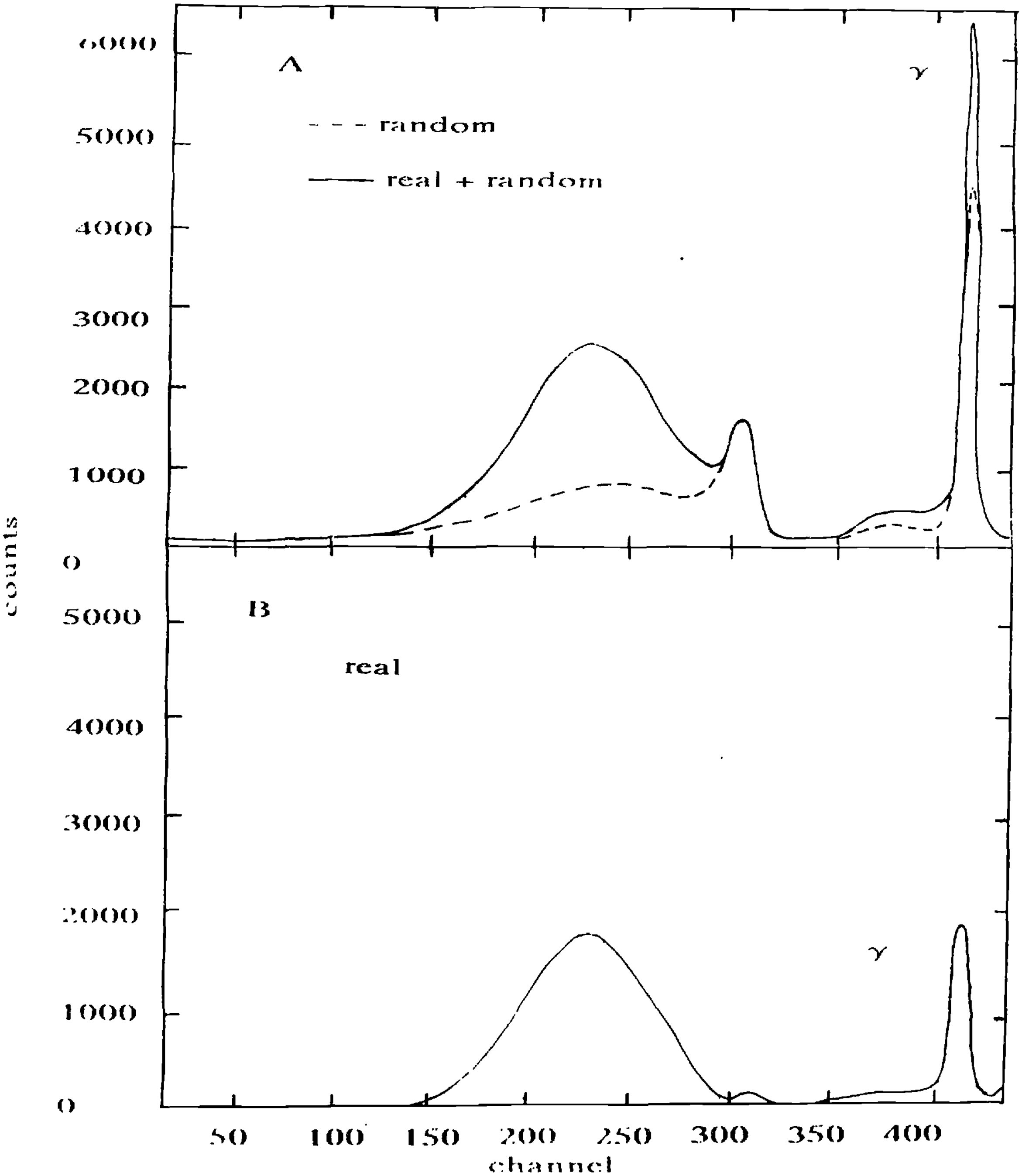


Fig. 3 Fission neutron TOF spectrum

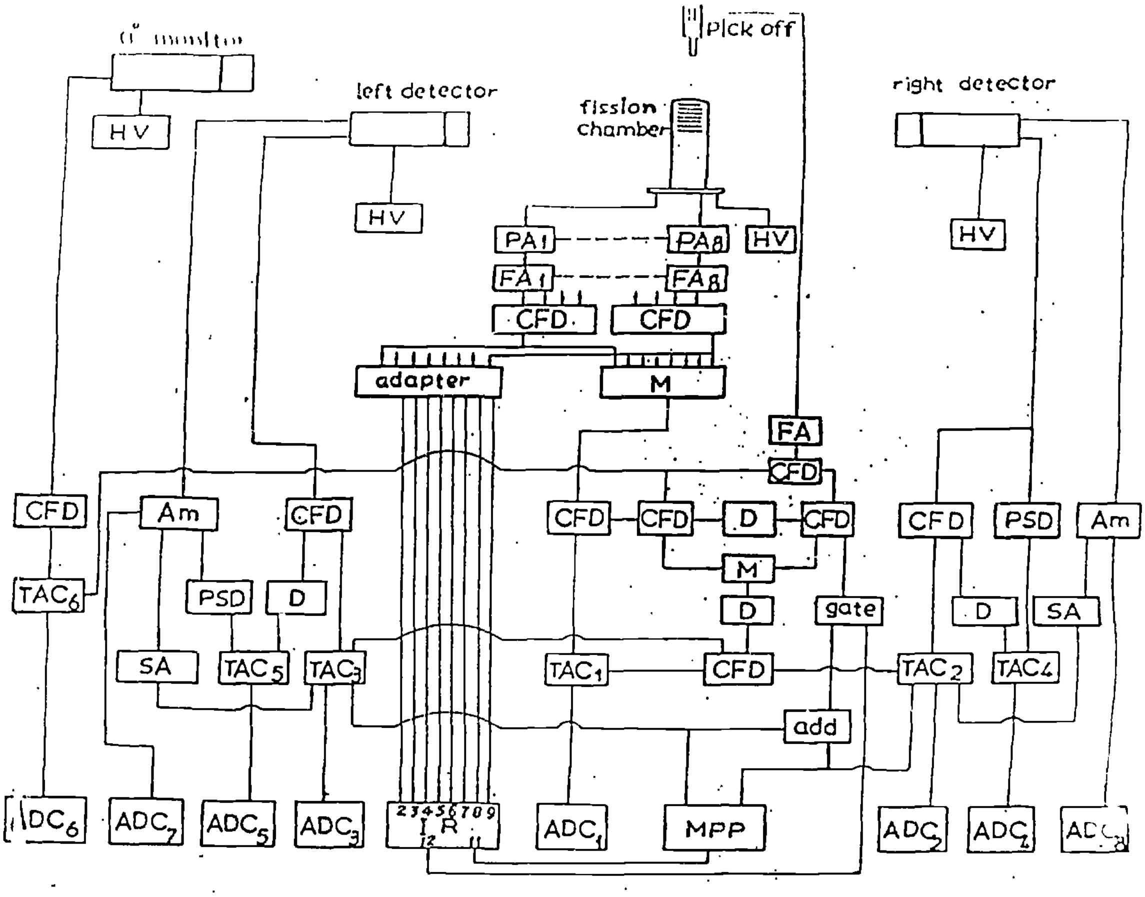


Fig.4. Block diagram of the electronics
HV--high voltage power supply; Am--amplifier; PA--preamplifier; D--delay; FA--fast amplifier; CFD--constant fraction discriminator; SA--single channel analyzer; MPP--multi parameter plate; PSD--pulse shape discriminator; M--mixer; IR--input register

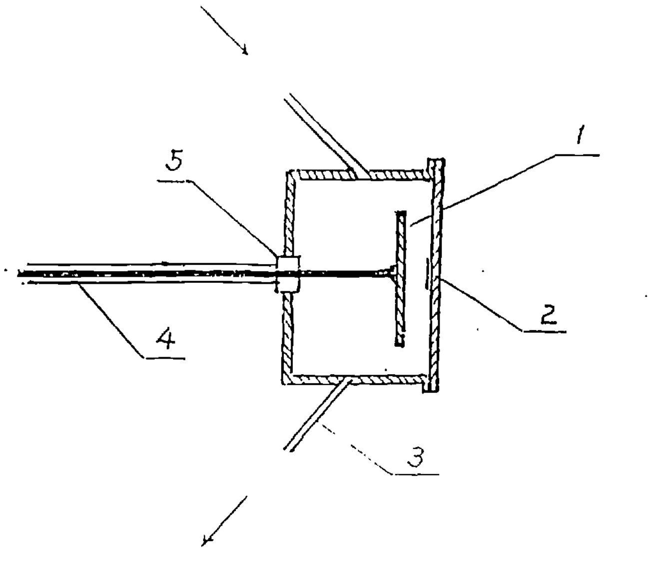
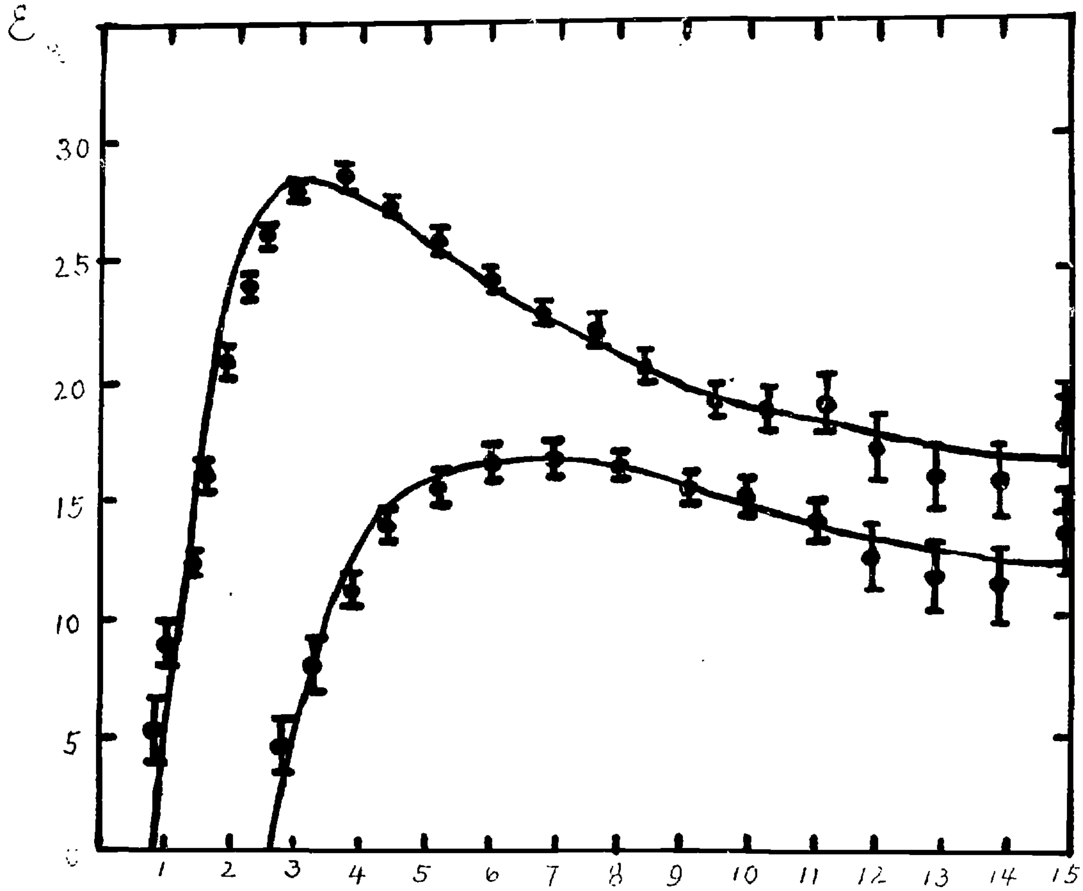


Fig. 5 A sketch of the miniature fast fission chamber of ^{252}Cf
1 collecting electrode; 2 deposited ^{252}Cf;
3-pipe for flowing methane; 4 output cable; 5 electric insulator.



E_n MeV

Fig 6 The efficiencies of the neutron detector

— calculated curves

I experimental calibration with [illegible]

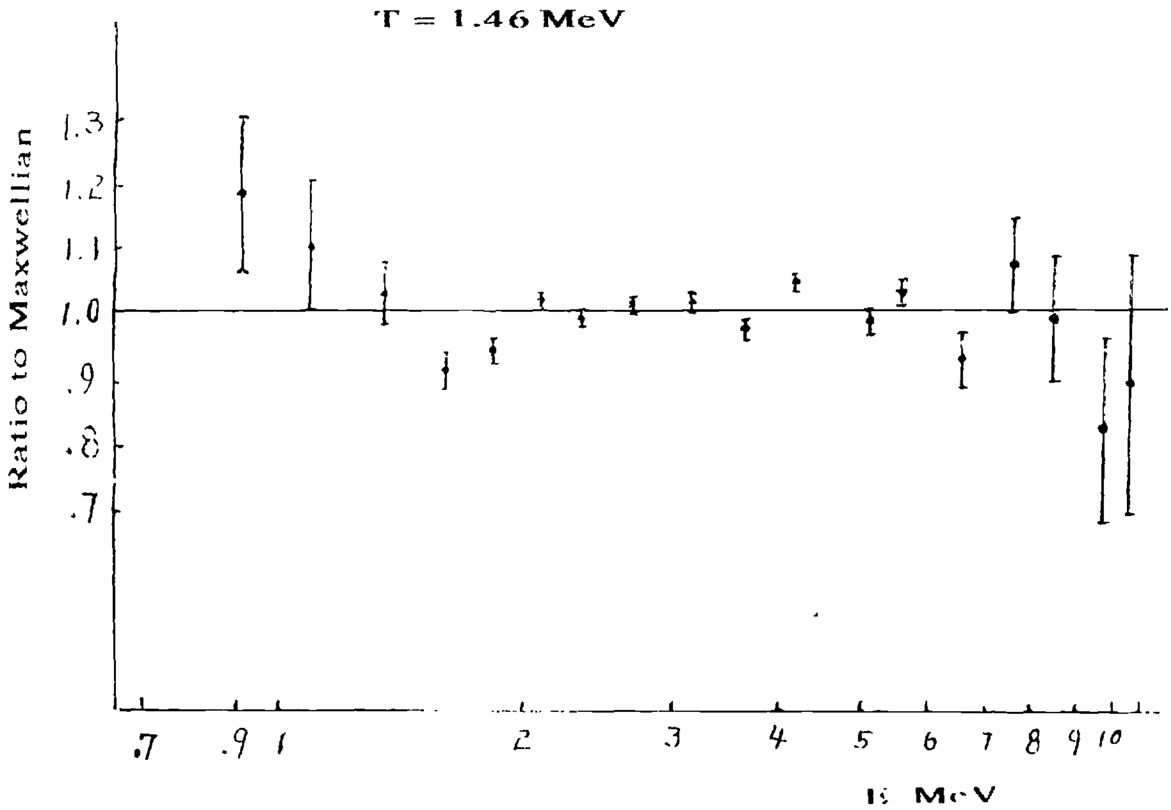


Fig. 7 The measured prompt neutron spectrum of ^{238}U fission induced by 12 MeV neutrons

THE DATA OF ENERGY SPECTRUM N(E) PLOTTED IN FIG. 7

Energy Range (MeV)	Assign-ed E(MeV)	ΔE (MeV)	N(E)-Counts Norma-lized to ΔE=1 MeV	Relative Error (%)	Maxwe-llian Fitting Value with T=1.46 MeV	The Ratio of Data to Fitting Value
11-10	10.5	1.0	585	20.0	657	0.89
10-9	9.5	1.0	1020	14.0	1243	0.82
9-8	8.5	1.0	2306	10.0	2337	0.99
8-7	7.5	1.0	4681	7.3	4364	1.07
7-6	6.5	1.0	7471	4.3	8077	.93
6-5.5	5.75	0.5	13162	2.6	12718	1.03
5.5-5	5.25	0.5	16758	2.3	17135	0.98
5-4.5	4.75	0.5	22882	2.0	22981	1.00
4.5-4	4.25	0.5	31966	2.0	30651	1.04
4-3.5	3.75	0.5	39534	1.7	40596	0.97
3.5-3	3.25	0.5	53919	1.6	53287	1.01
3-2.5	2.75	0.5	69678	1.6	69114	1.01
2.5-2.25	2.375	0.25	82029	1.6	83109	0.99
2.25-2	2.125	0.25	94871	2.4	93347	1.02
2-1.75	1.875	0.25	98134	3.5	104120	0.94
1.75-1.5	1.625	0.25	104623	3.5	115098	0.91
1.5-1.25	1.375	0.25	128060	5.0	125833	1.02
1.25-1	1.125	0.25	148800	10.0	135157	1.10
1-0.8	0.9	0.2	167800	12.5	141105	1.19

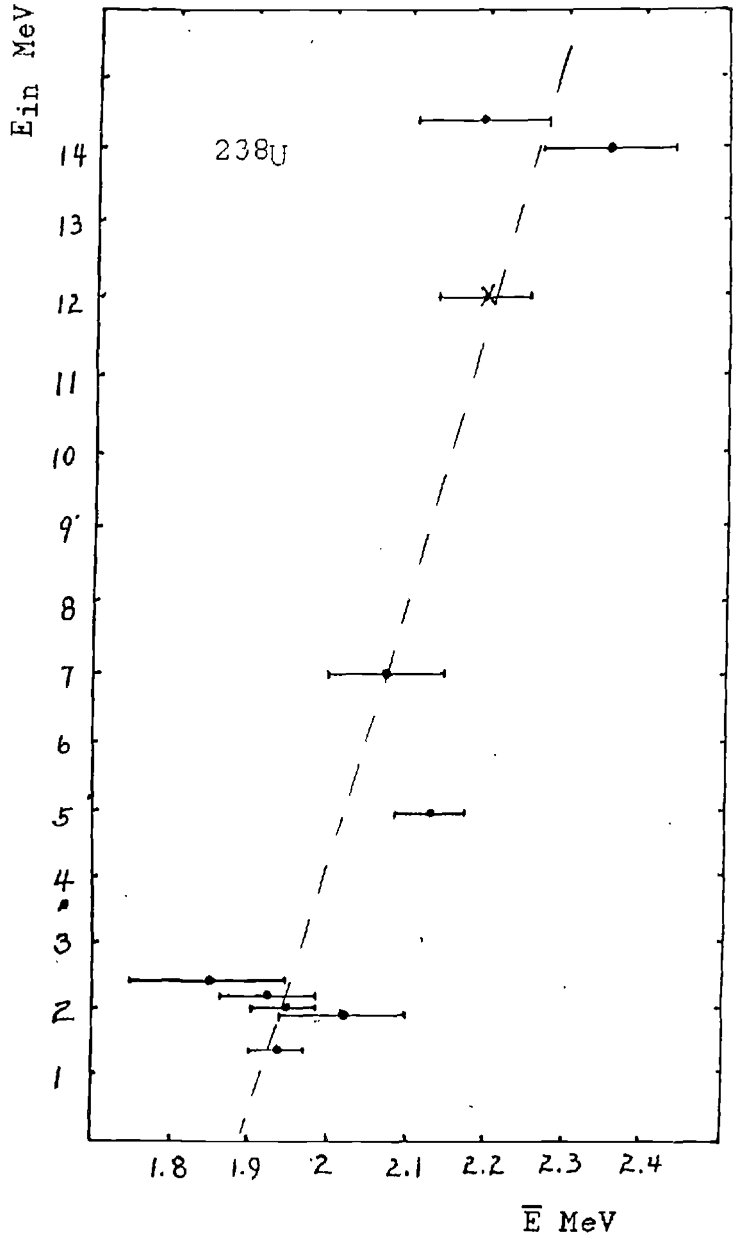


Fig.8 Comparison of our result with some previous data
present result
previous data(See André BERTIN, Robert BIOS, Joël FREHAUT, Rapport-R-4913, Juin 1978)