MEASUREMENT OF PROMPT NEUTRON SPECTRA OF ^{238}U FISSION INDUCED BY 10.17 AND 12.12 MeV NEUTRONS

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ABSTRACT

Experimental method to measure the prompt neutron spectra of ^{238}U fission induced by fast neutrons has been developed at HI-13 Tandem Van de Graaff Accelerator Laboratory of CIAE. These techniques employ a multi-segment fission chamber and two liquid scintillator neutron detectors. TOF (time of flight) techniques are used for primary neutrons to select the fission events induced by monoenergetic neutron from ^{2}H(d, n) reactions instead of breakup neutrons from ^{2}H(d, np) reactions. The fission neutron TOF spectra are measured in coincidence with the fission fragments to distinguish fission neutrons from other secondary neutrons. The method permits measurements to a fairly good accuracy under large neutron and gamma ray background. The techniques are described and experimental spectra are presented.

Keywords Fission neutron spectrum, TOF technique, Fission induced by fast neutron, Uranium 238

1 INTRODUCTION

The knowledge of the neutron spectrum of ^{238}U fission and its dependence on incident neutron energy is of importance for designing fast neutron devices such as fast breeder reactor and fusion-fission hybrid reactor. So far there are no experimental data in the incident energy range 8 to 13 MeV for lack of monoenergetic neutron source. In the case of incident energy greater than 6 MeV, second chance fission (n, n′f) might occur. The n′ neutrons have perhaps an observable influence on fission neutron spectrum. The present measurements at 10.17 and 12.12 MeV should be helpful.

One of the key points in this experiment is how to distinguish the fission neutrons from serious background ones. The fission fragment signals coming from a fast fission ionization chamber are used in coincidence with the fission neutron signals to reduce the background to 10^{-3}. The layer of the deposited natural uranium should be thin enough to permit most of the fission fragments to pass through it. The total quantity of the sample is only 5 g, even the fission chamber contains 103 plates both sides coated with uranium. The average distance between the deuterium gas cell and the fission sample is

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64 cm, which is not long enough to clearly separate the monoenergetic neutron peak and the continuous breakup neutrons in the primary neutron TOF spectrum. This problem was solved by some means instead of longer flight path, which would make counting rate decrease. The compromise between the counting rate and the time resolution has to be made in a limited beam time. The amount of material seen by neutron detectors is much larger than the quantity of the uranium, so that the random coincidence background is still comparable to the effect and it should be measured simultaneously. That makes the experiment more complicated.

2 EXPERIMENTAL ARRANGEMENT

The measurements have been carried out at HI-13 Tandem Van de Graaff Accelerator of CIAE. The experimental arrangement is shown in Fig.1. The primary neutrons are produced at 0° direction via ^{2}H (d, n)^{3}He reaction. The neutron-production target is a 2.5 cm long cylindrical cell with a window of 0.25 mel thick Havar foil and pressurized deuterium gas at 0.45 MPa. The axis of the gas cell is along the accelerated deuteron beam direction. The repetition rate of the pulsed beam with a pulse width of 1.0 ns is 4 MHz and its typical beam intensity is 1.2 μA. The energies of the deuteron beam are 7.4 MeV for 10.17 MeV neutrons and 9.4 MeV for 12.12 MeV neutrons respectively.

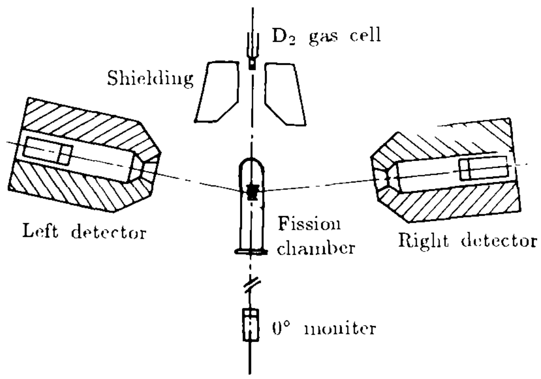

Fig.1 The experimental arrangement

A design principle of the fission chamber is to make material around the fissile sample as little as possible. The ionization fission chamber is a stainless steel cylinder with 10 cm in diameter and 50 cm in length. The thickness of its wall is 1 mm. It contains 103 parallel disks with 9 cm in diameter in spacing of 1.5 mm. It was located at the beam direction. The natural uranium is both-sides electro-deposited on the 0.2 mm thick disks of stainless steel with deposition layer of about 0.5 mg/cm^2 thick, which is thin enough to permit most of the fission fragments to pass through. The diameter of the deposited uranium layer is 8 cm. The amount of the deposited natural uranium is about 5 g. The chamber is filled with pure methane at 0.43 MPa. The working voltage of the chamber is +470 V. As shown in Fig.1, the fission chamber is placed at the zero degree direction with respect to the beam, and the distance between centers of the gas cell and the sample is 64 cm. This is the minimum distance necessary to obtain adequate time separation between the arrival of the monoenergetic neutrons and the continuum neutrons. The sample has been loaded near the front end of the chamber, the heavy material including a flange with cable terminals and preamplifier is at the other end and can not be seen directly by neutron detectors. The 103 disks are divided into eight separate segments for following reasons: 1) To reduce the uncertainty of flight path, because the distance from the first disk to the last one is about 17 cm, which is rather large in comparison with the flight path of the primary neutrons. That results in different flight time of the primary neutrons reaching different disks and difficulty in separating monoenergetic neutrons from the breakup neutrons in the primary neutron TOF spectrum. 2) To reduce the interdisk capacitances and to make the rise time of fission fragment pulses faster. Each segment is connected to individual preamplifier, fast filter amplifier and constant fraction discriminator as shown in Fig.2. The eight timing outputs are mixed together and then fed into a TAC. Therefore eight primary neutron TOF spectra could be measured with a single ADC, each of them has their own flight path, while these timing outputs are also fed into connectors 2 to 9 of an input register (IR) in the computer interface to distinguish which segment the fission event belongs to.

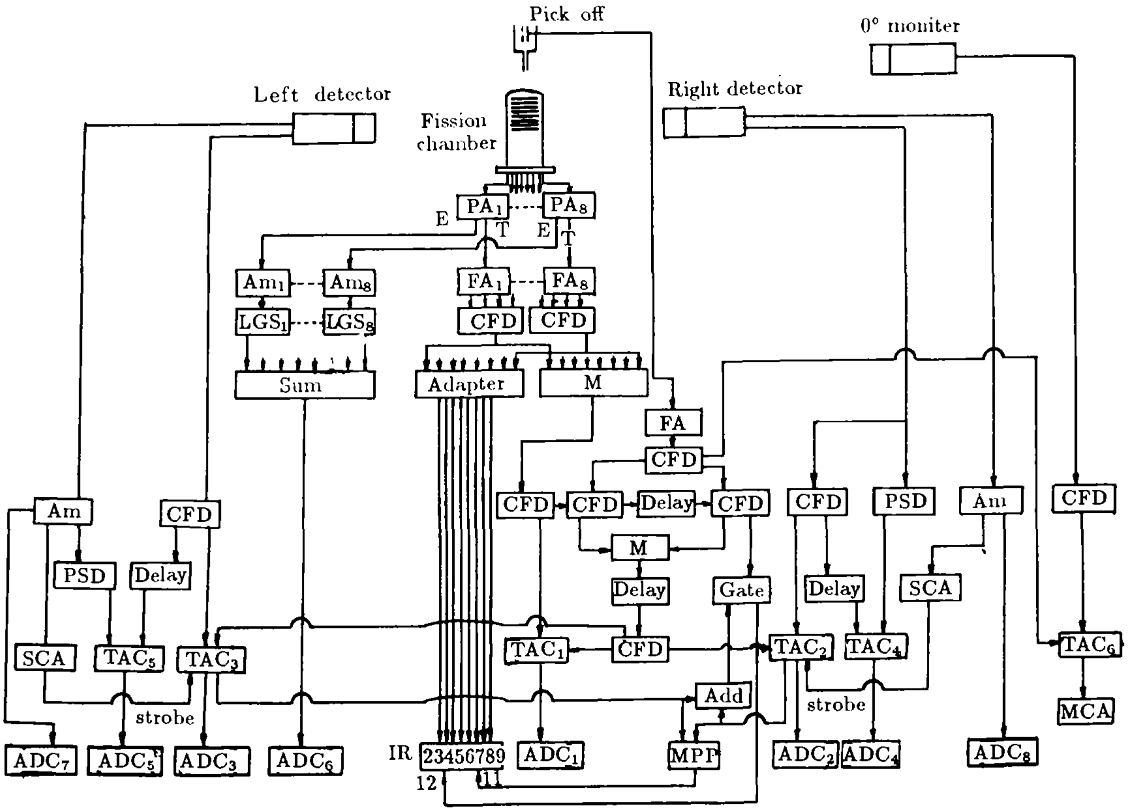

Fig.2 The block diagram of electronics

PA—Preamplifier; FA—Fast amplifier; Am—Amplifier; LGS—Linear gate stretcher; TAC—Time to amplitude converter; SCA—Single channel analyzer; M—Mixer; IR—Input regester

The arrival of the deuteron beam pulses on target is detected with a capacitive pickoff loop located in front of the neutron-production target in the beam tube. These pickoff signals are used to measure both primary neutron and fission neutron TOF spectra as stop signals.

A small liquid scintillation neutron detector located at 0° direction and 3.1 m away from the gas cell served as a monitor of the primary neutron TOF spectrum. The measured spectrum is shown in Fig.3.

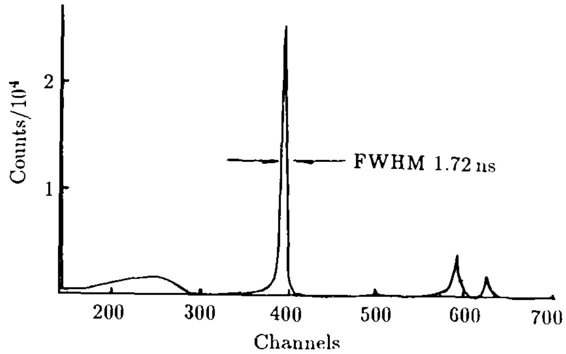

Fig.3 Primary neutron TOF spectrum measured by 0° monitor at 12 MeV

The fission neutrons are recorded by two heavily shielded detectors, consisting of ST-451 liquid scintillators of 25 cm in diameter by 5 cm thick and XF-2040 photomultipliers, which are placed at 100° direction with respect to the primary neutron beam on opposite sides. TOF is used with flight path of 2.5 m for both neutron detectors. If the angles between the primary neutron beam and the direction of the neutron detectors were close to 90°, the flight paths of fission neutrons emitted from different segments of the fissile sample would have been almost same. Although it would have been convenient for data treatment, but both neutron detectors would have seen the opposite shieldings, which could have increased seriously the backgrounds in the fission neutron TOF spectra. In addition, self-absorption effect of the fission neutrons in backing and the depositing layer would have distorted the fission neutron TOF spectrum. Those are the reasons why 100° is chosen. At this angle, the flight path difference of the fission neutrons emitted from the first and last segments is about 3 cm, which is less than the diameter of the deposited uranium layer and could be acceptable.

3 DATA ACQUISITION AND TREATMENT

Two biases at $E_p = 0.65$ and 1.65 MeV are set for each neutron detector by electronics and software, respectively. The higher bias is aimed at upgrading the effect-to-background ratio in higher energy region of the fission neutron TOF spectrum. Moreover, pulse shape discrimination is used only for the higher bias to eliminate gamma ray background. In measuring fission neutron TOF spectrum the pickoff signals are employed instead of the fission fragment signals because the timing characteristic of the latter is not well enough. In this case the timing outputs of the pickoff signals have to pass through a gate set by fission fragment timing signals before being fed into TACs.

As an example, a measured primary neutron TOF spectrum for the 6th segment of the chamber is shown in Fig.4(a). The monoenergetic neutron peak with an obtained FWHM of 8.6 ns could not clearly be separated from the continuum neutrons coming from the three-body breakup process ^{2}H(d, n)pd for the flight path of 64 cm. If monoenergetic neutrons were selected out only by setting a software gate A, indicated by the arrows in Fig.4(a), then a lot of monoenergetic neutrons would have been lost. Alternatively a new method is adopted by us to improve it. For constant fraction discriminators connected with the fission chamber the zero-crossing time is a function of the amplitude of the input signals. According to the amplitude the linear spectrum of the fission fragments is divided into eight groups by setting gates in offline analyses, the corresponding primary

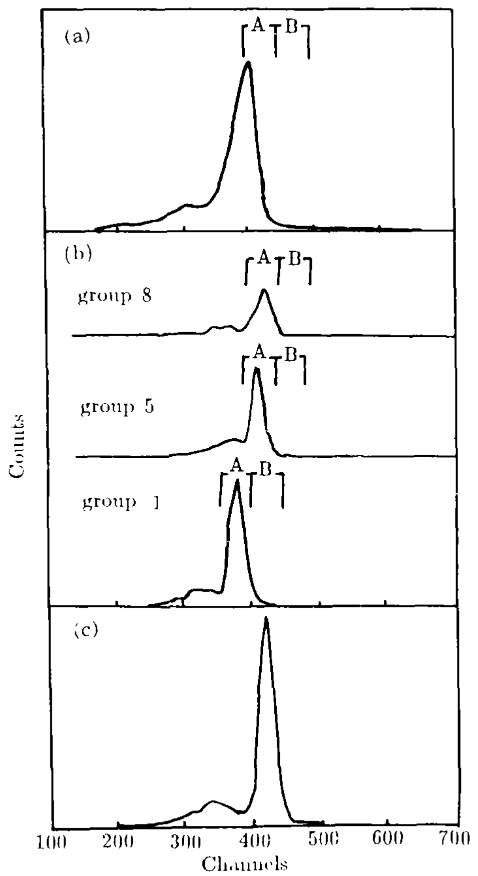

Fig.4 Primary neutron TOF spectrum at 10 MeV for segment 6 of the fission chamber

(a) Total spectrum; (b) Divided spectra corresponding to different amplitude ranges on the fragment linear spectrum. Gate A only covered monoenergetic peak and gate B for background measurement; (c) Sum spectrum of eight divided spectra shifted by aligning positions of the valley between monoenergetic peak and continuum neutrons

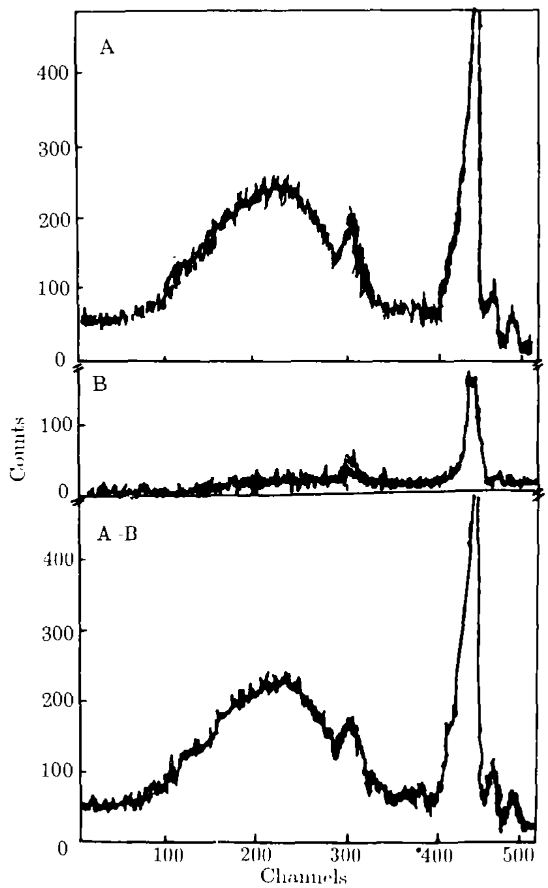

Fig.5 Fission neutron TOF spectra for segment 6 of the fission chamber and left neutron detector with low bias at 10 MeV

The effect plus background spectrum A corresponding to the gate A on the primary neutron TOF spectra and background spectrum B corresponding to the gate B shown in Fig.4

neutron TOF spectra are shown in Fig.4(b). As can be seen from the figure, the positions of the TOF spectra shifted along x axis with changing of amplitude. In such case, the primary neutron peaks with typical FWHM of 5.7 ns could be clearly separated from the continuum neutrons.

The backgrounds are treated as follows. At first, in the monoenergetic peak of incident neutron beam the scattered background must be subtracted. Then, the accidental (i.e. random) coincidence events between signals from fission chamber and neutron detectors should also be subtracted. So altogether four spectra (A, B, C and D, which are defined later) ought to be measured. The true effect spectrum will equal to which are defined later) ought to be measured. The true effect spectrum will equal to (A−B)−(C−D). As shown in Fig.4(b), gate A and B are set on each of these partial primary neutron TOF spectra. Gate A only covers the monoenergetic peak and rejects the continuum breakup neutrons. Gate B, with the same width as gate A, is set at the right of the monoenergetic peak for fissions induced by scattered neutrons randomly in time (background). Both gate A and B shift according to the positions of the monoenergetic peaks in different partial primary neutron TOF spectra. Therefore, most fission events induced by the monoenergetic neutrons could be effectively extracted. Corresponding to the software gate A and B on the primary neutron TOF spectra, an effect plus background spectrum A and the background spectrum B are obtained respectively for each segment of the fission chamber and for each neutron detector. A spectrum, called (A–B), is obtained by subtracting B from A. The spectra A, B, and (A–B) for the left neutron detector and the 6th segment are shown in Fig.5.

The use of fast-fast coincidence between the signals from fission fragments and those from neutron detectors enables the fission neutrons to be distinguished from other secondary ones. But a small amount of the background leaks in via random accidental coincidence with fission events, the amount of which is still comparable to the effect. Such a random coincidence background TOF spectrum is measured simultaneously by the following means. The timing output of fission chamber is delayed by several integral cycles of pulsed beam and then feeds into a CFD (constant fraction discriminator) as a gate input, through which the pickoff signals pass and lead into the same TACs used to measure fission neutron TOF spectra. The TOF spectra obtained in this operation reproduce fairly the random coincidence in the same cycle. The random spectra are for all of the segments together, because no corresponding segment-induced signals are fed into the input register for the delayed fission events. The pickoff signals gated by delayed fission timing outputs are gated again by TAC output signals of either of the neutron detectors and then fed into connector 12 of the input register to indicate, that these are the random coincidence events. For the random coincidence measurements the primary neutron TOF spectra are also obtained and two gates, C and D, are set on it, which cover monoenergetic neutron peaks and background respectively as same as gate A and B in effect measurements. Corresponding to the gate C and D, two random coincidence spectra, called spectra C and D, are obtained respectively. The random spectrum (C–D) is obtained by subtracting spectrum D from spectrum C for each of the neutron detectors. The spectra C, D for the left detector are shown in Fig.6.

The random spectra (C–D) are for eight segments together and (A–B) spectra for each of the segments so that eight (A–B) spectra should be summed and formed a "real plus random" spectra. These (A–B) spectra for different segments shift along x axis, and they must be moved back by aligning the positions of gamma peaks before actual data acquisition. Fig.7(a) shows the fission neutron TOF spectra for the left neutron detector at low bias, the "real plus random" spectrum (A–B) and the random spectrum alone (C–D). As can be seen from the figure, elastic scattering neutrons leak in by random coincidence and form a elastic scattering peak on the fission neutron spectrum. The peak disappears after subtracting the random coincidence as shown in Fig.7(b).

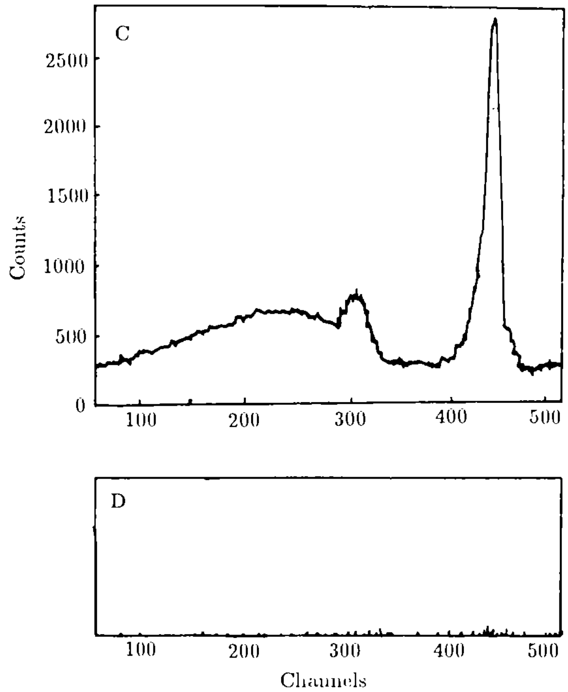

Fig.6 Random coincidence TOF spectra for left neutron detector with low bias at 10 MeV

Spectra C, D correspond to gates C, D on the primary neutron TOF spectrum respectively

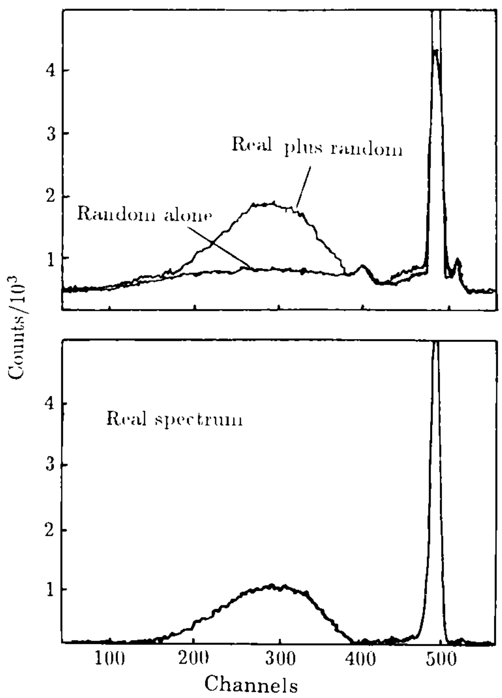

Fig.7 Fission neutron TOF spectra for left neutron detector at low bias with 10 MeV

(a) The real plus random and random alone;
(b) Real spectrum

Logic output signals of TACs (TAC-2 and TAC-3, see Fig.2) used in measurements of fission neutron TOF spectra for either left or right neutron detector are fed into MPP (multi-parameter plate) as general triggers, which lead to LAM (look at me) requisitions. It implies that the coincidence between neutron signals and fission signals is employed to trigger data acquisition. One advantage of using outputs of TACs as triggers is to reduce the counting rate at the computer interface, and consequently decrease the computer dead time and save recording tapes. A bit output on the rear-panel of the MPP is connected with connector 11 of the input register to indicate which neutron detector recording the fission neutron.

The primary neutron TOF spectrum measured by 0° monitor is recorded with a MCA (multi-channel analyzer) as seen in Fig.3. FWHM of the monoenergetic neutron peak is typically 1.72 ns. Two small peaks on the right of the monoenergetic peak are attributed to the gamma rays emitted from a diaphragm and the gas cell respectively. On the left of the monoenergetic peak there are continuum breakup neutrons. A gate is set on the spectrum to contain the monoenergetic peak. The area in this gate is used as a preset number to stop data acquisition of a run during measurement process.

The data accumulation time is about 120 h for each incident neutron energy. A ^{137}Cs gamma ray source is utilized several times during experiment to check biases of two neutron detectors. The multi-parameter events have been stored one by one into buffer tapes for online data acquisition and the events recorded in tapes would be sorted during offline analyses.

4 SUMMARY

The method described in this article is somewhat similar to that used in Ref.[1], but some new techniques are firstly adopted in this measurement. For example, linear spectrum is measured for each segment of the fission chamber and corresponding individual TOF spectra is obtained. In such case the monoenergetic neutrons are separated more clearly from the breakup neutrons. In addition, two big neutron detectors are used to increase the counting rate and improve the statistics with keeping adequate time resolution.

These techniques are developed especially for measuring prompt neutron TOF spectra of fissions induced by 8 to 13 MeV neutrons. It efficiently selects the available neutrons from a huge quantity of neutrons and gamma ray background.

Obviously the method is particularly well suited for incident neutron energy less than 10 MeV, where the monoenergetic neutrons are separated easily from the breakup neutrons by TOF technique. At energies above 14 MeV a large number of low energy continuum neutrons are produced by three- and four-body breakup processes in the source reactions, and the flight time differences between them get smaller. It is difficult for their separation. In this case ^{3}H(d, n) reaction instead ^{2}H(d, n) is a better choice.

Data analyses and experimental results will be given in Ref.[2].

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