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ν(m*) MEASUREMENTS FOR ^{233}U AND ^{235}U(n_{th},f)

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Abstract: Number of prompt neutrons as a function of individual fragment mass ν(m*) was measured for the thermal neutron-induced fission of ^{233}U and ^{235}U. By measuring the velocities and energies of two fission fragments simultaneously, preneutron-emission fragment mass m* and postneutron-emission fragment mass m were obtained. ν(m*) was deduced by subtracing m from m*. The fragment velocity was measured by a time-of-flight (TOF) method, and the start time was detected by a very thin plastic scintillator film detector. A silicon surface barrier detector was used to measure the fragment energy, which was also used as a stop detector of the TOF. The result of ν(m*) for ^{233}U(n,f) was in agreement with other data in the heavy fragment region but was 20 to 50% larger than those in the light one. ν(m*) for ^{235}U(n,f) showed a factor of 1.5 to 2 larger in the light fragment region and smaller in the heavy one than the other data.

(^{233}U, ^{235}U, thermal neutron, fission, number of prompt neutrons, fragment mass, velocity, kinetic energy, thin film detector)

Introduction

For the study of the shape and excitation energy of a fission fragment, it is important to know the number of prompt neutrons as a function of the individual preneutron-emission (initial) fragment mass ν(m*). Average total number of prompt neutrons are reported by many authors/1/, but the data of ν(m*) are little.

A measurement method of ν(m*) is classified in 'direct' and 'indirect' measurement methods. The direct measurement method is of measuring the velocities of both fission fragments and the emitted-neutrons simultaneously. The neutrons are generally detected by using a large liquid scintillator tank/2,3/. Whereas the indirect measurement method is of determining ν(m*) from the mass difference between the initial and the postneutron-emission (final) fragment mass numbers. These fragment masses are obtained by measuring the velocities and the kinetic energies of both fragments. The velocity of the fragment is usually measured by the time-of-flight (TOF) method and the energy is detected by an ionization chamber or a silicon surface barrier detector (SSB)/4,5,6,7,8,9/.

We measured the velocities and the kinetic energies of both fission fragments simultaneously ("Double-velocity Double-energy measurement method) and derived ν(m*) for the thermal neutron-induced fission of ^{233}U/10/ and ^{235}U.

Principle of ν(m*) Determination

In the fission phenomena, the mass and the momentum are conserved as

$$m_1^* + m_2^* = M \qquad (1)$$

$$m_1^* v_1^* = m_2^* v_2^* \;, \qquad (2)$$

where the asterisk means the quantities of initial fragment, m_i* and v_i* (i=1,2) are the mass and the velocity of the fragment respectively, and M is the fissioning nucleus mass. From Eqs.(1) and (2), the initial fragment mass is given by

$$m_i^* = \frac{v_i^*}{v_i^* + v_j^*} M \qquad (i=1,2 \quad j=3-i). \qquad (3)$$

The velocity measured experimentally, v_i, is that of the final fragment because the neutrons are emitted from the initial fragment within about 10^{-14} s after scission. Assuming the neutrons are emitted isotropically, the averaged fragment velocity does not change before and after the neutron emission, namely

$$v_i^* = v_i. \qquad (4)$$

The relation between the velocity and the kinetic energy E of the final fission fragment is given by

$$E_i = \frac{1}{2} m_i v_i^2. \qquad (5)$$

In this experiment SSBs were used for measuring the fragment kinetic energy. Then the following relationship between the energy and the pulse height/11/ is given as

$$E_i = (a + a'm_i)x_i + b + b'm_i, \qquad (6)$$

where x_i is the pulse height, a, a', b and b' are energy calibration constants. By using Eqs.(5)

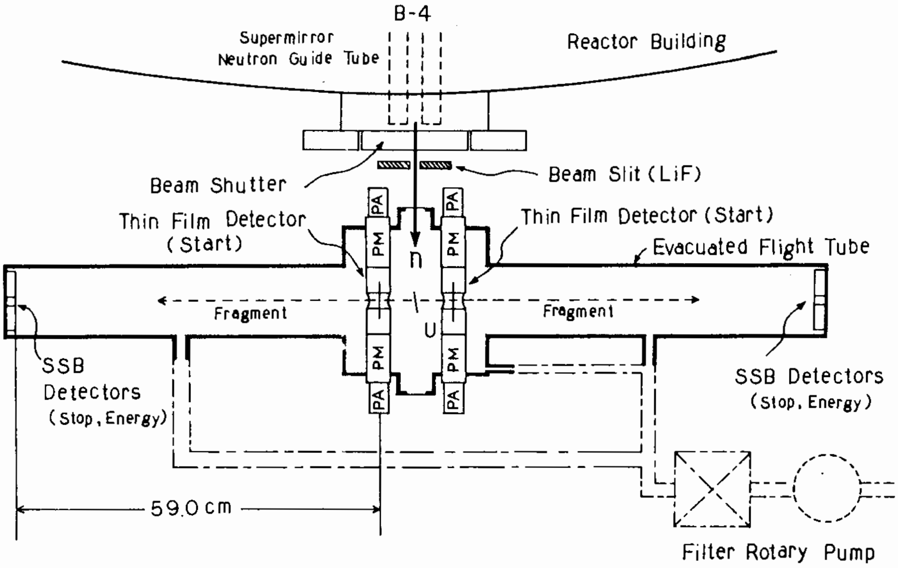

Fig. 1 Experimental arrangement for double-velocity double-energy measurement

and (6), the final fragment mass is obtained as

$$m_i = \frac{ax_i + b}{v_i^2/2 - a'x_i - b'} . \qquad (7)$$

The number of emitted-neutrons are determined by subtracting Eq.(7) from Eq.(3),

$$\nu(m_i^*) = m_i^* - m_i. \qquad (8)$$

Experiment

Apparatus

The experiments of double-velocity double-energy measurement for the thermal neutron-induced fission of ^{233}U and ^{235}U were carried out at the super mirror neutron guide tube facility of the Kyoto University Reactor (KUR)/12/. The experimental arrangement is shown in Fig.1. The neutrons were guided by the facility at distance of 11.7 m from the KUR core. The thermal neutron was collimated to 1 cm x 7 cm by a beam slit made of LiF, and the flux at the uranium target position was 5×10^7 n/cm² s.

The fragment velocity was obtained by a time-of-flight (TOF) method. The flight path was 59 cm. To obtain the start time of the fragment, very thin plastic scintillator film detector (TFDs) were used. On each end of the flight tubes, three SSBs (ORTEC F-series detectors) were mounted to detect the stop time and also to measure the fragment kinetic energy. TFDs, SSBs and a uranium target were installed in a evacuated chamber and two flight tubes. The vacuum was kept at about 10^{-4} Torr.

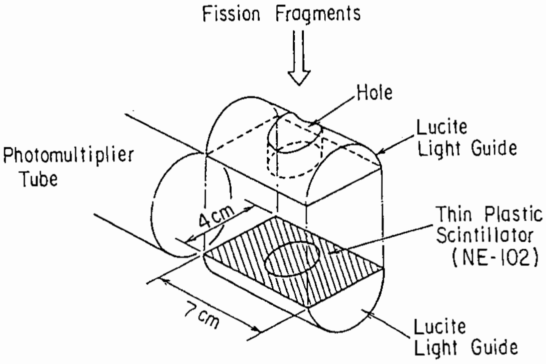

Fig. 2 Illustration of thin plastic scintllator film detector (TFD)

The uranium target was made from a very thin nitrocellulose film in which organic uranium compound was dissolved. The diameter of the target was 8 mm and the thickness was 7 μgU-233/cm² or 9 μgU-235/cm², which was determined by counting the number of fission events. The enrichment of ^{233}U was 99.47% and that of ^{235}U 90%.

The TFD illustrated in Fig.2 was placed at 3 cm apart from the uranium target on each fragment path. TFD has been developed by Muga et al./13/ and we have established a fabrication technique of thinner (less than ~50 μg/cm²) TFD. The characteristics of TFD have been reported elsewhere/14, 15/. The TFD used consists of a thin plastic scintillator film (NE-102), two lucite light guides and photomultipliers. The film whose thickness was 20 μg/cm² was sandwiched in two hemicylindrical light guides. The thickness of the film was determined by measuring the energy loss of α-particles of ^{252}Cf in the film. A hole of 1 cm diameter was bored in the light guide for the fission fragments passing through the film.

The electronics of the double-velocity double-energy measurement system is shown in Fig.3. The timing signal, start or stop signal, was fed into a time-to-amplitude converter (TAC) through a timing amplifier and a constant fraction discriminator (CFD). Only coincided four signals, two TAC signals and two energy ones, were taken by the Multi Parameter Data Aquisition System/16/. The data were accumulated in 1024 channels for each parameter and stored on a floppy disk event by event.

The time calibration of the TOF system was performed by measuring the time spectra of ^{252}Cf light fragment group with different length flight paths and using a time calibrator (ORTEC Model 462). The time resolution was 133 ns. The energy calibration was performed by using a spontaneous fission fragments of ^{252}Cf.

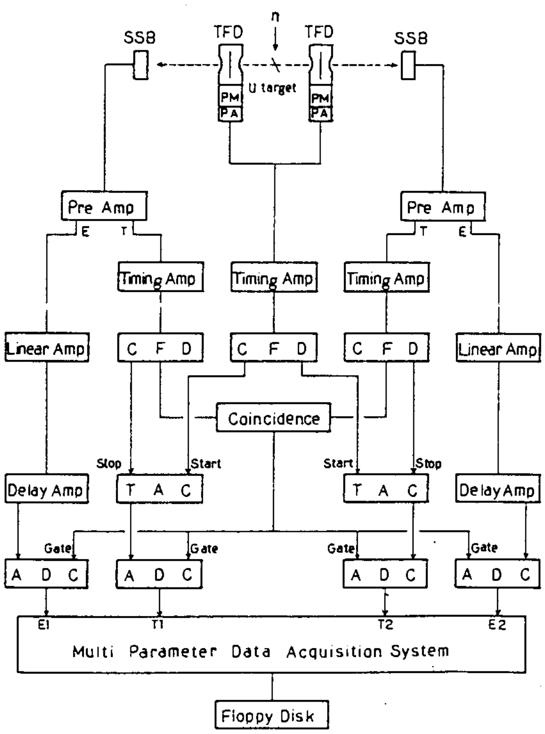

Fig. 3 Block diagram of electronic circuit for double-velocity double-energy measurement

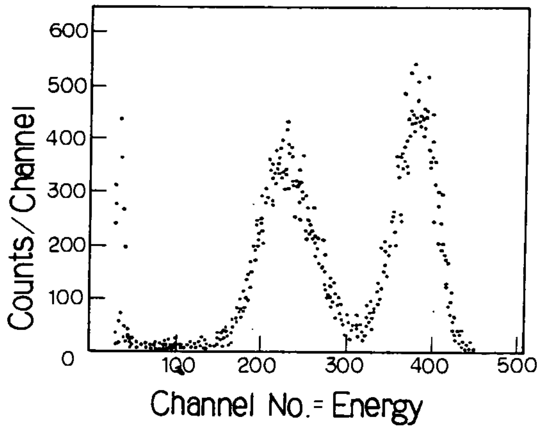

Fig. 4 Typical fragment TOF spectrum for $^{233}U(n,f)$

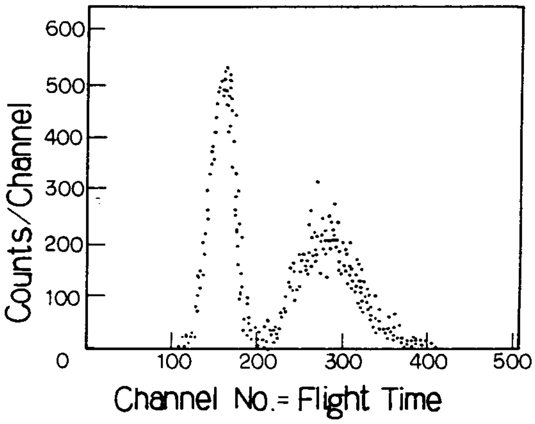

Fig. 5 Typical fragment kinetic energy spectrum for $^{233}U(n,f)$

Table 1. Mean values and standard deviations of the initial fragment mass, velocity, energy and average number of prompt neutrons for the thermal neutron-induced fission of ^{233}U and ^{235}U.

	$^{233}U(n,f)$		$^{235}U(n,f)$		
	Present	Milton and Fraser[4]	Present	Milton and Fraser[4]	Andritsopoulos [7]
$\langle m_L^* \rangle$ (amu)	94.36±0.23	94.57±0.10	95.93±0.23	96.08±0.10	95.87±0.07
$\sigma(m_L^*)$ (amu)	6.21	5.85	6.26	5.77	6.3
$\langle m_H^* \rangle$ (amu)	139.64±0.23	139.43±0.10	140.07±0.23	139.92±0.10	139.87±0.07
$\sigma(m_H^*)$ (amu)	6.21	5.85	6.26	5.77	6.3
$\langle V_L^* \rangle$ (cm/ns)	1.44	1.442	1.423	1.409	1.415
$\sigma(V_L^*)$ (cm/ns)	0.072	0.068	0.075	0.062	0.051
$\langle V_H^* \rangle$ (cm/ns)	0.975	0.963	0.977	0.966	0.97
$\sigma(V_H^*)$ (cm/ns)	0.073	0.070	0.073	0.071	0.086
$\langle E_L^* \rangle$ (MeV)	101.38±0.72	99.9±1.0	100.55±0.71	99.8±1.0	99.08±0.07
$\sigma(E_L^*)$ (MeV)	5.95	6.2	6.57	6.0	5.9
$\langle E_H^* \rangle$ (MeV)	68.78±0.34	67.9±0.7	69.25±0.34	68.4±0.7	68.190±0.10
$\sigma(E_H^*)$ (MeV)	7.48	7.3	7.73	7.5	8.7
$\langle E_K^* \rangle$ (MeV)	170.16±0.80	167.8±1.7	169.80±0.79	168.3±1.7	167.45±0.2
$\sigma(E_K^*)$ (MeV)	10.65	11.2	11.59	11.41	14.2
$\bar{\nu}(m_L^*)$	1.68±0.69	1.40	1.94±0.69	1.19	1.16±0.09
$\bar{\nu}(m_H^*)$	0.85±0.72	1.03	0.89±0.72	1.23	1.27±0.09

Results and Discussion

A typical fragment TOF spectrum for $^{233}U(n,f)$ is shown in Fig.4. The peak in the lower channel corresponds to the light fragment group and its mean flight time is 40.97 ns. The mean flight time of the heavy fragment group is 60.51 ns. In Fig.5, a typical fragment energy spectrum for $^{233}U(n,f)$ is shown. The peak in the higher channel corresponds to the light fragment group and its energy is about 101 MeV.

The mean values and errors concerning fragment mass, kinetic energy and velocity are listed in Table 1. The values of the present results agree well with other works within the errors.

For $^{233}U(n,f)$, the number of prompt neutrons as a function of initial fragment mass is shown in Fig.6. $\nu(m^*)$ is indicated with a solid circle and the total number of prompt neutrons as a function of heavy fragment mass with an open circle. The result of Apalin et al./2/ and of Milton et al./3/ are also plotted, which were obtained by 'direct' measurement methods. Present result is close to the data of Milton et al. in the heavy fragment region, while in the mass region of 100 - 110, the result is close to the data of Apalin et al. In the light fragment region the result disagrees with the other data and is 20 to 50% larger than the data of Apalin et al.

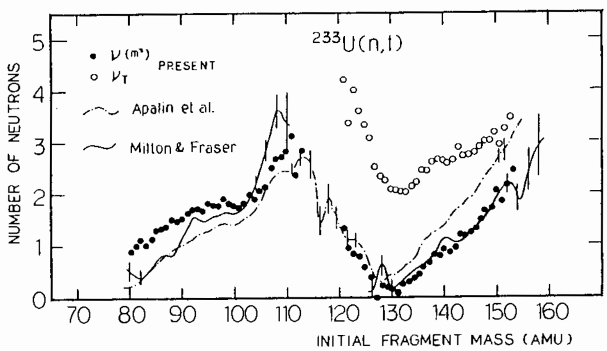

Fig. 6 Prompt neutron distribution $\nu(m^*)$ for thermal neutron-induced fission of ^{233}U

For $^{235}U(n,f)$, the present result of $\nu(m^*)$ is shown in Fig.7. In the light fragment region, our result is approximately a factor of 1.5 to 2 larger than the other data. On the contrary, it is a factor of 1.5 to 2 smaller than those in the heavy fragment region. The structure of $\nu(m^*)$ is similar to the data of Milton et al.

The $\nu(m^*)$-values are also listed in Table 1.

Conclusions

The number of prompt neutrons as a function of initial fragment mass $\nu(m^*)$ was measured by using the double-velocity double-energy method for the thermal neutron-induced fission of ^{233}U and ^{235}U. The $\nu(m^*)$ distribution obtained for $^{233}U(n,f)$ was in agreement with the result of Milton et al. in the heavy fragment region, but disagreed with the results of Milton et al. and

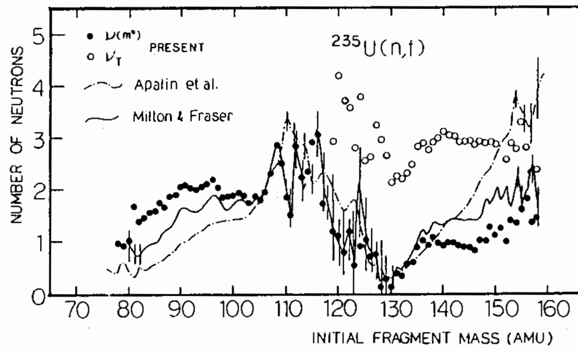

Fig. 7 Prompt neutron distribution $\nu(m^*)$ for thermal neutron-induced fission of ^{235}U

Apalin et al. in the light fragment region. Especially, the $\nu(m^*)$ in the light fragment region was 20 to 50% larger than the data of Apalin et al.

The result of $\nu(m^*)$ for $^{235}U(n,f)$ was a factor of 1.5 to 2 larger in the light fragment region and a factor of 1.5 to 2 smaller in the heavy fragment region than the other data. But the structure of $\nu(m^*)$ was similar to the data of Milton et al.

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