MEASUREMENT OF DOUBLE DIFFERENTIAL NEUTRON EMISSION CROSS SECTIONS OF U-238 INDUCED BY 14.2 MeV NEUTRONS

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Abstract: Double differential neutron emission cross sections of uranium-238 at 14.2 MEV have been measured by means of associated particle time of flight technique. The neutron flight path is 3.055m. The neutron detector consists of an st-451 liquid scintillator (ϕ105 x50mm) and an XP-2040 photomultiplier tube. The time resolution of the TOF spectrometer is about 1.2 ns. The double differential cross sections in the effective energy range 2 to 12 MEV are obtained at 13 angles between 5 to 155 degrees with an overall error of 5 to 15%. The data are corrected for neutron flux attenuation, multiple scattering and finite geometry with a Monte-Carlo code. The experimental results are compared with theoretical calculations and good agreement is achieved.

(Uranium-238,14.2 MEV neutron,double differential cross section)

Introduction

Uranium-238 is a very important fuel material in fast neutron breed reactors and fission-fusion hybrid reactors. Because of rapid change of the fission cross sections of uranium-238 with neutron energy, an accurate measurement of the secondary neutron spectrum of uranium-238 is of importance both for calculation of fission rate and for check of nuclear models.

Double differential neutron emission cross sections of uranium-238 at 14 MEV have been measured in a few laboratories. Bertrand(1) and Voignier (2) in Geel made spectrum measurements in the lower neutron energy region of 0.1 to 8 MEV. Kammerdiener et al.(3) in Lawrence Livemore Laboratory performed a measurement with Livemore multi-angle fast neutron TOF facility. The energy range of the measured spectra is wide. However, because of a long flight path (10.5 meters),the statistical error in the higher energy part of the spectrum (8-12 MEV) is rather poor. At the same time, there exist some discrepancies between these two laboratories in the overlapped energy region. Degtyarev et al. at Kiev state University(4) made a spectrum measurement on uranium-238 at 14 MEV. However, the measurement was performed only at five angles. For clarifying the discrepancy and obtaining more accurate data, especially in the higher energy part of the spectrum, a measurement is made in our institute.

Experimental procedure

The details of the α-particle associated TOF spectrometer have been described proviously(4). Here a brief introduction is given only. Fig.1 shows the experimental arrangement. 14.2 MEV neutron is produced at the Cochcroft-Walton accelerator through the T(d,n)He-4 reaction in the 90 degrees with respect to the deuteron beam.The uranium-238 sample is a hollow cylinder of depleted uranium metal with an outside diameter of 3 cm and an inside diameter of 1 cm and a hight of 3 cm. The neutron detector is composed of an ST-451 liquid scintilator(ϕ105x50 mm) and an XP-2040 photomultiplier tube. The detector bias is 1.75 MEV. γ-produced background is reduced by exploiting a pulse shape analyzer. The distance between the neutron detector and the sample is 3.055 meters. The time resolution of the spectrometer is 1.2 nanoseconds.

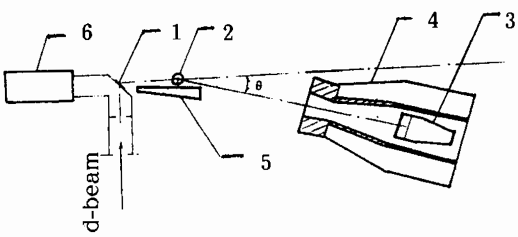

Fig.1 Experimental arrangement
1-Tritium target(TTi), 2-^{238}U sample
3-neutron detector, 4-shield,
5-shadow bar, 6- -detector

The linearity of the spectrometer is shown in fig.2. The integral linearity is better than 1% and the differential one better than 2%. The neutron detector efficiency is calibrated by measuring the n-p scattering angular distribution and shown in Fig.3. The measured efficiecy isfitted with orthogonal polynomials. Its uncertainty is about 3%(except for two points near the threshold).

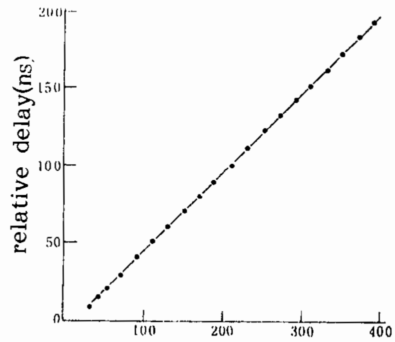

Fig.2 Linearity of the spectrometer

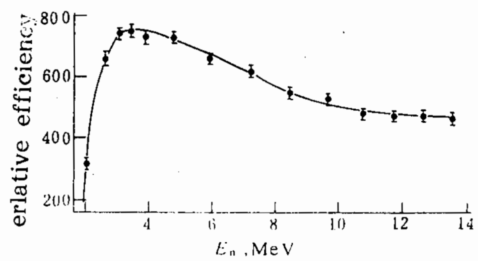

Fig.3 Neutron detector efficiency
• -- measured value, ——fitted curve

To obtain the neutron energy spectrum in 4π space, the measurement is performed at 13 angles in a rather wide angular range 15 to 155 degrees. For comparing with nuclear theoretical calculations,the measurement is focused on the spectra at 25, 45, 60 , 75, 120 and 145 degrees, of which the uncertainty of 5% (for the lower part of the spectrum, i,e. $En \leq 8$ MEV) or 10% (for the higher part, i,e. 8 to 12.5 MEV) is required. Fig.4 shows a measured neutron TOF spectrum of uranium-238 at 35 degrees . During the measurement, the stability of the instruments is monitored, the detector bias is frequently checked and the alpha-particle counting rate is kept as constant as possible.

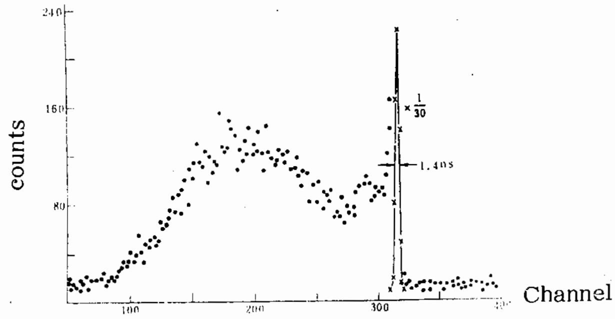

Fig.4 Neutron TOF spectrum of ^{238}U induced by 14.2 MEV neutrons

To get the absolute value of the double differential cross sections of uranium-238, the n-p scattering differential cross section at 25 degrees is used as a reference standard.Fig.5 shows a neutron TOF spectrum at 25 degrees measured with a polythene sample being of the same size as uranium-238 sample and under the same experimental condition as the uranium-238 measurement. From Fig.5 it can be obviously seen that the n-p scattering peak is completely seperated with elastic and inelastic peak of C-12 .

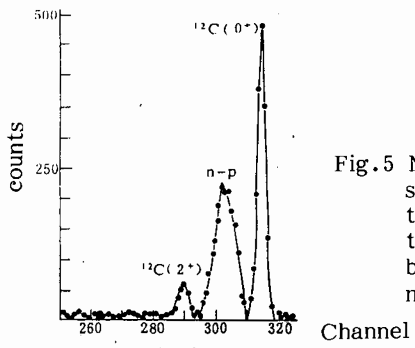

Fig.5 Neutron TOF spectrum scatted from polythene sample by 14.2 MEV neutrons

Data reduction

After subtraction of the background and the "tail" of the elastic scattering peak, the net neutron TOF spetrum of uranium-238 is obtained. For the measurements at angles which are greater than 35 degrees, the average counts on the right hand side of the elastic peak is used as the background. For the measurements at angles which are less than or equal to 35 degrees, time- correlated background, which decreases with the increase of the angle, should be considered. Sample-out measurements are required. Fig.6 shows a background TOF spectrum measured at 20 degrees.

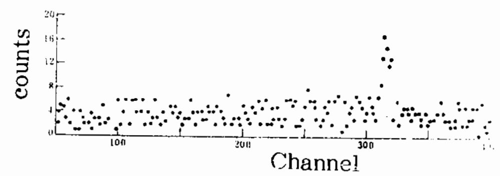

Fig. 6 Sample--out TOF spectrum $\theta_L = 20^{o}$

The incident neutron TOF spectrum is used for elastic "tail" subtraction.

The net neutron TOF spectrum is converted into neutron energy spetrum. considering the time resolution of the spectrometer, a 0.2 MEV energy interal is chosen in the 2-5 MEV region of the spectrum, a 0.25 MEV in the 5-8 MEV region and a 0.5 MEV in the 8-12.5 MEV region.

The double differential cross sections of uranium-238 is obtained by the following expression

$$\sigma(E_i,\theta) = \frac{N_u(E_i,\theta)\ n_H\ \varepsilon_H(E_H)}{N_H(25^o)\ \ n_u\ \varepsilon_u(E_i)}\ \ \sigma_H(25^o)$$

where θ is the scattering angle in the laboratory system, n_H and n_u are the numbers of hydrogen nuclei in the polythene sample and of uranium-238 nuclei in the uranium-238 sample respectively, $\varepsilon_H(E_H)$ and $\varepsilon_u(E_i)$ are the neutron detection efficiencies respectively for n-p scattering neutrons at 25 degrees and neutrons with energy of E_i, $N_H(25^o)$ is the total counts of the n -p scattering peak at 25 degrees. $N_u(E_i,\theta)$ is the counts in the energy interal between E_i and $E_i+\Delta E$ of the spectrum at the angle of θ, $\sigma_H(25^o)$ is the n-p scattering differential cross section at 25 degrees, for present work $\sigma_H(25^o)$=192.1 mb/Sr.

Results

The measured double differential neutron emission cross sections at difrent angles together with the results of Voignier and Kammerdiener are shown in Fig.7.Generally, present data and Kammerdiener 's results are in agreement within the experimental

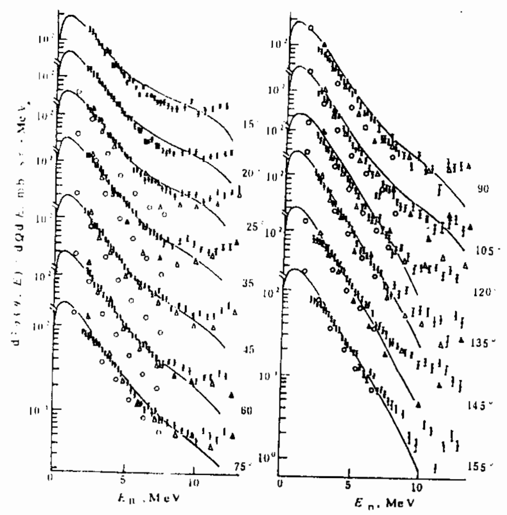

Fig.7 double differential neutron emission spectra of uranium-238 induced by 14.2 MEV neurtons
•--present work, ▲-- Kammerdiener,
o--Voignier, solid curve--evaporation model calculation

error. The count statistics of the present work is better than the two others, especially in the greater than 8 MEV region. The experimental result is compared with theoretical calculations of the evaporation model with preequilibrium emission mechanism. A good agreement is achieved for the region of less than 10 MEV. For the higher part of the spectrum, the calculation is much lower than the measurement,because direct inelastic scattering is not included in the calculation(5).

The angular distribution of double differential cross sections is shown in Fig.8. For comparison,the results of references(2) and (3) are in Figs.9 and 10 respectively. It can be seen from Figs.8 and 9 that when $E_n \gtrsim 5$ MEV, the angular distrbutions are forward peaked. For the angular distribution of 11-13 MEV energy neutrons, the cross section at the small angle is an order of magnitude higher than that at large angles.

The integral spectrum of uranium-238 over the whole space is shown in Fig.11.

The error varies with the angle and spectrum neutron energy. The typical value and sources of the error are listed in table 1. The major error sources come from count statistics and n-p scattering differential crosssection. The error due to subtraction of the "tail" of the elastic scattering peak is decreased with the increase of scattering angles in the small angle region. At the angles which are greater than 25 degrees, it can be neglected.

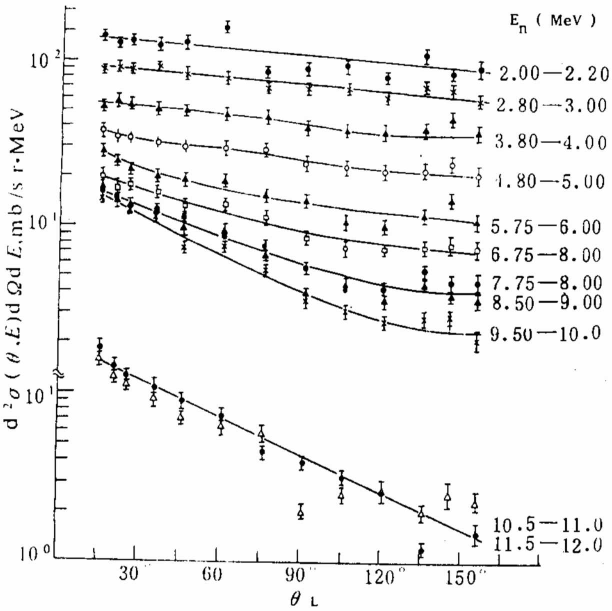

Fig.8 Double differential cross section angular distributions of uranium-238 measured by present work

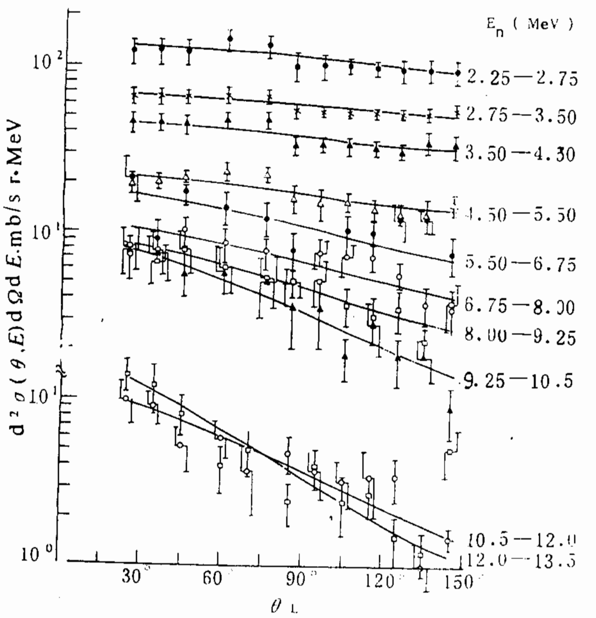

Fig.9 Double differential cross section angular distributions of uranium-238 measured by Kammerdiener et al.

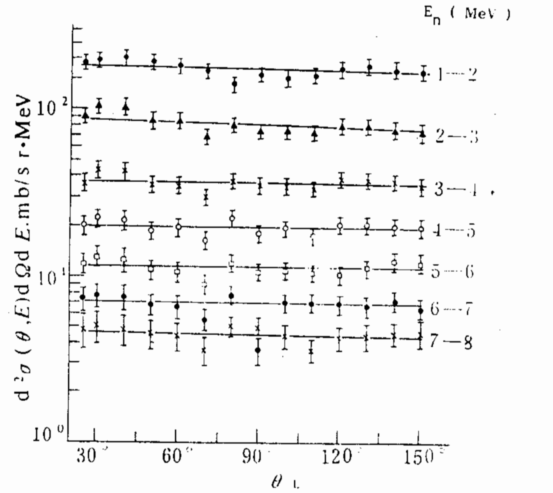

Fig. 10 Double differential cross section angular distributions of uranium-238 measured by Voignier et al.

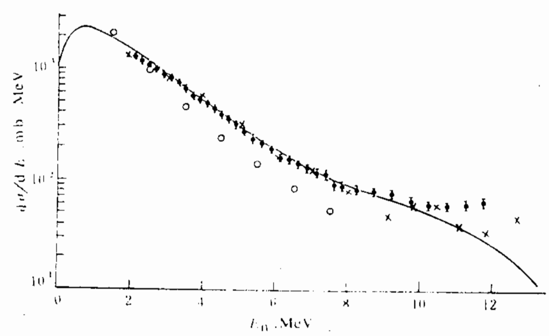

Fig. 11 The integral spectrum over the whole space

•-- present work

o--Voignier's data

x-- Degtyarev's data,obtained by averaging over the emission angles in the forward semisphere

solid curve-- calculations of the evaporation model with preequilibrium emission mechanism

Table 1 ERRORS AND THEIR SOURCES

error source	E_n(MeV)	2—4	4—6	6—8		8—10		10—12					>12				
	θ(degree)	15—155	15—155	<75	≥90	<75	≥90	15	20	25	30—75	≥90	15	20	25	30—75	≥90
count statistics (%)		2—5	3—7	4.5—9	6—12	5—8	9—13	8.2-9	6-6.5	6.9-7	6—9	10-14	4-6.5	4-6.3	4-6.7	2—7	6—15
$\sigma_{n\text{-}p}(25^{o})$		3% for the whole energy region															
count of n-p scattering peak		3% for the whole energy region															
detector efficiency		3% for the whole energy region															
Monte-carlo correction		0.1--0.5% for the whole energy region															
dead time correction		0.3% for the whole energy region															
number of ^{238}U nuclei		less than 10^{-5}, neglected															
time-correlated background								1%	1%	1%			1.5%	1.5%	1.5%		
subtraction of the elastic peak								6%	1.5%	0.5%			9%	5%	1%		
overall error, %		4.8-6.7	5.3-8.3	6.3-10	7.4-13	6.7-9.1	10-13	11-12	7.7-8.1	8-8.5	6.7-10	11-14.7	11-12	7.9-9.3	6.3-8	4.8-8.3	7.4-15.6

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