Measurement of Neutron Inelastic Scattering Cross Section of ^{238}U

Takako MIURA, Mamoru BABA, Masanobu IBARAKI, Toshiya SANAMI,
Than Win, Yoshitaka HIRASAWA, Shigeo MATSUYAMA, Naohiro HIRAKAWA
Department of Quantum Science and Energy Engineering, Tohoku University
Aramaki-Aza-Aoba, Aoba-ku, Sendai, 980-77, Japan
email : takako@rpl.qse.tohoku.ac.jp

Neutron scattering from the 0^+, 2^+ (1-st) and 4^+ (2nd) levels of ^{238}U was measured for incident energies between 0.4 and 0.85MeV at the Tohoku University 4.5MV Dynamitron facility, using the time-of-flight (TOF) method with monoenergetic pulsed neutrons by the ^{7}Li(p,n) reaction. The results are presented in comparison with other experimental data and evaluated data.

1. Introduction

^{238}U is one of the main constituent element in fast and accelerator-based reactors. The inelastic scattering cross section of ^{238}U, therefore, is of great importance in the design of the reactors. However, experimental data of neutron inelastic scattering cross section and secondary neutron spectra of ^{238}U are discrepant largely in spite of the significance. Then large differences exist among the evaluated values of the inelastic scattering cross section of ^{238}U. Cooperation for the improvement of the data status is in progress in OECD NEA.

In this study, following our previous works on the double differential neutron emission cross sections of ^{238}U[1], we have studied the excitation of low lying levels of ^{238}U for hundreds keV incident neutrons that is important as the basis for the evaluation of the ^{238}U nuclear data .

2. Experiment

The experiment was carried out at the Tohoku University 4.5MV Dynamitron facility, using the-time-of flight (TOF) method with mono-energetic pulsed neutrons by the ^{7}Li(p,n) reaction. Figure1 shows the experimental set up. The sample is a metallic cylinder of elemental uranium, 2cm diameter and 5cm long, and packed in an aluminum can, 0.5mm thick. The same size aluminum can was used for the background measurement. In addition we employed a lead sample with the same size as the uranium sample, to simulate the shape of the elastic peak of uranium (cf. section 3). The main detector is a 5" diameter and 2" thick NE213 scintillation detector. It was heavily shielded in a massive collimator made of water and paraffin. Data were acquired by 3-paramerer list mode for pulse height, pulse shape, and TOF.

The detector efficiency was determined from the measurement of well-known angular distributions of the ^{7}Li(p,n) neutrons.

In the present experiment, the separation between peaks are essential. To separate clearly the elastic and 1-st inelastic peaks, therefore, we optimized the experimental conditions as follows. The lithium target was made thin to make the energy spread ~10keV, the flight path was long enough, 4～6m, and the target-sample distance was ~12cm to narrow the incident neutron energy width caused by the solid angle. Besides, the measurement was made at backward emission angles (120° and 135°) to minimize the effect of the elastic peak.

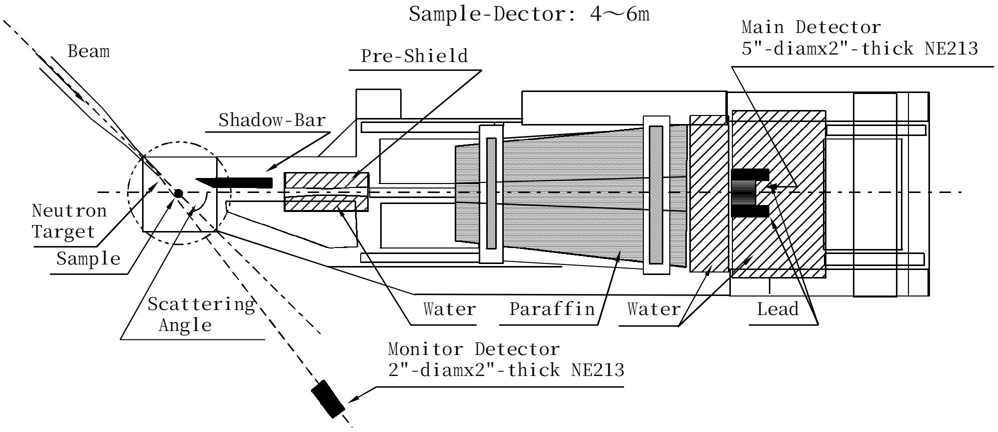

Fig.1 experimental arrangement

Data Reduction

The TOF spectra were transformed into energy spectra after subtracting the sample independent background and gamma-rays from the active sample. In fig.2, typical TOF spectra are shown. The peaks are separated fairly well, but the tail of the elastic peak extends down to the first inelastic peak.

Then we carried out peak fitting to separate the first inelastic peak from the elastic peak by the following way. The shape of the elastic peak of lead was used to simulate the elastic peak of ^{238}U, and the inelastic peak of the 2^+ level (excitation energy 44.9keV) was deduced by subtracting the appropriately normalized elastic peak of lead from the spectrum of ^{238}U. The spectrum fitted is shown in fig.3.

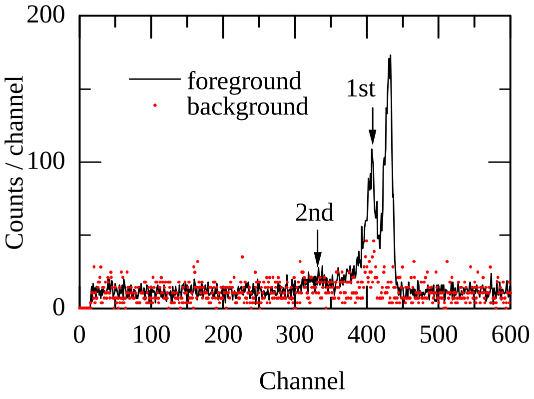

Fig.2 ^{238}U scattered neutron TOF spectrum at 120 ° for En=465 keV

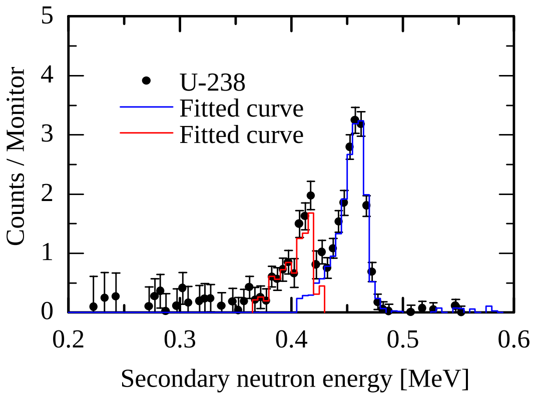

Fig.3 Fitted curve for the elastic peak and inelastic peak of ^{238}U

The absolute value of the cross section was determined by taking the ratio of scattered neutron yields to the source neutron yield measured at 0°. Differential cross sections were derived by the following equation.

$$\frac{d\sigma}{d\Omega}(E_0,E,\theta)=\frac{Y(E_0,E,\theta)}{Y(E_0,0)}\cdot\frac{d^2}{N}\cdot\frac{D^2(\theta)}{D^2(0)}\cdot\frac{\varepsilon(E_0)}{\varepsilon(E)}\cdot f\cdot A(E_0,E,\theta) \qquad ,$$

where

$Y(E_0,E,\theta)$, $Y(E_0,0)$ = the monitor-normalized yields of the scattered neutrons of energy E at angle θ and of the incident neutrons of energy E_0 at 0°, respectively

d = the target-sample distance

N = the number of atoms of the sample

$D^2(\theta)$, $D^2(0)$ = the sample-detector distance at θ and at 0°, respectively

$\varepsilon(E_0)$, $\varepsilon(E)$ = the relative detector efficiency for incident and scattered neutron, respectively

f = the correction factor for the effects of source neutron anisotropy and the geometry in the source-sample arrangement

A = the correction factor for finite size effects in the sample.

The correction factor *f* is given by the following expression [2]

$$f=\left[1-\frac{1}{8d^2}\left(kR^2+\frac{k+2}{3}H^2\right)\right]^{-1} \qquad , \qquad k=\sum_i\frac{i(i+1)}{2}a_i \qquad ,$$

where R and H are the radius and the height of the sample, respectively, a_i is the coefficient of Legendre polynomial expansion for the angular distribution of source neutrons.

The correction factor *A* was deduced by using a Monte Carlo code SYNTHIA[3]. In this work, this factor was 1.1～1.2, 0.95～1.1 and 0.9～1.0 for the 0^+, 2^+(1-st) and 4^+(2nd) levels of ^{238}U, respectively.

The experimental error was estimated considering the error sources of (1) counting statistics, (2) detector efficiency 5%, (3) integration of the peak yield 10%, (4) data correction 10%

3. Results and Discussion

The experimental angular differential cross sections of the 0^+ level (ground state) of ^{238}U at 120° are shown in fig.4. The present values are close to the values of JENDL-3.2.

Figure 5 and fig.6 show the preliminary values of angle-integrated cross sections of 2^+ and 4^+ levels of ^{238}U, respectively, deduced by multiplying the data at 120° by 4π.

For the 1-st level, several experimental data have been reported in the energy range of the present study. However, their values are different up to 50% or more, and the evaluated values of JENDL-3.2 and ENDF/B-VI are close to the lowest experimental values. The present results at 700keV and 850keV are lower than the data by Haouat et al.[2] and by Beghian et al.[4], but close to the evaluated values in the angle-integrated values. However, the differential cross section by the present experiment (120°) is in good agreement with that by Haouat et al.(125°). Therefore the angular distribution should be taken into account in the data comparison. The present data at 465keV and 550keV are also close to the evaluations and lower than those by Guenther et al.[5]. However, the values in this region are sensitive to the detector threshold, and further studies will be made. The present values of 2nd level are close to the data by Haouat et al. and Begian et al., while the experimental errors are relatively large.

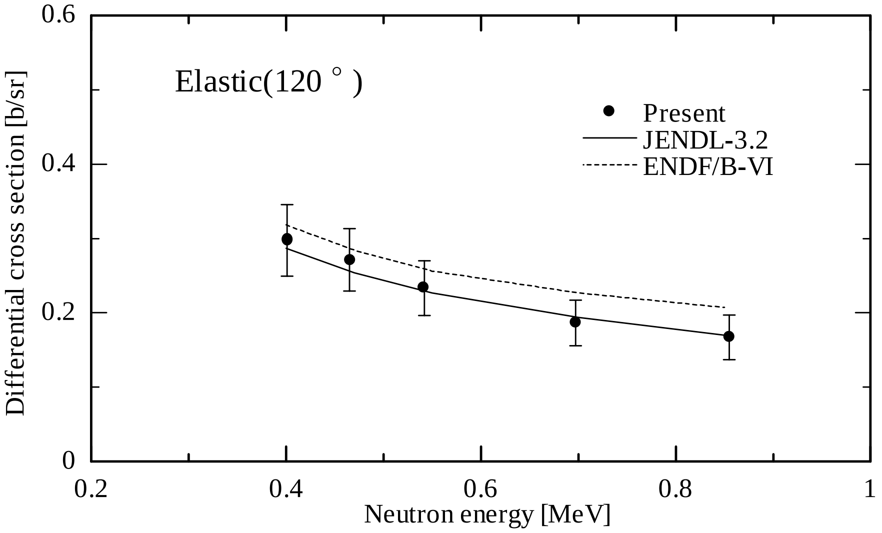

Fig.4 Elastic scattering cross section of ^{238}U at 120 °

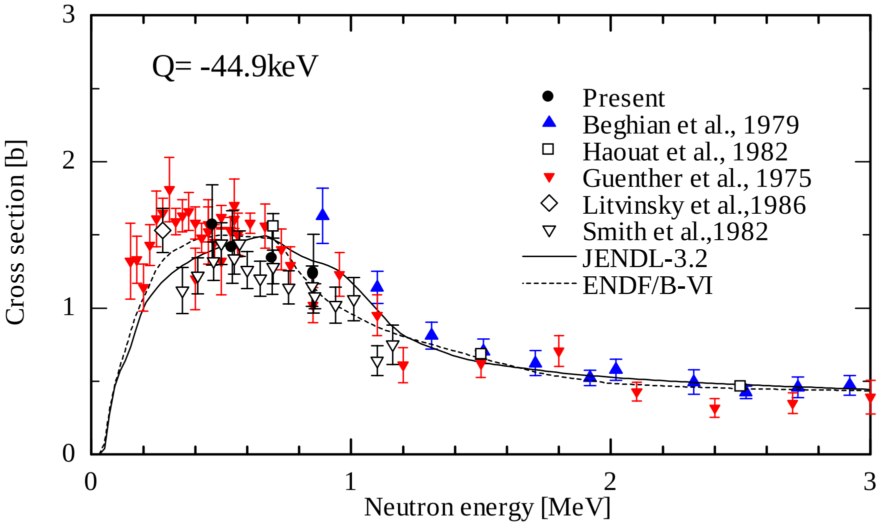

Fig.5 Inelastic scattering of 1-st level of ^{238}U

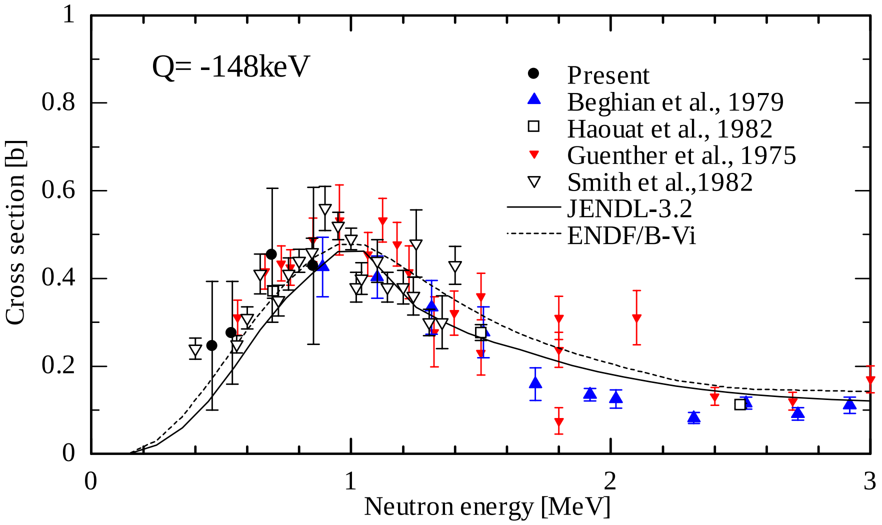

Fig.6 Inelastic scattering of 2nd level of ^{238}U

4. Summary

By using the TOF technique, neutron scattering cross sections of low-lying levels of ^{238}U were measured for 0.4 -0.85 MeV incident neutrons. The peaks by the elastic and inelastic scattering could be separated fairly well, and the cross sections of the 0^+, 2^+ and 4^+ levels were deduced. Further data analysis and experiment, however, will be needed to reduce the experimental error and to confirm the data consistency.

References

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