Measurements of Double-Differential Neutron Emission Cross Sections of ^{238}U and ^{232}Th for 2.6 and 3.6 MeV Neutrons

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Double-differential neutron emission cross sections (DDXs) of ^{238}U and ^{232}Th were measured using the time-of-flight (TOF) method for 2.6 and 3.6 MeV neutrons. The data for ~3 MeV incident neutrons are required because of a large change of the spectra from discrete to continuum between 2 MeV and 4 MeV. The present data show that discrete structures consisting of Ex~0.7 and ~1.0 MeV groups of excited states are dominant in 2.6 MeV, while a continuum is major in 3.6 MeV.

1. Introduction

^{238}U and ^{232}Th are one of the main constituent elements in breeder reactors. The energy spectra of scattered neutrons from ^{238}U and ^{232}Th, therefore, are of great importance to evaluate the slowing down of neutrons in the reactors and to neutronics-design of the reactors. However, experimental data of secondary neutron spectra of ^{238}U and ^{232}Th are very scarcely. Hence large differences exist among the evaluated data.

In our previous works, the double differential neutron emission cross sections (DDXs) of ^{238}U and ^{232}Th were measured for 1.2, 2, 4, 6, 14 and 18 MeV neutrons /1//2/. In the present work, the DDXs were measured for 2.6 and 3.6 MeV neutrons using the time-of-flight (TOF) method following our previous works. The data around 3 MeV incident energies are required because a large change of the spectra was found between 2 and 4 MeV.

2. Experiment

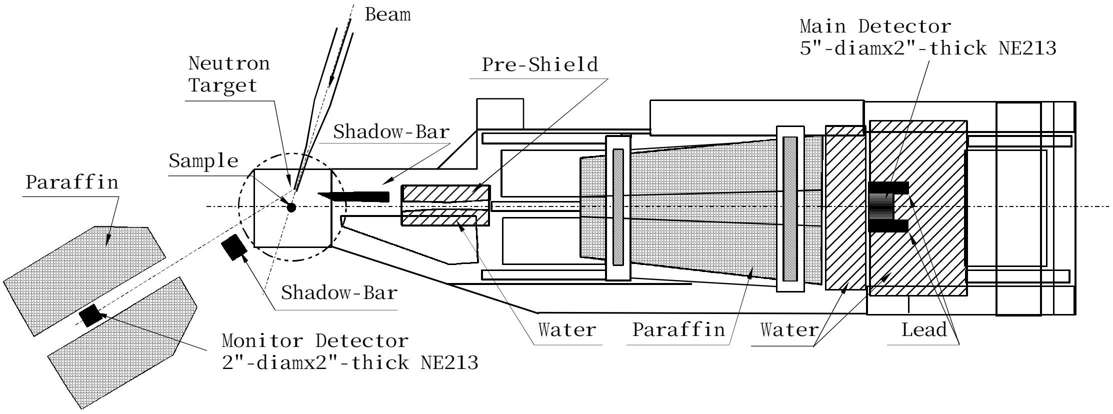

Fig.1 Experimental geometry

DDXs of ^{238}U and ^{232}Th for 2.6 and 3.6 MeV neutrons were measured using the TOF method at Tohoku University 4.5 MV Dynamitron facility. The experimental arrangement is shown in fig.1. Primary neutrons of 2.6 and 3.6 MeV were produced by the T(p,n) and D(d,n) reaction using a Ti-T and D_2 gas cell (1cm-diam×1.5cm-long, 1atm) target, respectively. In the 2.6 MeV source neutron spectrum, contaminant neutrons lower than 1.2MeV were found with an intensity of ~17 % fraction to the primary neutrons. The effect of the contaminant neutrons was corrected for based on a Monte-Carlo calculation /3/. Scattering samples were metallic cylinders of elemental uranium and thorium, 2-cm-diam ×5-cm-long, and encased in 0.5-mm-thick aluminum cans. An empty aluminum-can was used for the background measurement. The neutron detector was a massively shielded NE213 scintillator, 12.7-cm-diam×5.1-cm-thick, and the flight path was ~4 m. Neutron spectra were measured at 6 angles between 30° and 145°. A monitor detector of a NE213 scintillator, 5.08-cm-diam×5.08-cm-thick, measured the spectrum and intensity of source neutrons at ~40° relative to the incident beam. This detector was shadowed from the samples to avoid radiations from the uranium and thorium samples. Three-parameter data for TOF, pulse-shape (n-γ) and pulse-height were collected in a list mode. Absolute cross sections were determined relative to the H(n,n) cross section by measuring a polyethylene sample. A curve of relative efficiency was determined by measurement of the fission neutron spectrum from ^{252}Cf and calculation of SCINFUL-code /4/.

3. Data Reduction

The TOF spectra for 2.6 and 3.6 MeV incident neutrons are shown in fig.2 and fig.3, respectively. Foreground spectra and a background spectrum were normalized using counts of the monitor detector. The TOF spectra were converted into energy spectra considering the relative efficiency. The energy spectra were corrected further for the effects of sample-dependent backgrounds and finite-sample-size by a Monte-Carlo calculation /3/.

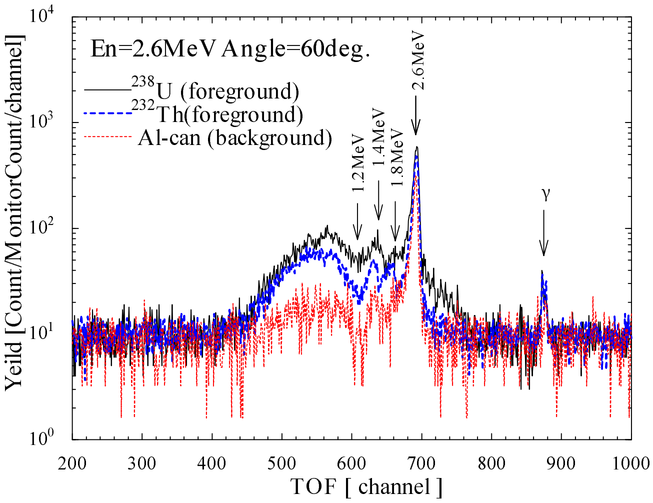

Fig.2 TOF spectra for En=2.6 MeV at 60°

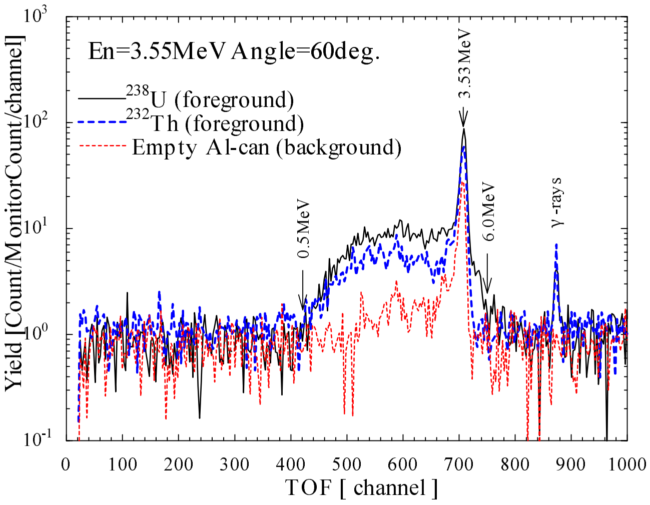

Fig.3 TOF spectra for En=3.6 MeV at 60°

3. Result

Figure 4 and Fig.5 show the present DDX results for 2.6 and 3.6 MeV incident neutrons in comparison with the evaluated nuclear data, respectively. ^{238}U and ^{232}Th are even-even nuclei with close atomic numbers. For this reason, they show similar structures of excited states around Ex~0.7 and ~1 MeV due to vibration levels. In the spectra for 2.6 MeV, the discrete structures of Ex~0.7 and ~1 MeV groups are distinct, while in the case of 3.6 MeV, the spectra change to continuous. For ^{238}U, the data of JENDL-3.2 are fairly close to the present data, but for ^{232}Th, the data of both JENDL-3.2 and ENDF/B-VI overestimate the excitation of Ex~0.8 and ~1.2 MeV groups in both incident energies.

Figure 6 and fig.7 show angular distributions of the elastic group (0^+, 2^+, 4^+, 6^+) for 2.6 and 3.6 MeV incident neutrons, respectively. For ^{238}U, both the evaluated data are in agreement with the present data. For ^{232}Th, the data of JENDL-3.2 is slightly different from the present data in the distribution.

[1] M. Baba *et al.*, J. Nucl. Sci.and Technol., **27** (1990) 601-616.

[2] S. Matsuyama *et al.*, JAERI-M 91-032.

[3] M. Baba *et al.*, Nucl. Instrum. and Methods **A372** (1995) 354-365.

[4] V. V. Verbinski *et al.*, Nucl. Instrum. and Methods **A65** (1968) 8.

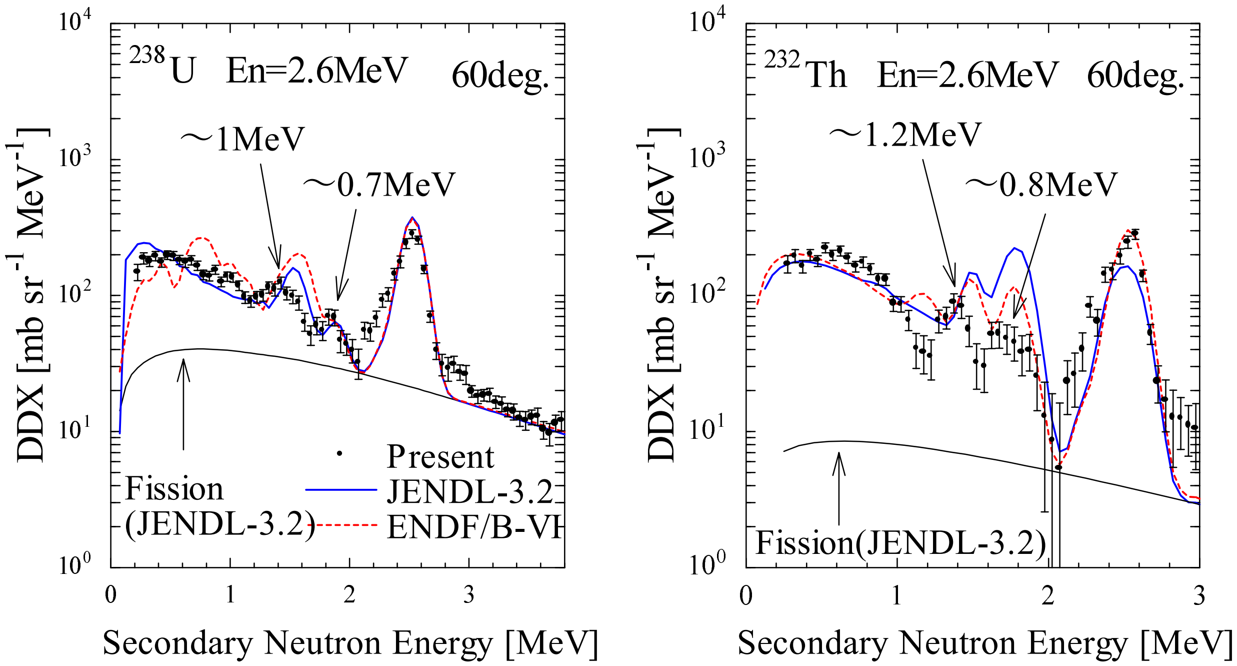

Fig.4 DDXs of ^{238}U and ^{232}Th for En=2.6 MeV at 60°

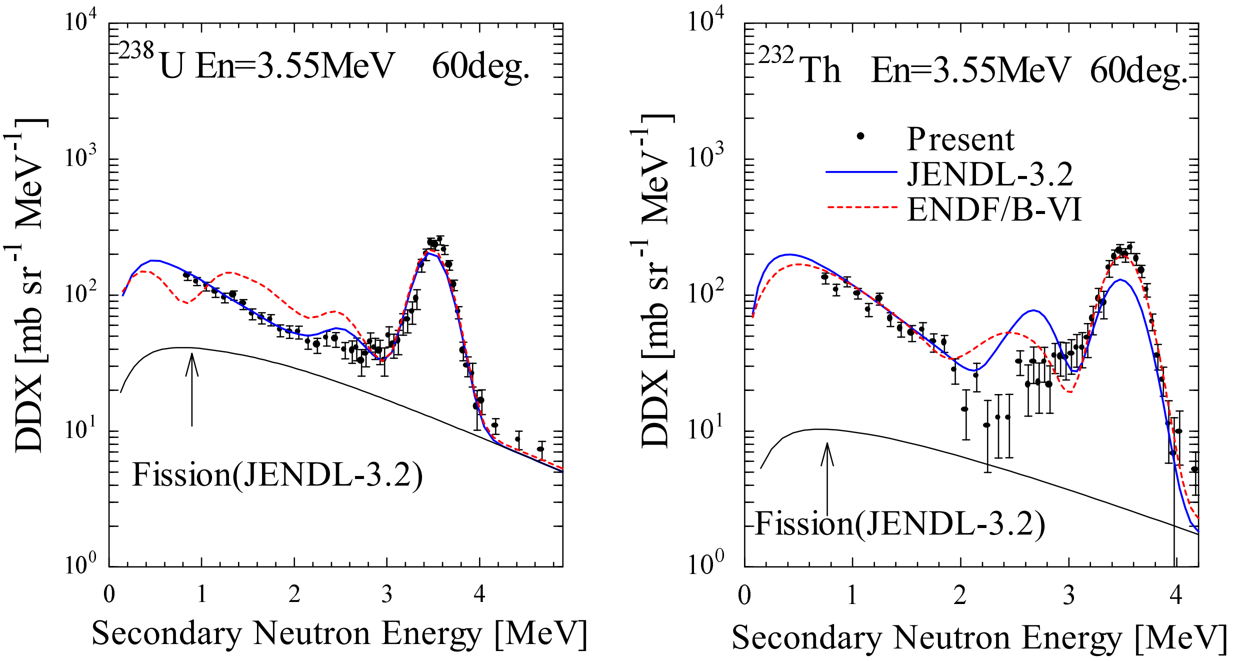

Fig.5 DDXs of ^{238}U and ^{232}Th for En=3.6 MeV at 60°

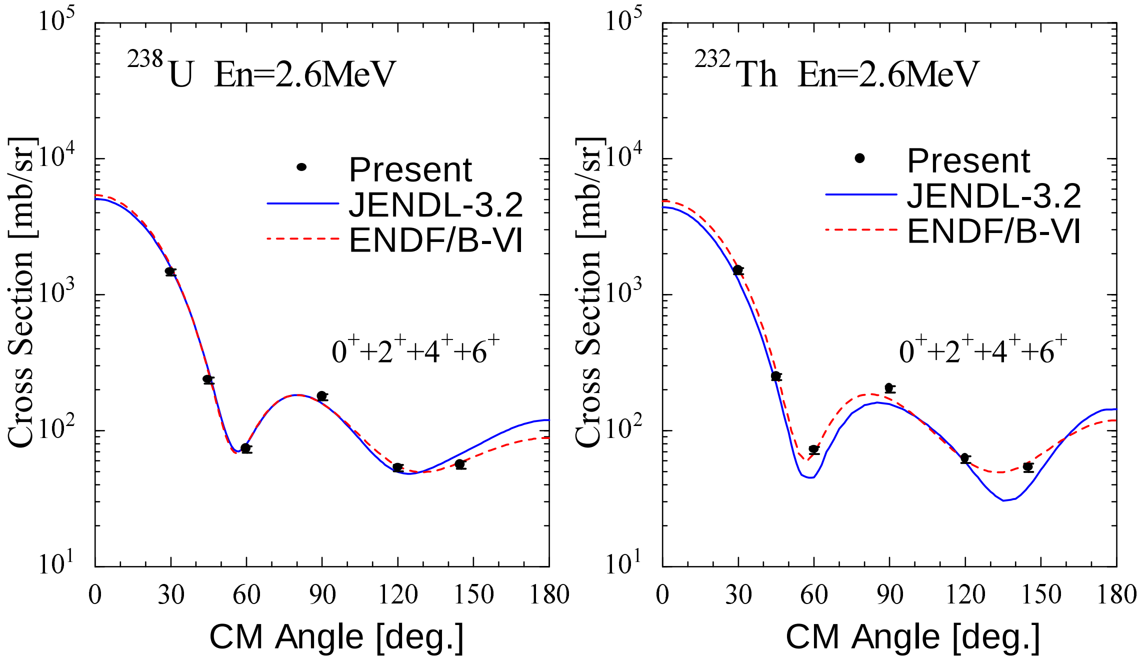

Fig.6 ADXs of ^{238}U and ^{232}Th for En=2.6 MeV

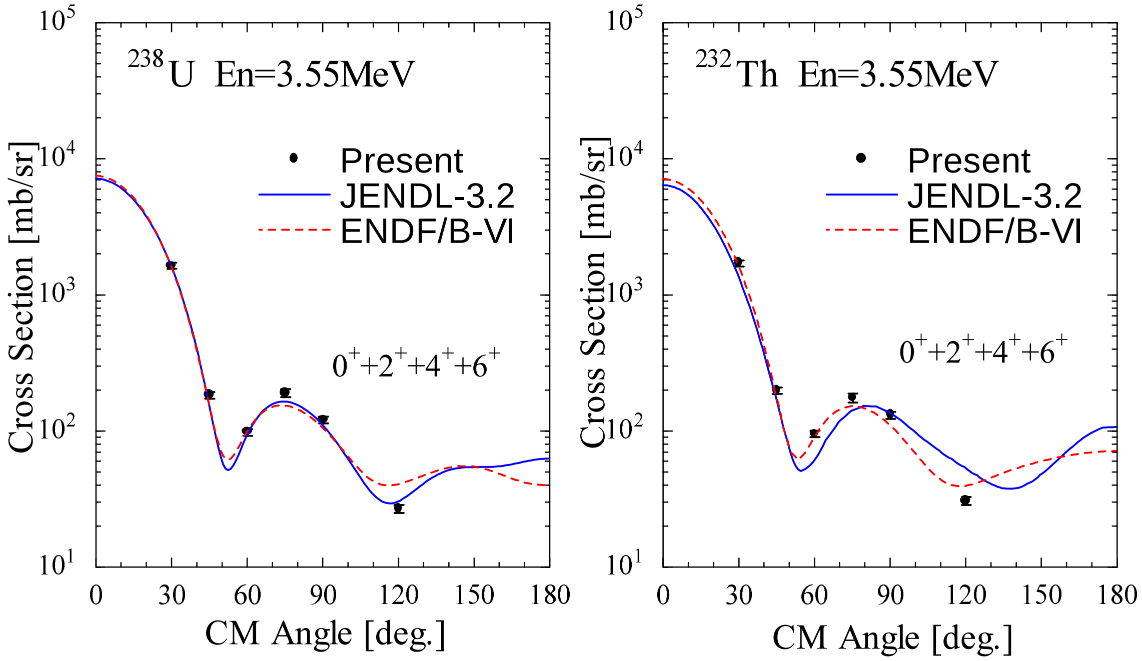

Fig.7 ADXs of ^{238}U and ^{232}Th for En=3.6 MeV