Measurements of Fast Neutron-Induced Fission Spectra of ^{233}U, ^{238}U, ^{232}Th

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The prompt fission neutron spectra of ^{233}U, ^{238}U, and ^{232}Th for fast neutron-induced fission were measured by using the time-of-flight (TOF) method at Tohoku University 4.5 MV Dynamitron facility. We obtained new experimental data for ^{233}U at En=0.55, 1.9, 4.1 MeV, ^{238}U at En=1.9, 4.1 MeV, and ^{232}Th at En=4.1 MeV following our previous works for ^{238}U and ^{232}Th at 2.0 MeV, and ^{237}Np at 0.55 MeV.

1. Introduction

^{233}U, ^{238}U, and ^{232}Th are one of the main constituents of fast breeder reactors and accelerator-driven breeder reactors. Their prompt fission spectra for neutron-induced fission are, therefore, of great importance for the design of reactors. These data are of high priority also as the basis for evaluation of nuclear data for actinide. Fission spectra are described by conventional Maxwellian or Watt type functions, or theoretical one by Madland-Nix model and others with appropriate parameters like the level density or the nuclear temperature. For determination of the parameters, experimental data are indispensable, but not enough both in quantity and quality, in particular for ^{233}U and ^{232}Th.

Following our previous works for ^{238}U and ^{232}Th at 2.0 MeV [1], and for ^{237}Np at 0.55 MeV [2], new experimental data were obtained in the present work for ^{233}U at En=0.55, 1.9, 4.1 MeV, ^{238}U at En=1.9, 4.1 MeV, and ^{232}Th at En=4.1 MeV. The results were compared with the evaluation and the Maxwellian temperatures were also deduced by least square fitting in order to compare with other data.

2. Experiment and Data reduction

The measurement was performed by using the time-of-flight (TOF) method at Tohoku University 4.5 MV Dynamitron accelerator facility. The experimental arrangement is shown in **Fig.1**. The details of experiment for ^{233}U at 0.55 MeV were similar with that for ^{237}Np [2].

The fission samples were solid ones of ^{233}U, ^{238}U, ^{232}Th and Pb. The ^{233}U sample consisted of 24 plates, 12.7 mm x 12.7 mm x 1 mm, of U_3O_8 powder dispersed in an aluminum metal and the amount of ^{233}U is only 2.28 g. The ^{238}U and ^{232}Th samples were metallic cylinders of elemental uranium and thorium, 2 cmϕ x 5cm, and encased in 0.5 mm-thick aluminum cans. The Pb sample was employed in order to evaluate background components and the tail of the elastic peak to the high energy side.

Neutron source was the $^{7}Li(p,n)$ reaction for En=0.55 MeV, the T(p,n) reaction for En=1.9 MeV and the D(d,n) reaction for En=4.1 MeV. These targets were metallic lithium, solid Ti-T, and D_2-gas cell for the $^{7}Li(p,n)$, the T(p,n) and the D(d,n) reactions, respectively. The ion beam was 2 MHz repetition rate with

3~3.5μA.

The neutron detector was a massively shielded 12.7 cmϕ x 5.1 cm NE213 scintillator and the flight path was 2 m. Observation angle was selected to minimize contribution of elastic scattering; 90° for En=0.55 MeV, 135° for En=1.9 MeV, and 115° for En=4.1 MeV. Data were acquired by 3-parameter list mode for pulse-height, pulse-shape, and TOF to enable flexible data analysis with optimal experimental parameters. Total time taken for the measurements is shown in ***Table 1***.

The TOF spectrum of ^{238}U for 1.9 MeV is shown in **Fig.2** as a typical one without n-γ discrimination to show the γ-ray peak. Raw list data were processed for optimum n-γ discrimination and pulse-height bias by software treatment. The experimental spectra were corrected for two effects of 1) time resolution which make apparent spectrum harder and 2) the neutron attenuation within the sample.

3. Results and Discussion

Figure 3 shows the present prompt fission spectra divided by $\sqrt{E}$ with a best-fit line of the Maxwellian function,

$$\chi(E)_M = C\sqrt{E}\exp(-E/T_M),$$

where $\chi(E)_M$, T_M, and C are the Maxwellian function (fission spectrum) expressed by the energy of prompt fission neutrons, the Maxwellian temperature and normalization constant, respectively. The uncertainty for En=4.1 MeV data is fairly large, because they do not have enough counting statistics and are affected by large backgrounds due to a deuteron beam. All of the present data are in close agreement with the Maxwellian function below ~10 MeV. The present data of ^{233}U for En=0.55 MeV, in particular, are of enough counting statistics in spite of small amount of the sample and in good agreement with the Maxwellian function.

The present Maxwellian temperatures deduced by fitting are presented in ***Table 2***. The present result of ^{238}U for En=1.9 MeV is consistent with our previous one [1] within the quoted uncertainty. The present temperatures are also shown in **Fig.4** with other experimental data and Howerton-Doyas formula as a reference data. Howerton-Doyas formula is a semi-empirical one based on the average number of neutrons emitted per fission, which is known accurately. This formula was employed in evaluations, while it is replaced with theoretical models in the current evaluations. Our data are generally consistent with other experimental data, but Howerton-Doyas formula deviate systematically from the experimental data.

The present fission spectra were compared with the evaluated nuclear data, JENDL-3.2 and ENDF/B-VI. For ^{233}U at En=0.55 MeV, the both evaluated data are of good agreement with the present data as shown in **Fig.5**. The difference between the evaluated data become larger as incident neutron energy goes higher. In particular in the case of ^{232}Th at En=4.1 MeV, difference is large markedly. The spectra for ^{232}Th at En=4.1 MeV are shown in **Fig.6**, where the present data are normalized to JENDL-3.2 because of relative value in the present data. For more detailed discussion, therefore, comparison in absolute value is desirable.

The uranium-233 samples are on loan from Kyoto University Research Reactor Institute.

[1] M. Baba et al., Nucl.Sci.Technol., 27(7) (1990) 601-616

[2] Than Win et al., Nucl.Sci.Technol., 36(6) (1999) 486-492

Table 1 Total measurement times

Sample	En (MeV)	Time (h)
U-233	0.55	13
	1.90	14
	4.10	3.5
U-238	1.90	5
	4.10	1.2
Th-232	4.10	2

Table 2 Maxwellian Temperatures (preliminary)

Present		
U-233	En = 0.55 MeV	$T_M = 1.31 \pm 0.04$ MeV
	En = 1.90 MeV	$T_M = 1.36 \pm 0.04$ MeV
	En = 4.10 MeV	$T_M = 1.39 \pm 0.05$ MeV
U-238	En = 1.90 MeV	$T_M = 1.28 \pm 0.05$ MeV
	En = 4.10 MeV	$T_M = 1.34 \pm 0.04$ MeV
Th-232	En = 4.10 MeV	$T_M = 1.28 \pm 0.08$ MeV
Previous		
U-238	En = 2.00 MeV	$T_M = 1.26 \pm 0.03$ MeV
Th-232	En = 2.00 MeV	$T_M = 1.24 \pm 0.03$ MeV

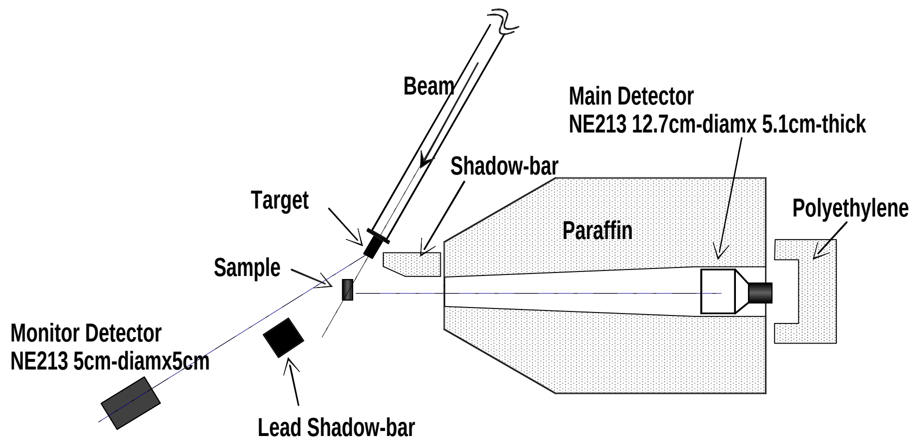

Fig.1 Experimental setup

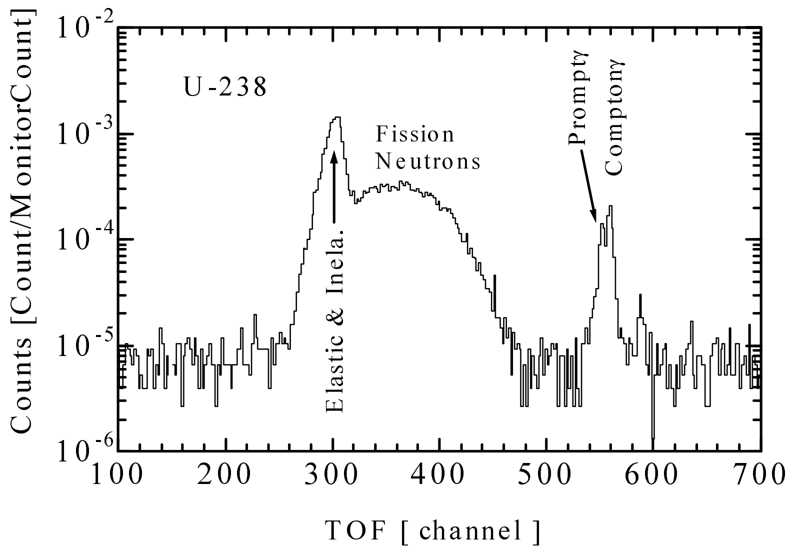

Fig.2 TOF spectrum for ^{238}U at En=1.9 MeV (without n-γ discrimination)

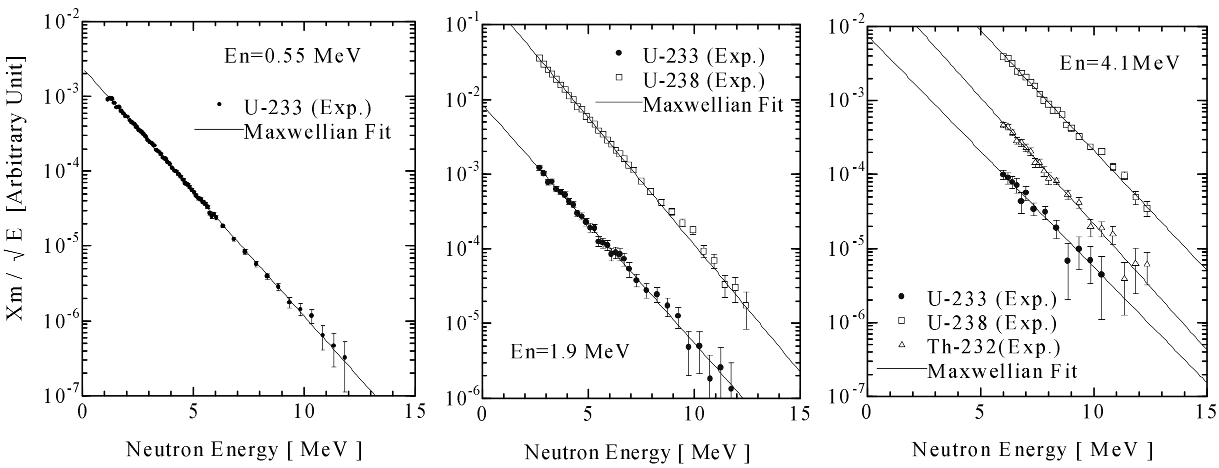

Fig.3 Fission spectra divided by $\sqrt{E}$ for En=0.55 MeV, 1.9 MeV, 4.1 MeV

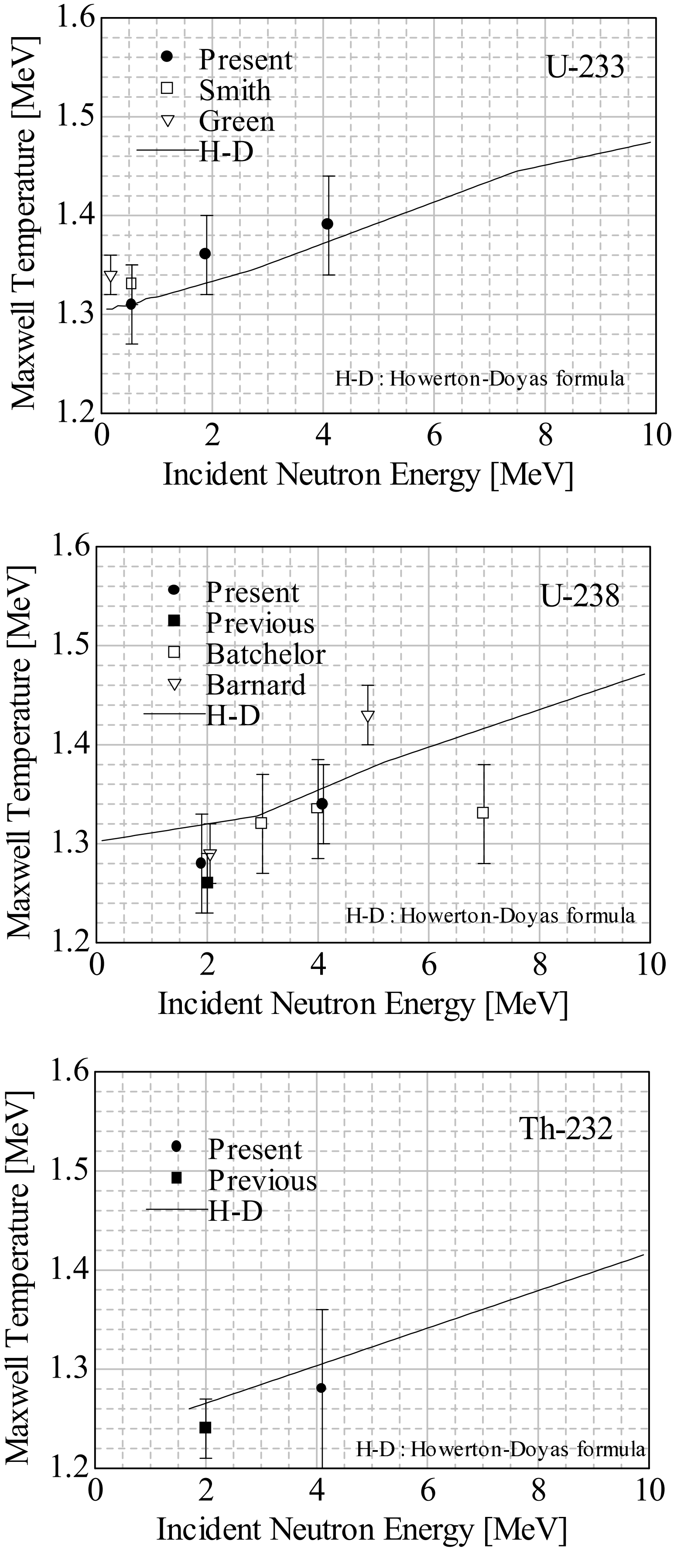

Fig.4 Maxwellian Temperature

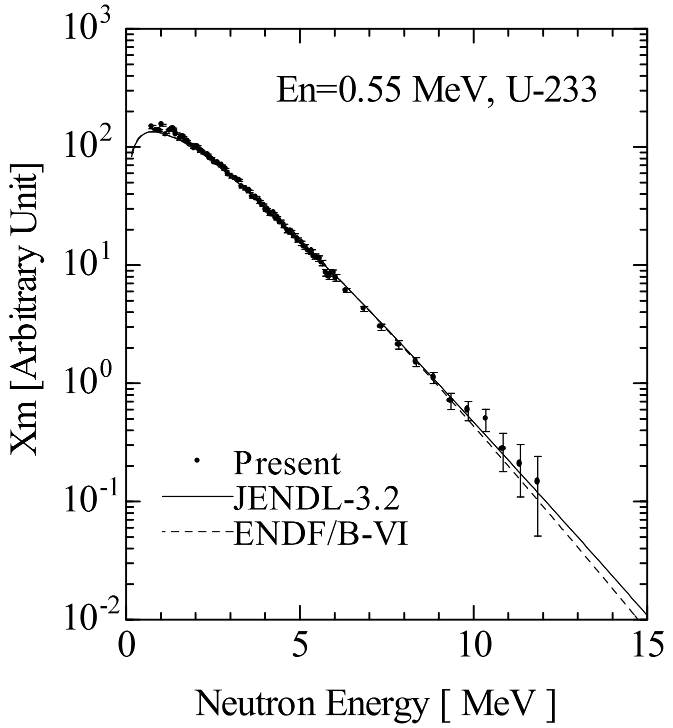

Fig. 5 Fission spectrum of ^{233}U at En=0.55 MeV compared with JENDL-3.2 and ENDF/B-VI

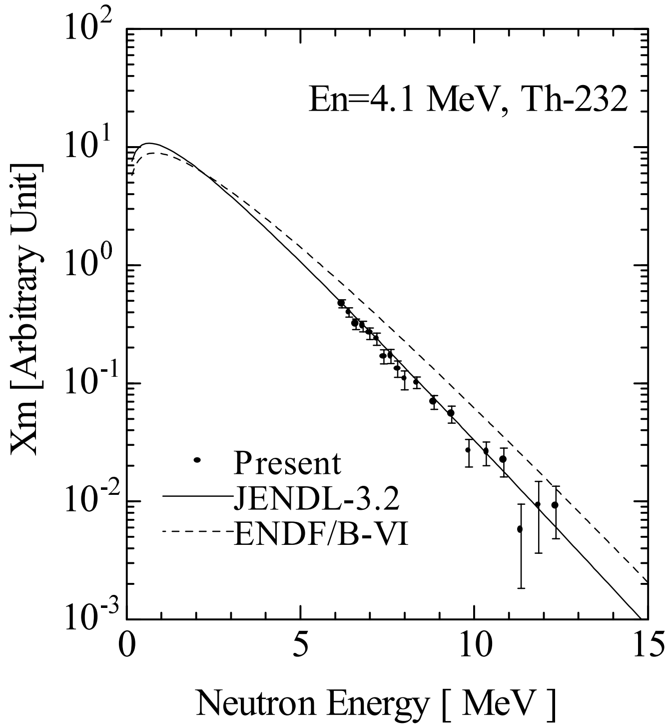

Fig. 6 Fission spectrum of ^{232}Th at En=4.1 MeV compared with JENDL-3.2 and ENDF/B-VI (Experimental data are normalized to JENDL-3.2)