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Precision measurements of ^{252}Cf, ^{233}U, ^{235}U and ^{239}Pu prompt fission neutron spectra (PFNS) in the energy range 0.04 - 5 MeV

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ABSTRACT

The fission neutron spectra have been measured at the flight distances of 0.5 m and 1.0 m by the time-of –flight method with a scintillation detector based on the anthracene crystal which has a low energy threshold for neutrons of about 20 keV.

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Precision measurements of ^{252}Cf, ^{233}U, ^{235}U and ^{239}Pu prompt fission neutron spectra (PFNS) in the energy range 0.04 - 5 MeV

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(V.I. Lenin NIIAR)

Abstract

The fission neutron spectra have been measured at the flight distances of 0.5 m and 1.0 m by the time-of –flight method with a scintillation detector based on the anthracene crystal which has a low energy threshold for neutrons of about 20 keV.

Needs of PFNS measurements are related both to the nuclear technology applications as well as to the study of neutron emission mechanism. However, there is practically no PFNS data available for the thermal-induced-fission on ^{233}U, ^{235}U and ^{239}Pu targets for outgoing neutron energies below 0.5 MeV [1,2]. Measured data in the region 0.5 - 1 MeV are discrepant [3]. Therefore we measured new PFNS data for outgoing neutron energies 0.04 – 5 MeV with special emphasis in the energy region 0.04 - 1.5 MeV.

PFNS were measured by TOF method in the horizontal channel of the SM-2 reactor. Neutron and photon beam was filtered by a quartz glass (12 cm) and bismuth (8 cm), and was then shaped by a steel collimator with rectangular-hole dimensions 1.5 x 15 mm^2. A fission fragment detector was setup in the thermal neutron beam, and a neutron detector was located perpendicular to the neutron beam and to the plane defined by the layer of the fissile nuclide at 0.5 or 1 meter distance from the fissile target.

Neutrons were detected by a scintillator detector made of anthracene crystal (18 mm diameter, 4 mm height) mounted on a FEU-71 photomultiplier. Anthracene crystal was fully extracted from packaging, was covered with a thin aluminium foil, and fixed on the photocathode of the photomultiplier.

Detector body was made of a copper foil of 0.05 mm thickness; the voltage divider and all plugs were located at 1 meter from the photomultiplier. A 30 mm diameter lead foil of 1 mm thickness was placed in the front of the scintillator crystal to reduce gamma background.

Fission fragments (FF) were detected by four identic ionization chambers (IC) weighting 2.5 g each. Every IC contained one of the studied nuclide ^{252}Cf, ^{235}U, ^{233}U, ^{239}Pu. Nuclide layer with 20 mm diameter was carefully deposited on carefully electrically-polished stainless steel backing of 25 mm diameter and 0.04 mm thickness. The gap between the steel backing and the collecting electrode was 3 mm. Chambers were filled with methane. The FF count rate dependence on the discrimination level allowed to find the total detection efficiency of the fragments which reached 98 ± 2 (^{252}Cf), 97 ± 2 (^{239}Pu), 95 ± 2 (^{235}U) and 92 ± 2% (^{233}U). Some FF were not detected due to FF energy losses in the steel backing and in the fission layer itself. For selected discrimination levels we detected 300, 5000, 2700 and 3 pulses of noise and alpha-particles per second from ^{252}Cf, ^{239}Pu, ^{235}U and ^{233}U layers, respectively. Fission count rate for each fissile target was 65000 fission/sec.

The electronics set-up corresponds to scheme of slow-fast coincidences. Pulses from the FEU-71's anode were amplified by a fast amplifier, and IC pulses via the pre-amplifier were fed into the form-discriminator, and then to the time-amplitude convertor (TAC). At the same time, the pulses from the last FEU-71 dynode were fed through an emitter repeater to the spectrometric amplifier, and then were fed to a differential discriminator. From the output of the discriminator the signals were applied to the input "control" of the BAP-5 unit of the AI-1024 multi-channel analyser. The pulses from the TAC were applied to the input of the BAP-5 unit.

PFNS measurements were undertaken using three low and three high discrimination levels equal to 0.02, 0.1, 0.25 MeV (LOW) and 2, 5, 10 MeV (HIGH) in the neutron energy scale. For the LOW threshold of 0.02 and HIGH threshold of 2 MeV the time resolution was 5 ns. For higher thresholds, the resolution improved up to 3 ns. Measurements were carried out 24hours/day for 6 months.

The measurement procedure included: selection and control of the discrimination level of the neutron detector using gamma sources of ^{55}Fe (E_γ = 5.9 keV) and ^{241}Am (E_γ = 59.5 keV); determination of the time bin of the multi-channel analyser using calibrated delay line and ^{252}Cf(s.f.) neutron transmission measurements through ^{19}F (ftoroplast compound) layer (resonance energies E_n = 27.02; 49.1 and 97 keV); determination of the shape of the time distribution for isolated mono-energetic neutrons in described transmission experiment; background measurement of the scattered neutrons for each nuclide and discrimination level using brass cones located between the IC and the neutron detector; determination of the contribution of the delayed gammas by measuring their time distributions after the replacement of the anthracene crystal by a liquid scintillator (C_6F_6) using the discrimination levels which correspond ones for the anthracene crystal; and control of the count rate stability for FF and neutron detection. Spectra processing included the background subtraction of the random coincidences and "recycled" neutrons, backgrounds of scattered neutrons and delayed photons. After the data processing and checking we estimated: 2-5% as the statistical uncertainty of the measurements; uncertainty of the time channel bin - 0.3 %; uncertainty of the "zero" time – 0.3 ns; uncertainty of the distance target-detector - 1 mm; stability of discriminator level – 0.03 keV in the Compton-electron energy scale; delayed-photon contribution – 2%; the shape of the neutron time distribution was close to the Gaussian.

In the first step of the spectra processing we took their intensity ratios normalized to one fission event. These ratios are equal to the ratios of the detected number of neutrons for a given channel of the time analyser, and were also normalized to one fission event. Such processing allows to reduce systematic uncertainties, and the knowledge of the neutron detection efficiency is not needed. Measured data are shown in Figs. 1 and 2. If we assume that ^{252}Cf $\overline{\nu}$ = 3.77 [4] and the ^{252}Cf PFNS is described by a Maxwellian distribution with temperature T = 1.417 MeV [5], then we obtain for the other measured PFNS: $^{239}Pu+n_{th}$ – $\overline{\nu}$ = 2.89 and T = 1.367 MeV; $^{235}U+n_{th}$ – $\overline{\nu}$ = 2.383 and T = 1.306 MeV; $^{233}U+n_{th}$ – $\overline{\nu}$ = 2.578 and T = 1.333 MeV. These data agree with results of Ref. [6]

In Fig.1 and 2 we can see noticeably higher (about by 8-10%) number of fission neutrons for ^{252}Cf (s.f.) and $^{235}U+n_{th}$ compared to the $^{239}Pu+n_{th}$ neutrons in the energy region 0.04 - 0.8 MeV. This result is in agreement with results from refs. [1-3]. At the same time, the measured ratios of PFNS of ^{252}Cf(sf), $^{235}U+n_{th}$, and $^{233}U+n_{th}$ are in agreement with the ratios of corresponding Maxwellian distributions.

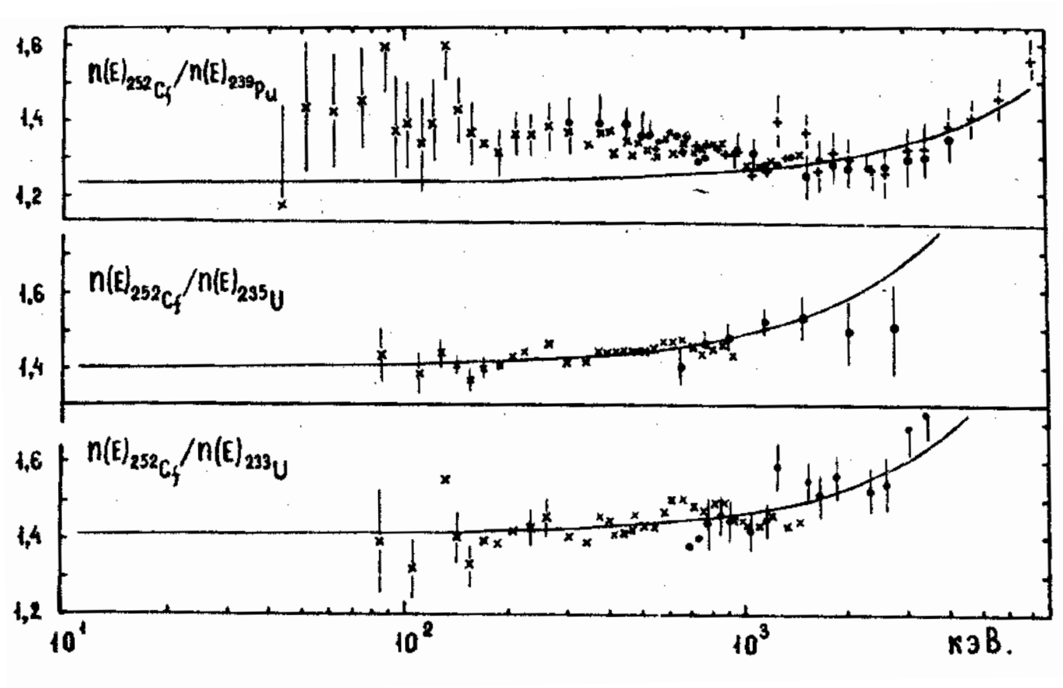

Fig.1. Ratios of ^{252}Cf PFNS to ^{239}Pu+n_{th}, ^{235}U+n_{th}, and ^{233}U+n_{th}. Ratios $n(E)_{Cf}/n(E)_{Pu}$ were measured for the following thresholds: cross x – 20 keV; dot ● – 100 keV; plus + – 250 keV. Ratios $n(E)_{Cf}/n(E)_{235U}$ and $n(E)_{Cf}/n(E)_{233U}$ were measured for the following thresholds: cross x – 20 keV; dot ● – 100 keV; plus + – 250 keV. The ratio of the Maxwellian distributions (solid lines) was calculated with the following parameters (from top to bottom):

($\overline{\nu}$ = 3.77 and T = 1.417 MeV) and ($\overline{\nu}$ = 2.89 and T = 1.367 MeV);

($\overline{\nu}$ = 3.77 and T = 1.417 MeV) and ($\overline{\nu}$ = 2.383 and T = 1.306 MeV);

($\overline{\nu}$ = 3.77 and T = 1.417 MeV) and ($\overline{\nu}$ = 2.578 and T = 1.333 MeV).

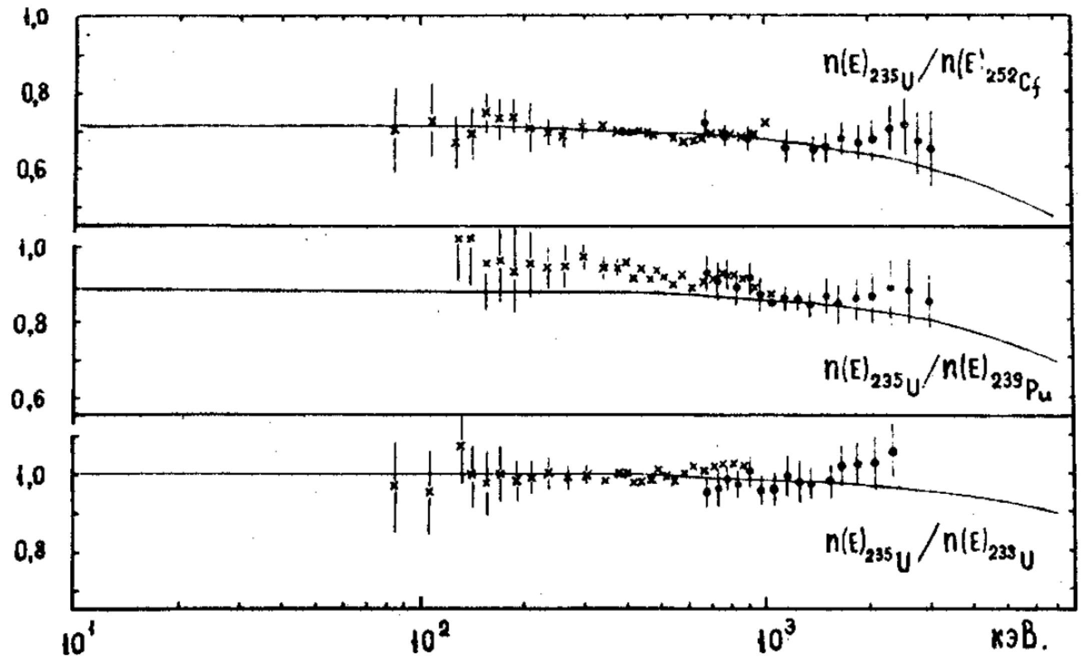

Fig.2. Ratio of ^{235}U+n_{th} PFNS to the measured PFNS for the other nuclei: Data were measured for the following thresholds: cross x – 20 keV, and dot ● – 250 keV. The ratios of the Maxwellian distributions are shown as solid line.

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