# Study of prompt fission neutron energy spectra in fast neutron induced fission of $^{232}$Th at average neutron energies of 1.5 MeV and 2.1 MeV

Sukanya De[1,2], R. G. Thomas[1,2], G. Mishra[1,2], Ajay Kumar[1], A. Mitra[1]

[1]Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085, India
[2]Homi Bhabha National Institute, Anushaktinagar, Mumbai-400094, India

## Introduction

Measurement of prompt fission neutron spectra (PFNS) for fast neutron induced fission of actinides has gained renewed interest due to its significance in the development of impending Generation IV reactors and accelerator driven systems for the transmutation of nuclear waste [1]. Knowledge of the prompt neutron spectra and multiplicity enables us to gain understanding about fission dynamics, particularly the energy partitioning in fission process, the re-organization of nuclear matter around scission and the subsequent de-excitation process.

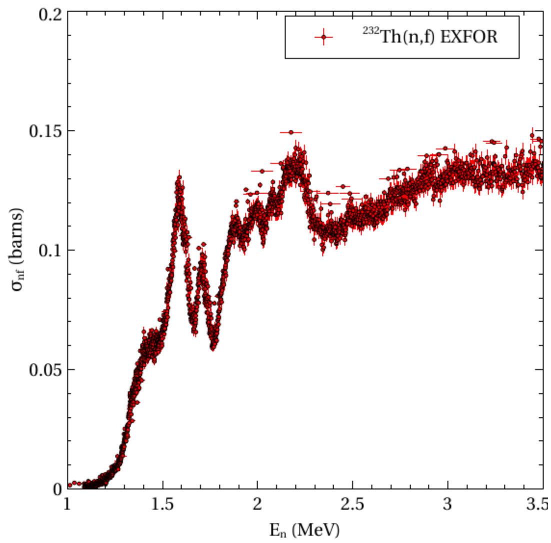


Fig.1.Fast neutron induced fission cross-section for $^{232}$Th.

It is known that structures in $^{232}$Th(n,f) cross-section shown in Fig. 1 appear because of its triple humped fission barrier in the multi-dimensional potential energy surface [2]. To investigate whether this fact also reflects in the energy partitioning at scission, we have initiated a program to measure the PFNS obtained in the fast neutron induced fission of $^{232}$Th at varying incident neutron energies. In this work, we report the measurements done for the PFNS obtained from the fast neutron induced fission of $^{232}$Th at average neutron energies of 1.5 MeV and 2.1 MeV.

## Experimental set-up

The experiment was carried out at the Folded Tandem Ion Accelerator (FOTIA) facility, BARC, Mumbai. The primary quasi mono-energetic neutrons were obtained using the $^{7}$Li(p,n)$^{7}$Be reaction by bombarding the proton beam on a natural $^{7}$Li metallic target of thickness ~ 4.0 mg/cm$^2$. Two 1.0 cm × 1.0 cm foils of $^{232}$Th of thickness ∼2.0 mg/cm$^2$ were placed on either side of the cathode of a twin section parallel plate trigger ionization chamber. The cathode and the anode diameter were 4.5 cm and were separated from each other by 2.0 mm Teflon spacer rings. Fission trigger rate was ~10 fissions/sec. Approximately 10 lakh fissions were collected for each incident neutron energy. Two EJ301 liquid scintillation detectors (12.7 cm in diameter and 5.0 cm thick) placed at a distance of 77.5 cm and 82.5 cm from the ionization chamber respectively. Threshold of the two neutron detectors were kept at 0.06 MeVee and 0.05 MeVee. Three standard radioactive sources namely $^{22}$Na, $^{60}$Co and $^{137}$Cs, were used for the energy calibration of the detectors.

## Analysis of experimental data

The analysis of experimental data was carried out in the ROOT framework to extract all the observables. The fission fragments deposit a fraction of their energies within the ionization chamber by generating electron-ion pairs which give rise to an electrical signal. This is used as the trigger for the time-of-flight (TOF) measurement. A certain threshold was set to cut down the events due to alpha particles. Pulse shape discrimination technique was used to separate the neutrons from the gammas. The TOF spectra measured using the EJ301 detectors were converted into corresponding energy spectra after appropriate calibration of the TDC channels. In order to obtain the genuine neutron spectrum, the energy spectrum of the background of width similar to the prompt neutron coincidence region in the TOF spectrum was subtracted from the measured prompt neutron energy spectrum. A commonly used approximation for prompt fission neutron spectra is the Maxwellian distribution given as:

$$N_M(E) = \frac{2\sqrt{E}}{\sqrt{\pi}T_M{}^{3/2}} e^{-\left(\frac{E}{T_M}\right)}$$

where $T_M$ is the Maxwellian temperature [3].

If it is assumed that all fragments have the same kinetic energy per nucleon Ef, then the laboratory neutron spectrum shape is a Watt spectrum

$$N_w(E) = \frac{2 \cdot A^{3/2}}{(\pi \cdot B)^{1/2}} \times \exp\left(-\frac{B}{4A}\right) \times \exp\left(-A \cdot E\right) \times \sinh\left(B \cdot E\right)^{1/2}.$$

The Watt parameters A and B are related to the physical quantities by the relations: $A = 1/T_e$ and $B = 4E_f/T_e^{2}$.

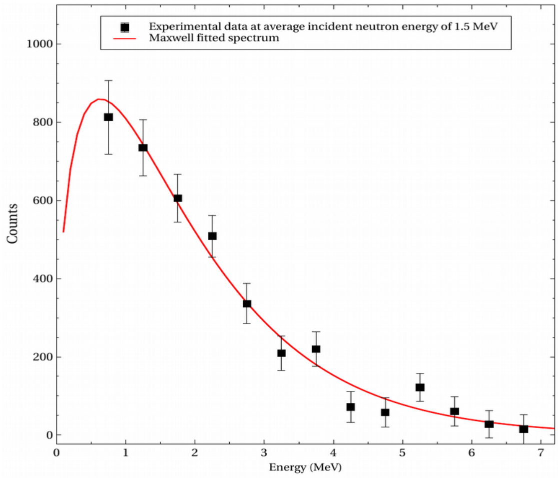


Fig. 2. PFNS measured at average incident neutron energy of 1.5 MeV and fitted with Maxwellian distribution (red line).

The efficiency corrected neutron energy spectra for both the detectors were added and fitted with the Maxwellian (red line) and Watt distribution (blue line) for average incident neutron energy of 1.5 MeV are shown in Figs. 2 and 3 respectively. The error bars along the y-axis consists of the statistical uncertainties in the measurement of neutron counts and the systematic uncertainties in the background subtraction technique. From the data available in literature [4] (shown by green dots), $T_M$ for the fast neutron induced fission of $^{232}$Th at different incident neutron energies along with present measurement (shown by red dots) and previous measurement [5] (shown by black dot) are shown in Fig. 4. The GEneral description of Fission observables (GEF) model [6] predicts a slowly rising Maxwellian temperature from 1.24 to 1.3 MeV as incident neutron energy increases from 1 to 5 MeV (solid blue line). Details of the experiment and the interpretation of the results will be presented in the symposium.

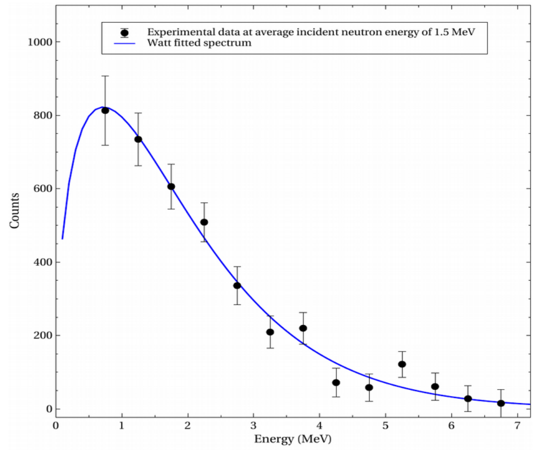


Fig. 3. PFNS measured at average incident neutron energy of 1.5 MeV and fitted with Watt distribution (blue line).

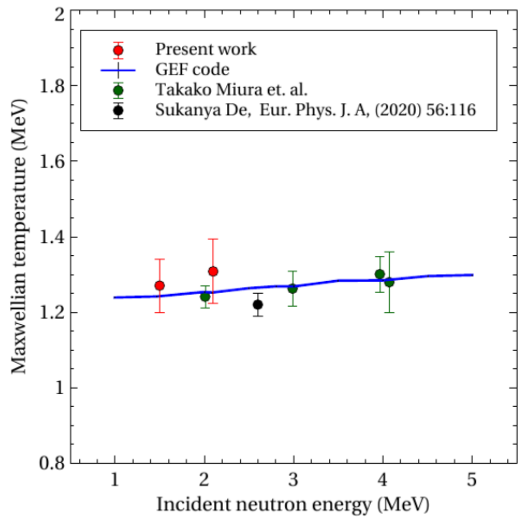


Fig.4. Variation of Maxwellian temperature with incident neutron energy

## References


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