Pre- and near-scission components of α-particle emission in the fission of $^{225}U^*$

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Introduction

Since the discovery of nuclear fission by Hahn and Strassmann in 1939, it has been a topic of continued research interest. Despite decades of extensive research, many aspects of nuclear fission remain unclear. The study of fission dynamics plays a crucial role, as how the nucleus evolves from a low-deformation, mononuclear state to a highly deformed scission stage, and how changes in potential energy influence this process, are still open questions. The role of nuclear viscosity in fission dynamics is somewhat ambiguous, in particular, the dependence of viscosity on temperature near the scission point is not understood well. Charged particle multiplicity spectra serve as an important tool for studying fission dynamics. During the fusion-fission process, particle emission occurs continuously. These emissions can be categorized into two major groups: those emitted from the fissioning compound system (pre-scission) and those from the accelerated fission fragments (FFs) (post-scission) [1, 2, 4]. In addition to pre- and post-scission emissions, a certain fraction of particles is emitted very near the neck region, close to the scission stage. It has been understood for quite long time that α particles are emitted at right angles to the scission axis [2, 4, 5] in a process known as "Equatorial emission" [4–6]. More recently, it has been observed that, in the case of protons, a portion is also emitted along the scission axis, which is referred to as "Polar emission" [6].

Besides the near scission multiplicity, the another important observable is the peak energy of the NSE α particles. In low energy fission (spontaneous fission, thermal neutron, and photo fission) this peak energy is constant around 15.5 MeV [3] . But, in heavy-ion fission the NSE peak energy data are very much limited and do not lead to any sytematics as these are scattered from 12.5 to 19.5 MeV for different systems. A systematic understanding of the NSE peak energy can provide valuable information about the saddle to scission dynamics.

Experimental Details

We have measured the α-particle energy spectra in coincidence with FFs in $^{19}F + ^{209}Bi$ reaction at a beam energy of 99 MeV by using a state-of-the-art experimental setup. The experiment was performed using ^{19}F (99 MeV) beam from BARC-TIFR 14-MV Pelletron accelerator facility at Mumbai. The compound nucleus was populated to an excitation energy of 40.2 MeV. After correcting for pre-scission neutron multiplicity to be around 2.5 (estimated from Ref. [7]), the fissioning nucleus is predominantly ^{225}U. A self-supporting metallic foil of ^{209}Bi ($\sim$1.8 mg/cm^2) was used as the target. FFs produced in the reaction were detected using two large area Multi-Wire Proportional Counters (MWPCs), placed in folding angle configuration. The MWPCs were placed at θ_f=60° (ϕ=0°) and 104°(ϕ=180°) with angular openings of 27.8° and 42.3°, respectively. Fission events were clearly separated from other reaction products by plotting cathode pulse height from one MWPC against the other.

The α-particle emitted in the reaction were detected by five collimated CsI(Tl)-Si(PIN) de-

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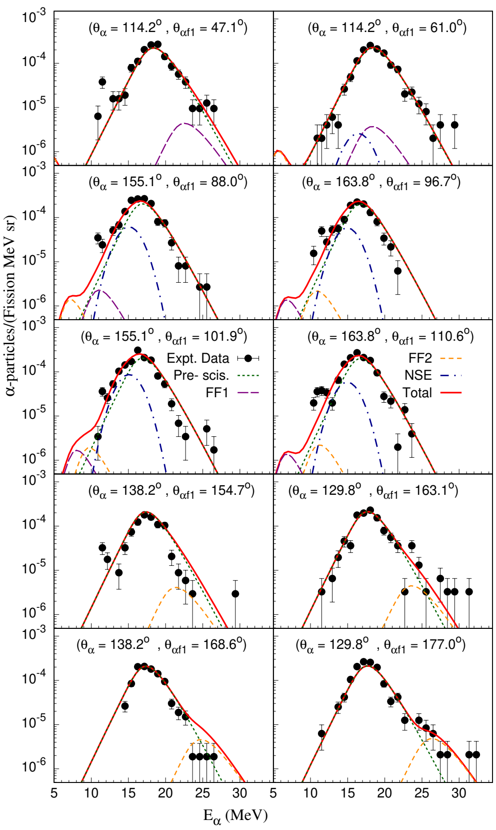

FIG. 1: α-particle multiplicity spectra along with MSDA fits with pre-, post-, and near-scission sources.

tectors. Each detector had an angular opening of $\pm 4°$. All the CsI(Tl) detectors were energy calibrated periodically during the experiment using ^{229}Th α-source. Extrapolation of the light yield produced in CsI(Tl) detectors beyond 8.4 MeV was estimated using in-beam data from earlier measurements [2]. Time correlations between FFs detected by the two MWPCs were recorded using a time-to-amplitude converter. Around 10^7 fission coincidence events were recorded. Time correlations between fission events and α particles were also recorded.

After correcting the energy loss of the α-particle within the target and accounting for random coincidences, the normalized α-particle multiplicity spectra were obtained by dividing the coincidence energy spectra by the total number of fission-single events. The fission events were divided into two angular segments. Considering five widely positioned charged-particle detectors and two angular segments of the fission events, a total of 10 combinations of α multiplicity spectra, with each having different relative angles with respect to the FF1 ($\theta_{\alpha f1}$) and the beam (θ_α), were obtained.

Results and Discussion

The Moving Source Disentangling Analysis (MSDA) is carried out by including three usual sources; pre-, post-, and near-scission emissions. The α-particle energy spectra in the rest frames for pre-, post-, and near-scission emissions are calculated using the recipe given Refs. [4, 5]. In the MSDA, the emission barrier heights and temperatures for compound nuclei and FFs were kept fixed, whereas the pre- and post-scission multiplicity were varied. The fitted spectra for the individual source and after summing are shown in Fig.1 for all 10 angular settings. The best fitted values of the parameters are found to be $\alpha_{\text{pre}} = (1.22 \pm 0.19)\times10^{-3}$, $\alpha_{\text{post}} = (1.01 \pm 0.01)\times10^{-5}$, $\alpha_{\text{nse}}=(1.14 \pm 0.4)\times10^{-4}$, $\epsilon_\alpha = 17.8 \pm 0.42$ MeV, $\sigma_\epsilon = 1.68 \pm 0.29$ MeV, and $\sigma_\theta = 12.7^o \pm 5.8^o$ corresponding to a minimum χ^2/(degree of freedom) value of 3.6, where α_{pre}, α_{post}, α_{nse}, are the pre-, post- and near-scission α-particle multiplicities, and σ_ϵ, and σ_θ are standard deviations of the energy and the angular distributions, respectively for NSE.

The fraction of the near scission α-particle component relative to the total pre-scission component is (8.5 ± 3.2)%, which is consistent with the global systematics developed earlier [2]. The negligibly small post-scission multiplicity is consistent with the very low excitation energy of the FFs, around 19.3 MeV. It is interesting to compare the NSE peak energy, obtained for the present reaction (17.8 ± 0.42 MeV) with other heavy-ion fission data. Detailed results from systematics of NSE peak energy will be presented.

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