Pre-scission proton multiplicity spectra in ^{16}O + ^{232}Th reaction at E_{Lab}=96 MeV

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Introduction

Despite the continued intensive research for the last several decades, the heavy-ion induced fusion- fission reveals often surprises. Several fission observables from the direct detection of fission fragments (FFs) such as the mass-distributions, angular-distributions. etc. deviate the expectations of fission decay from an equilibrated compound nucleus when it is induced by heavy-ion fusion reactions [1]. Traditionally, several terms, such as "quasifission", "pre-equilibrium fission" [2, 3], "slow quasi-fission" [4], etc. have been associated with aforesaid different observations. However, the underlying mechanism is not very well understood.

It is of significant interest to further investigate the heavy-ion induced non-equilibrium fission via other experimental probes. Among others, the particle emission is also a quite useful probe to learn about the overall complex fission dynamics. During the heavy-ion induced fission, neutron and charged-particle (mainly proton and α-particle) emissions take place from various stages namely from the fissioning compound system (pre-scission) and from the accelerated fission fragments (post-scission) [5–7]. Very recently, a new signature of non- equilibrium fission has been observed from pre-scission α-particle multiplicity data [8]. Systematic comparison of ^{11}B, ^{12,13}C, ^{16}O, and ^{19}F induced fission of ^{232}Th shows that the α_{pre} makes a changeover from high to a very low value while crossing the Businaro Gallone point in mass asymmetry in the entrance channels. Similar discontinuous behavior with respect to the entrance channel mass asymmetry has also been observed in fission fragment angular anisotropy data. While the measured anisotropies in ^{11}B and ^{12}C-induced fission were found to be in agreement with the predictions of the standard Halpern-Strutinsky theory, they were anomalously large in the case of ^{16}O and ^{19}F induced fission. Observed similarities between the results of α_{pre} and angular anisotropy for the same set of reactions with similar energetics point towards a common underlying mechanism leading to the non-equilibrium fission.

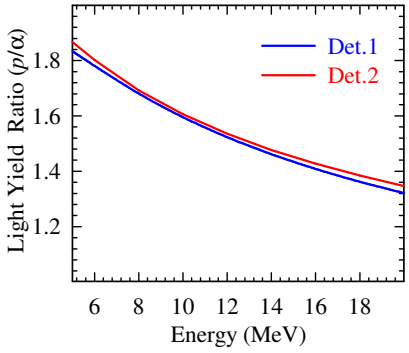

FIG. 1: Light yield ratio of proton to α-particle (p/α) as measured in earlier experiments [6, 7].

The discontinuous behavior as discussed above has not been observed for the pre-scission neutron multiplicity (ν_{pre}) data. Rather, it is shown that the ν_{pre} after normalizing with E_{CN} remains almost the same over a wide fissility range [9]. Insensitivity of the ν_{pre} with respect to non-equilibrium fission has been observed in an another work also [10]. A transition to quasifission is clearly observed in ^{16}O + ^{238}U fission at beam energies just below the Coulomb barrier from fission fragment mass and angular distributions, however, the ν_{pre} does not show any discontinuity with decreasing beam energy [10].

Unlike the ν_{pre} and α_{pre} data, a systematic study for pre-scission proton multiplicity (π_{pre}) data is not available so far. It is of utmost importance to investigate the aforesaid discontinuous behavior through proton channel also. With that motivation we have analyzed the proton energy spectra in ^{16}O + ^{232}Th reaction measured at E_{Lab}=96 MeV.

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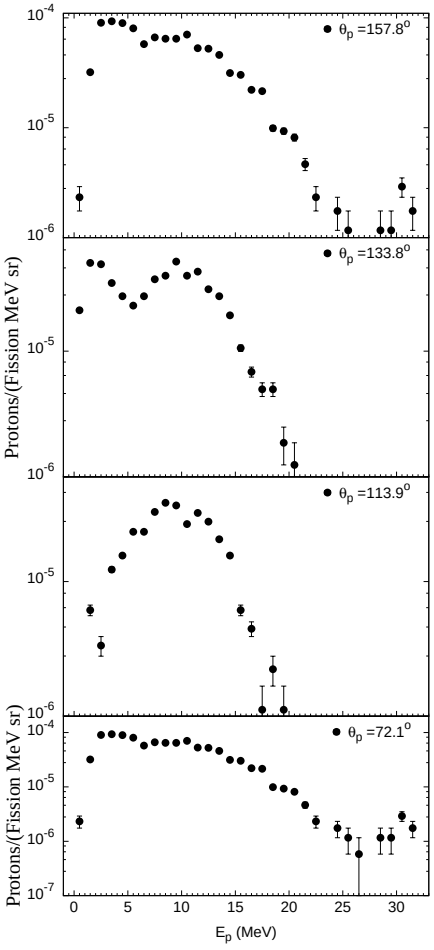

FIG. 2: Proton multiplicity spectra in ^{16}O (96 MeV) + ^{232}Th reaction at different laboratory angles.

Experimental Details and Results

96-MeV ^{16}O beam was obtained from 14-MV BARC-TIFR Pelletron facility, Mumbai. A self-supporting metallic foil of ^{232}Th (∼1.6 mg/cm^2) was used as the target. The FFs from reaction were detected using two large area Multi-Wire Proportional Counters (MWPCs), placed in folding angle configuration. The charged particles emitted in the reaction were detected by twelve collimated CsI(Tl)-Si(PIN) detectors, covering a wide range of relative angles. Zero Crossover Time (ZCT) as well as Ballistic Deficit (BD) were used for the particle identification in CsI(Tl) detectors. Time correlations between the charged particle detectors and the fission detectors were obtained using a TAC. More details about the experimental techniques can be seen from Ref. [8].

All the CsI(Tl) detectors were energy calibrated periodically at every 24 hours during the experiment using ^{229}Th source. In earlier experiments, the light yield ratio of proton to α-particles (p/α) were measured in a α-particle range of 5 to 20 MeV [6, 7]. The p/α ratios are observed to be approximately same for the different CsI(Tl) detectors as shown in the Fig.1 for two typical detectors. These p/α ratios enabled us to calibrate the different CsI(Tl) detectors for protons. After correcting for random coincidences, the normalized proton multiplicity spectra were obtained by dividing the coincidence energy spectra with total number of fission single events. Typical four multiplicity spectra are shown in the Fig. 2. Each spectrum has contributions from pre- and post-scission sources. Similar to the α particles, the spectra might have some contribution from proton emission at near-scission stage (ternary emission). Preliminary analysis indicates that the overall proton multiplicities are a factor of 10 lesser than those for α-particle in ^{16}O (96 MeV) + ^{232}Th reaction. The difference in proton and α-particle multiplicities is consistent with the predictions of statistical model code, JOANNE2. The above difference is also in agreement with exit channel Q-values. These are -5.53 MeV and +6.36 MeV for proton and α-particle emissions, respectively.

Details about the moving source fit to disentangle the contributions in proton multiplicity from different stages of the fusion-fission process will be presented.

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