Investigating effect of collective enhancement in level density in the fission of a heavy fissile compound nucleus.

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Introduction

The complex process involved in the collective re-arrangement of nuclear matter in fission is still an intense topic of research. Among many probes to explore fission, pre-scission neutron multiplicity (ν_{pre}) is one of the best probes to understand the evolution of the compound system from ground state configuration to scission configuration. Observation of excess emission of ν_{pre} than standard statistical model (SSM) [1] predictions indicates that nuclear fission is a dynamical process. This anomalous neutron emission is manifested in terms of dissipation involved in the dynamical nature of fission process [2].

Neutron multiplicity measurements reported recently, observed a strong energy dependence of dissipation [3]. On the other hand, measurements on evaporation residue cross sections resulted a constant dissipation strength, which is independent of excitation energy [4]. In a recent modeling of fusion-fission [5], it is reported that, apart from dissipation, the inclusion of other effects such as shell effects, collective enhancement of level density (CELD) and K-orientation effect in the fission width provide a consistent picture of fission in pre-actinide nuclei. In another measurement, it is shown, however that, inclusion of CELD was not necessary to reproduce the evaporation residue (ER) cross section of a compound nucleus (CN) formed in actinide region [6]. In this context, we report here our measurements on neutron multiplicity for the ^{30}Si+^{197}Au reaction leading to the formation of highly fissile (actinide) CN, ^{227}Np, over a wide range of excitation energies.

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Experimental Setup

The experiment was performed at the National Array of Neutron Detectors (NAND) [7] facility of IUAC, New Delhi. Pulsed beams of ^{30}Si with a pulse repetition rate of 250 ns delivered from 15 UD Pelletron + LINAC accelerator system were used in the experiment to bombard on ^{197}Au targets of thickness 300 μg/cm^2. Neutron multiplicity measurements were performed at seven energies between E_{lab}=152.3 to 192.4 MeV. Emitted neutrons from the fusion-fission reactions were detected in coincidence with the complementary fission fragments using 50 organic liquid scintillators (BC 501) of 5" x 5" dimensions kept at a distance of 175 cm from the target. Fission fragments were detected using two large area, position sensitive MWPCs kept at the fission folding angle with respect to the beam direction and at a distance of 16.5 cm from the target position. The fast timing signals from the MWPCs were used to obtain the time of flight of the fission fragments and other reactions products.

Data Analysis

Discrimination between neutron and gamma was made using time of flight (TOF) technique as well as pulse shape discrimination based on zero crossing method [8]. The TOF spectra were converted into neutron energy by considering prompt gamma peak as the reference line. Neutron energy spectra were gated with fission fragment TOF spectra to ensure that the neutrons were emitted only from respective fusion-fission/capture process. MWPC position spectra were further sliced and gated with the neutron energy spectra in order to minimise the angular uncertainty due to the large area of the MWPCs. The pre- and post-scission components of neutron multiplicities and temperature were ob-

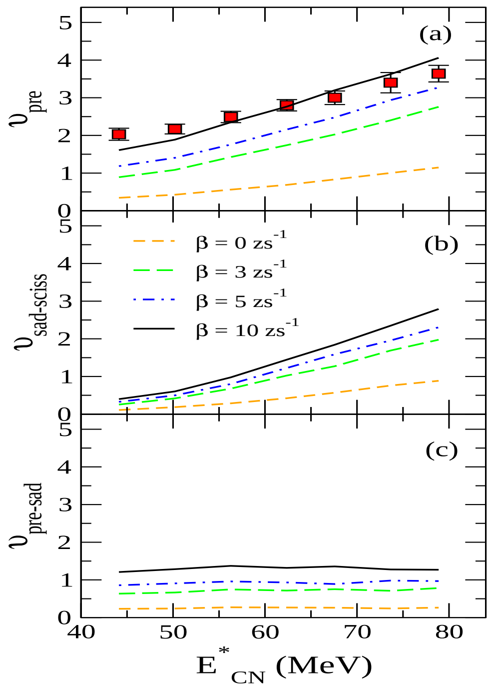

FIG. 1: Measured ν_{pre} excitation function for ^{30}Si+^{197}Au reactions along with the theoretical model predictions.

tained from measured neutron energy spectra using least square fitting of the Watt expression [9].

Theory and results

The experimental ν_{pre} excitation function is analysed within the framework of a statistical model, in which, emission of neutron, proton, α and γ rays have been considered as decay channels for an excited CN in addition to fission. Shell effects in the fission barrier (RFRM) and level densities, the effect of CELD and the K-orientation effect in variouse decay widths are incorporated in the calculations. Effect of CELD is employed according to the fomulation of Bjørnholm, Bohr and Mottelson [10] given as

$$\rho(E^*) = K_{coll}(E^*)\rho_{intr}(E^*) \tag{1}$$

where $\rho_{intr}(E^*)$ is the intrinsic level density and $K_{coll}(E^*)$ is the enhancement factor. Kramers [11] modified fission width due to dissipation is used in this analysis and is given as

$$\Gamma_K(E^*, l) = \Gamma_f(E^*, l)\left\{\sqrt{1 + (\frac{\beta}{2\omega_s})^2} - \frac{\beta}{2\omega_s}\right\} \tag{2}$$

where $\Gamma_f(E^*, l)$ is the K-equilibrated Bohr-Wheeler fission width and β denotes the reduced dissipation coefficient.

Statistical model predictions of ν_{pre}, $\nu_{sad-sciss}$ and $\nu_{pre-sad}$ are shown in panel (a), (b) and (c) of Fig. 1. The larger yield of neutrons prior to fission than Bohr-Wheeler prediction ($\beta = 0\ zs^{-1}$) could only be understood in terms of dissipation. $\beta = 10\ zs^{-1}$ well reproduces the experimental ν_{pre} and the results show temperature independent nuclear dissipation unlike previous reports. Analysis shows that $\nu_{pre-sad}$ does not show any dependence on CN excitation energy. It is also observed that, major contribution to ν_{pre} is from the neutrons emitted in the post-saddle phase of shape evolution.

Further, to investigate the effect of CELD and K-orientation in pre-scission neutron emission, three sets of analysis was performed, one excluding CELD but keeping all other effects, another excluding K-orientation but keeping the others and the last one excluding both CELD and K-orientation but with the rest of the effects. We find that, the influence of CELD and K-orientation degrees of freedom in fission of such heavy nuclei are weak, unlike fission of pre-actinides. This observation is connected to the large deformation at the ground state of the CN and the limit to populate maximum angular momentum in the CN, respectively.

Acknowledgments

Two of the authors (M S and A C V) are thankful to KSCSTE for financial assistance in the form of fellowship. One of the authors (EP) acknowledges DST for support from DST-RFBR fellowship.

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