# Nuclear dissipation at high excitation energy and angular momenta in reaction forming $^{227}$Np

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Neutron multiplicity excitation function has been measured for the $^{30}$Si + $^{197}$Au reaction populating the $^{227}$Np compound nucleus at excitation energies in the range 44.1–78.8 MeV using the National Array of Neutron Detector facility of Inter University Accelerator Centre, New Delhi. Measured pre-scission neutron multiplicity values are analyzed using a statistical model incorporating Krammer's fission width due to the dissipative drag in nuclear fission, shell corrections in fission barrier and level density, collective enhancement of level density, and $K$-orientation effect. The present work demonstrates that a strong fission hindrance is essential to reproduce the experimental pre-scission neutrons, whereas the temperature dependent dissipation coefficient as observed in a few recent measurements is not required to reproduce the experimental $\nu_{\text{pre}}$ data. No substantial effect of collective enhancement of nuclear level density and tilting away effect of compound nucleus spin on neutron emission prior to the scission configuration was observed unlike fission of preactinides.

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## I. INTRODUCTION

Nuclear fission is a dramatic phenomenon that involves a subtle interplay of macroscopic and microscopic effects. Microscopic effects such as shell effects and pairing play important roles in low energy fission [1], which becomes less significant at high excitations. On the other hand, fission is also known to be a highly dissipative process [2,3] and dissipative effects become increasingly important at higher excitation energies. Though the onset of dissipation has been reported in measurements using various observables [4–6], the exact nature of dissipation and its dependence on various quantities are still not clear.

Pre-scission neutron multiplicity is one of the most important probes to explore the fission dynamics in heavy ion fusion reactions. Neutrons may be emitted from the compound nucleus (CN) itself during the pre-scission stage and/or from the fission fragments after scission. Nonequilibrated processes such as quasifission [7–9] can also contribute to the total neutron multiplicity in reactions involving heavy nuclei. However, such neutrons emitted from the fission fragments (post-scission neutrons) show strong angular correlations due to the kinematic focusing of the fast moving fission fragments, which serves the basis of their separation from the pre-scission neutrons experimentally.

Theoretically, it is possible to estimate the two components of pre-scission neutron multiplicity, the pre-saddle neutron multiplicity ($\nu_{\text{pre-sad}}$), and the post-saddle neutron multiplicity ($\nu_{\text{post-sad}}$). $\nu_{\text{pre-sad}}$ is the average number of neutrons emitted from the system before reaching the saddle point whereas $\nu_{\text{post-sad}}$ is the average number of neutrons evaporated during the descent from the saddle point to the scission point. Estimation of these components of neutron multiplicity was reported to be necessary for the analysis of mass-energy distribution and angular distribution of fission fragments [10,11]. For heavy fissile systems (actinide nuclei), a major contribution to $\nu_{\text{pre}}$ comes from the $\nu_{\text{post-sad}}$. This is due to the fact that the nuclei in this region have smaller fission barrier height and also the saddle and ground state configurations have similar deformation values. Hence major de-excitation occurs in the post-saddle phase of shape evolution. Similarly, it is reported that major enhancement in $\nu_{\text{pre}}$ with increasing excitation energy is due to the neutrons emitted from the post-saddle phase of the fission process [10,11].

It was reported long ago that the measured pre-scission neutron multiplicities ($\nu_{\text{pre}}$) are significantly higher than the statistical model predictions [12–16] assuming the Bohr-Wheeler formalism of fission. Similar observations have also been made for the pre-scission charged particles [17–19] and giant dipole resonance (GDR) $\gamma$ multiplicities [20–22]. This excess emission is a clear experimental signature [23,24] of dissipation in fusion-fission. Dissipation slows down fission and enhances the particle evaporation probability during the transition of the CN from equilibrium configuration to the scission configuration.

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