Fission fragment angular distributions in pre-actinide nuclei

Tathagata Banerjee,[1,*] S. Nath,[1] A. Jhingan,[1] Gurpreet Kaur,[2] R. Dubey,[1] Abhishek Yadav,[1] P. V. Laveen,[3] A. Shamlath,[3] M. Shareef,[3] J. Gehlot,[1] N. Saneesh,[1] E. Prasad,[3,†] P. Sugathan,[1] and Santanu Pal[4,‡]

[1]*Nuclear Physics Group, Inter University Accelerator Centre, Aruna Asaf Ali Marg, Post Box 10502, New Delhi 110067, India*
[2]*Department of Physics, Panjab University, Chandigarh 160014, India*
[3]*Department of Physics, School of Mathematical and Physical Sciences, Central University of Kerala, Kasaragod 671314, India*
[4]*CS-6/1, Golf Green, Kolkata 700095, India*

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Background: Complete fusion of two nuclei leading to formation of a heavy compound nucleus (CN) is known to be hindered by various fission-like processes, in which the composite system reseparates after capture of the target and the projectile inside the potential barrier. As a consequence of these non-CN fission (NCNF) processes, fusion probability (P_{CN}) starts deviating from unity. Despite substantial progress in understanding, the onset and the experimental signatures of NCNF and the degree of its influence on fusion have not yet been unambiguously identified.

Purpose: This work aims to investigate the presence of NCNF, if any, in pre-actinide nuclei by systematic study of fission angular anisotropies and fission cross sections (σ_{fis}) in a number of nuclear reactions carried out at and above the Coulomb barrier (V_{B}).

Method: Fission fragment angular distributions were measured for six ^{28}Si-induced reactions involving isotopically enriched targets of ^{169}Tm, ^{176}Yb, ^{175}Lu, ^{180}Hf, ^{181}Ta, and ^{182}W leading to probable formation of CN in the pre-actinide region, at a laboratory energy (E_{lab}) range of 129–146 MeV. Measurements were performed with large angular coverage ($\theta_{\mathrm{lab}} = 41^\circ$–$170^\circ$) in which fission fragments (FFs) were detected by nine hybrid telescope (E-ΔE) detectors. Extracted fission angular anisotropies and σ_{fis} were compared with statistical model (SM) predictions.

Results: Barring two reactions involving targets with large non-zero ground state spin ($\mathcal{J}$), viz., ^{175}Lu ($\frac{7}{2}^+$) and ^{181}Ta ($\frac{7}{2}^+$), experimental fission angular anisotropies were found to be higher in comparison with predictions of the statistical saddle point model (SSPM), at $E_{\mathrm{c.m.}}$ near V_{B}. Comparison of present results with those from neighboring systems revealed that experimental anisotropies increasingly deviated from SSPM predictions as one moved from pre-actinide to actinide nuclei. For reactions involving targets with large nonzero $\mathcal{J}$, this deviation was subdued. Comparison between measured σ_{fis} and predictions of SM indicated the presence of NCNF in at least four systems, when shell effects, both in the level density and the fission barrier, were included in the calculation.

Conclusions: Systematic SM analysis of measured fission angular anisotropies and σ_{fis} confirmed the onset of NCNF in pre-actinide nuclei. Discrepancies between results about the degree of its influence on complete fusion, as deduced from various experimental probes, remain challenges to be solved. Complete measurement of all signatures of NCNF for many systems and preferably a dynamical description of the collisions between projectile and target nuclei are warranted for a deeper understanding.

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I. INTRODUCTION

Production of a fully equilibrated massive compound nucleus (CN) by fusing two heavy nuclei is known to be inhibited by competing fission-like processes. Fast fission [1], quasifission [2], and pre-equilibrium fission [3], often collectively called non-CN fission (NCNF), may cause reseparation of the composite target-projectile system after its capture inside the potential barrier. The presence of NCNF in a reaction thus reduces the probability of synthesis of a heavy evaporation residue (ER), which is the cold residual nucleus formed following evaporation of light particles and emission of γ rays from the excited CN. Besides suppression of ER cross sections (σ_{ER}) [4–6], NCNF is reported to have other experimental signatures, viz., increase in the width of the fission fragment (FF) mass distribution [7–9] incompatible with fission of the CN (CNF), anomalous FF angular anisotropies [10,11], and FF mass-angle correlation [12]. NCNF in a reaction causes the *fusion probability* (P_{CN}) to deviate from unity. Determining the NCNF cross section, σ_{NCNF} (or the complementary fusion cross section, σ_{fus}) as a fraction of capture cross section, σ_{cap}, is a difficult task, especially for the less fissile systems. This is because the characteristics of the experimental observables from CNF and NCNF in these nuclei often show considerable overlap. Moreover, there are disagreements between the quanta of NCNF in a given reaction, as deduced from different experimental probes.

*he.tatha@gmail.com
†Presently at Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 2601, Australia.
‡Formerly with Physics Group, Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, India.

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