Status of asymmetric fission in the preactinide region

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The study of fission fragment mass distribution in the preactinide region remains a dynamic area of nuclear fission research. This presentation will highlight recent results from our experimental campaign on charged-particle-induced fusion-fission reactions in preactinide region at the BARC-TIFR Pelletron LINAC Facility. We will compare these measurements with data from other facilities, offering an overview of experimental trends, and discuss the findings in the context of advanced theoretical models.

Introduction

Nuclear fission, the process by which an atomic nucleus splits into fragments, is an extraordinarily complex phenomenon that continues to challenge both theorists and experimentalists. For physicists studying nuclear structure, fission offers wide array of nuclei far from stability to explore. For many-body theorists, it serves as a striking example of large-scale collective motion within the nucleus, providing a testing ground for state-of-the-art computational and mathematical techniques. For nuclear astrophysicists, fission imposes limits on the existence of the heaviest elements in nature and may contribute to the creation of elements heavier than iron.

Although the basic features of the fission process can be described by the simple liquid-drop (LD) model [1], the early discovery of the dominant mode of asymmetric fission in low-energy reactions of actinides could not be explained by this macroscopic approach. To reconcile the model with experimental data, it became necessary to account for the effects of nuclear shell structure [2].

Asymmetric fission in the preactinide region

Based on the understanding from actinides, low-energy fission in the preactinide region around lead was expected to be mass symmetric. However, evidence for asymmetric fission in preactinides near the beta-stability line was first observed in the 1980s [3]. The discovery of a strong asymmetry in the β-delayed fission of neutron-deficient ^{180}Hg [4], which was expected to produce two semimagic $^{90}_{40}$Zr$_{50}$ fragments, sparked a significant worldwide experimental and theoretical effort in the study of fission in the preactinide region. In β-delayed fission, the fissioning nucleus is populated just above the fission barrier, allowing it to fully experience the effects of shell corrections. However, β-delayed fission can only be studied in a limited number of systems, and even in these cases, the statistics are low due to the extremely small cross-section [5].

Alternatively, charged-particle-induced fusion-fission reactions have been used to study fission properties in this mass region. These studies are generally limited to excitation energies around 20 MeV above the saddle point due to the Coulomb barrier of the entrance channel. Although shell corrections diminish significantly at these energies, fusion-fission studies have still been found to be sensitive to them [6–8].

To gain a deeper understanding of the development of asymmetric fission in the pre-actinide region, we have initiated an ongoing experimental program at NPD, BARC. A series of measurements have been performed on pre-actinide nuclei such as ^{204}Pb [6], ^{187}Ir [7], and ^{193}Tl [8] using charged-particle-induced fusion-fission reactions at the BARC-TIFR Pelletron LINAC Facility in Mumbai. Fragment mass and total kinetic energy (TKE) were determined by measuring the time-of-flight and emission angles of the fragments. A multi-Gaussian fit was applied to extract the mean positions, widths, and fractions of the asymmetric components from the experimental mass distributions. The analysis of ^{204}Pb revealed a sig-

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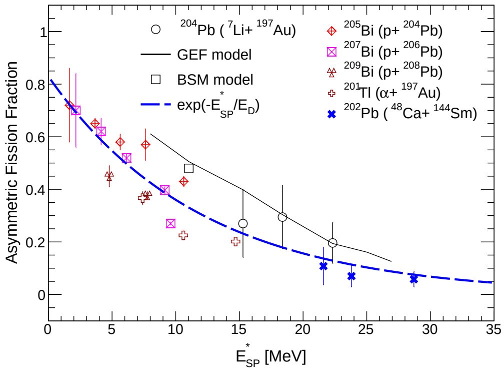

FIG. 1: The fraction of asymmetric fission for ^{204}Pb in dependence on excitation energy at the saddle point. The measured asymmetric fission fractions is compared with the predicted trend of the GEF and BSM model as well as with measurements for near by systems [6]

nificant contribution from the asymmetric fission mode at all three measured excitation energies[6], while the mass distributions for ^{187}Ir were predominantly symmetric [7].

Figure 1 displays the measured asymmetric fission fractions for ^{204}Pb as a function of excitation energy at the saddle point. The experimental results align well with the predicted trends of the GEF and BSM models, as well as with measurements from nearby systems [6]. As expected, the fraction of asymmetric fission decreases as the excitation energy at the saddle point increases for all studied systems. The blue dashed line represents an exponential decay fit, $\exp(-\mathrm{E}^{*}_{\mathrm{SP}}/\mathrm{E}_{\mathrm{D}})$, with a resulting damping parameter, $\mathrm{E}_{\mathrm{D}} = 11.99 \pm 0.01$ MeV, derived from a simultaneous fit of all the systems.

Summary

The study of fission fragment mass distribution in the preactinide region remains a dynamic and highly active area of nuclear fission research. This presentation will highlight the latest results from our ongoing experimental campaign on charged particle-induced fusion-fission reactions at the BARC-TIFR Pelletron LINAC Facility. We will explore how these new measurements compare with data obtained at other facilities, providing a comprehensive overview of experimental trends across the field. Additionally, the results will be discussed in the context of state-of-the-art theoretical models, allowing us to assess their accuracy and highlight areas where further improvements may be required.

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