# Low energy fission in Neptunium (Np) isotopes

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## Introduction

Even after 8 decades of its discovery, fission continues to be a hot topic in nuclear physics research. Fission is strongly influenced by the collective and microscopic degrees of freedom. One of the key signatures of this competition is reflected in the fragment mass distribution. Though the liquid-drop model predicts symmetric mass split in fission, the low-energy fission in actinides was observed to be asymmetric. This was later attributed to the fragment shell properties. With increasing excitation energies, a transition to a symmetric split has been observed, due to the damping of shell effects with increasing excitation energy [1]. This transition is a sensitive probe of nuclear structure and collective dynamics. A transition to symmetric division is observed with decrease in mass number [2]. Further, asymmetric fission has been observed in the low energy fission of Hg isotopes [3]. Recently, the driving force of these asymmetric fission is attributed to deformed shells [4]. In the present work, we have investigated the fission of three neptunium isotopes, $^{225,227,238}$Np, through mass ratio analysis ($M_R$) of fission fragments. A systematic analysis and theoretical calculations have been performed to explore the mechanism of fission in these isotopes in this work.

The experiment was performed using the pulsed beams of $^{30}$Si from the Pelletron and SCLinac of the IUAC. Beams with a pulse seperation of 250 ns was used to bomard $^{197}$Au target of thickness 300 $\mu$g/cm$^2$. Measurements were performed at the laboratory energies of the range 140.0 - 186.4 MeV. The complimentary fission fragments were detected using a pair of identical position-sensitive multiwire proportional counters (MWPCs) having active areas of 11 × 16 cm$^2$.

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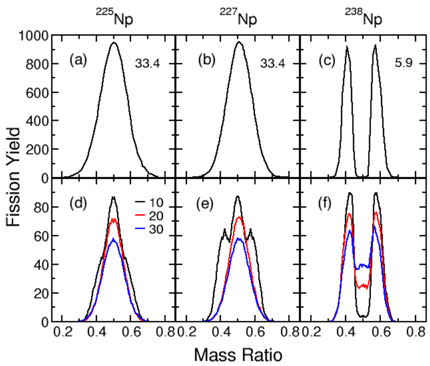


FIG. 1: The measured $M_R$ distribution of fission fragments from $^{225,227,238}$Np nuclei are shown in upper panels and the GEF calculations are shown in the bottom panels for $E^*$ =10, 20, 30 MeV.

## Analysis and Result

The kinematic reconstruction method [5] was used to obtain the mass angle distributions of the $^{30}$Si+$^{197}$Au reaction from the position and timing signals received from the MWPC detectors [6]. The measured $M_R$ distribution of fission fragments from $^{225,227,238}$Np [7, 8] nuclei are shown in Fig. 1 (upper panels). The $E^*$ values are also shown in the top panels. The GEF calculations are shown in the bottom panels for $E^*$ =10, 20, 30 and the lowest measured $E^*$ values

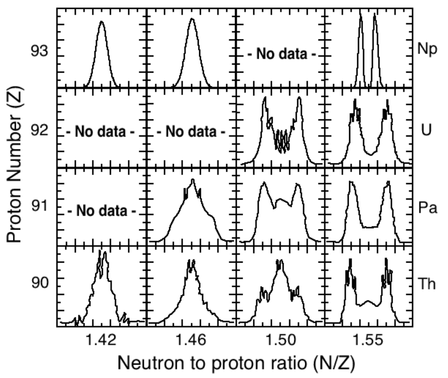


FIG. 2: Fission fragment mass distribution of selected isotopes of Th, Pa, U and Np.

for $^{225,227}$Np (33.4) nuclei. While experimental data is limited to low E$^*$ value in $^{238}$ Np, mass-asymmtric fission is predicted by GEF model even at high E$^*$. Interestingly GEF predicts symmetric splits in $^{227,225}$Np in agreement with the experimental observations.

Further, we compiled the fragment mass distributions of a few isotopes of Np, U, Pa and Th isotopes [1, 2], having similar neutron to proton number ratio (N/Z) in Fig. 2. It is observed that the mass division is asymmetric in the neutron rich isotopes of (N/Z $\sim$ 1.55) all four actinide nuclei. A transition to mass symmetry may be seen with decreasing N/Z values in all four cases, leading to a predominantly symmetric mass-split at lower N/Z values (N/Z $\sim$ 1.46 and below). Interestingly, the transition from asymmetric to symmetric split has been observed to be faster in Np isotopes.

Theoretical calculations within the macroscopic-microscopic model has been performed, where the shape parameters elongation ($c$) and mass asymmetry ($\alpha$) are defined from the Hill-Wheeler parametrization [9]. We have calculated free energy surfaces at $T = 0$ for all the three Np isotopes considered in the present work. For $^{238}$Np, the magnitude of the symmetric fission barrier along $\alpha = 0$ is much higher than the mass-asymmetric barrier at non-zero $\alpha$, indicating a larger probability for asymmetric mass splitting for this compound nucleus. To understand it more accurately, we extracted

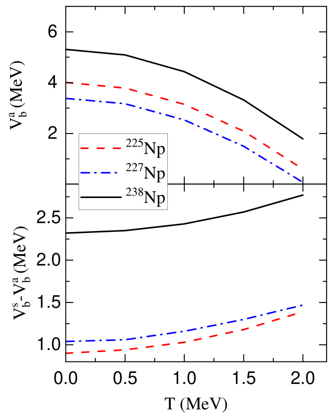


FIG. 3: Symmetric ($V_b^s$) and asymmetric ($V_b^a$) fission barriers for 3 isotopes of Np at different $T$.

the symmetric ($V_b^s$) and asymmetric ($V_b^a$) fission barriers for these isotopes at different $T$, which is shown in Fig. 3. The absolute and relative magnitude of $V_b^a$ for all the three isotopes are close to the results from the five-dimensional calculation given in Ref. [10]. As shown in Fig. 3, $V_b^a$ is higher for $^{238}$Np at all $T$. Moreover, the relative value $V_b^s - V_b^a$ is substantially higher for $^{238}$Np compared to the other two nuclei, which are close enough in this respect. These results suggests that the asymmetric splitting of $^{238}$Np is expected to sustain even at higher $T$, which may not be the case for $^{225,227}$Np.

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