Fusion-fission study at IUAC: Recent results

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Abstract. Several properties observed in heavy ion induced fission led to the conclusion that fission is not always originated from fully equilibrated compound nucleus. Soon after the collision of two nuclei, it forms a di-nuclear system than can fission before a compound nucleus is formed. This process termed quasi-fission is a major hurdle to the formation of heavier elements by fusion. Fission originated before complete equilibration showed anomalously large angular anisotropy and mass distribution wider than what is expected from compound nucleus fission. The standard statistical model fails to predict the outcome of quasi-fission and currently no dynamical model is fully developed to predict all the features of quasi-fission. Though much progress has been made in recent times, a full understanding of the fission dynamics is still missing. Experiments identifying the influence of entrance channel parameters on dynamics of fusion-fission showed contrasting results. At IUAC accelerator facility many experiments have been performed to make a systematic study of fission dynamics using mass distribution, angular distribution and neutron multiplicity measurements in mass region around $A \sim 200$. Recent measurement on mass distribution of fission fragment from reaction $^{19}F + ^{206,208}Pb$ around fusion barrier energy showed the influence of multi-mode fission in enhancing the mass variance at low excitation energy. In this talk I will present some of these results.

1. Introduction
Fission of heavy nuclei is a complex process involving rapid re-arrangement of nucleons and large shape changes. Soon after the experimental discovery of neutron induced fission of $^{235}U$ in 1939[1], the detailed understanding and the physics concepts behind the fission phenomenon was explained by Bohr and Wheeler[2]. Since then several decades of fission research have led to many applications and wealth of new knowledge in nuclear physics. Despite significant progress in fission studies, the dynamics of the fission process is still not yet fully understood in terms of quantum microscopic physics. The standard statistical model of fission was successful in explaining many of the features observed in light ion induced fission. However, it fails to explain many features of heavy ion induced fission. In recent years, there have been many experimental and theoretical efforts made towards better understanding of the dynamics of fission. These studies are important for understanding the formation of super heavy elements in laboratory. It is well known that a major hurdle in the formation of super heavy element is the presence of non-compound nuclear process such as fast fission or quasi fission(QF) that are dominant in heavy nuclear systems[3]. Near the fusion barrier energies the non compound process exhibit their own reaction characteristics which are distinguished by various measurements such as mass and angular distributions of fission fragments, mass-angle correlation, and pre-scission particle multiplicities etc. For example, presence of excess of pre-scission particle multiplicity, large anisotropy in angular distribution, strong mass-angle correlation and broadened mass...
distribution for fission fragments (FF) in some of the systems indicated strong evidence of non compound nuclear process and hindrance to fusion-fission process[4]. A large number of such experimental data using heavy ion fusion-fission reaction have been collected in the past and such measurements are still continued in many laboratories. At IUAC accelerator facility, we have been performing research on fusion-fission studies using heavy ion reaction and dedicated facilities. In the following, some of our existing experimental facilities for fission research and highlights of recent experiment will be discussed.

2. Facilities for fission study at IUAC
The accelerator facility at inter university accelerator centre (IUAC) consist of a 15UD Pelletron accelerator followed by super conducting LINAC[5]. Heavy ions with energy ranging from below barrier to above barrier are used to study fusion-fission dynamics in reactions involving stable target-projectile combination. The distinct features of fusion-fission reactions are studied in many measurements including fission excitation functions, angular distributions, mass-energy distributions, mass-angle distribution, mass-angle correlation and fusion evaporation residue (ER) measurements. Detection of light particles in coincidence with fission fragments also provide crucial information on the time scale and dynamics of the process. As each measurement demand efficient detector system specific for the type of particles to be detected, these measurements are carried out employing different kind of experimental facilities. For example, to measure angular distribution of fission fragments, array of charged particle detector telescopes covering angular range from 90° to 180° are typically used. Mass distribution of fragments is deduced from the velocity of the fragment measured from time of flight (TOF) and energy of the fragments. For velocity measurement, TOF setup using indigenously developed large area 2D position sensitive multi-wire proportional counters (MWPC) of dimension 20cm × 10cm are being used[6]. By placing the detectors in folding angle and detecting fragments in kinematic coincidence, full momentum transfer fusion-fusion events can be separated from incomplete fusion-fission events. At IUAC, these detectors are placed on two rotatable arms inside the 1.5 m diameter general purpose scattering chamber (GPSC), that has been extensively used for fission fragment angular and mass distribution measurements. Recently a new facility consisting 100 neutron detectors coupled with fission fragment detectors has been commissioned further enhancing our experimental research programs at IUAC[7]. Over the years we have performed several experiments devoted to the systematic study of the fission dynamics in nuclei around mass 200 region. Figure 1 shows photograph of typical set up used for FF mass distribution and angular distribution studies in GPSC[8].

![Figure 1](image_url). Picture of time of flight setup consisting two large area MWPC detectors mounted inside scattering chamber facility and array of charged particle telescope detectors (ΔE (gas) - E(Silicon)) detectors used for angular distribution measurement.
3. Experimental signatures of quasi-fission

3.1. Fission Fragment Angular distribution

The fission fragment angular distribution measurements have been used to investigate the dynamics of fission in heavy ion reactions for a long time. According to the standard transition state model (TSM) of fission theory, the fragments are emitted along the nuclear symmetry axis and their properties are determined at the transitional saddle point [9]. In this formalism, the angular anisotropy defined as the ratio of the yield at 180° or 0° to that at 90° (\(A = W(180°)/W(90°)\)) is given by the approximate expression

\[ A \sim 1 + \left( \frac{\langle l^2 \rangle}{4K_0^2} \right). \]  

(1)

with \(K_0^2 = T \times \frac{L_{eff}}{I_{bg}}\), where \(T\) is the temperature, \(L_{eff}\) is the effective moment of inertia at the saddle point and \(\langle l^2 \rangle\) is the mean square angular momentum of the fissioning system. Measurements of the fission anisotropy therefore gives the information about the effective moment of inertia of the fissioning nucleus at the saddle point of deformation.

For light charged particle induced reactions, observed anisotropy have been found to be in agreement with the TSM predictions. However it has been observed that in large number of reactions using actinide targets, angular anisotropy values larger than those predicted by TSM. These anomalously high anisotropies were attributed to the presence of pre-equilibrium fission (PEF) or orientation dependent quasi fission. In PEF fission [10], if fission barrier height is comparable to its temperature, the fission takes place before the K degree of freedom is fully equilibrated (K is the projection of angular momentum of compound nucleus on the symmetry axis). It is suggested that entrance channel mass asymmetry, \(\alpha\) plays major role in the occurrence of PEF; reactions having \(\alpha\) smaller than the Businaro-Gallone mass asymmetry \(\alpha_{BG}\) showed larger anisotropy where as for reactions with \(\alpha\) more than \(\alpha_{BG}\), anisotropies were normal [10, 11].

Experimental evidence of entrance channel dependence was observed in several systems such as \(^{11}\text{B} + ^{237}\text{Np}, ^{12}\text{C} + ^{236}\text{U}, ^{13}\text{C} + ^{235}\text{U}\) and \(^{16}\text{O} + ^{232}\text{Th}, ^{19}\text{F} + ^{232}\text{Th}\) etc having different entrance channel mass asymmetry values [12, 13, 14, 15]. However it was found that for actinide targets, due to channel couplings and consequent shift in \(\alpha_{BG}\) towards higher mass asymmetry the PEF occur irrespective of the \(\alpha\) on either side of \(\alpha_{BG}\) [16]. It was shown that apart from mass asymmetry, the target deformation and the intrinsic spin of target or projectile can also enhance the angular anisotropy at sub barrier energies [17, 18, 19]. Hinde et al observed that fragment anisotropy increases below barrier energy in reaction \(^{16}\text{O} + ^{238}\text{U}\) and this was interpreted due to presence of nuclear orientation dependent quasi-fission [17]. Here it was shown that below barrier energy, the projectile interaction with tips of the deformed target nucleus lead to quasi fission events whereas collisions with the sides lead to fusion-fission.

It is generally believed that quasi fission is expected in heavy systems with high fissility and charge product \(Z_p Z_t \geq 1600\). However Berriman et al. found that even low fissility system such as \(^{19}\text{F} + ^{197}\text{Au}\) showed signatures of quasi-fission [20]. They have observed broader mass distribution and suppression of evaporation residues in reactions \(^{19}\text{F} + ^{197}\text{Au}\) and \(^{30}\text{Si} + ^{186}\text{W}\) as compared to \(^{12}\text{C} + ^{204}\text{Pb}\), all three reactions forming same compound nucleus \(^{216}\text{Ra}\). This was attributed to presence of quasi fission in former two reactions. However the measurement of angular distribution of \(^{19}\text{F} + ^{197}\text{Au}\) system by Tripathi et al showed normal anisotropy consistent with TSM prediction implying absence of quasi-fission [21]. At IUAC also we have performed angular distribution measurements for \(^{11}\text{B} + ^{204}\text{Pb\) and \(^{18}\text{O} + ^{197}\text{Au}\) forming the nearby compound nucleus \(^{215}\text{Fr}\) and found that both systems exhibit normal values of anisotropies consistent with the TSM predictions, implying the absence of any PEF or quasi-fission in these reactions [22]. Similarly for the reaction \(^{16}\text{O} + ^{238}\text{U}\), Nishio et al measured the evaporation residues cross sections for the energy range from above- to extreme sub barrier and found that the cross section data
could be well reproduced by statistical model calculation implying the absence of any quasi-fission in this reaction\cite{23}. Thus there are contrasting results and a very clear distinction of quasi fission from complete fusion-fission process becomes more challenging.

3.2. Fission fragment mass distribution

Mass distribution of fission fragments is another observable by which one can study the property of fission process. In recent times, mass variance and mass-angle correlation of fragments have been used as a sensitive tool for identifying the presence of quasi fission events. Generally in heavy ion induced fission where fission is occurring from a fully equilibrated system, the mass distribution is expected to be a symmetric Gaussian with variance of the distribution given by

$$\sigma_m^2 = \lambda T + \kappa \langle l^2 \rangle. \quad (2)$$

where T is the temperature of compound nucleus (CN) at saddle, \(\langle l^2 \rangle\) mean square angular momentum and \(\lambda\) and \(\kappa\) are constants. It shows that the mass width increases linearly with temperature the compound nucleus. In the case of quasi fission process, the mass distribution becomes more asymmetric and exhibit strong mass-angle correlation\cite{24, 25}. It was observed that for a CN formed through different entrance channel reactions, even though no mass angle correlation is observed, the reaction dominated by quasi fission events exhibited large mass width compared to the pure fusion-fission reaction\cite{24, 26, 27}. For example, the fission fragment mass distribution from two reactions \(^{16}\text{O}+^{194}\text{Pt}\) and \(^{24}\text{Mg}+^{186}\text{W}\) forming the same CN \(^{210}\text{Rn}\) was measured at IUAC facility\cite{28}. Though neither of the two reactions showed any noticeable mass-angle correlations, the reaction \(^{24}\text{Mg}+^{186}\text{W}\) showed significantly different mass distribution with larger mass width as compared to reaction \(^{16}\text{O}+^{194}\text{Pt}\) where pure compound nucleus fission is expected. The broad mass distribution in reaction \(^{24}\text{Mg}+^{186}\text{W}\) was attributed to the presence of quasi-fission in the reaction. For this system, though the \(Z_pZ_t\) and fissility values are less than the classical limit, it shows a clear indication of onset of quasi fission in low fissile systems.

Even though large anisotropy and wider mass distribution in low fissile system may suggest the presence of quasi-fission, the unambiguous identification of quasi-fission still remains a challenging problem. For example, the mass distribution of fragments in reaction \(^{16}\text{O} + ^{238}\text{U}\) showed large deviation at below barrier energies\cite{29}. Here the target is deformed and the orientation dependent quasi-fission has been attributed to be the reason for enhanced mass variance at low excitation energies. It is to be noted that, for same reaction, large angular anisotropies were also observed around barrier energies\cite{17}. However, for the same reaction \(^{16}\text{O} + ^{238}\text{U}\), measurement of ER cross section at barrier and deep sub-barrier energies did not show any evidence of quasi-fission\cite{23}. Similar anomalous increase in width of mass distribution at below barrier energy was also observed in systems with the deformed target \(^{232}\text{Th}\)\cite{30}. It should be noted that, in the case of actinide nuclei, the increase in width of mass distribution \(\sigma_m^2\) at low energy could also be possible due to the presence of asymmetric fission manifested through the shell effects. For example, fragment mass distribution in reaction \(^{12}\text{C} + ^{235}\text{U}\) showed increasing yield of mass-asymmetric components at low excitation energies\cite{31}. Here the presence of asymmetric mass division was attributed to the role of shell effects. Though the reaction involved deformed target, no significant amount of quasi-fission was observed in this reaction. Hence, it is important to identify the contribution of asymmetric fission events in the mass distribution measurement using deformed targets.

4. FF mass distribution from reactions \(^{19}\text{F} + ^{206,208}\text{Pb}\)

Recently we have performed the measurements of mass distribution of FF from reactions \(^{19}\text{F} + ^{206,208}\text{Pb}\) forming \(^{225,227}\text{Pa}\) compound nuclei over a range of excitation energies\cite{32}. Since both \(^{206,208}\text{Pb}\) targets are spherical, the orientation dependent quasi fission effects are not expected
to play any role here. These reactions have low $Z_PZ_T$, low fissility (see Table 1) and it is expected to follow normal fusion-fission path. The fission fragment angular distribution data for $^{19}$F + $^{208}$Pb system did not show any anomalously large anisotropy implying absence of any non-compound process in the reaction[33]. In the absence of any non-compound process, the mass distribution measurement from these systems are expected to follow the results of standard normal fusion-fission dynamics only.

The experiment was carried out using pulsed $^{19}$F beams from the 15UD Pelletron accelerator at different beam energies. Pulsed beam had 250 ns repetition rate and $\sim 1.5$ ns time width. Beam was bombarded on isotopically enriched $^{206,208}$Pb targets of $\sim 110$ $\mu g/cm^2$ thickness deposited on $\sim 20$ $\mu g/cm^2$ thick $^{12}$C backings forming CN $^{225,227}$Pa. Beam energy steps were chosen to form compound nucleus(CN) with similar excitation energies. For the detection of complimentary fission fragments, two large area($20\times 10$) position sensitive multi-wire proportional counters (MWPCs) were used [6]. They were mounted on two arms of the GPSC and placed at folding angles. The detectors were operated with iso-butane gas typically at about two Torr pressure.

Table 1. Entrance channel reaction parameters for reactions populating $^{225,227}$Pa nuclei. Columns shows the reaction, compound nucleus (CN), $Z_PZ_T$, $\alpha_{bg}$, $\alpha (= \frac{A_T - A_P}{A_T + A_P})$, fissility ($\chi$), and the neutron number N of CN.

| Reaction  | CN   | $Z_PZ_T$ | $\alpha_{bg}$ | $\alpha$ | $\chi$ | N   |
|-----------|------|----------|---------------|----------|--------|-----|
| $^{19}$F + $^{206}$Pb | $^{225}$Pa | 738 | 0.87 | 0.831 | 0.773 | 134 |
| $^{19}$F + $^{208}$Pb | $^{227}$Pa | 738 | 0.88 | 0.832 | 0.786 | 136 |

4.1. Experimental results
The TOF and energy loss signals from MWPC detectors were used to discriminate fission events from elastic recoil events. Fig. 2a displays the kinematic coincidence plot showing correlation between the time signals in two MWPC detectors. Clean separation of fission events can be seen in the plot. The data analysis was performed by velocity reconstruction of events based on method given by [34]. From calibrated position and timing information, the fragment velocities and center-of-mass angles of were reconstructed for each event. The velocity vector components (parallel ($V_\parallel$) and perpendicular ($V_\perp$) to beam direction) of the fissioning nucleus were also determined for each event. Complete fusion events were selected by applying the condition for full momentum transfer (FMT) using the correlation of velocity components. This eliminates any possible contamination from transfer induced fission events. From the ratio of the velocities in the center-of-mass frame, the mass ratios defined as $M_R = \frac{m_1}{m_1 + m_2}$ ($m_1$ and $m_2$ are two fragment masses) were determined. Fig. 2b displays the spectra showing the correlation between mass ratio and $V_\parallel - V_{c.m.}$ (where $V_{c.m.}$ is the center-of-mass velocity) for fission events from the reaction $^{19}$F + $^{208}$Pb at below barrier energy. The intense region shown as black rectangle in the plot, corresponds to the events originated from FMT fission and a software gate around these events was used in the analysis of mass angle correlation and mass ratio distribution.

4.1.1. Mass angle correlation
The mass-angle correlation is the distribution of mass ratio as a function of emission angle in center of mass frame ($\theta_{c.m.}$). This correlation is a direct evidence for presence of quasi fission and provides information on its time scale[24]. For fusion-fission reaction, the mass ratio yield is independent of the emission angle of fragments whereas for fission coming from non-compound processes the yield depends on fragment angle $\theta_{c.m.}$. The
Figure 2. (a) Time correlation between two MWPCs showing fission events separated from recoils and (b) mass ratio distribution plotted against velocity components at below barrier energy for the reaction $^{19}$F+$^{208}$Pb. The events within rectangular box corresponds to FMT fission.

mass-angle distribution were generated for both reactions and figure 3 shows selected part of the mass-angle-correlation observed in $^{19}$F+$^{208}$Pb at below and above barrier energies. As one can see from Fig.3, the mass ratio yield is independent of emission angle $\theta_{c.m.}$ within the range from $\approx 110^\circ$ to $150^\circ$. Thus the absence of any mass-angle correlation in this case demonstrate that there is no significant presence of any non-compound process in this reaction around the barrier energies.

Figure 3. Mass angle correlation of fission fragments from reaction $^{19}$F+$^{208}$Pb at various excitation energies

4.2. Variation of mass variance with $E_{c.m.}/V_B$
In the present work, the mass distribution measurements have been performed at energy range of $0.93 \leq \frac{E_{c.m.}}{V_B} \leq 1.29$. The mass distributions of FMT events measured in the reaction $^{19}$F+$^{206}$Pb$\rightarrow^{225}$Pa$^*$ for different excitation energies are given in Figure 4. In all cases, the measured mass distribution appears to be symmetric centred around mass $M \sim \frac{A_{CN}}{2}$. The shape of the mass distribution could be described by fitting single Gaussian except at lowest excitation energy where the distribution appears to be non-symmetric. To understand how the distribution varies with energy, the standard deviation $\sigma_M$ of the mass distribution was extracted at each excitation energy after making best Gaussian fit to the data. The variance of
the mass distribution $\sigma_M^2$ as a function of energy (reduced barrier energy) is shown in the right panel of figure 4. Above the barrier energy, the widths of the FF mass distributions show a gradual increase over the energy. This is expected distribution from equilibrated system due to the influence of the increasing nuclear temperature. However at beam energies below the fusion barrier, the width increases again strongly with decreasing energy.

**Figure 4.** Mass distribution from reaction $^{19}$F + $^{206}$Pb at various excitation energies (left panel) and the mass variance $\sigma_M^2$ as a function of reduced Coulomb barrier $E_{c.m.}/V_B$ (right panel)

### 5. Discussion

The sudden increase in mass variance below barrier energy was earlier observed in fission induced by $^{16}$O and $^{19}$F projectile on deformed targets such as $^{232}$Th and $^{238}$U[30, 29]. This was attributed to orientation dependent quasi fission process dominating at below barrier energies. The presence of quasi fission increases the width of mass distribution. However, fission induced by similar projectiles on spherical targets such as $^{208}$Pb or $^{209}$B did not show any such evidence of quasi fission at below barrier energies. For the reaction $^{19}$F + $^{208}$Pb, experimental angular anisotropy as well as the theoretical calculation suggested that the reaction follows mainly fusion-fission path at near and sub-barrier energies[33, 35]. Comparatively low $Z_P/Z_T$ value, low fissility and absence of any mass-angle correlation also support that reaction is mainly fusion-fission only.

Considering quasi fission events are not dominant in these reactions, the observed enhancement in mass variance at low excitation energies signify some different characteristics of low energy fission. It is interesting to note that, an increase in mass variance at lower excitation energies have already been reported in earlier works on heavy ion induced fission in this region of the chart of nuclides where multi-mode fission was observed[36, 37, 38]. For example, mass distribution measurement from fission of $^{228}$U in the reaction $^{19}$F + $^{209}$Bi showed rapid rise of $\sigma_M^2$ near below the barrier energy and it was attributed to the possible contribution from asymmetric fission mode at low excitation energy[36]. Similarly, multi-mode fission were observed in induced fission of $^{224,226}$Th nuclei produced in the reaction $^{16,18}$O + $^{208}$Pb[37, 38]. In fact four fission
modes were observed in $^{226}$Th at 26 MeV of excitation energy[38]. In figure 5 the variation of $\sigma^2_M$ as a function of excitation energy for these nuclei are shown along with present data. It is to be noted that, all these reactions were studied at near barrier energies and they show similar characteristics of fragment mass distributions with respect to excitation energy. The $\sigma^2_M$ values decreases monotonically as energy is lowered, but rises again at lower excitation energies. The systematic analysis of present data shows that the increase in $\sigma^2_M$ values at low excitation energies indicates the presence of multi mode fission in present system also[32]. At low excitation energy, the shell effects come into play and superposition of two fission modes, one following the normal symmetric fission and the other following the asymmetric fission broadens the mass distributions. With excitation energy increasing the asymmetric mode disappears and the symmetric mode become dominant. But at low excitation energy the contribution of asymmetric mode will come into play leading too enlarged widths of mass distributions.

Multi-mode fission has been experimentally verified in low energy fission of light actinide nuclei[39, 40, 41, 42, 43]. Measurement by Schmidt et al. suggested that in this region of nuclei, a transition from the symmetric to the asymmetric fission mode takes place around mass $A \approx 226$[44]. Theoretically, the origin of multi-mode fission has been attributed to fragment shell structures affecting the potential energy surface (PES) of the deformed fissioning nucleus[45, 46, 47]. Multi dimensional potential energy calculations applying standard Strutinsky shell correction method [48] have been successfully used in explaining existence of different modes that corresponds to distinct valleys in the potential energy landscape of the deformed system [49, 50, 51, 52]. For the present system also, a theoretical investigation has been made by calculating the adiabatic potential energy in four dimensional deformation space using NRV code[53]. The code uses liquid-drop model for calculating macroscopic energy and two-center shell model(TCSM) for applying microscopic shell correction[53, 54]. The results of the calculation is shown in Fig. 6.

Figure 6 (left panel) shows the adiabatic potential energy ($V_{Adh}$) of deformed $^{225}$Pa nucleus plotted as a function of mass asymmetry parameter $\eta$ ($\eta = \frac{m_2-m_1}{m_2+m_1}$) and elongation $R$. Clearly one can see multiple valleys in the potential energy surface of the system. The global minimum valley corresponds to mass asymmetry $\eta \sim 0.17$ favouring mass asymmetric fission with heavy fragment mass $\sim 132$ and light fragment mass $\sim 93$. The calculation indicates the potential energy landscape being influenced by the shell closure in the heavy fragments due to its proximity to doubly magic $^{132}$Sn (Z=50, N=82). Similar results have also been observed in multi dimensional PES calculation by other authors [55, 38]. Experimentally measured mass and charge distribution of fission fragment from $^{225}$Pa in reaction $^{16}$O + $^{209}$Bi also
Figure 6. Calculated potential energy surface of fissioning nucleus $^{225}$Pa as a function of mass asymmetry $\eta$ and elongation $R$. On right side is the measured mass ratio distribution from reaction $^{19}$F + $^{206}$Pb at 31MeV excitation energy best described by superposition of three peaks[57].

showed presence of asymmetric fission components with relative yield about 10% of total fission yield[56]. Figure 6(right panel) shows the mass ratio distribution of $^{225}$Pa measured at the lowest excitation energy fitted by three Gaussian distributions. The experimental data closely matches to the description of superposition of three distributions, one centred around symmetric mass ($M_R \sim 0.5$) and others centred around light fragment ($M_R \sim 0.41$) and heavy fragments ($M_R \sim 0.59$) respectively[57].

6. Summary & Conclusion
Using the TOF setup at IUAC, fission fragment mass distribution have been measured for fission induced by $^{19}$F projectile on spherical target $^{206,208}$Pb at different excitation energies. No mass-angle correlation have been observed in the reaction. Experimental data on angular anisotropy as well as theoretical prediction suggest that the reaction is dominated by complete fusion-fission events. However, increase in widths of mass distribution have been observed in low excitation energy data. Contribution from QF is found to be negligibly small for present reaction. Systematic analysis of mass variance data in nearby actinide nuclei suggest that multi-mode fission manifested at low energy could broaden the mass distribution due to presence of asymmetric fission modes. At lower excitation energies nuclear shell effects comes into effect and asymmetric fission mode becomes dominant. As the excitation energy is increased, shell effects wash out and a transition from multi mode fission to symmetric fission is observed. Superposition of symmetric and asymmetric modes can increase the width of fragment mass distribution at low excitation energy. In conclusion, it appears that fission induced by projectiles with mass $A_p < 20$ on spherical targets and $Z_pZ_T (< 800)$ are dominated by fusion-fission events only, but the mass distribution at low energy could possibly contain contribution from multi-mode fission events also. Theoretical calculation of multi-dimensional potential energy surface also shows shell structure influencing the multi-modal nature of fission in actinide nuclei.

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