# Mass distribution of fission fragments in coincidence with alpha in $^{6,7}$Li +$^{238}$U reactions

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## Introduction

From our earlier study[1], a sharp increase in the peak to valley (P:V) ratio of fission-fragment (FF) mass distribution with the decrease in bombarding energy in $^{6,7}$Li + $^{238}$U reactions was observed when all events were assumed to be CN fission. The full width half maximum (FWHM) of the FF folding angle distribution was found to increase at sub-barrier energies, unlike the reactions involving tightly bound projectiles where a linear decrease in FWHM is expected. These anomalous behaviors have been qualitatively understood to be due to the presence of breakup/transfer induced fission along with CN fission. Exclusive measurements of fission fragments in coincidence with projectile breakup fragments are necessary to explain the above observations quantitatively.

The present work includes both inclusive as well as exclusive measurements of fission fragments and light charged particles produced in $^{6,7}$Li + $^{238}$U reactions and their results, confirming the earlier observations of breakup or transfer effect on fission with quantitative explanations.

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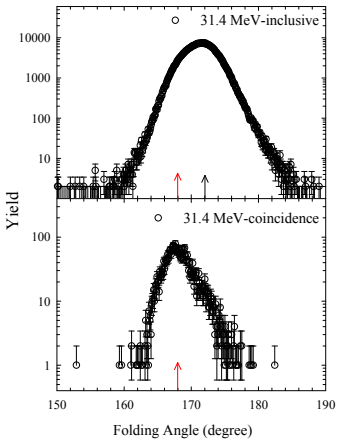


FIG. 1: A typical folding angle distribution in lab frame obtained in $^{7}$Li +$^{238}$U reaction for 31.4 MeV projectile energy for inclusive fission (top) and in coincidence with $\alpha$ detected at $\sim$165°(bottom).

## Measurements and Results

The experiment on $^{6,7}$Li + $^{238}$U reaction was carried out at 15-UD Pelletron facility at Inter University Accelerator Centre, New Delhi using 30, 34 and 40 MeV $^{6}$Li beam and 31.4 and 41.4 MeV $^{7}$Li beam. Time of flights of fission fragments were measured by two MWPC detectors placed at folding angles and energies of light charged particles were detected by 16 CsI scintillation detectors in an angular range of $\sim$101-169° ($\sim$71-139°) for

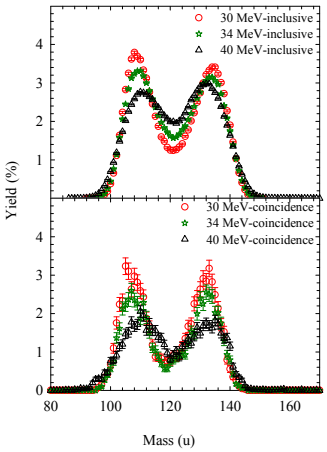


FIG. 2: FF mass distributions obtained for $^{6}$Li $+^{238}$U reaction at 30, 34 and 40 MeV beam energy for inclusive fission (top) and exclusive fission in coincidence with $\alpha$ (bottom).

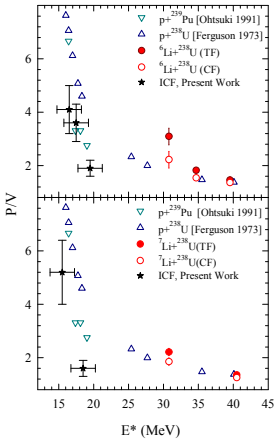


FIG. 3: P:V ratio of FF mass distribution for ICF, CF and total fission (stars, hollow circles and filled circles) obtained from $^{6}$Li $+^{238}$U (top) and $^{7}$Li $+^{238}$U reaction (bottom), compared with P:V ratio of similar compound nuclei formed in proton induced reaction.

beam energies of 30, 31.4 and 34 MeV (40 and 41.4 MeV). Two more transmission-type fast timing small MWPCs placed near the target centre were used to get the start of the timing signal. Applying 2-body and 3-body kinematics, mass distributions were obtained for CN-fission and transfer (deuteron/triton) induced fissions respectively, taking into account the change in velocity due to the energy loss in the start detector.

A typical folding angle distribution of inclusive fission events in lab frame for $^{7}$Li $+^{238}$U reaction at 31.4 MeV assuming CN fission is shown in Fig 1. Similar to our earlier observation[1], a small kink in the distribution at $\sim$168° due to transfer induced fissions has been observed in addition to the main peak at $\sim$172° in the laboratory frame. The FF folding angle distribution of the events in coincidence with $\alpha$ (ICF-fission) found to peak at same $\sim$168° confirms the presence of breakup induced fission in which linear momentum transferred to the target nuclei is different from CN-fission. Hence this ICF-fission is responsible for the increase in the FWHM of folding angle at below barrier as shown in Ref. [1]. Similar observation has been made for $^{6}$Li $+^{238}$U reaction at 30 and 34 MeV.

The mass distribution for inclusive fission events (Fig.2 (top)) and those for exclusive fission in coincidence with $\alpha$ (ICF-fission)(Fig.2 (bottom)) were obtained for different beam energies. Present P:V ratios for inclusive fission reproduce the values reported in Ref. [1]. The P:V ratios for the ICF fission obtained for deuteron or triton induced fission as shown by star in Fig.3 are much higher than that of complete fusion (CF) fission (hollow circles). This was expected as excitation energies of the composite nuclei formed by breakup fragment capture are much lower than the CN. So, the net P:V ratio of inclusive (CF+ICF) fission increases.

Thus present exclusive measurements not only provide direct evidence of the presence of breakup induced fission but also give quantitative explanations to the ambiguous behaviors observed in FF folding angle distribution and the P:V ratio of FF mass distribution due to the contamination of breakup induced fission.

## References

[1] S. Santra *et al.*, Phys. Rev. C **90**, 064620 (2014) and references therein.