Fission fragment mass distribution in ^{32}S + ^{160}Gd reaction

R. Kumar[1],* M. Maiti[1],† A. Pal[2,3], S. Santra[2,3], M. Sagwal[1], P. Kaur[1], A. Singh[1], P. C. Rout[2,3], A. Baishya[2], Ramandeep Gandhi[2,3], and T. Santhosh[2]
[1]*Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, INDIA*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai- 400085, India and*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, India*

Introduction

Recent endeavors to understand the fission dynamics of nuclei in the sub-lead region have provided necessary insights into the fusion-fission phenomenon. The center-point of studying fission in these nuclei being the possibility of a new kind of asymmetric fission found in A≤200 nuclei with the discovery of mass asymmetric fission in low energy (β-delayed) fission of ^{180}Hg [1] which reported the masses to be peaked at 80(1) and 100(1) u, a contrary to the fact that spherical shell gaps in ^{90}Zr would demand a symmetric fission. A series of theoretical and experimental indulgence brought out the fact that indeed the mass distribution in A≤200 nuclei is asymmetric [2]. The vital role of octupole stabilized deformed proton shell gaps in driving the asymmetric fission was put forth recently by Scamps *et al.* [3] which were then used by Bogachev *et al.* [4] to explain the mass distributions of Hg and Pb isotopes quite reasonably well.

Although a reasonable understanding about the fission dynamics in pre-lead nuclei has been reached, the emergence of quasi-fission in such nuclei [5] have posed an open question as to how one can thoroughly explain the fission phenomena in A≤200 nuclei. In this scenario, we have made mass and total kinetic energy distribution measurement of ^{192}Hg nuclei using ^{32}S + ^{160}Gd reaction at projectile energies 140, 152, and 163.6 MeV to further investigate the region for observed peculiarities.

*Electronic address: rkumar4@ph.iitr.ac.in
†Electronic address: moumita.maiti@ph.iitr.ac.in

Experiment

The experiment on ^{32}S + ^{160}Gd reaction was performed at 14-UD BARC-TIFR Pelletron- Linac facility, Mumbai using pulsed beam of ^{32}S with energies ranging from 140 MeV to 163.6 MeV. A ^{160}Gd target of thickness ≈ 50 $\mu g/\mathrm{cm}^2$, backed by a layer of ^{12}C of thickness ≈ 20$\mu g/\mathrm{cm}^2$, was used in the experiment. Two position sensitive multi-wire proportional counter (MWPC) detectors having an active area of 12.5 cm x 7.5 cm were placed at folding angles to detect the coincident fission fragments [6]. From the timing correlation spectra of the two fission fragments, fission events were separated from quasi-elastic events. Position spectra were calibrated using a mask and timing calibration was done using a timing calibrator. From the known positions in MWPC, θ and ϕ information were extracted for each event. Using time of flight and hit positions of the events, fragment velocities were obtained and a typical v_{par}-v_{cn} vs v_{per} plot obtained at 163.6 MeV beam energy is displayed in Fig. 1, which shows a clear distinction between full momentum (mainly complete fusion-fission) and partial momentum transfer events (transfer induced fission). The events corresponding to full momentum transfer as shown inside a red circle in Fig. 1 were analyzed by applying the timing difference method to obtain the fission fragment mass distribution (FFMD) for the projectile energies ranging from 140 MeV to 163.6 MeV and such a FFMD obtained for 163.6 MeV beam energy (E* = 74.4 MeV) is shown in Fig. 2.

Results and discussion

It can be clearly observed from Fig. 2 that the mass distribution for ^{192}Hg* fission-

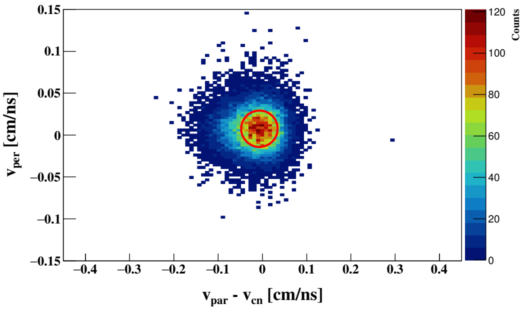

FIG. 1: Correlation between the two velocity components v_{par}-v_{cn} vs v_{per} (v_{par} = parallel component and v_{per} = perpendicular component) of ^{32}S + ^{160}Gd reaction at E_{beam} = 163.6 MeV. The area inside the red contour corrresponds to the binary events following the complete fusion process.

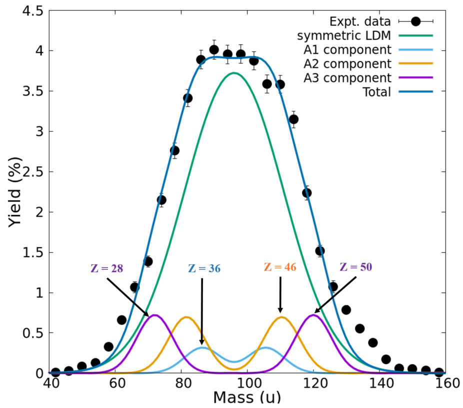

FIG. 2: Mass distribution obtained for ^{32}S + ^{160}Gd reaction at E_{beam} = 163.6 MeV (black circles). FFMD fitted with multiple guassians representing symmetric LDM (green line) and A1 (cyan line), A2 (yellow line), and A3 (purple line) asymmetric components.

ing nucleus is flat-topped, a distinctive feature now known to exist for sub-lead nuclei [4, 5] and a signature of the presence of asymmetric fission. Recently, Bogachev *et al.* [4] has suggested decomposing this mass distibution using multiple asymmetric components along with the symmetric component arising from the Liquid Drop behaviour. The different asymmetric components are adopted as a consequence of proton shell at Z ≈ 36, 38 (A1), Z ≈ 45, 46 (A2), and Z = 28/50 (A3). Using the same analysis we have fitted the obtained mass distribution with symmetric and different asymmetric components and deduced their relative strengths. The width of the LDM symmetric component has been constrained using the formalism adopted by Itkis *et al.* [7], while the widths of the asymmetric components have been taken as 4-6 u which has been experimentally provided by Andreyev *et al.* [1].

The sum of all the components (blue line) fit the mass distribution reasonably well especially in the central flat-top region. However, a slight deviation at the tail can be observed which could be due to the interference of quasi-fission process which has been suggested as a contributing process in these nuclei [5]. The contibutions of different components are: symmetric ≈ 68%, A1 ≈ 6%, A2 ≈ 12.6%, and A3 ≈ 13.4%.

Conclusion

Fission fragment mass distribution was measured for ^{32}S + ^{160}Gd reaction. The FFMD of $^{192}Hg^{*}$ was found to be flat-topped in nature indicating presence of asymmetric fission. The mass distribution was found to fit well with multiple gaussians pertaining to different asymmetric components and the LDM symmetric part. The relative strengths of the different components have been reported.

Research fellowships from INSPIRE(DST) and MHRD, Government of India, are gratefully acknowledged.

References

[1] A. N. Andreyev *et al.,* Phys. Rev. Lett. **105**, 252502 (2010).
[2] K. Mahata *et al.,* Phys. Lett. B **825**, 136859 (2022).
[3] G. Scamps and C. Simenel, Phys. Rev. C **100**, 041602R (2019).
[4] A. A. Bogachev *et al.,* Phys. Rev. C **104**, 024623 (2021).
[5] S. Gupta *et al.,* Phys. Lett. B **104**, 024623 (2021).
[6] A. Pal *et al.,* J. Instrum. **15**, P02008 (2020).
[7] M. G. Itkis and A. Ya. Rusanov, Phys. Part. Nucl. **29**, 160 (1998).