# Break-up effects of $^{19}$F projectile at ≈ 4-6 MeV/A

Mohd Shuaib[1,*], Vijay R. Sharma[1], Abhay V. Agarwaal[1], Abhishek Yadav[2], Pushpendra P. Singh[3], D. P. Singh[4], Manoj K. Sharma[5], R. Kumar[2], R. P. Singh[2], S. Muralithar[2], B. P. Singh[1,#] and R. Prasad[1]

[1]*Department of Physics, Aligarh Muslim University, Aligarh-202 002, INDIA*
[2]*Inter University Accelerator Centre, Aruna Asif Ali Marg, New Delhi-110 067, INDIA,*
[3]*Department of Physics, Indian Institute of Technology, Ropar, Punjab- 140 001 , INDIA*
[4] *Department of Physics, University of Petroleum and Energy Studies, Dehradun-248 007, INDIA*
[5]*Physics Department, S. V. College, Aligarh-202 002, INDIA*
*email:*shuaibphy67@gmail.com , #bpsinghamu@gmail.com*

The study of heavy-ion induced reactions has been a topic of extensive investigation in recent years [1]. At projectile energies around the Coulomb barrier, the most important nuclear reaction mechanism is the complete fusion (CF), in which the entire projectile merges with target nucleus, loses its identity to form an excited composite system [2,3]and then decays. However, several studies have indicated that incomplete fusion (ICF) is also a competing fusion like process at the above barrier energies [4]. In the ICF process, the projectile breaks-up into fragments, one of the fragments fuses with the target nucleus while the other one moves in the forward direction with approximately the same velocity as that of the projectile. The presence of ICF events at slightly above barrier energies ($E_{lab} \geq V_b$) and its effect on the CF has gained a revival interest in recent years [4]. As such, due to the complex nature of fused complex system formed via ICF mode, there are certain parameters which are required to be explored i.e., dependence of ICF on (i) projectile energy (ii) driving input angular momenta (iii) mass asymmetry (iv) $Q_\alpha$-values (v) deformation of interacting partners etc. Several theoretical models [4] have been employed to understand the reaction dynamics of ICF, but none of them is found to reproduce the experimental data satisfactorily. To get a detailed study of ICF process at energies ≈ 4-6 MeV/A, which may provide a rich data set, a program of precise measurement and analysis of excitation functions for a large number of heavy-ion induced reactions has been undertaken. In the present work analysis of excitation functions (EFs) has been used to deduce the energy dependence of ICF strength function and to study the effect of $Q_\alpha$-values and that of mass asymmetry. To explore the influence of ICF on CF in $^{19}$F + $^{159}$Tb reactions in the energy range ≈ 80-110 MeV, an off-line γ-ray spectroscopy technique has been employed. The present results have been compared with the existing data of $^{12,13}$C + $^{159}$Tb [4], and $^{16}$O + $^{159}$Tb [5] systems.

The experiment for the system $^{19}$F + $^{159}$Tb has been performed at the Inter University Accelerator Centre (IUAC), New Delhi, India. The $^{19}F^{7+}$ ion beam produced using 15UD Pelletron Accelerator was focused on the $^{159}$Tb target. To cover the wide range of energy, energy degradation technique has been used in a single irradiation. In the present work, four stacks each consisting of three target-catcher foil assemblies were irradiated with $^{19}$F beam. The thickness of the targets which is isotopically (99.9%) pure is taken ≈ 1.2-2.5mg/cm$^2$. Keeping the half-lives of interest in mind, the irradiations were carried out, for ≈ 8-10 hrs of duration for each stack, in the General Purpose Scattering Chamber (GPSC) having in-vacuum transfer facility. The activities induced in the samples were recorded using a high resolution, pre-calibrated HPGe detector coupled to a PC with CAMAC. The efficiency and energy calibration within the specified geometry has been done using a standard $^{152}$Eu source of known strength. The reaction residues of known γ-rays intensities have been identified and confirmed by decay curve analysis.

In order to explore the break-up reaction dynamics in terms of ICF, the EFs for several reaction channels viz., $^{159}$Tb($^{19}$F, 4n)$^{174}$W, $^{159}$Tb($^{19}$F, 5n)$^{173}$W, $^{159}$Tb($^{19}$F, 6n)$^{172}$W, $^{159}$Tb($^{19}$F, p4n)$^{173}$Ta, $^{159}$Tb($^{19}$F,α3n)$^{171}$Hf, $^{159}$Tb($^{19}$F, α4n)$^{170}$Hf, $^{159}$Tb($^{19}$F, αp3n)$^{170}$Lu, $^{159}$Tb($^{19}$F, 2α3n)$^{167}$Yb, $^{159}$Tb($^{19}$F, 2αp2n)$^{167}$Tm, and $^{159}$Tb($^{19}$F, 2αp4n)$^{165}$Tm have been identified. The production cross-section of these reaction

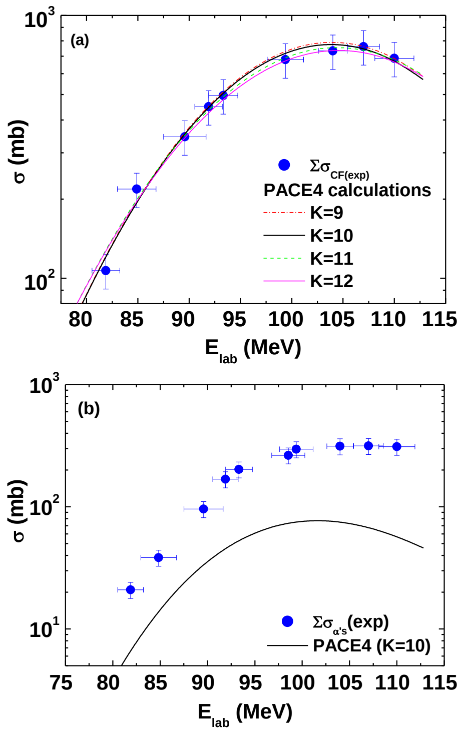


**Fig. 1:** (a) Sum of experimentally measured EFs of all the *xn and pxn* channels i.e., $\sum\sigma_{CF(exp)}$ compared with code PACE4 for K= 9-12. (b) The experimentally measured EFs of all α emitting channels are compared with those predicted by PACE4 for level density parameter a=A/10MeV$^{-1}$.

residues were computed using standard formulations [6] and compared with the predictions of statistical model code PACE4 [7]. In this code, the level density parameter (a=A/K, where A is the mass number and K is the free parameter) has been varied from K = 9 to 12 to match the experimental data. The experimentally measured cross-sections for the sum of all *xn* (*x* = 4-6) and p4n-channels i.e., $\sum\sigma_{CF(exp)}$ are compared with PACE4 predictions and presented in Fig. 1 (a). As shown in figure, the $\sum\sigma_{CF(exp)}$ is very well reproduced by the PACE4 predictions for the level density parameter a=A/10MeV$^{-1}$. This indicates the production of these residues solely by CF process. Further, the sum of all identified α-emitting channels $\sum\sigma_{\alpha's(exp)}$ is compared with that estimated by PACE4 in Fig. 1(b). It may be pertinent to mention that the theoretical model PACE4 didn't take into account the ICF calculations. As shown in this figure the experimentally measured EFs for α emitting channels are significantly higher than PACE4 predictions for the same value of level density parameter a=A/10MeV$^{-1}$, which has been used to reproduce the CF residues in the present work. The observed enhancement in the experimentally measured EFs over the theoretically predicted ones indicates the contribution of ICF process in the population of these residues. The ICF contribution has been found to increase with energy indicating its importance with the increase in energy. Further details regarding α-Q value, mass asymmetry systematics will be presented.

The authors thank to the Director, IUAC, New Delhi and to the Chairperson, Department of Physics, AMU, Aligarh, for providing all the necessary facilities to carry out this work. RP, BPS, VRS, and MS thank to the DST project SR/S2/HEP-2012 for financial support.

## References

[1] A. Diaz-Torres et al., J. Phys. G: Nucl. Part. Phys. **37,** 075109 (2010).
[2] F. Schussler et al., Nucl. Phys. **A 584**, 704 (1995).
[3] E. Gadioli et al., Nucl . Phys. **A 641**, 271 (1998).
[4] Abhishek Yadav et al., Phys. Rev. C **85**, 034614 (2012) and ibid. **85**, 064617 (2012).
[5] Pushpendra P. Singh et al., Phys. Rev. C **77,** 014607 (2008).
[6] Vijay R. Sharma et al., Phys. Rev. C **84**, 014612, (2011) and ibid. **89**, 024608, (2014).
[7] A. Gavron, Phys. Rev. C **21**, 230 (1980).