# Systematics on Incomplete Fusion Dynamics at low energy

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In the last couple of decades, great efforts have been made in the study of incomplete fusion reaction (ICF) in heavy ion induced reactions at energy above Coulomb barrier and below 10 MeV/nucleon. It has been shown that at energies not too much above the Coulomb barrier, the fusion process was playing an important role in reaction cross section [1]. The widely used statistical model code PACE-2 [2], describes the fusion cross section. At higher projectile energy, fusion probability decreases and corresponding ICF probability increases, where projectile break-up will takes place and decreasing the reaction cross section corresponding to the fusion. Large no. of reports have been appeared that CF and ICF is the dominating mode of reaction at energies above the coulomb barrier [3, 4]. Fusion occurs when interacting nuclei have sufficient kinetic energy to overcome the Coulomb barrier and are subsequently trapped inside the potential pocket to form the composite nucleus, in which all the angular momentum of the system is retained. On the other hand, if only part of the projectile, following break-up, fuses with the target nucleus, the process is called incomplete fusion (ICF). Britt and Quinton [5] and later on Galin *et al.*, [6] pointed out the break-up of projectile $^{12}$C, $^{16}$O and $^{14}$N into α-clusters in an interaction with the target nuclei below 10 MeV/nucleon. Parker *et al.*, [7], Tserruya *et al.*, [8] also found evidence for ICF process. Cavinato *et al.*, [9], Crippa *et al.*, [10], Tomar *et al.*, [11] and Ali *et al.*, [12] have measured the excitation functions (EFs) and/or forward recoil range distributions (FRRDs) of the evaporation residues produced in CF and ICF of heavy ions, by employing recoil catcher activation technique, for a large number of projectile-target systems.

In order to study the entrance channel effect like imparted angular momentum to the system, projectile energy and structure of the projectile, α-separation energy on incomplete fusion and mass-asymmetry of target-projectile system, number of experiments have been performed at VEC-machine (Kolkata) and 15UD Palletron (New Delhi). The details of the experimental set-up are shown somewhere else [12]. Activation technique has been used for the present measurement. In this technique, stack of targets viz; $^{55}$Mn, $^{144}$Sm, $^{159}$Tb and $^{156}$Gd along with Al-catcher foils have been used. For the above measurement, targets of $^{55}$Mn, $^{144}$Sm, $^{159}$Tb and $^{156}$Gd were prepared by rolling machine and/or evaporation technique and thickness of the samples comes out to be in the range ~1.0-2.5μg/cm$^2$. In the present work, an attempt has been made to study CF and ICF reaction dynamics extensively by using activation and particle-γ coincidence techniques. The excitation functions (EFs) of evaporation residues (ERs) in $^{20}$Ne + $^{55}$Mn, $^{19}$F + $^{144}$Sm, $^{20}$Ne + $^{159}$Tb and $^{16}$O + $^{156}$Gd systems in the energy range ~ 3-8 MeV/nucleon have been measured by using recoil catcher activation technique followed by γ-ray spectrometry. In such cases, independent cross-sections have been deduced from the measured cumulative cross-sections, using Cavinato *et al.*, [13] formalism. The independent cross-sections of ERs have been compared with theoretical statistical model code PACE-2, an appreciable enhancement in the measured independent cross-section over theoretical predictions have been observed in α-emission products. This enhancement may be understood from the break-up of the projectile in target nuclear field into α–clusters [i.e., for example; $^{20}Ne \Rightarrow {}^{16}O + {}^{4}He$ (α) and/or $^{12}C + {}^{8}Be$ (2α) et.] leading to various ICF processes. An attempt has been made to estimate ICF contribution for individual α-emission products in the above systems and its dependence over projectile energy has been obtained. Moreover, dependence of ICF fraction on projectile-target mass-asymmetry has also been studied. It has been found that ICF fraction increases with projectile energy and mass-asymmetry of the above studied systems. Present observation shows that the increase in incomplete fusion probability with projectile energy is in accordance with Morgenstern systematic [14].

In order to study the qualitative information regarding ICF reaction dynamics, the forward recoil range distribution (FRRDs) of evaporation residues (ERs) populated in $^{20}Ne + {}^{159}Tb$ and $^{16}O + {}^{156}Gd$ systems in the energy range 4-8 MeV/nucleon have been measured. The measured mean recoil ranges of ERs from the analysis of FRRDs strongly revealed that significant contribution form the partial linear momentum transfer (LMT) of the projectile associated with incomplete fusion reaction. The partial LMT components associated with break-up of the projectile have been observed. The measurement and analysis of the FRRD of evaporation residues strongly revealed that significant contributions coming from partial linear momentum transfer of projectile associated with ICF reaction dynamics in several α-emission products. In general, it has been found that the residues are not only populated via CF but ICF also plays an important role at respective projectile energies.

In order to deduce the angular momentum involved in various CF and/or ICF reaction products, spin distribution and side-feeding intensity profiles of radio-nuclides populated via CF and ICF channels in $^{16}O + {}^{160}Gd$ system at projectile energy, E ~ 5.6 MeV/nucleon, have been studied. The spin distribution of ICF products are found to be distinctly different than that observed from CF products, which indicates entirely different de-excitation patterns in CF and ICF products towards band head. For the ICF products, yields are almost constant up to certain angular momentum and then decreases with transition spin, while for CF products, yields decreases exponentially with transition spin. It clearly indicates that significant side-feeding takes place in broad spin range in case of CF products, while narrow spin population arises in case of ICF products, where projectile like fragments (PLFs) are emitted to release excess angular momentum. The driving input angular momentum associated with ICF products have been found to be relatively higher than that involved in the production of CF products, and found to be increasing with direct-α-multiplicity. The present observation clearly indicates that production of fast α-particles arises from relatively high angular momentum, which leads to peripheral interaction. These features of side feeding in ICF reaction product results are consistent with Inamura *et al.,* [15]. The experimental results on the systematics of ICF for the present systems will be presented and discussed during the conference.

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