Breakup fusion in ^{14}N+^{169}Tm system at low energies

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A substantial contribution of incomplete fusion (ICF) has been observed at slightly above barrier energies, where complete fusion (CF) is supposed to be the sole contributor [1, 2]. The incomplete fusion (ICF) reaction may be considered to take place when the projectile breaks up near the vicinity of target nuclear field, into fragments, one of which fuses with the target nucleus forming an excited composite system which may eventually de-excite by particle and γ emission, while the other part of fragment moves into the forward direction without any interaction and acts as spectator. In 1984, Trautmann et al. [3], observed that ICF is associated with peripheral collisions, while some studies [4, 5] suggest the involvement of lower angular momenta as well than the critical angular momentum (ℓ_c) for complete fusion (CF) to occur in these reactions. Nonetheless, the above mechanism is still not clearly understood, and is an active area of investigation. Further, the dependence of ICF processes on various entrance channel parameters viz., projectile type/energy, imparted input angular momentum (ℓ) to the system, α-break-up energy (Q_α), mass-asymmetry of the interaction partners, etc., has been studied but an unambiguous picture is yet to emerge.

In order to explore the underlined issues, an experiment using ^{14}N^{6+} ion beam on ^{169}Tm target at energies ≈ 4-7 MeV/A were carried out at the IUAC, New Delhi, India using 15-UD Pelletron Accelerator. The targets of ^{175}Lu (≈ 99.9%) of thickness ≈ 1.3 - 2.4 mg/cm^2 and Al-catchers (≈ 1.5-2.5 mg/cm^2) were prepared by rolling method. Targets followed by Al-catcher foils have been irradiated in the General Purpose Scattering Chamber having an in-vacuum transfer facility. Several stacks of target-catcher assembly have been irradiated to cover a wide energy range. The activities induced in the samples were recorded by counting each target alongwith the catcher foil kept behind using a pre-calibrated HPGe γ-ray spectrometer coupled to a CAMAC based CANDLE software. The intensities of the characteristic γ-rays have been used to determine the cross-sections for the residues populated via CF and/or ICF processes.

Experimental excitation function of ^{179}Os (4n), ^{179}Re (p3n) and ^{178}Re (p4n), ^{177}W (α2n), ^{176}W(α3n), ^{175}W (α4n), and ^{174}W (α5n) evaporation residues populated via CF/ICF have been analysed in the framework of equilibrated CN-decay using statistical model code PACE 4 [6]. In order to have our measurements accuracy and to test the adopted data reduction procedure, an attempt has been made to deduce the value of fusion barrier (V$_B$) in the lab system, from the analysis of experimentally measured complete fusion cross section. According to Gutbrod et al. [7], the normalized CF probability may be given as

$$\sigma_{CF} = \pi R^2_{int.}(1 - V_B/E_{lab}) \quad (1)$$

Since, the experimentally measured complete fusion cross-section matches with compound nucleus decay based statistical model

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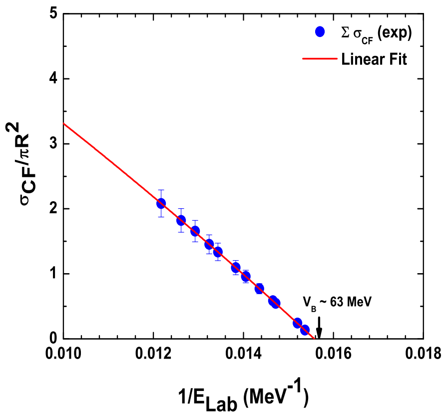

FIG. 1: CF cross sections as the function of $1/E_{Lab}$ found to reproduce the Coulomb barrier for ^{14}N+^{169}Tm system. The dashed line through the data points is achieved by best fitting procedure of data.

code PACE 4, the normalized values of σ_{CF} is plotted as a function of $1/E_{Lab}$ in Fig. 1. As shown in this figure, the data points follow a straight-line which intersects the x-axis at E_{Lab} corresponding to 63 MeV with an uncertainty of 2%, which reproduces the calculated fusion barrier of the ^{14}N+^{169}Tm system and gives confidence in our measurements [1].

Further, it has been observed that the onset and strength of ICF strongly depend on projectile type and projectile energy. Therefore, we extended this study in terms of charge dependence on ICF fraction. In order to display, the charge dependence, the ICF strength function for the presently studied system at the constant relative velocity (vrel ≈ 0.053c) is plotted as a function of $Z_P Z_T$ (i.e. product of the projectile (Z_P) as well as target Z_T of the system) and is presented in Fig. 2 alongwith F_{ICF} of systems available in the literature to have $Z_P Z_T$ systematics. As can be seen from this figure, the percentage of incomplete fusion fraction F_{ICF}, follows almost a linear growth as the charge product $Z_P Z_T$ increases. Further, the value of F_{ICF} is found to be more for larger $Z_P Z_T$ values, which indicates the role of Coulomb repulsion on ICF

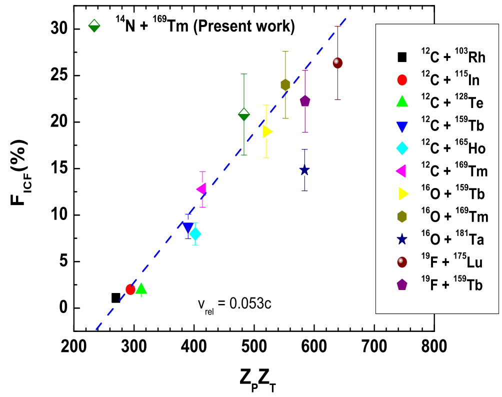

FIG. 2: (color online) Incomplete fusion strength function (F_{ICF}) of various systems (see text) as a function of $Z_P Z_T$. The dashed line is drawn to guide the eyes.

fraction i.e. as the projectile comes near the field of the target nucleus (for higher $Z_P Z_T$) it may break-up easily as compared to low $Z_P Z_T$ projectile target combination. An increase in the value of $Z_P Z_T$ enhances the strength of the Coulomb interaction resulting in the larger break-up probability. Hence, in the development of the ICF modeling at low energies, $Z_P Z_T$ should also be taken into account. Further details will be presented in symposium.

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