Chapter 6

Conclusions and Future Perspective

On the basis of results and analysis presented in this thesis, significant information about CF and ICF reactions and the angular momentum dependence of PEQ-emission processes have been obtained. The Chapter-2 presents the EFs of several radio-nuclides populated via CF and/or ICF in \(^{12}\text{C} + ^{159}\text{Tb}\) and \(^{13}\text{C} + ^{159}\text{Tb}\) systems measured in the energy range \(\approx 4-7\ \text{MeV/A}\). These EFs have been analyzed in the framework of equilibrated CN-decay using statistical model code PACE4. During the decay curve analysis for the identification of different reaction products, it has been found that some of the \(pxn\) and \(\alpha xn\)-channels have contribution from pre-cursor decay of higher charge isobar. An attempt has been made to deduce the independent production cross-section from cumulative and pre-cursor decay contributions. The experimentally measured EFs of \(xn/pxn\) channels have been found to agree reasonably well with the statistical model predictions, indicating their production via CF only. However, in case of all the \(\alpha\)-emitting channels, significant enhancement, in the production cross-sections, have been observed as compared to the PACE4 predictions. This enhancement has been attributed due to the ICF of \(^{12,13}\text{C}\) with \(^{159}\text{Tb}\). It has been observed that the probability of ICF processes increases with incident projectile energy, mass-asymmetry and/or target mass. The results presented are found to follow Morgenstern’s mass-asymmetry systematics [39] for individual projectiles separately. On the basis of results and analysis presented, it may be concluded that apart from CF, the ICF is also a process of considerable importance at projectile energies \(\approx 4-7\ \text{MeV/A}\). The analysis of ICF fraction
has been found to follow ‘alpha-Q-value systematics’. As the alpha-Q-value becomes more negative the incomplete fusion contribution decreases. The present results in light of the previously studied systems may be used to conclude that the alpha-Q-value plays an important role in ICF-reactions.

The recoil range distributions of a large number of radio-nuclides viz; \(^{168}\text{Lu}\) (3n), \(^{167}\text{Lu}\) (4n), \(^{165}\text{Lu}\) (6n), \(^{167}\text{Yb}\) (p3n), \(^{165}\text{Tm}\) (α2n), \(^{163}\text{Tm}\) (α4n), \(^{161}\text{Ho}\) (2α2n), \(^{160}\text{Ho}'\) (2α3n) and \(^{160}\text{Ho}''\) (2α3n) populated in \(^{12}\text{C} + ^{159}\text{Tb}\) interactions at three above barrier energies have been measured. The analysis of the measured FRRDs of reaction products presented, strongly reveal a significant contribution from the partial LMT of the projectile associated with ICF in several α-emitting channels. Different partial LMT components are attributed to the fusion of \(^{8}\text{Be}\) and α from the \(^{12}\text{C}\) projectile to the target nucleus. The percentage ICF contributions are found to have onset from \(\approx 12\%\) above the Coulomb-barrier. It has been found, in general, that the residues are populated not only via CF but ICF is also found to play an important role in the production of different reaction products involving direct α-cluster emission. The present results have also been compared with literature results, and it may be concluded that the projectile structure as well as alpha-Q-value are important parameters in the energy range of interest. The SUMRULE model calculations are found to highly underestimate the deduced ICF cross-sections. This discrepancy may be due to the assumption in the SUMRULE model that a substantial contribution to ICF comes from the collision trajectories with \(ℓ > ℓ_{\text{crit}}\). In the present study, substantial amount of ICF contribution has been reported at studied energies, where \(ℓ_{\text{max}} < ℓ_{\text{crit}}\), thus collision trajectories with \(ℓ < ℓ_{\text{crit}}\) significantly contribute to ICF processes. More data on such reactions is needed to explore the above aspects, so that the assumptions of the SUMRULE model for energies near the barrier, where \(ℓ < ℓ_{\text{crit}}\), may be improved upon to explain the experimental data.

In order to obtain information about the angular momentum dependence of ICF reaction processes, the measurement of spin distributions and feeding intensity profiles of different CF and ICF products populated via \(xn/pmn/αxn/2αxn\) channels in the \(^{12}\text{C} + ^{169}\text{Tm}\) system have been carried out at the energies \(\approx 5.6\) and \(\approx 6.5\) MeV/A. The spin distributions of ICF-(αxn
/2αxn)-channels are found to be distinctly different than those observed for CF-(xn /pxn/αxn)-channels, and show entirely different de-excitation patterns for CF and ICF products. The spin distribution(s) of CF products are found to reflect strong feeding over a broad range of spin towards the band head. However, the spin distribution(s) associated with ICF channels are found to arise from a narrow spin population. This indicates the competition from successively opened ICF channels for each value of ℓ above ℓ_{crit} for normal fusion (CF) at respective projectile energies. Moreover, the population of low-spin states are found to be hindered and/or less fed in the case of ICF. It has been observed that the direct α-multiplicity in the forward cone increases with the ⟨ℓ⟩ value at a particular projectile energy. Hence, it may be concluded that the peripheral interactions essentially contribute to open up direct-α-emitting channels at high ℓ-values. It may further be pointed out that the higher ⟨ℓ⟩-values associated with 2α-emitting channels may be considered to originate from higher impact parameters than that associated with the production of single direct-α-emitting channel. One of the important observations of the present work is that ICF can populate high-spin states in final reaction products, which is not possible to be achieved via CF at a given projectile energy.

In last measurement, the forward(F)-to-backward(B) yield ratios show significant enhancement over the unity line, which signify finite contributions from PEQ-emission in \(^{16}\text{O}+^{169}\text{Tm}\) system at as low as 5.6 MeV/A energy. The maximum observed spin (J_{obs}^{max}) is found to decrease with the number of proton emitted from the composite nucleus during EQ and/or PEQ-decay. As such, on the basis of results presented, it may be concluded that PEQ-emission in HI-induced reactions is a process of importance at energies as low as 5.6 MeV/A, which may be investigated by yield ratio measurements. Further, the result presented on PEQ-emission can be supplemented by more conclusive measurements.

Further, in order to have better understanding of underlying processes and to have perfect modeling for ICF reaction dynamics, it would be quite interesting to perform more detailed experiments for various projectile-target combinations. However, additional information about the PEQ-emission can be obtained by measuring the multiplicity, the angular distribution, and en-
ergy spectra of emitted light nuclear particle(s), which may serve as extra degrees of freedom to enhance the understanding of underlying processes.

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Bibliography


[4] E. Rutherford, Philosophical Magazine, 37, 537 (1919); ibid 37, 562 (1919); ibid 37, 571 (1919); ibid 37, 581 (1919).


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