Chapter 5

Summary and Conclusions

In the present work, an attempt has been made to study complete and incomplete fusion reaction dynamics extensively by using various techniques. Excitation functions (EFs) of thirteen evaporation residues (ERs) in ^{20}Ne + ^{55}Mn system [1], ten ERs in ^{20}Ne + ^{159}Tb system and fifteen ERs in ^{16}O + ^{156}Gd system in the energy range ~ 3-8 MeV/nucleon have been measured by using recoil catcher activation technique followed by γ-ray spectrometry. Many of the residues in above said systems are populated both directly and in the decay of the populated pre-cursor isobars. In such cases, independent cross-sections have been deduced from the measured cumulative cross-sections, using Cavinato *et al.,* [2] formalism. The independent cross-sections of ERs have been compared with theoretical predictions of statistical model code PACE-2. As discussed in Chapter 2, appreciable enhancement in the measured independent production 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) and / or ^{8}Be + ^{12}C (3α)] leading to various ICF processes. Attempt has been made to estimate the ICF contribution for individual α-emission products in the above systems. Further, as discussed in Chapter 2, ICF fraction has been deduced 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. For ^{20}Ne + ^{55}Mn system, the ICF fraction is estimated be ~ 2% of the total fusion cross-section at ~ 51 MeV and approaches to 49% at ~164 MeV energy. Similarly, for ^{20}Ne + ^{159}Tb system

ICF fraction is estimated as ~ 5% at ~ 95 MeV energy and it approaches to 49% at ~ 164 MeV energy and for ^{16}O + ^{156}Gd system, the ICF fraction is found to increase from ~ 7 % to ~ 48 % between ~ 68 and ~ 98 MeV energy. Hence, it has been found that the ICF-fraction of the total fusion cross-section also increases with projectile energy. It may be observed that percentage of ICF contribution approaches the same value for ^{20}Ne + ^{55}Mn and ^{20}Ne + ^{159}Tb systems at higher energy. This may be because of the fact that effect of Coulomb barrier diminishing as projectile energy increases. Present observation shows that the increase in incomplete fusion probability with projectile energy is in accordance with Morgenstern systematic [3]. In addition to this, ICF fraction have been deduced for presently studied systems along with few other projectile-systems at the same relative velocity V_{rel} = 0.044c and has been plotted as a function of mass-asymmetry of the interacting partners. ICF-fraction is found to increase in mass-asymmetric system than mass-symmetric system. It has also been observed that data for ICF could not explain only on the basis of mass-asymmetry of the interacting partners but would be interesting if its dependence on projectile structure be also investigated. It may be possible that projectile structure effects also play an important role in the mass-asymmetric system. Further, from the observation of large ICF fraction, it may be attributed to prompt break-up of projectile into α-clusters. The projectile break-up probability increases with projectile energy. The discussions on ICF based on the measurement and analysis of EFs strongly reveal that apart from CF, the ICF is also a process of greater importance at these energies, and hence, while predicting the total reaction cross-section, the contribution coming from ICF may also be taken into consideration.

In order to study the qualitative information regarding ICF reaction dynamics at projectile energy ~ 4-8 MeV/ nucleon, the forward recoil range distribution (FRRDs) of nine ERs; ^{174}W, ^{175}Ta, ^{173}Ta, ^{172}Ta, ^{173}Hf, ^{164}Yb, ^{166}Tm, ^{165}Tm and ^{163}Tm populated in ^{20}Ne + ^{159}Tb system at energy, E ~164 MeV, and eight ERs; ^{168}Hf, ^{167}Lu, ^{167}Yb, ^{162}Yb,

^{165}Tm, ^{163}Tm, ^{159}Ho and ^{157}Dy populate in ^{16}O + ^{156}Gd system at three different energies E ~ 72, 82 and 93 MeV have been measured. The measured mean recoil ranges of the evaporation residues 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 linear momentum transfer (LMT) component associated with break-up of the projectile viz; ^{20}Ne into ^{16}O + ^{4}He (α) and/or ^{12}C + ^{8}Be (2α) and /or ^{8}Be + ^{12}C (3α), while in case of ^{16}O breaks-up into ^{12}C + ^{4}He (α), ^{8}Be + ^{8}Be (2α) and /or ^{4}He + ^{12}C (3α) have been observed. The measurement and analysis of the FRRD of evaporation residues presented in Chapter 3 strongly revealed that significant contributions coming form partial linear momentum transfer of projectile associated with incomplete fusion 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. An attempt has also been made to validate the experimentally measured forward recoil ranges $R_p(\exp)$ deduced from fitting of experimentally RRD data points. The experimentally measured most probable recoil ranges have been compared with theoretically calculated most probable ranges $R_p(theo)$ for CF and /or ICF component, using range-energy relation for the reaction products produced in the interaction of ^{20}Ne, ^{16}O with ^{159}Tb & ^{156}Gd are found to be in good agreement 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 eleven 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 and presented in Chapter 4. On the basis of the results presented in Chapter 4, spin distribution of ICF products (ICF- α and 2α-emission in forward direction) are found to be distinctly different than that observed from CF products (CF-xn and α and 2α-emission in backward direction), 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 (low spin states are strongly hindered), where projectile like fragments (PLFs) are emitted to release excess angular momentum. It indicates the competition from successively opened ICF channels for each value of ℓ above ℓ_{crit} for CF. Moreover, side feeding pattern of the residue populated via ICF are distinctly different than that of CF-products. It gain clearly indicates that low impact parameters do not contribute to the ICF reaction. Furthermore, spin distribution in α/2α-emitting channels indicates the absence of side feeding effect in the lower members of the yrast band suggesting that the low partial waves are strongly hindered in fast α-emission channels. 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 value $<\ell>$ for CF-xn channels is found to be ~7$\hbar$, ICF-αxn ~9$\hbar$ and ICF-2αxn ~11$\hbar$. It is concluded that in ICF-products, mean input angular momentum increases with fusion incompleteness as compared to CF-products. 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.,* [4]. Furthermore, it is emphasize that the value $<\ell>$ associated with 2α-emitting channels is originated from larger value of impact parameter than that of associated with 1α− emitting channel. This clearly indicates that ICF can populate high spin state in reaction products that can not achieve from CF at given energy.

In addition of the present work, it is proposed to carry out some more experiments to measure ‘angular distribution’ of projectile like fragment (PLF) to understand the present findings. The extension of the present work would be interesting at relatively higher energy for various projectile-target combinations, which would be helpful for the refinement of the present findings. The data of the present measurements may be of use in developing the theoretical model for incomplete fusion.

References

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