Study of fusion incompleteness in $^{13}C+^{165}Ho$ from excitation function measurements at energies ≈ 3-7 MeV/nucleon.

Muntazir Gull[1,*], Kamal Kumar[1], Sabir Ali[2], S. Dutt[1], S. Prajapati[3], M. Kumar[3], Avinash Agarwal[3], A. Yadav[4], R. Kumar[4] and I.A. Rizvi[1]

[1]*Department of Physics, Aligarh Muslim University, Aligarh (U.P)- 202002, INDIA*

[2]*MANNU Polytechnic Darbhanga, Maulana Azad Urdu University, Hyderabad, - 500032, INDIA*

[3]*Department of Physics, Bareilly College Bareilly (U.P) - 243005, INDIA*

[4]*NP-Group, Inter University Accelerator Center, New Delhi – 110067, INDIA*

** email: muntazirgull1@gmail.com*

Extensive efforts [1-4] have been put forth to understand the incomplete fusion (ICF) reaction dynamics in the heavy ion collisions at intermediate energies since its first observation by Britt and Quinton [5]. Complete and incomplete fusion processes are expected to be the dominant modes at these energies (3-7 MeV/A). In case of complete fusion (CF) process, a complete amalgamation of the projectile-target takes places. However, the projectile breaks into fragments near the nuclear field of the target nucleus in the ICF process. Till now no theoretical model is available which could reproduce ICF data satisfactorily below 8MeV/nucleon, thereby study of ICF is still a resurgent interest to understand the dynamics of such reactions. To figure out the convenient mechanism of ICF reaction dynamics, the dependence of ICF on various entrance channel parameters like α-Q value, projectile energy, Coulomb factor (Z_PZ_T), target deformation etc. need to be explored. In the present work, an attempt has been made to understand the dependence of ICF on the α-Q value of projectile along with the coulomb factor (Z_PZ_T) from the excitation functions (EFs) measurement of evaporation residues for the $^{13}C+^{165}Ho$ system at energies 3-7 MeV/A.

Experimental Details

The present experiment was performed at Inter University Accelerator Center (IUAC), New Delhi using the ^{13}C ion beam by employing the activation foil technique. The main advantage of activation foil technique is that at different energies many target foils can be irradiated together in single irradiation through which a wide energy range with more number of possible reactions can be studied. The rolling technique has been followed for the preparation of targets of ^{165}Ho of thickness ≈ 1.5-1.8 mg/cm^2 and Al-foils of thickness ≈1.4-2.0 mg/cm^2 respectively. Through the α-transmission method, the thickness of target foils and Al-foils have been determined. Also, Al-foils used serve both as catchers as well as energy degraders to cover the desired energy range. Two stacks each having four ^{165}Ho target foils backed by Al-foils were irradiated for about 10 hours in General Purpose Scattering Chamber (GPSC), keeping in mind the half-lives of interest. After irradiation, the off-line measurements of target catcher assemblies were performed. The precalibrated High Purity Germanium detector (HPGe) has been used for counting the activities produced in the target catcher assemblies individually coupled to a CAMAC based data acquisition system CANDLE. ^{152}Eu source of known strength was kept at different source-detector positions for determining the energy and geometry dependent efficiency of the HPGe detector.

Results and Discussion

In the interaction of $^{13}C+^{165}Ho$, excitation functions (EFs) of various evaporation residues viz. $^{175-172}Ta$ (xn; x = 3-6), ^{173}Hf (p4n), and $^{172-169}Lu$ (αxn; x = 2-5) etc. have been measured to understand the reaction mechanisms involved in the production of these residues. The experimental data has been examined within the framework of theoretical code PACE-4 [6], in which the CF cross-sections are calculated using Bass formula [7]. At each level of de-excitation, the angular momentum projections are calculated, which in turn makes it possible, to

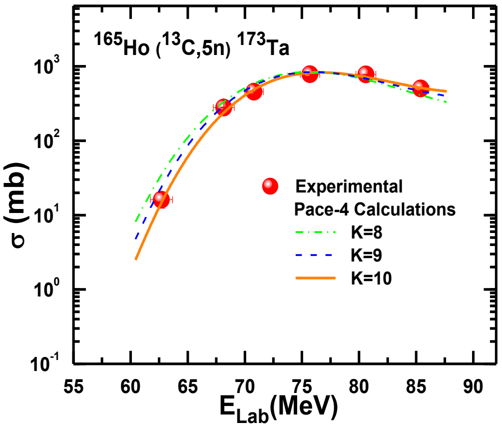

Fig.1. **Excitation Function of residue ^{173}Ta (5n) produced in the ^{13}C+^{165}Ho system.**

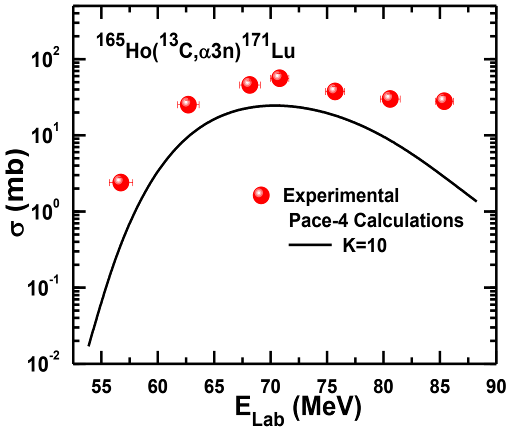

Fig.2. **Excitation Function of residue ^{171}Lu (α3n) produced in the ^{13}C+^{165}Ho system.**

determine the angular distribution of emitted particles. It is observed that some of the xn/pxn channels have a contribution from higher charge isobar precursor through β^+ /or electron capture.

The reaction mechanism involved in the production of evaporation residues populated through xn/pxn channels ($^{175-172}$Ta (xn; x = 3-6), ^{173}Hf (p4n)) is studied by varying the level density parameter a=A/K, where K is the free parameter that has been varied at different values (K= 8, 9, 10) to reproduce the experimentally measured cross sections. As a representative case, the EF of ^{173}Ta populated through emission of 5n is shown in Fig.1.

It is clear from the Fig.1 that for the level density parameter a = A/10 MeV^{-1}, the experimental cross sections match nicely with PACE-4 predictions. It confirms that the evaporation residue ^{173}Ta (5n) is formed through CF of ^{13}C with ^{165}Ho target nuclei. The comparison for all the experimentally measured cross sections of xn/pxn channels shows good agreement with the PACE-4 calculations for K = 10, hence, confirming the population of these residues though CF process. Thus, the free parameter K=10 can be used as a fixed parameter for all the residues populated in the interaction of ^{13}C+^{165}Ho through both the CF and ICF processes. As shown in Fig.2, an enhancement in measured cross-sections over theoretical predictions is observed for the EF of residue ^{171}Lu (α3n). This enhancement is attributed to the ICF process and indicates that the ICF process also contributes in the population of ^{171}Lu (α3n) along with the CF process. The strength of incomplete fusion function for the ^{13}C+^{165}Ho interaction has been deduced and compared with the previously studied systems involving the same target with ^{12}C, ^{16}O & ^{20}Ne [2-4] as projectiles. Results of the present data indicate that ^{13}C projectile shows less incomplete fusion contribution as compared to ^{12}C, ^{16}O and ^{20}Ne projectiles due to its more negative α-Q value. Furthermore, it has been observed that the breakup probability almost increases linearly with Z_P*Z_T.

Acknowledgements

The authors are grateful to the Director IUAC, New Delhi and Chairman, Department of physics, AMU, Aligarh for providing necessary facilities to carry out this work.

References

[1] Muntazir Gull et al., Phys. Rev. C **98**, 034603 (2018) and references therein.
[2] S. Gupta et al., Phys. Rev. C **61**, 064613 (2000).
[3] Kamal Kumar et al., Phys. Rev. C **87**, 044608 (2013).
[4] D. Singh et al., Nucl. Phys. A **879**, 107 (2012).
[5] H.C. Britt and A.R. Quinton et al., Phys. Rev. **124**, 877 (1961).
[6] A. Gavron et al., Phys. Rev. C **21**, 230 (1980).
[7] R. Bass, Nucl. Phys. A **231**, 45 (1974).