A Study of Recoil Range Distribution in $^{12}C + {}^{93}Nb$ System at ≈ 80 MeV

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Introduction

It has been found from earlier studies [1] that incomplete fusion is also a process that starts competing with CF even at energies just above the coulomb barrier. The incomplete fusion reactions are fast binary processes in which the part of the projectile fuses with the target, while the remainder continues its flight with the approximate beam velocity. Recently, there is a renewed interest in the study of the ICF dynamics after the observation of these reactions at relatively low bombarding energies [2]. Moreover, the ICF reactions are considered to be a promising route to populate high spin states in heavy residues using moderate heavy–ion beams (A ≤16) even at low bombarding energies [3]. The study of the ICF dynamics in the view of all these developments may provide key parameters to determine optimum irradiation conditions for the production of radioactive ion beams (RIBs) [4]. As such, in order to have a better understanding of the ICF dynamics, precise experimental data covering a wide range of the periodic table and energies are required. In view of the availability of limited data covering only a few projectile- target combinations at E/A ≈ 5-7 MeV, our group has undertaken a program of precise measurement and analysis of excitation functions (EFs), recoil range distributions (RRDs) for various projectile–target combinations over a wide range of projectile energy. In the present contribution, as a supplement to our earlier work, the RRDs for the residues have been measured at ≈ 80 MeV using recoil catcher technique followed by off-line gamma spectroscopy.

Experimental Details

In the irradiation chamber, the target was mounted with Al-backing facing the beam so that the catcher stack immediately followed the niobium layer. The beam energy incident on front Al - surface was ≈ 80 MeV. After an energy loss of ≈ 3.47 MeV in the Al thickness, the incident beam energy was reduced to 76.53 MeV on the niobium material. A stack of 13 thin Al – catchers of thickness varying from ≈102-113 $\mu g/cm^2$ was used to trap the recoiling nuclei. The duration of irradiation was about 4 hours with a beam fluence of ≈ 408.6 μc. The activities induced in each thin catcher were followed off-line for about two weeks using a pre-calibrated high resolution HPGe detector of 100 cm^3 active volume coupled to CAMAC based software FREEDOM [5] at IUAC, New Delhi. The same software was used for analyzing the data. The experimentally measured cross-sections for particular reaction products in different catcher foils were obtained using equation taken from Ref. [6]. In order to obtain the yield distribution as a function of cumulative depth in the catcher stack, the yield in each catcher was divided by its measured thickness. The resulting yield has been plotted against cumulative catcher thickness to obtain the differential recoil range distributions.

Results and Discussion

As can be seen from Figs 1(a-b), the RRDs for $^{101,100}Pd$ isotopes produced via (^{12}C, p3n) and (^{12}C, p4n) channels respectively have a peak at only one value of cumulative catcher thickness (≈770 $\mu g/cm^2$).

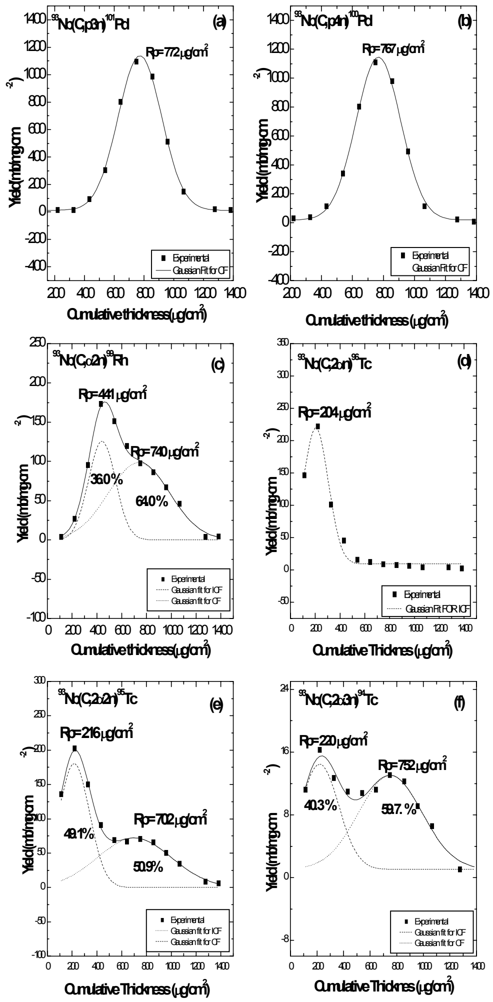

Fig.1. (a-f) Gaussian fit to the experimentally measured RRDs.

The RRD of Pd isotopes are Gaussian in nature having peaks at a thickness corresponding to the expected recoil range of the composite nucleus $^{105}Ag^*$ in aluminum, calculated using the classical approach and the stopping power tables of Northcliffe and Schilling [7], meaning hereby that these products are formed by the complete fusion process only, followed by the evaporation of n and/or p. However, for the reaction $^{93}Nb(C,\alpha 2n)$ ^{99}Rh Fig.[1(c)] the RRD has two peaks, one at a relatively lower value of cumulative catcher thickness ≈ 441 μg/cm^2 (due to ^8Be fusion) and the other at ≈ 740 μg/cm^2 (due to ^{12}C fusion) respectively. The incomplete fusion contribution in this case is found to be 36.0 % with an uncertainty of 5%. Regarding the $^{93}Nb(C, 2\alpha n)$ ^{96}Tc reaction, the RRD show a dominant low range component due to the ICF of an α particle (peak at ≈204μg/cm^2) while a long range tail as shown in Fig. [1(d)] demonstrates almost a negligible CF part.

In case of reactions $^{93}Nb(C, 2\alpha 2n)$ ^{95}Tc and $^{93}Nb(C, 2\alpha 3n)$ ^{94}Tc, shown in Figs.[1 (e & f)], the RRDs have two peaks; one is at relatively lower values of catcher thickness ≈ 216/220 μg/cm^2(due to α fusion) and the other at ≈ 702/750 μg/cm^2 (due to ^{12}C fusion). The relative contribution of the ICF [as indicated in Figs.[1 (e &,f)] of α particle in the population of ^{95}Tc and ^{94}Tc residues is found to be ≈49.1% and 40.3% respectively.

Conclusion

In light of the above facts, it may be concluded that the ICF plays an important role in the heavy–ion reactions. A detailed study on the angular distribution of projectile-like fragments may provide important additional information on the incomplete fusion reaction dynamics.

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