A study of forward recoil range distributions of incomplete fusion reaction in ^{16}O + ^{156}Gd system at energies E ~ 72, 82 & 93 MeV

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Introduction

In past few decades, one of the most important reaction in heavy ions are complete fusion (CF) and incomplete fusion (ICF), plays an important role at energy above the Coulomb barrier [1-3]. At energy above the Coulomb barrier, CF expected to dominant reaction mode. While in few decades, a number of studies had confirmed that ICF is also contributes at such energies [4-6]. ICF reaction is first studied by Britt and Quinton [7] in early sixties. However, Inamura *et al.* [8] provides major advances in the study of ICF process from the information based on particle-γ coincidence measurement. The CF and ICF processes have also been categorized on the basis of angular momentum (ℓ) in the system. In CF process, attractive nuclear potential is no longer strong enough to capture entire projectile by the target nucleus and CF gives the way to ICF process. Wilyczynski's SUM-RULE model predicts ICF process exists only for angular momentum greater than the critical angular momentum (ℓ_{crit}). The break-up fusion (BUF) model [9] explained ICF in terms of breakup of the projectile into α-clusters. Other models include hot spot model [10], promptly emitted particle (PEP) model [11], and multistep direct reaction model [12] etc. have been used to fit the experimental data above 10.5 MeV/nucleon energies. However, at energies less than 10 MeV/nucleon, no theoretical model is available to explain ICF process data satisfactorily. With the motivation of partial LMT for ICF reaction products, the FRRDs of residues produced in the ^{16}O + ^{156}Gd system have been measured at three different energies 72, 82 & 93 MeV. It is noteworthy that the FRRDs of evaporation residues (ERs) for the present system are reported for the first time, to the best of our knowledge. In the light of recently reported observations based on FRRD measurement [13, 14], the present measurement in turn may be helpful in bridging the gap between the ICF studies of tightly and weakly bound projectiles at energies above the Coulomb barrier.

Experimental Details

The experiments have been performed using energetic ^{16}O-ion beam delivered from 15UD-Pelletron Accelerator of Inter University Accelerator Centre (IUAC), New Delhi. In FRRD measurement for ^{16}O + ^{156}Gd system, targets and catcher foils were prepared at target laboratory of IUAC. The irradiations have been carried out using GPSC facility at IUAC at three different projectile energies, E ~ 72, 82 & 93 MeV. Stack of Al catcher foils were placed just after the target. The duration of irradiation ~15, 13 & 12 hrs at respective projectile energies with beam current 15nA, 60nA and 48nA. After the irradiation, target-catcher assembly was taken out from the scattering chamber. The activity induced in each catcher-foil counted separately using high resolution HPGe detector.

Results and Discussions

In order to get the information about partial LMT associated with CF and/or ICF reaction products, FRRDs for 7 radio-nuclides populated in the interaction of ^{16}O with ^{156}Gd target have been measured at three different projectile energies i.e., $E_{proj} \approx$ 72, 82 and 93 MeV. The FRRD of ^{168}Hf (4n) are shown in Fig.1. It can be observed from Fig.1 that measured FRRDs of ^{168}Hf shows only single peak at three different projectile energies, and there are only single

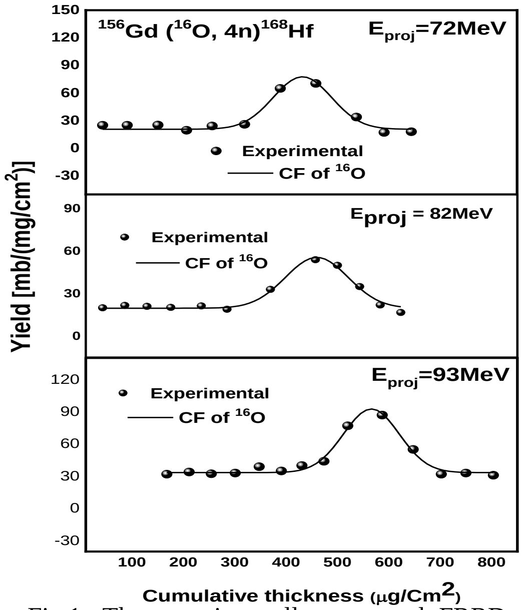

Fig.1: The experimentally measured FRRD of ER ^{168}Hf produced via CF for ^{16}O+^{156}Gd system at energies, E_{proj} ~72, 82 & 93 MeV.

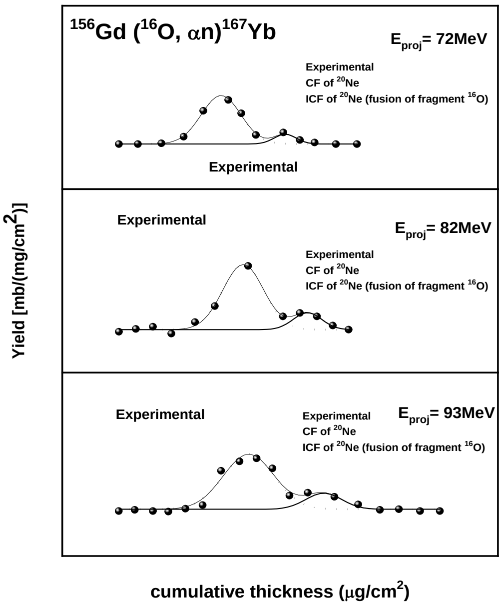

Fig.2: The experimentally measured FRRD of ER ^{167}Yb produced via CF & ICF for ^{16}O+^{156}Gd system at energies, E_{proj} ~72, 82 & 93 MeV.

LMT components involved in the production of ER ^{168}Hf. The reaction products ^{168}Hf populated via 4n channel is associated with entire LMT from projectile to target nucleus and may be represented as; $^{16}O + {}^{156}Gd \Rightarrow {}^{172}Hf^{*} \Rightarrow {}^{168}Hf + 4n$ On the other hand, the FRRD of ER ^{167}Yb (α n) are shown in Fig.2. It can be observed from Fig. 2 that FRRDs of residues ^{167}Yb have two peak structures, one corresponding to complete LMT events (due to fusion of ^{16}O) and another corresponds to partial LMT components (due to fusion of ^{12}C) with ^{156}Gd. The peak corresponding to full LMT at cumulative Al catcher foil thickness ~ 417, 494 & 548 μg.cm^{-2} at energies E_{proj} ~72, 82 & 93 MeV, while another peak corresponding to partial LMT (fusion of ^{12}C) at cumulative Al catcher foil thickness ~ 302, 357 and 382 μg.cm^{-2} at energies E_{proj} ~ 72, 82 & 93 MeV. It may also be observed that experimentally measured most probable ranges R_p(exp) shifts towards higher cumulative thickness as projectile energy increases as expected. The residue ^{167}Yb may populated via CF and ICF of the following type;

Fusion of ^{16}O is as follows

$$^{16}O + {}^{156}Gd \Rightarrow {}^{172}Hf^{*} \Rightarrow {}^{167}Yb + \alpha\, n$$

ICF of ^{16}O i.e., fusion of ^{12}C is as follows

$$^{16}O\,(^{12}C + \alpha) + {}^{156}Gd \Rightarrow {}^{168}Yb^{*} \Rightarrow {}^{167}Yb + n$$

(α-particle as spectator

Further, reaction products ^{162}Yb, ^{165}Tm, ^{163}Tm, ^{159}Ho & ^{157}Dy, the FRRD show the peak corresponding to ICF of ^{16}O [i.e., fusion of ^{12}C, fusion ^{8}Be and fusion of ^{4}He]. In these ERs, experimental CF contributions are not observed. It may again be inferred that these residues produce predominantly through ICF dynamics. It may further be pointed out that observation of FRRDs obtained in the present work may be considered as the confirmation of ICF process respective projectile energies.

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