A study of precursor contribution in ^{189,190}Au residues populated in ^{19}F + ^{175}Lu system at low energies

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The study of incomplete fusion (ICF) reactions in heavy-ion collisions at energies near and above the Coulomb barrier has been a topic of extensive investigation in recent years due to its prescence at energies as low as ≈ 4 MeV/nucleon [1]. In general, at these energies the most dominating mode of nuclear reaction is the complete fusion (CF) [2], where projectile merges with the target nucleus to form an excited composite system which then decays. However, several experimental studies have indicated the presence of ICF reactions as well at these energies [1, 2]. In the case of ICF process, the projectile breaks-up into fragments to provide sustainable input angular momenta. One of the fragments fuses with the target nucleus while the remnant moves in the forward direction with approximately same velocity as that of projectile. Several theoretical models [1, 2] have been developed to understand the reaction dynamics of ICF, but none of them is found to reproduce the experimental data satisfactorily at energies ≈ 4-7 MeV/nucleon. Further, in a nuclear reactions, when composite system is formed, it may decay with the emissions of lighter particles like neutrons, protons and some combinations of particles like proton & neutron (pxn, where x = 1,2,3...) and followed by the emission of γ-rays. In such reaction channels (i.e pxn) there exist a finite probability that such residues are strongly fed from its higher charge isobar precursor through β^+/EC decay. In such cases, the extraction of cross-sections for the independent population (σ_{ind}) of residues becomes important. In the present work, in the system ^{19}F + ^{175}Lu the reaction residues ^{189,190}Au are found to be strongly fed from their corresponding precursor nuclei. Therefore, an attempt has been made to deduce the independent cross-sections of ^{189,190}Au residues using the successive radioactive decay formulations prescribed by Bateman equations.

The experiment for the system ^{19}F + ^{175}Lu has been performed at the IUAC, New Delhi, India. The ^{19}F^{7+} ion beam has been produced using 15UD pelletron accelerator. In the present work, stacked foil activation technique has been employed to measure the cross-sections of the reaction residues. Two stacks, were irradiated. Keeping the half-lives of interest in mind, the irradiations were carried out for ≈ 8-10 hrs of duration for each stack, in the General Purpose Scattering Chamber (GPSC) having in-vacuum transfer facility (ITF). The activities induced in the samples were recorded using a high resolution, precalibrated HPGe detector coupled to a PC with CAMAC. The efficiency and energy calibration within the specified geometry have been done using a standard ^{152}Eu source of known strength.

During the analysis, the ^{190}Au(p3n) and ^{189}Au(p4n) residues, identified from the γ-spectra, are found to be strongly fed from their high charge isobar precursor residues ^{190}Hg(4n) and ^{189}Hg(5n) respectively,

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through β^+/EC decay. As representative case, the different possible routes of ^{190}Au(p3n) formation are;

(i) ^{19}F + ^{175}Lu $\rightarrow^{194}$Hg* $\rightarrow^{190}$Au + p +3n

(ii) ^{19}F + ^{175}Lu $\rightarrow^{194}$Hg* $\rightarrow^{190}$Hg +4n

$$^{190}\text{Hg} \Rightarrow \beta^+/\text{EC} \Rightarrow ^{190}\text{Au}$$

As such, the residues ^{190}Au may be populated via two different routes. Therefore, the cross-sections for the production of ^{190}Au will have cumulative contribution from (i) direct population and (ii) through precursor decay. The measured EF for the production of ^{190}Au has been compared with PACE4 predictions and is shown in Fig. 1(a). As can be seen from this figure that the measured cross-sections are quite large as compared to corresponding theoretical predictions, which indicate the contribution to these residues via precursor decay as well. The independent cross-section (σ_{ind}) of ^{190}Au may be deduced from the cumulative cross-sections (σ_{cum}) using the Cavinato et al., [3] prescription as,

$$\sigma_{ind} = \sigma_{cum} - P_{pre}\frac{t^{d}_{1/2}}{(t^{d}_{1/2} - t^{pre}_{1/2})}\sigma_{pre} \qquad (1)$$

Here $t^{pre}_{1/2}$ and $t^{d}_{1/2}$, are the half-lives of precursor and daughter nuclei respectively. P_{pre} and σ_{pre} are the branching ratio and cross-sections of precursor residues. Using the eq. (1), the independent production cross-sections for ^{190}Au has been deduced from the cumulative cross-section and presented in Fig. 1(b). As can be seen from this figure, the independent cross-section of the residues ^{190}Au(p3n) are very well reproduced by the statistical model code PACE4 for the level density parameter a = A/10 MeV^{-1}, indicating its population via CF process. The precursor contribution in ^{190}Au residues via β^+/EC decay is shown in Fig. 1(c). Similarly, the independent cross-sections (σ_{ind}) of reaction residues ^{189}Au(p4n), which is strongly fed from its precursor ^{189}Hg(5n) are also well reproduced by

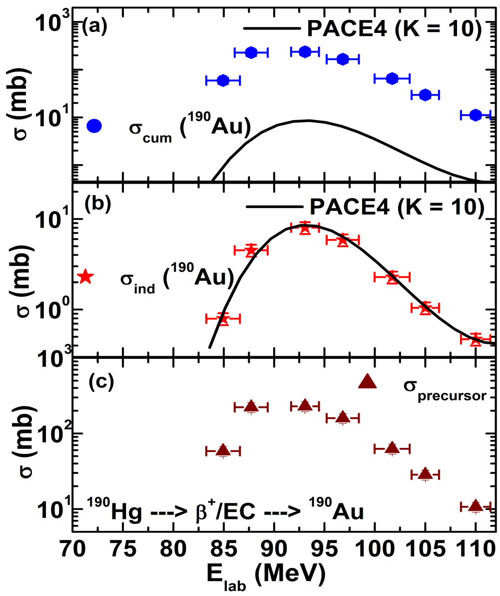

FIG. 1: (a) Cumulative and (b) independent cross-sections of ^{190}Au(p3n) residues compared with corresponding PACE4 predictions. (c) precursor contribution (see text for details).

the theoretical predictions of PACE4 code for the same level density parameter a = A/10 MeV^{-1}. The analysis done, which is important in case of singles measurement, clearly indicates the population of these residues via CF process and represents the importance of precursor decay in the nuclear reactions. Further details will be presented.

The authors thank to the Director of IUAC, New Delhi & the Chairperson, Department of Physics, AMU, Aligarh for providing the necessary facilities to carry out the work. We also thank DST-SERB project no. EMR/2016/002254 for financial support.

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