Inclusive study of low energy complete and incomplete Fusion-Fission

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Introduction

The study of nuclear reaction cross-section for both the light and heavy ion (HI) induced reactions has been a topic of interest not only from the basic physics point of view, but also due to the requirement of such data for the research and development of various nuclear energy systems. The data for, the nuclear reaction cross-sections are needed over a wide range of energy and projectile-target combinations, where it may further can be used for the development of recently proposed Accelerator Driven Sub-critical (ADS) reactor systems [1]. As a matter of fact, the design of ADS is difficult to be realised with limited nuclear reaction cross-section data. Hence, more experimental data is required to determine the optimum irradiation conditions for producing radioactive isotopes of interest. Most of the investigators have concentrated on nuclei like ^{235}U and ^{239}Pu, to produce a tremendous amount of high precision data necessary for the technical application in nuclear reactors [1]. Though, measurement and analysis of the fusion and fission residues in HI interactions have been extensively carried out during the last few years [2, 3] but proper understanding of the dynamics of HI reactions is still lacking. It may be pertinent to mention that HI reactions can be classified as (i) complete fusion (CF), (ii) incomplete fusion (ICF), (iii) fission of excited composite nucleus, (iv) quasi-fission, (v) Direct inelastic collisions, etc. The details on CF and ICF can be found elsewhere [4]. Also, reactions induced by HIs are important, because large input angular momentum is involved and therefore, the composite system may be produced with relatively high spin [5]. It may also be mentioned that HIs have been extensively used as projectile to study the splitting of excited composite system leading to the production of fusion-fission or quasi fission events over a wide range of fissility (Z^2/A), excitation energy (E^*) and entrance channel angular momentum [2, 3]. It has relevance in view of the fact that one of the most important observations in earlier studies was the discovery of asymmetric mass distribution in the low-energy fission of the majority of the actinides [6]. The asymmetric mass distribution may be explained on the basis of nuclear shell effects. Asymmetry in the mass distribution decreases with the increase in excitation energy. This may be explained as a result of gradual washing out of shell effects with increasing excitation energy of the composite system. In view of the above, the study of the dynamics of heavy-ion collisions and systematic studies of the competition of the various reaction processes which contribute to the total reaction cross sections are of considerable importance. In this regard, Sharma et al. [2], reported an influence of low energy fusion-fission in terms of mass asymmetry for the ^{16}O+^{181}Ta system. Moreover, Singh et al. [3] reported the mass distribution for the ^{16}O+^{159}Tb and ^{16}O+^{169}Tm systems. With a view to study the fusion-fission reaction dynamics in ^{13}C+^{169}Tm at energy 4-7 MeV/A an experiment has been performed at the Inter University Accelerator Centre, New Delhi. Brief details of the experiments are given below.

Experimental Details

In order to explore the dynamics of fusion-fission and to deduce the isobaric and isotopic yields in $^{13}C+^{169}Tm$ system, an experiment was performed using the recoil-catcher technique followed by off line γ-spectroscopy. The experiment was performed using $^{13}C^{6+}$ beam from the 15UD Pelletron accelerator at the IUAC, New Delhi. Self supporting ^{169}Tm targets of thickness ≈ 1.5–2.5 mg/cm^2, and Al-catcher foils of thickness ≈ 1.0–3.0 mg/cm^2 were prepared using a uniform pressure rolling technique. Detailed experimental handling can be found elsewhere [4].

Result and Discussion

Excitation functions for a large number of reactions in this system were analyzed to study the complete and incomplete fusion processes in the energy range ≈65-85 MeV [4]. However, an attempt has been made to explore the dynamics of fusion-fission reactions at the energy i.e. ≈ 85 MeV. In the present work, production cross sections of ≈ 12 fission like fragments ($25 \leq Z \leq 45$) produced in $^{13}C+^{169}Tm$ interaction have been measured. A list of the identified fission fragments at E_{Lab} ≈ 85 MeV is given in Table 1. The measured values for the total fission cross-section gives only a lower limit as many fission fragments, either stable or of short half-lives, could not be observed in the present work. Further an attempt has been made to give strength to our findings via statistical model code NRV [7]. Mass distribution is one of the important observables directly related to the collective dynamics of fission processes. A typical plot of experimentally determined production cross sections at E_{lab}= 85 MeV shown in Fig.1. The upward arrows indicate that only the metastable states have been measured and the total production cross sections of these fission fragments are expected to increase. Further detail will be presented.

Table 1: List of the identified fission fragments at E_{Lab} ≈ 85 MeV.

Identified residues	Identified γ-ray energy (keV)	Half – life (Hr)	I γ (%)
^{132}Ce	155	3.5	10.5
^{129}Ba	202	2.23	0.30
^{106m}Rh	222	2.18	6.43
^{66}Ge	272	2.26	10.44
^{133m}Ce	364	4.9	1.25
^{105}Ru	413	4.44	2.27
^{90}Mo	472	5.56	1.42
^{117m}Cd	484	3.36	1.02
^{81}Rb	510	4.5	5.3
^{133m}Ce	611	4.9	2.60
^{106m}Rh	646	2.18	2.74
^{108}In	1033	0.96	35.00

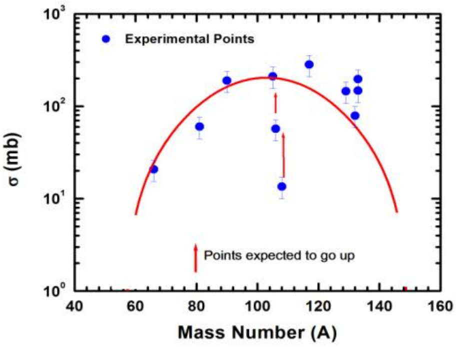

Fig.1 - Mass distribution of fission like products.

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