Study of the role of excitation energy and transfer contribution on fission mass distributions in $^{12}C+^{232}Th$ reaction

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Introduction

The presence of the neutron and proton shells govern the fission process to a large extent at low to moderate excitation energies [1]. The study of the nature of mass distribution as a function of excitation energy for actinide targets can provide useful information regarding the role of shell effects and contribution from transfer induced fission (TF) [2]. The mass distribution in heavy-ion induced fission of the actinides is dominated by Gaussian distribution due to complete fusion fission (CFF) process along with contribution from TF. With the recent availability of the semi-empirical code GEF ("GEneral description of Fission observables"), it is possible to obtain information about various fission observables [3]. The calculations of GEF code can be very useful in validating the role of different shells in governing the mass distribution along with the de-convolution of the contribution from different fission channels by comparing with the experimental data on the mass distribution.

In the present study, fission product (FP) mass distribution has been measured in $^{12}C+^{232}Th$ reaction to investigate the transfer fission contribution and role of excitation energy on mass distribution. There are very limited studies for this system [4,4]. The experiment was carried out using the recoil catcher technique to collect the recoiling fission products followed by the off-line γ-ray spectrometry. A detailed comparison has been carried out between the experimental mass distributions and GEF calculations in order to investigate the contributions from various fission modes.

Experimental Details

Experiments were performed at the BARC-TIFR Pelletron-LINAC facility at TIFR, Mumbai. Self-supporting ^{232}Th targets of thickness ~2 mg/cm^2 sandwiched between two Al catcher foils of thickness 6.75 mg/cm^2 were placed at 45° inclination inside the irradiation chamber. The beam energy incident at the target was estimated as 62.5 and 102.9 MeV, respectively with an upper limit of uncertainty of ~1.3 MeV. After the irradiation, target and catcher foils were counted using high-resolution γ-ray spectrometer from ~5 mins to ~50 days of cooling time. The acquired γ-ray spectra were analyzed using PHAST [6] to obtain peak areas.

Results and Discussion

Formation cross-section of the FPs were obtained from activities of FPs at the end of irradiation. Charge distribution parameters, Z_P were obtained using UCD hypothesis and σ_z was estimated by reproducing the ratio of experimental yields of ^{131}Te and ^{131}I obtained by solving the parent-daughter equation by fitting the measured activity of ^{131}I and was obtained as 0.81±0.02. In the present study, mass distribution has been reported for CFF and TF at beam energy of 102.9 MeV which has been compared

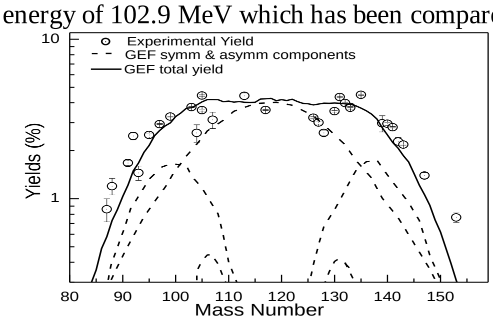

Fig. 1. Mass yield distribution curve of 12C+232Th reaction at Elab = 62.5 MeV [7].

in detail with the lower energy data [7] as well as GEF calculations. At lower beam energy of 62.5 MeV, mass distribution was observed to have flat-top nature [7] as shown in Fig. 1. Mass

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distribution was in reasonable agreement with GEF calculations (2021/1.1) which predicted significant contribution from asymmetric mode of fission with S2 mode (Z ≈ 55) having dominant contribution. On the other hand, the mass distribution at 102.9 MeV, as obtained in the present study, follows a broad Gaussian curve (Fig. 2a), though yields of some of the isobaric chains in the mass region 132-145 are anomalously higher which may be due to the contribution from TF. The excitation energies of the target like product formed in proton and alpha transfer channels were calculated. The negative excitation energies for proton transfer channel due to the highly negative Q_{gg} value (-10.7 MeV), suggests the contribution of only α transfer fission channel. In order to delineate the contribution from the CFF and TF, measured FP yields were fractionated according to the ratio of yields of fission products as predicted by GEF for the fission of nuclei formed in CFF and TF. Contribution from TF was found to be negligible at 62.5 MeV. However, significant TF contribution (≈15%) was found at 102.9 MeV. The observed decrease in the TF cross section relative to CFF can be attributed to the less rapid increase in the relative transfer cross section with decreasing beam energy in the case of $^{12}C+^{232}Th$ reaction as observed in ref [9] along with the absence of the TF contribution from the proton transfer channel. Mass distribution for the TF was found to be asymmetric (Fig. 2(b)) for 102.9 MeV due to the low excitation energy of the fissioning system.

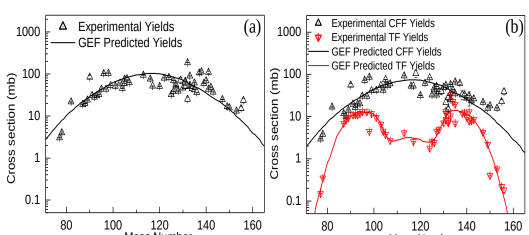

Fig. 2. *Overall mass distribution (a) and CFF (black triangle) and TF (red triangle) contribution (b) at 102.9 MeV with GEF Predictions (solid line).*

Mass distribution for CFF was observed to be in reasonable agreement with the GEF calculations (shown as solid line), however, some of the mass yields deviate significantly from the GEF calculations which may be due to the variation in Z_p due to the charge polarization effect. The fission cross sections at 62.5 and 102.9 MeV were found to be 36.7 and 1666 mb, respectively which were found to be in reasonable agreement with those calculated using CCFUS [8] and that reported in literature [4].

Conclusions

The yields of the mass and charge identified FPs were measured using the recoil catcher technique followed by off-line gamma-ray spectrometry. Contrary to the flat-top mass distributions observed at 62.5 MeV beam energy in the previous study, the present study at higher beam energy (102.9 MeV) shows a broad Gaussian mass distribution indicating negligible contribution from asymmetric fission. However, the flat-top mass distribution at lower beam energy indicates significant contribution from asymmetric fission, with S2 (Z ≈ 55) mode having the dominant contribution. A ssignificant contribution (~15%) from transfer induced fission was observed at higher beam energy (102.9 MeV). Mass distribution for TF was observed to be asymmetric. The overall fission cross sections were found to be in reasonable agreement with the CCFUS calculations.

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