Radiochemical measurement of mass distribution in $^{16}O+^{238}U$ reaction at sub-barrier energy

T. N. Nag[1], R. Tripathi[1]*, S. Sodaye[1], K. Sudarshan[1], P. K. Pujari[1], B. K. Nayak[2], K. Ramachandran[2]
[1]*Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
** email: rahult@barc.gov.in*

Introduction

Mass distribution is an important fission observable which provides information about the potential energy landscape of the fissioning nucleus. The asymmetric mass distribution in low energy fission of actinides could be explained by incorporating the shell corrections to the liquid drop model potential energy. In heavy ion induced fission, the nature of mass distribution has been observed to depend on the projectile target combination and on the mechanism whether it is complete fusion fission (CFF) or transfer induced fission (TF). The mass distribution has been observed to be asymmetric for both CFF as well as for TF in $^{7}Li+^{232}Th$ reaction [1]. Whereas in $^{20}Ne+^{232}Th$ [2], $^{19}F+^{232}Th$ [3] reactions, mass distributions have been observed to be symmetric for CFF and asymmetric for TF. In addition entrance channel dynamics also plays an important role in governing the mass distribution. In the on-line measurement of mass distribution in $^{16}O+^{238}U$ reaction a sudden increase in the width of the mass distribution was observed at sub-barrier energy, which was attributed to the contribution from quasi-fission [4].

In the present, radiochemical study of the mass distribution in $^{16}O+^{238}U$ has been carried out at sub-barrier energy to investigate the nature of mass distribution in CFF and TF channels. In addition, cross sections of evaporation residues formed in one nucleon transfer/pick-up reactions have also been measured.

Experimental details

Experiment was carried out using BARC-TIFR Pelletron-LINAC facility at Tata Institute of Fundamental Research, Mumbai. Self-supporting target of ^{nat}U (Thickness: 3 mg/cm^2) was irradiated with 87 MeV ^{16}O) beam. The beam energy range in the target was 87 MeV ($E_{incident}$) to 80.7 MeV (E_{out}) corresponding to E_{cm}/V_b values of 0.97 to 0.90, where E_{cm} is the projectile energy in the centre of mass frame of reference and V_b is the entrance channel Coulomb barrier. Fission products recoiling out of the target were stopped in a super pure Al catcher foil having thickness 6.75 mg/cm^2. Irradiation was carried out for about ~10 hrs. Beam intensity was continuously monitored during irradiation to correct for fluctuations in the beam intensity

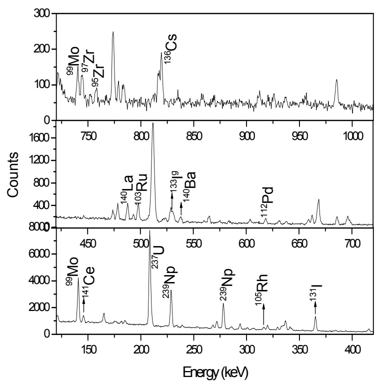

Fig. 1 Gamma-ray spectrum of the fission products formed in $^{16}O+^{238}U$ reaction

during irradiation. After irradiation, the catcher foil was assayed for the gamma-ray activity of the fission products using a HPGe detector. Efficiency calibration of the HPGe detector was carried out using standard source of $^{152}Eu^{g}$ source.

Results and discussion

Fig. 1 shows a typical gamma-ray spectrum of the fission products formed in $^{16}O+^{238}U$

reaction. Gamma-lines of the different fission products and evaporation residues are marked in the figure. The gamma-ray spectra were analyzed using the software PHAST to obtain the peak areas for characteristic gamma-rays of various fission products which were used to obtain their formation cross section. In order to obtain mass yields, cross sections of fission products were corrected for charge distribution. For the fission products with A/Z <2.5, charge distribution parameter for CFF [2] was used. For the products with A/Z≥2.5, charge distribution parameter for TF [5] was used. Mass yields obtained in $^{16}O+^{238}U$ reaction is shown in Fig. 2. Filled symbols are experimental yields and open symbols are the reflected points i.e. experimental yield assigned to the complimentary fission product. It should be mentioned here that mass yields obtained from the independent yields of Sb isotopes (not shown in the figure) were significantly higher compared to those obtained from the cumulative yields. This suggests that the use of literature values for the charge distribution parameters is not good enough for independent yields. However, the present discussion is based mainly on the mass yields obtained from cumulative yields which do not undergo any significant change due to the charge distribution correction.

As seen from Fig. 2, the overall mass distribution is asymmetric. The mass distribution was fitted with the sum of two Gaussian functions. The centroid values for the lower and heavier mass wings were 104.6±0.8 and 141.0±1.0 respectively. These values correspond to the asymmetric fission for full momentum transfer fission in $^{16}O+^{238}U$ reaction. The mass distribution corresponds to the average beam energy $<E_{lab}>$ =85. 3 MeV (weighted by fusion cross section [6]) and excitation energy of 41.6 MeV. The mass distribution for transfer induced fission is also present in the observed mass distribution. However, as mass distribution for both CFF and TF is asymmetric, it is difficult to accurately determine the contribution from TF. However, an approximate estimate was obtained as ~30% after subtracting the fusion cross section [6] from the total fission cross section.

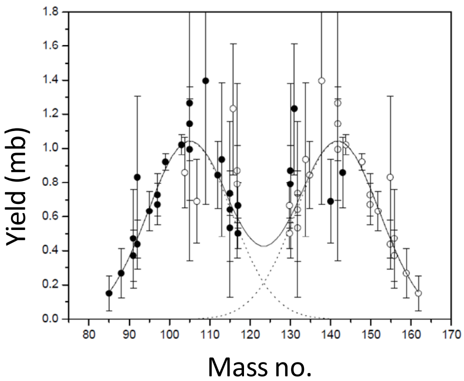

Fig. 2 Mass distribution in $^{16}O+^{238}U$ reaction at $<E_{lab}>$=85.3 MeV.

Contribution to TF from one nucleon transfer channel is not expected to be significant due to the lower excitation energy of the fissioning system compared to fission barrier as evident from substantial cross sections for ^{237}U (31.3±3.5 mb) and ^{239}Np (13.7±0.7 mb). Significant contribution from TF would be expected from alpha transfer channel which would bring more angular momentum and excitation energy (~9 MeV).

Conclusions

Mass distribution in $^{16}O+^{238}U$ reaction has been observed to be asymmetric at sub-barrier projectile energy. The centroid values of the two peak mass distribution corresponding to the full momentum transfer reaction are 104.6±0.8 and 141.0±1.0 respectively. An approximate estimate of transfer induced fission was obtained as ~30%. Dominant contribution to TF is expected from alpha transfer channel.

References

[1] R. Tripathi *et al.*, Radiochim. Acta **90**, 185 (2002).
[2] S. Sodaye *et al.*, Phys. Rev. C **87**, 044610 (2013).
[3] G.K. Gubbi *et al.*, Phys. Rev. C 53, 796 (1996).
[4] K. Banerjee *et al.*, Phys. Rev. C 83, 024605 (2011)
[5] M. C. Duh *et al.*, Nucl. Phys. A **550**, 281 (1992).
[6] K. Nishio *et al.*, Phys. Rev. Lett **93**, 162701 (2004).