Mass and isotopic yield distributions of fission-like residues in $^{16}O + ^{181}Ta$ system at $E_{Lab} \approx 6$ MeV/A

Vijay R. Sharma[1],* Abhishek Yadav[1], Devendra P. Singh[1], Pushpendra P. Singh[2], Unnati[1], Manoj K. Sharma[3], R. Kumar[4], K. S. Golda[4], B. P. Singh[1],† A. K. Sinha[5], and R. Prasad[1]

[1]*Department of Physics, Aligarh Muslim University, Aligarh (UP)-202 002, INDIA*
[2]*INFN-Laboratori Nazionali di Legnaro, I-35020 Legnaro, ITALY*
[3]*Physics Department, S.V. College, Aligarh-202 001, INDIA*
[4]*NP-Group, Inter-University Accelerator Centre, New Delhi-110 067, INDIA*
[5]*UGC-DAE-CSR, Bidhan Nagar, Kolkata-700 098, INDIA*
*email: *phy.vijayraj@gmail.com, †bpsinghamu@gmail.com*

The study of fission like events in heavy ion (HI) reactions at low energies has been a topic of interest for the last several years. Reactions induced by HIs are important, as both the projectile and target are heavy ions, so large input angular momentum is involved and, therefore, the composite system can be produced with relatively high spin. Since, the de-Broglie wavelength associated with incident HI's is comparable to the nuclear dimensions, therefore, the interaction may be treated semiclassically. The classical trajectories of a projectile leading to the different reaction processes may be classified on the basis of impact parameter [1]. Furthermore, on the basis of driving input angular momenta (ℓ) imparted to the system, the reactions may be categorized broadly into complete fusion (CF) and incomplete fusion (ICF) processes. For $\ell > 0$ to $\ell < \ell_{Crit}$ the CF occurs, however for $\ell > \ell_{Crit}$, ICF takes place. It may, further, be pointed out that the resultant composite system formed via CF and/or ICF may attain thermodynamic equilibrium and at later stages the compound nucleus may de-excite via the emission of light nuclear particle(s) and the characteristics γ-rays. The excited composite system, on the other hand, may also undergo fission depending on the available excitation energy, angular momentum, entrance channel mass asymmetry, etc. [2, 3]. The measurement of production cross-sections of such fission residues in HI interactions, have been extensively carried out during the last few years and a large amount of experimental data for various fissioning systems has been generated, leading to the development of various nuclear models [4-6]. Studies on the effect of excitation energy and angular momentum on various fission observables have provided deeper insight into the nuclear reaction dynamics. 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 [7]. The development of future nuclear power reactors with applications of hybrid technologies using accelerator based incineration systems [7] require knowledge of precise experimental cross-sections of such nuclear reaction products in a wide range of energy and projectile-target combinations. Moreover, such experimental data is also required to determine optimum irradiation conditions for producing radioactive isotopes/beam of interest.

In view of the above, experimental studies for $^{16}O + ^{181}Ta$ system have been performed at the Inter University Accelerator Centre (IUAC), New Delhi, India using the recoil-catcher technique followed by γ-spectroscopy. Self supporting samples of ^{181}Ta ($\approx$ 99.99%) of thickness $\approx$1.5 mg/cm^2 were pasted on Al-catcher foils. The irradiations were carried out in the General Purpose Scattering Chamber (GPSC), of 1.5 m diameter having an In-vacuum Transfer Facility. Further details of the experiment are given elsewhere [8].

In the present work, production cross-sections of $\approx$ 30 fission fragments ($30 \leq Z \leq 60$) produced in $^{16}O + ^{181}Ta$ interaction have been measured at 97 and 100 MeV incident energies. A list of the identified fission fragments at $E_{Lab} \approx$ 97 MeV and 100 MeV beam energies are given in Table I. The total production cross-sections for the presently measured fission fragments are found to be ≈ 408 and ≈ 579 mb, at 97 and 100 MeV, respectively. It may, however be pointed out that these measured values for the total fission cross-section give only a lower limit as many fission fragments, either stable or of short half-lives, could not be observed in the present work.

Table I: A list of identified fission-like residues.

Nuclides	Nuclides	Nuclides	Nuclides
^{71m}Zn	^{90m}Y	^{110}In	^{128m}Sb
^{75}Ge	^{91m}Y	^{110m}In	^{129}Sb
^{77}Kr	^{93}Y	^{111}In	^{132}La
^{85m}Kr	^{98m}Nb	^{111m}In	^{132}Ce
^{85m}Y	^{99m}Rh	^{113m}In	^{132m}I
^{86}Y	^{105}Ru	^{117}Cd	^{134m}Pr
^{87}Kr	^{108}In	^{117}Sb	^{137}Nd
^{88}Kr	^{109}In	^{121}Xe	^{141m}Sm

The mass distribution of fission products is one of the important observables directly related to the collective dynamics of processes [9]. In the present work the measured mass distribution of fission fragments have been found to be symmetric, as expected. Further, in some cases several isotopes of a given element have been found to be populated. As a representative case experimentally determined yield distribution of Yttrium isotopes at 100 MeV incident energy is shown in Fig.1. Since, only the metastable states of ^{90,91}Y have been measured, the contribution of ^{90,91}Y isotopes shown in Fig.1, are expected to go up which is indicated by upward arrows. As may be seen from this figure the isotopic yield distribution has Gaussian shape, as expected. Furthermore, the variance (σ^2) of the isotopic yield distributions obtained in the present measurements agree closely to the literature values [10] for other fissioning systems. The present experiments at low energies (≈ 6 MeV/A) indicate that apart from complete fusion and incomplete fusion processes [11], fission of the excited composite system is also quite significant. As such, contributions of fission should also be taken into account while predicting the total reaction cross-sections. Additional information on various observables of fusion-fission reaction dynamics may be obtained by measuring the angular distribution of the fission fragments. The details of the present measurements will be presented.

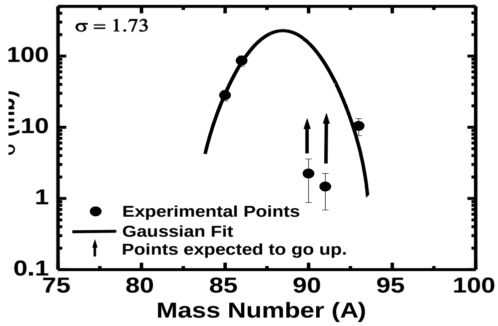

Fig.1 Isotopic yield distribution for Yttrium isotopes in ^{16}O + ^{181}Ta system at E_{lab} ≈ 100 MeV.

The authors thank to the Chairman, Department of Physics, and the Director, IUAC, New Delhi, India, for providing all the necessary facilities to carry out the work. A.Y. thanks to the UGC, BPS, MKS and RP thanks to the DST and UGC for providing financial support.

References

[1] P. E. Hodgson, E. Gadioli and E. Gadioli Erba, Introductory Nuclear Physics (Clarendon Press, Oxford, 1997) Chapter 23.
[2] W. J. Swiatecki, Phys. Scr.**24**, 113(1981).
[3] C. Gregoire et al, Phys. Lett. B **99**, 17(1981).
[4] K. H. Schimidt et al, Nucl. Phys. A **693**, 169 (2001).
[5] C. Waggemans, The Nuclear Physics Process (CRC, London, 1991).
[6] D. J. Hinde et al, Nucl. Phys. A **472**, 318 (1987).
[7] C. Rubbia et al, Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier, Report CERN/AT/95-94(ET) 1995.
[8] D. P. Singh, Ph. D. Thesis, A.M.U., Aligarh, INDIA (2010).
[9] A. C. Berriman et al, Nature (London) **413,** 144 (2001).
[10] Pushpendra P. Singh et al, Int. J. Mod. Phys. E **17**, 549 (2008).
[11] D. P. Singh et al, Phys. Rev. C **81**, 054607 (2010).