Observation of fission-like events in the ^{12}C+^{169}Tm system at $E^* \approx$ 69, 63, and 57 MeV

Arshiya Sood[1],* R. N. Sahoo[1], Pawan Kumar[1], Mohd. Shuaib[2], Abhishek Yadav[3], Vijay R. Sharma[3], D. P. Singh[4], Unnati Gupta[5], R. Kumar[3], S. Aydin[6], Pushpendra P. Singh[1],† Manoj K. Sharma[3], B. P. Singh[7], H. J. Wollersheim [1,8], and R. Prasad[7]

[1] *Department of Physics, Indian Institute of Technology Ropar, Rupnagar-140 001, Punjab, India*
[2] *Department of Physics, S. V. College, Aligarh-202 001, U.P., India*
[3] *Inter-University Accelerator Center, New Delhi-110 067, India*
[4] *Department of Physics, University of Petroleum and Energy Studies, Dehradun-248 007, U.K., India*
[5] *Department of Physics, Delhi University, New Delhi-110 067, India*
[6] *Department of Physics, University of Aksaray, Aksaray, Turkey*
[7] *Department of Physics, A. M. University, Aligarh-202 002, UP, India and*
[8] *GSI Helmholtzzentrum fur Schwerionenforschung, Planckstrasse 1, 64291 Darmstadt, Germany*

The formation of super-heavy elements through fusion of two heavy-ions is influenced by the survival of compound nucleus, equilibrated in all the degrees of freedom, against its fission. In macroscopic models of heavy-ion collisions, the multi-dimensional potential 'energy landscape' sways the dynamics of fusion process from touching configuration to the formation of compound nucleus [1]. According to liquid drop model (LDM), the limit for stability against fission for a nucleus reaches for Z≥104 as no fission barrier exists beyond this resulting in a symmetric, single-humped mass distribution of fission fragments. The observation of asymmetric mass distribution in low energy fission of majority of actinide targets, and synthesis of elements beyond Z=104 [2] was explained by incorporating shell corrections to LDM [3]. The asymmetry in the mass-distribution decreases at higher excitation energies due to the gradual fading of shell effects. Over the last few decades, the heavy-ion reactions have attracted a great deal of efforts across the globe, as they offer the most drastic rearrangement of nucelons in a many body system [4]. In a fusion-fission process, the compound nucleus formed via complete and/or incomplete fusion may proceed towards fission depending upon the available excitation energy and other entrance channel parameters, *i.e.*, mass-asymmetry ($\mu = \frac{M_T - M_P}{M_T + M_P}$), deformation, and Coulomb factor (Z_1Z_2). The final reaction products may be populated via the emission of light nuclear particles and/or characteristic γ-rays from the fission fragments. Nishio *et al.* [5] reported incomplete fusion-fission as one of the dominant reaction modes in addition to the complete fusion-fission at intermediate energies. The phenomenon of nuclear fusion-fission with heavy-ions has been prodigiously investigated for a wide range of fissility, excitation energy, and other entrance channel parameters [6, 7]. Although a large amount of cross-section data has been generated in light- and heavy-ion induced reactions on highly fissile actinide targets yet there is a dearth of comprehensive understanding of underlying dynamics in the below actinide region. The cross-section data for fission fragments in a diverse range of projectile-target system is also of the essence for its application in the areas of nuclear astrophysics, development of next generation nuclear reactors, and radiochemistry for national security.

With the spur to study different aspects of heavy-ion induced fission following the evo-

*Electronic address: arshiya.sood@iitrpr.ac.in
†Electronic address: pps@iitrpr.ac.in

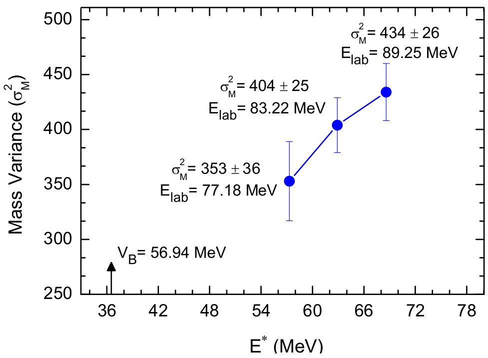

FIG. 1: Mass variance, σ^2_M, as a function of excitation energy (E^*) for deformed thulium target. The arrow indicates the E^* corresponding to the Coulomb barrier.

lution of composite system formed via complete and/or incomplete fusion, the experiments have been performed with beams of ^{12}C (E_{lab}= 77.18, 83.22, and 89.25 MeV) on deformed ^{169}Tm target, $\approx 900\ \mu g/cm^2$ thick, using the pelletron accelerator facilities at IUAC New Delhi. An *Al* foil of sufficient thickness was placed behind the target foil to stop the recoiling products. Recoil-catcher activation technique followed by the off-line γ-spectroscopy with two pre-calibrated HPGe detectors was used to measure the production cross-sections of fission fragments. The identification of residues was done by their characteristic γ-rays and vetted by decay-curve analysis. In this communication, 26 fission-like events have been identified at different energies [8].

To discern various reaction mechanisms, two post-fission observables: mass and charge distribution were used. In heavy-ion induced reactions, the mass distribution of fission fragment is, generally, found to be symmetric because in most of the cases a compound nucleus is formed with an excitation energy which is well above the fission barrier. The mass distribution of fission fragments produced in ^{12}C+^{169}Tm is obtained at E_{lab}= 77.18, 83.22, and 89.25 MeV. The mass dispersion of fission fragments is found to be symmetric and can be fitted with one Gaussian function manifesting their production by compound nuclear processes. The observed variation in mass variance with excitation energy is shown in Fig.1. The mass variance is found to increase with excitation energy at above the Coulomb barrier energies as reported by Ghosh *et al.* [9] for deformed Thorium target. The charge distribution parameters were obtained for the Kr and Tc isotopes at E_{lab} = 83.22 and 89.25 MeV; and are found to be in good accord with the experimental values reported in the literature.

To summarize, present work suggests that fission is one of the competing modes of de-excitation of the complete and/or incomplete fusion composites at the excitation energies where the evaporation of light nuclear particle(s) and/or γ-rays are assumed to be sole contributors. A single-peak broad Gaussian mass dispersion curve substantiated the presence of compound nuclear fission at all the studied energies. In this conference, the experimental details and results of the measurements will be delineated and discussed.

One of the authors P.P.S. thanks SERB for Young Scientist Research Grant No. YSS/2014/000250.

References

[1] P. Moller and A. J. Sierk, Nature **422**, 485 (2003).

[2] Yu. Ts. Oganessian *et al.*, Nature **400**, 242 (1999).

[3] V. M. Strutinsky, Nucl. Phys. A **95**, 420 (1967).

[4] B. B. Back *et al.*, Rev. Mod. Phys. **86**, 317 (2014).

[5] K. Nishio *et al.*, Phys. Rev. Lett. **93**, 162701 (2004).

[6] V. S. Ramamurthy *et al.*, Phys. Rev. Lett. **65**, 25 (1990).

[7] G. K. Gubbi *et al.*, Phys. Rev. C **59**, 3224 (1999).

[8] Arshiya Sood *et al.*, Phys. Rev. C **96**, 014620 (2017).

[9] T. K. Ghosh *et al.*, Phys. Lett. B **627**, 26 (2005).