Mass-gated neutron multiplicity measurements for ^{48}Ti + ^{208}Pb reaction

Meenu Thakur[1],* B.R. Behera[1], Ruchi Mahajan[1], N. Saneesh[2], Gurpreet Kaur[1], Priya Sharma[1], R. Dubey[2], Kushal Kapoor[1], A. Yadav[2], Neeraj Kumar[3], S. Kumar[4], Kavita Rani[1], P. Sugathan[2], A. Jhingan[2], A. Chatterjee[2], M.B. Chatterjee[2], S. Mandal[3], A. Saxena[5], Santanu Pal[6], and S. Kailas[5]
[1]*Department of Physics, Panjab University, Chandigarh - 160014, INDIA*
[2]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA*
[3]*Department of Physics and Astrophysics, University of Delhi - 110007, INDIA*
[4]*Department of Nuclear Physics, Andhra University - 530003, INDIA*
[5]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and*
[6]*CS - 6/1, Golf Green, Kolkata - 700095, INDIA (Formerly with VECC, Kolkata)*

Introduction

A fair understanding of fusion-evaporation and fusion-fission (FF) dynamics is a prime need for exploring more about the super-heavy elements. It helps in choosing the different combinations of target and projectile to maximize the formation probability of super-heavy nuclei. For these elements, there is a significant contribution from quasi-fission (QF) processes along with FF processes [1]. Reaction probes like fission fragment angular distribution, mass distribution (MD), mass-energy distribution (MED) and mass-gated neutron multiplicity could be employed to disentangle these processes. Neutron emission probe, based on the measurement of time-scales of these processes is used where MD and MED fail to distinguish QF and FF in the fission path of heavy elements [2]. Based on the fact that neutron multiplicity values are different for QF and FF processes [3], this method could be used to explore the reaction dynamics of heavy systems. Current studies are based on the measurement of mass-gated neutron multiplicity for the ^{48}Ti + ^{208}Pb system populating the near super-heavy compound nucleus (CN) ^{256}Rf (Z=104). The selection of this system provides the advantage to make use of already existing fusion probability and evaporation residue cross-section for CN with Z=104, populated through the reaction ^{50}Ti + ^{208}Pb [4]. In the present work, we are reporting the results for mass-gated neutron multiplicity for the ^{48}Ti + ^{208}Pb system. This experiment was performed using the dedicated facility National Array of Neutron Detectors (NAND) [5] at Inter University Accelerator Centre (IUAC), New Delhi. All the experimental details and preliminary data analysis for the average neutron multiplicity are described elsewhere [6].

Data Analysis and Results

The extracted fission fragment mass-energy correlation for ^{48}Ti + ^{208}Pb system is shown in FIG. 1. Since, there is overlap of QF and FF events in the near symmetric mass valley. So, neutron multiplicity measurements were performed in correlation with fission fragment masses to distinguish the QF events from the true FF events. For this purpose, the MED of fission fragments was divided into three different mass splits: symmetric ($A_{FF} = \frac{A_{CN}}{2} \pm 20$), asymmetric ($68 < A_{FF} < 108$) and projectile like fragments (PLF) ($38 < A_{FF} < 68$), to analyse the neutron data. The observed 350 neutron energy spectra corresponding to each mass cut were simultaneously fitted with three moving source evaporation components (Watt expression) to obtain the correct pre-scission (ν_{pre}) and post-scission (ν_{FF1}, ν_{FF2}) neutron multiplicities. In fitting procedure, the angular acceptance of

*Electronic address: meenu.thakuroct@gmail.com

TABLE I: Neutron multiplicity values for the ^{48}Ti + ^{208}Pb system as a function of fission fragment mass cuts.

Neutron multiplicity	PLF mass cut 38 <A_{FF} <68	Asymmetric mass cut 68 <A_{FF} <108	Symmetric mass cut 108 <A_{FF} <148
ν_{pre}	0.15 ± 0.008	1.66 ± 0.067	2.23 ± 0.068
ν_{FF1}	0.10 ± 0.003	1.89 ± 0.028	3.01 ± 0.033
ν_{FF2}	0.19 ± 0.006	3.43 ± 0.046	3.01 ± 0.033
ν_{total}=ν_{pre} + ν_{FF1} + ν_{FF2}	0.44 ± 0.010	6.98 ± 0.086	8.25 ± 0.095
χ^2/NDF	2.42	2	1.72

the neutron detectors and MWPCs were taken into consideration.

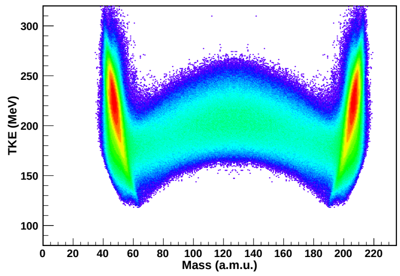

FIG. 1: The mass-energy distribution for ^{48}Ti + ^{208}Pb system.

The extracted multiplicites values corresponding to each mass cut are given in TABLE I. These extracted neutron multiplicity values were verified with the energy balance equation. In present work, the measured total neutron multiplicity (ν_{total}) is slightly less than the value obtained in recently performed similar measurement for ^{258}Rf at LNL, Italy [7]. This deviation might be due to the fact that the present system is a slightly lighter Rf isotope populated at comparatively lower excitation energy. Double differential neutron multiplicity spectra corresponding to three mass cuts for the two neutron detectors placed at different angles with respect to the fission axis are shown in FIG. 2. It is also observed that pre-scission neutron multiplicity increases from value of 1.66±0.067 to 2.23±0.068 as we go from asymmetric to symmetric mass region.

This increase is attributed to the difference in reaction mechanism and time-scales of FF and QF processes. Statistical model calculations however are unable to reproduce the experimental multiplicities which indicate that non-equilibrium (QF) processes possibly play an important role for such heavy systems.

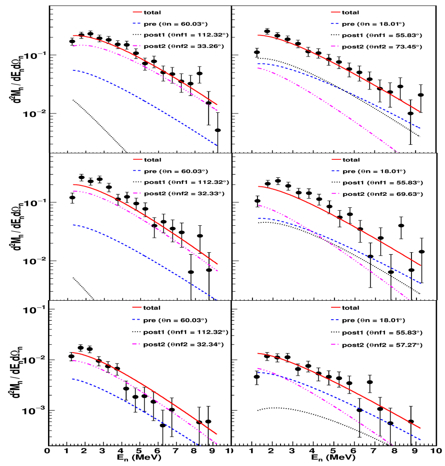

FIG. 2: Double differential neutron multiplicity spectra for symmetric (upper panel), asymmetric (middle panel) and PLF mass cut (lower panel) from the neutron detectors placed at 18° and 60° with respect to the fission axis.

References

[1] M.G. Itkis *et al.*, Nucl. Phys. A **734**, 136 (2004).

[2] P.K. Sahu *et al.*, Phys. Rev. C **72**, 034604 (2005).

[3] Y. Aritomo *et al.*, Nucl. Phys. A **759**, 342 (2005).

[4] R.S. Naik *et al.*, Phys. Rev. C **76**, 054604 (2007).

[5] P. Sugathan *et al.*, Pramana **83**, 807 (2014).

[6] Meenu Thakur *et al.*, Proceedings of the DAE-BRNS Symp. on Nucl. Phys. **60**, 358 (2015).

[7] M. Cinausero *et al.*, Proceedings of Science (X LASNPA), 060 (2013).