Average neutron multiplicity measurement for the ^{28}Si + ^{232}Th system

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Introduction

During last few decades, the topic of synthesis of super-heavy elements (SHE) is of an immense interest in nuclear physics. The main obstacle in super-heavy mass region is the presence of quasi-fission (QF) processes along with the fusion-fission (FF) processes [1]. The entrance channel properties, such as deformation, magicity and mass asymmetry etc., of the interacting heavy nuclei play a crucial role to understand the QF and FF processes. An optimum selection of projectile and target combinations and a suitable projectile energy thus helps to probe the competition between the QF and FF processes, which is further useful in enhancing the formation probability of SHE. A number of experimental probes such as mass distribution, mass-energy and mass-angle correlations, and neutron multiplicity measurements have been adopted to separate out these processes. However, in the heavier or super-heavy mass region, neutron multiplicity measurement is the most suitable probe as it helps in determining timescales of these processes. Current studies are based on the neutron multiplicity measurement for the ^{28}Si + ^{232}Th system populating the near super-heavy compound nucleus (CN) ^{260}Rf (Z=104). The selection of this system allows us to compare the results of our neutron multiplicity obtained from the fission of ^{256}Rf populated by the ^{48}Ti + ^{208}Pb system [2]. This system also offers an opportunity to study the role of entrance channel deformation and shell effects on the QF and FF processes. In the present paper, we are reporting some of the results from our recently performed experiment for the ^{28}Si + ^{232}Th system using the National Array of Neutron Detectors (NAND) facility [3] at Inter University Accelerator Centre (IUAC), New Delhi.

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Experimental Setup

The experiment was carried out using a pulsed beam of ^{28}Si from the 15UD Pelletron + LINAC accelerator facility at IUAC. ^{28}Si beam (current = 0.9 pnA and repetition rate = 250 ns) with the laboratory energy of 200 MeV was bombarded on thick ^{232}Th target of thickness 1.5 mg/cm^2. The target ladder was tilted to an angle of 15° with respect to the beam axis in order to minimize the shadowing to fission detectors. Neutrons were detected using NAND facility which consists of 100 organic liquid scintillators (BC501A) mounted on a geodesic dome structure. For fission fragment detection, two large area position-sensitive multiwire proportional counters (MWPCs) (6.4″ × 4.4″) were used [4]. MWPCs in forward and backward directions were placed at distance of 21 cm and 16 cm from the target on movable arms on either sides of the beam axis at angle of 28° and 131° respectively. Along with this, two silicon surface barrier detectors (SSBD) kept at ± 12.5° with respect to the beam direction were used to monitor the beam flux. The fission fragment detected in any of the MWPCs in coincidence with RF is used as trigger for list mode data collection with LAMPS as the acquisition software.

Data Analysis and Results

Since the BC501A neutron detectors are sensitive to both γ's and neutrons, pulse shape discrimination (PSD) with IUAC home made PSD modules [5], based on the zero-cross over technique and time-of-flight (TOF) method, was used to discriminate neutrons and γ's. Figure 1 shows the TOF spectra for one of the neutron detector. TOF spectra are calibrated using a precision time calibrator and the prompt γ peak as a time reference. The

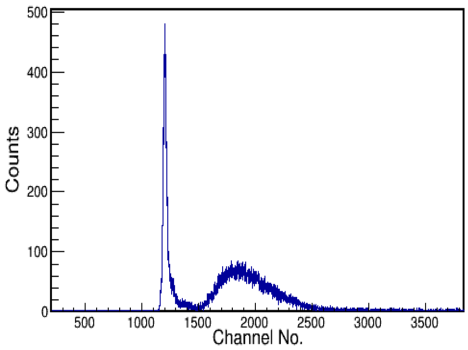

FIG. 1: Raw neutron TOF spectrum for ^{28}Si + ^{232}Th reaction at beam energy of 200 MeV.

calibrated neutron TOF are then converted into neutron energy. Further, the neutron energy spectra are gated with neutron lobe (in 2D plot of TOF vs. PSD) and fission fragments. For the present work, we have extracted neutron energy corresponding to only middle slice (of size 3.0 cm × 3.0 cm) of MWPC to minimize the angular uncertainty. However, in future we will also consider more number of slices for a complete analysis. The efficiency corrections for the neutron detectors

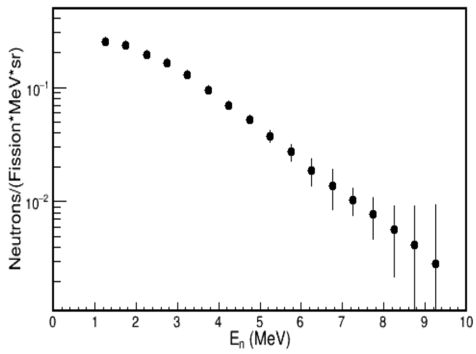

FIG. 2: Double differential neutron multiplicity spectrum for the ^{28}Si + ^{232}Th reaction at beam energy of 200 MeV.

are performed using FLUKA [6] code. Double differential neutron multiplicity spectrum for one of the neutron detectors placed at 0° with respect to the fission axis is shown in Fig. 2. Further, to extract the pre and post-scission components of neutron multiplicities from the neutron energy spectra for the 50 neutron detectors using the moving source fitting analysis is in progress.

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References

[1] M.G. Itkis *et al.*, Nucl. Phys. A **734**, 136 (2004).
[2] Meenu Thakur *et al.*, Phys. Rev. C **98**, 014606 (2018).
[3] P. Sugathan *et al.*, Pramana **83**, 807 (2014).
[4] Akhil Jhingan, Pramana J. Phys. **85**, **483** (2015).
[5] S. Venkataramanan *et al.*, Nuclear Instruments and Methods in Physics Research A **596**, 248 (2008).
[6] A. Ferrari *et al.*, FLUKA: A Multi-Particle Transport Code CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.