# Probing fusion-fission dynamics in $^{203}$Bi using evaporated neutrons

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Pre-scission neutron multiplicity has been established as an important tool to study fission time scale in heavy ion-induced fusion-fission reactions [1]. In recent years, several experiments have been performed which ascertains that pre-scission neutron multiplicities are more than the same predicted from the standard statistical model. The excess neutron emission could be attributed to the dynamical time delay in fission process. Thus, the dynamical evolution of fission need to be incorporated in the theoretical calculation to address this problem properly. Here we report measurement of neutron multiplicities in coincidence with fission from the compound nucleus (CN) $^{203}$Bi, formed in the reaction $^{19}$F+$^{184}$W, at beam energies ($E_{\rm lab}$) near the Coulomb barrier. Evaporation residue (ER) excitation function and ER-gated CN angular momentum distribution for this system were reported earlier [2, 3].

The experiment was performed at the 15UD Pelletron accelerator facility of the Inter University Accelerator Centre (IUAC), New Delhi. A pulsed $^{19}$F beam with 250 ns pulse separation and ∼1 ns pulse width was bombarded onto a 210 $\mu$g/cm$^2$ $^{184}$W target [4] on a 110 $\mu$g/cm$^2$ $^{\rm nat}$C backing. Measurements were carried out at $E_{\rm lab}$ = 89.8, 99.8, 109.8, and 119.8 MeV (energy at the half thickness of the target). Two silicon detectors were mounted at ±10° with respect to the beam direction in plane and at a distance of 70.0 cm from the target for monitoring beam flux and positioning the beam at the centre of the target.

Two multi-wire proportional counters (MWPCs) [5] of active area 20×10 cm$^2$ were mounted on the two rotating arms inside the scattering chamber. The MWPCs were kept at folding angles to record the complimentary fission fragments (FFs) in coincidence. The forward detector (MWPC1) was centered at polar angle ($\theta$) = 60.8° (azimuthal angle, $\phi$ = 90°) and the backward detector (MWPC2) was centered at $\theta$ = 88° ($\phi$ = 270°). The shortest distances to MWPC1 and MWPC2 from the target were 55.9 cm and 39.3 cm, respectively. The two MWPCs were operated with isobutane gas at a pressure of 3.0 mbar. Position information of the FFs were obtained from the delay-line readout of the wire planes. The fast timing signals from the anodes of the two MWPCs were used to obtain the FF time of flight (TOF) with respect to the beam pulse.

Neutrons emitted during the reaction were detected in coincidence with fission events by four NE213 organic liquid scintillator detectors (127 mm diameter × 127 mm thickness). The detectors were placed outside the scattering chamber at a distance of 103.5 cm from the target. These detectors were kept at angles of 30°, 60°, 90° and 120° with respect to the beam direction. TOF signals were recorded for the four neutron detectors.

A fast coincidence between any of the anode

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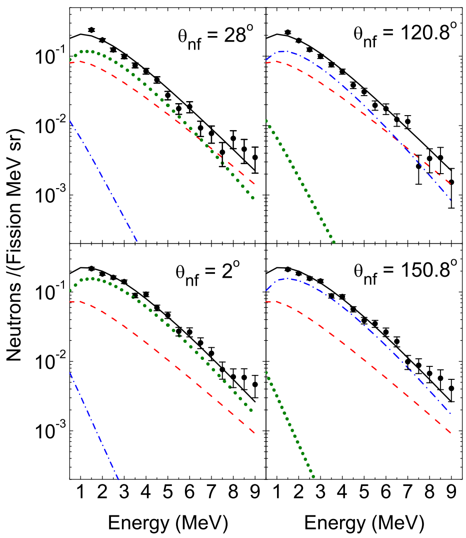


FIG. 1: Differential neutron yield measured in different neutron detectors in coincidence with fission fragments at $E_{\rm lab}$ = 100 MeV. $\theta_{\rm nf}$ is the mean angle between the neutron detector and the MWPC. Symbols denote experimental data. Contributions from pre-scission (dashed line) and post-scission (dotted line for one FF and dot-dashed line for the complimentary FF) neutrons are also indicated. The solid line is the sum of the three components.

signals and the radio frequency (RF) pulse was used as the master trigger for data acquisition system. IUAC's in-house data acquiring software CANDLE [6] was employed to record list mode data while analysis was performed with ROOT [7].

Neutrons were discriminated from $\gamma$-rays with the help of TOF and pulse shape discrimination (PSD) based on the zero-crossing technique. The prompt $\gamma$-ray in TOF spectrum was used for calibrating time in the TOF spectrum. Angular spread of FFs was restricted to $\pm 5^\circ$ in $\theta$ on each MWPC. Finally, the TOF of neutrons were converted to neutron energy spectrum with energy bins of 500 keV for each detector. Detection efficiency of the neutron detectors at different energies were taken from Ref. [8]. Extracted neutron multiplicities at CN excitation energy ($E^*$) of 64.5 MeV are shown in Fig. 1.

Neutron multiplicities consist of contributions from three neutron emitting sources, viz. CN and the two fragments. Three moving sources were considered while fitting experimental neutron energy spectra to obtain pre-scission ($M_{\rm pre}$) and post-scission ($M_{\rm post}$) neutron multiplicities. The $M_{\rm pre}$ and $M_{\rm post}$ values as a function of $E^*$ are plotted in Fig. 2. The detailed statistical model [9] analysis is under process.

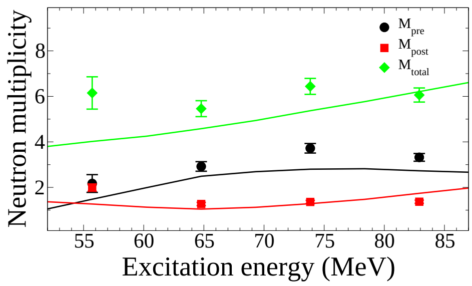


FIG. 2: Neutron multiplicities as a function of $E^*$. Solid lines are results obtained from statistical model calculation.

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