Fission Dynamics Study of Heavy and Super-heavy Nuclei through Neutron Multiplicity and Mass Distribution Measurements

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In this talk I will be presenting the results of the first few measurements with the National Array of Neutron Detectors (NAND) facility installed at Inter University Accelerator Center (IUAC), New Delhi. The summary of the results are given below:

Binary fragmentation of the near super-heavy compound nucleus ^{256}Rf has been studied through the reaction ^{48}Ti + ^{208}Pb at a bombarding energy well above the Coulomb barrier. For a better understanding of its reaction dynamics, the mass distribution, mass-energy distribution and mass-angle distribution of the fission fragments produced from ^{256}Rf have been investigated thoroughly. The masses and kinetic energies of the fission fragments were reconstructed event-by-event from their measured velocities and emission angles. From the mass-energy analysis, a sizeable contribution from the asymmetric fission was observed on the edges of symmetric mass distribution. Evidence of asymmetric fission was also clued from the observed correlation between the masses and emission angles of the fission fragments. Contribution of the quasi-fission products has also been estimated by performing the theoretical di-nuclear system calculations

In the second part of the measurements, the neutron emission in coincidence with the fragments have been investigated for the ^{48}Ti + ^{208}Pb reaction populating the near superheavy compound nucleus ^{256}Rf at an excitation energy of 57.4 MeV. The National Array of Neutron Detectors facility is used for a precise determination of the prescission (M^{pre}_n) and postscission (M^{post}_n) neutron multiplicities as a function of fission observables. A moving source fitting procedure has been adopted to deduce M^{pre}_n and M^{post}_n. The variation of M^{pre}_n with the mass-split and total kinetic energy (TKE) of the fission fragments have been studied to understand the fission dynamics of ^{256}Rf. It is observed that M^{pre}_n increases from the value of 1.66 ± 0.07 to 2.23 ± 0.07 with transition from the asymmetric to the symmetric mass region. M^{pre}_n is also found to increase with the decrease in TKE, which is probably due to the neutron emission during the acceleration time of the fission fragments in this heavy system. The experimental results for neutron multiplicity have also been compared with the theoretical predictions from the statistical model calculations. From this comparison, the value of reduced dissipation strength for the ^{256}Rf nucleus is found to be $(13.0 \pm 1.0) \times 10^{21}\ s^{-1}$ and a fission delay time of $(67.3+5.3\ -3.9) \times 10^{-21}$ s has also been estimated. For the spontaneous fission of ^{256}Rf, the extracted average neutron multiplicity M^{sf}_n is found to be 4.4 ± 1.0 which is in good agreement with the recently reported value for the ^{258,260}Rf isotope.

The presence of QF processes has been confirmed through the MD, MED, and MAD analyses of the fission fragments produced in the 48Ti + 208Pb reaction populating near superheavy CN ^{256}Rf at an excitation energy of 57.4 MeV. In the present results, the dependence of neutron multiplicities on the fission observables (mass and TKE) has been investigated to further understand the fission dynamics of ^{256}Rf. Besides the neutron multiplicity measurements, the experimental neutron angular distributions have been measured which indicate the kinematic focusing of emitted neutrons in the direction of accelerated fragments. The analysis of mass-split and TKE dependence of M^{pre}_n also reveals nonnegligible contributions of QF processes along with the FF processes. M^{pre}_n is observed to increase while moving from asymmetric to symmetric mass region, which is due to the different timescales of the FF and QF processes. Mpre n is found to increase with decreasing TKE, a trend which the recoil and kinematics corrections can only reinforce. This trend is mainly an artifact of neutron emission during acceleration of the fragments, which are identified as the prescission component in the fits. Increasing thermal energy by reducing the TKE results in even shorter lifetimes and thereby increases the neutron emission during acceleration. Additionally, the dependence of neutron multiplicities on mass split has been compared with the outcomes based on the energy balance equation and are found to be consistent with each other within a systematic uncertainty of 5%. Statistical model calculations show that most of the prescission neutrons are emitted during the saddle-to-scission transition of the compound nuclei for the symmetric fission. The strength of the reduced dissipation coefficient to account for the experimentally measured multiplicity of prescission neutrons is found to be $(13.0 \pm 1.0) \times 10^{21}\ s^{-1}$. Alternately, the experimental prescission neutron multiplicity for the symmetric mass cut is also reproduced by introducing a delay time of $(67.3+5.3\ -3.9) \times 10^{-21}$ s in the saddle-to-scission stage of fission. No attempt is, however, made in the present work to reproduce the prescission neutron multiplicities obtained with asymmetric mass cut since the statistical model analysis is limited to symmetric fission. The average neutron multiplicity (M^{sf}_n) from the spontaneous fission of ^{256}Rf is also extracted from the measured total neutron multiplicity for the symmetric mass split and found to be 4.4 ± 1.0, which is compatible with the recently published data for ^{258,260}Rf isotopes and the previously reported findings for the superheavy nuclei. In future, we plan to extend these measurements over wider range of excitation energies in order to estimate the contributions of QF and FF processes quantitatively.

In another study we have also measured pre- and post-scission neutron multiplicities (M^{pre} and M_{post}) from two compound nuclei, namely ^{192,202}Po populated by ^{48}Ti + ^{144,154}Sm systems at 72 MeV of excitation energy. Statistical model analysis has been performed for ^{48}Ti + ^{144,154}Sm along with already existing data for ^{12}C + ^{194}Pt and ^{18}O + ^{192}Os covering compound nuclei of Po (^{192,202,206,210}Po) with neutron number N_C = 108, 118, 122, and 126 respectively. Variation of experimental Mpre with N/Z of the compound nucleus does not show any special feature at neutron shell closure (N_C = 126) at compound nucleus excitation energy around 72 MeV considered here. In particular, it is found that dissipation alone is unable to reproduce the experimental Mpre for ^{192}Po, and the role of entrance channel dynamics should be considered in future works.

It is also planned to study the role of entrance channel effects in the reaction dynamics to form super-heavy nuclei.

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