Past, present, and future of nuclear astrophysics research at IUAC

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IUAC has various types of particle accelerators delivering beams of energies in the range of a few 10s of keVs to a few 100s of MeVs. Topics relevant to nuclear astrophysics have been studied using experimental facilities at IUAC, especially in low-mass regions using surrogate methods. The studies on nuclear fission throw light into the element synthesis in mass 100 - 200 amu region. The studies carried out in nuclei away from the line of stability are of topmost importance. Highlights of those research activities are described here. The forthcoming high-current injector facility with an ECR ion source at IUAC opens up a new research horizon. A brief description of the upcoming facility has also been given.

1. Introduction

Inter-University Accelerator Centre (IUAC), New Delhi has particle accelerators of different types delivering beams of energies varying from a few 10s of keVs to a few 100s of MeVs. The 15UD pelletron accelerator and the superconducting linear accelerator(LINAC) are the two major accelerators that are used for nuclear physics experiments at IUAC. Some of the nuclear reaction studies carried out using these accelerators are significant from the nuclear astrophysics point of view.

2. Research highlights

It has been well established that breakup reaction influences the fusion probability for reactions involving loosely bound nuclei. Verma et al. [1] carried out an extensive study of ^{7}Be + ^{9}Be and ^{7}Li + ^{9}Be systems at beam energies in the range of 15 - 30 MeV. The elastic and quasi-elastic angular distribution was measured for these reactions. The optical model analysis of these data was carried out to extract the optical model parameters. The measured yield of alphas and tritons was found to be much larger at lower angles owing to the breakup contribution. In another work ^{12}C+ ^{7}Li reaction was used as a surrogate method to calculate the astrophysical S factor for the ^{12}C(α, γ) reaction at Gamow energy [2]. The angular distribution of deuterium was measured producing ^{16}O at different discrete states. The data was analyzed using continuum discretized coupled channel-coupled reaction channel (CDCC-CRC) calculations to extract the astrophysical S factor.

Most of the elements heavier than iron are produced by r-processes. Nuclear fission plays a major role in determining the end point of r-processes. Moreover, the fission cross-section, mass and charge distribution of the fragments, etc determines the elemental availability in the 100 - 200 amu mass region. A complete and comprehensive model to predict the fission process is still lacking. Recent developments in this direction have been reported by Sadukhan et al. [3] by comparing the theoretical model predictions based on density function theory and experimental data. In this context, we have carried out a few studies on the multi-modal fission at actinides and pre-lead mass region [4–6]. The mass-gated pre-scission neutron multiplicity data of ^{227}Pa was analyzed with the semi-empirical formalism called GEF. The average neutron multiplicity for the symmetric mass split was found to be lower than that for the symmetric mass split at low excitation energy, which a clear indication of multi-chance fission. The asymmetric fission in neutron-deficient isotopes in the Mercury mass region is relatively a new

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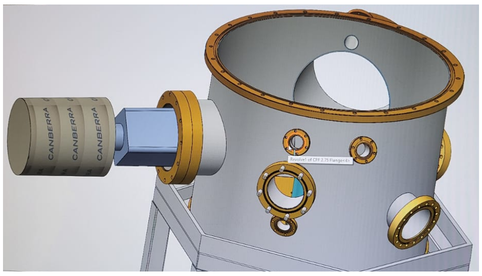

FIG. 1: Artists view of the chamber fabricated for the upcoming facility.

phenomenon[5, 6]. From an astrophysics point of view, the production of elements away from the line of stability is very crucial. Gupta et al., [5] have found a weak flattening of the total kinetic energy distribution with the mass of the fragments for ^{198}Po at $\sim$ 35 MeV excitation energy suggesting asymmetric mass split. In another experiment, the fission of neutron deficient ^{186}Pt has been studied at different excitation energies. The measured mass distribution showed the clear signature of asymmetric mass split at lower excitation energies. In addition, through the multiple Gaussian fit to the mass distribution, the influence of quadrupole-deformed shell gaps in the fission process was demonstrated.

3. Details of upcoming facility

The IUAC High Current Injector (HCI) system [7], to be coupled to LINAC very shortly will give many beams which are presently not possible with Pelletron. The HCI facility at IUAC has a high-temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) for beam production. It has Radio Frequency Quadrupoles (RFQs) and Drift Tube LINACs (DTLs) to accelerate the beams up to $\sim 1.8 MeV/A$ for heavy ions having A/q $\leq$ 6. The initial commissioning of the HCI facility has been recently completed and the final tuning of various beam line components is being done to deliver the HCI beam to the experimental facilities. The beam from HCI directly can be used for nuclear physics research in the low energy region in the range of 0.5 to 1.8 MeV/ nucleon. A 60 cm diameter stainless steel scattering chamber has been fabricated to carry out experiments with these beams Fig. 1. This facility will have a rotatable target ladder to hold the beam-viewing quartz and the targets. The target ladder can also be moved up and down as per the requirement. To have an angular distribution measurement, there will be two remotely controllable rotatable detector arms on which the charged particle detectors will be placed. An in-vacuum target transfer facility incorporated will enable quit transfer of irradiated samples for offline gamma ray measurements. To tackle the heating up of the target due to the high beam current, provision for target cooling using LN2 or chilled water supply is also provided. The beam will be dumped in a Tantalum Faraday cup properly shielded with borated paraffin and lead. There is provision to put a high purity germanium clover detector at 120 degrees w.r.t. the beam direction. This will enable particle-gamma coincidence measurements. The chamber has been fabricated and successfully leak-tested. The primary motive of this facility is the study of nuclear reactions in the low-mass regions. The facility will be commissioned shortly.

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