Indian National Gamma Array at IUAC

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Abstract. Indian National Gamma Array (INGA) is a 4π multi-detector gamma-ray spectrometer based on twenty four Compton-suppressed Clover Germanium detectors with a total photo peak efficiency ~ 5 %. INGA was designed to perform high resolution gamma-ray spectroscopy to study nuclear structure at high spins with stable ion beams at Inter University Accelerator Centre (IUAC). Description of the facility and performance of the array are presented in this paper. Since its commissioning, a number of nuclear spectroscopic investigations have been carried out using the array.

1. Introduction

The γ-ray spectroscopic study of nuclei offers an opportunity to explore a rich variety of inter-nucleonic interactions. By studying nuclear structure at high spins one can significantly extend knowledge of nucleon-nucleon interactions and collective excitation modes. The availability of heavy ion accelerators coupled to high efficiency Germanium (Ge) detector arrays has enabled study of nuclear phenomena like Magnetic rotation, Anti-Magnetic rotation, Chirality, etc. In India, a large array of germanium detectors called Indian National Gamma Array has been set up by pooling resources from Tata Institute of Fundamental Research, Bhabha Atomic Research Centre, Saha Institute of Nuclear Physics, Variable Energy Cyclotron Centre, UGC-DAE-Consortium for Scientific Research, IUAC and Universities. This paper describes the INGA facility [1] developed in IUAC, New Delhi and presents its performance.

2. Facility

The INGA consists of in-house developed sub-systems namely, mechanical support structure, high voltage power supplies, front-end electronics required for analogue and digital processing and an automatic liquid nitrogen filling system. The facility is based on twenty four Compton suppressed Clover Ge detectors [2] yielding a total photopeak efficiency of ~ 5 %. Clover

detectors were mounted in Anti-Compton Shields (ACS) at five different angles [3] in two support structures movable along rail as shown in Fig. 1. Fig. 2 depicts inside view of the array with beam port that holds the glass scattering chamber. Schematic of target chamber along with cross section of detectors is given in Fig. 3. The HYbrid Recoil mass Analyser (HYRA) [4] will be combined with INGA in future for carrying out evaporation residue gated nuclear structure studies.
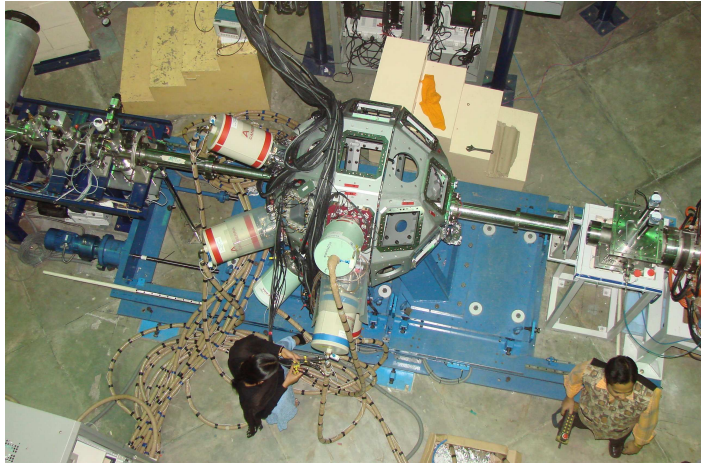

Figure 1. Top view of INGA with suppressed Clover Ge detectors mounted on movable support structure on rails.
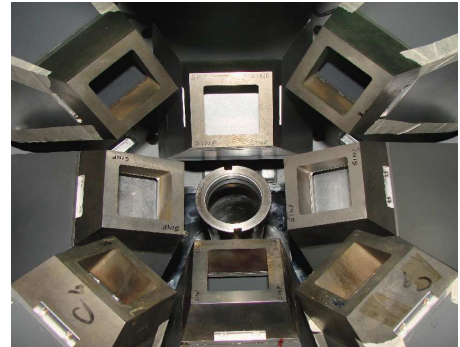

Figure 2. Inside view of INGA with beam port of scattering chamber.

2.1. Detector bias supplies

For ease of maintenance and to conserve resources, custom designed bias supplies [5] of ACS, Clover detectors, preamplifier power supplies, and preamplifiers for ACS were fabricated in-house. All power supplies have protection against over-current and output short-circuits. Double
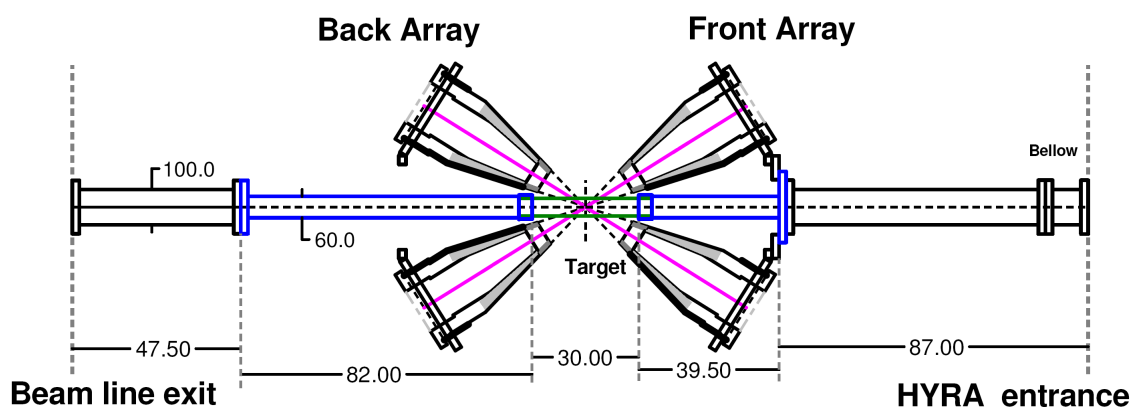
Figure 3. Schematic diagram of beamline with cross section of scattering chamber and detectors. The diameters of chamber are given in mm while the lengths are given in cm.
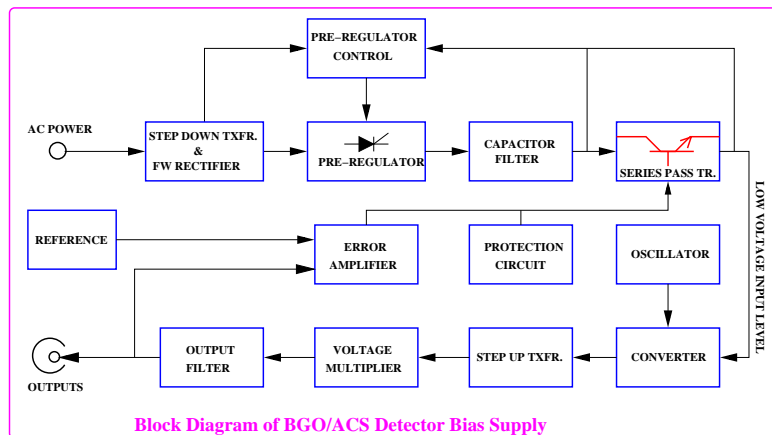
**Figure 4.** Block diagram of 3 kV power supply for biasing ACS.
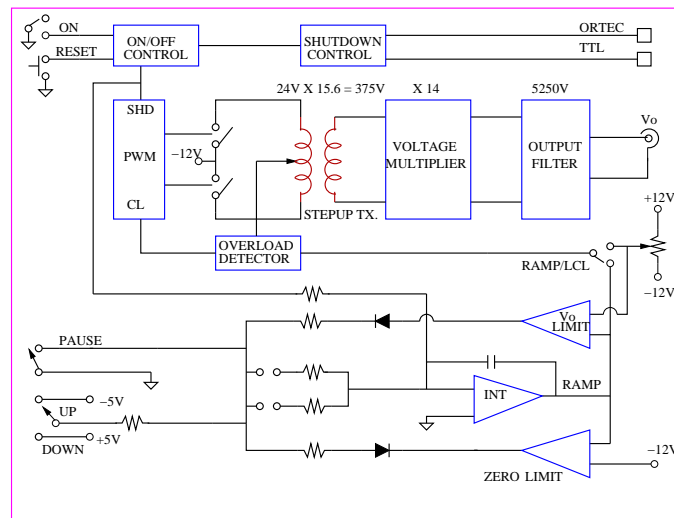
Figure 5. Block diagram of 5 kV high voltage power supply for biasing Clover Ge detector.

width NIM module power supply was made for biasing ACS, which work on switched mode amplitude modulation technique operating at 24 kHz and provide extremely stable, low noise high voltage output upto $\pm$ 3 kV. Block diagram of the power supply is shown in Fig. 4.

Single width NIM module power supplies, which work on switched mode technique and provide high voltage upto $\pm$ 5 kV, 50 μA generated by Cockroft-Walton multiplier, were made to bias Clovers. The power supply has an automatic output ramping facility where output always starts at zero volt and then ramps up to the value set by front panel potentiometer at the chosen ramping rate (5 kV in 30 minutes). Block diagram of the power supply is given in Fig. 5.

2.2. Electronics and Data acquisition system

IUAC Clover electronic modules [6] were used for processing energy and time signals from Clover detectors and ACS. Employing such a compact custom made module for processing Clover signals has avoided use of bulk commercial modules and associated extensive cabling. Energy signals
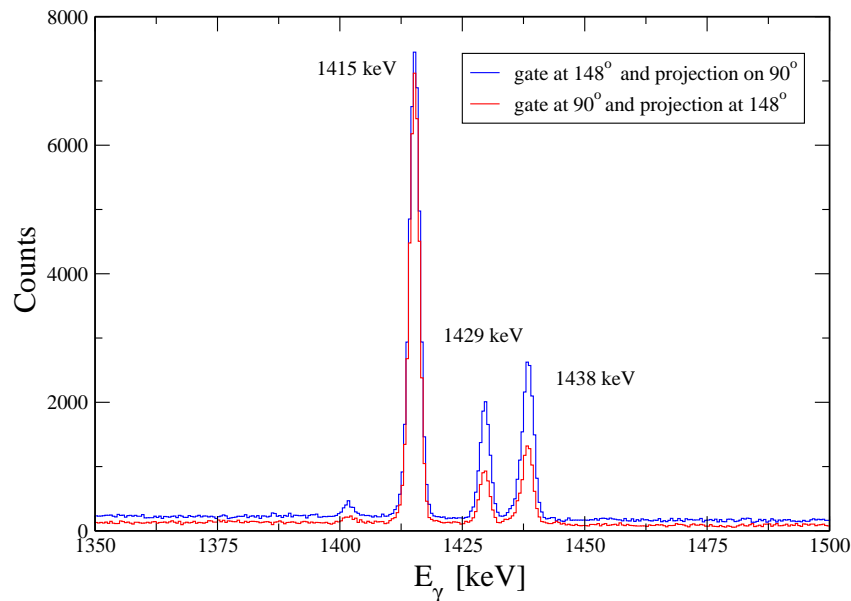
Figure 6. The 438 keV gated spectrum from ^{107}In indicates type (dipole or quadrupole) of γ transition by DCO ratio method.

from Clovers were digitised using 14-bit 8-channel CAMAC AD814 ADC [7]. The TDC's (7186) were used to record time information from all Clovers in each event. List mode data was collected using the software CANDLE [8]. Custom designed Global Event-identifier Module (GEM) [9] generated the event trigger for data collection based on multiplicity (γ or $\gamma\gamma$ or $\gamma\gamma\gamma$) of each event. The use of this module avoided usage of commercial electronics required for generating event trigger logic and significantly increased data throughput in data acquisition system, by reading only the ADC and TDC's having non-zero data for each event. As data acquisition using GEM records global time reference in list mode data, one can acquire multi strobe data which will record prompt gammas along with recoil nuclei separated by HYRA, enabling study of nuclear isomers in μs range by recoil decay tagging experiments in IUAC.

3. Performance of INGA

In a typical fusion evaporation reaction, compound nucleus is formed in a state with its angular momentum vector perpendicular to the axis defined by direction of beam. Evaporation of particles subsequently causes some smearing in its orientation, but even then the nucleus retains a high degree of orientation. When a nucleus in such a state emits γ-radiation, its angular distribution depend on the multipolarity of transition which can be measured by Directional correlation of oriented nuclei (DCO) ratio method [10]. As Clovers were mounted at five different angles in INGA, data from detectors at forward or backward angle (32° or 148°) and 90° with respect to beam direction can be used for DCO ratio measurement. High spin states of ^{107}In were investigated [11] using reaction ^{94}Mo(^{16}O,p2n) at a beam energy of 70 MeV and beam was delivered by 15UD Pelletron accelerator at IUAC [12]. Fig. 6 shows a gated spectrum with gate on 438 keV (E2) transition of ^{107}In from backward detector in coincidence with detectors at 90° and vice versa. The spectra clearly indicates the type of transition (dipole or quadrupole) by differing or same intensities.

Special geometry of Clover detector allows it to be used as four-fold Compton polarimeter [2] and to measure the linear polarization of γ-rays. The $\gamma\gamma$ coincidence data from the above
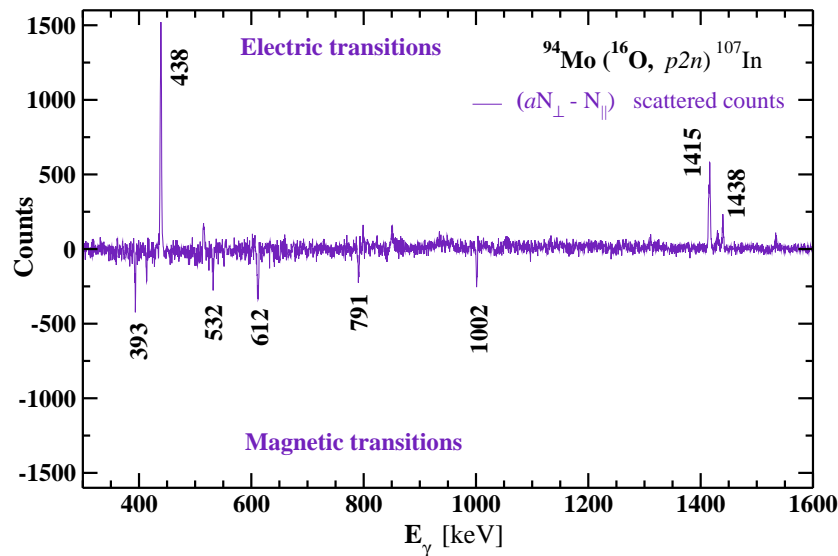
Figure 7. The polarisation spectrum from the ground state band transition gated difference spectrum of perpendicular and parallel scatterings in Clovers at 90° with respect to beam.

mentioned reaction were sorted offline using Ingasort [13] to produce an angle dependent E_γ-E_γ 4k×4k matrix with data from detectors at 90° in one axis and rest of the detectors in other axis. Fig. 7 shows the normalised difference spectra in perpendicular and parallel scattering of γ-transitions in Clovers at 90° with coincidence in γ-transitions of energies 150, 204, 393, 438, 1415, 1429, 1438 keV of ^{107}In detected by the array. The spectrum clearly indicates electric and magnetic nature of γ-transition, by positive and negative peaks respectively.

The study of isomers in nuclei helps to identify active quasiparticle configurations of nuclear levels. In one of the experiments ^{139}Pr [14] was populated using reaction ^{130}Te(^{14}N, 5n) at 75 MeV pulsed beam at 4 MHz. As time information from all Clovers were recorded for each event, both prompt and delayed events upto 400 ns can be extracted, after using the calibration of individual TDC channels in offline analysis, for study of isomers. Fig. 8. gives the TAC spectra generated (with respect to pulsed beam) for prompt gamma (900 keV) and delayed γ-transition of isomer (708 keV with $T_{1/2} = 36$ ns) of ^{139}Pr.

The array was used to study different aspects of nuclear structure. Evolution of nuclear shape with increase in angular momentum in ^{75}Kr[15] was done by measuring transitional quadrupole moment. A decreasing trend of B(M1) strengths with increasing spin deduced for the $\Delta I=1$ band indicated the presence of a shears mechanism in ^{107}In [11]. Effect of nuclear structure in the dynamical evolution of fissioning nucleus [16] was studied by measuring mass distribution of fission fragments through $\gamma\gamma$ coincidence.

4. Summary
The INGA facility in beam hall II at IUAC allows a high resolution γ-ray spectroscopy with total photopeak efficiency of ~ 5 %. The combination of recoil spectrometer, HYRA coupled with the multi-detector array INGA using stable beam from Pelletron and LINAC will provide new research opportunities in the fields of astrophysics, nuclear structure, and reactions.
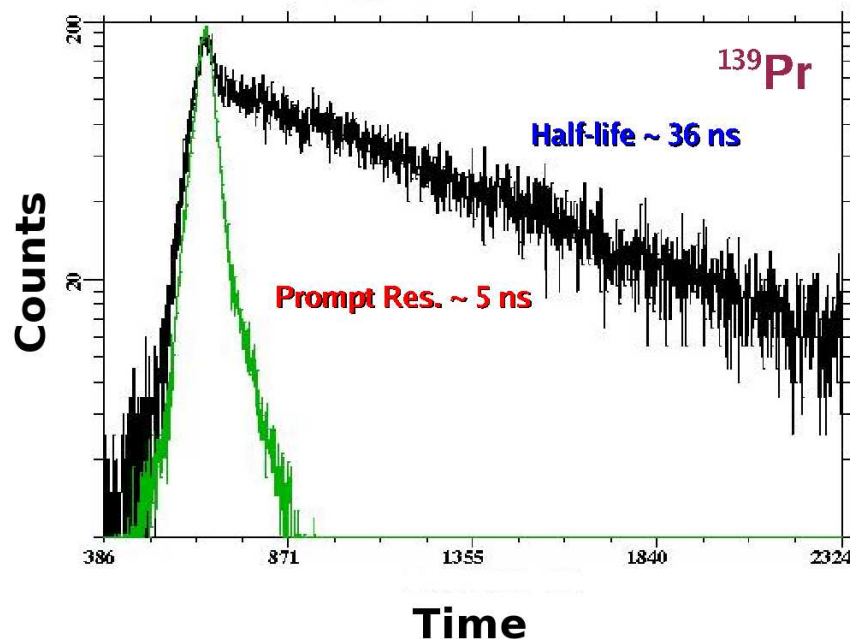
Figure 8. The TAC spectra generated (with respect to pulsed beam) for 900 keV prompt γ-transition and 36 ns isomer gamma (708 keV) of ^{139}Pr populated in fusion evaporation reaction.

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