Chapter 4

EXPERIMENTAL FACILITIES IN BEAM HALL

4.1 Scattering chamber and neutron array

R. Prajapati, T. Bar, K. Rani, Mohit Kumar, N. Saneesh, Golda K. S., A. Jhingan and P. Sugathan*

*till May, 2024

4.1.1 Operation

Both the General Purpose Scattering Chamber (GPSC) and the National Array of Neutron Detectors (NAND) facilities have been intensively used for nuclear reaction experiments throughout the year. The GPSC has been used for materials science research activities also. The following table summarises the details of the nuclear physics experiments carried out in the GPSC and the NAND using Pelletron beams in the last year.

Table 4.1: Details of nuclear physics experiments carried out using GPSC and NAND facilities.

Sl. No.	User/Affiliation	Title of the experiment	Beam	No. of shifts
1	Mr. Lakhyajit Sarma, Guwahati University	Studies on fusion inhibition by measurements of complete, incomplete fusion and fission cross sections	^{12}N	15
2	Mr. Vikas Mundlia, Kurukshetra University	Fusion-fission studies in medium mass region through the mass and angular distribution of fission fragments	^{28}Si, ^{11}B	18
3	Mr. R. Yatoo, Thapar Institute of Engineering & Technology	Quasielastic and transfer reaction studies around the Coulomb barrier	^{28}Si	18
4	Dr. A. Yadav, Amity University of Science and Technology	Simultaneous measurement of elastic, inelastic, transfer events to understand the reaction mechanism	^{16}O, ^{35}Cl	21
5	Mr. Gobind Ram, Lucknow University	Disentangling the role of different entrance channels on the transfer reaction mechanism	^{14}N	15

We have used NAND for a couple of experiments using standard neutron sources in addition to scheduled user experiments. One such experiment was carried out to study the response function of the BC501 neutron detector using γ-ray tagged neutron time-of-flight method. This is an initiative to extract the neutron multiplicity distribution from the experimental observables using the Monte-Carlo technique. The neutrons emitted by a ^{252}Cf spontaneous fission neutron source has been detected with the neutron detectors of the NAND array in coincidence with a small BaF_2 detector as the start detector. The time-of-flight, light output pulse height and pulse shape distribution have been recorded in event-by-event mode. A Monte-Carlo simulation using GEANT4 is being done to compare with the experimental measurements. This work is carried out in collaboration with a group from the BARC.

4.1.2 Maintenance

(with support from Chandra Pal, Ashok Kothari, P. Barua, Prem Kumar Verma, S. K. Suman, Rajesh Kumar, Mamta Jain and Arti Gupta)

Routine maintenance servicing of the high-voltage power supplies and signal processing electronics has been carried out. A thorough performance testing of the modules has been carried out after the servicing to ensure satisfactory performance.

The software and operating system of the computer used for VME-based DAQ system of NAND has been upgraded during this period. A CAMAC-based DAQ, with LAMPS acquisition software was used in NAND for routine testing of the detector performances and user experiments with fewer numbers of detectors. The computer used for this DAQ crashed during one such operation and later it was found that it was non-repairable. FREEDOM, the old data acquisition software of IUAC has been installed in a new computer with necessary drivers to revamp the CAMAC DAQ. The system has been presently used for routine testing of detectors.

4.1.3 New developments

Repairing of deteriorated neutron detectors

(In collaboration with M. B. Chaterjee, Saha Institute of Nuclear Physics, Kolkata)

The National Array of Neutron Detectors (NAND) facility consists of one hundred organic liquid scintillators mounted on a geodesic dome structure. Since 2013, the facility has been used for various experiments. While most of the BC501A detectors in the NAND array are functioning as expected for studying nuclear fission and related phenomena, leakage of organic liquid has been observed in some of the neutron detectors. The loss of detector liquid leads to inferior performance of the detector. These detectors have shown reduction in light output, lower counting efficiency and poorer neutron-γ discrimination. Higher levels of noise have also been observed in these detectors, which could be due to deterioration in the light sealing. To address these issues, faulty detectors have been inspected by dismantling the cylindrical liquid container from the photo multiplier tube (PMT). The liquid level in the container, bubble formation, quality of the coupling grease, performance of PMT, and the coupling of the capillary tube to the cylindrical cell have been compared with a good-quality detector. From careful investigation, it has been observed that the gradual degradation of the seal applied at the joint between the capillary tube and the cylindrical cell led to the leak and the resultant decrease in the volume of the scintillation liquid in the detector cell.

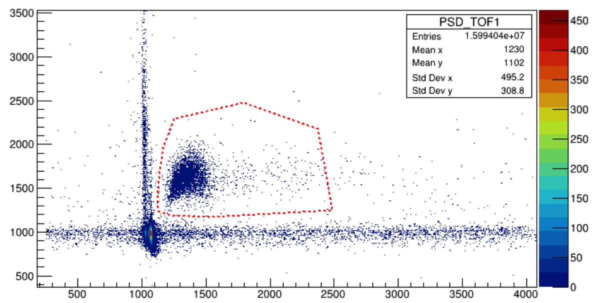

Figure 4.1: Scatter plot of neutron-γ discrimination versus TOF for one of the repaired detectors.

The defective liquid cells and PMTs have been replaced with good-quality cells and PMTs. The PMTs have been shielded from stray electromagnetic fields using a μ-metal shield. The performance of the re-coupled detectors, in terms of light output, neutron-γ discrimination, and counting efficiency have been evaluated by comparing them with a good-quality detector. Fig. 4.1 shows the 2D correlation of neutron-γ discrimination with particle time of flight (TOF) for the refurbished detector.

Scattering chamber for low-energy nuclear physics research

(With support from Naresh Kumar, G. K. Chaudhari, S. K. Saini, A. Kothari and P. Barua)

A new experimental facility is being developed in beam hall I to carry out low-energy nuclear physics research relevant to nuclear astrophysics. A cylindrical scattering chamber of 45 cm height and 60 cm diameter is being fabricated at IUAC mechanical workshop for this facility. This stainless steel chamber will have two rotatable detector platforms with remote control facilities for angular distribution measurements. The target ladder will have facility for linear and rotary motion which can also be controlled remotely.

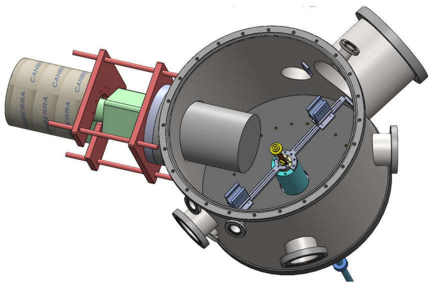

Figure 4.2: Engineering drawing of the scattering chamber.

In order to effectuate particle gamma coincidence measurements, a re-entrant cup is provided that can hold a Clover HPGe detector. A large exit port is provided in the chamber to facilitate a large flight path for ToF measurements, in the future. The same can be used for accommodating large area annular PPAC for evaporation residue detection. Considering the high intensity of the beam from HCI, target cooling arrangement is provided in the chamber with chilled-water / liquid nitrogen. Fig. 4.2 shows the 3D engineering drawing of the scattering chamber with a clover detector mounted to it. The chamber has been vacuum tested satisfactorily. The facility is expected to be commissioned very soon.

4.1.4 Relative efficiency calibration of BC501A neutron detectors

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Neutron scattering cross sections play a crucial role in various applications, including nuclear energy production, reactor design and the development of nuclear reaction models. Accurate measurements of these reactions depend on precise neutron detection, which requires well-calibrated detector efficiency. Any uncertainty in detector efficiency directly impacts the reliability of measured cross sections, making efficiency calibration an essential aspect of experimental nuclear physics. In the present work, we report on the relative efficiency calibration of BC501A liquid scintillation neutron detectors arranged in the NAND neutron detector array at IUAC. The efficiency measurement was carried out using the time-of-flight (TOF) technique with a detection threshold of approximately 2 MeV, enabling a focus on higher energy neutrons relevant to pre-equilibrium reactions.

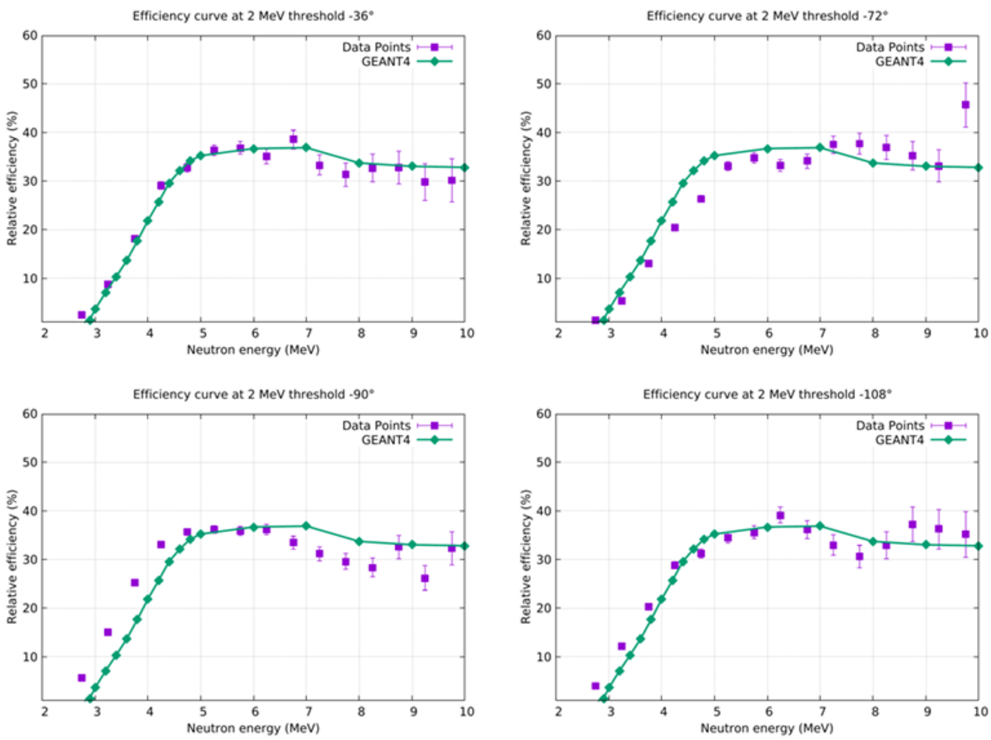

Figure 4.3: Measured and simulated efficiency curves for four neutron detectors.

GEANT4-based Monte Carlo simulations were employed to supplement and validate the experimental efficiency measurements. These simulations take into account various factors influencing neutron detection, including energy-dependent interactions, light output response, and threshold effects. Fig. 4.3 presents the efficiency measurement data along with GEANT4 simulation results for four detectors placed at 36°, 72°, 90° and 108° with respect to the direction of the beam.

The comparison between simulated and experimental efficiency values shows appreciably good agreement, establishing a reliable efficiency curve and ensuring consistency between theoretical and measured results. The appreciably good agreement observed validates the accuracy of the calibration procedure and enhances confidence in neutron detection at higher energies.

4.2 Gamma detector arrays: GDA and INGA

Yashraj, Indu Bala, Arti Gupta, U. S. Ghosh, Khamosh Yadav and R.P. Singh

4.2.1 Maintenance activities

Routine maintenance of the Indian National Gamma Array (INGA) electronics, vacuum system, detectors and LN2 system was carried out.

4.2.1.1 FET Replacement of a Clover detector

Drift in the signal of one of the crystals of a Clover detector was observed; the problem was traced to the FET at the input stage of the preamplifier. By opening the preamplifier section and accessing the cryo-section after venting through dry nitrogen we could successfully replace the FET. The detector was then out-gassed. After the test no drift was observed and the energy resolution from the crystal was found to be satisfactory.

Table 4.2: List of experiments performed in INGA / GDA facilities.

Sl. No.	User/Affiliation	Title of the experiment	No. of shifts	Set up
1	Prof. G. de. Angelis LNL, Italy	Coherent contribution of protons and neutrons to octupole collectivity; ^{64}Zn	18	INGA + $LaBr_3$
2	Dr. Vinod Kumar Lucknow University	Spectroscopic Study of ^{99}Nb and ^{99,101}Mo	12	INGA
3	Ms. Rozina Rahaman IIEST, Shibpur	Spectroscopic study of a few $1f_{7/2}$ Mn Isotopes	27	INGA
4	Ms. Madhu IIT Roorkee, Roorkee	High-spin spectroscopy of neutron deficient TI and Ir isotopes	12	INGA + $LaBr_3$
5	Ms. Puja Hazari INMAS, New Delhi	Radioactive samples (^{64}Cu and ^{44}Sc) charaterization by gamma ray spectroscopy	Not applicable	INGA
6	Ms. Prerna Singh Rawat University of Delhi	Investigation of octupole collectivity and octupole $\Delta I = 3$ isomers in $A = 200$ region	30	INGA

4.2.2 New developments

4.2.2.1 BGO multiplicity filter testing with source

Indu Bala, U. S. Ghosh, Khamosh Yadav and R. P. Singh

We have integrated a BGO (Bismuth Germanate) multiplicity filter array consisting of 14 elements (7 on the top and 7 on the bottom) into the INGA setup. Due to the high atomic number (Z) of bismuth, BGO crystals exhibit excellent efficiency for γ-ray detection, making them highly suitable for measuring γ-ray multiplicities. By employing multiplicity tagging, we can selectively access different levels in the nuclear level scheme. For instance, tagging events with multiplicity 2 or 3 significantly suppresses Coulomb excitation and x-ray background, thereby yielding cleaner γ-ray spectra. Additionally, gating on higher multiplicities enhances the sensitivity for observing high-spin states in nuclei.

We have tested the performance of the BGO array using a ^{152}Eu source (Fig. 4.4) and successfully recorded multiplicity spectra, some optimization of the electronics would be required.

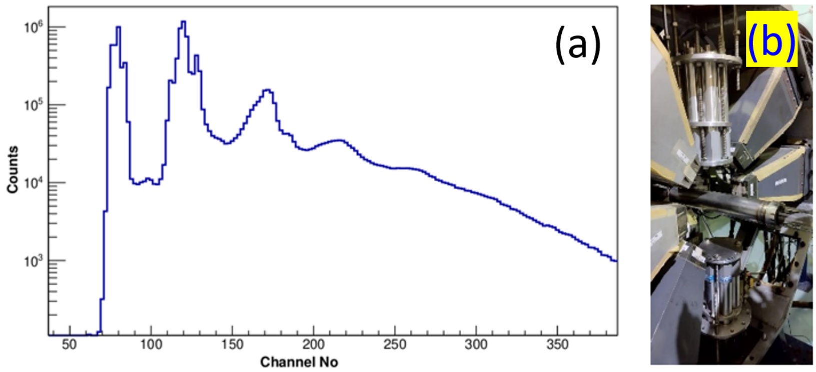

Figure 4.4: (a) Multiplicity spectra with BGO array for the ^{152}Eu source and (b) BGO multiplicity filter array of 14 elements mounted in the INGA array.

4.2.2.2 Simulation studies for $LaBr_3$ detectors

U. S. Ghosh, Yashraj, Indu Bala and R. P. Singh

Simulation using GEANT4 was carried out for 2″×2″ $LaBr_3$ detectors (Fig. 4.5) to extract the energy and time characteristics of these detectors. In the simulation ^{137}Cs and ^{60}Co radioactive sources were considered.

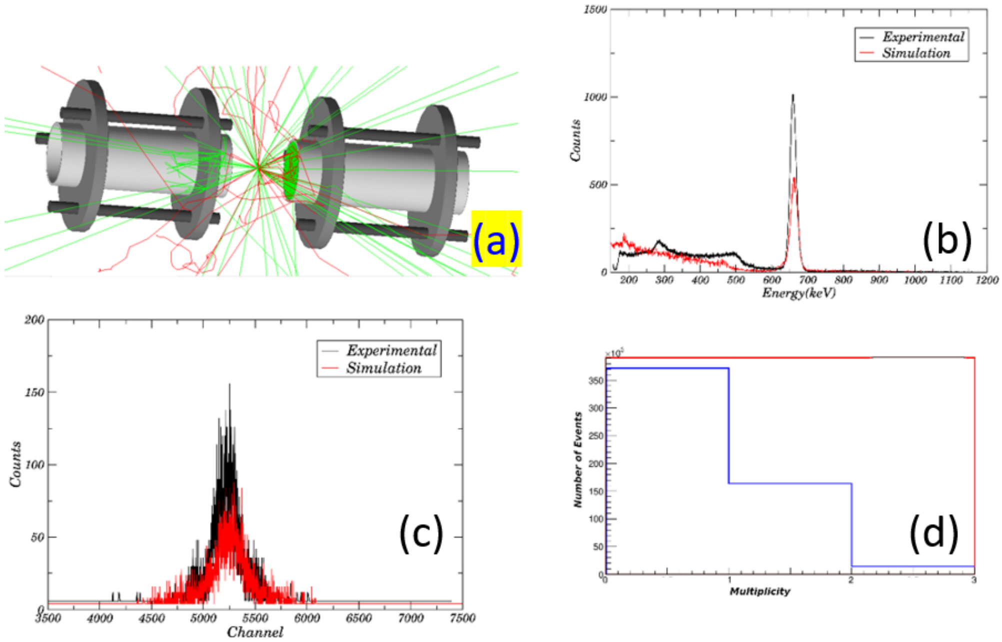

Figure 4.5: (a) Visualization of the Geant4 simulation geometry with a few representative events, (b) energy spectra of $LaBr_3$ detectors exposed to a ^{137}Cs source (c) TAC spectra for $LaBr_3$ detectors placed face to face with a separation of 11 cm and (d) multiplicity distribution of events detected by the two $LaBr_3$ detectors with a ^{60}Co source.

The detectors were considered enclosed in 0.5 mm thick aluminum casings placed in supporting structure consisting of iron plates and rods were positioned face to face with an 11 cm separation as seen in figure below. Energy spectrum for 137Cs is shown below The simulation incorporated key physical processes such as the photoelectric effect, Compton scattering and pair production, along with optical processes like light propagation and reflection. In the simulation, involving around 1 million events, we analyzed the energy spectra, Time-to-Amplitude Converter (TAC) spectrum and multiplicity distribution to provide a comprehensive assessment of the detectors performance.

4.2.2.3 Development of new electronics

Arti Gupta

A PMT active voltage divider was developed for the neutron detectors in the NAND setup. This divider provides PMT current on demand without any limitation on the maximum anode current. A 3 channel CFD and a 2 channel TAC units required for pelletron beam pulsing system was made and given to the beam pulsing group.

4.3 Recoil separators

4.3.1 Heavy Ion Reaction Analyzer

Gonika, J. Gehlot, Chandra Kumar, Alankar Singh, Rishabh Kumar, T. Varughese, S. Nath and N. Madhavan*

*till May 2024

Five user experiments were conducted using the HIRA facility, focusing on fusion, quasielastic and transfer measurements in intermediate mass systems. Additionally, three BTR2 (thesis) proposals involving HIRA were approved in the recently concluded AUC meeting (December 2024). These were prepared by investigators in collaboration with the HIRA-HYRA group. Two B.Sc. students also completed their summer training (June 2024) in the HIRA / HYRA lab under the supervision of group members. In the HIRA focal plane, the detection system was upgraded by installing a newly-fabricated deep ionization chamber.

Table 4.3: List of user experiments carried out in the HIRA beam line.

Sl. No.	User/Affiliation	Title of the experiment
1	Ms. Prameela K. Andhra University	ER cross-section measurements for the systems ^{16}O+^{138}Ba,^{124}Sn around the Coulomb barrier
2	Ms. Prameela K. Andhra University	ER cross-section measurements for the systems ^{30}Si+^{138}Ba,^{124}Sn around the Coulomb barrier
3	Ms. Anjali Merin Central University of Kerala	ER cross-section measurements for the systems ^{28,30}Si+^{142,150}Nd,^{124}Sn around the Coulomb barrier
4	Ms. Jinu K. Calicut University	Fusion and quasi-elastic measurements for the systems ^{16}O+^{170,172}Yb around the Coulomb barrier
5	Mr. Rajesh K. Sahoo Central University of Jharkhand	Fusion and transfer measurements for the systems ^{28}Si+^{58,62}Ni around the Coulomb barrier

Maintenanve activities of the HIRA:

- The multi-wire proportional counter (MWPC) installed at the HIRA focal plane showed multiple sparks and a nonuniform position spectrum during testing with ^{241}Am α-source. Inspection revealed loose wires and black patches on the frames, likely causing electric field irregularities and loss of position information in some areas. The old wire frames were replaced with newly fabricated ones, followed by a source test.

New developments:

- Several detector mounts and collimators for silicon detectors (E and ΔE-E) were designed and fabricated for installation in the HIRA target chamber. These were / will be positioned at backward angles to detect quasielastic events and at forward angles to identify elastically-scattered particles during facility tests and user experiments.

- A newly developed multi-anode deep ionization chamber, installed at the focal plane of HIRA behind the MWPC, was tested using α-particles from ^{241}Am source and a ^{252}Cf fission source to evaluate its response to both light and heavy ions. Initial tests confirmed that all segments of the detector were responsive and a clean single peak was observed while summing the individual signals. The detector's performance had been evaluated under varying gas pressures and electronic settings.

In-beam tests were performed for the testing of ionization chamber in the actual experimental conditions. It was evaluated for the unambiguous identification of fusion and quasielastic events produced in both symmetric and asymmetric reactions. The test aimed to evaluate the detector's performance for fusion at deep sub-barrier energies using an asymmetric reaction, and for multi-nucleon transfer using a symmetric reaction. In both the cases, excellent background suppression was achieved.

Fig. 4.6 shows the two scatter plots (a) ΔE (from MWPC cathode) vs TOF and (b) E_{total} (sum of all the individual ΔE signals from the IC) vs TOF for the system ^{28}Si+^{180}Hf at projectile energy of 80 MeV, to emphasize the capability of the IC for identification the particles of interest (target-like events in this case) at the HIRA focal plane.

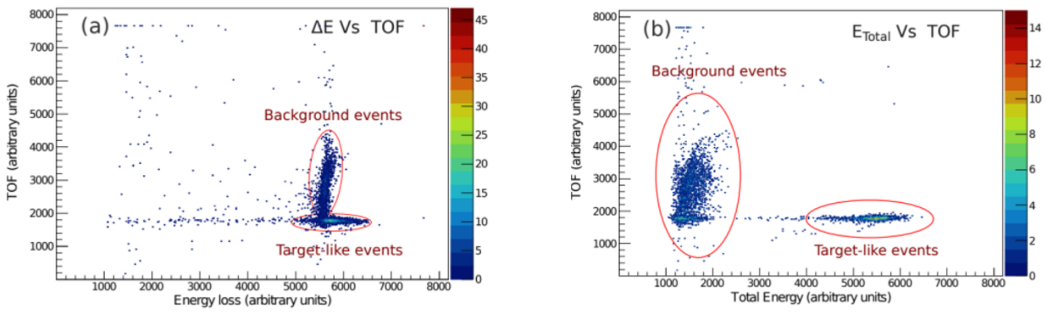

Figure 4.6: Performance test of the ionization chamber.

The detector is routinely being used by the HIRA users. This development has significantly enhanced the selectivity and the energy limits for fusion, quasielastic and transfer measurements, It is important to mention here that in one of the user experiments (Anjali *et al.*) the fusion measurement could be extended down to ∼ 15 % below the barrier. Another user experiment (Sahoo *et al.*) for fusion and transfer measurements for the symmetric systems ^{28}Si+^{58,62}Ni was possible only due to this detector, as ERs or the transfer events were not distinguishable in our conventional setup with MWPC only. This was also helpful in separating the ER events in ^{30}Si+^{124}Sn,^{138}Ba reactions (Prameela *et al.*).

- The hardware add-ons of the HIRA for the production of ^{7}Be RIB were made operational after nearly two decades. The rotary-linear target assembly were refurbished and two new stepper motor controllers were installed. The slit-assembly, located at the centre of the dipole magnet of the HIRA, was re-calibrated and made leak-proof. The entire experimental setup is scheduled to be tested in an upcoming facility test.

4.3.2 HYbrid Recoil mass Analyzer

Gonika, J. Gehlot, Chandra Kumar, Alankar Singh, Rishabh Kumar, T. Varughese, S. Nath and N. Madhavan*

till May 2024

The TIFR 4π spin spectrometer and associated electronics were stationed at IUAC to perform collaborative experiments for many years. All the AUC-sanctioned experiments with this setup were completed. This setup was recently taken back by TIFR to carry out experiments at the BARC-TIFR Pelletron-linac facility. The HIRA-HYRA group extended support to complete all the formalities and facilitated the transportation of the setup.

The following developments are planned for HYRA, subject to the availability of funds, to enhance its capabilities and facilitate the use of beams from the high current injector:

- Installation of a large-aperture, room-temperature quadrupole doublet magnet along with its accessories and high-stability power supplies.
- Development of an advanced focal plane detector system for recoil decay tagging, incorporating state-of-the-art position-sensitive silicon detectors, electronics, and a readout system.

- A rotating target system and a rotating window or windowless distributed pumping system to fully exploit the full configuration of HYRA and the planned high intensity beams from the high current injector.

4.4 Materials science facilities

Ambuj Tripathi, Debulal Kabiraj, Fouran Singh, Sivakumar Valiveti Venkata, Saif Ahmad Khan, Indra Sulania, Sanjay Kumar Kedia, Ramcharan Meena and Ambuj Mishra

The Materials Science facilities are supporting research programmes of a large number of users from different Universities and research Institutions. There were nearly 34 beam time experiments carried out in the Beam Hall I utilizing 115 shifts and 3 beam time experiments in the Beam Hall II utilizing 15 shifts by the users for their beam time irradiation experiments. The beam line facilities were made compliant as per the safety guidelines and protocals of AERB norms.

4.4.1 Materials science beamline in Beam Hall I

Ambuj Mishra, Indra Sulania, S A Khan, V. V. Siva Kumar and Ambuj Tripathi

4.4.1.1 Maintenance of Irradiation chamber in Beam Hall I

There were many regular maintenance activities, few of them are given below.

There is a rotary stage (RMTG-600, MDC make) connected to the chamber to rotate the ladder for side change with the help of a spindle as shown in Fig. 4.7 (without breaking the chamber vacuum).

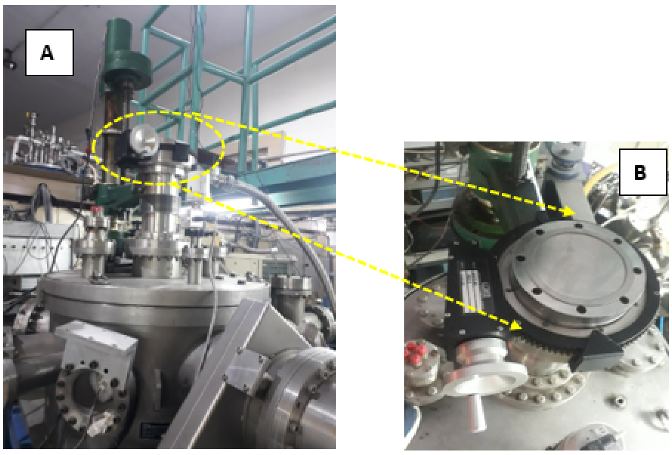

Figure 4.7: (A) Rotary stage (RMTG-600, MDC make) connected to the chamber (B) Top view.

It generated some minor leak which became evident due to deterioration in the chamber vacuum at the time of ladder rotation and need replacement. It is MDC make. Arrangements are being made to procure it with compatible dimensions and replace it. Engineer visited to take dimension of Rotary stage, installed with the HV chamber of the Mat Sci. Beamline, from VT Vacuum. They may provide us the spare of same configuration from Kurt J lesker.

A: Safety committee visited the beam line, with their feedbacks, a check list is put up in the beam line in BH-1 for the users to ensure that all the steps are followed properly for the beam time experiments.

B: Scroll pump of higher capacity was installed with the HV chamber. Faulty Turbo controller was replaced with a new one.

C: A test run was conducted by the Pelletron Group in March 2025 to check the BPMs and the first line valve. For the same the chamber was put in vacuum 2.5×10^{-6} Torr. It was found to be working fine from the Control Room. The irradiation chamber was maintained at high vacuum. Mat. Sc. last BPM testing was performed at different currents and the performance was found to be satisfactory.

4.4.2 Beamline facilities in Beam Hall II

Sanjay K. Kedia, R. C. Meena, Chandrapal, P. Barua, Fouran Singh, V. V. Siva Kumar and Ambuj Tripathi

The beam hall-2 is specifically designed and developed to perform the in-situ irradiation experiments, including in-situ X-ray diffraction, in-situ micro-Raman, in-situ high-temperature irradiation, and in-situ XRD in controlled gas environment for various materials and thin films grown and/or modified by energetic ions at various densities of electronic excitations. In-situ measurements hold a distinct advantage over ex-situ measurements due to the elimination of sample-to-sample variations and the capability to conduct measurements without exposing the sample to ambient conditions. This year, we efficiently executed three high-temperature irradiation experiments at $\sim$ 1000 K (Fig. 4.8), for three distinct users by utilizing a total of 15 shifts of the beamtime.

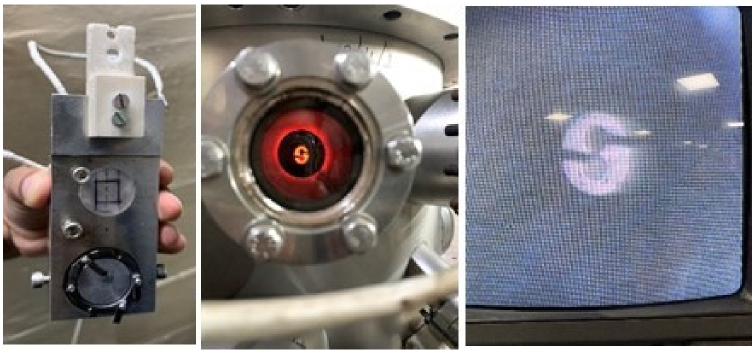

Figure 4.8: Illustration of the various steps of the high-temperature irradiation experiments, wherein samples are affixed onto a one-inch circular surface of a high-temperature cylindrical heater, elevating the sample temperature to 1000 K in a high vacuum environment and the radiant glow of the heater is observable through a vacuum viewing port through viewing camera.

The group members were also involved in conducting the first test experiment in association with Prof. S. V. S. Nageshwar Rao from Central University of Hyderabad using the available beam from High Current injector in Beam Hall II. This was to explore the feasibility of conducting materials Science experiments using HCI beam with and without acceleration by the linac in near future. It may be noteworthy that it was decided based on the workshop conducted for the utilization of HCI beams, where Prof. Rao and Dr. Fouran Singh have delivered presentations for the possible utilization of beams from HCI facility. The preparation of this experiment was handled by Dr. Fouran Singh and supported by Dr. Meena, Dr. Kedia. Dr. Jyoti, Mr. Mandeep and vacuum lab. Since, it is becoming difficult to carrying out the experiments from the data room near the control and thus we are in the process of having a data room in newly allotted area of room number 125.

A $\sim$ 3 pnA Ne^9 ion beam at 36 MeV was successfully developed using various accelerating sections (i.e., drift tube linacs) and bunching sections (i.e., multi-harmonic and spiral bunchers) of the indigenously built high-current injector at IUAC. The ion beam was subsequently injected into the zero-degree beamline (just before the superconducting super-buncher) for transport to Beam Hall II. It is worth noting that a running rotary pump went bad in the middle of the scheduled experiment which was temporarily replaced by another rotary pump to conduct the experiment uninterrupted. The first experiment has been successfully completed in the materials science irradiation chamber of Beam Hall II. Data analysis is currently underway.

4.4.3 Centre for materials characterization and measurements

A Mishra, R. C. Meena, S. K. Kedia, I Sulania, S. A. Khan, V. V. Siva Kumar and A. Tripathi

A Centre for Materials Characterization and Measurement (CMCM) is being established to house all the synthesis, microscopy, optical and transport offline facilities for the materials characterization and measurement at one place. The area for CMCM in LEIBF building of IUAC was renovated and the identified instruments were installed. The reorganization of characterization and measurement facilities including shifting of many equipment such as E beam set up, Solar simulator, FTIR, UV-Vis-NIR spectrophotometer, UV-Vis spectrophotometer, Contact angle measurement setup, Optical microscope, and Photoluminescence setup was implemented last year. Installation and testing of polarization vs. electric field (P-E) loop measurement setup and dark room for optical measurement facilities was also completed. These facilities put under CMCM are under regular utilization and experiments of large number of users have been scheduled through online request portal. The experiments are conducted as per the approval of AUC meeting at different times.

4.4.4 Materials synthesis and microscopy laboratory

Indra Sulania, Saif Ahmed Khan, V. V. Sivakumar and Ambuj Tripathi

The laboratory has few synthesis facilities for the growth of thin films and Nano-powders and some characterization facilities such as Scanning Electron Microscope, Scanning Probe Microscope, Optical Microscope, UV-Vis Spectrophotometer and Contact Angle measurement set-up. The facilities are in proper working condition. The Microscopy facilities have been extensively utilized by IUAC user community belonging to different universities / institutes.

4.4.4.1 Scanning electron microscope

S. A. Khan, I. Sulania and A. Tripathi

TESCAN's MIRA II LMH Field Emission Scanning Electron Microscope (FE-SEM) was working fine except for instances when noise was observed particularly at magnifications over 100x. The emission current has been increasing over the year indicating that the electron source may have to be replaced in the coming years. In November, the secondary electron detector was occasionally not detected by the FE-SEM. However, this issue has not been encountered since December. The instrument along with the Oxford Instruments dispersive X-ray Spectroscopy was utilized by 61 users from more than 30 different institutes / universities for characterization of their 380 samples. The dedicated sputter coater was utilized for coating the Au-Pd thin layer whenever necessary before these measurements.

4.4.4.2 Scanning probe microscope

Indra Sulania, S. A. Khan and Ambuj Tripathi

Most of the Scanning Probe Microscope modes such as AFM, MFM, C-AFM, STM, STS and F-d mode etc are available at IUAC and used in user experiments. J-scanner was repaired and tested for standard samples. Repaired AFM scanner received from Bruker and tested for full range of scan; It was repaired with epoxy and soldering by a Bruker engineer. Standard grid Scanned on 19th Jun 2024 for a maximum scan range. Scanner was calibrated with standard samples (Fig. 4.9). User support performed from June to Oct. 2024. Problem occurred with AFM head (Nov. 2024).

The facility was used from June to Oct. 2024 for User Support. In total there were 52 samples characterized for 11 users in AFM / MFM mode.

The facility is under maintenance at present, though there is no support from the OEM due to obsolete nature of the equipment. Problem occurred with AFM head as the LED did not glow on AFM head, but working for STM head; Ribbon cable tested for connections etc.

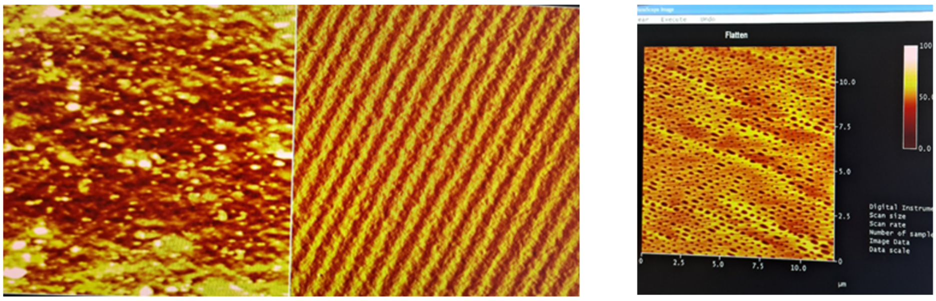

Figure 4.9: Images of standard samples taken under (left image) MFM mode and (right image) AFM mode, using J-scanner.

4.4.4.3 Optical microscope

Indra Sulania and Ambuj Tripathi

The laboratory has a high-end optical microscope from Zeiss, which can magnify the images up to 100x. It is mostly used as a tool to predetermine the sample's area before performing the SPM measurements. It is especially useful to track the single or multilayer graphene flakes etc. Recently the LCD screen command window was not interfacing with the main system. Optical microscope engineer was called from Carl Zeiss. It was found that the control card was faulty. The same will be repaired soon.

4.4.4.4 The UV-Vis spectrophotometer

Indra Sulania and Ambuj Tripathi

UV-Vis Spectrophotometer, which was procured from Hitachi, is capable of doing measurements in Absorbance/ Transmission mode. The UV-Vis spectrophotometer was used to characterize 112 samples of 12 users.

4.4.4.5 Contact angle measurement facility

Indra Sulania

The laboratory has a unique Instrument, Drop Shape Analyzer, DSA100, from Kruss GmbH, Germany. It is a high-quality system for knowing the wetting and adhesion properties of solid surfaces with water drop. From the basic unit, for precise measurement of the contact angle to the fully automatic expert instrument for serial measurement of surface free energy. When an interface exists between a liquid and a solid, the angle between the surface of the liquid and the outline of the contact surface is described as the contact angle (lower case theta). The contact angle (wetting angle) is a measure of the wettability of a solid by a liquid. This year, it was utilized by 06 users scanning nearly 45 samples. The set-up is working satisfactorily and no major maintenance was required.

4.4.5 Transport measurement facilities

Ramcharan Meena, Ambuj Tripathi, D. Kabirraj, Fouran Singh and V.V. Siva Kumar

Operation: The transport lab of the material science group consists of various offline facilities for materials characterization, such as resistivity measurements are performed using the source meter (Keithley 2612B) or delta mode (Keithley 2182 A nanovoltmeter along with Keithley 6221 AC and DC current source) and electrometer (6517 B electrometer) in the two or four probe mode. The source meter or delta mode are used for the low-resistive samples, while the electrometer is used for the high-resistive or insulating samples. The dielectric behavior of the insulating samples is checked using the Agilent LCR meter (Model: E4980 A) in the frequency range of 20 Hz – 2 MHz. The dielectric measurements are performed using the auto-balance bridge method. The various parameters, such as dielectric constant, dielectric loss, inductance, quality factor, impedance, phase angle, and reactance, can be measured using this setup.

The various physical properties of a semiconductor sample, such as carrier concentration, mobility, magnetoresistance, Hall coefficient, and sheet concentration, are determined using the Ecopia Hall effect measurement system (Model: HMS 3000). The measurements are performed using the static magnetic field of 0.57 Tesla. The various types of semiconductor devices such as diodes, BJT (Bipolar Junction Transistor), FET (Field-Effect Transistor), and MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) are characterized by performing the current (I) - voltage (V), capacitance (C) - voltage (V) measurements by Agilent B-1500 semiconductor device analyzer. The measurements are performed using the tungsten (W) metal pressure probes.

The charge storage efficiency of an insulating material can be checked by performing the polarization (P) vs electric field (E) measurements. The insulating samples can be polarized using the external voltage amplifier (±10 KV), and the resulting polarization current is measured as a function of the electric field. The samples are dipped into the silicon oil to prevent the sparks at high electric fields.

The measurements using these facilities are performed using the user-friendly LabView programs. The resistivity, dielectric, I-V, and C-V measurements can be performed at 20 K − 300 K and 80 K − 450 K. The temperature-dependent P-E loop measurement can be performed from room temperature to 250 C. The user-friendly programs are designed to change the input parameters during the measurements, and temperature stability and tolerance can be set as required.

The numbers of users of these offline facilities, in this year, are mentioned in Table 4.4. These offline experiments were scheduled in the regular group meetings.

Table 4.4: Usage of offline facilities.

Sl. No.	Measurements	Number of users
1	Resistivity measurements	10
2	Dielectric measurements	11
3	Hall-effect measurements	10
4	I-V, C-V measurements	5
5	P-E loop measurements	5

In addition to the above, a sample or device's in-situ electrical transport characterization can be performed in the material science beamline of beam Hall-1. The characteristics of temperature-dependent resistivity, current-voltage (I-V), and capacitance-voltage (C-V) can be measured as a function of ion fluence for selected beam energy. The sample temperature is measured using the Pt-100 sensor, and sample heating is performed using the 50-ohm cartilage heater. The data is recorded using the user-friendly LabView program. The sample holder for the in-situ measurements is designed in such a way that five different types of samples can be mounted at a single time.

Maintenance: The facilities available in the transport lab are calibrated from time to time using standard samples. $BaTiO_3$ (BTO) ceramics are used for the dielectric setup calibration, and standard resistors (10 Ω for low resistivity and 1 GΩ for high resistivity) are used for resistivity calibration. The Implanted Ge-wafer is used for the Hall effect calibration, and the Si-diode is used for the semiconductor device analyzer. The $PbZrTiO_3$ (PZT) sample calibrates the P-E loop setup. The thermo-electric setup is calibrated using the chromal and alumal thermocouple. All the facilities were operational in the previous academic year except for a slight breakdown in the dielectric and P-E loop facility. The faculty Pt-100 temperature sensor was replaced in the dielectric setup. The P-E loop setup was sent to the factory for repair (a problem in the high-voltage power supply was encountered).

4.4.6 Structure and spectroscopy laboratory

M. Chahal, Jyoti Yadav, Sanjay K. Kedia and Fouran Singh

The laboratory is equipped with several facilities of development and characterizations / measurements of materials namely RF sputtering, e-beam evaporator, tubular furnace, high-temperature furnace, in-situ micro-Raman spectrometer, in-situ X-ray diffractometer, UV-Vis-NIR spectrometer, FTIR spectrometer, UV Photoluminescence setup, solar simulator, etc. These research facilities have been extensively used by the users for many years for their accelerator-based research activities. However, many of them are having aging issues and will be upgraded/replaced in a phased manner with state of art facilities in the coming years. Nevertheless, in the present scenario regular operation and upkeep has become a very challenging issue.

The micro-Raman facility is now operational which has been down for quite some time with the support of service engineer on the old XP based system only and as it is known that XP system has been obsolete long back. Therefore, parts of such equipment will not be compatible with existing windows platform. The issues with system performance have been investigated / inspected & tested the complete system including spectrometer, CCD Detector, microscope and laser for proper functioning. Angle tuned for 514 nm laser filter to get optimize maximum white light transmission. Angle & optimized laser beam through spectrometer & onto the video crosshair for through focus. Aligned & optimized the slit & CCD area to get maximum signal intensity. The system has been calibrated using standard calibration source. However, now system is again down and possibilities of recovery are being explored, but it is noteworthy that system parts are obsolete and thus planning of the new system is also in plan.

4.4.6.1 Upkeep and maintenance of the x-ray diffraction system

Sanjay K. Kedia, Fouran Singh and Ambuj Tripathi

The in situ and low-temperature XRD system (Fig. 4.10) has remained operational for nearly 21 years in BH-II, despite aging-related challenges. Throughout last year, all servicing and maintenance activities including the resolution of alarms, faults, and minor glitches were carried out in-house. To address recent performance issues, two key components the electronics associated with the tube stage and the X-ray tube were procured and successfully installed. Following installation, the system was calibrated and is now fully functional in gonio mode. However, detector scan counts remain on the lower side. Efforts are currently in progress to enable operation in glancing angle mode as well. Last year, we have characterized ∼ 150 samples for ∼ 30 different users.

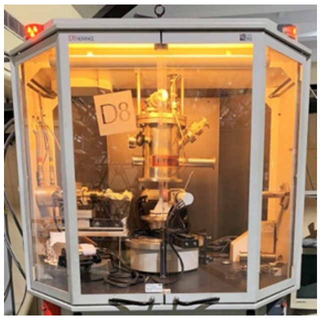

Figure 4.10: The Bruker make D8 advanced diffractometer.

4.4.6.2 FTIR, UV-Vis-NIR, UV photoluminescence and solar simulator facilities in the CMCM

M. Chahal, Jyoti Yadav, Sanjay K. Kedia, R. C. Meena and Fouran Singh

The UV-Vis-NIR and Fourier Transform Infrared (FTIR) was in regular operation in the CMCM area for the regular experiments and about 213 Spectra from 13 users and 222 spectra from 17 users have been taken using FTIR and UV-Vis-NIR facilities, respectively. The both spectrometers are being in regular operation without any breakdown as being regularly checked for their upkeep and the pics of same can be seen in Fig. 4.11 (left). The PL for many users has been tried as per the request, however due to week emission signal only a few good experiments were conducted. It may be noted that the process of having spectrophotometer going on for last few years. Similarly, the solar simulation measurements system is also placed and some good experiments need to be conducted and both UV-Pl and solar simulator system can be seen in Fig. 4.11 (right).

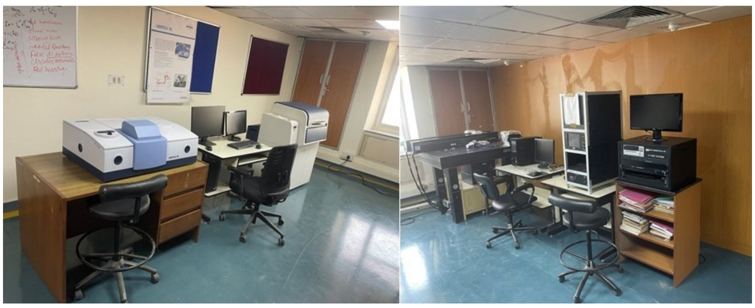

Figure 4.11: (Left) The Bruker vortex70 spectrometer and Hitachi U-4150 spectrometer, (Right) UV photoluminescence and solar simulation measurements in the CMCM area.

4.4.7 Thin film deposition systems and high-temperature furnaces

Sanjay K. Kedia, Fouran Singh and V. V. Siva Kumar

The sputtering system has been enhanced by repairing or replacing several key components such as the substrate rotation system, temperature and PID controllers, vacuum gauges, thickness monitor, and water and air pipelines. Currently, the system is fully functional within the designated CMCM area. To date, we have assisted approximately 11 users in the fabrication of over 50 thin films using the RF sputtering method, tailored to meet their individual research needs. Similarly, the evaporation system is capable of depositing thin films using both thermal and electron beam evaporation techniques. Internal diagnostics and maintenance have effectively resolved issues related to the chiller, electron beam power supply, and a malfunctioning vacuum gauge. The system has maintained full operational status throughout the year. Over the past year, we supported around four users by fabricating 25 thin films to assist with their research. Additionally, the high-temperature furnaces have been in regular use for processes such as calcination, annealing, and sintering, accommodating a wide range of temperature requirements. Heat treatments were carried out in controlled steps for nearly 100 samples, benefiting about ten users in their respective projects.

4.4.8 High-resolution transmission electron microscopy facility

Ambuj Mishra and Debdulal Kabiraj

Energetic ion beams play a crucial role in modifications of the materials and can change their physical properties. TEM is a state-of-the-art technique that is used to investigate morphological, structural, and compositional modifications in a material. The IUAC TEM and TEM sample preparation facilities are being utilized by various users of different universities and research institutes.

TEM specimen preparation facility: The TEM specimen preparation facility is equipped with an Ultrasonic bath, Hot Plate, Traditional Lapping/Grinding Tools, Dimple Grinder, Diamond Wire Saw, and Precision Ion Polishing System (PIPS). All these instruments are regularly used for TEM sample preparation. Planar TEM, Cross-sectional TEM (XTEM), and Powder samples on TEM Grids are prepared for TEM characterization. The TEM specimen preparation facility has been utilized to prepare approximately 50 TEM samples including 10 XTEM and 04 planar samples by various users during this academic year 2024-2025.

High-resolution scanning transmission electron microscope (HR-STEM) facility: Maintenance of TEM is very important for smooth operation and is done as and when required. Some of the regular TEM maintenance activities undertaken are the Bake-out process followed by HT conditioning, ACD heating, Camera warmup, etc. TEM Bake-out cycle has been performed in the month of August 2024 and January 2025. Upgraded EELS is now also operational. During this period, EELS was performed to study the light elements in nanocomposites, semiconductor planar samples and 2D materials. More than 110 samples of users have been characterized for TEM, HRTEM, SAED, STEM-EDS, and STEM-EELS.

4.5 Radiation biology

Abhay S. Deore, Rushmika Rawat, Supriya Mehta, Sourav Ghosh, Suresh. K. Thokchom, Saif A. Khan and Debdulal Kabiraj

The radiation biology group at IUAC has a dedicated laboratory and a radiation biology beamline housing ASPIRE (Automated Sample Positioning and Irradiation system for Radiation biology Experiments). Following are the highlights of the group activities in this academic year.

Operation

The following experiments were conducted:

- Effect of carbon and oxygen ions on GJIC in normal and cancer cells with relevance to mechanism of radio-resistance, P. I.: Dr. B. N. Pandey (BARC, Mumbai) on 17th April 2024
- Study of metastatic potential of p53 mutant human lung cancer cells, H1299 irradiated with carbon ion, P. I.: Dr. U. Ghosh (Kalyani University, Kalyani) on 13th May 2024
- Chromosomal damage induced by High LET Carbon beam radiation in comparison to gamma radiation in human peripheral blood lymphocytes/ Chinese hamster fibroblast (V79) cells and the effect of Diclofenac sodium in modulating it, P. I.: Mr. Amit Alok (INMAS, Delhi) on 20th May 2024 (partially executed due to the development of pin holes in the exit Aluminum foil of the ASPIRE facility)

- Study of metastatic potential of p53 mutant human lung cancer cells H1299 irradiated with carbon ion, P. I.: Dr. U. Ghosh (Kalyani University, Kalyani) on 24th August and 2nd September 2024.

Maintenance:

The major repair works carried out are the following:

- The exit foil of the ASPIRE facility developed pinholes during the beamtime that commenced on 20th May 2024, so it was replaced with a new foil in this period.
- Centrifuge repair: Microprocessor board was repaired by a service vendor. Also, the shorted motor was removed, re-varnished, rewinded, and reinstalled in the centrifuge unit

New development:

A. Subculture and cryopreservation of newly procured cell-lines (Fig. 4.12) from NCCS, Pune and collaborators from INMAS-DRDO and AIIMS, Delhi, respectively:

- U-87 (Human Glioblastoma cell line),
- MCF-7 (Human breast cancer cell line), and
- G-415 (human gallbladder carcinoma cell line)

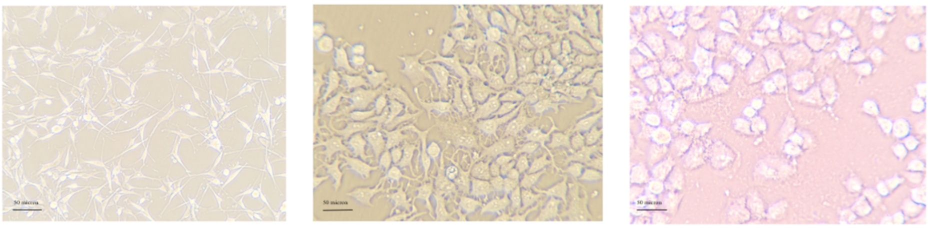

Figure 4.12: The optical image of U-87 cell line (left), MCF-7 cell line (centre) and G415 cell line (right) cultured on Petri dishes.

B. The following items, apart from necessary consumables, were added to the laboratory for strengthening the facility:

- Motorized Pipette Controller (Thermo Scientific™ S1 Pipette Fillers, 9501) for aseptic dispensing of sterilized cell culture media and reagents, minimizing contamination during subculturing and seeding.
- Tabletop Mini Centrifuge (iFUGE, M08VT) for various applications including quick spin-downs of small samples, Microfiltration and Separating molecules based on density and size
- Microwave oven (Samsung, M423A3515AK) for use in gel electrophoresis experiments.
- Temperature controlled water bath (Laatu, PRYG-WB-24223M15) for thawing cryopreserved cells and warming refrigerated media and reagents at 37°C.
- Mini Rotary Shaker (Remi, RS-12R) for controlled/gentle mixing of reagents in well plates during biological assays.
- Inverted optical microscope (Dewinter, Victory) for visualizing and monitoring cell growth and status during culturing and seeding processes.

C. Following are the new approved beamtime proposals in radiation biology group:

- Exploring radio sensitizing potential of a natural phenolic compound in human lung carcinoma : highlighting macromolecular oxidation and DNA: Dr. Ujjal Das, UGC-DAE CSR, Kolkata Center
- In vitro evaluation of carbon ion and gamma radiotherapy in combination with cisplatin in gallbladder carcinoma cell line G-415: Dr. Suresh Kumar Thokchom, Inter-University Accelerator Centre, Delhi.
- Radio-sensitisation of human cancer cell line with silver nano particle (SP):Dr. Sourav Ghosh, Inter-University Accelerator Centre, Delhi.
- In-Vitro Modulation of High LET Radiation-Induced DNA Damage and Repair by TLR agonist Mannan Oligosaccharide: Dr. Damodar Gupta, INMAS, DRDO, Delhi
- Effect of Carbon Ion Radio-therapy in combination with GAS-STING agonist on triple negative breast cancer cell: Dr. Souren Paul, TERI School of Advance Studies, Delhi.
- Investigating the Effects of Convolvulus prostatus (Shankhapushpi) Extracts on the Response of MCF-7, MCF-10, and MDA-MB-231 Cell Lines to High Energy Carbon-ion Irradiation: Dr. Saif Ahmad Khan, Inter University Accelerator Centre, Delhi.

- Impact of Lithium-Ion Beam Irradiation on Phenotypic Variation, Nutritional Composition and Biochemical Parameters in Glycine max (L.) Merr: Dr. Akshay Talukdar, IARI, Delhi
- Investigating the ability of tardigrades to tolerate lethal ionizing radiations: Dr. Sandeep M Eswarappa, Indian Institute of Science, Bangalore.
- A Comparative Analysis of High LET Carbon Ion vs. Low LET Gamma Radiation-Induced Bystander Effects in Human NSCLC A549 Cells with PARP-1 Inhibitors: Mr. Roni Paul C/o. Dr. Utpal Ghosh, University of Kalyani
- Exploring the impact of poly-ADP ribosylation on telomere maintenance in human lung cancer cells: Ms. Rima Das C/o. Dr. Utpal Ghosh, University of Kalyani,
- Modulation of cancer cell death by Anthocyanins: Mechanism based experimental approach: Ms. Zofa Shireen C/o. Prof. Sanjit Dey, University of Calcutta
- In-Vitro Study on Radiation Sensitization of Nanoparticles in Photon and heavy ion Irradiation of Cancer Cells: Dr. Mudasir Ashraf Shah, Aligarh Muslim University, Aligarh

4.6 Atomic and molecular physics

4.6.1 Status of general purpose atomic physics chamber at Beam Hall II

D. K. Swami and C. P. Safvan

Experiments involving the collision of highly charged ion beams with solid targets, followed by X-ray measurements, are carried out in the General Purpose Atomic Physics Vacuum Chamber (GPAC) located in Beam Hall-II. In this setup, two silicon drift detectors (SDDs) are placed at different angles to the ion beam to detect X-rays, with a resolution of about 130–140 eV at 5.9 keV. Additionally, two silicon surface barrier detectors are used to detect scattered and backscattered charged particles. The setup allows the use of multiple targets at once for detailed studies. During the experiments, the vacuum inside the chamber is carefully maintained between 10^{-6} and 10^{-7} mbar to ensure proper conditions.

This year, two experiments were carried out in the GPAC chamber, focusing on X-ray spectroscopy. In these experiments, Fe (Fig. 4.13) and Cu ion beams with varying energies were used to irradiate carbon targets of different thicknesses.

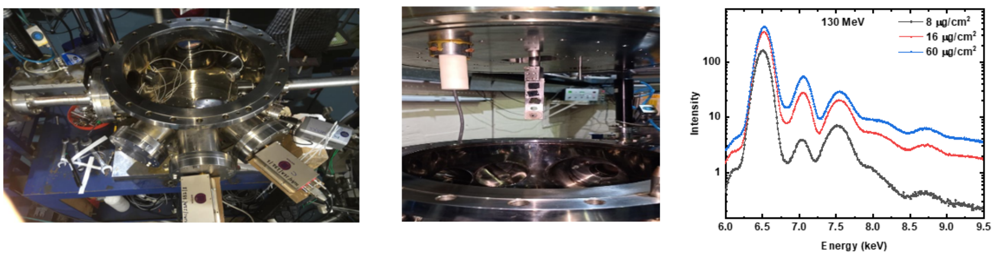

Figure 4.13: Experimental setup and X-ray spectra for a 130 MeV Fe beam incident on carbon targets of varying thickness.

4.6.2 Development of the ion trap facility

Sugam Kumar[1], C.P. Safvan[1], D.K. Swami[1], C.P. Veena[1], Pragya Bhatt[1], Wolfgang Quint[2], Manuel Vogel[2], Irene Marzoli[3] and Lekha Nair[4]

[1] *Inter-University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi, India*
[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*
[3] *University of Camerino, Camerino, Italy*
[4] *Department of Physics, Jamia Millia Islamia, New Delhi*

To support advanced research in atomic and quantum physics, IUAC is developing three dedicated ion trap setups. Each of these setups is designed to focus on a specific scientific goal:

1. **Delhi Penning Trap (DPT)** for measuring relativistic electron impact ionization cross-sections and radiative lifetimes.
2. **Zero-Point Energy Trap (ZPET)** to directly measure the quantum ground-state energy of a harmonic oscillator.
3. **Planar Penning Traps for Quantum Computing (PPTQC)** to build a scalable platform for trapped-electron quantum computation.

4.6.3 Delhi Penning Trap: A national user facility

The Delhi Penning Trap (DPT) facility (Fig. 4.14) has been developed at IUAC with the primary goal of enabling precise measurements of electron-impact ionization cross-sections in the relativistic energy regime (1–8 MeV). The motivation stems from the scarcity of experimental data on ionization of highly charged ions at such energies, especially in the context of deviations observed from theoretical models such as the relativistic binary-encounter Bethe (RBEB) and its modifications. This facility will allow background-free experiments using stored ions and a pulsed relativistic electron beam from the Delhi Light Source.

Figure 4.14: Photograph of the Delhi Penning Trap system: (left) LN2 cooling system and electron gun integrated into the vacuum chamber; (right) complete system with diagnostic electronics and control units.

4.6.3.1 Current status

A cylindrical Penning trap with open-endcap geometry has been successfully assembled and commissioned. It is equipped with an NdFeB-based permanent magnet that produces a field of 1.1 T at the trap center. The trap design includes access for optical detection and dynamic ion capture capabilities. The system has been integrated into an ultra-high vacuum (UHV) chamber and has been cryogenically cooled to 100 K using a custom-built LN_2-based cooling system.

A Kimball Physics electron gun operating at 1 keV has been installed and used for generating low-energy ions by ionizing residual and injected gases. These ions were dynamically captured and subsequently identified using time-of-flight (TOF) techniques.

TOF spectra for various injected gases such as He, N_2, and Ar have been successfully recorded under both room temperature and cryogenic conditions. Several charge species, including He^+, N^+, O^+, and Ar^+, were clearly observed, confirming reliable ion trapping and ejection from the Penning trap. Fig. 4.15(a) shows the TOF spectra of different ions, while Fig. 4.15(b) presents a calibration plot demonstrating the linear relationship between TOF and $\sqrt{m/q}$. This confirms ion identification. The signal stability over time also indicates consistent trap operation and reliable detection.

The DPT facility is now ready for integration with the relativistic electron beam from the DLS. A cryogenic axial resonator for non-destructive detection has been designed and is under testing. The complete system is expected to be moved to the FEL beamline by the end of 2025. This will allow the first-ever background-free measurements of relativistic ionization cross-sections for highly charged ions with kinetic energies between 1–8 MeV.

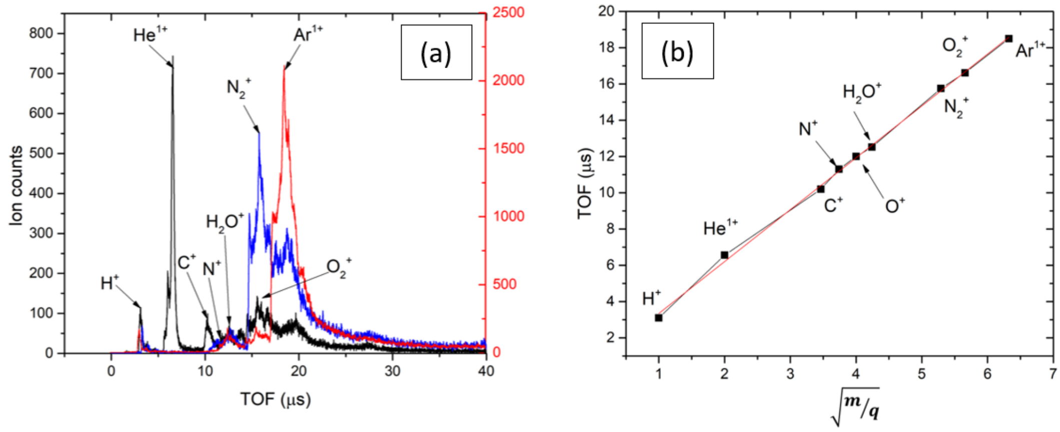

Figure 4.15: (a) TOF spectra of trapped ions including H^+, He^+, C^+, N^+, O^+, N_2^+, O_2^+, and Ar^+. (b) TOF calibration plot showing a linear relation with $\sqrt{m/q}$, confirming mass-to-charge identification of trapped ions.

The success of this setup not only enables precision ionization experiments but also opens pathways to study metastable lifetimes, spectroscopy of forbidden transitions, and fundamental QED effects in high-Z systems.

4.6.3.2 Funding and future plans

Delhi Penning trap: The Delhi Penning Trap (DPT) facility has been funded under the Core Research Grant (CRG) scheme of the Anusandhan National Research Foundation (ANRF). While the experimental setup has already been developed and demonstrated successfully, the sanctioned funds will be utilized for the procurement of a Pulse Tube cryo cooler. This will enable long-term cryogenic operation of the trap, thereby improving ion confinement time and measurement precision during relativistic electron impact ionization cross-section experiments.

Zero-point energy experiment: In parallel, another ANRF-funded project is focused on the first direct experimental measurement of the zero-point energy (ZPE) of a quantum harmonic oscillator using a single trapped anion. This novel approach aims to provide an independent, non-interferometric validation of vacuum fluctuations—a fundamental quantum effect responsible for phenomena like the Lamb shift and Casimir force. In this experiment, an anion will be confined in an electrically compensated Penning trap, and a laser will be used to induce photodetachment. The threshold behavior of the emitted electron, in the presence of a well-characterized trap potential, will be analyzed to infer the quantized ground-state energy, offering a rare direct measurement of ZPE.

Quantum computing with planar Penning traps: Additionally, a proposal has been submitted under the National Quantum Mission (NQM) to build a two-dimensional array of planar Penning traps for developing a quantum computing platform using trapped electrons. This quantum computing setup will be independent of the DPT and will operate in an ultra-high vacuum chamber at very low temperatures (millikelvin range) using a dilution refrigerator.

To support this effort, a refurbished dilution refrigerator with an inbuilt 5 T superconducting magnet has been arranged from GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany. Although the system has not yet been transferred to IUAC, it will eventually provide the stable magnetic field and ultra-low temperature environment needed to preserve quantum coherence and carry out precise quantum logic operations.

While the NQM project is still under review for funding, we have started making preparations to use the refurbished system to build a prototype quantum processor. This prototype will act as a proof of concept and help establish the core technologies required for a scalable quantum computer.

Together, these projects reflect a coordinated national effort to advance both fundamental and applied research using Penning trap technologies across multiple domains of atomic, molecular, and quantum physics.