अन्तर–विश्वविद्यालय त्वरक केन्द्र
Inter-University Accelerator Centre
(विश्वविद्यालय अनुदान आयोग का स्वायत्त अंतराविश्वविद्यालय केन्द्र)
(An Autonomous Inter-University Centre of UGC)
Post Box 10502, Aruna Asaf Ali Marg, New Delhi - 110 067
Ph: 11-26893955, Fax: 26893666, Website: www.iuac.ernet.in

## First experiment with LINAC beam

The first module of booster Superconducting Linear Accelerator consisting of eight niobium quarter wave resonators has become operational. In September 2006, $^{28}Si^{+10}$ beam of 130 MeV energy from the Pelletron has been accelerated further by five niobium resonators of the first Linac module to an energy of 151 MeV. A stable beam of 148 MeV was delivered for an experiment to study fusion-fission reaction dynamics using neutron multiplicity measurement in beam hall II.

Acceleration through five resonators from the first Linac cryostat had been demonstrated in the past but the energy gain was much less than what was expected from the design value. Several reasons had been identified for the poor performance. One of them was the use of high power (150-300 watts) to operate the superconducting resonators, leading to cable melting, metal coating on the niobium surface and increased cryogenic losses. Inadequate cooling of the resonators by liquid helium also contributed towards restricting the resonators from attaining high accelerating fields. The other problem was the cold leak in the tuner bellows from the vacuum seal and/or from the electron beam joints of the bellow convolutions of the tuner.

To address these problems, a novel way of damping the mechanical vibrations was implemented which reduced the power requirement. A special new drive coupler was designed and fabricated to eliminate coating on the niobium surface. The resonator cooling was improved by

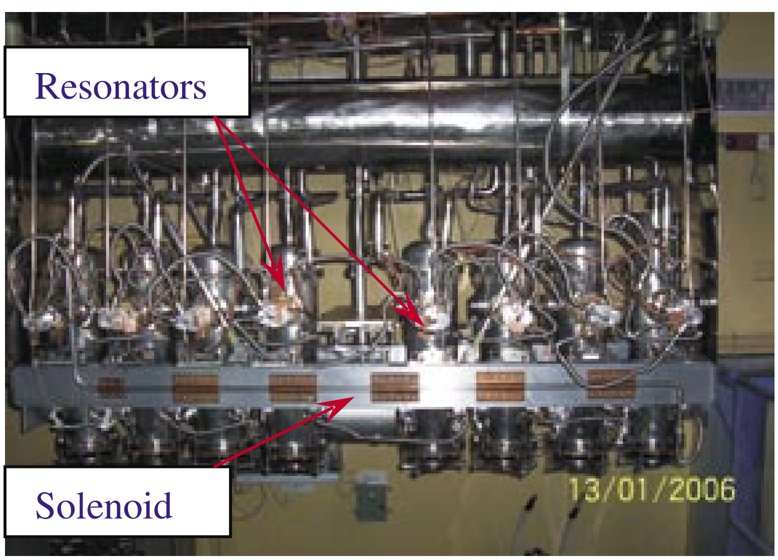



Fig.1. Eight niobium resonators and a solenoid were installed prior to first beam acceleration

installing a hemispherical dome structure on each resonator to provide buffer volume of liquid helium. Finally the fixture of the tuner was modified to avoid the cold leaks. All the modifications were tested successfully and during the recent off-line test, an average field of 3.9 MV/m at 6 watts of input power was achieved from the resonators in first linac cryostat.

During this test, along with the Tandem accelerator, multiharmonic buncher, high energy sweeper, phase detector, superbuncher containing a single niobium resonator and the first Linac cryostat containing eight resonators with a solenoid magnet were used. However, all eight resonators could not be used and five resonators out of eight took part to accelerate the beam. Initially, 130 MeV, $^{28}Si^{+10}$ beam from Pelletron accelerator was pre bunched by multiharmonic buncher and high energy sweeper and a FWHM of 1.4 ns was injected into superbuncher. After a quick adjustment of phase and amplitude and phase of the superbuncher, a FWHM of ~ 450 ps was produced at the entrance of Linac. The beam was then injected into the five resonators of Linac and after optimizing the phase of every resonator, a total energy gain of 21 MeV was obtained, as shown in fig 2. Afterwards a stable beam of 148 MeV (130 MeV from Tandem accelerator and 18 MeV from Linac) was delivered for about four days to conduct an experiment on nuclear physics. During this beam acceleration experiment through Linac, a transmission of close to 100% was achieved through the resonators of the first Linac cryostat. Proposals for experiments using the LINAC Beam may be presented to the AUC for the meeting to be held in Dec., 2006.

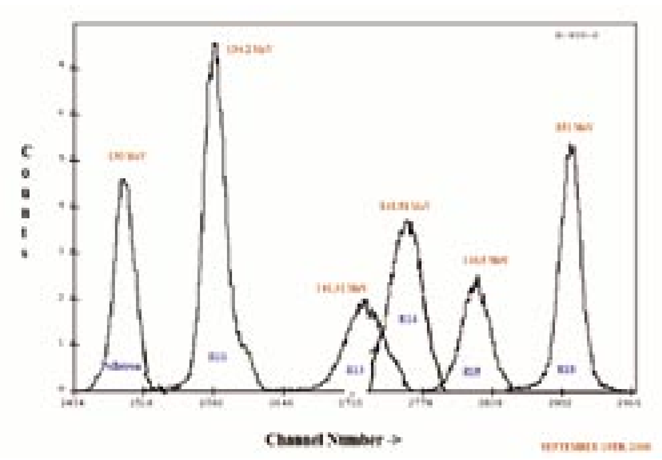



**Fig.2. The energy spectrum of $^{28}Si^{+10}$ beam after gaining acceleration from five quarter wave resonators of the first linac cryostat**

## Status of Hybrid Recoil mass Analyzer (HYRA) Facility

HYRA first stage components have been set up in QQ-MD1-Q-MD2 configuration and has been energised. In preparation for tests with gas-filled mode, gas pressure tests have been carried out in HYRA with a nickel foil separating the target chamber from the beam-line. Helium gas is introduced into the target chamber and is pumped out from MD1 chamber. The gas pressure is maintained by a gas pressure control unit which actuates a solenoid valve by comparing the measured value with reference value. The gas pressure is measured using Baratron gauges in MD1 and MD2, independently and has been found to be same over a pressure range of 0.5 to 1.5 Torr. The beam-line is maintained low $10^{-7}$ Torr vacuum throughout. Recently, $^{16}O$ beam of 100 MeV energy from Pelletron was used on $^{197}Au$ target in initial test with HYRA. To begin with, HYRA was maintained at high vacuum. The focal plane detector was a two-dimensional Si resistive detector of size 50 mm x 50 mm. The magnetic fields were initially tuned for fusion evaporation residues of 10+ charge state. The beam rejection factor achieved was ~ 4 x $10^6$ and beam-like particles of charge states 4+, 5+, 6+ and 7+ reached the focal plane with same $E/(q^2)$ ratio (Fig. 1). Subsequently, helium gas was introduced in HYRA at 0.5 Torr pressure. The magnetic fields were tuned to ERs of charge state 5+ (~ (Z)1/3). The beam-like particles of higher charge states were effectively cleaned (Fig. 2) as they were bent through trajectories of smaller radii in MD1. The beam rejection factor achieved in this case was close to $10^9$ with only lowest charge states of beam-like particles contributing to background, though optimization is not done. Further tests are planned shortly in conjunction with LINAC test.

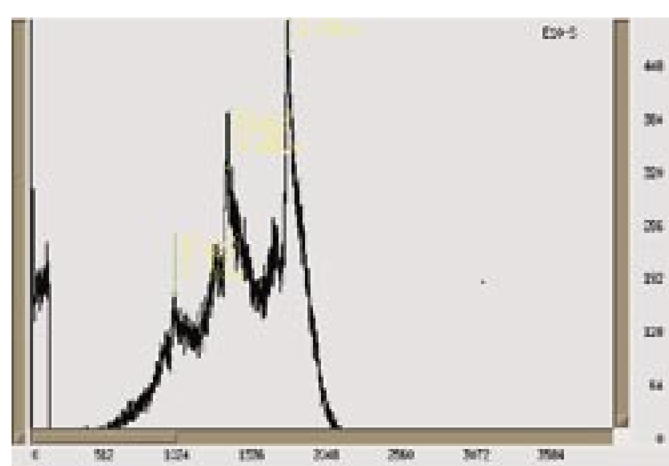


**Fig.1. Vacuum mode of HYRA 1$^{st}$ stage showing various charge states of beam**

The second stage magnets (four quadrupoles and one dipole) with their chambers and support structures and the power supply for the dipole have been received. These magnets have been field mapped thoroughly and found to be within specified tolerances. The indigenous power supplies for last four quadrupole magnets are being developed and are expected to be ready by March next year. The development of superconducting quadrupole doublet (Q1-Q2) is in progress. A wire-winding machine and aluminium formers for coils have been indigenously fabricated. Initially, it is planned to wind copper wire for trouble shooting, if any, and later to take up superconducting wire winding.

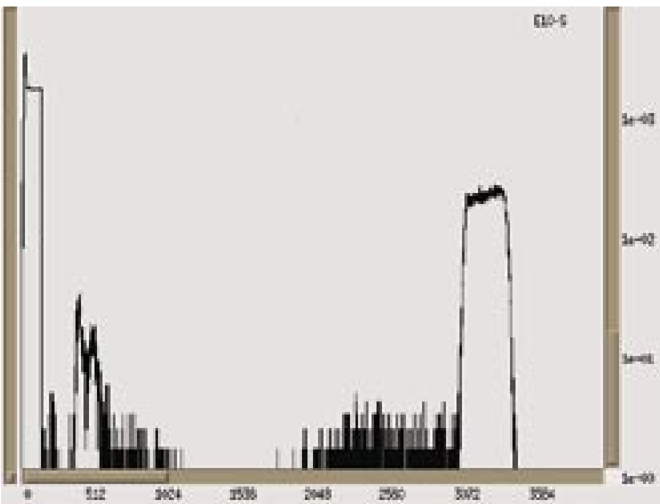


**Fig.2. Gas filled mode of HYRA 1st stage showing better beam rejection**

## Fabrication of prototype RFQ

A prototype RFQ is being made at IUAC as part of the developments for the high current injector which would be an alternative source for the superconducting linear accelerator (SC-LINAC). The RFQ would receive ions from the High Tc superconducting ECR source (PKDELIS) and accelerate the ions to 180 KeV/u. The accelerated and bunched beams would then be injected into a drift tube LINAC, that would further accelerate the beams to energies compatible for injection into the SC-LINAC.

For gaining experience in fabrication and operation of room temperature RFQ cavities, a prototype is being built. The prototype is a full scale model of the final design. The design parameters like RF frequencies, shunt impedance, water cooling, tunability, mechanical vibrations and stability would be investigated with this prototype.

The prototype RFQ has been fabricated with unmodulated vanes and low power RF tests (bead pull and capacitance perturbation) have been carried out. The results have validated the simulated design (using CST Microwave studio). The design is similar to the Frankfurt and RIKEN RFQ's, since they are found to be efficient at these low frequencies (48.5 MHz for us).

Figure 1 shows the prototype RFQ with unmodulated vanes with the bead pull apparatus. The modulated vanes are being fabricated and the mechanical accuracies are being checked. Figure 2 shows one of the modulated vanes being tested for mechanical dimensional accuracy.

**Fig.1. Bead pull apparatus and prototype RFQ**

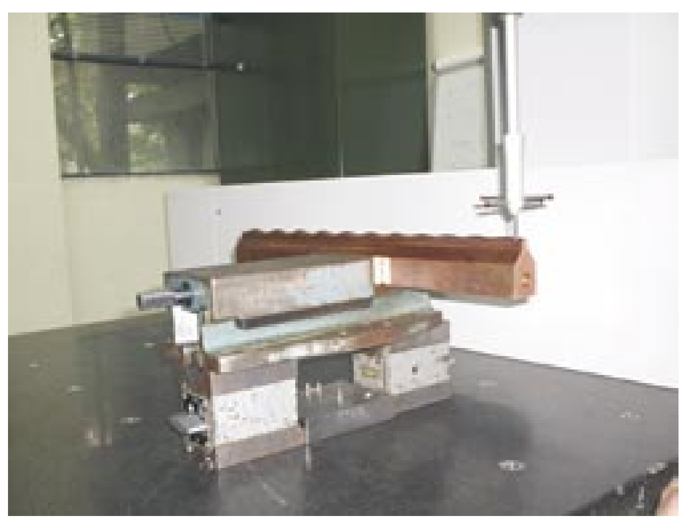


**Fig.2. Modulated vanes being tested for dimensional accuracy.**

## National Array of Neutron Detectors (NAND)

National Array of Neutron Detectors (NAND) is a large array of neutron detectors setup at Phase II beam hall. The array at present consists of about 30 organic liquid scintillators (NE213 detectors coupled to Philips make XP4512B PMT) of 5" diameter and 5" thick by pooling detectors available at different institutions in the country. NAND is a national collaborative effort of IUAC, TIFR, SINP, PU and DU.

The primary motive behind the development of this array is to study fusion-fission reaction dynamics in the energy domain near the coulomb barrier by measuring pre and post-scission neutron multiplicity and multiplicity distribution. Another aspect of neutron measurement is the study of super heavy nuclei. Neutron emission from such a heavy mononuclear system in competition with the fission enhances survival probability of the heavy system. Cross-section of super heavy nucleus formation is of the order of a few pb. Large neutron detector array is preferred to overcome the limitation of cross section.

### Study of reaction dynamics using NAND

A preliminary attempt has been made to study fusion-fission reaction dynamics using neutron array set up. Our interest was to study the nuclear orientation dependence on quasi-fission versus fusion-fission by neutron multiplicity measurements. 148 MeV $^{28}Si^{10+}$ beam from the Pelletron-LINAC combination was put on a 200 $\mu g/cm^2$ $^{181}Ta$ target to measure pre- and post-scission neutron multiplicities and fission fragment angular and mass distribution. Fission fragments were detected in two large area position sensitive MWPCs placed at folding angle. Fission detectors placed at a distance of 19 cm from target position had average angular coverage of $30^0$ each. Two monitor detectors, 300 μm thick silicon surface barrier, kept at $\pm 16^0$ were used for beam flux normalization purpose and on-line monitoring of beam phase and time. Neutron time of flights were measured in 16 neutron detectors placed at a distance of 2 m from target around the scattering chamber in a cylindrical fashion. Pulsed beam with a repetition rate of 250 ns enabled a good neutron gamma separation at 2 meter flight path. Beam was dumped in borated paraffin shielded Ta Faraday cup 4.5 m down stream from the target. Time of Flight (TOF) method was used to measure the energy of neutrons (Figure1) as well as the velocity of fission fragments. RF signal from the beam buncher was used as the time reference. For coincidence between any neutron detectors with any fission fragment detectors, the arrival times for neutrons and fission fragments were recorded with respect to the timing signal from the beam buncher. Neutron TOF spectra was collected by setting a cutoff of neutron energy of about 0.5 MeV by measuring the maximum Compton electron recoil energy using different gamma ray sources. Pulse shape discrimination technique (Figure 2) was adapted for rejecting gamma rays detected by neutron detectors. CAMAC based data acquisition system was used to collect 60-parameter list mode data. The detailed analysis of the data is still on progress.

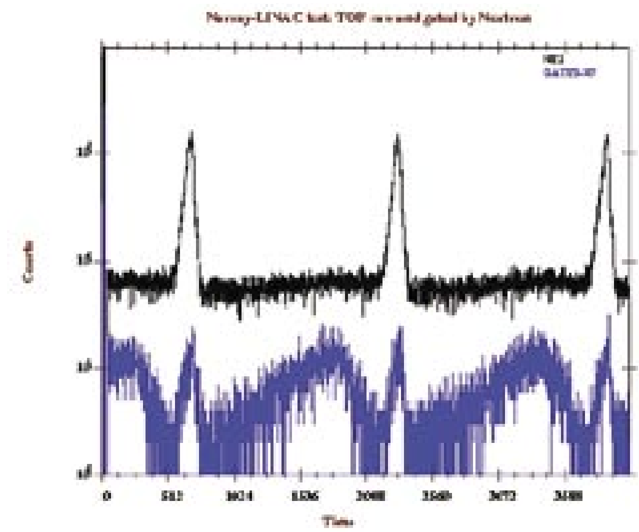


**Fig.1. Time of flight spectrum from neutron detector; Black curve is the raw spectrum and blue with neutron gating from PSD spectrum.**

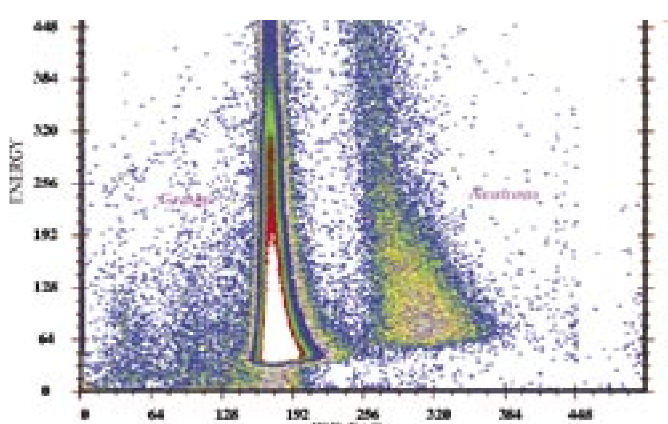



**Fig.2. PSD TAC vs. Energy spectrum showing clear separation of neutron from gamma**

## Materials Science

Recently, the ferromagnetism in irradiated fullerene films using magnetic force microscopy (MFM) and superconducting quantum interference device (SQUID) was reported. Figure 1 shows the curves of magnetization versus applied field recorded for the pristine and 92 MeV Si ion irradiated fullerene films at different fluences at 15 K. All samples exhibit a dual magnetic response composed of a weak ferromagnetic signal and a diamagnetic signal. The ferromagnetic contribution increasing with the ion fluence, gives clear evidence of ferromagnetic signal in irradiated films. PIXE was performed to eliminate the possibility of the ferromagnetic behavior due to the magnetic impurities.

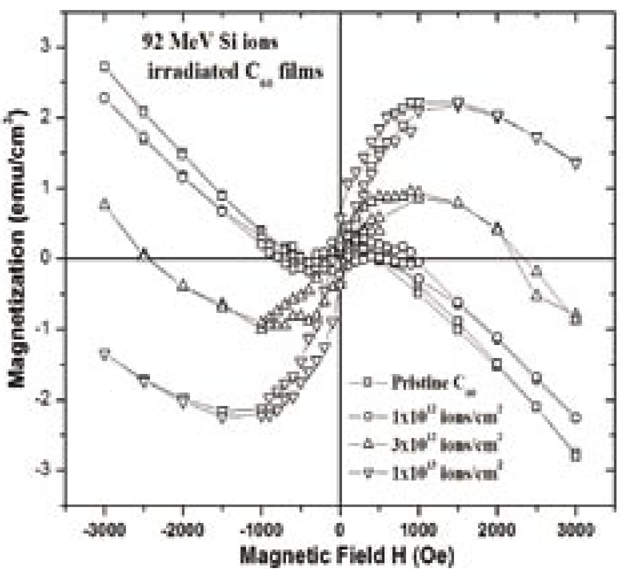



**Fig.1. Magnetization measurements on 92 MeV Si ion irradiated C60 film (at indicated fluences) at 15 K.**

The MFM pictures of pristine and irradiated films are shown in figure 2. The scan area was 1x1 μm$^2$ and the tip at 20 nm height from the surface. The study of the fullerene irradiated by different ions and energies (150 KeV - 200 MeV ) revealed that the electronic excitation has higher efficiency of creating magnetization than that of collision cascade.

The vacuum chamber for in-situ XRD set up was fabricated at the workshop of IUAC. This XRD chamber consists of two windows sealed with Kapton foil, for incident and reflected X-rays. It was interfaced to the goniometer and the beam line using two gate valves and a bellow. Figure 3 shows the in-situ X-ray diffractometer at materials science beam line in beam hall-II.

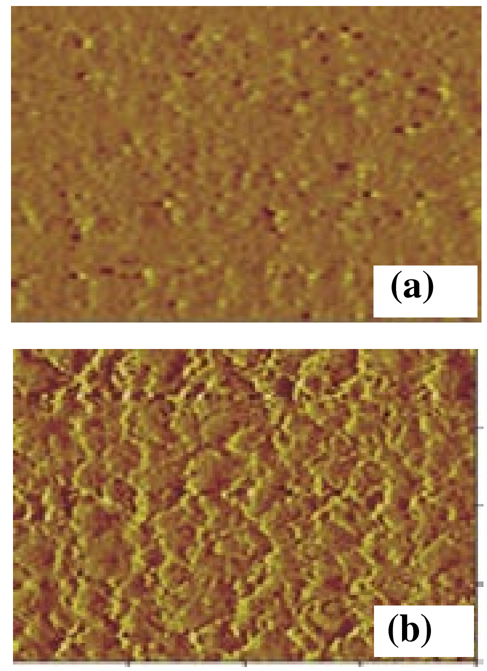



**Fig.2. Magnetic force microscopy images of (a) pristine and (b) ion irradiated fullerene films at a fluence of 1x10$^{12}$ ions/cm$^2$.**

**Fig.3. In-situ X-ray diffractometer at materials science beam line at beam hall-II.**

The test of in-situ XRD was done using 90 MeV Ni ion beam. Thin films (140 nm) of silica embedded with gold nanoparticles on quartz substrates was irradiated with 90 MeV Ni ions in the vacuum chamber of in-situ XRD set up. Vacuum inside the XRD chamber was achieved with the help of a rotary and turbo molecular pump and it was ~ $10^{-5}$ torr during irradiation. The XRD spectra were recorded in the step of fluence of 2 x $10^{13}$ ions $cm^{-2}$ using the Vantec detector. A continuous decrease in FWHM in the XRD spectra is observed with fluence indicating the growth (4 nm to 9 nm) of nanoparticles with ion fluence.

A $\Delta$E-E telescope detector along with dedicated electronics is installed in the phase II beam line of materials science. It is fixed to a 45° port of a high vacuum chamber in Materials Science beam line as shown in Fig. 4.

The detector offers the possibility to discriminate C, N, O and other light masses (which otherwise is not possible

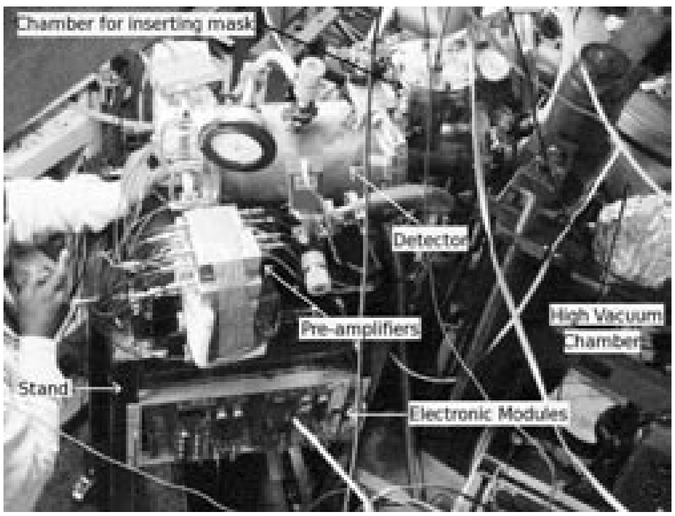



**Fig.4. A photograph of the telescope detector with its support electronics fixed on its movable stand. Also shown here is the gas handling set up and the intermediate chamber for inserting a position calibration mask.**

by single conventional semiconductor detector). The $\Delta E_2$ segment has been converted into backgammon structure to derive directly the horizontal coordinate (x) of each event. The x-position resolution derived using the mask is around 1.4 mm, which translates into angular resolution of 0.1°. The knowledge of this position coordinate is useful in correcting the kinematic broadening of the detector (~17% in the present ERD geometry due to its large acceptance angle of ±2.4°) by the application of kinematic correction.

The detector is being used in ERDA experiments. On-line monitoring of stoichiometric changes allows one to study changes with fluence using just one sample, which eliminates the effects due to thickness variation in different samples during film deposition. Another advantage is that the data can be further analyzed for smaller fluence intervals (statistically permissible), once it has been recorded in list mode for a large fluence.

The project 'intensifying research in high priority areas' on 'Swift heavy ions in materials engineering and characterization' funded by department of science and technology has been completed successfully in Oct. 2006.

## Workshops and schools at IUAC (April – October, 2006)

A workshop on "Cryogenic Science and Technology in India : Present & Future" was held on April 10- 11, 2006 at IUAC in collaboration with Indian Cryogenics Council. The objective of this workshop was to review the current status of Research & Development in the field of cryogenics and low temperature physics being pursued in leading research and academic institutions and the cryogenic Industry in India. There were about 100 participants from Universities, Scientific labs (DAE, ISRO, CSIR) and Industry. Workshop was inaugurated by Dr. Vikram Kumar, Director National physical Laboratory and Key note address on " Role of Cryogenics for Indian Atomic Energy Programme" was delivered by Dr. B. Bhattacharjee, Special Adviser of Chairman DAE.

A Workshop on Physics with Accelerators (in honour of Dr. S.K. Datta, Senior Scientist, IUAC, on his completion of 60 years) was organized on April 21 to focus on some of the recent technological developments and researches in the fields of Nuclear Physics, Materials Science, Atomic Physics, and accelerator mass spectroscopy as a result of development of Accelerators and subsequent availability of precisely controlled ion beams of high energy.

A School on Radiation Biology titled "First National School on Biological Effects of Ionizing Radiation: Cellular and Molecular Approaches" was organised during June 4-9, 2006. 22 participants including two from Nepal, and 5 outstation faculties participated.

A five day School on X-ray techniques in Materials Science was held in June 2006 at IUAC. Lectures were given on the scattering, emission and absorption properties of X-ray radiation, most commonly X-ray based techniques used by materials scientists such as X-ray diffractometry (XRD), X- ray reflectivity (XRR), Small angle X-ray scattering (SAXS) and X-ray fluorescence (XRF) spectrometry and their applications in swift heavy ion (SHI) induced materials modification. Around 50 participants from several Universities and Institutes attended the school.

A two day workshop on Nuclear Physics with LINAC beam was held on September 14-15, 2006 in which faculty members were invited to present proposals for possible experiments utilising the higher energy ion beams from the LINAC and the recently installed HYRA, neutron array and upcoming INGA facilities. Participation of students in the installation cum testing phase of facilities was encouraged for providing hands-on experience. Auxiliary facility requirements to increase the selectivity of reaction channel were also discussed in the workshop. There were 59 participants from 22 Universities and Institutes.

Functional oxide materials such as high-Tc superconductors, colossal magneto resistance (CMR), spintronics, ferrites, ferroelectric and multiferroic materials are of great interest from fundamental physics as well as application point of view. A workshop was organized on Sept. 25-26 to consolidate the earlier research works carried out at IUAC and provide a platform to formulate focussed group proposals using swift heavy ion irradiation on functional oxide materials. There were 46 participants from 19 Universities and Institutes.

Understanding of Nanostructures and tuning their properties is both interesting and challenging. Hence, a Workshop on Nanotechnology with ion beams and possible applications was organized on Oct. 31 and Nov.1, where around 70 participants came from 22 Universities and Institutes. The topics covered were Ion beam synthesis of embedded nanoparticles with low energy ions, Creation of nanodots and nanoripples by energetic ions, Synthesis and modification of nanostructures by swift heavy ions, Ion track technology, Self-organization of surfaces and thin films by sputtering and diffusion processes, synthesis by plasma assisted or sputtering deposition techniques, applications in medical, biological and interdisciplinary areas. There were twenty one invited talks, ten oral presentations and twenty four posters.

Apart from these there was a Acquaintance Programme at Kolkata which was organized by IUAC. One more in Coimbatore will be held on December 1.

## Status of 15UD Pelletron (April 1 to October 31, 2006)

Operation of Pelletron was quite satisfactory from 1st April 2006 to 31st October 2006. There was no major breakdown for this period. There was only one scheduled tank opening for routine maintenance of Pelletron. This maintenance took place in the month of June 2006 and it included routine maintenance jobs like, terminal foil stripper loading, column support post and accelerating tube resistors maintenance, charging system maintenance, in-tank ion pump maintenance and maintenance of rotating parts inside tank. Apart from routine maintenance jobs, few other problems related to working controllers of offset quadrupole and gas stripper, were rectified. Fibre optic cables, used to control the operation of devices in terminal and high energy dead section area, got damaged in the month of March 2006. All of these fibre cables were repaired using indigenously developed mechanical splicers. All of the cables could not be repaired but these repaired cables worked upto satisfaction for the proper operation of Pelletron. In June scheduled maintenance, these repaired fiber cables were replaced by new one.

Maximum terminal voltage achieved during high voltage conditioning was 14.3 MV. $^{19}F$ pulsed beam (162 MeV) was delivered to user at the maximum terminal potential of 13.37 MV. Out of total beam time of 2579 hours, 714 hours were used for pulsed beam runs using multi harmonic buncher (MHB).

$^{16}O$, $^{19}F$, $^{28}Si$ and $^{40}Ca$ beams were bunched for different experiments. Chopper and traveling wave deflector were also used, along with MHB, in case of $^{16}O$, $^{19}F$ and $^{40}Ca$ bunch beams and high energy sweeper was used, along with MHB for $^{28}Si$ bunch beam. $^{40}Ca$ beam was delivered to user for the first time and this run lasted for 144 hours.

130 MeV of $^{28}Si$ bunch beam was injected into LINAC. This beam was then further accelerated by LINAC to get energy boost of 20 MeV. This accelerated beam from

LINAC was then tuned upto GPSC chamber of beam hall - II for the first experiment using LINAC accelerated beam. All the pulsed beam runs were quite stable.

Ion source test bench is operational and a new electrostatic quadrupole and a steerer were installed for the improvement of beam optics. Effect of these newly installed components was tested with $^{28}Si$ beam. Beam currents from ion source were observed at different parameters of newly installed quadrupole and steerer and observed that these components play major role in increasing the beam transmission. The quadrupole was operated in doublet as well in triplet configuration and beam transmission was maximum in triplet configuration. Beam spot of ~3 mm to 5 mm was also seen on CsI crystal, mounted on target ladder in the experimental chamber.

The uptime of machine for this period was 98.68%. The beam utilization time was 59.68%.

## Statistical Summary

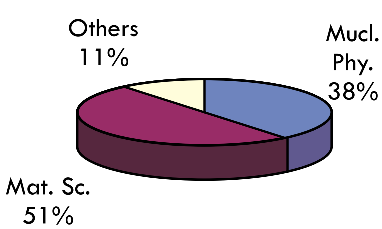
| | |
|---|---|
| Total Chain Hours = | 4321 Hrs. |
| Beam utilization time = | 2579 Hrs. |
| Beam change time = | 7 Hrs. |
| Machine Breakdown time = | 57 Hrs. |
| Machine scheduled maintenance = | 792 Hrs. |
| Accelerator conditioning = | 1678 Hrs. |

## User List

April – October, 2006

| University/ Institute | No. of shifts utilized |
|---|---|
| Agra University | 07 |
| Anna University, Chennai | 10 |
| Bangalore University | 03 |
| BH University, Varanasi | 03 |
| Calcutta University | 14 |
| Dayalbagh Institute, Agra | 05 |
| Delhi University | 21 |
| G Gh. University, Bilaspur | 02 |
| GND University, Amritsar | 03 |
| Gulbarga University | 03 |
| H P University, Simla | 07 |
| HNB Garhwal University | 03 |
| IIT, Delhi | 09 |
| IIT, Roorkee | 15 |
| IOP, Bhubaneswar | 12 |
| ISRO | 02 |
| IUAC, New Delhi | 70 |
| IUC, Indore | 05 |
| Karnataka University | 24 |
| Kurukshetra University | 05 |
| MD University, Rohtak | 01 |
| MSU, Baroda | 03 |
| Mumbai University | 02 |
| NEHU, Shillong | 02 |
| Pune University | 05 |
| Punjab University | 21 |
| Rajasthan University | 10 |
| Ratnagiri College, Maharashtra | 03 |
| S N College, Kerala | 02 |
| Saurashtra University | 03 |
| SINP, Kolkata | 12 |
| Stuttgart University, Germany | 04 |
| Tezpur University | 06 |
| U P Technical University | 03 |
| Utkal University | 03 |

FIELDWISE BREAKUP OF UTILIZED BEAMTIME (APRIL - OCTOBER, 2006)




USERWISE BREAKUP OF UTILIZED BEAMTIME (APRIL - OCTOBER, 2006)