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Acceleration of seven ion beams from ^{12}C to ^{108}Ag through LINAC

The superconducting linear accelerator (LINAC) of Inter University Accelerator Centre (IUAC) will consist of five cryomodules (figure 1), viz. the superbuncher (SB) housing a single quarter wave resonator (QWR), the next three linac cryomodules housing eight QWRs each, and the last one having two QWRs used as rebuncher/debuncher (RB). At present, the SB, the first linac module, and the RB are operational.

In the past, several cold tests of the first Linac module were carried out. Beam acceleration was also demonstrated on a few occasions and the accelerated beams were delivered for experiments. But during the last operation in April-May 2009, it was the first time when all the eight accelerating resonators were active in the acceleration process of the ion beam. A variety of ion beams were accelerated and delivered for user experiments. Table 1 lists the different beams, the energy gains (both from the Tandem and the Linac) and the time widths at the entrance of Linac and at the target location. Rebunching of the ion beams with a time waist at the target location was performed for three beam species as per the requirement of the experiments. In the other cases, the rebuncher cavity was not operated. The energy gain obtained from the first accelerating Linac module was in the range of 2.5 to 3.5 MeV per charge state, the lower range of the energy gain was dictated by the energy requirement of the experiments.

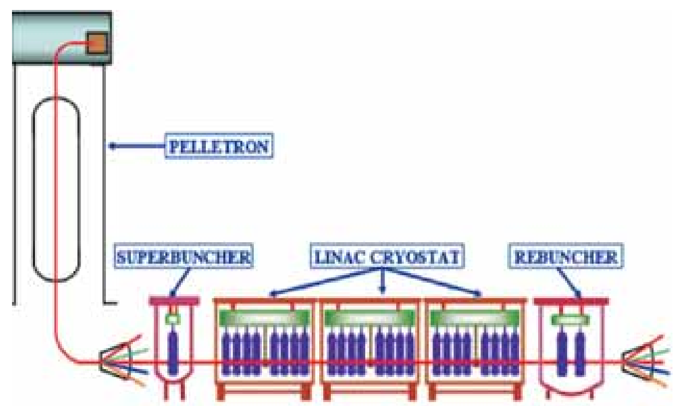


Fig. 1. The schematic of the Pelletron and the superconducting linear accelerator of IUAC

Besides a few problems encountered during the entire duration of one and half months, the whole operation was fairly smooth. However, occasional unlocking of the Linac resonators and re-locking them locally had forced us to expedite the automation of the linac operation. Already the remote operation of the phase locking of the resonators had been demonstrated successfully. The developments in the other parts of the Linac automation are also progressing well.

The second and third accelerating modules are in the final stage of commissioning and they will be integrated in the beam line by the end of this year. The cold test of the entire Linac is expected to begin around the spring of 2010.

Table 1: Ion Beams accelerated through Linac

Beam	Energy from Tandem (MeV)	ΔT at SB (ps)	Energy gain from Linac (MeV)	ΔT (RB) at Target (ps)
${}^{12}C^{+6}$	87	250	19.2	OFF
${}^{16}O^{+8}$	100	163	18	342
${}^{18}O^{+8}$	100	182	20	378
${}^{19}F^{+9}$	115	190	25.8	354
${}^{28}Si^{+11}$	130	182	37.5	OFF
${}^{48}Ti^{+14}$	162	176	51.2	OFF
${}^{107}Ag^{+21}$	225	232	74.6	OFF

Beam Transport System for HCI

The High current injector (HCI) consists of an ECR ion source producing highly charged ions, Radio Frequency Quadrupole (RFQ) and Drift Tube LINAC (DTL) to inject beams with $A/q \leq 6$ of 1.8 MeV/u into LINAC. The beam transport System for HCI consists of three parts:

i) Low enrgy Beam Transport (LEBT) which extends from ECR to RFQ.

ii) Medium energy Beam Transport (MEBT) from RFQ to DTL and

iii) High energy section (HEBT) from the exit of DTL to entrance of LINAC.

The beam optics from ECR to entrance of LINAC has been simulated to transport beam with minimum loss and longitudinal phase has been maintained by placing bunchers at appropriate location. This transport line (~ 40meter) consists of four bends and all the bends have been designed in momentum achromat mode. The layout of different components has been designed.

Copper plating of Prototype RFQ

The stainless steel chamber of the prototype Radio Frequency Quadrupole (RFQ) was successfully copper plated by a local vendor. A plating thickness of more than 100 m was achieved and low power RF measurements were made. The Q value of the cavity improved from 1200 to 3200 and the shunt impedance changed from 28.4 kΩm to 82.1 kΩm on Cu plating. This implies that the RF power required to achieve the design voltage would reduce from 86.2 kW to 29.9 kW.

Fig. 1. Copper plated prototype RFQ chamber

Development of Drift Tube LINAC

The DTL for the High Current Injector Project has been designed to accelerate ions from 180 keV/u to 1.8 MeV/u, using six IH type RF resonators operating at 97 MHz. The beam dynamics and generation of the drift tube geometry is done using the LANA code. The electrical design of the first resonator tank has been done using CST Microwave Studio. Frequency and electric field profile measurements have been done on a full size prototype resonator.

Prototype IH DTL Development

The prototype is fabricated using SS304 material. Flanges and all ports are welded in and the vacuum test was carried out successfully. The cavity has an inner diameter of 85 cm and length of 38 cm after final fabrication. The ridges which hold the stems of the drift tubes are made from aluminium, and the stems and drift tubes are made from copper as well as aluminium. The 11 gap IH structure has 10 drift tubes, each supported alternately from top and bottom. The machining of the ridges, stems and drift tubes has been done using the in house CNC vertical milling machine. Provision for water cooling has been made in each of the stems as well as the end walls of the cavity. Low power RF tests were conducted on the prototype cavity.

Fig. 1 Prototype resonator with one end-plate removed

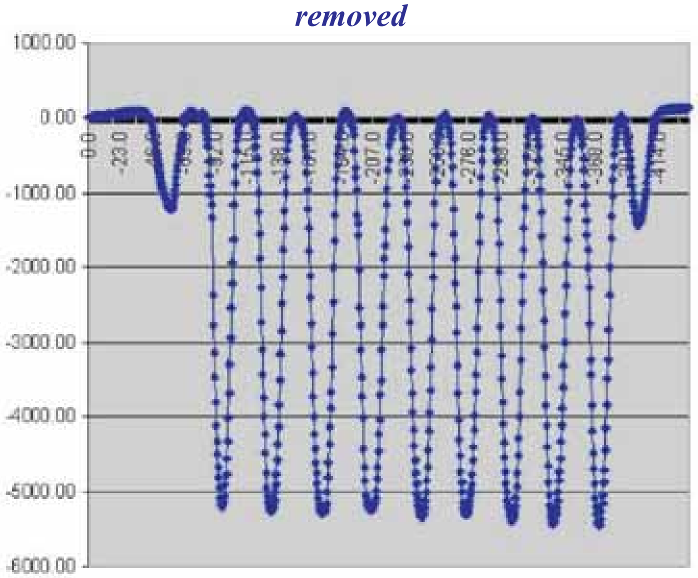


Fig. 2 Result of Bead-Pull test showing the Electric Field profile

For determining the various parameters, bead pull tests and network analyzer based measurements were carried out. The measured resonant frequency of the prototype was near 98 MHz and it was brought to the design value of 97 MHz by using a tuner plate on one side. A bead pull test was done to measure the electric field profile along the beam axis. A sapphire bead was pulled along the beam axis of the cavity and the resonant frequency measured. The shift of the resonant frequency caused by the presence of the bead is proportional to the electric field at the position of the bead. It was seen that even though the uniformity of the electric fields in the central gaps has been achieved to a large extent, the end gaps have a smaller field than expected. This discrepancy can be explained by the end gaps that were larger than specified due to manufacturing issues, and will be corrected in the final tank.

Accelerator Mass Spectrometry Activities: April - Oct. 2009

IUAC AMS facility for the measurement of ^{10}Be is in operation and has been utilized by various user groups. Now efforts are made to detect ^{26}Al from standard Al sample procured from University of California, Berkley USA. In the last experiments, ^{26}Al from the standard sample was detected. The blank value (sensitivity) was found to be 7.44E-14. Future experiments will be conducted with geological samples.

Ultra-clean chemistry lab for the processing of the geological samples is under development at IUAC. The lab will be metal free with a positive pressure of 10000 class air and equipped with all modern facilities. Laminar Flows stations of 100 class air environments will be utilized for performing the column chemistry. Chemistry lab will have its own water and acid purification units.

Status of INGA (Indian National Gamma Array)

The Indian National Gamma Array (INGA) was installed at the new beam hall of IUAC in early January, 2008 and regular user experiments started from Feb 28. During the first Cycle of INGA operation (Feb 2008 - July 2008) fifteen user experiments were conducted. This was followed by three students' Ph.D. thesis experiments in Oct, 2008. Some of the interesting problems that were addressed during these experiments were (i) search for band termination in magnetic rotation band in A~140 region (ii) role of proton and neutron orbits in magnetic rotation for A ~ 137 nuclei (iii) high spin structure in ^{112}In and search for chiral bands (iv) spectroscopy of magnetic rotation bands near Z~64 N~82 shell closure (v) spectroscopy of neutron-rich nuclei near ^{132}Sn produced by heavy-ion induced fission (vi) spectroscopy of trans-lead nuclei $^{210-212}$Ra, $^{208-211}$Fr and (vii) study of octupole correlation in $^{239-241}$Pu, $^{237-240}$Np.

The second cycle of experiments using INGA setup that started from May, 2009, has now been completed. Fifteen experiments were taken up during this period. Many of the experiments were aimed at studying the life times of M1 bands. An experiment to measure lifetimes in ^{102}Rh has been completed in collaboration with INFN group, Italy to test chiral behaviour in nearly degenerate M1 bands. A number of isomeric levels in Pr isotopes have been identified.

We are planning to have an extensive shutdown in beam hall II for a period of one year for the installation of LINAC components. The second phase (vacuum mode mass identification) of HYRA would also be installed during this period. It would be possible to do experiments with INGA-HYRA combined setup with higher beam energies next time the INGA facility is used at IUAC.

GEM Global Event-identifier Module

A module to simplify the electronics for event identification (in terms of multiplicity) as well to enhance the event rate of the actual events of interest has been developed. It replaces the following existing modules by combining their functionality in a single width CAMAC module.

Trigger Generator / Reader.
Bit Pattern Module (Phillips 7106).
Summing Module (Phillips 744).
Discriminator Latch (Phillips 711).
Coincidence Unit (ORTEC CD 4010)
Fan In/ Fan Out (ORTEC LF 4000).
Delay module. (ORTEC GG 8010).
Level Translator (ORTEC LA8000)
One NIM crate

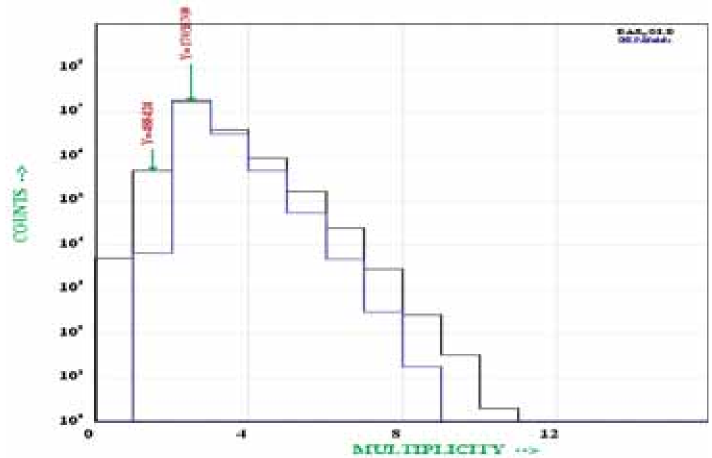


Fig. 1 Multiplicity comparison GEM Vs OLD DAS

Features:

- 12 input Hit Pattern. User settable re stretched inputs from 50 ns to 5 µs in steps of 10 ns.
- Four modules can be cascaded in Master-Slave mode connected using standard ether net UTP (CAT5) cables.
- Four Programmable width (50ns to 5us in steps of 10ns) multiplicity outputs from 48 signals.
- Any of the multiplicity output may be used as veto input through remote commands.
- **Time Stamp** with 10ns resolution and 32.5 days range.
- Facilitates **multi strobed data acquisition systems** with time tag.

HYbrid Recoil mass Analyzer (HYRA)

HYRA has been used with its first stage operated in gas-filled mode. Initially, it was used to detect evaporation residues in Calicut university student's thesis work. The beam rejection factor was better than 10^{12} and the experimentally extracted evaporation residue transmission efficiency is comparable with that of Dubna Gas-filled separator for similar kinematics, though a smaller focal plane detector has been used with HYRA. Subsequently, it has been used to efficiently select the target-like elastic recoils at 0^o in a test experiment using pulsed ^{48}Ti beam (boosted to 213 MeV by first module of superconducting LINAC accelerator with 2 microsecond pulse separation) and natural Pb target. Beam rejection factor was better than 10^{13} and the transmission efficiency was experimentally determined to be constant over a change of 15 MeV beam energy. The spectra shown below, of energy loss signal in MWPC (x-axis) versus total energy of heavy elastic recoils in 2D silicon detector (y-axis) at focal plane from thick natural Pb target (Fig. 1a) and corresponding beam background from aluminium target (Fig. 1b) collected for similar duration, clearly demonstrate the selection of elastic recoils (in Fig. 1a) and beam rejection capability of HYRA at 0^o in gas-filled mode (through Fig. 1b). The fabrication of electrostatic dipole for the second stage has been completed and it is expected to be shipped by this year end, after acceptance tests.

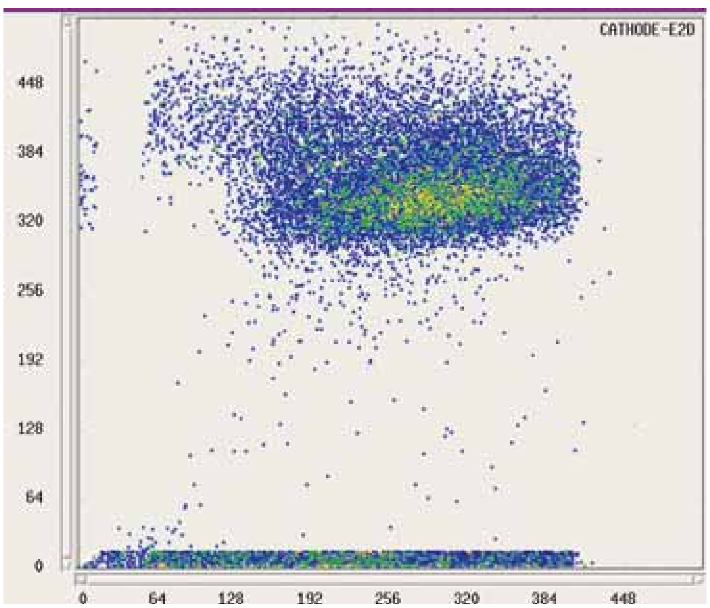


Fig. 1a Energy loss versus total energy of selected heavy elastic recoils from ^{48}Ti on thick natural Pb, at 0^o

Workshop on "Physics with HYRA"

A two-day workshop on "Physics with HYRA" was held on May 29 and 30, 2009 at IUAC. Nearly 35 outstation participants, 15 students and several IUAC staff attended the workshop. There were 11 experimental proposals, mostly from young faculty members from universities and institutes, out of which 10 were presented and discussed at length. In the subsequent July AUC meeting, the updated proposals were presented again and have been sanctioned beam time. Four experiments propose to study fusion cross-section, three for focal plane isomer decay and one each for exclusive GDR, 180^o quasi-elastic scattering and pairing/clustering effect, the last using vacuum momentum achromat mode of first stage. Next set of HYRA experiments using gas-filled mode and facility test of momentum achromat mode with beam are planned to begin in early January 2010, after accelerator maintenance.

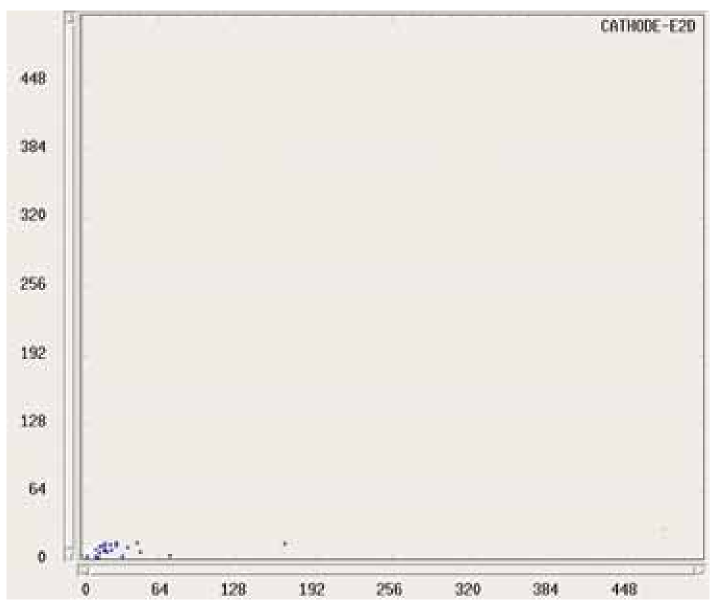


Fig. 1b Energy loss versus total energy for ^{48}Ti on ^{27}Al but with HYRA set as in Fig. 1a; Focal plane is free from beam background

Heavy Ion Reaction Analyzer (HIRA)

HIRA has been used to study transfer around barrier in $^{28}Si + ^{90,94}Zr$ as part of Delhi University student's thesis work using HIRA. Kinematic coincidence technique was employed with target-like nuclei separated from beam and mass dispersed by HIRA around 6^{o} and identified by two-dimensional position sensitive MWPC in coincidence with back scattered projectile-like nuclei detected in a position sensitive silicon detector around 162^{o}. The spectrum (Fig. 2), X-MWPC vs. (T_0-TOF), shows excellent separation of multi-nucleon transfer channels (up to 4 nucleon pickup and 2 nucleon stripping) from elastic channel. M/q ambiguity is clearly resolved in this two-dimensional spectrum with each charge state group distinguishable from the rest.

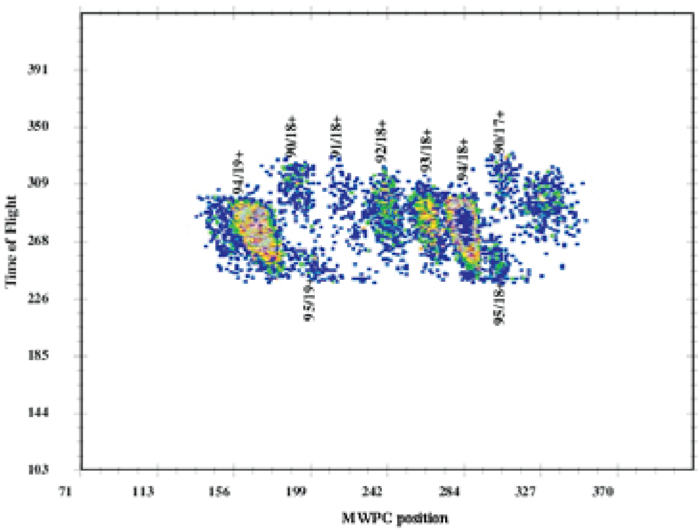


Fig. 2 Position at focal plane (M/q) versus (T_0-TOF) for ^{28}Si (97 MeV, 2 microsecond pulse separation) on ^{94}Zr; M/q ambiguity is resolved and so are the transfer channels

Materials Science Activities

A scanning electron microscope (SEM) from TESCAN, with field emission gun has been installed to boost research activities in nanomaterials, in a project funded under Nano Initiative program of Department of Science and Technology. It has a secondary electron detector and a backscattered electron detector for imaging and energy dispersive X ray detector (from OXFORD) for elemental analysis.

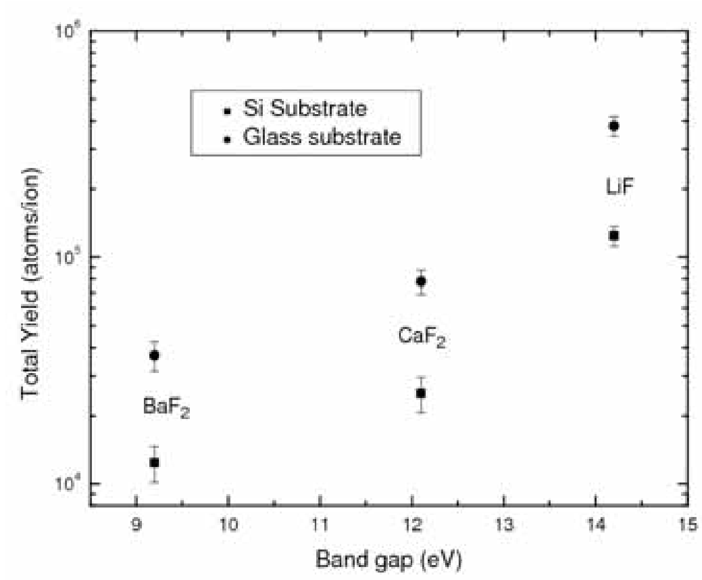


Fig. 1 Dependence of electronic sputtering on the band gap of the halide thin films

Experiments on electronic sputtering of halide thin films have shown that the electronic sputtering is highest for LiF, followed by CaF_2 and BaF_2. Figure 1 shows the sputtering yield under swift heavy ion impact for these three halide thin films on two different substrates. Thermal spike model is invoked for explanation of the results.

An Indo-French conference on 'Nanostructuring by ion beams' was organized at Bhubaneshwar from 26th Feb. to 1st March, sponsored by Indo French Centre for Promotion of Advanced Research, New Delhi, to highlight the role of ion beams in the field of nanostructures. Dr. J.C. Pivin, CSNSM Orsay and Dr. D.K. Avasthi, IUAC Delhi were the conference chairs.

Workshops /Schools/Acquaintance Programs (April - October, 2009)

A two days workshop on **"Materials Science and Atomic/Molecular Physics Experiments using the Low Energy Ion Beam Facility (LEIBF)"** was held at IUAC during 9-10 July 2009. The aim of this workshop was to use the full potential of LEIBF in interdisciplinary research fields. New and internationally competitive research proposals from various universities/research institutes were received for this purpose. The accepted proposals were reviewed and discussed for beam time sanction and 27 such research proposals were approved for beam time allotment.

A one day workshop on **"Surface and Interface"** was held at Allahabad University which was organized by IUAC in March 2009. Ion beam induced modification of material is one of the main areas of research at IUAC. Energetic heavy ions deposit large energy density in a nanometer sized zone in picosecond time scales, leading to materials modifications. This large energy density deposition due to electronic and nuclear energy loss results in surface modification, re-construction, electronic sputtering and ion beam mixing. The workshop reviewed the work done on these effects at IUAC and discussed future possibilities.

Another workshop on **"Oxide Materials"** was held at Aligarh in May 2009 which was organized by IUAC in collaboration with Dept. of Applied Physics AMU, Aligarh. The research on the thin films and nanostructures of oxide materials has driven a lot of research interest due to the multifunctional applications of these materials. The workshop focused on the swift heavy ion (SHI) irradiation induced engineering and modifications of the materials for advanced functional applications. The workshop mainly emphasized on the use of SHI irradiation to tackle the challenges for the further progress of research.

One more workshop titled **"Simulation Studies and Large Scale Computing"** was recently held at IUAC on 31st October, 2009 which was aimed at providing a platform for interaction between experts and potential users of large scale computing and simulation in the areas of materials science, atomic and molecular physics, nuclear physics and radiation biology.

A one day **Acquaintance Programme** of IUAC at the National Institute of Technology **Rourkela** was held on November 21 2008. Dr. D. Behera from the Department of Physics, NIT Rourkela coordinated the Programme. Approximately 60 participants comprising of faculty members, research scholars and students from the neighbouring colleges and institutions attended the programme. Possibilities of experimental research at IUAC in the fields of materials science and nuclear physics were discussed at length. The Programme ended with an open discussion with the participants**.** Similar programmes were held this year at **Manipur** (May 2009), **Hissar, Udaipur** and **Vellore** (all in Oct. 2009). Topics related to Nuclear Physics, Materials Science and Radiation Biology were discussed which generated a lot of enthusiastic response from the participants. The participants warmly interacted with the IUAC resource persons and expressed their interest on ion irradiation research work.

Status of Teaching Lab: Computer interfaced science experiments based on Phoenix is now being used by some of the Universities. Two training programs on Phoenix were conducted at IUAC, New Delhi, one at Western Region Instrumentation Centre, Mumbai. One Malaysian University, UPSI, acquired Phoenix hardware and conducted a 4 day workshop. Several new experiments have been developed. Those who are interested in information about training programs may join the mailing list by registering at the website www.iuac.res.in

Status of 15 UD Pelletron (April 1 to October 31, 2009)

Operation of Pelletron was quite satisfactory from 1st April to 31st October 2009. There was no fresh tank opening maintenance in this period, although 130 hours of maintenance was used as an overflow of March 2009 scheduled tank opening maintenance. There was a short maintenance for four days from 5th to 8th October 2009. Routine maintenance of MC-SNICS ion source and maintenance of Traveling Wave Deflector (TWD) were carried out in this maintenance.

Complete MC-SNICS source was dismantled and cleaned thoroughly. It was assembled again and aligned with the help of alignment jig after cleaning. Five gm of fresh Cesium was also loaded in cesium reservoir. A resistor of einzel lens was repaired. Cleaning of HV deck and GP tube was done. HV conditioning of GP tubes was also carried out. One of the switching banks of TWD was loading power supplies (+200Vdc and -200Vdc). These power supplies play an important role for changing the repetition rate of chopped beam. Two switching channels of this faulty bank were repaired to solve the problem. Compressed air line of pneumatic devices was modified by introducing an extra valve in between, so that the device can be isolated from main compressed line. This is quite useful during the maintenance.

Maximum terminal voltage achieved during high voltage conditioning was 14 MV. ^{107}Ag (225 MeV) and ^{27}Al (128MeV) beams were delivered to users at a maximum terminal potential of 12.82 MV and ^{11}B beam

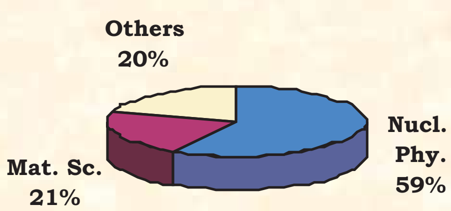
(36 MeV) at a minimum terminal potential of 7.18 MV. Out of total beam time of 3151 hours, 1284 hours of beam time was used by INGA users and 815 hours were used for pulsed beam runs using multi harmonic buncher (MHB) along with low energy chopper and TWD. 538 hours of total pulsed beam was delivered to users, after boosting beam energies using LINAC. Energies of ^{12}C, ^{16}O, ^{18}O, ^{19}F, ^{28}Si, ^{48}Ti and ^{107}Ag were boosted by using LINAC. ^{12}C and ^{28}Si beams were bunched for different experiments for remaining 277 hours of pulsed beam. All the pulsed beam runs were quite stable.

The uptime of machine for this period was 99.69% and the beam utilization was 74.56%.

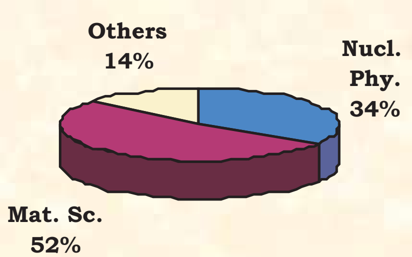
Statistical Summary

Total Chain Hours	=	4226 Hrs.
Beam utilization time	=	3151 Hrs.
Beam change time	=	7 Hrs.
Machine Breakdown time	=	13 Hrs.
Machine scheduled maintenance	=	130 Hrs.
Accelerator conditioning	=	924 Hrs.
Beam tuning time	=	134 Hrs.
Experimental setup time	=	17 Hrs.

FIELDWISE BREAKUP OF UTILIZED BEAMTIME (APRIL - OCTOBER, 2009)



USERWISE BREAKUP OF UTILIZED BEAMTIME (APRIL- OCTOBER, 2009)



User List: April to October, 2009

University / Institute / College	Shifts utilized
AM University, Aligarh	10
Bangalore University	02
Bareilly College	2
BH University, Varanasi	18
Bhartidasan University	03
Calcutta University	20
Calicut University	15
Delhi University	29
GBPant University	02
GNDU, Amritsar	06
Gujarat University	03
Guwahati University	02
Himachal Pradesh University	03
HNB Garhwal University	02
Hyderabad University	05
IIT, Delhi	05
IIT, Mumbai	09
IIT, Roorkee	09
Istanbul University, Turkey	02
IUAC, New Delhi	102
JMI, Delhi	04
Kashmir University	03
Kurukshetra University	04
Kuvempu University	03
LNL-INFN, Italy	09
Manipur University	02
MMH College, Ghaziabad	03
MNIT, Jaipur	02
MSU, Baroda	15
Pondichery University	03
PRL, Ahmedabad	16
Punjab University	41
RBS College, Agra	02
SINP, Kolkata	27
SV College, Aligarh	03
Tezpur University	04
TIFR, Mumbai	09
VECC, Kolkata	09