Executive Summary:

The experimental nuclear physics programs have been carried out extensively during this year using the light ion beams from K-130 cyclotron at VECC, Kolkata and with different state of art detection system available at this centre. Several developmental activities have been also taken up for the facility development of K-130 cyclotron and superconducting cyclotron. Significant progress towards this direction has been achieved.

Collaborative studies between BARC and VECC on radiation damage using ion beam from Variable Energy Cyclotron and ECR ion sources at VECC, are being carried out on different nuclear structural materials.

Radioactive ion beam of Oxygen-14 (half-life 71 sec) was recently accelerated through RFQ linac to energy of 1.4 MeV at VECC. Typical intensity of the beams was around 3000 particles per second. This is first acceleration of radioactive ion beams in the country. RFQ or radio frequency quadrupole is the most suitable machine for accelerating low energy heavy-ion beams and has been indigenously designed and built for the first time in India by VECC for the Radioactive Ion Beam (RIB) facility project. Apart from $^{14}$O, low energy RIB of $^{42}$K (12.4 hrs), $^{43}$K (22.2 hrs) and $^{41}$Ar (1.8 hrs) have also been successfully produced.

The phase control loop for the 3-phase RF System of K500 Superconducting cyclotron was upgraded that improved the performance of the phase stability of the system. A novel high voltage power supplies was developed and installed for the electrostatic ion beam deflector for the ECR system.

In line with various accelerator programmes of DAE, R&D on development of multi-cell medium-$\beta$ Superconducting RF linac cavity had been taken up at VECC. In this respect, state-of-the-art Inductive Output tube (IOT)-based high power RF amplifier was developed and tested. The supervisory system was indigenously developed as were the required biasing power supplies with fast protection circuits placed inside a HV deck specifically designed for the purpose.

The power conditioning system for the prototype Superconducting Magnetic Energy Storage (SMES) System was developed and tested prior to integration to the main system and the conceptual design of the 5MJ SMES coil was taken up.

Cryogenic Plant and Instrumentation Section is responsible in running two liquefiers in tandem – one as refrigerator for providing liquid helium to the superconducting cyclotron and other as liquefier for producing liquid helium to other projects.

A prototype of a Variable Temperature Insert (VTI) has been developed in-house, which was put in a glass cryostat. This is used as a cryogenic thermometer calibration facility commissioned in fulfillment of the very stringent requirements on the temperature control of the cryogenic systems. The calibration facility is designed for calibrating industrial cryogenic thermometers that include a temperature sensor and the wires heat-intercept in the 2.2 K to 325 K temperature range. The calibration facility is operated in an automatic mode by a cryogenic temperature controller which can be programmed by a computer. The isothermal section of the calibration block onto which the thermometers are mounted is weakly linked with the temperature control zone mounted with cooling capillary coil and cryogenic heater. The connecting wires of the thermometer are thermally anchored with the support of the
temperature insert. The calibration procedure begins once the temperature of the support is stabilized. Measured data is presented and it is possible to infer that the absolute accuracy that can be obtained is better than ±0.5% of the reading for the full temperature range.

In collaboration with BRIT, Kolkata an automated $^{99m}$Tc generator, AUTOSOLEX was developed and tested. The entire development starting from the hardware design, the firmware code and the software application were done inhouse.

Computer & Informatics Group has upgraded the software “Mounisara 1.0”, which translates Bangla Text to Sign Language for the hearing impaired, to “Mounisara 2.1” and also developed its Hindi version to extend the usefulness of such software in the national level. E-books for the primary school children based on sign language have also been developed. A Mobile robot based online radiation mapping system has been developed and successfully used in different experiments to measure the dose rate at various regions of K-130 cyclotron facility at Kolkata. VECC’s computing facility has been augmented by addition of two high-end computing servers.

Mechanical Engineering group has designed and fabricated innovative neutron shutter for beam lines of superconducting cyclotron. A  $4\pi$ Charged Particle Detector Array (CPDA) is also being developed to understand basic properties equations of state of nuclear matter, liquid gas phase transition, isoscaling etc using Superconducting cyclotron beam. Further a Spiral Inflector for VECC Superconducting Cyclotron has been developed.
Head: MP-5 Basic Research

5.02 Physics

The experimental Nuclear Physics Division at VECC have several experimental program using the light ion beams from K-130 cyclotron at VECC, Kolkata, as well as using heavy ion beams from other accelerator facilities of India. The experimental physics programs carried out during 2012-13 are highlighted below as different subgroups.

Critical behaviour of the GDR Width at low Temperature

The first experimental giant dipole resonance (GDR) width systematics, in the temperature region 0.8–1.2 MeV for $^{201}$Tl, a near Pb nucleus, has been carried out to investigate the evolution of the GDR width in shell effect and pairing dominated region. The experiments were performed using $^4$He beams from the K-130 room temperature cyclotron and employing the LAMBDA photon spectrometer & Gamma Multiplicity Filter array. It has been found that the extracted GDR widths remain constant up to a critical temperature and increases thereafter which is in complete contrast to the predictions of thermal shape fluctuation model (TSFM). A similar behavior of the GDR width is also observed for $^{63}$Cu and $^{119}$Sb nuclei. To explain this, it has been proposed that the GDR vibration itself induces a quadrupole moment causing the nuclear shape to fluctuate even at $T = 0$ MeV. Therefore, when the giant dipole vibration having its own intrinsic fluctuation is used as a probe to view the thermal shape fluctuations, it is unlikely to feel the thermal fluctuations that are smaller than its own intrinsic fluctuation. Applying this novel idea, a new phenomenological model has been proposed which is known as the Critical Temperature Fluctuation Model (CTFM) (solid lines) for a better understanding of the GDR width systematics for the entire range of mass, spin and temperature.
Lifetime measurement and decay spectroscopy of neutron-rich $^{132}$I:

The structure of odd-odd nuclei around doubly magic $^{132}$Sn is important to understand and develop the effective proton-neutron interaction near the major shell closure. In the present work, the low lying states of odd-odd $^{132}$I, which has three proton particles and three neutron holes with respect to the closed shell configuration of $^{132}$Sn, have been characterized from decay spectroscopy. The latest generation LaBr$_3$(Ce) scintillators, with its good time resolution as well as good energy resolution can overcome this problem. In the present work, the life times of excited states of $^{132}$I have been measured from the decay of $^{132}$Te, ($T_{1/2}$=3.204 d) using LaBr$_3$(Ce) scintillators. $^{132}$Te was produced as fission product of alpha induced fission of $^{235}$U. Alpha beam of 40 MeV was obtained from K-130 cyclotron of Variable Energy Cyclotron Centre (VECC), Kolkata. Radiochemical separation of Te from other fission products was carried out and $\gamma-\gamma-t$ coincidence data were collected in LIST mode with a setup of three LaBr3(Ce) detectors. The TAC spectrum corresponding to 228-49 keV cascade is shown in Fig.1. The lifetime of the 49 keV level has been extracted by slope method and was found to be 1.002(7) ns. The decay of the high spin isomer (8$^-$), which cannot be populated from the decay of $^{132}$Te, has been precisely measured by separating Iodine from the fission products and following its IT decay with a Low Energy Photon Spectrometer (LEPS) of segmented planar Ge detector. A representative LEPS spectrum is shown in Fig.2, where 96.7 keV is identified as the isomeric decay transition.

**Picosecond lifetime measurement with LaBr$_3$ detectors:**

The picosecond lifetimes of the excited levels of odd-odd $^{146}$Eu has been measured following the mirror symmetric centroid difference technique utilizing the unique combination of moderate energy resolution and a very good time resolution of a LaBr$_3$ detector. This technique is very new in its application compared to other commonly known techniques for the measurement of lifetime of the order of few picoseconds. Excited states of $^{146}$Eu were produced from EC decay of $^{146}$Gd which was produced by ($\alpha$, 2n) reaction with 32 MeV alpha beams from the Variable Energy Cyclotron, Kolkata. The prompt
The prompt reference curve has been shown with the solid blue line, obtained from the $^{60}$Co data, shown with black solid circles. The pink points show the results for $^{152}$Eu and the greens are the measured values for the $^{146}$Eu levels.

**β−γ coincidence setup with segmented planar Ge LEPS detector:**

The success of the beta gamma coincidence technique utilizing the beta response of a thin window planar segmented Ge LEPS detector has been achieved for the measurement of endpoint energies, even for very weak beta branching. The coincidence setup has been made with one segmented LEPS detector having a 300 micron Be window and one 10% coaxial p type HPGe detector. Singles and coincidence measurements with several beta decaying sources, both $\beta^+$ and $\beta^-$, have been performed and the experimental Fermi Curie plots for specific beta branches were made in order to determine the end point energies. Experimental plots have been compared with simulation produced by the code GEANT3 and observed to have excellent agreement with the data points. The end point energies of known beta branches were reproduced and the same corresponding to several branches of $^{106}$Rh decay has been determined for the first time using the developed setup.
Neutron detector and Charged Particle Detector Array (CPDA) facility development:

A new laboratory for fabrication of neutron detector has been developed at VECC. Several neutron time of flight (TOF) detectors of dimension 7”x 5” have been developed and A detector with new design has been fabricated on the basis of R&D carried out on various design aspects of neutron detector made of liquid scintillators.

For the Charged particle detector array (CPDA), a clean room facility of class 100000 has been developed for Storage and mounting of silicon detectors, CsI(Tl) crystals. The mechanical structure of the forward part of the array is completed. The forward part of the array will house 24 telescopes, each made up of Aluminum alloy. The assembly was so made that the front face form a part of sphere of radius 20 cm.
Development of Cryogenic Penning Trap at VECC

The Magnet-Cryostat of VECC Penning Ion Trap that would house the Penning trap assembly was commissioned on 17/2/2012. The magnet-cryostat system was kept at liquid helium temperature (4 K) for quite some time and cryostat stability was tested for any quenching effect before powering up the magnet. Then it was powered up by inserting a detachable charging wand through the charging port of the system. The 5 Tesla superconducting magnet operated successfully in persistent mode.

Simulation studies of a five electrode cylindrical Penning trap assembly that would provide the quadrupolar potential have been done taking into account realistic gap effects between adjacent electrodes. Electrode assembly designed as per simulation studies was fabricated entirely at VECC workshop and high precision machining (~10 micron tolerance) of copper electrodes and MACOR rings has been achieved as shown in Fig 1. Laser welding of copper pins to electrodes for electrical connections has been done at RRCAT, Indore shown in Fig 2. Vacuum oven brazing of cryogenic feed-throughs to an OFHC copper plate is under progress in association with CGCRI, Kolkata.

Nanostructures Developed at VECC

Multifunctional materials are of today’s quest. Miniaturization, i.e. development of these materials in the form of nanomaterials is of primary need considering their application in devices. Moreover, if these are obtained in nanostructured form, they can bring wonders. With this end in view, activities in Condensed Matter Physics and materials Science group have been initiated, which cover following dimensions- 1) Multiferroic materials with Ferro magnetic, electric and elastic ordering 2) Conducting polymer based nanocomposite supercapacitor with application in energy cells. The materials have been developed in different nanostructured forms (like nanowires, nanotubes, nanorods etc.) through simple cost effective electrochemical and chemical means. Co and Ni nanowires were developed by
electrochemical deposition using Anodised Alumina (AAO) templates with pore sizes up to 200nm. Figures display the FESEM images of Co and Ni nanowires.

Nanotubular structure of conducting polymer poly(3,4-ethylenedioxythiophene)(PEDOT)--NiFe$_2$O$_4$ nanocomposites has been developed by chemical route of reverse microemulsion polymerization technique using sodium bis (2-ethylhexyl) sulfosuccinate (AOT) as surfactant in n-hexane medium. TEM image supports the formation of mesoporous nanotube having diameter in the range $\sim$20 nm. Recently, a simple chemical method has been adopted for developing multiferroic BiFeO$_3$ (BFO) with simultaneous antiferromagnetic, ferroelectric & ferroelastic behaviour in form of nanostructures like nanorods, nanowire etc. by employing AAO template with various pore sizes from 20nm with solution route followed by controlled vacuum filtration and sintering.. SEM pictures of a few of them are shown in Figures.
The effect of ion irradiation on Zr-1%Nb alloy which is the cladding material for 1000 MWe VVER type pressurized water reactors has been investigated using 7MeV proton from Variable Energy Cyclotron. Two sets of samples with different heat treatment have been irradiated with similar doses to understand the subtle variation in the microstructure. X-ray diffraction line profile analysis (XRDLPA) results and hardness measurements by nanoindentation technique showed marked difference between these two sets of samples indicating that initial heat treatment plays a significant role in determining the microstructure after irradiation.

Irradiation studies of candidate structural material (Nb-1Zr-0.1C alloy) of Compact High Temperature Reactor using 7.5MeV proton from Variable Energy Cyclotron have been carried out. XRDLPA has been carried out on irradiated samples as a function of dose and the defect states of these materials have been evaluated. With increasing dose, there is evidence of formation of more number of vacancy loops. Studies on irradiation induced phase transformations, characterization of...
defects generated due to irradiation and dissolution and re-precipitation of the carbide phases in the alloy are being carried out under Transmission Electron Microscope (TEM) at MSD, BARC.

- Ferritic-Martensitic steel T91 has been irradiated with 315 KeV Ar\textsuperscript{49} ions for different doses i.e. at 5dpa, 10dpa and 20dpa. Microstructure has been characterized by XRDLPA using GIXRD at two different depths, one in the intermediate region and another up to the peak damage region as a function of dose. Nanoindentation technique has been used to find out the changes in the hardness and yield strength values with dose of irradiation. Transmission electron microscopy has been carried out to study the changes in the microstructure. XRDLPA of the irradiated samples have shown that there is a decrease in the domain size. Nanoindentation on irradiated material has shown increase in hardness with dpa which appears to saturate at the value of 1.5 GPa with respect to the unirradiated material.

- The effect of 12 MeV α- ion irradiation on microstructure and mechanical properties for nano crystalline nickel (nc-Ni) has been studied systematically. Microstructure evolution as a function of α- ion dose are studied and compared with unirradiated nc-Ni using XRD and TEM. Mechanical behaviour after irradiation has been evaluated in detail by conventional tensile and nanoindentation techniques. Mechanical dynamic parameters like strain rate sensitivity and activation volume for nc-Ni was examined with an aim to understand the rate controlling deformation mechanisms in nc-materials after irradiation.

\textbf{Theoretical Physics Division activities at VECC:}

Theoretical Physics Division is actively engaged in basic research in low, intermediate and high energy nuclear physics. Some important research works in high, low and intermediate energy nuclear physics are mentioned below.

\textbf{High energy nuclear physics:}

Heavy quark energy loss in a deconfined medium, its effect on azimuthal anisotropy was investigated in detail. It was shown that the heavy quarks loses energy almost in a similar fashion like light quarks through radiative decay process. Heavy quarks correlation was also investigated. Heavy quark correlation found to be sensitive to medium effect as well as on the production mechanism. In a detailed investigation, system size dependence of nuclear modification factor and azimuthal anisotropy of jet quenching was studied. Dileptons are known probe of QGP. Dilepton elliptic flow was computed and it was shown that a judicious selection of invariant dilepton mass window can be used to extract the collective properties of quark matter, hadronic matter and also get a distinct signature of medium effects on vector mesons. Dimuon spectra in In+In collisions at SPS was investigated in detail. It was shown that the non-monotonic behavior of the inverse slope parameters is only explained with the assumption of an initial quark gluon plasma phase. A computer code was developed at the division for event-by-event hydrodynamic simulation of heavy ion collisions. The code was successfully used to investigate, triangular flow, sensitivity of viscosity to higher order flows, decorrelation of higher order flows etc. J/psi suppression in FAIR energy collisions was also investigated and shown to be sensitive to J/psi production mechanism.
Low and intermediate energy nuclear physics:

Lifetimes of proton radioactivity was estimated by calculating the tunneling probability through the potential barrier consisting of nuclear, Coulomb and centrifugal contributions. Estimated lifetimes agree with experimental measurements. Sensitivity of the half-lives on the incompressibility effective mass, and on different Skyrme forces, were also explored. Light element abundance in big-bang nucleosynthesis was computed with improved nuclear reaction rates. Improved reaction rates marginally increase helium abundance. Einstein’s equations for rotating stars using pure nuclear matter and quark core were solved to obtain the maximum mass of neutron star compatible with experimental data. At the division, a model for projectile fragmentation was developed. The model was extended to include impact parameter dependence of input temperature, to enable analysis of more peripheral collisions. Statistical models based on canonical and grand canonical ensembles are extensively used to study intermediate energy heavy-ion collisions. In an important study, equivalence between the canonical and grand canonical ensembles was established for fragmentation of finite nuclei. In another investigation, the ratio of symmetry energy coefficient to temperature was extracted from different prescriptions using the isotopic as well as the isobaric yield distributions, in different projectile fragmentation reactions. It was shown that the symmetry energy coefficient is best estimated using the fragment yield at the breakup stage of the reaction. Also grand canonical model for the fragmentation analysis give better result.

5.11 International Research Collaboration

India’s participation in the International collaborative experiments in high energy physics have been in the news prominently over last one year. The participation of VECC scientists at LHC-CERN for the quest of Quark Gluon Plasma (QGP) has borne fruits in terms of analyzing huge amount of data collected from p+p and Pb+Pb collisions. The Photon Multiplicity Detector (PMD) built under the leadership of VECC has been a strong partner in data taking. Presently, dedicated efforts on data analyses are under way. First results on the system size and energy dependence of the photon multiplicity, their pseudo-rapidity distributions at forward rapidity have been extracted. The figure showing the pseudo-rapidity distributions of photons as measured by PMD at the center of mass energy of 7 TeV at LHC gives only a glimpse of such results which is work under progress.

Additionally, researchers and students from VECC are involved in understanding other important aspects of the particle production at LHC energy. Prominent among the topics which are being pursued by VECC collaborators include (a) collective flow using information from PMD (b) correlated particle production and formation of jets (c) production of resonances (d) fluctuations of net-charge, net-baryon numbers and strangeness.
We have made significant contributions both in hardware and analysis in STAR experiment at BNL-USA. The first Multigap Resistive Plate Chamber (MRPC) module, built at VECC, has been installed in the STAR experiment after detailed testing performed by STAR. The MRPC module built at VECC will be taking its first data in STAR in February 2013. On analysis front, for the first time, we have presented the final results on the correlated production of photons obtained from PMD and charged particles from Forward Time Projection Chamber at forward rapidity region in STAR. The results presented in Quark Matter 2012, the largest International conference of practitioners of high energy heavy ion collisions show some interesting features which could not be explained using known physics results. The results are expected to be published very soon. The figure shows the results where the observables for correlated production of photons and charged particles do not match the trend given by known models. VECC researchers have also contributed in studying energy dependence of the fluctuation of net-charge and net-protons. These observables have a potential to shed light on the search of the critical point in the phase diagram of the strongly interacting matter. Many of the above results and analyses have been presented in several international conferences and symposia.

**Detector R&D for future upgrades and planned experiments**

On the avenues of future heavy ion experiments and upgrades, considerable progress has been made in developing advanced detector systems. The silicon detectors, developed in collaboration of BARC and built by BEL, as the detecting elements of the Forward Calorimeter (FOCAL) in ALICE upgrade, have been tested in the laboratory at VECC and CERN very successfully. The system used was a prototype sampling calorimeter using silicon as sensitive medium and tungsten as converter. Two types of readout system, one based on MANAS and other based on ANUSANSKAR ASIC developed at BARC, were used. The figure below shows the setup along with a layer of silicon detector. The response of the detector to pions and electrons are measured thereby giving information on shower profile of the showers formed by the electrons.

(Left) Pseudo-rapidity distribution of photons as measured by PMD in ALICE at 7 TeV center of mass energy (right) observable (∇_{dyn}) representing correlation between photon and charged particles as measured in STAR experiment at center of energy of 200 GeV.
Test beam setup for a prototype FOCAL detector, showing four layers of tungsten plates sandwiched with four silicon pad detector arrays. The inset shows a 5x5 array of silicon pad.

Response of the prototype FOCAL detector to pions (left panel) and 4 GeV electrons (right panel). For the figure on the right panel, tungsten of four radiation length has been placed in front of the detector.
Another future experiment, in which VECC researchers have been playing a major role, is the CBM experiment at FAIR. VECC, along with other Indian institutes are to build the major part of the muon detection system for CBM. The progress for this project has been multidirectional. They include (a) simulation for the optimization of the setup (b) R&D on GEM detector for handling high data rate (c) development of radiation hard electronics (d) design of the mechanical and electronic systems of the chambers in muon system. The technical design report (TDR) of this detector system is scheduled to be submitted by the end of 2013. The close-to-final simulated design has been done based on the optimization of detector geometry. A mechanical layout as obtained after detailed design study is shown in figure below. The detector R&D has advanced one stage further, where it has been demonstrated, as shown in fig. 4, that the detector gain does not change with higher intensity beams. The detector has been tested upto 1.4 MHz/cm^2 rate using X-rays and using conventional NIM electronics for readout.

An arrangement consisting of alternating layers of detectors and absorbers (mini-MUCH) resembling the muon setup for CBM has been employed for the first time. This consists of 5 GEM detectors to face the muon and pion beam at CERN. Two sets of absorbers, one of 20 cm thickness and other of 70 cm thickness were inserted at different places. At low intensity, the tracking has been demonstrated to work very well. At intensities larger than 1 MHz/cm^2, where the data rate is very high, the performance of the readout electronics is under investigation.
In collaboration with IIT-Kharagpur, considerable progress has been made on building a serializer ASIC which will be used to transfer data at very high speed (2.5 GHz). This ASIC will be extremely useful in handling high rate data from self-triggered electronics of CBM.

A prototype MRPC-based TOF system has been installed to demonstrate the proof-of-principle of using MRPC for such a system. Extremely good time resolution of MRPC suits it to become a potential less-expensive candidate for TOF-PET imaging. We have already demonstrated the capability of building MRPC system for STAR experiment. Two smaller-size MRPCs were assembled with a provision of including more glass electrodes. The increase in the number of electrodes increases the efficiency of detection of 511 KeV photons from positron annihilation. We have tested the system using a Na-22 source which gives two anti-parallel photons. The efficiency of detection is close to what is expected from the available material. Next step is to study the timing properties in detail.

The INO-prototype laboratory has been working continuously over last one year at VECC. Students from all over the country take part in data taking and data analysis.

Head: MP-4 Advance Technologies and Radiation Technologies and their Applications
4A: Advanced Technologies and their Applications

4.08 Accelerators
On-line Production and Acceleration of Radioactive Ion Beams at VECC RIB facility

Radioactive ion beams (RIB) of $^{14}$O (71 sec), $^{42}$K (12.4 hrs), $^{43}$K (22.2 hrs) and $^{41}$Ar (1.8 hrs) have been successfully produced at VECC, using a novel gas-jet recoil transport coupled Electron Cyclotron Resonance (ECR) ion-source technique. The RIB of $^{14}$O has been further accelerated through the Radio Frequency Quadrupole (RFQ) accelerator to an energy of 1.4 MeV. Radioactive ion beam of $^{14}$O was produced in one neutron evaporation reaction of proton on nitrogen whereas $^{41}$Ar, $^{42}$K and $^{43}$K were produced from alpha particle reactions on argon gas target. Primary beam (proton & alpha-particle) intensity was around one micro-ampere on target. The target chamber was placed inside the cyclotron vault as shown in figure for these experiments. Radioactive atoms produced in the target were transported 15m away to the RIB project site through a 1.4 mm inner diameter tygon capillary and injected online into the ECR ion-source for ionization. The low energy RIB was selected in an isotope separator downstream of the ECR ion-source and further accelerated through the RFQ linac to 100 keV/u. At the separator focal plane the measured intensity for $^{42}$K and $^{43}$K was $2.7 \times 10^3$ particles per second (pps) and $1.2 \times 10^3$ pps respectively whereas the same for $^{41}$Ar was $1.3 \times 10^3$ pps. The RIB energy was typically 10 keV. The measured intensity for $^{14}$O$^{2+}$ beam before and after the RFQ was respectively $4.4 \times 10^3$ and $3 \times 10^3$ pps. Typical measured $\gamma$-ray spectra measured in these experiments are shown.

Study of super-allowed beta decay of nuclei such as $^{14}$O along with other experiments provides a test of the unitarity of the CKM matrix which gives an important laboratory test for the Standard Model. The RIB of $^{14}$O is also important for study of astrophysical reactions crucial in understanding the nucleosynthesis path from hot CNO cycle to rp-process. Radioactive potassium isotopes $^{42}$K and $^{43}$K have several bio-medical applications whereas $^{41}$Ar is an industrial tracer also used in engineering and environmental science studies.
<table>
<thead>
<tr>
<th>RIB</th>
<th>Prod. route</th>
<th>T1/2</th>
<th>Intensity (pps*) before ECR</th>
<th>Intensity (pps) after ECR</th>
<th>Intensity (pps) after separator</th>
<th>Intensity (pps) after RFQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}$O</td>
<td>$^{14}$N(p, n)</td>
<td>71 s</td>
<td>$4.4 \times 10^3$</td>
<td>$6.7 \times 10^4$</td>
<td>$4.4 \times 10^4$</td>
<td>$3.0 \times 10^3$</td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>$^{40}$Ar(α,pn)</td>
<td>12.36 hr</td>
<td>$1.5 \times 10^5$</td>
<td>$3.1 \times 10^4$</td>
<td>$2.7 \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$^{43}$K</td>
<td>$^{40}$Ar(α,p)</td>
<td>22.3 hr</td>
<td>$9.4 \times 10^4$</td>
<td>$2.0 \times 10^4$</td>
<td>$1.2 \times 10^3$</td>
<td>-</td>
</tr>
</tbody>
</table>

* pps : particles per second

Floor diagram of the VECC K130 cyclotron and the RIB beam-line. The labeled items are: D1 - D4: HPGe detectors; ECR: Electron Cyclotron Resonance ion-source; FC1 - FC3: Faraday cups; RFQ: Radio Frequency Quadrupole linac; QQ: Quadrupole doublet; L1 - L3: heavy-ion Linac modules; RB: Re-buncher; Sol: solenoid magnet
4.05 Accelerators

**Development of high power IOT based RF amplifier along with its associated high voltage power supplies and associated protective devices for Superconducting RF cavity project**

The development of multi-cell medium-β Superconducting RF linac cavity has been taken up at VECC as an R&D project in line with various accelerator programmes (Indian SNS, ADSS and advanced RIB) of DAE. As a part of this project, the design and development of high power RF amplifier has been done based on Thales Inductive Output tube (IOT).

The state-of-the-art technology of IOT-based high power amplifier developed and tested at VECC is the first of its kind in India. The amplifier can be operated at 704 MHz/650 MHz at maximum output RF power of 60 kW at 50 Ohm load with proper tuning of its primary and secondary cavities. The PC-PLC-based RF interlocks, Control and monitoring of various parameters have also been developed indigenously.

Besides these, the electromagnetic design and analysis of 650 MHz, β=0.61, 5-cell Superconducting RF cavity has been performed using 3D CST Microwave Studio and also the Multipacting analysis of the said cavity has been carried out successfully using MultiPact 2.1 code.

The necessary high voltage power supply (-30 kV, 3.2A) with fast (~microsecond) crowbar protection circuit for biasing Cathode of the IOT was designed, Installed and commissioned at VECC and
final testing has been carried out. The power supply incorporated two power transformers, each rated at 100 KVA, 415V/12KV, 3-phase, 50Hz (vector group Dy11, Yy0), force air cooled, operating in 12 pulse mode. The input 3-phase is connected to each of two transformers via air core choke and back to back SCR in each line through fast interrupting circuit breakers. The Primary SCR bank at the input of the Transformer is used in closed loop as a primary regulating device. Rectified outputs (15 KV each) of both transformer’s secondary are connected in series and then a LC filter (400uH, 1.9uF/60KV capacitor) is used to keep the ripple in desired limit. Special feature of this power supply is Crowbar Protection system against internal Arcing and short circuiting in the IOT by using high Voltage Ignitron. Other protections i.e. Over Current, Over Voltage, Over Temperature phase failure etc. have been incorporated and tested with the IOT.

Anode power supply of IOT and HV Deck housing the rest of the Power Supplies

Other power supplies to bias Grid (-300V, 0.5 A), Ion Pump (3KV, 0.1mA) and Filament (20V, 25Amp) which are connected with respect to the Cathode of the IOT are floating at high voltage. Therefore, a HV Deck is specially designed in house to place these power supplies which are floating at 30KV. Inside the HV Deck, these power supplies are powered by an Isolation transformer (5KVA, 60KV isolation) and controlled by a PLC which communicates through an Optical Fiber link to the PC.

The high power IOT-based amplifier along with power supplies and interlocks etc. has been installed and already tested up to 40 kW with 50 ohm water-cooled dummy load at 704 MHz.

The IOT fed by the -30KV/3.2 power supply, is required to be protected against the internal arcing. The IOT are prone to internal arc that can lead to a permanent damage of it, if stored energy is not removed or diverted through a switch to ground after occurrences of fault. Thus to bypass the energy, a shunt diverter topology is used. In this the stored energy in electrical system is diverted to the ground terminal by quick shorting the output terminals of the power supply through ignitron. The crowbar protection system was developed which involves switching device ignitron NL7703EHV which is rated at 50KV, current transformer having sensitivity of 0.01V/A with response time 20ns is installed in ground line of power supply for sensing rate of change of current during fault. When IOT draws more current or arc occurs, CT
senses the rate of change of current which is fed to the electronic control card which gives a tripping signal. This signal triggers a SCR through optical fiber to discharge a charged capacitor (~5J energy) through a pulse transformer for the generation of fast rising pulse of 2-3 KV peak. This is used to trigger the ignitron which short circuit the power supply to protect the IOT. The same tripping signal is used to trip main circuit breaker and withdraw the gate pulse of SCR to protect the power supply. Isolation between control circuit and power circuit has been done by using optical fiber.
4.11 Advanced Technologies

Superconducting Magnetic Energy Storage (SMES) System Technology Development

Design and development of VSI-Chopper based Dynamic Voltage Restorer

The power electronic device comprising of a Voltage Source Inverter (VSI) along with DC-DC Chopper is employed in the development of the Dynamic-Voltage-Restorer (DVR) using the SMES coil.

A high current two-quadrant dc-dc chopper has been designed and developed (rated up to 400A) for charging the SMES coil to a constant current value for energy storage and for discharging to a constant dc capacitor voltage. A novel topology of Hysteresis-Band current controller is being adopted for the development of the two-quadrant chopper.

A 10kVA three-phase Voltage Source Inverter (VSI) has been designed and developed that has the dc capacitor voltage as the input and injects the missing voltage cycles into the mains system through the series injection delta / open transformer whenever sags are present in the mains supply voltage, as a result the sags are unseen by the critical loads.

A 12-bit multi-channel 12.5 MSPS ADC samples the input mains and feeds to a DSP based 32-bit controller that ultimately generates the switching gate signal to the IGBTs of the VSI. Employing a feed-forward control topology, input phase is identified by a Software PLL algorithm and final gate-triggering is based on Space-Vector PWM.

Energization of 0.6MJ SMES Coil with the Two-Quadrant dc-dc chopper

The NbTi based cryostable and solenoid type 0.6MJ SMES coil with HTS (BSCCO-22237) based current leads along with related instrumentations, quench detection and protection system, dump resistors and the data-logging systems are assembled, integrated and connected for energization of the coil. The coil with 800kg of cold mass and inductance 1.86H underwent rigorous cryogenic tests and thereafter cooled down to 4.5K. The “Hysteresis Band Current Controller” based two-quadrant dc-dc chopper
designed and developed in-house has been used for charging the superconducting coil upto 400A, thus storing ~ 0.15MJ of energy producing 3.5T of magnetic field inside the coil.

In view of developing SMES technology in the country, our centre has already developed a 0.6 MJ SMES coil along with associated power converter system. With continuation of XI five year plan, in the next phase we have initiated of developing toroidal field magnet of 5 MJ/1 MW composed of modular solenoid coils connected in series and arranged in a toroidal symmetric form because of its inherent reduced stray magnetic field outside the coil. In the recent years several SMES projects have been started over the world aiming to address fault situation in the utility grid using high temperature superconductor (HTS). However, HTS tapes commercially available till date are not technically feasible for large AC or pulsed mode operation as required in SMES application. Even today, especially after the commercial availability of 4.2 K cryo-cooler with helium re-condensation technology, NbTi conductors (LTS) is believed to be the best material of choice for SMES application. While designing SMES coil for commercial use several factors such as ac loss, conductor volume, steady state heat load, etc. need to be
addressed. Rutherford type NbTi cable because of its inherently low ac loss with respect to other available conductor has been chosen for this design study. Among the layers of winding, there will be FRP picket fence in a azimuthally symmetric fashion to provide liquid helium channel into the conductor. This ensures cryo-stability of the conductor. As part of design study, Von Mises stress distribution of the toroidal coil along with its support structure is as shown in Figure. Toroidal magnetic field contour at the magnetic meridian (Y=0) is as shown in Figure. Overall weight of the cold mass would be around 1.6 ton and will be hung from top plate of the helium cryostat. The intermediate shield of the cryostat will be kept at 50-55 K through a single stage GM type cryocooler. Detailed design study of cryostat lay-out, quench protection, dynamic heat load, etc. is underway.

**Development of high-voltage power supply for electrostatic ion beam deflector**

High-voltage power supplies (0 to +2kV / 1mA max and 0 to -2kV / 1mA max., Regulation: < 0.01% (line and load)) has been designed and developed for the electrostatic ion beam deflector. A novel topology of half-bridge parallel resonant dc-dc converter with high-voltage / high frequency step-up transformer followed by Cockroft-Walton multiplier stages has been used for the development of these power supplies. Output voltage regulation is achieved by changing the input dc bus voltage of dc-dc converter using a high control bandwidth series pass transistor working in the linear region.

![Power Supply Images](image)

**Cryogenic Plant, Instrumentation and Electrical Services Group**

**Cryogenic Plant and Instrumentation Section**

Cryogenic Plant and Instrumentation Section is responsible in running two liquefiers in tandem – one as refrigerator for providing liquid helium to the superconducting cyclotron and other as liquefier for producing liquid helium to other projects. By these two liquefiers, we could manage to run the superconducting cyclotron uninterruptedly. In the year 2012, operation of superconducting cyclotron at rated cryogenic loads with the old liquefier/refrigerator 250W @ 4.5K was successful. This has enabled us to take shut down of the new liquefier/refrigerator 415W @ 4.5 K for preventive maintenance.

*Prototype development of an experimental variable temperature setup suitable from 2.2K to 325K for temperature sensor calibration at VECC, Kolkata*
In cryogenic applications, the most important measurement parameter is temperature. The difficult problems of sensor mounting and heat sinking require greater care than similar measurements at room temperature. The calibrated cryogenic temperature sensors are three times more expensive than the uncalibrated one. The increase in cryogenic activities at VECC and in India demands low-cost calibration facilities and indigenous development of cryogenic instrumentation. A prototype of variable temperature set-up has been developed in-house using a glass cryostat for calibration of different temperature sensors. The temperature of Variable Temperature Insert (VTI) is controlled by the cryogenic process: cooling down by passing gaseous helium as heat exchange gas through a capillary copper coil wound around the thermal block and warming up with the help of electrical heaters. Both the calibrated and the uncalibrated types of sensors are mounted on the calibration copper block and thus the sensor thermal anchoring with the copper isothermal substrate of the calibration block.

The use of a capillary tube and active pumping allows getting temperatures below 4.2K in the regulation block without cooling down the liquid helium bath. The calibration block consists of two sections – one isothermal section and one regulated section as shown in figure. Isothermal section consists of one calibrated and two uncalibrated sensors. The regulated section is equipped with a 25W electrical heater for heating and a spiral capillary coil wound around it for cooling. The two sections are weakly linked by reducing the cross-section of the copper block, which reduces the advancement of the thermal perturbation to the isothermal section. Uniformity in temperature sensing is ensured by placing the sensors symmetrically. In order to ensure pressure drop liquid helium is pumped from the glass cryostat through a capillary coil, of which a part is coiled on the regulated section of the thermally stabilized copper block. The pumping is done in a controlled way using a scroll pump through the VTI to attain sub-atmospheric pressure. The temperature is made variable using the heater and changing heat transfer rate by controlled gas pressure. Thus, variable temperature can be produced and calibration of temperature sensor is feasible.

The calibration is performed by comparing with a Lakeshore make Calibrated Silicon Diode DT470. The uncalibrated sensor may be of any make and of any type – silicon diode, cernox type, Carbon-Glass Resistance type RTD etc.
The power of the electrical heater is adjusted by varying constant current output of a PID temperature controller, Lakeshore make Model 331, which gets feedback of temperature from the calibrated sensor. It is possible to achieve any temperature between 2.2K and 325K.

Apiezon N grease is used for mounting temperature sensor and heater in order to improve thermal contact with the copper block. In order to achieve the best operating conditions, all wires are thermally anchored to the calibration isothermal copper block. All thermometers are measured in a four wire configuration. The electrical feed-through, developed in-house, is shown.

Steady-state simulation of the calibration block is done using ANSYS for different heat inputs by the heater. It is assumed that different temperatures are maintained at different axial position of the coil depending upon the throughput of the vacuum pump for helium. The basic average temperature calculation is done simply by considering that the heater input power is directly transferred to the exchange gas resulting in phase change and enthalpy. Exchange gas properties are chosen from the average temperature. Forced convection equations are utilized to compute the pressure drop and heat transfer coefficient. A temperature distribution calculated over the calibration block using these properties is shown. With no heater power, it is assumed that exchange gas possesses single phase liquid flow and minimum temperature achieved at the point of temperature sensor is 2.265 K. With 5W heater power average temperature distribution is 73.537 K. The simulation shows that the homogeneity of the calibration block is within 0.01K both with and without heater.

The actual temperature sensor calibration setup in operation is shown. The temperature at sub-atmospheric pressure is measured using a calibrated sensor and the corresponding pressure is noted. The temperature corresponding to the pressure at this region is evaluated from a polynomial interpolation. The figure represents the calculated temperature from pressure and that from the Temperature sensor forward voltage drop. The percentage error in temperature reading with respect to the temperature corresponding to pressure is also shown. The maximum percentage error occurs in the region from 200 to 600 mbar and its value is 6%. This value should be actually less than 1%, i.e., 40 mK, which is reflected at the pressure region near atmospheric pressure. The problem of accuracy occurs because stability in pressure is very difficult to achieve in the middle region of sub-atmospheric pressure. This problem can be rectified by using a cryogenic valve in place of the capillary tube. The pressure gauge is used to measure the sub-atmospheric pressure and its minimum division in scale is 50 mbar. The better measurement is possible by introducing piezo-resistive type vacuum/pressure electronic type transducer.
Temperature measurements from 2.2K to 4.3K

Two calibrated DT470 Silicon Diode Temperature Sensors were mounted symmetrically in the calibration block in order to confirm the good isothermal conditions of the copper block. It is found that both thermometers are very well correlated (better than 0.005 K) in the 2.2 K to 325 K temperature range. The difference is within the precision range of their calibration.

Temperature is measured at different points by stabilizing temperature using controlled flow by positive pumping and manipulating heater power from a PID controller. The calibration curve for sensor 1 is downloaded from a PC to the controller for directly measuring the actual temperature of the copper block. Constant current of 10 $\mu$A is fed to DT470 diode sensor and the corresponding voltage drop is measured. Similarly in case of Cernox Sensors the current is controlled (from 0.1 $\mu$A to 1 $\mu$A) in such a way that the voltage drop should be less than 1 mV. This restricts the heat input due to measurement to nW. Temperature from calibrated sensor and corresponding voltage drop across uncalibrated sensor #1 is measured using lakeshore make temperature controller model 331. Current is fed to sensor #2 by Keithley make current source model 224 and corresponding voltage drop is measured using Keithley make 6.5 digit multimeter model 2000.

The calibrated sensor acts as a feedback temperature of the controller. Once a stabilized condition is reached by controlling the needle valve in line with the pumping system of VTI, the PID controller output is made on and Proportional gain and Reset time were adjusted to achieve a stabilized temperature. This procedure is followed for each and every point and the forward voltage drop for the uncalibrated sensor was logged. The measured data satisfies closely the behaviour of calibrated sensor. The expanded view one below 28K and another above 28K are shown to match them with those of calibrated one.

Uncalibrated Temperature Sensor DT470 forward drop vs. Calibrated Temperature

Expanded view of the temperature sensor calibration curve from 2.2 K to 28 K
Expanded view of the calibration curve from 28K to 325 K

Two Cernox temperature sensors’ resistances measured value with temperature calculated from calibrated sensor.

The similar measurements were made with cernox type uncalibrated sensors and are shown in figure 10. To deduce the equivalent error when working with a non-calibrated cernox™, the resistance at 4.2 K is estimated from the calibration data. This estimation selects the 2 closest points around 4.2 K and the resistance is estimated by using a linear interpolation. By using the 2 calibration points around 4.2 K, the sensitivity (it is the slope of the interpolation: dR/dT) is estimated. The sensitivity is then applied as multiplying factor to the resistance difference between the Lake Shore data and the estimation made by using the linear interpolation; the result is considered as the error that will be done when using non calibrated cernox™ temperature sensors but that do use an individual approximation. The similar procedure is followed for error estimation at 77.35 K and 305 K.

TABLE I. CALIBRATION DATA BY INTERPOLATION FROM TWO CLOSEST MEASURED POINTS AND FIXED FIXED POINT DATA SUPPLIED BY THE MANUFACTURER

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Resistance ($)</th>
<th>Interpolated Resistance ($)</th>
<th>Sensitivity $dR/dT$ (/K)</th>
<th>Error in Calibration $T$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor #1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>5133</td>
<td>5163.896</td>
<td>1991.31</td>
<td>0.01551</td>
</tr>
<tr>
<td>77.35</td>
<td>310</td>
<td>310.9859</td>
<td>3.81592</td>
<td>0.25837</td>
</tr>
<tr>
<td>305</td>
<td>82.4</td>
<td>82.59437</td>
<td>-0.26285</td>
<td>0.73949</td>
</tr>
<tr>
<td>Sensor #2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>2484</td>
<td>2500.379</td>
<td>754.957</td>
<td>-0.02169</td>
</tr>
<tr>
<td>77.35</td>
<td>225</td>
<td>224.3954</td>
<td>2.43229</td>
<td>0.24858</td>
</tr>
<tr>
<td>305</td>
<td>68.4</td>
<td>68.50328</td>
<td>0.19375</td>
<td>0.53307</td>
</tr>
</tbody>
</table>
The spread of the calibration points and the deviation of the calibration results with the supplied fixed point values are shown in figure. A typical calibration between 325 K and 2.2 K generates about 50 temperature and resistance pairs of values. The calibration temperature values are distributed logarithmically to provide a better match with the characteristics of the cernox™ sensor. The data is clustered in a relatively narrow temperature range and the estimation error shall be less than 0.01 K. Table I shows the error in calibration is below 0.2 K at 4.2 K, 0.25K at 77.35K and 0.74K at 305 K.

The stability of temperature of the isothermal section is important for measurement point of view so that all the sensors should be at the homogeneous condition. The short-term stability in temperature up to 0.02 K is for 2 mins at 53.3 K, 76.6K and 100.3 K.

Hence, it can be concluded that the developed setup is of very low cost and achieves very good homogeneity, stability and accuracy for calibration of any type of sensors from 2.2K to 325K. The similar set up can be made in metal cryostat for more accurate and stable applications.

**Air Conditioning Division**

*Design & Development of Low temperature Refrigeration Machine for Diffusion Pump*

*Baffle cooling using two stage Vapor Compression Refrigeration (VCR) cycles*

VECC, Kolkata having two nos. of very big Diffusion Pump (Capacity 42,000 LPS each) for creating vacuum in the beam line of K-130 Cyclotron. For reducing the back streaming and improve the quality of vacuum these baffle are required to cool with continuous operating low temperature refrigerating Machines. Using the R404A/R-23 combination in two stage of vapor compression refrigerating cycle can maintain a very low temperature ( -60˚C to -70˚C ) or below, definitely a better choice over R-12/R-22 ( -40˚C ) combination. Two stage cascade system for the long time continuous running of D.P. a cheap and better option over the costly cryogenics system for producing the vacuum in the range of $\sim$1 Torr.

The effort has been taken to design and manufacture low temperature two stage ( cascade type ) refrigeration units utilizing the combination of R-404A & R23 refrigerants ,which are environmental friendly refrigerant having ‘O’Ozone Depletion Potential (O.D.P.) . These refrigerant are also easily available in market. Details analysis of refrigeration cycle, cascade design, control logics have been worked out for approaching towards a theoretical system.

Design & fabrication of Tube in tube type cascade heat exchanger ,pre-cooler,receiver ,selection of pipe lines & chilled water cooled condenser,etc. , are one of the most important achievements to develop and explore such kind of low teperature refrigeration job.
An indigenous development has been materialized after the total inhouse fabrication of machine, which has been commissioned and being tested under the simulated load condition. This machine is running efficiently after giving the required temperature at the evaporator (-60°C to -70°C) with more than 1TR load.

After getting shut down of the cyclotron system this machine will be installed at pit and will be commissioned with Diffusion Pump Baffle, where it will maintain low temperature for reducing the back streaming and improve the vacuum.

**Two stage cascade type Low temperature Refrigeration Machine**

**Low Temperature Machine connected with testing chamber**

**Vacuumized Testing Chamber- evaporator inside with simulated heat load**

**Result- One Reading with Load condition**

**Electrical Section:**

Electrical system of Variable Energy Cyclotron Centre receives power at 33KV from West Bengal State Electricity Distribution Company Limited. The power is utilized by stepping down the 33KV supply voltage to 433 volt by 5 Nos. 2 MVA power transformers for providing electrical power to Room Temperature Cyclotron, Super conducting Cyclotron, different experimental facilities and Departmental housing complex. In case of power failure 5 Diesel generators of total capacity 2250KVA are available to provide back up for critical loads and 55 UPS units of total capacity 1250KVA are available to provide back up for very critical loads of the centre like cryogenic system, vacuum system, magnet power supplies and cooling system which runs on round the clock basis.

**4.12 Special Program**

**Access control system**

A separate RFID type card was being used for access control in different zones in VECC campus. Recently RFID type attendance cards have been introduced for VECC employees. These have been programmed for access control too replacing the older cards. The system is being monitored by the Health...
4B: Radiation Technologies and their Applications

4.05 Health

Design, Development of automated $^{99m}$Tc-TCM-AUTOSOLEX generator for separation and recovery of $^{99m}$Tc from low-medium specific activity $^{99}$Mo

Technetium-99m ($t_{1/2}=6.02$ h; 140.51 keV (89%), principle $\beta$-emission energy) is known to be the most useful radioisotope in diagnostic nuclear medicine. More than 80% of all diagnostic procedures done worldwide in nuclear medicine centre are performed with $^{99m}$Tc. An automated closed cyclic module (TCM-AUTOSOLEX) for separation and recovery of various isotopes, radioactive or non-radioactive, using solvent extraction technique, and in particular, for separation and recovery of $^{99m}$Tc from low-medium specific activity $^{99}$Mo obtained in research reactor has been indigenously developed jointly by VECC and BRIT, Kolkata. The module may also be used for separation of $^{99m}$Tc produced in cyclotron. The module is safe and reliable and operated remotely through a PC, thus avoiding direct handling of radioactive and hazardous chemicals by an operator. The TCM-AUTOSOLEX generator system is based on the selective extraction of pertechnetate ($^{99m}$TcO$_4^-$) in methyl ethyl ketone (MEK) from aqueous alkaline ($n, \beta$)Na$_2^{99}$MoO$_4$ solution and subsequent purification of the organic phase by passing through an alumina column to remove traces of Mo, alkali etc. and careful evaporation of the organic phase. Finally, the residue obtained after evaporation is reconstituted in physiological saline (10 ml), purified through an on-line 0.22μ membrane filter to obtain pharmaceutical grade $^{99m}$Tc and collected in a sterile vacuum vial.
A 16-bit microcontroller based embedded system has been designed indigenously to automate the entire process. A PC based graphical user interface (GUI) has also been developed that communicates with the controller electronics over a serial link. The user sets the timing of each sequence of the process and also the temperature of a thermal bath that is used in the evaporation stage. These settings are sequentially sent via a serial link to the controller electronics that operates the heater system, valves and pump accordingly. A conductivity detector has also been designed and implemented to automate the separation of the chemicals based on difference in resistivity of the two liquids. Apart from setting and command interfacing between PC and the process, the controller unit also provides monitoring over the actuators, conductivity detector and heater temperature (±5°C) and sends the status to the GUI. An additional feature of time-stamped data logging is also built in the GUI for diagnostics purposes.

A prototype was installed in BRIT, Kolkata and several cold runs were carried out and demonstrations done. It was then shipped to BRIT, Mumbai and tested with actual activity. It was demonstrated successfully there and also in RMC, Parel.
5.07 Cyclotrons & their Utilisation

**Upgradation of Phase control loop for the 3-phase RF system of K500 Superconducting Cyclotron**

The phase stability of $\pm 1^\circ$ between the dees was achieved with the phase control loop adopting analog I/Q (In-phase/Quadrature) modulation technique. Recently, the existing phase control loop has been replaced with the newly developed one based on Direct Digital Synthesis (DDS) technique. An automatic phase correction system has been designed, developed, installed and commissioned using this DDS module (AD9959) and a programmable digital controller. There are significant advantages like $360^\circ$ phase rotation, constant amplitude irrespective of phase variation, linearity etc. of new control system over the analog phase controller. The performance of this new phase regulator has been remarkably improved achieving the residual phase modulation generated by cavity resonator within the stability of better than $\pm 0.2^\circ$ for the RF system of K500 Superconducting cyclotron.

![Plot of Dee Voltage, Phase and Vacuum data vs. time](image)

5.01 Mathematics and Computational Sciences

1) **DEVELOPMENTS ON EDUCATIONAL SOFTWARE FOR THE HEARING-IMPAIRED.**

VECC, in collaboration with Webel Mediatronics Limited, Kolkata, continued the development of software for the hearing-impaired persons that was initiated under the XI plan. Initial developments under this project were reported in the the DAE Annual Report 2009-2010 (page no. 119-120). The first version of the software—“Mounisara 1.0”—that translates input Bangla text to sign language, was formally released by Director, VECC in presence of the Hon’ble Minister-in-Charge, Department of Information Technology and Biotechnology, Government of West Bengal on June 08, 2009. After its release, this software was distributed free-of-cost among several deaf schools within the state of West Bengal. Based on the feedback received from the users, the scope of the software has been enhanced. The latest version of this software is “Mounisara 2.1”. Encouraged by the appreciation received on Mounisara 1.0, similar translator software with the input text in Hindi has also been developed to extend the usefulness of such software in the national level.

In addition, e-books for the primary school children based on sign language have also been developed. These e-books embody the contents of standard text books of primary school children in sign language, with textual subtitle. So far, e-books for the Bangla text books *Barnaparichay* (Part I and Part
II), *Kishalaya* (for class I) and *Sahaj Patha* (for class I) have been developed. A lesson on conversation in sign language has also been developed.

Graphical user interface of the Hindi version of Mounisara 1.0.


Reports on these activities have been published in several renowned Bengali and English newspapers. These softwares are freely available on DVDs to all institutes and organizations associated with hearing-impaired persons. This software is presently being beneficially used in around 45 schools for the deaf children as an educational aid.

2] **EXPERIMENTS WITH MOBILE ROBOT BASED ONLINE RADIATION MAPPING SYSTEM IN K-130 CYCLOTRON FACILITY AT KOLKATA.**

A mobile robot based radiation dose-rate mapping system was developed at this Centre in collaboration with DRHR, BARC and HPU, Kolkata [Ref: DAE Annual Report 2010-11, Page: 20, 27,163]. Experiments were carried out earlier with 30 MeV alpha beam at 12 pre-decided locations in vault and also during the period of reporting in those locations in vault with 10, 12, 15 and 18 MeV proton beams and 30, 35, 40, 50 and 60 MeV alpha beams, with primary beam completely stopping at Faraday Cup (FC-01). During this time, radiation measurement has also been done inside the High Intensity Cave–I for the alpha and proton beam of above mentioned energies with the beam dumped on a thick target. The thick target was placed at the end of the beam line. The experimental setup with the mobile robot at the High Intensity Cave-I is shown in Figure.
Following significant results have been obtained from the experiments:

♦ Complete neutron and gamma radiation field mapping done for different conditions (beam type and beam energy) for accidental exposure estimation.
♦ Locating the maximum beam loss positions and thereby improving beam optics resulting in increase of beam transmission efficiency.
♦ Optimization of beam internal parameters to reduce the ambient dose rate inside vault and pit areas and reduction of radiation damage to components and accidental radiation exposure.
♦ Significant reduction of induced activity produced at different parts of the machine components. This decreases the waiting time to enter active areas from a few hours to a few minutes. (A minimum waiting time of 10 minutes based on ventilation system is only followed).

3] AUGMENTATION OF COMPUTING FACILITY OF VECC.

VECC’s computing facility has been augmented by addition of (a) blade system with 32 nodes (total 256 cores), 32 GB memory per node, Infiniband interconnect, 120 GB disk per node running Linux cluster; and (b) blade system with 14 nodes (total 168 cores), 64 GB memory per node, 120 GB disk per node, Infiniband interconnect and SAN storage of 72 TB. The first system is presently being used to run LAMMPS ("Large-scale Atomic/Molecular Massively Parallel Simulator").

5.07 Cyclotrons and their Utilisation

DESIGN AND FABRICATION OF INNOVATIVE NEUTRON SHUTTER FOR BEAM LINES OF SUPERCONDUCTING CYCLOTRON

A neutron shutter is used in an accelerator to reduce radiation streaming to the experimental caves from the cyclotron area to acceptable limits. The shield wall plug has static and moving iron plates to attenuate radiation. A considerable length of iron present in the shield wall plug adds to the outgassing load to the vacuum system. Design of the neutron shutter was improved by placing the mild steel rotor blocks and other suitable attenuators in a sealed stainless steel pipe to form a single encapsulated rotor. The static plates in the shield wall plug supporting the rotary shaft have been totally eliminated. The shaft has been designed to support the weight of the attenuator at the ends only. The rotor is placed inside a stainless steel vacuum chamber. The drive shaft rotates by about 60° to move the rotor from closed position to open position by using a electrically actuated pneumatic cylinder. In the event of an electrical or pneumatic failure, the rotor moves to closed condition by inertia. The rotary motion was
enclosed in a vacuum space incorporating bellow sealed feed through to eliminate air leaks during operation. The new design of shield wall plug reduces the length to about 1 metre, volume to 0.08 m$^3$ and surface area to 1.1 m$^2$. The vacuum in the shield wall plug placed in the beam line was evaluated and found to improve considerably improving transmission of beam in the beam line substantially. Radiation protection aspects were also evaluated to ensure suitability of the neutron shutter.

**Design and development of Structure for CPDA**

A 4$\pi$ Charged Particle Detector Array (CPDA) is being developed at VECC to understand basic properties equations of state of nuclear matter, liquid gas phase transition, isoscaling etc using Superconducting cyclotron beam. According to types of detection system, the array can be divided into three parts. A. Extreme Forward part $\theta$=30-70 consists of plastic phoswitch detectors, B. Forward part $\theta$=70-450 consists of three layer highly granular charged particle telescope Si strip-Si strip-4 CsI(Tl) with 256 pixel and C. backward part $\theta$=450-1750 with all parts $\phi$ coverage 00-3600.

Geometry of the array is such that front face of the detectors form a part of sphere of radius 150 mm. The spherical surface was discretised with isosceles trapezoids which represents the functional face of a detector shaped like a frustum of a pyramid.

The backward part of CPDA has 6 rings with azimuthally symmetry. A numbers of detectors will be kept in the rings covering the solid angle. A support structure has been designed for mounting the detectors for the required orientation. Simulation for dismantling a single housing was carried out with CAD modelling software to ascertain the accessibility of individual detectors for maintenance. A radial out ward motion was imparted on each housing separately and the non interference zone between the swept volumes of two adjacent segments was identified. Support ring cross sections were designed such that the rings are contained entirely
within the non interference zone. The base plates and stands were also designed following the similar principle

The backward part of the detectors housing, their assembly, and support system have been designed, fabricated and assembled successfully using in-house fabrication facility at VECC.

**Development of Spiral Inflector for VECC Superconducting Cyclotron**

Spiral inflector for superconducting cyclotron is used to inject charged particles produced in an external ion source into the cyclotron. It consists of two electrodes, RF Shield and electrode holders. The surfaces of electrodes facing each other form a spiral helix. The gap between the electrode surfaces is 4 mm and the electrodes are placed inside a contoured profile shield made of copper kept at ground potential. Electrodes were made of aluminum and connected to the power cable through two feed-throughs mounted within insulator base.

Modifications were implemented to improve the performance of the inflector in respect of the width of the electrode surface, reduction of joints, stability of construction and positioning accuracy.

Fabrication of the integrated stem electrodes was carried out from single stock of Aluminium 2024 in a 4 axis CNC milling machine by adopting proper machining strategies and simulations in CAM software. Several combinations of cutting parameters and machining strategies were tried to reduce the distortion and chattering during machining of the slender stem in same set up. The electrodes and other components were fabricated very precisely and it was possible to achieve the electrode gap within 60 micron accuracy in the final assembly.

![RF Shield, Electrodes & Insulator base of the Inflector](image)

**INDUCTIVELY COUPLED PLASMA FOR GENERATING HIGH INTENSITY PROTON BEAM**

Proton beams have demands from various fields like neutron generators, neutral beam injectors, accelerators etc. Generally ECR ion sources are used to produce the high intensity proton beams. The emittance of beam extracted from ECR ion sources is large. An inductively coupled plasma ion source without using any magnetic field, operating at 13.56 MHZ with external antenna for producing high current CW proton beam is developed. The ion beam extraction system comprises of parallel two electrodes with single aperture. From hydrogen plasma, 5 mA of ion beam current could be extracted with
5kV extraction and 220W of RF power. Extraction characteristics show the slope of 1.3 mA / kV showing the capability of this ion source to produce much larger currents at higher extraction potentials and higher powers.

Since there is no magnetic field employed in the ion source, the emittance of extracted ion beam is low. Measurements on 1.5 mA beam extracted at 4 kV shows normalized rms emittance of 4x10^-3 mm mrad which is more than an order less than that of ECR ion sources. Proton fraction of the beam is yet to be measured. The hydrogen plasma at 200W and the ion beam extraction characteristics with applied RF power at 5kV extraction potential are shown. Besides high current proton beam, this ion source also can generate several mA of heavy ion beams of Ar, Kr and Xe etc.

**Superconducting Cyclotron:**

In the superconducting cyclotron at VECC, there have been several up-gradation and improvement of various subsystems which will be helpful for the extraction of beam. One of the major achievements was Improvement of RF phase stability. Previously the phase stability was ± 0.5° to 1°. New phase control loop based on Direct Digital Synthesis (DDS) technique achieved stability within ± 0.2°. RF conditioning at low duty cycle (5%) allowed us to reach about 20% higher dee voltage also. Meanwhile, the direct measurement of rf voltage using Brestrahlung technique has also been done. Another remarkable development is the development of beam phase measurement setup using BC418 plastic scintillator detector. This set up provided us a very useful tool for isochronisms tuning of the beam. However the most important development is installation of a new spiral inflector assembly which can be remotely be rotated and vertically moved to optimize its position with respect to the rf system. It has been proved very effective in the sense that we could accelerate more than 550 nA of beam current, which is enhancement by a factor of three. The figure below shows the beam current as a function of radius, i.e. equivalent to energy, for different rotational position of the inflector.

![Beam current versus radius for different rotation of inflector. The angular positions (in degrees) are mentioned in the legend.](image-url)
High temperature superconducting magnet for beam line:

As a XII-th five year plan, a project for developing high temperature superconducting magnets has been started. HTS tapes in principle, has several advantages over low-temperature superconductor (LTS) such as higher range of operating temperature, higher specific heat leading to rare occurrence of quench, etc. Since HTS systems have higher operating temperatures than LTS system, simpler cryogen free system with commercially available cryocooler of high cooling power can be adopted. Detailed magnetic design of X-Y steering magnet (±3° horizontal, ±1.5° vertical, field quality \( dB_y/B_y \sim 4.55 \times 10^{-3} \), \( dB_x/B_x \sim 2.5 \times 10^{-3} \)) for external beam line of K500 cyclotron has been carried out with commercial finite element code ANSYS. The magnetic field length in horizontal and vertical directions are 0.173 and 0.087 T-m respectively. The maximum field perpendicular to the tape surface is estimated to be 1.2 T for the nominal operating current of 175 A each. The positions of the coil are optimized to have good field homogeneity (better than 0.1%) throughout the good field region.

![Magnetic field (B_{mod}) contours](image1)

![HTS coils for steering magnet.](image2)

The steering magnet will be developed with two sets of racetrack coils as shown in Fig.3. Three double pancakes (3 DPC) will be used for each By racetrack coil. Two double pancakes (2 DPC) will be used for each Bx coil. We will use either bismuth-based first generation tape (BSCCO-2223) or yttrium-based second generation tape (YBCO-123). In between pancakes, anodized aluminum or copper plates of around 1 mm thickness will be put for conduction cooling. The magnet and shield will be cooled at around 20-25K by Gifford-McMahon (GM) cryocooler.

4K Cryo-cooler based Cryogenic Test Set-up

The 4K cryo-cooler based cryogenic test set-up is a general purpose test facility which allows to cool the samples/devices to 4.2K without the inconvenience and expense of liquid helium. The cryostat was designed, fabricated and successfully integrated with two numbers of Sumitomo Made 4K Cryo-coolers. The thermal performance of the system was tested successfully and different measurement was carried. Several Niobium (Nb) samples from BARC, Mumbai was characterised for purity through RRR measurements. The phase measurement was carried out from 320K-4K of Cobalt-Tin sample from SN Bose Institute, Kolkata of different compositions.
Test set-up mounted on a movable table

Sample mounting centre stick

Cool-down of test set-up cryostat which requires about 5-6 hours of time to reach 4.2 K

Measurement of cooling power under different temperatures. It also shows sample space temperature remains at 4K during measurement indicating thermal isolation.

Resistivity variation with temperature of one of the Nb sample

Phase transition of two different composition of Cobalt-Tin samples
**Room Temperature Variable Energy Cyclotron**

The variable energy cyclotron (VEC) has been delivering proton and alpha beams of a variety of energies and intensities. Presently, the available energies of proton and alpha beams are 7.5 MeV to 16 MeV and 30 MeV to 65 MeV respectively. The cyclotron is performing well, delivering good quality and very stable beam for conducting the experiments.

VEC cyclotron has also developed very low energy (1.0 to 4.0 MeV/nucleon) light ion beam and experimentalists are utilizing these beam for sub-coulomb fission experiments.

The cyclotron has already been operating for more than 2800 hours in terms of new beam development and delivering beam on target for conducting experiments in various fields of research mainly in nuclear physics, radio-chemistry, material science and producing of radio-active atoms etc.

**Development of Sub-Kelvin Technology at VECC**

In consonance with the emerging technologies involving very low temperature measurement of semiconducting and superconducting alloys besides nano-materials, we are developing an indigenous sub-Kelvin system at VECC. Basic objective of the project is to have a firsthand experience and to cultivate skill by way of overcoming the complex engineering challenges intrinsic to the sub-Kelvin temperature region. The system has three distinct temperature steps, namely 1.2K, 0.6K and 0.1mK. At the first place, we have successfully attained a temperature somewhat less than 1.0K and it was found to maintain that temperature over a considerable time period. Cooling power was measured to be ~17mW using manganin wire heater.

As to achieve the second and final temperature steps, we have finalized the design of $^3$He distillation chamber (Still), counter flow heat exchanger and mixing chamber, the place for final base temperature. As a way of operating continuously, the circulating gas essentially $^3$He needs to re-circulate through a closed circuit. This gas handling system is presently being fabricated in the laboratory. A prototype Still has been built up and the mixing chamber is in its final stage of fabrication and polishing. This project will also help us to decipher many subtle thermo-dynamical features involved in the process.
1K Helium Evaporator

Temperature profile for cooling down

Helium Evaporator placed inside the cryostat