OVERVIEW OF VECC ACTIVITIES

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in IJAS-2020 held at
VECC, Kolkata
Outline

- K130 Cyclotron
- K500 Superconducting Cyclotron
- Medical Cyclotron, 30 MeV
- RIB activities
- Technology Development
- Basic Sciences
- Other societal activities
Variable Energy Cyclotron Centre (VECC) -- one of the R&D units under the Department of Atomic Energy (DAE)

Primarily engaged in the area of research in Basic Science since its inception in 1969.

- **Basic Sciences**: Experimental Research in Low and High energy Nuclear Physics using accelerators and Theoretical Nuclear Physics
- Accelerator based applied research in the field of material science and radiation damage studies
- Societal applications: Medical Cyclotron for isotope production
- Indigenous accelerator development and R&D on Advanced Accelerators
- Technology Development in the area of RF/SRF technology, detectors, Data Acquisition system, Instrumentation, Power Electronics, mechanical and cryogenic engineering etc.
K130 Cyclotron

224 cm Variable Energy Cyclotron - operating since 1977
**Heavy ion acceleration program with K130 Cyclotron**

**Commissioning of axial injection system**

- Central plug for heavy ion acceleration
- New axial injection line for beam transport to cyclotron

- Modification of cyclotron central region compatible for heavy ion acceleration

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**Engineering layout of axial injection line**

SM: Solenoid magnet
ST: Steering magnet
**ECR ion source parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>14.45 GHz</td>
</tr>
<tr>
<td>ECR source</td>
<td>600W TWT generator</td>
</tr>
<tr>
<td>Axial mirror field</td>
<td>Two solenoids</td>
</tr>
<tr>
<td>Max. axial field</td>
<td>1.2 T</td>
</tr>
<tr>
<td>Radial Field</td>
<td>Hexapole (NdFeB)</td>
</tr>
<tr>
<td>Max. radial field</td>
<td>1.1 T @ 34.8 mm</td>
</tr>
<tr>
<td>Extraction system</td>
<td>Two electrode</td>
</tr>
</tbody>
</table>

**Vertical injection line**
Modification of central region

Central region for PIG ion source

Central region for ECR ion source
New beam development in ECRIS of Room Temperature Cyclotron

Sulphur, Iron, Chlorine beams have been developed in 14.45 GHz ECRIS using MIVOC (Metal Ions from VOLatilie Compounds) method.

- S\textsuperscript{10+}: 32 \mu A
- S\textsuperscript{11+}: 12 \mu A
- Fe\textsuperscript{11+}: 20 \mu A
- Fe\textsuperscript{12+}: 15 \mu A
- Fe\textsuperscript{13+}: 9 \mu A

Plan: To accelerate solid ion beams with K130 Cyclotron
## Performance of K130 Variable Energy Cyclotron
(April, 2018 - March, 2019)

<table>
<thead>
<tr>
<th>Projectile</th>
<th>Energy (MeV)</th>
<th>Beam Current (nA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>7 – 13</td>
<td>5000</td>
</tr>
<tr>
<td>Alpha</td>
<td>28 – 50</td>
<td>700</td>
</tr>
<tr>
<td>Nitrogen 5+</td>
<td>101–142</td>
<td>400</td>
</tr>
<tr>
<td>Oxygen 6+</td>
<td>116 – 162</td>
<td>300</td>
</tr>
<tr>
<td>Neon 7+</td>
<td>145 – 203</td>
<td>120</td>
</tr>
</tbody>
</table>

**Beam Availability**

- Beam availability: 5160 hrs
- Unplanned Shutdown: 1555 hrs
- System breakdown: 1266 hrs
- Planned Shutdown: 779 hrs

Beam Availability ➔ Achieved 5160 h
Performance of K130 Variable Energy Cyclotron

<table>
<thead>
<tr>
<th>YEARS</th>
<th>HOURS</th>
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<tbody>
<tr>
<td>2010-11</td>
<td>4367</td>
</tr>
<tr>
<td>2011-12</td>
<td>3669</td>
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<tr>
<td>2012-13</td>
<td>3206</td>
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<td>2013-14</td>
<td>3873</td>
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<td>2014-15</td>
<td>4599</td>
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<td>4775</td>
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<tr>
<td>2016-17</td>
<td>3737</td>
</tr>
<tr>
<td>2017-18</td>
<td>3507</td>
</tr>
<tr>
<td>2018-19</td>
<td>5160</td>
</tr>
</tbody>
</table>
K130 Cyclotron Users

- VECC
- SINP
- Materials Division, BARC
- AchD/BARC
- UGC-DAE-CSR-Kolkata
- IIEST-Shibpur
- Calcutta University
- TIFR
- University of Mumbai
- Nuclear Physics Division, BARC
- CEBS - Mumbai etc.
K500 SUPERCONDUCTING CYCLOTRON
Aim: To get rid of the unwanted first harmonic components in the magnetic field.

Mismatch between magnet centre and cryostat centre (~1.2 mm)

**STEPS**

- Warm up SCC magnet to room temperature
- Disassemble injection beam line from top, RF panels, cryogenic lines, Top part of the magnet, lift the cryostat – required to access the dowel pins of cryostat
- Shift Cryostat: Validate mechanically & by field measurement
- Reassemble everything

Error in central plugs, small and large hill additions: Completed in 2017-18
Super-conducting Cyclotron – Putting things back once again
Super-conducting Cyclotron – Putting things back once again

Ready for RF conditioning & Beam Trial
Before Correction

After central plug correction & first cryostat repositioning

After final cryostat repositioning

Earlier

Present (after correction)

N2+ beam extracted out of the machine in Dec-2019.

Further optimization → beam energy ~ 35 MeV/A ---- 80 MeV/A
Extracted N2+ beam from the VECC **K-500 Superconducting Cyclotron** transported to SHARC (the Segmented, Horizontal Axis, Reaction Chamber).
30 MeV MEDICAL CYCLOTRON (IBA-make)
<table>
<thead>
<tr>
<th>Radio-isotope (half life)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{201}$Tl (3.06d)</td>
<td>Myocardial perfusion (evaluates heart’s function and blood flow)</td>
</tr>
<tr>
<td>$^{67}$Ga (3.26d)</td>
<td>Soft tissue tumor imaging, Broncogenic carcinoma</td>
</tr>
<tr>
<td>$^{111}$In (2.8d)</td>
<td>Cisternography, Abscess imaging, Tumour imaging</td>
</tr>
<tr>
<td>$^{18}$F (1.8h)</td>
<td>Imaging for assessment of abnormal glucose metabolism to detect malignancy in patients</td>
</tr>
<tr>
<td>$^{68}$Ge (271d) / $^{68}$Ga (68m) Generator</td>
<td>useful in direct tumor imaging, especially leukocyte-derived malignancies and prostate cancer</td>
</tr>
<tr>
<td>$^{103}$Pd (16.99d)</td>
<td>Use in Diagnostic and also radiation therapy for prostate cancer and uveal melanoma.</td>
</tr>
<tr>
<td>$^{123}$I (13.2h)</td>
<td>Myocardial metabolism, Neuroendocrine tumor imaging</td>
</tr>
</tbody>
</table>
DAE Medical Cyclotron Facility at Chakgaria, Kolkata
Shifting and Rigging of Magnet & RF cavities of Medical Cyclotron

- 55T magnet system installed on 4 piers by VECC Engineers / Technicians and aligned within 100 micron accuracy.

Design of rail structure was done in-house
Medical Cyclotron (IBA#Cyclone-30) installed at Vault with 5 beam lines
PET cave, where F18 produced from the Target with enriched O18
Beam spot was seen in Beam viewer (Bright Spot)
Now, the machine is operated with IBA software and GUI.
Beam line for ADSS target study

Material Sc Beam line
Material Sc Cave
High Dose & Low Dose -- 2 Nos. of Material Sc Beam lines
High Dose & Low Dose --
2 Nos. of Material Sc Beam lines
5th Beam line (for ADSS target study) in Main vault
5th Beam line (for ADSS target study) in ADSS cave (-10m level)
Shuttle Transport system for Solid Targets (SPECT)
Solid target assembly

- Interface to beam line-cyclotron
- Water cooling system
- Pneumatic Transport system

Solid target station-1

Solid target station-2
PET Hot cells for production & dispensing of $^{18}\text{F}$-FDG

SPECT Hot cells
A few batches of F-18 has been produced in this cyclotron by irradiation of H$_2^{18}$O (97% enriched) $[^{18}$O(p,n)$^{18}$F] using 18 MeV proton beam (~35-45 μA current) for 30 min to 2 hours in PET vault.

Synthesis of $^{18}$F-FDG from $^{18}$F- (Fluoride) was carried out using automated, closed loop and computer-controlled IBA synthera module inside the Comecer make Hotcells (75 mm Pb thick wall) after transferring $^{18}$F-H$_2^{18}$O water. ABX, Germany reagents and ancillary kits along with IFP (Integrated Fluidic Processor) are utilized in the IBA Synthera module for the synthesis and purification of $^{18}$F-FDG.

The dispensing of the product is carried out using TIMOTHEO-LT dispensing module inside Comecer dispensing Hotcells having ISO Class A environment.

RC, BRIT, Kolkata is engaged in the production of $^{18}$F-FDG injection under aseptically condition following all norms of handling Radiopharmaceuticals.

The physico-chemical and bio quality control tests were performed as per USP specifications with satisfactory results.

The proposal has been submitted for RPC (Radiopharmaceuticals Committee) clearance is being sought for manufacture and supply of the $^{18}$F-FDG injection for clinical use in patients.

Successful human applications made to a volunteer.
RARE ISOTOPE BEAM (RIB) Facility
RIB (Rare Isotope Beams) programme at VECC

- K=130 Cyclotron
- Ion Source
- Separator
- RFQ Linac
- LINAC-1 & 2
- LINAC-3
- LINACs 4-5
- SC QWR

- Electron Linac
- Proton accelerator

- Low energy RIB facility with linear accelerators up to 1.0 MeV/u is built at Salt Lake campus; facility utilized for material science & RI beam development.

- Pre-project activity is going on for the proposed next generation RIB facility called ANURIB* at Rajarhat campus. ANURIB aimed at beams of higher intensity and variety; multi-disciplinary research.

- R&D on gap areas viz superconducting linacs and high power target technology development is underway.

*ANURIB (Applied and Nuclear Research facility with Rare Isotope Beams)
Typical measured $^{14}\text{N}^{4+}$ beam currents available to users

<table>
<thead>
<tr>
<th>Energy</th>
<th>Energy keV/u</th>
<th>Location</th>
<th>Beam current</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 keV</td>
<td>1.78</td>
<td>after ECR</td>
<td>1.1 µA</td>
</tr>
<tr>
<td>1.4 MeV</td>
<td>100</td>
<td>After RFQ</td>
<td>800 nA</td>
</tr>
<tr>
<td>4.0 MeV</td>
<td>289</td>
<td>After Linac-2</td>
<td>750 nA</td>
</tr>
</tbody>
</table>

415 keV/u commissioned
Newly installed beam-line in RIB Annex building
List of Radioactive Ion Beams

<table>
<thead>
<tr>
<th>RIB</th>
<th>Prod. route</th>
<th>T1/2</th>
<th>I(pps) @ before RFQ</th>
<th>I(pps) @ after RFQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}\text{O}$</td>
<td>$^{14}\text{N}(p, n)$</td>
<td>71 s</td>
<td>$5.0 \times 10^3$</td>
<td>$3.2 \times 10^3$</td>
</tr>
<tr>
<td>$^{42}\text{K}$</td>
<td>$^{40}\text{Ar}(\alpha, pn)$</td>
<td>12.36 hr</td>
<td>$2.7 \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$^{43}\text{K}$</td>
<td>$^{40}\text{Ar}(\alpha, p)$</td>
<td>22.3 hr</td>
<td>$1.2 \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$^{41}\text{Ar}$</td>
<td>$^{40}\text{Ar}(\alpha, 2pn)$</td>
<td>109 min</td>
<td>$1.3 \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$^{111}\text{In}$</td>
<td>nat $\text{Ag}(\alpha, xn)$</td>
<td>2.8 days</td>
<td>$1.6 \times 10^5$</td>
<td>-</td>
</tr>
</tbody>
</table>

List of Stable Isotope Beams

Carbon, Nitrogen, Oxygen, Helium, Argon, Iron, Nickel, Indium, Zinc, Boron; Typical beam currents ~ 1 – 100 micro-amps; depending on species & charge state
<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Date</th>
<th>Beam</th>
<th>Energy</th>
<th>Expt.name</th>
<th>User</th>
<th>Institution</th>
<th>Beam Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>09-02-2016</td>
<td>NBI+ stable</td>
<td>10keV</td>
<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>2</td>
<td>24 to 26-02-2016</td>
<td>Mass dist. of Th232 fission fragments</td>
<td>10kV-40kV</td>
<td>Fission fragments are transported using gas jet technique</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>3</td>
<td>18-04-2016</td>
<td>N+ stable</td>
<td>8keV</td>
<td>Nano patterning of Si</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>4</td>
<td>25-05-2016</td>
<td>N+ stable</td>
<td>5keV</td>
<td>Nano template formation</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>5</td>
<td>08-09-2016</td>
<td>11A+ stable</td>
<td>5keV</td>
<td>TiO2 irradiation</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>6</td>
<td>02-11-2016</td>
<td>43K RIB</td>
<td>keV</td>
<td>Gamma spectroscopy of 43K</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>7</td>
<td>Oct-Dec.2016</td>
<td>N+ stable</td>
<td>1.4MeV</td>
<td>RFQ Bunch width measurement</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>8</td>
<td>28-02-2017</td>
<td>N1+ stable</td>
<td>4keV</td>
<td>Ag ion implantation on Si(100)</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>9</td>
<td>20-05-2016</td>
<td>N+ stable</td>
<td>1.2MeV</td>
<td>Implantation on Si(100)</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>10</td>
<td>30-05-2016</td>
<td>N+ stable</td>
<td>1.4 MeV</td>
<td>Implantation on Si(100)</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
<tr>
<td>11</td>
<td>15/3 to 5/5/2017</td>
<td>N+ stable</td>
<td>5.8MeV</td>
<td>New beam line commissioning upto LINAC3</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>12</td>
<td>07-06-2016</td>
<td>10A+ stable</td>
<td>5keV</td>
<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>13</td>
<td>17-07-2016</td>
<td>10A+ stable</td>
<td>6keV</td>
<td>Ag ion implantation on Si(100)</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>14</td>
<td>26-07-2016</td>
<td>10A+ stable</td>
<td>4keV</td>
<td>Ag ion implantation on SiO2</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>15</td>
<td>28/11 to 13/12/2017</td>
<td>Ar8+ stable</td>
<td>4MeV</td>
<td>Damage study Vanadium</td>
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<tr>
<td>16</td>
<td>16-03-2018</td>
<td>N2+ stable</td>
<td>12keV</td>
<td>Amorphization of Si surface</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>17</td>
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<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>18</td>
<td>12-10-2018</td>
<td>Ge+ stable</td>
<td>8keV</td>
<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
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<td>Main beam</td>
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<td>19</td>
<td>23/7 to 29/8/2019</td>
<td>Ar+ stable</td>
<td>8keV</td>
<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>20</td>
<td>03-06-2019</td>
<td>(CO)+ molecular</td>
<td>14keV</td>
<td>Periodic silicon carbide zone formation</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>21</td>
<td>13-17/05/19</td>
<td>Ar+</td>
<td>5keV</td>
<td>Nano dot formation on GaSb</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>22</td>
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<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<td>23</td>
<td>23/7 to 29/8/2019</td>
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<td>8keV</td>
<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>24</td>
<td>03-06-2019</td>
<td>C+,N+,Ni+,O+,(O2)+ &amp; Ar+</td>
<td>5keV to 20keV</td>
<td>Nano structuring on Si and mica surface</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>25</td>
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<td>(CO)+ molecular</td>
<td>14keV</td>
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<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>26</td>
<td>13-17/05/19</td>
<td>Ar+</td>
<td>5keV</td>
<td>Nano dot formation on GaSb</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
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<td>27</td>
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<td>Beam development</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
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<td>Main beam</td>
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<tr>
<td>30</td>
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<td>(CO)+ molecular</td>
<td>14keV</td>
<td>Periodic silicon carbide zone formation</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>31</td>
<td>30/09/2019 to 01/10/2019</td>
<td>Ar+ stable</td>
<td>10 keV</td>
<td>Modification of Potassium hydrogen pat hate</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
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<tr>
<td>32</td>
<td>10-10-2019</td>
<td>Ar+ stable</td>
<td>10 keV</td>
<td>Modification of MnO2 surface for antibacterial studies</td>
<td>Rahul Tripathi/Debasish Banerjee</td>
<td>RIBFG/HBNI,VECC</td>
<td>Main beam</td>
</tr>
</tbody>
</table>
ANURIB – applied and nuclear research facility with rare isotope beams

Rajarhat Campus

Campus size 25 acres

33kV Sub-station

ANURIB
95mx100m

Future extension

Heerak Jayanti Guest-house

Lab-1

RMRC

UGC-DAE CSR

AMD/A ERB
Cryomodule reached VECC from TRIUMF Canada on Oct-19, 2019.
Liq. He plant commissioned in Oct 2019

Linde LR280 (500 W @ 4K, 235 l/hr)
## SC QWR Linac for heavy-ion beam acceleration beyond 1 MeV/u

<table>
<thead>
<tr>
<th><strong>Frequency [MHz]</strong></th>
<th><strong>113.4</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$ [%]</td>
<td>5.3</td>
</tr>
<tr>
<td>No. of resonators</td>
<td>8</td>
</tr>
<tr>
<td>$E_{\text{peak}}/E_{\text{acc}}$</td>
<td>$\sim 6.6$</td>
</tr>
<tr>
<td>$E_{\text{acc}}$ [MV/m]</td>
<td>5.5</td>
</tr>
<tr>
<td>Initial/final energy (MeV/u)</td>
<td>1.04/2.0</td>
</tr>
</tbody>
</table>

### Cryo-module

Beam & cryo-module vacuum will be separate

**1st VECC Niobium QWR cavity at TRIUMF**

(VECC-TRIUMF collaboration)
Technology Development
DEVELOPMENT OF LB650 SRF CAVITY (under IIFC)

- Design of low beta 650 MHz Superconducting cavity
- First VECC- make single-cell niobium cavity achieved 34.5 MV/m (Q0 =2E+09) ; 30 MV/m (Q0 =1.5E+10) tested in VTS at Fermilab, USA.
- Cavity sustained 74MV/m $E_{pk}$ and 137 mT $B_{pk}$
- Second single cell cavity fabricated with changes in welding sequence wrt first single cell cavity and is yet to be tested in VTS
VTS Results: VECC—make Single Cell LB650 SRF Cavity

First cavity of this type in the world and it has reached a world record gradient of 34.5 million-volt per meter (MV/m) at 2K temperature.

Cavity could sustain 74MV/m Peak Electric Field ($E_{pk}$) and 137 mT Peak Magnetic Field ($B_{pk}$), with accelerating gradient of 34.5 MV/m @ 2K (-271°C).

Maximum accelerating Gradient: 34.5 MV/m @2K

Accelerating Gradient of 30 MV/m @2K achieved with unloaded cavity quality factor $Q_0 = 1.5 \times 10^10$. 

Single-cell LB650 niobium cavity (EBW done at IUAC)
The first single cell Niobium cavity was fabricated in a welding sequence in which the **equator welding was done first** and then the iris welding was carried out.

However, the 5 cell cavity shall have the welding sequence in the exact **reverse way**. In order to validate the actual welding methodology, a second single cell cavity has been fabricated with changes in welding sequence where **iris welding is done before that of equator**.

**Electron Beam Welding** of the cavity has been carried out at **IUAC, Delhi**.

The cavity has passed cryo-shocking test with LN2 (MSLD : leak rate ~ 2E-9 mbar-lit/sec)

Frequency measurements of the cavity was done at VECC (645.9 MHz).
Under IIFC collaboration, VECC is involved in design of 5-cell LB650 cavity as per FRS/TRS criteria and design review for dressed LB650 cavity was held on 7th Nov and 8th Nov, 2019.

Increase in cavity wall thickness (from 4mm to 4.4mm) will **not improve** the LFD significantly and consequently LFD criteria in FRS/TRS has been decided to be increased to 2.2 Hz/(MV/m)^2, cavity wall thickness has been chosen as 4.4mm by Fermilab, probably to honor the collaboration with INFN, Italy who use of 4.4 mm niobium sheet for SRF cavities in European Spallation Neutron source.

In the prototype phase, **VECC will fabricate LB650 cavity with 4 mm niobium sheet**

VECC presented the design results for dressed LB650 cavity **with 3.75 mm cavity wall thickness and 90 mm stiffener ring**, in the design review meeting and all the results **satisfies FRS/TRS criteria**

---

**FRS/TRS BASED DESIGN OF 5 CELL LB650 CAVITY**

- **Accelerating mode (π-mode) at 650.02MHz**
- **Electric field, Magnetic field and Lorentz force on cavity wall (Superfish result)**
- **Multipacting Result (CST Particle Studio)**
- **Contour plot of Von-Mises stress in cavity**
- **df/dP vs Tuner Stiffness for Stiffener ring radius (at midcell/endcell) 70mm/90mm**
- **LFD vs Tuner Stiffness for Stiffener ring radius (at midcell/endcell) 70mm/90mm**
- **LFD vs Tuner Stiffness (kN/mm)**
FABRICATION OF 5 CELL LB650 CAVITY

- Three different Die –Punch assemblies fabricated for mid-cell, pen-cell and end-cell
- Try-out for three types of half cells carried out using 4 mm thick copper sheet and based on the measurements taken on those halfcells, die-punch assemblies are being modified to achieve the dimension of the halfcells within accepted tolerances.
Main Features of Amplifier

- **Output Power**: 1 Kwatt CW (individual module)
- **Frequency**: 5-30 MHz, 75.6 MHz, 37.6 MHz
- **Typical Gain**: > 45 dB
- **Gain Flatness**: ± 1 dB, 0.2 dB, 0.2 dB
- **Mode of operation**: Class AB
- **Efficiency**: 65% at Full Power
- **Protection against Over temperature**
- **Ruggedness**: Handles high VSWR
- **Air-cooled, Over temperature protection**
- **Additional radial combiner(1:8) stage for High power (>10kWatt) amplifiers**
- **75.6 MHz, 37.6 MHz versions are water cooled**
Amplifier at 5-30 MHz

- Rated power: 1 kW, four 250 W modules are combined
- Amplifiers are in Push pull configuration
- 4:1, 9:1 transmission line transformers are used in input/output matching networks
- High frequency Ferrite toroids are used
- Air-cooled: Thermal management is crucial
- Currently all the amplifiers are in use in K130 & K500 Cyclotron
Solid State Amplifier at 75.6 MHz

4 No of water-cooled amplifier and One 4:1 Wilkinson type combiner in a box

Amplifier in a 19” rack mountable cabinet

Amplifier :19” rack with modules and power supply

Tested at 2.5 kW
The plot shows the forward coupling $S_{31}$ and directivity $S_{32}$ with rotation for different position of coupler from centre of the coaxial line.

**Digital RF Power monitor**

- **In-house developed Dual Directional Coupler (DDC)**
- **Wide frequency range** – 30 to 115 MHz

**Measured**
- Fwd Coupling is 62.95 dB
- Ref Coupling is 62.70 dB
- Isolation more than 28.0 dB

For 45° and position is around 54.7 mm from centre of coaxial line.

DDC installed in RF line with amplifier for power test with power meter.
Digital RF Power monitor

- In-house developed Power monitor
- Wide frequency range – 30 to 115 MHz
- Configurable coupling factor and frequency range

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No. of channels</td>
<td>Two : (Forward + Reflected)</td>
</tr>
<tr>
<td>2</td>
<td>Input Range</td>
<td>-20 dBm to 14 dBm (Direct coupling)</td>
</tr>
<tr>
<td>3</td>
<td>Frequency Range</td>
<td>30 MHz to 120 MHz</td>
</tr>
<tr>
<td>4</td>
<td>Coupling factor</td>
<td>0 to 80</td>
</tr>
<tr>
<td>5</td>
<td>Resolution</td>
<td>16 bit (Forward), 12 bit (Reflected)</td>
</tr>
<tr>
<td>6</td>
<td>Communication</td>
<td>Modular (Wireless / RS232 / RS485)</td>
</tr>
<tr>
<td>7</td>
<td>Power supply</td>
<td>12 V DC, 110 mA</td>
</tr>
<tr>
<td>8</td>
<td>Display parameter</td>
<td>Power in dBm &amp; mW / W / kW</td>
</tr>
</tbody>
</table>

Performance comparison

![Graph comparing performance of DDC with Keysite and VECC power meters.](image-url)
Development of mini pico-ampere meter

- A miniature dual channel Pico ammeter of size 6 x 4 x 1 cm³
- Successfully tested under a of vacuum of 5x10⁻⁵ bar.
- Input range of 1.8-micro to 1-pico Amp
- 0.1% FSR measurement accuracy
- Facility of local and remote display

Mini(6x4x1 cm³) Pico-Ampere Meter has a special requirement (to be deployed in a very small cavity under high vacuum of the order of ~10⁻⁵ to ~10⁻⁸ bar) from RMP, Mysore
RESEARCH AND RESEARCH FACILITIES
Developmental Activities on Experimental Nuclear Physics

Neutron detector developmental activities

- Neutron detector fabrication laboratory
- Experiment using neutron detectors
- VECC Neutron TOF array
  - Neutron detector cell
  - Thin walled Scattering chamber
  - Fabrication of 50 detectors for the VECC TOF array is completed (April 2019).

Different stages of fabrications

1. Cleaning (removal of any suspended particles)
2. Deoxygenation
3. Liquid filling (vacuum suction technique)
4. Different components
5. Coupling of light guide
6. Sealing of liquid scintillator cell
7. Prototype detector

Nuclear reaction dynamics studies

- Neutron energy measurement using TOF detector
- Neutron multiplicity measurement to get the Information of Excitation of the system
- Study of exotic structure of nucleus using multi particle correlation

1 m diameter spherical chamber
3mm thick hemispherical segment

Thin Wall Scattering Chamber for Neutron Studies
Charged Particle detector array
A high-resolution, high-granularity 4-pi array for complete charged particle spectroscopy

Backward array: 112 CsI(Tl) detectors

Backward array with its electronics

Forward array

Extreme forward part

ChAKRA: The high resolution charged particle detector array at VECC, S.Kundu et al. Nuclear Inst. and Methods in Physics Research, A 943 (2019) 162411

VECC array for NUclear Spectroscopy (VENUS)
in-beam prompt spectroscopy

Offline decay study for $^{199}$Tl $\rightarrow$ EC decay $\rightarrow$ $^{199}$Hg

VECC Array for Nuclear fast Timing and Angular Correlation (VENTURE) studies: NIM A Volume 874, (2017)103-112

for off-beam decay spectroscopy

LEPS (Planer HPGe)
Clover HPGe with BGO shield
Cosmic muon background testing at Underground Lab, Jadugoda using LAMBDA array

**Phase-I**
Alpha: 28-40 MeV  
Proton: 7-10 MeV

15 experiments performed

- 7 Compton suppressed Clover HPGe
- 1 LEPS

**Phase-II**
Beams from ECR heavy ion source
Alpha: 45-53 MeV  
$^{20}$Ne: 140 MeV

- 7 experiments with alpha beam
- 1 test experiment with $^{20}$Ne

- 8 Compton suppressed Clover HPGe + 2 LEPS

**Unique Physics issues explored using light ion beams**

- Energy deposition inside individual detector element by cosmic muons ~ 23.1 MeV
- Detector threshold: above 3 MeV
- Trigger Condition: any two detectors out of four
- Run time: 17 hours
- Depth of the underground Lab: 555m
- Scalar reading in GDA Lab (ground level): 123710 counts
- Scalar reading in Underground Lab: 5 counts
- Reduction factor of cosmic muons inside underground Lab ~ $10^4$

Digital DAQ setup by UGC-DAE-CSIR  
Analog NIM Electronics and VME DAQ (VECC)  

Detector setup@555mL  
Electronic setup@555mL
New high precision study on the decay width of the Hoyle state


Result:
Precise estimation of the rare direct $3\alpha$ decay of the Hoyle state obtained $< 0.019\%$ at 95\% CL

Till date this is the precise limit with high statistical experiments


Reaction: Inelastic scattering of a of 60 MeV $\alpha$ from VEC on $^{12}$C target.
Measurement: 4$a$’s in coincidence.

Experimental setup

Comparison with previous measurements

<table>
<thead>
<tr>
<th>Total events</th>
<th>$DD(%)$</th>
<th>CL</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>21000</td>
<td>&lt;0.2</td>
<td>95</td>
<td>PRL, 113, 102501 (2014)</td>
</tr>
<tr>
<td>NA</td>
<td>1.1(4)</td>
<td></td>
<td>JPG, 43, 045110 (2016)</td>
</tr>
<tr>
<td>28000</td>
<td>&lt;0.043</td>
<td>95</td>
<td>PRL, 119, 132501 (2017)</td>
</tr>
<tr>
<td>93000</td>
<td>&lt;0.047</td>
<td>95</td>
<td>PRL, 119, 132501 (2017)</td>
</tr>
</tbody>
</table>
International Collaborations:

- **VECC - JINR Dubna collaboration**

  Fission experiment carried out at Dubna cyclotron revealed which is a better beam (projectile) and target combination for the synthesis of Super Heavy Element (SHE) $Z=114$ *Phys. Rev. C 99, 014616 (2019)*

- **VECC-MONSTER Collaboration under the FAIR Project**

  Experiment performed at the IGISOL facility at Jyväskyla, Finland *(March 2019* to measure the $\beta$-delayed neutron spectra from neutron rich $^{85,86}$As isotopes using part of MONSTER array

- **Indo-French Collaboration Project with GANIL, France**

  Studies on: High spin-Isospin Frontier with Isotopically Identified Fission Fragments

  Neutron-rich $^{152-158}$Pm isotopes, *S. Bhattacharyya et al, PRC98, 044316(2018)*

- **VECC has been recognized by the IAEA as the India Centre of the International Network of Nuclear Structure and Decay Data as of 12 April, 2019.**

  ![INTERNATIONAL NETWORK OF NUCLEAR STRUCTURE AND DECAY DATA EVALUATORS](image-url)
MATERIAL SCIENCE
Deformation induced phase transformation studies on austenitic stainless steel at different strain and strain rate

- Deformation of SS304 leads to martensite formation in the parent austenite phase.
- Martensite causes loss of ductility and hence detrimental in certain applications.
- Amount of martensite formed depends on the strain-rate and the initial sample condition.
- Aim: understand the effect of pre-strain and pre & post strain rates on the martensite formation.

- Deformation by Uniaxial tensile stress.
- Martensite (magnetic) phase characterised by XRD and VSM

Pre-strain: 0.4;
Pre-strain rate: $10^{-1}$

<table>
<thead>
<tr>
<th>Sample Id</th>
<th>Post Strain : Upto fracture &amp; Strain rate (per sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 (pre-strain only)</td>
<td>--</td>
</tr>
<tr>
<td>P11</td>
<td>$1\times10^{-4}$</td>
</tr>
<tr>
<td>P12</td>
<td>$5\times10^{-4}$</td>
</tr>
<tr>
<td>P13</td>
<td>$1\times10^{-3}$</td>
</tr>
</tbody>
</table>

High pre-strain rate and low post strain rate yields larger percentage of martensite.
Depth wise characterization of proton induced damage in pure Ti and Ti-6Al-4V alloy using XRD and microhardness

Variation of Domain size and Hardness with depth corroborate with each other for pure Ti & Ti-alloy

Radiation induced segregation is limited near the irradiated surface in Ti-alloy

Ti-alloy is more radiation resistant than pure Ti
Proton irradiation on Fe-9Cr-1Mo (T91) and Fe-2.25Cr-1Mo (T22): Comparative study of microstructural changes with dose using XRDLPA using Synchrotron source (RRCAT, Indore)

Ferritic and Ferritic-Martensitic steel: candidate materials for structural application in nuclear reactors.

3.5MeV proton irradiation

- Domain size and dislocation density saturates with dose in both samples
- Distinct changes in the dislocation character with irradiation in T91 and T22
- Dislocations are highly correlated
- Microhardness increases with dose in both samples
Experimental High energy physics and applications

Activities include:
1. Participation in the ALICE experiment at CERN-Geneva
2. Development of muon system for the CBM experiment at FAIR-Germany
3. Spin-off
4. Phenomenological studies: 14 publications
Participation in the ALICE experiment at CERN

ALICE upgrade:
- Common readout unit (CRU) prototypes built, 24 being built

- 500 million interactions recorded by PMD (pp, pPb, PbPb)
Participation at CBM (Compressed Baryonic Matter) experiment at FAIR (Facility for Antiproton and Ion Research)

**Ongoing R&D**
- GEM chambers for 1\textsuperscript{st} and 2\textsuperscript{nd} stations
- RPC for 3\textsuperscript{rd} and 4\textsuperscript{th} stations
- MUCH-XYTER electronics
- HV, LV
- Simulation,

Indian subsystem: leader-VECC

First integration test of the entire system in March 2019 (miniCBM)
Development of muon system in CBM

Two GEM chambers took data in miniCBM with MUCH-XYTER based readout and full DAQ; Prelim analyses show clear spill structure and time correlation.

Radiation resistant LV and HV distribution systems developed and deployed in mini-CBM.

Low-resistivity single-gap RPC tested with MUCH-XYTER in GIF++ as R&D for 3rd and 4th stations.

Design of the mechanical integration of the system is ongoing.
Fault tolerant Low voltage distribution board setup (built at VECC)

Two Low voltage power supply module installed in m-CBM experiment at Germany
RPC in Gamma Irradiation Facility (GIF++) for CBM Experiment

Electrode Material

- Bakelite

Gas Gap Size

- 2 mm

Bulk Resistivity

- $3 \times 10^{10} \Omega \text{-cm}$

Size of RPC

- 30 cm x 30 cm

Linseed Oil Coating

- Double layered

Humidity of Gas: 60 %

Gas Mixture R134a : iC$_4$H$_{10}$ : SF$_6$ :: 94.3 : 4.5 : 0.3

Efficiency of the RPC for 100 GeV muon detection as a function of voltage with zero gamma flux

Time Correlation of the RPC detector and Scintillator detector

RPC prototype

- TRD detectors

Finger Scintillator detector

Gas Gap Size: 2 mm

Upstream Area

Downstream Area

Cs$^{137}$ (~13.9 TBq) 662 keV gamma

Muon beam

RPC under Test

MuCh-XYTER FEE in GIF++

Back End in GIF++

GIF++ Beam Test Setup
GEM for high resolution X-ray imaging

A chamber at VECC
- Strip readout
- <500 micron position resolution
- R&D to improve X-ray conversion efficiency

1 mm brass wires with VECC shape

Stapler pins placed at 0.5, 1, 2 mm gaps

Resolution ~ 0.5 mm

Fish bone image

Image of stapler pin pieces using triple GEM
LHC Tier-2 GRID Computing Facility at VECC
(Listed in TopSuperComputers India List)

48 Nodes Cluster 51.6TeraFlops

Total cores 48*2*14*2=2688 (HT)
Theoretical Peak Performance
Rpeak = 51.6 Tflops Cluster
Linpack Benchmark performance Rmax = 43.0471 Tflops.

No AMC
24x7 Operation
90% availability

1.1 PB of EOS storage using low cost Disk based servers
Journal Publications : 137
PUBLICATIONS 2018-2019

- Nuclear Expt.: 61%
- Theory: 23%
- Others: 12%
- Material Science: 4%

Conference Proceedings : 57
DIFFERENT TYPES OF NUCLEAR IMAGING done at Regional Radiation Medicine Centre (RRMC), VECC on an average around 1600 patients per year
Acknowledgement

I am thankful to VECC Scientists, Engineers, Technical and Administrative staff for their valuable contributions to the achievement and also for providing necessary slides for this talk.
Thank you for your kind attention