Vision Documents

Radioactive Ion Beams (RIB)

Vaishali Naik
Head, RIB facility Group, VECC

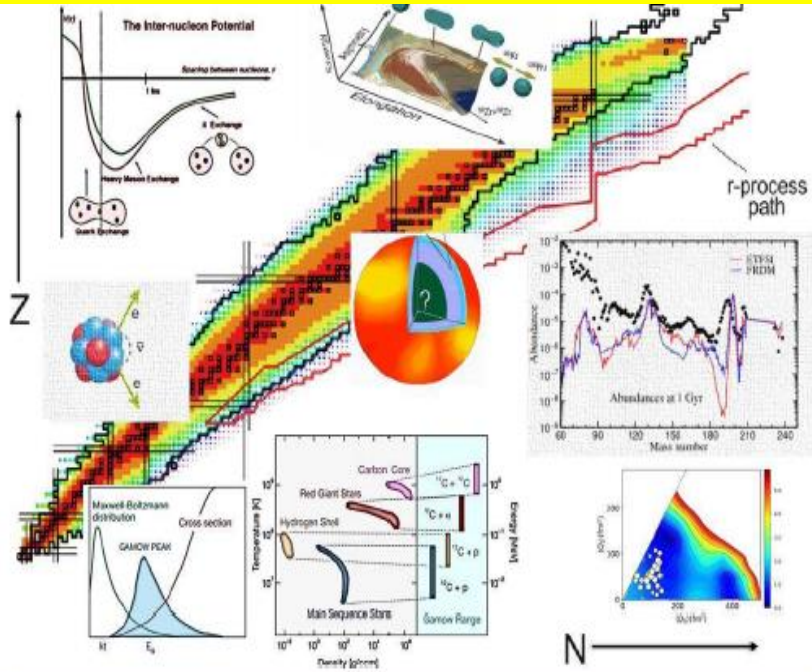
HORIZONS-2022, 14-17 Nov. 2022, ICTS, TIFR Bangalore
HORIZONS IN ACCELERATORS, PARTICLE/NUCLEAR PHYSICS AND LABORATORY-BASED QUANTUM SENSORS FOR HEP/NP

Mega Science Vision 2035-Nuclear Physics

Nuclear Physics: Recommendations

Investigation of the structure of nuclear matter at the extremes of isospin/angular momentum is a major goal in nuclear physics research. Another aspect of the field is to understand the various reaction mechanisms for the production of super-heavy elements and nuclei away from the line of stability. This will help in gaining a new insight into the role of strong interactions on the nuclear scale and in understanding the nuclear processes that drive the evolution of the stars, galaxies and the Universe.

We recommend development of new accelerator facilities within India for radioactive-ion beams (RIBs), high-current stable beams and underground laboratories for the low-energy nuclear physics programs. State-of-the-art detector systems at the existing accelerator facilities will be essential to cope with the developments in the field. We recommend a strong participation in the experiments at FAIR and other international nuclear physics facilities for RIBs and photon beams. A consortium can be formed to facilitate the usage of some of the international facilities by the low-energy NP groups in India.



How did visible matter come into being and how does it evolve? How does subatomic matter organize itself and what phenomena emerge? Are the fundamental interactions that are basic to the structure of matter fully understood?

How does equation of state of nuclear matter decide properties of neutron star? What will neutron star merger tell us about synthesis of heavy elements?

What is the origin of neutrino mass and are they their own antiparticles? Are there neutrinos species beyond the standard model ? What is dark matter and what are its constituents?

Courtesy Bedanga Mohanty, NISER, Member WG MSV-2035

Mega Science Vision 2035-Nuclear Physics recommendations

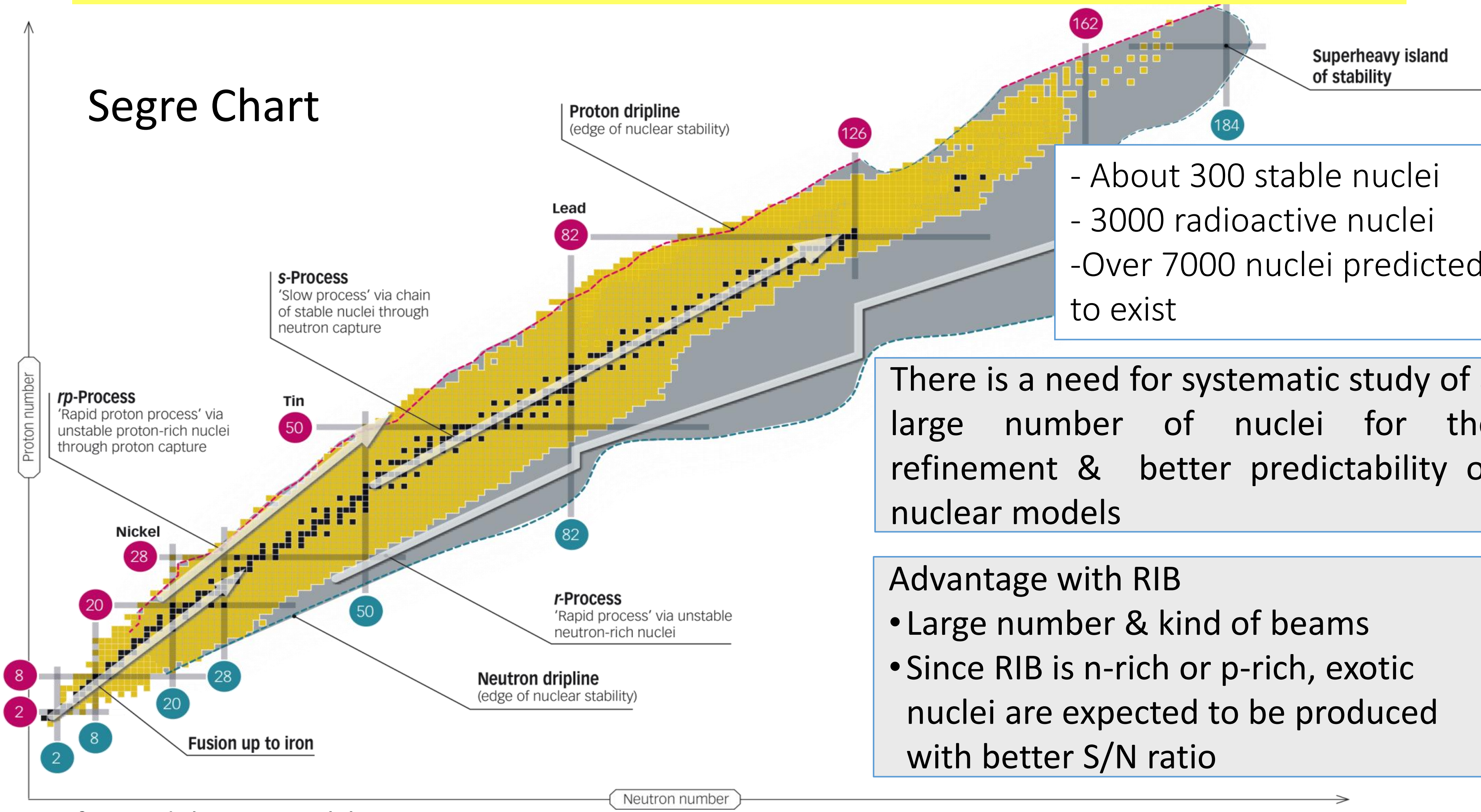
- Develop new accelerator facilities within India for radioactive-ion beams (RIB), high current stable beams and underground laboratories for the low-energy nuclear physics programs.

- Augment state-of-the-art detector systems at the existing accelerator facilities – this is essential to cope with the developments in the field.

- Continue strong participation in the experiments at FAIR and other international nuclear physics facilities for RIBs and photon beams.

Physics with radioactive ion beams (RIB) is the new frontier in nuclear physics & allied sciences

Segre Chart



- About 300 stable nuclei
- 3000 radioactive nuclei
-Over 7000 nuclei predicted to exist

There is a need for systematic study of a large number of nuclei for the refinement & better predictability of nuclear models

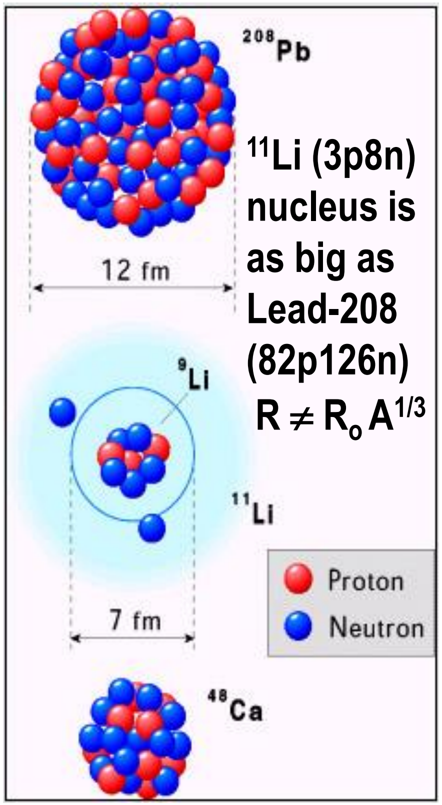
Advantage with RIB

- Large number & kind of beams
- Since RIB is n-rich or p-rich, exotic nuclei are expected to be produced with better S/N ratio

Ref. Magdalena Kowalska CERN

Phenomenal discoveries that are driving the field of RIB

Neutron Halo

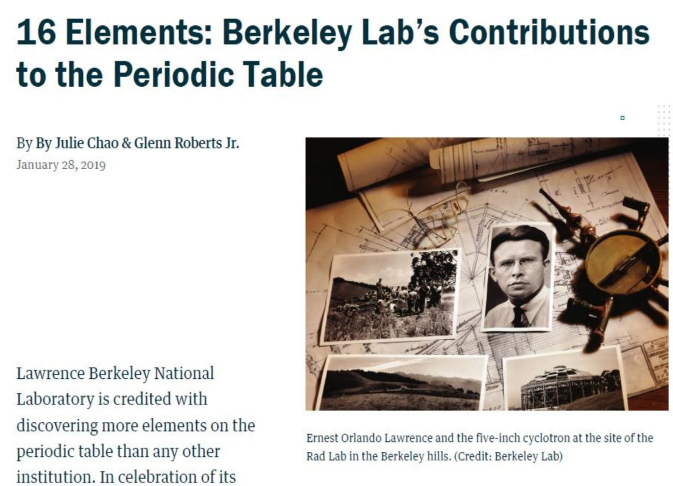


Discovery of Neutron Halo by Tanihata et.al., 1985, Bevelac Berkeley, ^{11}Li, ^{11}Be, ^{22}C

New Magic Numbers, weakening of Shell Structure

^{24}O (p8n16), ^{54}Ca (p20n34), doubly magic (RIKEN RIBF)

Discovery of new elements, SHE, new isotopes



16 Elements: Berkeley Lab's Contributions to the Periodic Table

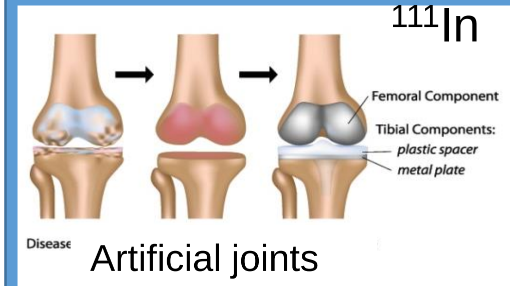
By By Julie Chao & Glenn Roberts Jr.
January 28, 2019

Lawrence Berkeley National Laboratory is credited with discovering more elements on the periodic table than any other institution. In celebration of its

Ernest Orlando Lawrence and the five-inch cyclotron at the site of the Rad Lab in the Berkeley hills. (Credit: Berkeley Lab)

Elements up to Z = 118 discovered. Leading labs in discovery of super heavy elements are Berkeley, GSI, Dubna, RIKEN. At RI Beam Factory RIKEN 45 new isotopes discovered in a single experiment!

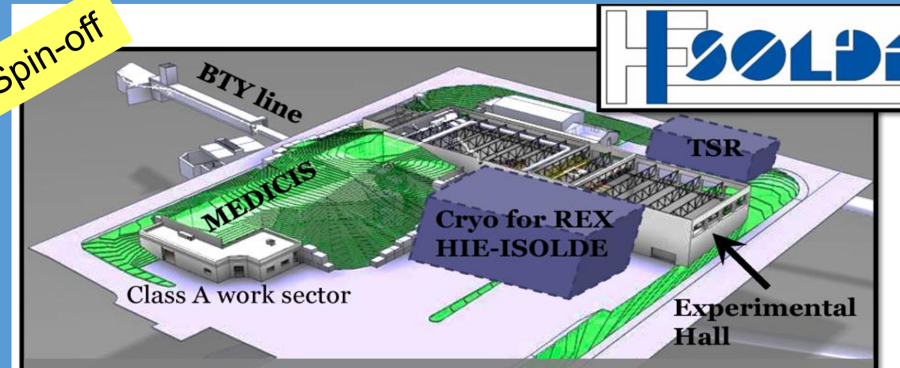
RIB – a tool for research in applied sciences



Wear studies on bio-medical implants

Implantable Radiotracer, e.g. wear study of UHMWPE polymer using ^{111}In RIB

Spin-off



Isotope harvesting on industrial scale from spent RIB targets, beam-dumps

REVIEW article
Front. Phys., 28 August 2020 | https://doi.org/10.3389/fphy.2020.00326

GSI Germany, NIRS, Japan

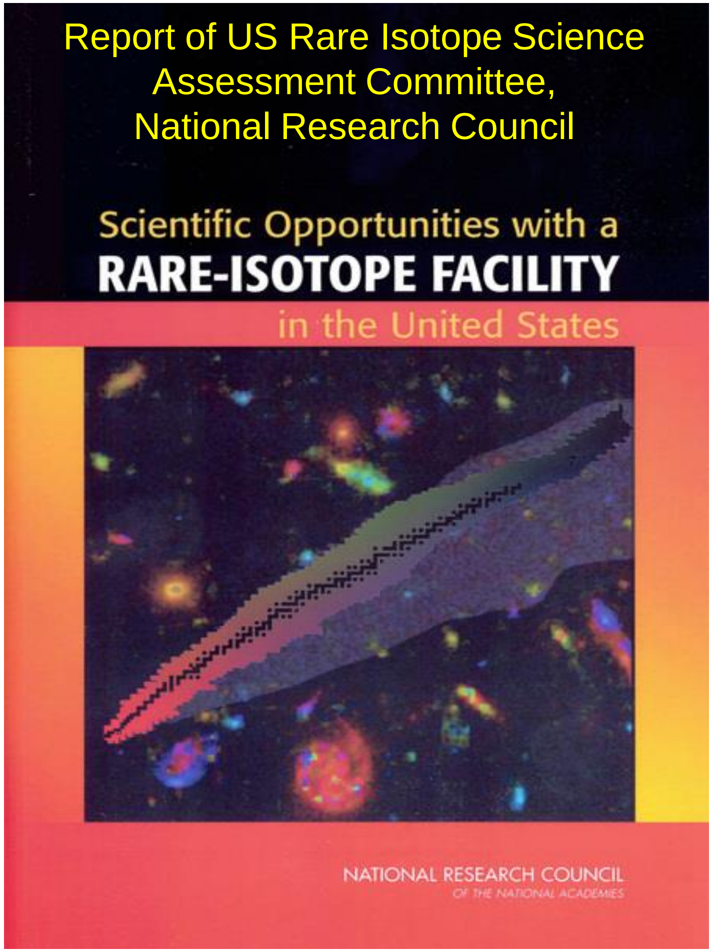
Radioactive Beams in Particle Therapy: Past, Present, and Future

Marco Durante[1,2*] and Katia Parodi[3]

[1]Biophysics Department, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Carbon Therapy using RIB ^{11}C (20 min), ^{10}C (19 sec), ^{14}O (71 sec), enables in-situ dose mapping and improved treatment planning ; focus of R&D – how to increase RIB intensity; need 10^8 pps per spill ; current tech 10^5 pps

World Scenario

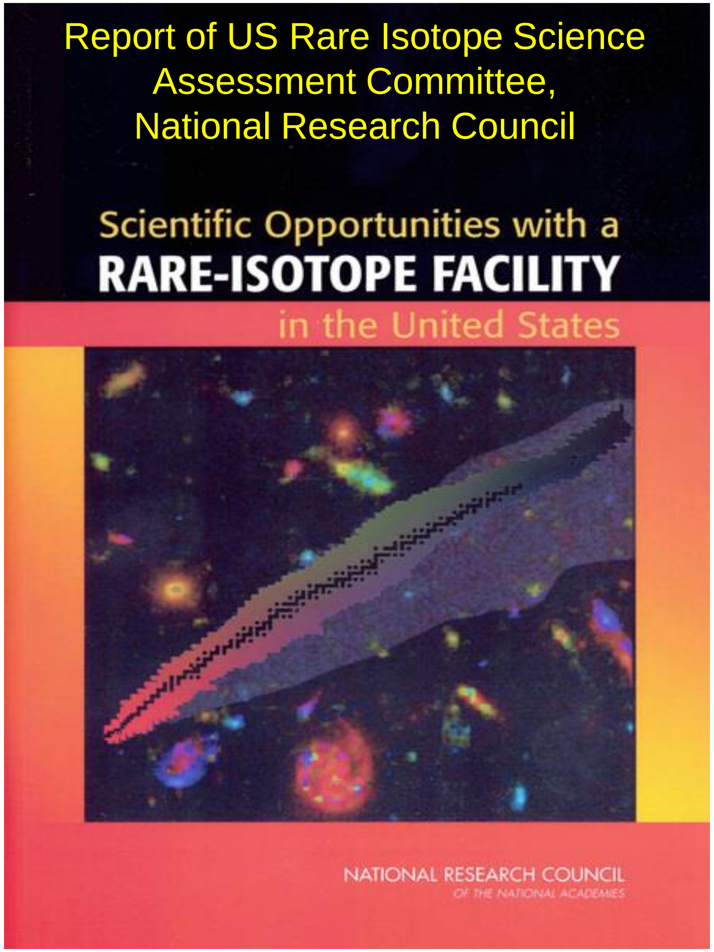


Selected List of Operating and Planned Rare-Isotope Facilities Worldwide

TABLE C.1 Selected List of Rare-Isotope Beam Facilities: Existing and Near-Term Capabilities in Asia, Europe, and North America

Facility	Region	Country	Type	Driver
BFRIB	Asia	China	ISOL	100 MeV, 200 μA cyclotron
HIRFL at IMP	Asia	China	IF	HI cyclotrons and storage ring and cooler
RARF at RIKEN	Asia	Japan	IF	HI linac and K540 cyclotron and K70 AVF cyclotron
RIBF at RIKEN	Asia	Japan	IF	Cascade of K520, K980, and K2500 HI cyclotrons to 440 (LI) and 350 (very HI) MeV/A **Most powerful today**
TRIAC at KEK-JAEA	Asia	Japan	ISOL	40 MeV, 3 μA tandem
VEC-RIB	Asia	India	ISOL	K130 cyclotron to 400 keV/A
CRC	Europe	Belgium	ISOL	30 MeV H^- cyclotron to 300 μA **First accelerated RIB**
DRIBS at Dubna	Europe	Russia	IF and ISOL	U400 and U400M and U200 HI cyclotrons 100 MeV/A
EURISOL	Europe	European Union	ISOL	Linac providing 1 GeV protons with up to 5 MW and multiple 100 kW targets

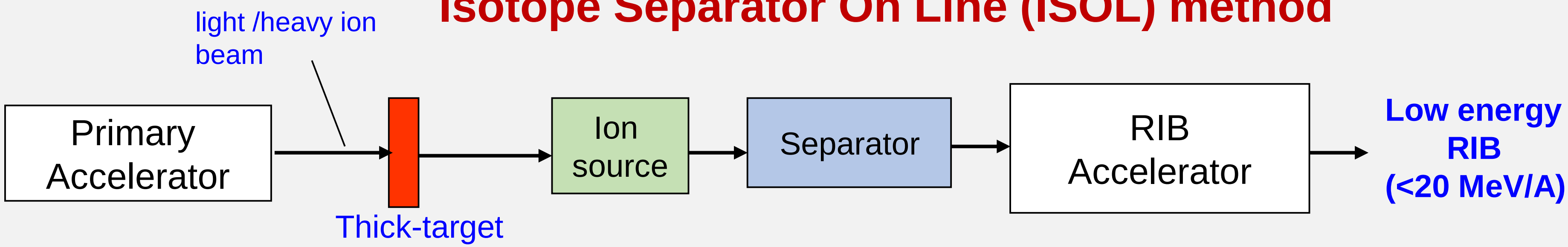
World Scenario cont…



EXCYT at LNS	Europe	Italy	ISOL	HI SC k = 800 cyclotron up to 1.3 kW on target
FAIR at GSI	Europe	Germany	IF	Uranium to 2 GeV/A for fragmentatio[n]
GSI FAIR	Europe	Germany	IF	Uranium to 1 GeV/A — Next Gen RIB facility
ISOLDE at CERN	Europe	European Union	ISOL	1.4 GeV synchrotron with up to 2 μA average — First ISOL RIB
MAFF	Europe	Germany	ISOL	Munich Research Reactor FRM-II
SPES	Europe	Italy	ISOL	100 MeV proton beam on UC x target
SPIRAL at GANIL	Europe	France	ISOL/IF	HI cyclotrons producing up to 95 MeV/A
SPIRAL 2 at GANIL SPIRAL-2	Europe	France	ISOL	SC linac produces 40 MeV and 5 mA [...] to 14.5 MeV/A — Next Gen RIB facility
HRIBF at ORNL	North America	United States	ISOL	42 MeV ORIC cyclotron
ISAC-I	North America	Canada	ISOL	100 μA, 500 MeV cyclotron
ISAC-II ARIEL	North America	Canada	ISOL	Accelerates ISAC-I beams — Next Gen RIB facility
NSCL at MSU	North America	United States	IF	HI coupled SC cyclotrons 80 to 160 MeV/A for LI and 90 MeV/A for U
RIA FRIB	North America	United States	ISOL/IF	400 kW linac providing 400 MeV/A HI a[...] — Next Gen RIB facility

How to produce RIB?

Isotope Separator On Line (ISOL) method

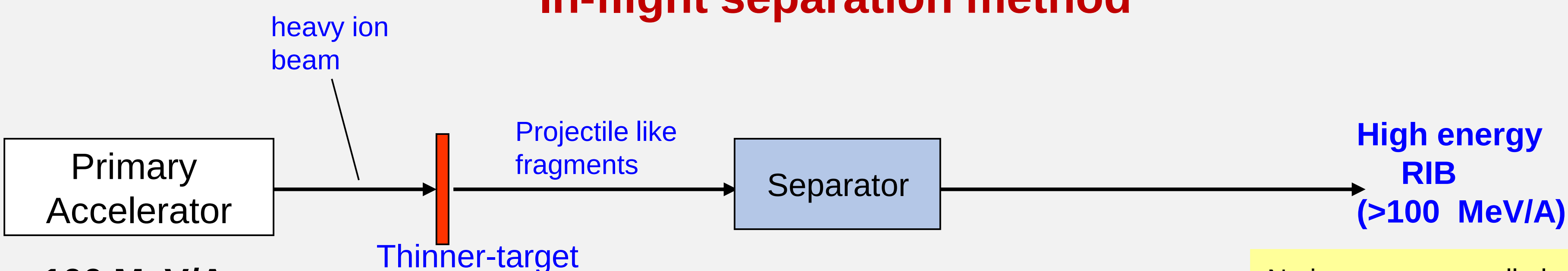


CN/Spallation/fission/
fragmentation
of target nuclei

Online : primary accelerator & RIB accelerator operate simultaneously

High beam purity, quality ,
But element dependent
intensity, $T_{1/2}$ limit ≥ 1sec

In-flight separation method



>100 MeV/A

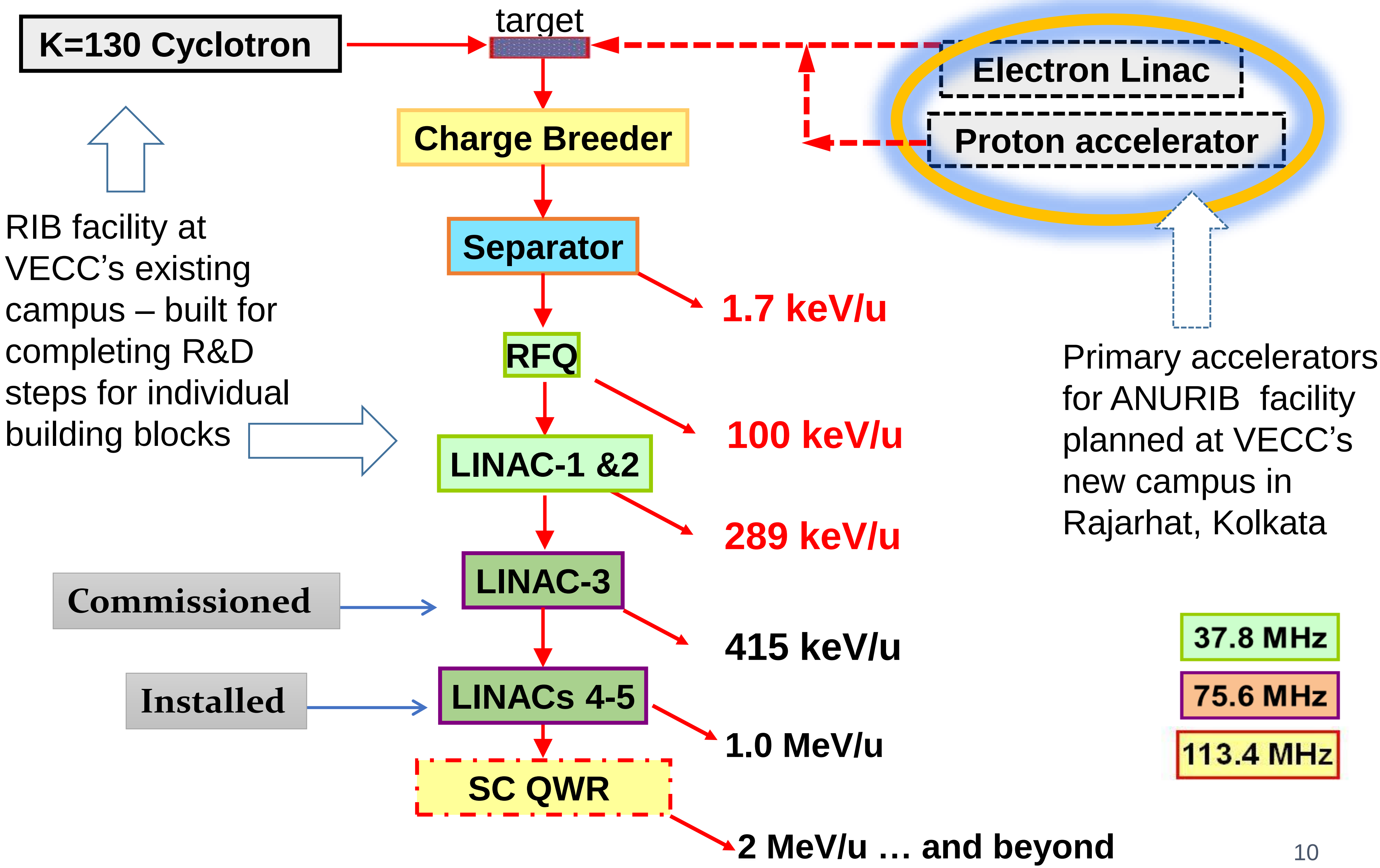
Fragmentation
of beam nuclei

Isotones cannot be separated;
rejection of primary beam a challenge

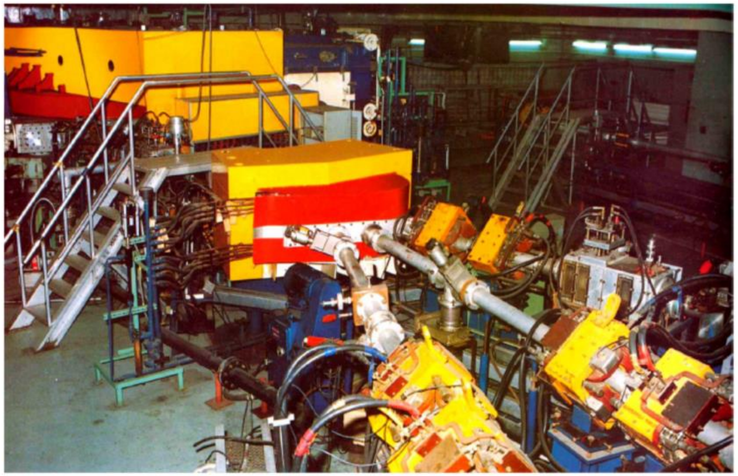
No ion-source, so all elements
transported, no half-life limit
But lower beam purity, quality

ANURIB Facility scheme

applied and nuclear research facility with rare isotope beams planned at VECC's new campus at Rajarhat Kolkata



Kolkata – the city of Cyclotrons



Room Temperature Cyclotron – June 1977

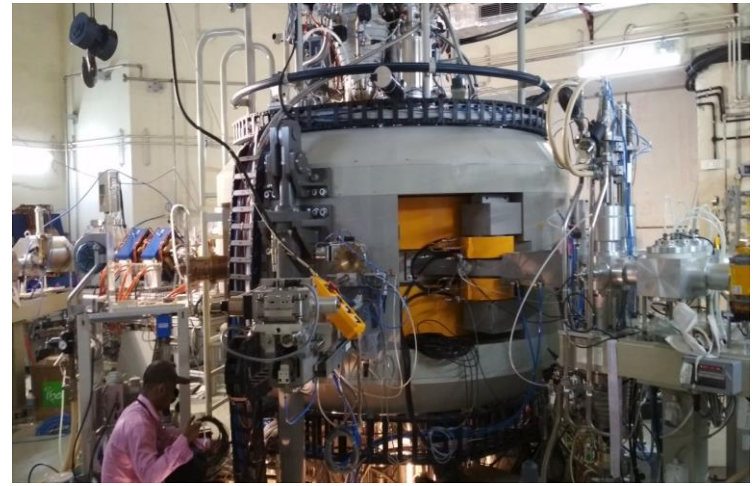
Alpha : 28-50 MeV
Proton : 7-12.5
Nitrogen : 105-140 MeV
Oxygen : 116-160 MeV
Neon : 145 -192 MeV
Sulphur : 218 MeV

Nuclear Physics Research
Radiation damage studies
Primary accelerator for RIB

Super-conducting Cyclotron – Dec 2020

Nitrogen : 252 MeV
Neon : 360, 386, 397 MeV
Oxygen : 309 MeV

Nuclear Physics Research
Radiation damage studies

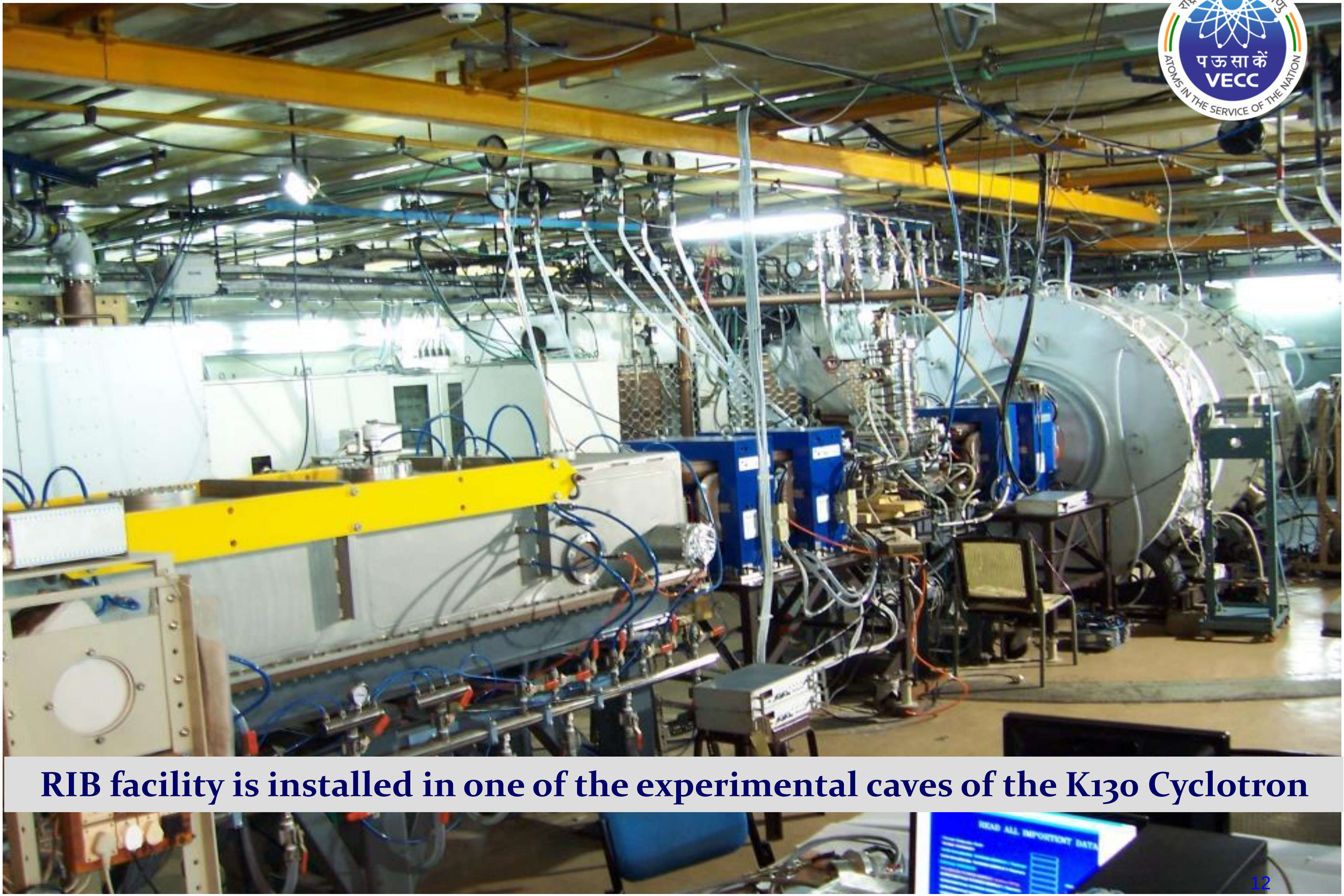


Medical Cyclotron – September 2018

Proton : 15-30 MeV, 500 μA

Production of radiopharmaceuticals
Fluro Deoxy Glucose (FDG)
Sodium Fluoride
Thallus Chloride-Tl-201 (SPECT)
68Ga PSMA (Prostate Specific Membrane Antigen)

Courtesy Arup Bandyopadhyay, Head Accelerator Phys. Group, VECC



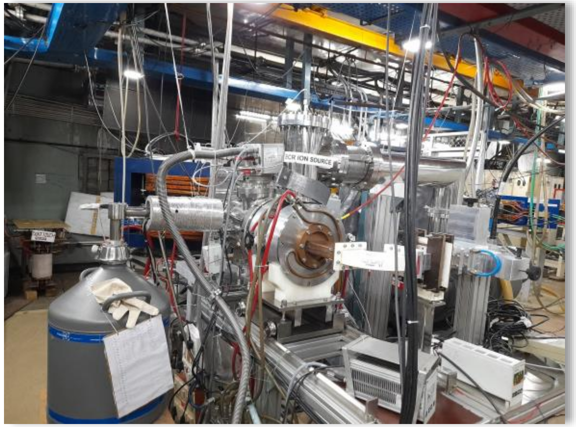
RIB facility is installed in one of the experimental caves of the K130 Cyclotron

List of beams accelerated in RIB facility so far

RIB	Prod. route	T1/2	I(pps) E(keV) before RFQ	I(pps) E(MeV) after RFQ
^{14}O	$^{14}N(p, n)$	71 s	5.0×10^{3} ; 10 keV	3.2×10^{3} ; 1.4 MeV
^{42}K	$^{40}Ar(\alpha,pn)$	12.36 hr	2.7×10^{3} ; 5 keV	-
^{43}K	$^{40}Ar(\alpha,p)$	22.3 hr	1.2×10^{5} ; 8 keV	-
^{41}Ar	$^{40}Ar(\alpha,2pn)$	109 min	1.3×10^{3} ; 5 keV	-
^{111}In	$^{nat}Ag(\alpha,xn)$	2.8 days	1.6×10^{5} ; 5 keV	-
^{11}C	$^{14}N(p, \alpha)$	20.4 min	5.0×10^{3} ; 10 keV	-

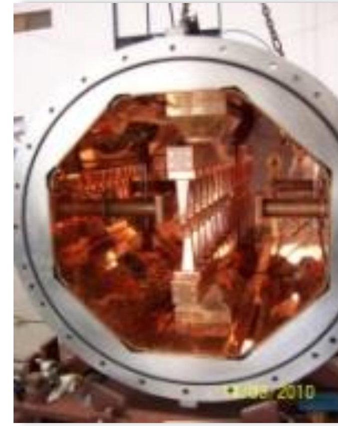
Stable isotope beam	**Max. Energy**	**Intensity (typical)**
Carbon	3.5 MeV	500 nA
Nitrogen	5.8 MeV	200 nA
Oxygen	4.6 MeV	400 nA
Argon	4.0 MeV	600 nA
Ni, Ag, Zn & Iron (metals)	10 keV ; 1.6 MeV for Fe-56	150 nA ; 400 nA

Technology milestones …



ECR ion-source & separator

RFQ linac



Heavy-ion LINAC

IIFC LB650 Niobium cavity, made at VECC, eb-welding at IUAC, 2K tested at Fermilab

Injector Cryomodule for E-Linac & QWR heavy-ion Linac Cryomodule developed with TRIUMF

Memoranda of Understanding (MoU)

RIKEN Japan – Physics design of accelerators, exotic nuclei physics

SAMEER Mumbai – RF transmitters

CSIR-CMERI, Durgapur – RFQ

TRIUMF Canada – e-linac, QWR CM

REPORT OF THE INTERNATIONAL ADVISORY COMMITTEE

Advanced National Facility for Unstable & Rare Isotope Beams - ANURIB

April 2012

1. Executive Summary

The International Advisory Committee (IAC) recognizes that ANURIB will be unique in the world and will attract a national and international user community. The IAC is confident that ANURIB will secure a science community with intimate knowledge of nuclear physics and will provide India with world class facilities. The committee is fully confident that the electron linac baseline design will achieve the performance required by the ANURIB science program. The IAC is confident that, with the planned enhanced project management support commensurate with this large facility, the VECC management team is well qualified to bring ANURIB successfully online.

IAC

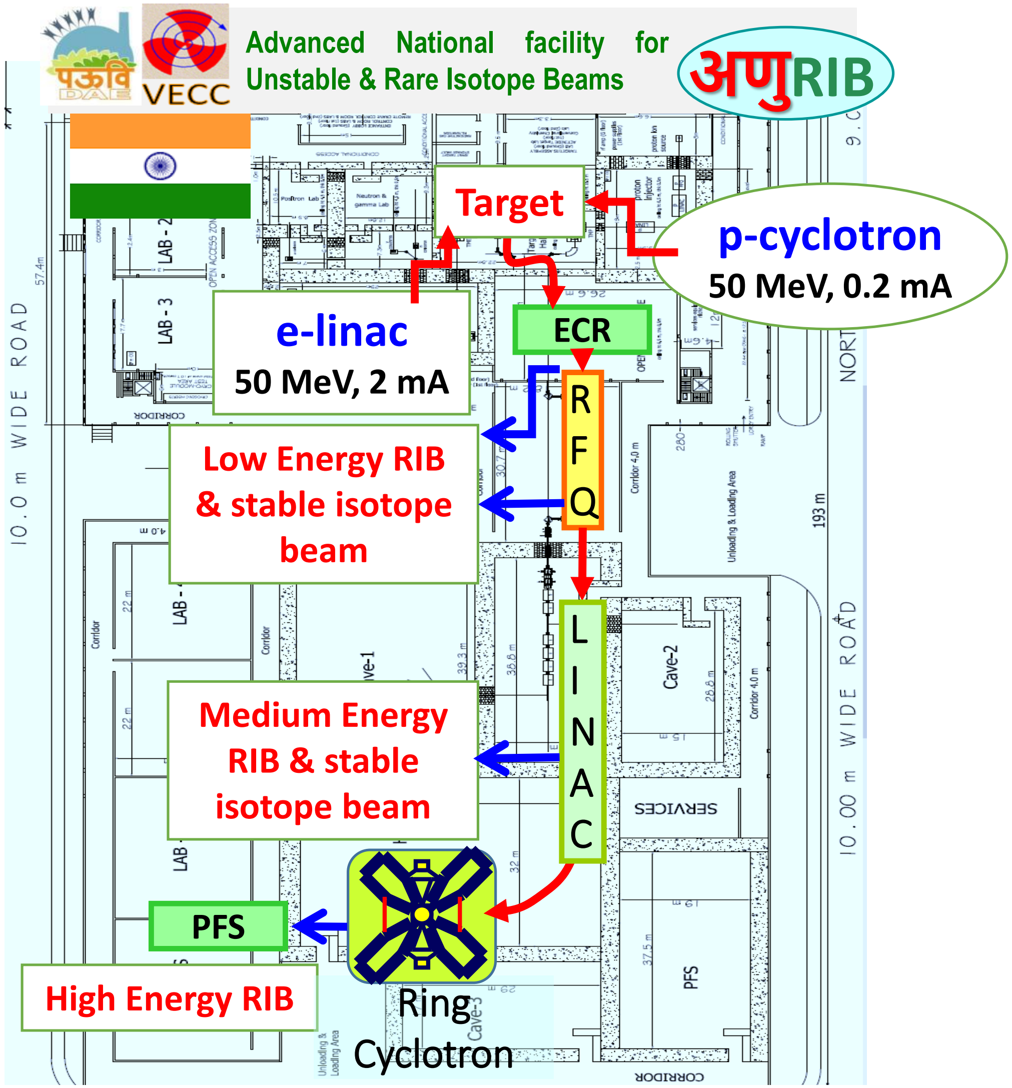
Dr. Nigel Lockyer
Dr. Swapan Chattopadhyay
Dr. Yasushige Yano
Dr Lia Merminga
Dr. Andrew Hutton
Dr. Mats Lindroos
Joint Secretary R&D DAE
Dr. Bikash Sinha
Dr. R.K. Bhandari
Dr. Amit Roy
Dr. S. Kailas
Dr. Alok Chakrabarti
Dr. A.K. Sinha

ANURIB science opportunities workshop **SCRIBE** (science with rare isotope beams) organized at VECC in year 2012 & 2014

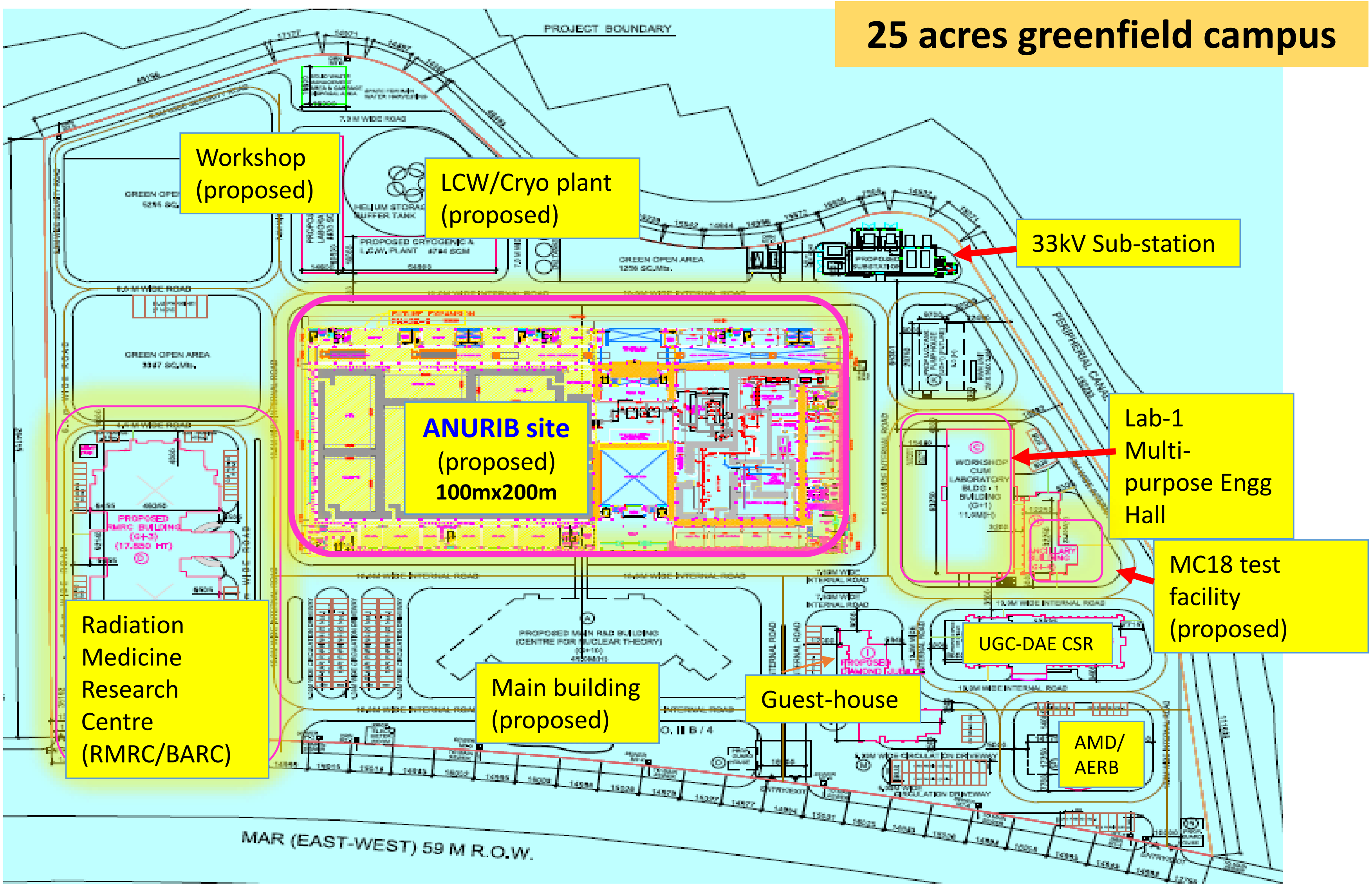
ANURIB

a facility for applied & nuclear research with rare isotope beams

- A low energy RIB facility is built at VECC as technology development for ANURIB – the next generation RIB facility planned at VECC's new campus in Rajarhat.
- Pre-project activity for ANURIB is ongoing. Site clearance from regulatory agency, building design, R&D on gap areas of technology – superconducting linac and high power actinide target development.
- ANURIB to be constructed in phases, approx. cost Rs. 1000 Cr, timeline : DPR to be submitted by Mar. 2024 to funding agency DAE ; T+10 years for construction & 2 years for beam commissioning & first experiment



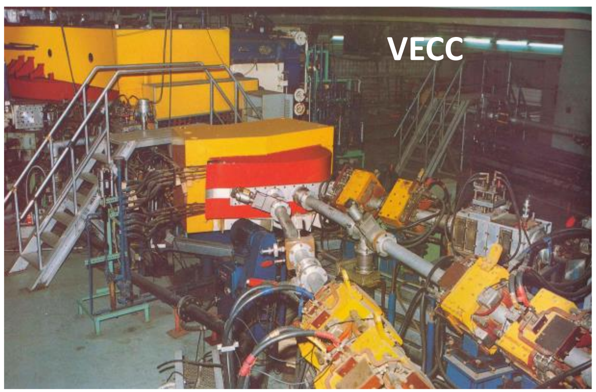
VECC Rajarhat Campus Masterplan

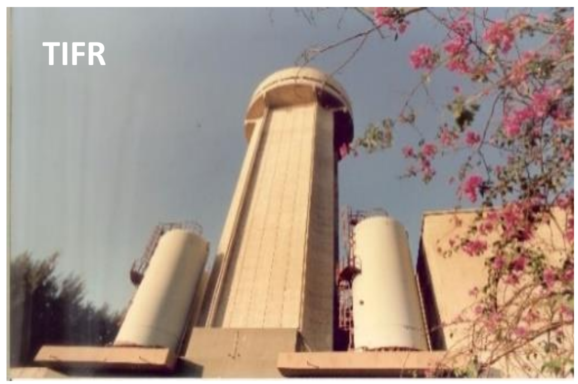


Experimental Nuclear Physics activities at VECC

Our experimental programme is based on investigations on properties of nuclei under different conditions of temperature, angular momenta, deformation and isospin degrees of freedom using the presently available accelerated ion beams from the K130 cyclotron and other accelerators (national & international laboratories). The nuclear structure and nuclear reaction studies are the two different means to explore the properties of nuclei.

Presently, the NP community uses mainly 3 accelerators in INDIA: that provide complimentary beam species and energies, Light & Heavy ions ; energy max. ~ 10 MeV/u





Courtesy Chandana Bhattacharya, Head Nucl. Phys. Division, VECC

Table 1: Details of currently operating accelerator facilities in the country for nuclear physics users

Accelerator	Available Beams	Energy and Current	Major Experimental Programs	Beam Lines and Major Experimental Facilities	Current Users
BARC-TIFR Pelletron-LINAC Facility, TIFR, Mumbai	^{1}H, ^{4}He, $^{6,7}Li$, ^{9}Be,$^{10,11}B$, $^{12,13}C$, ^{14}N, $^{16,18}O$, ^{19}F, ^{22}Na, ^{24}Mg, ^{27}Al, $^{28,30}Si$, $^{32,34}S$, $^{35,37}Cl$, ^{38}K, ^{40}Ca, ^{48}Ti,^{58}Ni, ^{107}Ag, ^{127}I, SF_6 molecular beam	5–8 MeV/A up to Ni. 1–5 pnA (for some of the beams such as Li and C, one can get up to 10–20 pnA)	• Nuclear Physics • Atomic Physics • Condensed Matter Physics • Radiochemistry • Agriculture • Terahertz Devices • Medical-isotope R&D • Accelerator Mass Spectroscopy (AMS) • Industrial and Space-science related applications	12 Beam Lines 1. 6M high current proton irradiation facility, 2. Two general purpose scattering chambers 3. Large HPGe array (INGA) 4. Neutron array 5. High-energy gamma detector 6. Fission MWPC detector array 7. Charged particle scattering chamber (CPSC) 8. Strip detector array 9. Low background facility 10. g-factor measurement setup with a 7 T magnet 11. Beam scanner 12. Isomer studies with beam chopper	260 Users – National, International Institutes/Centres, Universities, IITs, ISRO, etc.
K130 Room Temperature Cyclotron, VECC, Kolkata	H, ^{4}He, ^{14}N, ^{16}O, ^{20}Ne, ^{32}S	1–10 MeV/A 1enA–4 eμA	• Nuclear Physics • Atomic Physics • Material Science • Radiochemistry • Analytical Chemistry • Biology • RIB production	4 Beam Lines 1. Facilities for irradiation 2. General purpose scattering chamber 3. INGA 4. VENUS and VENTURE arrays 5. An array of neutron detectors 6. An array of large-area	National Institutes/Centres, Universities, IITs, ISAC(ISRO), IIEST, etc.

				array	
IUAC Pelletron-LINAC and LEIBF facility, New Delhi	^{1}H, ^{6,7}Li, ^{9}Be, ^{10,11}B, ^{12}C, ^{14,15}N, ^{16,18}O, ^{19}F, ^{24}Mg, ^{27}Al, ^{28,29,30}Si ^{31}P, ^{32,34}S, ^{35,37}Cl, ^{40}Ca, ^{45}Sc, ^{46,48}Ti, ^{51}V, ^{56}Fe, ^{58}Ni, ^{63}Cu, ^{64}Zn, ^{74}Ge, ^{79}Br, ^{107,109}Ag ^{120}Sn, ^{127}I, 197Au	3–8 MeV/A 1–5 pnA	• Nuclear Physics • Material Science • Device Fabrication • Radiation Biology • AMS • Radiation Physics	8 Beam Lines 1. Gamma Detector Array (GDA) 2. INGA 3. Heavy-ion Reaction Analyzer (HIRA) 4. HYbrid Recoil mass Analyzer (HYRA) 5. General purpose scattering chamber (GPSC) 6. National Array of Neutron Detectors (NAND) 7. ASPIRE (Automatic Sample 8. Positioning for Irradiation in Radiation Biology Experiments 9. Beam-foil spectroscopy apparatus	100 research groups (covering all accelerator-based research) from nearly 160 Universities, 85 Colleges and 60 other National laboratories.
FRENA Tandetron facility, SINP, Kolkata	^{1}H, ^{4}He, Heavy ions	0.2–3 MeV 50–300 μA	• Astrophysics	5 Beam Lines 1. Small target chamber for gamma spectroscopy and neutron detection	
Folded Tandem Ion Accelerator (FOTIA), BARC, Mumbai	^{1}H, ^{6,7}Li	6–12 MeV, 1–5 pnA	• Nuclear Physics • Atomic Physics • Radiochemistry • Biology	1. General purpose scattering chamber 2. PIXE 3. Rutherford Backscattering 4. PIGE	

Future Plans for Existing Facilities

BARC-TIFR Pelletron-Linac facility: The heavy-ion accelerator augmentation is in progress with the new accelerating tubes for the pelletron and the replacement of the Pb-based superconducting RF cavities by the Nb cavities in the entrance module. The upgradation of this accelerator is expected to be completed in the next 2-3 years.

IUAC: There has been considerable progress in the plan to develop a high current injector (HCI) for the superconducting linear accelerator (LINAC). A radiofrequency quadrupole, one unit of drift tube LINAC and a prototype Nb low-beta cavity have been designed and fabricated. The HCI will allow heavy-ion beams to overcome the Coulomb barrier for high-Z systems in the next five years.

VECC: A K500 superconducting cyclotron has been constructed at VECC. It comprises India's largest superconducting magnet that produces a magnetic field of 5 T (maximum). Recently, a significant milestone has been achieved by successfully extracting 252 MeV nitrogen-ion beam (i.e., 18 MeV/A) from the K500 superconducting cyclotron, which was delivered in the 0° line to the user target/scattering chamber.

science.

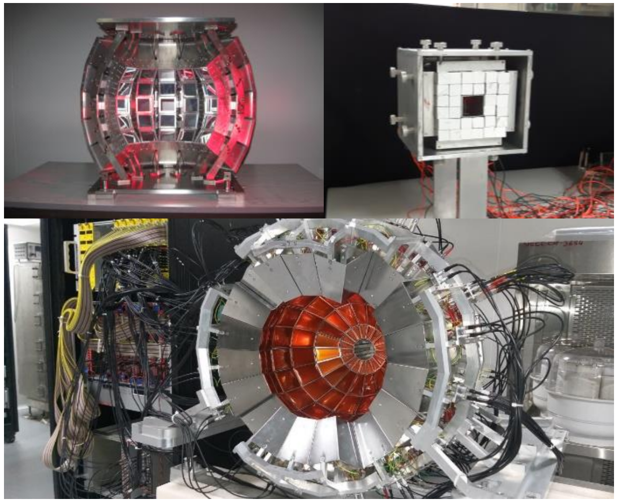
Proton-driver-based RIB:

Phase-wise development of the proton accelerator has already started for the 1 GeV Accelerator Driven Sub-System (ADSS) project that will be constructed at Visakhapatnam. As a part of it, a 3 MeV beam of proton with 300 μA current has been achieved at the Low Energy High Intensity Proton Accelerator (LEHIPA) facility. This accelerator is planned to be used as the driver accelerator for RIB once it reaches 50 MeV of proton energy. This will be complementary to the photofission-based facility. With the availability of a proton beam, it will be possible to not only produce neutron-rich radioactive ions via fission but also slightly proton-rich ions through transfer reactions. At later stages, if and when very high energy proton beams are made available at the accelerator complex at Visakhapatnam, fragmentation reactions can be used to produce an even broader range of radioactive ions. It is important to have a national RIB facility at Visakhapatnam with the possibility of multiple RIB species to perform research in frontier topics.

The post accelerator can be connected to two separate ECRs for multiplying the charge state of the stable and radioactive ions, respectively. Thus, the post accelerator can provide a high-current stable-ion beam as well as RIB.

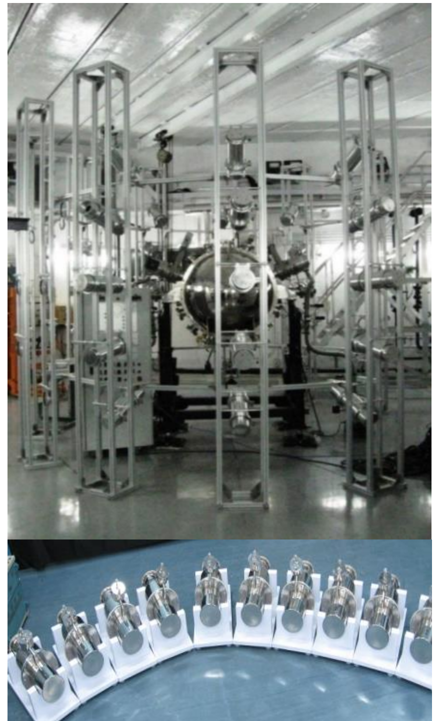
The cost of the above two projects will be around ₹1000 cr. The time-scale will be 8 to 10 years from the approval of the project.

Major facilities at VECC, for Nuclear Physics Experiments

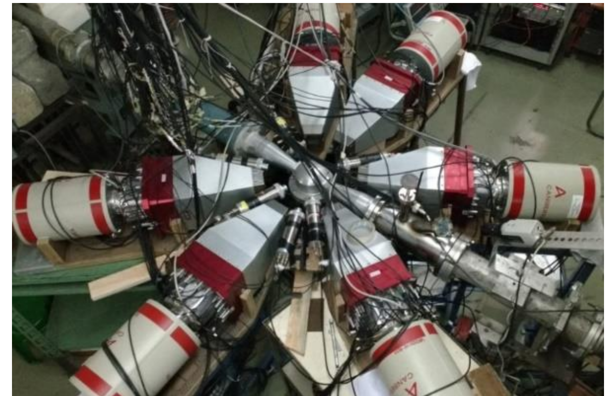


Charged particle detector Array for Kinematic Reconstruction and Analysis (ChAKRA)

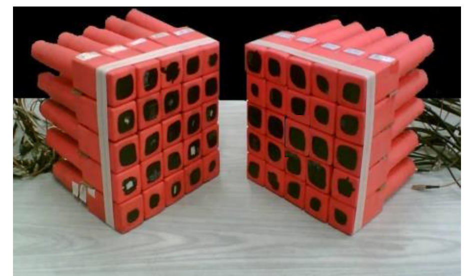
Courtesy Chandana Bhattacharya,
Head Nucl. Phys. Division, VECC



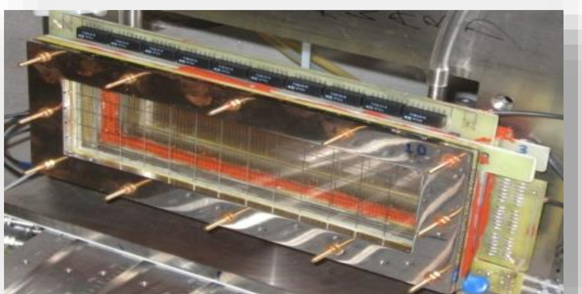
Neutron Detectors



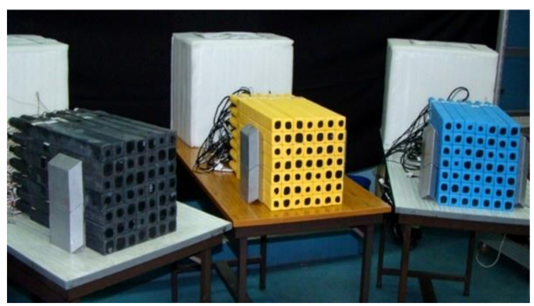
VENUS and VENTURE array



Gamma Multiplicity Filter

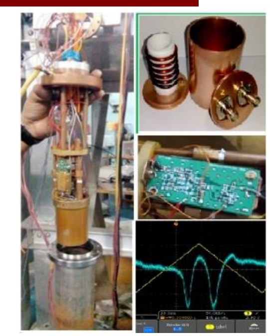


Multiwire proportional counter



LAMBDA Detector array

Segmented Clover

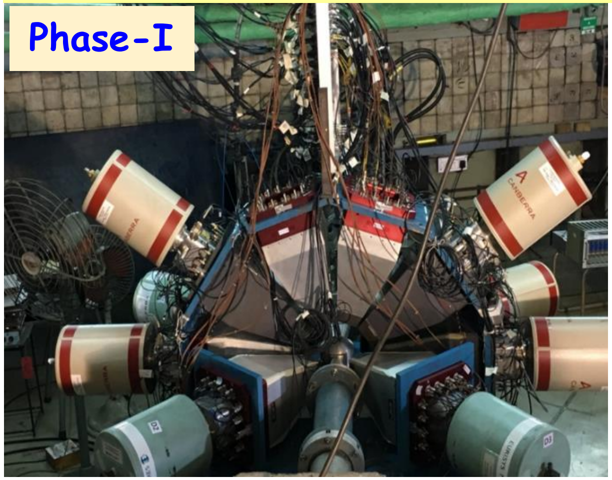


Penning Ion trap

Indian National Gamma Array (INGA) at VECC

7 Compton suppressed Clover HPGe , 1 LEPS

Phase-I



- *Up to 10 detectors*

→ **Compton suppressed Clovers and LEPS HPGe**

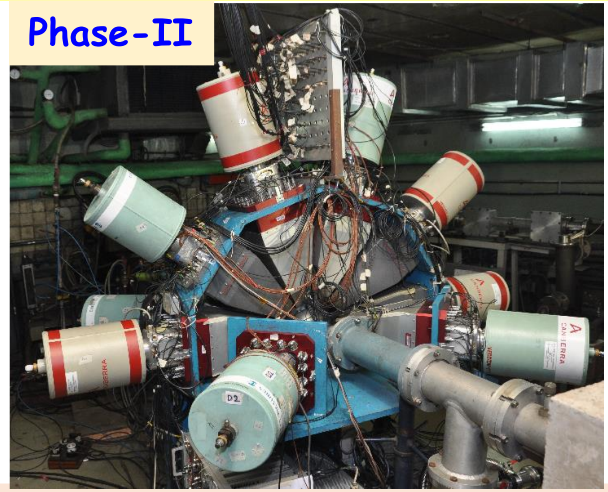
- ***Electronics and Data acquisition system (DAQ)***
- **1st campaign: Analog : NIM with CAMAC based DAQ**

2nd campaign: Digital : XIA: PIXIE-16 12 bit 250 MHz

(from UGC-DAE-CSR, Kolkata)

8 Compton suppressed Clover HPGe + 2 LEPS

Phase-II



2005 – 2006: using **heavy-ion beams (^{16}O, ^{20}Ne, ^{40}Ar)**

2017-18: using **light-ion beams (α, p)& HI**

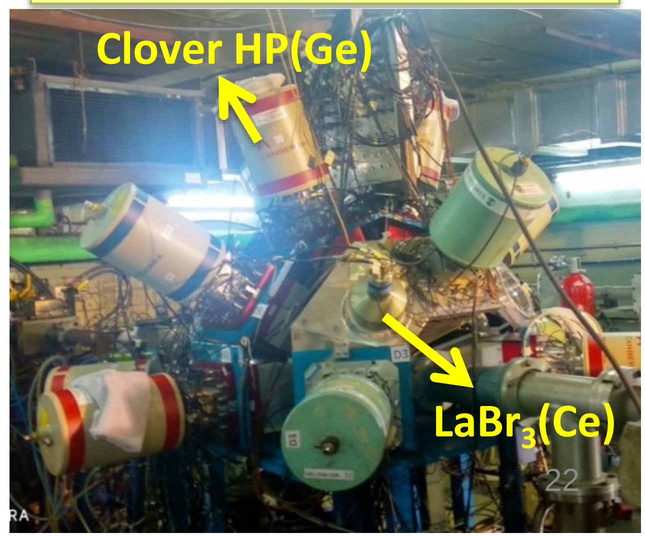
About 40 expts performed by users from all over the country in two campaigns

Recent (2020-2021) Campaign of a multi-detector Gamma Array : Collaborative endeavor among SINP, UGC-DAE-CSR and VECC, Kolkata

→ Up to 12 CS-clovers and LEPS + 3 $Labr_3$
→ Improved Digital DAQ
10 Experiments performed using light-ion beams

Courtesy Chandana Bhattacharya, Head Nucl. Phys. Division, VECC

Up gradation to INGA Structure



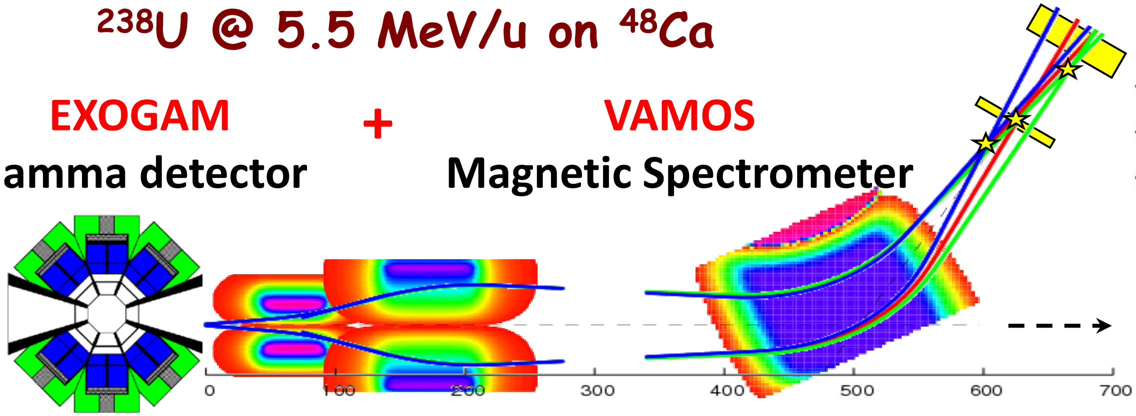
International Collaboration with GANIL, France
Evolution of shell structure of extreme neutron-rich nuclei

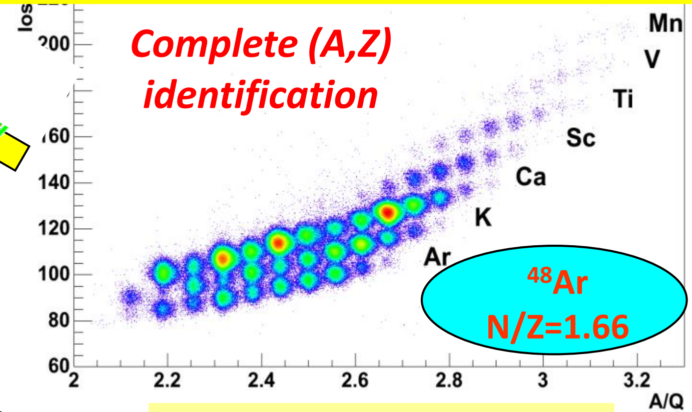
◆ Deep-inelastic multinucleon transfer reaction

^{238}U @ 5.5 MeV/u on ^{48}Ca

EXOGAM + **VAMOS**

Gamma detector — Magnetic Spectrometer



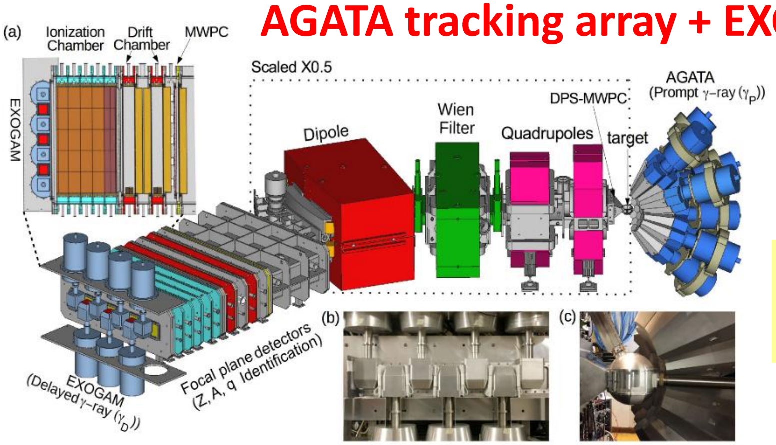


S. Bhattacharyya et al.
PRL 101, 032501 (2008)

- ➢ Probing the existence of N=34 new magic shell gap in neutron rich Ca isotopes
- ➢ First observation of triaxial shape near N=28 in ^{48}Ar (highest N/Z=1.66 produced)

◆ Prompt and delayed spectroscopy of (A,Z) identified fission fragments

AGATA tracking array + EXOGAM + VAMOS



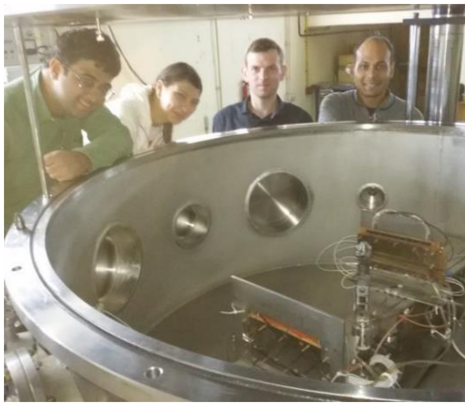
- ➢ Evolution of shell structure around ^{132}Sn (Z=50)
- ➢ First observation of high spin states above isomers in neutron rich Iodine and Pm isotopes

S. Bhattacharyya et al. PRC 98, 044316 (2018)
R. Banik et al., 102, 044329 (2020)

+ 10 publications (4 PLB, 4 PRC, 1 NIM, 1 Rev)

VECC - JINR Dubna collaboration

Under the umbrella of this collaboration joint experiments are being carried out to study the fission dynamics of Heavy Elements (HE) and Super Heavy Elements (SHE)



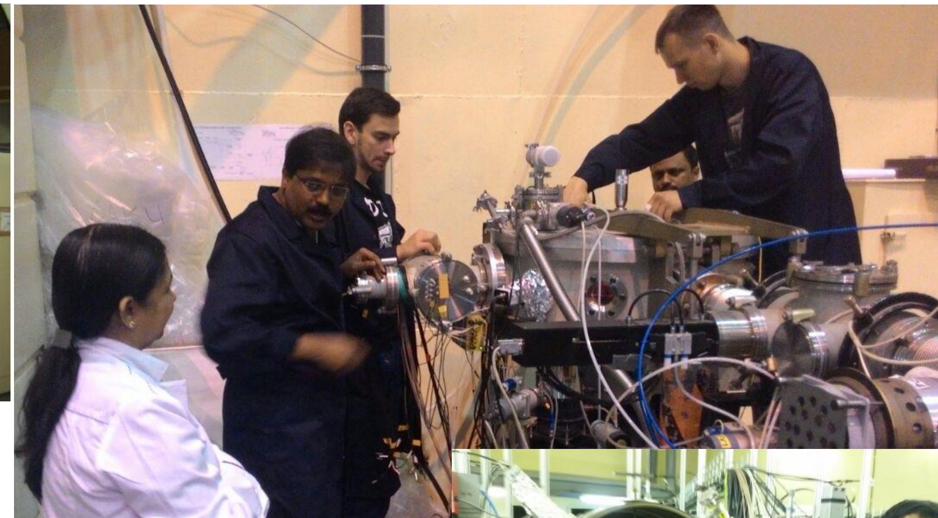
Fission study of HE in India

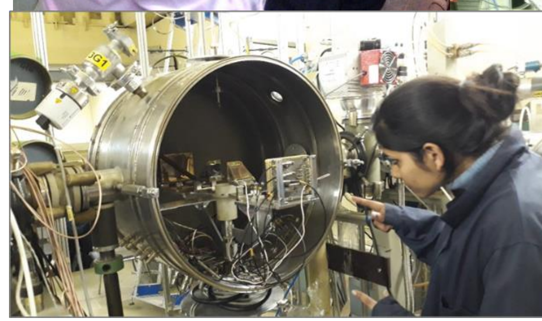
Kolkata cyclotron, Mumbai & Delhi Pelletron

While the reactions with ^{16}O beams were studied in India; reactions with ^{56}Fe,$^{84,86}Kr$ beams (that were not available in India) were studied in Dubna cyclotron.

The experiments were to explore the optimal condition for the synthesis of newest elements in the period table

Courtesy Chandana Bhattacharya, Head Nucl. Phys. Division, VECC





Fission study of SHE in Russia at Dubna

Fission of Ogenasson (Z=118) and Flerovium (Z=114) were studied

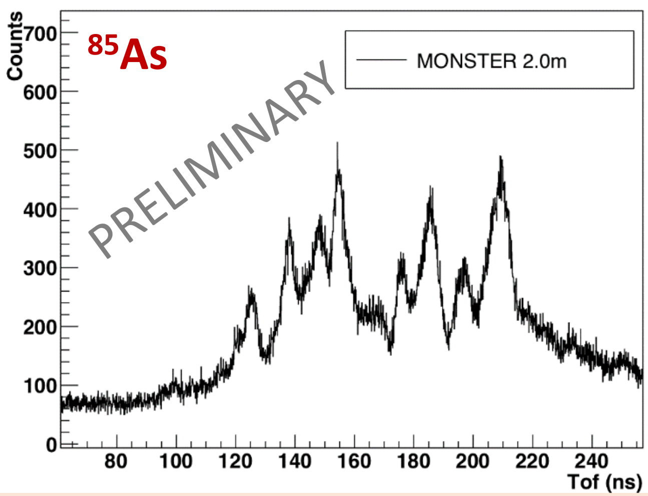
VECC-MONSTER Collaboration under the FAIR Project

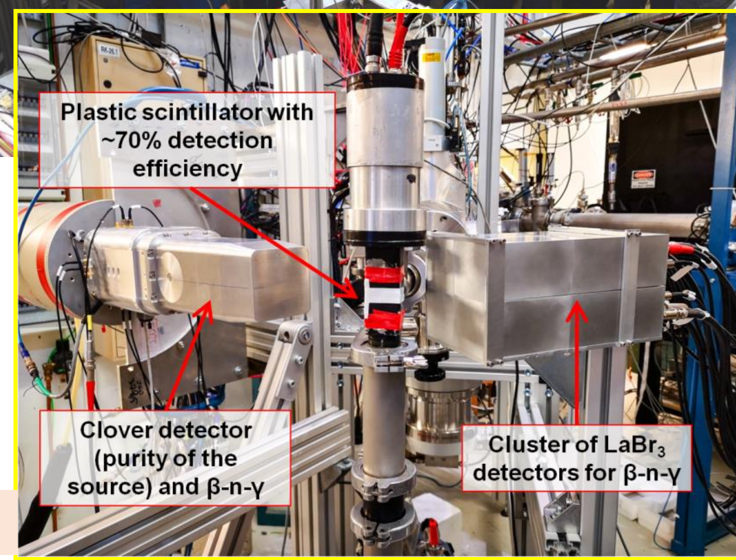
Experiment at the IGISOL facility at Jyvaskyla, Finland (March 2019)

Measurement of β-delayed neutron spectra from ^{85,86}As

First experimental test of the MONSTER array

Neutron rich As isotopes produced from the p induced fission of $^{nat.}$U.





Courtesy Chandana Bhattacharya, Head Nucl. Phys. Division, VECC

Summary

- Physics with radioactive ion beams (RIB) is the new frontier in nuclear physics & allied sciences. All major accelerator laboratories have operational RIB facilities and are constructing next generation mega RIB accelerators.

- A low energy RIB facility has been developed at VECC in preparation for ANURIB – the next generation RIB facility that is planned at VECC's new campus. Also, BARC is planning a 1 GeV proton driver based RIB facility at BARC Vizag campus.

- The development is well aligned with the Mega Science Vision – 2035 recommendations put forth by the nuclear physics community in the country
  - ➢ Develop new accelerator facilities within India for radioactive-ion beams (RIB), high current stable beams and underground laboratories for the low-energy nuclear physics programs.
  - ➢ Augment state-of-the-art detector systems at the existing accelerator facilities – this is essential to cope with the developments in the field.
  - ➢ Continue strong participation in the experiments at FAIR and other international nuclear physics facilities for RIBs and photon beams.

Thank you for your kind attention