Accelerator development activity at Variable Energy Cyclotron Centre, Kolkata, India

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Asian Forum for Accelerators & Detectors (AFAD-2021)

Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia

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VECC
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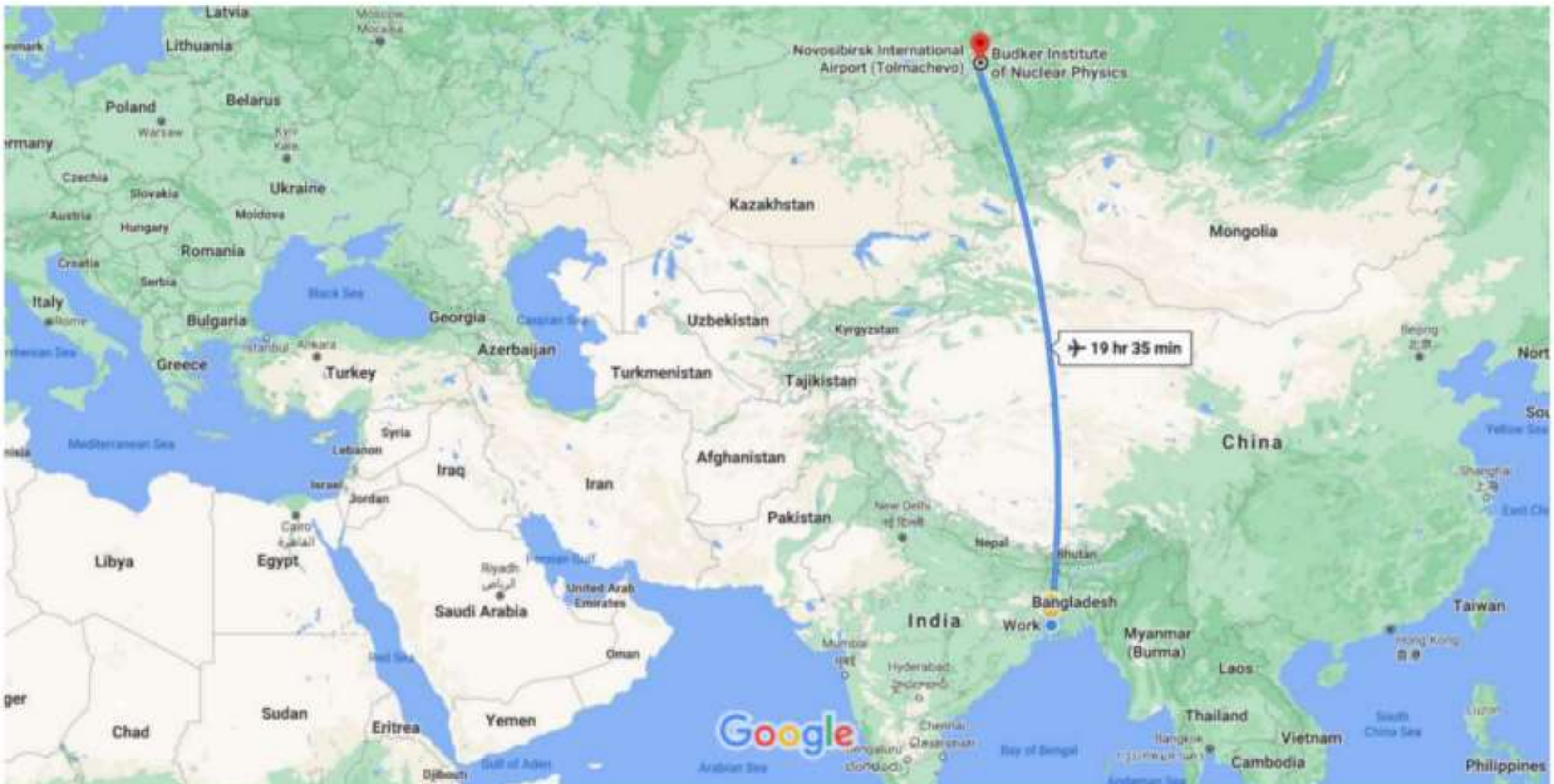
AFAD 2021

Google Maps Variable Energy Cyclotron Centre to Budker Institute of Nuclear Physics

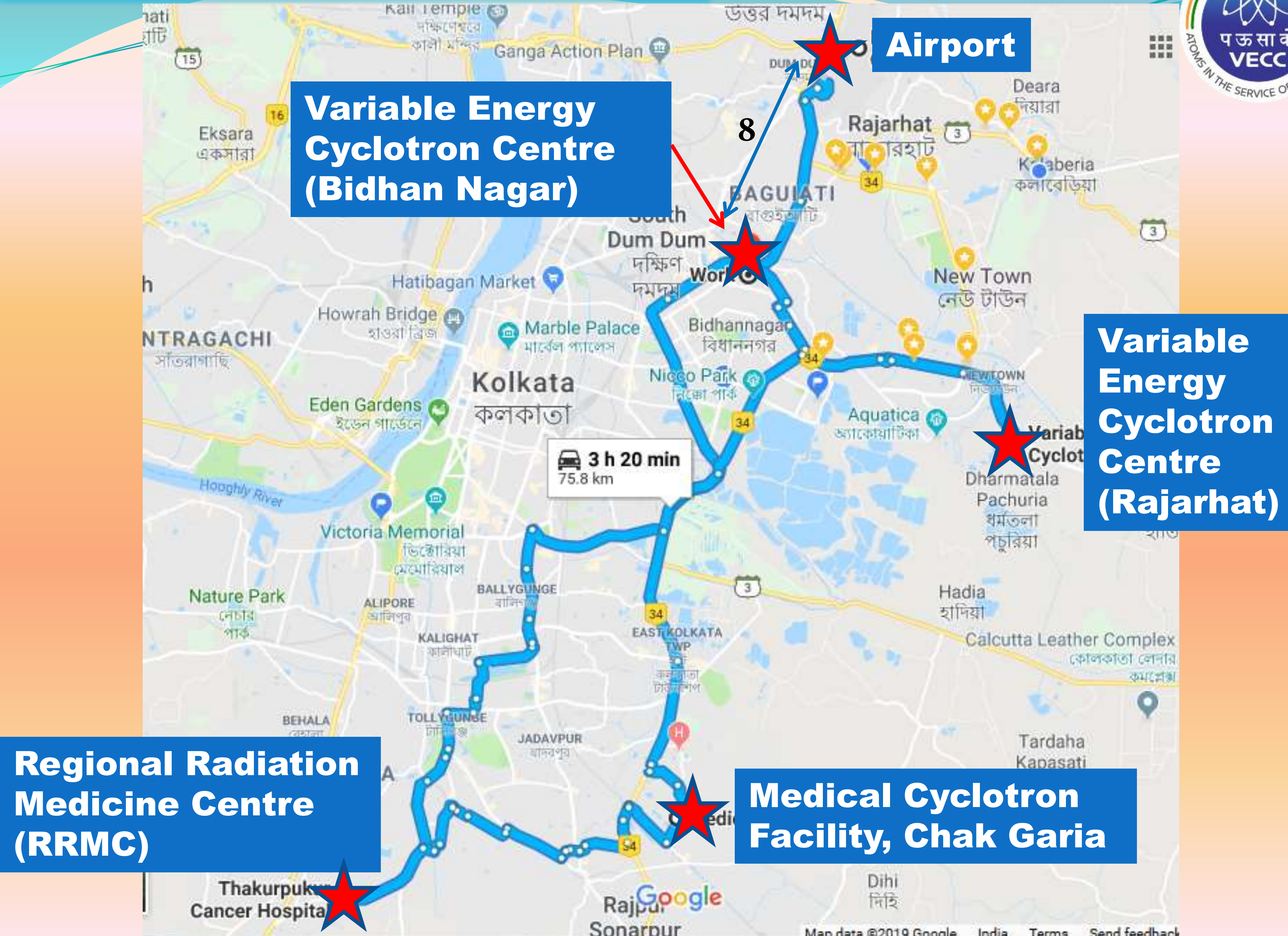


Map data ©2021 Google, SK telecom 500 km

Variable Energy Cyclotron Centre (VECC)

Bidhan Nagar Campus

Variable Energy Cyclotron Centre (VECC)



Plan of Talk

K=130 Room Temperature Cyclotron

K=500 Super-conducting Cyclotron

30 MeV Medical Cyclotron

ISOL post-accelerator type RIB facility

Variable Energy Cyclotron Centre (Bidhan Nagar)
Room Temperature Cyclotron (K=130) – June 1977

PIG / ECR

Alpha : 28-50 MeV
Proton : 7-12.5

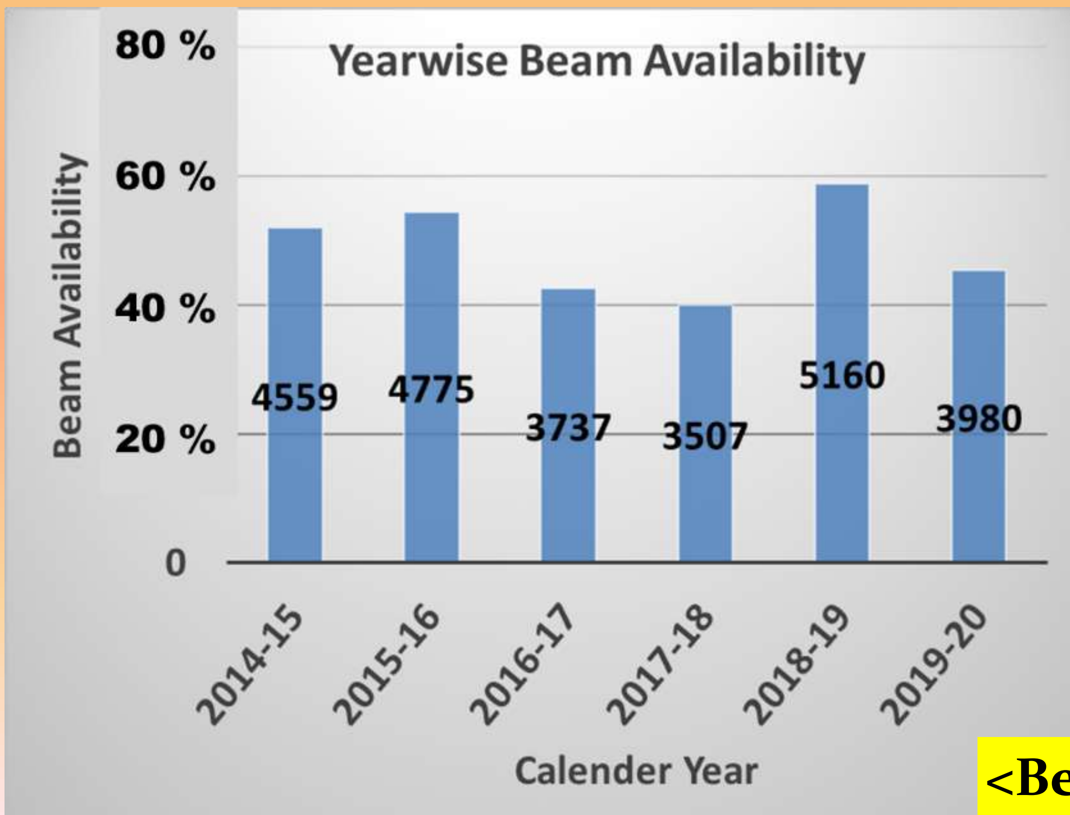
ECR

Nitrogen : 105-140 MeV
Oxygen : 116-160 MeV
Neon : 145 -192 MeV

Performance of cyclotron in last five years

Beam Availability : All systems are working, all tunings are completed, beam is either on target or on FC-01 on user's request.

24x365=8760 → 100%



2019-20

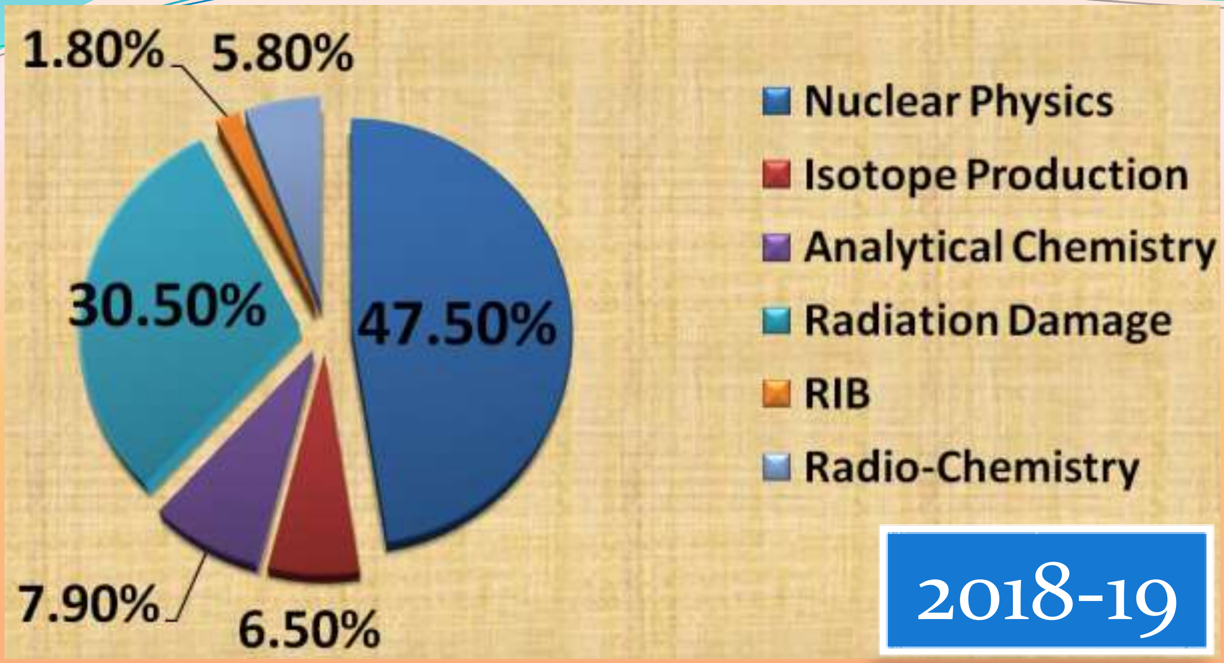
"Cyclotron availability time" 5994 h (68.2%)

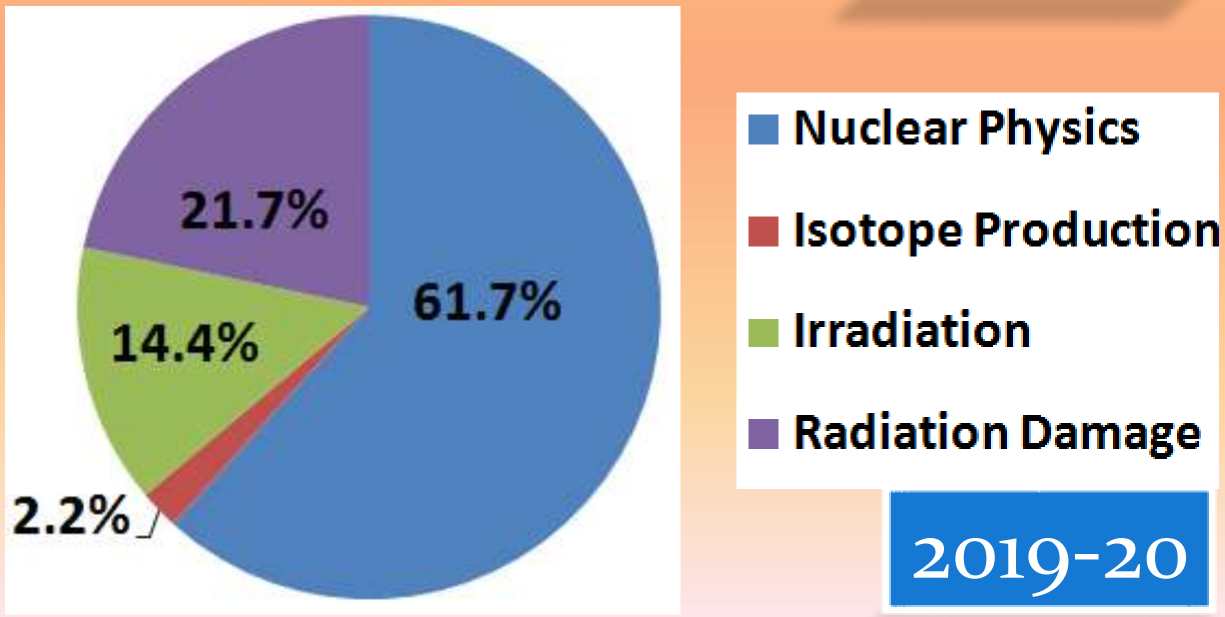
"System startup & beam tuning" time 2014.5 h (23%)

"Beam on target" time of 3980 h (45.4%)

<Beam availability>=4286h = 48.9%

Utilisation of cyclotron in last two years





The major utilization of the cyclotron are for Nuclear Physics & Radiation damage studies

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500) – August 2009

Max. Energy : 80 MeV/u for light ions
5-10 MeV for heavier ions

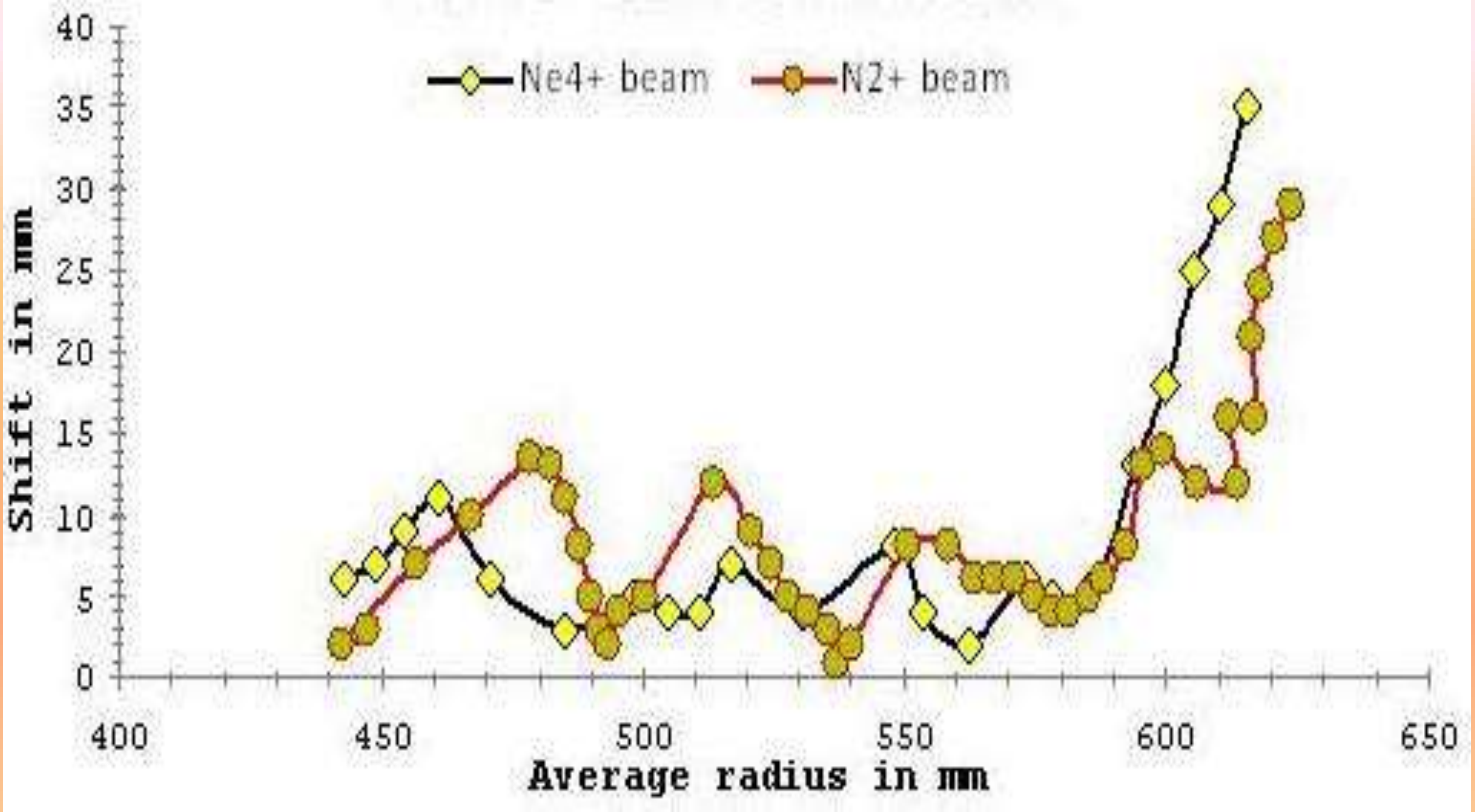
Max. mag field : 5 Tesla
Pole gap (Hill) : 64 mm
Magnet Diameter : 3.05 m
Total Magnet height : 2.18 m
Weight : 80 Ton

Main coils : Two – NbTi
Trim coils : Thirteen - Cu

RF :
Freq – 9 to 27 MHz
Three cavities
Max Dee voltage 80 kV

Variable Energy Cyclotron Centre (Bidhan Nagar)

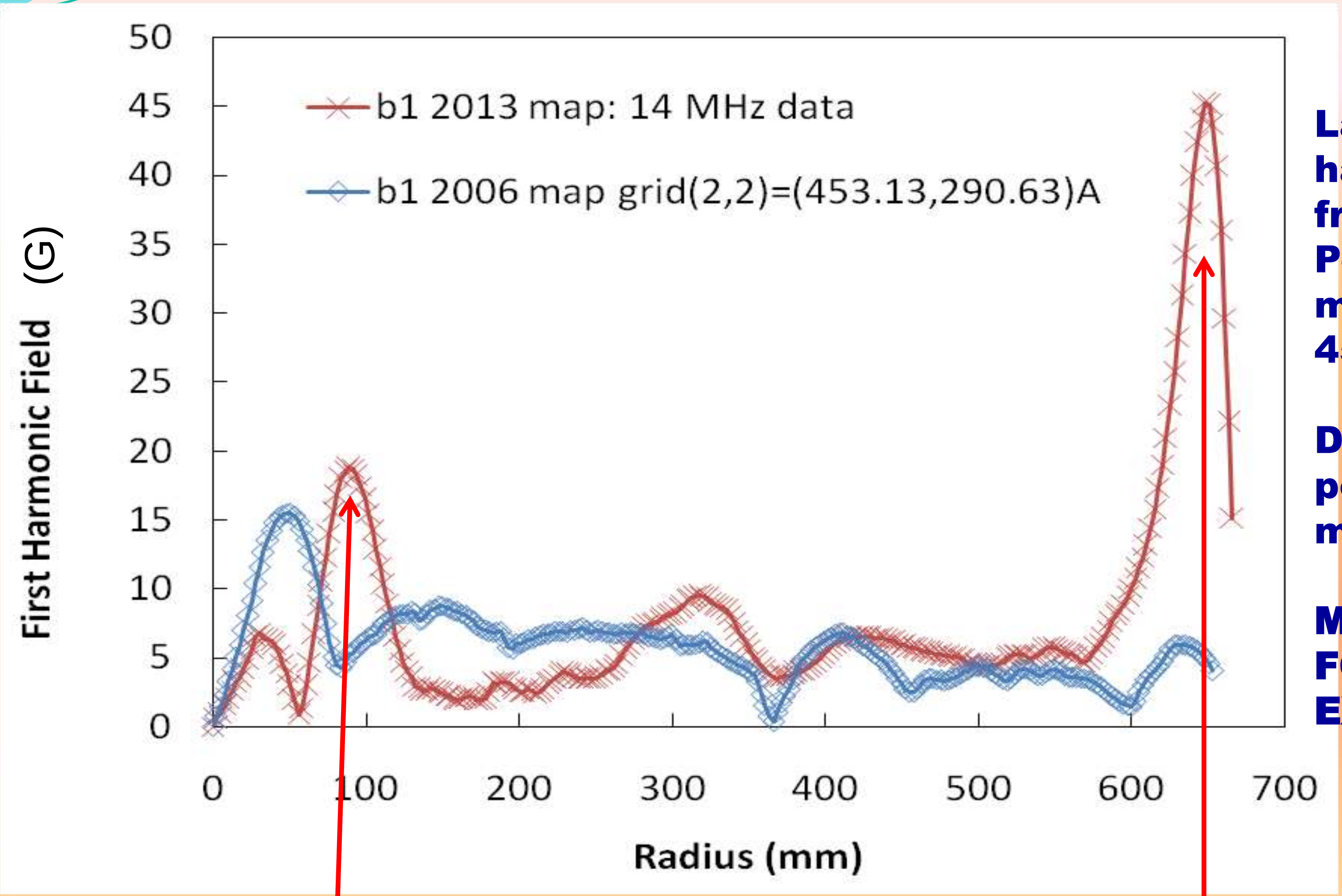
Super-conducting Cyclotron (K=500)



Beam gets off-centered after 600 mm radius

Deflector position at 667 mm

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500)



Large first harmonic field from 610 mm. Peaks at 650 mm, 45 Gauss !!!

Deflector position is 667 mm

MAIN HURDLE FOR BEAM EXTRACTION

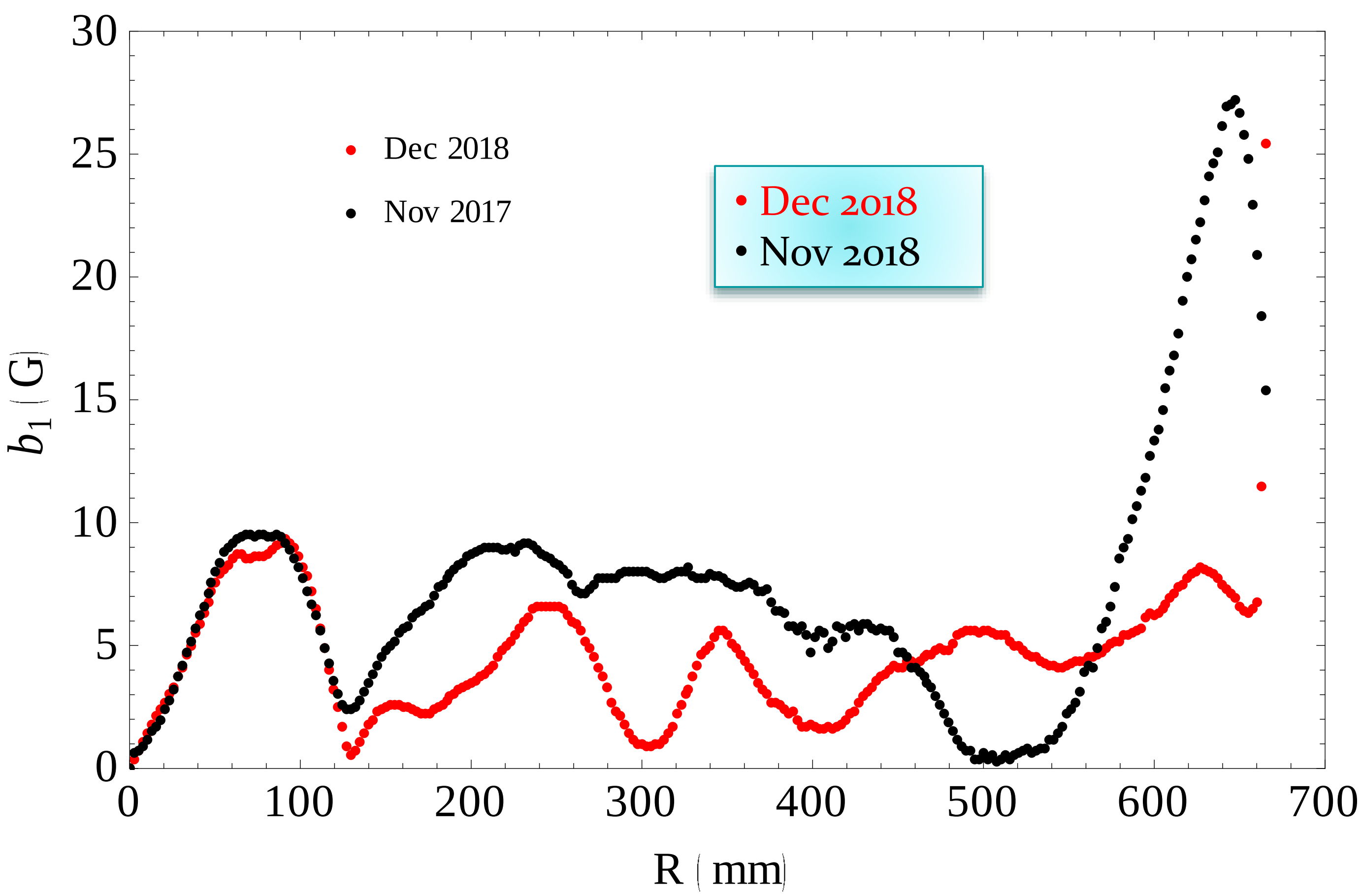
Error in central plugs, small and large hill additions

Mismatch between magnet centre and cryostat centre

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500)

The cyclotron was almost completely disassembled to rectify the problems and assembled again

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500)



Results of magnetic field measurement with new Central plug (Black dots) & Cryostat shift (Red dots)

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500)

First beam extraction from SCC on 29th Dec 2019

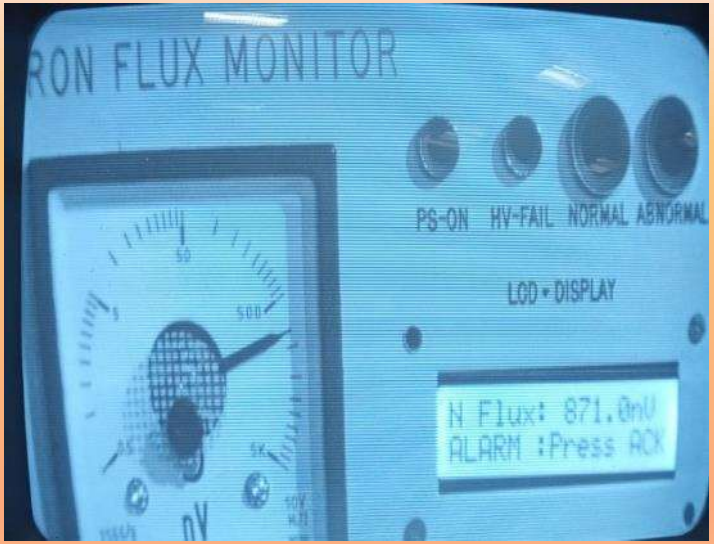
Beam spot viewed at the alumina mounted at the target position
Diameter: ~ 5 mm

First beam at the target position at SCC (00:04 hrs 19th January, 2020)

- **Elastic scattering of beam was measured from ^{197}Au, ^{27}Al , ^{12}C targets**
- **Different fragments have been identified using (ΔE) – (E) telescopes**
- **Clear band corresponding to ^{14}N has been identified**

Variable Energy Cyclotron Centre (Bidhan Nagar)
Super-conducting Cyclotron (K=500)

252 MeV N^{4+} beam extraction @14 MHz from Superconducting Cyclotron



Neutron monitor showing neutron flux, kept inside the vault

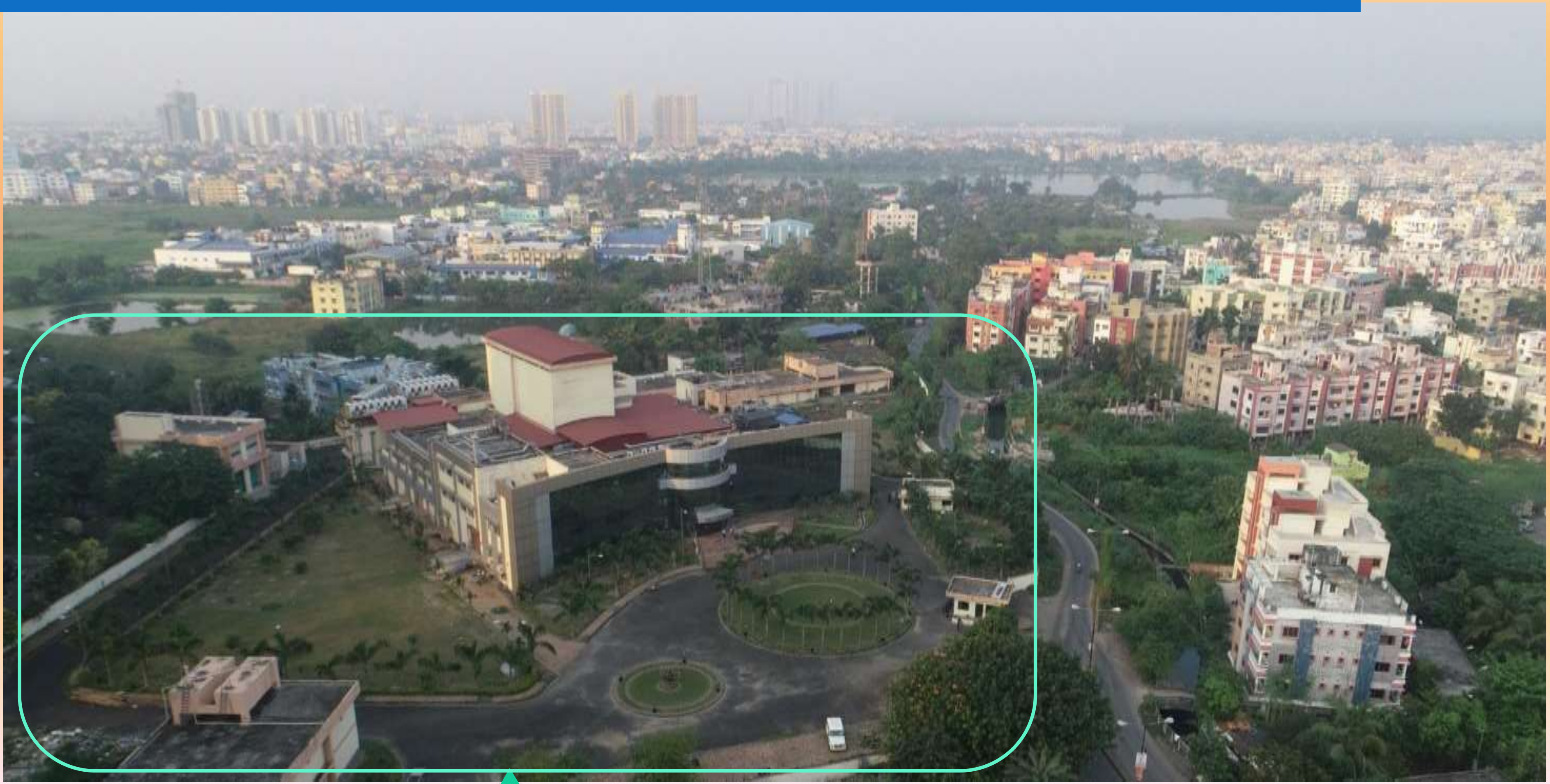
N^{4+} beam on BV-12

Variable Energy Cyclotron Centre (Chak-Garia campus)

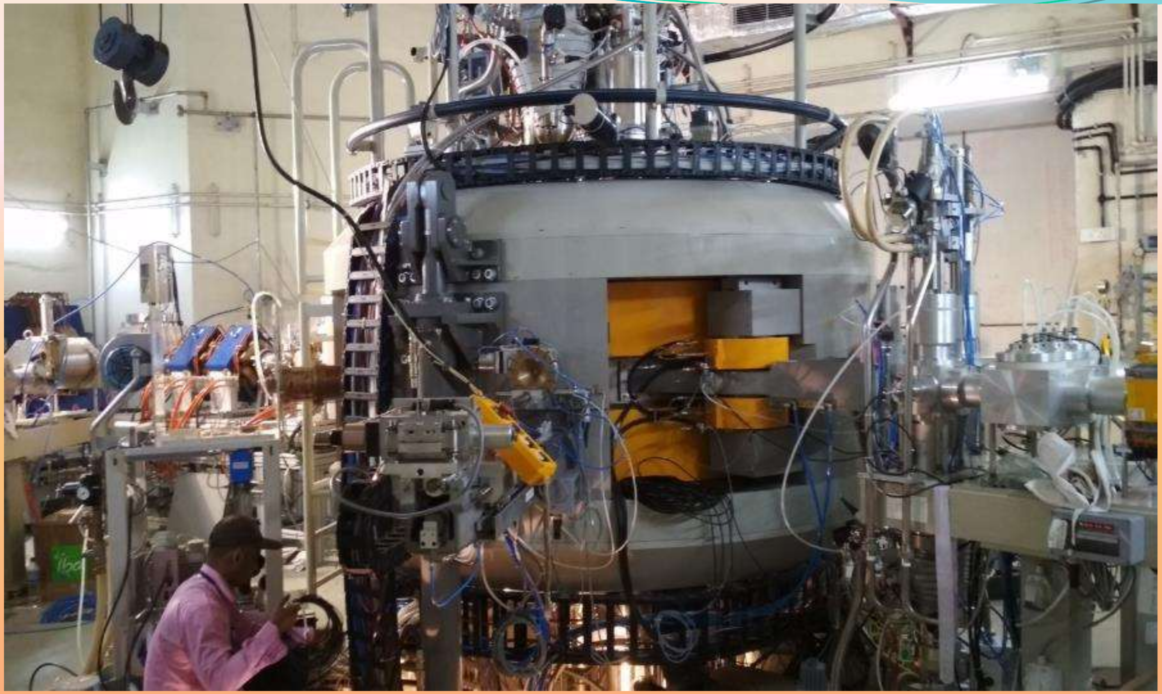
Medical Cyclotron Facility – Sep 2018

IBA Cyclone-30 (15 to 30 MeV, 350 μA p)

Production of SPECT (Ga^{67}, Tl^{201}) and PET (F-18) radio-isotopes and processing of radio-pharmaceuticals used in Nuclear imaging of cancerous tumors



Variable Energy Cyclotron Centre (Chak-Garia campus)



No. of sectors : 4
Hill field : 17 T
Valley field : 0.12 T
Sector angle ~55˚
Magnet Diameter : 3 m
Weight : 50 Tonnes

RF :
40 kW RF amplifier
Freq - 66±2 MHz
Two Dee structures at opposite valleys
Max Dee voltage 50 kV
Max power dissipation per cavity 5 kW

- IBA didn't agree to do the commissioning @original cost due to delay in civil construction : Commissioned by VECC
- Commissioned by VECC – Machine + Interface

Variable Energy Cyclotron Centre (Chak-Garia campus)

PET Hot cells for production & dispensing of ^{18}F-FDG

SPECT Hot cells

Variable Energy Cyclotron Centre (Chak-Garia campus)

- **Permission from regulatory authority for regular running of the machine**

- **A few batches of F-18 was produced in this cyclotron by irradiation of $H_2{}^{18}O$ (97% enriched) [$^{18}O(p,n)^{18}F$] using 18 MeV proton beam.**

- **Synthesis of ^{18}F-FDG from ^{18}F- (Fluoride) was carried out.**

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

- **The results were submitted for RPC (Radiopharmaceuticals Committee) clearance for manufacture and supply of the ^{18}F-FDG injection for clinical use in patients.**

- **Commercial production and supply of FDG started in June 2020.**

Variable Energy Cyclotron Centre (Chak-Garia campus)

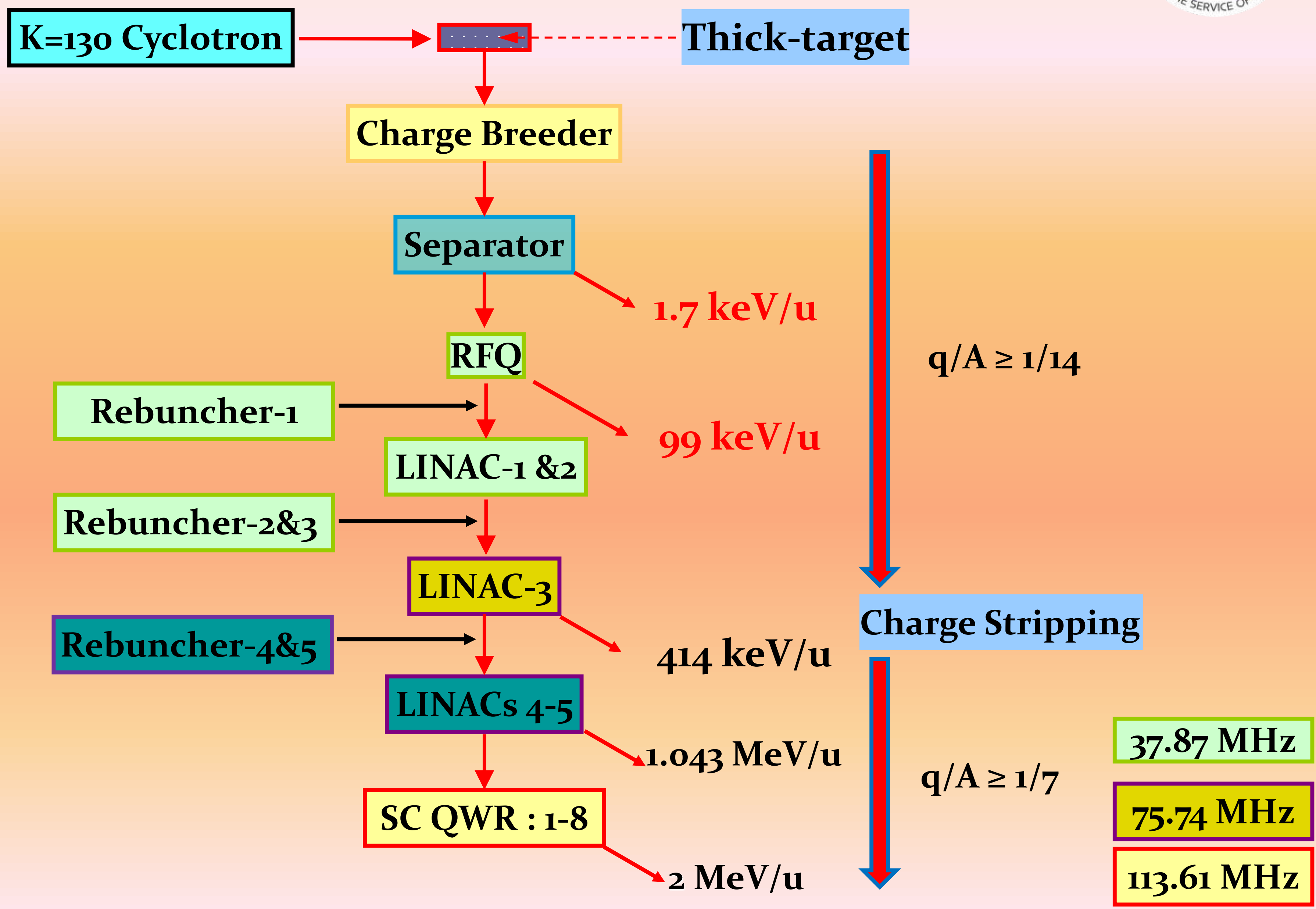
- **The following radiopharmaceuticals successfully produced on trial basis and will start commercial production after obtaining RPC clearance.**
  - **Ga-67-citrate.**
  - **Ga-68-PSMA**
  - **Ga-68-Dotatate**
  - **Tl-201-Chloride**

- ---

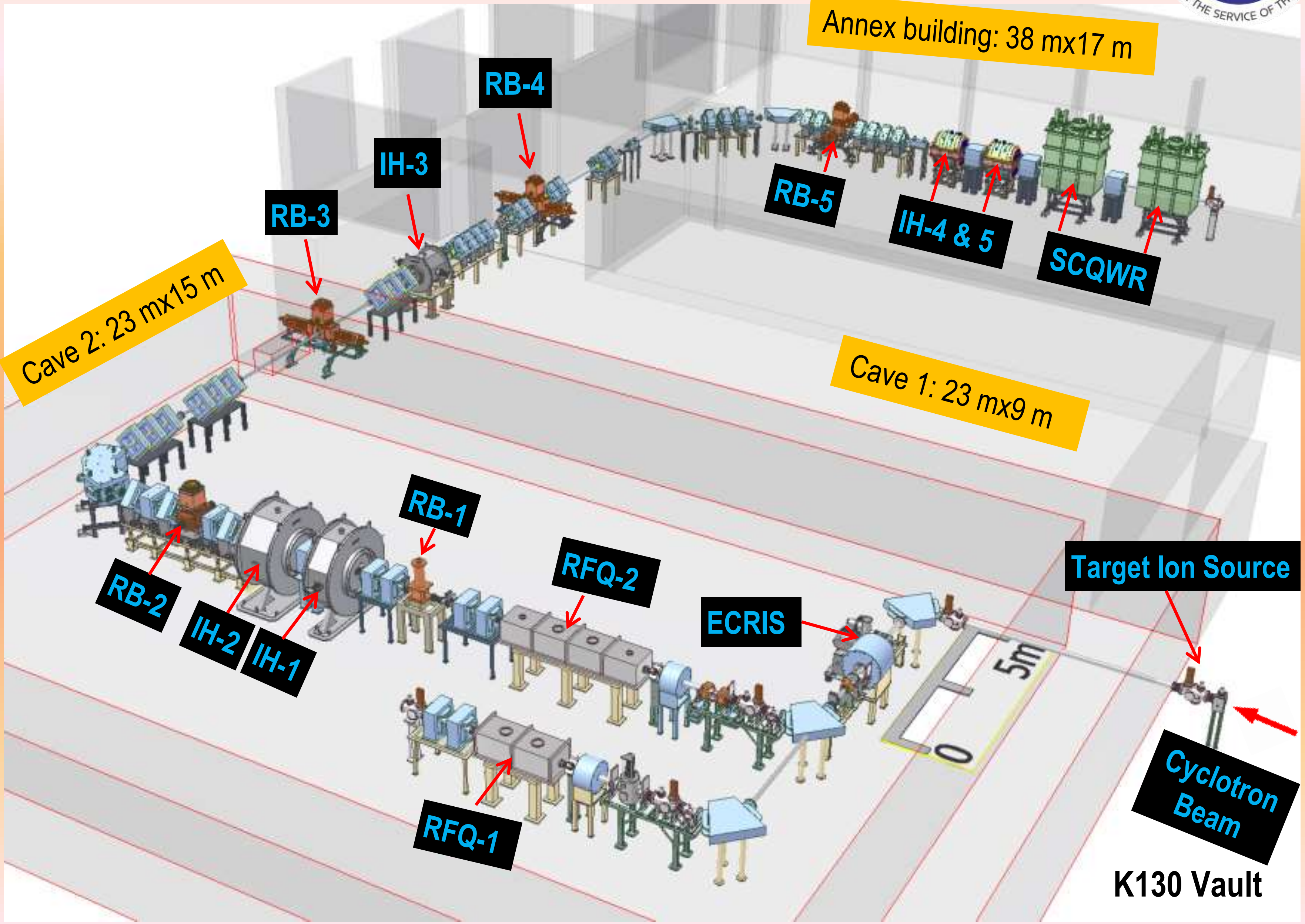
- **Near Future target:**
  - **Production of ^{68}Ge – ^{68}Ga generator.**
  - **Production of Pd-103**

- **Future Plan:**
  - **Production of Iodine-123 radioisotope from Xenon gas target.**
  - **Production of other radioisotopes**

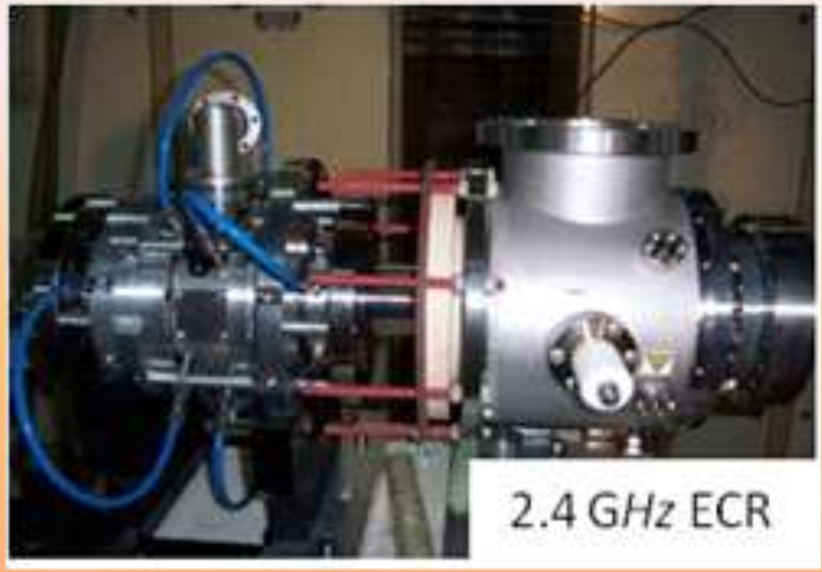
Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility

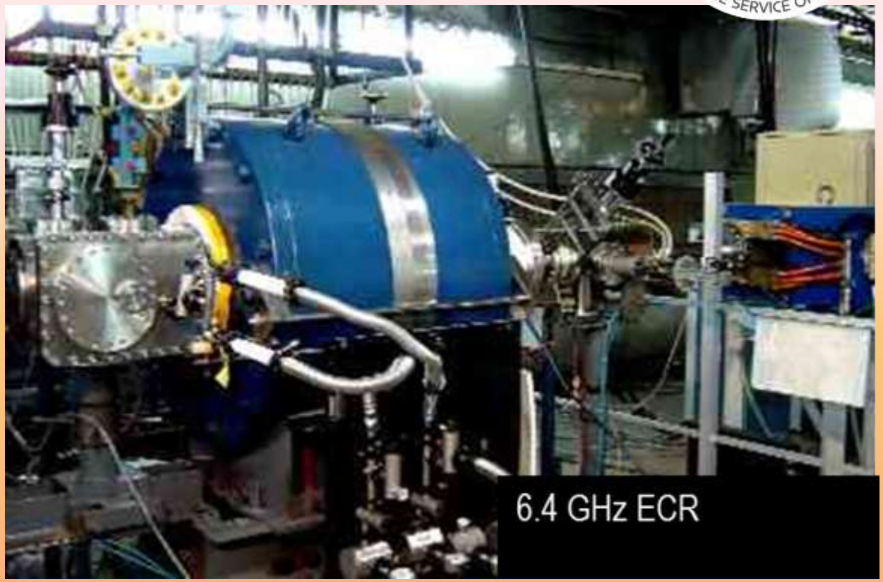


Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility



Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility





Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility

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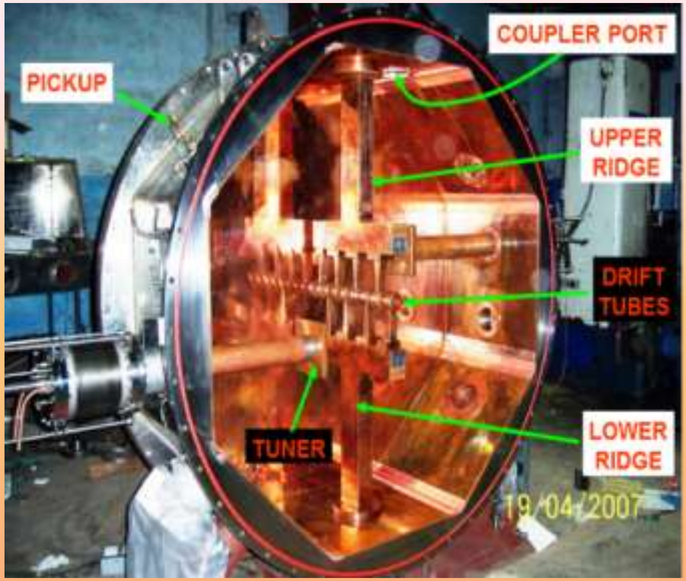
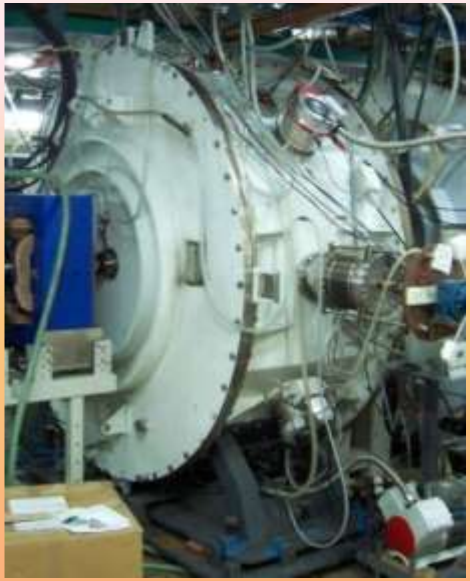
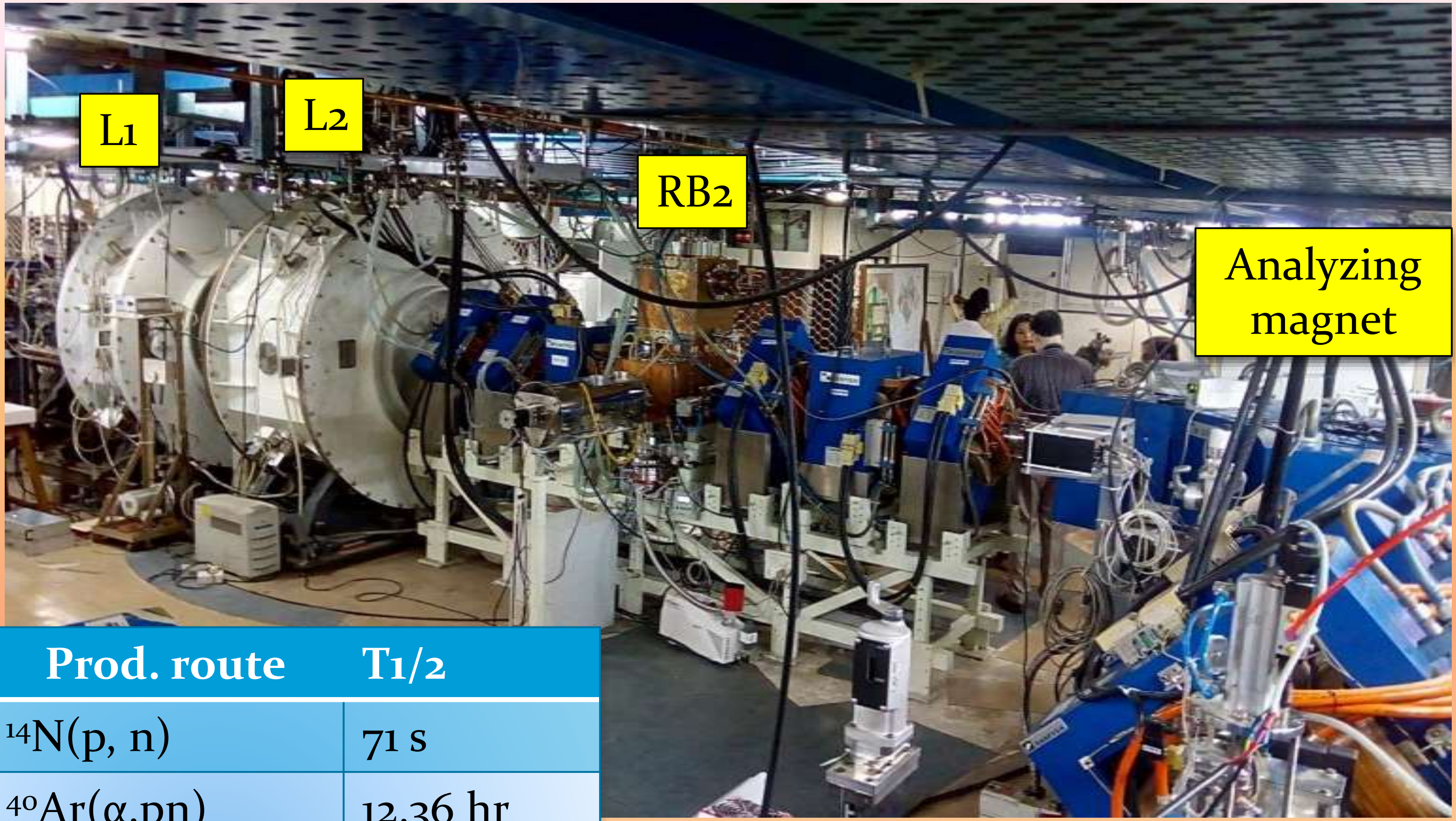




Variable Energy Cyclotron Centre (Bidhan Nagar)

Rare Ion Beam Facility



RIB	Prod. route	T1/2
^{14}O	^{14}N(p, n)	71 s
^{42}K	^{40}Ar(α,pn)	12.36 hr
^{43}K	^{40}Ar(α,p)	22.3 hr
^{41}Ar	^{40}Ar(α,2pn)	109 min
^{111}In	^{nat}Ag(α,xn)	2.8 days
Typical intensity 1,000 – 10,000 pps		

Variable Energy Cyclotron Centre (Bidhan Nagar)

Rare Ion Beam Facility

Variable Energy Cyclotron Centre (Bidhan Nagar)

Rare Ion Beam Facility

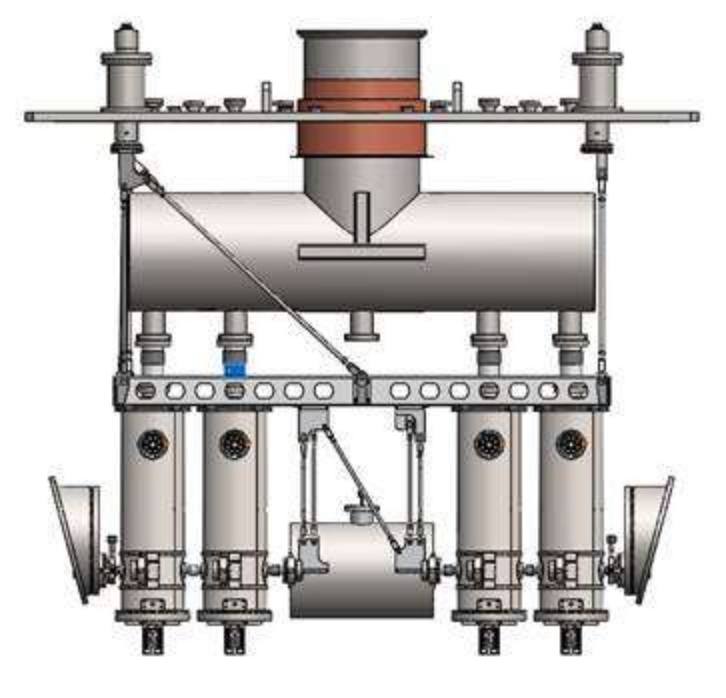
Superconducting Quarter Wave Resonator : 1-2 MeV/u

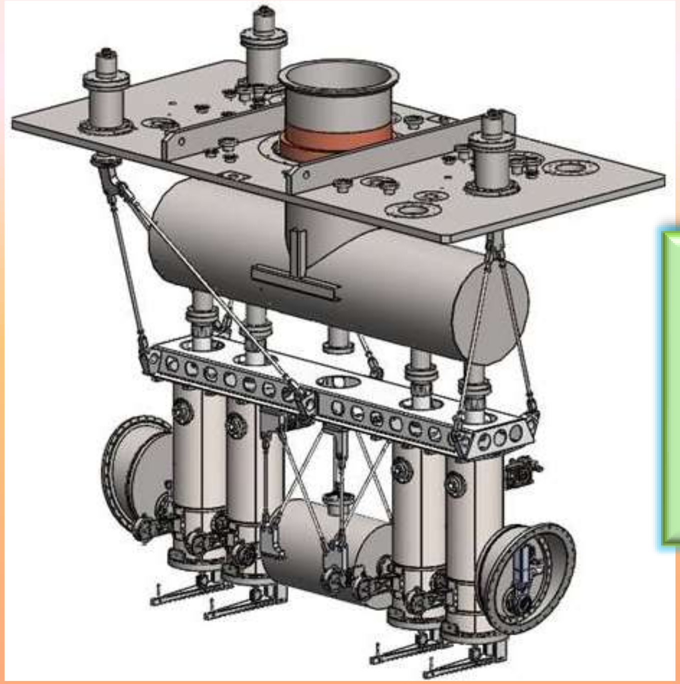
Frequency [MHz]	113.61
β_0 [%]	5.5
No. of resonators	8
Initial/final energy (MeV/u)	1.04/2.0
E_{acc}[MV/m]	6
E_{peak}/E_{acc}	~ 4.6
B_{peak}/E_{acc} [mT/(MV/m)]	~ 8.5
B_{peak} [mT]	51 @6 MV/m
E_{peak} [MV/m]	28 @6 MV/m
U [J]	1.836 @6 MV/m
$U/(E\_{acc})^2$ [J/(MV/m)^2]	0.051
R_{sh}/Q [Ohm]	491.3

Field Emission

Quenching

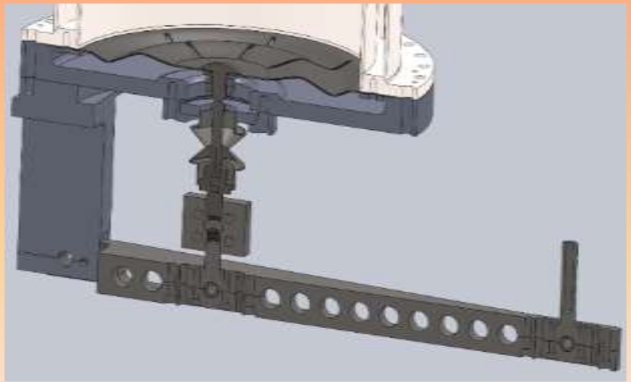
Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility

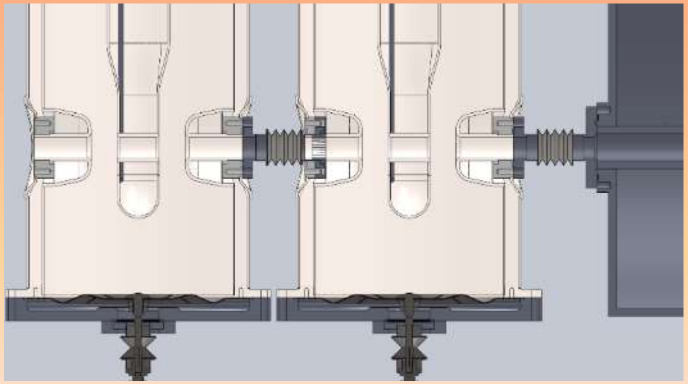




Lattice comprise of two cryo-modules:

Each have 4-QWRs and 1-SC Solenoid



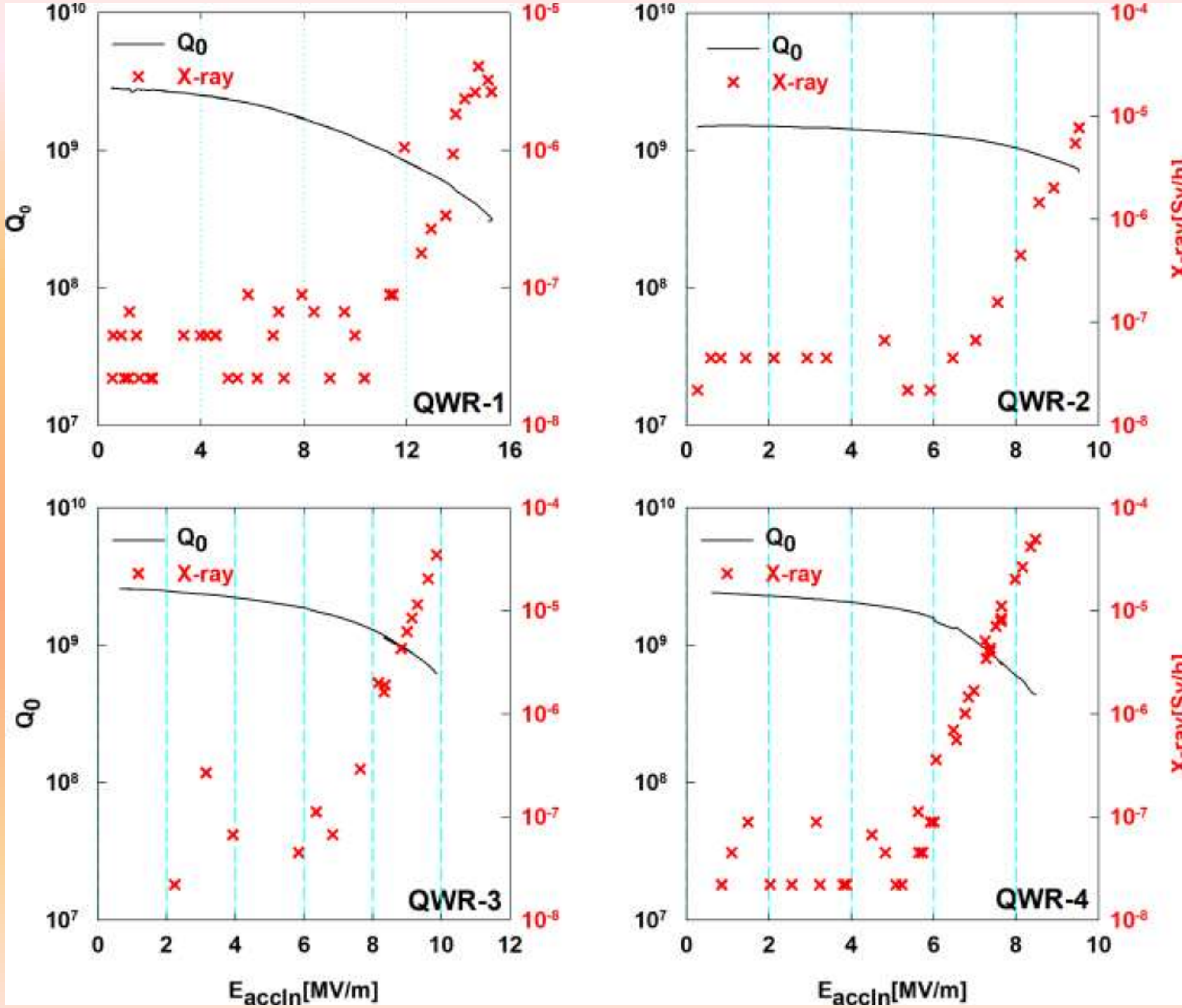


Hermetically sealed QWR cavities

Variable Energy Cyclotron Centre (Bidhan Nagar)
Rare Ion Beam Facility


Niobium QWR Cavities during fabrication

Variable Energy Cyclotron Centre (Bidhan Nagar)
ISOL post-accelerator type RIB facility



Conclusion

K=130 Room Temperature Cyclotron	Performing well in delivering light & heavy ions to experimentalists
K=500 Super-conducting Cyclotron	Successful beam extraction
30 MeV Medical Cyclotron	Commercial production & supply of PET isotopes started
ISOL post-accelerator type RIB facility	Successful development & testing of QWRs @113.61 MHz

Thank You all

Variable Energy Cyclotron Centre (Chak-Garia campus)

SPECT /PET Radioisotope	Half Life	Application
$^{203}Tl(p,3n)^{201}Pb \rightarrow {}^{201}Tl$ 98% enriched	3.06 d SPECT	Myocardial perfusion (Evaluates heart's function & blood flow)
$^{124}Xe(p,2n)^{123}Cs \rightarrow {}^{123}Xe \rightarrow {}^{123}I$ $^{124}Xe(p,pn)^{123}Xe \rightarrow {}^{123}I$	13.2 h SPECT	Myocardial metabolism, Neuroendocrine tumor imaging
$^{68}Zn(p,2n) \rightarrow {}^{67}Ga$ 98% enriched	3.26 d SPECT	Soft tissue tumor imaging Broncogenic carcinoma
$^{112}Cd(p,2n) \rightarrow {}^{111}In$ 98% enriched	2.8 d SPECT	Cisternography, Abscess imaging, Tumour imaging
$^{18}O(p,n) \rightarrow {}^{18}F$ 95% enriched HW	1.8 h PET	FDG: Use in oncology, brain function studies and cardiology NaF: Bone scan

Radioisotope production using up to 18MeV energy proton beam

Medical Isotope	$T_{1/2}$	Use	Nuclear Reaction	Energy Range (MeV)	Applications / Comments
$_{18}F$	109.8m	PET	$_{18}O(p,n)$	8 - 17	Used for the assessment of glucose metabolism in the heart, lungs, and the brain. For use in diagnosing Alzheimer's disease. FDG – Oncology, cardiology and neurology NaF – WB bone scan
$_{11}C$	20.4m	PET	$_{11}B(p,n)$	8 – 20	Used for studying brain physiology and pathology, in particular for localising epileptic focus, and in dementia, psychiatry, and neuro-pharmacology studies. They also have a significant role in cardiology.
$_{11}C$	20.4m	PET	$_{14}N(p,)$	12	
$_{13}N$	9.96m	PET	$_{16}O(p,)$	8 - 18	
$_{15}O$	2m	PET	$_{15}N(p,n)$	10-15	
$_{64}Cu$	12.7h	SPECT	$_{64}Ni(p,n)$	5 - 20	Used to study genetic diseases affecting copper metabolism, such as Wilson's and Menke's diseases, for PET imaging of tumours, and also cancer therapy. Tracer for blood flow, hypoxia and cell binding studies as PTSMa .
$_{99m}Tc$	6h	SPECT	$_{100}Mo(p,2n)$	19	proton irradiation of an enriched Molybdenum-100 target Used to image the skeleton and heart muscle, in particular; but also used for brain, thyroid, lungs (perfusion and ventilation), liver, spleen, kidneys (structure and filtration rate), gall bladder, bone marrow, salivary and lachrymal glands, heart blood pool, infections and numerous specialized medical studies
$_{103}Pd$	17.5d	Therapy	$_{103}Rh(p,n)$	10 -15	prostate cancer diagnostic & therapy
$_{124}I$	4.1d	PET	$_{124}Te(p,n)$	10 -18	Both PET imaging and radiotherapy. The interest is primarily related to relatively long half-lives (4.14 days). Such properties would enable studies to be performed where the kinetics are slow and exceed the ability for imaging with 18F
$_{68}Ga$	68m	SPECT	$_{68}Zn(p,n)$	15	neuro-endocrine tumour imaging ^{68}Ga-DOTA-TATE (DOTA-Tyrosine-3- Octreotate) for diagnosis of neuroendocrine cancers and ^{68}Ga-PSMA (Prostate specific Membrane Antigen) for prostate cancer diagnosis.

Radioisotope production using above 18MeV energy proton beam

Medical Isotope	$T_{1/2}$	Use	Nuclear Reaction	Energy Range (MeV)	Application / Comments
$_{15}O$	2m	PET	$_{16}O(p,pn)$	>26	PET imaging
$_{67}Cu$	61.9h	SPECT	$_{68}Zn(p,2p)$	>40	High uptake of Cu-67 in the tumor as well as in the liver and kidney, which are the major organs for copper metabolism. The longer-lived 67Cu decays exclusively by β − emission and has been used to label monoclonal antibodies and antibody fragments for radioimmuno-therapy
$_{67}Ga$	78.3h	SPECT	$_{68}Zn(p,2n)$	20 – 40	Ga 67-citrate used to diagnose cancer, such as Hodgkin's disease, lymphoma, or lung cancer. Also used to detect acute swollen lesions
$_{82}Sr$/ $_{82m}Rb$	25d/ 5m	PET	$_{85}Rb(p,4n)_{82}Sr \rightarrow Rb$	50 -70	Rubidium-82 used in myocardial perfusion imaging. Rapid uptake by myocardiocytes --- for identifying myocardial ischemia in PET imaging.
$_{111}In$	67.2h	SPECT	$_{112}Cd(p,2n)$	18 – 30	Indium-111 for specialized diagnostic applications, e.g., labelled antibodies. Indium-111 oxine useful for labelling blood cell components
$_{123}I$	13.2h	SPECT	$_{124}Xe(p,2n)_{123}Cs \rightarrow 123Xe \rightarrow$	25 – 35	sodium Iodide-I-123 used in nuclear medicine for the diagnostic study of thyroid disease.
$_{186}Re$	90.6h	Therapy/ SPECT	$_{186}W(p,n)$	>18	The Renium-186 HEDP (1-hydroxy-ethylidene-1,1diphosphonic acid) complex, used for palliative treatment of bone metastases originating from breast or prostate cancer.
$_{201}Tl$	l 73.5h	SPECT	$_{203}Tl(p,3n)_{201}Pb \rightarrow$	27 – 35	Thallium-201-Chloride used in myocardial perfusion imaging (MPI) using either planar or SPECT techniques for the diagnosis and localization of myocardial infarction.