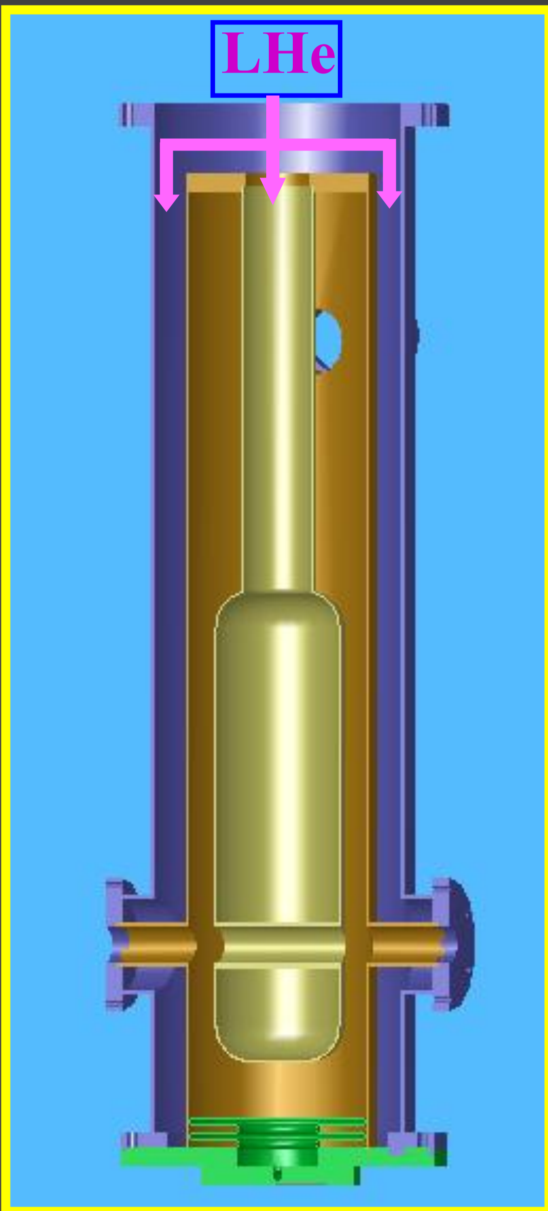
Industry Session—Report from India

Raghava Varma
Department of Physics
IIT Bombay
INDIA

Outline

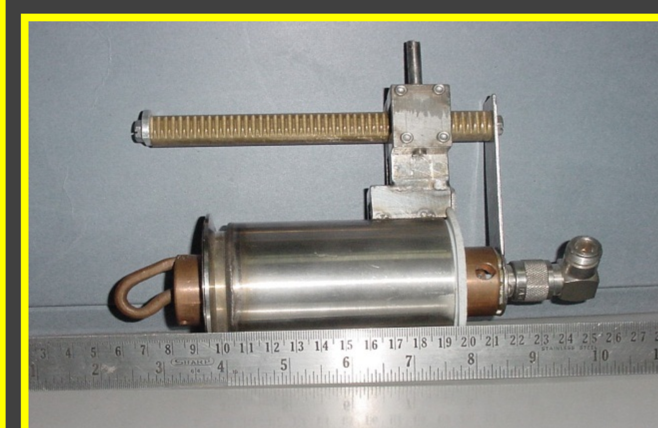
- Facilities in India
  - Inter University Accelerator Center (New Delhi)
  - Raja Ramanna Center for Advanced Technology (Indore)
  - Variable Energy Cyclotron Center (Kolkata)
  - Our own efforts at Sameer & IIT Bombay (Mumbai)

Quarter Wave Resonator (QWR) of IUAC



QWR sectional view

Mechanical tuner (Nb)



RF Power coupler

SS-jacketed Nb QWR

Electron Beam Welding

Surface Preparation Laboratory

High Voltage Furnace

Test Cryostat

Fabrication of QWR at IUAC
Developed by the facilities of M/S Donbosco & IUAC

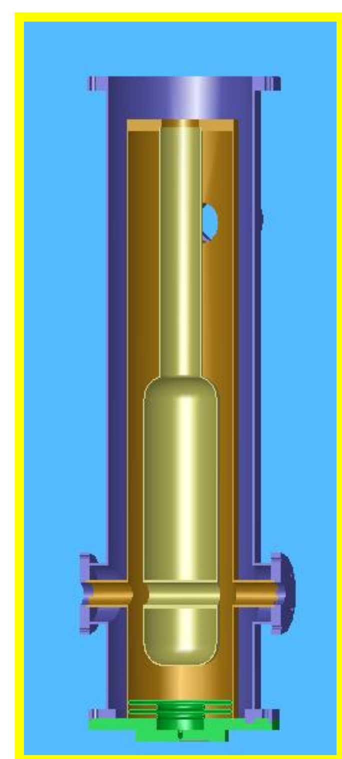
Central Conductor

Top Flange

Central Conductor & Housing

Electropolished niobium Central Conductors

Mechanical Tuner



Electropolished niobium Top Flanges (top middle), major Assemblies of the QWRs (above) and Slow Tuner bellows (left).

IUAC

अंतर विश्वविद्यालय त्वरक केंद्र

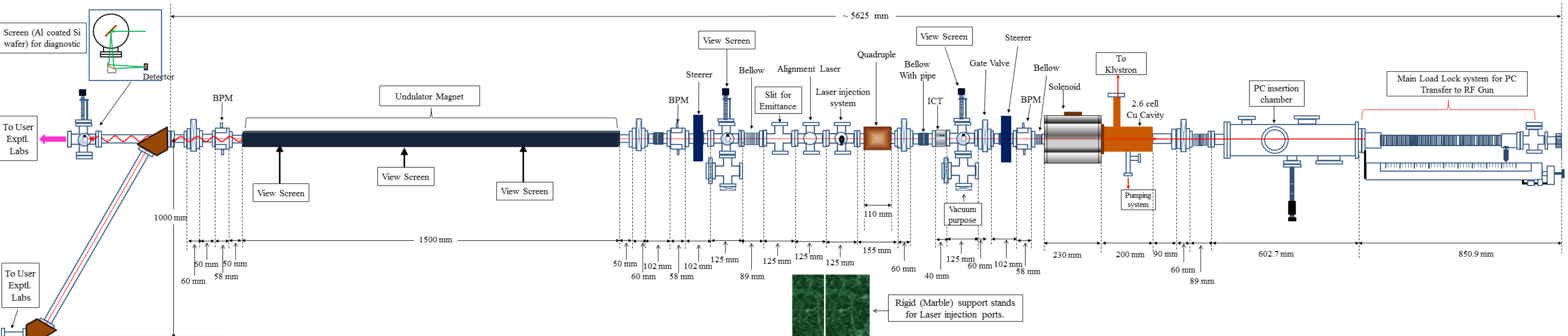
Inter - University Accelerator Center

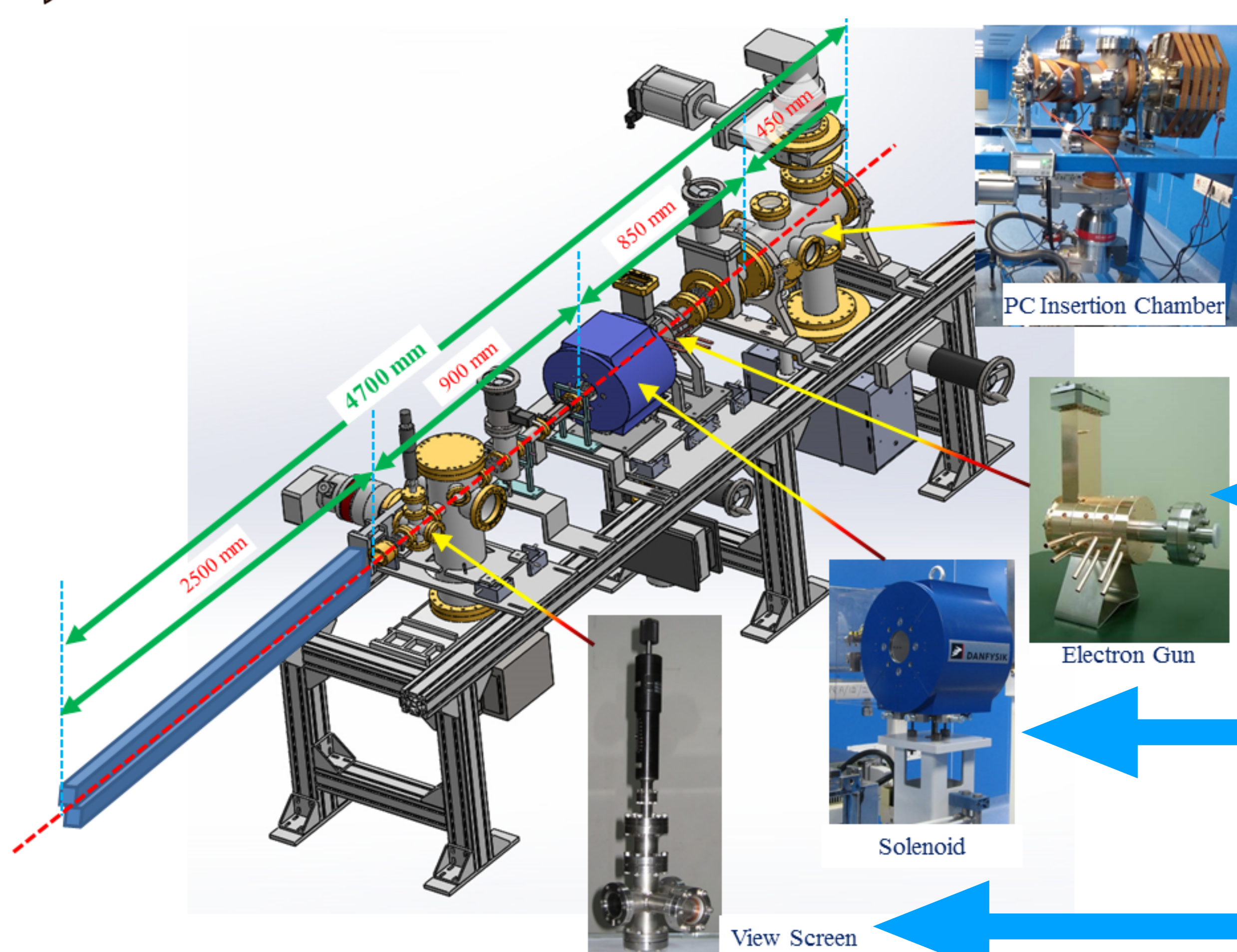
विश्वविद्यालय अनुदान आयोग का एक स्वायत अनुसंधान केंद्र

An Autonomous Research Centre of University Grants Commission

नई दिल्ली New Delhi

Beam Line of Light Source— a compact FEL facility





Local Industry INDIA

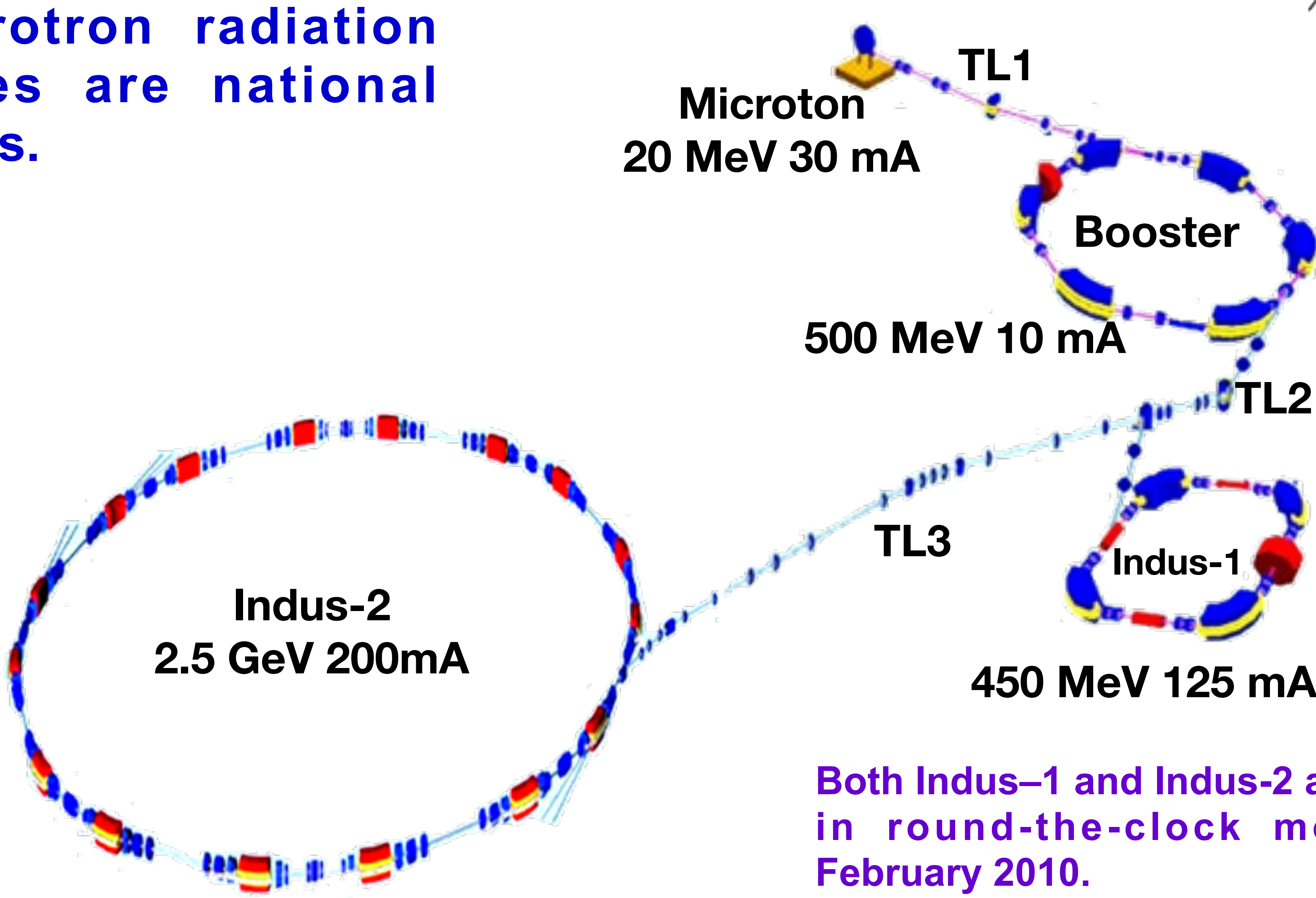
KEK Japan

Ms. Danfysik Denmark

Local Industry INDIA

Indus Accelerator Complex

Indus–1 and Indus-2 synchrotron radiation sources are national facilities.



Both Indus–1 and Indus-2 are operated in round-the-clock mode since February 2010.

Synchroton Radiation Sources Indus-1 and Indus -2

Indus-1

Indus-2

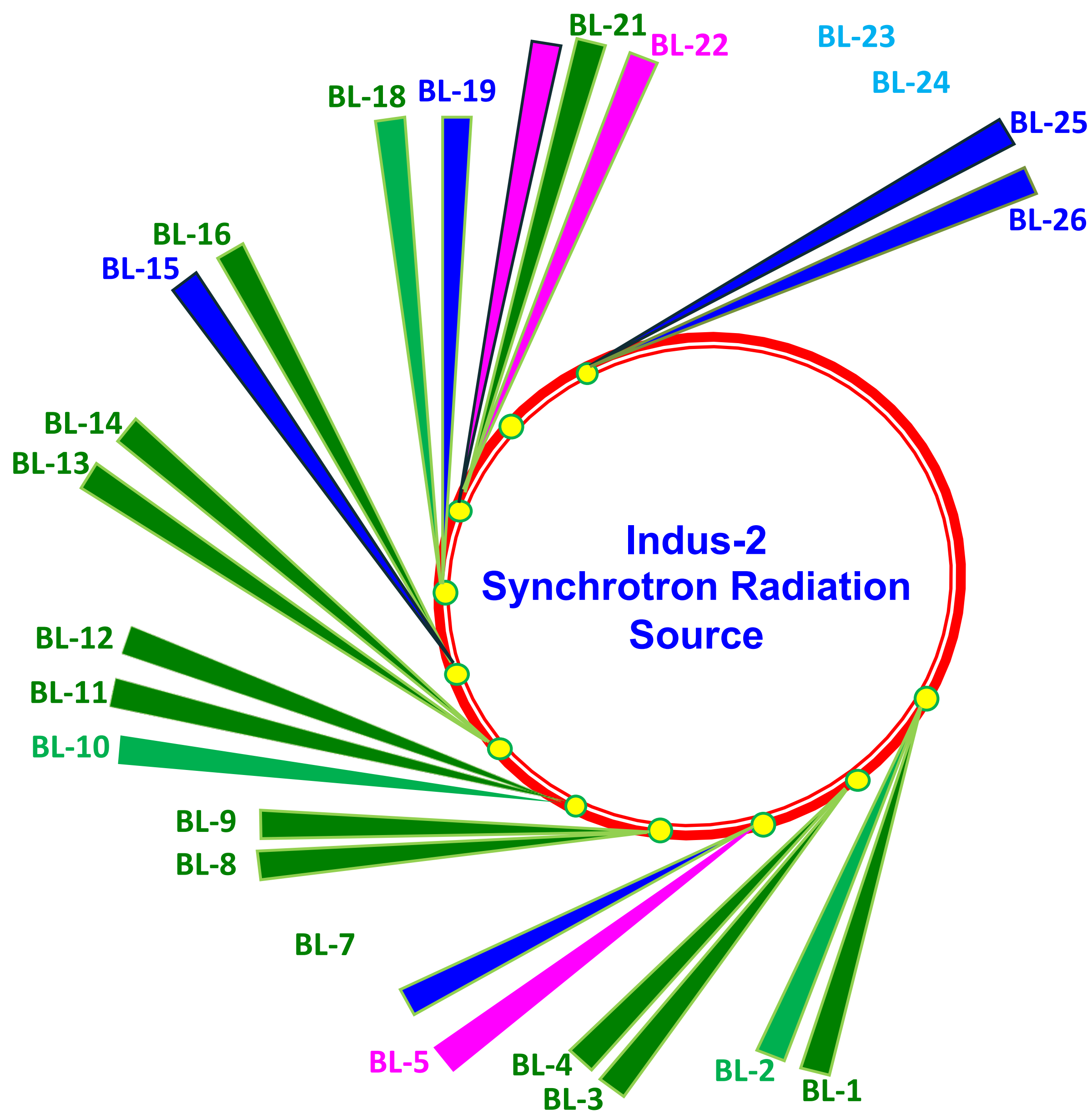
BL-01	AMPD, BARC	High Resolution VUV Spectroscopy beamline
BL-02	UGC-DAE-CSR	Angle Integrated Photo-Electron Spectroscopy beamline
BL-03	AMPD, BARC	Angle Resolved Photo-Electron Spectroscopy beamline
BL-04	SUS-RRCAT	Soft-X-ray Reflectivity beamline
BL-05	AMPD, BARC	Photo-Physics beamline
BL-06	HPSRPD, BARC	Infra-Red beamline
BL-07*	TPD-BARC	Photo-Absorption Spectroscopy Studies beamline

- Indigenous Synchrotron radiation sources (SRS) - Indus 1 & 2 are working for more than a decade on 24 x 7 basis catering to users from different areas of science and technology within DAE as well as from outside DAE.
- Indus-1:
  125 mA at 450 MeV, Emittance: 190 nm-rad, brilliance: 10^{12} ph/s/mm²/mrad²/0.1% BW, circumference:18.97m, RF freq: 31.613MHz, Harmonic no: 2, with 06 operational beamlines
- Indus-2:
  200 mA at 2.5 GeV, Emittance: 58 nm-rad, Brilliance : 10^{17} ph/s/mm²/mrad²/0.1% BW, circumference: 172.47m, RF freq: 505.808 MHz, with 16 operational Beamlines
- By 2021, Indus-1 will have 07 and Indus-2 will have 21 operating beamlines.
- Beam availability to the users in the calendar year 2018
  Indus-1: 7349 hours
  Indus-2: 5534 hours
- Beam lifetime in Indus-1 at 100 mA: ~ 5hrs
- Beam lifetime in Indus-2 at 100 mA, 2.5 GeV: ~ 80hrs (best so far)

Indus— 2 Beamlines

Beamlines ready for commissioning(1) [by Dec 2019]

Beamlines under installation and commissioning(2) [by Sep 2020]



Operational beamlines (16)

- Soft X-ray Absorption Spect. (BL-01) [DAE-CSR]
- Soft X-ray Reflectivity (BL-03) [RRCAT]
- X-ray Imaging (BL-04) [BARC]
- X-ray Lithography (BL-07) [RRCAT]
- Dispersive EXAFS (BL-08) [BARC]
- Scanning EXAFS (BL-09) [BARC]
- Extreme Conditions AD/ED XRD (BL-11) [BARC]
- Angle Dispersive XRD (BL-12) [RRCAT]
- X-ray Photo-Electron Spect. (BL-14) [BARC]
- X-ray Fluorescence Microprobe (BL-16) [RRCAT]
- Protein Crystallography (BL-21) [BARC]
- Visible Diagnostic (BL-23) [RRCAT]
- X-ray Diagnostic (BL-24) [RRCAT]

Accomplished in last 9 months

- Grazing Incidence X-ray Scatt. (BL-13) [SINP]
- Engg. Appl. beamline (BL-02) [RRCAT]
- Small and Wide Angle X-ray Scatt. (BL-18) [BARC]

Ready for commissioning (1): Commissioning by Dec'19

- ARPES beamline on U-2 (BL-10) [RRCAT]

Installation and Commissioning (2): Commissioning by Sep'20

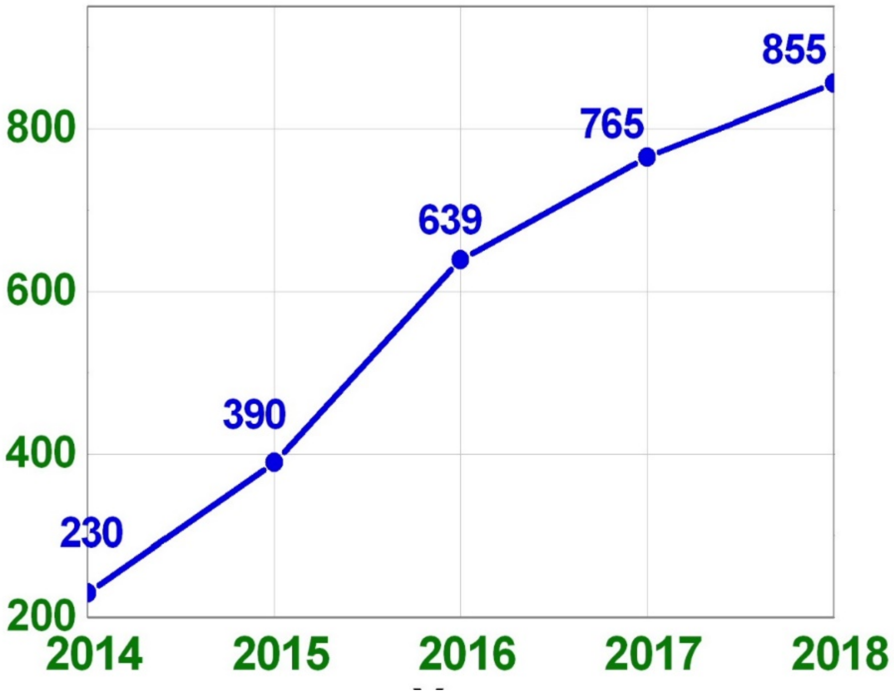
- Photo-Emission Ele. Microscopy (BL-22) [BARC]
- X-ray Mag. Circ. Dichr. on U-3 (BL-20) [RRCAT]

Under construction (2)

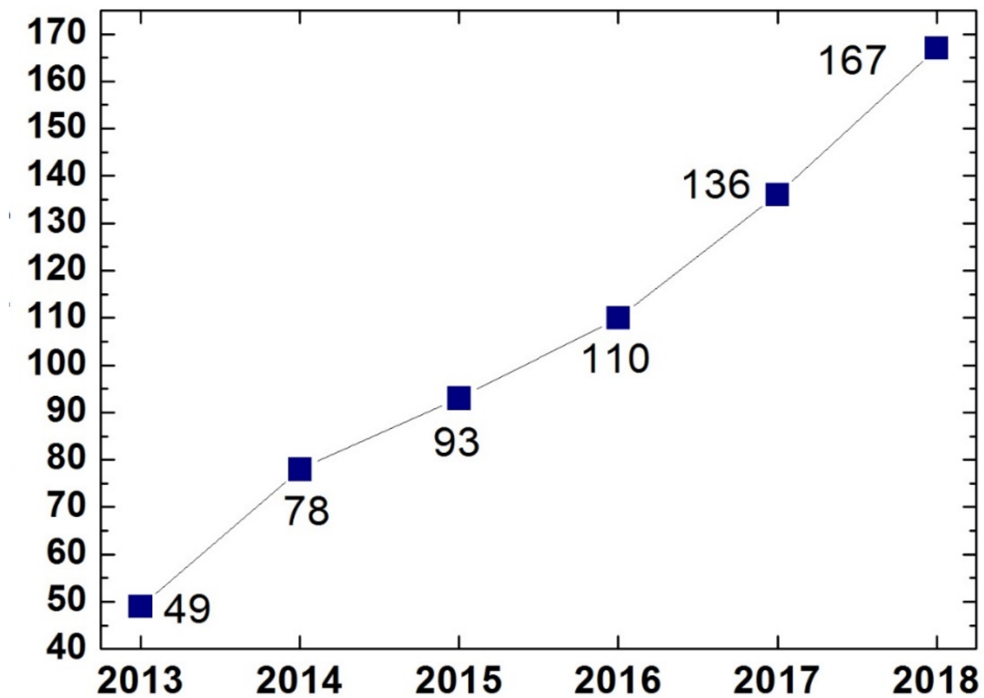
- AMOS beamline on U-1 (BL-05) [BARC]
- BL for Radiological Safety Studies (BL-17) [BARC]

Indus Synchroton Radiation Sources : Utilization

User experiments per year



Beamline based publications per year

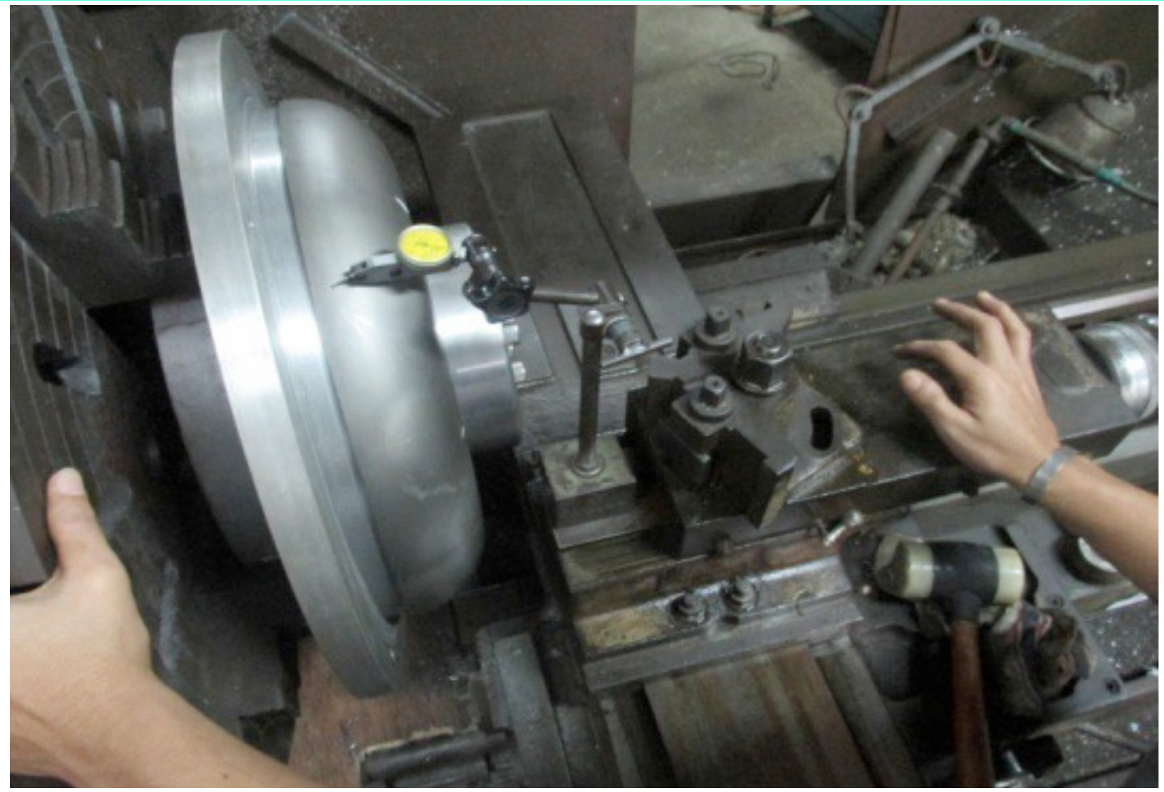


RRCAT has following additional facilities

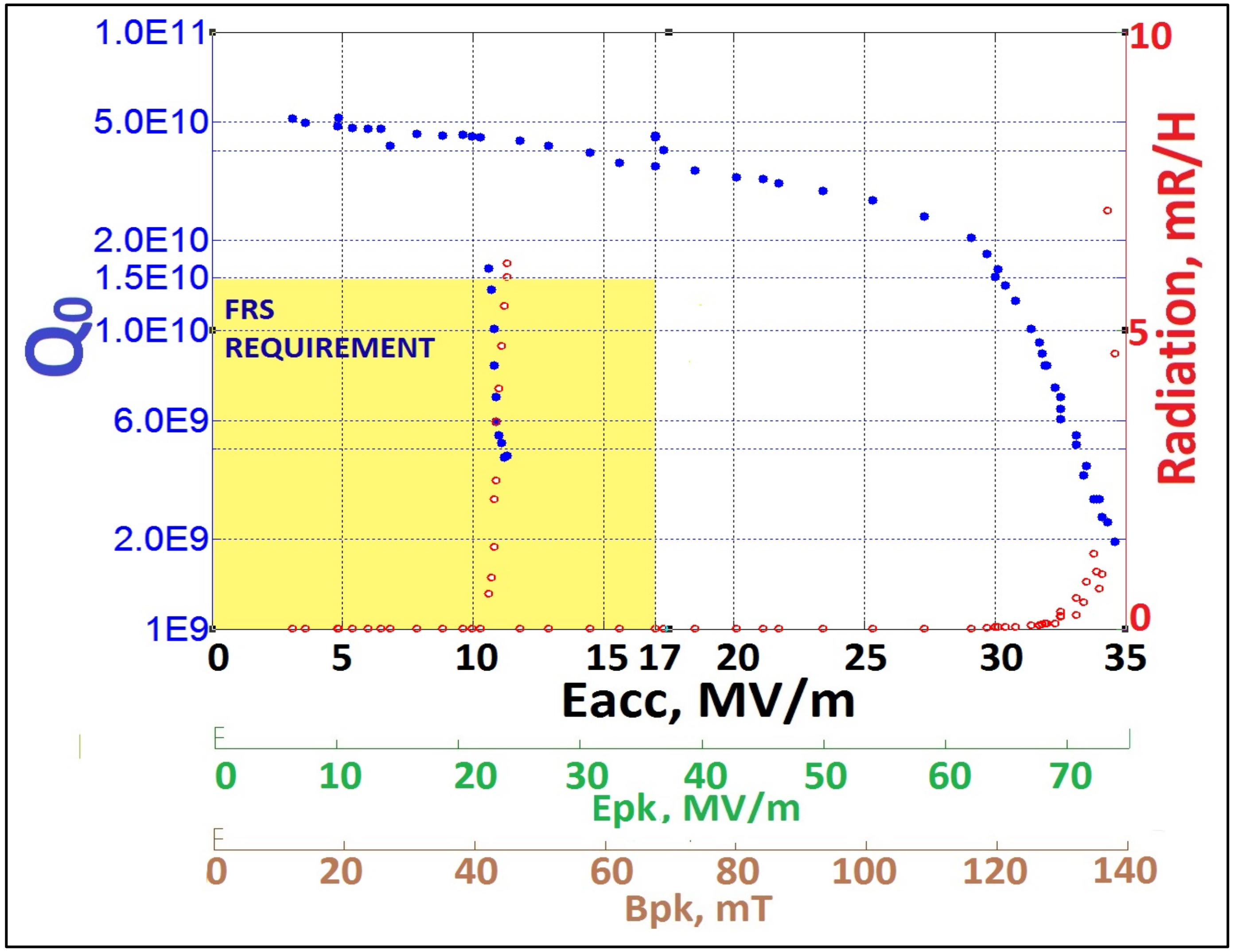
- Has full capabilities to fabricate SCRF Nb Cavities
- Has successfully fabricated magnets
- Has developed an industrial unit for food irradiation.

Superconducting RF Cavity Development at VECC

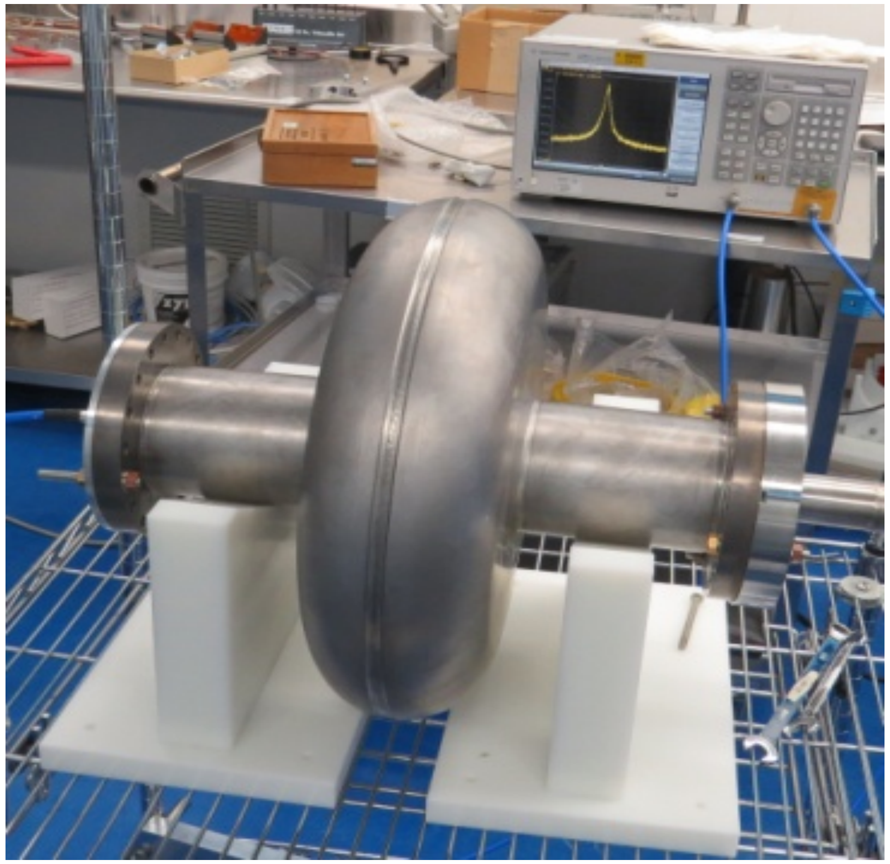
राष्ट्र की सेवा में परमाणु
प ऊ सा कें
VECC
ATOMS IN THE SERVICE OF THE NATION



VTS Results — VECC test Results for Single Cell SRF Cavity



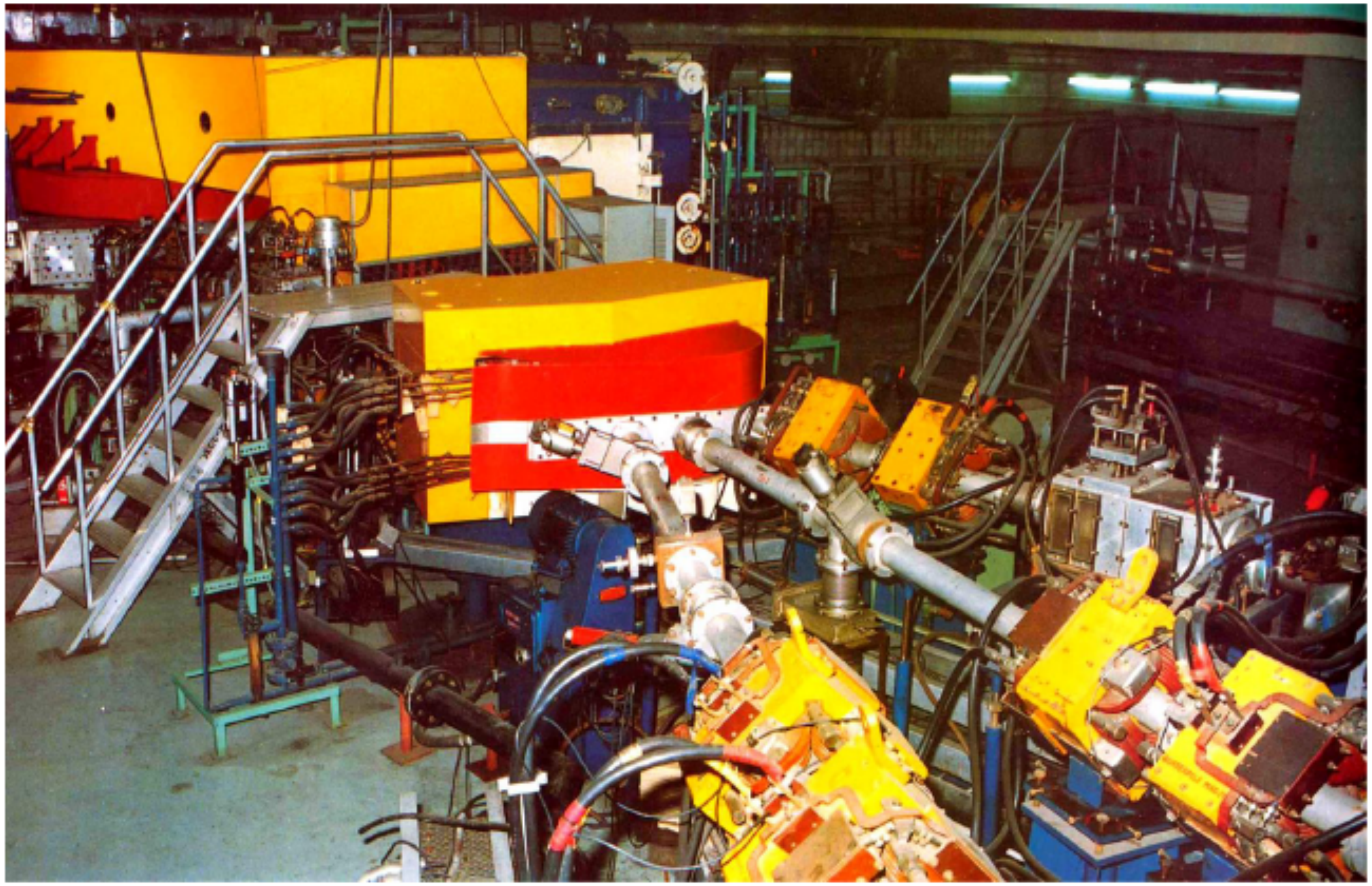
Cavity could sustain 74MV/m Peak Electric Field (E_{pk}) and 137 mT Peak Magnetic Field (B_{pk}), with accelerating gradient of 34.5 MV/m @ 2K (-271^0 Celcius).



Maximum accelerating Gradient: 34.5 MV/m @2K
Accelerating Gradient of 30 MV/m @2K achieved with unloaded cavity quality factor Q_0 =1.5E+10.

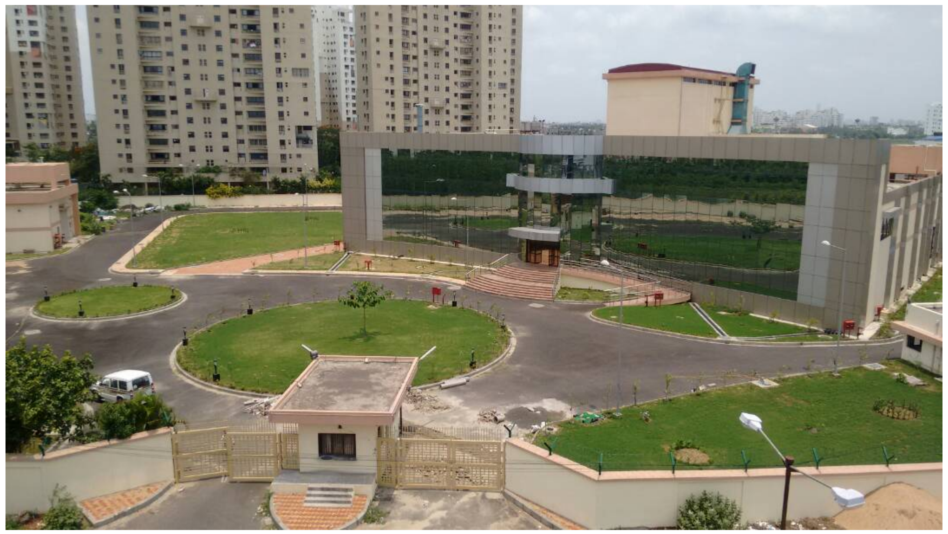
Variable Energy Cyclotron

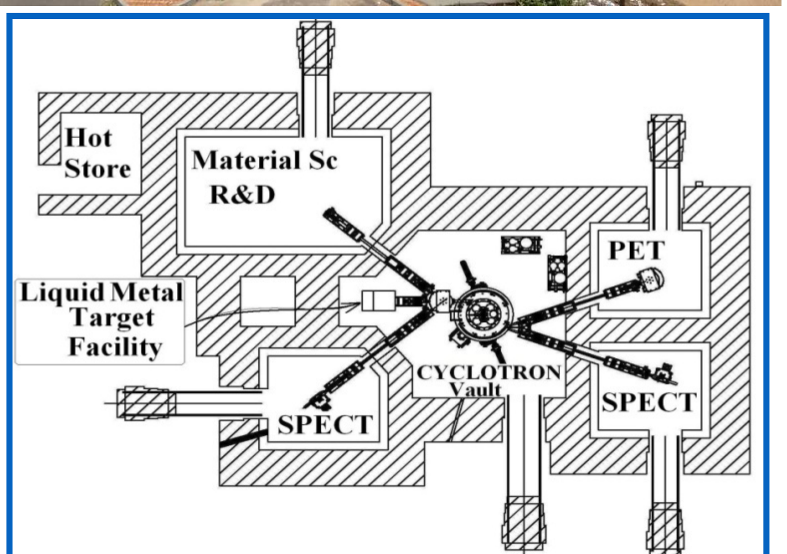
224 cm Variable Energy Cyclotron - operating since 1977

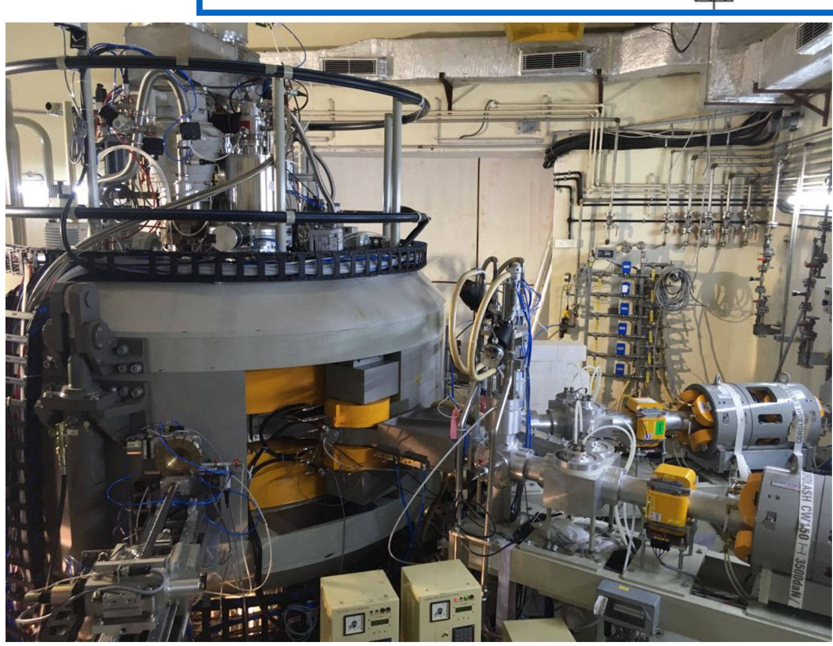


Projectile	Now being operated unto (in MeV)
Proton	18
Alpha	65
Nitrogen	101.8
Oxygen	161.8
Neon	193

30 MeV, 350 mA Medical Cyclotron at VECC, Kolkata





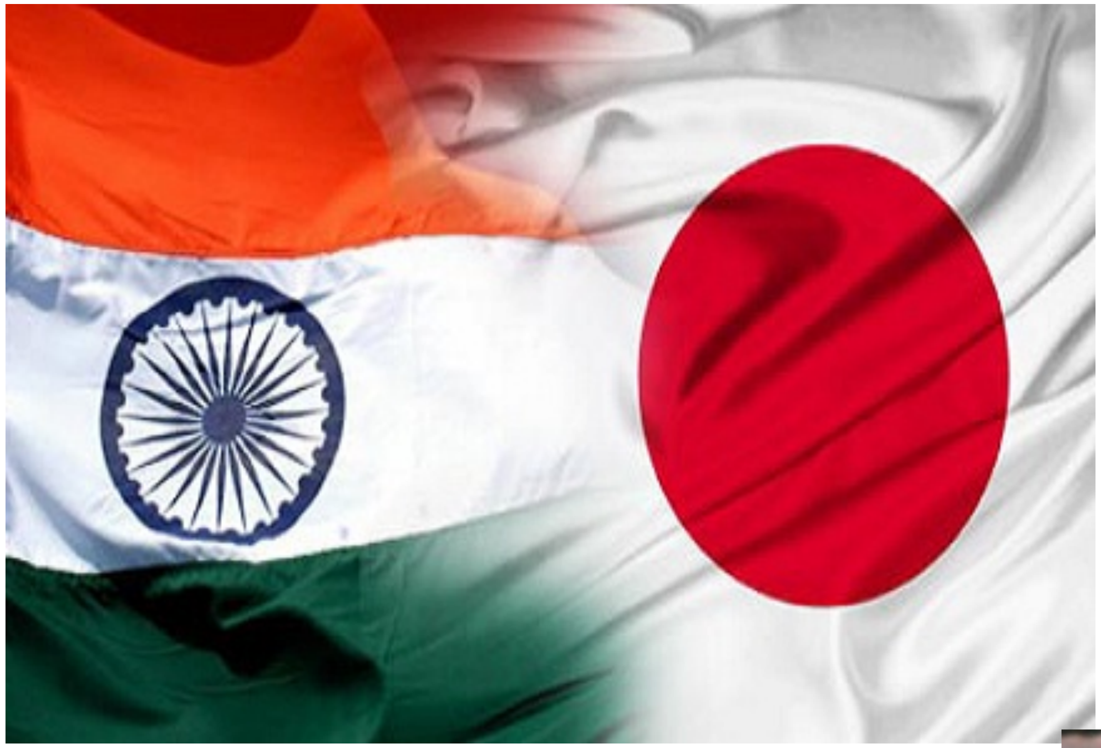


SPECT / PET Radio-isotope (half life)	Application
^{201}Tl (3.06d)	Myocardial perfusion (evaluates heart's function and blood
^{123}I (13.2h)	Myocardial metabolism, Neuroendocrine tumor imaging
^{67}Ga (3.26d)	Soft tissue tumor imaging Broncogenic carcinoma
^{111}In (2.8d)	Cisternography, Abscess imaging, Tumour imaging
^{18}F (1.8h)	**Use in oncology, brain function studies and cardiology**

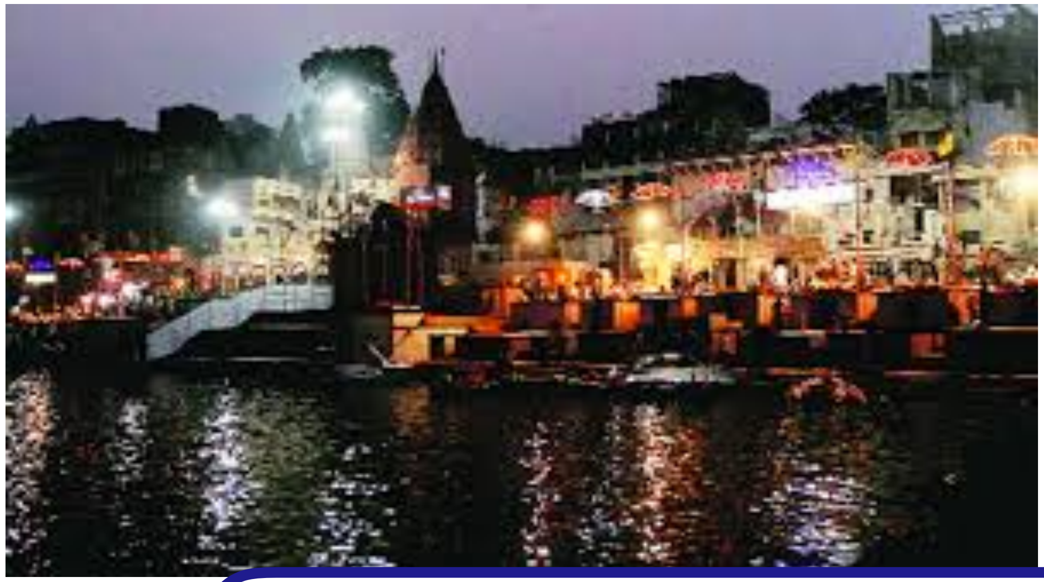
USE TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

India - Japan together can do wonders Shinzo Abe, (PM Japan)

INDIA has manpower



JAPAN has the technology

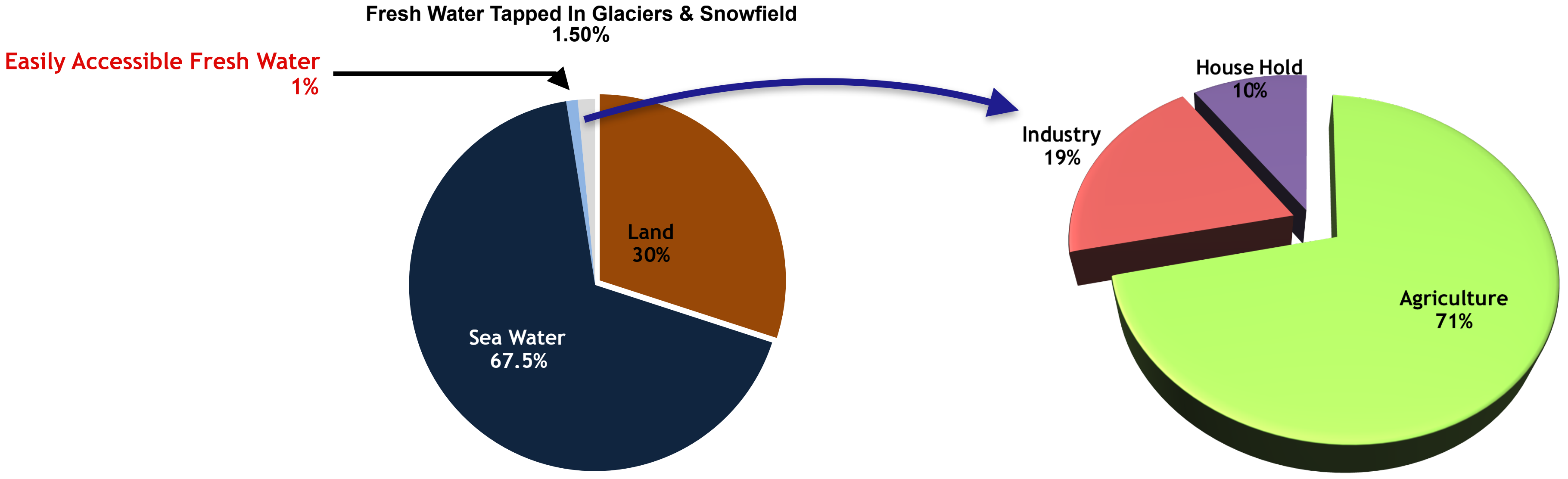


WILLINGNESS
&
Good Will

Use the opportunity to benefit both the nations

IIT Bombay & Sameer Initiatives

Develop a Compact Electron Accelerator with the help of KEK, Japan as a prototype for treating Industrial as well as domestic effluents



- **India is the world's highest user of groundwater, ¼ of the world** – equivalent to 230 cubic kilometres per year.
- Most of the groundwater is used for irrigation ~ 70%.

- International Water Management Institute pointed out that India's groundwater use went from about 7km³ in 1940 to about 270 km³ over the past decade*(The Hindu, 11 July, 2017)*.

Recent example of water crisis is Chennai: On 19 June 2019, **Chennai city officials declared "Day Zero (no water is left)"**

What we Desire from a Treatment Plant

- Mineralization of toxic and hazardous organic chemicals into non-toxic reaction by-products.
- Should be flow through and have the ability to destroy pathogens.
- To treat water of differing quality, including the presence of suspended particles up to 10%.
- To treat soil contaminated with toxic organic chemicals.
- Capable of treating mixtures of organic chemicals and be relatively insensitive to solute concentration effects.

What is being done

- Removal of the parent compound and pollutants are then sent to a land fill.

  → **The "disposed" waste has the long term environmental effects**!!

- An extension of this approach : carbon and aeration stripping → the chemical of interest transferred to another media. Problems with both carbon or aeration stripping.
- Other chemical/physical processes : supercritical oxidation and wet oxidation, bioremediation.

  → **Formation of reaction by-products → may be as bad or worse than the starting materials!!**

The present approaches cannot fulfil the demand.

Advantages of Radiation Process

It is inherently green and hence ecologically friendly.
- There is no secondary waste generation.
- There are no catalysts and no heating is required.
- It is Chemical less.

There are economical advantages not only in terms of capital cost but also in operation & Maintenance.

For Flue Gas and Sludge the treatment process additionally results in Fertilizers as by products.

It removes organic impurities with radiation chemical reactions.

It removes colour by destruction of the double bonds.

It removes odour by opening up rings in aromatic compounds.

It disinfects the water by destroying the DNA of micro organisms.

It destroys the endocrine disruptors by radical reaction.

How does it work

Radiation essentially works on the principle of radiolysis of water. It results in very reactive radical particles.

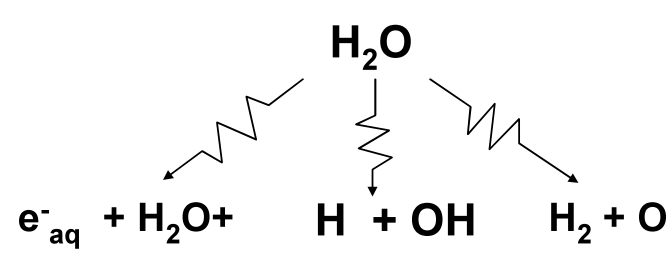
The final result is

- Hydrated electrons → e^{-}_{aq} (reducing agent)
- Hydrogen atoms → H (reducing agent)
- Hydroxyl radical → OH^{-} (oxydising agent)

The high dielectric constant of water helps.

This results in maximum number of reducing as well as oxidising agents much larger than is possible by any chemical reagent.

Radiation ionises the water, resulting in water molecules in highly excited states. They decay in less that 10^{-12} seconds resulting in



Four Active Radicals e_{aq} H^{*} OH^{*} H_2O_2 to burn the bio degradable waste completely as well as to oxidising heavy elements.

Advantages over other Facilities

- High energy electron beam is used → survival chance of bacteria is minimal.
- System is very **compact** and require much smaller footprint.
- **No use of chemicals** like Chlorine and Ozone used in current technologies.

  → **They are easy to handle and are environmentally 'clean'!!**
- Can be duplicated at various places where the space available is limited because these cities are flourishing since 2500 BC.
- The average **life of such facility is very long** and recurring costs are moderately low.

The Proposal has been approved by the Government of India and is to be now examined by JICA & JST. The proposal has been adopted by the National Commission for Clean Ganga.

Accelerator Parameters

Parameter	Value
Energy	1 MeV
Beam Current	40 mA
Beam Power	40 kW
No of Cells	2
Cavity Type	ILC-type
Cooling System	Cryo-cooler
Electron Gun	Integrated, Thermionic
Particles	Electrons, Photons
Beam Scanning	Using Magnet

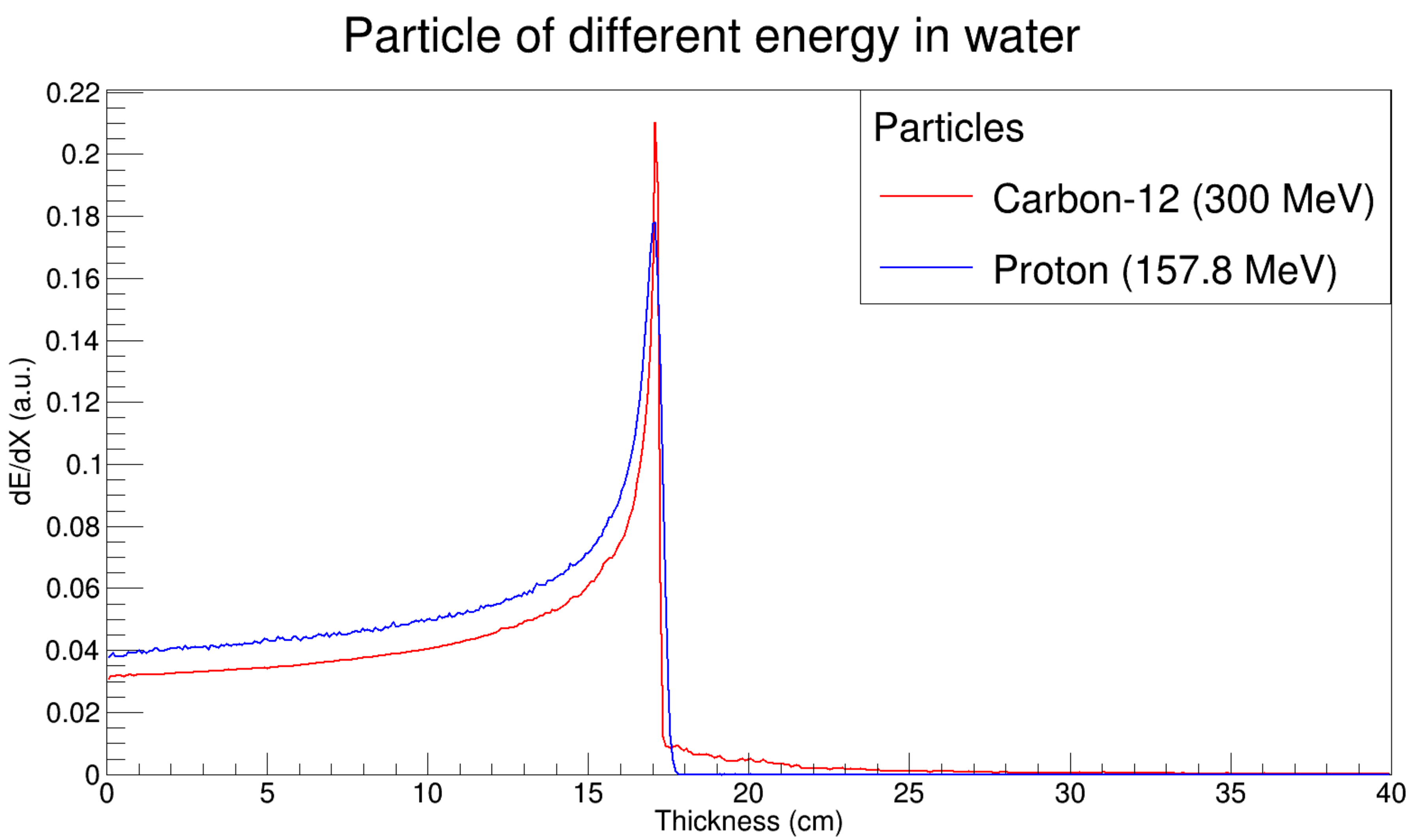
Cost Estimate

		INR	INR Crore
SYSTEM		20,73,75,000	20.7375
LABORATORY SETUP		3,77,00,000	3.7700
CONSUMABLES		2,40,00,000	2.4000
SUB-TOTAL		26,90,75,000	26.9075
INTEREST	0.08	**2,15,26,000**	2.1526
DEPRICIATION	0.05	**1,34,53,750**	1.3454
ELECTRICITY		**41,77,778**	0.4178
LABOUR		**39,60,000**	0.3960
OPERATION	0.05	**61,90,972**	0.6191
TOTAL		**4,93,08,500**	4.9309

If we could increase the power the cost will reduce in that proportion.

Cost	**₹ 4,93,08,500**	
Water	**2000**	**meter³ per day**
Days	**360**	
Unit Cost	**₹ 68.50**	**per MLD**

All ion Digital Accelerator for treatment of Cancer

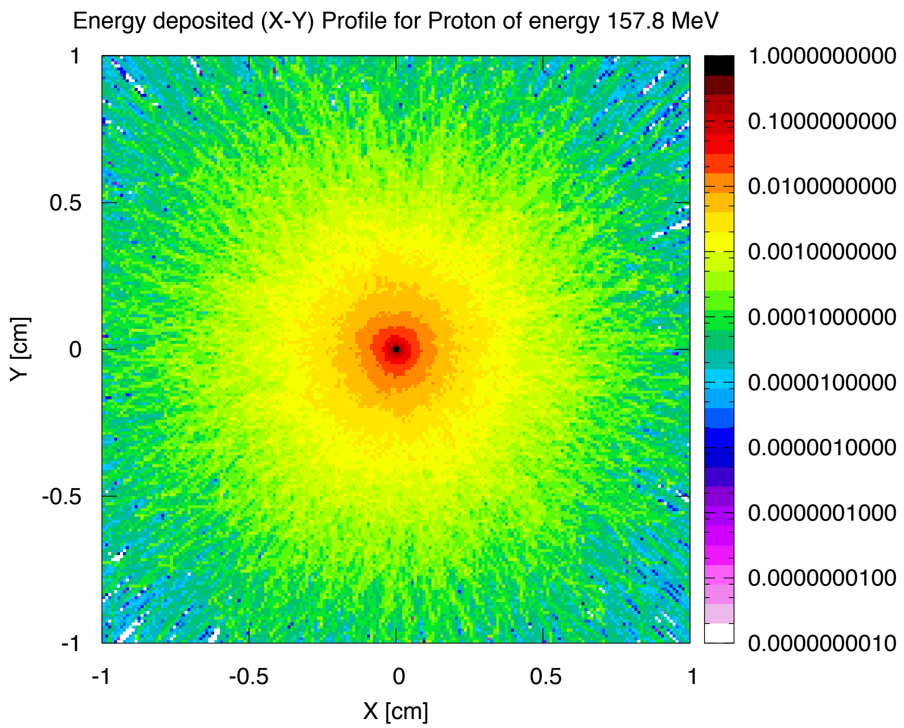


"The FLUKA Code: Developments and Challenges for High Energy and Medical Applications" T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, **Nuclear Data Sheets 120, 211-214 (2014).**

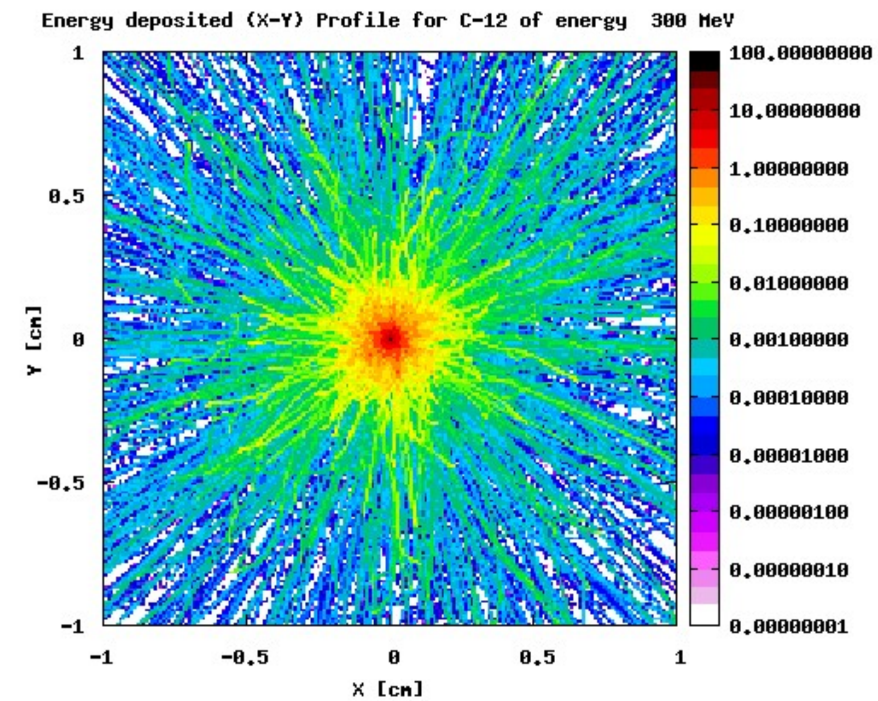
"FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J.Ranft, **CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.**

Beam Profiles of Proton & Carbon Compared

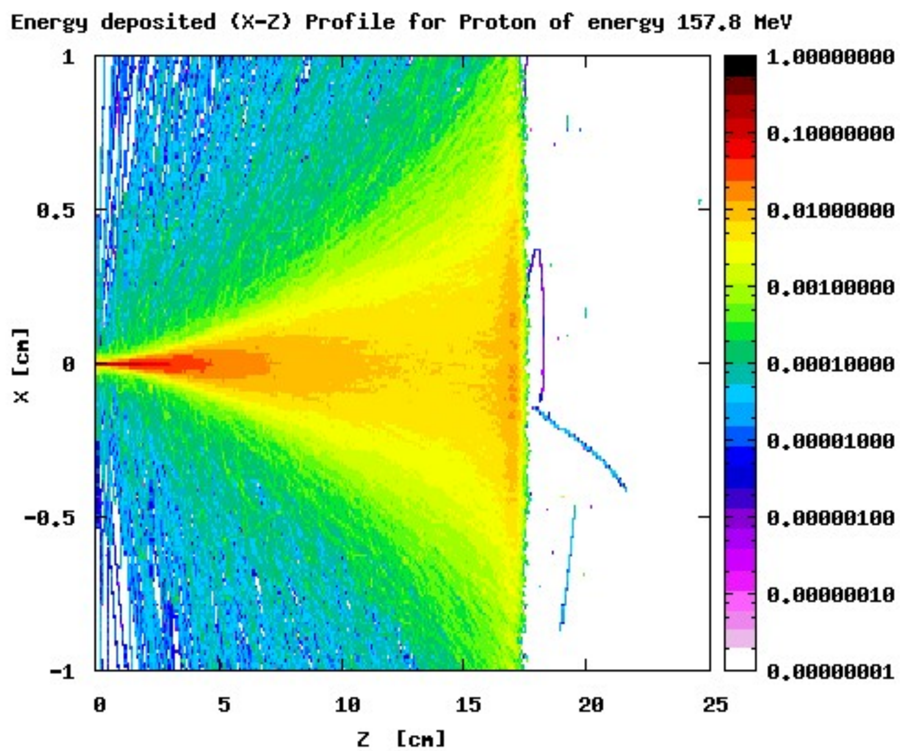
X-Y Beam Profile for Proton



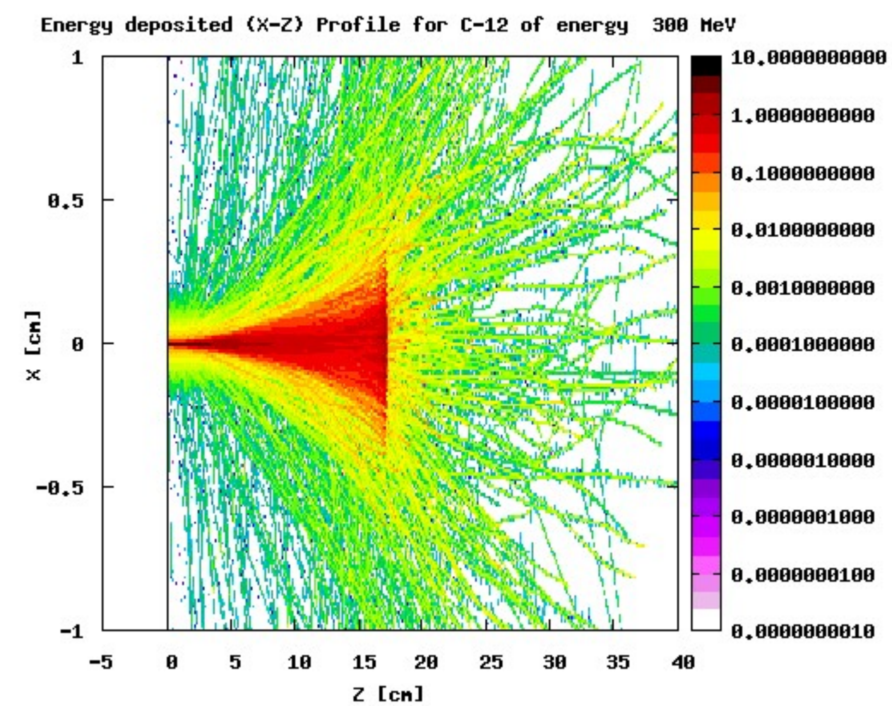
X-Y Beam Profile for Carbon



X-Z Beam Profile for Proton

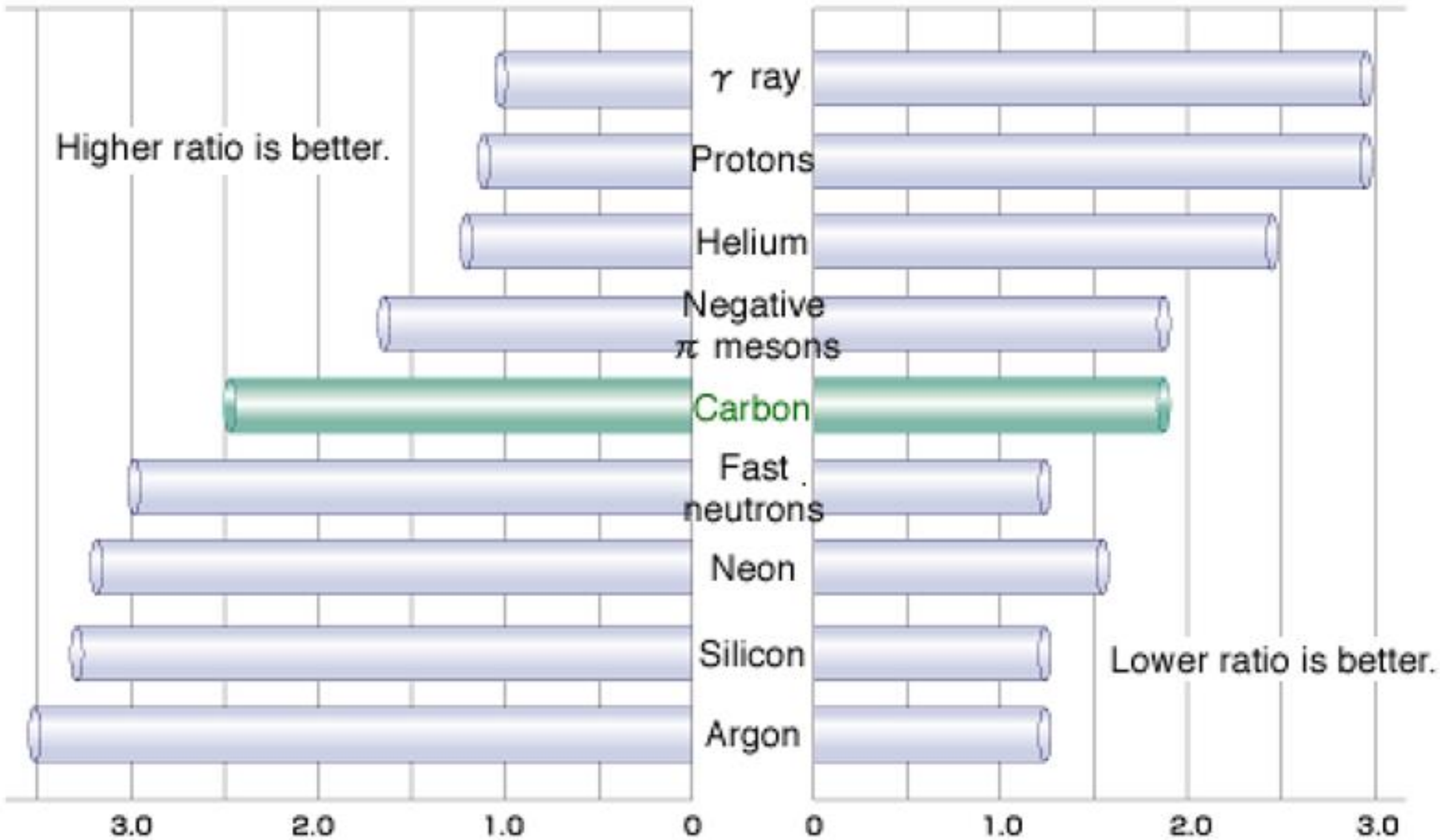


X-Z Beam Profile for Carbon



RADIOBIOLOGICAL ASPECTS

Relative biological effectiveness (RBE) and
oxygen enhancement ratio (OER) of various radiation types

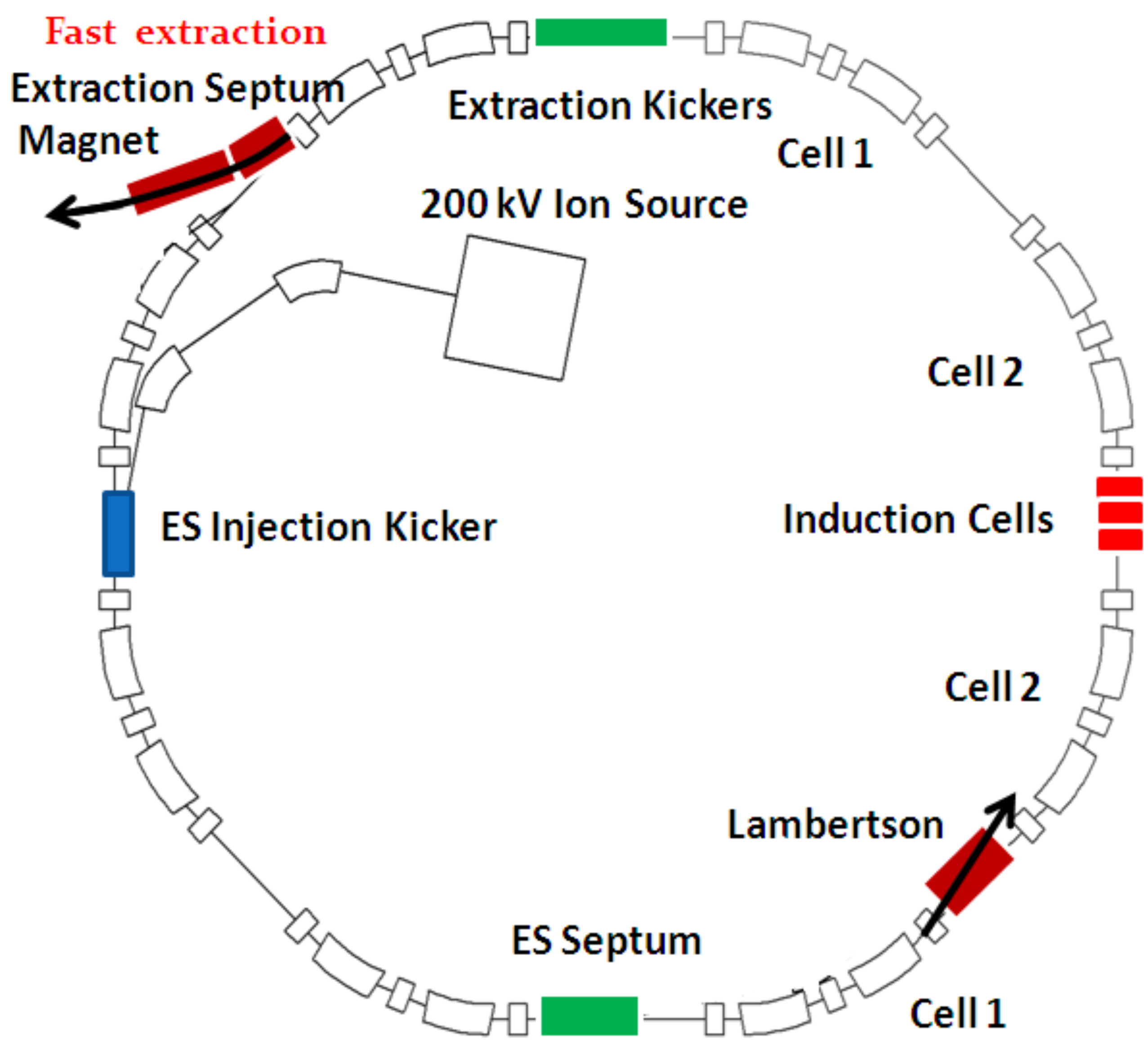


RBE represents the biological effectiveness of radiation in the living body.
The larger the RBE, the greater the therapeutic effect on the cancer lesion.

OER represents the degree of sensitivity of hypoxic cancer cells to radiation.
The smaller the OER, the more effective the therapy for intractablecancer cells with low oxygen concentration.

Hadron Therapy Machine

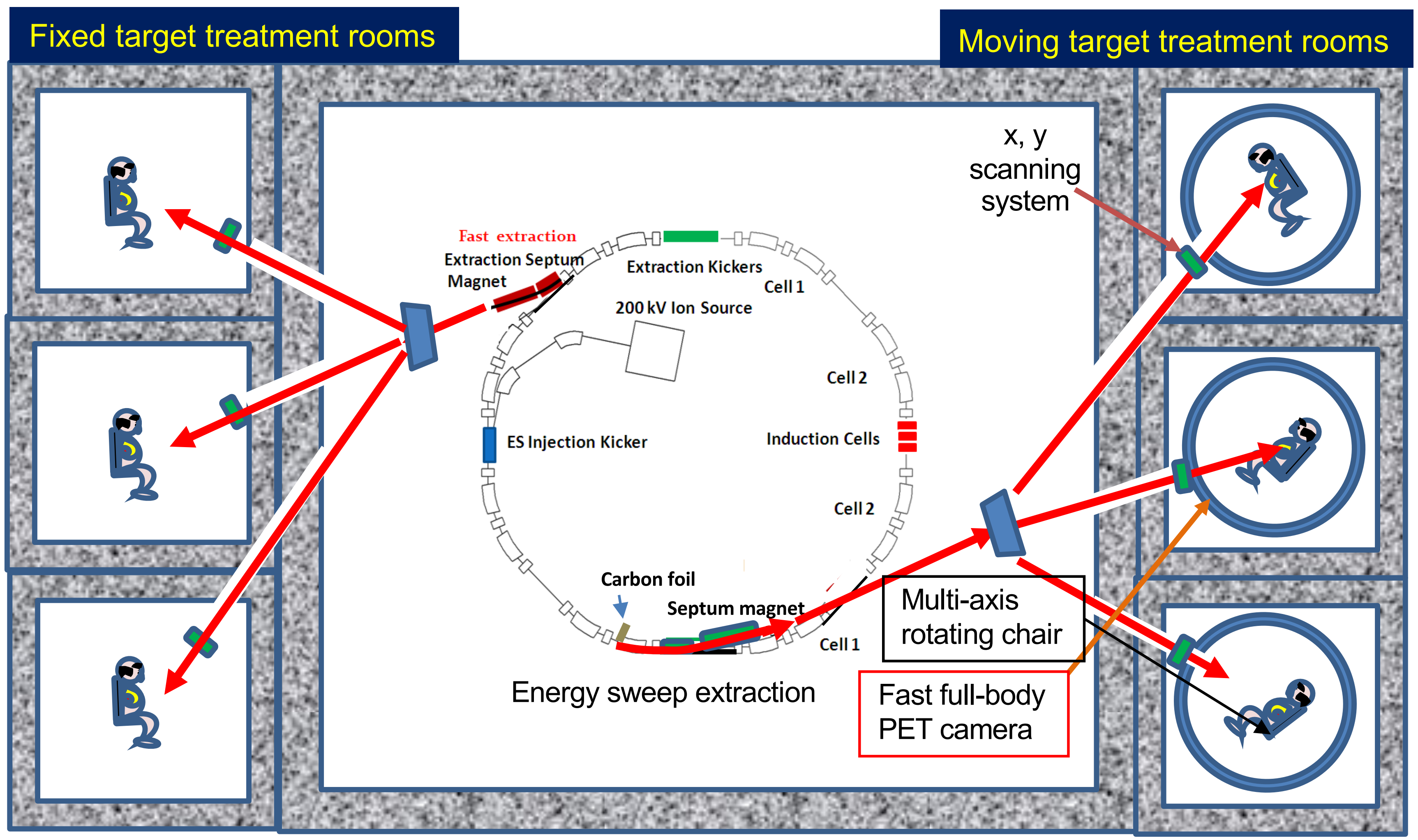
Energy	656 MeV for proton 200 MeV/nucleon for $A/Q = 2$ ion
C_0	52.8 m
Ion species	Gaseous/metal ions
Ion source	Laser ablation IS ECRIS
Injector	200 kV (electrostatic)
Ring	Fast cycling (10 Hz)
	$B_{max} = 1.5$ T
	$\rho = 2.8662$ m
	FODOF cell with edge focus of B
	Mirror symmetry
	$\nu_x/\nu_y = 1.3143/1.4635$
	2m long dispersion-free region 3m long flat large dispersion region
	α_p=0.273088 γ_T=1.92, E_T=864.7 MeV
Acceleration	Induction cells driven by SPS employing SiC-MOSFET $V_{acc} = \rho C_0 dB/dt$ (max 7 kV)
Vacuum	10^{-8} Pa



Leo K.W., T. Monma,T. Adachi, T. Kawakubo, T. Dixit, and K. Takayama, "Compact Hadron Driver for Cancer Therapies using Continuous Energy Sweep Scanning", *Phys. Rev. ST-AB* 19, 042802 (2016)

Hadron Therapy Machine

- Injector-free
- 10 Hz Continuous energy sweep extraction
- Any heavy ions such as p, ^{3}He, C, etc. can be delivered.



Beam Dynamics Study for Hadron Therapy Machine

1. Lattice Design
so as to meet the essential demands:
- Energy
- two long straight sections (dispersion-free/flat large)
- Avoiding integer/half integer tune

2. Various linear orbit corrections and estimation of tolerance
COD, Tune, Chromaticity
assuming
- Alignment error (tilt of B in the s-direction, rotation of B/Q in the x-y plane, displacement of Q in the x-y plane)
- Gradient errors in Q magnets
- B_y errors caused by production errors (core material variation)

3. Nonlinear Lattice Consideration
- Tolerance estimation on nonlinear components of B/Q
  Sextupole component in B
  Ocutupole component in Q
- Dynamic aperture survey taking into account these nonlinear components and sextupole fields for Chromaticity correction

5. Space-charge effects consideration
- Linear analysis
- Multi-particle orbit tracking by using PATRASH (Shimosaki-code) or others

6. Beam Injection/Extraction consideration
- Matching at the injection point
- Charge exchange extraction orbit calculation
- 1 turn extraction calculation
- Energy sweep extraction orbit calculation

7. Coherent instability considerations
- Wake field induced by a bunch
- Head-tail instability
- Multimode instability

8. Beam loss/emittance blow-up consideration
- Coulomb scattering due to residual gas molecules
- Intra-beam scattering

Acknowledgements

Thanks to
Prof. Ajit K. Mohanty, Director BARC, Mumbai
Dr. D. Kanjilal & Dr. S Ghosh IUAC, New Delhi
Shri Debasis Das, Director RRCAT
Dr. Sumit Som, Director VECC
Dr. Tanuja Dixit & Dr. Abhay Deshpande, SAMEER

Thank You for your Patience