IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2020.
Presentation AT-3 given at ACASC/Asian-ICMC/CSSJ Joint Conference, 6-9 January 2020, Okinawa, Japan.

Joint Conference
10th ACASC
2nd Asian-ICMC
CSSJ

Present Thrust Area in the Field of Applied Superconductivity & Cryogenics in India

T S Datta

Indian Institute of Technology. Kharagpur
India

(4.2 K In India)

First Helium Liquefier in India (Make ADL, USA Collins type, Capacity 4 L/hr with LN2 precooling was established At National Physical Laboratory (NPL, Delhi) in 1952

Dr. K S Krishnan along with foreign Delegates from Russia in front of Helium Liquefier at NPL in 1955

In the Same Year First Helium Liquefier was Commissioned at Tohuku University, Japan

1952 was the starting period of Superconductivity Research in Japan & India

Today In India we have approx. 40 Helium liquefier with total capacity of approx. 2500 litres/ hr.

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Outline of my Lectures

1. **Present on going Major Programme in the field of Applied Superconductivity and Cryogenics :**

   A. **Accelerator & Fusion**
   B. **Space Cryogenics**
   C. **MRI & Other**

2. **Future Trend**

   A. **HTS & Cryo cooler**

3. **Conclusion on Activity**

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Superconductivity for Accelerator & Fusion

Accelerator

Magnet:

- **Superconducting Cyclotron at VECC (Kolkata),**
- **RRCAT – LHC collaboration on SC Corrector magnet**

Cavity:

- **SC Heavy ion Accelerator at IUAC (Delhi) & TIFR (Mumbai)**
- **ADS Programme based on Superconducting Cavity (Fermi lab collaboration) : RF SC Cavity**
- **E-linac for RIB Facility (RF SC Cavity) : TRIUMF Collaboration**

Fusion

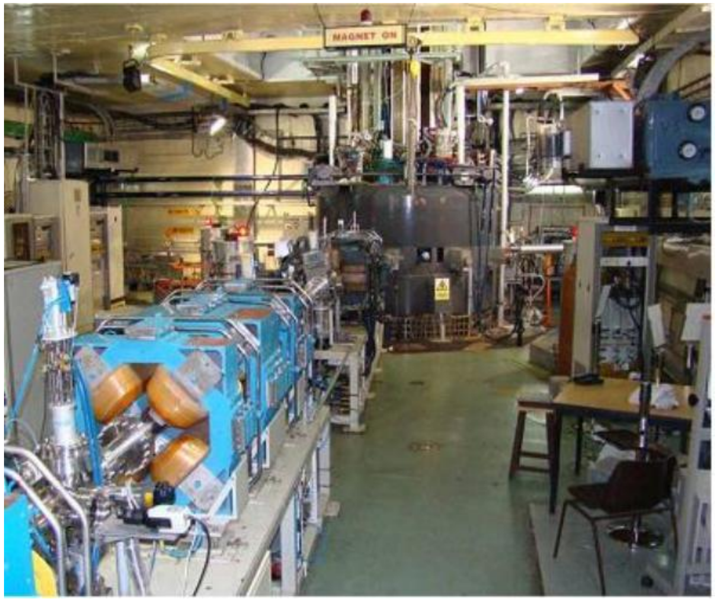
- **SC Tokamak at IPR (Gandhinagar)**
- **India ITER Participation on Complex Cryoline :** Cryogenics

First Major Accelerator Programme in India with Superconductivity

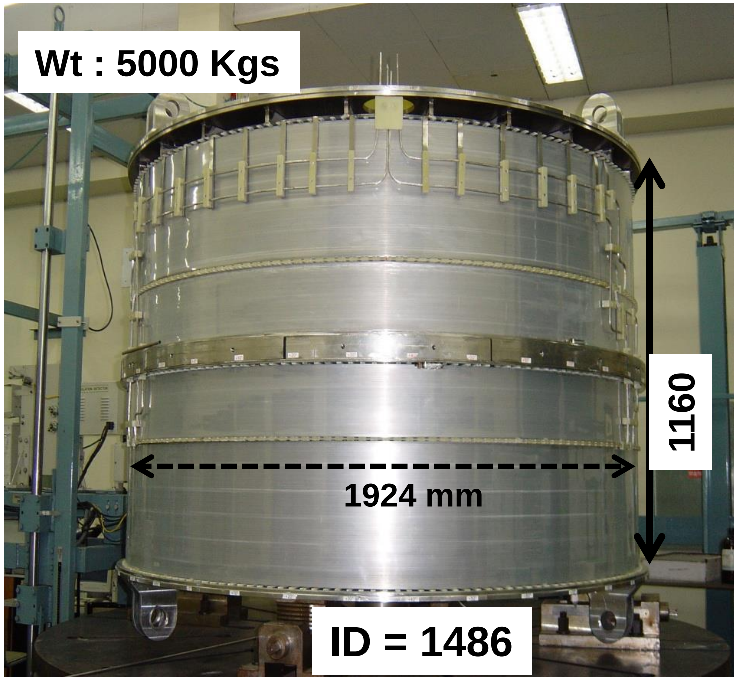
The variable energy K-130 cyclotron first of its kind in India, became operational in June 16, 1977. The machine is designed to accelerate protons from 6 to 60 MeV, and alpha from 25 to 130 MeV.

The superconducting cyclotron (K- 500) with a large superconducting solenoid (5 Tesla) was constructed to enhance the energy of 80 MeV/A for lighter ions and 5-10 MeV/A for heavier ions

Beginning
1995

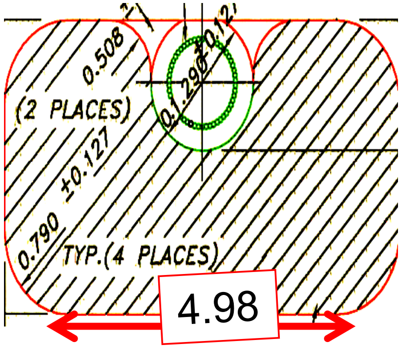


Superconducting Magnet (5 T) Coil for K-500 S.C.Cyclotron

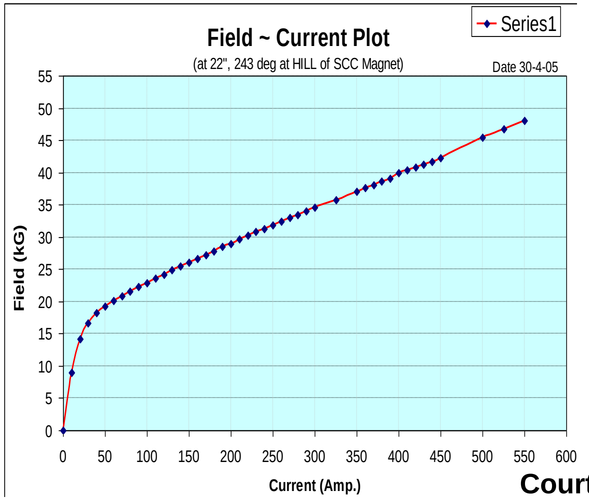


Conductor : Nb-Ti Wire soldered in Copper Channel
Critical Current : 1030 A at 4.2 K and 5.5 Tesla

SC: Cu :: 1:20

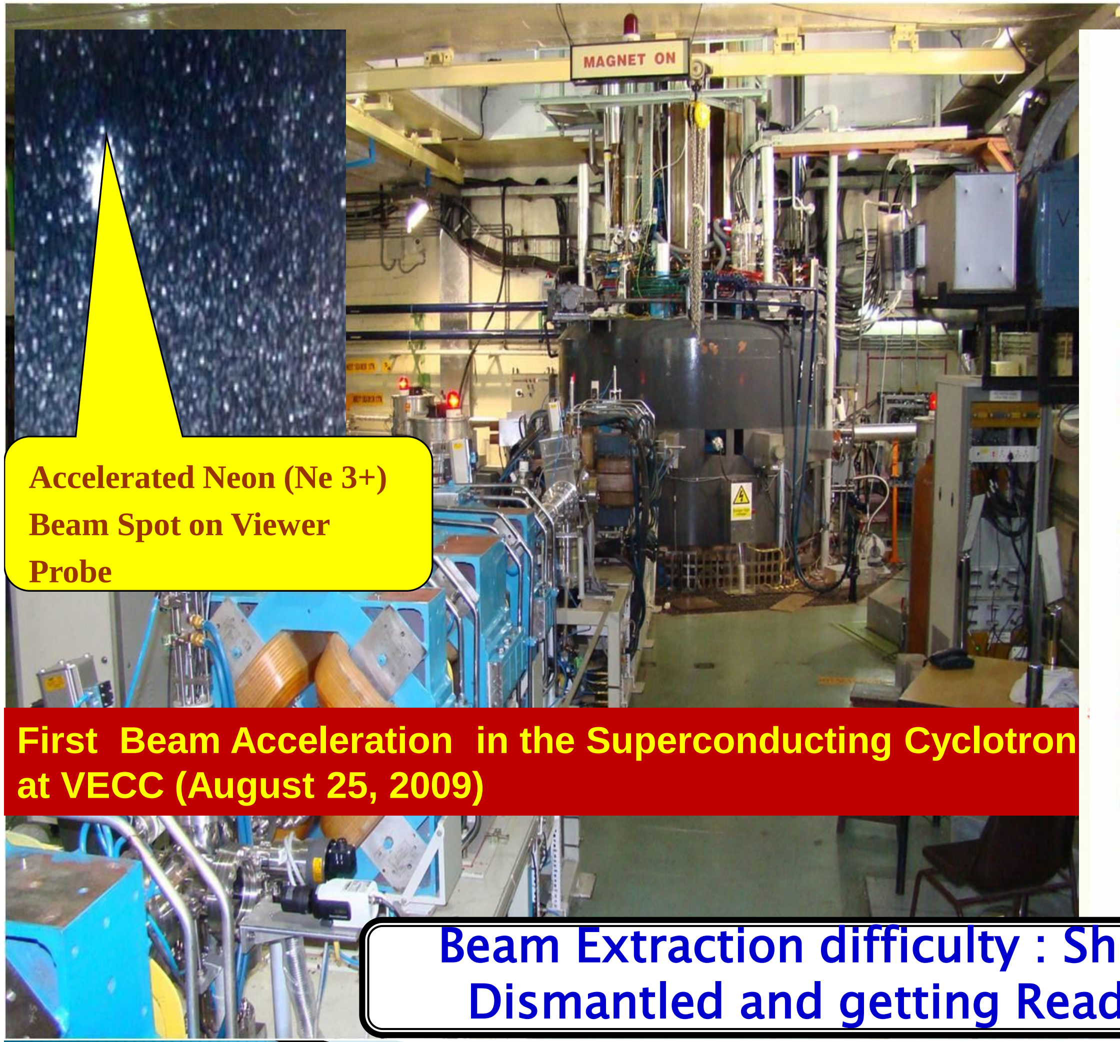


- **No. of Coils : 2 Alpha + 2 Beta**
- **No. of Layers : 36**
- **No. of turns/layer : 30 / 62**
- **Total Length of SC Cables : 35 Km.**
- **Stored Energy : 22 MJ**



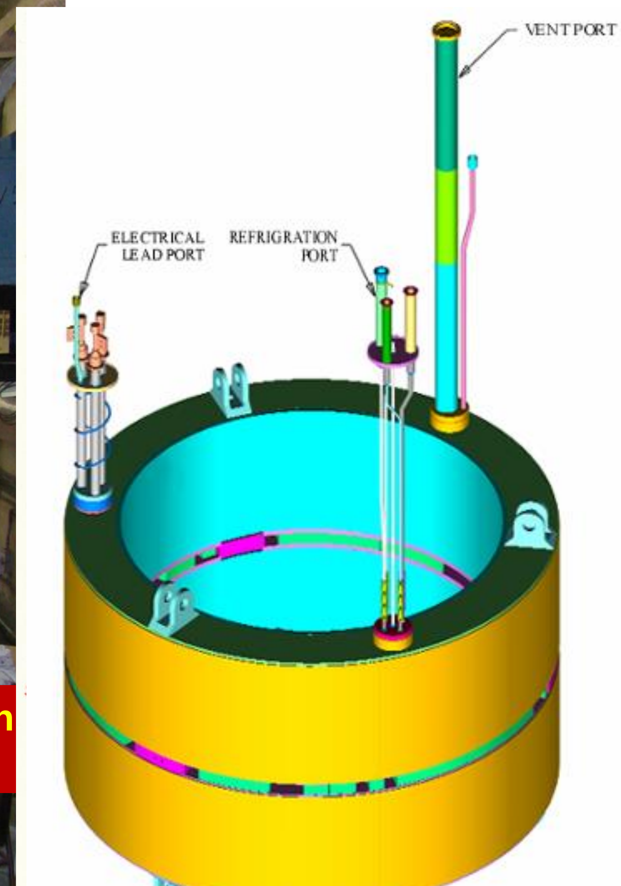
Courtesy : VECC

K-500 Superconducting Cyclotron at KOLKATA with its Beam Line



Accelerated Neon (Ne 3+) Beam Spot on Viewer Probe

First Beam Acceleration in the Superconducting Cyclotron at VECC (August 25, 2009)



Beam Extraction difficulty : Shifting of Magnet Axis.
Dismantled and getting Ready for next operation


INDIA CERN Collaboration AT RRCAT (INDIA) FOR LHC in 199
Our Man power & Indian Industry was exposed and Trained with International Community
International Platform
Function
• To correct the systematic field errors of the LHC Main Dipole
• They Share the same cryostat as that of Main Dipol
Sextupole Magnet
Approx 2000 Corrector Magnets (NbTi) , Developed at RRCAT, India and Supplied to CERN

Movement from SC Magnet to SC RF Cavity

International Trend (LHC to ILC)

We also Followed it

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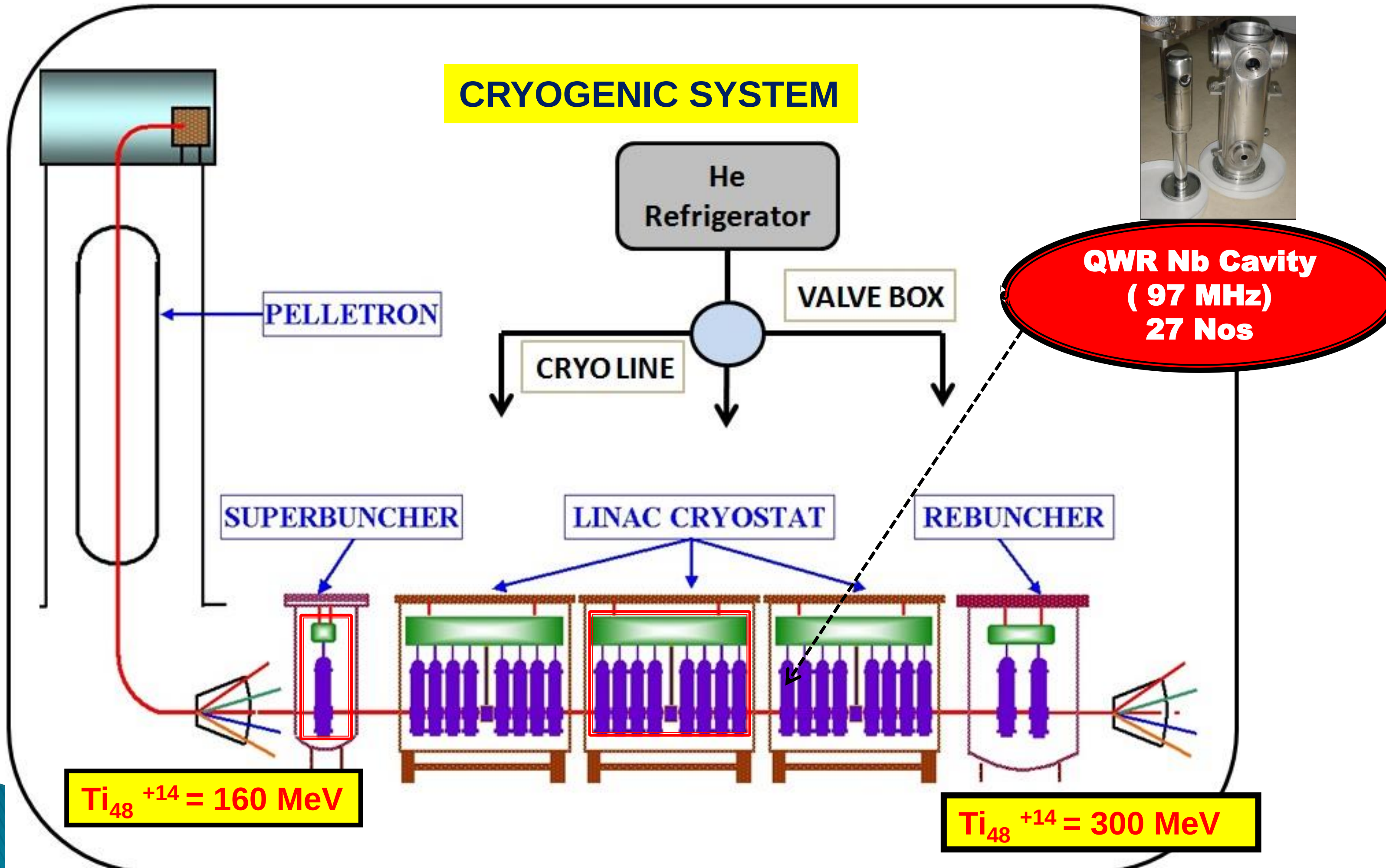
Superconducting Linear Accelerator at IUAC, DELHI

To increase the energy of Heavy ion from Pelletron

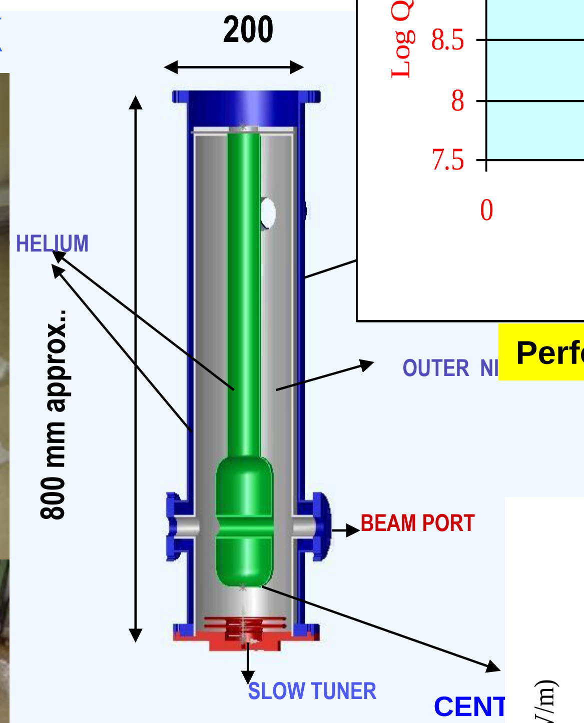


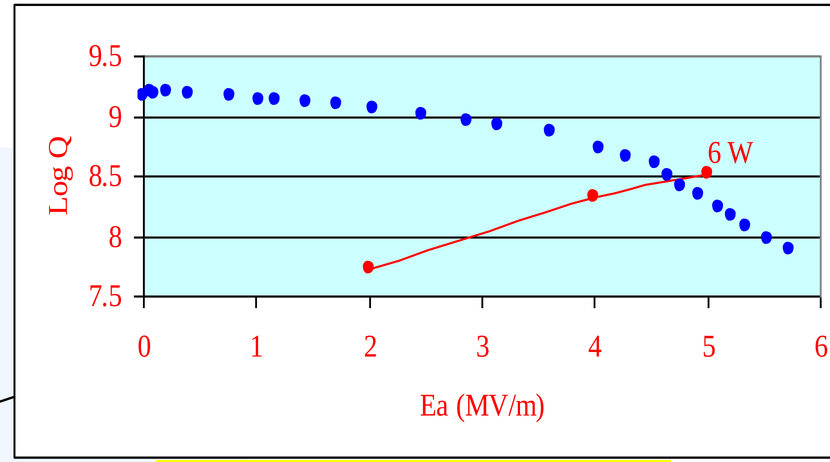
DELHI RF SUPERCONDUCTING CAVITY (QWR)

Bulk Niobium (RRR : 200)

ß = .08c , f= 97MHz,

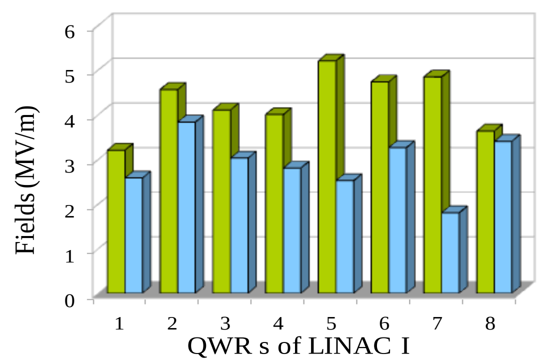
E_{acc}= 4 MV/m at 4. 2 K





Performance Curve of a Cavity

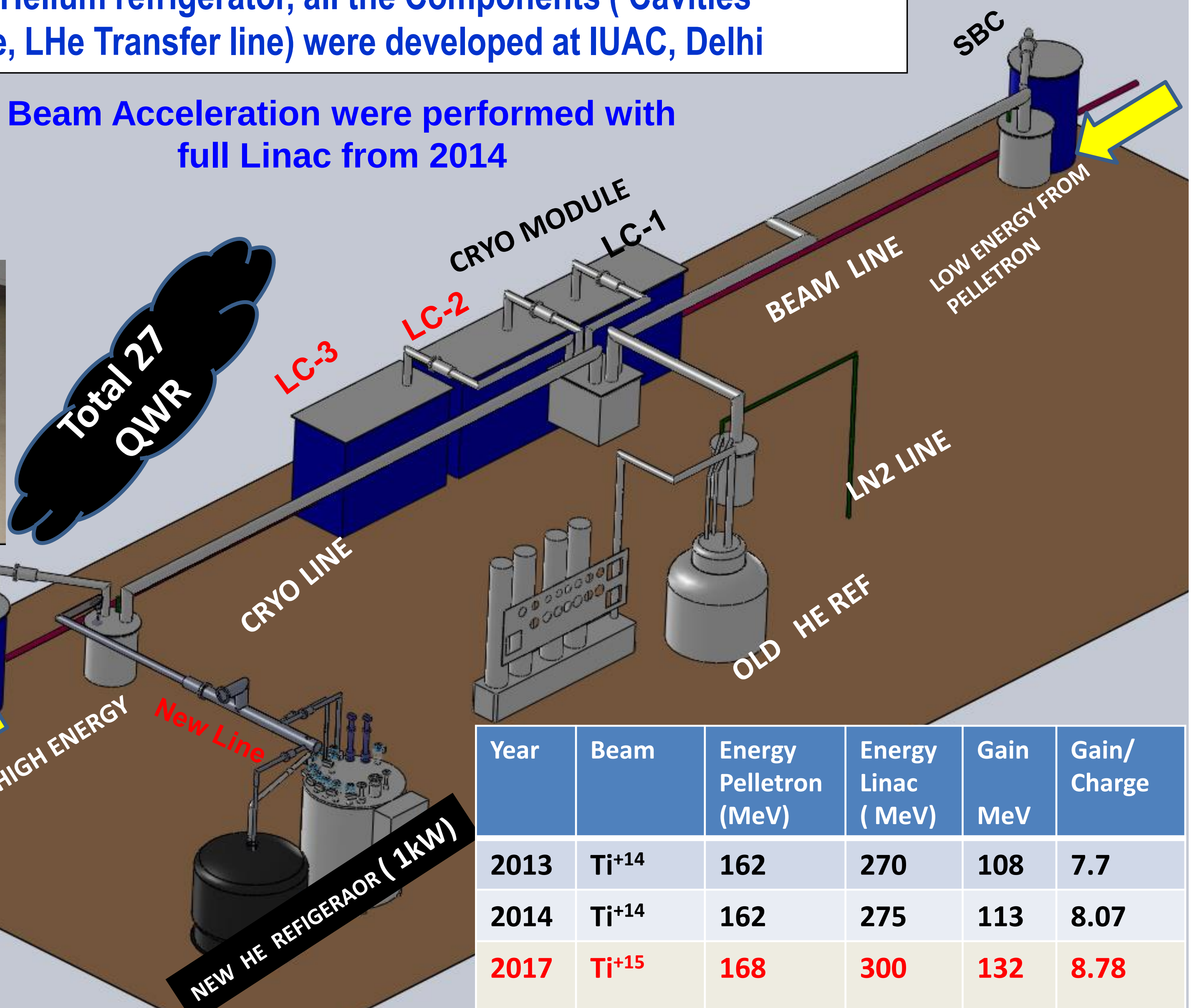
Fields@ 6W and locked fields during for LINAC-1



Argonne, USA Collaboration

Except the Helium refrigerator, all the Components (Cavities Cryomodule, LHe Transfer line) were developed at IUAC, Delhi

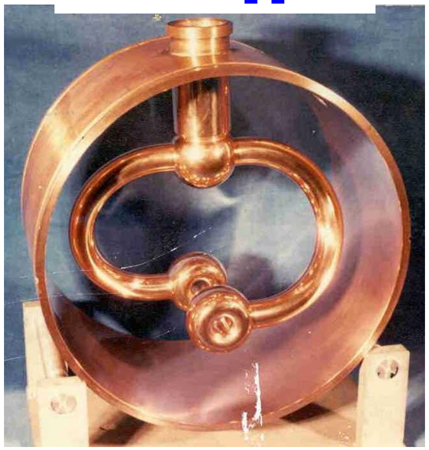
Beam Acceleration were performed with full Linac from 2014



Year	Beam	Energy Pelletron (MeV)	Energy Linac (MeV)	Gain MeV	Gain/ Charge
2013	Ti^{+14}	162	270	108	7.7
2014	Ti^{+14}	162	275	113	8.07
2017	Ti^{+15}	168	300	132	8.78

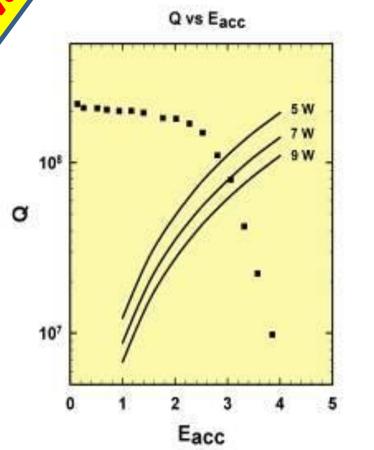
Lead Plating on Copper for TIFR RF Cavity

Bulk Copper



After Pb Plating

Low field because of low Hc value



Quarter Wave Resonators Material : OFHC Cu
Superconducting surface : 2 µm thick. Pb
Frequency : 150 MHz Cavity
Length 64 cm
Cavity Diameter 20 cm
Design goal 2.5 to 3 MV/m @ 6 to 9 Watts

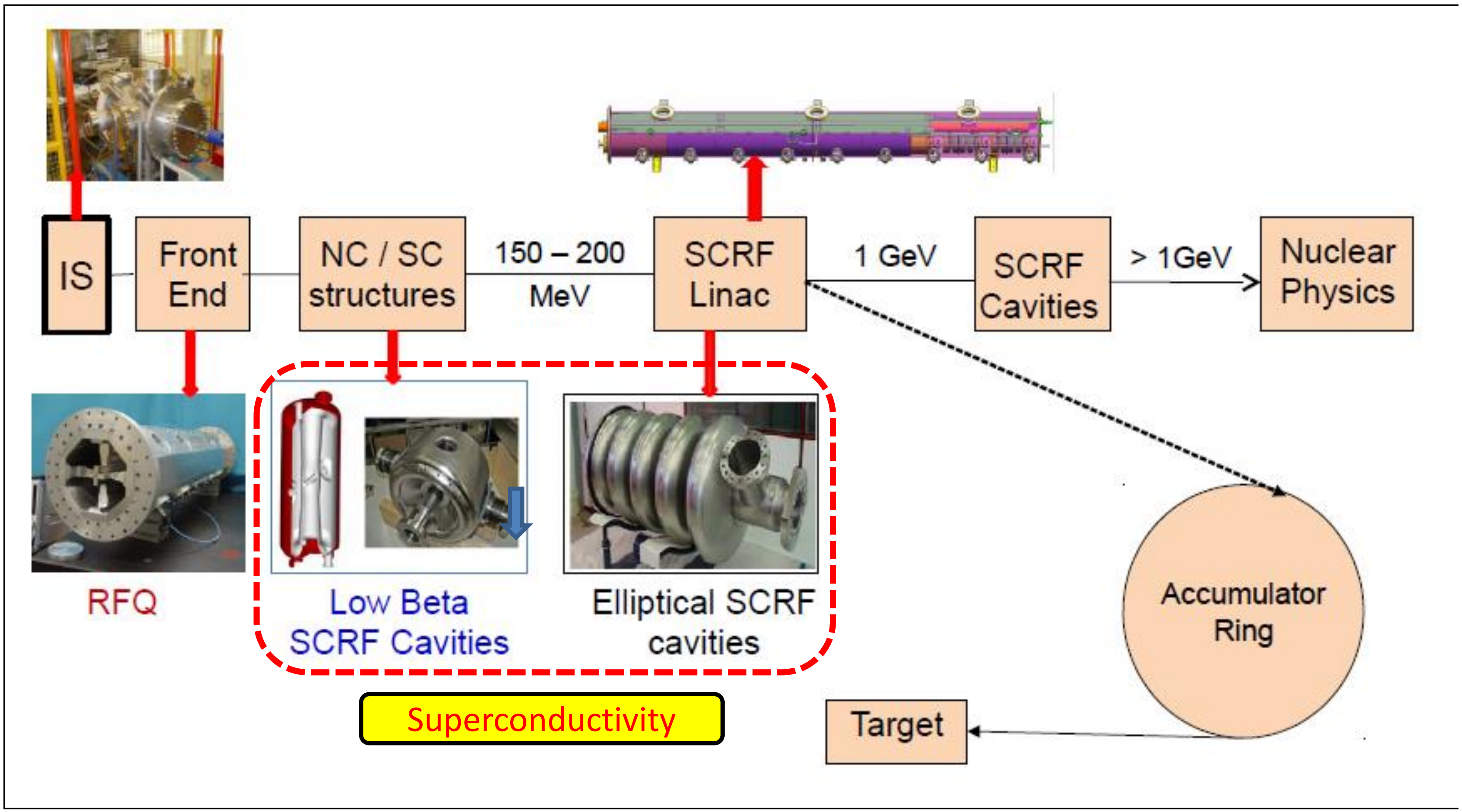
Now Replacing with Bulk Niobium Cavity

Courtesy : TIFR, Mumbai

High Energy Proton LINAC Based Spallation Neutron Source (RRCAT)

Collaboration between Fermi Lab & Indian Institutes

Ongoing/ Future

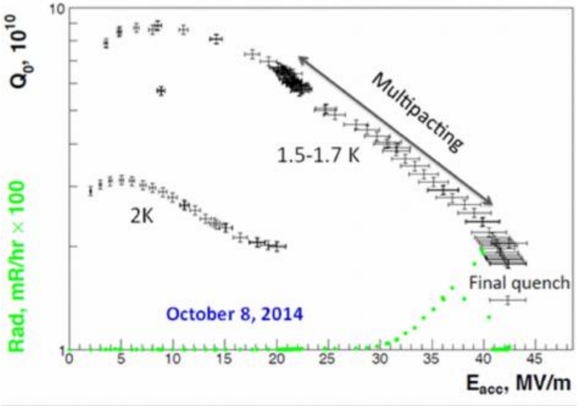


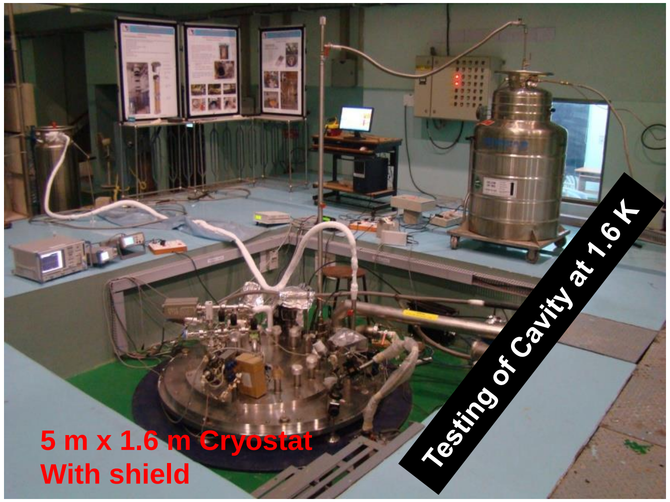
Courtesy : S C Joshi

5 Cell 1.3 GHz SCRF cavity developed at RRCAT/IUAC

Surface Preparation Lab & EBW are Commissioned

E_{acc} = 20.3 MV/ m at 2 K
= 42 MV/m at 1.6 K





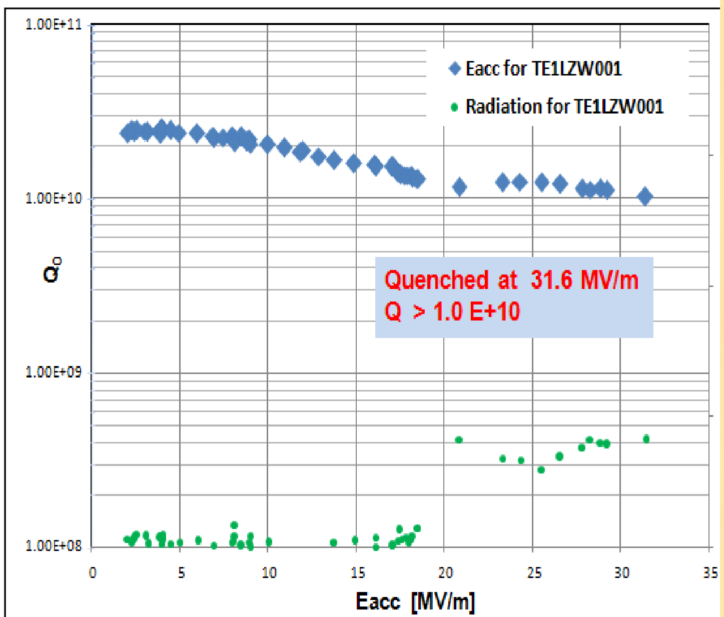
High Pressure Water Rinsing System

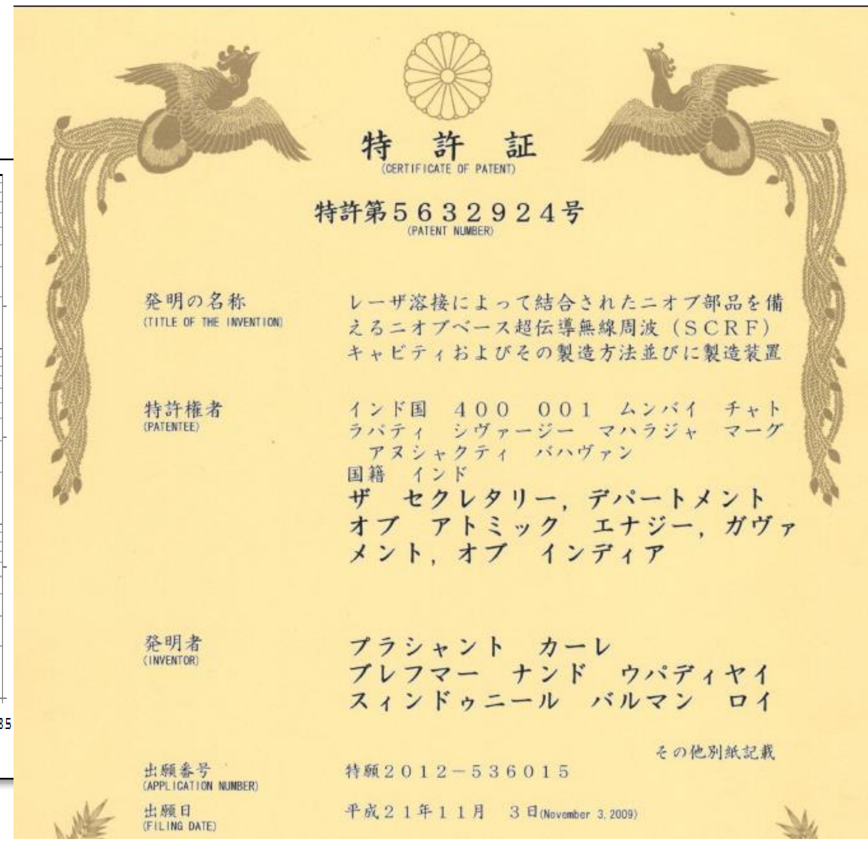
Courtesy : S C Joshi & P K Kush

World's FIRST 1.3GHz Laser Welded SCRF Cavity (RRCAT)

**Advantage : No Vacuum, less capital cost.
Low HAZ, Low Shrinkage & Distortion**

Japan office grants patent for Laser Welding Technique developed at RRCAT





特　許　証
(CERTIFICATE OF PATENT)

特許第５６３２９２４号
(PATENT NUMBER)

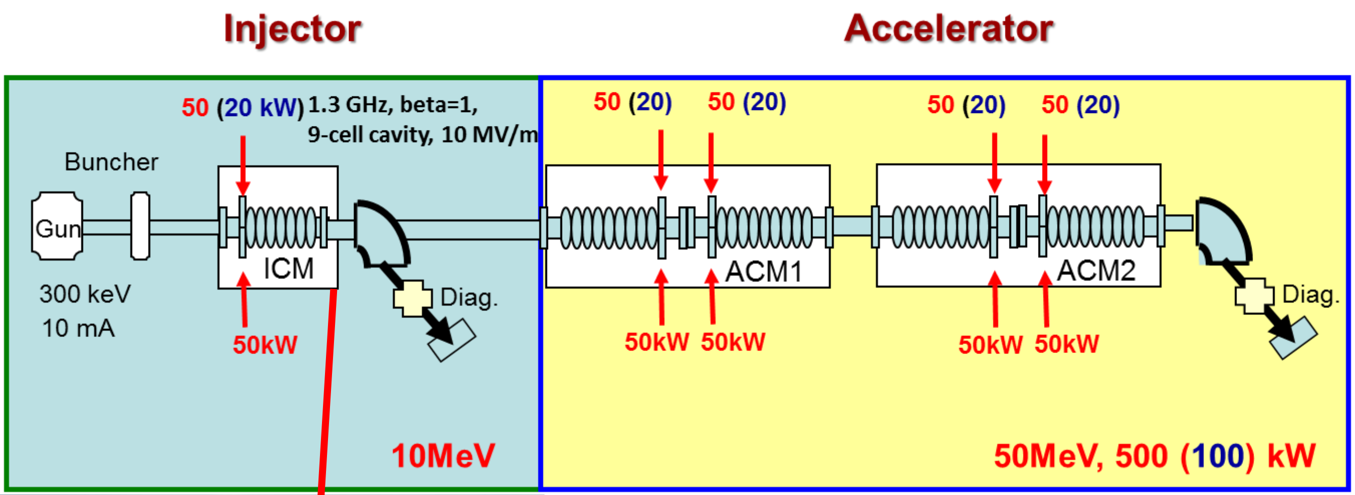
発明の名称 (TITLE OF THE INVENTION)	レーザ溶接によって結合されたニオブ部品を備えるニオブベース超伝導無線周波（ＳＣＲＦ）キャビティおよびその製造方法並びに製造装置
特許権者 (PATENTEE)	インド国　４００　００１　ムンバイ　チャトラパティ　シヴァージー　マハラジャ　マーグ　アヌシャクティ　バハヴァン 国籍　インド ザ　セクレタリー，デパートメント　オブ　アトミック　エナジー，ガヴァメント，オブ　インディア
発明者 (INVENTOR)	プラシャント　カーレ ブレフマー　ナンド　ウパディヤイ スィンドゥニール　バルマン　ロイ その他別紙記載
出願番号 (APPLICATION NUMBER)	特願２０１２－５３６０１５
出願日 (FILING DATE)	平成２１年１１月　３日(November 3, 2009)

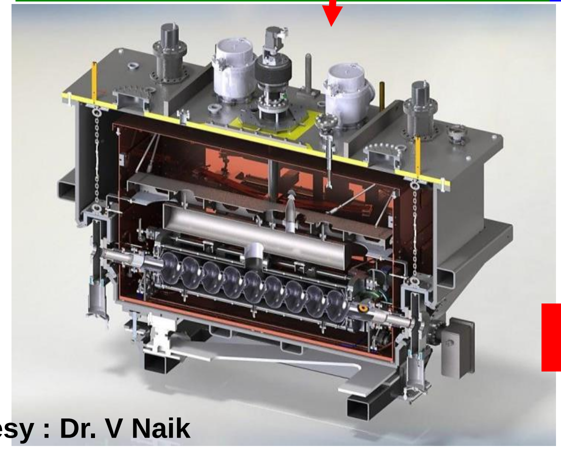
Courtesy : S C Joshi & Prashant Khare

Superconducting Electron Linac for ANURIB

Ongoing/ Future

50 MeV, 100 kW cw; based on 1.3 GHz SRF technology
Injector built in collaboration with TRIUMF Laboratory, Canada





Courtesy : Dr. V Naik

5 nine-cell Niobium elliptical cavities
needed for 50 MeV
Acceleration gradient of 10 MV/m,)

Injector Cryomodule developed and Installed

Heart of the ICM

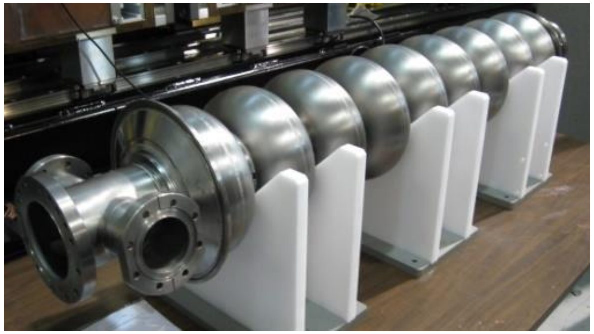
Niobium accelerating cavity

Cornell type (modified Tesla cavity to suit cw

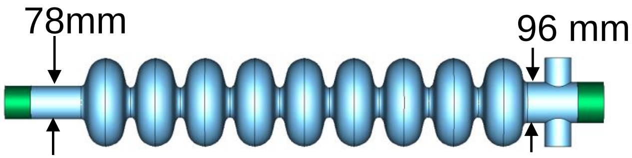
Made by TRIUMF & M/s PAVAC, Canada

- ICM cavity
  - nine-cell cavity
  - End groups modified to accommodate two 50kW couplers
  - Cleaning, 120 μm BCP (TRIUMF), 800 deg C degassing at Fermilab

Parameter	Value
Active length (m)	1.038
RF frequency	1.3 GHz
R/Q (Ohms)	1000
Q_0	1e10
E_a (MV/m)	10
P_{cav} (W)	10
P_{beam} (kW)	100
Q_{ext}	1e6
Q_L*R_d/Q of HOM	<1e6



bare cavity



Courtesy : Dr. V Naik

SUMMARY ON RF SUPERCONDUCTING CAVITY

1990- 2000 :

Quarter Wave Cavity at TIFR & IUAC

Developed in India, E_{acc} = 2.5 to 6 MV/m
f= 150 MHz, & 97 MHz

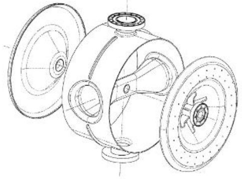
2010- 2019 :

Elliptical Cavity for Proton LINAC at RRCAT, BARC, VECC (Dept of Atomic Energy)

(Developed In India, Surface preparation and Testing at USA : > 30 MV/m, f = 1.3 GHz, 650 MHz)

Spoke Cavity and Low β cavity at IUAC
For Project X at Fermi Lab and HCI at IUAC

Delivered to Fermi Lab and Performance Satisfactory



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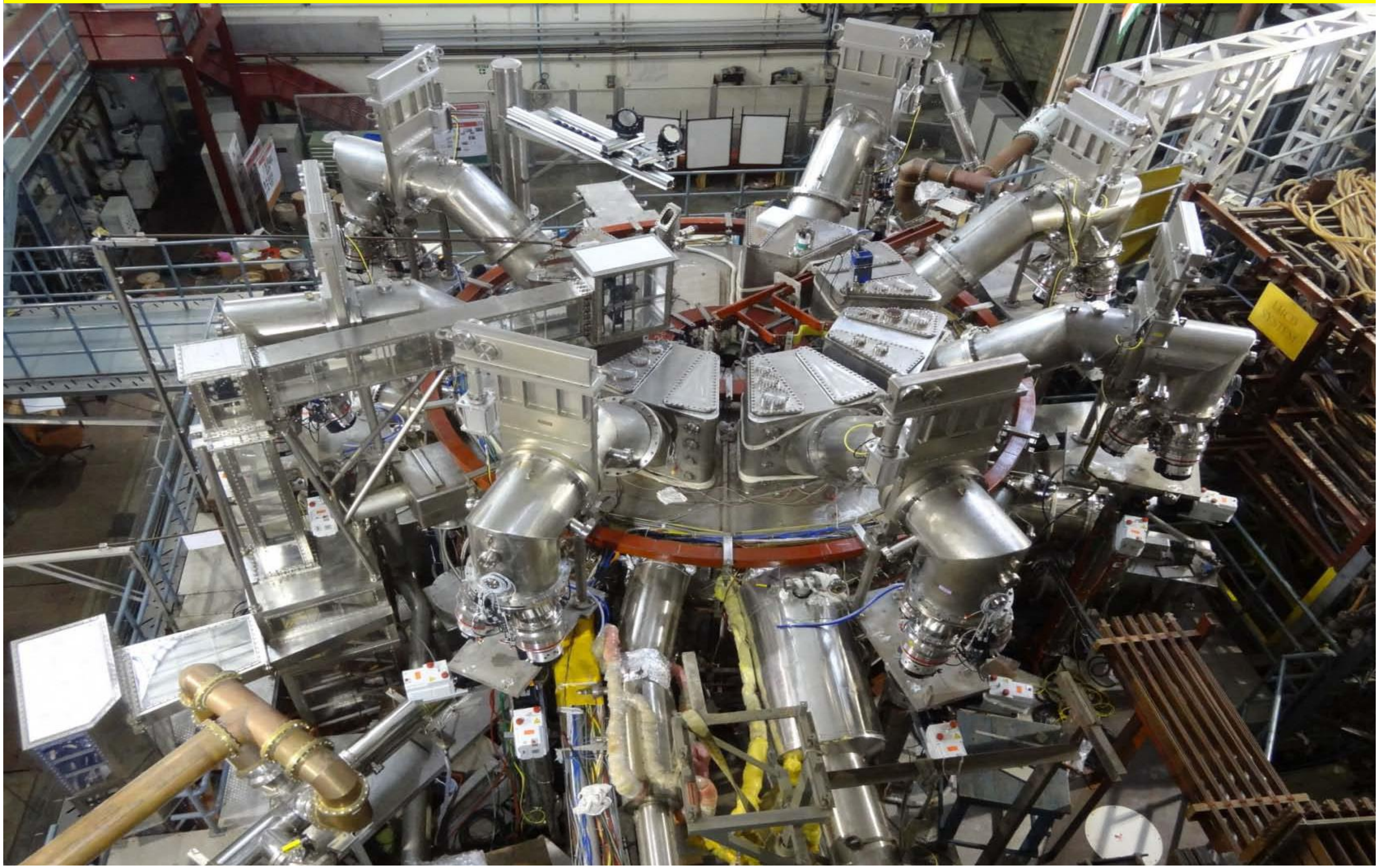
Steady State Superconducting Tokamak (SST-1) developed at Institute for Plasma Research, Gandhinagar



SST-1 Tokamak

Machine Parameters

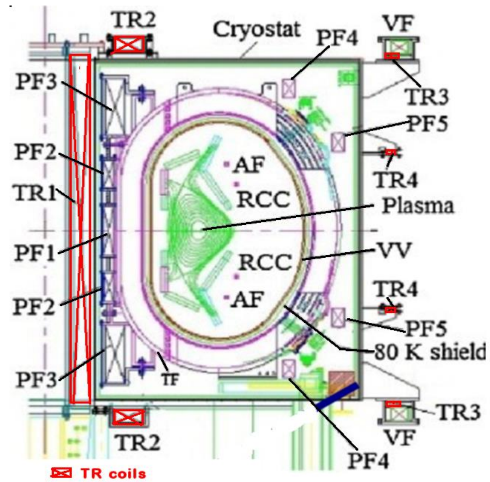
- Major Radius 1.10 m
- Minor Radius 0.20 - 0.25 m

16 Toroidal Field Coils
9 Poloidal Field Coils
Operating Current : 10 kA

Parameters: Planned & Achieved

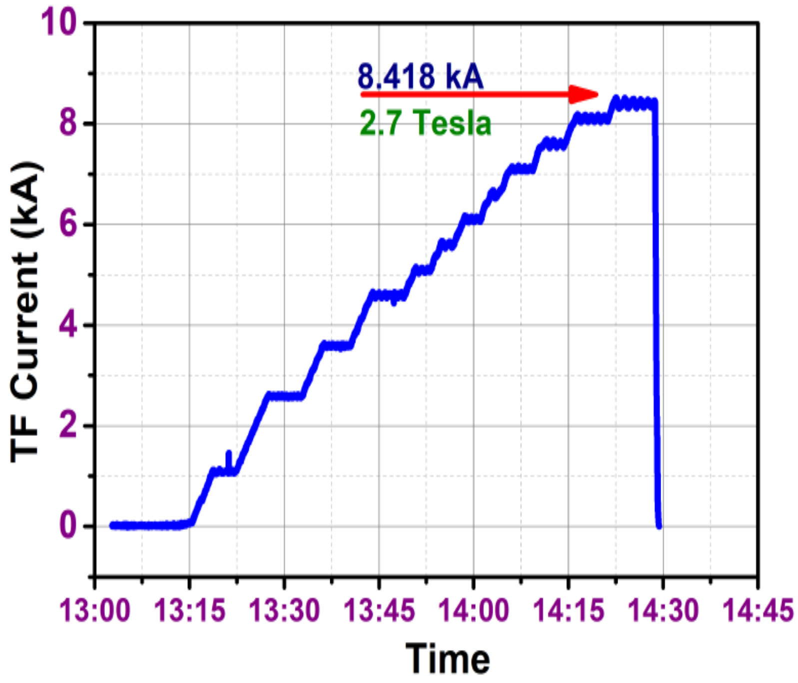
Parameters	Design value		Achieved (Maximum)
	Phase-I	Phase-2	Recent Experiments
Toroidal Field (T)	1.5	3	1.5 (tested @2.7)
Plasma Current (kA)	110	220	~100
Plasma Duration (ms)	100	1000	650
Plasma configuration	Circular	Transition from Circular to shaped	Circular
Plasma temperature (eV)	250	1000	250

Cross-sectional view of SST-1 showing location of various Copper and Superconducting coils

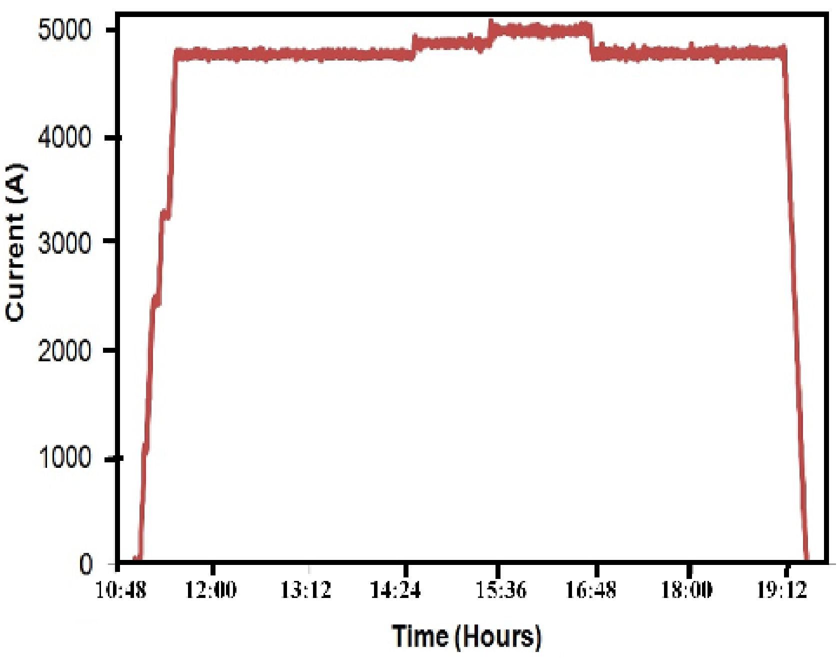


Performance of TF Magnets

TF magnets charged up to 8.4 kA at 5 K to produce 2.7 T at major radius of 1.1 m



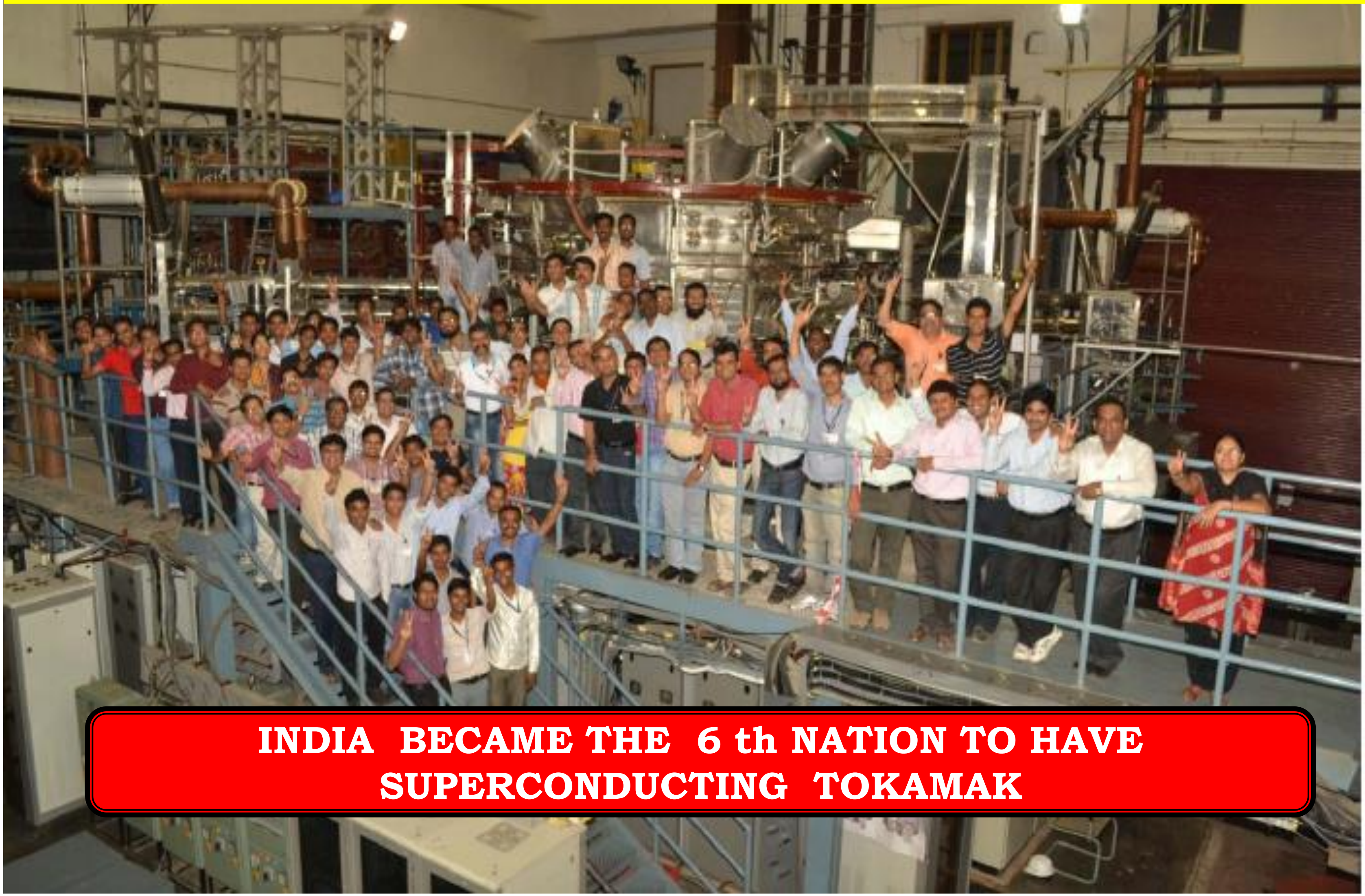
Long Pulse operation of TF magnets@ 1.5-1.6 T



Earlier CICC procured from Hitachi Cables. Now IPR and BARC together have developed their own Nb- Ti & Nb_3Sn CICC

CSSJ

SST-1 device has achieved the mission objective of obtaining a plasma current in excess of 100 KA at a central field of 1.5 T on 21st February, 2016 during the 16th experimental campaign.



Scenario of Cryogenics (4.2 K and 20 K in India)

A. Space Cryogenics at 20 K and 80 K
B. Helium Liquefier Development
C. Cryoline for ITER

INDIAN SPACE RESEARCH ORGANISATION & CRYOGENICS

CRYOGENICS BECOAME HOUSEHOLD NAME IN INDIA BY NEWS REPORT WHEN WE DENIED CRYOGENIC ENGINE TECHNOLOGY BY RUSSIA In 1990

That Motivates to develop Cryogenic Engine in India

GSLV-D5, launched on 5 January 2014, was the first successful flight using the indigenously developed cryogenic engine, the CE 7.5 (Thrust 75 kN)

(Annotated Slide)

Indigenous Cryogenic Upper Stage is integrated with GSLV-D5 Second Stage

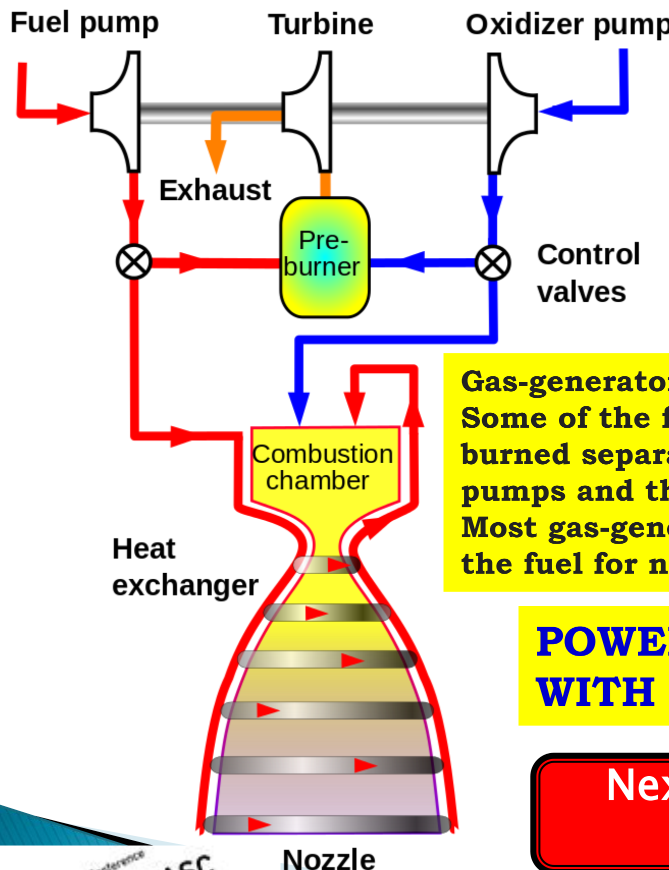
Fuel : Liquid Hydrogen (20 K) & Liquid Oxygen (90 K)
Fuel Mass : 12 Tons
Duration : 720 Sec
Thrust : 75 kN

CE-7.5

First ISRO Cryogenic Engine CE 7.5

Three Stage (Solid, Liquid & Cryogenic) Launch Vehicle with Cryo Engine

Next CE 20 is the first Indian cryogenic engine to feature a Gas Generator Cycle. The high thrust cryogenic engine is one of the most powerful upper stage cryogenic engines in the world.



Gas-generator rocket cycle. Some of the fuel and oxidizer is burned separately to power the pumps and then discarded. Most gas-generator engines use the fuel for nozzle cooling.

POWERFUL ENGINE CE 20
WITH THURST 200 kN , Fuel (H_2+O_2 : 27 Tons

Next is Semi Cryogenic Engine with Liquid Oxygen and Kerosene

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India on July 22, 2019 Successfully Launched Second Lunar Mission Chandrayan- 2 by powerful rocket GSLV-MkIII with CE- 20 Cryo Engine on upper stage

INDIAN CRYOGENIC COMMUNITY ARE PROUD WITH ISRO ACHIEVMENT

Inaugural Address of NCCS by Respected Chairman

In December, 2019, LPSC/ ISRO organised National Conference on Cryogenics for Space (NCCS2019) with total Delegates more than 300

Visit to Testing Facility

Indigenous Helium Liquefier development In India

At RRCAT, Indore

Claude Cycle with two Reciprocating Engine

Capacity : 35 Litres/hr

Running Since 2010 (Started with 6 L/hr)

At BARC, Mumbai

Turbine Based / Plate fin HX

Capacity : 20 litres/hr

Commissioned in 2015

Now Going for 1 kW class Refrigerator

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Cryolines and Cryodistribution System for ITER

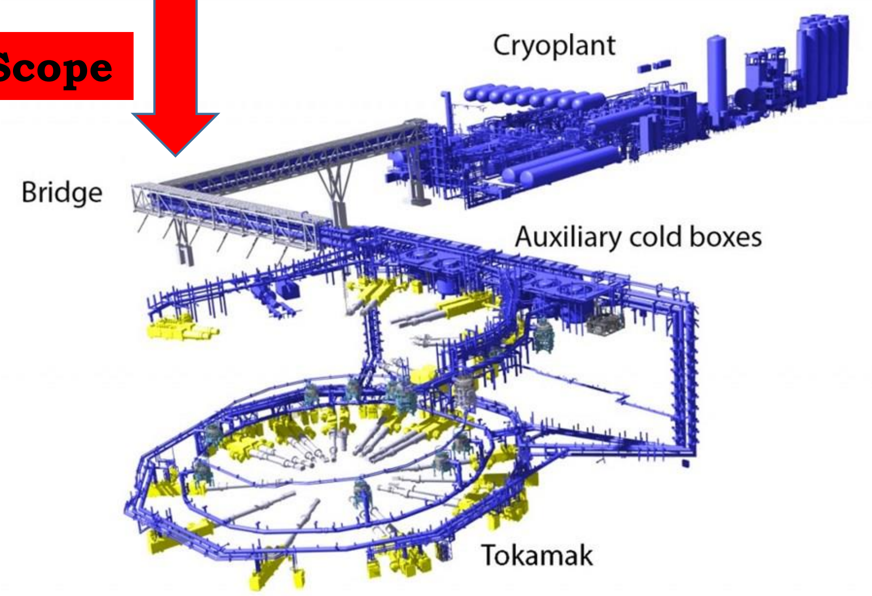
ITER Cryogenic System

Cryoplant → Cryolines + Cryodistribution → Clients

75 kW at 4.5 K
1MW at 80 K

Indian Scope

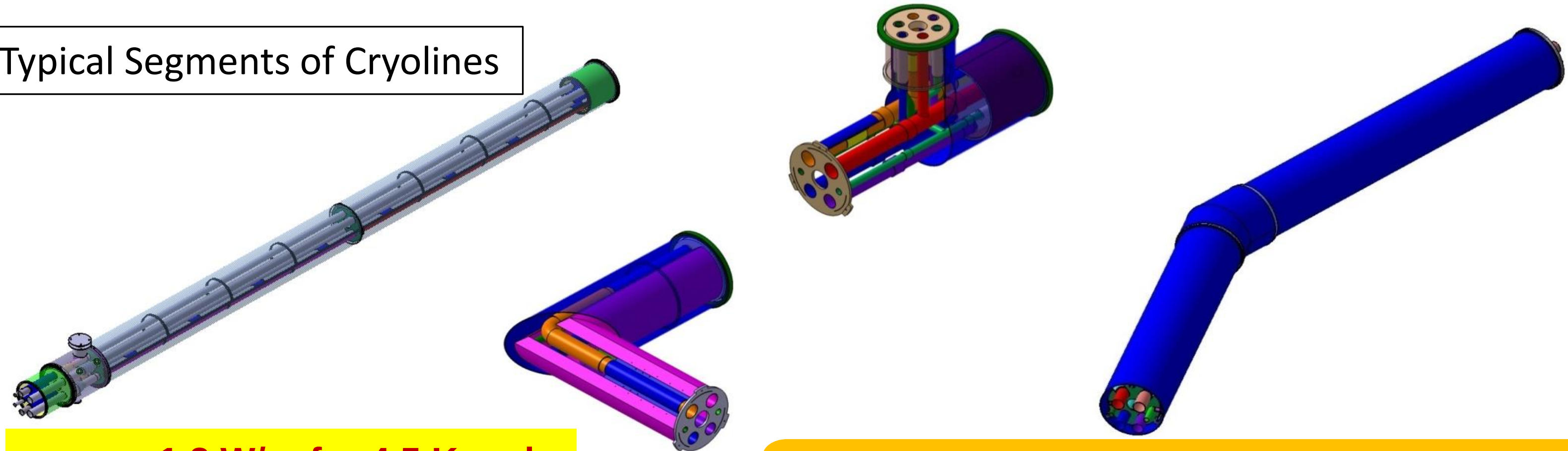
- **Cryogenic Users are;**
  - Superconducting magnets with forced flow supercritical helium at 4 K level
  - Cryostat and thermal shields with forced flow of He at 80 K
  - Cryosorption pumps with supercritical He at 4 K level



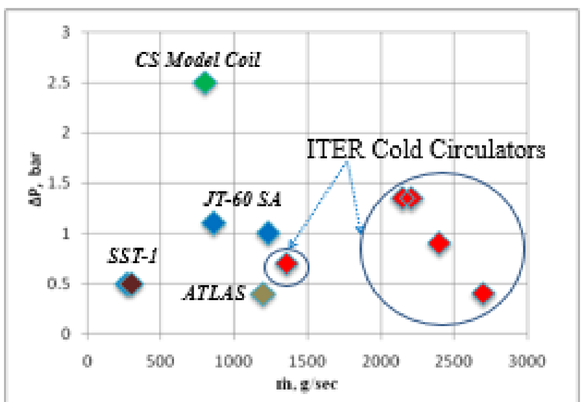
Indian scope : 4 km long cryolines , 7 km long warm lines, 7 cryodistribution boxes

Main Features of ITER Cryolines

Typical Segments of Cryolines



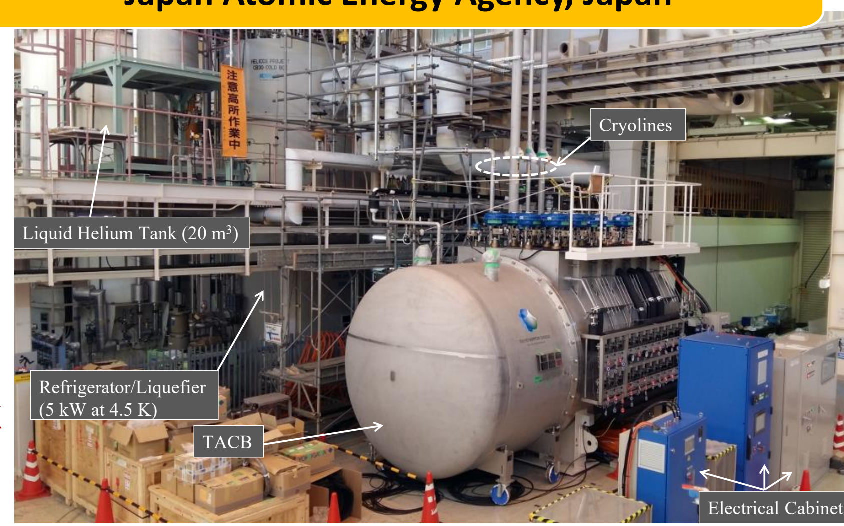
- 1.2 W/m for 4.5 K and
- 4.2 W/m for 80 K lines



kg/s at 4.3k

IHI, Japan

Cold Circulator Performance Test at Japan Atomic Energy Agency, Japan



Prototype Cryoline Installation & Testing at IPR, India

Installation of Warm Lines at ITER, France

MRI INITIATIVE IN INDIA

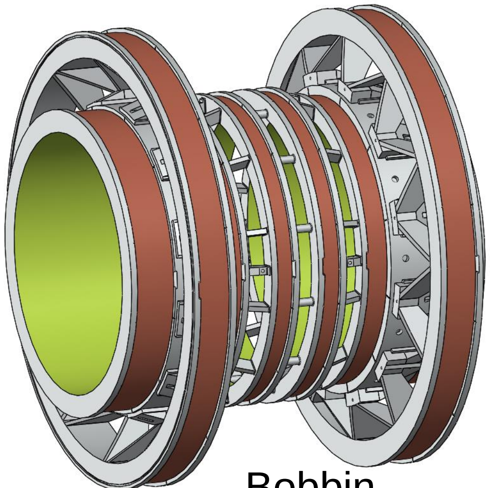
- **First MRI with Superconducting magnet in India in 1986 at INMAS**
  - **Siemens Make 1.5 Tesla**
- **Present about 1200 MRI in India (one MRI per Million, Japan 50)**
- **Projected MRI in India : 20000 in 2025**

Collaborative R & D Project
Initiated by
Ministry of Electronics and Information Technology
On
Development of 1.5 T MRI

Collaborative Institutes

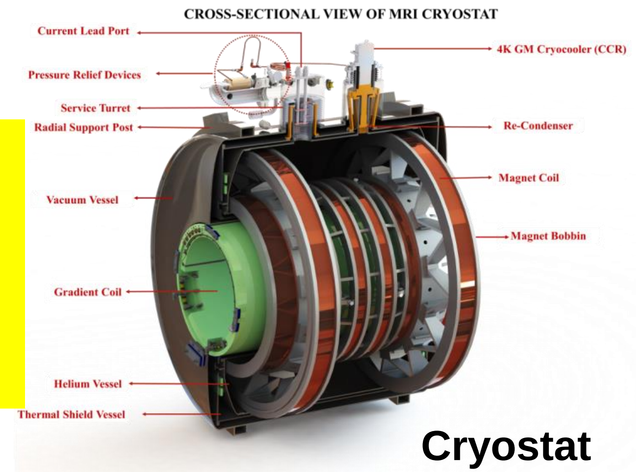
1. SAMEER, Mumbai
2. IUAC, New Delhi
3. CDAC, Trivandrum
4. CDAC- Kolkata
5. 5. Dayanand Sagar Institutions, Bangalore

MRI DEVELOPMENT AT DIFFERENT STAGE at IUAC. Delhi

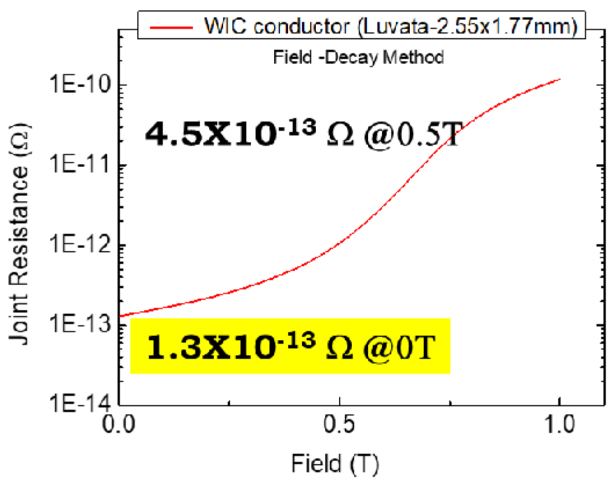


Bobbin

Total conductor length
Primary 6 Coils – 30.87
Shield Coils - 17.94
Total (km) 48.81
Operating Current : 463 A

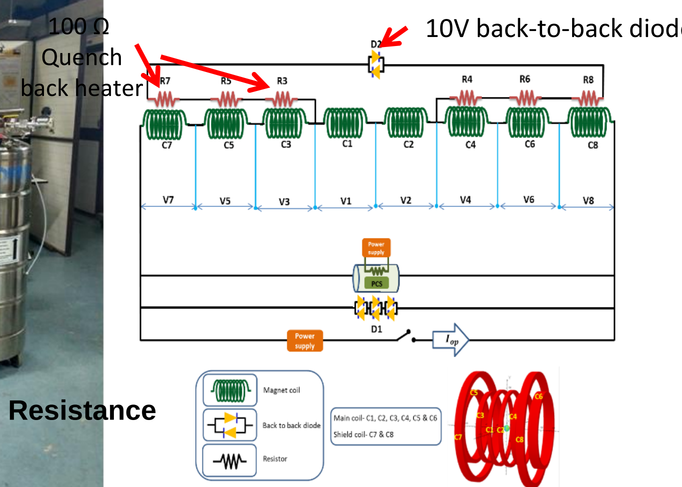


Cryostat



Joint Resistance

Quench Protection



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Small Scale Development with HTS

1. **Superconducting Motors by BHEL**
2. **Superconducting Fault Current Limiter at IUAC**
3. **Superconducting Cable at IIT Kharagpur**

Time ????

Summary

Joint Conference 10th ACASC 2nd Asian-ICMC CSSJ

- Over the last 30 years there is a significant growth of activity in the field of Applied Superconductivity & Cryogenics in India
- Accelerator & Fusion Programme dominates along with Space Cryogenics & It will continue in Future
- India's Participation in LHC and ITER in this field are significant. Hope for the same with ILC in Japan
- Superconductivity (HTS & Cryo Cooler) for Power Application is yet to take the momentum in India
- Under the banner Make in India, MRI development is under progress considering potential market in India
- We have a strong Academic base in Cryogenic Engineering

Joint Conference
10th ACASC
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CSSJ

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I will Cherish the First Asian ICMC Conference in Kanazawa in 2016
Thank You
Wonderful Evening