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Development of SCRF Infrastructure at RRCAT

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Outline

- Introduction of Plan Activity
- SCRF cavity fabrication
- Cavity Processing
- Building for Cavity Fabrication and Processing
- Development of Test Facilities
  - ✓VTS
  - ✓HTS

SCRF Infrastructure at RRCAT

Started in December 2007 under funding received from DAE for XI Plan Program

- **Motivation: Domestic & International Programs**

1. **Indian participation in ILC & Proton Driver**.
2. **Superconducting Materials R & D** for SCRF
3. **Development of SCRF Cavity Science and Technology including setting up a facilities that would be useful for development of cavities for HIPA.**
4. **Application of SCRF including development of an infrared source to give coherent radiation using a superconducting post-accelerator.**

Development of Superconducting Cavities and Associated Technologies for High Energy Accelerators and their Applications

Dt. of sanction	10th Dec., 2007
Sanctioned cost	~ USD 20 million
Expected completion date	31^{st} March, 2015

Project Objective :

- **Technology development and setting up of an infrastructure for the SCRF cavity fabrication, chemical processing, cleaning, assembly and testing at required accelerating gradient for accelerator applications like XFEL, SNS, ERLs etc**
- **To establish Cryogenic Infrastructure to operate large systems operating at liquid helium environment**
- **Experimental research in bulk and thin film superconducting materials to find out what bestows the best superconducting properties from the point of building accelerating cavities with high gradient and high quality factor**

SCRF Infrastructure Facility

- **During planning stage of SCRF Cavity Infrastructure Facility at RRCAT, important inputs were also received from SCRF facilities planned at Fermi National Accelerator Lab:**
  - Clean room facility
  - Cavity RF Measurement techniques
  - Chemical Polishing of cavity (ANL)
  - Vertical Test Stand Facility
  - Horizontal Test Stand Facility
  - Electron beam welding machine specifications
  - Experience & exposure received during visit to Fermi lab

Special thanks to colleagues at FNAL: Robert Kephart, Shekhar Mishra, Rich Stanek, Harry Carter, Tom Peterson, Mark Champion, Ruben Carcagno, Joe Ozelis, Camille Ginsburg, Cosmore Sylvester, Tug Arkan, Mike Foley, Charlie Cooper and many more……

New Facilities Planned at RRCAT

SCRF cavity fabrication Facilities:
120 Ton Hydraulic Press, Nb machining, EBW Machine etc.

Chemical & thermal processing facilities
EP/BCP/CBP, HPR & Annealing Furnaces etc.,

Cavity Inspection Facilities
3-D CMM, UTM, Optical inspection bench, 3-D confocal microscope, SIMS

Cavity RF Measurement & Tuning Facility
Half Cell, dumbell and multi-cell cavity frequency measurement
Cavity Frequency & field tuning machine (under planing)

Assembly & testing set up.
Clean-room, Test cryostats, RF sources etc.

Development of Cavity Fabrication facility

Development work done on Forming & Machining

Developed forming tooling & process for 1.3 GHz SCRF cavity.

Forming

Inspection

120 T - HYDRAULIC PRESS

Machining

Formed Niobium Half cell

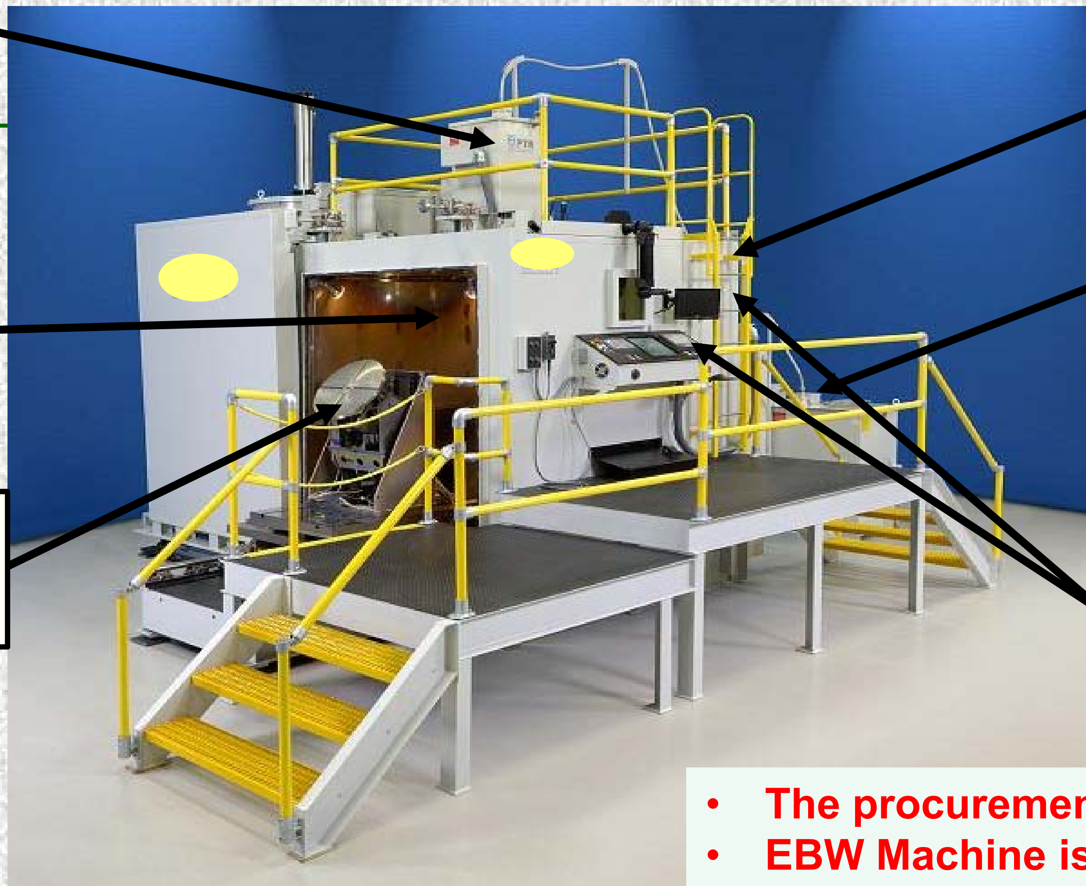
Procurement of Electron Beam Welding Machine

Electron Beam welding is required for manufacturing of SCRF cavities (low to high β range) made of high RRR Niobium for Proton Linac and other Accelerators to be developed at RRCAT.

EBW Gun

Vacuum Chamber

Work Table with Manipulator



High Voltage power supply

Vacuum System & control Electronics

Console & Viewing System

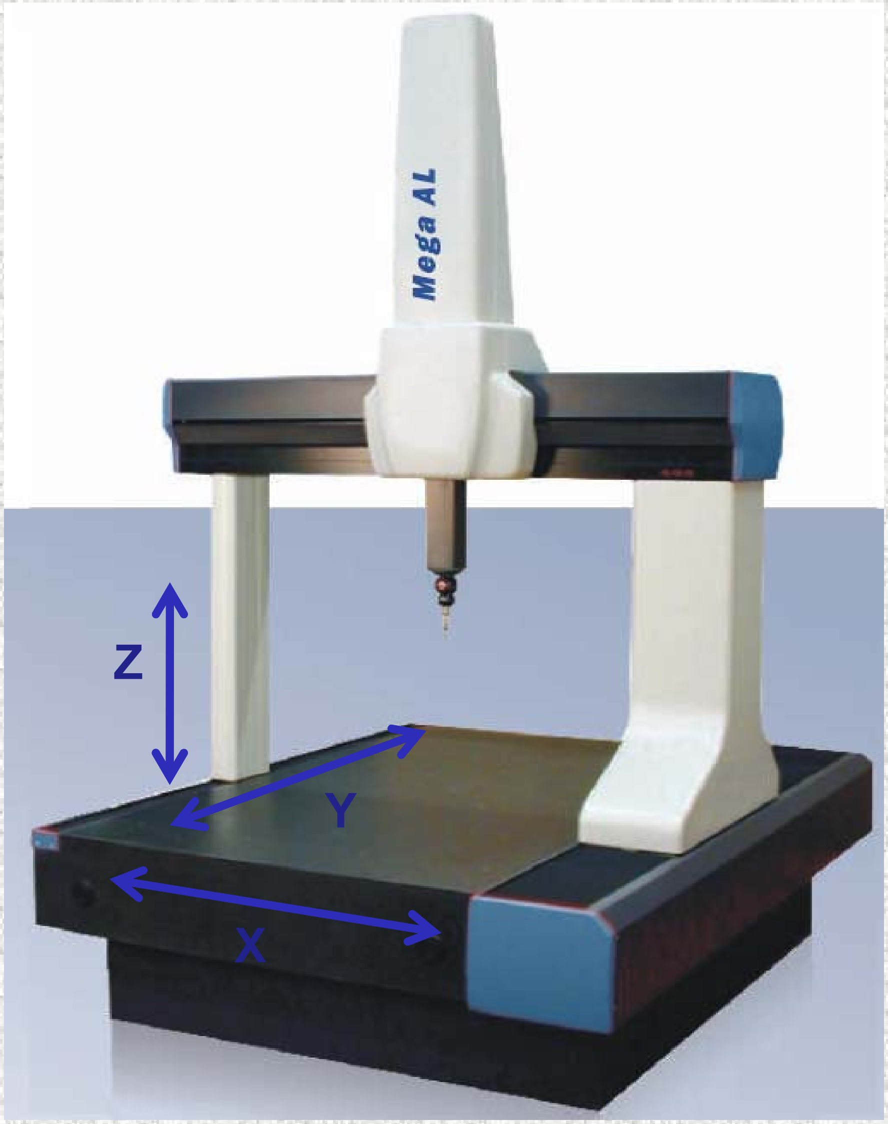
- **The procurement is in process.**
- **EBW Machine is expected to be commissioned by mid 2013.**

Major specifications of EBW Machine

Beam power	15 kW
Gun Voltage	90 to 150 kV
Duty cycle	100%
Beam current range	0 - 100 mA or wider
Beam current setting resolution	0.1 mA
Beam oscillations	1 – 1000 Hz or more
Beam deflection	± 2.5° min
Focus range	Ceiling to bottom of chamber, programmable
Beam focus diameter	0.25 mm or less
Inner size of chamber	3650 x 1500 x 1800 LxBxH mm^3 (min)
X-Y table size	1780 mm x 710 mm (nearest standard)
Travel of X Y table	1780 mm x 660 mm
Linear speed	1-2500 mm per minute
Vacuum ready pressure	< $5x10^{-4}$ mbar in 30 minutes
Ready for welding pressure	< $2x10^{-6}$ mbar in 60 minutes
Load Capacity	2500 kg
X – radiation leakage limit	less than 0.1 mR/hr at full accelerating voltage
Online optics	With CCD camera and suitable illumination system

Inspection, Measurement & Cavity Test Facility

Procurement of High Precision 3D CMM



Measuring Range	
X axis	1200 mm
Y axis	2000 mm
Z axis	1000 mm
Accuracy	1.6 + L/400 μm
Resolution	0.1 μm
Measuring Table	Granite Surface Plate (Grade 0)
Probing Systems	TP 20, SP 80, Laser Scanner

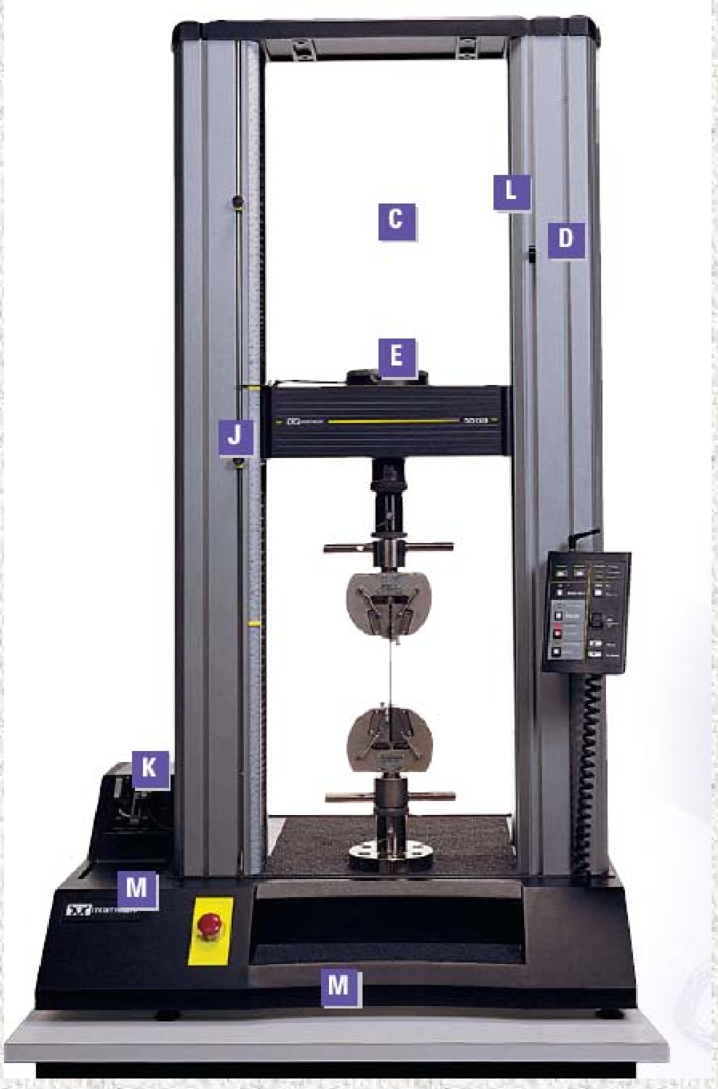
Purchase Order placed on Aug 2010

Expected Delivery – **March - 2011**

Universal testing machine for evaluation of mechanical properties

Instron UTM Model: 5569

- **Load:** **± 50 kN**
- **Testing speed:** **0.001 – 500 mm/min**
- **Accuracy of Load:** **± 0.5% for 0.5 – 50 kN**
- **Strain measurement Accuracy: ASTM E 83 Class B or better**
- **Total cross head travel:** **1500 mm**



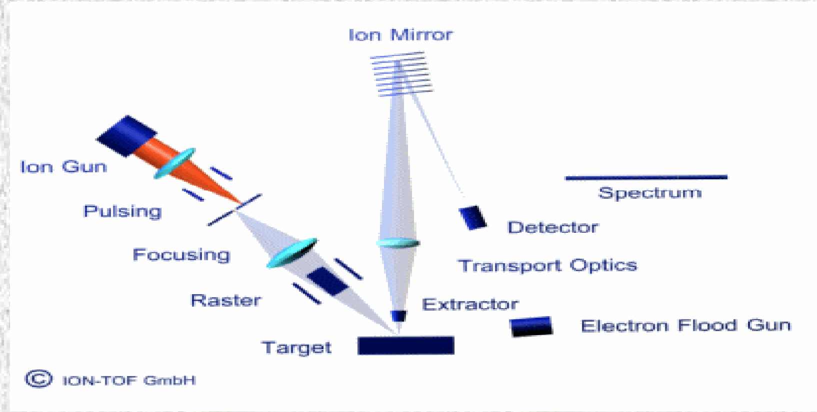
Measurements:

- Yield strength, ultimate tensile strength
- Elongation
- Plastic strain ratio, Strain hardening exponent.
- Cavity Stiffness measurement

Secondary Ion Mass Spectrometer (SIMS)

To develop understanding of impurity distribution near the top layer (~100 -200 nm) of niobium by 2-D, 3-D ion mapping of the impurities.

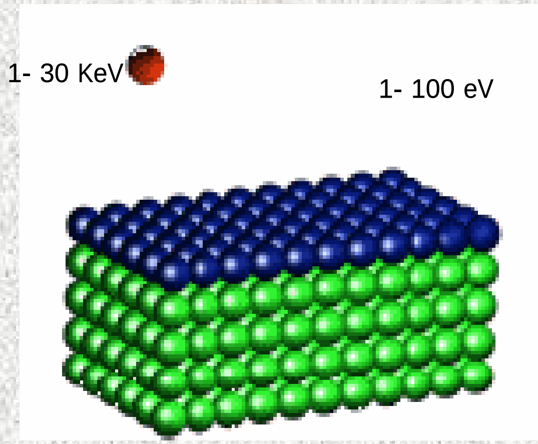
Quantification of the elemental impurity distribution using niobium standards .



Red ball : Primary ion

Blue ball : First atomic monolayer of the sample

Green balls : Inner layers



TOF SIMS 5 Specifications

Mass analyser	Energy focussing reflectron time-of-flight (TOF) analyser
Detector type	A combination of microchannel plate (MCP), scintillator, and photomultiplier for secondary ions detection.
Ion sources	**Analysis source:** Field emission cluster ion bismuth source **Sputter source :** Thermal ionization Cesium source & Electron impact gas ion source (Oxygen, Argon)
Mass range	1 – 10000 amu
Mass resolution	Better than 10000 at mass 29 amu
Detection limit	Better than 1 ppm
Depth resolution	1 nm or better
Depth profiling range	1 nm – 10 micron
Minimum Lateral resolution	150 nm or better with primary ion analysis gun
Base pressure reached after bakeout	< 5 x 10^{-10} torr
Sample size	100 mm x 80 mm or smaller sized samples
Specimen holder/manipulator	Sample heating and cooling (computer controlled, -150 °C to 600 °C) in the analysis chamber.

- **Purchase order placed.**
- **SIMS is expected to be delivered by Q3- 2011.**

3D Laser scanning confocal microscope

Imaging Method	3-D Laser Scanning Confocal system
Z - Resolution (Depth)	≤ 10 nm
Z - Measurement repeatability	12 nm
Z – measurement range	10 mm
X-Y Resolution	0.12 µm

Olympus LEXT OLS 4000 Laser scanning confocal microscope

- Purchase order placed.
- The equipment is expected to be delivered by May 2011.

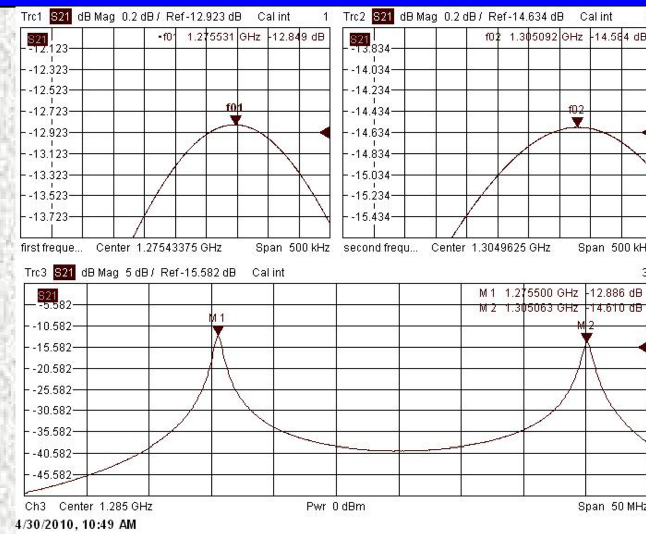
Cavity Optical Inspection

Cavity internal surface measurement using a small digital CCD camera with magnification 10X-200X

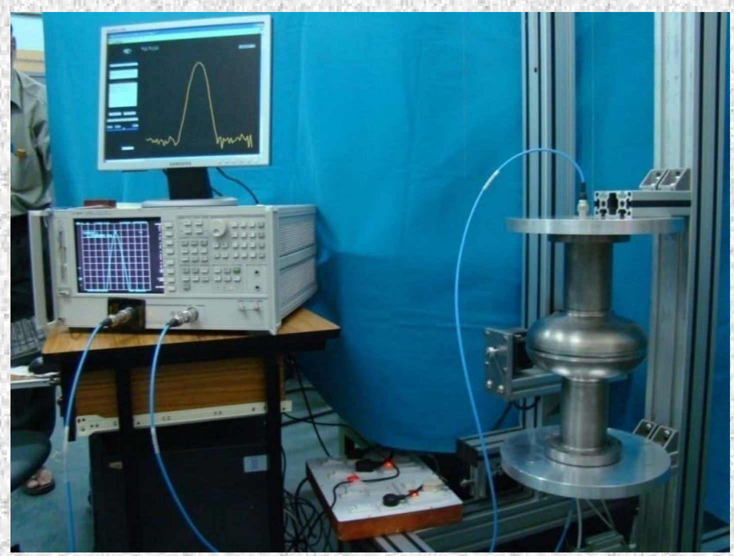
Motorized Optical inspection bench for cavity internal inspection (under development), it can accommodate 9 cell cavity

RF MEASUREMENT SETUP

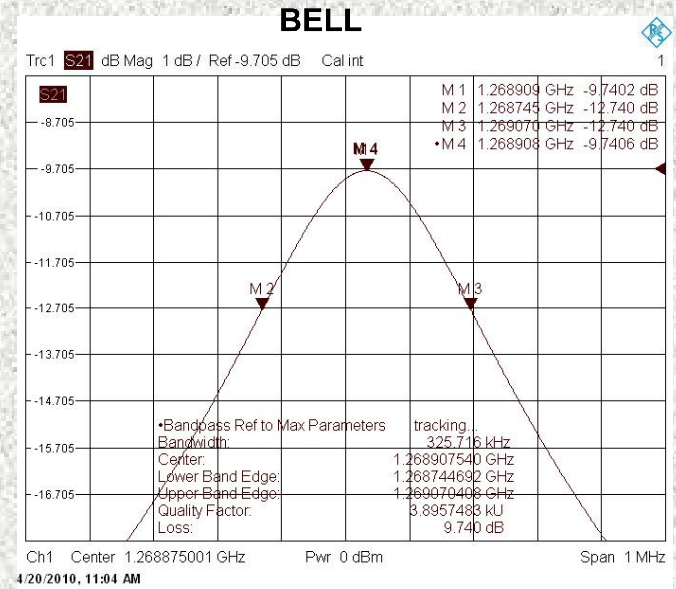
RF FREQUENCY MEASUREMENT SETUP



RF FREQUENCY PEAKS OF DUMB-BELL



RF MEASUREMENT SET UP FOR FREQUENCY AND FIELD DISTRIBUTION



RF FREQUENCY PEAKS OF SINGLE CELL CAVITY

Cavity processing facility

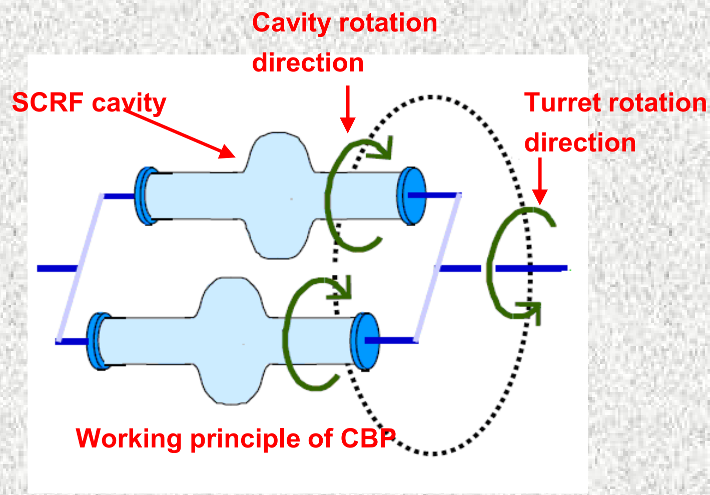
Cavity Processing

- Cavity Washing, degreasing
- CBP
- EP/BCP
- Thermal Processing @ 600^0-800^0 C
- Cavity Tuning
- HPR
- Drying & evacuation.
- Thermal Processing~120^0C

Centrifugal Barrel Polishing (single Cell)

Main features of CBP machine

❖Turret and Barrel rotate in opposite direction
❖Turret speed – 0 – 200 rpm (variable)
❖Barrel speed – 0 – 200 rpm (variable)
❖Barrel size – 320 X 320 X 500 mm

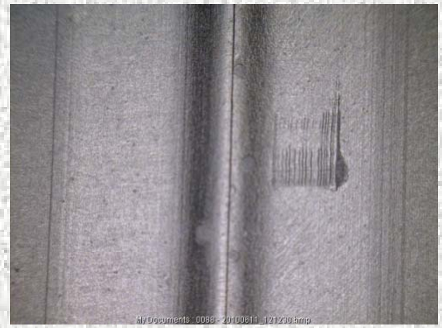


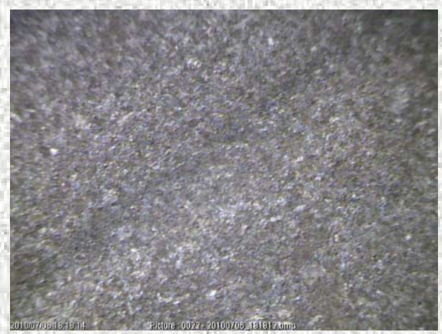
Cavity ready for mounting in CBP m/c

Cavities mounted in CBP machine

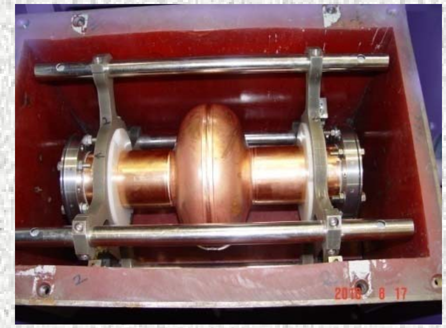
Initial Trial Results of CBP

Aluminum Cavity




Copper Cavity



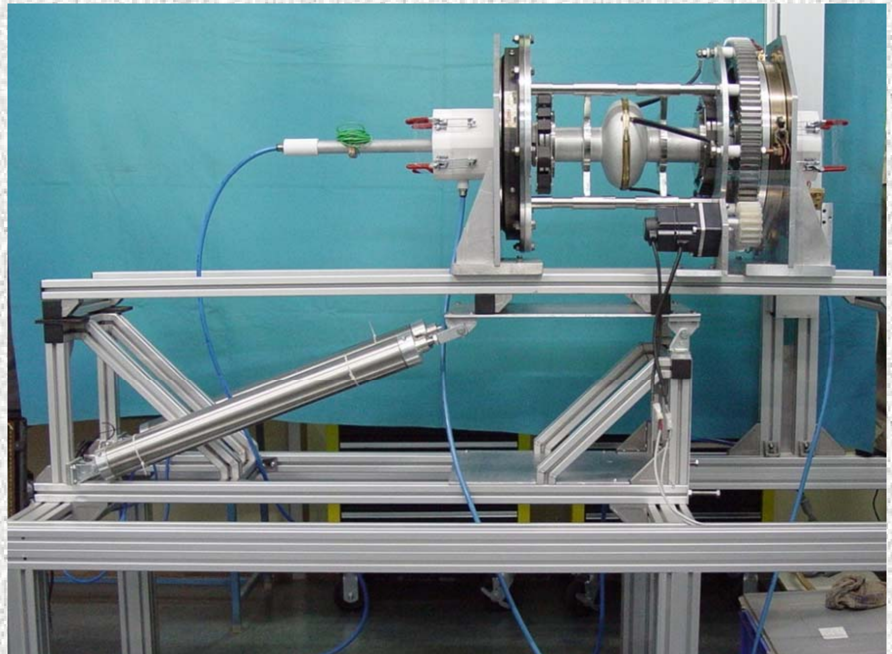


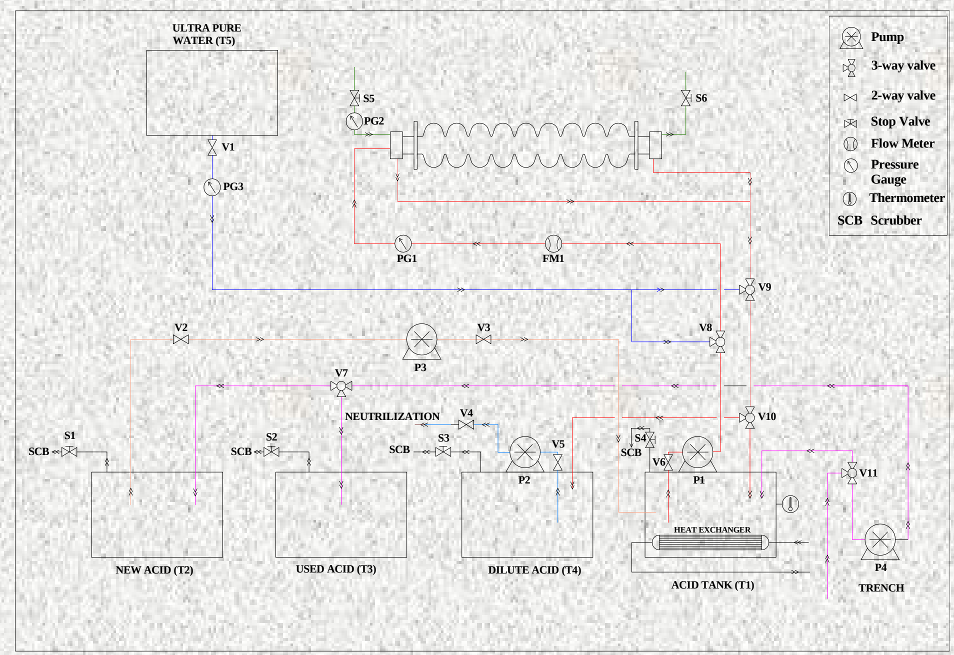
Ultrasonic cleaning facility

Ultrasonic cleaner for single cell cavity & small components

Ultrasonic cleaner for 9 cell cavities

Electro polishing setup





- Bench for electro-polishing of SCRF cavity has been developed, it can process up to nine cell cavity.
- Acid pumps, valves & plumbing for Sulphuric & Hydroflouric acid have been procured.
- 25V – 1000A DC Power supply has been procured.
- The hydraulic circuit has been tested with water

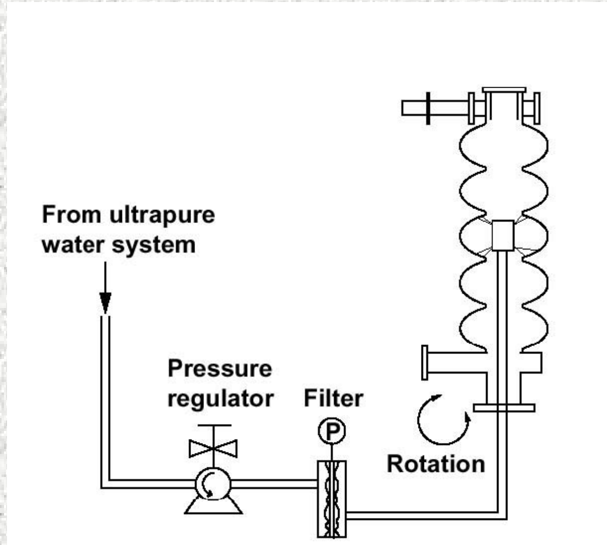
Current density: ~ 50 – 100 mA/cm^2
Material removal rate ~ 0.5 μm/min
Rotational speed~ 0.2 -1 rpm

High Pressure Rinsing Setup

<u>Features:</u>

- Cavity / wand Rotational speed: 2-20 RPM
- Vertical Stroke: 1300 mm
- Vertical movement speed: 60 mm/min
- Ultra-pure water jet. pressure: 80 – 100 bar

Ultra Pure Water Plant



High Pressure Rinsing Set up in Clean enclosure (Class 100)

Thermal Processing Facility

Specification of High Vacuum Furnace	
Orientation	Horizontal
Temperature range	Option-1 1000°C Max Option-2 1400°C Max
Working Vacuum	<1 x 10^{-7} mbar (600°C -1000°C) <1 x 10^{-6} mbar (> 1000°C)
Working Volume	Diameter 400mm Depth 1500mm

- The procurement of high vacuum annealing furnace is in process.
- The facility is expected to be commissioned by mid 2012.

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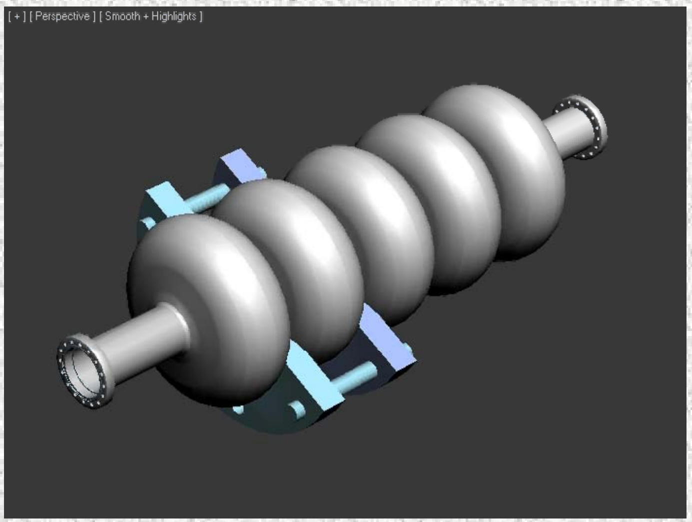
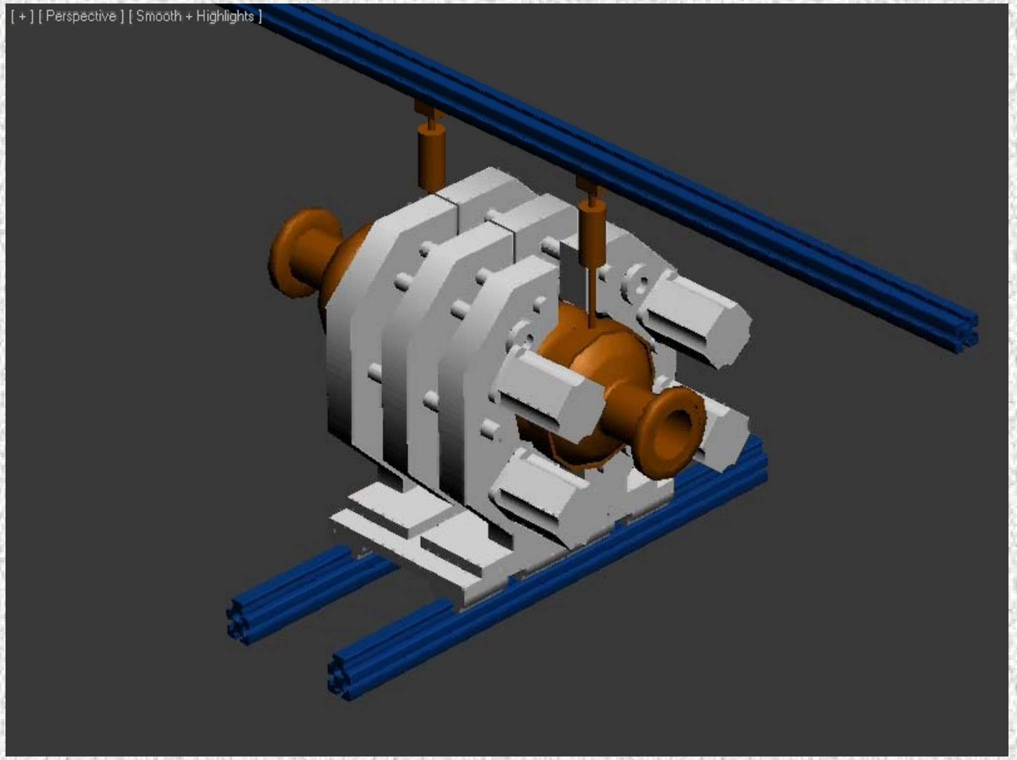
Tuning of SCRF Cavity

- A multicell elliptical accelerating cavity requires a “flat” electrical field profile at the target π-mode frequency
- $E_{min}/E_{max}>0.98$

- Cavity requires cell to cell tuning due to shape deformation during fabrication, material removal at various stages of polishing & also deformation during thermal processing.
- Cavity must be straight & requires an alignment

Tuning Machine is needed for 650 MHz cavity





•A semi automatic tuning machine for 650 MHZ cavity is being planed at RRCAT
.
•Fermi Lab has developed Instrumentation, software and integration for 1.3 GHz Automatic Tuning Machine (DESY, FNAL & KEK Collaboration). This expertise will be beneficial for IIFC to develop a tuning machine for 650 MHz.

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Manual Tuning of single cell

Cavity testing facility

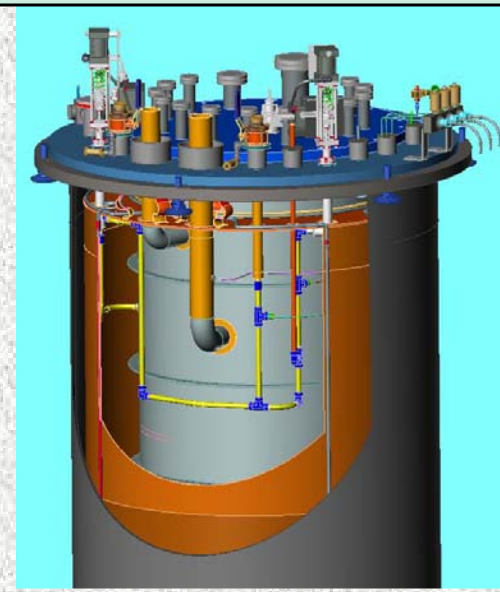
Development of Vertical Test Stand

- Engineering Design of VTS completed in collaboration with FNAL, USA
- Fabrication of VTS for RRCAT in progress with an US industry.
- Data Acquisition and RF Systems for RRCAT VTS in progress.
- Building for housing VTS & cryogenic infrastructure expected to be ready by ………

Development of VTS-2 in collaboration with FNAL

- Single & 9-cell Tesla-style cavities (2 – 6 cavities)
- Single Spoke Resonator cavity 325 MHz
- Triple Spoke Resonator Cavity 325 MHz
  - Measure Q vs. T (T_{min}~1.5 K)
  - Measure Q vs. E_{acc} at 2 K
- cryogenic capacity ~250 W at 2 K
- Magnetically shielded cryostat
  - External (room-temperature) Amumetal® (80% Ni alloy) and internal Cryoperm 10® magnetic shield, designed to attenuate field to <10 mG at cavity
- Radiation shielding to maintain "Controlled Area" status
  - < 5 mrem in an hour immediately outside the shielding

Outside diameter of Vacuum Vessel + outside magnetic shield	≤ 58 inches
Length of Vacuum Vessel (from top flange to crown of head)	211.375 inches
Clear aperture of the Helium Vessel	34 inches
Length of Helium Vessel (from top flange to crown of head)	191.35 inches
80K Shield sits in space between Helium Vessel OD & Vacuum Vessel ID	

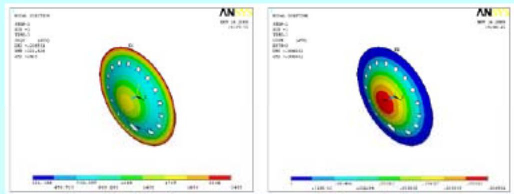


Engineering Design & Analysis of VTS Cryostat

FEA for Top Insert Plate

Analysis with 15 psid external pressure and 4800 lbs uniformly distributed static load conditions

Top Insert Plate Diameter = 43", Thickness = 1.5"



Stress Distribution — Deformation Pattern

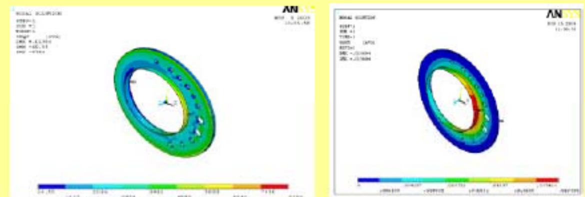
Maximum stress = 2465 psi

Maximum displacement = 0.00655 inch

FEA for Helium Vessel Top Flange

Analysis with 15 psid external pressure and 30312 lbs static load conditions

Flange OD = 60", ID = 37.08", Thickness = 1.5"



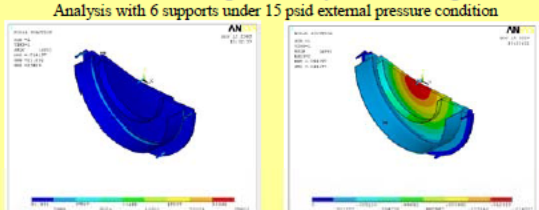
Stress Distribution — Deformation Pattern

Maximum stress = 8786 psi

Maximum displacement = 0.0196 inch

FEA for Top Insert Plate, Helium Vessel Top Flange and Vacuum Vessel Flange Assembly with Leveling Pads

Analysis with 6 supports under 15 psid external pressure condition



Stress Distribution — Deformation Pattern

Maximum Stress in Assembly=5757 psi

Stress at supports ~ 14359 psi

Maximum displacement = 0.0142 inch

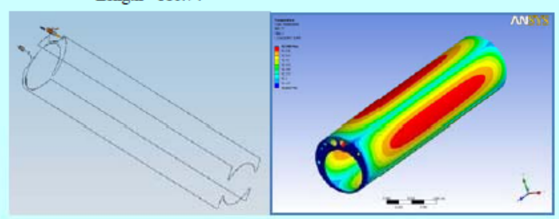
Thermal Design for 80K Shield

Cooling tube lay out for 80 K shield

OD of shield = 49.75"

Length =186.74"

Temperature distribution in 80 K shield assembly



Maximum Temperature = 92.798 K, Minimum Temperature = 92.055 K

MAGNETIC SHIELD DESIGN

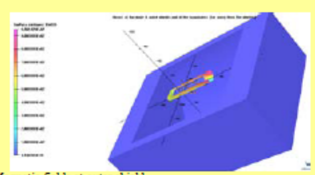
Outer Magnetic Shield :	
Material	Amumetal
Diameter of shield	ID ϕ 54"
Thickness	0.0393"
Location of top of shield from top insert plate	10.75"
Location of bottom of shield from top insert plate	217 "
Inner Magnetic Shield :	
Material	Cryoperm
Diameter of shield	ID ϕ 34. 458"
Thickness	0.0393"
Location of top of shield from top insert plate	43.95"
Location of bottom of shield from top insert plate	185.67"

Surface contours of magnetic fields in the shields

Background Field Bx: 0.5 G,

Relative Permeability - Outer Shield: 40,000,

Inner Shield: 10,000

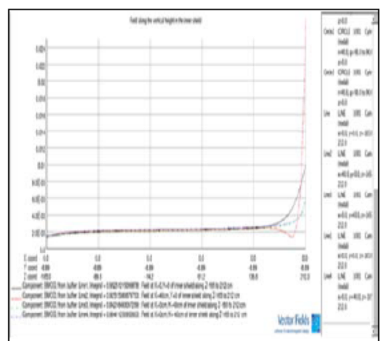


Magnetic fields at outer shield

Maximum : 950 gauss Minimum : 6.56 gauss

Magnetic fields at inner shield

Maximum : 31.81 gauss Minimum : 0.61 gauss



Field along the vertical height in inner shield

Development of Vertical Test Stand

RRCAT & Fermi Lab jointly carried out design of design of various components of 2K VTS Cryostat:

- Liquid Helium Vessel
- 80K shield
- Vacuum Vessel
- Top Insert Plate
- Magnetic shielding (2K + room temperature)
- Piping layout for liquid helium
- 3-D model of the complete VTS-2 assembly

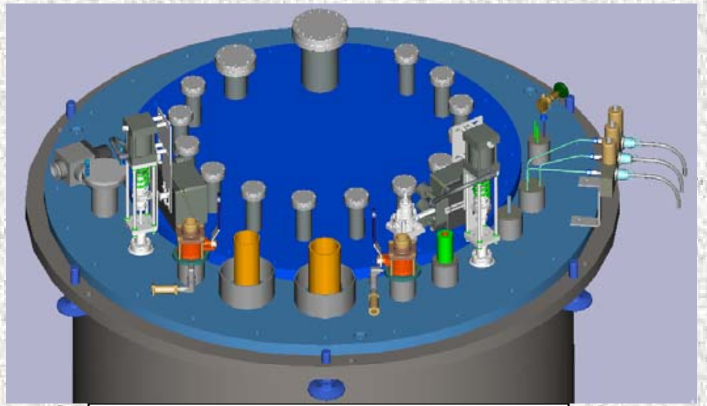
Three VTS cryostats are under fabrication at US vendor under joint supervision of engineers from Fermi Lab and RRCAT.

Expected delivery schedule : Nov 2010 – Feb 2011.

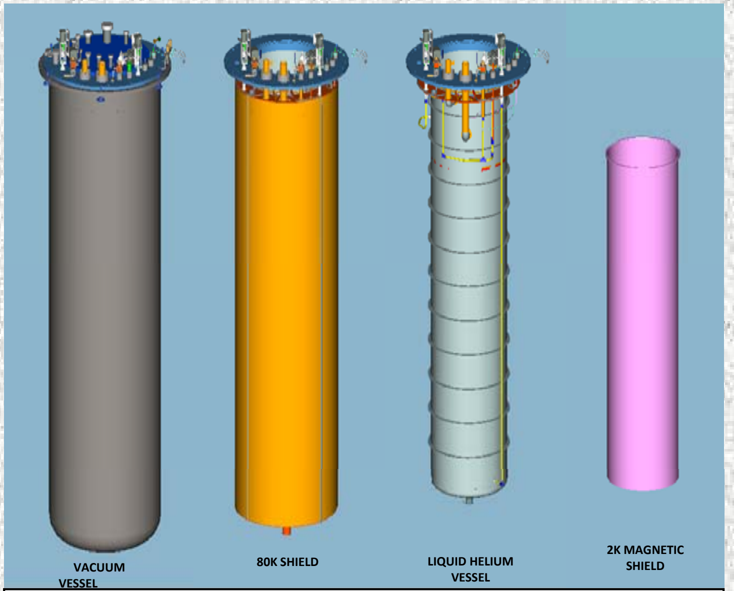
Building to house VTS at RRCAT is under construction and expected to be ready by Mid of 2011

Cryogenics system under process (P K Kush &Team)

Components of RF and DAQ system fro RRCAT VTS is under process and expected to be ready by Dec 2011.
(P Shrivastava & Team – RF and T A Puntambekar & Team – DAQ)



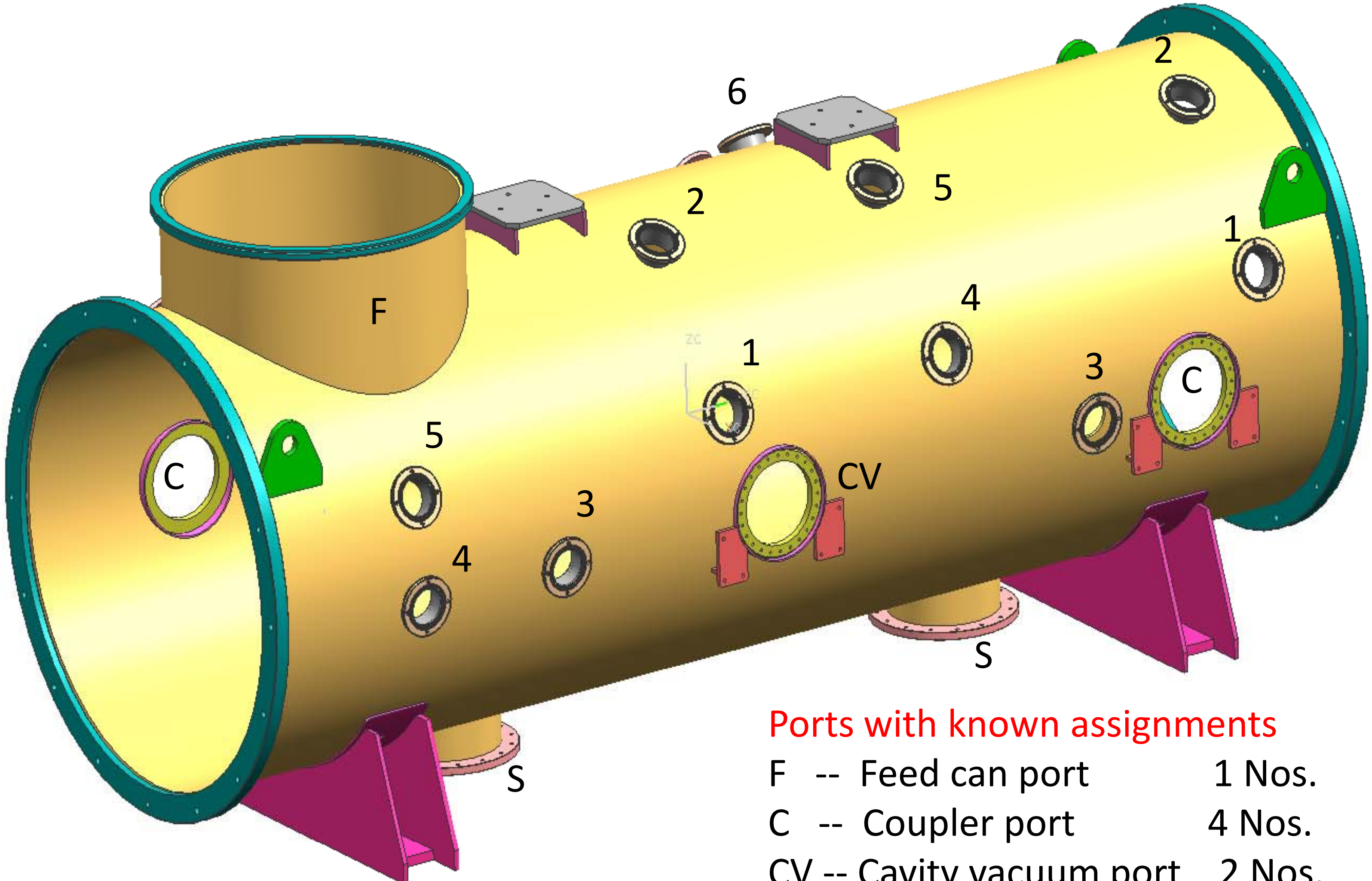
VTS-2 TOP PLATE – CRYOGENIC & VACUUM INSERTS



3-D MODELS OF VTS-2 VESSELS

Pictures of VTS under fabrication at vendor

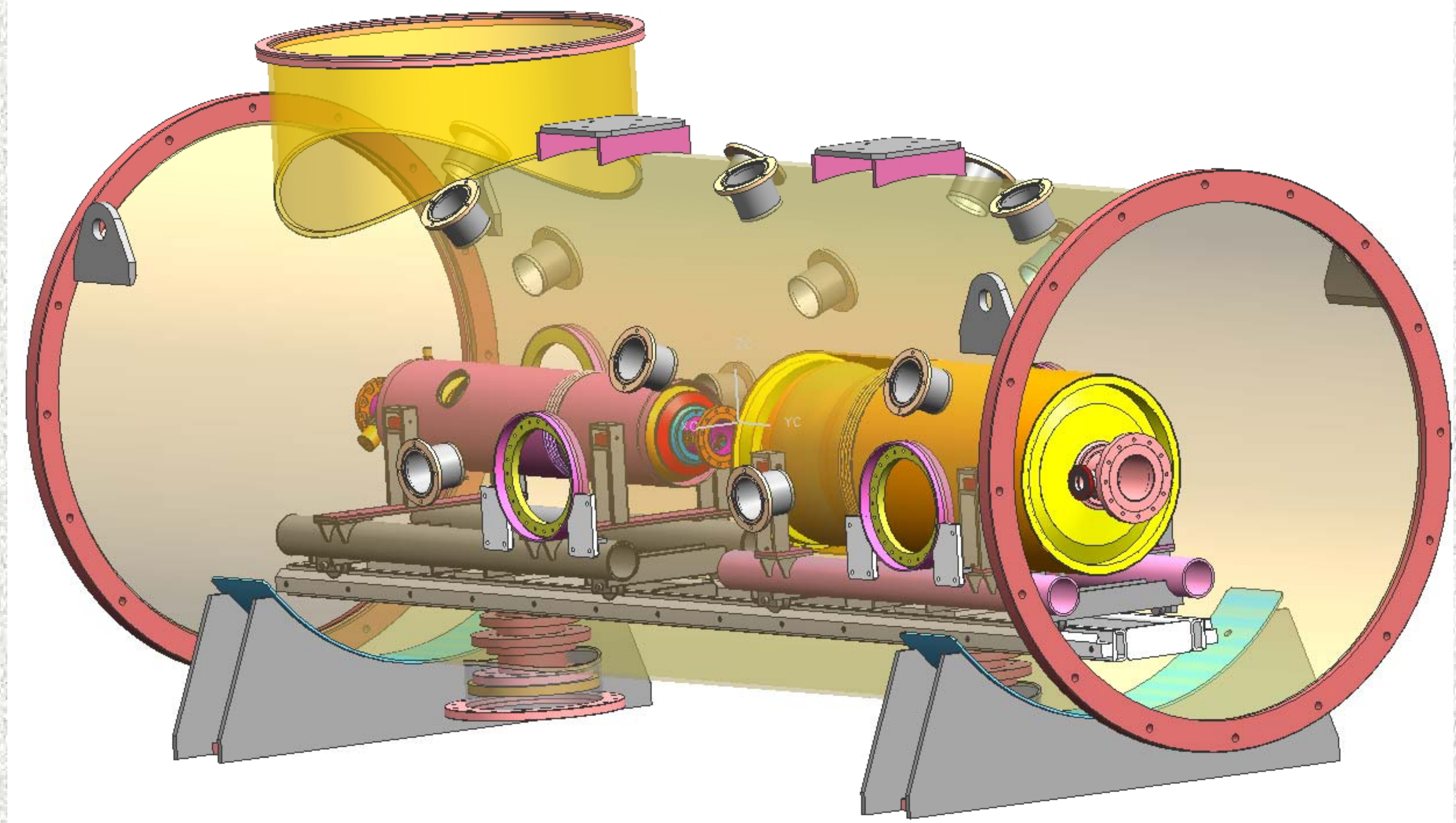
The 3-D Model of Vacuum Vessel of HTS-2
developed at RRCAT in Collaboration with FNAL



Ports with known assignments

F -- Feed can port 1 Nos.
C -- Coupler port 4 Nos.
CV -- Cavity vacuum port 2 Nos.
S -- Support post port 2 Nos.

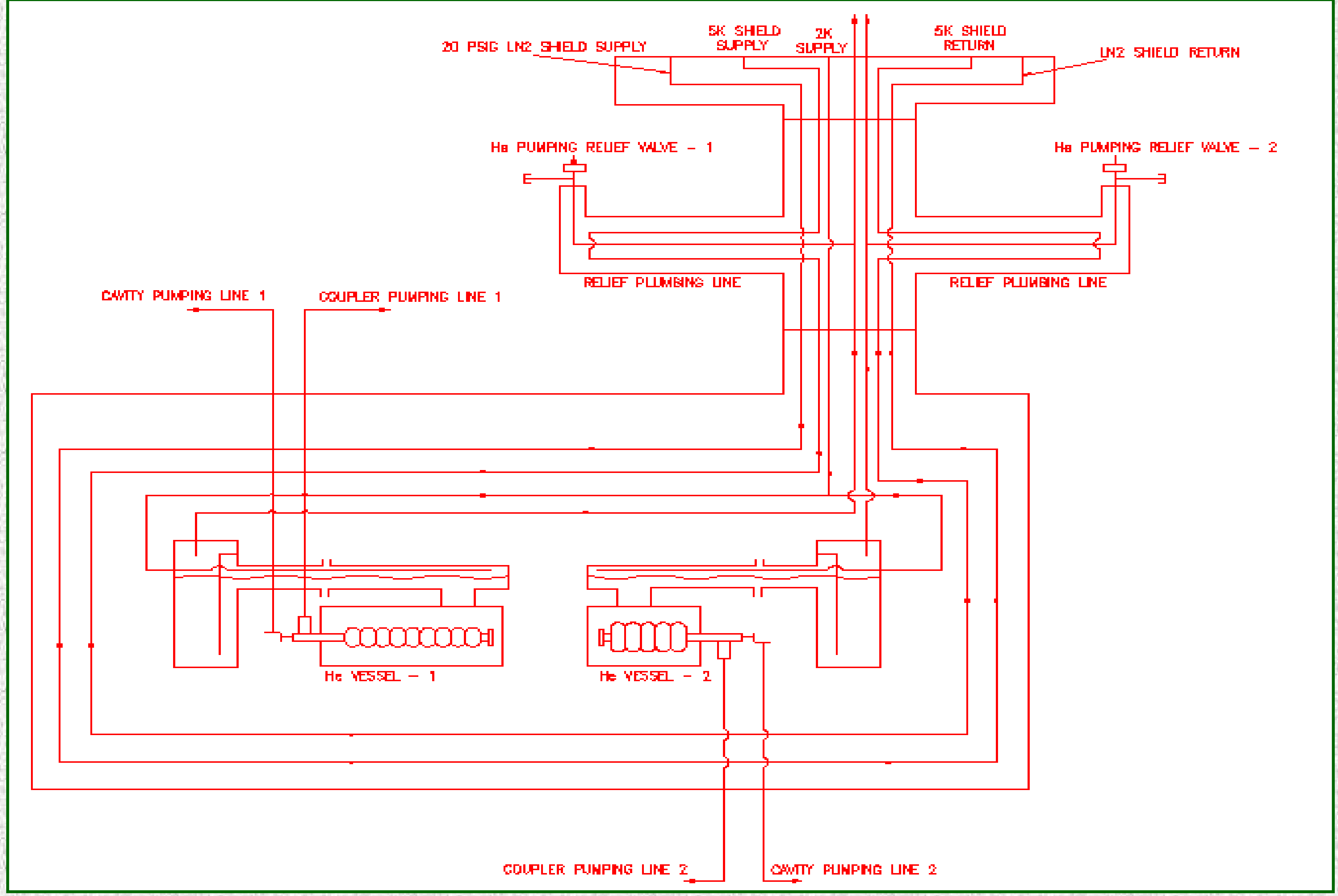
HTS - 2



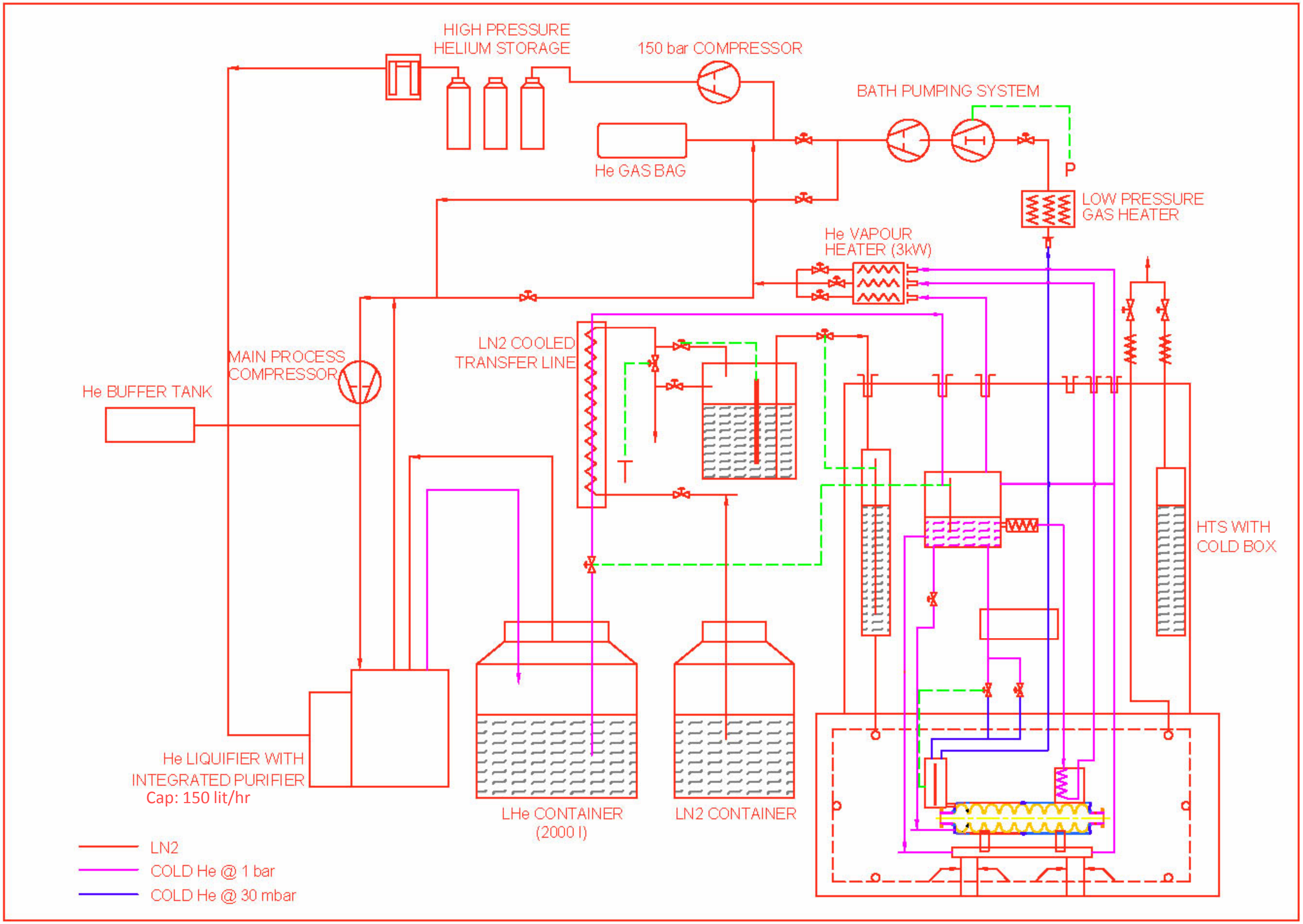
Required Specifications of HTS

Parameter	Value
Mechanical	
Interior usable length	3.5 m
Interior diameter	0.965 m
Option for testing number of cavities	Two 9 cell cavities or operate as a cryomodule
Main Cryogenics	
Temperature	1.8 – 2.2 K, 4.2 K
Capacity	90 W/ 170 W (1.8 K/4.2 K)
Pressure Stability	±0.1 mbar/1 mbar (1.8 K/4.2K)
Static losses	12 mW at 1.8 K (with 4 K shield) (without load of coupler and instrumentation leads)
Secondary Loop	
Table cooling loop	4.5 K
Cavity fill	4.5 K
Coupler cooling	4.5 - 20 K
Radiation shield	77 K
Vacuum Pumps	
Suction pressure	14 mbar
Speed	9000 m^3/hr
RF Power	
Frequency	1.3 GHz
Power	10 kW

HTS-2 Cooling Circuit Option

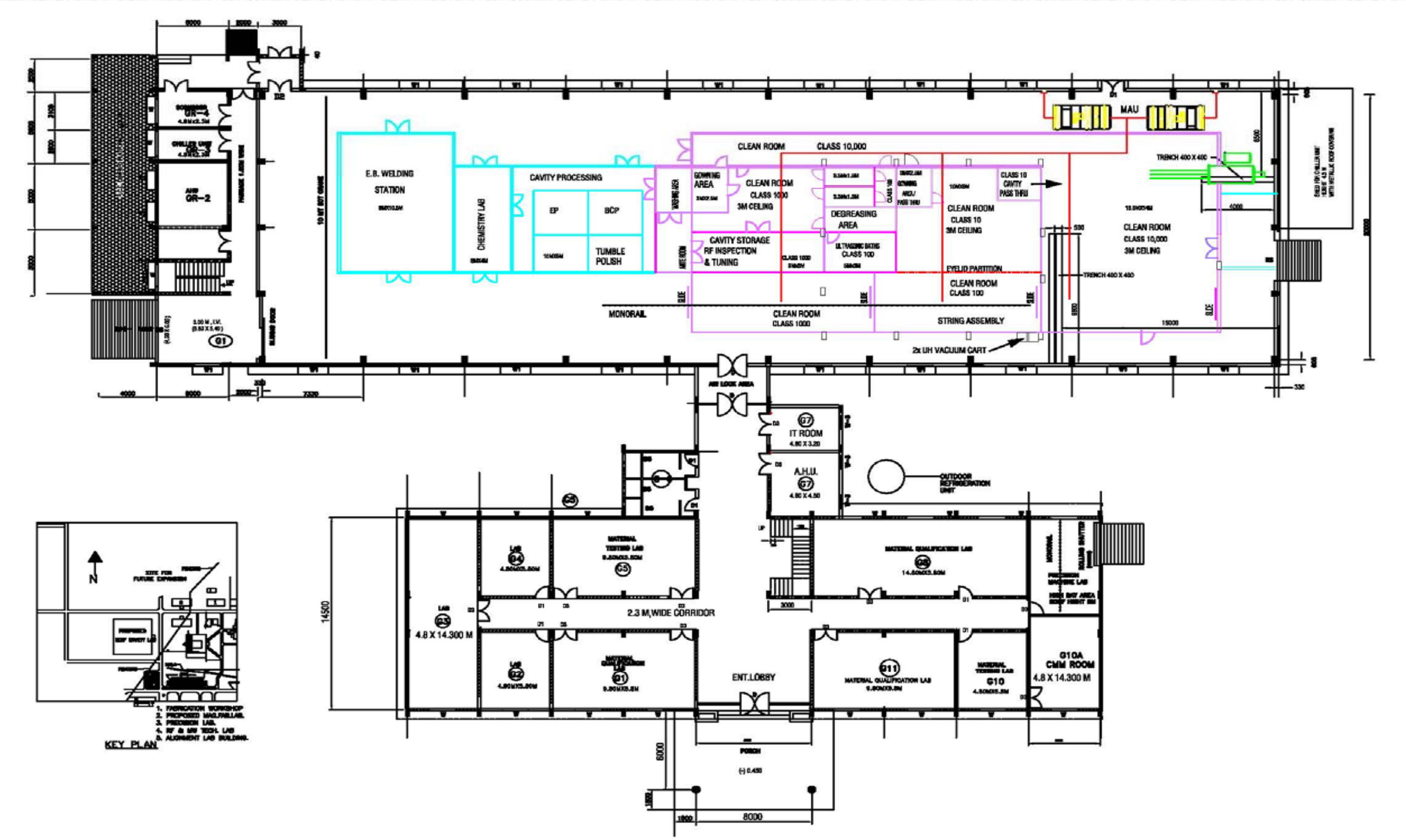


Cryogenic Process Circuit proposed for Horizontal Test Stand

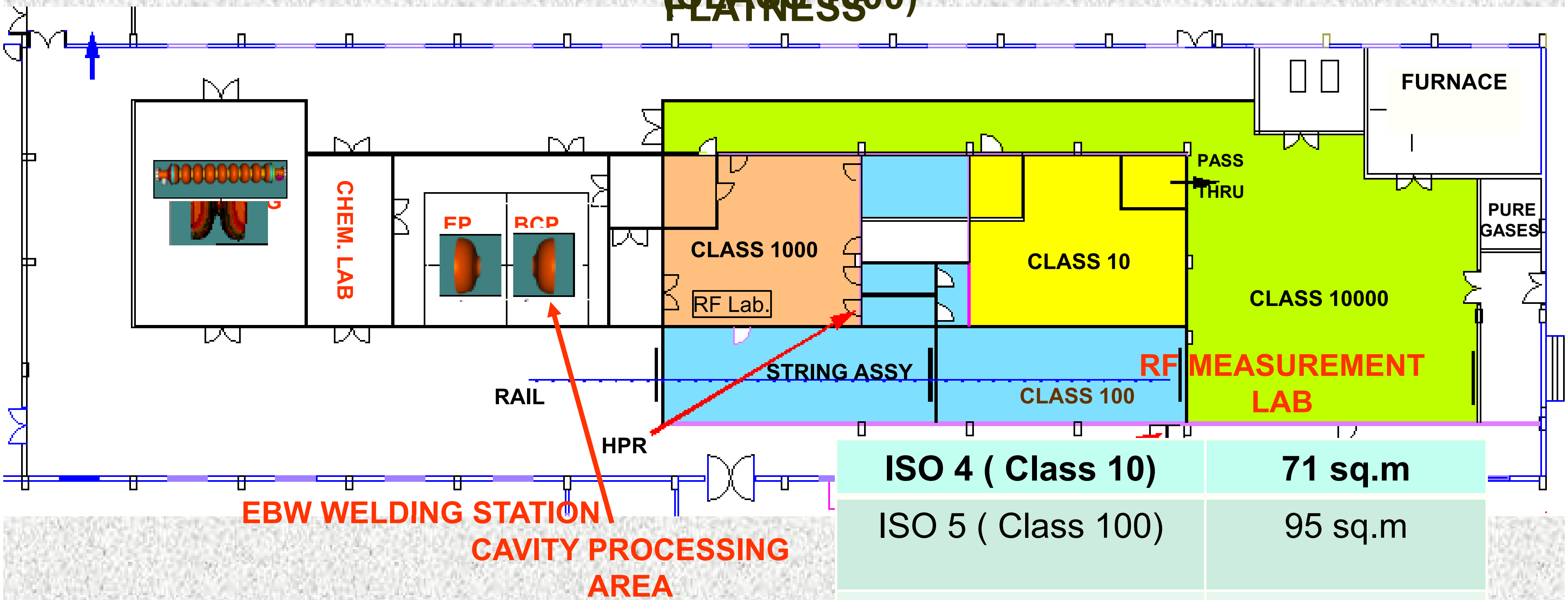


SCRF building & clean room facility

Building Plan for SCRF Facility



SCRF Cavity Movement in SCRF Building



ISO 4 (Class 10)	71 sq.m
ISO 5 (Class 100)	95 sq.m
ISO 6 (Class 1000)	113 sq.m
ISO 7 (Class 10000)	265 sq.m
Total Area	544 sq.m

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Building for SCRF Cavity Development

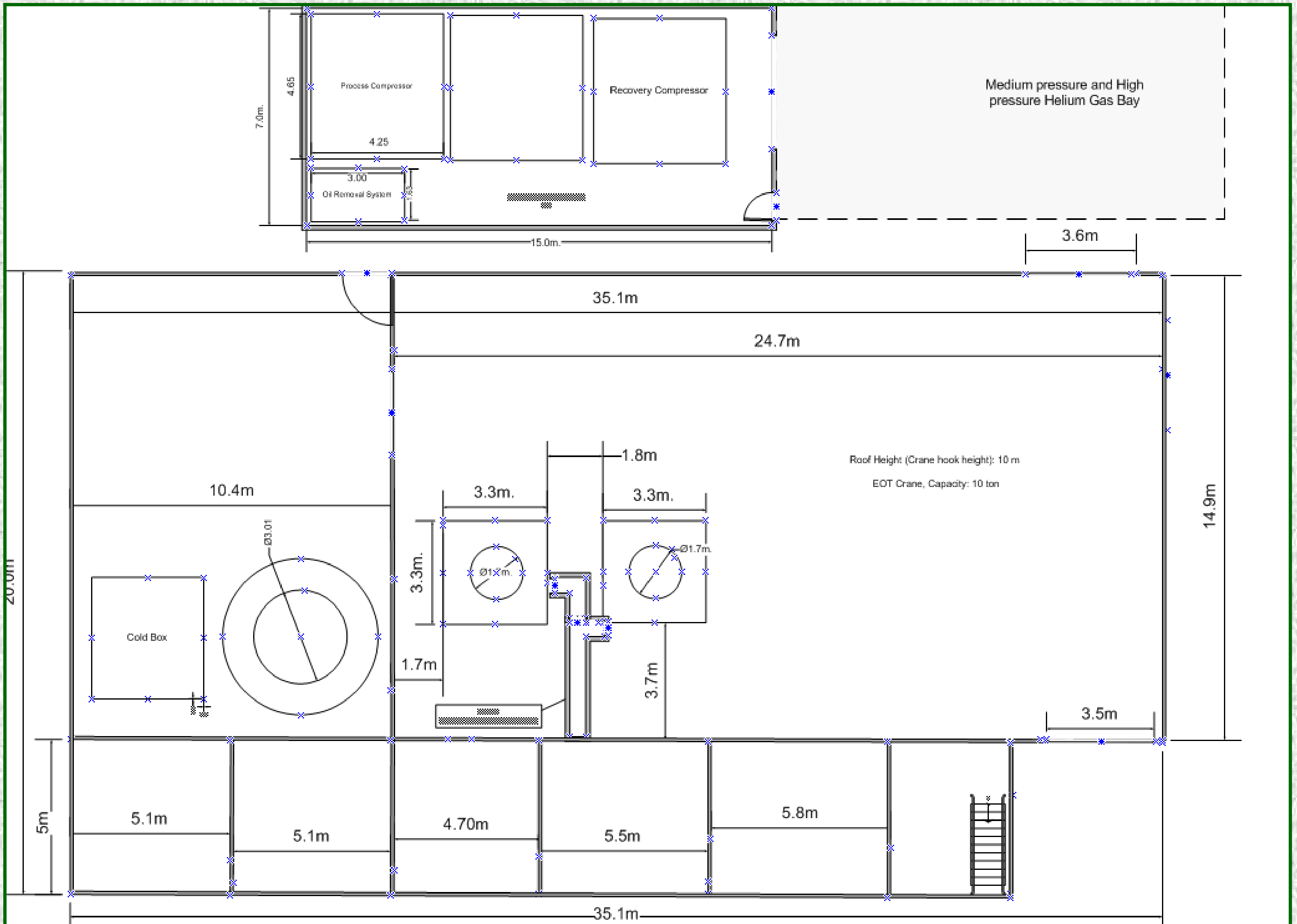
Cavity Processing Building

- Expected to be ready by Apr 11
- The building will house clean rooms, Electron Beam welding machine. High Vacuum Annealing Furnace, Electro-polishing setup, Centrifugal barrel polishing machine etc.

SCRF Lab Building

- Expected to be ready by June'11
- The building will house CMM, SIMS, material testing facility etc

Building for VTS/ HTS, Liquefiers and associated Helium gas handling Equipment



Status of Building during March 2011

Cryogenic Infrastructure

Present facilities:

- Liquid Helium: Linde TCF 20, Capacity 40 Litres/ hr
- Liquid Nitrogen: Capacity 60 liters/ hr

Facility Upgradation in process:

- Liquid Helium Plant 150 lit/hr
  with 10,000 liter capacity main Dewar
- Matching High Pressure Gas Storage
- Helium gas recovery Compressors
- 2K Mechanical Booster pumps
- Cooling water chiller systems

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