IIFC Status Update - DAE

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DAE Technical Coordinators

DOE CD-2/3a Independent Project Review
January 28, 2020

A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

About Us

Srinivas Krishnagopal
Technical Coordinator (DAE), IIFC
Head, Ion Accelerator Development Division, BARC

Accelerator physicist with 33 years experience. Worked on: beam-beam interaction, free-electron lasers, photocathode guns, electron linacs, RFQ, DTL, superconducting proton linacs, beam dynamics and space charge, laser wakefield acceleration.

Purushottam Shrivastava
Technical Coordinator (DAE), IIFC, Director, Proton Accelerator Group, RRCAT
High power RF and Microwave engineering and commissioning of particle accelerators, vertical and horizontal test stands for SCRF cavities, SCRF cavity development. Ion sources, RFQ, DTL, SCRF cavity and solid state amplifiers and state of the art pulse modulators for pulsed proton Linac. Project coordinator, contributions from India in CERN accelerators LHC, CLIC and Linac4.

Outline

- Introduction
- IIFC R&D Phase
- PIP-II Construction Scope
- Breakdown of Deliverables, Schedule and Achievements
- Infrastructure
- Risk Management
- QA
- EH&S
- Summary

1. Does the proposed technical design satisfy the performance requirements? Do the Key Performance Parameters (KPP's) provide a satisfactory indication of the project's completeness?
2. Are the interfaces to the existing accelerator complex identified and defined? Do the planned hardware upgrades to the existing complex fully support the ultimate performance goal of 1.2 MW operation of the complex?
3. Is the resource-loaded schedule complete, consistent and credible so that it can serve as the cost and schedule part of the project's performance baseline? Is it compatible with the funding guidance provided by High Energy Physics? Have the project's risks been fully analyzed and accounted for in the contingency estimate?
4. Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?
5. In-kind international contributions are described in bi-lateral agreements called Project Planning Documents (PPD's). Does the project baseline and in-kind scope contributions defined in the PPD's present the complete scope required to meet the KPP's? Are the delivery dates for in-kind scope sufficiently understood to establish the credibility of CD-4 date? Does the Project have a credible plan for managing the deliverables including acceptance, Q/A, and risk management.
6. Does the project have a certified Earned Value Management System and have they demonstrated their ability to utilize it as an effective project management tool?
7. Is the documentation required by DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* for CD-2 complete and in good order?
8. Are Environment Safety and Health aspects being properly addressed?
9. Has the project responded satisfactorily to the recommendations from the previous independent project review?
10. In regard to CD-3a; is the scope of the 3a package appropriate and justified? Are the associated designs sufficiently mature to support the requested CD-3a cost and schedule? Have the appropriate design reviews been completed?

Introduction

- India is interested in High Intensity Superconducting Proton Accelerator (HISPA) technology for building an Indian Facility for Spallation Research (IFSR), radio-isotope production, Radio-active Ion Beam (RIB) facility, etc.

- Participation in PIP-II will enable us to get proven HISPA technology, train our scientists and engineers, and develop essentially all individual components of a HISPA system.

- Hence our interest in contributing a wide spectrum of components to PIP-II construction, besides involvement in the PIP-II R&D phase.

Indian involvement in PIP-II R&D Phase

1) SSR1 cavity fabrication and dressing
2) SSR2 cavity design, fabrication, dressing, processing and testing
3) LB650 cavity design, fabrication, dressing, processing and testing
4) HB650 cavity design, fabrication, dressing, processing and testing
5) SSR2 and HB650 cryomodule design
6) RF couplers at 325 & 650 MHz
7) 325 MHz RF amplifiers (7 kW & 20 kW)
8) 650 MHz RF amplifiers (40 kW and 70 kW)
9) NC quadrupoles and SC solenoids
10) LLRF & RFPI systems
11) HTS

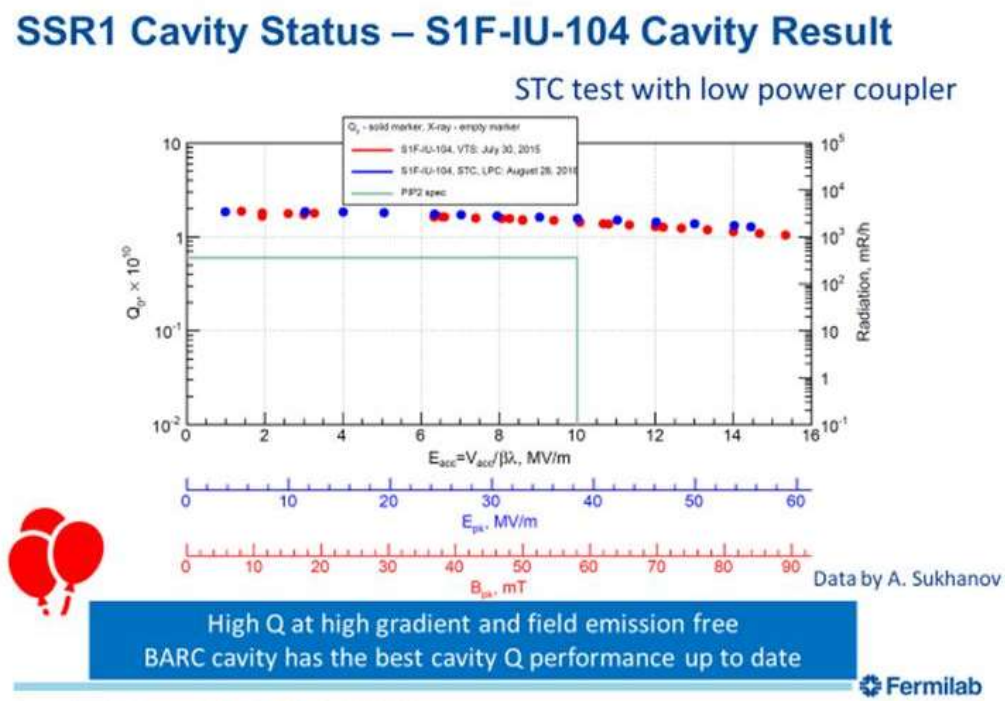
Proposed DAE scope in PIP-II construction phase

1) SSR1 cavities and components
2) **SSR2 cryomodule with cavities and components**
3) LB650 cavities and components
4) **HB650 cryomodule with cavities and components**
5) HB650 cavities and components
6) 325 MHz RF amplifiers
7) 650 MHz RF amplifiers
8) Superconducting solenoids and warm magnets

(1A) SSR1 cavities and components: Deliverables & Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
SSR1 cavities and components			
SSR1 Jacketed cavities	18	Apr 2022	Sep 2025
SSR1 Tuners	18	Apr 2022	Sep 2025
SSR1 Superconducting Solenoids	10	Feb 2023	Dec 2023
RFPI for one SSR1 cryomodule	8	Sep 2023	Dec 2023
LLRF for one SSR1 cryomodule	4	Sep 2023	Dec 2023

(1B) SSR1 cavities and components: Achievements



Two 325 MHz Single Spoke Resonator (SSR)-1 type Niobium cavities have been manufactured & dressed (jacketed) with SS Helium vessel by DAE under IIFC.

One of these cavities, S-104, has been integrated into the first SSR1 cryomodule in PIP2IT.

(2A) SSR2 cryomodule with cavities & components: Deliverables & Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
SSR2 cryomodule with cavities and components			
SSR2 Jacketed Cavities	5	Feb 2026	June 2026
SSR2 RF Couplers	5	Feb 2026	June 2026
SSR2 Tuners	5	Feb 2026	June 2026
SSR2 CM + Components	1	Feb 2026	June 2026
Superconducting Solenoids	4	Feb 2026	June 2026
RFPI systems	5	Feb 2026	June 2026
LLRF systems	3	Feb 2026	June 2026

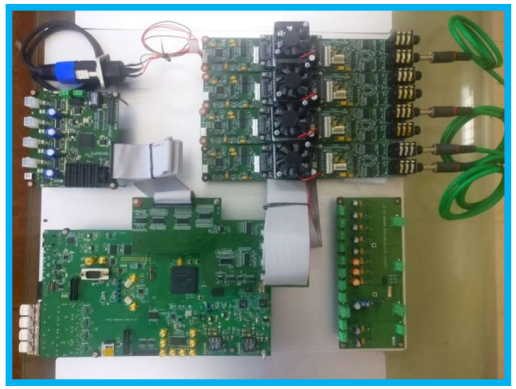
(2B) SSR2 cryomodule with cavities & components: Achievements

- SSR2 physics & mechanical design has been done independently by BARC.
- DAE visitors at Fermilab involved in SSR1 cryomodule.
- During the PIP-II R&D phase DAE will design the SSR2 cryomodule, based on the SSR1 CM design
- SSR1 tuners already developed
- One 325 MHz RF coupler almost ready. 650 MHz coupler under development.

TRS Parameter	TRS Value	SSR2 v3.1 FNAL	SSR2 v3.1 IPNO	SSR2 v3.2 BARC
Sensitivity to LHe pressure fluctuations of dressed cavity, Hz/mbar	< 25	0.8	1.67	9.06
Lorentz Force Detuning coefficient, Hz/(MV/m)^2	< 4	-3.65	-3.87	-3.97
Longitudinal stiffness, kN/mm	< 16	17.3	16.8	10.06
Operating frequency tuning sensitivity, kHz/mm	> 250	315	315	330.8

LLRF

Digital Module



Boards of Resonance Control System

RFPI

LLRF & RFPI systems installed and operating in the LEHIPA accelerator at BARC.
Advanced versions will be tested at HTS at RRCAT.

(3A) LB650 cavities & components: Deliverables & Schedule

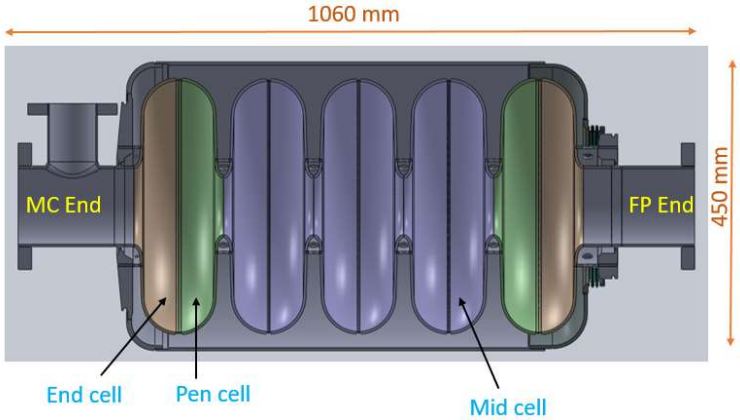
Deliverables	Quant.	Early Delivery	Late Delivery
LB650 cavities and components			
LB650 Jacketed Cavities	4	Apr 2026	Jun 2026
LB650 RF Couplers	4	Apr 2026	Jun 2026
LB650 Tuners	4	Apr 2026	Jun 2026

(3B) LB650 cavities & components: Achievements

Design & analysis of low beta (ß = 0.61) 5 cell LB650 cavity

✓ Optimization of cavity parameters have been carried out based on the following criteria as per FRS

- Lorentz Force Detuning Coefficient
- Helium Pressure Sensitivity
- Cavity tuning sensitivity
- Cavity longitudinal stiffness



✓ The optimized stiffener ring radius is taken as 100 mm for tuner stiffness of 40 kN/mm and thickness of cavity wall & stiffener ring as 4.2 & 4.0 mm respectively.

Fabrication of second single cell cavity

✓ Electron Beam Welding of the cavity has been carried out at IUAC, Delhi.

✓ Frequency measurements of the cavity was done at VECC and the value is found to be 645.9 MHz.

(4A) HB650 cryomodule with cavities & components: Deliverables and Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
HB650 cryomodule with cavities and components			
HB650 Jacketed Cavities	6	Jun 2025	Aug 2025
HB650 RF Couplers	6	Jun 2025	Aug 2025
HB650 MHz Tuners	6	Jun 2025	Aug 2025
HB650 CM + Components	1	Jun 2025	Aug 2025
RFPI systems	6	Jun 2025	Aug 2025
LLRF systems	3	Jun 2025	Aug 2025

(4B) HB650 cryomodule with cavities & components: Achievements

1. Design of 70K Thermal Shield

- Calculations for mass flow rate and h value finished, Transient thermal analysis of shield indicates 24 Hrs safe linear cool down.
- Experimentation in scale down thermal shield are under progress

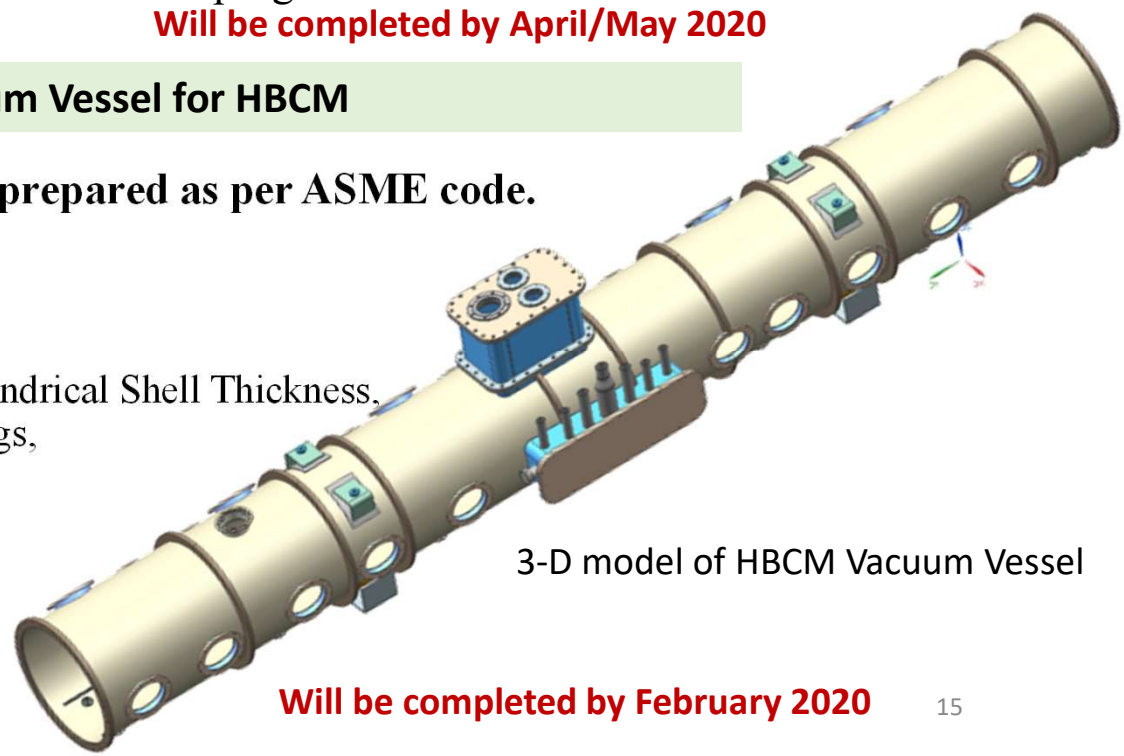
Will be completed by April/May 2020

2. Design of Vacuum Vessel for HBCM

Vacuum vessel design note for HB650 has been prepared as per ASME code.

Calculations and analysis done for:

- Vacuum Vessel Cylindrical Shell Thickness,
- Permissible Out of Roundness of the Vessel Cylindrical Shell Thickness,
- Analysis and Calculations for the Stiffening Rings,
- Main vessel Shell Openings (As per Sec VIII),
- Saddle support of Vacuum Vessel
- Flanges, Bolts and Welds for the Vacuum Vessel



3-D model of HBCM Vacuum Vessel

Will be completed by February 2020

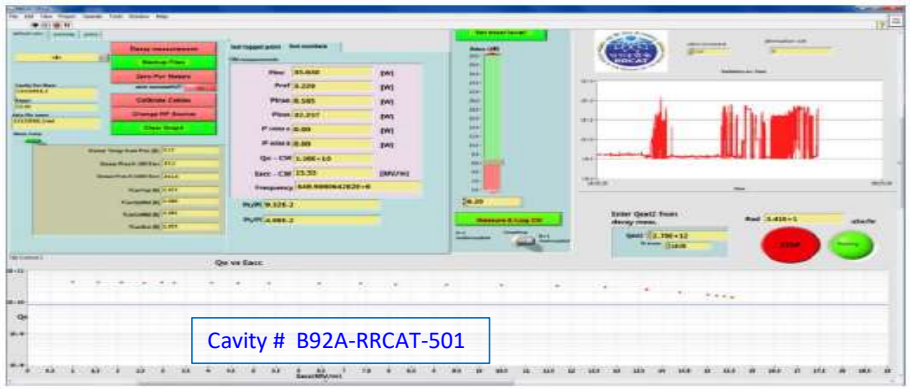
(5A) HB650 cavities & components: Deliverables and Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
HB650 cavities and components			
HB650 Jacketed Cavities	14	May 2025	Aug 2027
HB650 RF Couplers	14	May 2025	Aug 2027
HB650 MHz Tuners	14	May 2025	Aug 2027

(5B) HB650 cavities & components: Achievements

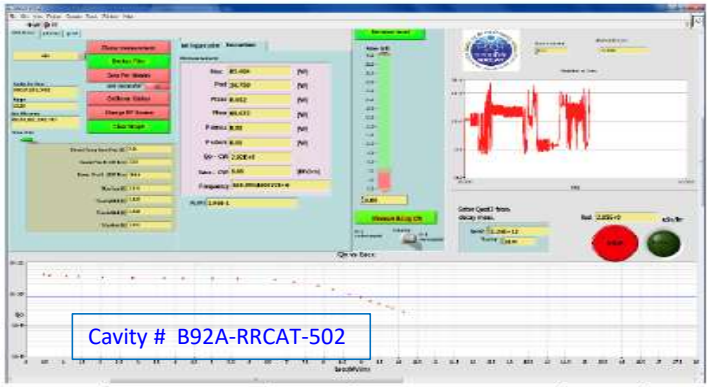
➢Four Five-cell SCRF cavities fabrication have been completed.

Lever Tuner – Testing and qualification up to LN2)



The cavity achieved E_{acc} = 15.5 MV/m with low field Q = 5×10^{10}

VTS test result



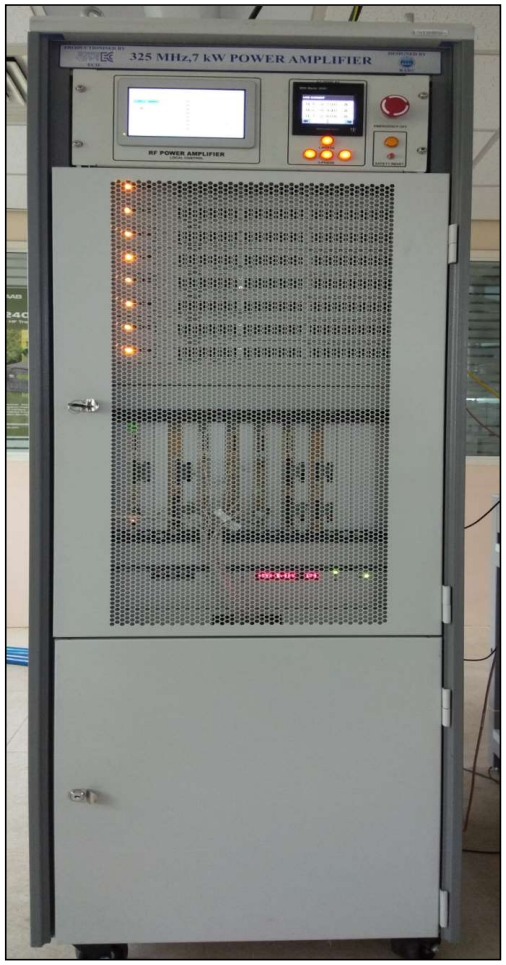
The cavity achieved E_{acc} = 10.1 MV/m with low field Q = 6×10^{10} ,

- Cavity # B92A-RRCAT-502 : Shipped to Fermilab (Jan 2020)
- Cavity # B92A-RRCAT-503 : Ready for VTS test after cable change (Jan 2020)
- Cavity # B92A-RRCAT-504 : Under processing, expected to be VTS tested in Feb 2020
- Cavity # B92A-RRCAT-501 : Preparation to dressing in progress. planned in Jan, 2020

(6A) 325 MHz RF Amplifiers: Deliverables and Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
325 MHz RF Amplifiers			
7 kW 325 MHz Solid State RF Amplifiers	9	Mar 2024	Jun 2024
20 kW 325 MHz Solid State RF Amplifiers	40	Oct 2024	Oct 2026

(6B) 325 MHz RF Amplifiers: Achievements



First 325 MHz RF amplifier has been successfully tested at ECIL in presence of Fermilab & DAE officials on April 30th and May 1st , 2019. This amplifier is now at Fermilab and ECIL team is here to commission it.

Next 8 amplifiers are being wired and tested and are expected to be shipped to Fermilab by the end of Feb 2020.

(7A) 650 MHz RF Amplifiers: Deliverables and Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
650 MHz RF Amplifiers			
40 kW 650 MHz Solid State RF Amplifiers	40	Sep 2024	Apr 2026
70 kW 650 MHz Solid State RF Amplifiers	31	May 2025	Feb 2027

(7B) 650 MHz RF Amplifiers: Achievements

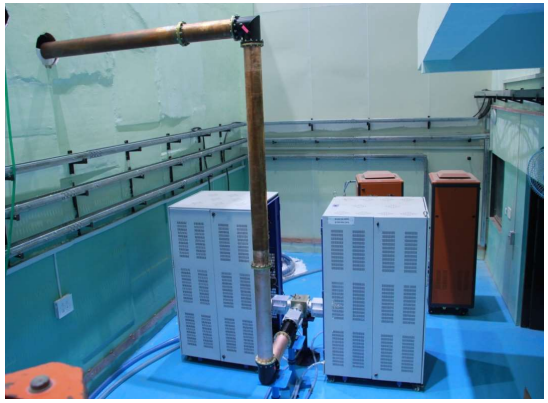
650 MHz RF amplifier acceptance testing at RRCAT by Fermilab Team

Tests : Output Power (650 MHz) : 36 kW ,harmonics < -30 dBc

Gain: 70 dB, RF radiation<0.1 mW/cm2 at 1m,

Input Mains supply: 3 Phase AC

650 MHz amplifier integrated with HTS at RRCAT

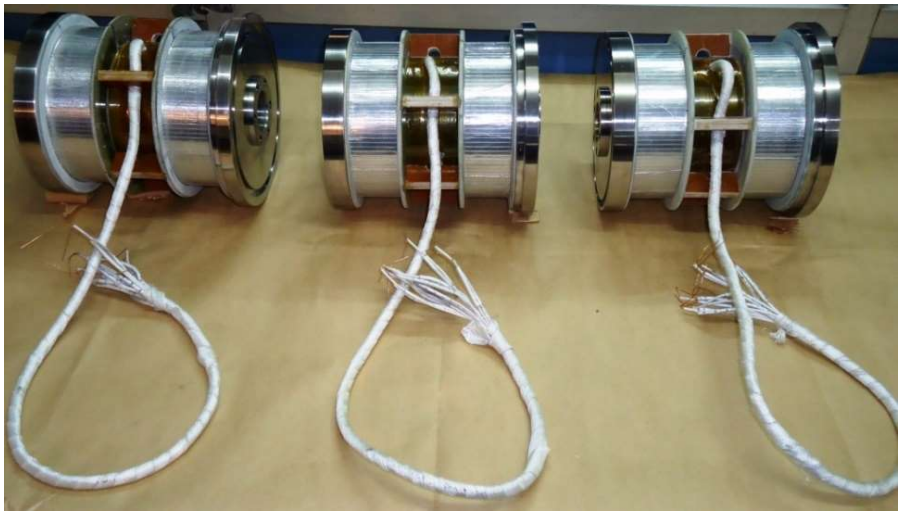


(8A) Superconducting solenoids & warm magnets: Deliverables and Schedule

Deliverables	Quant.	Early Delivery	Late Delivery
Superconducting Solenoids and Warm Magnets			
Superconducting Solenoids	19	Aug 2023	Sept 2024
LB/HB650 Warm Unit Quads	47	May 2023	Nov 2024
LB/HB650 Warm Unit Correctors	44	Aug 2023	Nov 2024
MEBT Quadrupoles (3 triplets = 9 individual quads)	3	Jan 2023	Apr 2023

(8B) Superconducting solenoids & warm magnets: Achievements

- All PIP2IT MEBT magnets (quads and dipole correctors) designed and built at BARC.
- Magnets installed in PIP2IT and operated successfully, with beam.



- Room temperature electrical and magnetic qualifications done on fabricated magnet assemblies.
- Cold tests at 4.2 K & 2.1 K successfully carried out at BARC.

SRF Infrastructure in DAE Laboratories

- Substantial SRF infrastructure for cavity fabrication, processing and testing already set up at RRCAT
- Infrastructure for magnet & RF coupler development and testing set up at BARC
- Infrastructure for RF amplifiers set up at BARC and RRCAT, and for series production of RF amplifiers set up and being augmented at ECIL
- Infrastructure for RF electronics set up at BARC
- Infrastructure for cavity fabrication being set up at BARC. Infrastructure for cavity processing and testing being pursued at BARC and VECC.

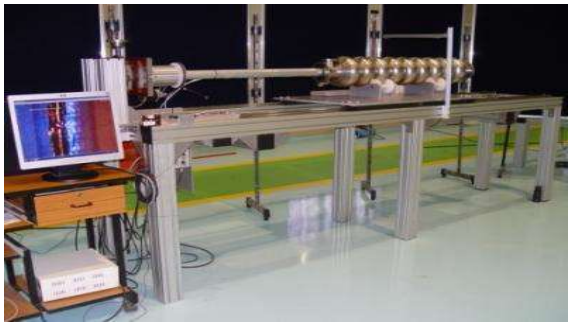
Infrastructure for SRF cavity fabrication & inspection

Cavity fabrication & inspection facility

Cavity Forming Facility

15 kW EBW Machine

3D CMM



Optical Inspection Bench

Material Characterization facility

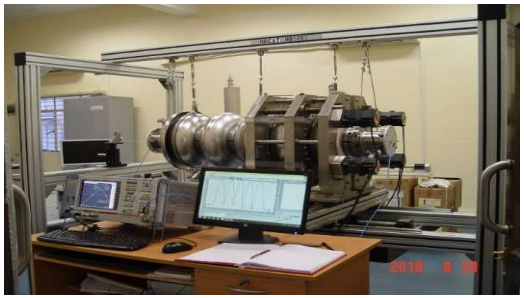
SIMS Facility

Universal Testing Machine

Laser scanning confocal microscope

Infrastructure for processing SRF cavities

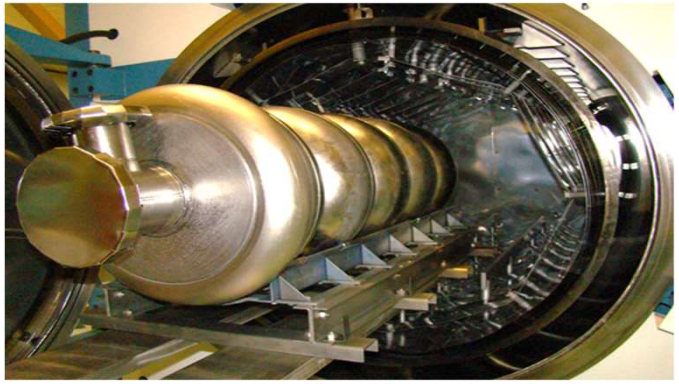
Optical Inspection



Cavity Tuning

Electropolishing

High Pressure Rinsing



High Temperature Annealing

Low temperature baking at 120°C

Cleanroom Assembly

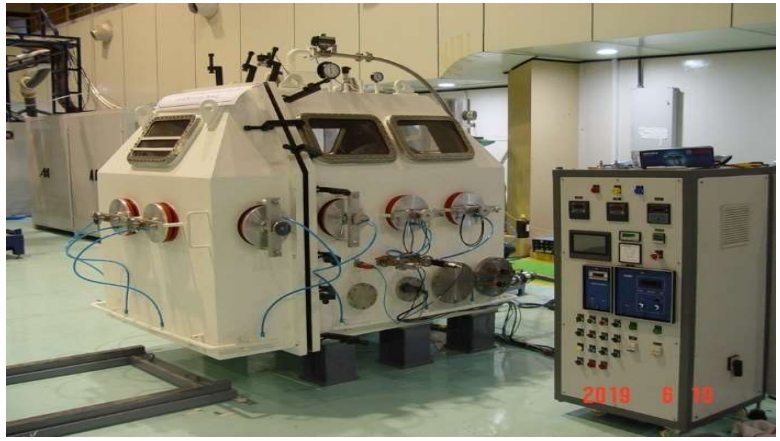
Infrastructure for testing of SRF cavities at 2K and dressing

Cavity mounted on VTS insert

Cavity being lowered in VTS cryostat

Vertical Test Stand Facility

Insertion bench



Welded glove box for Cavity Dressing

Risk Management

- DAE has identified three major general, non-technical, risks: export control, third-party IPR and unsatisfactory conclusion of the PIP-II R&D phase. DAE continues to engage with Fermilab and DOE to mitigate these risks.

- Many technical risks will be addressed during the PIP-II R&D Phase, when DAE will be making prototypes of almost all the construction phase deliverables.

- Before and during the construction phase DAE will engage with Fermilab in identifying and addressing all residual risks, and for activating remedial measures to mitigate these risks.

Quality Assurance

- DAE already has strong QA/QC processes and procedures in place in its laboratories. Most of the R&D phase deliverables are being delivered in conformance with these procedures, and the successful development and testing of these deliverables will serve to validate them.

- For the construction phase, DAE will continue to follow all QA processes and regulations that are already in force at its laboratories.

- The QA/QC Coordinators will work with their Fermilab counterparts to ensure that PIP-II QA/QC requirements are met.

EH&S

- DAE already has strong EH&S processes in place in its laboratories. Most of the R&D phase deliverables are being delivered in conformance with these processes, and the successful development and testing of these deliverables will serve as validation of these Plans.

- For the construction phase, DAE will continue to follow all Safety processes and regulations that are already in force at its laboratories. These procedures cover industrial, chemical, fire and radiation safety, hazard analyses, etc. Construction phase activities will be governed by the oversight and regulatory processes and authorities already in place in the DAE laboratories.

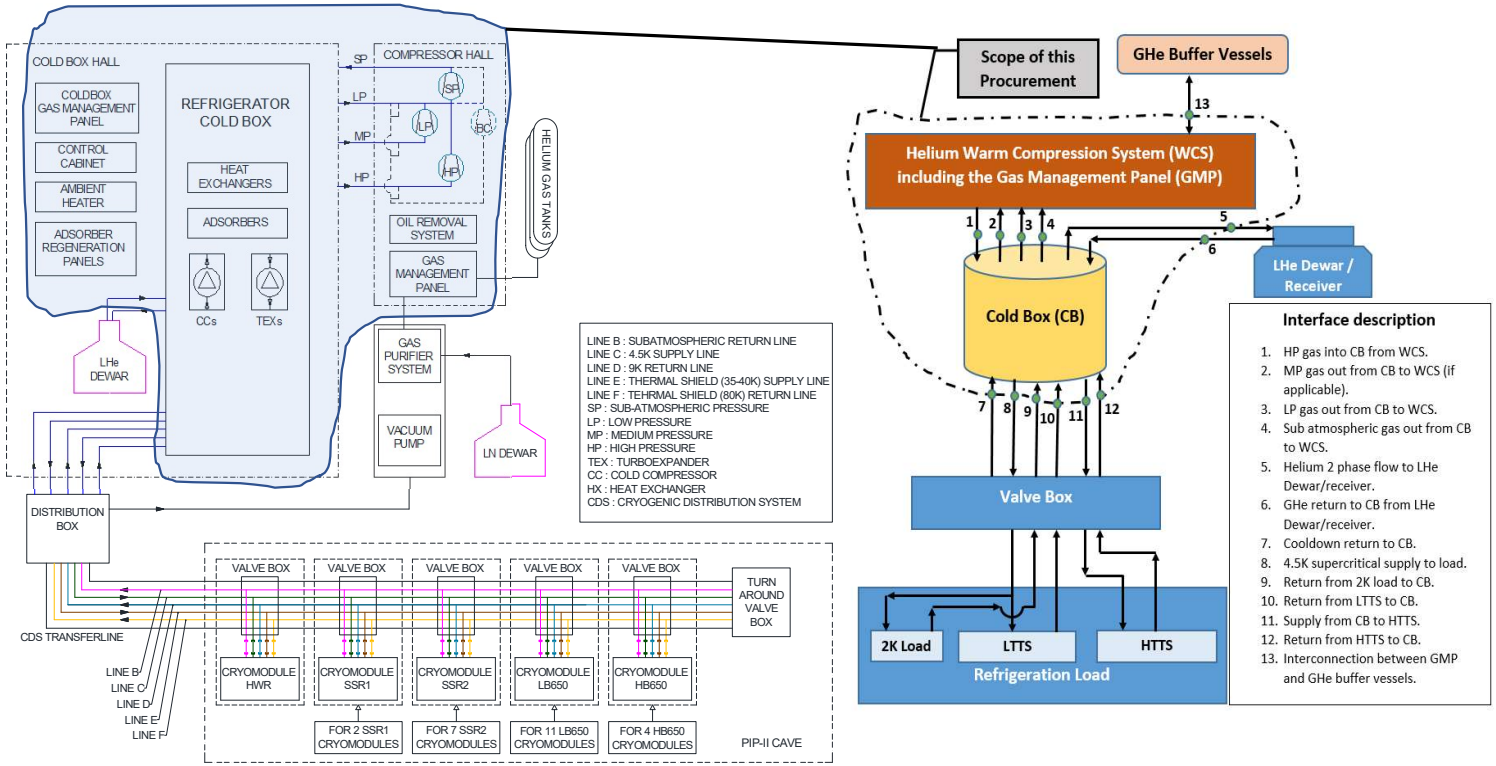
- DAE will share with Fermilab and other Partners any relevant information related to safety issues found with any of the deliverables, either in design or production.

Conclusion

- DAE has a strong interest in HISPA technology and therefore in participation in PIP-II.
- Much infrastructure has been set up, technology has been mastered, people have been trained in the PIP-II R&D phase – and the process continues.
- DAE has a clear plan for its deliverables in the PIP-II construction phase, and is gearing up to augment SRF infrastructure.
- DAE will work with Fermilab to ensure that requisite technical and safety requirements are met.

One more thing …

Superfluid Helium Cryogenic Plant (SHCP)



Required Refrigeration Capacity of the SHCP

Capacity (W)	HTTS (70 K)	LTTS (5 K)	2 K
Maximum	≥ 9,100	≥ 1,500	≥ 1,900
Nominal	≥ 7,000	≥ 1,150	≥ 1,750

Total Cost

In Euro	In INR
18 million	143 crores

Expect to place PO in a week or two.