FT3-4Ra

First experiments with SST-1 Tokamak

Y.C. Saxena and SST-1 Team

FT3-4Rb

Superconducting Magnets of SST-1 Tokamak

Subrata Pradhan, Y. C. Saxena, B. Sarkar, G. Bansal,
A. N. Sharma, K. J. Thomas, V. Bedakihale, B. Doshi,
C. P. Dhard, U. Prasad, P. Rathod, R. Bahl, A. Varadarajulu,
A. Mankani & SST-1 Team

Institute for Plasma Research, Bhat, Gandhinagar 382 428, INDIA

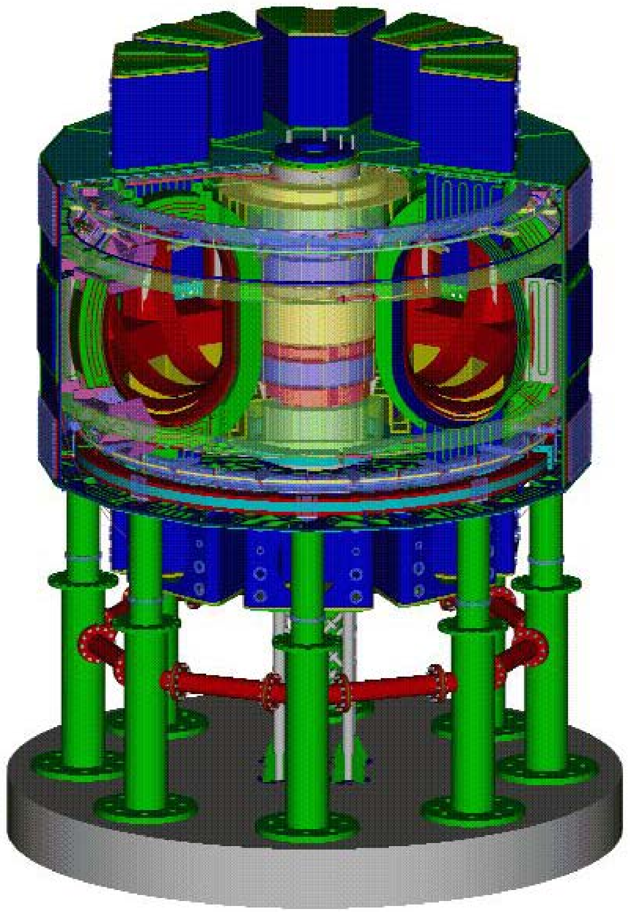
Plan of Talk

- Objectives of SST-1 Tokamak
- SST-1 Parameters
- SST-1 Subsystems, assembly and integration
- Cryogenics system performance
- Results of cool down of TF coil
- Summary

SST-1 : A steady state superconducting tokamak

OBJECTIVES:

- Study Physics of Plasma Processes in tokamak under steady-state conditions.
  - Particle Control (fuel recycling and impurities)
  - Heat removal
  - Divertor Operation (radiation, detachment , pumping etc)
  - Current maintenance
  - –LHCD, Bootstrap, advanced configurations
- Learning new Technologies relevant to steady state tokamak operation:
  - Superconducting Magnets
  - Large scale Cryogenic system (He and LN2)
  - High Power RF Systems
  - Energetic Neutral Particle Beams
  - High heat flux handling



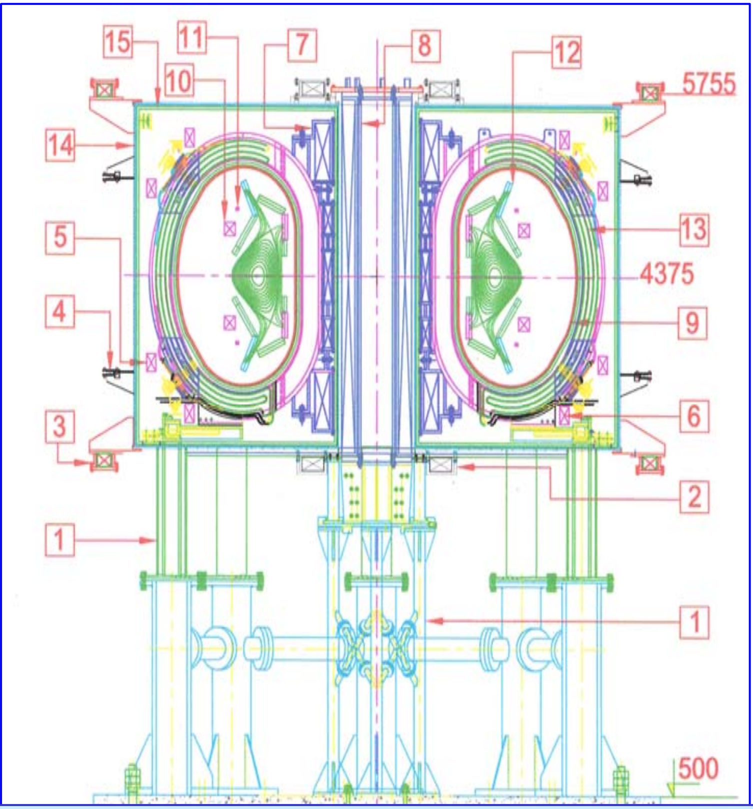
SST1 MACHINE PARAMETERS

- MAJOR RADIUS : 1.1M
- MINOR RADIUS : 0.2 M
- ELONGATION : 1.7-2
- TRIANGULARITY : 0.4-0.7
- TOROIDAL FIELD : 3 T
- PLASMA CURRENT : 220 kA.
- AVERAGE DENSITY : $1\times10^{13}cm^{-3}$
- AVERAGE TEMP. : 1.5 keV
- CONFIGURATION: DOUBLE NULL POLOIDAL DIVERTER

HEATING & CURRENT DRIVE:

Total Incident power, at any time limited to 1 MW due to limits of heat extraction at the first wall

- LOWER HYBRID (3.7 GHz) : 1.0 MW
- ECRH (84 GHz) : 0.2 MW
- ICRH (22-91 MHz) : 1.0 MW
- NEUTRAL BEAM (50 keV) : 0.8 MW



A cross-section of SST-1 (1-Support Structure; 2-TR2 Coil ; 3-VF Coil; 4 -TR3 Coil; 5-PF5 Coil; 6-PF4 Coil; 7 -PF1, PF2 & PF3 Coils; 8-TR1 Coil; 9-Vacuum Vessel;10 - PF6 Coil; 11-Feedback Coil; 12-PFC; 13 -TF Coil;14- Cryostat; 15- LN2 Panels)

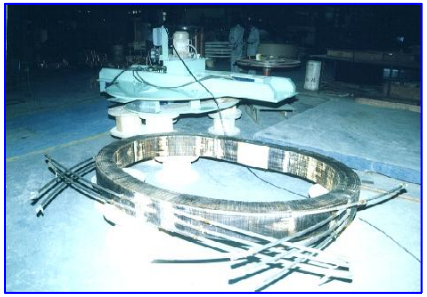
SUPERCONDCTING MAGNETS

PARAMETERS OF TF COILS:

- Total No. of Coils : 16
- Turns per Coil : 108

(6 Double Pancakes ; 9 turns per pancake)

- Current per turn (3T Field): 10 kA
- Max. Field at Conductor: 5.1 T
- Maximum Field Ripple : 0.35%
- Total Inductance : 1.12H
- Total Stored Energy: 56MJ
- Dump Time Constant: 12 s
- Peak Dump Voltage: ±600V



Double pancake (left) and winding pack(right) of TF coil

TF COIL Winding Pack:

Modified D-Shape

Base Conductor: NbTi based CICC

X-section:194x144 mm^2

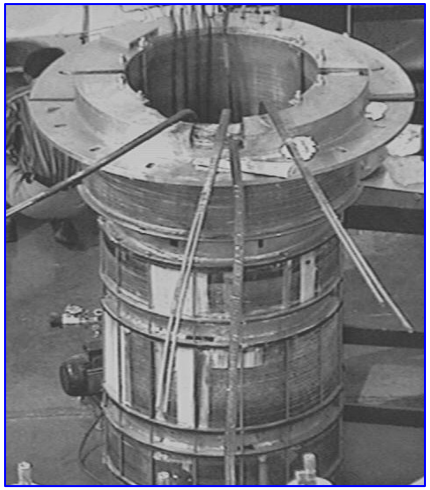
Consolidated by VPI & encased in SS316L case

TF coil

SUPERCONDCTING MAGNETS

Parameters of PF Coils

Coil type	# coils	Coil Radius (m)	Vertical Location (m)	Winding Cross-section (mm^2)	# turns
PF1	1	0.45	0.0	71x320	80
PF2	2	0.45	±0.43	71x163	40
PF3	2	0.50	±0.93	136x380	192
PF4	2	1.72	±1.03	85x136	40
PF5	2	2.01	±0.65	85x136	40
PF6	2	1.35	±0.35	100x100	16



Conductor for SST-1 Superconducting Magnets

Conductor Characteristics

Conductor type : CICC

Dimensions : 14.8×14.8 mm^2

No. of Strands : 135

Cabling Pattern : 3×3×3×5

Last stage wrapped (half overlap) with 25 µm thick SS304 tape.

Twist Pitches:

I stage : 40 mm; II stage : 75 mm

III stage: 130 mm; IV stage: 290 mm

Conduit Material : SS 304L

Conduit thickness : 1.5 mm

Void Fraction : ≥ 36 %

I_c @ 5T, 4.2K : 36 kA

I_{op} @ 5T, 4.5K : 10 kA

Strand Specifications

Material : NbTi in Cu

Strand Dia : 0.86 mm

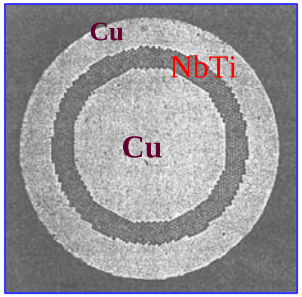
Filament Dia. : 10 µm

Filaments per strand : 1272

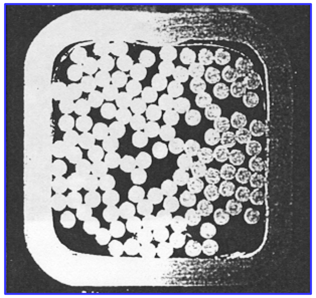
Cu : NbTi : : 5 : 1

Cu RRR : 100

Hysterisis Losses: <100 mJ cm^{-3}



Strand Cross-section

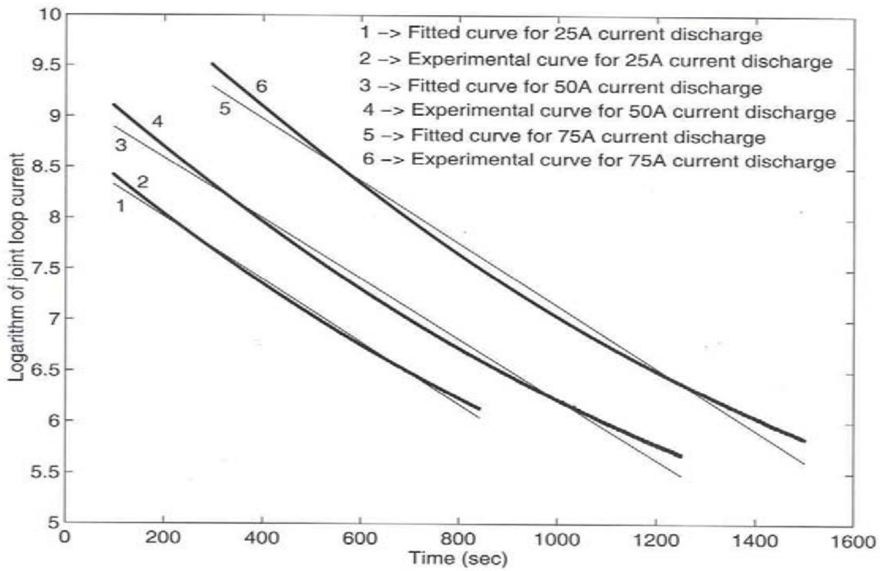


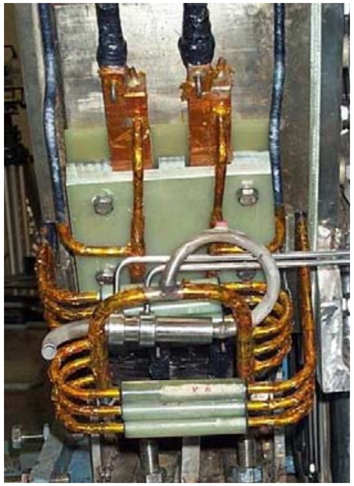
CICC Cross-section

Joints for SCMS

- Shake Hand Soldered Overlap type
- Overlap length: 320 mm
- Copper RRR : 10
- Solder Alloy : 95 Sn 05Ag (cable space)
- Solder Alloy : 60 Pb 40Sn (termination)
- Series cooled with the magnet winding pack
- The joints have been characterised in experiments done at 4.5k. The current was induced in a closed loop containing the coil and decay time of the current measured to obtain the resistance.

Joint resistance of 3 nOhm was obtained.

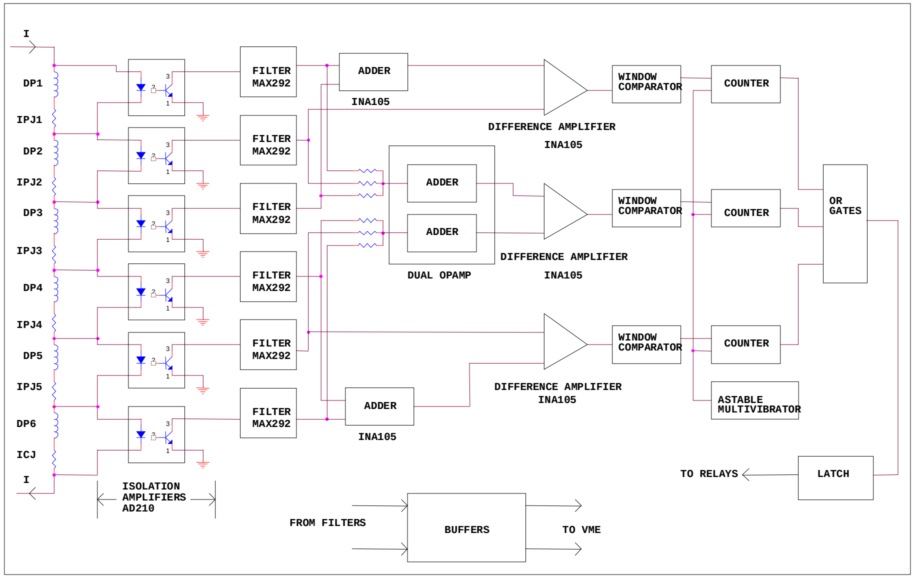




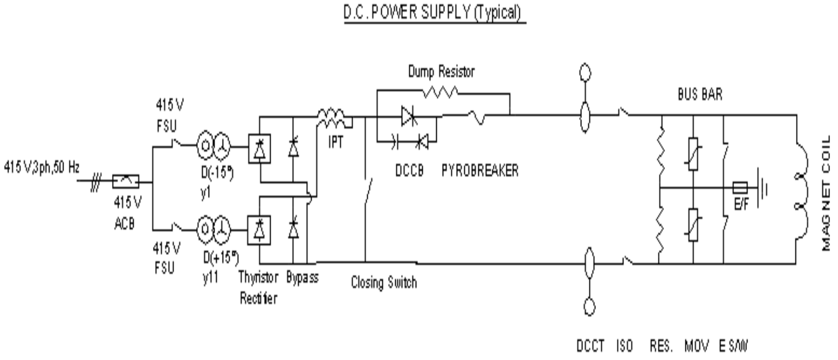
Sensors, Diagnostics and Quench Detection in SCMS

The magnet system is equipped with 520 sensors (300 voltage taps across winding packs for quench detection, 173 temperature sensors helium outlets and cold mass support, flow meters at the inlet of each of the coils)

A subtraction logic based quench detection has been adopted for the SST-1 magnets



Protections for SCMS quench are included in the dc circuit of the TF and PF coils. In the event of quench detection, the dc current in the power supply is commutated to the controlled bypass, which provides a reliable and stable path. The dc circuit is, then opened with on-load mechanical DC breaker and the current is commutated to the dump resistor connected in parallel to the DC breaker.

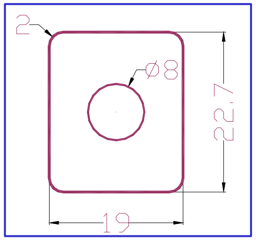


COPPER MAGNETS (WATER COOLED)

- Ohmic Transformer (TR) Coils : 7 #
- Vertical Field (VF) coils : 2 #
- PF Coils 2 #
- Position Control Coils (in-Vessel): 2 #

Parameters of Ohmic Transformer

Coils	#	Radius (m)	Turns (#)	X-section (mm^2)	Center (m)
TR1	1	0.20	672	120×2600	0.00
TR2	2	0.49	40	195 × 95	± 1.40
TR3	2	2.42	3	58 × 23	±0.73



Conductor for the copper coils

The TR1 coil of the Ohmic transformer. The transformer has a flux storage of 1.4 Vs with field strength of 8 T in the TR1 bore.

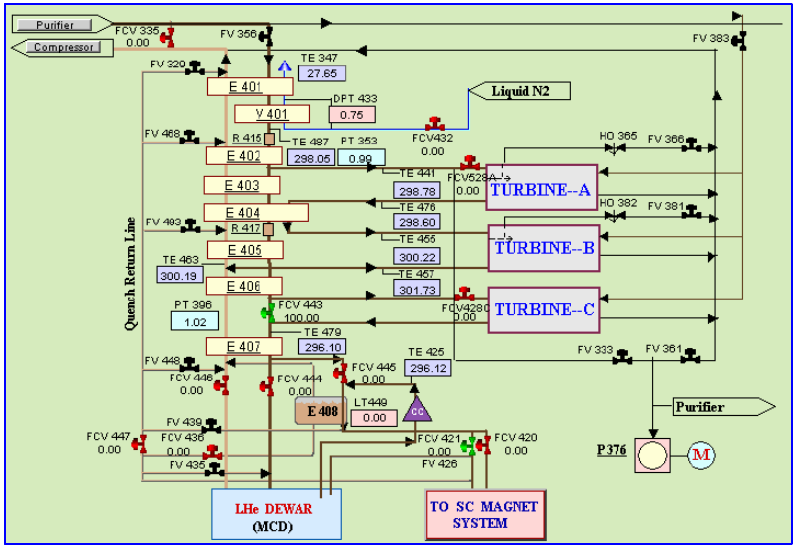
Helium Cryogenic System

Features of He Plant

- Fully automated refrigerator/liquefier
    - 400 W for SCMS + 250 W for Cold Circulation Pump
    - 200 l/h Liquefaction for Current leads
- 2500 l capacity Master Control Dewar with heat exchanger
- A full flow online gas purifier
- Cold Circulation Pump with Heat exchanger
    - 300 g/s flow of SHe through SCMS:
    - 4.5K, 4.0 bar(a) Inlet to SCMS; <5.0K, > 3.0 bar(a) at outlet to SCMS

Operational features of the Helium Plant

- Controlled cool down and warm up of SCMS between 300K to 4.5K
- Maintaining SCMS at 4.5K during the current ramp up and sustaining of current in TF coils.
- Transient heat absorption during ramp up of current in PF coils (plasma pulse 1000 s duration) for 7 pulses per day.
- Absorption of transient heat during quenches (TF & PF systems) and recovery to normal state.
- Power saving in standby mode.
- Provision for two phase flow (50 g/s)
- 20K outlet for High T_c current leads.



SST1 Vacuum Vessel

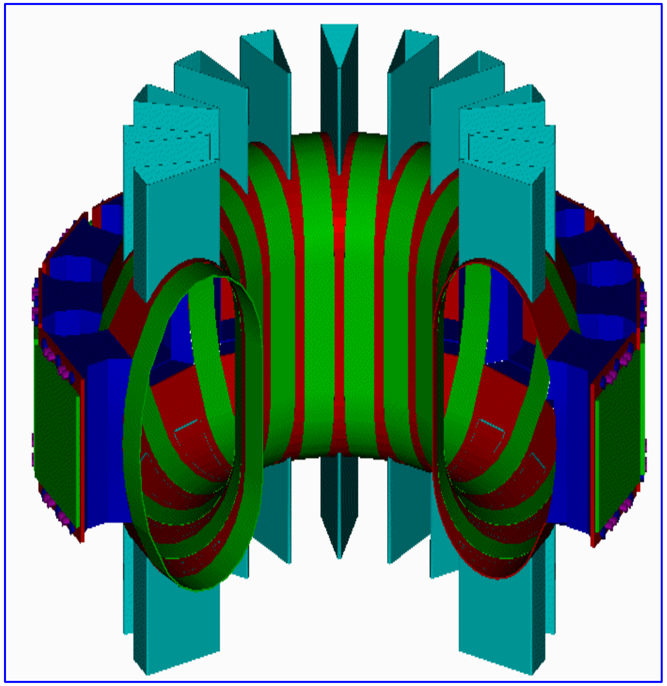
Vacuum vessel

Modular construction

16 vessel sectors, each with one radial ports and two vertical port

16 interconnecting rings

Vertical semi axis	: 0.81m
Radial semi axis	: 0.53 m
Total surface area	: 75 m^2
Total volume	: 16 m^3
Total weight	: 4100 kg
Material	: SS 304L
Vacuum	: 10^{-8} mbar



Cryostat

Sixteen sided polygon connected to vacuum vessel at radial, top and bottom ports.

32 ports for SCMS diagnostics and pumping.

Vertical Height: 2.6 m

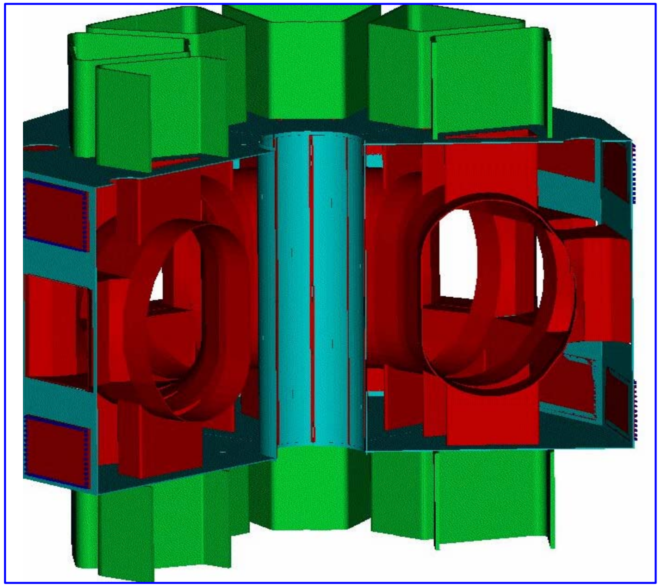
Wall Thickness: 10mm

Surface Area: 59 m^2

Total Volume: 39 m^3

Total Weight: 4520 kg

Material : SS304L



PUMPING SYSTEM FOR SST-1 TOKAMAK

NORMAL PUMPING OF VACUUM VESSEL:

- Out gassing gas load ≤ 1 x 10^{-4} mbar l/s
- Design base pressure ≤ 1 x 10^{-8} mbar
- Required pumping speed ≥ 10,000 l/s
- 2# TMP each (5000 l/s)
- 2# of Cryopumps (10,000 l/s)

DIVERTOR PUMPING OF SST-1 TOKAMAK:

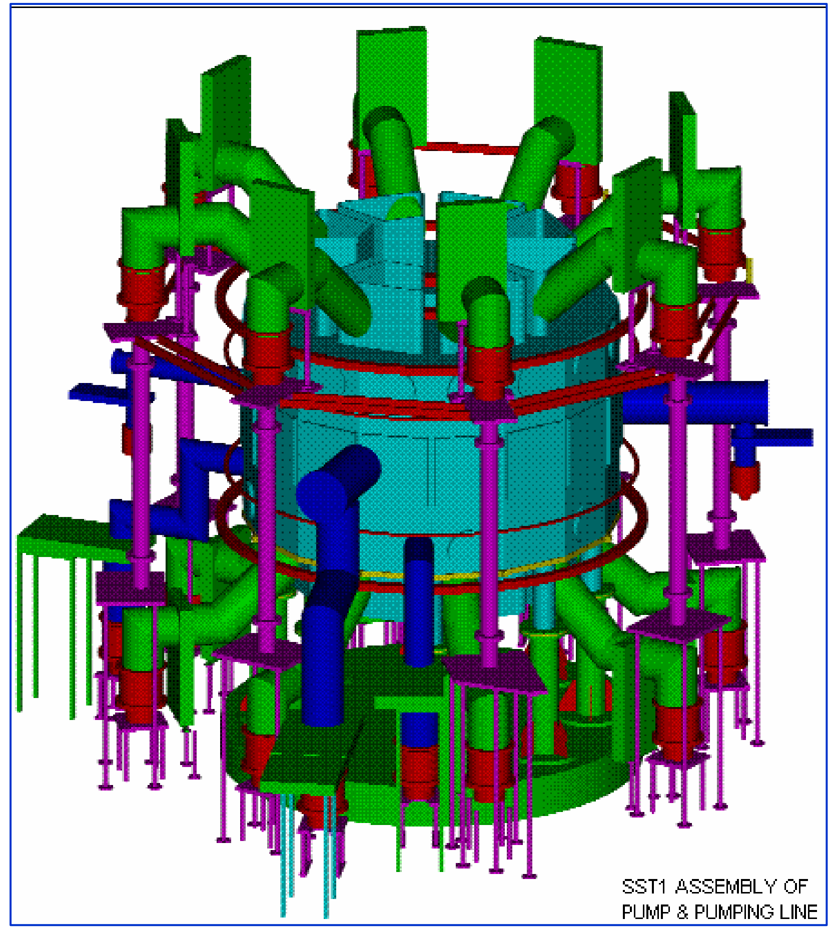
- Particle exhaust rate : 22 mbar l/s at 1×10^{-3} mbar
- Required pumping speed : 22000 l/s for hydrogen

Pumping speed provided : 44600 l/s for hydrogen

- 16 # TMP (5000 l/s each) on top and bottom ports

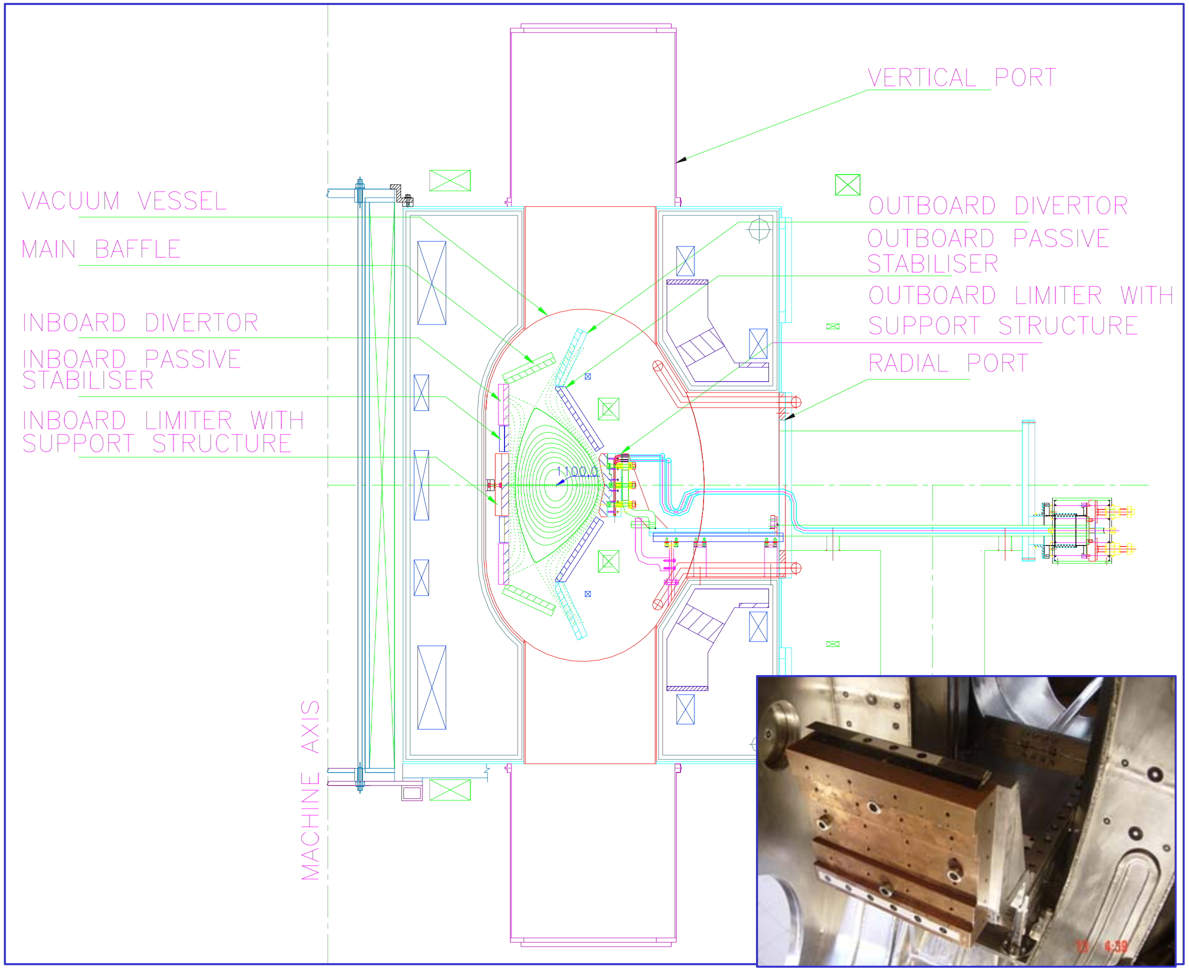
CRYOSTAT PUMPING:

- Out gassing gas load ≤ 5 x 10^{-2} mbarl/s
- Design base pressure ≤ 1 x 10^{-5} mbar
- Required pumping speed ≥ 5,000 l/s
- 2# TMP (5000 l/s) on Cryostat ports

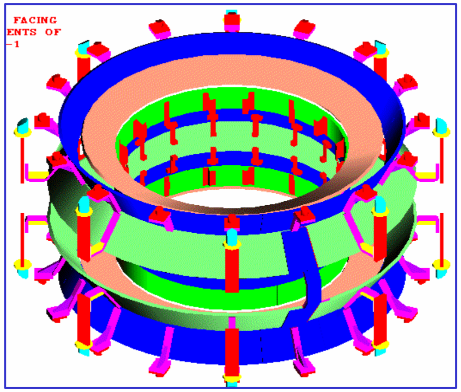


Plasma Facing Components of SST-1

PFC are designed for total of 1 MW input power.



- Tiles made of isostatically pressed, low ash content graphite, mechanically attached to high strength copper alloy (CuZr & CuCrZr) backplates; are used as PFC.
- Cooling tubes (SS304) are embedded in & vacuum brazed to the back plates.



Erection and Assembly of SST-1 Tokamak

ALIGNMENT AND DIMENSIONAL CONTROL STRATEGY:

- Basic alignment strategy adopted is the application of dimensional control at each major stage of the assembly process using the combination of optical metrology equipment.

- The dimension control of major stages is verified using the ECDS (Electronic Coordinate Determination System) surveying process.

- Weld joints of vacuum vessel and cryostat are controlled for distortion following the staggered welding and controlling the heat affected zone.

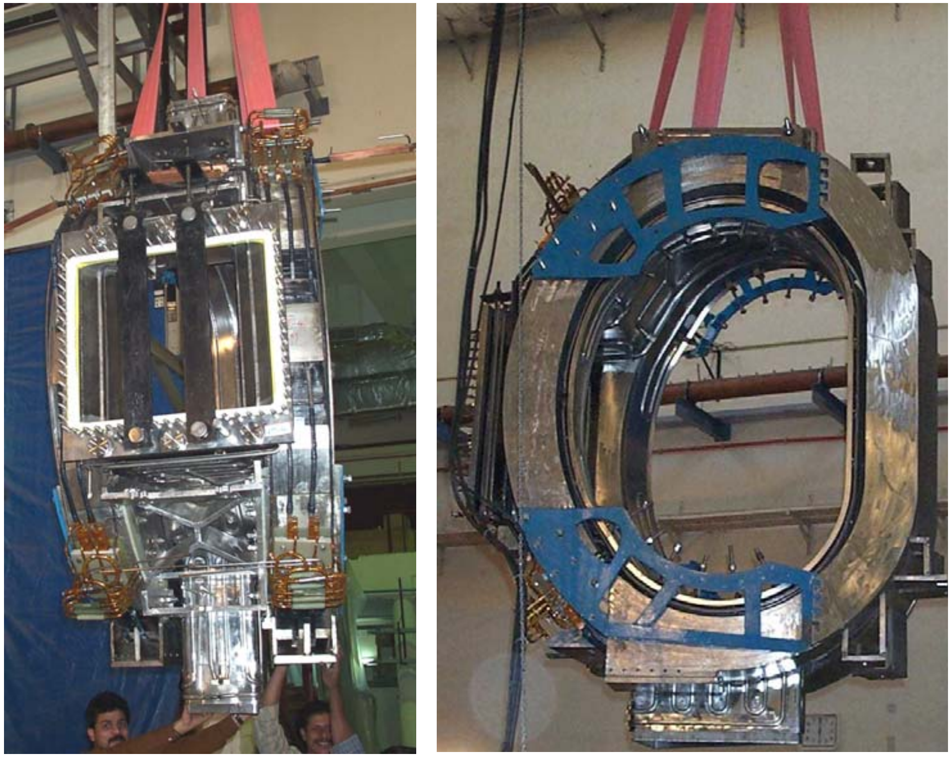

4. 6. 2002


28. 8. 2002

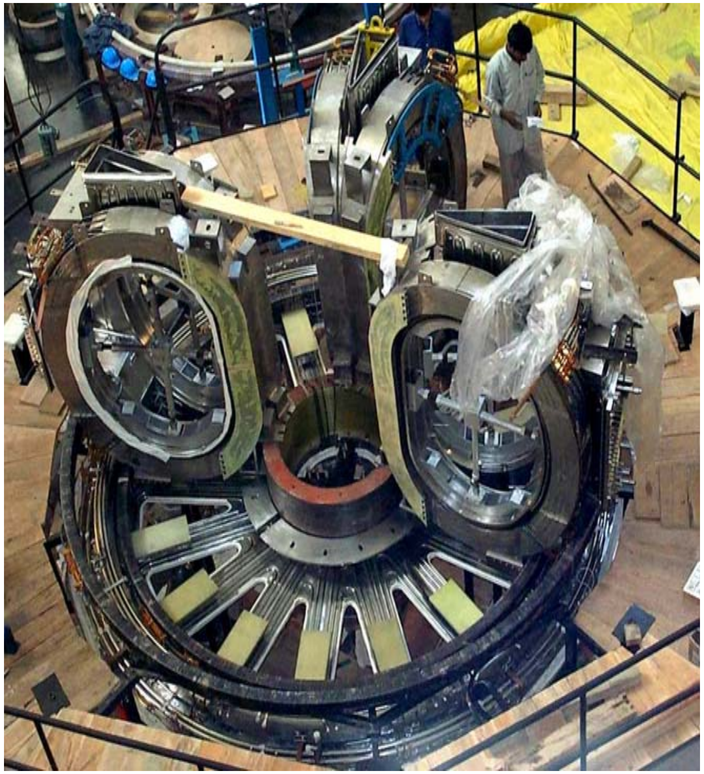

9. 7. 2002

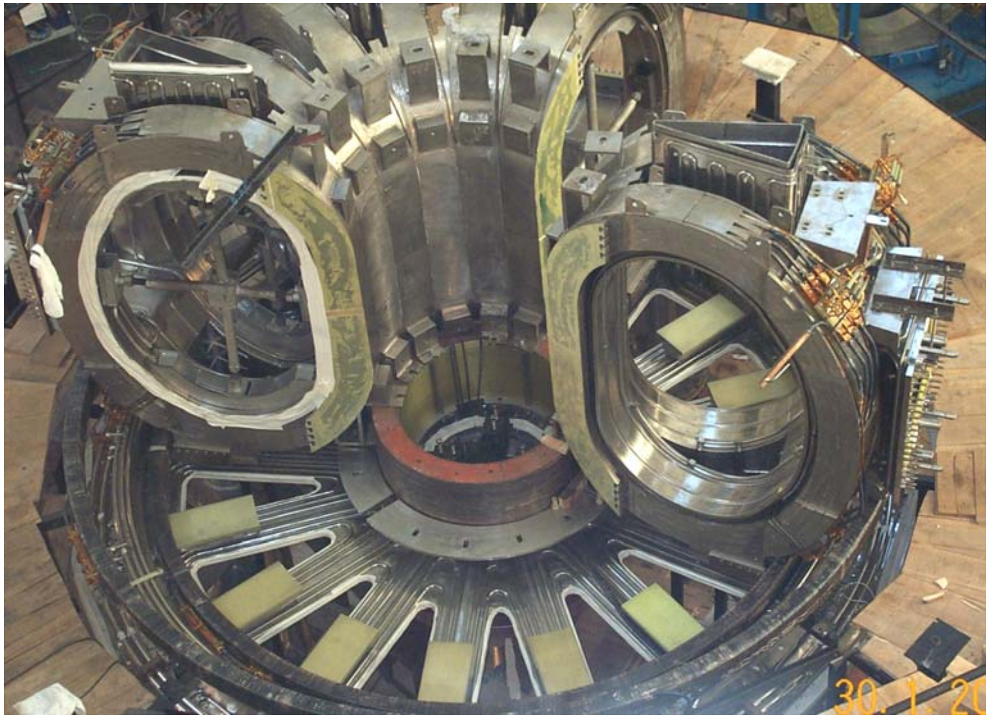

27. 3. 2003

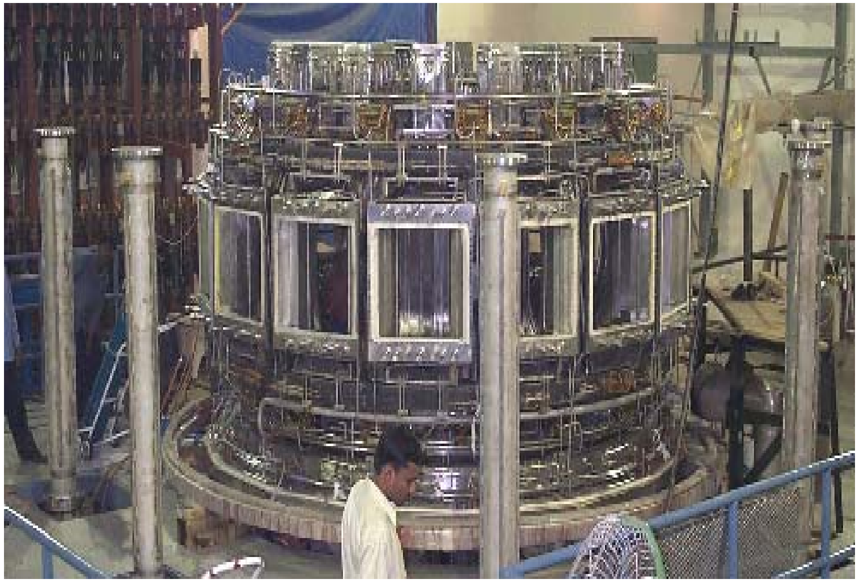
Views of the Vessel Module assembled from one vessel sector and two rings



Assembly of TF coils and vessel module




30. 1. 20

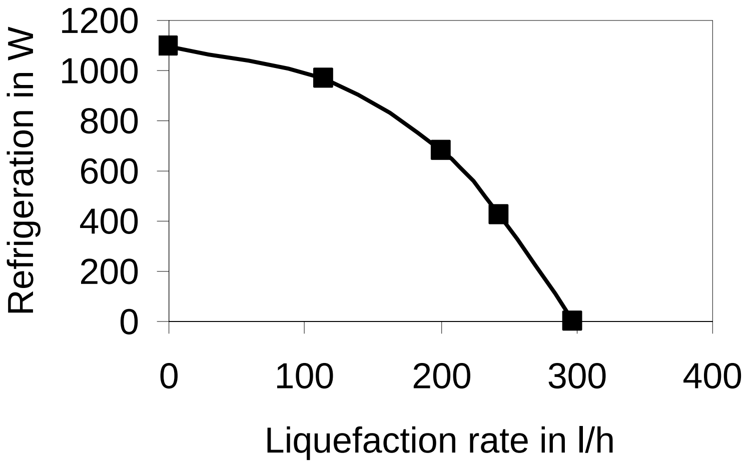


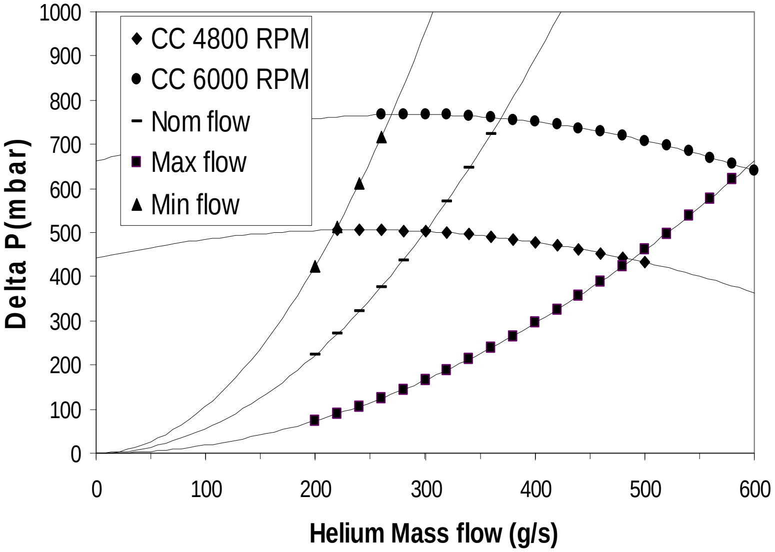

18. 6. 2004


A view of the SST-1 Tokamak
28. 10. 2004

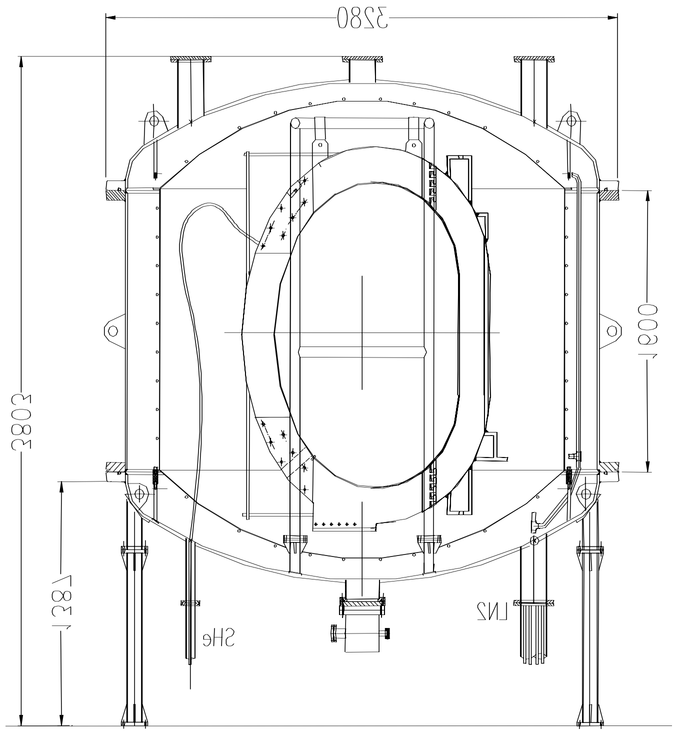
Cryogenic System Performance

- The cryogenic system for the SST-1 has been commissioned.
- The operating parameters and all operational modes have been established.
- Two-phase cooling scheme for the SCMS was tested with 50 g/s flow rate.
- The heat load (up to 400 W for steady state condition and 600 W for transient state) was supplied by the heater connected to the IFDC.
- It was observed that process parameters for MCD and associated heat exchangers were within the required value.



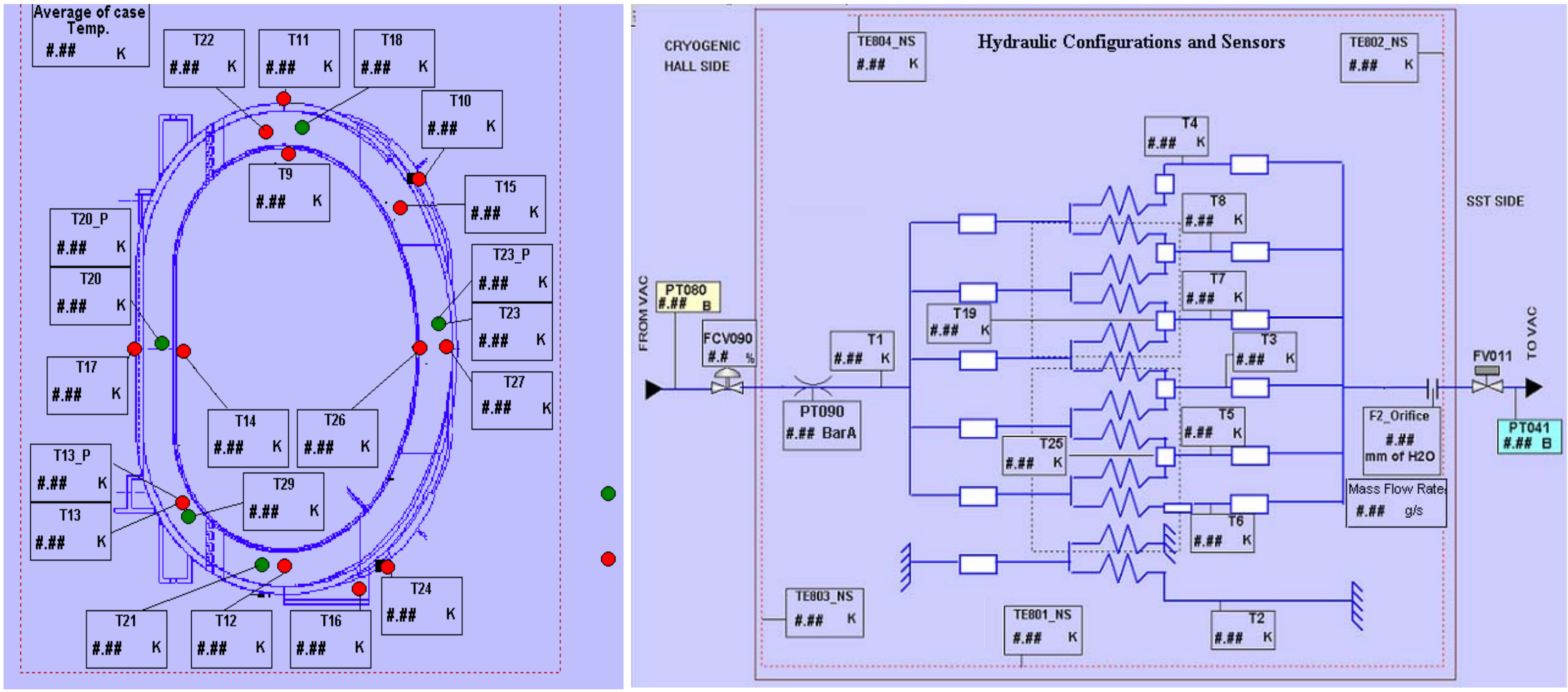


TF coil cool down

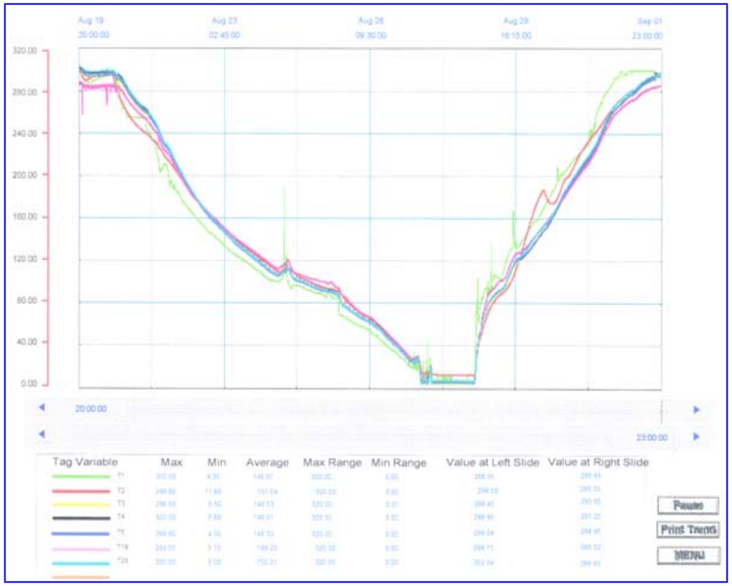


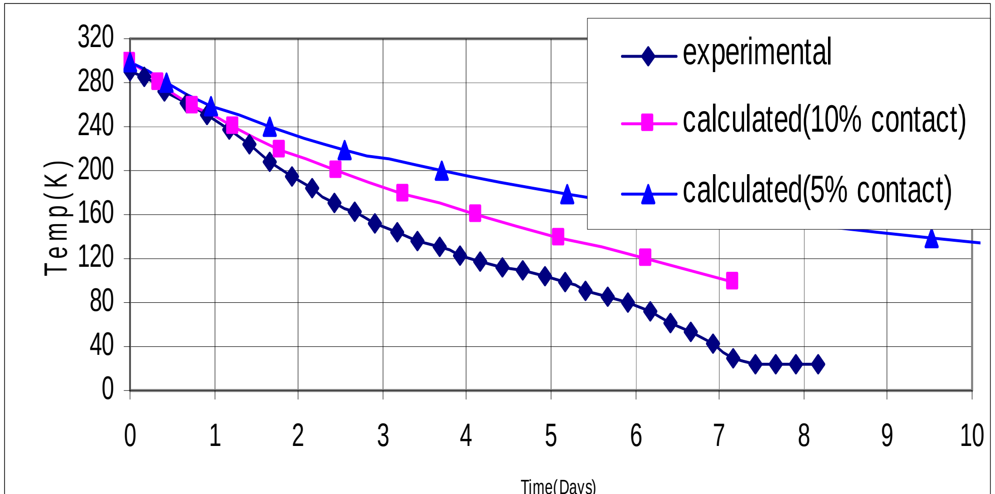
Test set up

Views of spare TF coil mounted in the cryostat for cool down test



Location of the temperature sensors on TF casing (left) and in the flow paths (right)





Experimental cooldown rate of casing of TF compared with estimated values for different % of contacts

Cool down and warm rate for TF coil

Summary

SST-1 is now getting ready for the final stages of assembly. The welding of the cryostat plates will be completed in November 2004 and will be immediately followed by its evacuation and the SCMS cool down.

Helium refrigerator has been commissioned and tested for its design parameters and operational modes. Cool down characteristics of the TF coil have been studied and hydraulics found to be satisfactory.

If the SCMS are commissioned successfully we expect Ohmic Plasma shots in early 2005.