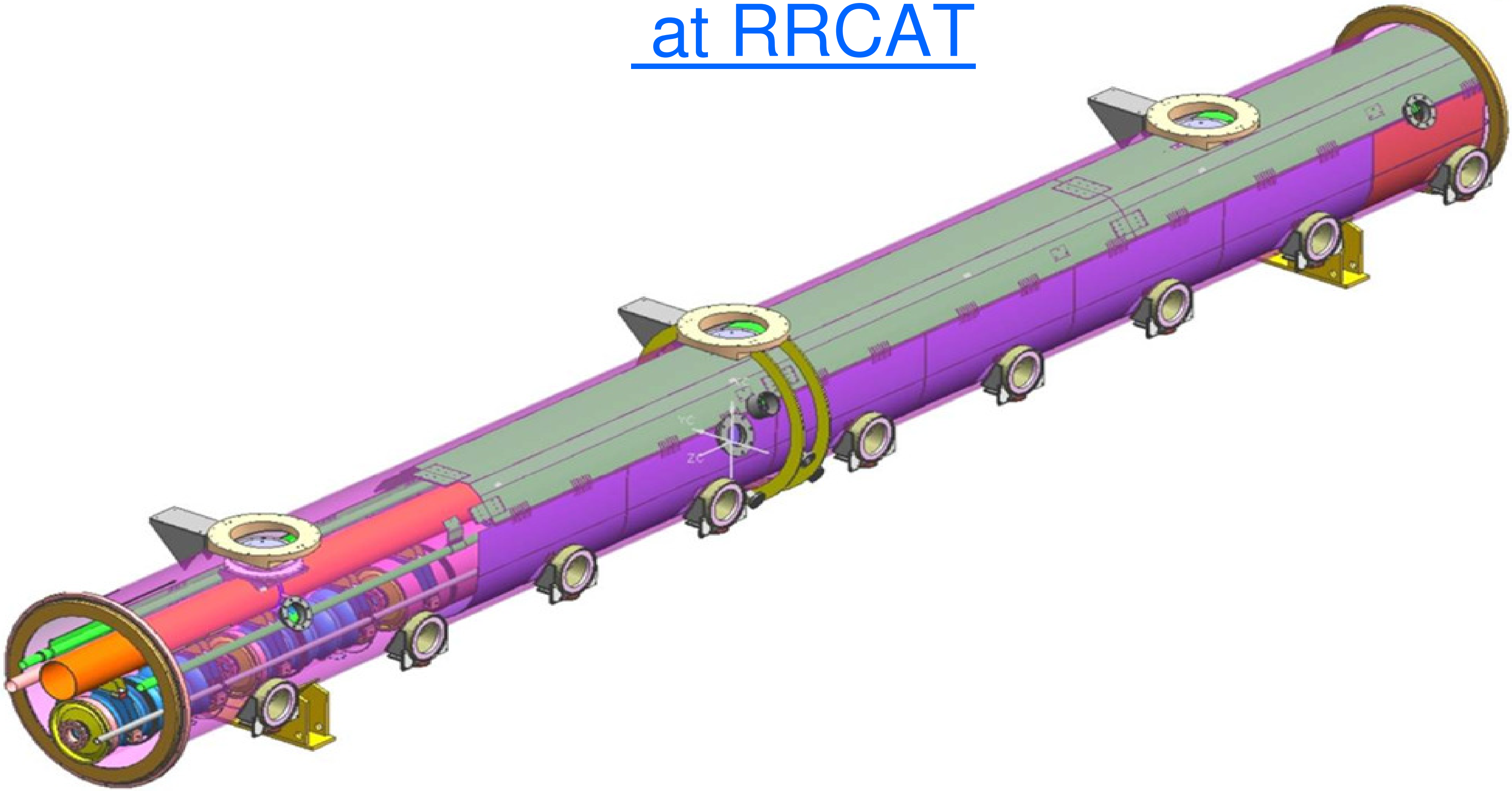
650 MHz Cryomodule Design at RRCAT



Prashant Khare, Pradeep Kush
Shailesh Gilankar , Rupul Ghosh, Abhishek Jain
Rajeev Chaube, A.Laxminarayanan

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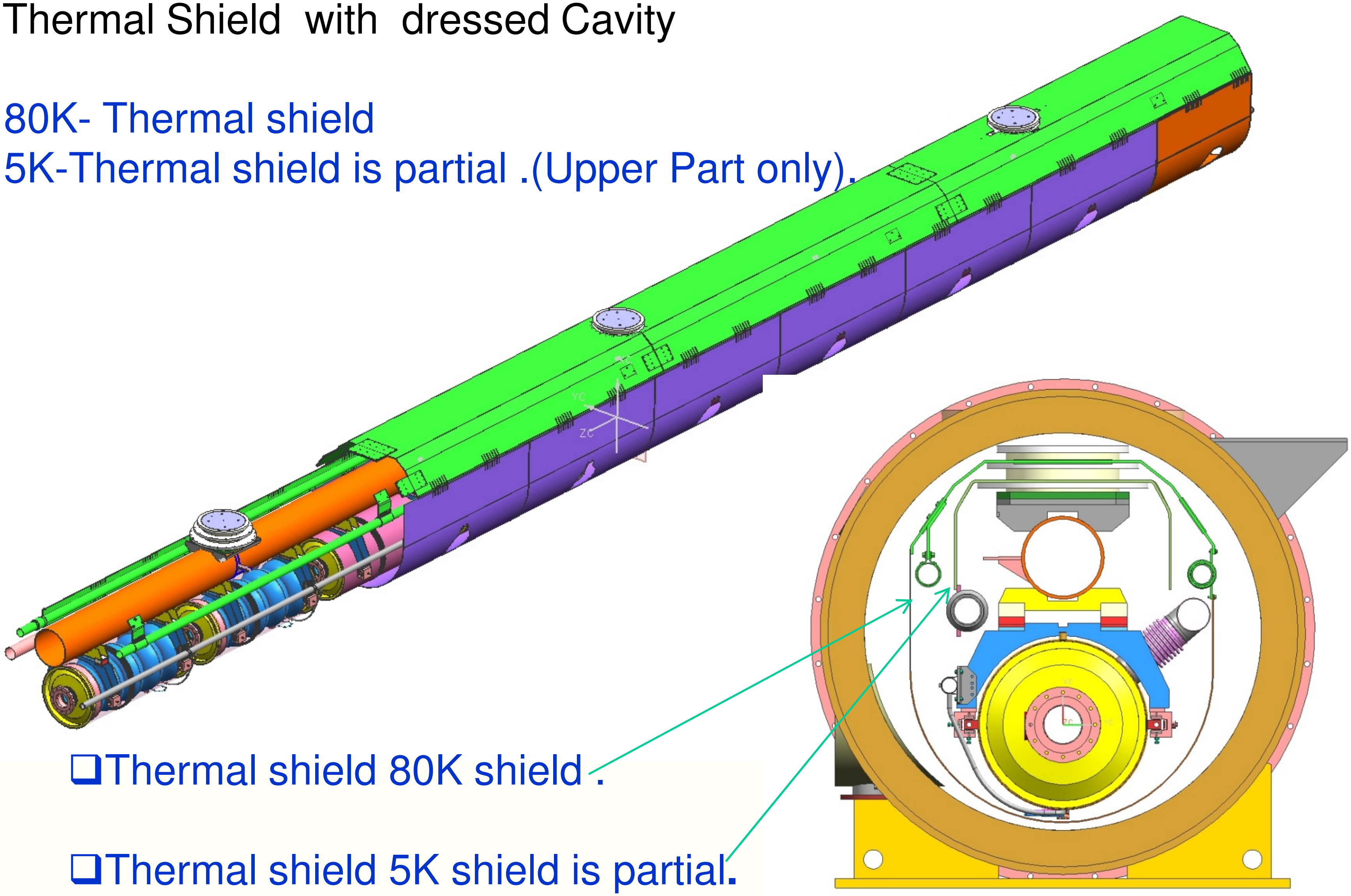
1. Ground Covered Earlier

A. 3-D model for 650 Hz cryomodule
B. Calculations of cold positions
C. Vacuum vessel design
D. Estimation of cool down time of thermal shield
E. Design of cavity support system
F. Design and prototyping of cryogenic support post

A. Glimpse of 3-D Model

Thermal Shield with dressed Cavity

- ❑ 80K- Thermal shield
- ❑ 5K-Thermal shield is partial .(Upper Part only).



- ❑Thermal shield 80K shield .
- ❑Thermal shield 5K shield is partial.

B. Cold Position of Main Elements

Coupler Positions

Temp	Cplr.1	Cplr.2	Cplr.3	Cplr.4	Cplr.5	Cplr.6	Cplr.7	Cplr.8
Room	-4664	-3315.8	-2011.18	-684.48	1948.5	3295.2	4621.9	5948.6
At 2K	-4665.4	-3316.7	-2011.6	-684.5	1949.0	3296.2	4623.3	5950.5
Diff.	1.43	0.959	0.50	0.038	0.48	0.95	1.41	1.88

Chimney Positions

Temp	Chn.1	Chn.2	Chn.3	Chn.4	Chn.5	Chn.6	Chn.7	Chn.8
Room	-4983	-3656.6	-2329.9	-1003.2	1909.8	3236.5	4563.2	5889.9
At 2 K	-4981.2	-3655.3	-2329.05	-1002.8	1910.3	3237.5	4564.7	5891.8
Diff.	1.777	1.3135	0.8492	0.3848	0.5437	1.0080	1.4724	1.9367

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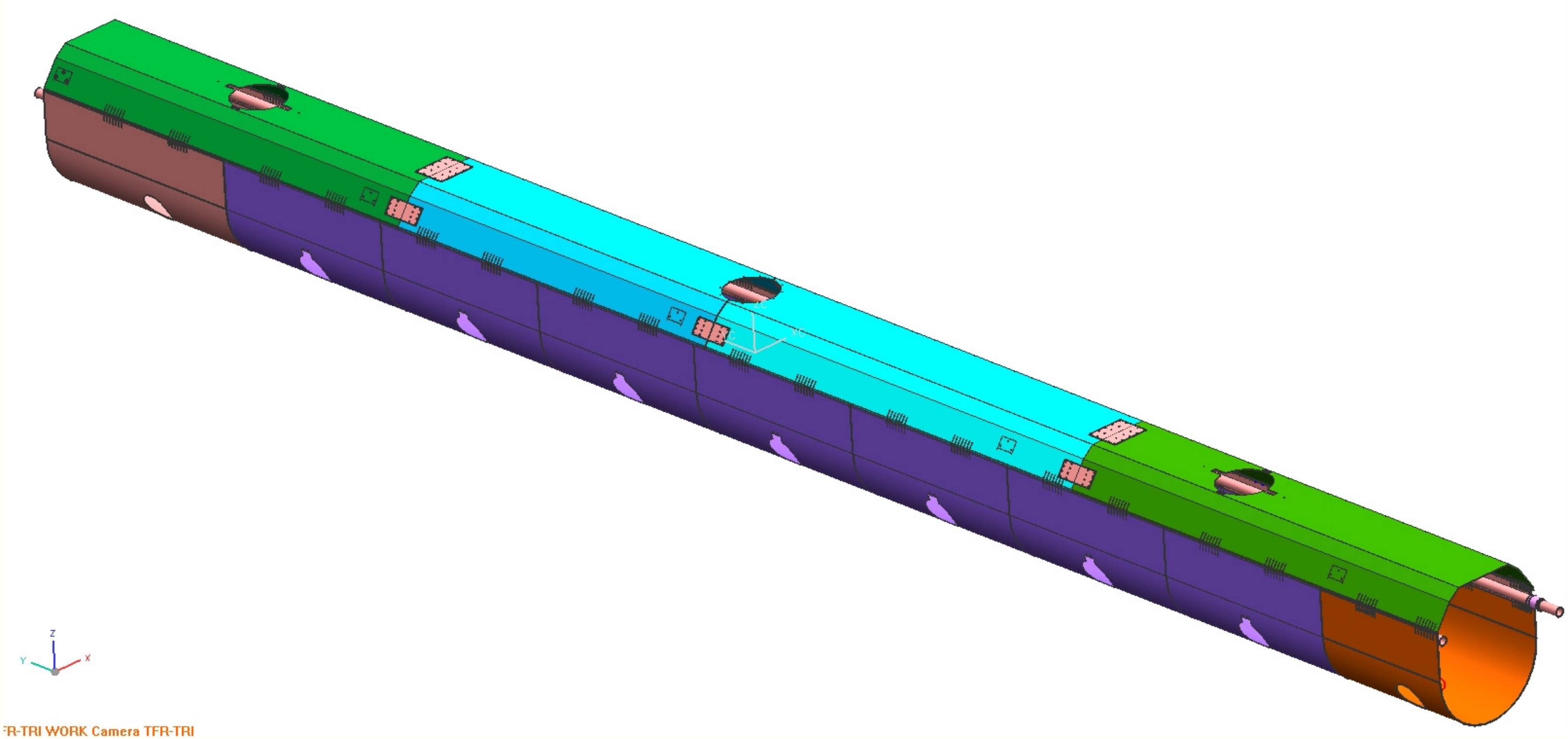
C. Design of Vacuum Vessel :Basic Features

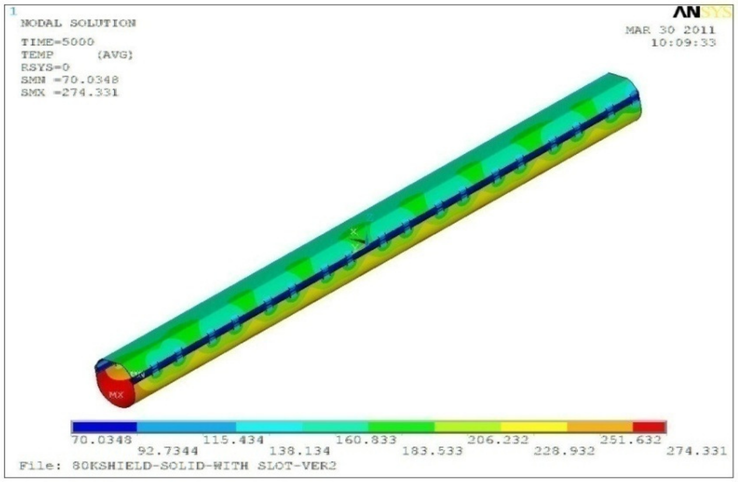
Preliminary vacuum vessel of Cryomodule	Designed value	Remark
Diameter of Steel Vessel*	44 inch	Necessary as cavity size is 400mm
Overall Length of Vessel	472.44 inch	Minor adjustments may be made This figure is as per lattice position given by Jim
Nominal Thickness of Vessel	0.375 inch	Does not change for 42 inch diameter

Verified with ASME Boiler and Pressure Vessel Code Sec.VIII Div1,(2004)

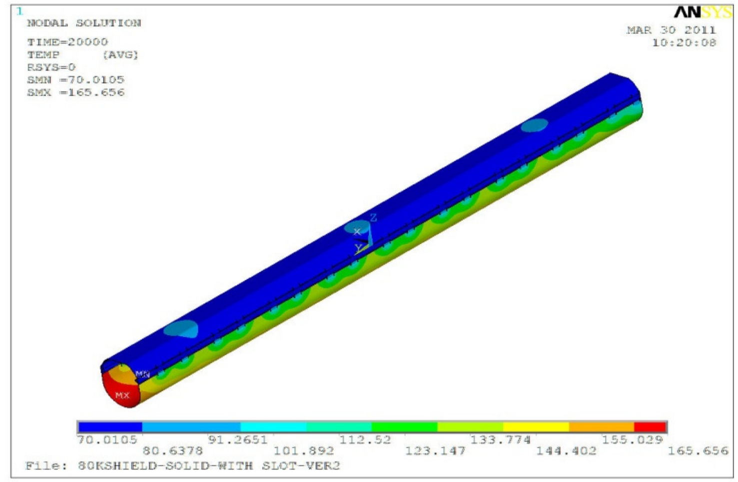
D. Estimation of Cool Down Time of Thermal Shields



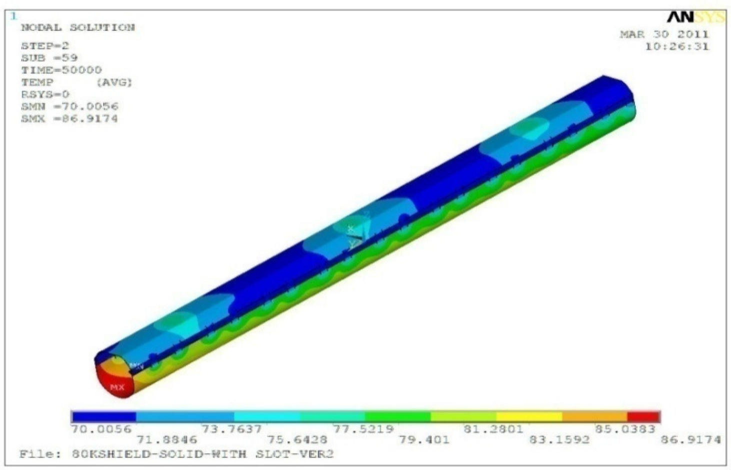
Results of Thermal Analysis



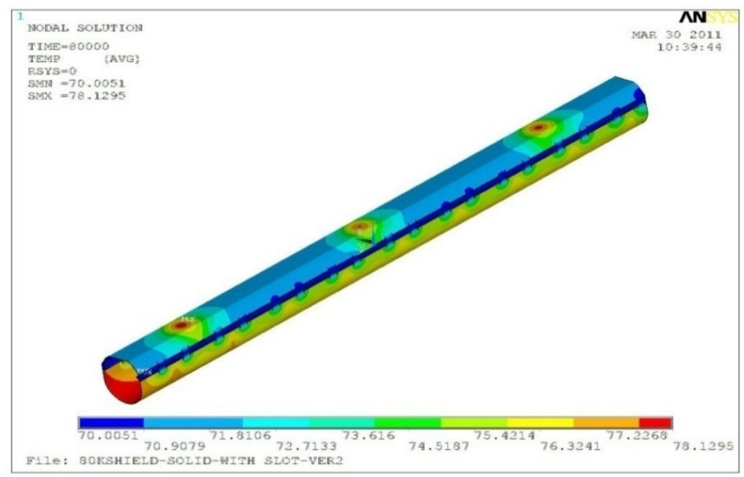
Temperature plot after 1.38 hours



Temperature plot after 5.55 hours

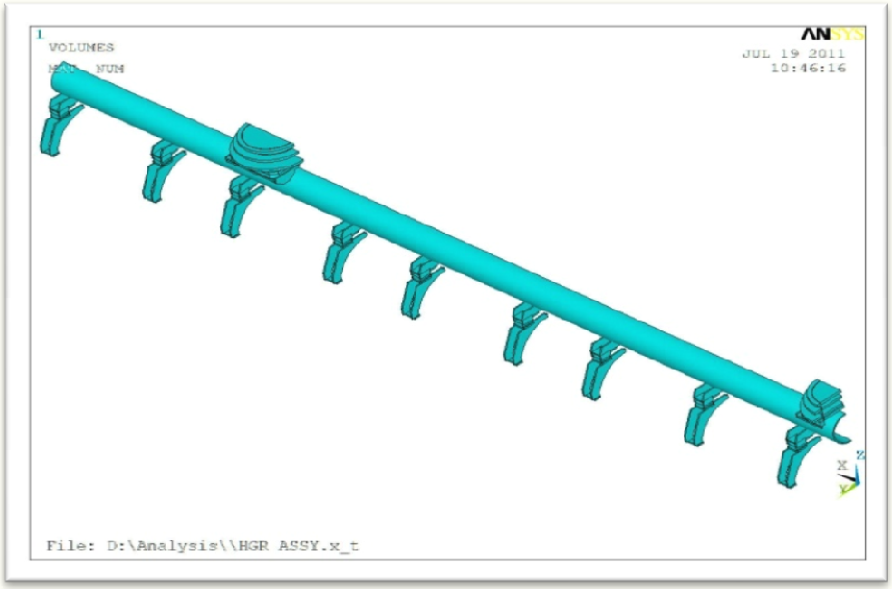


Temperature plot after 13.88 hour



Temperature plot after 22.22 hours

E. Design of Cavity Support System



¼ th Geometrical Model

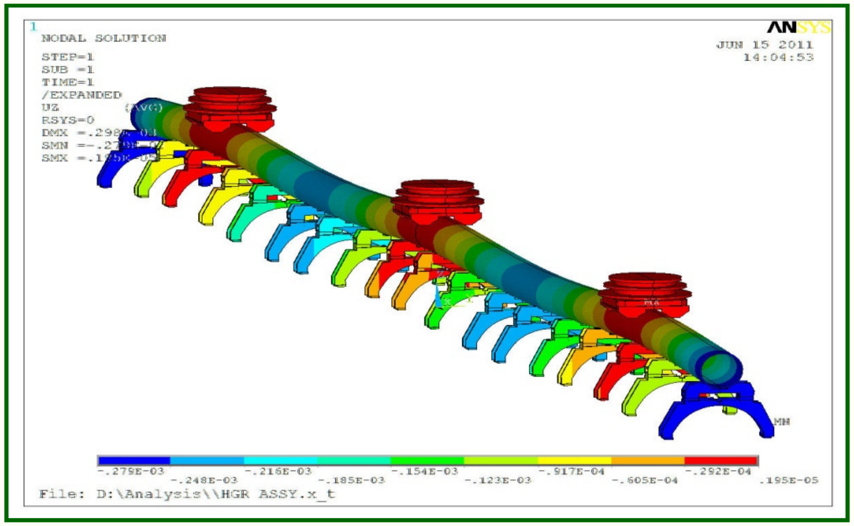
Meshed Model

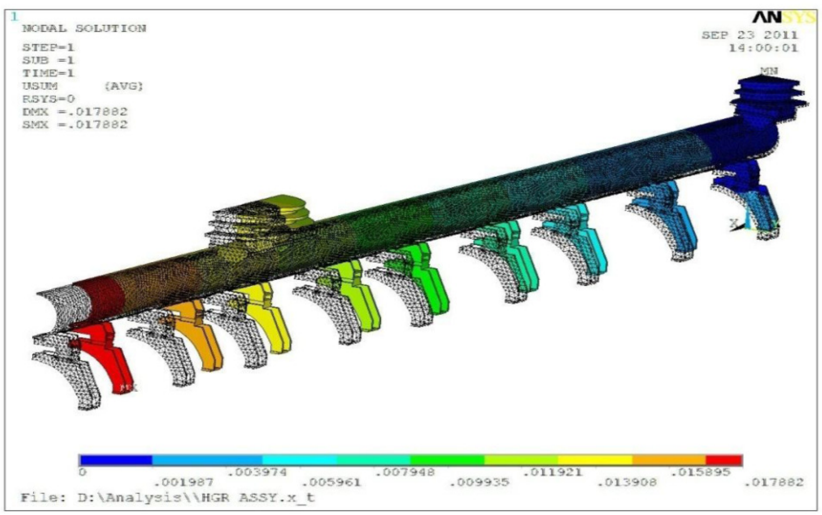
Boundary Conditions:

- Cavity Weight 0f 150 kg is taken
- Center support post – Fixed post
- End support post- Sliding post (free to move in axial direction)

- Material : SS 304
- Temperature dependent material properties are taken into consideration
- 20 nodes solid element

E. Cavity Support System





Straight pipe results

Hangers position

	At 300 K	At 2 K
Hangers	Downward (mm)	upward(mm)
1	0.279	2.22
2	0.11	2.15
3	0.0291	2.051
4	0.0624	2.033
5	0.152	2.09
6	0.233	2.17
7	0.227	2.22
8	0.133	2.15

Results:

- ✓ Maximum deflection at free end is found to be 0.279 mm.
- ✓ At cool down condition, the deviation in hangers position is found to be 187 micron

F. Design and Prototyping of Cryogenic Support Post

Result for T4CM

Po =	19.91	N/mm2
Pi =	20.72	N/mm2
Fo =	10340	Kg
Fi =	10601	Kg

P_i is Inner Contact Pressure between Disc and Tube
P_o is Outer Contact Pressure between Tube and Ring

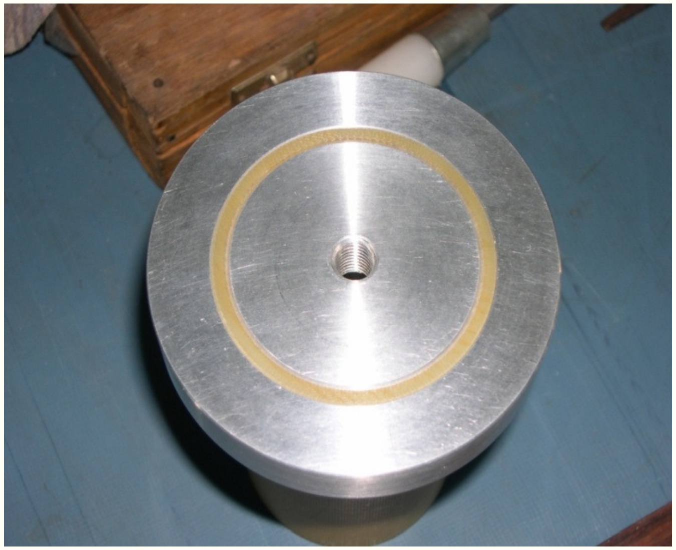
F_i is Max Axial Load Carried by Inner Disc
F_o is Max Axial Load Carried by Outer Ring

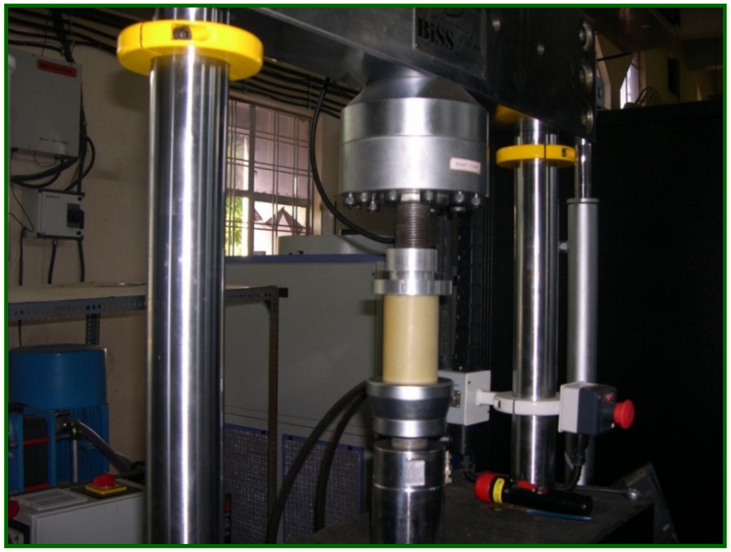
ID of SS Disc, d1	8
ID of G11Tube, d2	295.58
OD of G11Tube, d3	300
OD of SS Disc, d4	350
Diametral Interference Disc and Tube, δi	0.43
Diametral Clearance Ring and Tube, δo	0.2

Poisson's Ratio SS304 Disc μ1	0.3
Poisson's Ratio G11 Tube μ2	0.2
Poisson's Ratio SS304 Ring μ3	0.3
Young's Modulus SS304 Disc,E1	200
Young's Modulus G11 Tube, E2	28
Young's Modulus SS304 Ring,E3	200

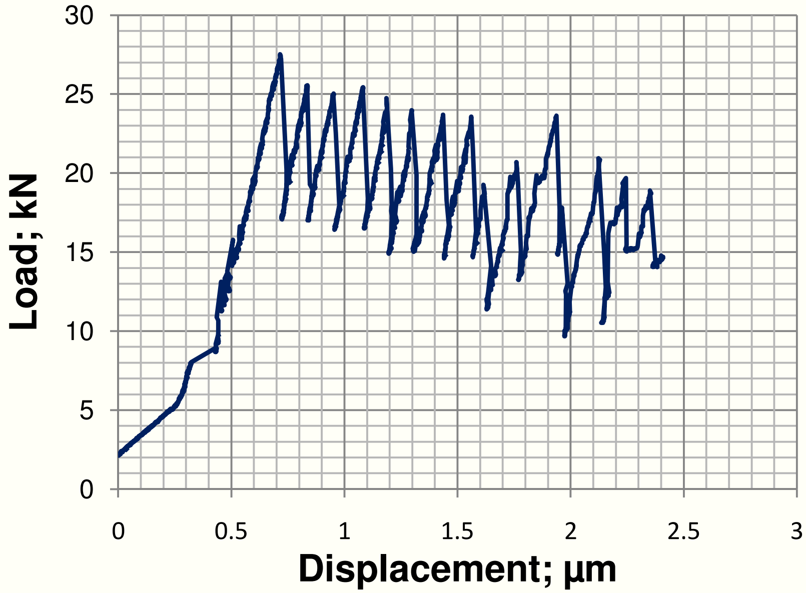
- Cryogenic Support post is theoretically capable of taking 10Ton load.
- The cold mass is estimated to weighs about 3Tons.
- There are 3 support posts. We are now making a prototype which can then be tested to validate our calculations.

Prototyping & Testing





Load Testing of Shrink-Fit Joint



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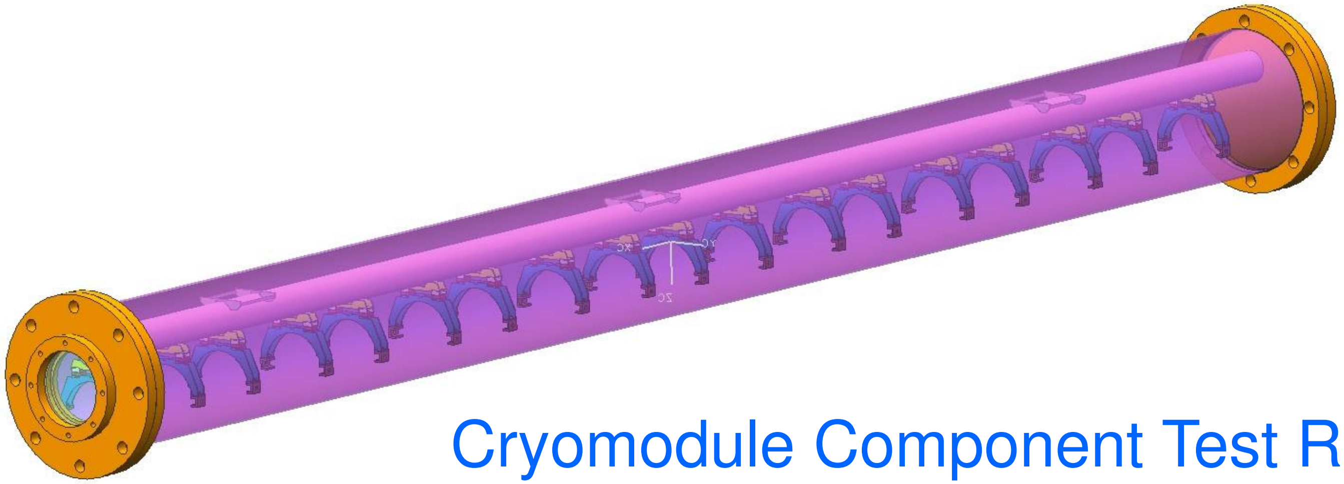
2. Work in Progress (In last 3-4 months)

A. Test bench developed for cryomodule components(CCTR)
B. Prototype fabricated for cavity support system
C. Prototype thermal shield for cryomodule under fabrication
D. Planning for experiments

The New Facility for Cryomodule Subsystems

CCTR and It's Rework Facility

A. Test bench developed for cryomodule components

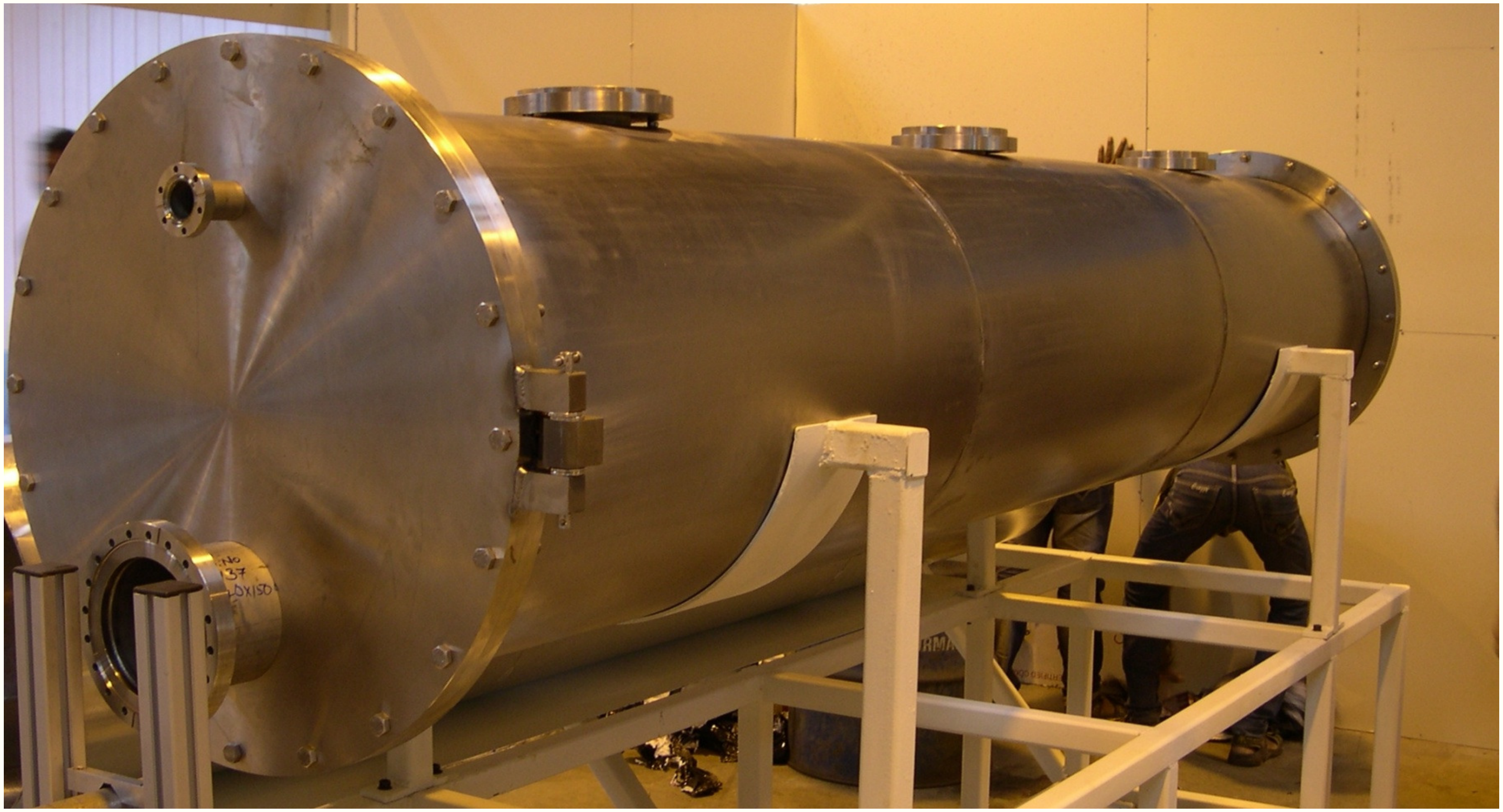


Cryomodule Component Test Rig

Objectives:

- ✓ Validate ANSYS results. Ex. Thermal Shield cool down.
- ✓ Evaluate cryomodule concepts prevalent in other cryomodules Ex. Comparison of Tesla type support system & SNS type support system.
- ✓ Evaluate value engineering concepts. Ex laser welded cavity support system.
- ✓ Beginning of hands on experimentation for cryomodule at our lab.

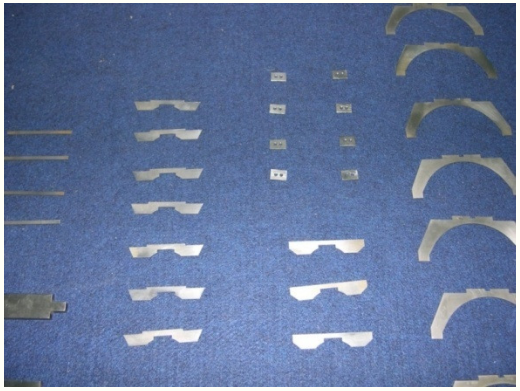
Cryomodule Component Testing Rig



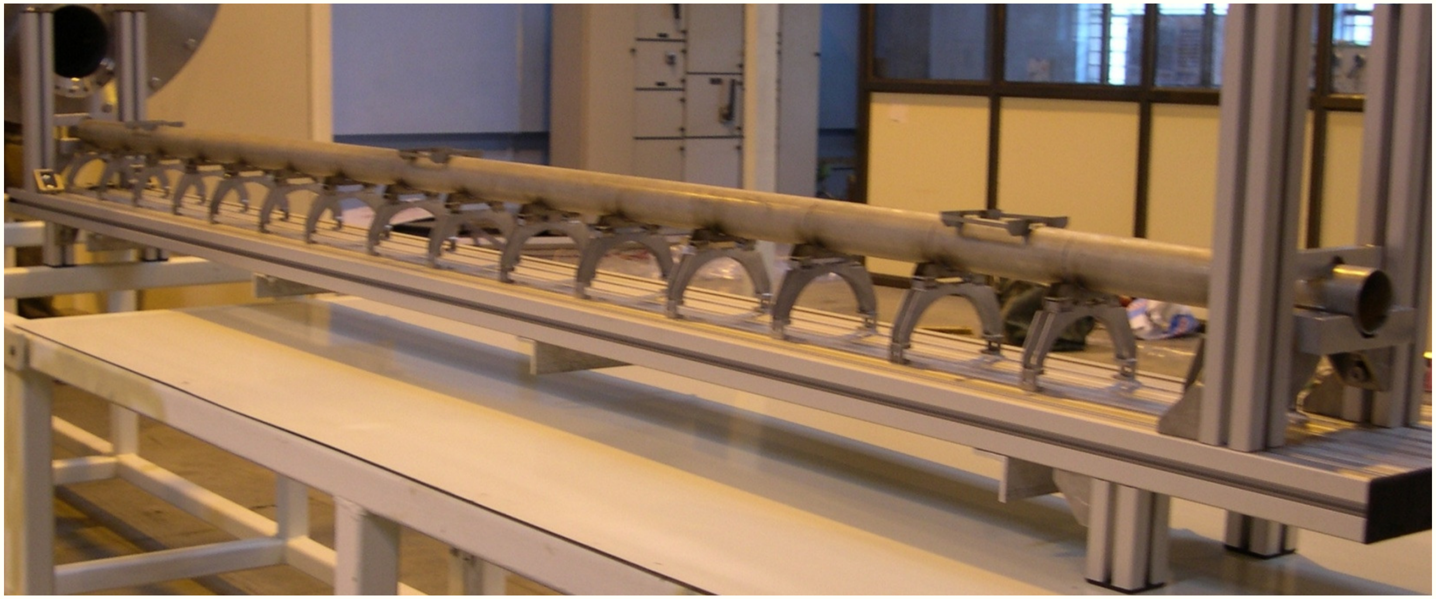
1. Vacuum Vessel of CCTR (Qualified in Vacuum Leak test)
2. Thermal Shield is under fabrication
3. Cavity Support System is ready

B. Prototype of Cavity Support System

Helium Gas Return Pipe



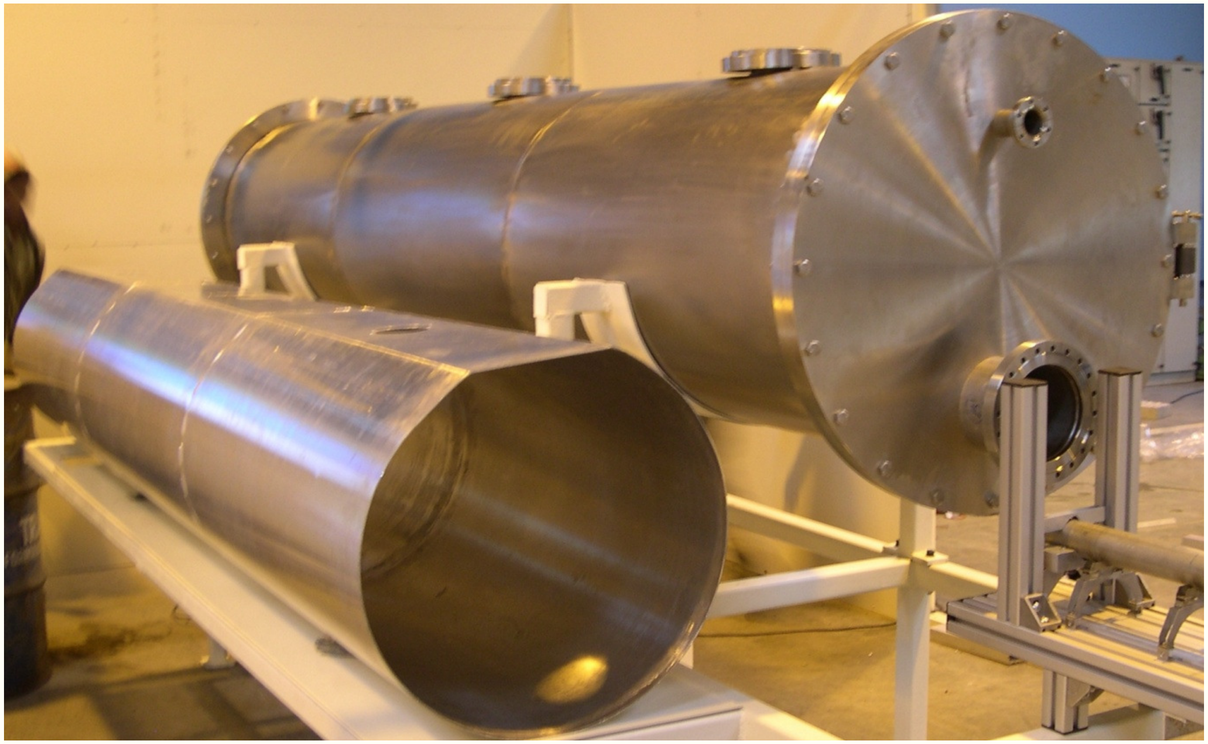
Components of prototype



Laser welded prototype of the cavity support system

C. Thermal Shield of Cryomodule under fabrication

- **The thermal shield is under fabrication.**



- **The cooling tubes are being welded**

C. Thermal Shield of Cryomodule under fabrication

- **The thermal shield is under fabrication.**

- **The cooling tubes are being welded**

Proposed Experiments in CCTR

We have completed calculations (including Finite element Analysis) for two systems namely

A. Cavity Support System
B. Thermal Shield (Cool down)

Now we wish to perform some experiments to validate these calculations.

1. In case of cavity support System we would like to see

   a. How to correct the initial camber of the support pipe with the help of C-T joints which are laser welded.

   b. How much movement occurs for the pads of the cavity support system during cool down.

   c. Can we monitor this movement when all this is happening inside a vessel and actual site is covered with thermal shields

Proposed Experimental Rig

2. In case of thermal shield we would like to see

   a. Can we perform some studies on cool down ex. Effect of thickness of shield or pipe size as suggested by Tom earlier.
   b. How much distortion/shrinkage/ bowing effect occur in the thermal shield.
   c. Can we monitor this movement when all this is happening inside a vessel.

In short we want to verify our calculations

This is an extremely simplified version of Cryostat Thermal Model (CTM) of CERN which was developed at LHC by Central Cryogenic Laboratory (CryoLab) at CERN.

In this meeting we seek your comments on

- What other experiments can be performed if such a system is made?

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Planning for Experiments

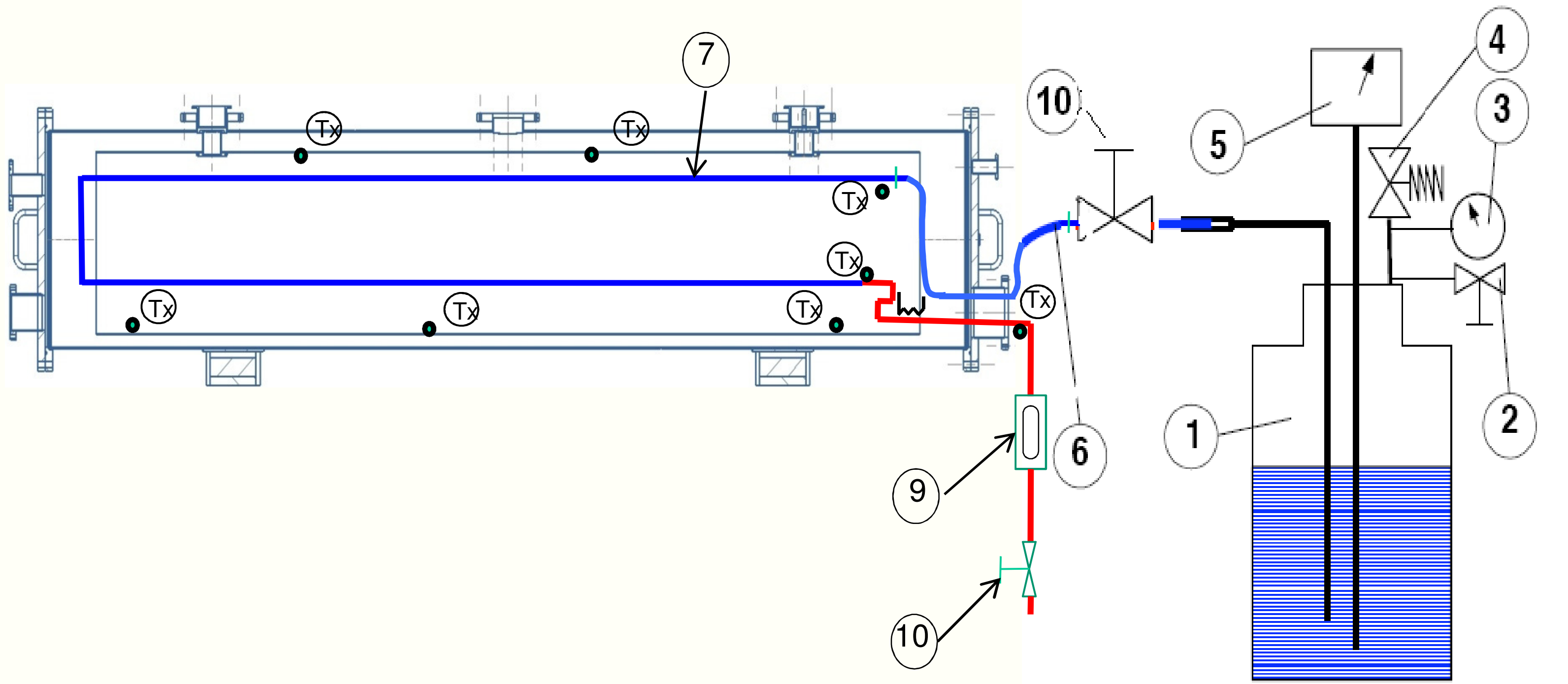
List of Experiments Planned in CCTR

1. To perform cool-down test of prototype 80 K thermal radiation shield of HTS2 in CCTR. (Validate ANSYS Calculations)
2. To perform cool-down test prototype 80 K thermal radiation shield of cryomodule with liquid nitrogen in CCTR. (Validate ANSYS Calculations)
3. Estimation of total static heat in leak through Tesla type cryomodule cryogenic support posts to 80 K sink in CCTR.
4. Estimation of total static heat in leak through cryogenic support posts of HTS-2 to 80 K sink in CCTR
5. Measurement of positional changes of angers/shapes in prototype (HGR pipe based) modified cavity support system in cool down to 80 K in CCTR due to shrinkage

Planning for Experiments (Contd.)

6. Measurement of cool down performance of frame bridge prototype of HTS-2 during cool down to 80 K in CCTR.
7. Study of assembling sequence of Tesla type cavity support system and loading in vacuum vessel of cryomodule with the help of CCTR.
8. Study of different design of cavity support system, like space-frame of SNS cryomodule in CCTR.
9. Studying/prototyping of SSR type cavity support system for low beta cryomodule.

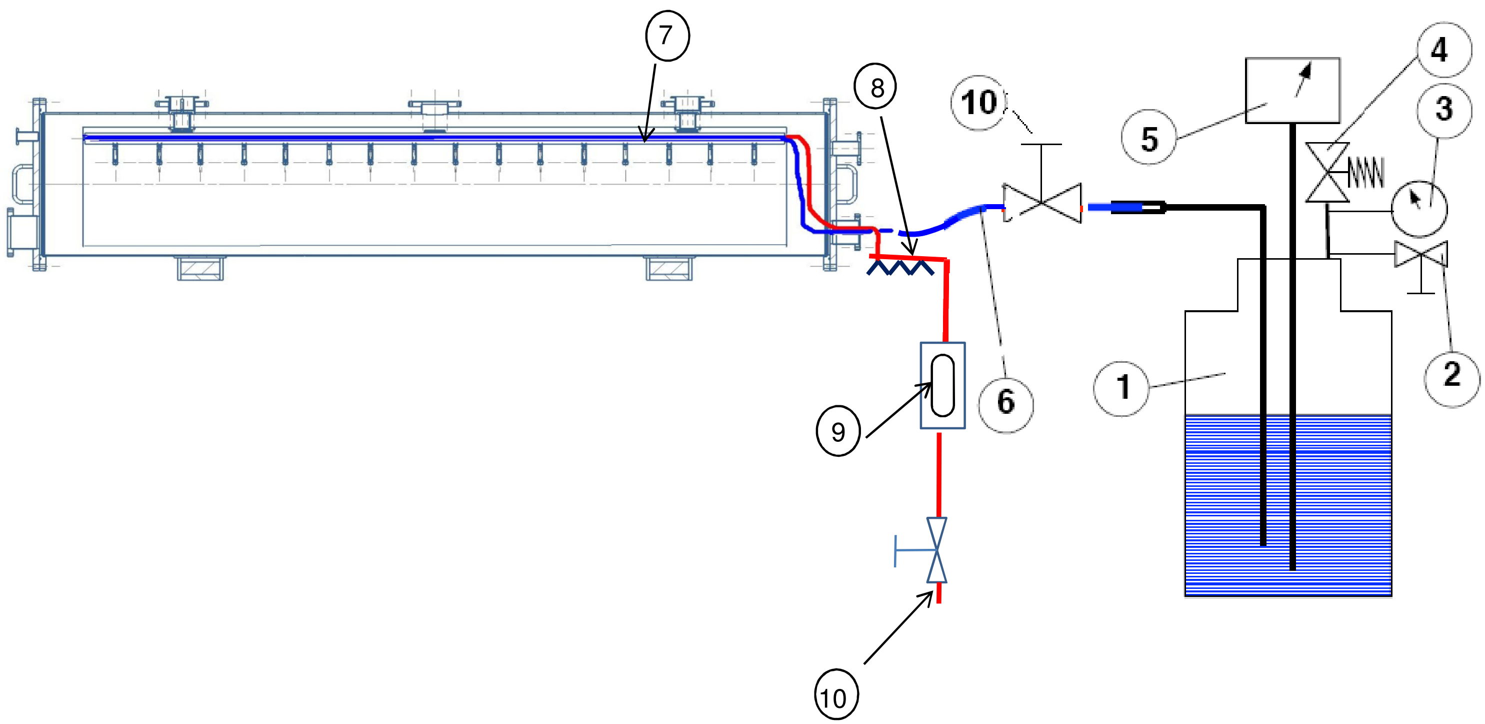
Typical Experimental layout for thermal shield cool down



LEGEND

1	Self pressurized LN2 storage tank	6	Vacuum insulated transfer line
2	De-pressurization valve	7	Radiation shield heat exchanger tubing
3	Manometer	8	Heating tube (Electrically or equivalent)
4	Overpressure valve	9	Flow-meter(say rotameter or equivalent)
5	Liquid nitrogen level gauge	10	Regulation valves

Typical Experimental layout for Cavity Support System testing (In Second Phase)



LEGEND

1	Self pressurized LN2 storage tank	6	Vacuum insulated transfer line
2	De-pressurization valve	7	Support system heat exchanger tubing
3	Manometer	8	Heating tube (Electrically or equivalent)
4	Overpressure valve	9	Flow-meter(say rotameter or equivalent)
5	Liquid nitrogen level gauge	10	Regulation valves

3. Initiation may start on Following activities 1st List

A. Decision to be taken on size of pipe 300mm or 200mm.(CD2)

(issues related to trace tubing, thermal intercepts etc)

B. Vacuum vessel size, should it be kept 44 inches. (CD3)

C. Assembly tooling (CD2)

(decision will depend on cavity support system design)

D. 2-phase pipe configuration for pressure loads, thermal contraction, and assembly (CD1)

E. Location of Heat Exchanger (CD1)

F. SNS-like separate cryoline with individually cooled cryomodules

(Is it Decided)

THANK YOU