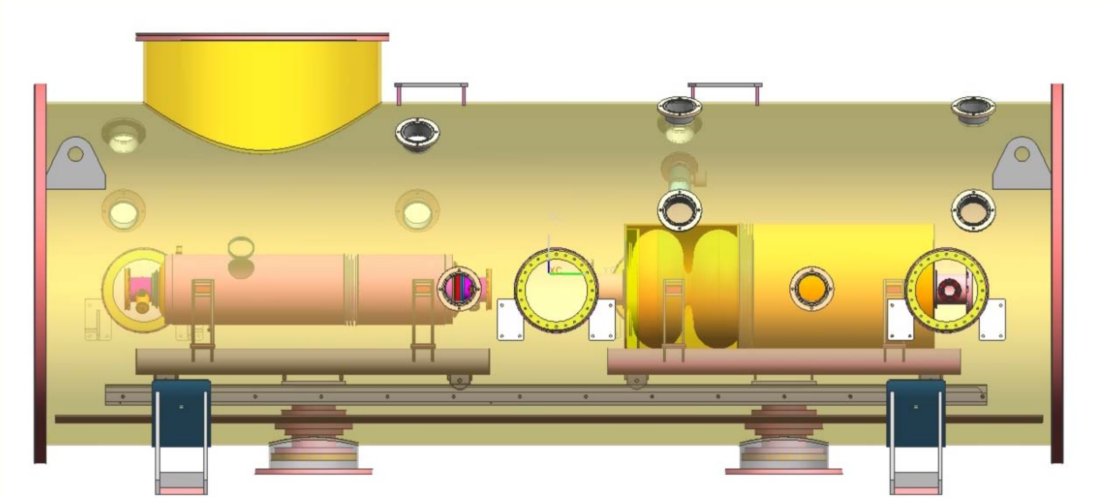
# Horizontal Test Stand -2 Development Effort at RRCAT

A 3-D Model as developed by RRCAT

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# Outline of the Talk

- Introduction
- Status of the design effort
- Path to be traversed
- Details of the work carried out so far in
    A. Vacuum Vessel
    B. Cavity Support system
    C. Thermal Shields
    D. Cryogenic Circuit
    E. Glimpses of the 3-D model developed in UGNX-4
- Queries related with this system so far.
- Conclusion

# Introduction

- HTS-2 has to be designed and developed at RRCAT for testing of fully dressed SCRF cavities: 1.3GHz and 650MHz in both CW and pulsed mode.
- Fermilab has expressed that

"With Fermi Lab's help, RRCAT will fabricate a minimum of two cryostats, one of which will be delivered to Fermilab (Q2 of 2012 preferably or end of Q4-2012)".

- The work has been initiated to design a cryostat of HTS-2. Some glimpses are given in next few slides.
- There are certain dark areas and also there are certain queries in the areas that we are working, which are also presented.

# Status of Design Effort

- Design efforts were initiated in 2009 to design and develop HTS-2.
- A functional requirement specification (FRS) draft document was prepared and sent to FNAL in Jan/Feb 2010.
- After a pause of about 6 months, FRS document was received by us in August 2010.
- Without waiting for other documents like Technical Requirement Specification and Technical Design Report we have initiated design of following subsystems
  - A. Vacuum Vessel
  - B. Cavity Support system
  - C. Thermal Shields

  } All are Related to cryostat to be supplied
- The idea is to cover some ground till we receive detailed reports and then modify the drawings/model accordingly. Thus we intend to save some time.
- With the same thought a complete 3-D model has been completed for HTS-2 which gives us an insight into the internal configuration and sizing of components.

# Path to be traversed

Instead of waiting for the initiation of Technical requirement Specification.

1. We performed literature survey of similar facilities
2. Studied the drawings of HTS-1
3. Prepared a model to visualize the mechanical arrangement
4. Started working on designing the subsystems. The idea is to prepare drawings/models/calculations & if technical design report indicates changes then we will incorporate those changes.

Objective was to minimize the time required

- Like to receive answers to queries, enlisted in further slides.
- The effort has now to begin on
    - A. RF powering
    - B. Instrumentation and Controls

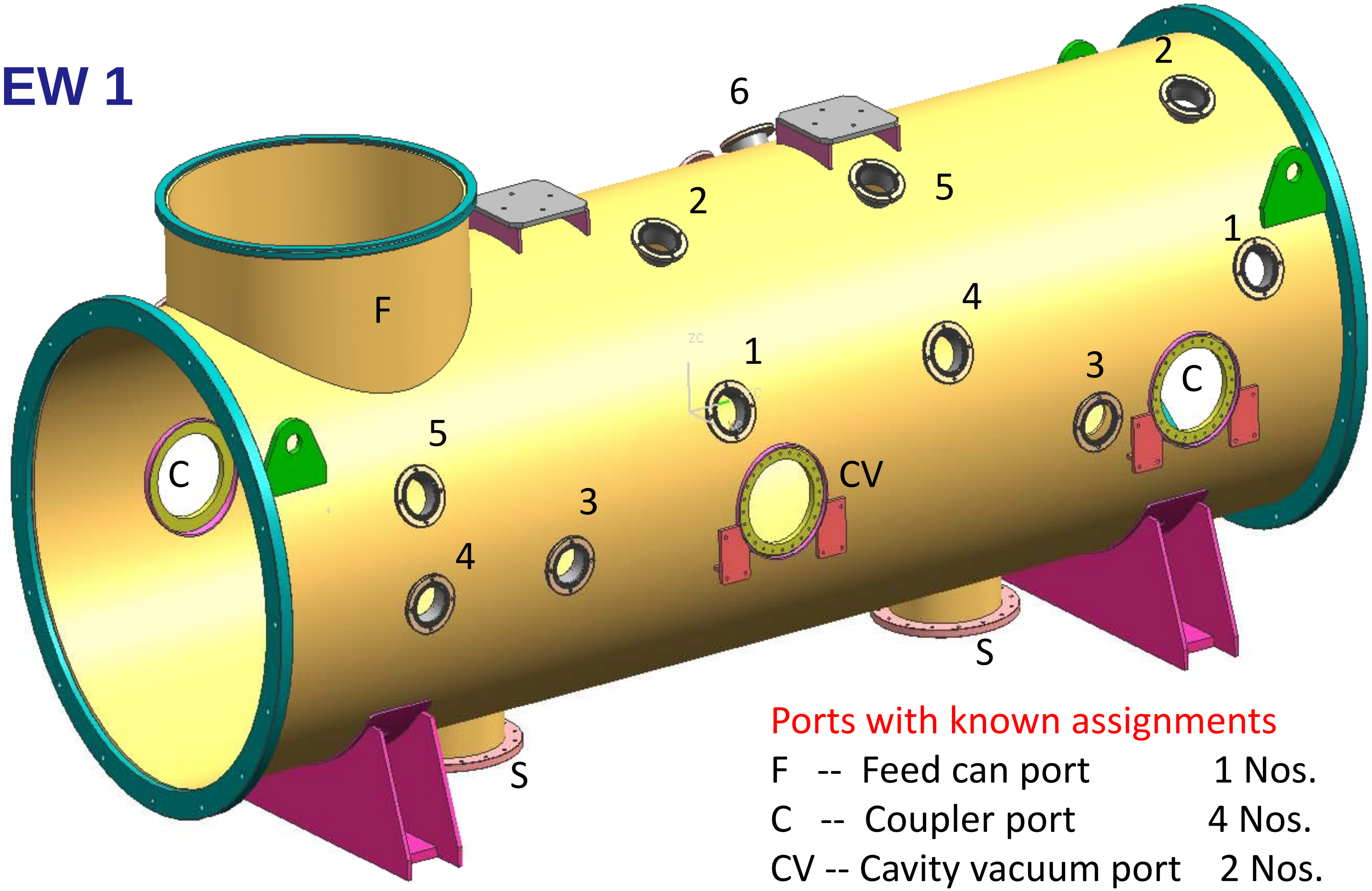
# Details of Works Carried out

## Specifications assumed for the Initiating the Task

| Parameter | Value |
|---|---|
| **Mechanical** | |
| Interior usable length | 3.5 m |
| Interior diameter | 1.2 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 Vacuum Vessel ( 3-D Model in UGNX-4)
## - Developed at RRCAT

VIEW 1

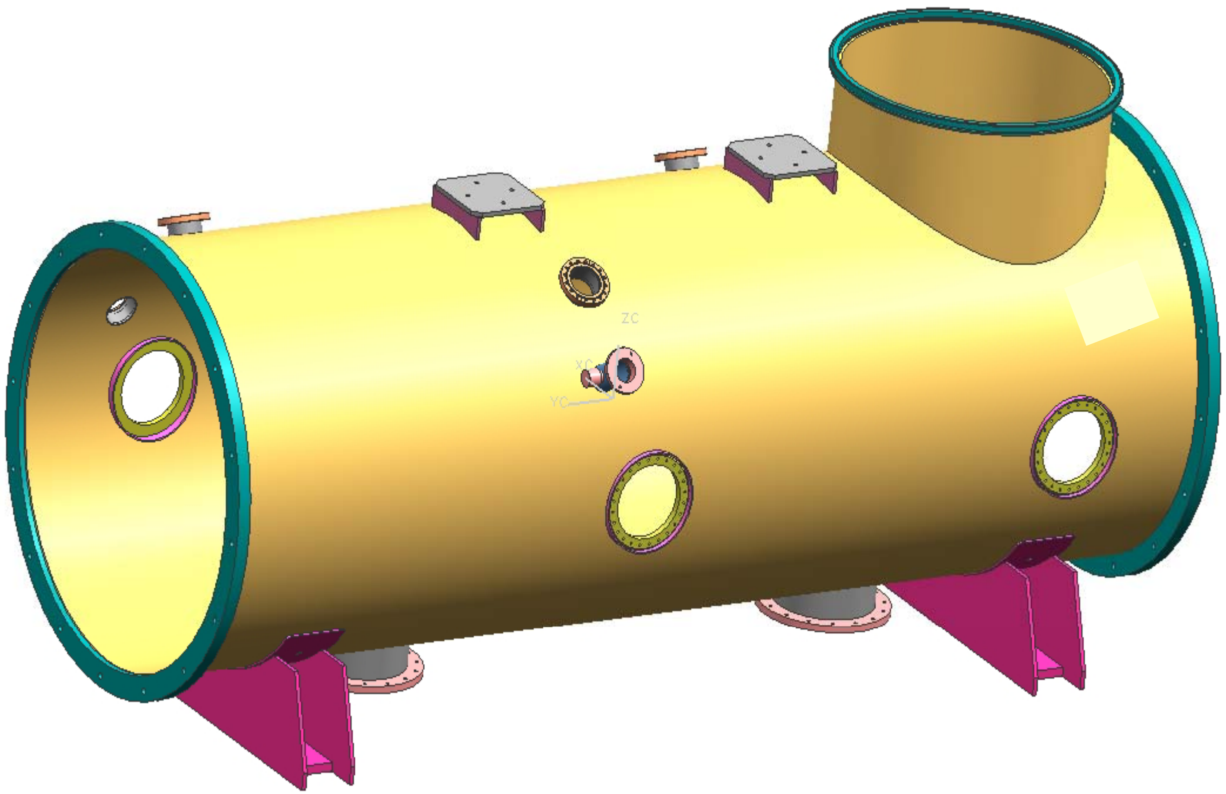



Ports with known assignments

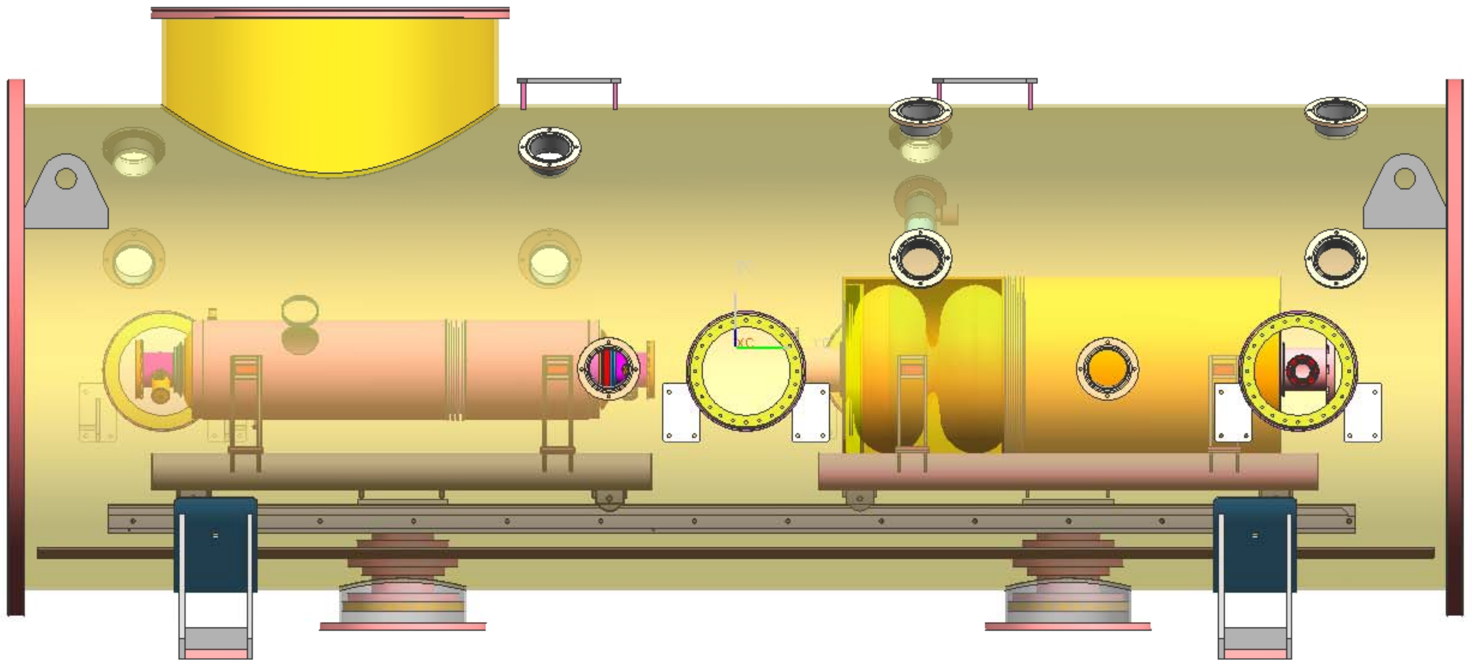
F -- Feed can port 1 Nos.
C -- Coupler port 4 Nos.
CV -- Cavity vacuum port 2 Nos.
S -- Support post port 2 Nos.

# HTS-2 Vacuum Vessel ( 3-D Model in UGNX-4)
## - Developed at RRCAT

**VIEW 2**



# Design & Development of Horizontal Test stand



**3-D Model Completed in UGNX-4 at RRCAT**

**Status**

A. Internal configuration finalized.
C. Cavity support System Prototyping in Progress.
D. Initiated thermal shield design.
E. Vacuum vessel design note -1st draft ready.

# Preliminary Vacuum Vessel Parameters

| Preliminary vacuum vessel of HTS-2 | Designed value | Remark |
|---|---|---|
| Diameter of SS 304 Vessel* | 46 inch | Considering testing of 650 MHz cavity also |
| Overall Length of Vessel | 137.7 inch | Considering testing of two SCRF cavities |
| Nominal Thickness of Vessel | 0.375 inch | |

Verified with ASME Boiler and Pressure Vessel Code Sec.VIII Div 1,(2004)

# Other Vacuum Vessel Parameters

| Description of *openings* in vessel | Size | Numbers | Remark |
|---|---|---|---|
| Feedcan port | 32 inch | 1 | Size dependant upon final cryogenic feedbox design (port wall thickness 0.312” ) |
| Main RF coupler Port | 11.32 inch | 4 | Number of ports according to way the numbers of cavities tested ( port wall thickness 0.187 “ ) |
| Support Post Port (bottom) | 12 inch | 2 | ( Wall thickness 0.25” ) |
| Other Instrumentation Ports | 4 inch | 12 | Number of ports considering two cavities (Wall thickness 0.12” ) |
| Ports for Vacuum Pumping (Same is used for parallel plate type relief valve ? ) | 4 inch | 1 | (Wall thickness 0.12” ) |
| Port for Parallel Plate Relief Valve (with seal off valve ?) | 2.88 inch | 1 | (wall thickness 0.12” ) |

**Note:** No external reinforcement is required for any of the above openings

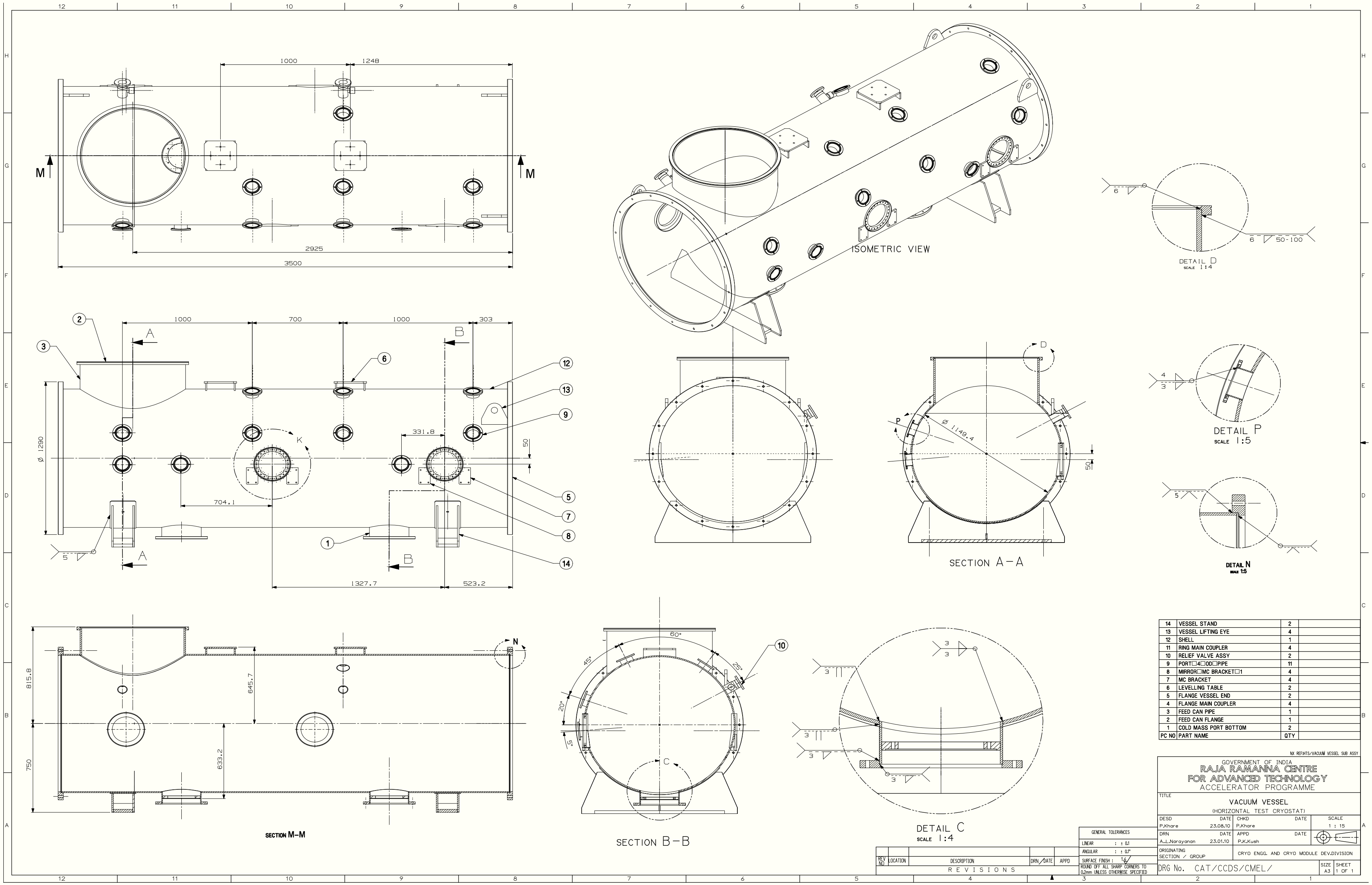
# Tentative Assignment of Instrumentation Ports

## (Referred from documents on internal instrumentation for HTS-1)

| Port No. | Size of ports (in) | Identification as | No. of ports | Remarks |
|---|---|---|---|---|
| 1 | Ø 4 | Coupler and RF | Two | Location ? |
| 2 | Ø 4 | Farady cup and miscellaneous | Two | Location ? |
| 3 | Ø 4 | Cryostat Instrumentation | Two | Location ? |
| 4 | Ø 4 | Fast Tuner | Two | Location of second port due to increased Feedcan port ? |
| 5 | Ø 4 | Miscellaneous | One | Location of second port due to increased Feedcan port ? |
| 6 | Ø 4 | Slow Tuner and miscellaneous | One or Two ? | Number of ports and location? |
| 7 | Ø 2.88 ? | Parallel plate relief port and vessel pumping port | One or Two ? | |

# HTS-2 Vacuum Vessel ( 2-D Drawings)

## Being Prepared at RRCAT



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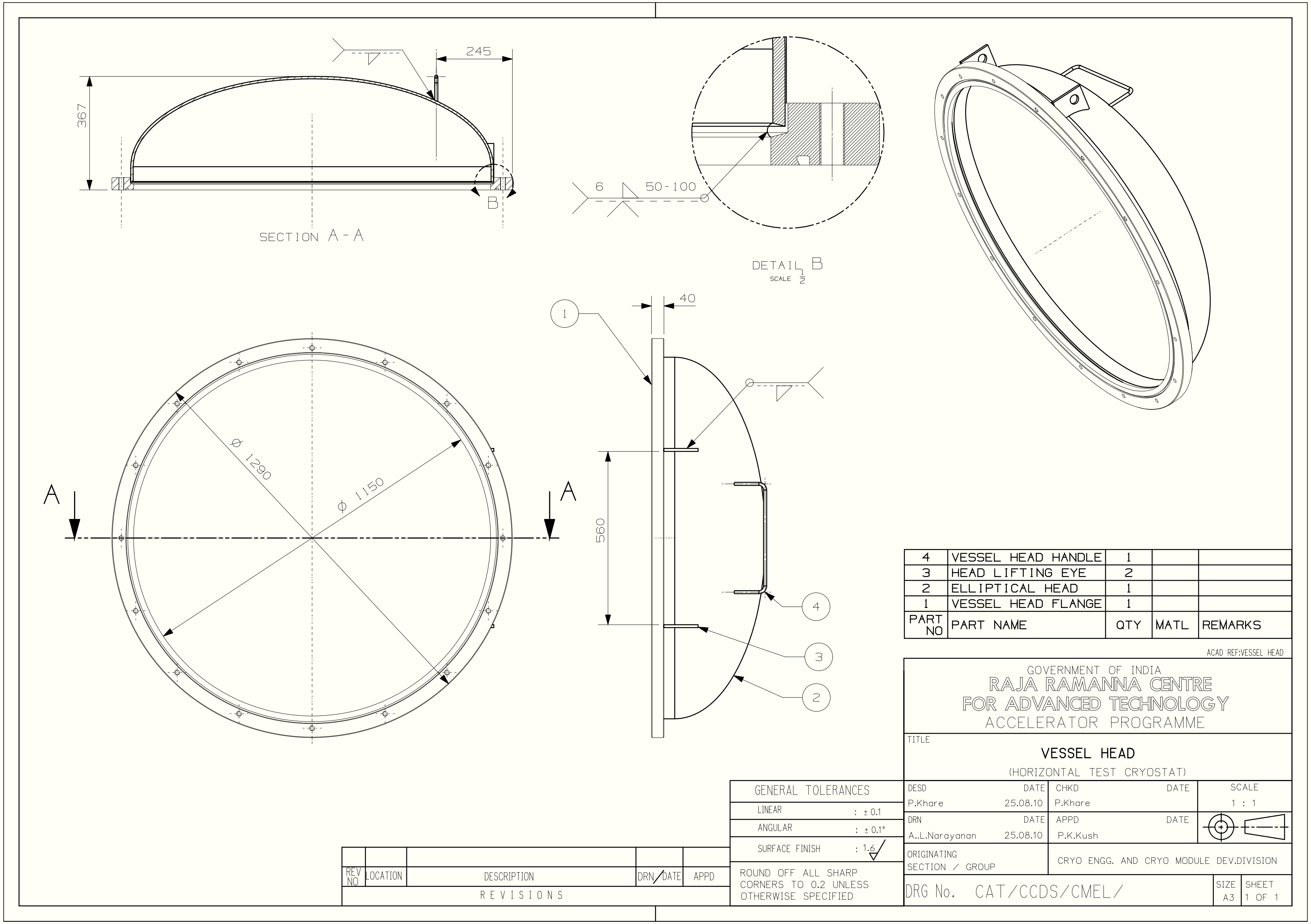

# HTS-2 Vacuum Vessel ( 2-D Drawings)

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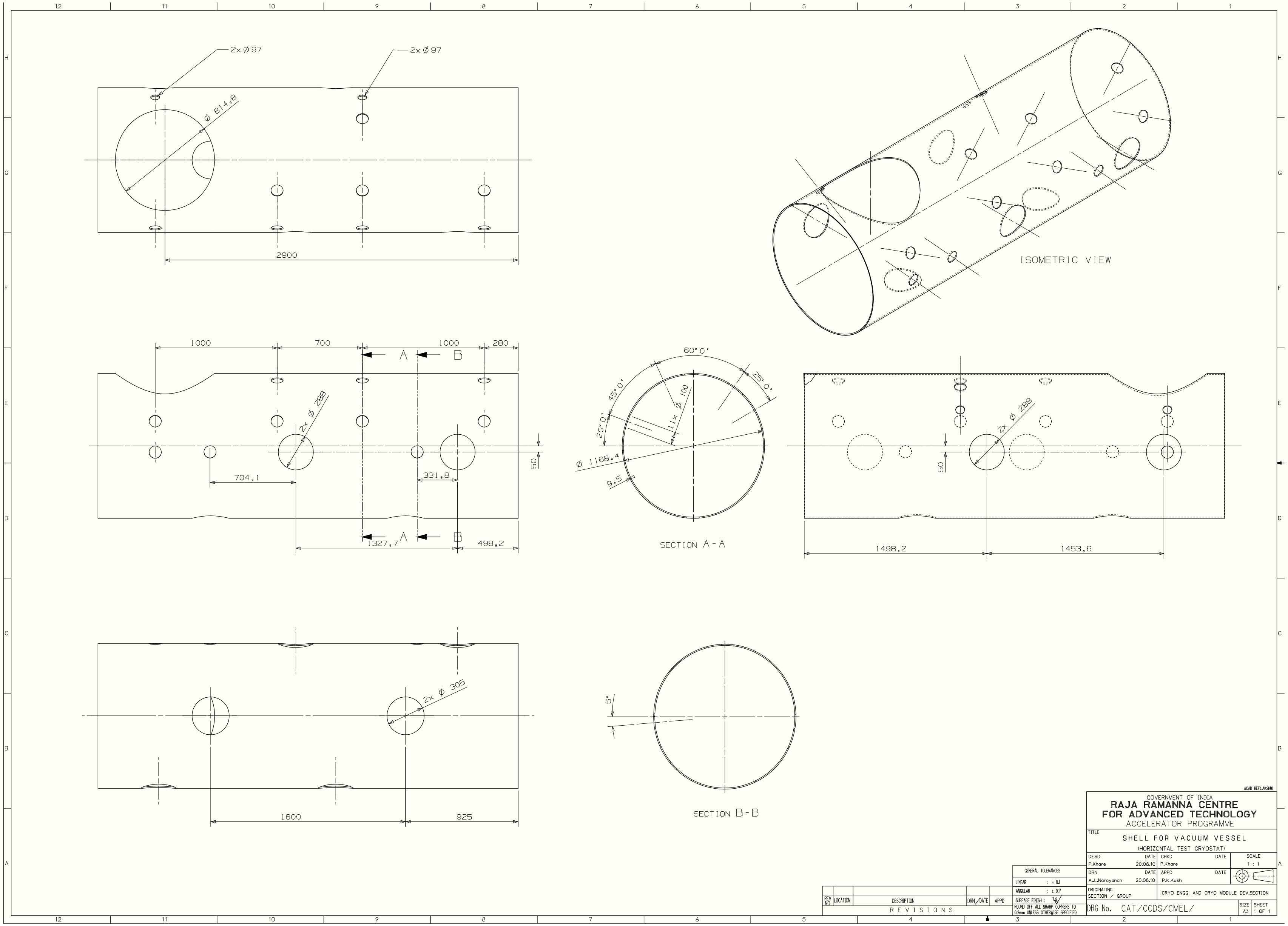
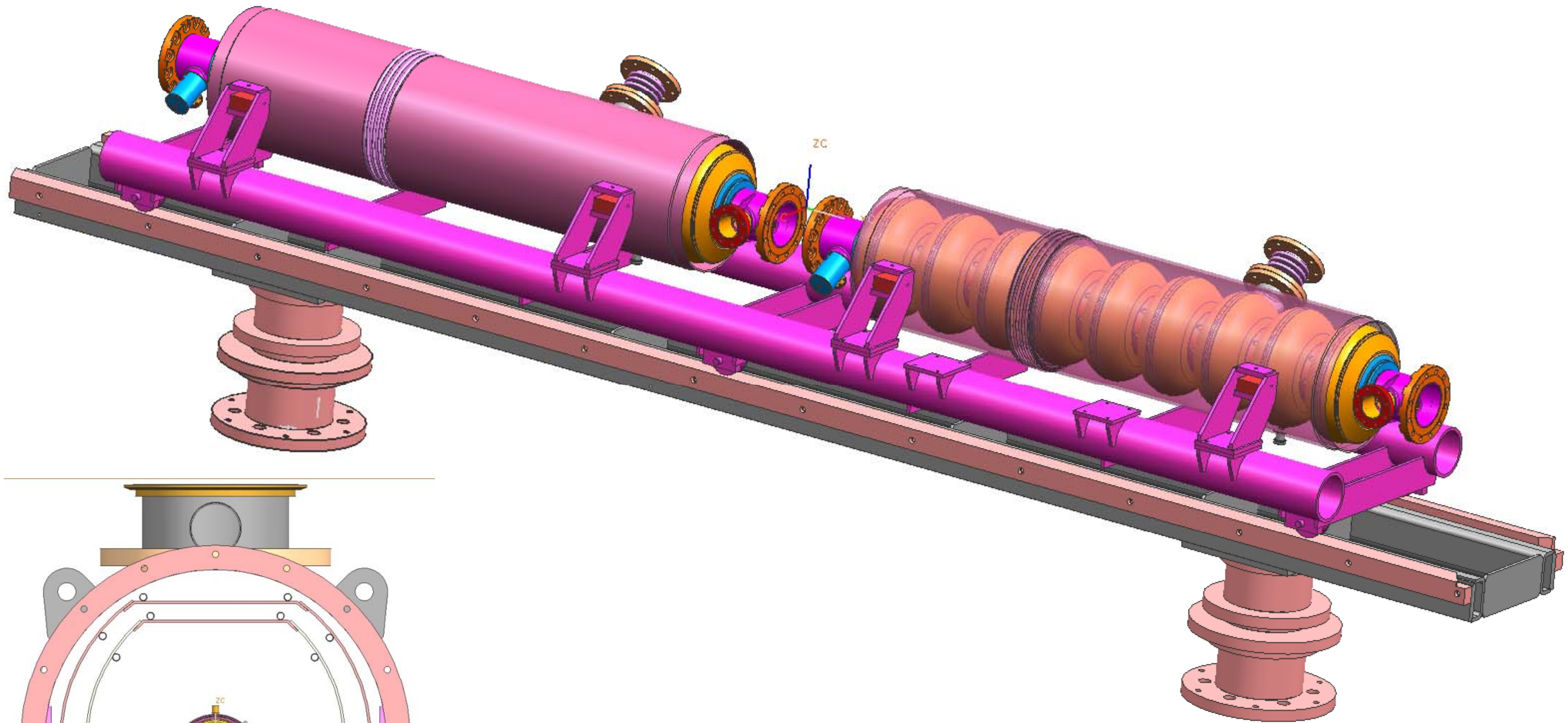
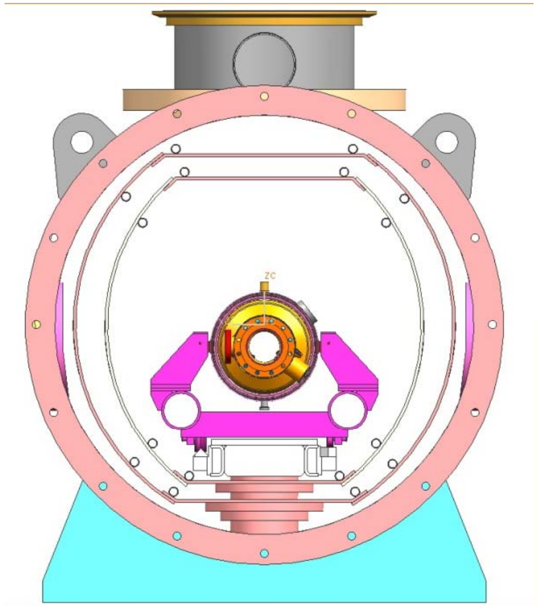


# HTS-2 Cavity Support System- 3d model
## Being Prepared at RRCAT



# Cold Support Post

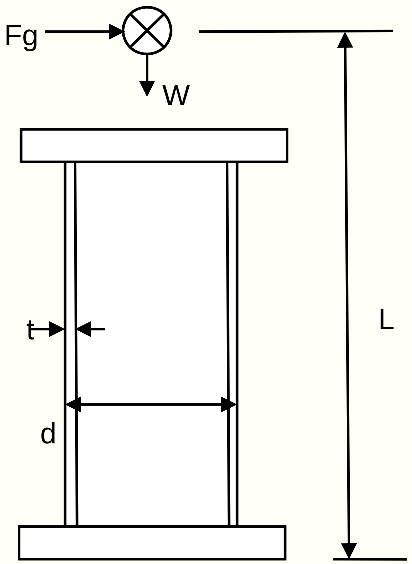
The cold support post of Tesla type IV cryomodules is identical to cryogenic support post design of LHC support post.

We are making an effort to design the cold support post from the first principle. The reason for which is two fold

a. There is no design available, what is available is just the partial drawings of cryogenic support post. Until and unless we understand how it was designed we will not be able to check cryogenic support post for new load conditions.
b. We also want to explore whether there is a possibility to reduce the overall length of support post in order to create space for 4K shield in same diameter of vacuum vessel.

# Structural Analysis of Support Post
## ( Type :2 Ring system)

# Calculate Thickness required for G11 tube




**Considering Tensile Stress due to Bending and Direct Compression at the Base**

$$\sigma = \frac{F_g L d}{2I} - \frac{W}{A} \Rightarrow t = \frac{1}{\sigma}\left[\frac{4F_g L}{\pi d^2} - \frac{W}{\pi d}\right]$$

**Next Check for Elastic Instability**

$$\sigma_e = \frac{2Et}{1.5\sqrt{3}\sqrt{1-\mu^2}\, d}$$

$$t^2 = \frac{1.5\sqrt{3}\sqrt{1-\mu^2}}{2E}\left[\frac{4F_g L}{\pi d} - \frac{W}{\pi}\right]$$

**$F_g$ is lateral component of shipping, handling and seismic load**

**'W' is load per support post**

**'L' is the distance of C.G. of cold mass from base of support post**

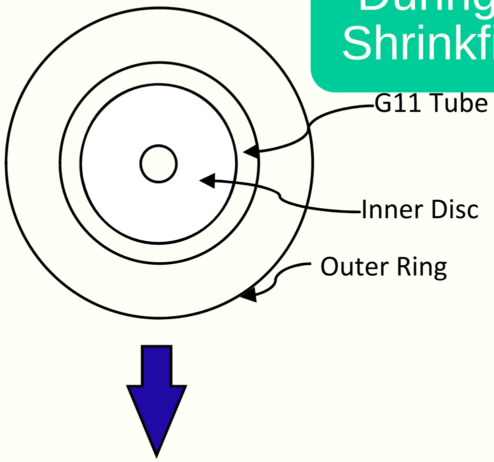
# Basic Model for Analyzing Shrink fit Joint of Support Post

**Before Assembly**

- Interference $\delta_i$ between Inner Disc and Tube
- Clearance $\delta_o$ between Tube and Outer Ring

**During Shrinkfit**

- ID of G11 Tube Increases while OD of Disc Decreases to a Common Inner Interface Diameter
- OD of G11 Tube Increases along with Outer Ring to a Common Outer Interface Diameter




**For Inner Joint**

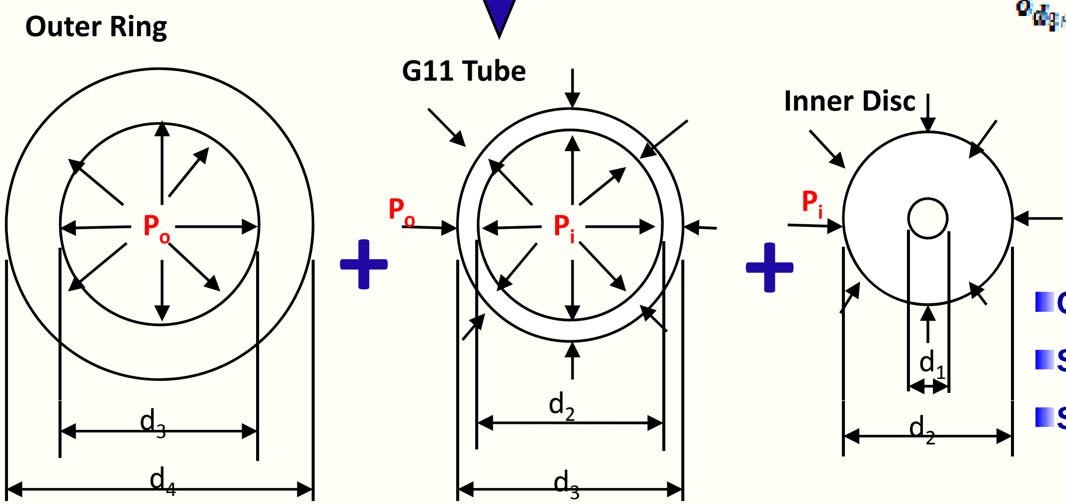
$$ID_{G11} + \delta_{d_2,G11} = OD_{disc} - \delta_{d_2,Disc}$$

$$\delta_{d_2,Disc} + \delta_{d_2,G11} = OD_{disc} - ID_{G11} = \delta_i$$

**For Outer Joint**

$$OD_{G11} + \delta_{d_3,G11} = ID_{Ring} + \delta_{d_3,Ring}$$

$$\delta_{d_3,G11} = ID_{Ring} - OD_{G11} + \delta_{d_3,Ring} = \delta_o + \delta_{d_3,Ring}$$




$\delta_{d_2,Disc}, \delta_{d_2,G11}, \delta_{d_3,G11}, \delta_{d_3,Ring}$ ⇒ Change in ID/OD of Disc, Tube and Ring

- Compound Cylinder with Three Components
- Stress Formulae for Thick Cylinders Used to Find $\delta$
- Solve for $P_i$ and $P_o$ from Two above Coupled Equations

# Load bearing Capacity for HTS

## Result for HTS

| | | |
|---|---|---|
| Po = | 20.44 | N/mm2 |
| Pi = | 21.35 | N/mm2 |
| Fo = | 4494 | Kg |
| Fi = | 4617 | Kg |

| | |
|---|---|
| ID of SS Disc, d1 | 19mm |
| ID of G11Tube, d2 | 149.9mm |
| OD of G11Tube, d3 | 152.4mm |
| OD of SS Ring, d4 | 178mm |
| Diametral Interference Disc and Tube, δi | 0.22mm |
| Diametral Clearance Ring and Tube, δo | 0.1mm |

| | | |
|---|---|---|
| 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 | | 200Gpa |
| Young's Modulus G11 Tube, E2 | | 28Gpa |
| Young's Modulus SS304 Ring,E3 | | 200Gpa |

$P_i$ 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

# Further Work to be performed

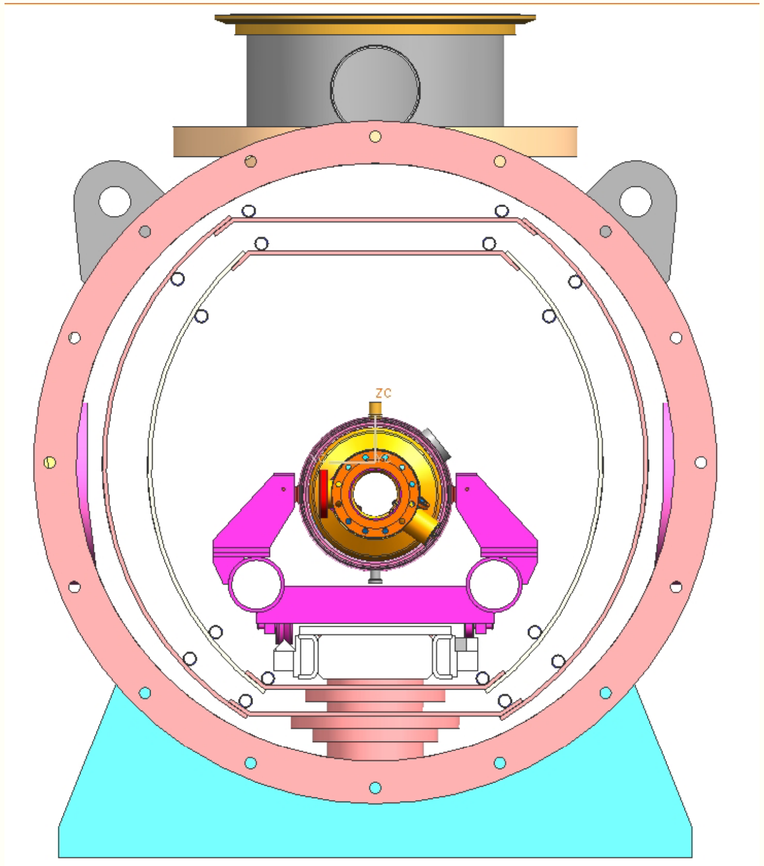
## ❑ Work to be Performed

- ❖ Find Optimum Position of 80K and 4K Intercept by Minimizing Total Room Temperature Refrigeration Load
- ❖ Calculate Heat Loads at 80K, 4K and 2K
- ❖ Finite Element Analysis of Support Post Structure

## ❑ Need Inputs for Completing the analysis

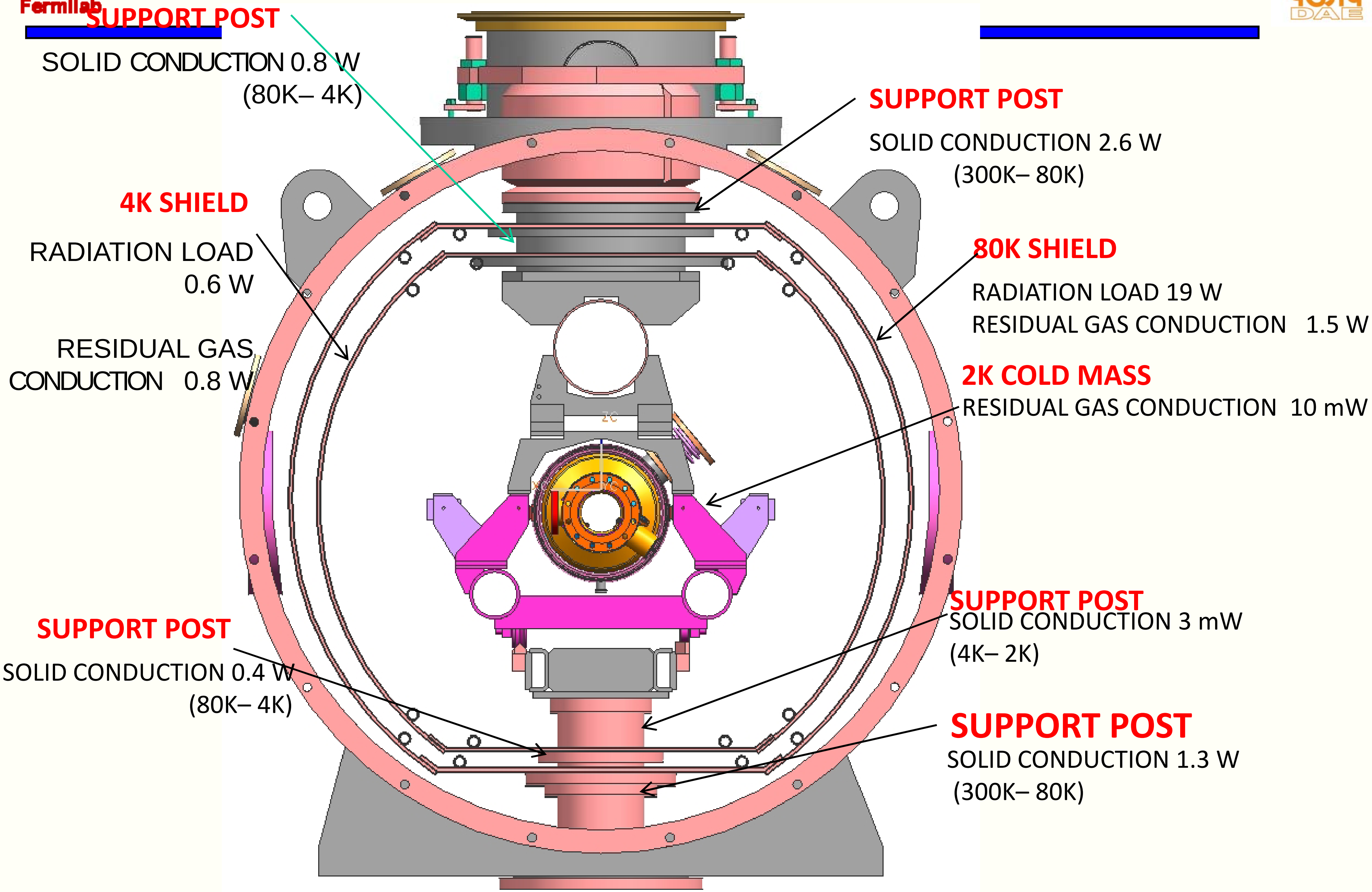
- ❖ Details of Cold Mass Weight and Distribution
- ❖ Details of Shock Loads
- ❖ Estimate Lateral resonant Frequency of Support Post

# HTS-2 Thermal Shields - 3d model Being Prepared at RRCAT




1. Assumed Vessel Dia to be 46 inch
2. Thermal shields 80K and for 5-8K
3. Two three options for layout of cool down pipes being contemplated.
4. We are targeting a figure of 24 hrs for the cool down.

# Crossection & Heat Leak Initial Estimates (CCDS, RRCAT)



# Formulation of Problem for the analysis

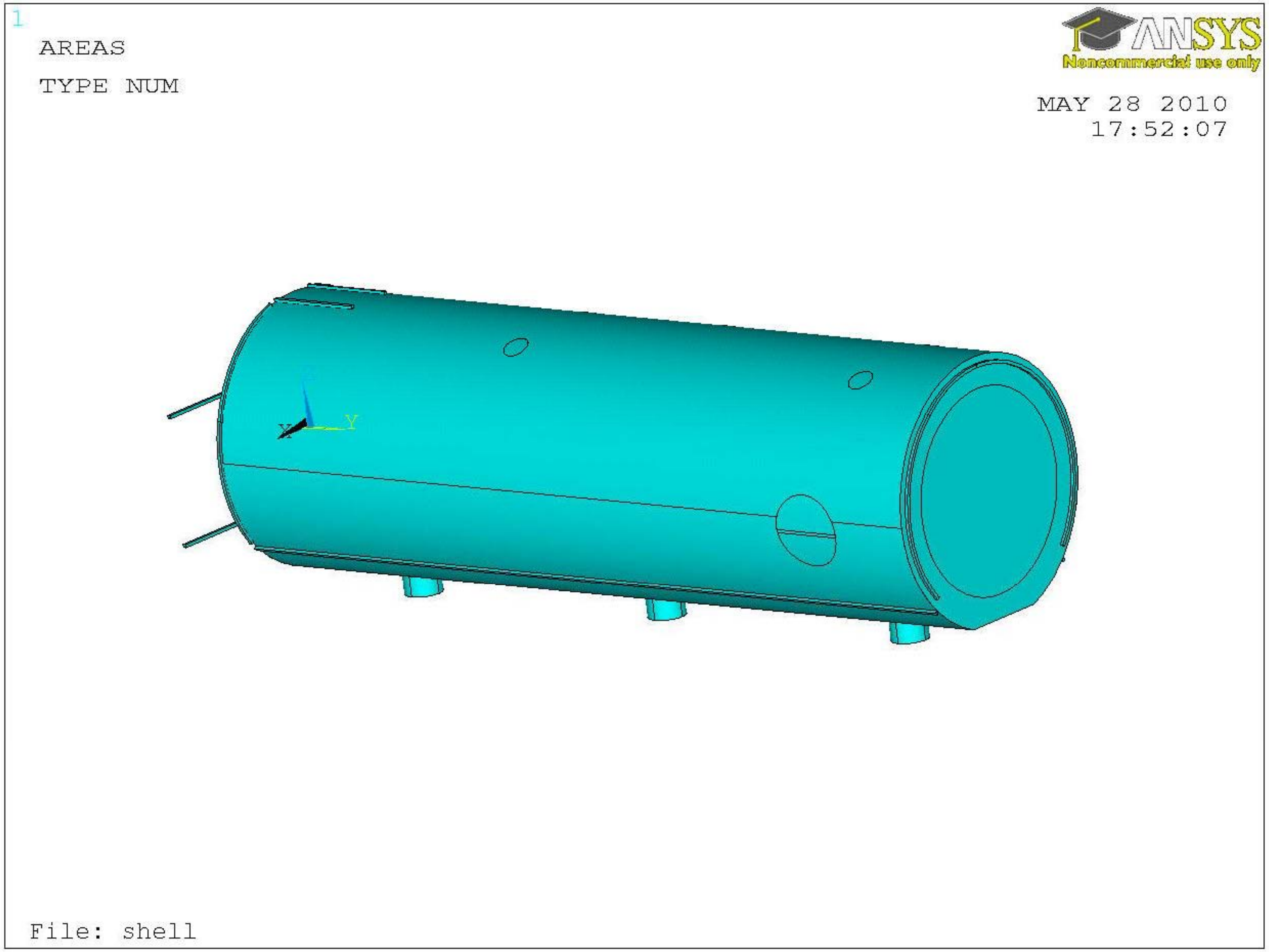
## Based on this We have formulated our problem as

- Keep temperature of Cooling pipes initially at 80K
- Assume emissivity as 1.97e-3
- Ignore the initial 25 minutes when cooling tube comes to 80K
- Keep cooling circuit
  - A. As in present HTS-1
  - B. As proposed for HTS-2
  - C. Based on the behavior of exercise A&B evolve our own scheme

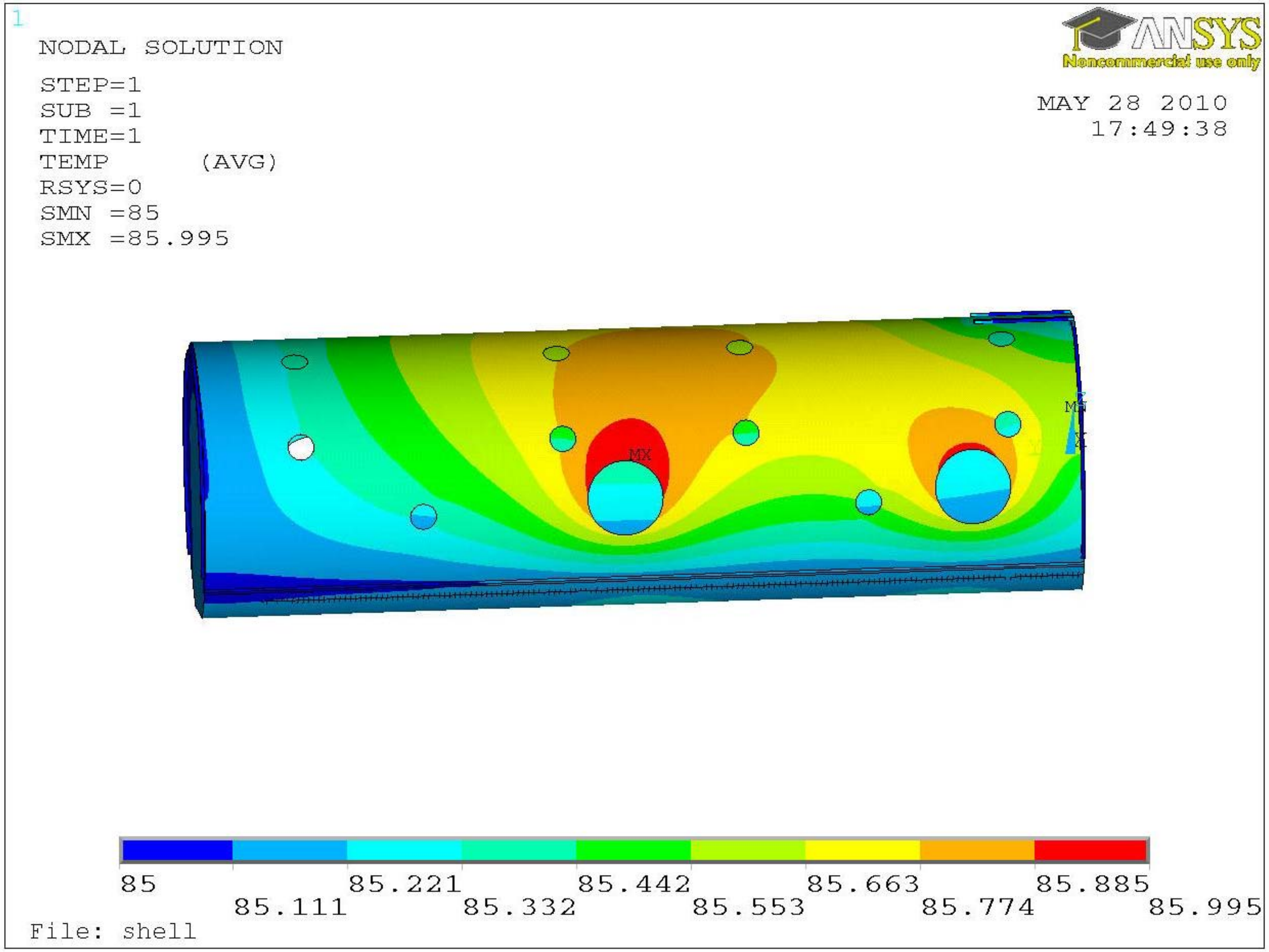
**We want to find out**

1. Steady State analysis to find out max. Temperature gradient.
2. Transient analysis to find out cool down time.
3. Transient analysis to find out maximum temperature gradient during cooling down.
4. Transient analysis to find out induced deformations.
5. Match the results with those available for HTS-1 or some other results.

# The 3-D Model of thermal Shield



# Steady State Analysis



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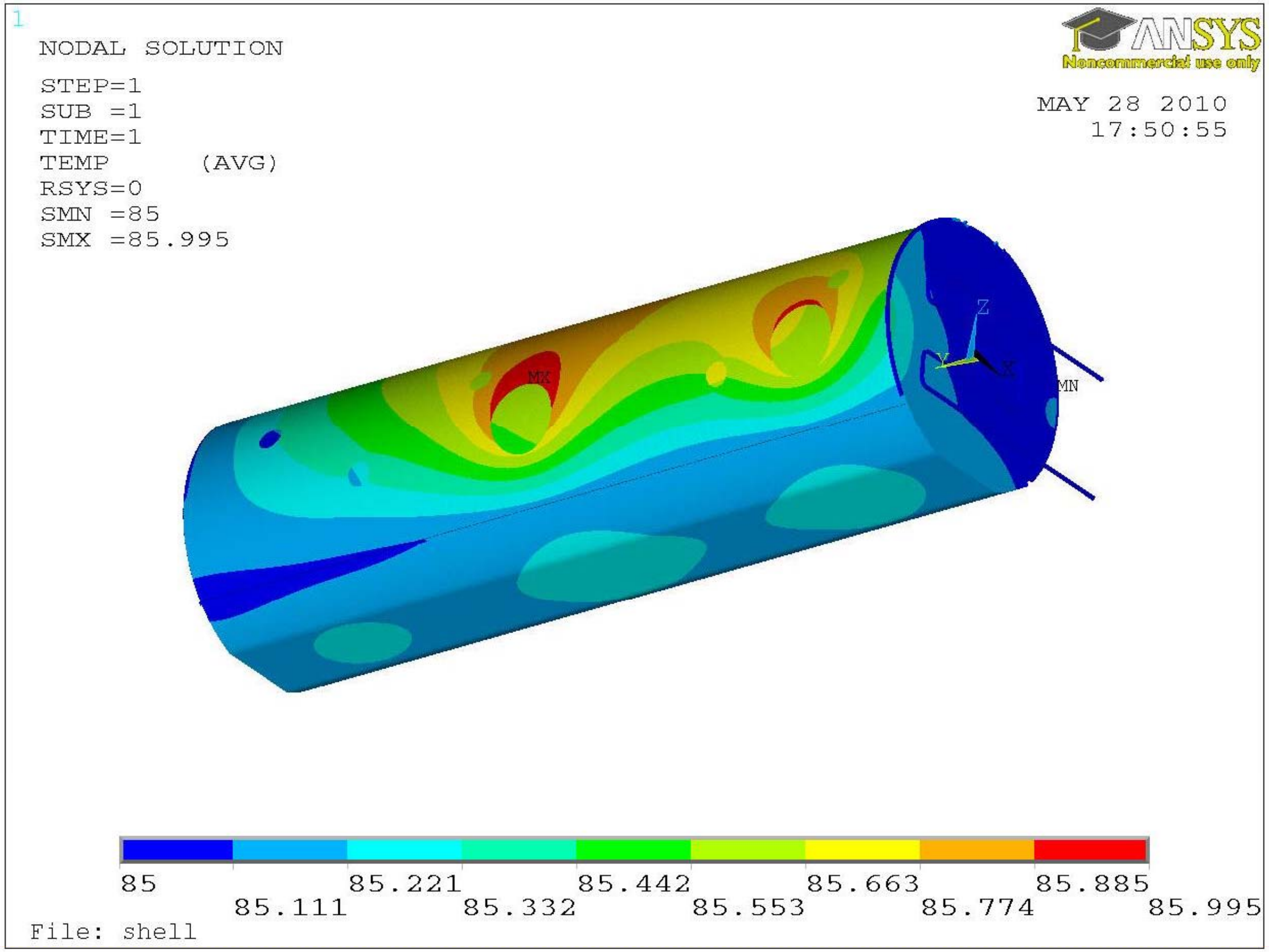
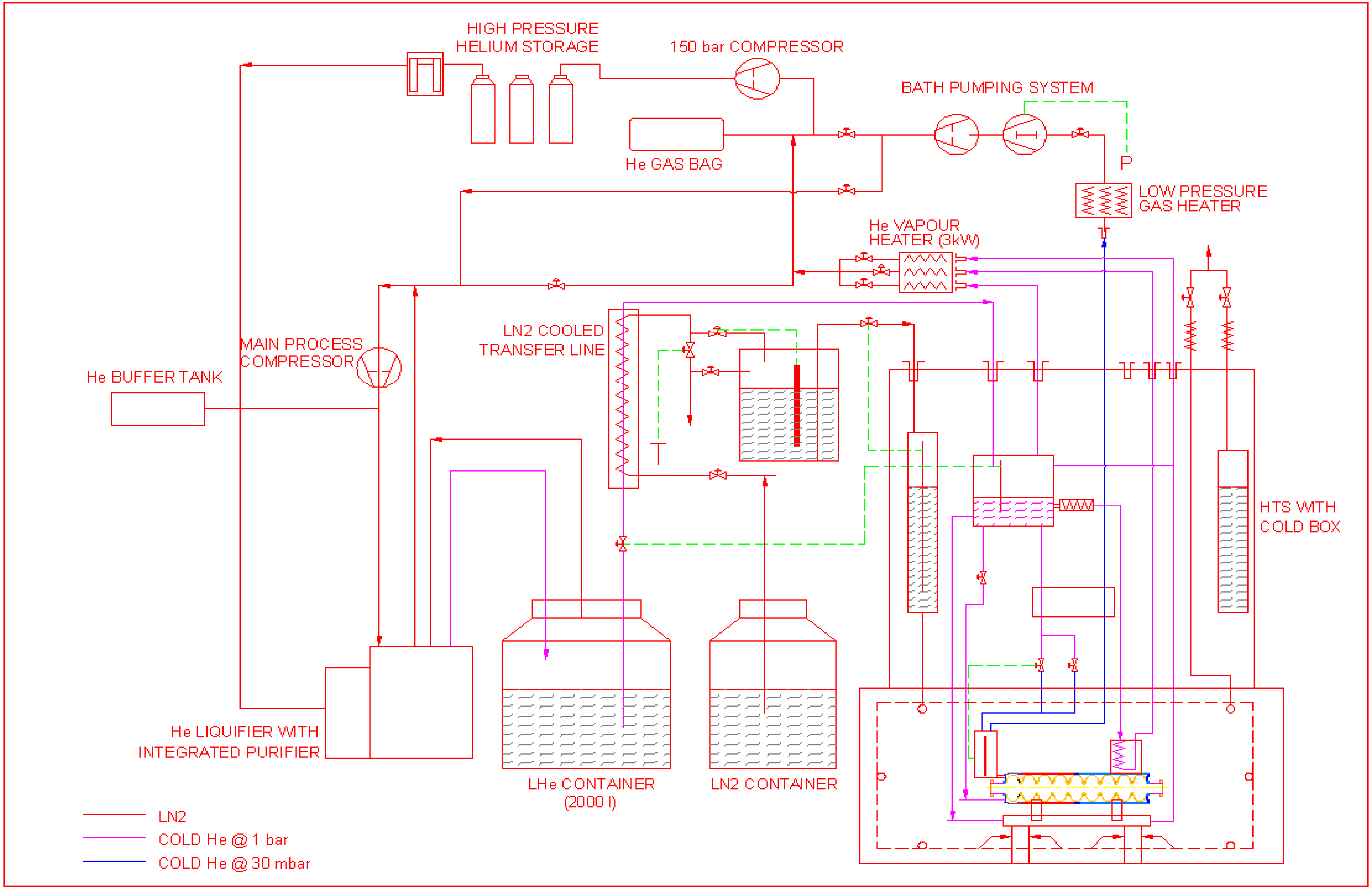


# Cryogenic Circuit

- **P & I Diagram for HTS**
- **Heat exchanger 4.5 K to 2K**
- **2K Supply system**
  - **Although beam tubes of both the cavities will be isolated, but Cryogenically they may be tested jointly, to study cryogenic complications in case of CW operation.**
- **Pressure Stability requirements during CW operation**
- **Retention of 4K thermal shield:** **Now larger inventories of liquid helium is to be provided for CW testing. Also larger ratio of dynamic to static heat load is expected for CW testing. Can one think for omission of a 4 K thermal radiation shield?**

# External Cryogenic Process Circuit proposed for HTS



# Some Topics For Discussion

- Time schedule of HTS cryostat looks extremely tight.

  After finalization of drawings we will need minimum 18 months for fabrication. The HTS functional Requirement specifications document itself took 6 months. We can not go for fabrication till drawings are final.
- Need details of Cryogenic feed box (for size of port)
- Need details of cryogen requirements.
- Need to identify someone at FNAL end to begin RF power supply discussions.
- Need to identify someone at FNAL end to begin discussions on instrumentation and control.

# Thank You