Cryostat and Subsystems Development at ITER

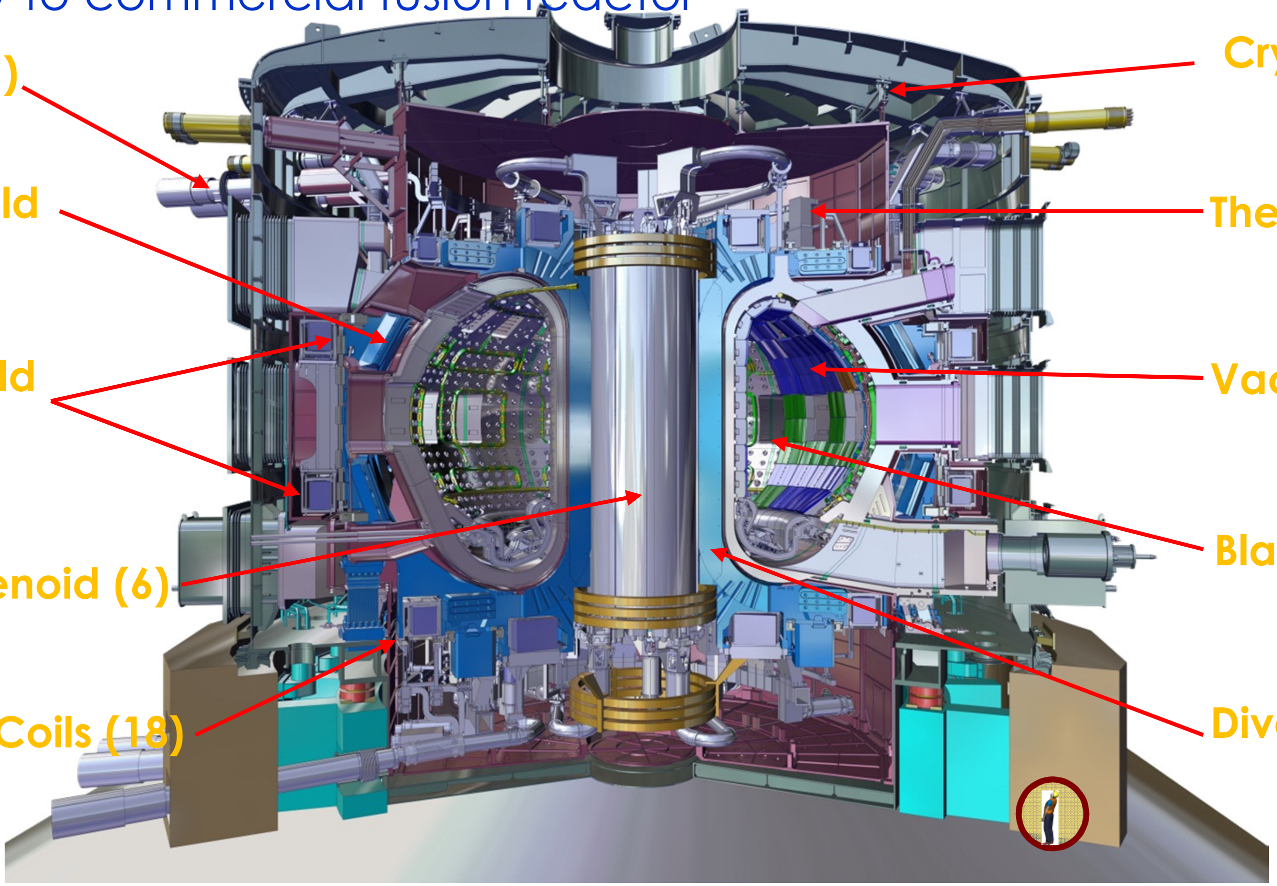
Igor Sekachev
Michael Meekins, Carlo Sborchia,
Guillaume Vitupier, Han Xie, Caipin Zhou

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

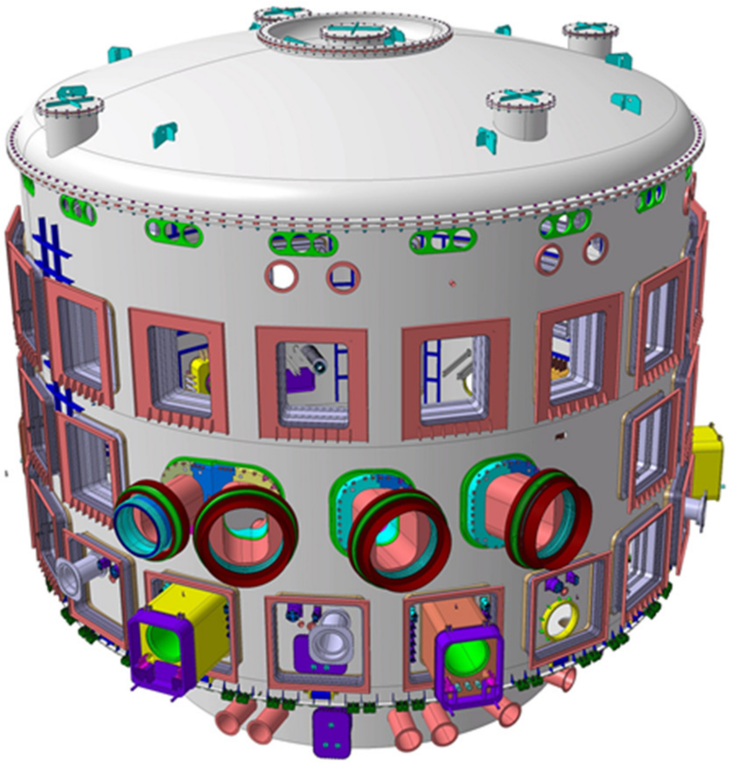
Introduction of ITER Tokamak

The ITER tokamak is an experimental fusion reactor. The self-sustained D-T burning plasma in ITER generates 10 times more power (500 MW) than it receives (50 MW)

ITER will demonstrate the availability and integration of science and technologies, and safety features for a fusion reactor. ITER is a necessary step on the way to commercial fusion reactor



Cryostat overall parameters



Cryostat is a single wall fully welded stainless steel cylindrical chamber with internally vertical and toroidal ribs. It has top dome shape lid and bottom flat head.

Cryostat Outside Diameter (max)	28.54 m
Cryostat Height	29.25 m
Wall Thickness	40mm-180mm
Number of Sections	4
Main cylinder Shell Thickness	50 & 60 mm
Material of Main Construction	Dual mark304L/304
Toroidal Resistance	>10 μΩ
Design base Pressure	1×10^{-4} Pa
Required Leak Rate of completed Cryostat (including inside components)	$\leq 1\times10^{-4}$ Pam^{-3}/s
- Cryostat Surface Area	~3400 m2
- Interior Free Volume	~8500 m3
- Interior Total Volume	~16000 m3
Mass (Approximate)	
- Top lid Main	656 ton
- Upper cylinder	600 ton
- Lower Cylinder (+ TCPH)	809 ton (1023 ton)
- Base Section	1250 ton
- Total mass	~3500 ton

Role of ITER Cryostat

- ITER Cryostat forms a vacuum tight container, surrounding the entire Tokamak Machine. It provides the vacuum insulation environment for the superconducting magnets operating at 4.5K and for the thermal shield operating at 80K. Cryostat is a large volume vacuum vessel subjected to external pressure and designed to evacuate to a base pressure of $1x10^{-4}$ Pa.
- Cryostat supporting system is designed to provide the support to Superconducting magnet systems and Vacuum Vessel. Cryostat transfer all the loads to the floor of the pit through sliding bearings between the cryostat pedestal ring and concrete crown structure.
- Cryostat provides access ways to the vacuum vessel for different equipment. Cryostat has penetrations for the equipment connecting elements of systems outside the cryostat to the corresponding elements inside the cryostat.

Cryostat Design Code & Classification

Code & Standard

- The ASME Section VIII Division-2 is used as a reference code and additional requirements of ITER Vacuum Handbook are applied for design, construction and testing of the cryostat.
- ITER Cryostat is analysed to confirm the structural integrity for different load cases as per the code criterions.

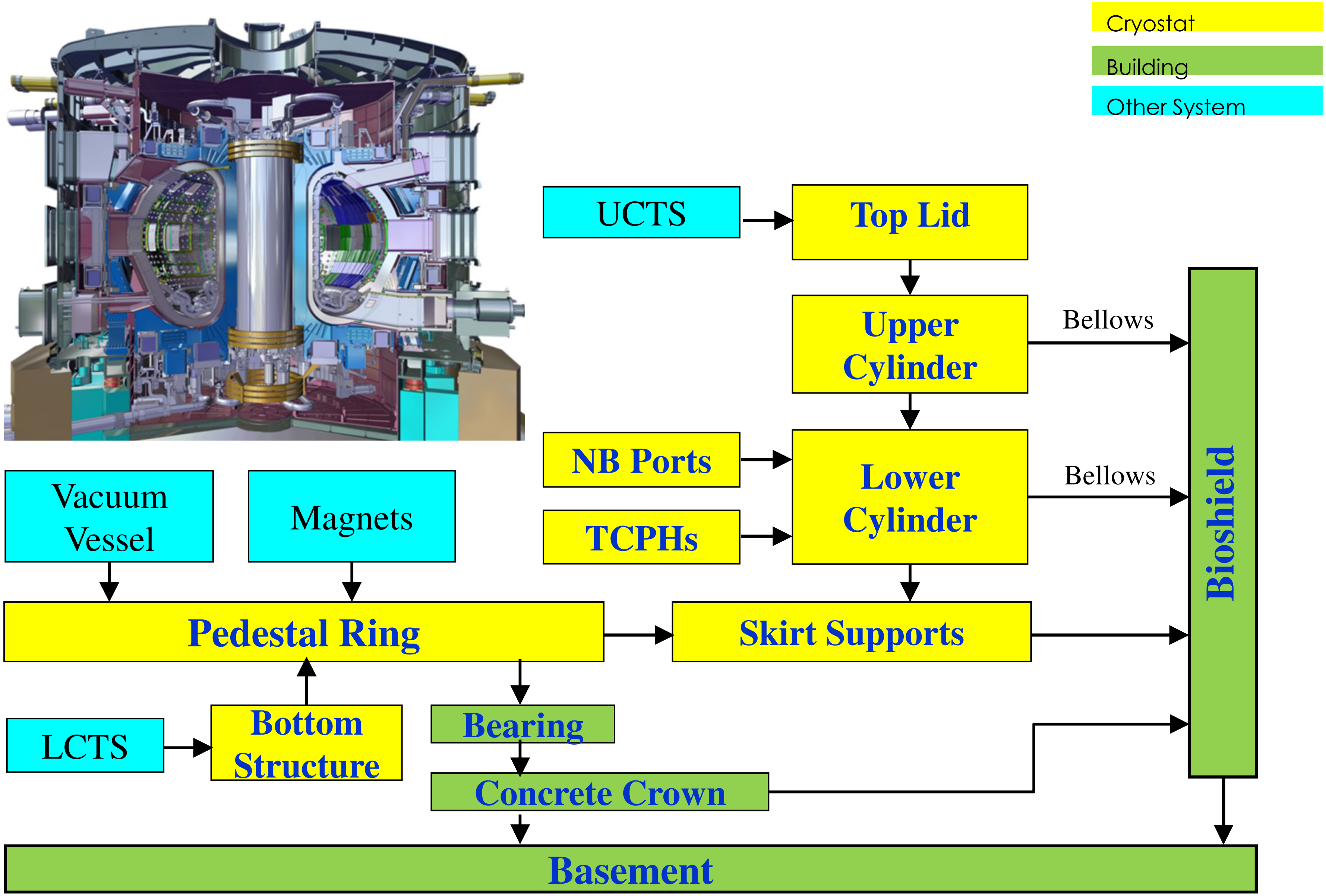
Design classification

- Cryostat support system and Torus Cryopump Housing (TCPH) is PIC-1, the rest of Cryostat system is PIC-2.

  (PIC=Project Importance Component)
- Cryostat is VQC-2A, QC-1 and SC-2

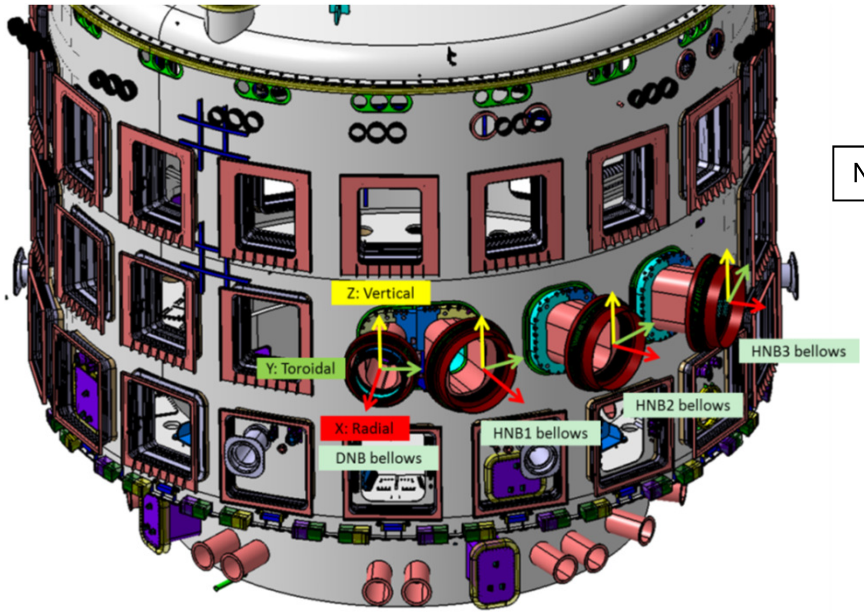
  (VQC=Vacuum Quality Class; QC=Quality Class; SC=Seismic Class)
- The local leak rate of 10^{-9} $Pa.m^3/s$ is expected to meet the ultimate vacuum requirement.

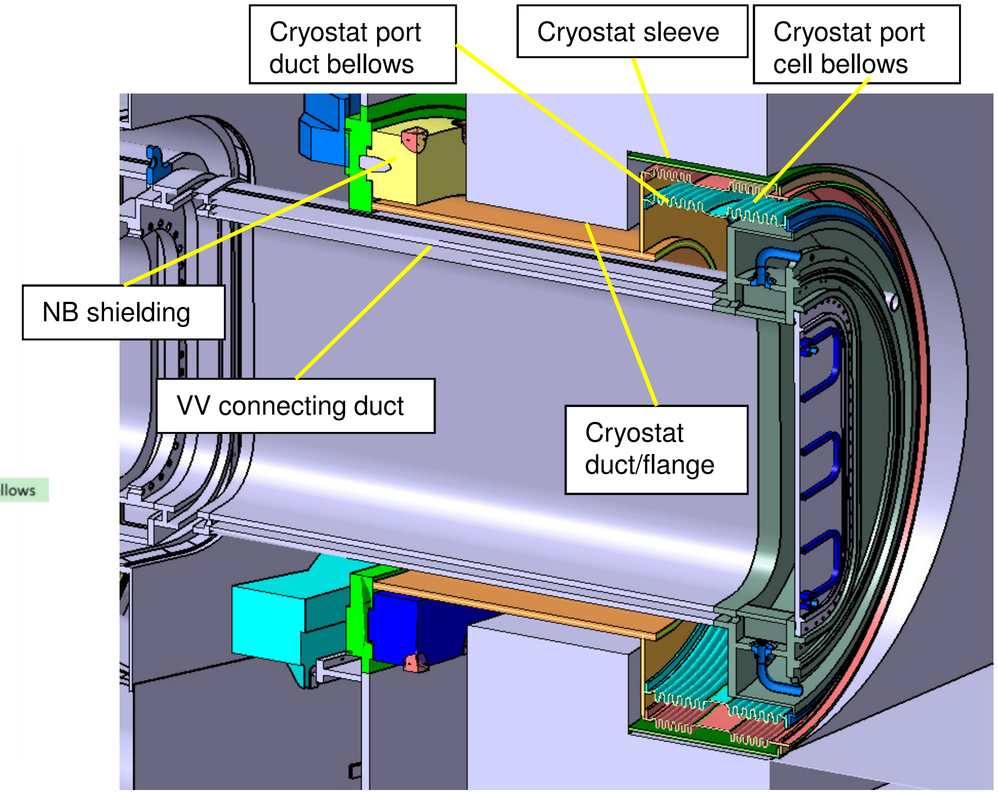
The structural load paths



Cryostat Sub system - NB Port bellows

Equatorial NB Ports (circular)



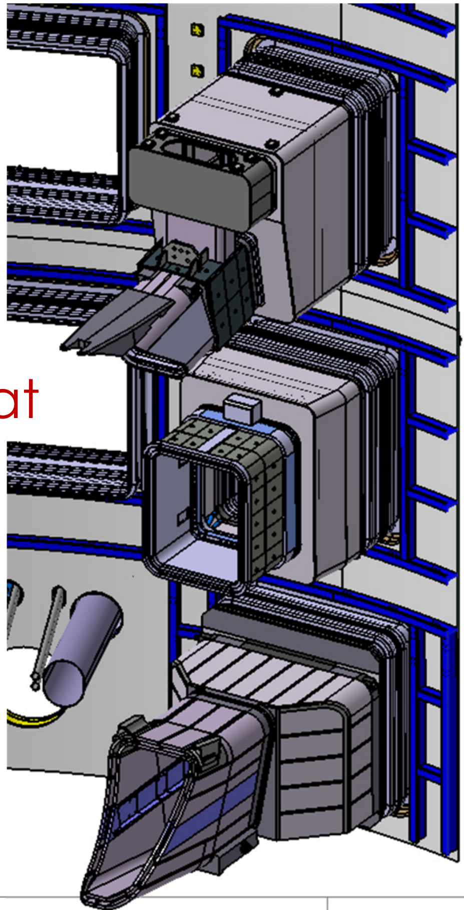


- VV, Cryostat, Building are subject to differential movements (thermal, seismic motion, EM, etc.).
- NB Port are located at the Equatorial level where are three HNB ports and one DNB port with associated Circular Port Duct Bellows and Port Cell Bellows

Cryostat Sub system: Rectangular Port bellows

- Rectangular bellows is to connect the VV & CR on three level for thermal, VDE and seismic excursion
- Multilayer (with interspace monitor) is utilized and stiffness needs optimization
- Prototype and testing is on-going to verify the design

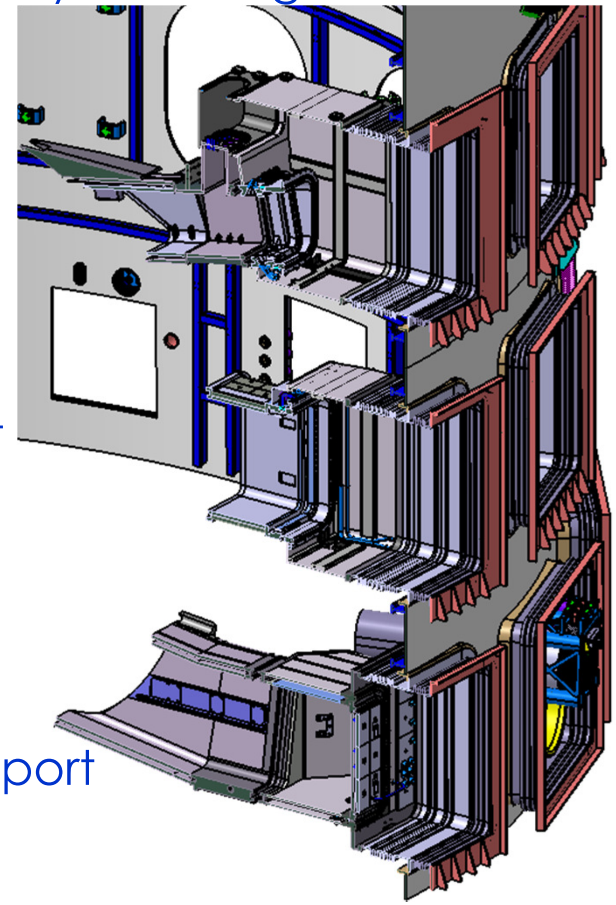
Inside Cryostat



Upper port

Equatorial port

Lower/Divertor port



outside Cryostat

Rectangular Bellows: full-size prototype testing

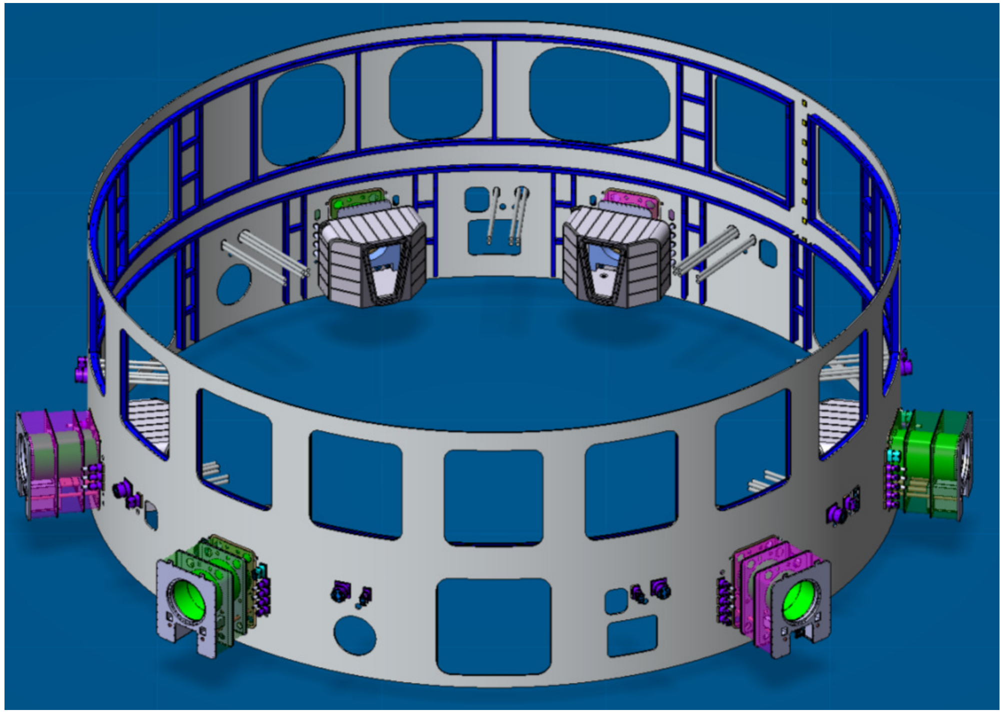
Full scale prototype of bellow, measuring 3.6 x 3.2 m, was tested for spring rate in kompaflex

The large weights of steel and concrete give an idea of the resulting force from the combined spring rates due to different relative movements. Further tests on the prototype will follow to measure its stability under vacuum and to test helium leakage.

Cryostat Sub system: TCPH x 6

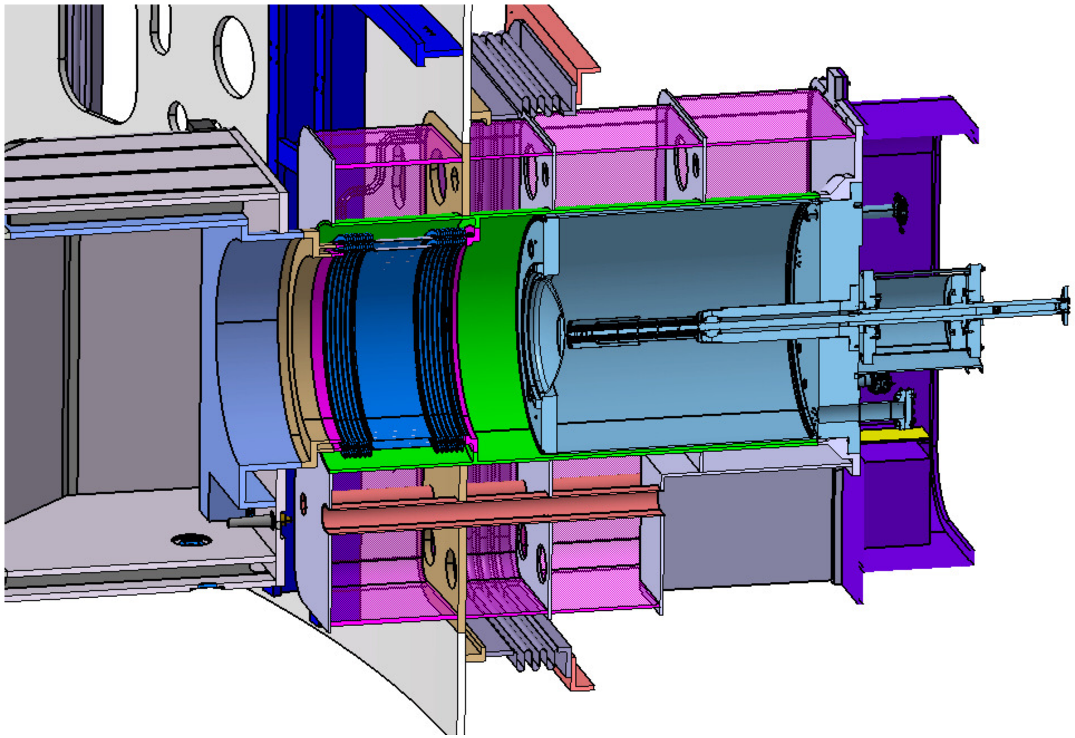
The functions of Torus Cryopump Housing (TCPH)

- Support the torus cryo-pumps
- Connect the cryo-pumps to the torus vacuum
- Provide volume for cryo-pump regeneration
- Provide tritium confinement and primary vacuum boundary
- Provides RH docking compatibility for removal of cryo-pump



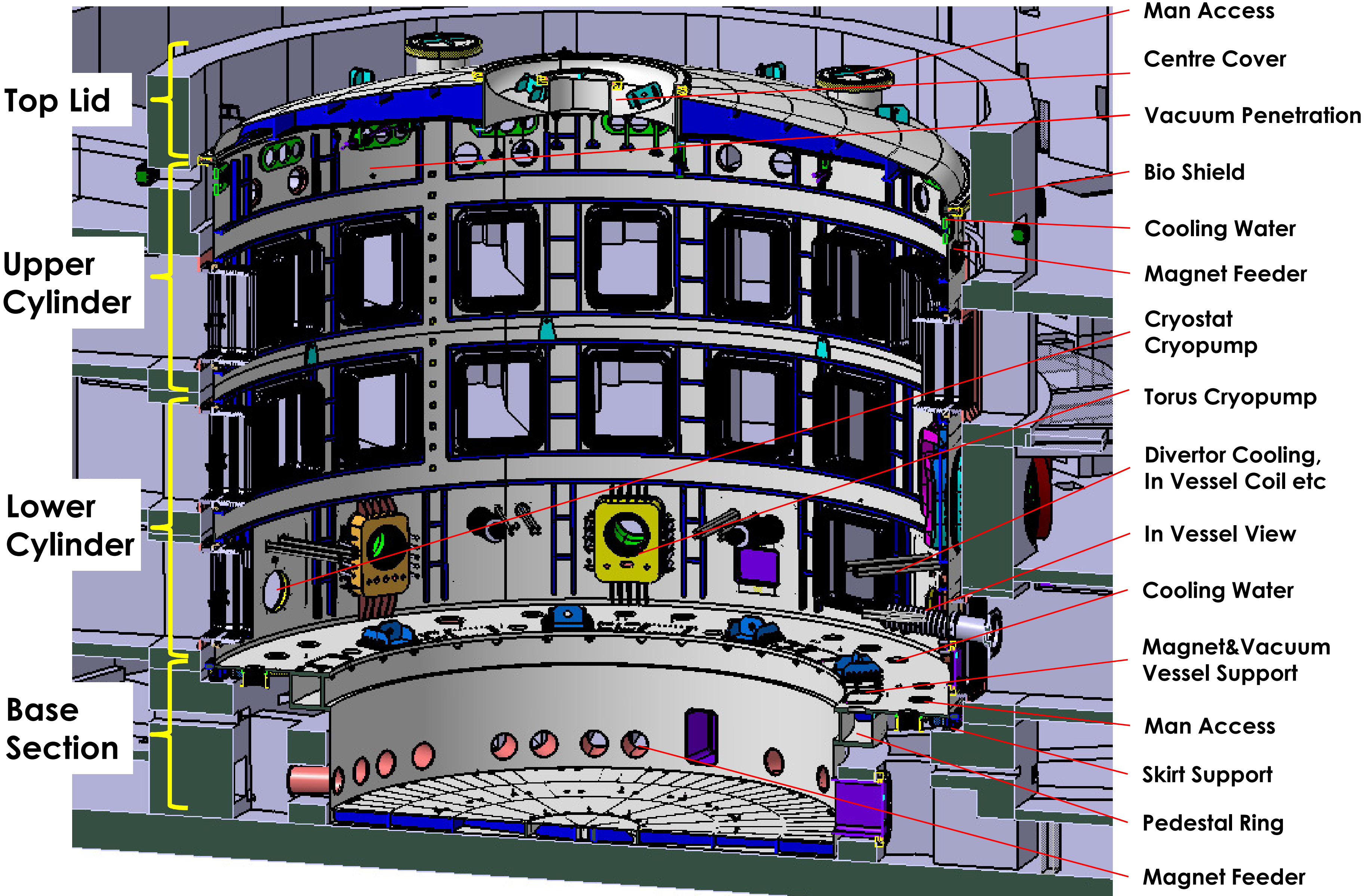
TCPH with TCP inserted

- VV is pumped by 6 TCPs inserted into 6 uniform TCPHs, which are connected to the VV port extension by bellows and duct. The internal volume of each TCP of 2.9 m^3, with connecting pipe of 0.1 m^3 and with volume of each TCPH of 12 m^3 form total regeneration volume of 15 m^3

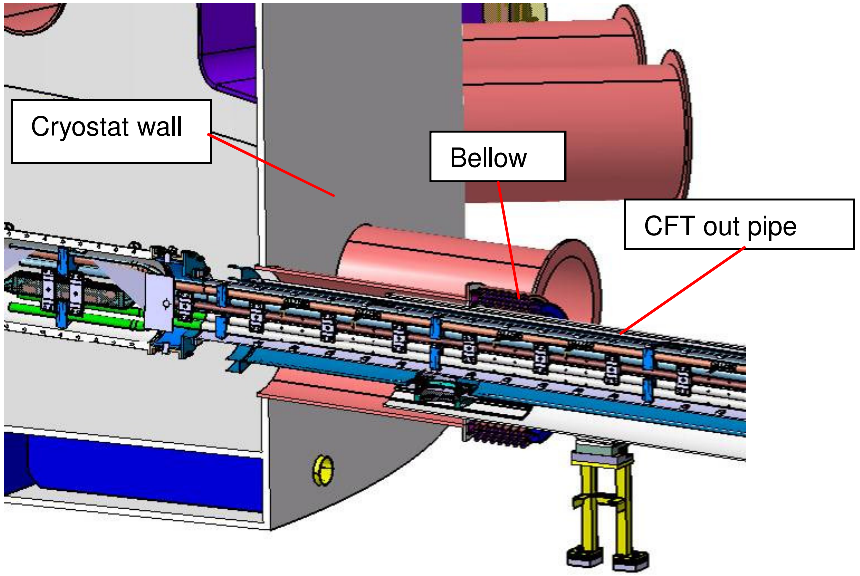


- Because TCPH is first confinement barrier for Tokamak device, it has to be designed and manufactured as per "RCC-MR Edition 2007".
- TCPH is PIC 1,
  VQC-1A,
  QC-1,
  SC-2

Cryostat Interface - Overview



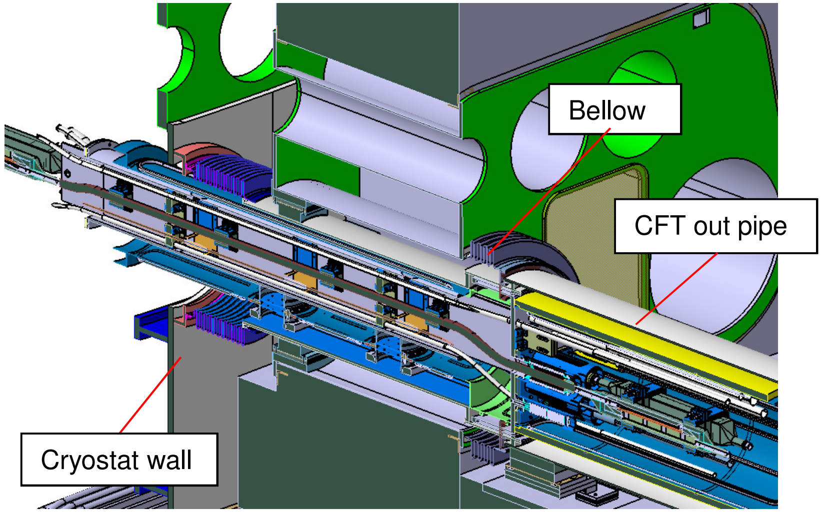
Cryostat Interface – with Magnet

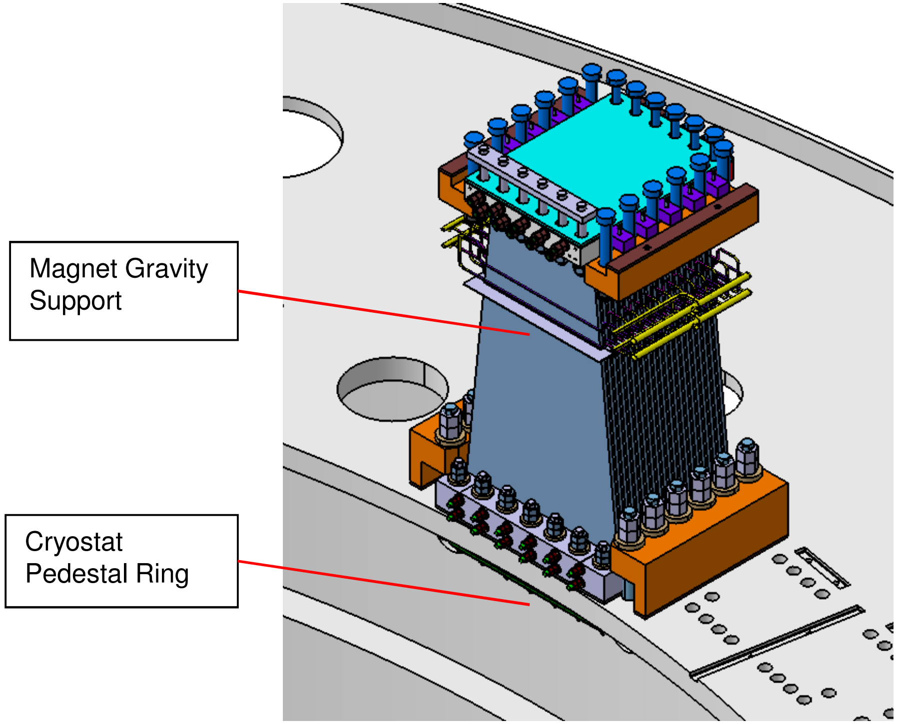


Penetration for upper Magnet Feeder

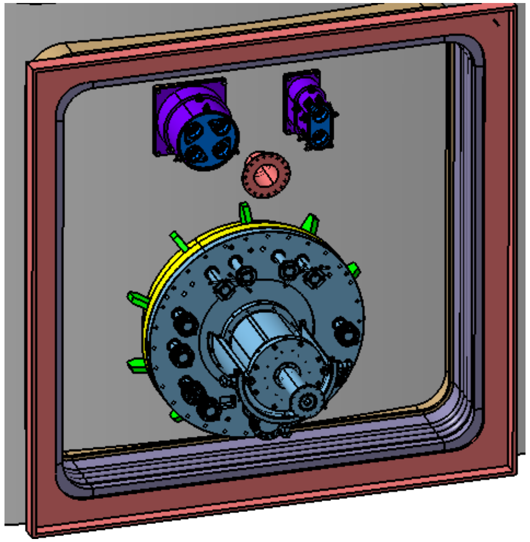
Penetration for lower Magnet Feeder

Pedestal Ring for Magnet Gravity Support

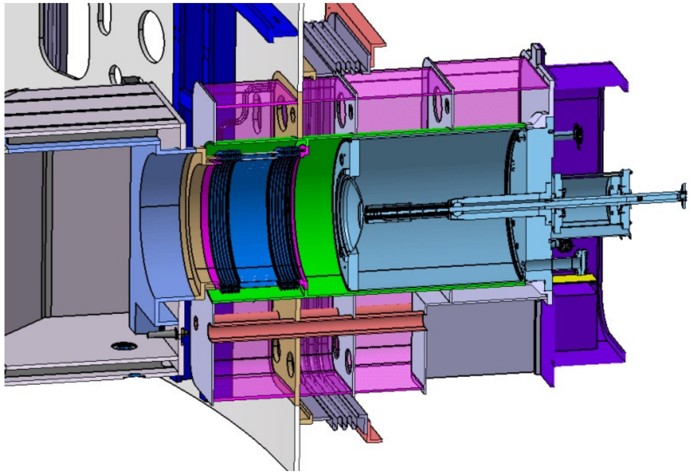




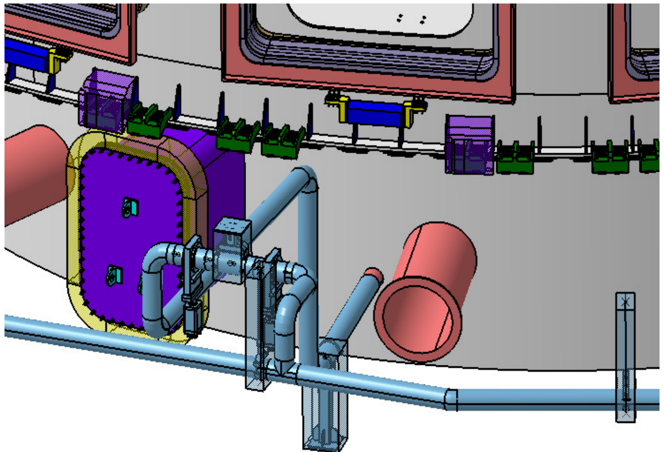
Cryostat Interface – with Vacuum



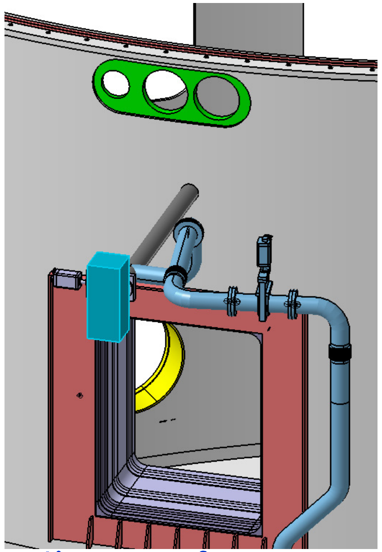
Penetration for Cryostat Cryopump x 2



TCPH for TCP x 6

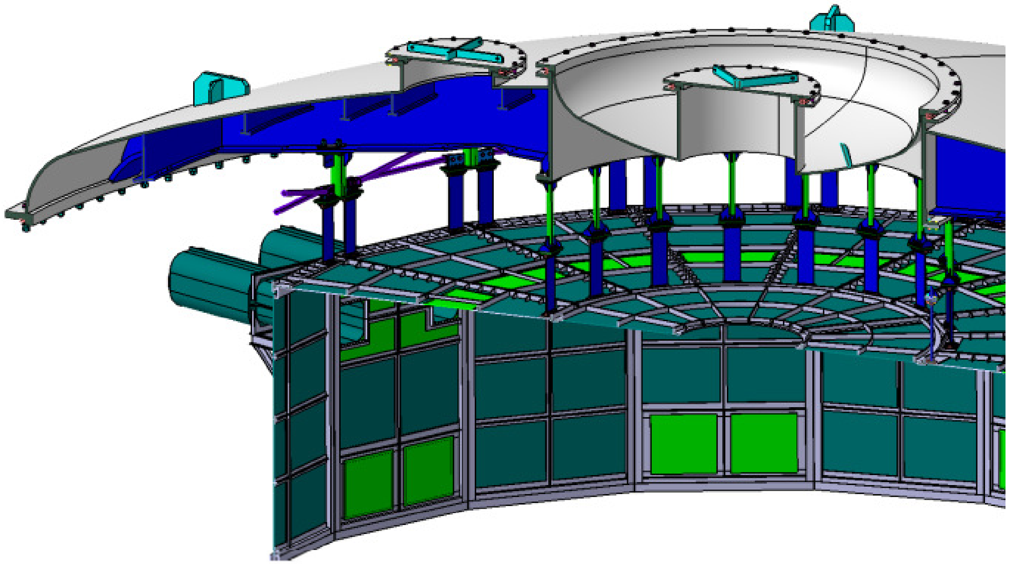


Penetration for Vacuum Roughing Line



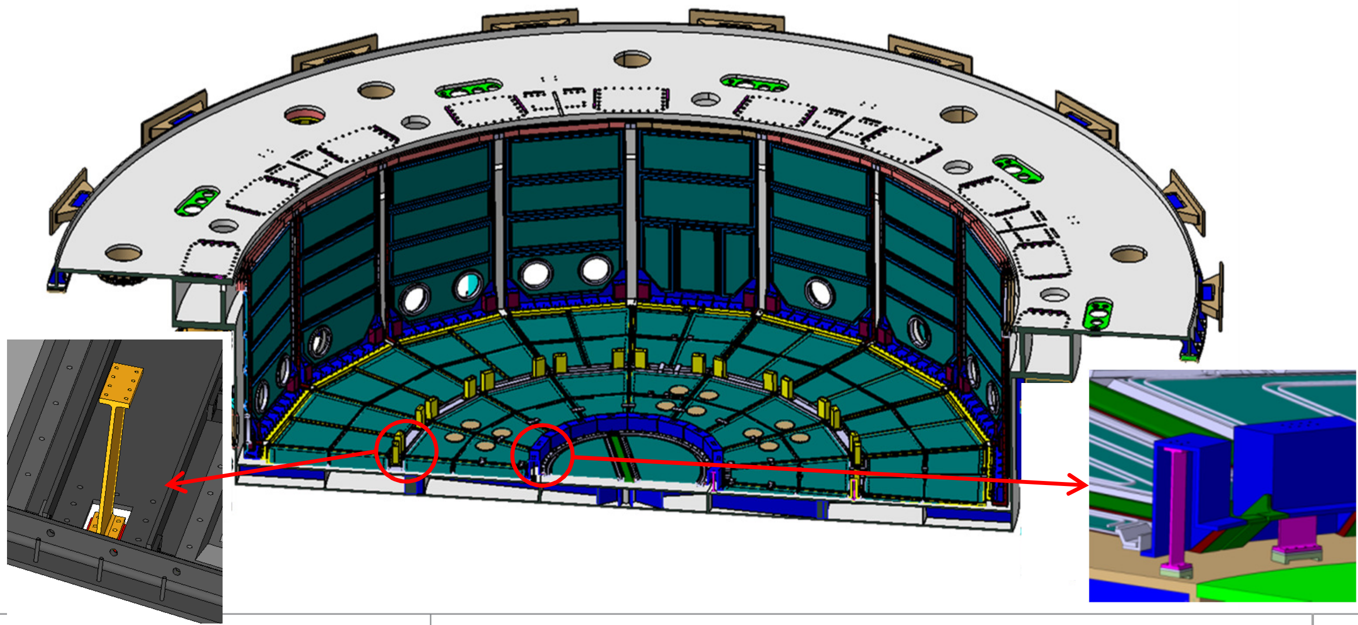
Penetration for Venting/ Purging Line

Cryostat Interface – with Thermal Shield



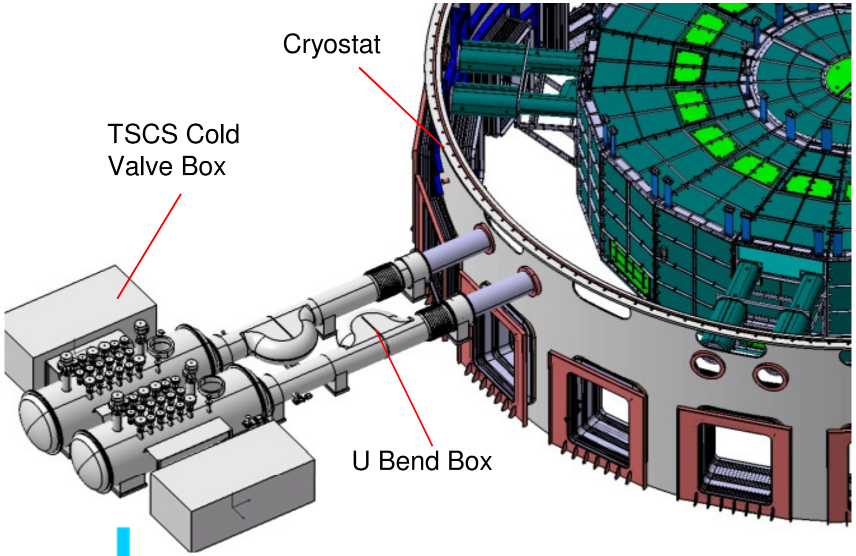
Support for Upper Cryostat Thermal Shield

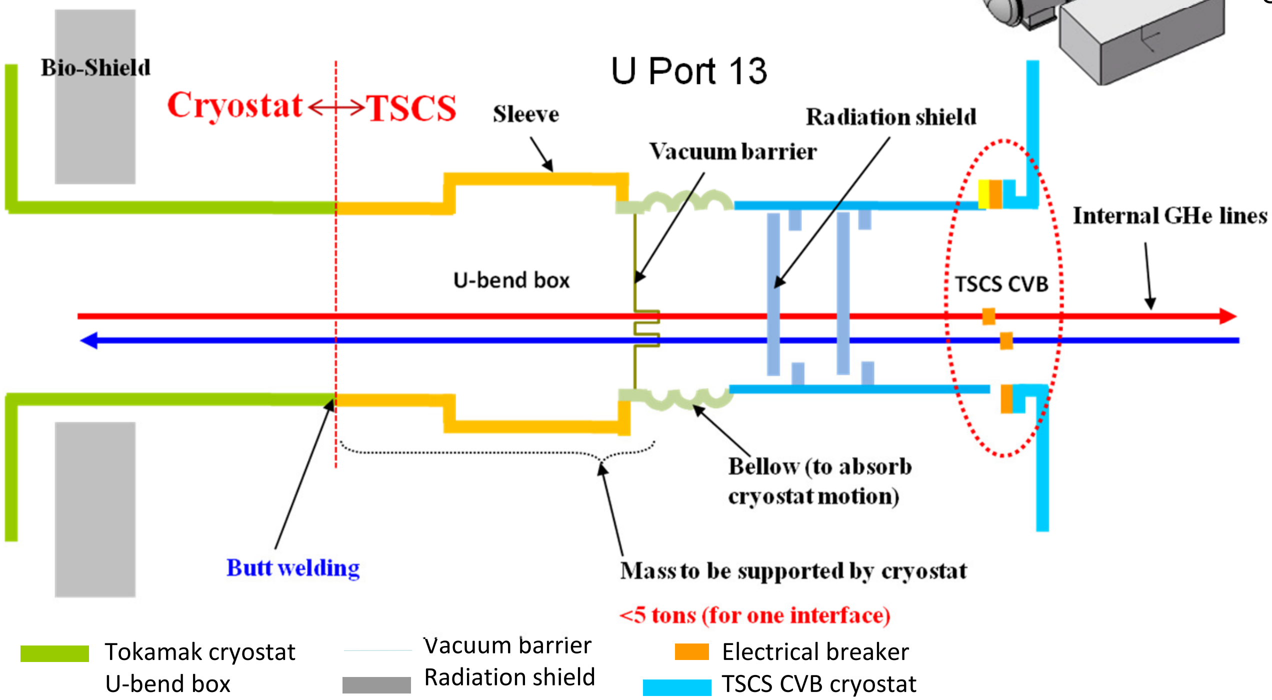
Support for Lower Cryostat Thermal Shield



Cryostat Interface – with Cryogenic

The internal lines of the two identical TSCS (Thermal Shield Cooling System) CVB's are connected to the two identical manifold system of the thermal shields via the two identical U-bend boxes.





The two vacuum duct of the U-bend boxes need to be welded to the two penetrations on cryostat upper cylinder

Cryostat Schedule

Activity	Time
Cryostat Conceptual Design Review	Nov-2009
Cryostat Preliminary Design Review	Jun-2010
Cryostat Final Design Review	Nov-2010
Cryostat PA Signature (2.4.P1A.IN.01) between IO and INDA	Sept-2011
Cryostat Manufacture Contract between INDA and Larson &Toubro	Aug-2012
Manufacture Readiness Review for Cryostat Base Section and Lower Cylinder	April-2013
Manufacture Start	Jan-2014
Manufacture Readiness Review for Cryostat Upper Cylinder and Top Lid	Oct-2014
CR Base Section - Delivered by IN-DA to IO at ITER Site	Sep-2016

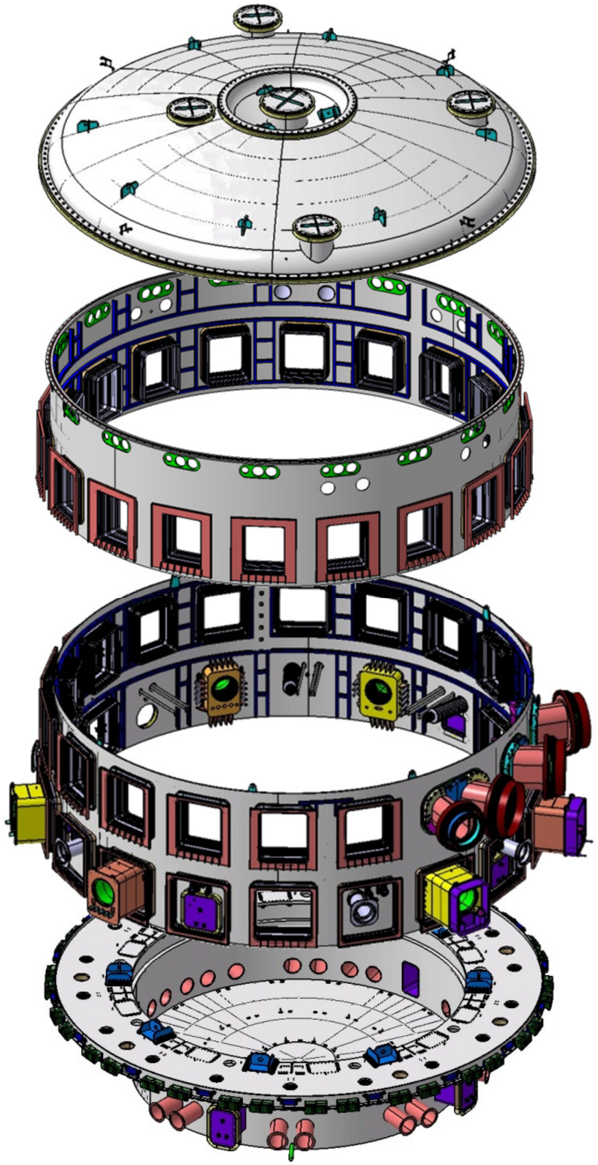
Cryostat Manufacturing

Cryostat Engineering/Manufacturing

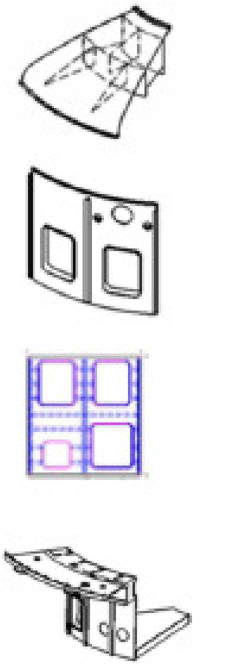
- Cryostat Base Section
  - Manufacturing Study
  - Material Procurement
  - Industry Side Manufacturing
  - IO Site Manufacturing
  - Assembly in Tokamak Pit
  - Final Acceptance
- Cryostat Lower Cylinder
- Cryostat Upper Cylinder
- Cryostat Top Lid

General three stages of Cryostat manufacturing & final acceptance

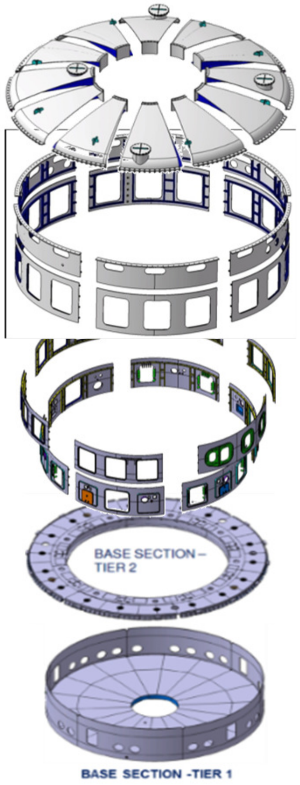
- Segment fabrication in the factory
- Assembly of segments in Site Workshop
- Assembly of Cryostat in Tokamak pit



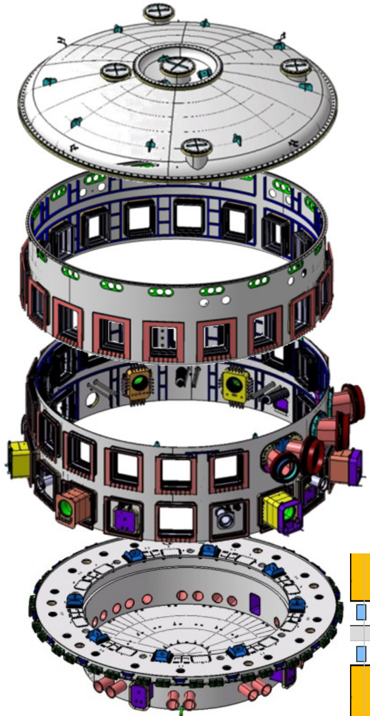
Cryostat Manufacturing - Procedure



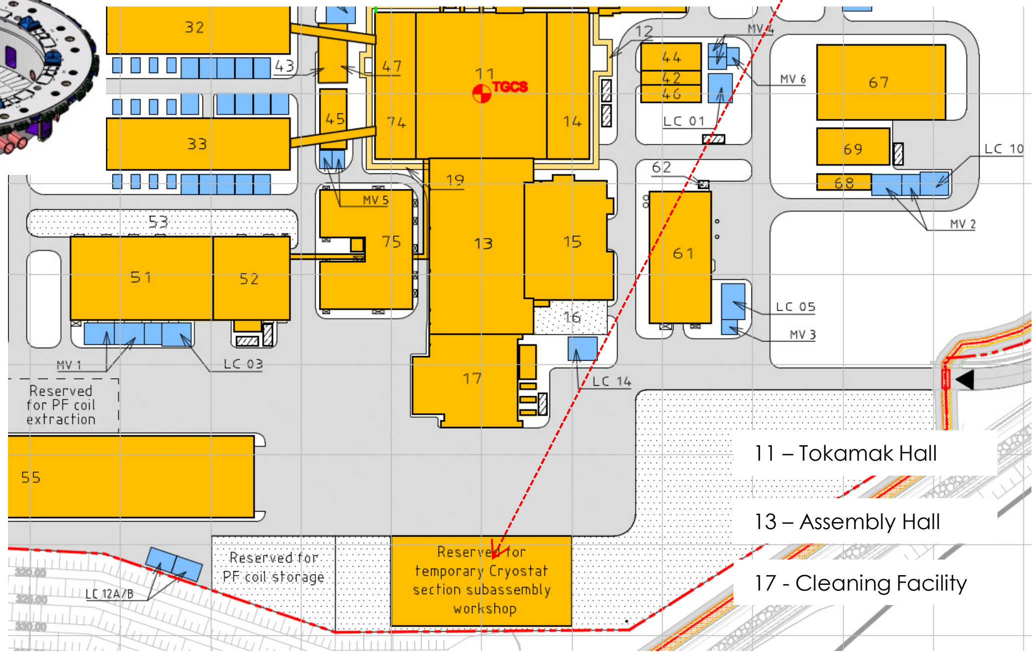
Factory Fabrication



Site workshop Fabrication



Final Assembly in Tokamak Hall



Cryostat Manufacturing - Challenges

The major challenges involved in Cryostat manufacturing design are stringent tolerances, many penetrations, high vaccum compatible welding of large wall thicknesses, access limitation for welding and Non Destructive Examination, in-situ leak detection of each factory and field weld joint and interfaces with large number of tokamak systems.

- Total length (about 350 m)of full penetration weld joints of 50/60 mm thick plate for site assembly in pit
- Total weight of deposited metal during site assembly
- Many welding machines to operate in synchronization for these joints
- Few hundred meters of full penetration weld joints for sub-assemblies in site workshop
- Requirement for welding automation (TIG, MIG, SMAW)
- NGTIG technology will be implemented
- Various NDT to be performed at site (RT, UT, MSLD etc.)

Cryostat Manufacturing - Status

- Cryostat manufacturing contract has been awarded to Larsen & Toubro
- Cryostat material contracts are awarded by L&T to Industeel, Jindal & L&TSHF
- QP, MIP and documents for base material and manufacturing procedure are approved by IO
- Cryostat site workshop is nearly completed
- Prototype (40 degree) manufacture of the Cryostat base section is on-going



Cryostat pedestal ring- top plate 200 mm and skirt plate 105 mm thick welded together


Cryostat pedestal ring- bottom plate (180 mm) & side plates (120 & 80 mm) are being welded together

The End