Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Vacuum Vessel, Cryostat & Remote Handling

Villa Mondragone, Monte Porzio Catone (Rome), Italy – 14/12/2018

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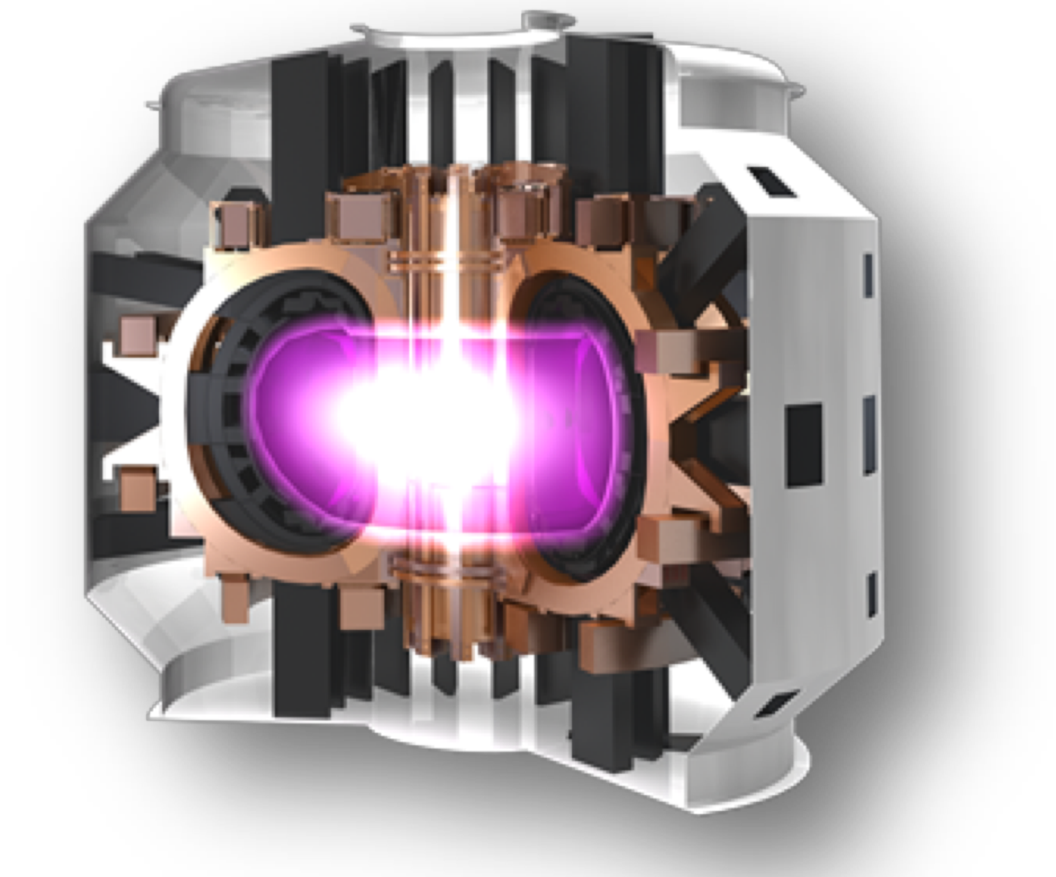
DTT Integration



VACUUM VESSEL

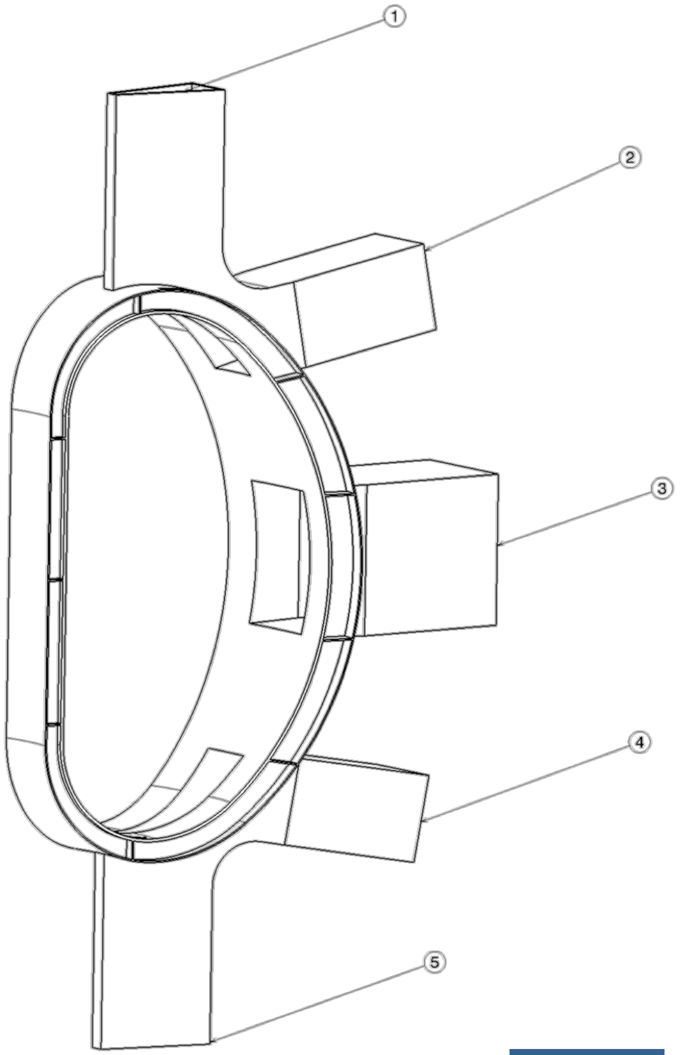
DTT Vacuum Vessel

Overall external dimensions of the VV are 3600 mm in height with a diameter of 2430 mm at the inboard side and a diameter of 6760 mm at the outboard side.
VV main material is SS AISI 316 L(N).
VV main components are: the main vessel, the port structures and the VV supporting system.

*The **main vessel** is a torus with "D" shaped cross-section, segmented in 18 sectors of 20°. It is double wall structure. The thickness of both the inner and the outer shells is 15 mm.*

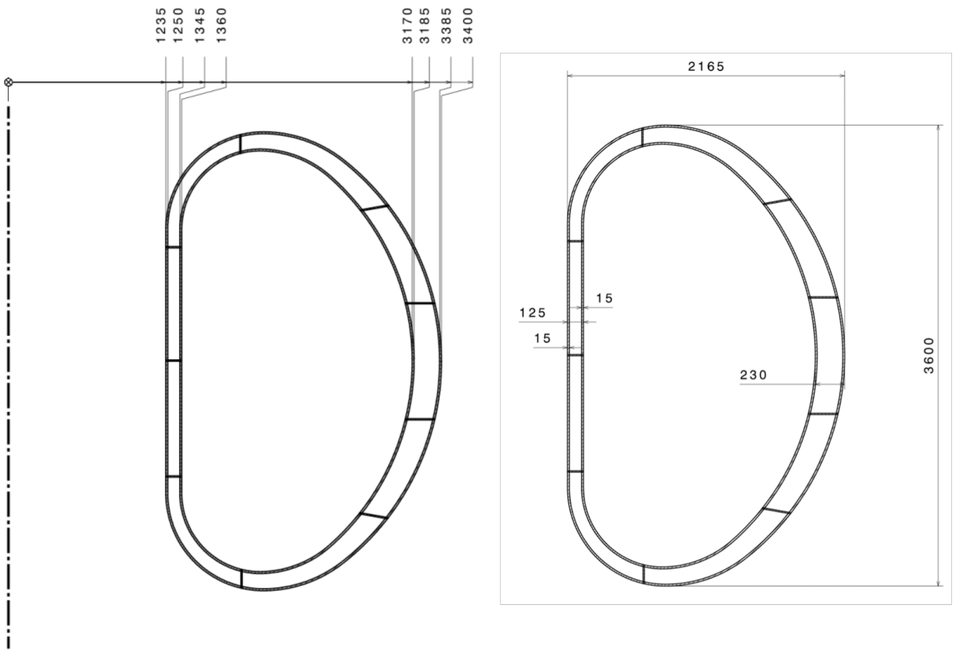
*Each sector has **5 access ports** conceived as single-walled structures welded to the main vessel. Their thickness is 25mm.*

*The VV is vertically **supported** by sliding supports resting directly on the cryostat base.*

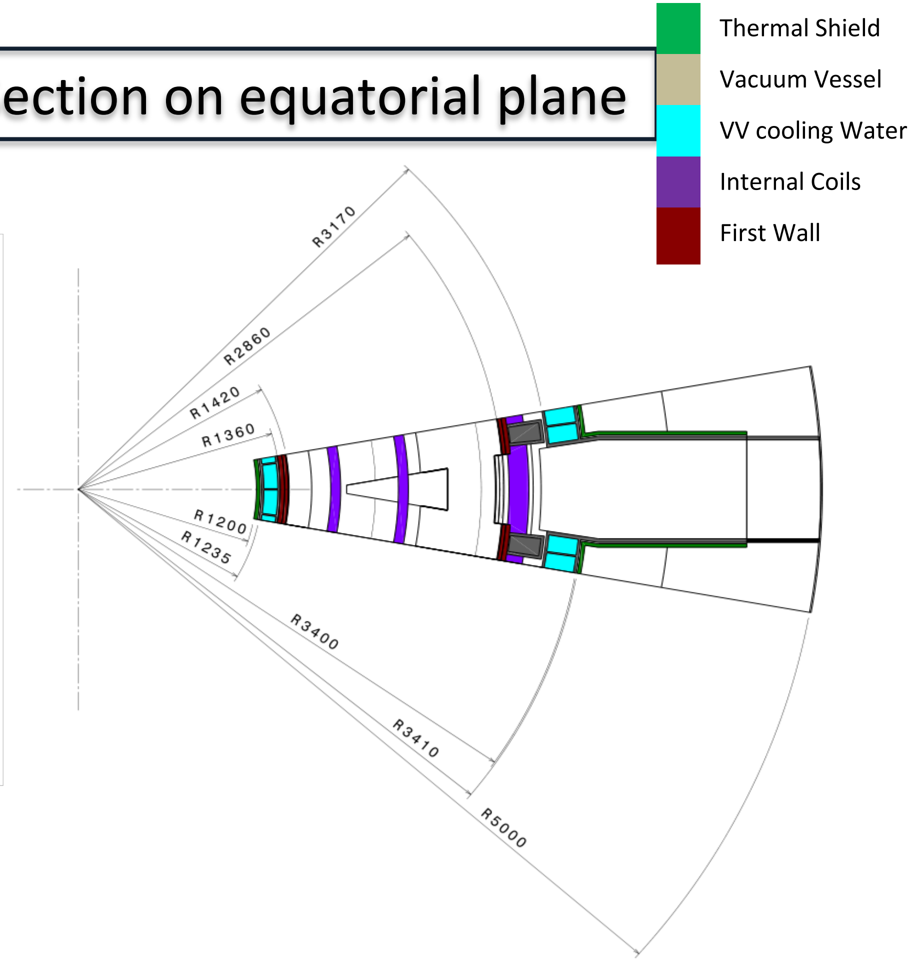


DTT Vacuum Vessel – main vessel

Radial build



Section on equatorial plane



DTT Vacuum Vessel – main vessel

Internal ribs dimensioning

Reference design loads:
Internal pressure: 10 bar

Material: AISI 316L(N)
Temperature: 100°C

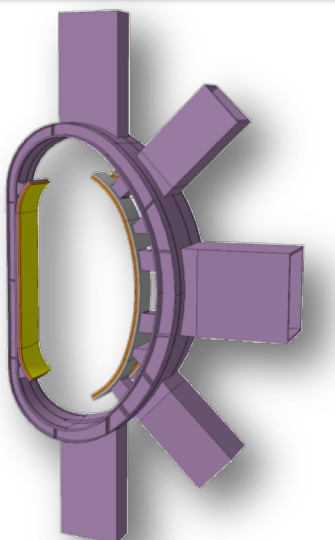
Reference standard:
ASME BOILER AND PRESSURE VESSEL CODE – Section VIII Div. 1

DTT Vacuum Vessel

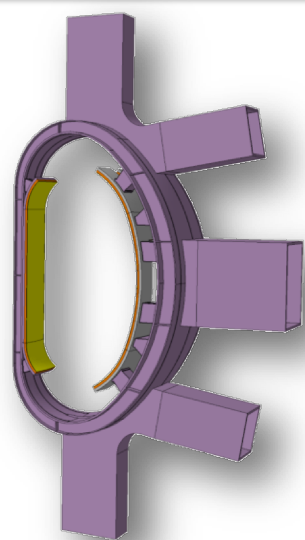
At the current stage, the following VV modules have been preliminary designed :

- No.8 Standard modules (20°): two ports aligned with plasma centre
- No.4 Remote handling modules (20°): two ports for divertor RH purposes
- No.2 NBI modules (60°): for the installation of neutral beam injections (NBI) at the equatorial port

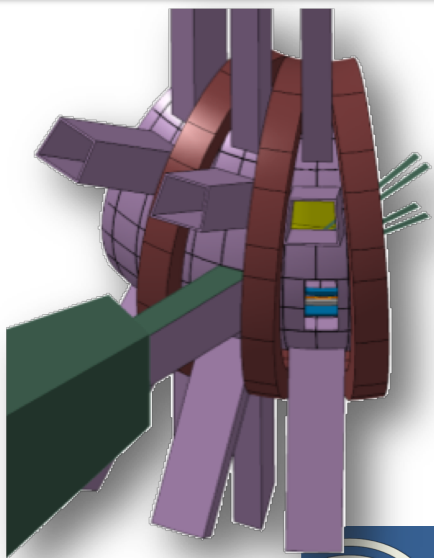
Standard module



RH module

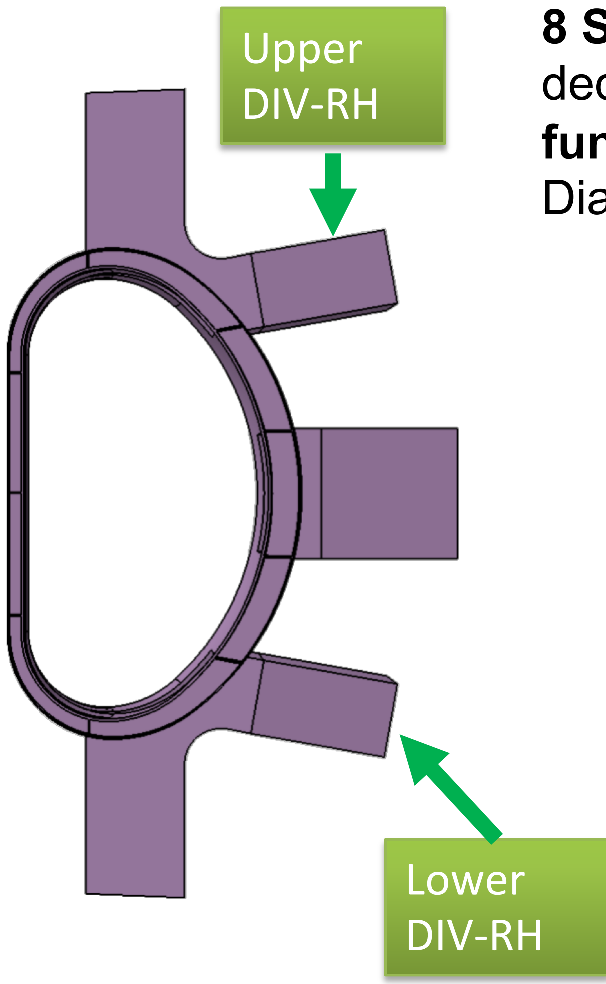


NBI module

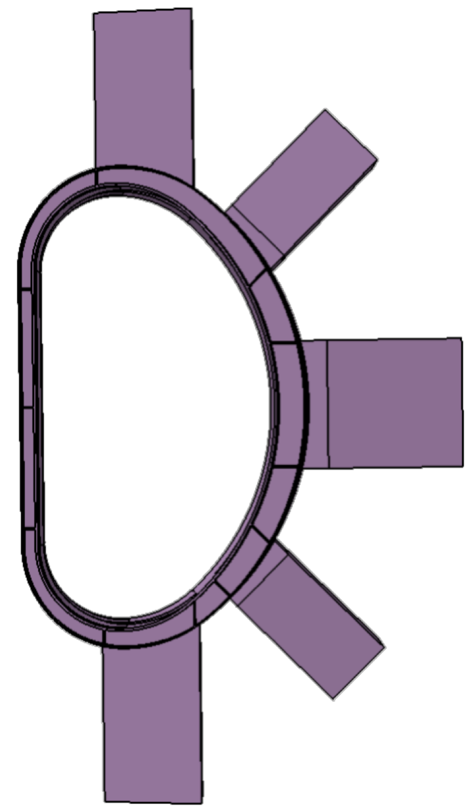


DTT Vacuum Vessel

4 Sectors with 2 ports dedicated to upper and lower **divertor RH** tasks

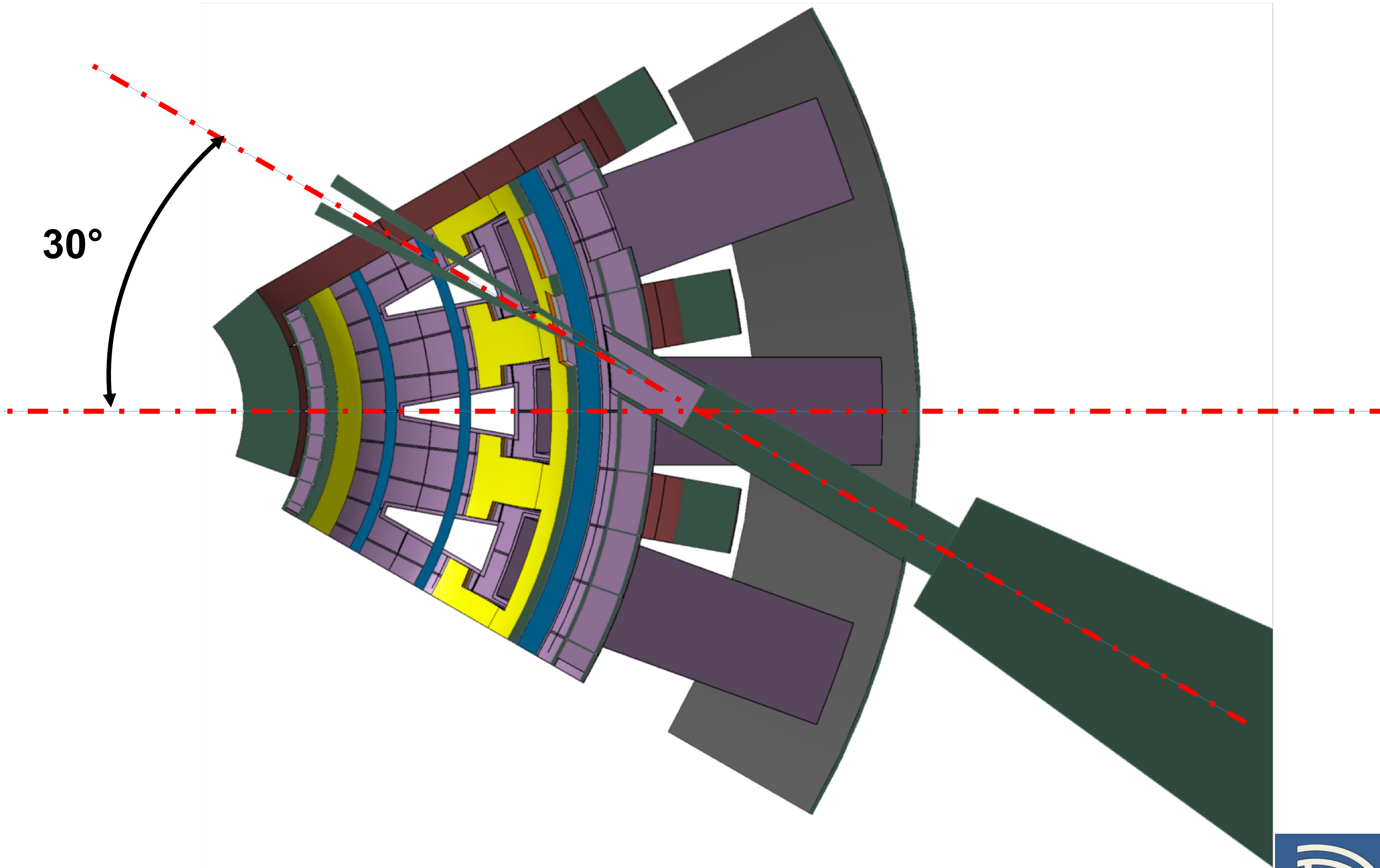


8 Sectors dedicated to **other functions**: Heating, Diagnostics, etc.



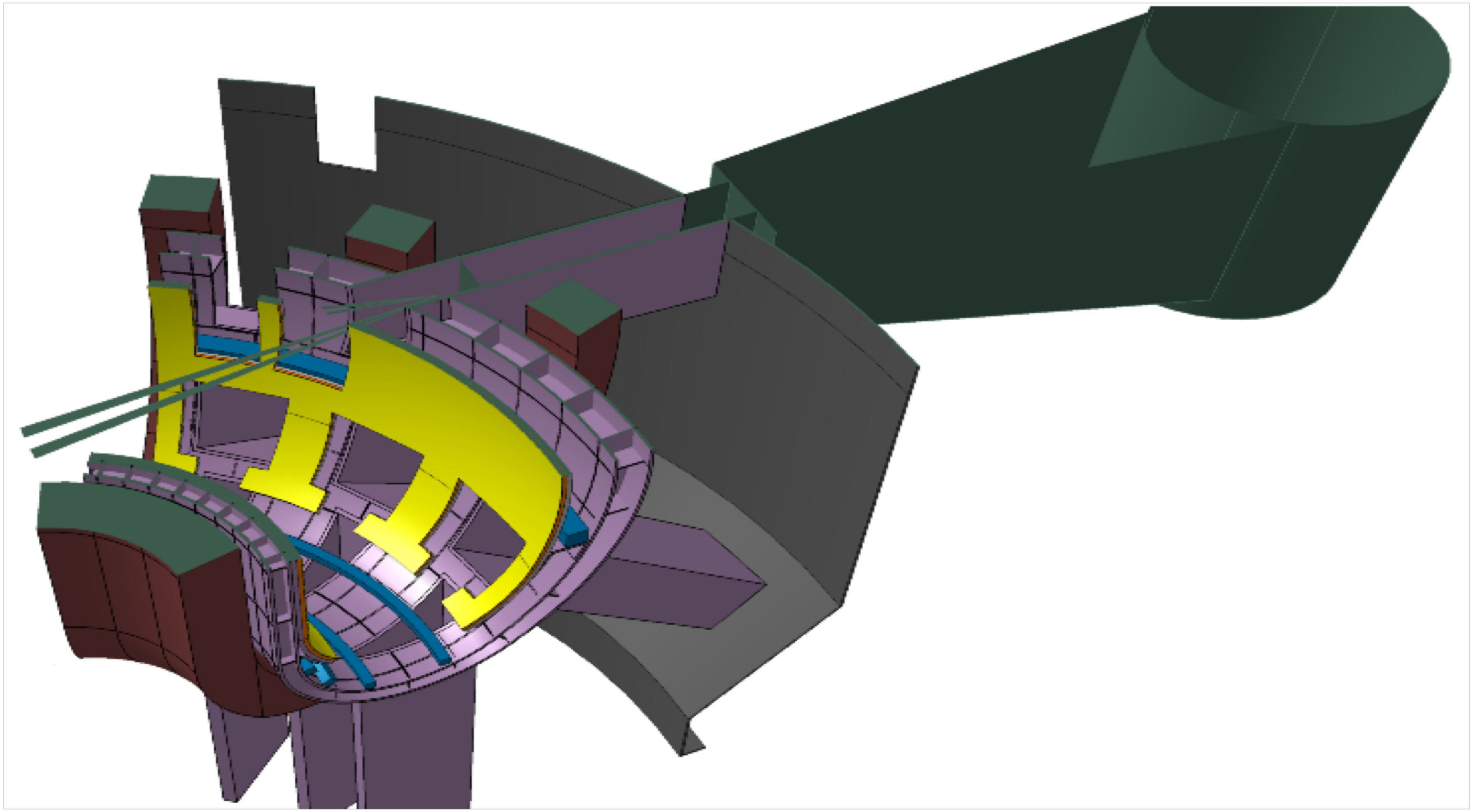
DTT Vacuum Vessel

NBI module



DTT Vacuum Vessel

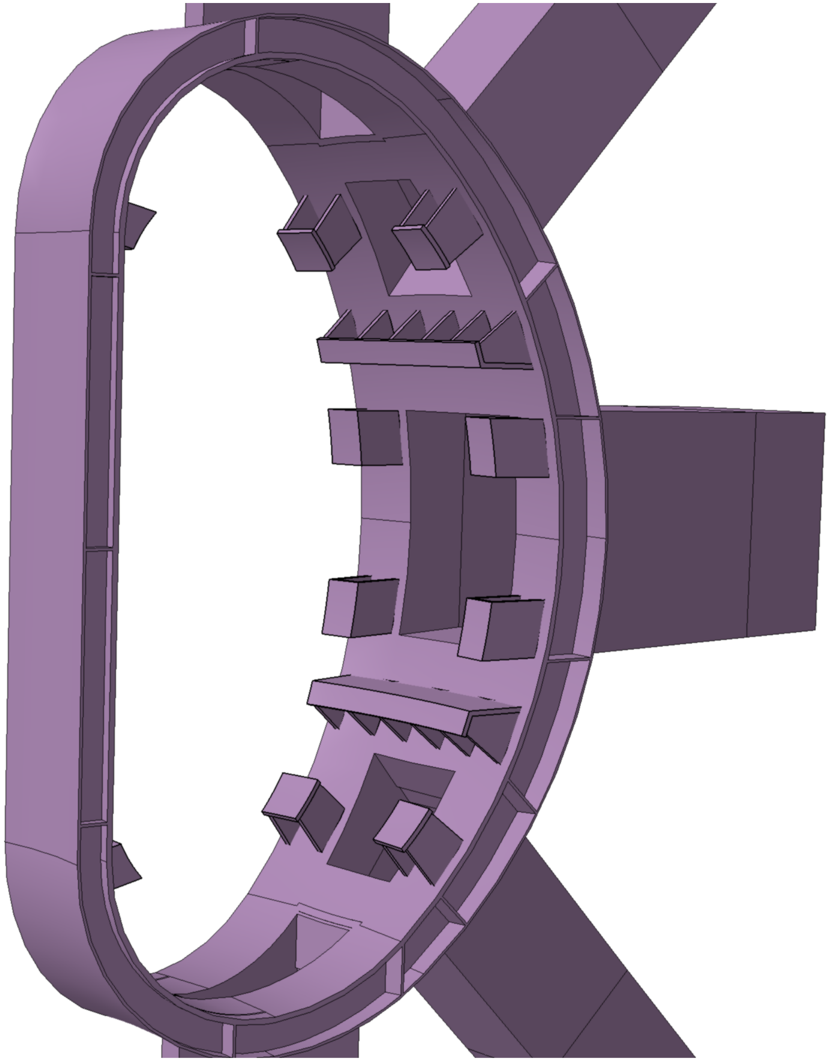
NBI module



DTT Vacuum Vessel

First wall supporting structure

Box steel structure



DTT Vacuum Vessel

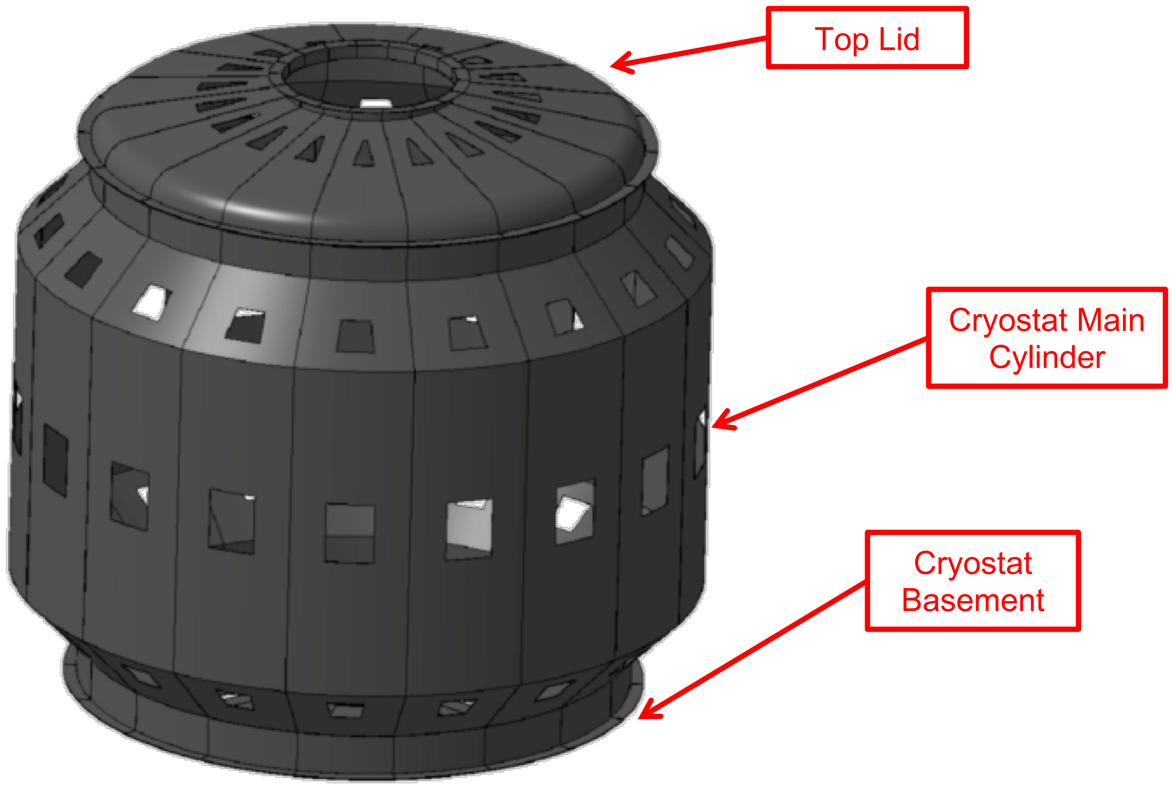
	1 sector	DTT Tokamak complex [18 sectors]
Component	**Mass [Kg]**	**Mass [Kg]**
Main Vessel	2050	36900
Port#1	1100	19800
Port#2	900	16200
Equatorial Port (Port#3)	1200	21600
Port#4	900	16200
Port#5	1000	18000
TOTAL VV	7150	128700

CRYOSTAT

DTT Cryostat

DTT Cryostat has been conceived as composed by three main subassembly :

1. ***Cryostat Basement***
2. ***Cryostat Main Cylinder***
3. ***Cryostat Top Lid***



DTT Cryostat - functional requirements

- provides a ***vacuum environment*** to avoid excessive thermal loads applied to the components at cryogenic temperature;
- provides a ***gravity support*** for the vacuum vessel and all the superconducting magnets;
- provides ***access to the CS coil*** for possible direct removal;
- guarantees the ***access to VV ports and heating devices***;
- guarantees the ***access for maintenance***;
- guarantees the ***access to the equipment connection elements*** of systems (magnet feeders, water cooling pipes, instrumentation feedthroughs, CV pumping system),
- supports the ***diagnostic port plugs***;
- ***transfers all the loads***, which derive from the tokamak basic machine and the cryostat itself, to the floor and basement tokamak torus hall;
- includes ***overpressure protection*** by a rupture disk
- provides the spaces for ***assembly and maintenance of in-cryostat components***

DTT Cryostat - structure

❖The ***cryostat vessel body*** is built by cylindrical sections connected by truncated-conical elements in the inclined ports regions.

❖The ***top lid*** will be built with a toro-spherical shape shifted up by about **1.6m** to maximize the inner space for the assembly and maintenance of cryogenic devices such as in-cryostat feeder, insulation break and TF terminal joints.

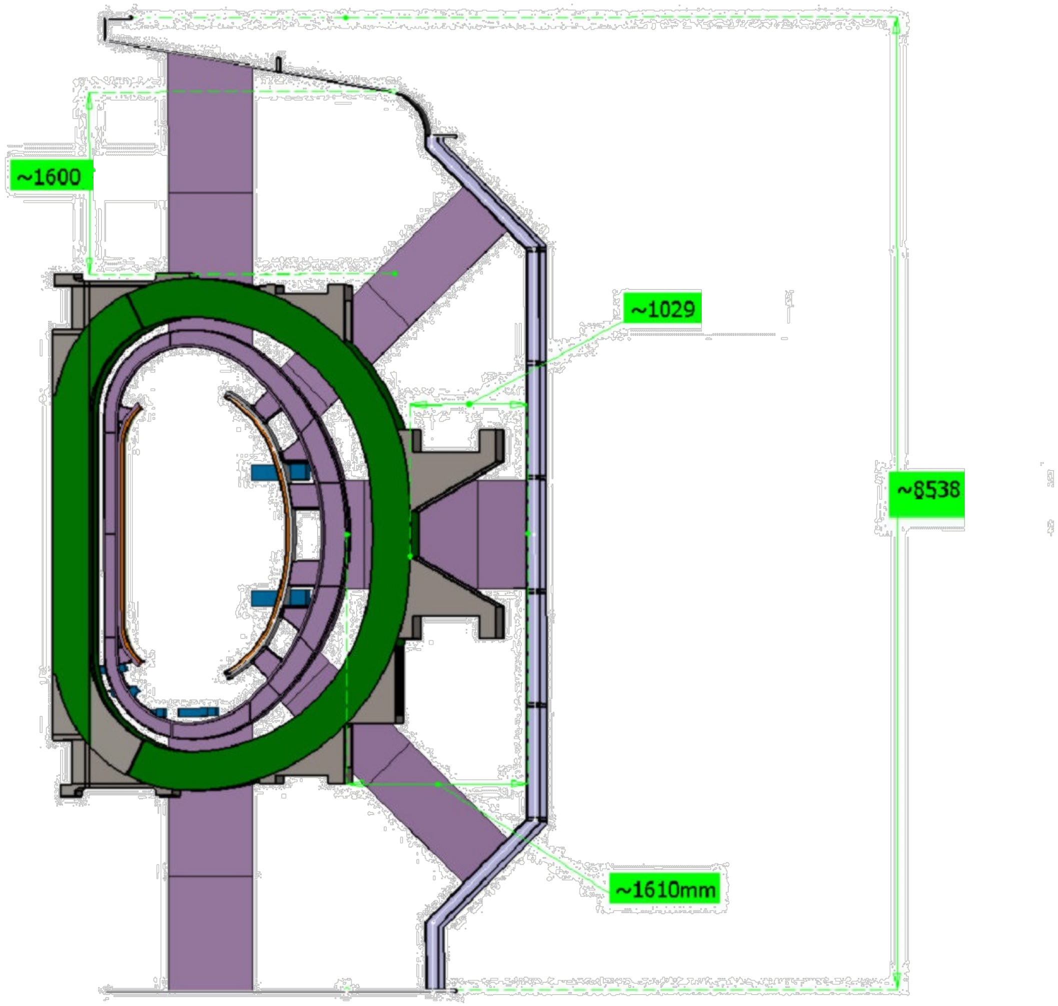
❖The ***Cryostat main cylinder*** is shifted radially of about **1m** with respect to the TF and of about **1.5m** with respect the outer shell of VV (dimensions are computed on DTT equatorial plane)

❖The skin has a structure to support the weight of **all port plugs** and also to withstand the vacuum pressure. The different parts of the main cylinder, cryostat base and top lid are connected by bolts and clamps at the flanges and sealed by means of inside light welding.

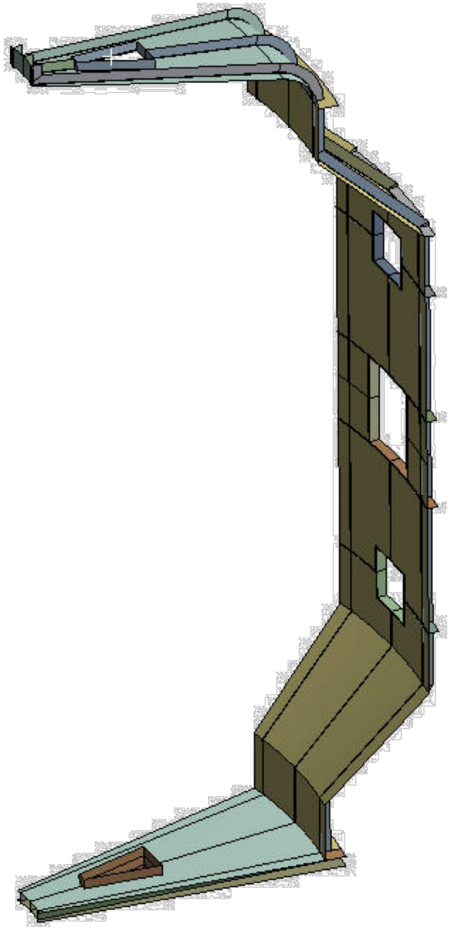
❖The reference material is assumed to be **AISI 304 L (Co<0.05 wt%)**

❖The Cryostat Vessel body is conceived as single walled structure with shell of **30 mm in thickness**, the structure will be provided with ***ribs to increase its bending stiffness***

DTT Cryostat – main dimensions



DTT Cryostat – main dimensions



Radius	5000 mm	Main cylinder shifted radially of about 1m with respect to the TF and of about 1.5m with respect the outer shell of VV (dimensions on equatorial plane)
Material	AISI 304 L (Co<0.05 wt%)	
Thickness	30mm	Single walled structure with ribs increasing its bending stiffness
External pressure	0.1 MPa	Normal operations under vacuum
Absolute internal pressure	0.12 Mpa	In case of ICE (Ingress of Coolant Event)
Operational pressure	10^-3 Pa	
Design temperature	293 K	

Mass: 5000 kg

DTT Cryostat – main design loads

- external pressure: **0.1 MPa** for normal operation under vacuum;

- **Accidental events**:
  - Cryostat Ingress of Coolant Event (Cr ICE);
  - Cryostat loss of vacuum accident (Cr LOVA);

- dead weight, seismic loads, electromagnetic forces and thermal loads between the cryostat base, the cold magnet system and thermal shields;

- operational pressure: **10^{-3} Pa**;

- design temperature: **293K**

- Structural criteria: **American Society of Mechanical Engineers (ASME) ¨Boiler and Pressure Vessel Code. Section VIII¨**

Remote Handling

Overview

DTT RH Needs

DTT RH Requirements

DTT RH Strategy

DTT Divertor RH Equipment

DTT First wall RH Equipment

DTT RH Control Room

Conclusions

DTT RH Needs

The expected neutron rate in DTT varies from a minimum of 0.3×10^{17} ns^{-1} for AT scenarios to a maximum of 1.3×10^{17} ns^{-1} for the H-mode extreme scenario. ***The short/medium term activation is not negligible, making remote handling mandatory***.

Remote handling will be necessary only after a long period at the maximum performances, e.g. at least 6-12 months (it will partially depend from the initial available additional power) operations after the commissioning phase.

However our assumption is that the remote handling will operate also during the machine assembling phase. This will allow to test and commission the remote handling during a phase when it is not at all necessary.

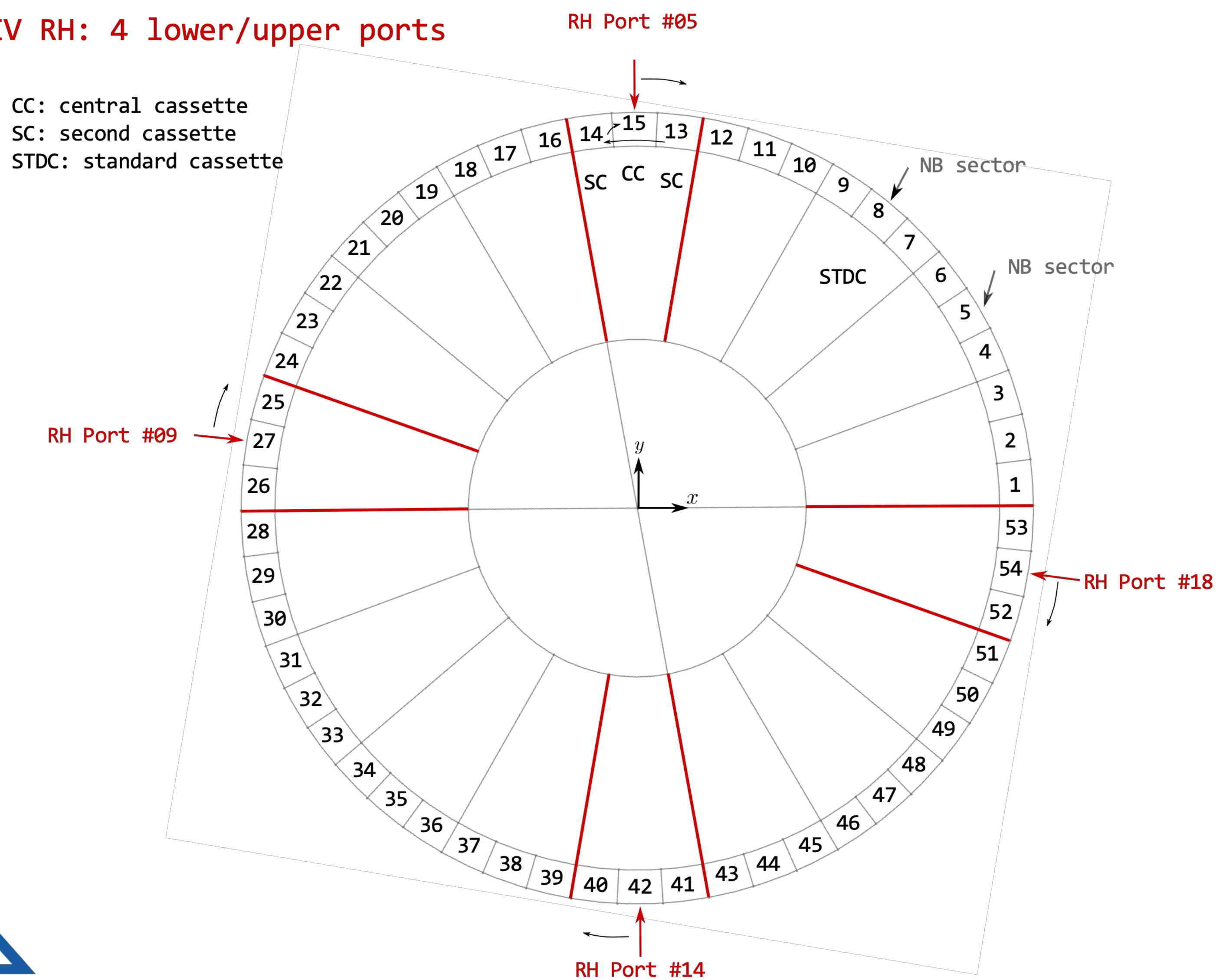
DTT RH Requirements

- **Remote handling scheme should be flexible to be adapted to all configurations**
- **Remote handling equipment should be flexible to manage replacement of first wall with *"upper vertical targets"* in case of double null configuration**
- **Remote handling equipment should be flexible to manage different shapes of first wall in case of Super-X configuration**
- **Remote handling equipment should be flexible to manage liquid metal divertor**
- **The maintenance operation shall be performed through lower, upper and equatorial port**.

- RH system must be flexible enough to work during scheduled maintenance as well as in case of failure.
- The component inside the tokamak are RH-compatible, so RH engineers have been involved in the design of components from the earliest stages of design.
- RH operators need feedback during operations. Forces and Torques sensors as well as cameras are necessary to get information. Virtual reality techniques can help, given that cameras can only show limited views of inside chamber.

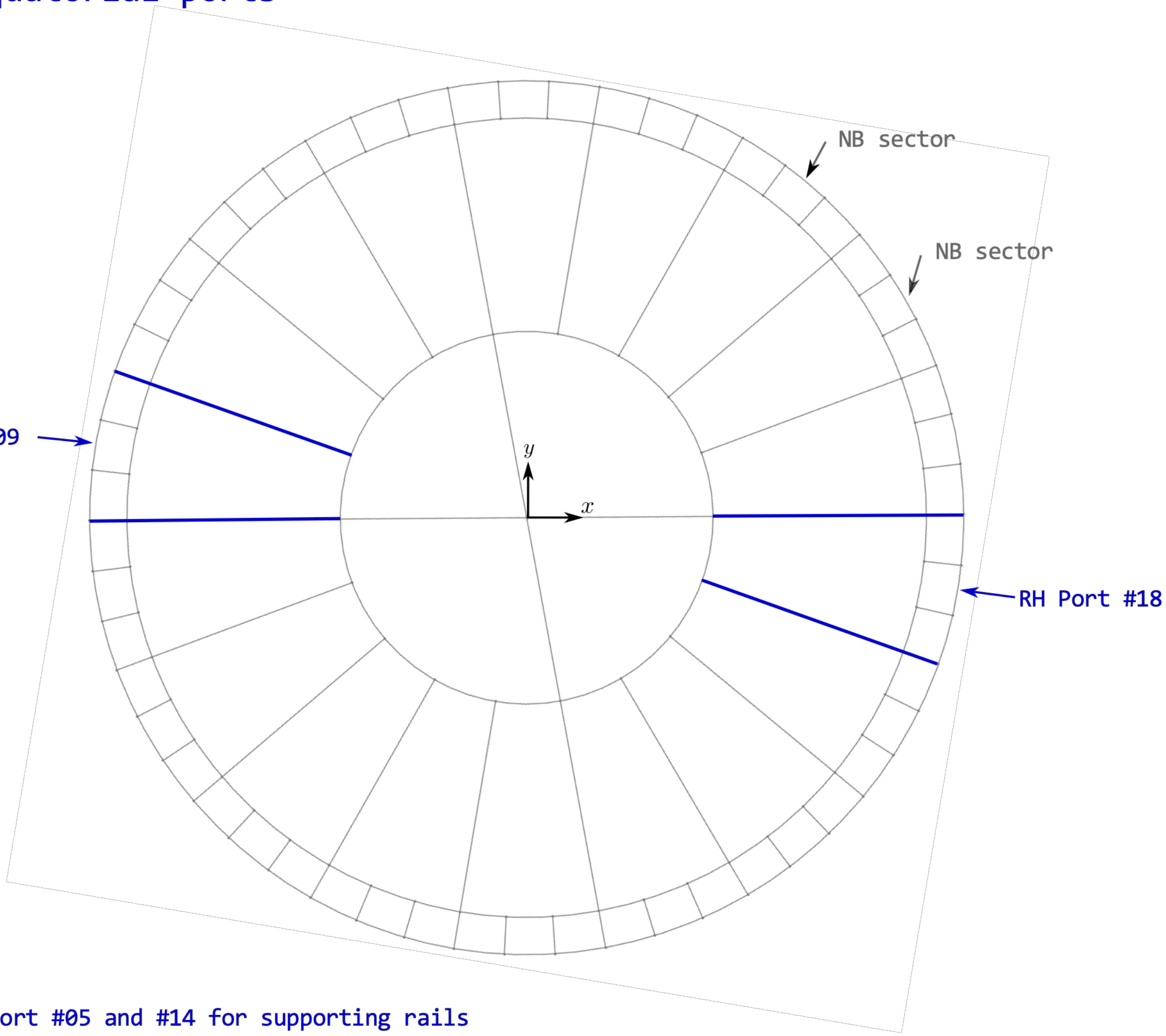
DTT RH Strategy

DIV RH: 4 lower/upper ports



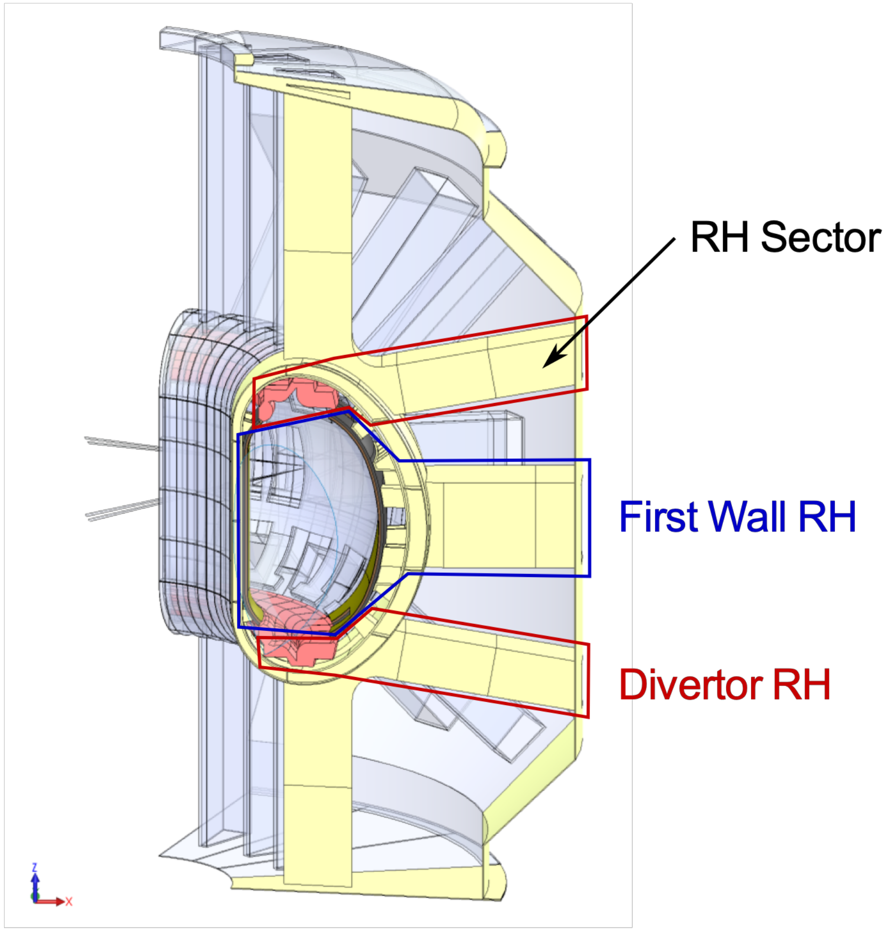
DTT RH Strategy (cont'd)

FW RH: 2 equatorial ports



eventually, RH Port #05 and #14 for supporting rails

DTT RH Strategy (cont'd)



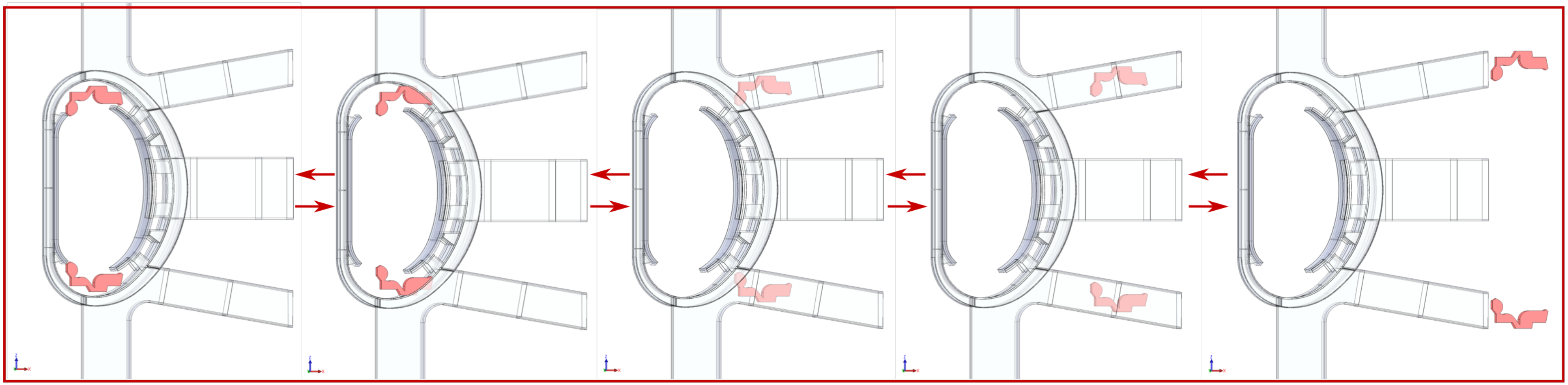
Divertor RH Equipment

System functions:

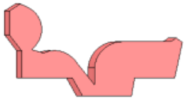
- Insertion / extraction of divertor cassettes and divertor diagnostic as well as their transportation to/from a transfer cask docked at divertor RH ports
- Cutting, welding, alignment and inspection of cassette cooling pipes
- Transportation of the divertors and the equipment from the vacuum vessel to a storage place (using a proper Transfer Cask)

Divertor RH Equipment (cont'd)

Possible motion sequence for divertor insertion/extraction



DIV weight: about 300 kg



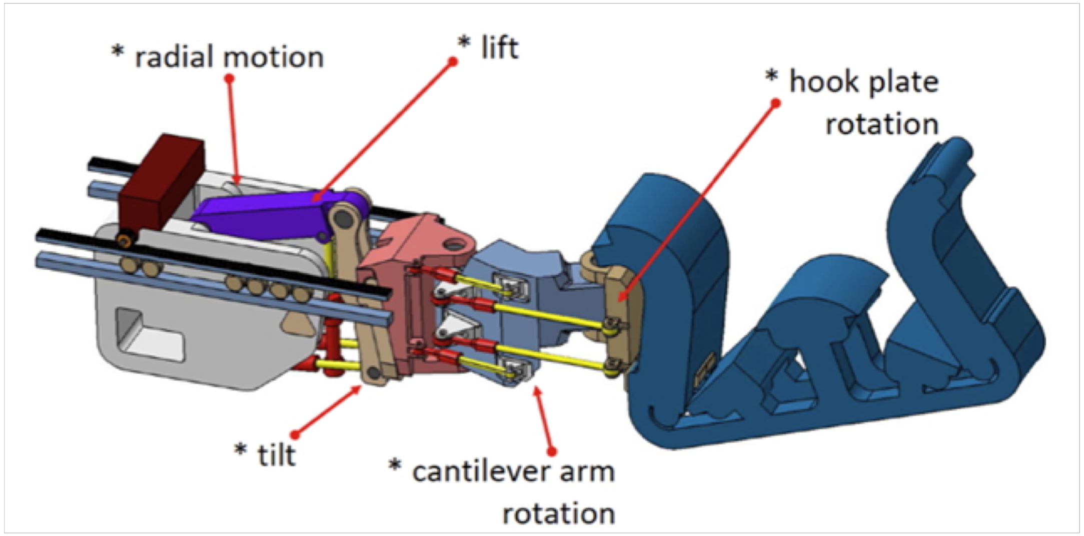
Divertor RH Equipment (cont'd)

List of equipment:

1. Cassette multifunctional mover
2. Cassette toroidal mover (going only left)
3. End-effectors (for cassette positioning): Central cassette end-effector; Second cassette end-effector (right/left); Standard cassette end-effector (only left)
4. General purpose robotic manipulator (for cassette fixation)
5. Tooling (for cassette fixation)
6. Transfer Cask

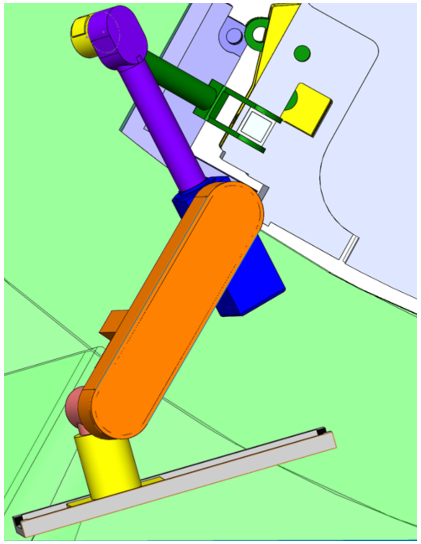
Divertor RH Equipment (cont'd)

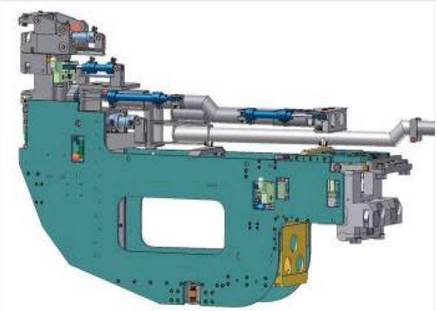
Examples of possible concept design:



Cassette multifunctional mover with second cassette end-effector

General purpose robotic manipulator





Cassette toroidal mover

First wall RH Equipment

System functions:

- Insertion / extraction of first wall modules as well as their transportation to/from the vacuum vessel

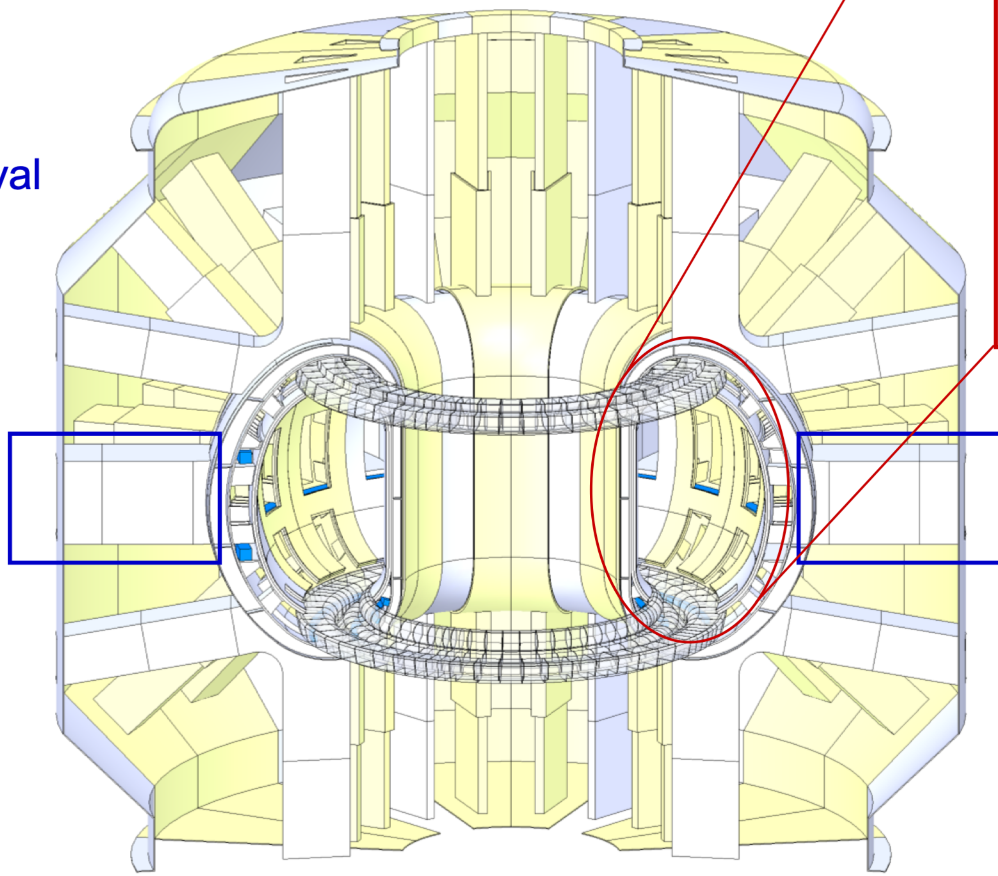
- Bolting for fixing modules; dust removal; rescue operations; vacuum vessel inspection; in-vessel diagnostic maintenance

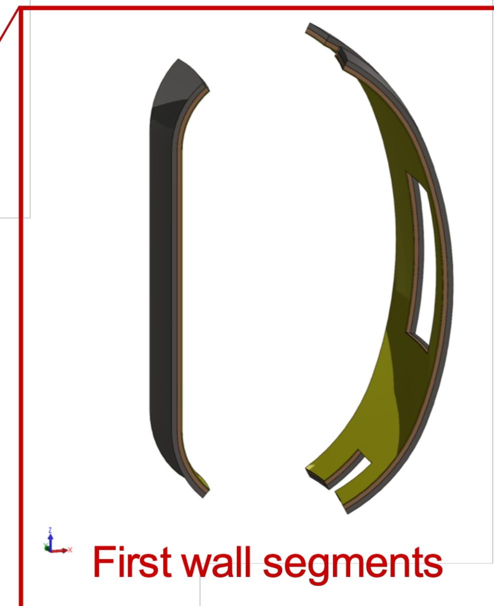
- Cutting, welding and inspection of cooling pipes

First wall RH Equipment (cont'd)

FW segment: 5 mm tungsten (density of 19000kg/m3)
55 mm steel (density of 7850 kg/m3)

FW weight: For a 1.2m2 segment, about 600 kg
For a 0.2m2 segment, about 100 kg



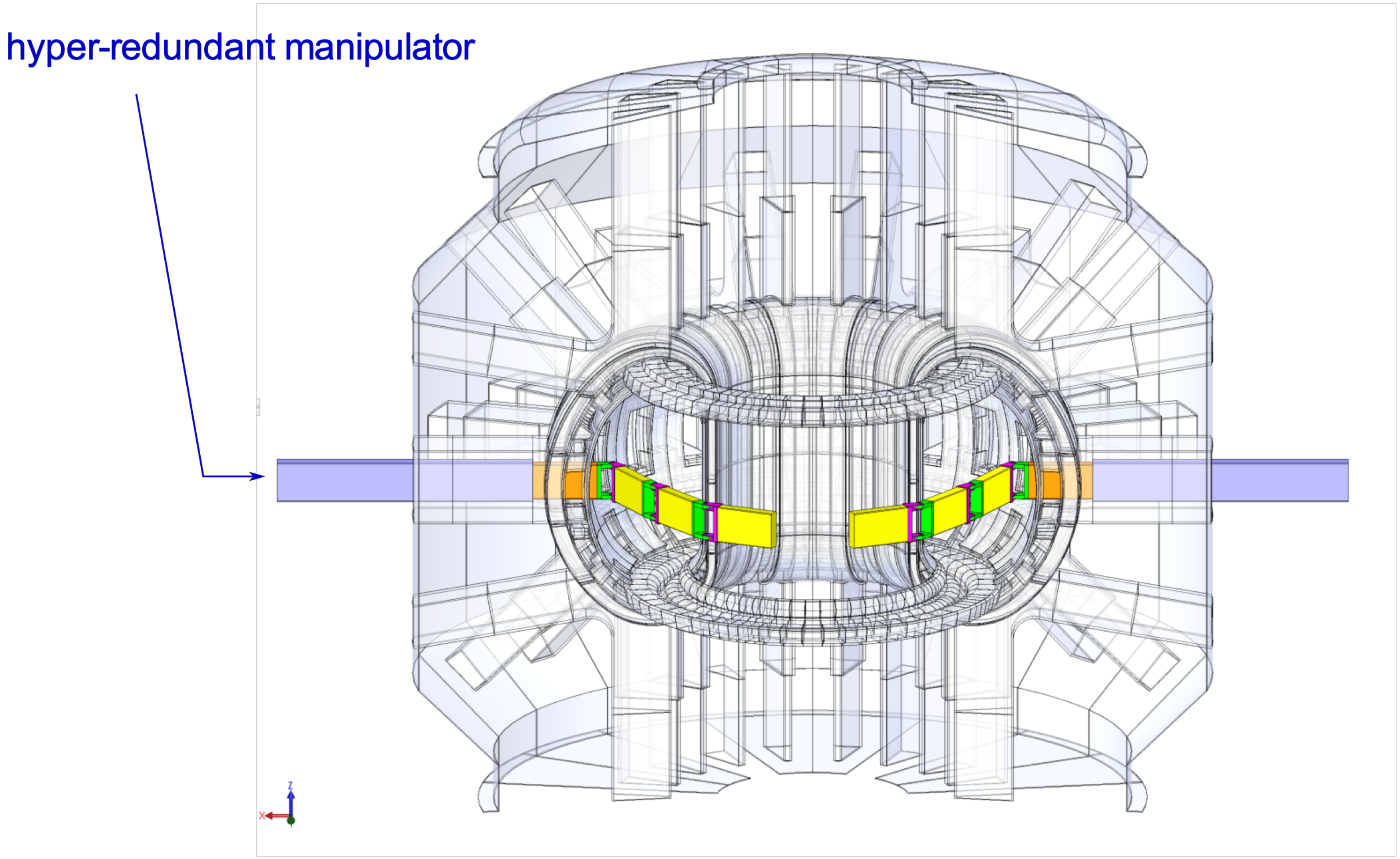


First wall RH Equipment (cont'd)

List of equipment:

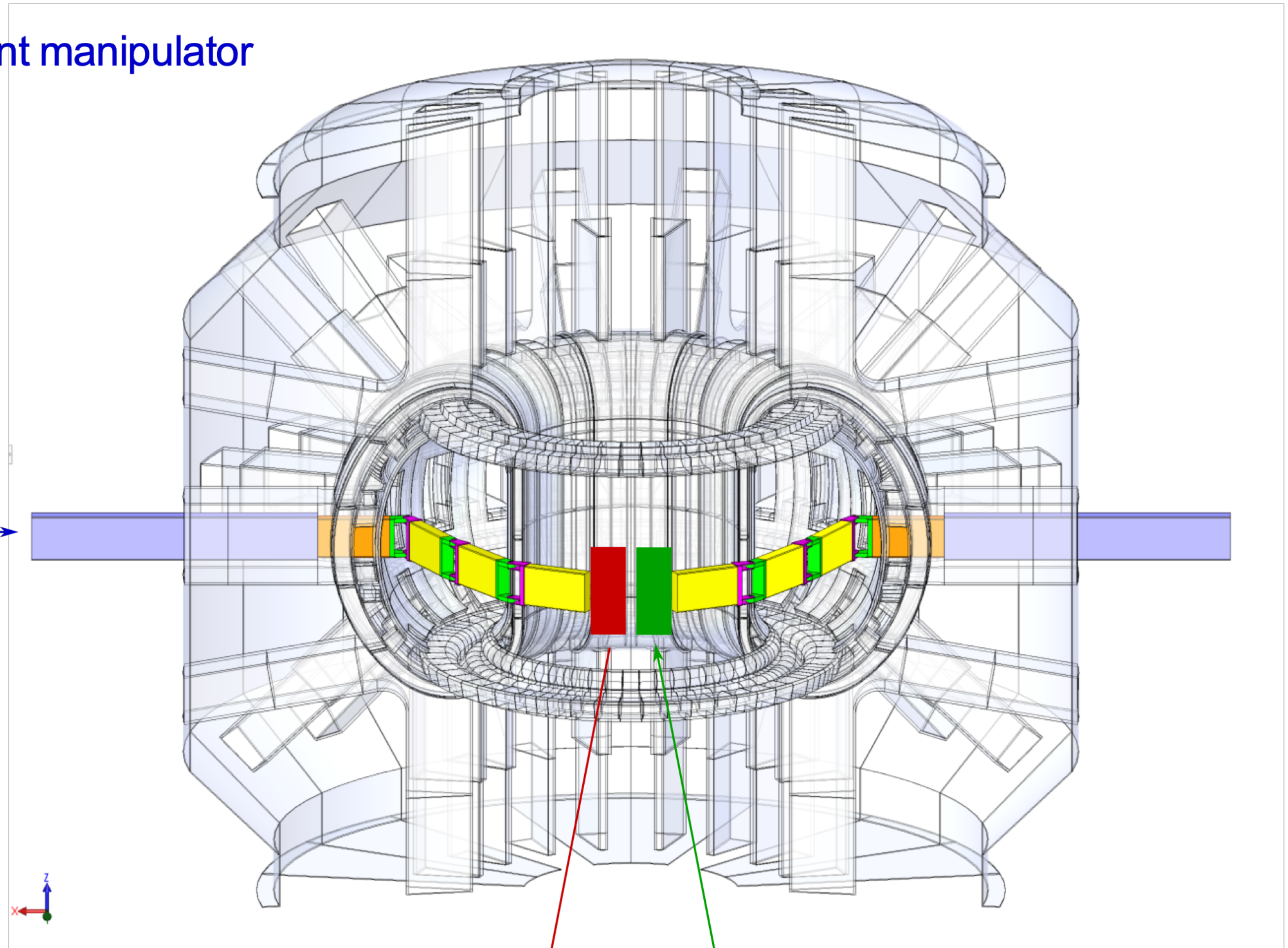
1. Hyper-redundant robotic manipulators
2. Master-slave servomanipulator
3. Task module
4. End-effector
5. Tooling
6. Overhead crane

First wall RH Equipment (cont'd)



First wall RH Equipment (cont'd)

hyper-redundant manipulator



coupling with task module

coupling with M/S servomanipulator

DTT RH Control Room

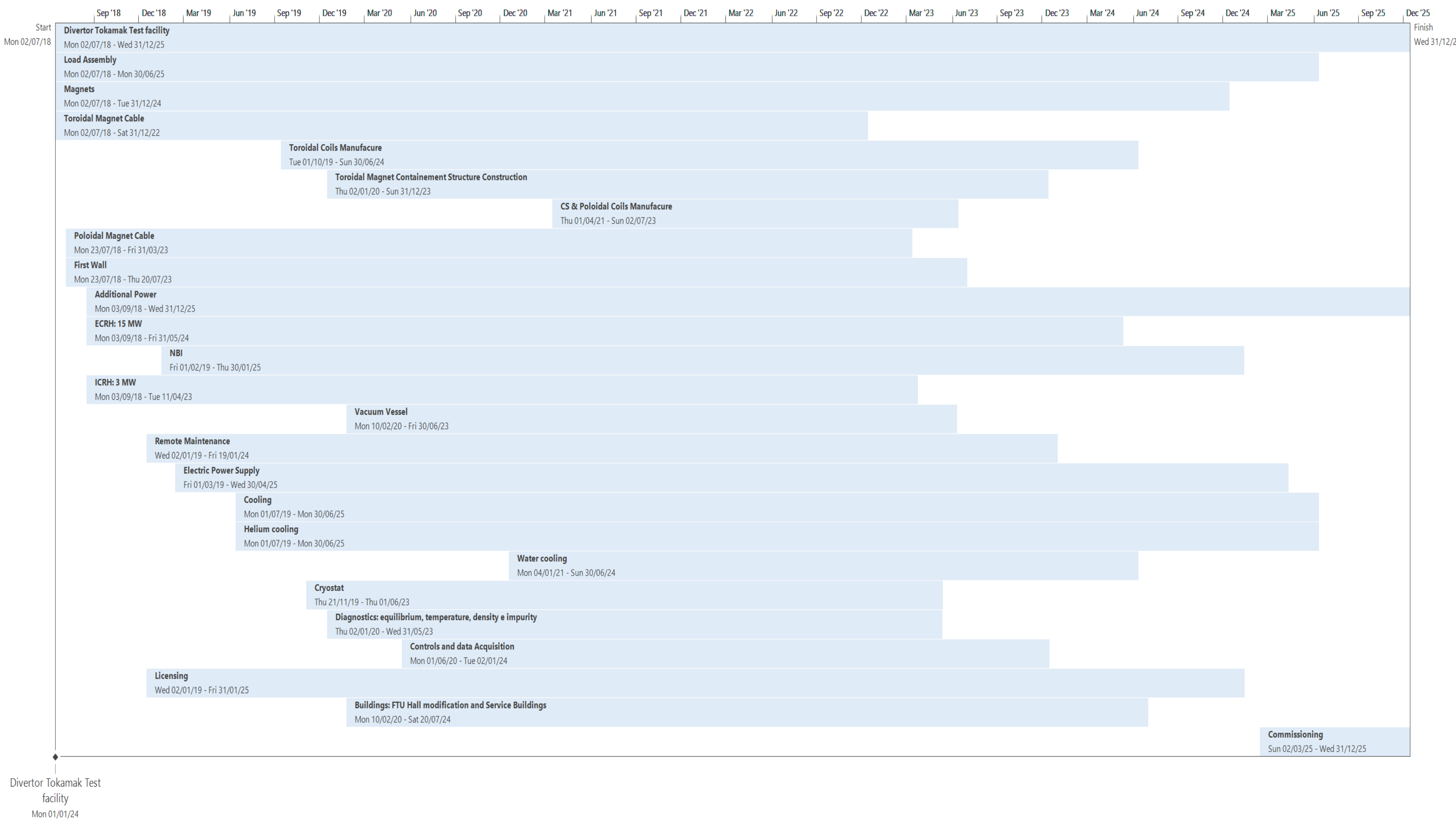
System functions and equipment:

- Human-machine interfaces with force-feedback for remote operations on in-vessel components by human operators (from full teleoperated to full autonomous)

- Virtual reality simulator for training of human operators on remote operations

- Supervisory system of the remote handling equipment

Time schedule



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