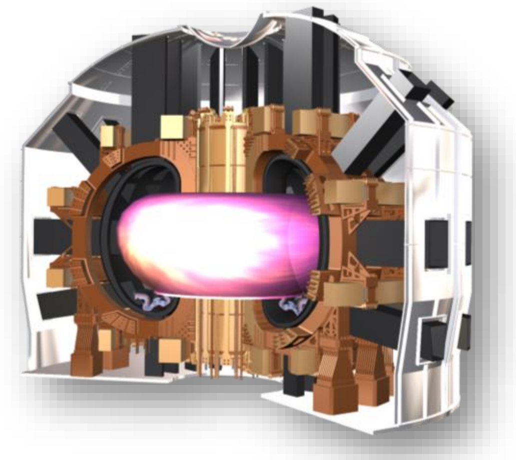
DTT
Global Mechanical Integration



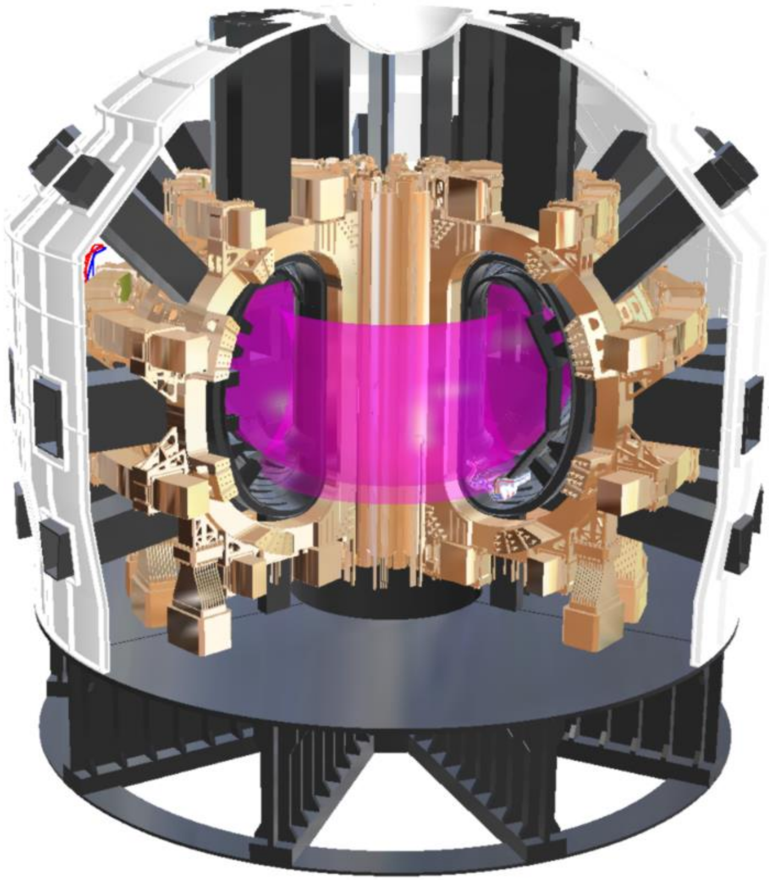
Giuseppe Di Gironimo*
on behalf of the DTT team

**Consorzio CREATE / Univ. Napoli Federico II*

Introductory remarks

Main confinement structures

- Vacuum Vessel
- Ports
- Cryostat
- In-Vessel Components
- Remote Handling



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DTT Vacuum Vessel – Main components

Overall external dimensions of the VV:

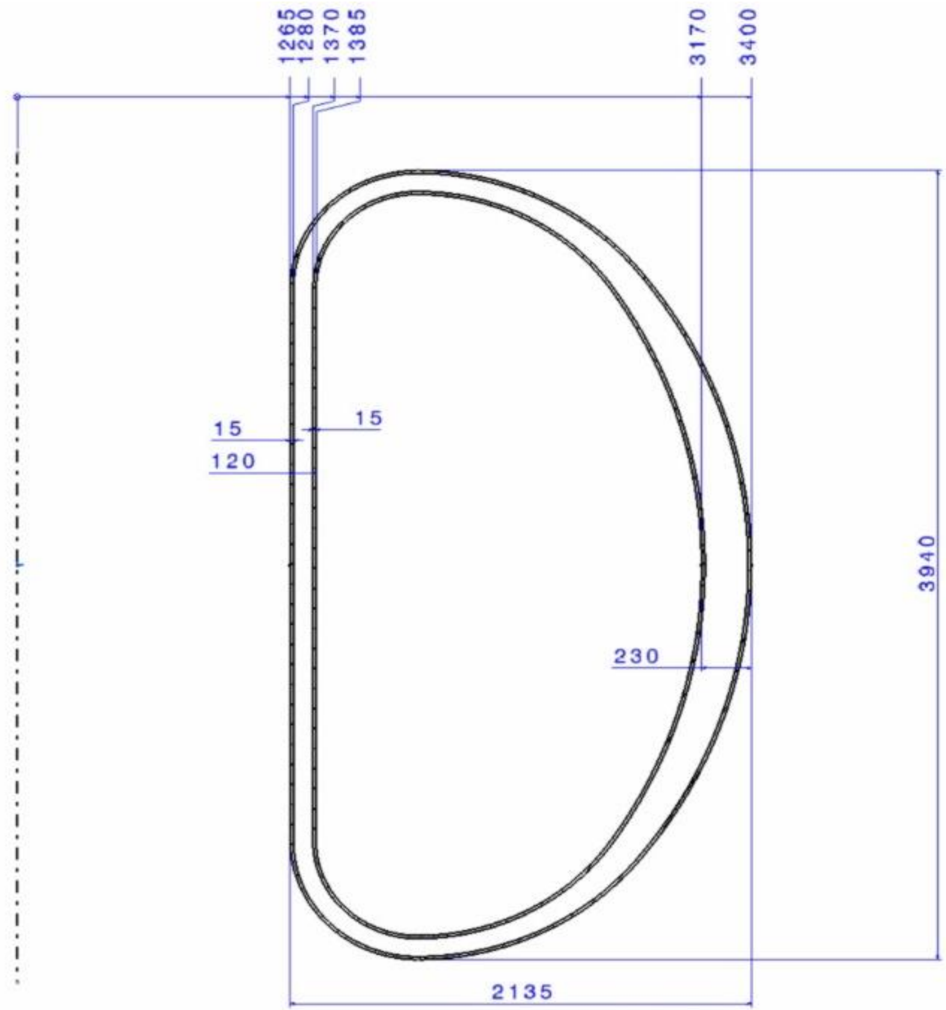
- *Height: **3940** mm*
- *Radius at the inboard side: **1265** mm*
- *Radius at the outboard side: **3400** mm*

*VV main material is **SS AISI 316 L(N)**.*

*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 the shells (inner and outer) 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 9 legs with leaf-springs resting directly on the cryostat base.*



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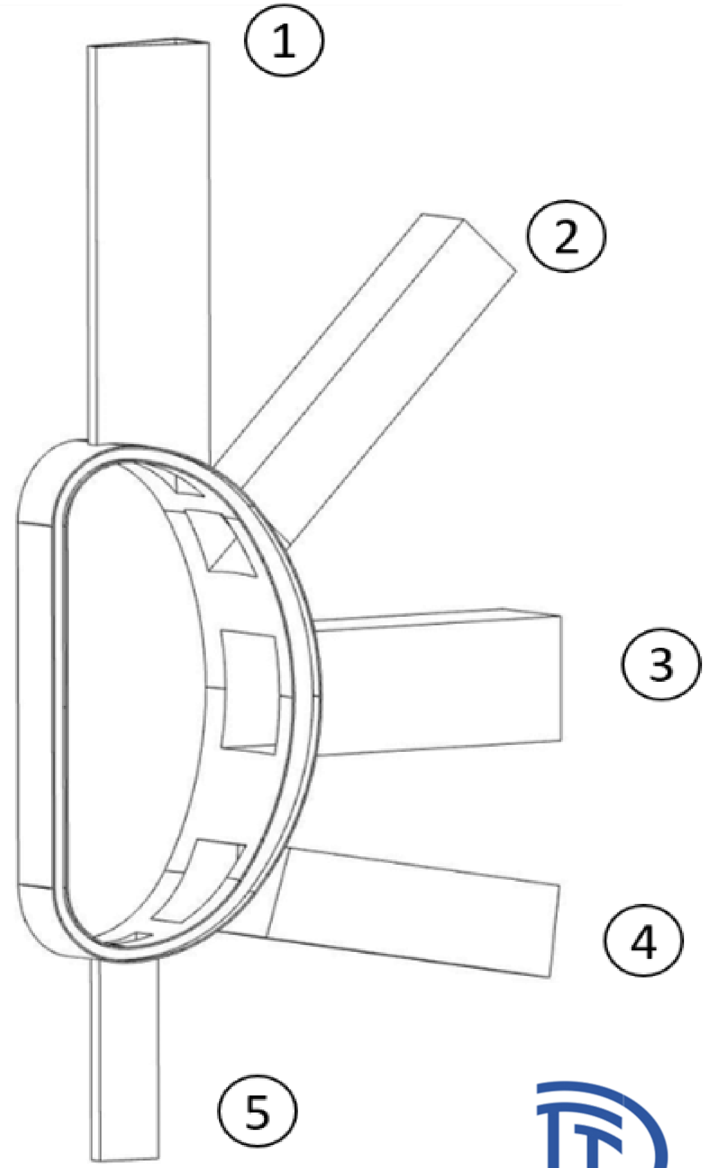

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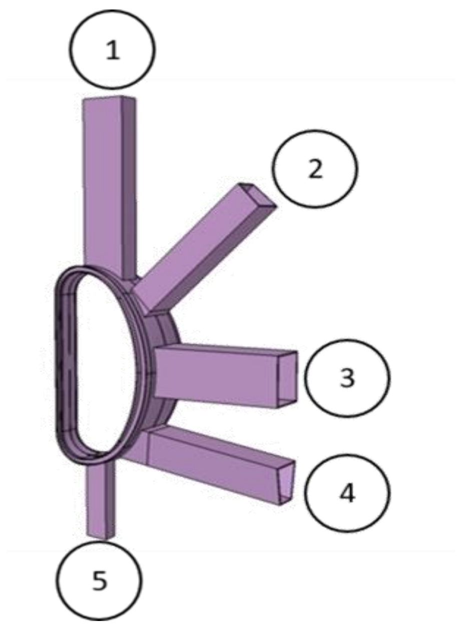
DTT Vacuum Vessel - Segmentation

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

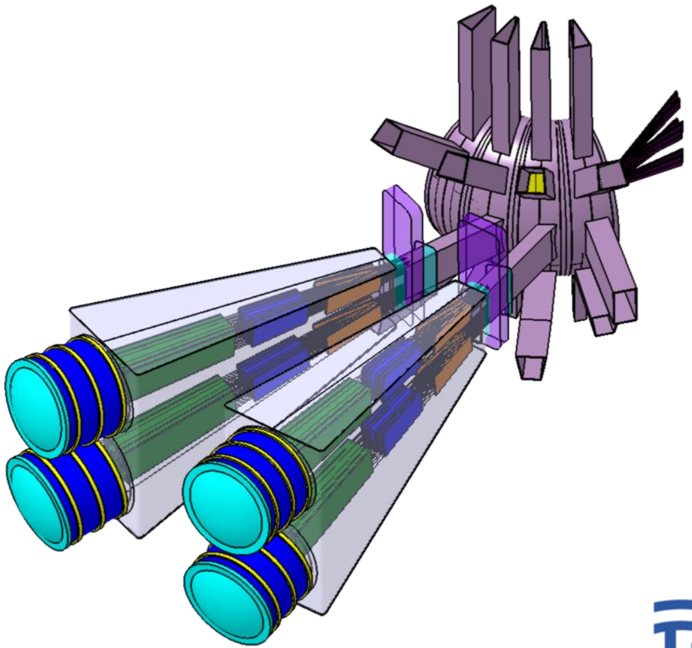
- No.14 Modules (20°): No.10 with 1 port aligned with plasma centre (Diagnostics, Heatings)
  No.4 Remote handling modules (20°): Ports n.4 for divertor RH purposes
  Ports n.3 for FW RH purposes

- No.1 NBI module (80°): for the installation of 2 neutral beam injections (NBI) at the equatorial port

Standard and RH modules

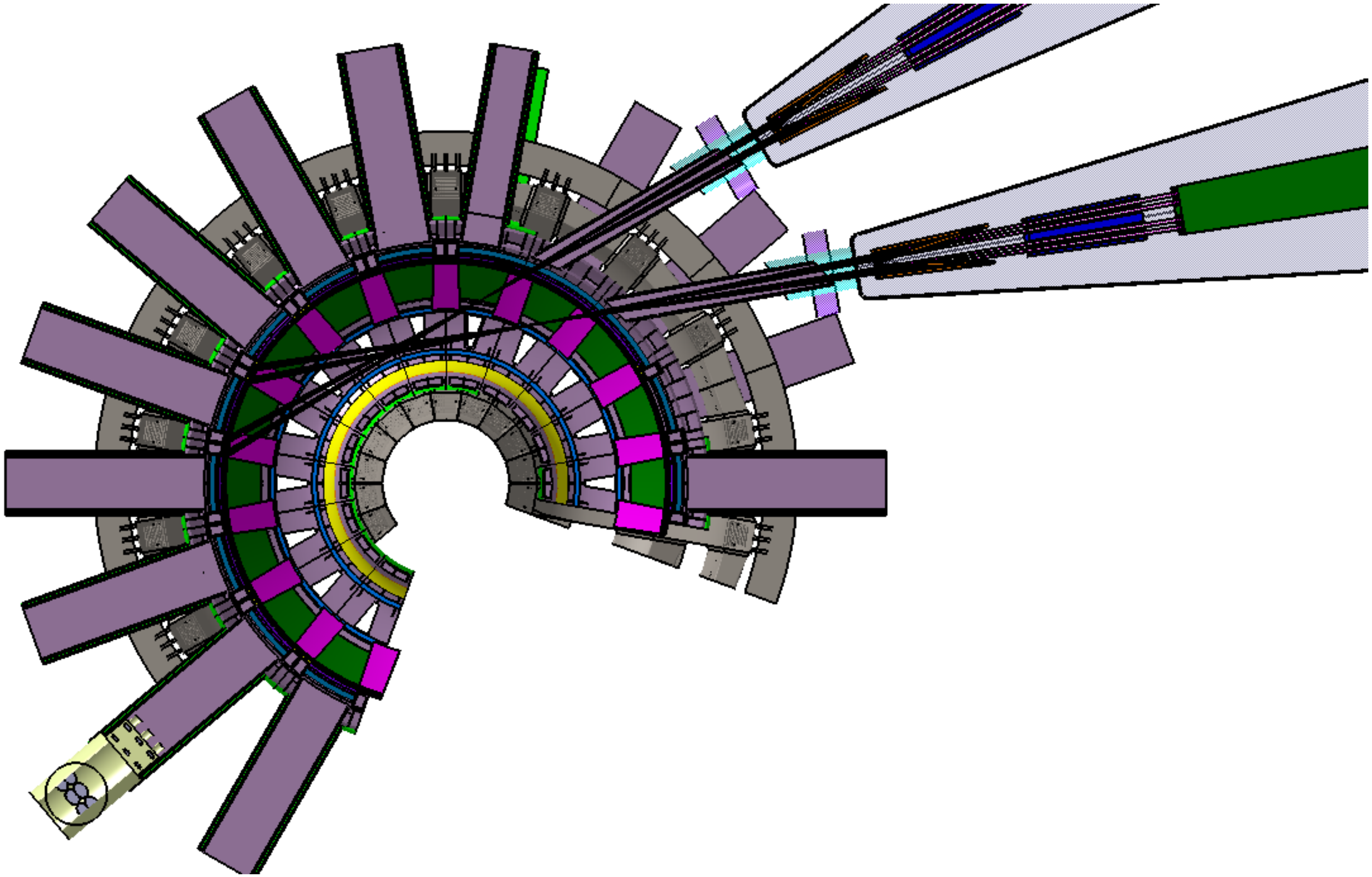


NBI module



DTT Vacuum Vessel - Segmentation

NBI module



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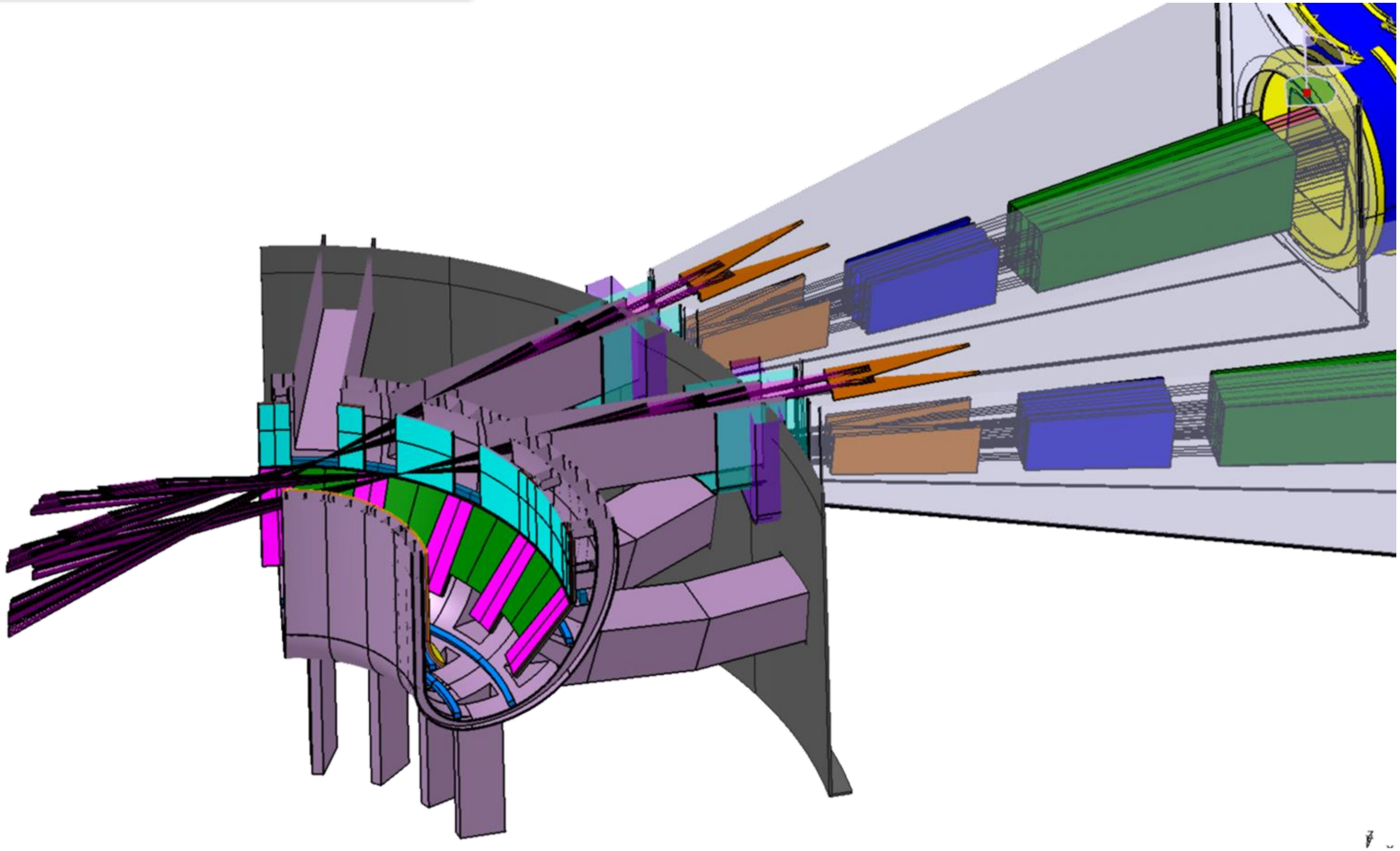
DTT Vacuum Vessel - Segmentation

NBI module



Equatorial port aimed at accommodating the co-tangential NBI beam among the TF coils

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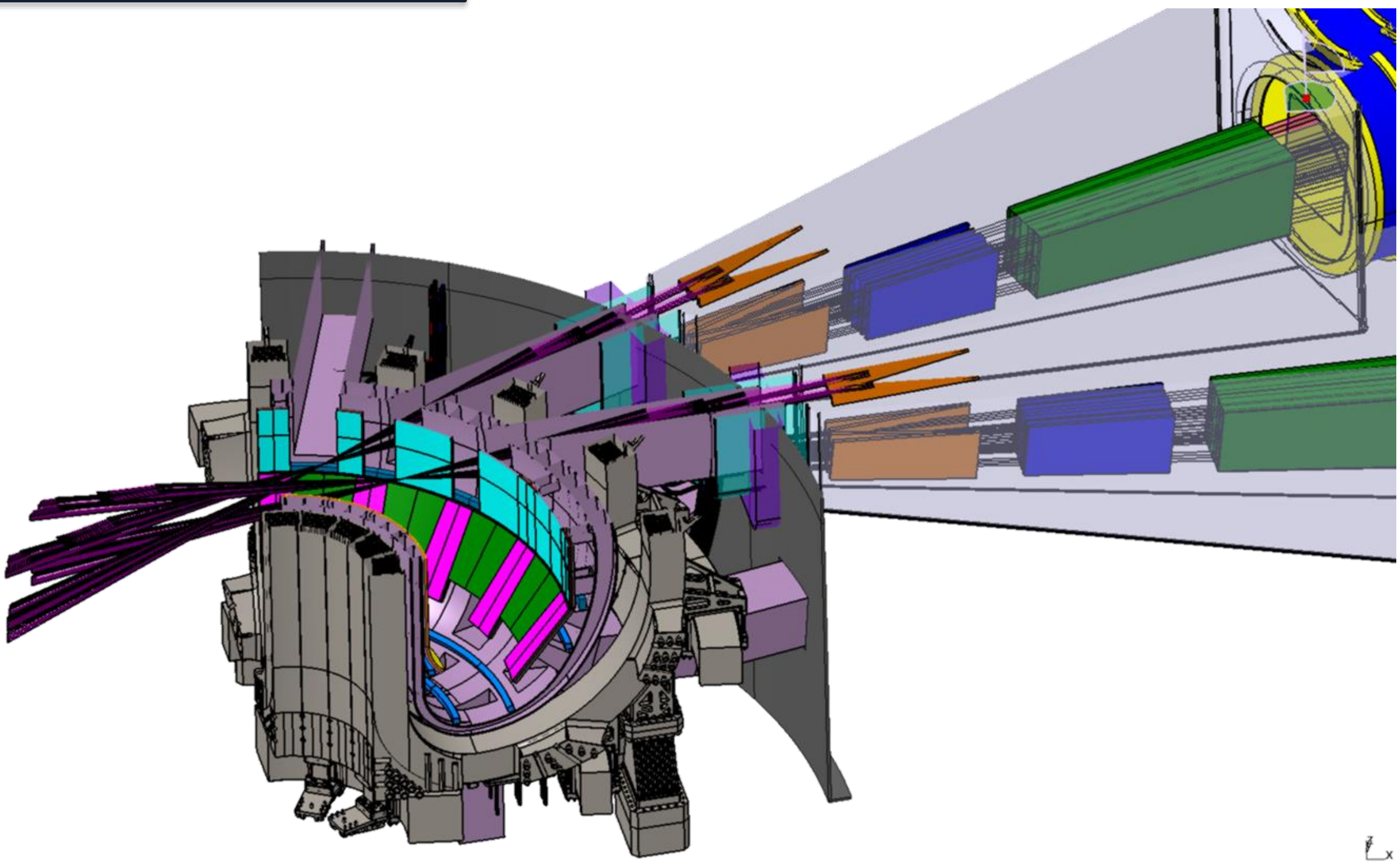
DTT Vacuum Vessel - Segmentation

NBI module



Equatorial port aimed at accommodating the co-tangential NBI beam among the TF coils

DTT Vacuum Vessel – Main parameters

Shell Thickness (inboard)	15 mm
Shell Thickness (outboard)	15 mm
Ports Thickness	25 mm
Ribs thickness	10 mm
Torus outside diameter	6800mm
Torus inside diameter	2530mm
Torus height	3940mm
External surface of the vacuum vessel (holes subtracted)	111,5 m^2
Volume of the shielding water	13,5 m^3
Volume of the VV – plasma side	75 m^3
Material	AISI 316-L(N)
Weight of main vessel body	36900 kg
Plasma Operating Temperature of the VV (max)	80°C
Baking temperature of the VV (max)	110°C

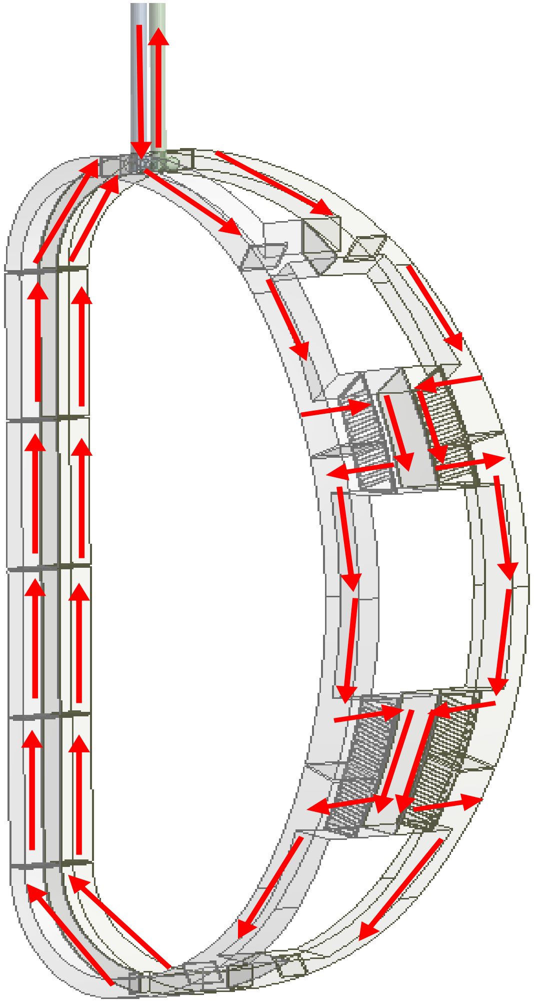
DTT Vacuum Vessel - Cooling

The volume between the inner and the outer shells is designed to allow the ***circulation of the borated water***, which acts as ***coolant and neutron streaming moderator***, in order to reduce the nuclear heating density in the TF winding pack to acceptable limits.

A requirement for the VV design is that the **minimum temperature** should be kept at **50 °C** during normal experimental operations.

The **maximum temperature** shall be kept below **80 °C** to avoid issues related to corrosion effects of boric acid at high temperature.

The overall structure of the VV includes, besides the inner and outer shells, perforated **poloidal and toroidal ribs**, aimed at stiffening the structure and defining the flow path.



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DTT Vacuum Vessel – Access Ports

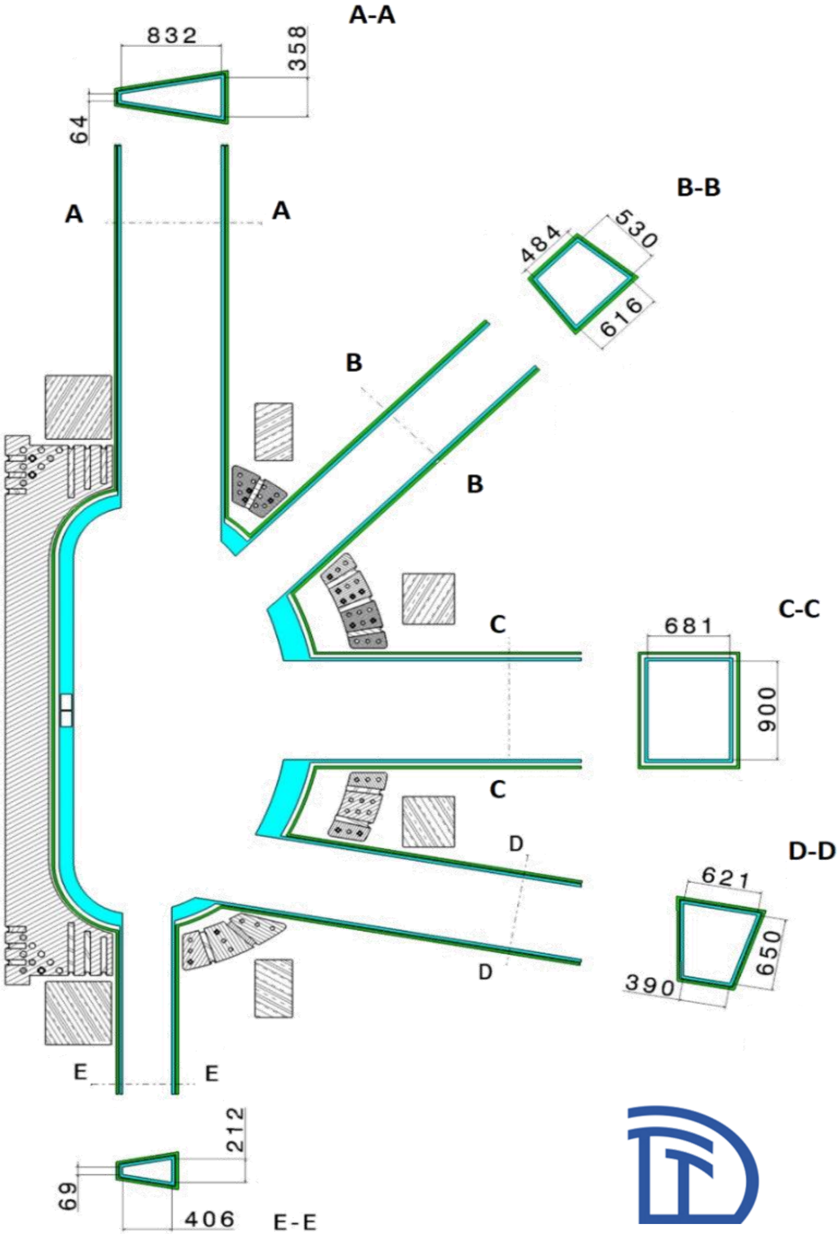
PORT 1 (vertical top):
- FW inboard segments RH
- VV cooling pipes

PORT 2 (vertical side):
- Heatings, Diagnostics, FW OB cooling pipes

PORT 3 (Horizontal - Equatorial):
- Heatings, Diagnostics, FW OB RH

PORT 4 (DIV-RH lower-side):
- DIV-RH, Diagnostics, cooling pipes

PORT 5 (lower):
- Pumps, cooling pipes



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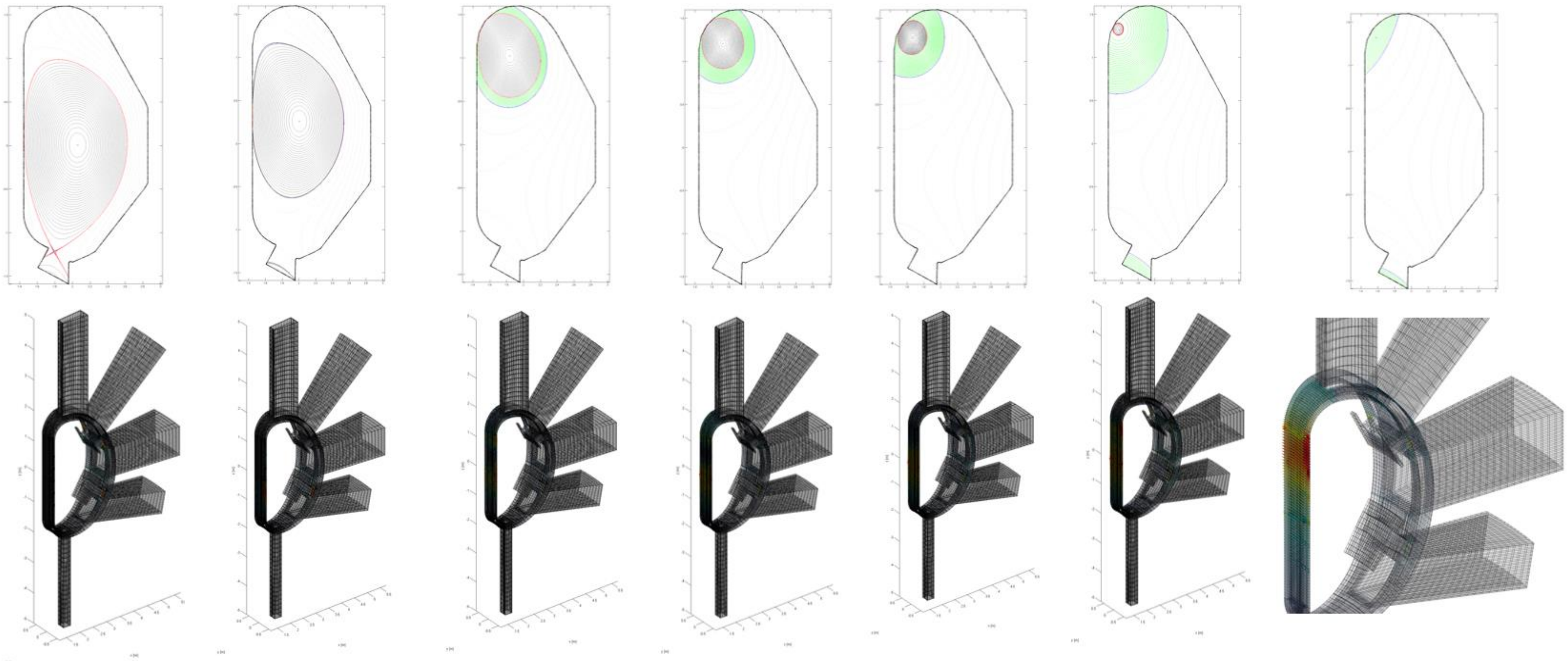
DTT Vacuum Vessel - Structural Analysis

Loads

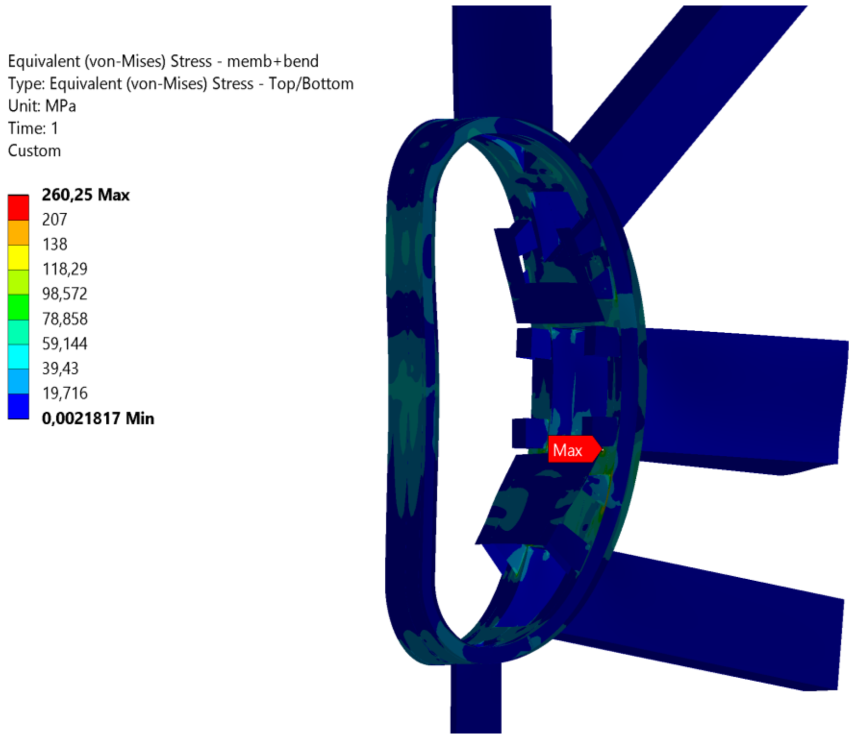
The loads applied came from the **EM analysis** on the Vacuum Vessel during a **Major Disruption at 40ms Current Quench**.

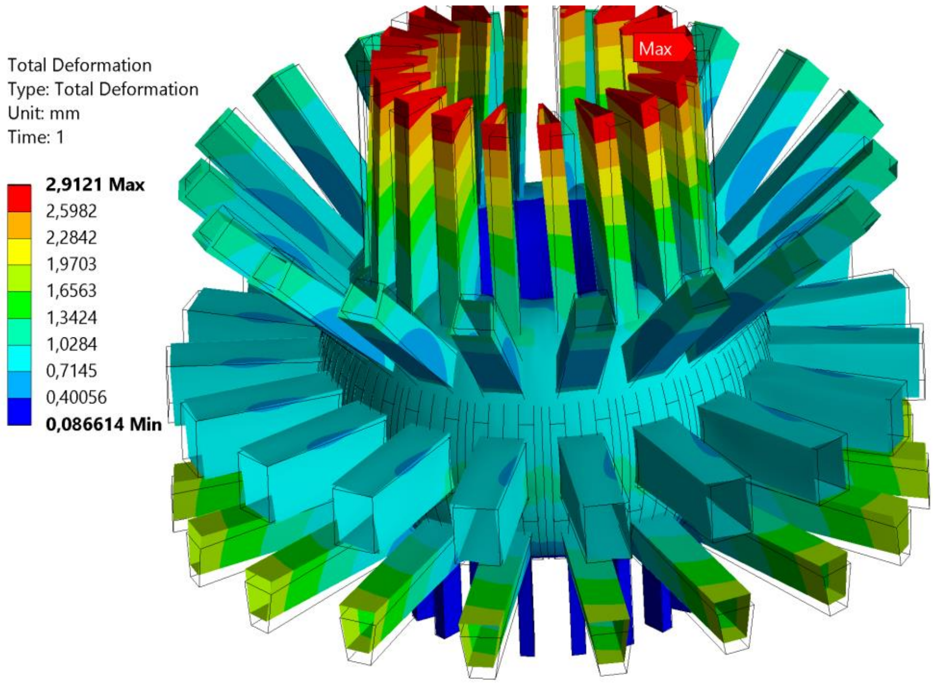


DTT Vacuum Vessel - Structural Analysis

Design criteria : **<u>ASME boiler and pressure vessel code section VIII Div. 2</u>**.

Good results both in terms of ***<u>equivalent stress (Von Mises Stress)</u>*** and ***<u>Displacements</u>***.

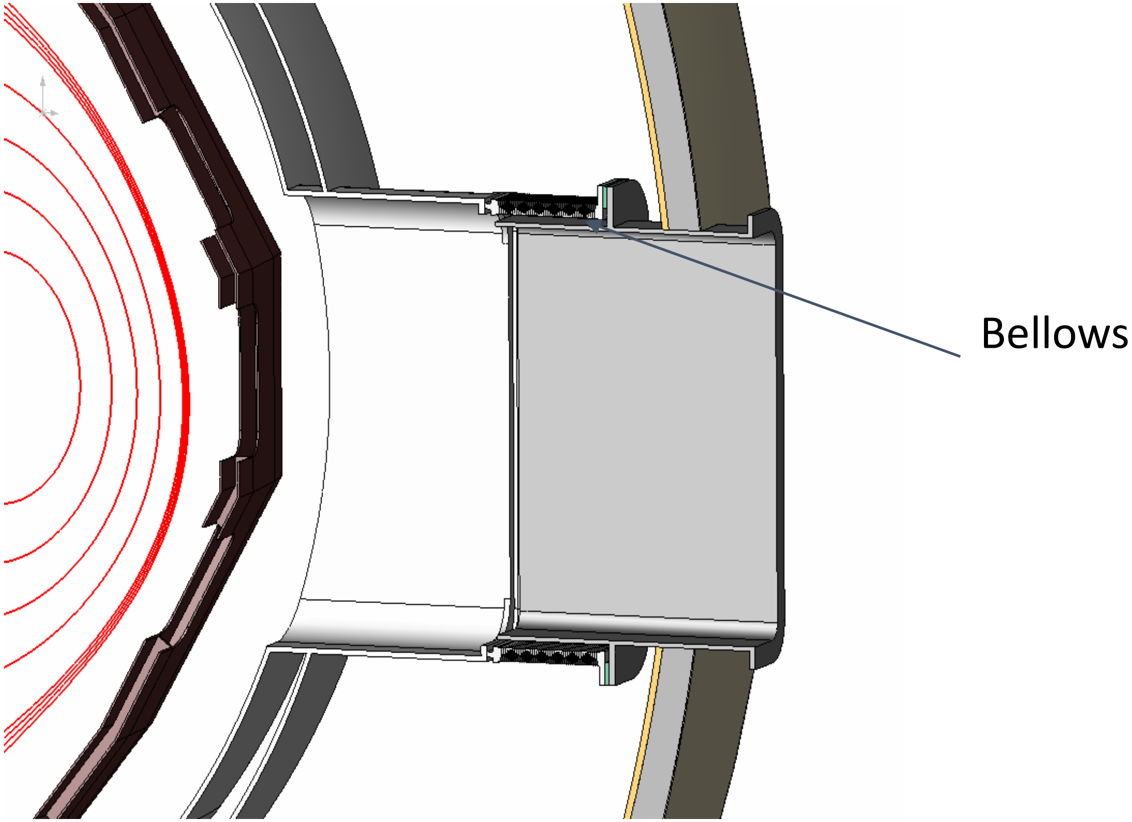




DTT Vacuum Vessel - Bellows

Joining of VV port extensions with cryostat

The ports of the vacuum vessel are connected to the cryostat ports with bellows to be dimensioned based on loads and temperature ranges.



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DTT Vacuum Vessel - Bellows

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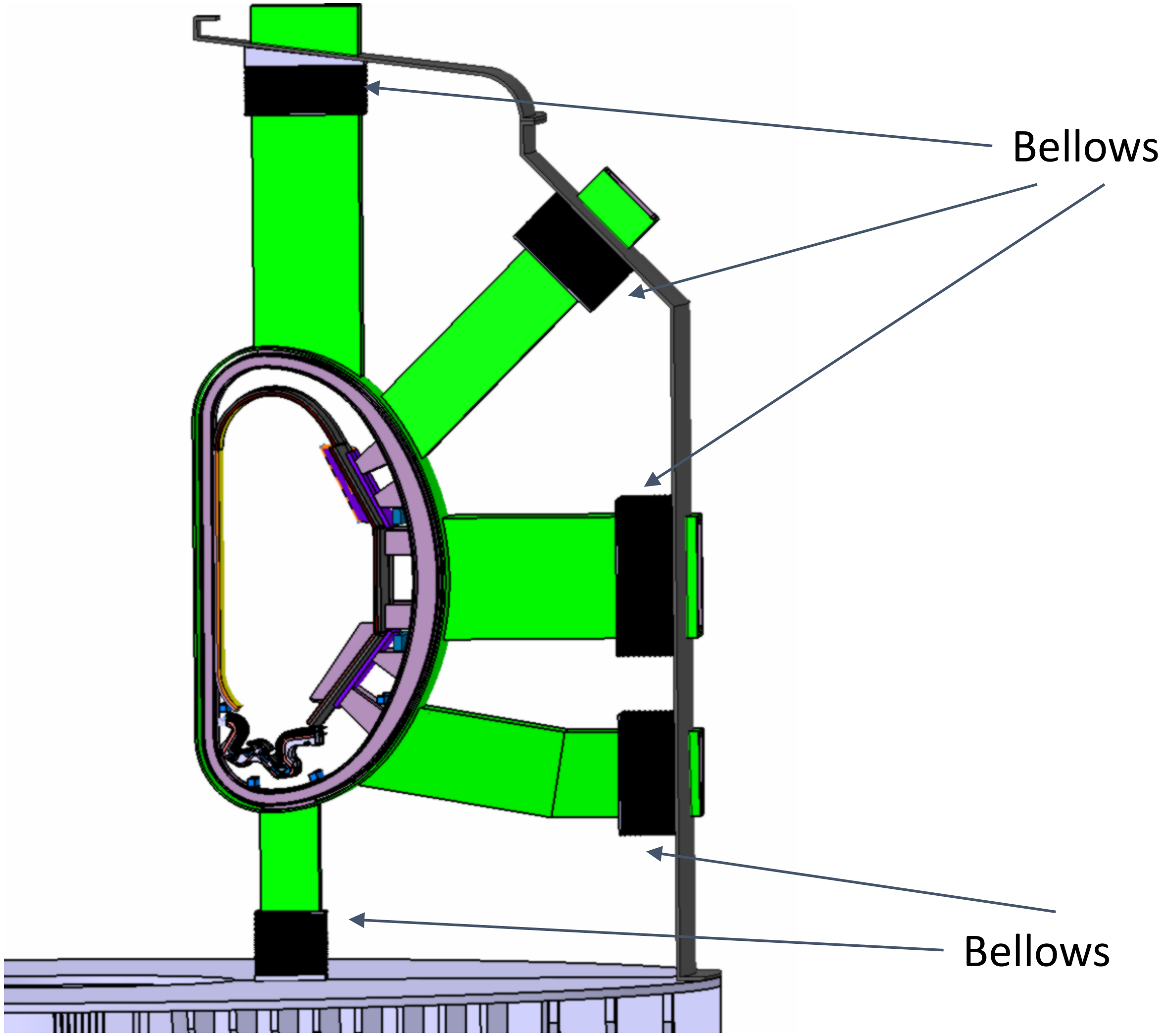

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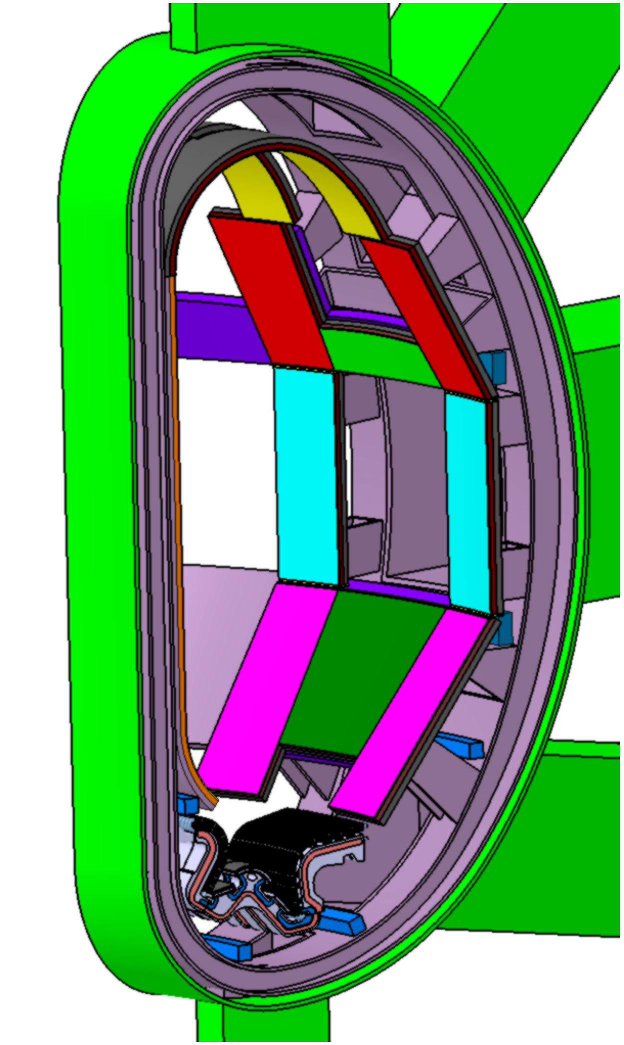
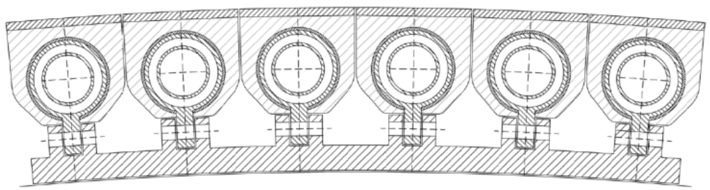
DTT First Wall

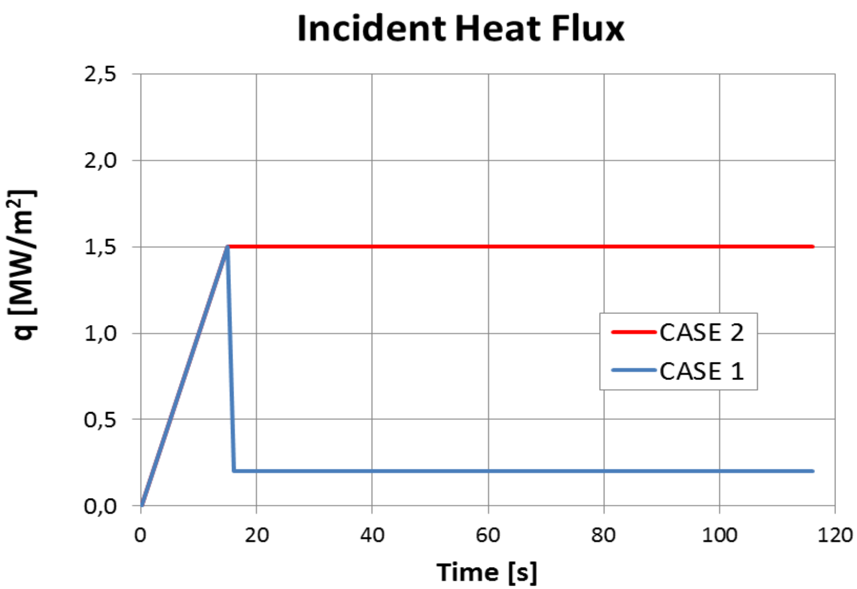
- ***Compatibility with the liquid lithium divertor***. The minimum temperature of the plasma-facing surface must be above the melting point of lithium: 200°C.
- ***Compatibility with the remote handling system***.
- ***Compatibility with the diagnostic system***.
- ***Compatibility with DEMO***. Materials with high and moderate activation, such as copper, must be avoided as structural material and reduced as much as possible for applications as functional material.
- ***Compatibility with the electromagnetic loads***. The fixing system of the FW modules onto the vacuum vessel must sustain the loads due to the Lorentz Force, both during nominal and undesired transients (e.g. breakdown, disruptions).

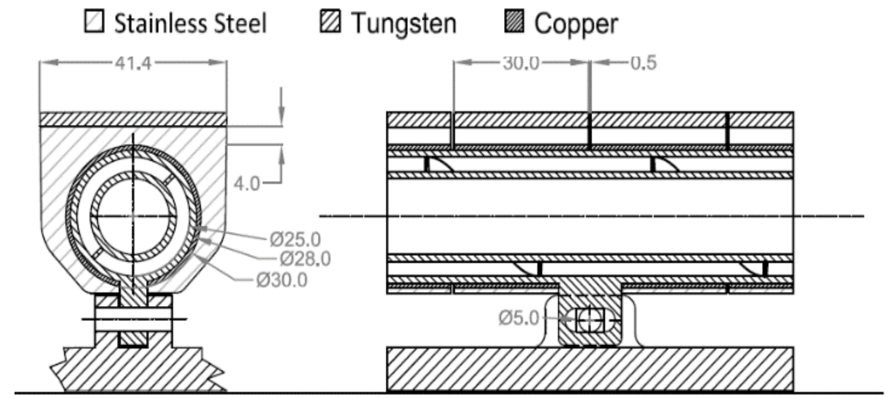


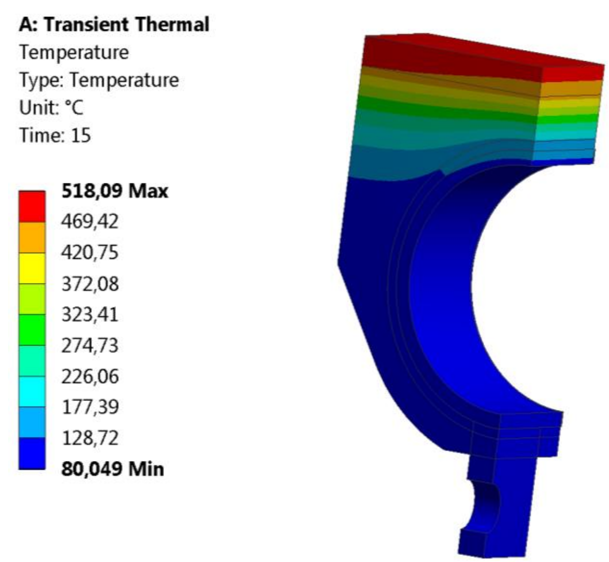
DTT First Wall

FW module - plasma facing unit









A thermo-mechanical analysis has been carried out considering a thermal load ramped up to 1.5 MW/m2 in 15 s followed by constant load of 0.2 MW/m2 for 100s.

Design criteria (ASME section VIII Div. 2) are satisfied

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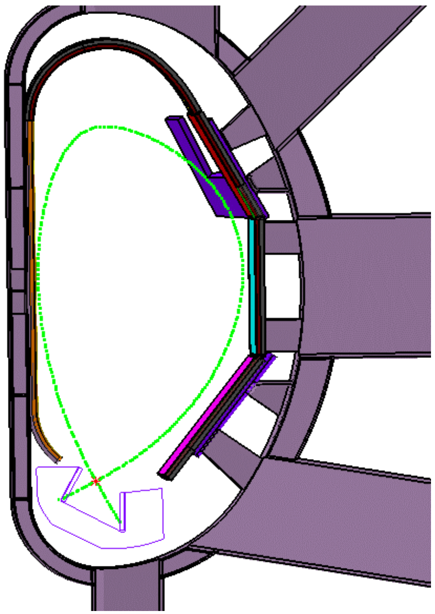
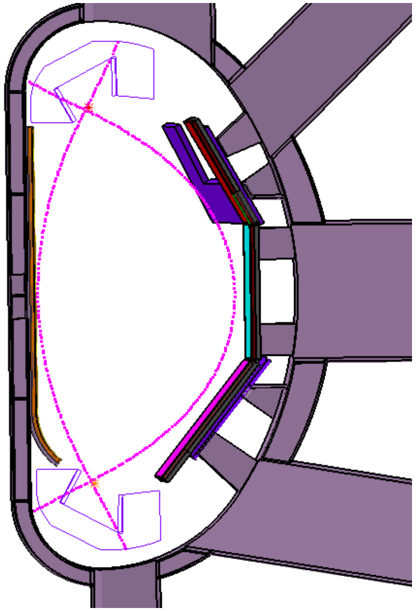
DTT DIVERTOR

- DTT will have the capability to perform **different magnetic configuration**, such the Single Null (SN), the Double Null (DN) or the Snow-Flake (SF) configurations
- Divertor can be "conventional", or it can be an "alternative" divertor to allow for alternative magnetic configurations: **SPACE AVAILABLE IS ENOUGH**
- DTT will allow for screening test with different materials, including ***liquid metal targets***
- Currently, a conventional divertor solution characterized by PFUs Tungsten (W) mono-blocks is integrated in the DTT conceptual design





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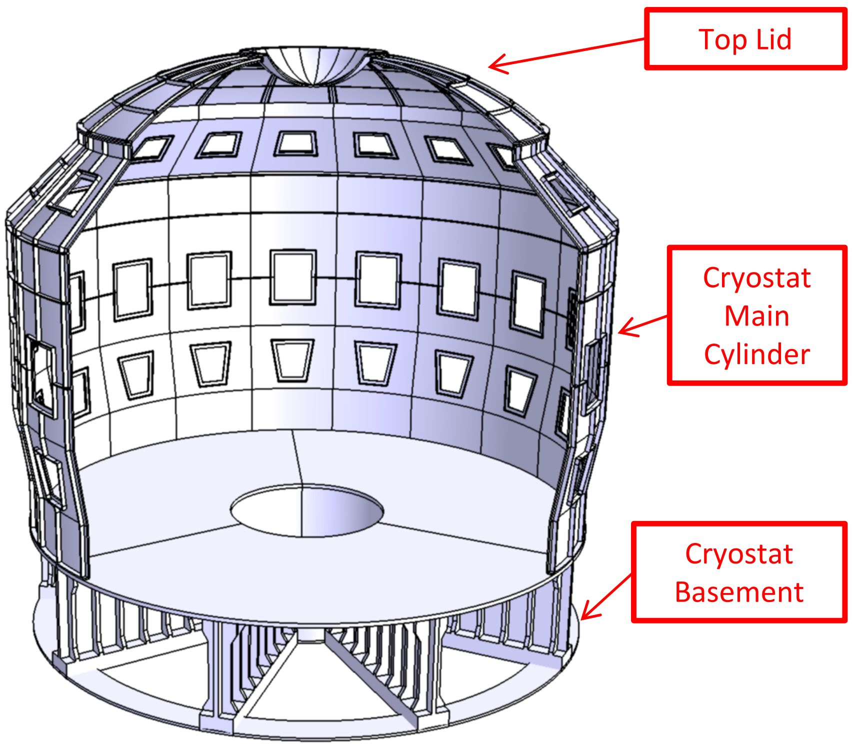
DTT Cryostat

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

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



Major diameter at equatorial section	**~11.2m**
Maximum height including basement	**~11m**
Basement Height	~2m
Structural Material	**SA-240 304LN**
Operational pressure (Vacuum)	**10^{-3} Pa**
Design temperature of cryostat wall	**293 K**
Thickness of the Cryostat walls	**30 mm**
Thickness of the external ribs	**25 mm**
Estimated Mass of CV main cylinder	~66 tons
Estimated Mass of CV top lid	~16 tons
Estimated Mass of CV basement	~220 tons

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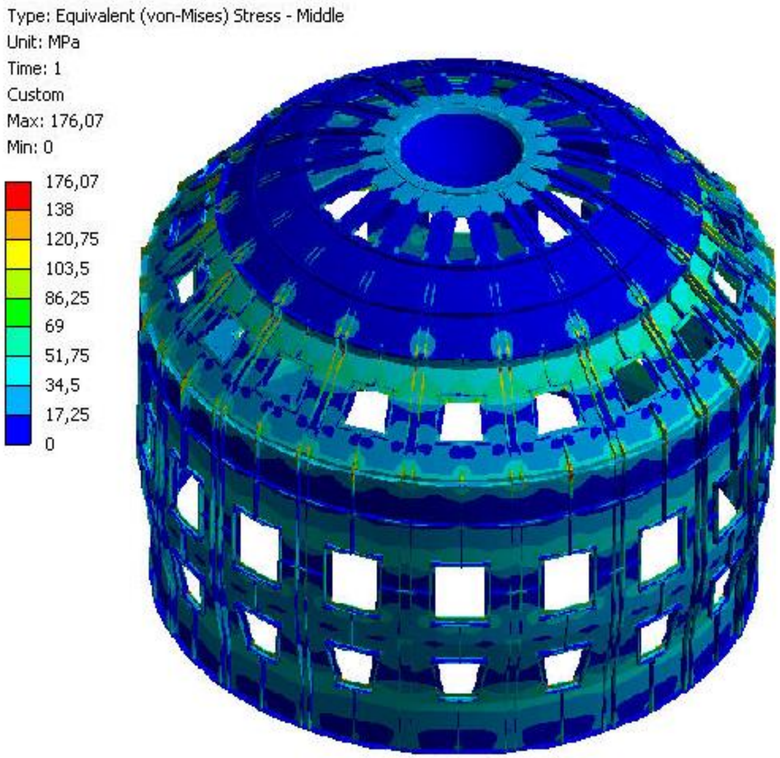
DTT Cryostat Structural Analysis

Structural FEM analyses in two different load conditions have been carried out :

- ***Normal Operation***: External ambient pressure 0.1 MPa (inside vacuum of 10^{-3} Pa) plus dead weight
- ***Accident Condition***: 0.15 MPa as CV internal pressure, in case of loss of fluid from the piping line plus external pressure of 0.1MPa and dead weight

The linear elastic analysis method has been adopted.



The **results** of the linear elastic analysis showed that the design criteria are met in all points of the CV both in Normal Operation and in Accident Condition. Values of stress above the limits are due to geometrical singularity points

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DTT Remote Handling

- Estimated contact dose rate level at 1 day at the end of DTT operations: ~100 mSv/h in tungsten. At longer cooling times, higher induced radioactivity is observed in steel mainly because of nickel, cobalt, and tantalum activation (i.e. ~10 mSv/h in VV at one month after shutdown).

The radioactivity level may require the preparation of an ad hoc temporary repository ("Shielded and restricted area") to store some of the dismounted activated components.

- However, within 50 years from the shutdown, the contact dose of all components should be <10 μSv/h, and the level of activity should not cause waste management problems.

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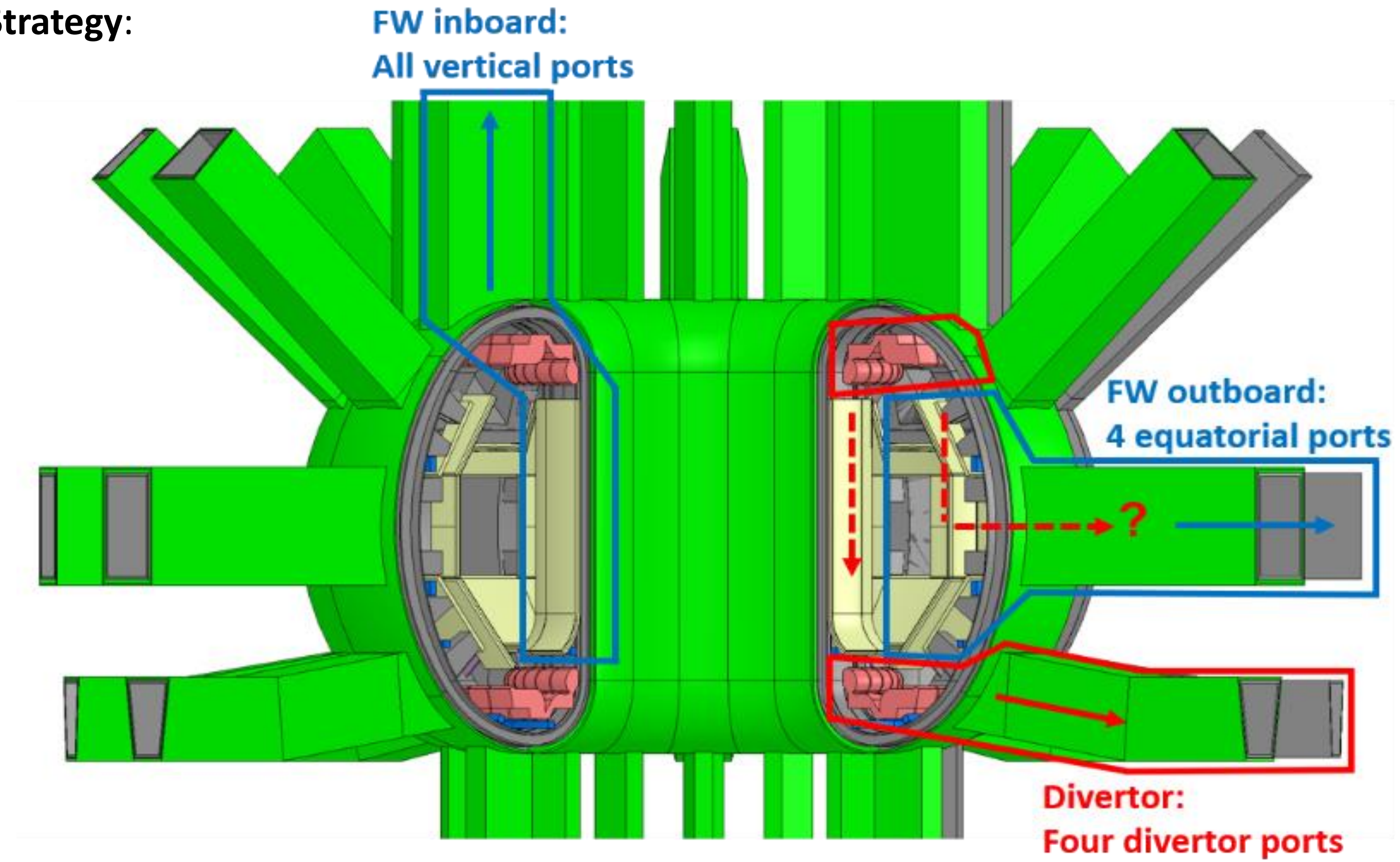
DTT Remote Handling

Strategy:



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DTT Remote Handling

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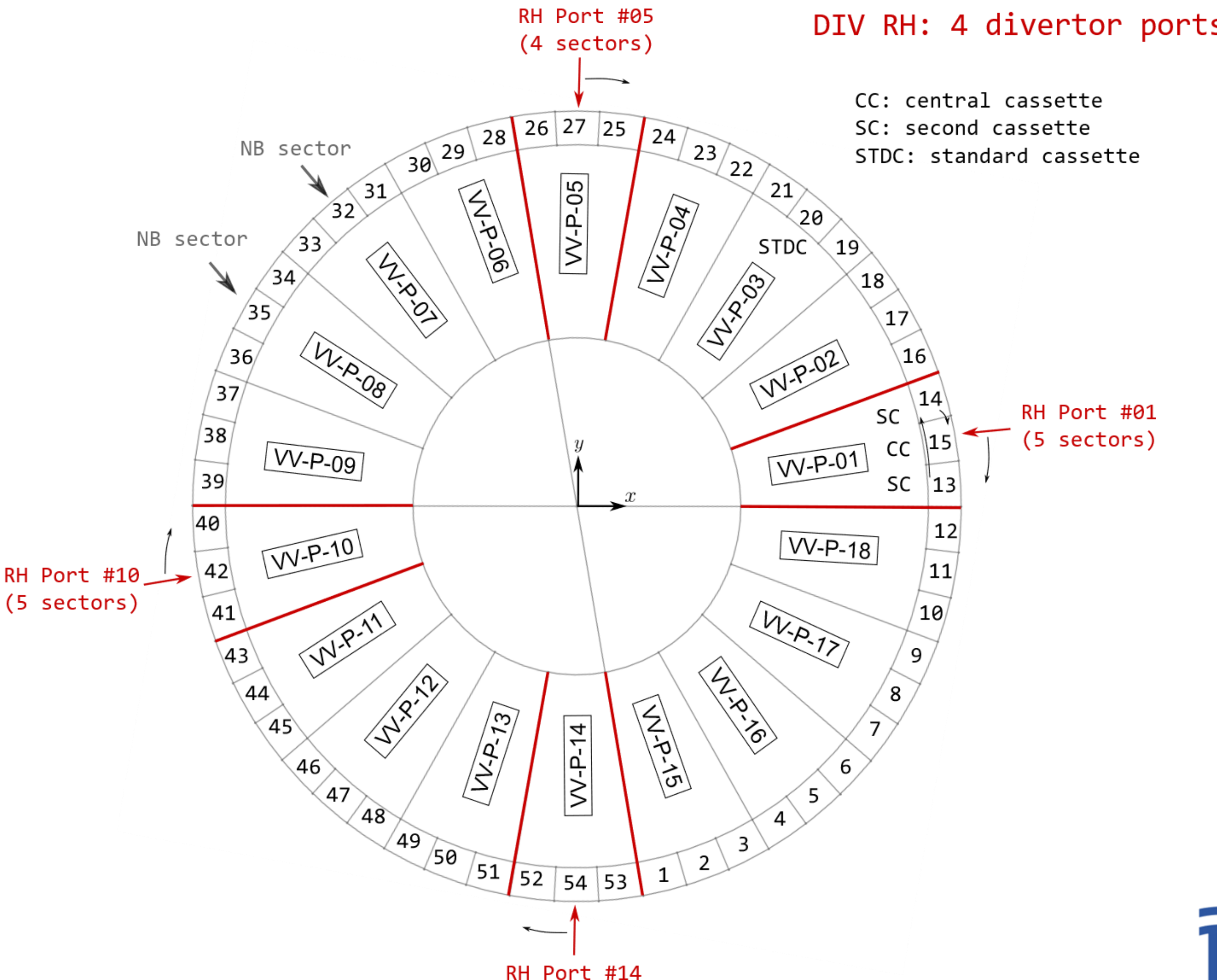
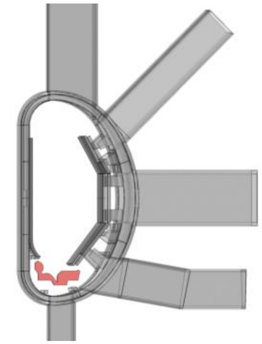


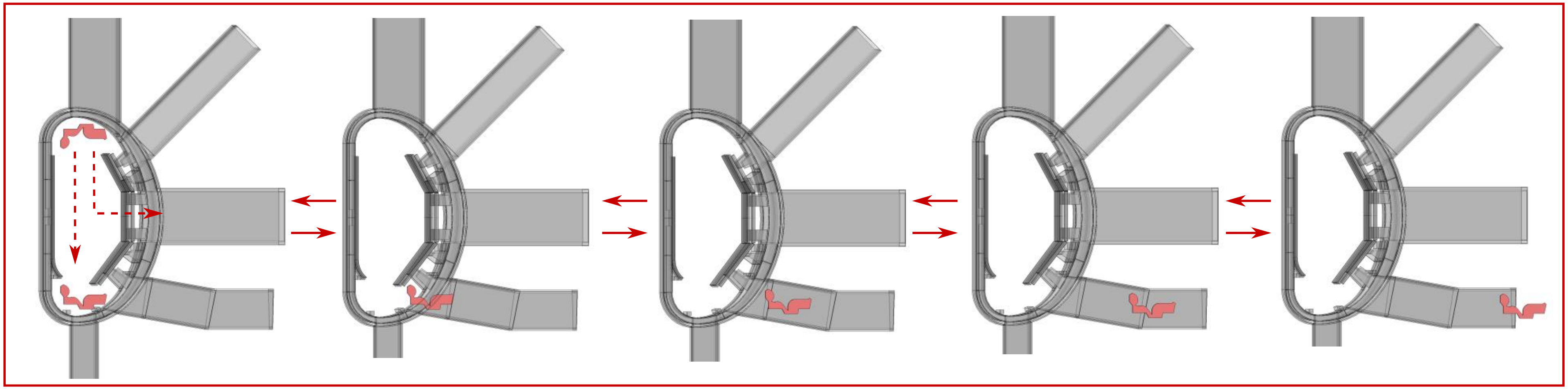
DTT Remote Handling - Divertor

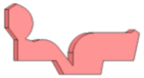
System functions:



- 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)

Motion sequence



 DIV weight: about 200 kg

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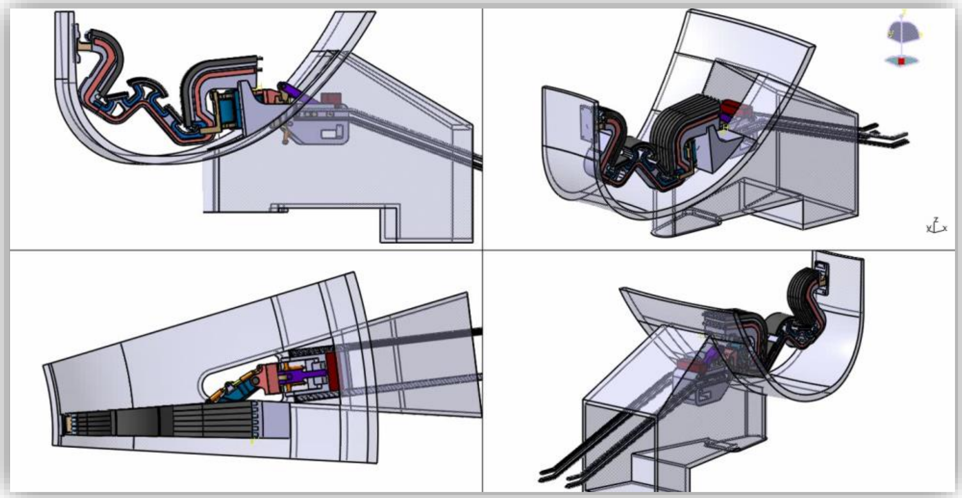
DTT Remote Handling - Divertor

Baseline
- 54 cassettes
- 18 sectors

DIV RM Planned equipment
- Cassette Multifunctional Mover CMM (x1)
- Cassette Toroidal Mover CTM (x1)*
- End effectors:
  - Central Cassette End Effector CCEE (x1)
  - Second Cassette End Effector-Right SCEE-r (x1)
  - Second Cassette End Effector-Left SCEE-l (x1)
  - Standard Cassette End Effector StdCEE (x1)*
- General Purpose Manipulator
- Tooling (for cassette fixation)
- Transfer Cask System (x1)



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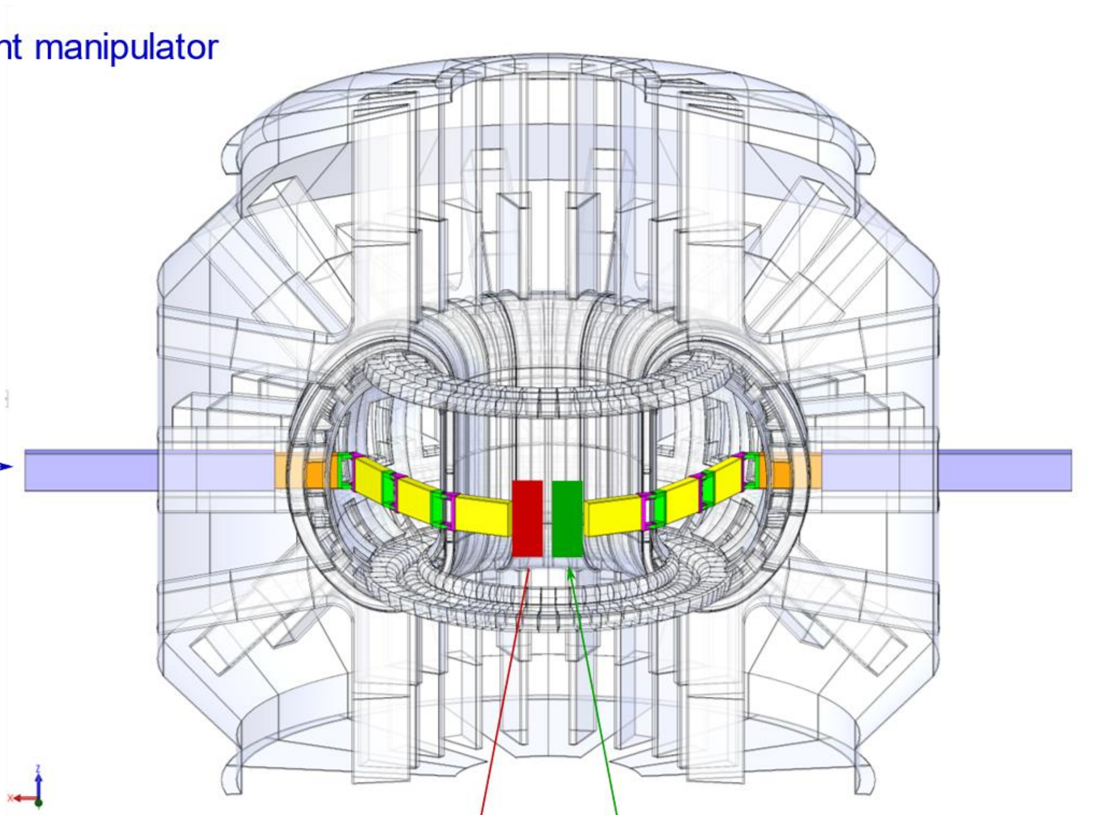
DTT Remote Handling – First Wall

it should be as planar as possible (no deflections) to have the function of an actuated rail for transporting manipulators, end-effectors, grippers and tooling

hyper-redundant manipulator



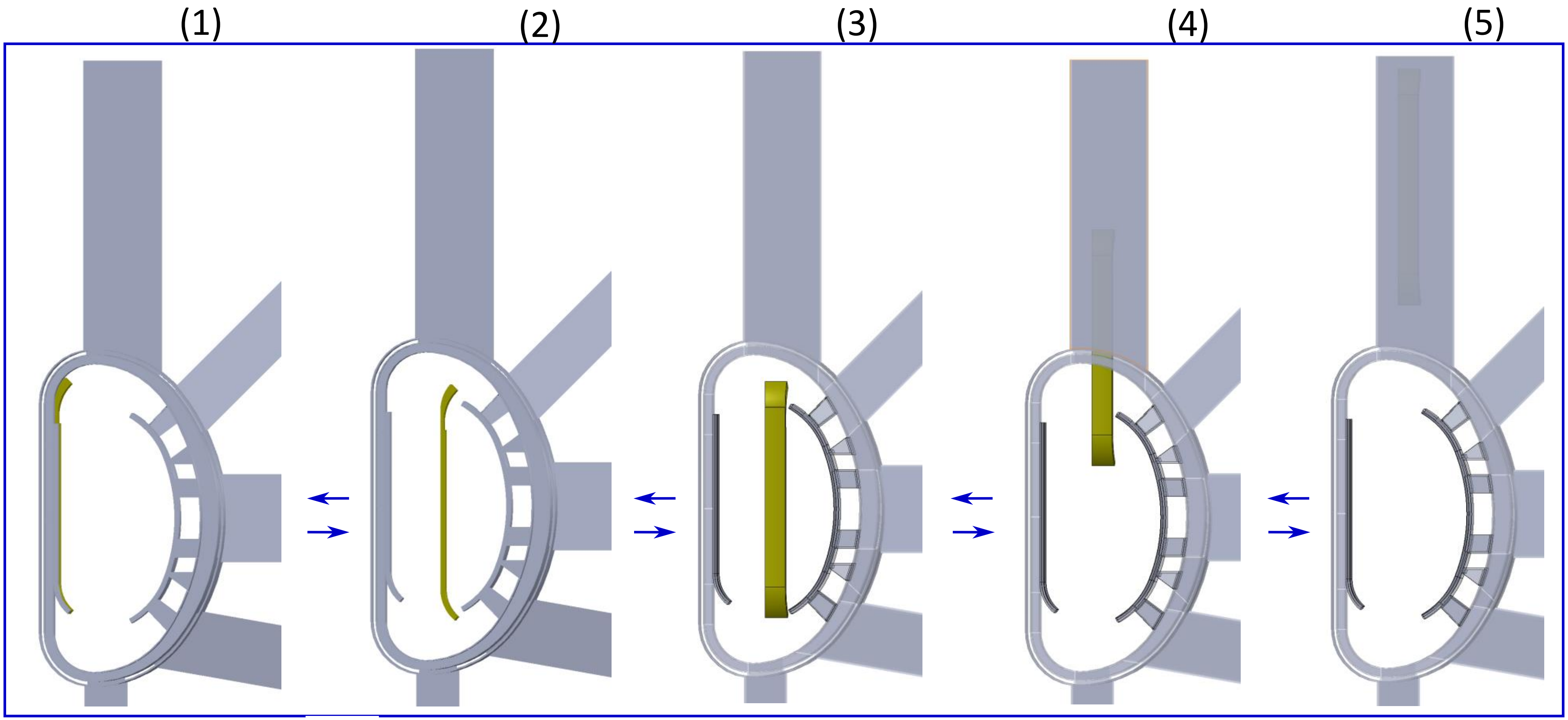
coupling with task module

it can be used to transport tools and
to in-vessel temp storing of OFW modules

coupling with M/S servomanipulator
(3 Positional DOF + 3 Rotational DOF E-E)

this 6 DOF system is joined with the FW gripper

DTT Remote Handling – First Wall



IFW module: about 300 kg weight / about 2.4 m height

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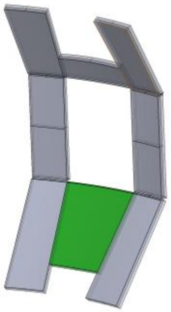
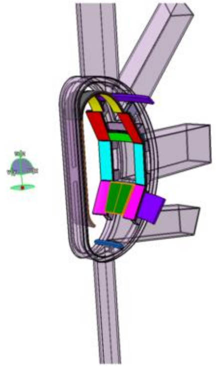
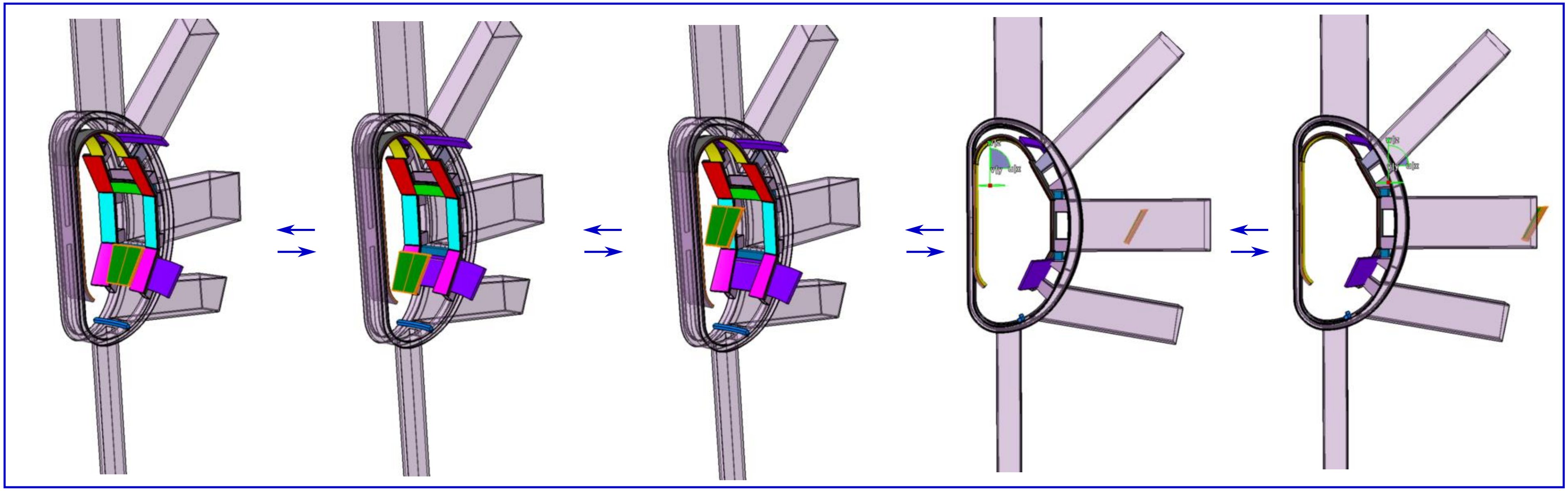
DTT Remote Handling – First Wall



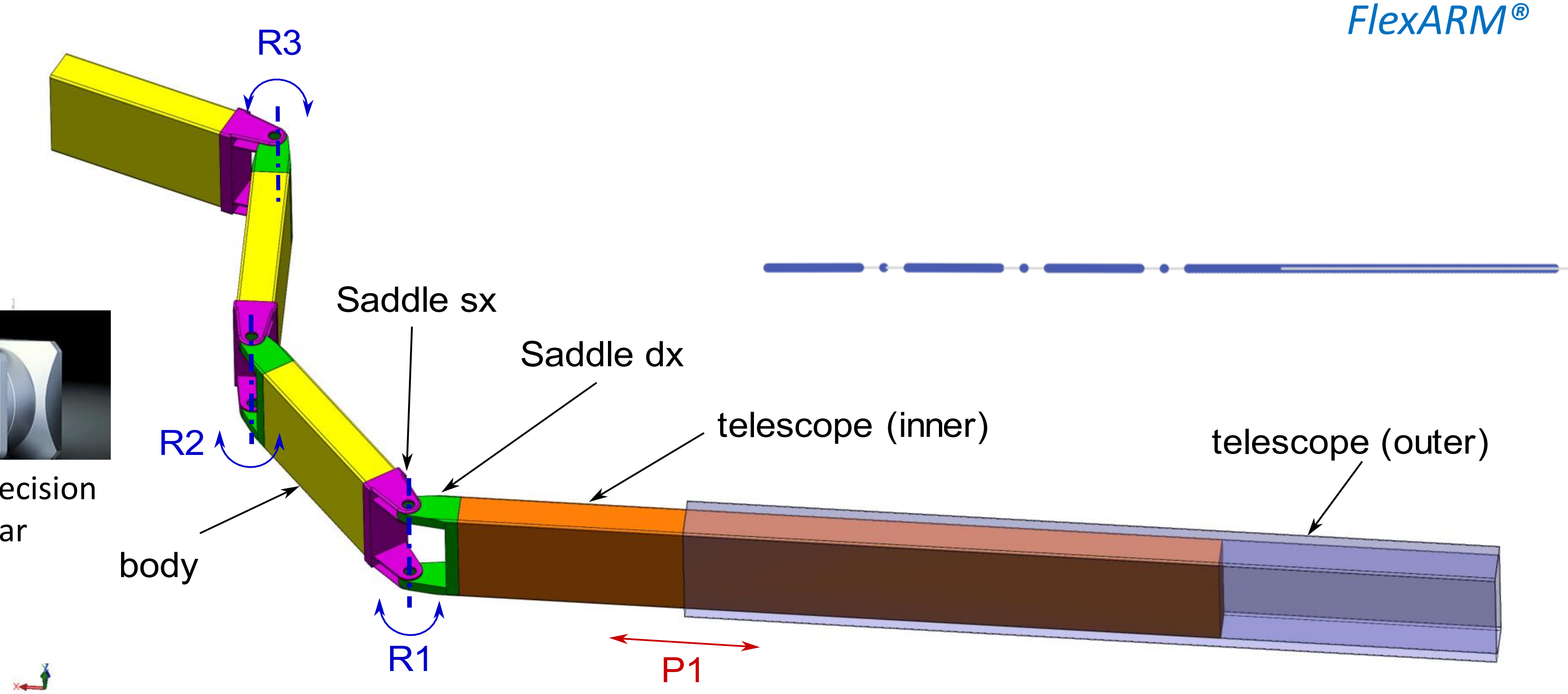
OFW Low module





DTT Remote Handling – First Wall

FlexARM®



Main features:
- current design is compliant with the present DTT design
- electrical actuators
- flexible joints (harmonic drive gears)
- links design to be stiff, even if they exhibit flexibility (especially when the manipulator is in maximum extension and transport a payload)
- final flange has to be designed s.t. a M/S servomanipulator (as MASCOT at JET) or a task module can be coupled

DTT Remote Handling – First Wall

Problem:

- These robotic systems usually transport payloads which can be heavy (manipulators + in-vessel components); they are designed to be stiff
- However, flexibility arises due to: (i) their weights; (ii) the geometric configurations they undergone; (iii) the payloads that they have to transport. Nothing can be made rigid enough such that the deformations can be ignored

ENEA-CREATE has experience on: (1) physical-based models to predict such deformations; (2) control algorithms to suppress undesired vibrations

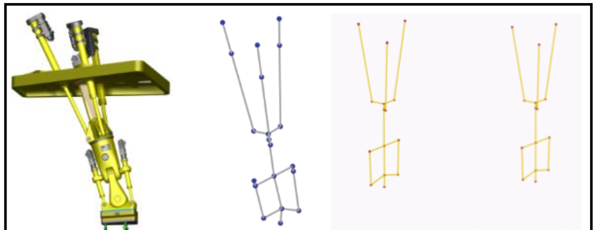
FlexARM

Flexible robots enabling Autonomous Remote Maintenance in nuclear fusion environments

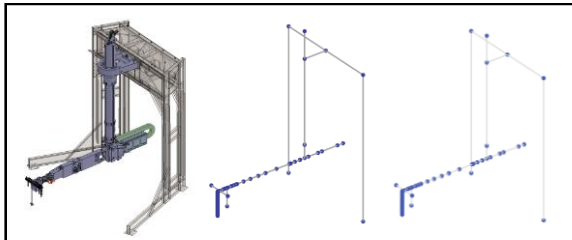
(http://www.flexarm-project.eu/)

[FED19] S. Grazioso, G. Di Gironimo, B. Siciliano "Modeling and vibration control of flexible mechanical systems for DEMO remote maintenance: results from the FlexARM project", *Fusion Engineering and Design*, 2019

FlexARM solver used for analyses on:



Hybrid Kinematic Mechanism [FED19]
(handling of DEMO blanket modules)



Telescopic Articulated Remote Mast [FED19]
(remote handling of JET, now RACE)

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DTT Remote Handling – 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

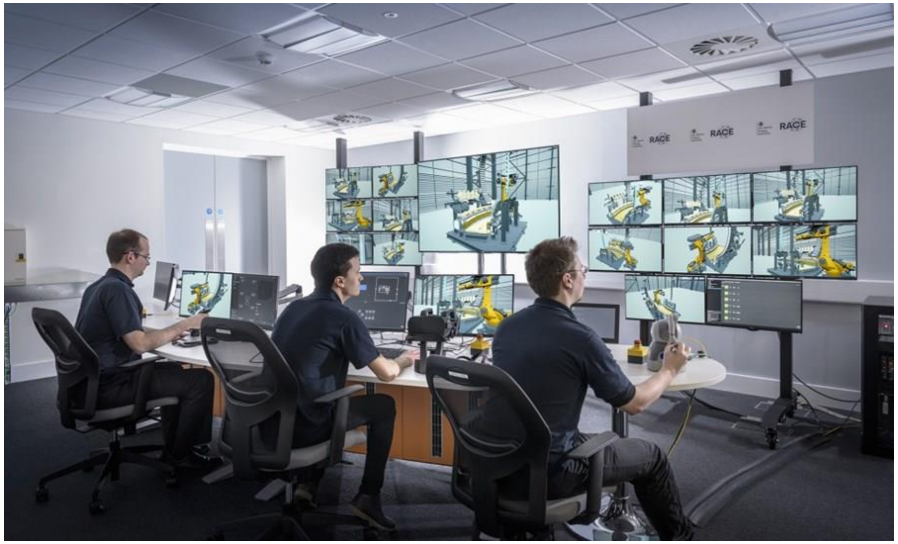

Figure - *The RACE control room with VR screen, haptic devices with force feedback and supervisory systems*

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