



DTT Thermal Shield: system integration and procurement



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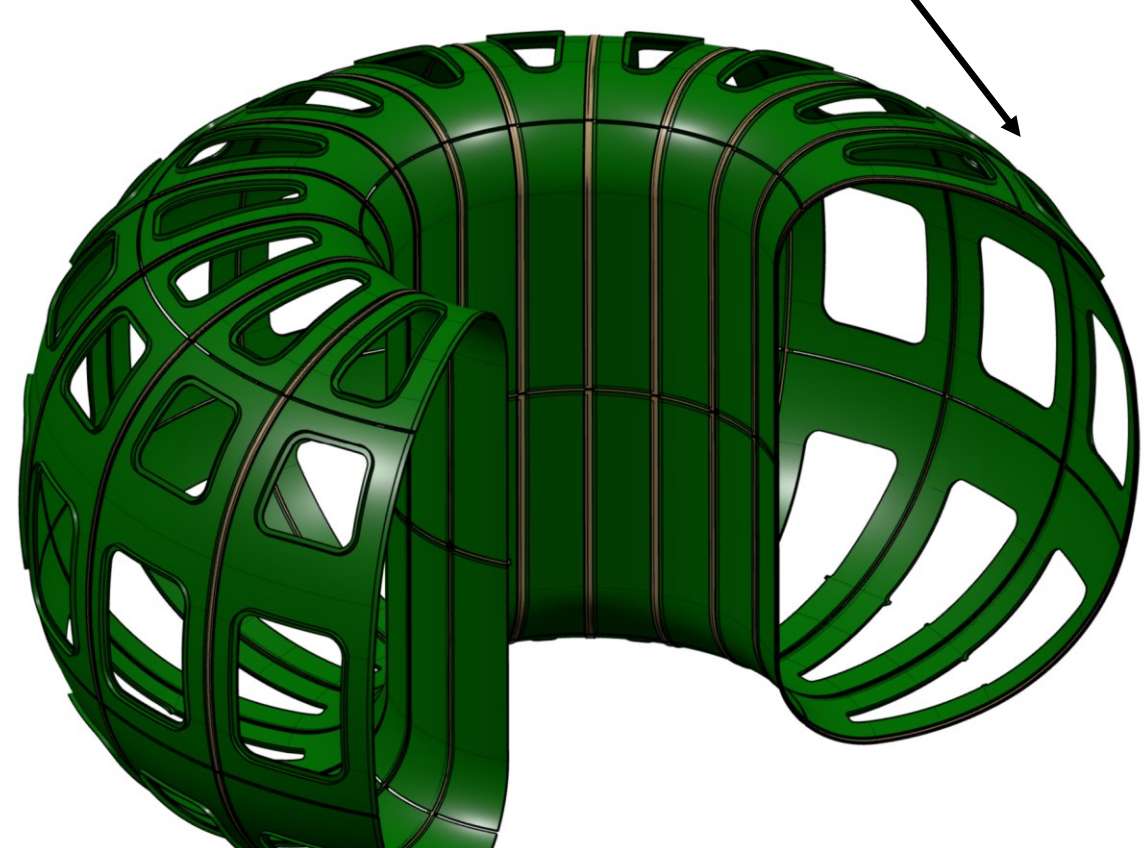
ABSTRACT

- DTT is one of the largest superconducting tokamaks with the mission to get scientific and technological proofs of power exhaust in prospect of the first nuclear fusion power plant.
- Superconducting magnets (poloidal field coils, toroidal field coils, and central solenoid) to reach the superconducting state will be cooled down to 4.3 K by means of supercritical Helium.
- The function of the thermal shield system is to intercept the radiation heat loads from the machine warm components (Vacuum Vessel, Ports, and Cryostat) to the superconducting magnetic system. The thermal shield consists of a series of actively cooled panels to be installed into the small gaps between the warm and ultra-cold components, also assuring an adequate clearance towards each interface, for any machine operating state.
- The paper describes the rationale for the thermal shield gravity supports based on a robust mechanical anchoring system to withstand static and mechanical loads, reducing, at the same time, the magnitude of heat flux towards the fastening interface. Further, the positioning and installation sequences are described during the machine assembling operation.
- In perspective of procurement phase, the main manufacturing requirements are addressed in terms of panel manufacturing, tube welding and surface finishing to optimize the shielding effectiveness of the component.

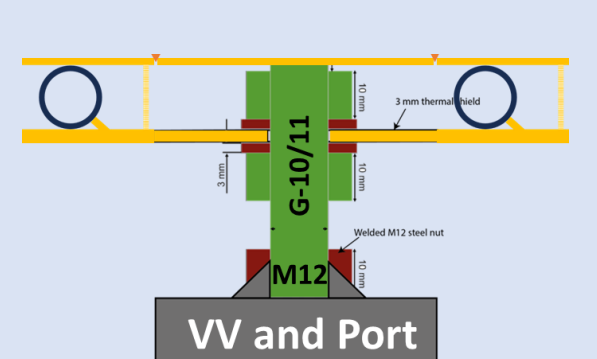
THERMAL SHIELD SUB-ASSEMBLIES

1. Vacuum Vessel Thermal Shield (VVTS)

VVTS Toroidal Sectors (18 x 20°)

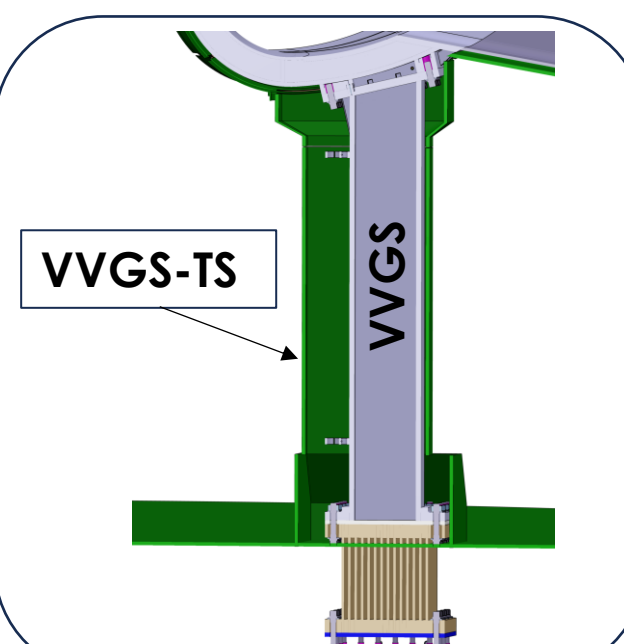
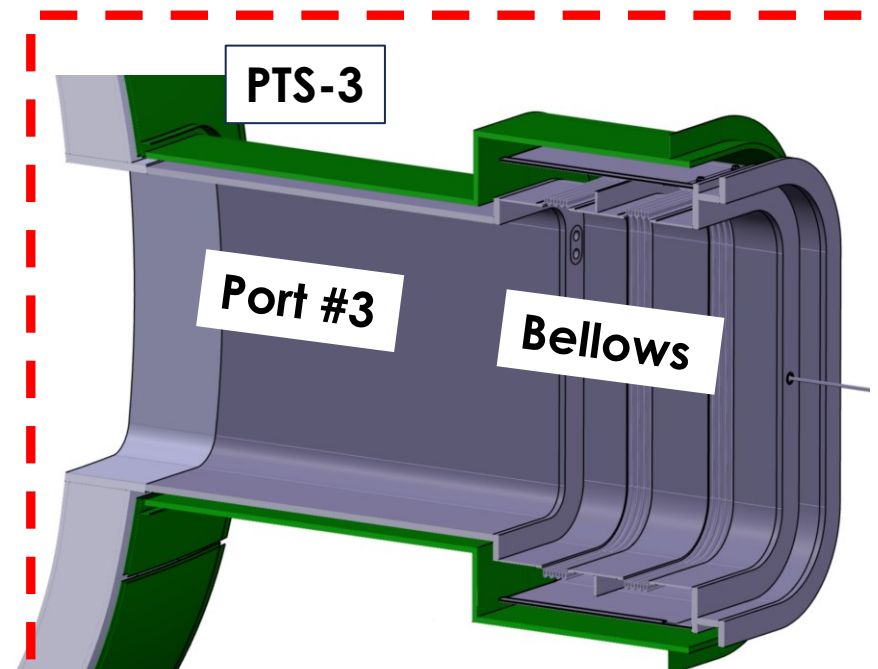
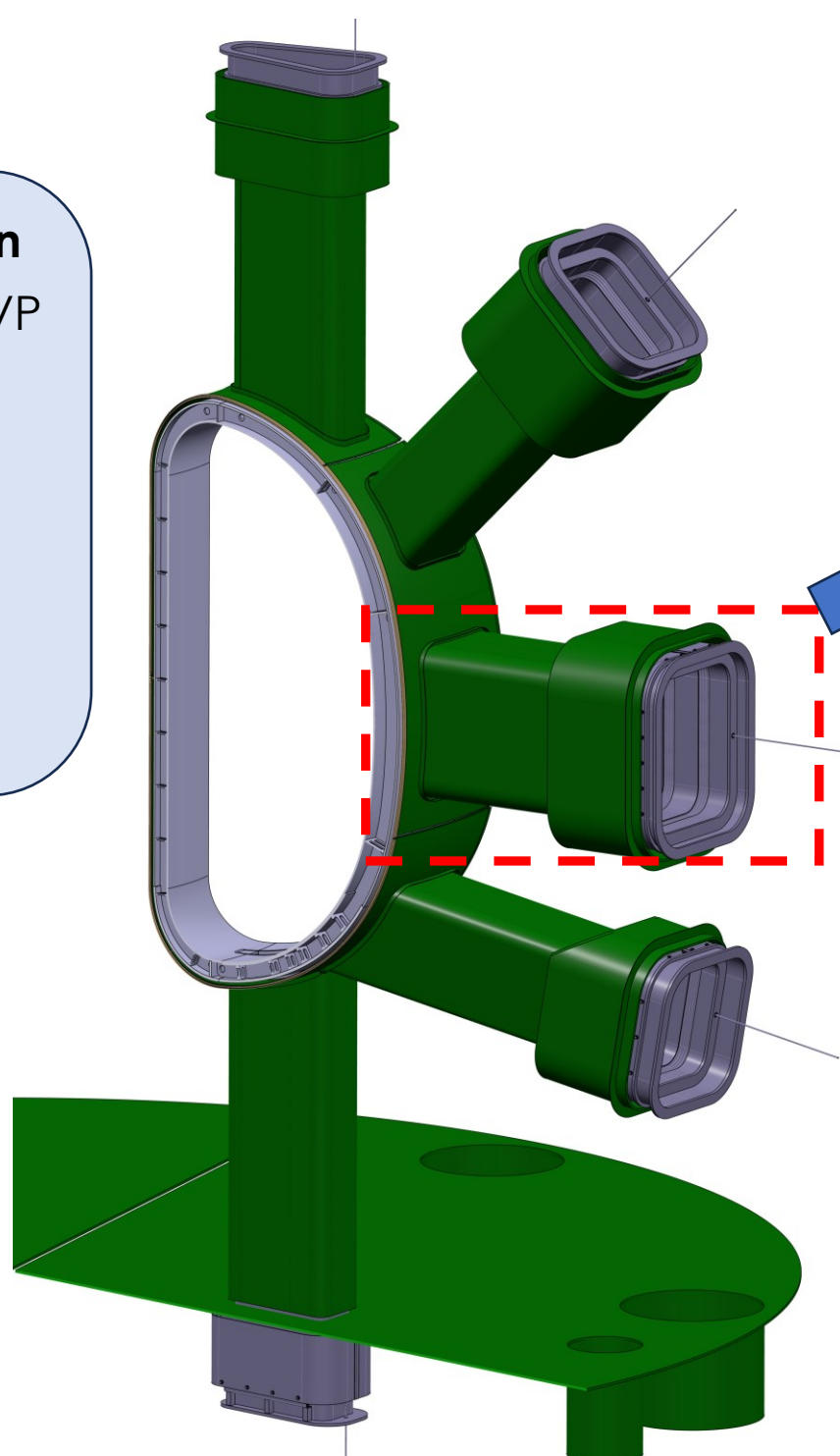


- Double panel configuration
- VVTS/PTS anchored to VVP outer surface



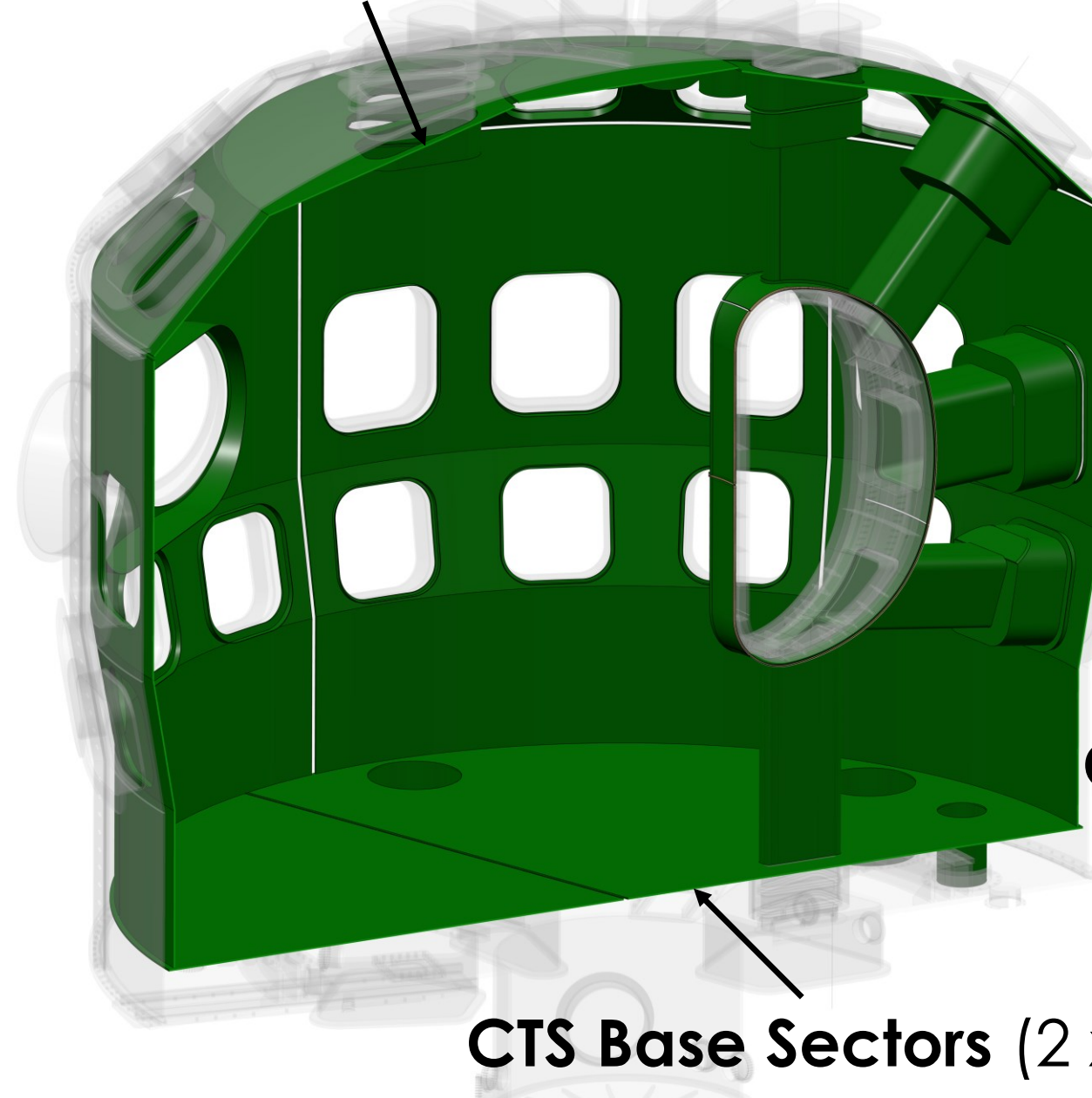
- 20°-module poloidally divided into 5 segments: 2 I.B. + 3 O.B. ;
- Xx Electrical insulation
- Modules made of a double panel structure actively cooled by a He(g) @ 80K circuit;
- VVTS anchored to the VV outer shell with Nut&Bolts (G10): acts as gravity supports

2. Port Thermal Shield (PTS): 82 PTS+6 VVGS-TS



3. Cryostat Thermal Shield (CTS)

CTS Dome Sectors (2 x 180°)



- Single panel conf. + MLI
- CTS anchored Cryostat inner surface

CTS Cylindrical Sectors (6 x 60°)

CTS Base Sectors (2 x 180°)

THERMO-MECHANICAL ANALYSIS OF VVTS

FEM ANALYSIS

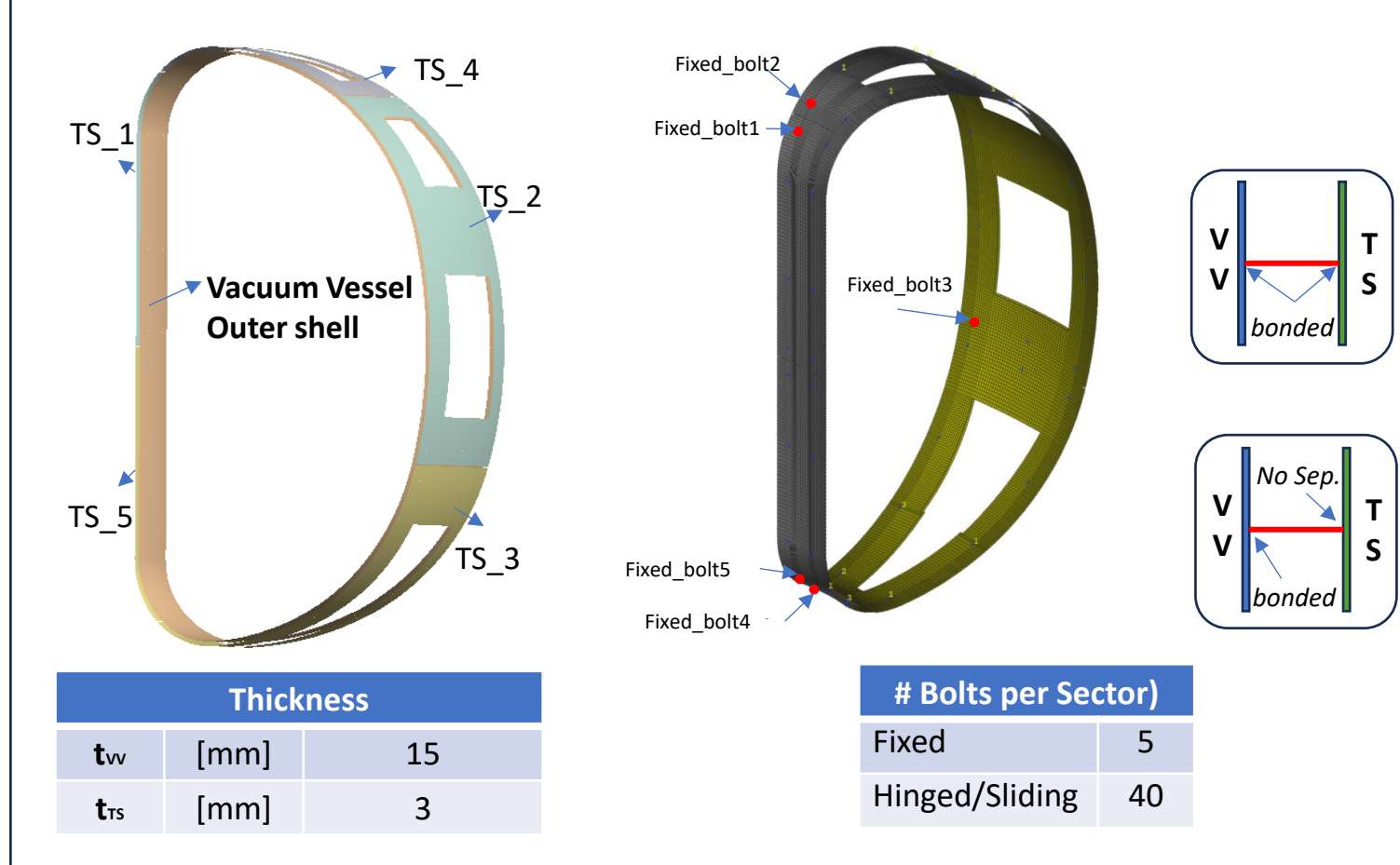
INTRODUCTION:

- VVTS panels are mechanically fastened to VV during assembling operation at room temperature (RT), while in operation:
 - TS is cooled down to -193°C (80 K) → **contraction**;
 - VV could reach a max. temperature of 200°C → **expansion**;
 - High stress are induced on TS panels, tubes and bolts.
- The following measures are introduced:
 - Slotted holes** for bolts are drilled in both toroidal and poloidal direction to permit sliding of TS panels;
 - Cooling tube provided with **Ω shaped (Expansion Loop)**;

FEM ANALYSIS OBJECTIVES:

- Evaluate deformation field of VV and VVTS subjected to thermal loads, in presence of piping;
- Assess the effect of TS contraction by considering different toroidal lengths of expansion Loop

GEOMETRY: 20° VV and VVTS (5 Segments) coupled with bolts



FINITE ELEMENT MODEL:

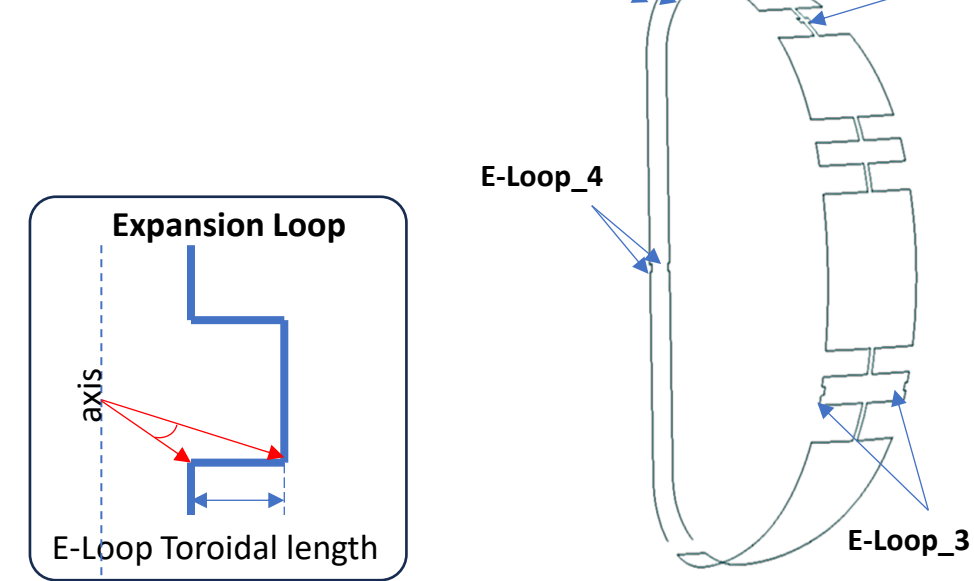
- Shell element for VV and VVTS;
- Beam elements for bolt and piping;
- Hinged Bolts modelled as "no separate contact"
- Cyclic condition applied to VV
- Material Thermo-mechanical properties function of temp.;

TEST MATRIX

- CASE-1: T_{VV} = 60°C, T_{TS} = -193°C
- CASE-2: T_{VV} = 200°C, T_{TS} = -193°C

CASE	Exp. Loop Length [mm]	Note
1.0	2.0	0 (no E-Loop)
1.1	2.1	50
1.2	2.2	75
1.3	2.3	90
2.4	50	2.1 + Fixed Bolt_2 on TS
2.5	50	2.1 with Fixed Bolt_5 on TS

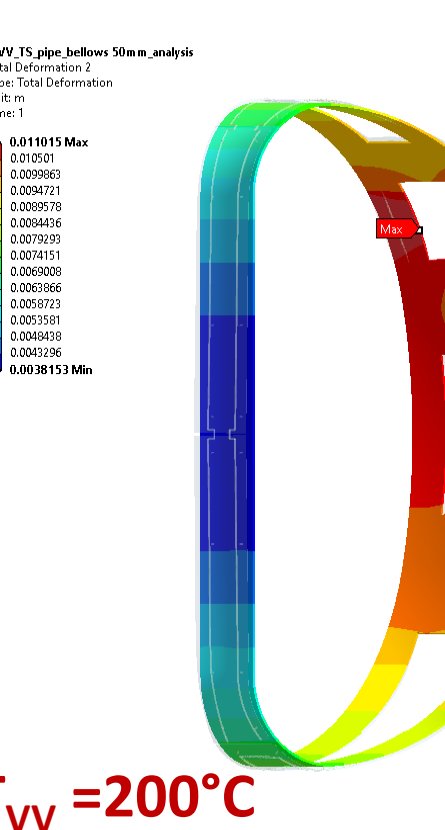
COOLING PIPE



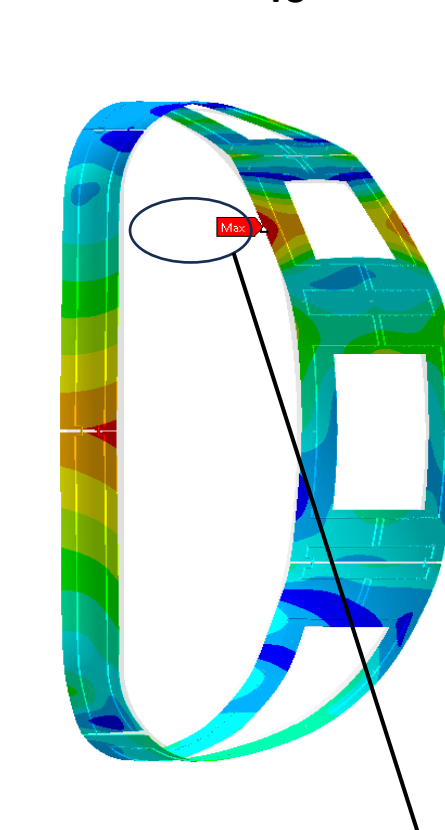
OUTCOMES

CASE-2.1 EXP-LOOP LENGTH. = 50 MM

Vacuum Vessel



VVTS T_{TS} = -193°C



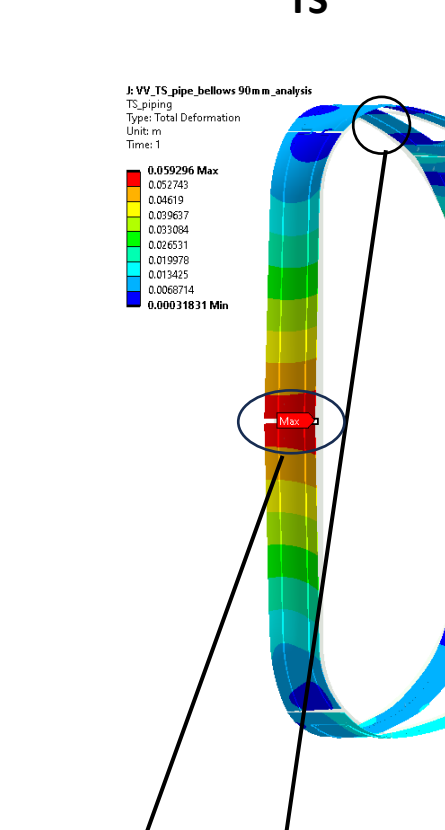
T_{VV}=200°C

Displacement	UoM	VV	O.B.
Max Global	[mm]	11	40
Radial	[mm]	10	-30
Tangential	[mm]	0	-1
Axial	[mm]	5	-26

- Presence of piping induces a complex deformation on TS with **bending effects on most of the panels** due to the higher stiffness of the piping and bolt connections;
- The highest displacement of TS towards the VV is for Case-2.1 (minimum Length of Exp. Loop);
- Bolts are significantly subjected to high stress.
- Varying the toroidal length of the Expansion Loop helps reducing bending effects, as well as reducing stress on the bolts.

CASE-2.3 LEN. = 90 MM

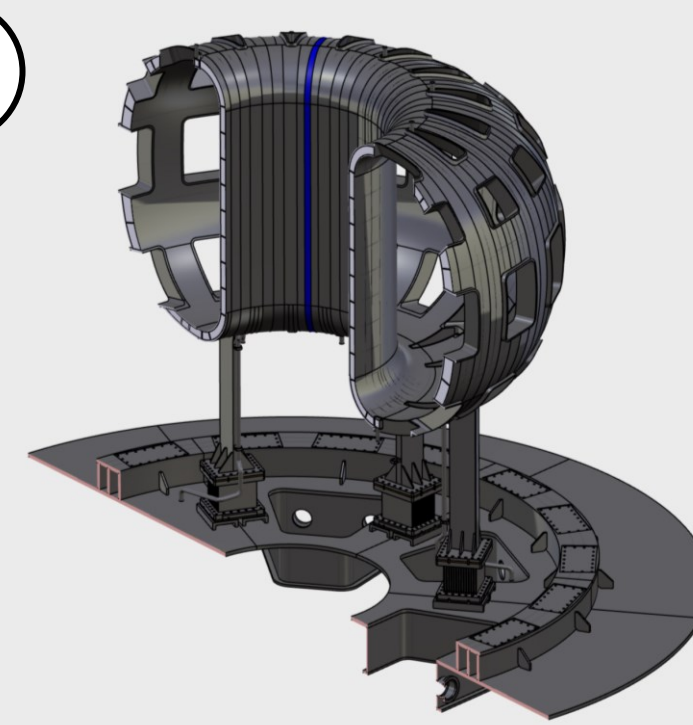
VVTS T_{TS} = -193°C



I.B.	O.B. (TS_4)	O.B. (TS_2)
59	13	24
3.6	-1	-16
59	1	4
4.3	-13	-17

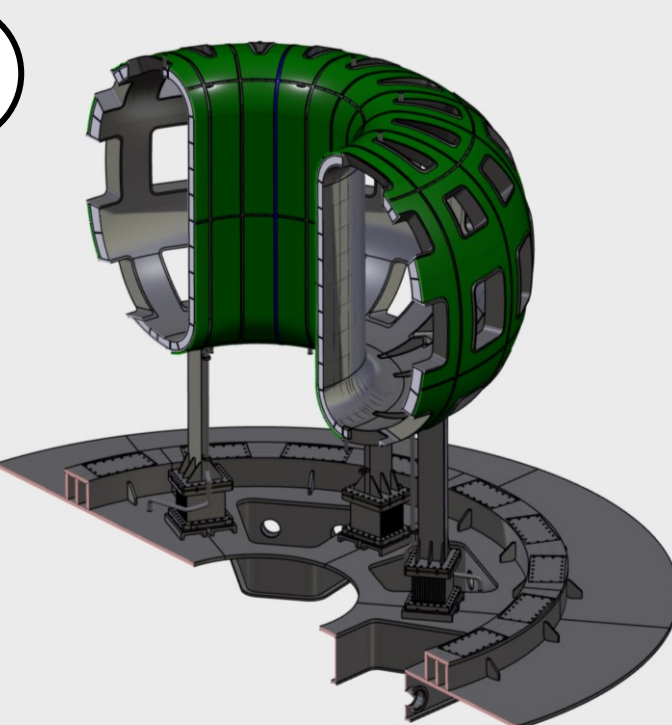
THERMAL SHIELD ASSEMBLING SEQUENCE

1



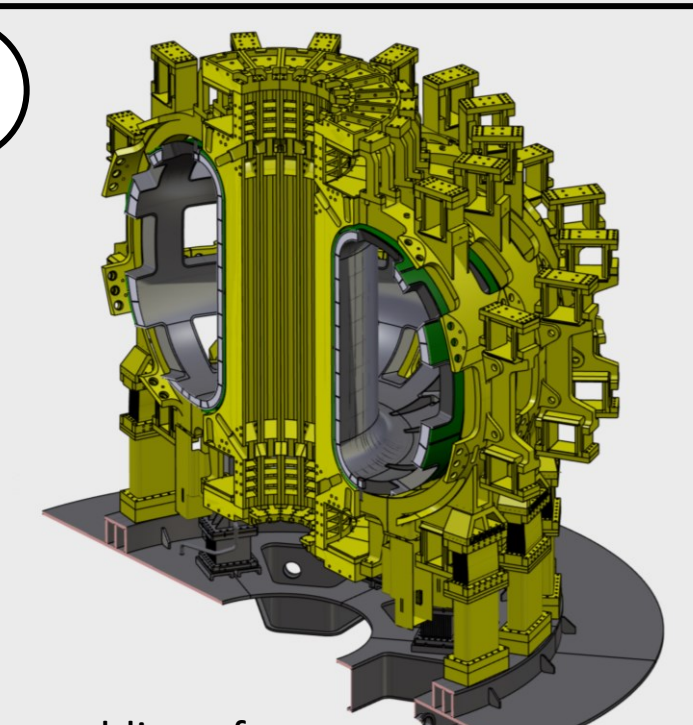
- Vacuum Vessel (340-deg.) positioned on cryostat base;

2



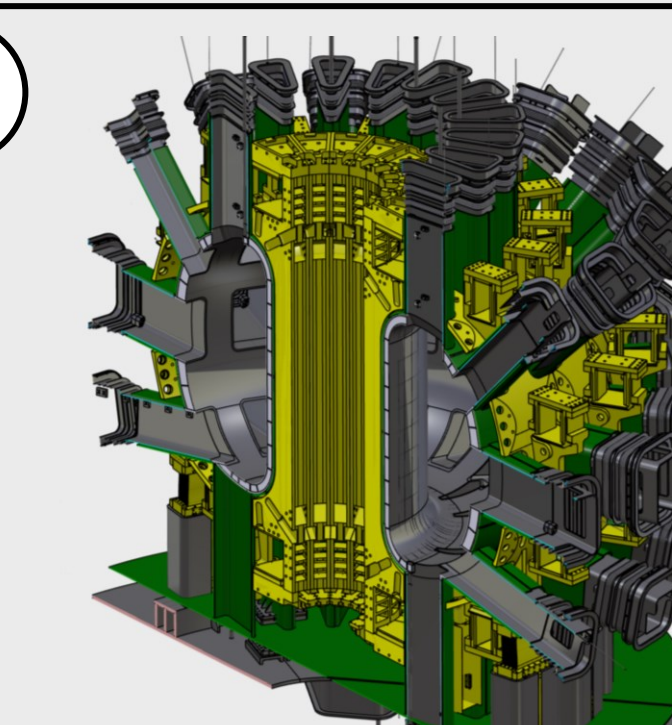
- 340-deg. VVTS installed on VV outer shell;

3



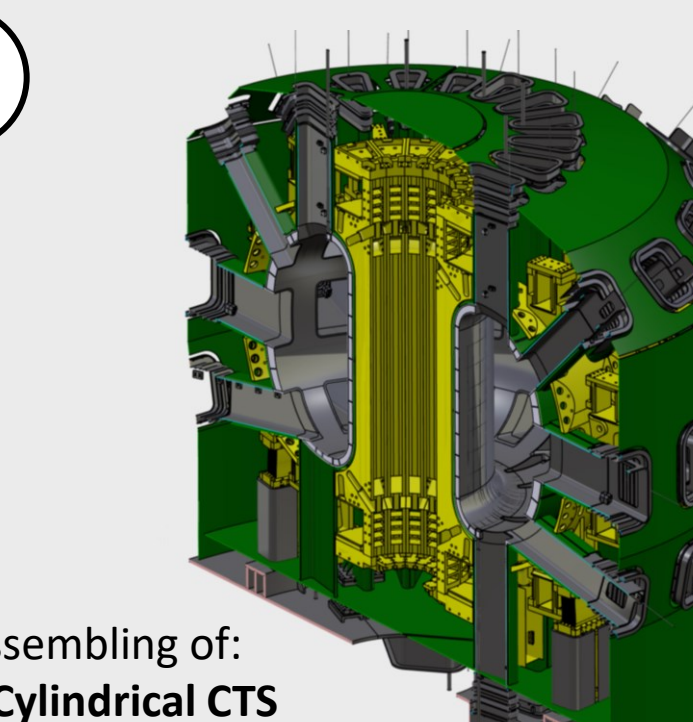
- Assembling of:
 - 17 out of 18 TF-Coils;
 - 20-deg. Final Sector (VV+TCF+VVTS);
 - Upper&lower PFC + CS;

4



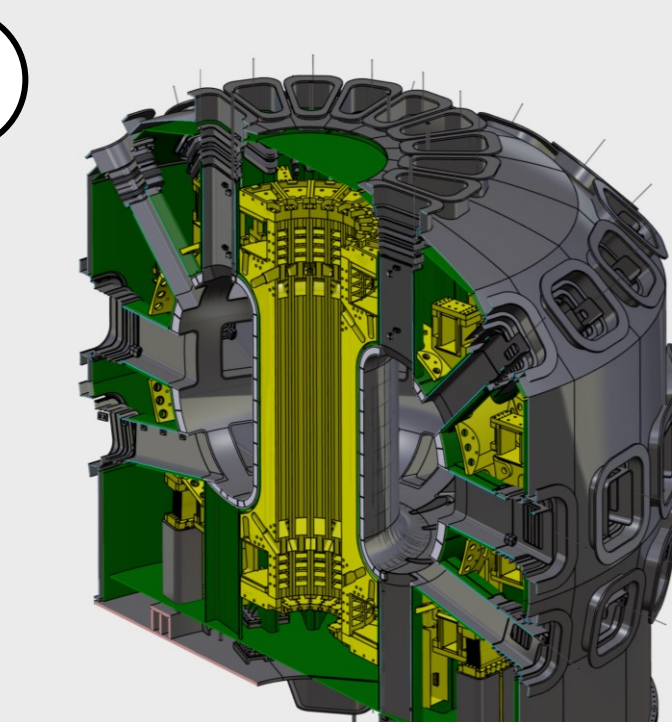
- Assembling of:
 - Ports + PTS (pre-assembled on ports);
 - Cryostat base CTS

5



- Assembling of:
 - Cylindrical CTS
 - Top lid CTS
- Actual Option: CTS pre-assembled on Cryostat structure;

6



- Assembling of:
 - Cryostat structure

MAIN MANUFACTURING REQUIREMENTS OF THS PANELS

Table 1.2 — Comparison of arithmetical mean deviation R_a and roughness grade numbers — (Table C.1 of ISO 1302:1992)

Roughness value R_a μm	Roughness grade numbers (given in the previous edition of ISO 1302)
50	N 2000
25	N 1000
12.5	N 500
6.3	N 250
3.2	N 125
1.6	N 63
0.8	N 32
0.4	N 16
0.2	N 8
0.1	N 4
0.05	N 2
0.025	N 1

JT-60SA like panels [https://doi.org/10.1016/j.fusengdes.2019.03.194]:

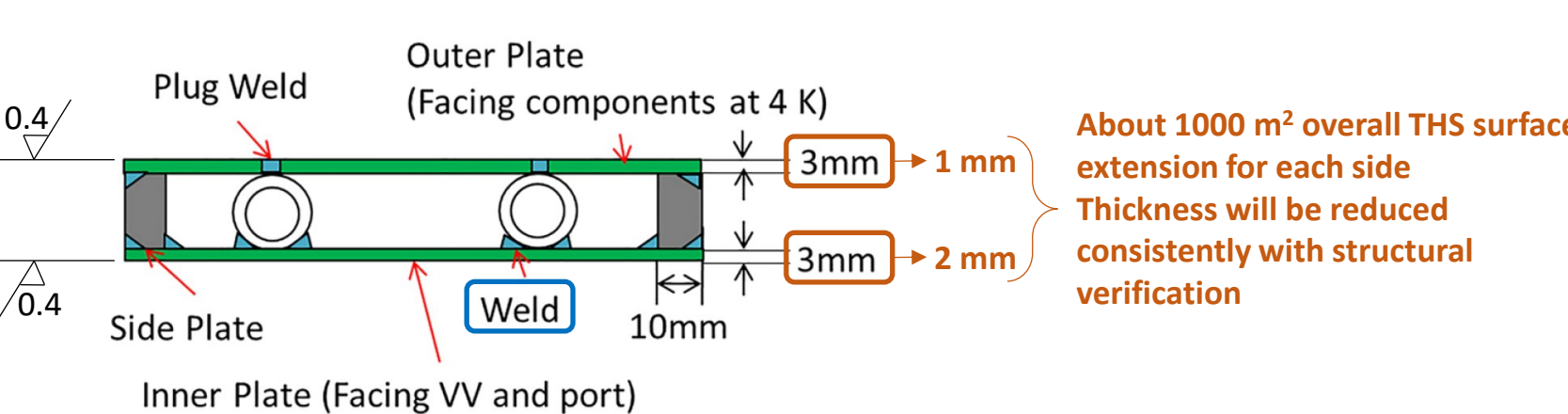
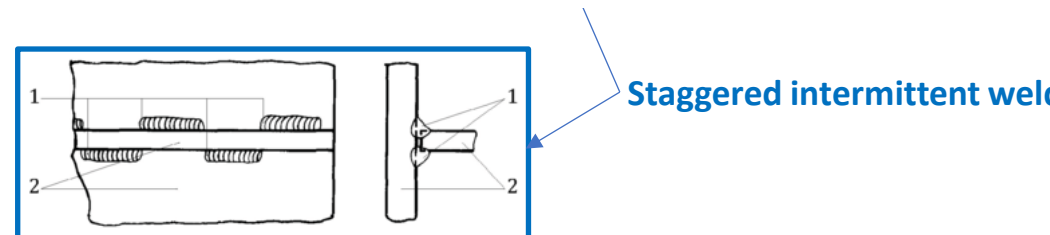


Fig. 3. Section view of double wall structure and cooling pipe in PTS and VVTS.



- Double wall configuration structure
- Tube outer diameter: **13.5 mm**, wall thickness: **2 mm** (in accordance with **ISO 4200** and **EN 10220**)
- External surfaces of plates shall be polished: **$R_a \leq 0.4 \mu m$**
- Cleaning requirements apply for vacuum compatibility
- Helium leak testing of the cooling circuit will be specified
- Use of emissivity meter (TSS-5X)
- Normal and hemispherical thermal emittance calculated from **ASTM E1585-93**

PERSPECTIVE AND FUTURE DEVELOPMENTS

- Refinement of mechanical FEM model:
 - Assess the hypothesis of **2 distinct VVTS cooling circuits** inboard and outboard circuit, → stress & bending reduction;
 - Consider the possibility of fixing one single bolt (fixed) on the TS side → reduction of bending effect and stresses on bolts is expected;
 - Model the presence of the holes on TS;
- Structural verification of THS panels, bolts and tubes against:
 - EM & Seismic Loads
- Assessment of fixed bolts preload;

For further details refer to Poster "Design of the thermal shield for the DTT facility" by R. Bonifetto