COMPASS
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Vacuum Vessel of the COMPASS-U tokamak

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This document is intended for the companies who shown interest in the Preliminary Market Consultation for COMPASS-U Vacuum Vessel system to initiate discussion have feedback on fabrication viability of the system.
It will provide very basic information about the system which is in the Design Phase.

Basic parameters of COMPASS-U

- The COMPASS-U will be a high magnetic field (5 T) medium-sized tokamak with high wall temperature (<500°C) operation.
- The scientific program is aimed to address topics of plasma exhaust, liquid metals, enhanced confinement modes and edge plasma physics.

Basic dimensions and parameters:

R = 0.894 m

a = 0.27 m

B_T = 5 T

I_p = 2 MA

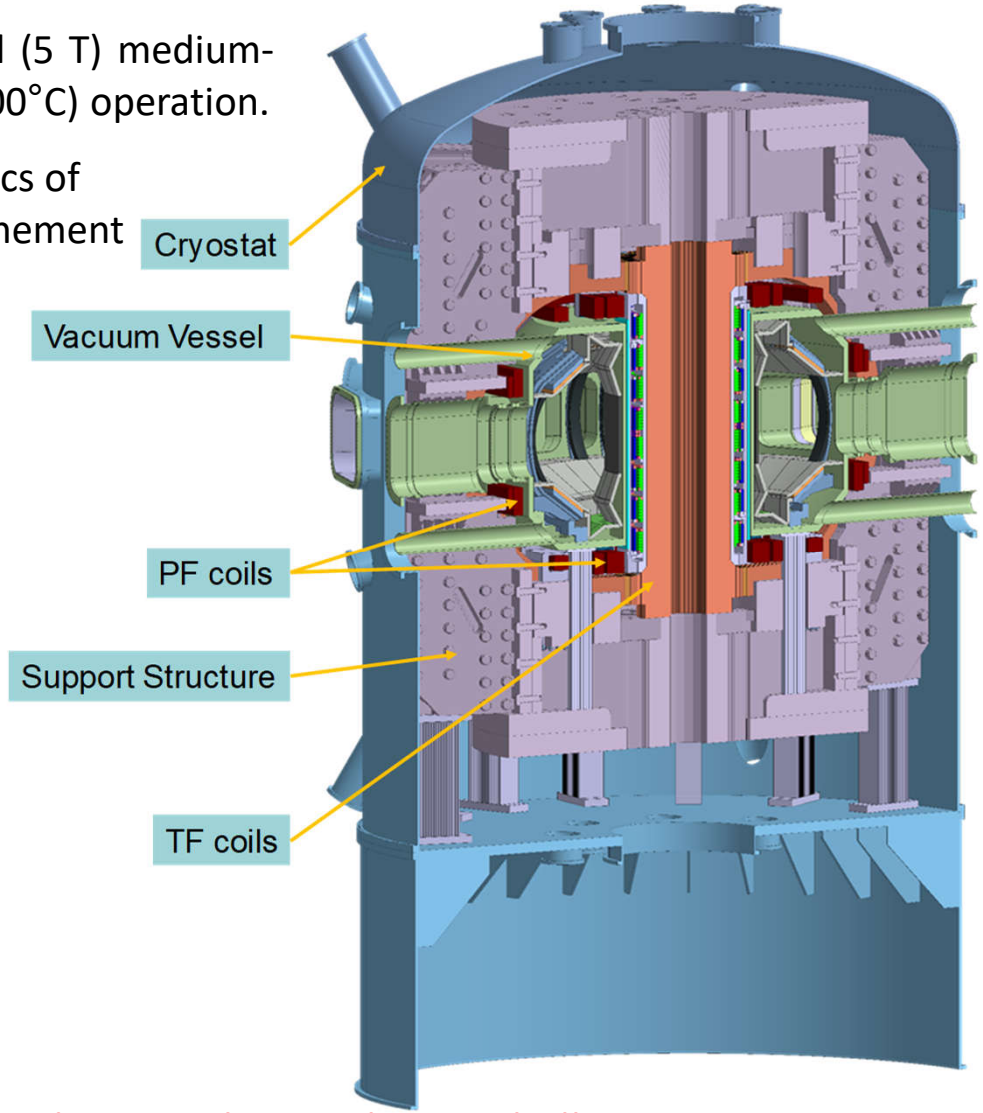
$t_{flat\text{-}top}$ ~ 2 s

δ = 0.5

κ = 1.8

V_{Plasma} ~ 2 m^3

T_{wall} ≤ 500 °C



High capability to address the key Plasma Exhaust Physics challenges

COMPASS-U Vacuum vessel- Requirements and Constraints:

➢ **Design Requirement**

- Provide high vacuum boundary for plasma experiments
- Provide access ports for external diagnostic systems, Heating and Current Drive systems and in-vessel components maintenance.
- Provide structural support for the in-vessel components e.g. PFC, divertor, passive stabilizing plates.
- Provide support to Multi-layer insulation thermal shield?
- Provide required toroidal electrical resistance to allow plasma break down.
- Provide Plasma vertical stability

➢ **Design constraints**

- Provide a reliable structural boundary for life time of the tokamak
  - It shall withstand all possible load combinations from external pressure, component weight, electromagnetic loads and seismic load.
- It should be compatible with high temperature (500 °C) operations.
- Material of VV should have high electrical resistance
- High toroidal electrical resistance to allow plasma break down
- It should remove decay heat by Passive/Active cooling system
- Geometrical space limitation with coils outside and PFC position inside
- Price
- Manufacturability

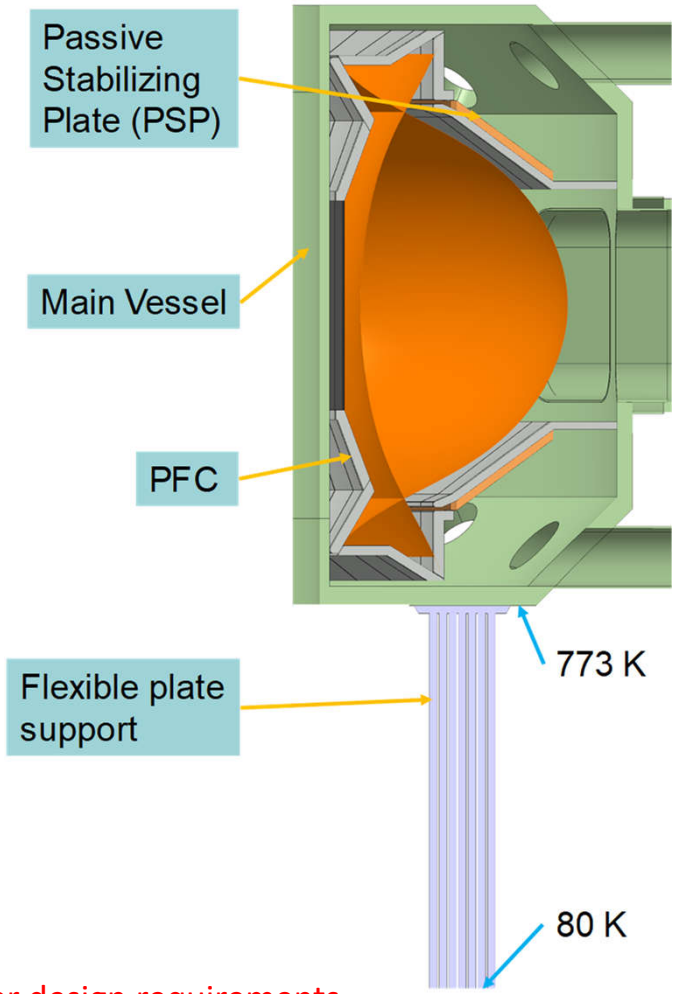
Choice of the material

Property	*Unit*	**Inconel 625**	**SS316L**	**Nitronic 50 (XM-19)**
Density	*(kg/m3)*	8440	7960	7880
Poisson's ratio		0.28	0.3	0.312
Melting Temp.	*°C*	1290	1375	1415
Electrical Resistivity	*Ω m*	**1.3E-06**	7.7E-07	8.2E-07
Specific heat	*J/kg K*	410	494	
Mechanical properties at room temperature (21 °C)				
Youngs modulus	*(GPa)*	207	195	199
Yield Strength	*(MPa)*	454	173	538
Tensile Strength	*(MPa)*	910	483	855
Coefficient of thermal expansion	*(µm/m/k)*	12.8	15.3	16.2
Thermal conductivity	*(W/m * K)*	9.8	14.18	15.6
Mechanical properties at cryo-temperature (300 °C)				
Youngs modulus	*(GPa)*	192	175	170
Yield Strength	*(MPa)*	**410**	109	372
Tensile Strength	*(MPa)*	866	387	676
Coefficient of thermal expansion	*(µm/m/k)*	13.3	17.64	17.3
Thermal conductivity	*(W/m * K)*	14.1	18.34	17.9
Mechanical properties at cryo-temperature (500 °C)				
Youngs modulus	*(GPa)*	180	160	
Yield Strength	*(MPa)*	**405**	94	331
Tensile Strength	*(MPa)*	827	363	614
Coefficient of thermal expansion	*(µm/m/k)*	14	18.54	18.4
Thermal conductivity	*(W/m * K)*	17	21.2	20.3

- **Price:** Inconel ~ 10x more expensive
- **Mechanical properties:** Inconel significantly better at high temperatures
- **Electrical conductivity:** Inconel about ~50% more resistive
- **Material activation:** Inconel ~4x more active than SS

COMPASS-U Vacuum vessel

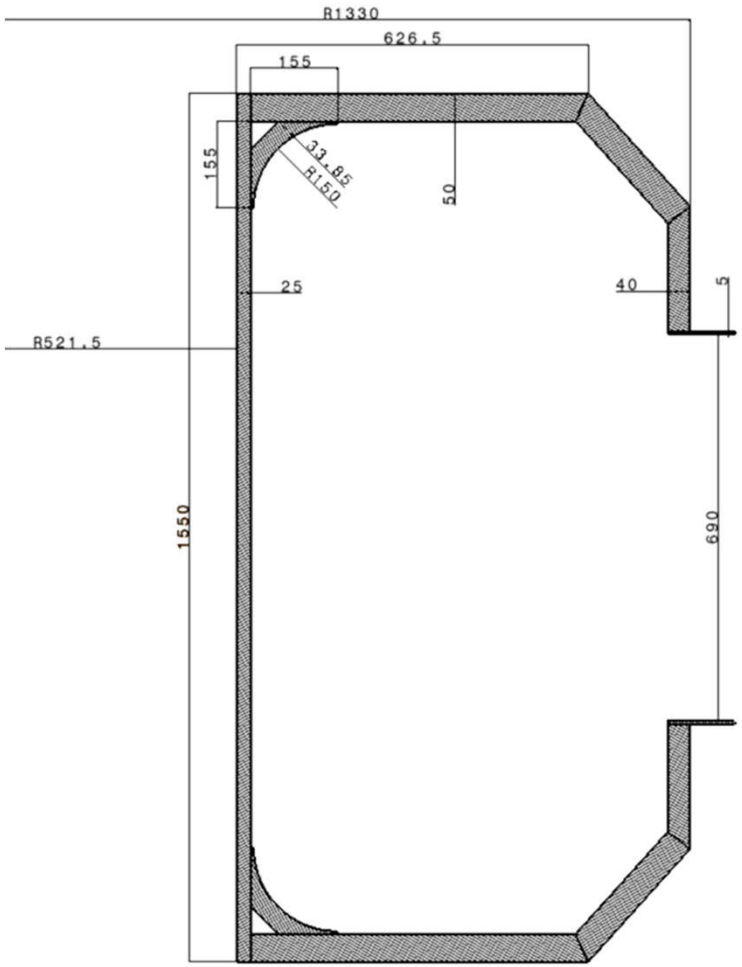
- The COMPASS-U Vacuum vessel system includes;
  - ✓ Main vessel,
  - ✓ Port extensions
  - ✓ Vacuum vessel support
- It has to provide first confinement barrier, a high quality vacuum, specific toroidal resistance a reliable structural boundary for the lifetime of the machine, and remove heat from in-vessel component.
- The vessel is 1.55 m in height, the inner radius of 0.52 m and the outer radius of 1.33 m. The thickness of the shell is varying from 25 to 50 mm for 1st iteration of design concept.
- The vessel is single wall structure with “D”-shaped cross-section and flat top and bottom.
  - ✓ The design kept simple to reduce the fabrication complexity and to lower cost
- VV will be vertically supported by Flexible plates support
  - ✓ To support about 11 MN vertical force against fast transient events
  - ✓ To accommodate movement during thermal expansion, 6.5 mm @ 500 °C @ Radius 0.89 m
  - ✓ 8 supports toroidally, each contains 7 flexible plates, 100x20 mm c/s, 1.24 m length

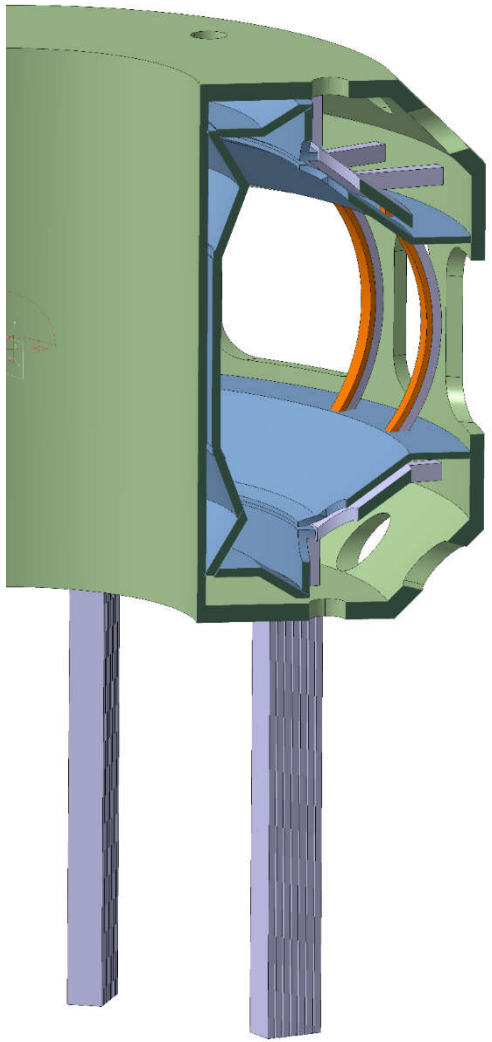


Vacuum vessel system are under design process and can be modified later as per design requirements

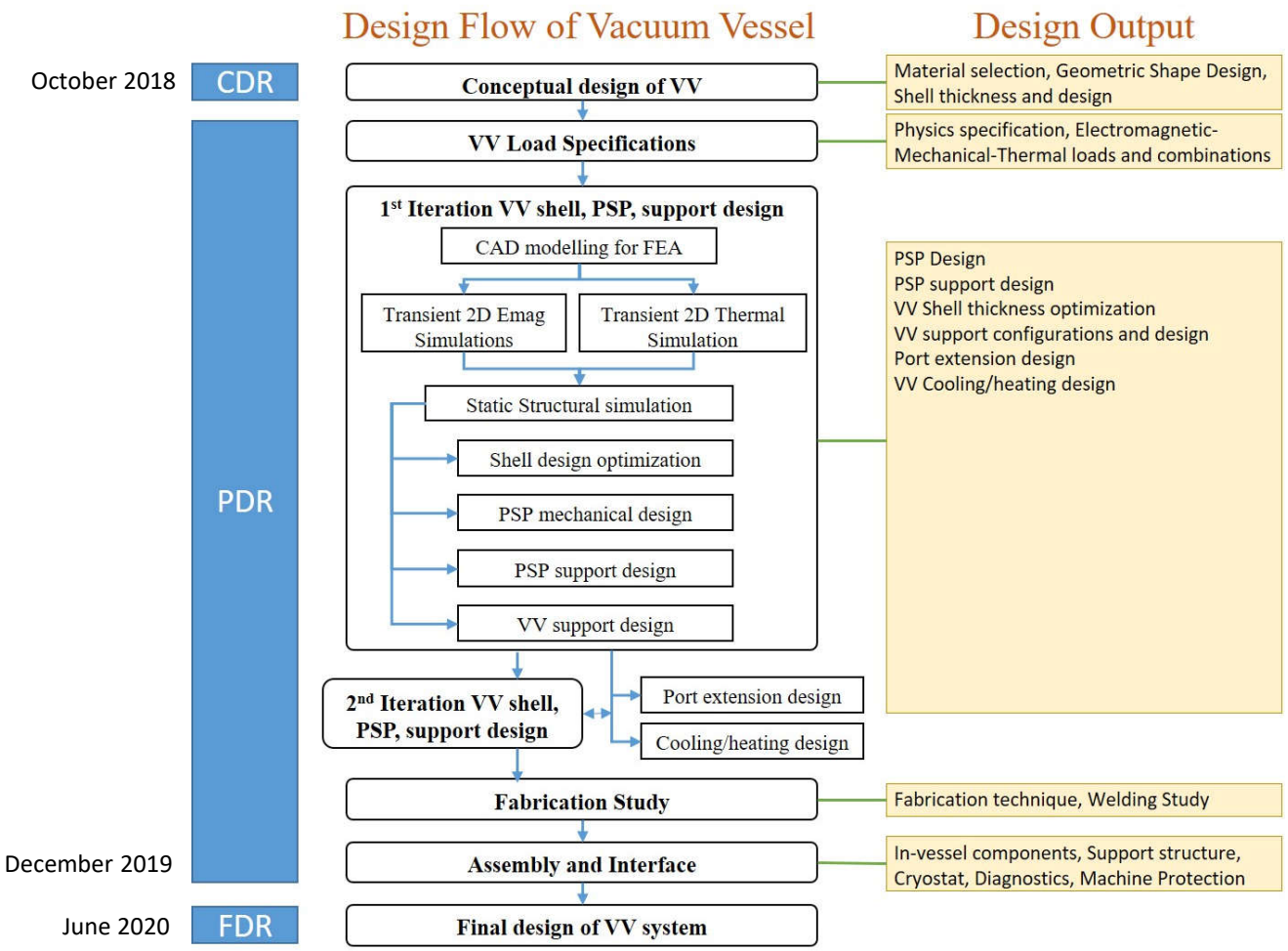
Present design of Vacuum Vessel

Main VV parameters	
Mechanical parameters	
Surface	23.6 m^2
Volume	6.0 m^3
Material	Inconel 625
Mass	8 tons
Shell thicknesss	25 – 50 mm
Rib thickness	20 mm
Operating temperature	300 – 500 °C
Electrical parameters	
Toroidal	
• resistance	45.3 μΩ
• inductance	0.61 μH
• time constant	13.4 ms
Poloidal	
• resistance	36.9 μΩ
• inductance	0.25 μH
• time constant	6.8 ms





Design flow of Vacuum Vessel



- The vacuum vessel is based on high normal and off-normal electromagnetic forces and thermal loads.
- Tight spatial constraints are applicable on total shell thickness and maximum outer dimensions of VV design

Queries

- What are the possible options for the fabrication of 1st iteration of vacuum vessel design
- Possibility of forming of 50mm thick Inconel 625 plate, Ribs or Formed corners?
- Fabrication challenges with Inconel 625 comparison with other materials
- Confirmation on material properties of Inconel 625 at 500 °C
- Weldability of Inconel 625, challenges and precautions required, Post weld treatments or limitations
- Weld efficiency of materials and joints
- Costing effect: Forming, Bending, Machining, welding
- Possible options for vessel cooling considering fabrications: cooling pipe, half pipe or Dimple jacket