# DTT Vacuum Vessel

Mauro Dalla Palma
on behalf of DTT Team

Industrial Liaison Officers (ILO) Network Italia

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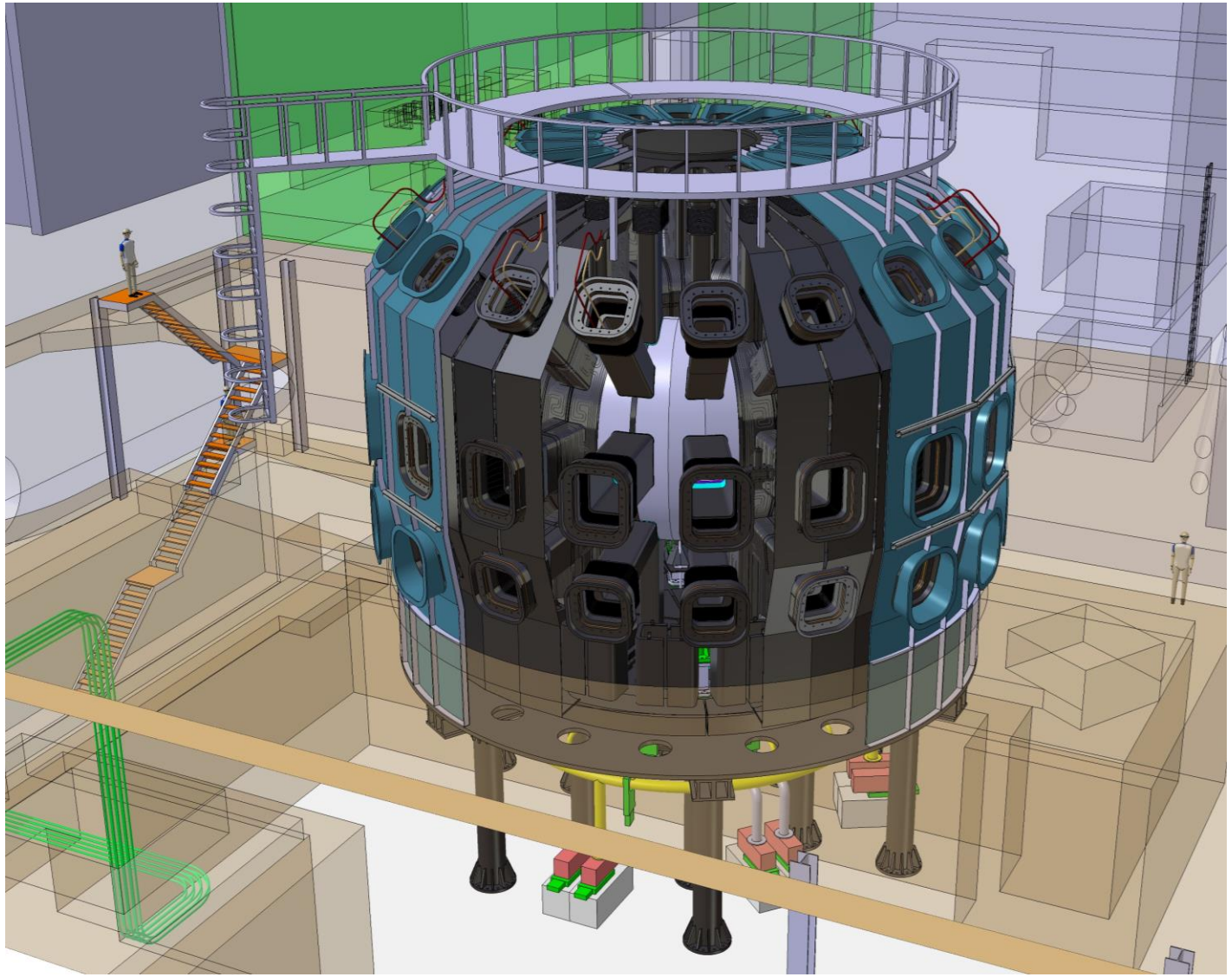
Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Capodimonte (Napoli)

# Components and Systems

Vessel and Out Vessel components of the DTT tokamak:

- Cryostat Structure (CRS)
- Thermal Shield (THS)
- Vacuum Vessel and Ports Project (VVP)
- Tokamak Auxiliary Systems:
  - Vacuum Pumping System (VPS)
  - Fueling Control Systems (FCS)
  - Machine Cleaning (CLS)



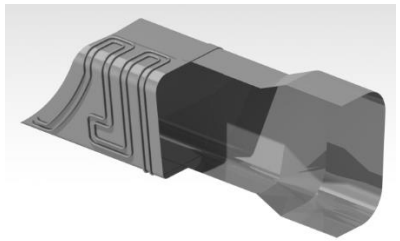
# Cryostat Structure (CRS)

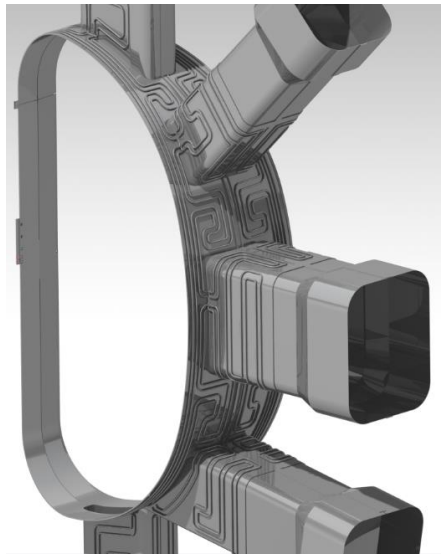
- CRS parts: cylindrical body, top lid, base with central pit and manhole
- Status of CRS parameters is conceptual and they will be revised and confirmed during EDA

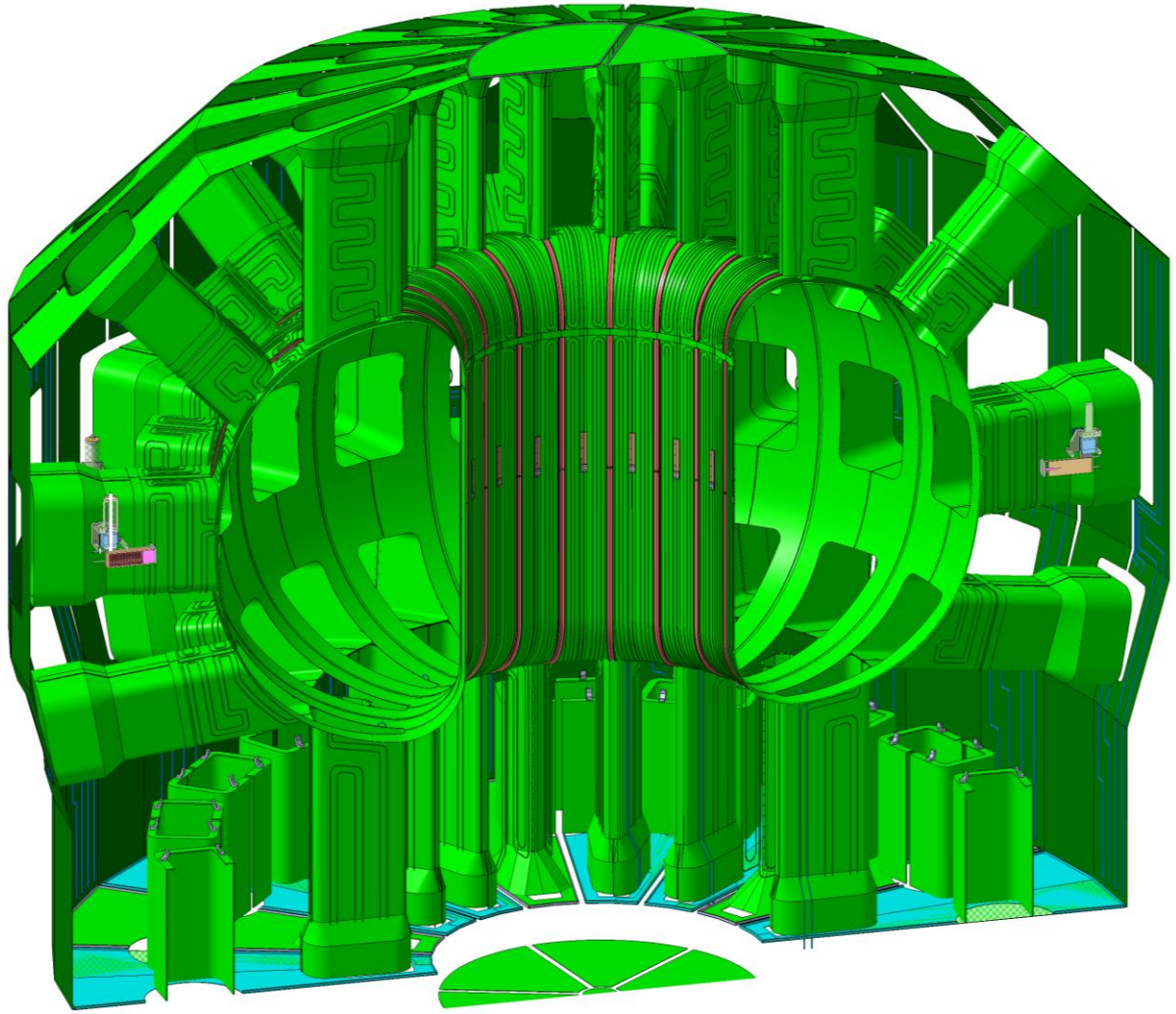
| Parameter | Units | Value |
|---|---|---|
| Major diameter at equatorial section | [m] | 11.2 |
| Diameter at top plate basement level | [m] | 10.8 |
| Maximum height including basement | [m] | 11 |
| Basement Height | [m] | 2.3 |
| Maximum height of top lid | [m] | 1.3 |
| Structural Material | -- | 304LN - Co<0.05 wt% |
| Operational pressure Vacuum | [Pa] | $10^{-4}$ - $10^{-3}$ |
| Thickness of the Cryostat walls | [mm] | 30 |
| Thickness of the external ribs | [mm] | 25 |
| Manufacturing tolerances | [mm] | ±5 - ±10 |
| Estimated Mass of CRS cylindrical body | [tons] | 66 |
| Estimated Mass of CRS top lid | [tons] | 16 |
| Estimated Mass of CRS basement | [tons] | 200 |
| Number of ports interfaced with the vacuum vessel | -- | 82 |

# Thermal Shield (THS) - 1

THS parts: Vacuum Vessel Thermal Shield (VVTS), Ports Thermal Shield (PTS), Cryostat Thermal Shield (CTS)







# Thermal Shield (THS) - 2

THS main characteristics:

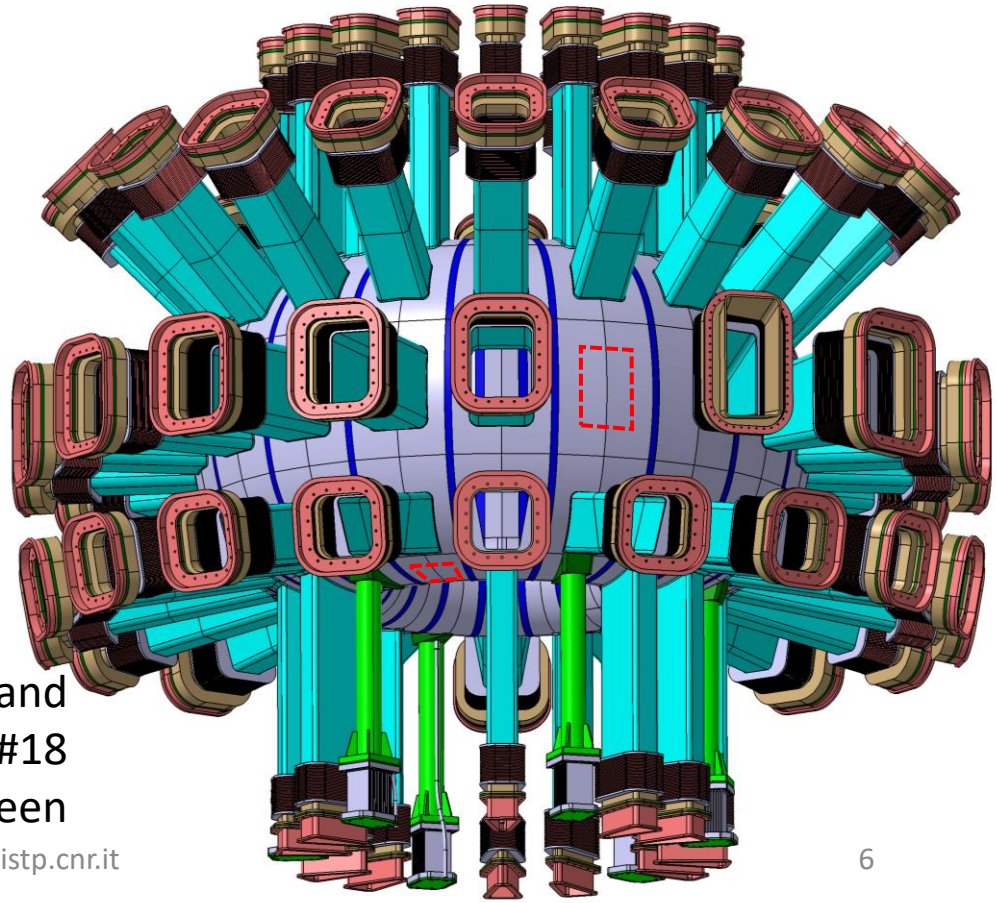
- Tube-on-panel configuration (single wall)
- Silver plating
- Independent cooling loop for each toroidal sector
- Toroidal and poloidal electrical isolation

| Parameter | Unit | Value |
|---|---|---|
| Surface areas of VVTS | $m^2$ | 105 |
| Surface area of PTS | $m^2$ | 560 |
| Surface area of CTS | $m^2$ | 310 |
| Panel thickness | mm | 20 |
| Total weight | kg | $60 \cdot 10^3$ (panels + frames + tubes) |
| Coolant | - | Gaseous Helium |
| Number of parallel cooling lines | | 36 with 100% redundancy (total of 72) |
| Cooling tube outer diameter | mm | 13.5 / 17.2 |
| THS Vacuum environment | Pa | $10^{-4}$ - $10^{-3}$ |
| Material | - | 316LN (VVTS, PTS), 316LN or 304LN (CTS), G-10 |
| Manufacturing tolerance | - | ±5 mm (VVTS), ±10 mm (PTS and CTS) |

# Vacuum Vessel technical description - 1

DTT Vacuum Vessel (VV) functions and characteristics:

- first boundary of the plasma
- toroidal configuration with double wall D-shaped poloidal cross section
- double wall structure with inter-shell filled with water during plasma operation and with nitrogen during baking
- division in 17 sectors
- inclusion of 82 ports located:
  - every 20° in the toroidal direction
  - in 5 poloidal positions enumerated from the top, port #1, to the bottom, port #5
- inclusion of 6 gravity supports with spring plates
- smooth inner shell: field welding (on site) of supports of the in-vessel components

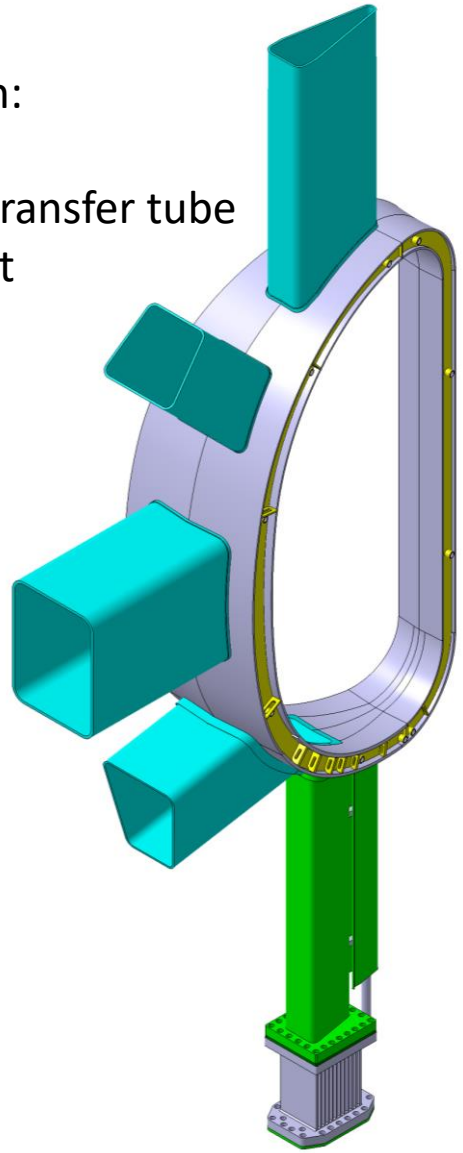


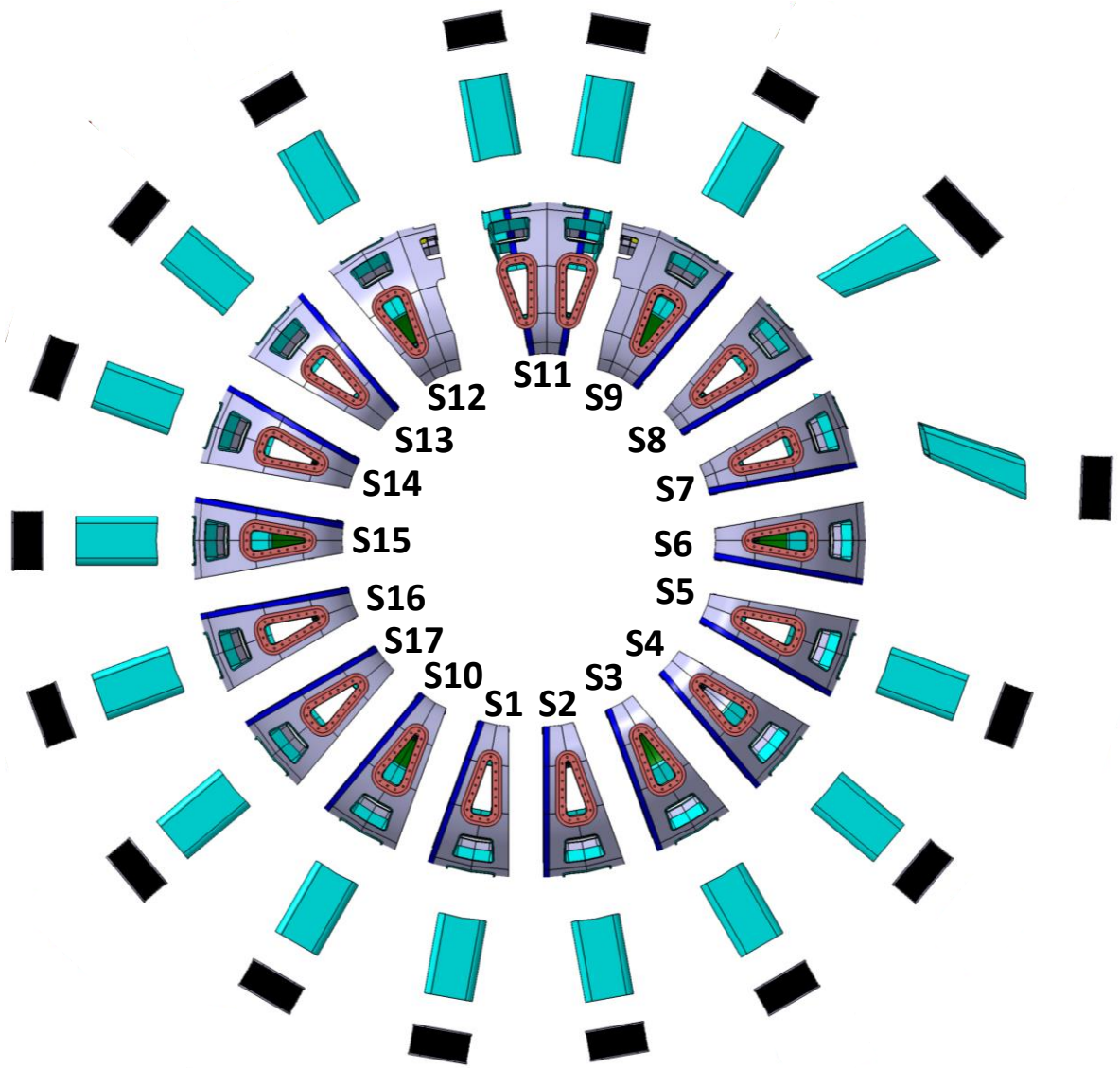
port #3 of toroidal position #6 and
ports #5 of toroidal positions #3, #4, #6, #9, #12, #15, #18
are not foreseen

# Vacuum Vessel technical description - 2

Vessel sector with:

- ports
- primary heat transfer tube
- gravity support
- spring plates





# Vacuum Vessel main parameters

| Parameter | Unit | Value |
|---|---|---|
| Shell thickness (inboard) | [mm] | 15 |
| Shell thickness (outboard) | [mm] | 15 |
| Distance between shells (inboard) | [mm] | 90 |
| Distance between shells (outboard) | [mm] | 200 |
| Ports thickness | [mm] | 10-20 |
| Material | -- | 316LN - Co<0.05 wt% |
| Thickness of inter-shell ribs | [mm] | 10-20 |
| Torus outboard diameter | [mm] | 6900 |
| Torus inboard diameter | [mm] | 2530 |
| Weight | [ton] | 40 (main vessel body)<br>80 |
| Torus height | [mm] | 3910 |
| Inter-shell volume | [$m^3$] | 13.5 |
| Volume of the VV - plasma side | [$m^3$] | 75 |
| External surface of the vacuum vessel (holes subtracted) | [$m^2$] | 112 |

# Technical specification structure

Technical specification main document

General provisions, Quality mgmt., Interfaces

| Annex A | Annex B | Annex C | Annex D | Annex E | Annex F |
|---|---|---|---|---|---|
| Prototype sector | Vacuum Vessel | Expansion Joints | Machine Sensors | Internal Jig | Transportation & Rotation Tool |

Advantages of this structure: No requirements mixing

Clear work package definitions

Easy work breakdown build up

Useful if subcontracting is used

Simpler requirements management

# Procurement deliverables

Hardware deliverables:

- Prototype sector
- Vacuum Vessel sectors including:
  - vessel ports
  - gravity supports
  - machine sensors
- Splice plates:
  field welding (on site) for sector integration thus providing structural
  continuity and forming the vacuum boundary
- Expansion joints (82 flanged bellows)
- Internal Jig to be used for sector handling and integration
- Transportation & Rotation Tool

Documentation, logistic, and assistance deliverables:

- Manufacturing Readiness Review
- Risk Register
- Qualification File
- Intermediate dimensional inspection using 3D metrology (laser tracker/ photogrammetry) integrated with manufacturing
- Manufacturing File with Drawings
- FAT (Plan and Report)
- Packing, Transport and Delivery
- SAT (Plan and Report)
- Operation and Maintenance Manual
- As built drawings and 3D CAD
- Welding Book including distortion management (Plan and Report)
- EU declaration of conformity
- Assistance in the first phase of on site assembly

# Design and Fabrication

- The vessel shall be manufactured consistently with the Codes and Standards requirements applying the design basis and loading conditions
- Code:
  - ASME Boiler and Pressure Code (BPVC), Section VIII, Division 2 apply to the DTT vacuum vessel
  - Design, Service, and Test Limits are defined in “NCA-2142.4 Design, Service, and Test Limits” of BPVC Section III, Subsection NCA (limits are shared with Section VIII)
- Procurement shall comply with the regulation of the Pressure Equipment Directive (PED)
- Classification: The DTT vacuum vessel fall within PED category III
- The VV manufacturer shall assume responsibility for the compliance of the pressure equipment with the requirements laid down in the PED and shall release the EU declaration of conformity stating that the fulfilment of essential safety requirements set out in Annex I of PED has been demonstrated

# Dimensional tolerances

Mandatory tolerances for construction:

1. General tolerances for machined products: class mK of ISO 2768-1 and ISO 2768-2

**Table 1 — Permissible deviations for linear dimensions except for broken edges**
(external radii and chamfer heights, see Table 2)

Values in millimetres

| Tolerance class | | Permissible deviations for basic size range | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Designation | Description | 0,5[a] up to 3 | over 3 up to 6 | over 6 up to 30 | over 30 up to 120 | over 120 up to 400 | over 400 up to 1 000 | over 1 000 up to 2 000 | over 2 000 up to 4 000 |
| f | fine | ± 0,05 | ± 0,05 | ± 0,1 | ± 0,15 | ± 0,2 | ± 0,3 | ± 0,5 | — |
| m | medium | ± 0,1 | ± 0,1 | ± 0,2 | ± 0,3 | ± 0,5 | ± 0,8 | ± 1,2 | ± 2 |
| c | coarse | ± 0,2 | ± 0,3 | ± 0,5 | ± 0,8 | ± 1,2 | ± 2 | ± 3 | ± 4 |
| v | very coarse | — | ± 0,5 | ± 1 | ± 1,5 | ± 2,5 | ± 4 | ± 6 | ± 8 |
| [a]For nominal sizes below 0,5 mm, the deviations shall be indicated adjacent to the relevant nominal size(s). | | | | | | | | | |

**Table 1 — General tolerances on straightness and flatness**

Values in millimetres

| Tolerance class | Straightness and flatness tolerances for ranges of nominal lengths | | | | | |
|---|---|---|---|---|---|---|
| | up to 10 | over 10 up to 30 | over 30 up to 100 | over 100 up to 300 | over 300 up to 1 000 | over 1 000 up to 3 000 |
| H | 0,02 | 0,05 | 0,1 | 0,2 | 0,3 | 0,4 |
| K | 0,05 | 0,1 | 0,2 | 0,4 | 0,6 | 0,8 |
| L | 0,1 | 0,2 | 0,4 | 0,8 | 1,2 | 1,6 |

2. General tolerances for welded constructions, class BF in accordance with EN ISO 13920

**Table 1 — Tolerances for linear dimensions**

| Tolerance class | Range of nominal sizes l in mm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 to 30 | Over 30 up to 120 | Over 120 up to 400 | Over 400 up to 1 000 | Over 1 000 up to 2 000 | Over 2 000 up to 4 000 | Over 4 000 up to 8 000 | Over 8 000 up to 12 000 | Over 12 000 up to 16 000 | Over 16 000 up to 20 000 | Over 20 000 |
| | Tolerances t in mm | | | | | | | | | | |
| A | ± 1 | ± 1 | ± 1 | ± 2 | ± 3 | ± 4 | ± 5 | ± 6 | ± 7 | ± 8 | ± 9 |
| B | | ± 2 | ± 2 | ± 3 | ± 4 | ± 6 | ± 8 | ± 10 | ± 12 | ± 14 | ± 16 |
| C | | ± 3 | ± 4 | ± 6 | ± 8 | ± 11 | ± 14 | ± 18 | ± 21 | ± 24 | ± 27 |
| D | | ± 4 | ± 7 | ± 9 | ± 12 | ± 16 | ± 21 | ± 27 | ± 32 | ± 36 | ± 40 |

**Table 3 — Straightness, flatness and parallelism tolerances**

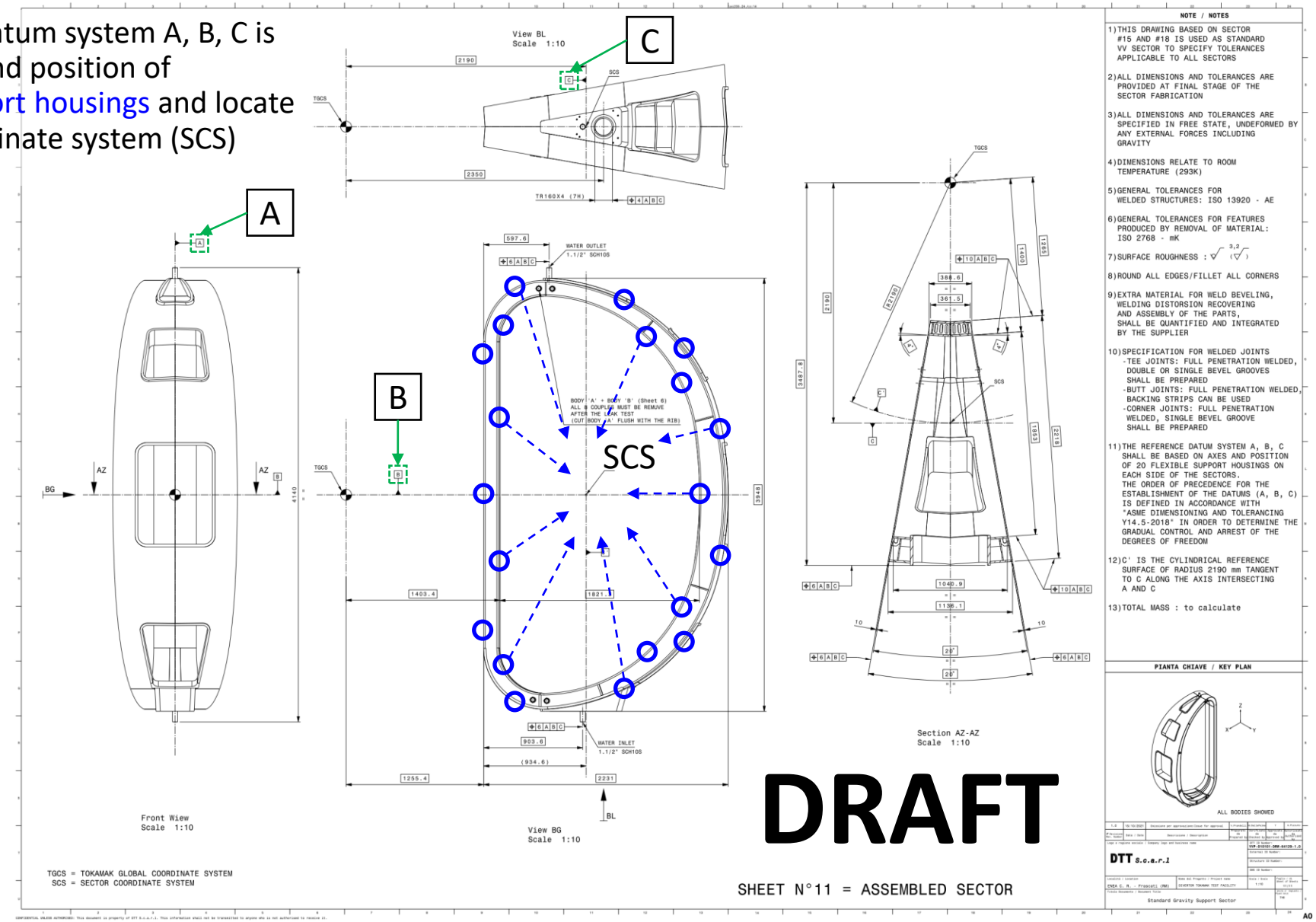
| Tolerance class | Range of nominal sizes l in mm (relates to longer side of the surface) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Over 30 up to 120 | Over 120 up to 400 | Over 400 up to 1 000 | Over 1 000 up to 2 000 | Over 2 000 up to 4 000 | Over 4 000 up to 8 000 | Over 8 000 up to 12 000 | Over 12 000 up to 16 000 | Over 16 000 up to 20 000 | Over 20 000 |
| | Tolerances t in mm | | | | | | | | | |
| E | 0,5 | 1 | 1,5 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| F | 1 | 1,5 | 3 | 4,5 | 6 | 8 | 10 | 12 | 14 | 16 |
| G | 1,5 | 3 | 5,5 | 9 | 11 | 16 | 20 | 22 | 25 | 25 |
| H | 2,5 | 5 | 9 | 14 | 18 | 26 | 32 | 36 | 40 | 40 |

Inner shell overall dimensions and tolerance for **main body: 1800-3700 mm** → **± 5 mm**

**sector assy: 3400-8400 mm** → **± 10 mm**

# Technical specification drawings of DTT vessel sectors

The reference datum system A, B, C is based on axes and position of 20 flexible support housings and locate the sector coordinate system (SCS)



# Prototype sector - 1

One prototype sector used for **qualification of processes during the procurement for manufacturing production sectors**:

- sector lifting using the internal jig
- welding procedures (TIG on UHV side welded first, MIG on non-UHV side)
- weld repairs
- sequence of welds to minimize weld distortions on shells and ports
- measurement of post welding distortions (same tolerances of production sectors)

} Weld distortion management required to the manufacturer before fabrication can commence

- verification of accesses for weld execution and testing
- integration of port stubs and alignment of port ducts
- Non Destructive Testing, in particular helium leak testing and UT of welded joints.

Moreover, the prototype sector will be delivered for **qualification of processes on site**:

- integration of ports and bellows
- testing of automated welding processes
- frequency of intermediate dimensional tests for dimensional control
- integration of divertor and first wall supports.

# Prototype sector - 2

Welding procedures: TIG, MIG

Base material:

Standard 316LN (without limitation in the cobalt content) is specified for the protype sector (classified as austenitic stainless steels with Cr ≤ 19%, P-number.group number = 8.1) [Table QW/QB-422 of ASME BPVC.IX and ISO 15608].

Filler metal:

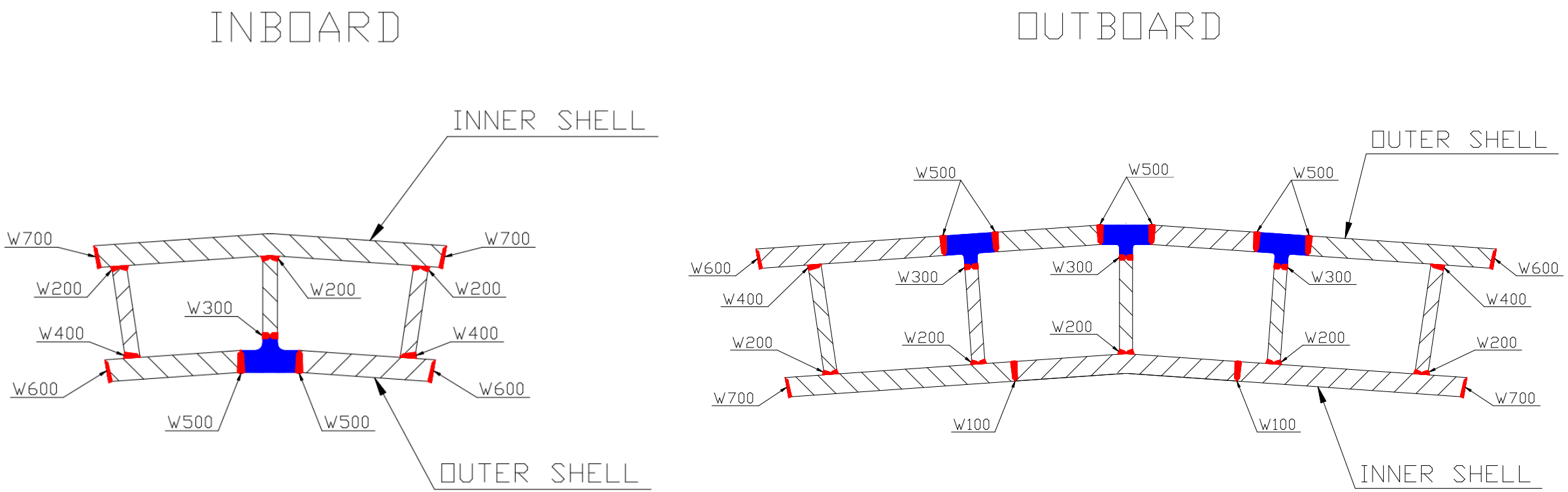
- Bare electrodes or rods of ER316LMn, nonmagnetic and with high Mn-content to stabilize the austenitic microstructure and to aid in hot cracking (classified AWS 5.9 Class ER316LMn, ASME SFA 5.9 Class ER316LMn, UNS S31682, DIN 1.4455 A#9 F#6).
- The same filler metal will be used for welding the production sectors.
- The tensile properties, bend ductility, and soundness of welds will be determined during welding procedure qualification.
- Procedures of tests for mechanical properties will be specified in accordance with Standard Methods for Mechanical Testing of Welds in QW-202 of ASME BPVC.IX and AWS B4.0M.

Alternative base material for manufacturing the prototype sector:

- In case 316LN will not be available on the market in order to manufacture the prototype sector within the required schedule, 316L can be procured instead because it belongs to the same base material group (8.1).
- Also using 316L, welds will be qualified for both prototype and production sectors as maintaining constant the welding variables that are critical to making acceptable welds (essential variables).

Magnetic permeability measured on welded 316L base metal should be carefully evaluated before considered as a significant measurement for the production of vessel sectors.

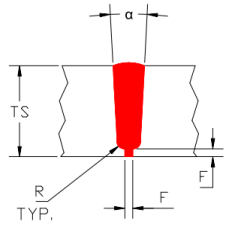
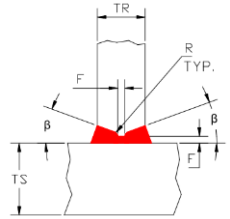
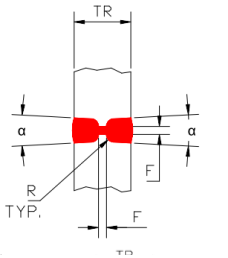
# Types of welds on inner and outer shells

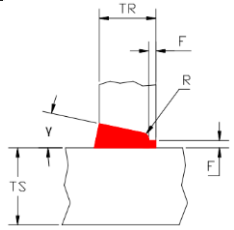
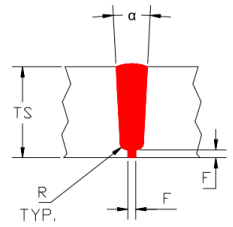
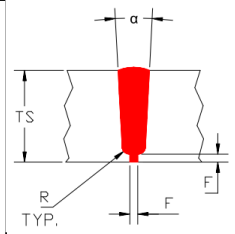
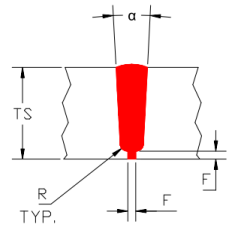



The inner shell will be the first fabricated part of the vacuum vessel double walled structure because of following reasons:

a) facing to the UHV (plasma) side of first and second passes at the weld root, made through the reliable and clean TIG process (MIG can be used to deposit passes over the first two for thick pieces);
b) larger toroidal width of plates to be joined thus reducing the welding heat input at the coolant-vacuum barrier;
c) inspectability with radiographic test (RT) after joining the shell plates and then after joining reinforcing ribs;
d) flexibility in positioning the welded joints for supports of in-vessel components in order to prevent lamellar tearing.

# Types and tests of welds

| Detail | | | | Weld process | | Non destructive testing | |
|---|---|---|---|---|---|---|---|
| Ref. | Weld joint sketch | Type of joint [RCC-MRx RD3800] | Edge preparation | Weld mode | Process number | Type | Extent |
| W100 |  | I.2<br>butt welding, full penetration, two sides accessible, gaseous back protection | single-U groove | 001 manual | 141 (TIG) root layer | VT | 100% |
| | | | | | | LT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | RT | 100% |
| | | | | | | ET | 100% |
| W200 |  | III.1<br>T, full penetration, two sides accessible, back welding | double-J groove | 001 manual | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | UT | 100% |
| | | | | | | ET | 100% |
| W300 |  | I.1<br>butt welding, full penetration, two sides accessible, back welding | double-U groove | 001 manual | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | RT | 100% |
| | | | | | | ET | 100% |

| Detail | | | | Weld process | | Non destructive testing | |
|---|---|---|---|---|---|---|---|
| Ref. | Weld joint sketch | Type of joint [RCC-MRx RD3800] | Edge preparation | Weld mode | Process number | Type | Extent |
| W400 |  | III.2<br>T, full penetration, back side inacessible, gaseous back protection | J-groove | 001 manual | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | UT | 100% |
| | | | | | | ET | 100% |
| W500 |  | II.1<br>butt welding, full penetration, back side inaccessible, gaseous protection | single-U groove | 001 manual | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | UT | 100% |
| | | | | | | ET | 100% |
| W600 |  | I.2<br>butt welding, full penetration, two sides accessible, gaseous back protection | single-U groove | 002 automatic | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | RT | 100% |
| | | | | | | ET | 100% |
| W700 |  | II.1<br>butt welding, full penetration, back side inaccessible, gaseous protection | single-U groove | 002 automatic | 141 (TIG) root layer | VT | 100% |
| | | | | | 131 (MIG) overlay layers | VT | 100% |
| | | | | | | UT | 100% |
| | | | | | | ET | 100% |

Quality levels for imperfections:

- Level B as per EN ISO 5817
- Level 1 in accordance with ISO 10675-1 (RT)

# Non destructive testing and weld repairs

Testing sequence:

A. Visual test (VT):
   i. after completion of the root pass (first TIG pass)
   ii. after completion of the repair

B. Volumetric test on the completed multi-pass weld:
   i. radiographic test (RT) will be performed
   ii. where RT is impractical → ultrasonic test (UT, phased-array) will be performed
   iii. where UT is impractical → the volumetric test is replaced by production proof samples (PPS):
      - visual inspection (VT)
      - penetrant testing (PT)
      - examination via sectioned macrographs and micrographs

C. Leak test (LT) after completion of the root pass

D. Pressure test (PT) after completion of the repair

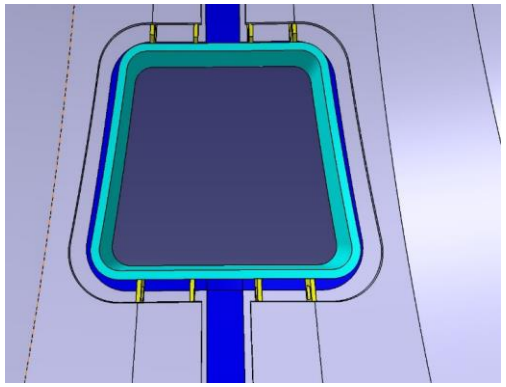
E. Leak test (LT) after completion of the repair
   high sensitivity is achieved by applying the hood method to check the leak tightness of the inter-shell volume, hood method in order to detect leakages down to 1E-9 - 1E-8 mbar l/s
   (EN 13185, ASTM E 1603-99, ASME V Art. 10)

# On site integration - final sector

Main requirements:

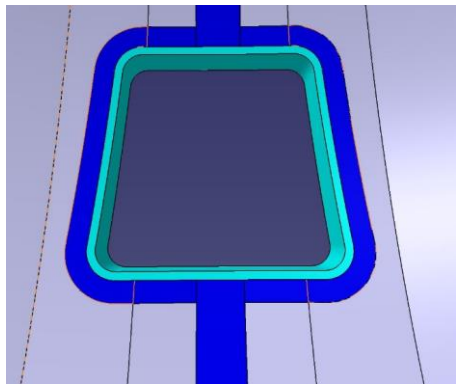
- in-vessel attachments as permanent supports of the in-vessel components will be welded in correspondence of the inter-shell reinforcing ribs
- also plates as temporary attachments of the internal jig will be welded in correspondence of the inter-shell reinforcing ribs for sector handling during manufacturing and assembly
- welding onto existing welds is denied as well as close to the heat affected zones
- non destructive testing of weld attachments will be required with visual test, eddy current, and ultrasonic tests (specific requirements will be prepared as for vessel construction welds)

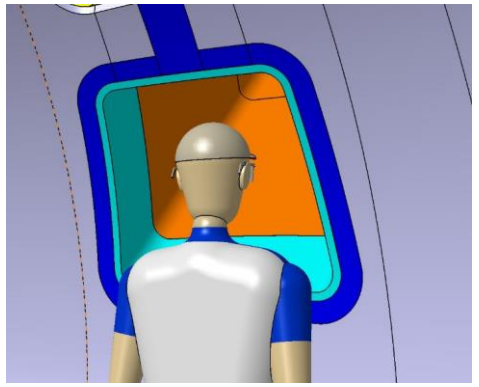
Final sector integration: port stubs made of a single part and welding of splice frame and splice plate:



Poloidal rib welding from the inner side

Welding of splice frame and plate from the inner side





Welding and inspection of the port duct

# Expansion joints (bellows) specifications

- Helium leak rate 1.0E-9 mbar l/s including interspace testing (Swagelok or similar fitting will be integrated in the construction)
- Number of cycles for bellows design: 2000
  - The number of cycles for bellows design is greater than the expected number of both plasma disruptions (1750) and baking cycles (150)
- Temperatures:
  - maximum expected operation temperature: baking temperature
  - minimum expected operation temperature: room temperature
- Expansion joint construction:
  - multi-ply bellows design
  - interspace testing with Swagelok or similar fitting integrated in the construction
  - inner/outer sleeve as support for heating/thermal insulation
- Bellows and flange material:
  - 1.4404, 1.4435 (316L) or 1.4406, 1.4429 (316LN)
  - Cobalt limitation (Co<0.05 wt%) could be negotiated considering the total mass of bellows material in the tokamak and the maintenance strategy
- Assumption about bellows expected expansions:
  - thermal expansions and shock loads obtained by simulations

# Ports and Expansion Joints

| vessel sector | port/ bellows | inner poloidal size [mm] | inner toroidal size [mm] | outer poloidal size [mm] | outer toroidal size [mm] | building length [mm] |
|---|---|---|---|---|---|---|
| Vessel standard sectors | port #1 | 794 | 288 | 824 | 318 | - |
| | bellows #1 | 845 | 320 | 985 | 460 | 450 |
| | port #2 | 530 | 600 | 560 | 630 | - |
| | bellows #2 | 620 | 660 | 760 | 800 | 450 |
| | port #3 | 900 | 680 | 940 | 720 | - |
| | bellows #3 | 950 | 730 | 1090 | 870 | 450 |
| | port #4 | 650 | 599 | 680 | 629 | - |
| | bellows #4 | 720 | 700 | 860 | 840 | 450 |
| | port #5 | 750 | 321 | 780 | 351 | - |
| | bellows #5 | 780 | 360 | 920 | 500 | 450 |
| Vessel special sector #7 | port #3 | - | - | - | - | - |
| | bellows #3 | 1200 | 800 | 1340 | 940 | 450 |
| Vessel special sector #8 | port #3 | - | - | - | - | - |
| | bellows #3 | 1090 | 1110 | 1230 | 1250 | 450 |

# Machine sensors

| Function | Location | Total measurement points | Number of sensors per sector | Total Sensors |
|---|---|---|---|---|
| Temperature condition monitoring | Inner VV | 144 | 16 | 900 |
| | Outer VV | 180 | 20 | |
| | VVP | 90 | 10 | |
| | VVS | 36 | / | |
| Temperature load characterization | Inner VV | 360 | 40 | 1980 |
| | Outer VV | 360 | 40 | |
| | VVP | 270 | 15 | |
| Displacement | Outer VV | 108 | 12 | 1692 |
| | VVS | 18 | / | |
| | VVP | 720 | 80 | |
| Deformation | Outer VV | 72 | 8 | 912 |
| | VVS | 24 | / | |
| | VVP | 360 | 40 | |
| Acceleration | Outer VV | 54 | / | 852 |
| | VVP | 360 | 40 | |
| | VVS | 12 | 24 | |

**DRAFT: quantity and position of sensors are under review**

# Schedule

Main assumptions with 40.3 months of procurement contract:

- one prototype sector will be produced first to qualify manufacturing and testing procedures;
- the prototype sector will be delivered 12 months after kick off meeting;
- standard 316LN (without limitation of Co content) will be procured for manufacturing the prototype sector;
- manufacturing drawings of production sectors will be updated and issued after completion of tests on the prototype sector;
- manufacturing of 1$^{st}$ sector requires 6.5 months to implement production processes;
- 40 days are considered between deliveries of sectors (from 2$^{nd}$ to 17$^{th}$).

# Schematic schedule

| # | Activity | month -4 | month -3 | month -2 | month -1 | month 0 | month 1 | month 2 | month 3 | month 4 | month 5 | month 6 | month 7 | month 8 | month 9 | month 10 | month 11 | month 12 | month 13 | month 14 | month 15 | month 16 | month 17 | month 18 | month 19 | month 20 | month 21 | … | month 39 | month 40 | month 41 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Independent EM analyses and structural verifications | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Design Review with External Panel | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Technical Specification Activity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Call for Tender + Evaluation of the tender submissions | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Selection of vendor & Award of contract | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | KoM + Manufacturing Readiness Review | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Manufacturing Drawings | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Procurement of raw materials | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | Tools & equipment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Internal jig + Transportation & rotation tool | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | Qualification of processes (manufacturing, welding, testing) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | Sector prototype manufacturing & testing | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | Drawing updated with outcomes of prototyping | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | Bellows + Splice plates + Sensors | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | VV sector 01 (fabrication + FAT + delivery + SAT) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | VV sector 02 (fabrication + FAT + delivery + SAT) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | VV sector 17 (fabrication + FAT + delivery + SAT) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Schedule - welding areas

Welding areas: 110 working days per sector (150 calendar days) -> 4 welding areas, full time, 1 working shift (clamping with specific templates will require more welding areas)

Three main welding areas working in parallel are identified for the fabrication of the inboard and outboard segments:

- rib welding on the inner shell
- welding of stubs
- outer shell welding

The number of welding areas for the fabrication of the segments and their integration is in the range 4-7.

Assuming 3 persons working in each area during 28 months (m12 -> m40), the amount of required PPY is up to 49 (excluding preliminary activities [mock-up/prototype], engineering and management).

Plate cutting area: 15 working days per sector (20 calendar days) -> 1 cutting area, half time, 1 work shift

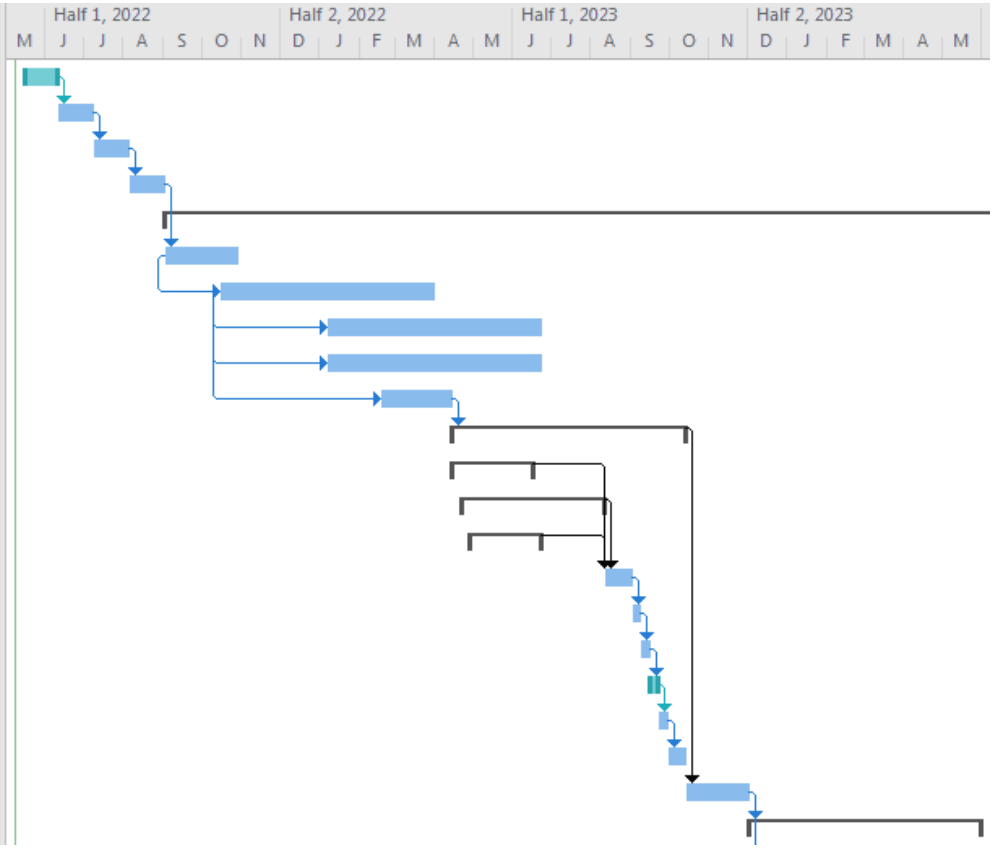
Plate shaping area: 15 working days per sector (20 calendar days) -> 1 shaping area, half time, 1 work shift

Machining centre (4 axes): 30 working days per sector (40 calendar days) -> 1 machining centre, full time, 1 work shift

# Schedule - detailed schedule

Procurement activities start with manufacturing & testing of the prototype sector to qualify fabrication processes:

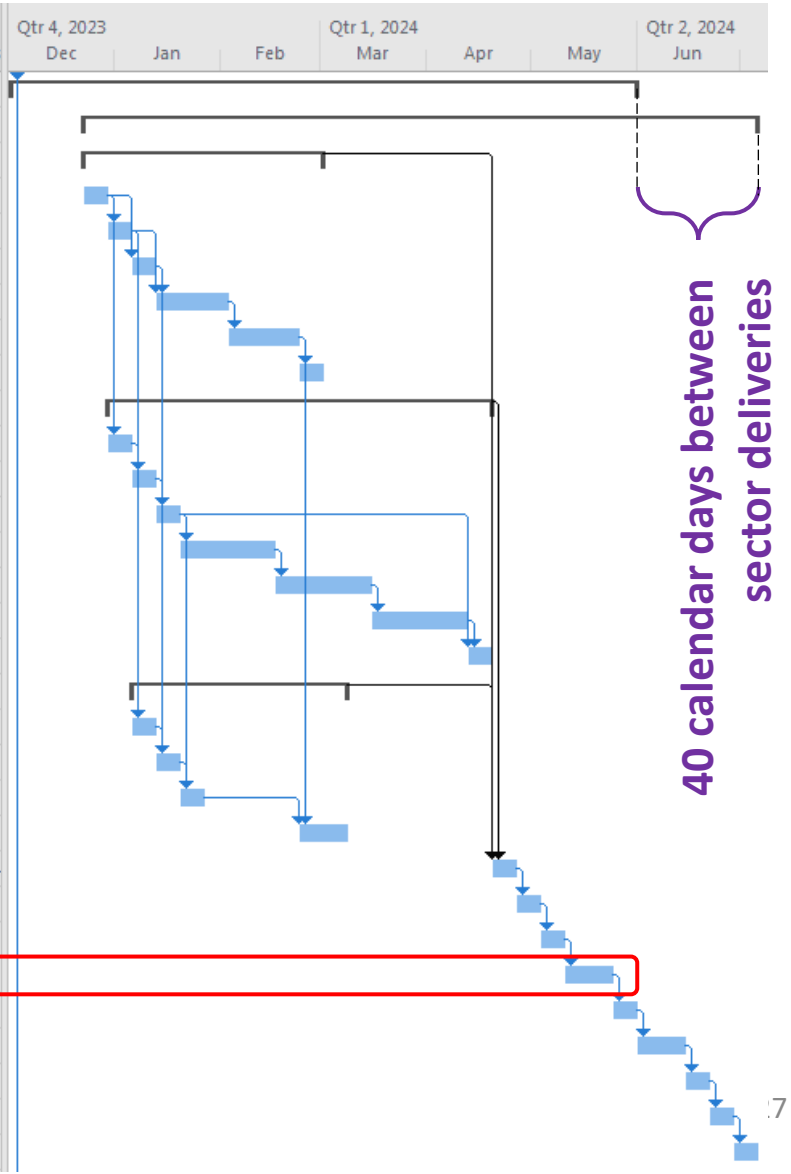
| | Task Name | Duration | Start | Finish | Predeces |
|---|---|---|---|---|---|
| 1 | Review Technical Specification Activity | 1 mon | Mon 16/05/22 | Fri 10/06/22 | |
| 2 | Call for Tender | 1 mon | Fri 10/06/22 | Fri 08/07/22 | 1 |
| 3 | Evaluation of the tender submissions | 1 mon | Fri 08/07/22 | Fri 05/08/22 | 2 |
| 4 | Selection of vendor & Award of contract | 1 mon | Fri 05/08/22 | Fri 02/09/22 | 3 |
| 5 | **VV procurement** | **815 days** | **Fri 02/09/22** | **Fri 17/10/25** | |
| 6 | KoM + Manufacturing Readiness Review | 2 mons | Fri 02/09/22 | Fri 28/10/22 | 4 |
| 7 | Manufacturing Drawings | 6 mons | Fri 14/10/22 | Fri 31/03/23 | 6SS+30 d |
| 8 | Procurement of raw materials | 6 mons | Fri 06/01/23 | Fri 23/06/23 | 7SS+60 d |
| 9 | Tools & equipment | 6 mons | Fri 06/01/23 | Fri 23/06/23 | 7SS+60 d |
| 10 | Qualification of processes (manufacturing, welding, testing) | 2 mons | Fri 17/02/23 | Fri 14/04/23 | 7SS+90 d |
| 11 | **Sector prototype manufacturing & testing** | **130 days** | **Fri 14/04/23** | **Fri 13/10/23** | **10** |
| 12 | **inboard segment fabrication** | **45 days** | **Fri 14/04/23** | **Fri 16/06/23** | |
| 19 | **outboard segment fabrication** | **80 days** | **Fri 21/04/23** | **Fri 11/08/23** | |
| 27 | **ports fabrication** | **40 days** | **Fri 28/04/23** | **Fri 23/06/23** | |
| 32 | evaluation of post welding distortions | 3 wks | Fri 11/08/23 | Fri 01/09/23 | 12;19;27 |
| 33 | welding of inboard and outboard segments (W2) | 1 wk | Fri 01/09/23 | Fri 08/09/23 | 32 |
| 34 | welding of ports and gravity support (W2) | 1 wk | Fri 08/09/23 | Fri 15/09/23 | 33 |
| 35 | machining of sector edges for welding on site (3+1 axes centre) | 1 wk | Fri 15/09/23 | Fri 22/09/23 | 34 |
| 36 | pressure and leak test | 1 wk | Fri 22/09/23 | Fri 29/09/23 | 35 |
| 37 | dimensional test | 2 wks | Fri 29/09/23 | Fri 13/10/23 | 36 |
| 38 | PRR: Drawing updated with outcomes of prototyping | 7 wks | Fri 13/10/23 | Fri 01/12/23 | 11 |
| 39 | **Sector 01 manufacturing & testing** | **130 days** | **Fri 01/12/23** | **Fri 31/05/24** | **38** |



# Schedule - detailed schedule

Sector 02 manufacturing & testing: 6.5 months

| | Task Name | Duration | Start | Finish | Predeces |
|---|---|---|---|---|---|
| 39 | **Sector 01 manufacturing & testing** | **130 days** | **Fri 01/12/23** | **Fri 31/05/24** | **38** |
| 68 | **Sector 02 manufacturing & testing** | **140 days** | **Fri 22/12/23** | **Fri 05/07/24** | |
| 69 | **inboard segment fabrication** | **50 days** | **Fri 22/12/23** | **Fri 01/03/24** | |
| 70 | cutting of plates | 1 wk | Fri 22/12/23 | Fri 29/12/23 | 56 |
| 71 | shaping of inner shell plates | 1 wk | Fri 29/12/23 | Fri 05/01/24 | 70;57 |
| 72 | machining of outer shell and ribs (3 axes centre) | 1 wk | Fri 05/01/24 | Fri 12/01/24 | 70;58 |
| 73 | welding of ribs on the inner shell (W3) | 3 wks | Fri 12/01/24 | Fri 02/02/24 | 72;71 |
| 74 | welding of outer shell (W3) | 3 wks | Fri 02/02/24 | Fri 23/02/24 | 73 |
| 75 | machining of segment (3 axes centre) | 1 wk | Fri 23/02/24 | Fri 01/03/24 | 74 |
| 76 | **outboard segment fabrication** | **80 days** | **Fri 29/12/23** | **Fri 19/04/24** | |
| 77 | cutting of plates | 1 wk | Fri 29/12/23 | Fri 05/01/24 | 70 |
| 78 | shaping of single curvature inner shell-outer shell plates | 1 wk | Fri 05/01/24 | Fri 12/01/24 | 77;71 |
| 79 | machining of shells, ribs, stubs (3+1 axes centre) | 1 wk | Fri 12/01/24 | Fri 19/01/24 | 78;72 |
| 80 | welding of inner shell plates and stubs (W4) | 4 wks | Fri 19/01/24 | Fri 16/02/24 | 79 |
| 81 | welding of ribs on the inner shell (W4) | 4 wks | Fri 16/02/24 | Fri 15/03/24 | 80 |
| 82 | welding of outer shell and stubs (W4) | 4 wks | Fri 15/03/24 | Fri 12/04/24 | 81 |
| 83 | machining of segment (3 axes centre) | 1 wk | Fri 12/04/24 | Fri 19/04/24 | 82;79 |
| 84 | **fabrication of ports (and gravity support)** | **45 days** | **Fri 05/01/24** | **Fri 08/03/24** | |
| 85 | cutting of plates | 1 wk | Fri 05/01/24 | Fri 12/01/24 | 77 |
| 86 | shaping of plates | 1 wk | Fri 12/01/24 | Fri 19/01/24 | 85;78 |
| 87 | machining of ports (3 axes centre) | 1 wk | Fri 19/01/24 | Fri 26/01/24 | 86;79 |
| 88 | welding of plates (W3) | 2 wks | Fri 23/02/24 | Fri 08/03/24 | 87;74 |
| 89 | welding of inboard and outboard segments (W4) | 1 wk | Fri 19/04/24 | Fri 26/04/24 | 69;76;84 |
| 90 | welding of ports and gravity support (W4) | 1 wk | Fri 26/04/24 | Fri 03/05/24 | 89 |
| 91 | machining of sector edges for welding on site (3+1 axes centre) | 1 wk | Fri 03/05/24 | Fri 10/05/24 | 90 |
| 92 | contingency margin | 2 wks | Fri 10/05/24 | Fri 24/05/24 | 91 |
| 93 | pressure and leak test | 1 wk | Fri 24/05/24 | Fri 31/05/24 | 92 |
| 94 | dimensional test | 2 wks | Fri 31/05/24 | Fri 14/06/24 | 93 |
| 95 | preparation for shipment | 1 wk | Fri 14/06/24 | Fri 21/06/24 | 94 |
| 96 | delivery at site | 1 wk | Fri 21/06/24 | Fri 28/06/24 | 95 |
| 97 | site acceptance test (SAT) | 1 wk | Fri 28/06/24 | Fri 05/07/24 | 96 |




GANTT CHART

Procedure for DTT Vacuum Vessel:

- Estimated time for launch: within 2022 (assembly sequence and design under revision)
- Type of procedure: open
- Delivery to Frascati DDP

Website:

- Bandi di gara pubblicati da  DTT S.C. a R.L. (www.dtt-project.it/index.php/dtt-tenders.html)

Thank you for attention and patience