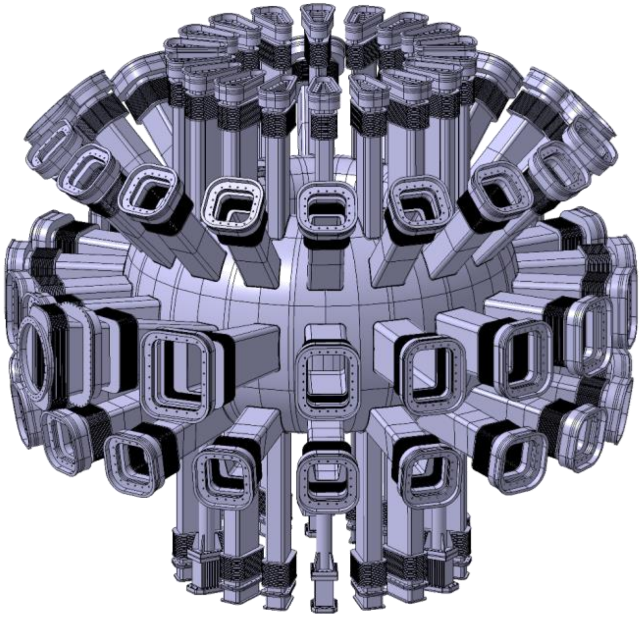
The material and information contained in this presentation are provided for information purposes only, and should not construed as basis for technical specifications of the call for tenders.

VVP tender: technical issues, planning and logistics



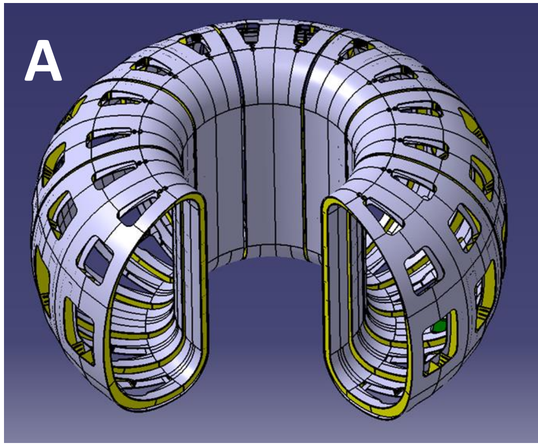
Web event: 09/12/2021 14.30 CET (via zoom)

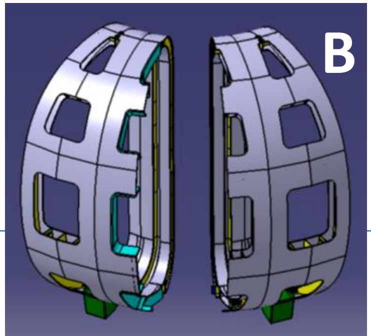
DTT INFO DAY – Vacuum vessel, ports and related accessories Procurement

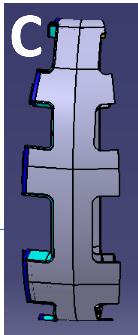
Scope of the supply

The system to be procured includes:

- 14 sectors with a toroidal extension of 20° (A in figure);
- 2 sectors with an extension of 30° (B in figure);
- 1 special sector of 20° without port ducts and without gravity support (C in figure);
- the vessel ports enumerated from #1 at the top to #5 at the bottom;
- the expansion joints (82 flanged bellows) connecting the ports to the cryostat;
- the gravity supports (6) of the vacuum vessel;
- the splice plates to be welded at the inner and outer shells between contiguous sectors in order to provide structural continuity and to form the vacuum barrier;
- the machine sensors;
- the internal jig to be used for assembling on DTT site the vacuum vessel sectors;
- the transportation & rotation tool for sector transportation and handling on site;
- a prototype sector to be used to qualify manufacturing and testing processes;
- support in the first phase of final assembly.







Technical description

DTT Vacuum Vessel (VV) is the first containment barrier to the plasma

The DTT VV has a double wall D-shaped poloidal cross section and a toroidal configuration

The double wall structure is filled with water during plasma operation and with nitrogen during baking

The mass of the vessel body is about 40 ton

The overall mass including ports, bellows, and gravity supports is about 180 ton plus 13.5 ton of water during plasma operation considering about 750 litres inside each typical sector

The assembly is about 9.5 m high with about 11.5 m diameter

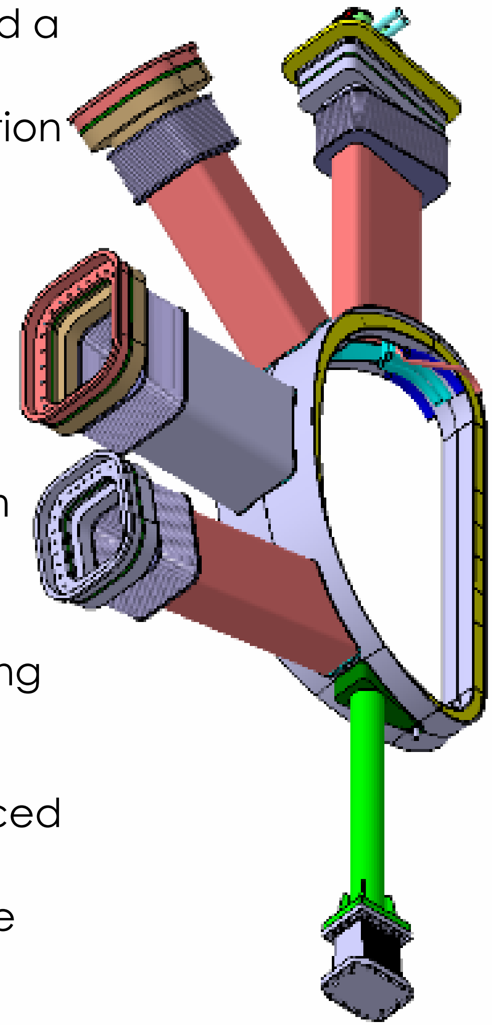
Typically, the sectors are interfaced with 5 ports enumerated from #1 at the top to #5 at the bottom

Six sectors are provided with gravity supports instead of port #5

Each gravity support is made of a vertical leg and is laid on the ring pedestal through a pack of spring plates to accommodate free thermal expansions along the radial direction

The inner shell will be procured smooth apart plates to be interfaced with the internal jig that will be used during VV assembly on site

(supports of in-vessel components will be welded to the VV on site within the assembly contract)



Design Basis Conditions & Construction

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

Vacuum vessel 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	--	AISI 316-LN Co<0.05 wt%
Thickness of inter-shell ribs	[mm]	10
Torus outboard diameter	[mm]	6900
Torus inboard diameter	[mm]	2530
Weight of main vessel body	[ton]	40
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]	111.5

Dimensions with cross sections of ports and building dimensions for 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

Technical specification structure

Technical specification main document

General provisions, Quality mgmt., Interfaces

Annex A	Annex B	Annex C	Annex D	Annex E	Annex F
Technical requirement VVP	Technical requirements Bellows	Technical requirements machine sensors	Technical requirements internal jig	Technical requirements transp&rot tool	Prototype sector

Advantages of the 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:

- Vessel sectors including:
    - vessel ports
    - gravity supports
    - machine sensors
- Expansion joints (82 flanged bellows)
- Splice plates
- Internal jig
- Transportation & rotation tool
- Prototype sector

Documentation, logistic and support deliverables:

- Manufacturing Readiness Review
- Risk Register
- Qualification File
- Metrology integrated within 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
- EU declaration of conformity
- Support in the first phase of final assembly

Procurement of raw material
Delivery conditions of semi-finished products

Flat products:

procured in accordance with EN 10028-7 “Flat products made of steels for pressure purposes - Part 7: Stainless steels” with process route 2D as surface finish.

Tooling, supports, jigs:

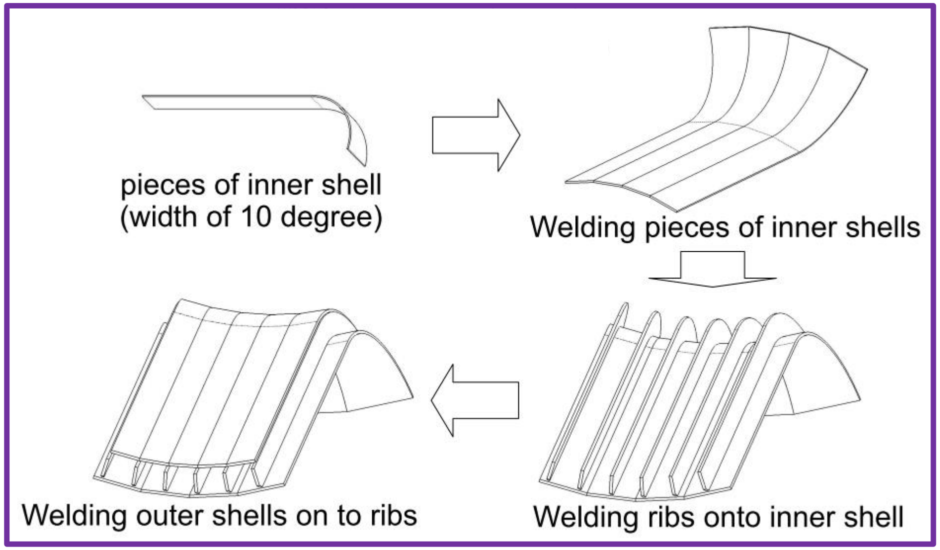
procured in accordance with EN 10088-4 “Stainless steels - Part 7: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for construction purposes”.

Bars, rods, sections:

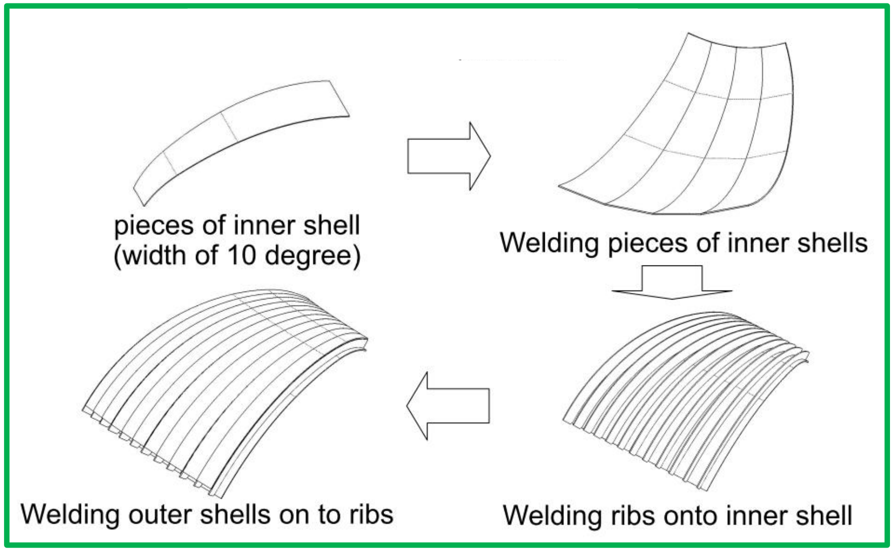
procured in accordance with EN 10088-5 “Stainless steels - Part 5: Technical delivery conditions for bars, rods, wire, sections and bright products of corrosion resisting steels for construction purposes” with process route 2D as surface finish.

Fabrication sequence

All welded joints realising coolant-vacuum barriers shall be full penetration joints to avoid trapped volumes that could result in virtual leaks and shall be volumetric and visual inspected



Inboard



Outboard

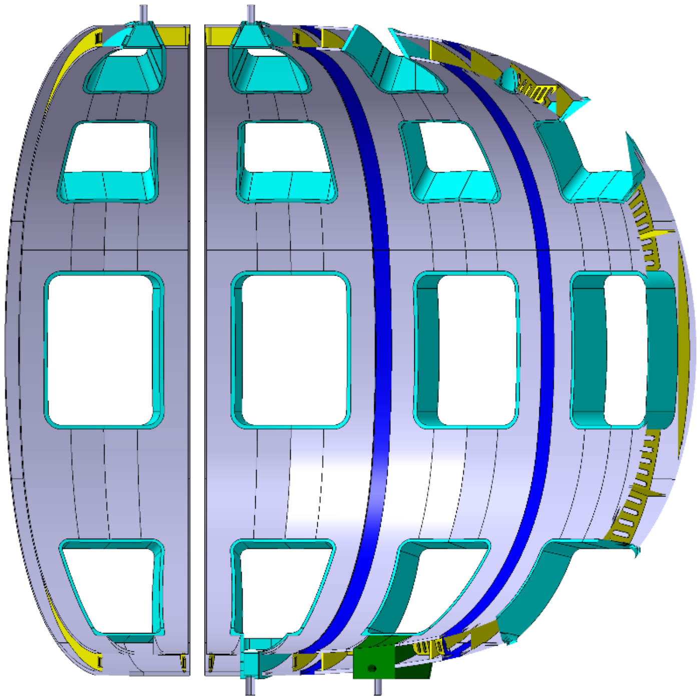
The inner shell will be the first fabricated part of the vacuum vessel double walled structure. Inspection: VT, RT (100%)

First root of outer shell will weld the shell plates to the reinforcing ribs in order to realise the structural continuity. When RT is not practical, the outer shell will be inspected using the phased array ultrasonic technology. Inspection: VT, RT/UT (100%)

Splice plates machining and welding

Pre-formed **splice plates** will be welded at the outer and inner shells between contiguous sectors in order to provide structural continuity and to form the vacuum barrier:

- The splice plates are used as compensation members of the dimensional chain between contiguous sectors
- After realising a first assembly, the dimension of the closing member is measured
- The error required to the closing member between sectors is controlled by adjusting the size of the splice plate in order to fit the toroidal shape
- The adjustment of the compensation member is performed through a reduction of the size of the splice plate with removal of material (machining). So, splice plates shall be procured with some extra material along the toroidal direction in order to allow the adjustment



Highlights:

Automated welding for maximum reliability

Preliminary evaluation of errors

Extensive direct control of dimensional variations

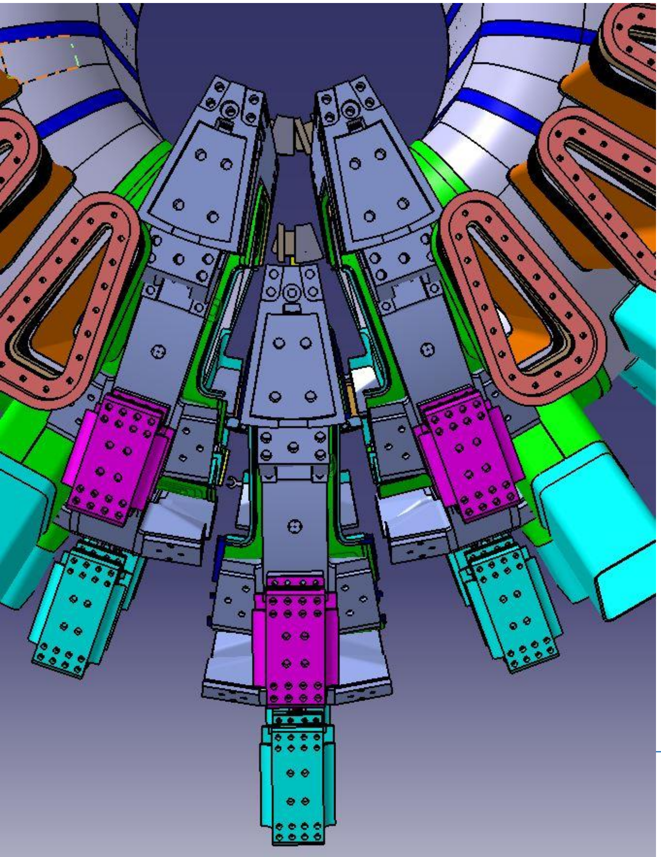
Support of the vessel Supplier in the first phase of final assembly (in particular for definition of edge details for welds between sectors and splice plates)

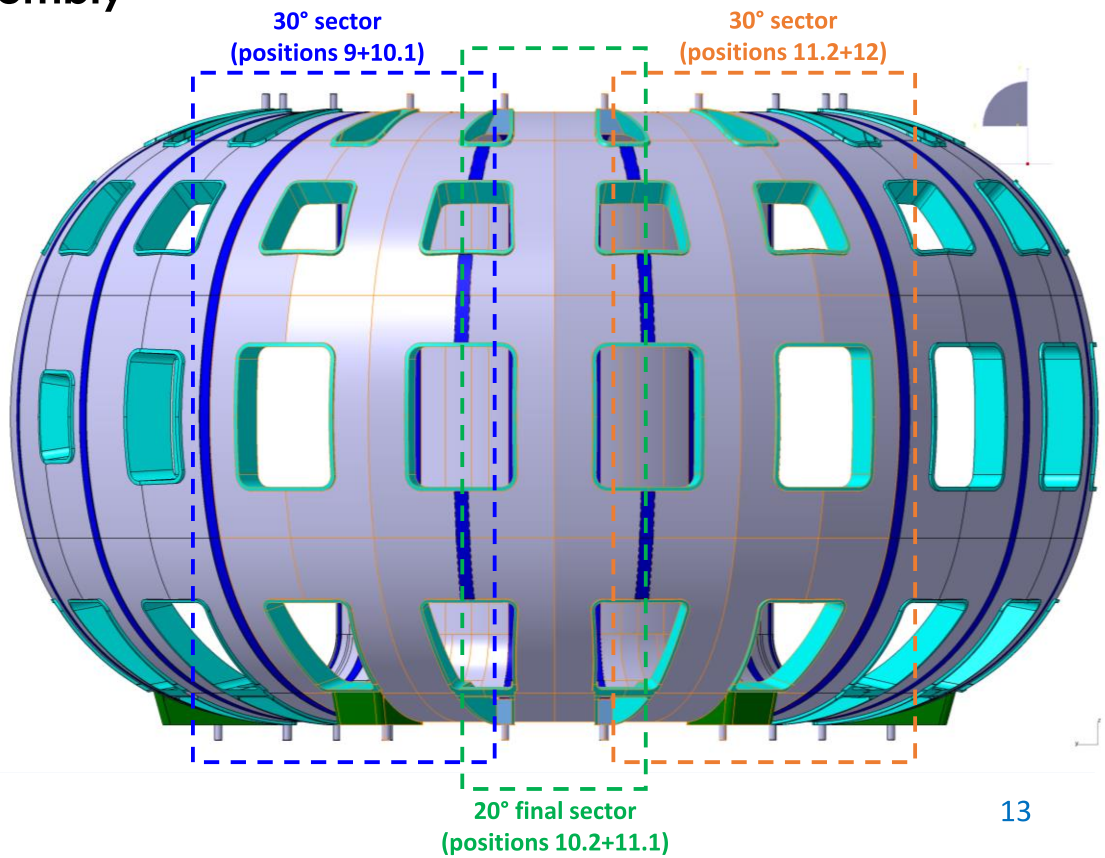
Final sector

The final sector will be integrated on site after positioning of the final toroidal field coil

The sector integration process will progress from the outboard to the inboard due to accessing requirements, then the first and second passes at the weld root of the inner shell will not be faced to the UHV (plasma) side

Edge details for field welds (on site) need to be defined for machining → **support on site during first phase of final assembly**





Inspection and testing

Inspection and testing performed before and during manufacturing:

- procurement of semi-finished products
- cleanliness conditions verified through wipe and visual methods
- dimensional inspection performed with direct and indirect tools (e.g. laser trackers/scanners, photogrammetry)
- welding inspection via radiographic testing (RT), ultrasound testing (UT), visual test (VT) performed at both sides of the weld when they are accessible
- pressure testing on each welded sector, 7.2 bar(a) pneumatic test for each sector with closed plugs to be removed after passing the leak test and before vessel integration on site
- leak testing: 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)

Dimensional inspection and tolerances

The dimensional inspection of the vacuum vessel will be performed by using reference datum systems

The sector reference datum system A, B, C shall be based on axes and positions of 20 flexible support housings on each side of the sectors

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

Welded constructions, class AE-BF in accordance with EN ISO 13920

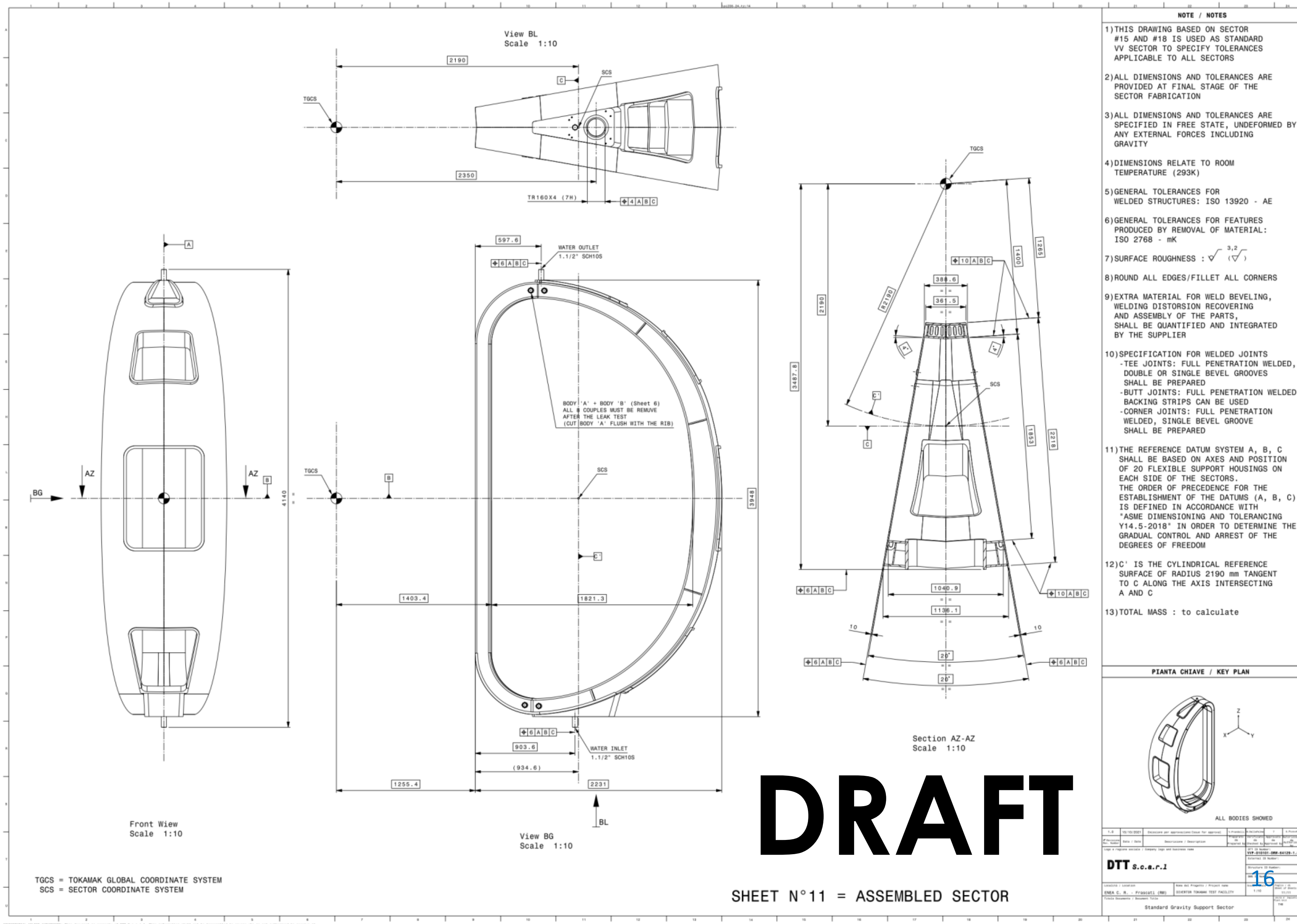
Table 1 — Tolerances for linear dimensions

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 00 0
	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

Sector drawing



Welded joints

Distortion management plan

- Defines the order of execution of operations and inspections
- Defines auxiliary jigs (if any)
- Contains evaluation of expected distortions (to be consistent with tolerances)
- Outlines recovery procedures for deformations (if any)
- Collects consideration on the welding sequence in the evaluation of the deformations

Qualification test for repairs of welds

- Repaired welds shall be “new” welds
- Precise parametrization shall be provided
- Qualification tests shall be performed to avoid detrimental effects
- Any test previously performed on the part shall be repeated

Quality levels for imperfections (under definition)

- Level B as per EN ISO 5817 (all fusion-welded joints except beam welding) and ISO 13919-1 (beam welding joints, if any)
- Level 1 in accordance with ISO 10675-1 (RT)

Volumetric inspection of welded joints

The UT is usually performed on procured semi-finished products.

Qualification of UT on welded austenitic stainless steel is needed with calibration on reference drilled holes and in welding coupons/test pieces in order to successfully perform the volumetric inspection where RT is impractical.

Each UT qualification will represent a specific type of weld.

Phased-array probes can provide improved volume coverage and offer the ability to interrogate the weld volume with multiple angles. In general, phased-array dual probes can provide improved signal to noise ratio for the inspection of coarse-grained materials.

The extent of volumetric inspection can be reduced (e.g. from 100% to 20%) when automated welding process is implemented.

Production proof samples (PPS) will be performed as laboratory tests when both RT and UT are not practical (e.g. when double side access is not allowed for RT film placement and when joint geometry is not compatible with UT like fillet welds).

Each PPS will only represent a specific type of weld and must use the same material, thickness and set-up as the production weld in order to be representative of the production welding/actual products.

The PPS will be subjected to visual inspection, penetrant testing (PT), and examination via sectioned macrograph and micrograph.

All vacuum sealing welded joints will be helium leak tested (LT).

Surface finish

Inner surface of inner shell: vacuum compatibility, cleanliness

- Ra < 3.2 μm: consistent w/process routes 2D, 2B, 2R as per EN 10088-2

Outer surface of outer shell: thermal radiation emissivity, vacuum compatibility, cleanliness

- Ra < 0.4 μm: consistent w/polishing with typical grit 320-600 → hemispherical emissivity in the IR ε = 0.10 – 0.15

Inter-shell surfaces: leak testing, cleanliness

- Ra < 3.2 μm consistent w/process routes 2D, 2B, 2R in accordance with EN 10088-2

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:
  - multiply 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 produced by simulations

Cleanliness for construction and testing

Working environment requirements:

- Clearly identified clean area
- Segregation from contaminants (e.g. rust, machining, chemical treatments, exhausts)
- Access control (people & materials)
- Trained personnel, in particular for non-destructive testing (level 2 or 3 in accordance with ISO 9712)

Supplier demonstration of good/sound practice with:

- Dedicated tools
- Use of clean gloves and coats
- Cleaning routines and checklists
- Helium leak testing using external calibrated leak attached to the vessel sector (EN 13185, ASTM E 1603-99, ASME V Art. 10)

Cleaning

Main steps for cleaning:

- Pre-cleaning: gross contamination and debris removal (no mechanical action)
- Degreasing: wiping with acetone, full immersion where possible
- Washing: hot water and a degreasing detergent
- Rinsing: running cold water, then demineralized water
- Drying: dry air flow (filtered against dusts, powders and oils)

Additional techniques may be used for final cleaning, e.g. CO_2 snow cleaning

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

Planning

The planning of procurement activities:

- the placement of the procurement contract;
- the kick-off-meeting (KoM) and manufacturing readiness review with the supplier;
- the qualification of manufacturing, welding, testing processes;
- the construction of the prototype sector;
- the manufacturing steps of all the hardware deliverables;
- the factory acceptance test and site acceptance tests;
- the preparation of the procurement documentation (documentation, logistic and support deliverables);
- the declaration of conformity with the delivery on site and site acceptance tests;
- the delivery on site including support in the first phase of final assembly.

F. Planning

#	Activity	Jan-22	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	…	Jul-25	Aug-25	Sep-25
1	Selection of vendor & Award of contract																												
2	KoM + Manufacturing Readiness Review																												
3	Manufacturing Drawings																												
4	Procurement of raw materials																												
5	Tools & equipment																												
6	Internal jig + Transportation & rotation tool																												
7	Qualification of processes (manufacturing, welding, testing)																												
8	Sector prototype manufacturing & testing																												
9	Ports + Gravity supports + Bellows + Splice plates + Sensors																												
10	VV sector 01 (fabrication+FAT+delivery+SAT)																												
11	VV sector 02 (fabrication+FAT+delivery+SAT)																												
	…																									…			
N-1	VV sector 17 (fabrication+FAT+delivery+SAT)																												
N	VV sector 17 (fabrication+FAT+delivery+SAT)																												

F. Planning

Delivery of items:

- Manufacturing Readiness Review, 3 months duration starting after KoM;
- Manufacturing Drawings, 6 months duration starting after KoM;
- Raw materials for 1st sector, 6 months duration starting after MRR;
- Internal jig + Transportation & rotation tool, 6 months duration starting after MRR. This activity includes the Tools & equipment needed for handling and testing;
- Qualification of processes (manufacturing, welding, testing), 6 months duration starting 3 months after KoM;
- Sector prototype (manufacturing, welding, testing), 9 months duration starting 3 months after KoM;
- 1st sector, 7 months duration starting after completion of qualification activities;
- Further vessel sector, delivery 40 days after the delivery of the previous sector.

F. Planning

Sectors will be fabricated through intermediate phases that are repeated for each sector. These phases are:

- Cutting and bending of plates forming the inner-outer shell and reinforcing ribs;
- Welding of plates to form the inboard half sector and the outboard one including intermediate checks;
- Assembling and welding of the half sectors to form an entire sector;
- Intermedia checks including NDT on welds, LT, 3D dimensional inspection;
- Welding of ports;
- FAT, packing;
- Transport, delivery, SAT.

F. Planning

Sectors will be delivered on the following dates:

- Prototype Sector: KoM + 12 months
- Sector 1: KoM + 19 months
- Sector 2: KoM + 19 months + 40 days
- … …
- Sector 16: KoM + 40 months
- Sector 17: KoM + 41 months

VVP tender: technical issues, planning and logistics on Information Day on Vacuum vessel, ports and related accessories Procurement

Enjoy the meeting and do not hesitate to send your requests of clarifications or questions via chat

Thank you for attention and patience
(if the case)