

Procurement of the DTT Vacuum Vessel and CE marking

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Ordine degli Ingegneri della Provincia di Roma

Seminario - Gli aspetti progettuali di fisica della fusione nucleare e della sicurezza del progetto
DTT - Divertor Tokamak Test facility

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Outlook

- DTT Vacuum Vessel and Ports - Description & procurement
- DTT Vacuum Vessel and Ports - Operating pressure and pneumatic pressure test
- Integration of devices for protection against exceeding the limits of pressure
- DTT Vacuum Vessel and Ports - Regulation (PED)
- Design and fabrication
- Risk & opportunity register
- Electromagnetic loads on vacuum vessel - Paths of halo currents
- Manufacturing and testing
 - ASME BPVC Sec. VIII Div. 2
 - Factory and Site Acceptance Tests
- Prototype sector - Qualifications for risk mitigation

DTT Vacuum Vessel and Ports - Description

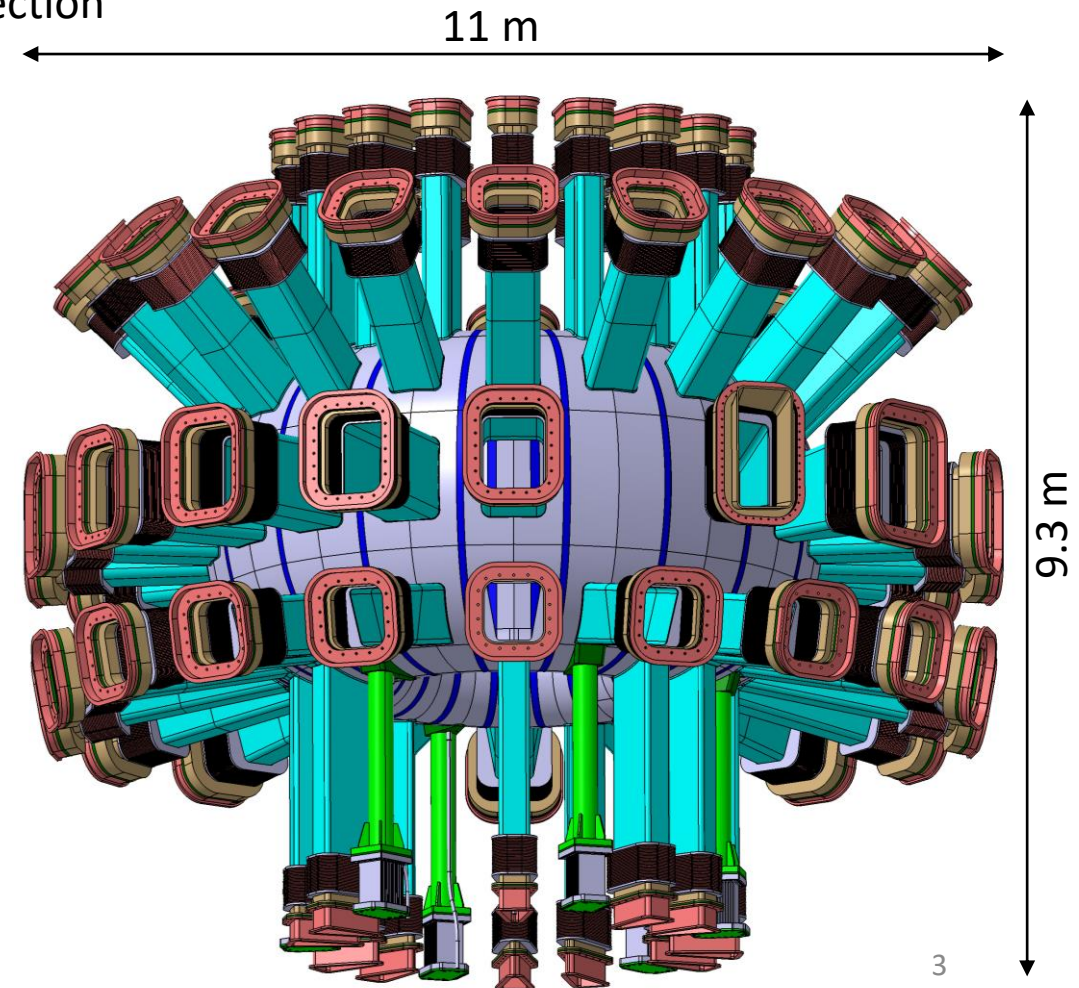


Functions and characteristics:

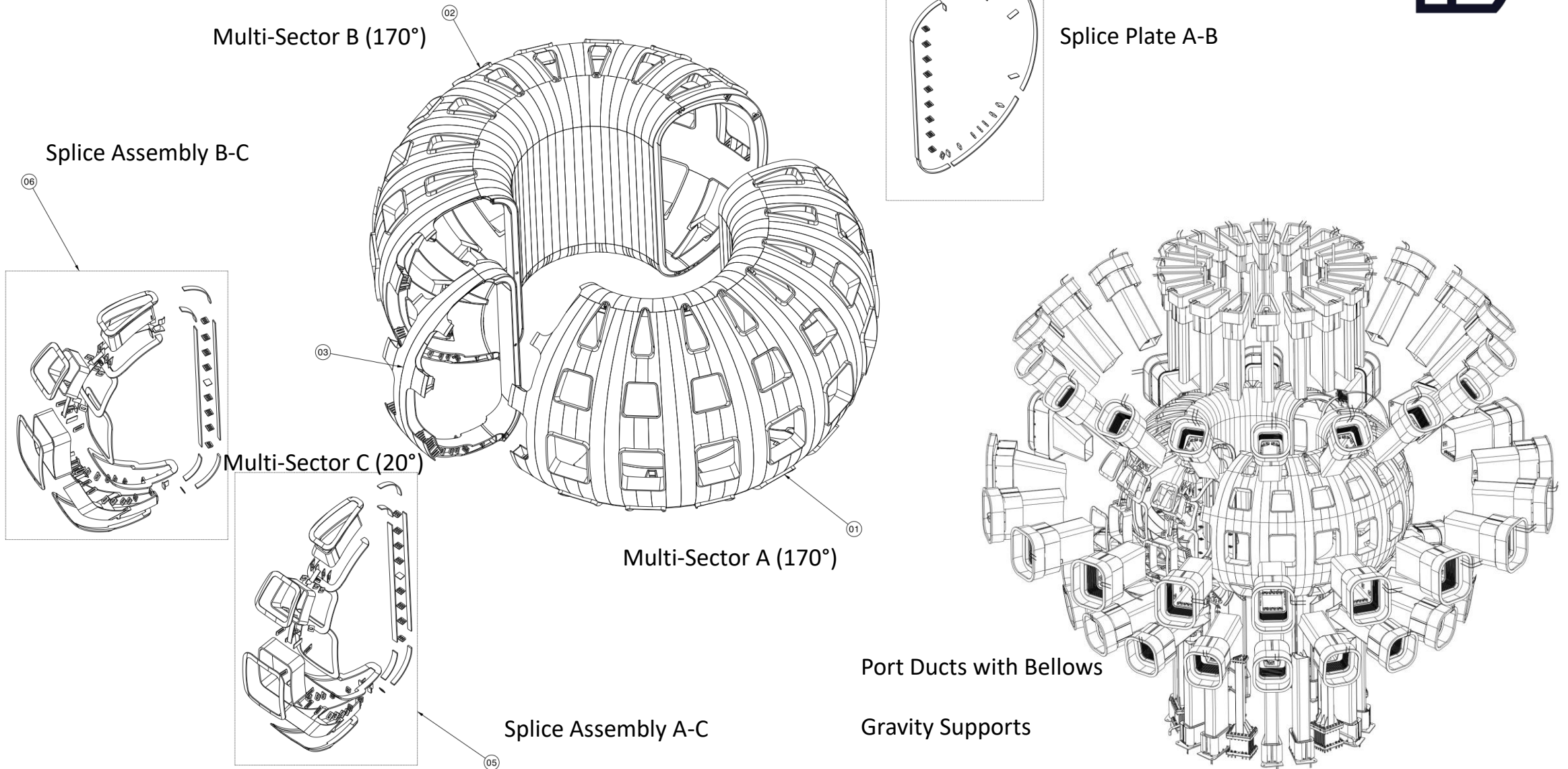
- first vacuum boundary for the plasma
- toroidal configuration with double wall D-shaped poloidal cross section
- inter-shell filled with water (borated later) as neutron moderator during plasma operation, with nitrogen during baking (200 °C)

Hardware deliverables:

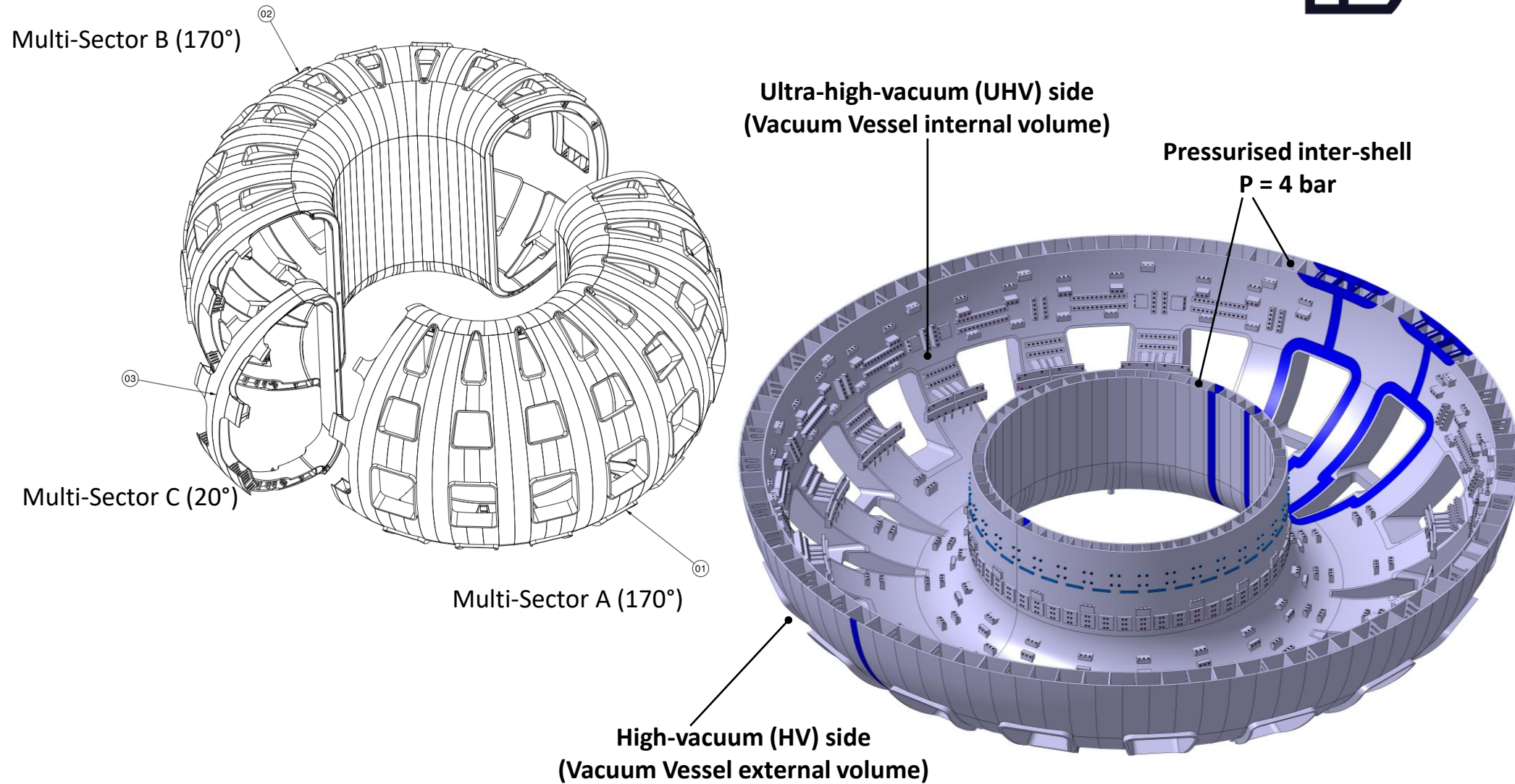
- 3 Multi-Sectors (2 x 170° + 1 x 20° toroidally)
- 82 ports & bellows, located:
 - every 20° in the toroidal direction
 - in 5 poloidal positions enumerated from the top (port #1) to the bottom (port #5)
- 6 gravity supports with spring plates for radial displacements
- splice-plates & splice frames
- machine sensors: field welds (on site) of supports



DTT Vacuum Vessel and Ports - Procurement

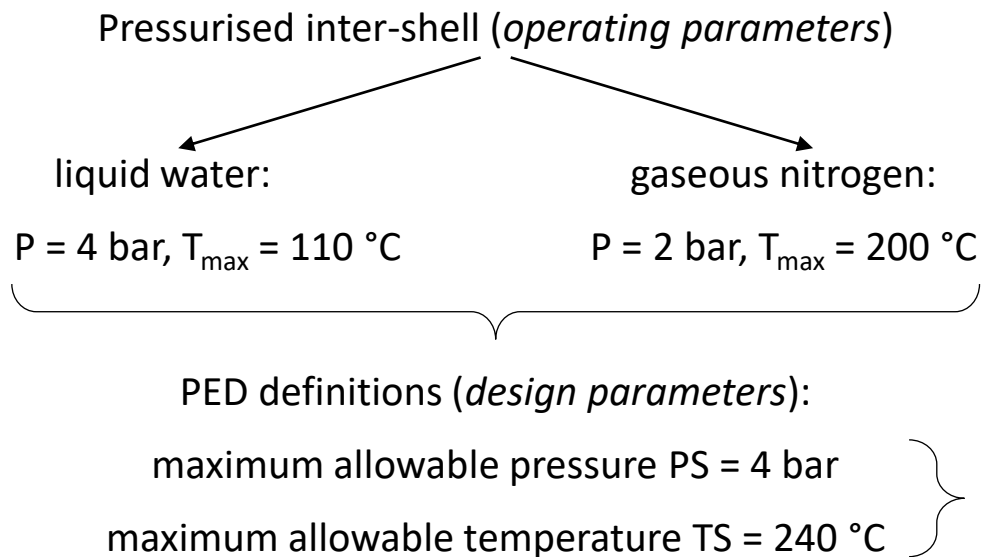


DTT Vacuum Vessel and Ports - Operating pressure



DTT Vacuum Vessel and Ports - Pneumatic pressure test

Pressure equipment presenting a risk due to pressure

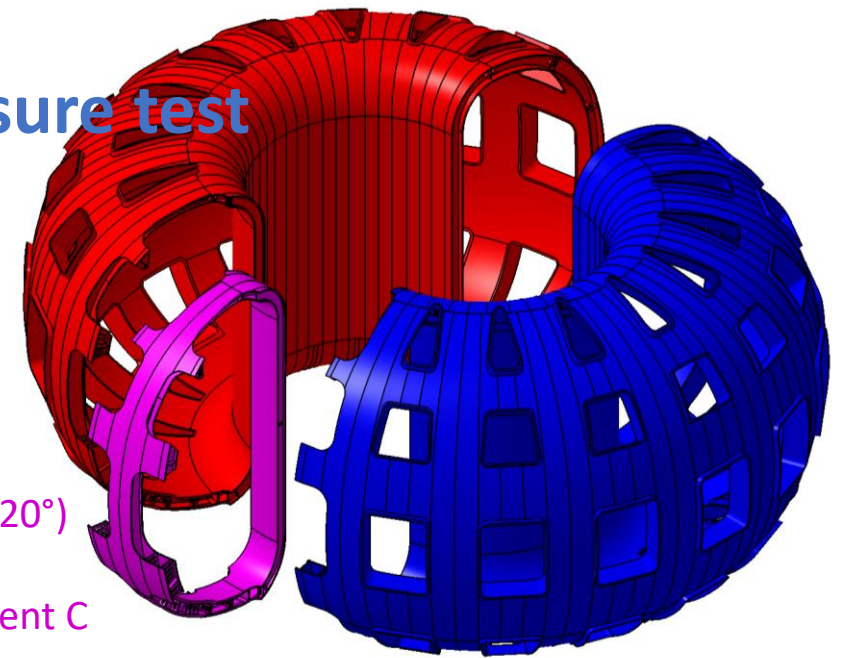


A pneumatic pressure test of the integrated Vacuum Vessel will be carried out on DTT site with monitoring of the joints between Multi-Sectors

Multi-Sector B (170°)
↓
Pressure equipment B

Multi-Sector C (20°)
↓
Pressure equipment C

Multi-Sector A (170°)
↓
Pressure equipment A



AISI 316LN: R_{p0.2}(20 °C) / R_{p0.2}(TS)

$$P_{test} = 1.15 \cdot \frac{Sm(T_{test})}{Sm(TS)} \cdot PS = 1.15 \cdot 1.33 \cdot 4.00 = 6.11 < 6.5 \text{ bar}$$

A pneumatic test will be used in lieu of the hydrostatic test because of the following two conditions applied to the components under consideration [PED]:

- the component cannot be safely filled with water
- traces of testing liquid cannot be tolerated in the component

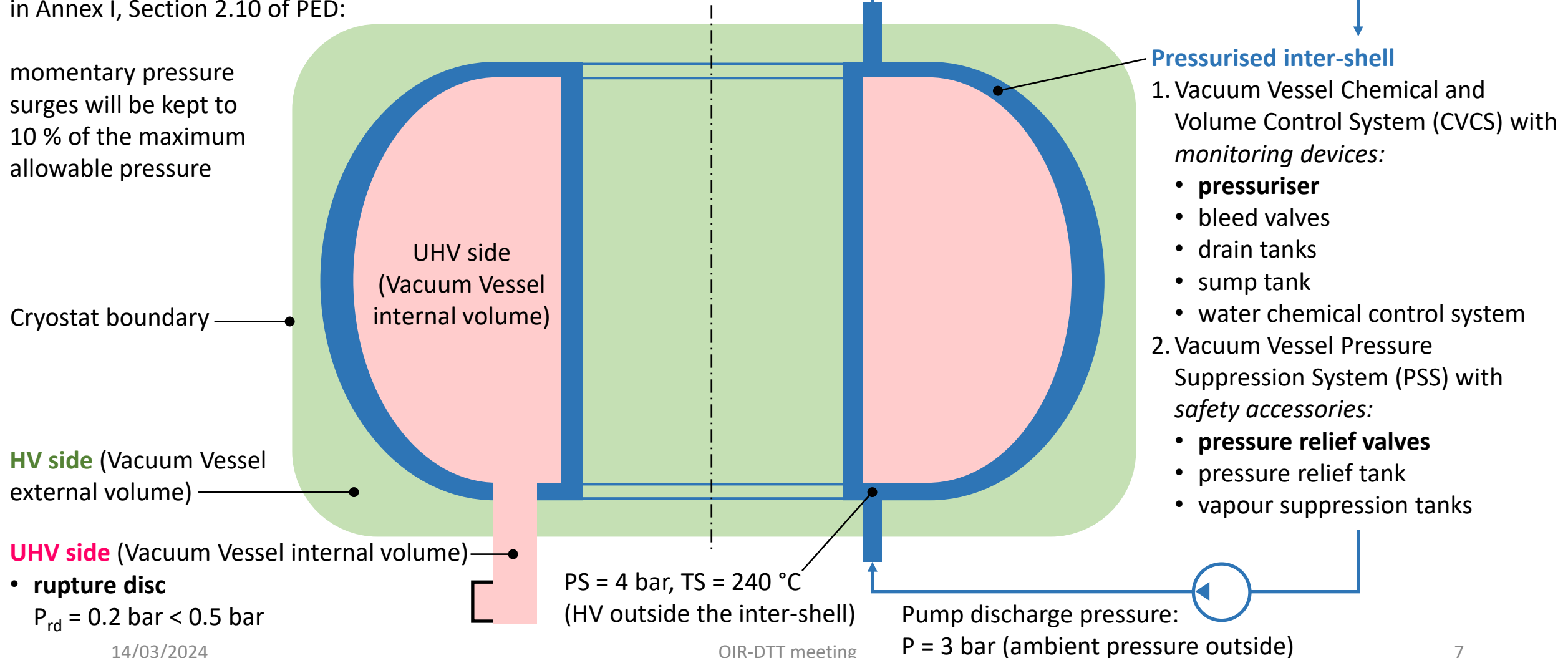
The pneumatic test pressure shall be not less than the specified test pressure P_{test} as defined in Part 8.3 of ASME BPVC Sec. VIII Div. 2

Integration of devices for protection against exceeding the allowable limits of pressure



Protective devices, such as pressure relief valves, will be integrated within the assembly against exceeding the allowable limits of pressure as required in Annex I, Section 2.10 of PED:

momentary pressure surges will be kept to 10 % of the maximum allowable pressure

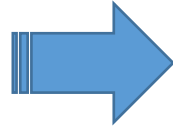


DTT Vacuum Vessel and Ports - Regulation (PED) 1/2

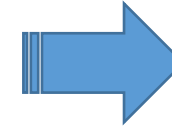


Certification steps identified with INAIL (Italian national institute for accidents at work):

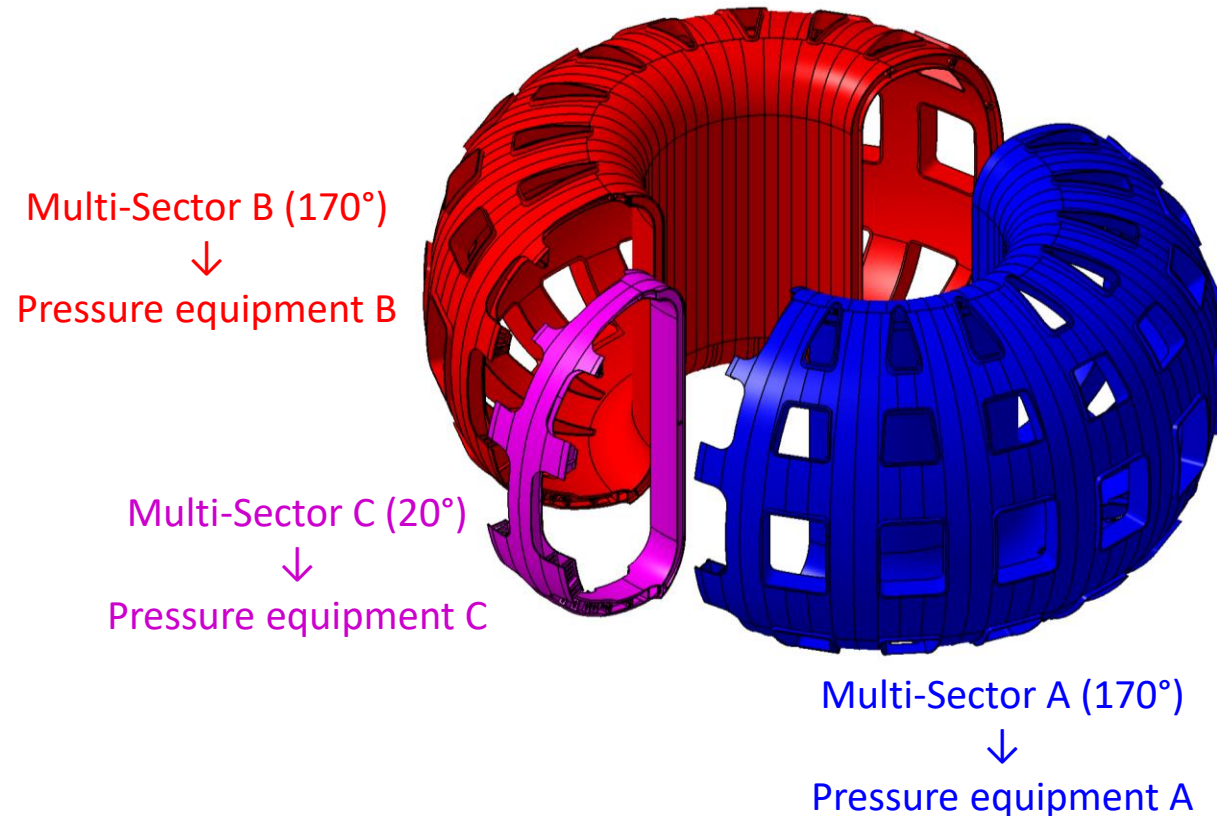
1 Manufacturer of the vacuum vessel:
NDE + pressure test + CE marking
of each multi-sector



2 Integrator of the vacuum vessel:
NDE + pressure test + CE marking
of the vacuum vessel



3 INAIL:
putting into service
of the vacuum vessel
including protective devices
with the cooling system



DTT Vacuum Vessel and Ports - Regulation (PED) 2/2



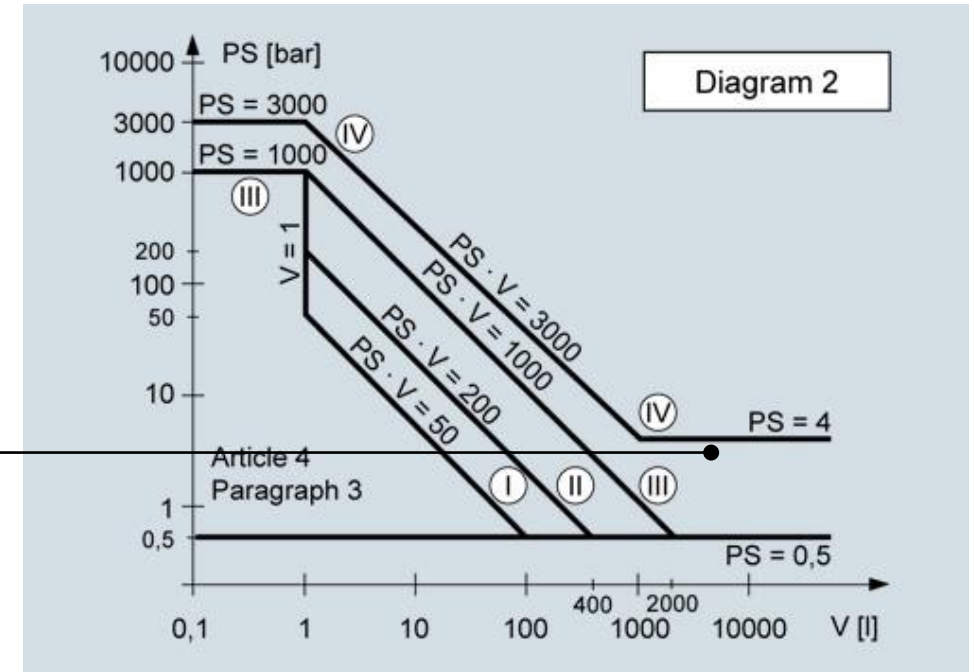
Applicable regulation for inter-shell pressurisation ($P > 0.5$ bar): PED

PED classification for the inter-shell of a Multi-Sector:

- Gaseous fluid in Group 2 (not hazardous)
- PS = 4 bar
- Multi-Sector volume $V = 6500$ l

PED category III

(conformity assessment for piping is not detailed in this slide because maximum category for piping is III)



Design and fabrication



The vessel shall be manufactured consistently with the requirements of Codes and Standards 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 accordance with “NCA-2142.4 Design, Service, and Test Limits” of BPVC Section III, Subsection NCA (limits are shared with Section VIII)

The procurement shall comply with the regulation of the Pressure Equipment Directive (PED):

- Classification: The DTT vacuum vessel fall within PED (category III)
- The VVP Contractor, in order to assume the design, will receive from DTT the risk register and the stress report which will be available to the notified body
- The VVP Contractor will be the manufacturer



Risk & opportunity register

A risk register will be shared with the VVP Contractor. Main identified risks are:

- Design:
 - definition of VVP requirements including steel chemical composition (to comply corrosion, strength, welding, radioprotection) → system and interface requirements, tech spec (3.2)
 - design of interfaces and supports for in-vessel components consistently with functional/plasma requirements, manufacturing tolerances, first installation, and remote handling
 - weld joint types consistently with the design code, vacuum, corrosion, inspectability, and structural integrity requirements → welding map
 - identification of forgings to be supplied from metalworking companies consistently with cost analysis & procurement strategy
 - definition of dimensional and shape errors on shells, ports, in/ex-vessel interfaces
 - definition of bellows design consistently with assembly, maintenance, and cost survey
 - definition of machine sensors, conduits, and diagnostic/auxiliary interfaces consistently with stray radiation and procurement strategy
- Interfaces:
 - heating & current drive, diagnostics, in/ex-vessel components,... → system and interface requirements
- Analysis and verification:
 - simulation of plasma scenarios, electromagnetic analyses, structural integrity verifications with normal operation (Major Disruption slow, Toroidal field coils Fast Discharge, all coils) and with emergency, faulted, and testing conditions → load comb. + stress report including relationship with investment protection and essential safety requirements (environment, personnel)
 - thermal/hydraulic/plant analyses including overpressure events like LOCA and LOVA → thermal/hydraulic/plant report
- Manufacturing:
 - qualification of manufacturing processes (including welding sequence and weld distortions) and NDEs → distortion plan, MIP, procurement of the prototype sector
 - qualification of re-pickling, re-passivation, and cleaning of welded joints for helium leak testing of the inter-shell → prototype sector
 - magnetic permeability at the completion of the fabrication processes → welding filler metal with minimal ferrite content + map of measurements at the completion of the fabrication processes
 - unavailability of qualified and certified personnel required to the supplier for qualification of NDE, 3D measurement systems → levels 2 and 3 in accordance with EN ISO 9712
- Component assembly-plant integration:
 - development of an assembly sequence to verify accesses, interfaces, and end effector designs → assembly specification
 - verification of functional/plasma requirements and manufacturing tolerances (compensation members) → as-built data management
 - tests of forming processes (in-vessel coils) and assembly sequence → procurement of the prototype sector
- Regulatory:
 - PED hazard classification and identification of the certification steps with INAIL (Italian national institute for accidents at work) → PED report, plant integration
 - integration of devices for protection against exceeding the allowable limits of pressure → PED report, plant integration
- Maintenance:
 - definition of the maintenance strategy for vulnerable components (bellows) and compatibility verification with remote handling → assembly specification
- Cost analysis & procurement strategy:
 - cost/market survey for bellows
 - techno-economic analysis for call for tender
 - in-port reduced access to integrate on site supports for services (cooling tubes, coils feeders, embedded sensors, supports of cryopumps) → supports included in the procurement
 - unavailability of personnel during the procurement follow-up in particular to manage promptly non-conformities → stable and permanent working Team at manufacturer premises

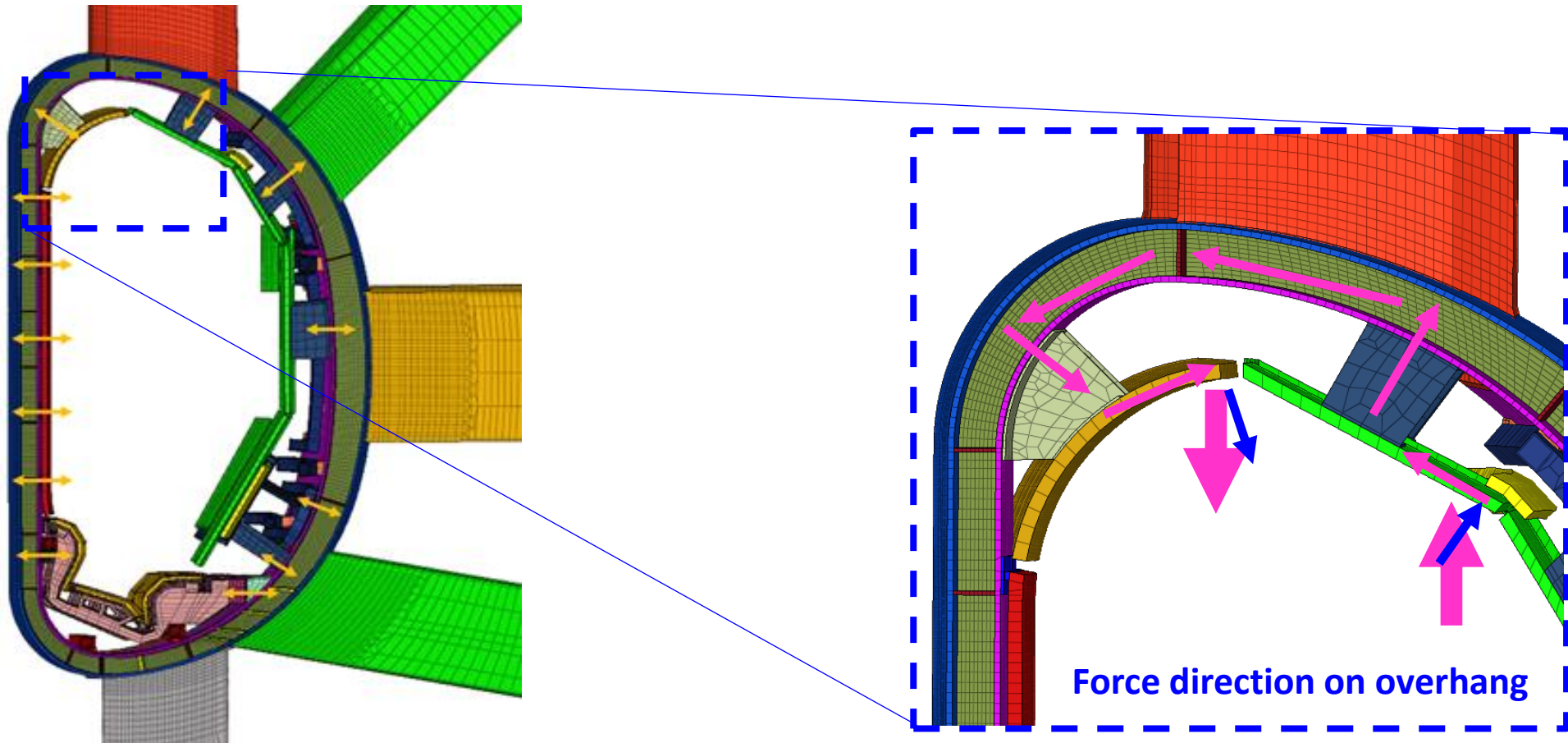
Electromagnetic loads on vacuum vessel - Paths of halo currents



Possible scenario for Upward Vertical Displacement Event (UVDE):

Halo Current (**HC**) circulating in the vacuum vessel

→ significant scenario with forces (**F**) to be used for the verification of the vacuum vessel and of the first wall



Manufacturing and testing - ASME BPVC Sec. VIII Div. 2



Technical requirements:

1. Design and manufacturing code: no nuclear safety req. → ASME Boiler and Pressure Code (BPVC), Section VIII, Division 2
2. Thermo-nuclear fusion requirements:
 - i. Vacuum compatibility requirements (leak detection + cleanliness)
 - ii. Electro-magnetic permeability requirements (possible impact on filler metal and welding processes)

Manufacturing and testing:

- A. Types of welded joints (e.g. full penetration butt joints for longitudinal and circumferential welds within the main shell)
- B. Types and extension of non-destructive examinations (NDE):
 - i. RT or UT: extent = 100% → $E = 1.0$ or extent = 10% → $E = 0.85$ (E is the weld joint efficiency in accordance with ASME BPVC)
 - ii. PT on the surface opposite to UHV for cracks, porosity, leaks
 - iii. VT, LT, magnetic permeability

Figure 4.2.1
Weld Joint Locations Typical of categories A, B, C, D, and E

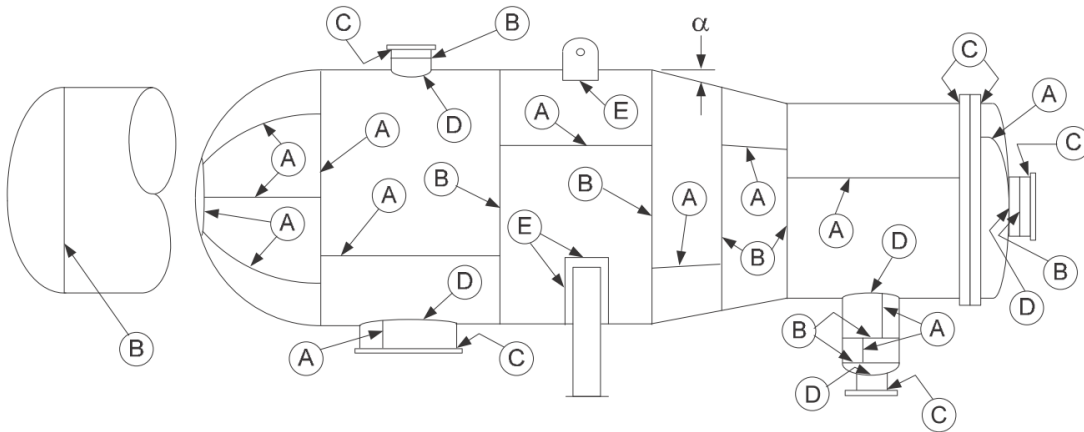


Table 7.2
Nondestructive Examination

Examination Group				1a	1b	2a	2b	3a	3b
Permitted Materials				All Materials in Annex 3-A [Note (18)]	P-No. 1 Gr 1 and 2 P-No. 8 Gr 1	P-No. 8 Gr 2 P-No. 9A Gr 1 P-No. 9B Gr 1 P-No. 11A Gr 1 P-No. 11A Gr 2 P-No. 10H Gr 1	P-No. 1 Gr 1 and 2 P-No. 8 Gr 1	P-No. 8 Gr 2 P-No. 9A Gr 1 P-No. 9B Gr 1 P-No. 10H Gr 1	P-No. 1 Gr 1 and 2 P-No. 8 Gr 1
Weld Joint Efficiency				1.0	1.0	1.0	1.0	0.85	0.85
Joint Category	Type of Weld [Note (1)]		Type of NDE [Note (2)]	Extent of NDE [Note (10)] [Note (11)] [Note (12)]					
A	Full penetration butt weld [Note (19)]	1	Longitudinal joints	RT or UT	100%	100%	100%	100%	25%
				MT or PT	10%	10% [Note (4)]	10%	10% [Note (4)]	10% [Note (4)]
B		1	Circumferential joints on a shell	RT or UT	100%	100%	100%	100%	10% [Note (3)]
				MT or PT	10%	10% [Note (4)]	10%	10% [Note (4)]	10% [Note (4)]

Manufacturing and testing - Factory and Site Acceptance Tests



Table 5-1 Summary of Factory Acceptance Tests and Site Acceptance Tests

Test description	Section	Required Tests	Factory Acceptance Test	Site Acceptance Test
Visual inspection	5.2	-	FAT.01	SAT.01
Weld inspection	5.3	-	FAT.02	-
Magnetic permeability	5.4	-	FAT.03	-
Surface roughness	5.5	-	FAT.04	-
Total hemispherical emissivity	5.6	TES.05	-	-
Dimensional inspection	5.7	-	FAT.06	SAT.06
Cyclic pressure test of inter-shell of the individual vessel Multi-Sectors	5.8	-	FAT.07	-
Helium leak test of the inter-shell boundary of the individual Multi-Sectors and Prototype Sector	5.9	-	FAT.08	SAT.08
Helium leak test of the torus vacuum boundary of the individual port assemblies	5.9	-	FAT.09	-
Tests of bellows	5.10	-	FAT.10	SAT.10
Assembly test of gravity supports (GS) on vacuum vessel (VV)	5.11	-	FAT.11	-
Electrical isolation tests	5.12	-	FAT.12	SAT.12
Functional tests of In-port Welding Equipment for field joining of port ducts to port stubs	5.13	-	FAT.13	-
Functional tests of sector equipment	5.14	-	FAT.14	-
Tests on vacuum vessel instrumentation	5.15	-	FAT.15	SAT.15
Flow test of the individual Multi-Sectors A and B	5.16	-	FAT.16	-

Please see next slides →

The pneumatic pressure testing is applied as a propaedeutic measure for detecting major early crack propagation before helium leak testing →

Prototype sector - Qualifications for risk mitigation

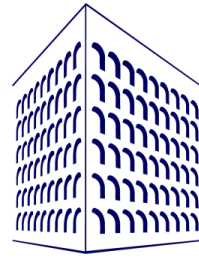


Prototype sector manufactured for **qualification of processes and product with the Contractor:**

- welding processes and procedures including weld repairs
 - optimisation of weld sequence to minimize weld distortions on shells and ports
 - measurement of post welding distortions (same tolerances of production sectors)
 - verification of accesses for weld execution and testing, including helium LT
 - integration of port stubs and verification of alignment tool for port ducts
 - re-pickling, re-passivation, and cleaning treatments of the welded joints in the inter-shell
 - measurement of the magnetic permeability at the completion of the fabrication processes
- } Evaluations are required to the manufacturer (weld distortion management plan) before fabrication can commence

The prototype sector will be delivered for **assembly tests and qualification of processes on site:**

- integration of port ducts with bellows on port stubs
- tests of automated/manual welding processes
- forming of in-vessel coils
- verification of the frequency of intermediate dimensional tests for dimensional control
- integration of divertor rails and first wall supports



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Thank you for your kind attention

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