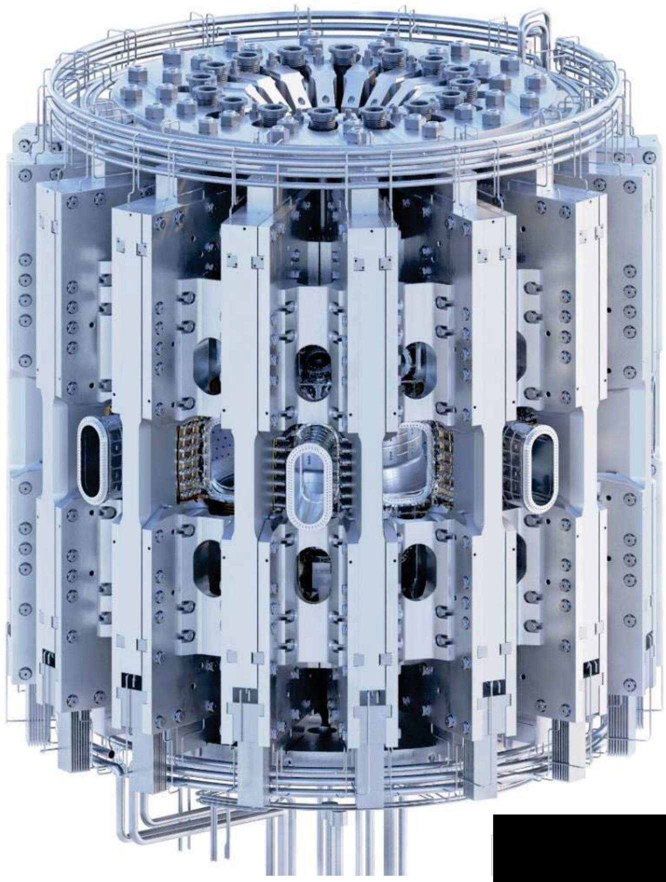
# Support structure of the COMPASS Upgrade tokamak

# TECHNICAL SPECIFICATION

*CU_CUPG-02_PTD_Annex1-TechnicalSpecification*



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## Inspection

| Name | Position | Inspected revision | Date | Signature |
|---|---|---|---|---|
| [redacted] | Chief Engineer | | | |
| [redacted] | Independent control | 22 | 9.6.2023 | |

## Approval

| Name | Position | Approved revision | Date | Signature |
|---|---|---|---|---|
| [redacted] | Head of Engineering Group | 26 | 27.7.2023 | |
| [redacted] | Deputy director | 22 | 9.6.2023 | |

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# LIST OF RELEVANT STANDARDS AND OTHER DOCUMENTS

All listed technical standards should be used in an up-to-date edition including amendments, the year/version included in the table is shown just for reference.

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| EN 1090-2:2009 | Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures |
| EN 10222-5:2017 | Steel forgings for pressure purposes - Part 5: Martensitic, austenitic and austenitic-ferritic stainless steels |
| EN 10250-4:2021 | Open die steel forgings for general engineering purposes - Part 4: Stainless steels |
| EN 10250-1:2022 | Open die steel forgings for general engineering purposes - Part 1: General requirements |
| EN 10283:2019 | Corrosion resistant steel castings |
| ASTM A1080/A1080M-19 | Standard Practice for Hot Isostatic Pressing of Steel, Stainless Steel, and Related Alloy Castings |
| EN ISO 3834-2:2021 | Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements |
| EN 1011-3:2018 | Welding - Recommendations for welding of metallic materials - Part 3: Arc welding of stainless steels |
| EN ISO 15607:2019 | Specification and qualification of welding procedures for metallic materials |
| EN ISO 15609-1:2019 | Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding |
| EN ISO 5817:2023 | Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections |
| EN ISO 9606-1:2017 | Qualification of testing of welders - Fusion welding – Part 1: Steels |
| EN 14732 | Welding personnel – Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials |
| ISO 15614-1:2017 | Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys |
| EN ISO 3506-1:2020 | Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs with specified grades and property classes |

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| EN 10253-3:2009 | Butt-welding pipe fittings - Part 3: Wrought austenitic and austenitic-ferritic (duplex) stainless steels without specific inspection requirements |
| EN 10204:2004 | Metallic products - Types of inspection documents |
| EN ISO 6892-1:2019 | Metallic materials — Tensile testing — Part 1: Method of test at room temperature |
| EN ISO 6892-3:2015 | Metallic materials — Tensile testing — Part 3: Method of test at low temperature |
| EN ISO 148-1:2016 | Metallic materials — Charpy pendulum impact test |
| EN 60404-15:2012 | Magnetic materials - Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials |
| ISO 21920-2:2021 | Geometrical product specifications (GPS) — Surface texture: Profile — Part 2: Terms, definitions and surface texture parameters |
| EN 10228-4:2016 | Non-destructive testing of steel forgings - Part 4: Ultrasonic testing of austenitic and austenitic-ferritic stainless steel forgings |
| EN 12681-1:2017 | Founding - Radiographic testing - Part 1: Film techniques |
| EN ISO 22825:2022 | Non-destructive testing of welds — Ultrasonic testing — Testing of welds in austenitic steels and nickel-based alloys |
| EN ISO 23279:2017 | Non-destructive testing of welds - Ultrasonic testing - Characterization of discontinuities in welds |
| EN 1779:1999 | Non-destructive testing - Leak testing - Criteria for method and technique selection |
| EN ISO 20485:2017 | Non-destructive testing — Leak testing — Tracer gas method |
| ASTM F21-20 | Standard Test Method for Hydrophobic Surface Films by the Atomizer Test |
| CEN/TS 13388:2020 | Copper and copper alloys - Compendium of compositions and products |
| ISO 2768-1 :1989 | General tolerances — Part 1: Tolerances for linear and angular dimensions without individual tolerance indications |
| EN ISO 10012:2003 | Measurement management systems — Requirements for measurement processes and measuring equipment |

# 1 DESCRIPTION OF THE WORK

## 1.1 Subject of the work

**[1.1.1]**
The subject of the work according to this technical specification is the manufacture and assembly of the support structure of the COMPASS Upgrade (COMPASS-U) scientific experimental device. The assembly of the support structure will take place at the place of manufacture of the structure (**the production site**). Once the structure is fully assembled at the Supplier's production site, the Supplier shall measure the dimensions of the structure and assess its compliance with the specification. The Supplier will then disassemble the structure, store it and arrange for the gradual delivery of the individual parts to the COMPASS-U assembly site (**the construction site**). The Supplier shall provide qualified technical assistance to assemble the structure on site.

## 1.2 Division of the work into parts

**[1.2.1]**
In order to coordinate the construction of the entire COMPASS Upgrade tokamak, the work is divided into basic performance and framework performance.

**[1.2.2]**
Basic performance - support structure - includes the design and manufacture of the support structure, assembly at the production site and handing over the work to the Contracting Authority in disassembled condition. This includes, among other things:

- Quality system documentation.
- Production and Assembly Documentation.
- Documentation of the assembly procedure.
- Securing raw materials for the production of the support structure according to the approved documentation.
- Material tests of all batches of used construction material, consisting of tests of mechanical and magnetic properties and chemical composition.
- Production of all components of the support structure according to the approved documentation.
- Demonstration of cleanliness, helium leak test and pressure test of cooling channels.
- Surface treatment of components according to approved documentation, coating of fasteners.
- Assembly of the support structure at the production site.
- Verification of the dimensional accuracy of the entire assembly.
- Measurement protocols of individual parts and the whole assembly.
- As-built Documentation.
- Disassembly, cleaning and packing of the work.
- Spare parts
- Lifting and handling equipment.
- Transport frames.

All expenses needed to cover mentioned activities and/or other deliverables related to the Basic performance shall be covered by the price of individual components as submitted via the public tender bid.

**[1.2.3]**
The framework performance is:

A. Technical support during assembly (in place and time of the COMPASS-U tokamak assembly).

B. Storage.
C. Transportation (i.e. transport of components of the support structure to the construction site).
D. Oversized transport (i.e. transport of oversized loads to the site).
E. Technical support for design changes (i.e. technical support of the Supplier in incorporating possible changes to the design of the support structure).

**[1.2.4]**
The Supplier's technical support in incorporating possible changes to the design of the support structure (point E [1.2.3] ) means:

1. Work of a Project Manager / Engineer / Mechanical Designer / Technician / Production Worker / Assembly Worker.
2. Work of a CNC machine (including CNC machine operator).
3. Work of a conventional/classical machine tool (including machine operator).
4. Welding work (including all costs for welding equipment + welder's work).

## 1.3 Purpose of the work

**[1.3.1]**
The COMPASS-U support structure is a steel skeleton of the new scientific device, the COMPASS-U tokamak. The purpose of the support structure is to provide support for the individual parts of the tokamak, especially the vacuum vessel and the magnetic coils.
The coils of the COMPASS-U tokamak will produce a strong magnetic field of up to 5 Tesla (T). This high magnetic field places high demands on the strength of the structure and the magnetic properties of the material used. Therefore, all material used to produce the work must be of high strength and non-magnetic (or only weakly magnetic) and it is essential to test each batch of the used material for its strength and magnetic properties. AISI 316 LN stainless steel (see below for a narrower specification of the chemical composition) was chosen as the main structural material for the support structure. Alternatively, DIN 1.4429 or AISI 310 S steel can be used.
Due to the high load and minimization of stresses in the structure of the device, it is necessary to follow the specified tolerances in the manufacture of individual components and especially in the overall assembly of the support structure. Any changes to the components and their geometry must be consulted with the Contracting Authority in order to maintain the strength characteristics of the structure and to allow final assembly/completion of the device.
The support structure will encircle and support other parts of the device, some of which will exert high forces on the structure. The vacuum chamber and the magnetic coils will put heavy static and dynamic stress on the structure during operation. Therefore, a series of computer simulations of the support structure was carried out to design the individual components so that the device would not be damaged during operation.
The Supplier shall submit the Production and Assembly Documentation to the Contracting Authority for approval so that the Contracting Authority can verify that any modifications proposed by the Supplier have not resulted in unacceptable deterioration of the parameters of the work (e.g. exceeding the strength limits of the materials used, increased clearance or deformation of the coils fixed in the structure, etc.). If the Contracting Authority's analysis reveals design deficiencies, the results will be forwarded to the Supplier, who will modify the design to achieve parameters consistent with the original specification.
The Supplier shall demonstrate dimensional conformity with the specification by assembling the work at the production site. The Supplier shall issue measurement reports for the assembled work proving that the work is executed within the prescribed tolerances. At the same time, the Supplier shall allow the Contracting Authority to inspect the assembled work.

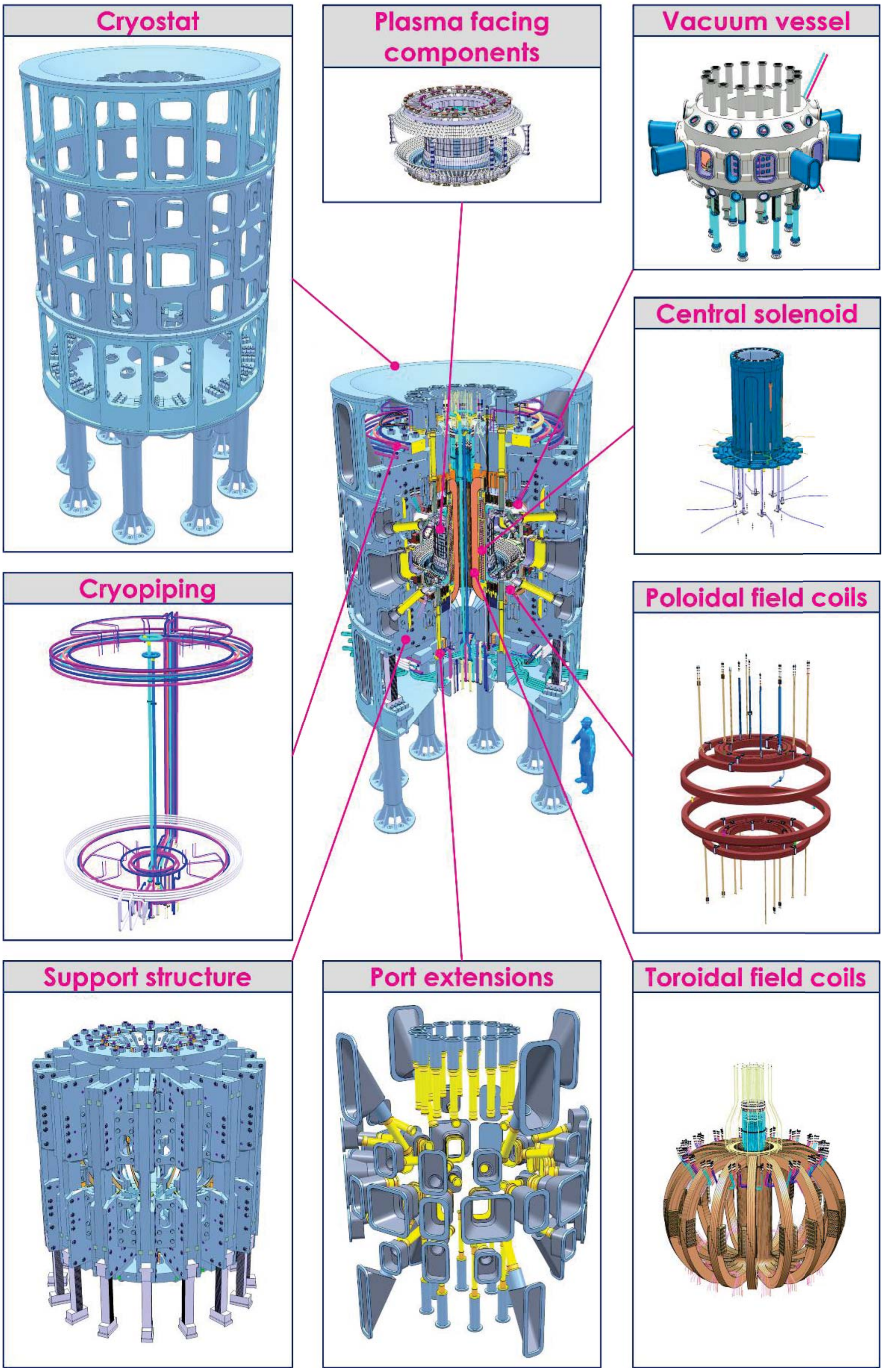


*Figure 1 Overview of the COMPASS Upgrade tokamak design.*

After confirmation by the Contracting Authority, the Supplier shall disassemble the work into individual components (or predetermined units), suitably pack them, place them on transport frames to prevent damage to the components during storage and transport, and shall draw up a hand-over protocol to the Contracting Authority. Thereafter, the Supplier shall store the packaged

parts for a period as agreed with the Contracting Authority, but not exceeding 2 years. During this period, the Supplier shall ensure the gradual transport of the parts to the construction site at the request of the Contracting Authority.
Assembly of the Work at the site of the equipment shall be carried out by the Contracting Authority through a third party in accordance with the Assembly Procedure to be supplied by the Supplier and with the technical assistance of the Supplier. First the bottom and middle part of the support structure will be assembled and then the magnetic coils and the vacuum vessel will be built into the structure. Once the installation of the magnetic coils is complete, the assembly of the support structure will be completed. Technical assistance in both phases of the assembly shall be provided by the Supplier through a qualified manager who has been involved in the assembly of the work at the production site.

**[1.3.2]**
The function of the support structure is to ensure a precise and stable position of the electromagnetic coils of the so-called toroidal magnetic field (hereinafter TF coils), the poloidal magnetic field (hereinafter PF coils) including the central solenoid (hereinafter CS), and the vacuum vessel of the device. This means supporting these components, fixing their position precisely, and then compensating for the dynamic forces that arise during operation, these include namely:

- Slowly varying forces acting mutually between the coils and from the coils themselves in the order of MN (millions of Newtons).
- Rapid shock forces generated by a sudden interruption of the current in the plasma acting on the vacuum vessel with a force of the order of MN transferred to the support structure.
- Thermomechanical forces associated with the operating temperature of the coils and the support structure in the temperature range of 70-293 K.

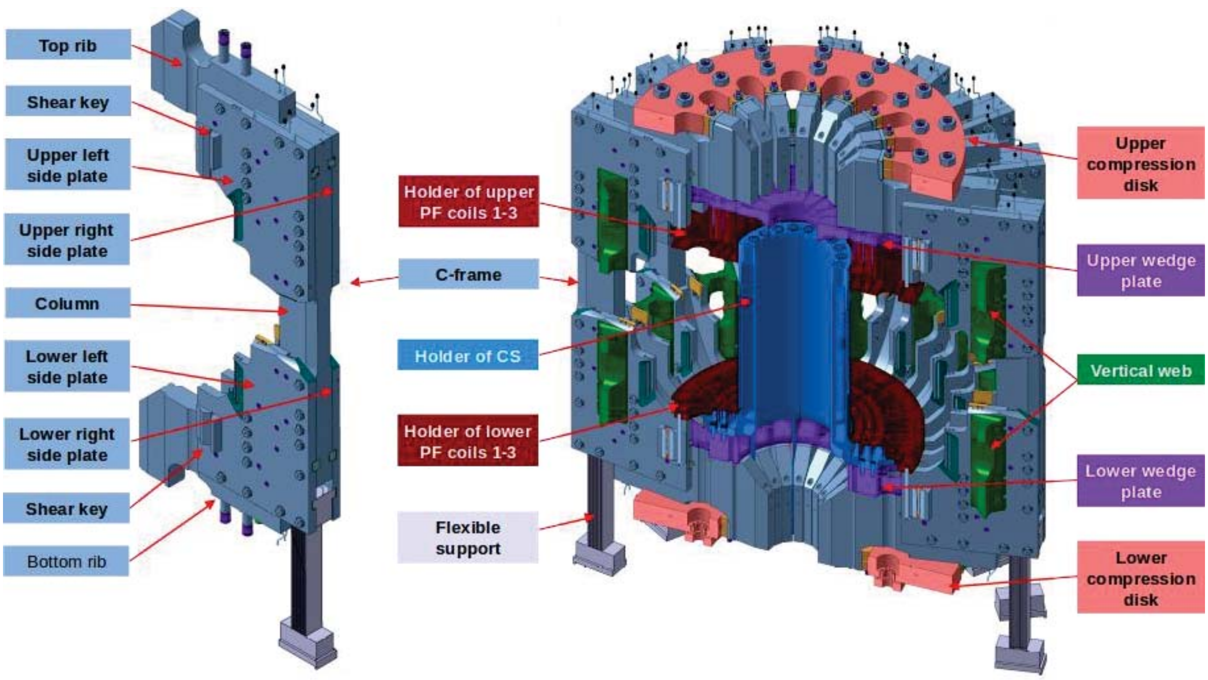


*Figure 2 C-frame assembly and a cross section of the support structure. The holder of CS and flexible supports are not part of the work.*

**[1.3.3]**
The main part of the support structure is designed to fix the D-shaped TF coils, which form the main

component of the magnetic field of the device. Each TF coil is subject to both in-plane and out-of-plane forces. In the coil plane, there are forces stretching the coil. These forces are compensated by a C-frame providing radial and vertical support to the coil. The individual C-frames are bound by compression discs. Out-of-plane (tipping) forces act perpendicular to the plane of the TF coil. The direction and magnitude of the forces may vary at different locations along the coil depending on the magnitude of the local magnetic field. These forces are compensated by wedge plate, C-frame side plates, vertical webs and shear keys between each C-frame. The upper wedge plate connects the centre column of the TF coil with its outer arms by means of the so-called crown.

A total of 8 CS coils and 10 PF coils create a variable magnetic field that induces an electric current in the plasma and controls the position and shape of the plasma. The CS coils and the set of lower 4 PF coils share a common bracket that is bolted directly into the lower wedge plate and the bottom of the support structure. The set of upper 4 PF coils also shares a common bracket, bolted directly into the upper wedge plate. The top of this holder also acts as a side support for the TF coils. Two additional outer PF coils are connected directly to the C-frame side plates. The forces acting on the PF coils can be either slowly varying or dynamic, but will generally be several times lower than the forces acting from the TF coils.

**[1.3.4]**
The most strain sensitive point is the sliding joint of the TF coils, where the TF coils are mechanically disconnected but electrically connected. By supporting both parts of the coils in the vicinity of the sliding joints (TF core and outer limb) with a single (support structure) part—the upper wedge plate—the deformation of this area is reduced.

**[1.3.5]**
The main loading element of the structure is the TF coils. At the maximum electric current in these coils, the total force vertically opening the structure reaches ~56 MN, at this moment ~3.5 MN is applied to each C-frame of the structure. The TF coil further loads the structure with a radial force, where each coil arm tries to move to a larger radius with a force of ~4 MN, and a toroidal force, which is time-varying and causes toroidal twisting of the structure of up to 6.5 mm at the maximum radius.

**[1.3.6]**
The operating temperature range of the support structure is 70 - 293 K. At 293 K the loading conditions are ~4 times lower than at 70 K.

**[1.3.7]**
Basic overview of the mechanical loading of the support structure is summarized in the document CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A4-FEManalysis.

## 1.4 Classification of the work

**[1.4.1]**
The work will be used as a supporting skeleton of a machinery product - the COMPASS Upgrade tokamak. The Supplier should follow the directive 2001/95/ES for the manufacturing and delivery of the work.

Even though the work is not classified by the Contracting authority as a steel structure according to the standard EN 1090, application of the standard EN 1090-2 EXC3 is required wherever it is not specified differently in this technical specification.

**[1.4.2]**
Classification of the equipment in terms of radiation protection:
The work does not contain any radioactive substances or sources of ionizing radiation.

**[1.4.3]**
Classification of equipment in terms of environmental protection:
The work does not contain any substances hazardous to the environment.

**[1.4.4]**
Classification of the equipment in terms of wiring:
The work is not a dedicated electrical installation.

**[1.4.5]**
Classification of the equipment in terms of the pressure equipment:
The work itself is not a pressure equipment according to the directive 2014/68/EU. It contains deep drilled cooling channels of 25 mm diameter in which helium at the temperature of 77 K will flow under the pressure of 2 MPa. After the final on-site assembly, the individual cooling channels will be connected to several cooling buses with an internal diameter of 60 mm becoming category I pressure equipment.

## 1.5 Vacuum compatibility

**[1.5.1]**
The support structure will be located inside a cryostat with strict high vacuum requirements (pressure of ~$10^{-5}$ Pa). This creates constraints on dead volume, outgassing and material finish requirements.

**[1.5.2]**
No part of the structure shall contain virtual leakage caused by the presence of dead spaces. Dead space means any free space in the volume of the material that is connected to the surface of the material by a passage with a cross-section <1mm$^2$.

**[1.5.3]**
All welds must be pickled or passivated either by chemical means (pickling gel/solution) or by electrochemical pickling. Any solution used must then be neutralised and thoroughly cleaned.

**[1.5.4]**
Parts of the support structure must be cleaned before packing for transport. When packing, it is necessary to make precautions to avoid any contamination of the cleaned parts. Used lifting devices, means of transport, auxiliary fasteners and tools must be thoroughly cleaned before handling parts to avoid contamination of cleaned parts and packing material.

**[1.5.5]**
Detailed specification of vacuum compatibility is provided in the accompanying document CU_ORD_VacuumRequirements.

## 1.6 Design of the support structure

**[1.6.1]**
Part of the Technical Specification is the initial design of the support structure. The supplier will prepare Production and Assembly Documentation based on this specification.

**[1.6.2]**
Partial modifications of the design of the support structure by the Supplier are possible, provided that the structural limits of the materials are not exceeded and the functional properties of the support structure are not limited (e.g. increase of the operational deformation of the magnetic field coils placed in the support structure, etc.).

**[1.6.3]**
In particular, it is possible to join parts of the lower C-frame assembly (see the description in [8.1.2]) in a single piece, if this is more cost-effective.

**[1.6.4]**
The combined mechanical and thermal stress shall not exceed two-thirds of the yield strength ($R_{p0.2}$) of the material of the structure at the operating temperature.

**[1.6.5]**
All changes to the support structure in comparison to the initial design must be described separately in the Production and Assembly Documentation and subsequently approved by the Contracting Authority.

## 1.7 Tests and inspections

**[1.7.1]**
The work includes the tests described in the chapter 5.

**[1.7.2]**
Tests 5.1 to 5.7 are interim checks.

**[1.7.3]**
Test 5.8 The assembly of the structure at the production site represents the final inspection of the work (Factory Acceptance Test, FAT).

# 2 TECHNICAL ASSIGNMENT

## 2.1 Construction material

**[2.1.1]**
The material for the support structure must meet the requirements arising from specific environmental conditions: high loads from electromagnetic coils, high vacuum, operating temperature at liquid nitrogen level, high magnetic field and large electric currents induced by rapid changes in the magnetic field.

**[2.1.2]**
The operating temperature of the support structure will be in the range of ~70-293 K.

**[2.1.3]**
The main construction material of most of the support structure is stainless steel (listed as AISI 316LN in the Bill of materials and in the Specification of components of the support structure). The steel composition shall conform to one of the following specifications:

1. AISI 316 LN-CU
2. AISI 316 LN-IG (ITER-grade)
3. DIN 1.4429*
4. AISI 310 S

Different composition could be used only with prior approval from the Contracting authority.

AISI 316 LN-CU is a specific modification of AISI 316 LN designed for the COMPASS Upgrade project. The addition of manganese and nitrogen improves the properties of this steel and allows the same mechanical parameters to be achieved in casted parts as would be possible with the basic steel composition in forged parts. This composition is recommended for any castings that will not undergo Hot Isostatic Pressing (HIP). [E.A. Kenik et al. Journal of Nuclear Materials 483 (2017) 35-43].

**[2.1.4]**
The maximum permissible content of Delta ferrite is 1%.
The normative chemical composition of the steels listed is:

| [weight %] | Fe | Cr | Ni | Mo | Mn | C | N | P | S | Si |
|---|---|---|---|---|---|---|---|---|---|---|
| 316 LN-CU | rem. | 17-18 | 12-12.5 | 2.3-2.7 | 2.5-3.1 | <0.03 | 0.25-0.3 | <0.025 | <0.005 | <0.5 |
| 316 LN-IG | rem. | 17-18 | 12-12.5 | 2.3-2.7 | 1.6-2.0 | <0.03 | 0.12-0.22 | <0.025 | <0.005 | <0.5 |
| DIN 1.4429* | rem. | 16.5-18.5 | 11-14 | 2.5-3 | ≤2.5 | <0.03 | 0.12-0.25 | <0.045 | <0.015 | <1 |
| 310 S | rem. | 24-26 | 19-22 | - | ≤2 | <0.10 | ≤0.11 | <0.045 | <0.015 | <1.5 |

* Higher Mn and N content allowed compared to standard DIN 1.4429

**[2.1.5]**
The steel used must meet the limits for yield strength $R_{p0.2}$ and ultimate strength $R_m$ in the temperature range of 70-293 K. The following table gives the mandatory requirements for the material of the support structure, irrespective of the type of steel:

| | $R_{p0.2}$ (293 K) Yield strength at 293 K | $R_{p0.2}$ (77 K) Yield strength at 77 K | $R_m$ (293 K) Ultimate strength at 293 K | $R_m$ (77 K) Ultimate strength at 77 K |
|---|---|---|---|---|
| Binding requirement | > 200 MPa | > 500 MPa | > 480 MPa | > 1000 MPa |

Furthermore, the used steel must achieve an absorbed energy value of at least 60 J at 77 K in the standard Charpy impact test (see EN ISO 148-1, $KV_2$ value).

**[2.1.6]**
Al-bronze will be used for the compression wedges between the C-frame and the compression disc and also in the shear pin assembly. The reason for this is to prevent vacuum welding of the contact surfaces under high pressure.

| [weight %] | Cu | Al | Fe | Ni | Mn | Zn | Si | Sn |
|---|---|---|---|---|---|---|---|---|
| Al-bronze<br>For example CW306G according to CEN/TS 13388 (421301) | Rem. | 9-11 | 2-4 | 1 | 1.5-3.5 | <0.5 | <0.2 | <0.1 |

**[2.1.7]**
Material of fasteners is prescribed in the bill of material in the document *CU_CUPG-02_PTD_Annex3-Price Schedule and Deliverables*.

**[2.1.8]**
The cooling channel outlets and cooling channel fittings as per [2.6.1] shall be made of AISI 316 or AISI 316L or 304L stainless steel.

**[2.1.9]**
Ensuring low magnetic permeability of the support structure components is a major requirement for the support structure materials. Sufficiently stable materials with a very low magnetic permeability in the temperature range of 70-293 K, for which the permeability does not increase even in locally loaded areas, must be used. Processing (e.g. welding) must be done using methods that do not lead to an increase in the magnetic permeability of the processed materials.

**[2.1.10]**
The used materials must meet the following limits for relative magnetic permeability:

| **Binding requirements for rel. magnetic permeability** | T=293 K | T=77 K |
|---|---|---|
| Basic material | < 1.02 | < 1.05 |
| Welds | < 1.1 | < 1.2 |
| Milled and otherwise machined surfaces (surface layer thinner than 2 mm) | < 1.2 | < 1.3 |
| Bolts larger than M30 under load | < 1.1 | < 1.2 |
| Bolts smaller than M30 under load | < 1.2 | < 1.3 |
| Cooling channels/cooling pipe fittings | < 1.2 | < 1.3 |

## 2.2 Method of production

**[2.2.1]**
The following methods can be used for production:

1. Forgings or rolled sheets wherever possible. Production must follow the applicable standards, such as EN 10250-4.
2. HIP-treated castings – castings with treated surface defects subsequently processed by Hot Isostatic Pressing (HIP) in order to heal volume defects. This method of production is regulated by the standard ASTM A1080/A1080M-19.
3. Castings – castings treated by solution annealing and removal of surface defects, this method of production is only permitted for a few components as specified in the attached Specification of components of the support structure. Compliance with the procedures described in EN 10283 is required.

**[2.2.2]**
The permitted methods for the manufacture of individual parts are specified in the Bill of materials and Specification of components of the support structure. Forgings are generally preferred due to their higher strength, impact resistance and better vacuum compatibility, but some specific parts (namely those without internal cooling channels) can be produced by casting.

## 2.3 Steel quality

**[2.3.1]**
The supplier shall verify the quality of the steel by classifying the internal defects in the material in accordance with EN ISO 10228-4 for forgings and EN 12681 for castings (or equivalent).

**[2.3.2]**
Quality class 3 according to EN ISO 10228-4 and EN 12681-1 is required for all forgings and castings, respectively. Acceptance of lower quality class in not significantly loaded parts of the support structure components is subject to approval by the Contracting authority.

## 2.4 Welds

**[2.4.1]**
Welds will be used to connect the cooling tubes to the drilled cooling channels and to their fittings. Structural welds can also be used to manufacture components where welding is an approved method of manufacture (see Specification of components of the support structure).

**[2.4.2]**
Structural welds shall not cause virtual leaks and closed volumes with capillary connection to the surface (see CU_ORD_VacuumRequirements).

**[2.4.3]**
Welds on all components must have a clean metal surface. It is not necessary to machine the welds. The welds must be free of scale, holes, capillaries, burns and other similar defects.

**[2.4.4]**
The selected weld metal material shall be compatible with the base material and with higher manganese content, e.g. 1.4455 for AISI 316 LN-based steels, which provides stability against delta ferrite formation and thus also limits the risk of increased magnetic permeability in the weld.

**[2.4.5]**
For structural welds, a non-destructive test of 100 % of the weld volume shall be carried out to detect possible defects. The Supplier shall design a suitable test method for each weld and describe it in the Production Documentation.

**[2.4.6]**
Welds and their inspection will be performed in accordance with standards EN ISO 3834-2 and EN 1011-3 and welding procedure qualification according to EN ISO 15607, EN ISO 15609-1, EN ISO

15614-1, and related standards, i.e. welding procedure specification (WPS) and welding procedure qualification report (WPQR) are required. Welding must be performed by personnel certified according to EN ISO 9606-1. The welding must follow EN ISO 5817 and meet the quality requirements for category B set in this standard.

**[2.4.7]**
If the option to use structural welds is used, the Contracting Authority also requires a demonstration on 3 sample welds with similar volume and geometry to the final product using the same materials. These samples will be submitted to the Contracting Authority for analysis.

**[2.4.8]**
The cooling tubes and fittings will be TIG (tungsten inert gas) welded with additional material compatible with the material of the support structure and the material of the fitting.

## 2.5 Surface treatment

**[2.5.1]**
The aim of surface treatments is to achieve vacuum and low temperature compatibility. The surface treatment of the structure parts shall minimize the actual surface area, allow cleaning of parts suitable for high vacuum and prevent vacuum low temperature welding.

**[2.5.2]**
The maximum permissible roughness of machined and unmachined surfaces of the support structure must not exceed the value Ra25, measured in accordance with ISO 21920-2:2021. Any stricter requirements are specified in the drawings or in the detailed Specification of components. The general Surface roughness requirement in the drawings could be loosened to Ra25 for non-functional/contactless surfaces after approval by the Contracting authority. The desired surface roughness can be achieved via:

- Machining.
- Stainless steel shot blasting or shot peening to compact the surface.
- Surface passivation.

The used technology must not introduce unwanted impurities into the surface of the material.

**[2.5.3]**
The surface must generally be easy to clean, and wiping with a cloth napkin must not tear the fibres of the napkin.

**[2.5.4]**
All cutting fluids must be water soluble, free of halogens, phosphorus and sulphur. Where this is not possible, a suitable cleaning method must be provided to maintain the required cleanliness of the part, see chapter 7 Cleaning.

**[2.5.5]**
All bolts must be treated against galling with regards to the high vacuum and cryogenic temperature environment. A suitable coating method for one-time application is for example silver plating.

**[2.5.6]**
The anti-seize coating will be applied to the functional part of the bolts, i.e. their threads. Always use a coated washer under the bolt head or nut. In cases where this is not possible, the entire surface of the bolt will need to be coated.

**[2.5.7]**
At other interfaces where there is a risk of sticking of parts together, different materials, usually Al-Bronze and stainless steel, are used to minimise the risk of welding.

**[2.5.8]**
The surface treatment is required for bolts for the final assembly at the Contracting Authority's site and for fasteners used in assemblies that will be shipped already assembled.

**[2.5.9]**
To avoid damage to the protective coating before final assembly on site, it is possible to use uncoated bolts with vacuum compatible lubricant for on-site test assembly. The lubricant shall be removed after disassembly before the final coating.

## 2.6 Cooling channels

**[2.6.1]**
Some of the cooling channels (especially at the top of the support structure) will be terminated with Swagelok VCR metal fittings or compatible fittings made of AISI 316, AISI 316L or AISI 316LN stainless steel. These channels are indicated on the drawings.

**[2.6.2]**
Fittings compatible with Swagelok VCR fittings must have the same or higher technical and operational parameters than Swagelok VCR fittings. The design of the fitting shall be tested by the manufacturer for helium leakage and shall guarantee a maximum helium leakage rate of 0.4 $\times 10^{-9}$ Pa.m$^3$/s (4 $\times 10^{-9}$ std cm$^3$/s).

**[2.6.3]**
The fitted fittings must be sealed immediately after welding with a sealing cap provided by the fitting manufacturer to prevent damage to the edge of the fitting and the entry of foreign bodies into the channel.

**[2.6.4]**
Channels without fittings must be sufficiently sealed against the entry of foreign bodies and liquids into the channel.

**[2.6.5]**
The contractor must minimize the amount and size of dead ends in the channels, for example from drilling.

**[2.6.6]**
The leakage of the cooling channels will be verified by a helium leak test and a pressure test, as specified in chapter 5.

**[2.6.7]**
The transition of the drilled channel to the stainless steel tube must be smooth. An acceptable transition shape is, for example, concentric reduction according to EN 10253-3 (Figure 3 left) or according to the attached drawing (Figure 3 right). The purpose of the gradual transition is to minimize hydraulic losses in the connection.

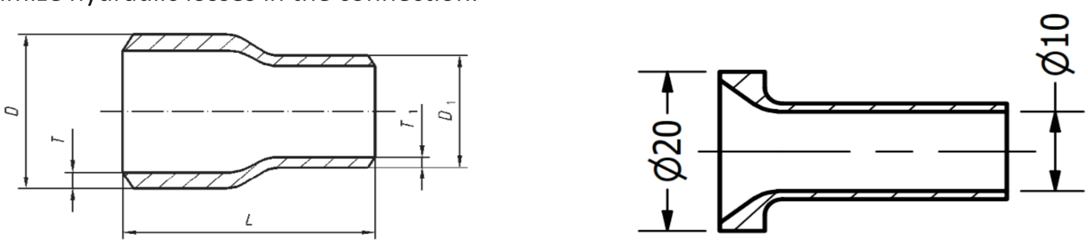


*Figure 3 Possible form of reduction of cooling channels.*

**[2.6.8]**
Welded connection of the transition piece to the cooling tube has to be performed by an operator qualified according to EN 14732.

### 2.7 Tolerances

**[2.7.1]**
Important manufacturing tolerances for main components are shown in drawing documentation or specified in *Specification of components* of the support structure.

**[2.7.2]**
ISO 2768-mK tolerances should be followed where not specified differently.

**[2.7.3]**
Tolerances for the assembly of the support structure are binding and the Supplier is obliged to comply with them. Proof of compliance with this commitment is provided by the protocol as specified in [5.4.2].

**[2.7.4]**
The manufacturing tolerances for individual parts result from the tolerance analysis and can only be changed after agreement with the Contracting Authority.

## 3 DESCRIPTION OF THE PARTS OF THE SUPPORT STRUCTURE AND SOURCE DATA

### 3.1 Parts of the support structure

**[3.1.1]**
The list of parts of the support structure is provided in the Bill of Materials *(CU_CUPG-02_PTD_Annex3-Price Schedule and Deliverables.xlsx*.

**[3.1.2]**
Detailed specification of individual parts is given in the Specification of components of the support structure *(CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A1- PartSpecification.docx*).

**[3.1.3]**
The drawings of the parts are available in the archive *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A2- DrawingDocumentation.zip*.

**[3.1.4]**
The 3D CAD models of the parts are available in the archive *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A3-CATIA.zip* and in the file *CU_CUPG-02-102530_V01_ASM_B02_CAD.stp*.

**[3.1.5]**
The documents referred to in [3.1.1]-[3.1.4] are an integral part of this Technical Specification.

**[3.1.6]**
In the event of a discrepancy between the information provided in different documents, the following order of importance shall apply from highest to lowest:

1. Technical specification (base document),
2. Bill of materials of the parts (CU_CUPG-02_PTD_Annex3-Price Schedule and Deliverables.xlsx)
3. Specification of components of the structure (the visualisation of the parts is for illustrative purposes only),
4. 3D CAD model,
5. Drawing documentation.

**[3.1.7]**
The locations for the bolt threads are marked in the 3D models with an RGB colour code: (128, 0, 255) (dark purple).

**[3.1.8]**
Tolerated dimensions include optional surface coatings (e.g. coating of the keys).

**[3.1.9]**
The areas marked in the 3D models with the RGB colour code (0, 128, 128) (green-blue colour) are not functional areas - they were created to make room for the passage of surrounding systems. After an agreement with the Contracting Authority, it is possible to modify the shape of such surfaces in order to optimize the machining process. Any modifications must not cause local stress concentrators, etc.

## 3.2 Spare parts

**[3.2.1]**
The Supplier shall supply spare parts according to the CU_CUPG-02_PTD_Annex3-Price Schedule and Deliverables.xlsx sheet BOM-pricing column H.

# 4 HANDLING OF PARTS

**[4.1.1]**
A crane and handling equipment are required to handle the parts of the structure. The structural design and manufacture of all handling equipment is part of the work and the handling equipment will be delivered together with parts of the support structure so that the final assembly of the support structure can be carried out on site using a bridge crane with a total capacity of 25 t available on site.

**[4.1.2]**
It is recommended to use existing part elements for the anchoring of parts during handling. New elements intended for the anchoring can be added, but they must be properly described and drawn in the Production Documentation and approved by the Contracting Authority within this documentation. These new elements must not reduce the strength characteristics of the parts.

**[4.1.3]**
The handling position (orientation) should match the position (orientation) of the part in the support structure assembly so that the assembly can be done without the requirement for a second handling position.

**[4.1.4]**
In case the transport position (orientation) of some parts or subassemblies differs from the handling position (orientation), the Supplier will produce handling equipment to flip the parts or subassemblies from the transport to the handling position. This equipment is part of the delivery and the Supplier shall deliver it to the Contracting Authority at the same time as the parts concerned.

**[4.1.5]**
A 4-arm cross with a capacity of 25 metric tons will be secured by the Contracting Authority and available for the final on-site assembly (e.g. for handling the compression discs and wedge plates). The clamping lugs on the cross will be placed on a radius of 890 mm and 1605 mm. The weight of the cross will be < 1.1 t.

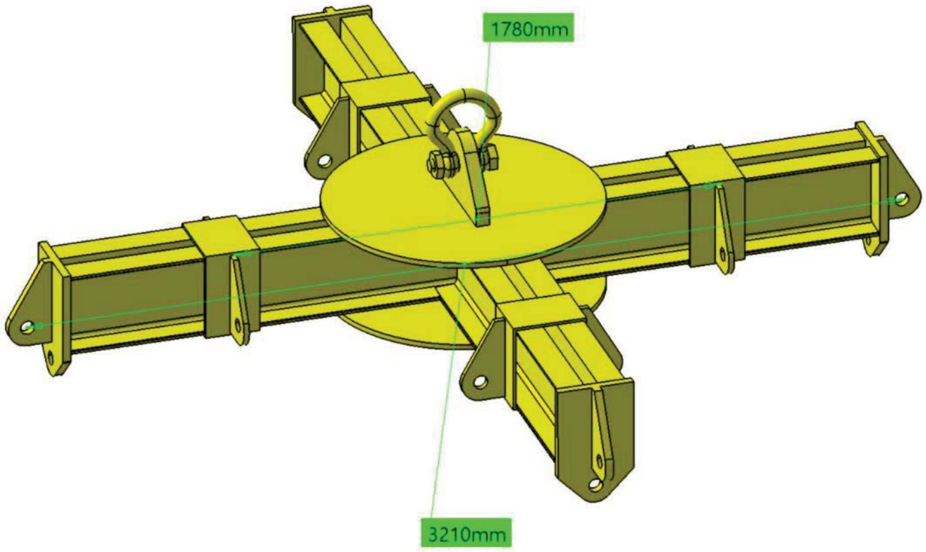


*Figure 4 Lifting cross secured by the Contracting authority*

**[4.1.6]**
For handling the lower assembly of the C-frame, a fork is considered for sliding into the upper horizontal grooves of the C-frame with a load capacity of at least 6 tonnes. The Supplier is responsible for the actual design and delivery of this tool.

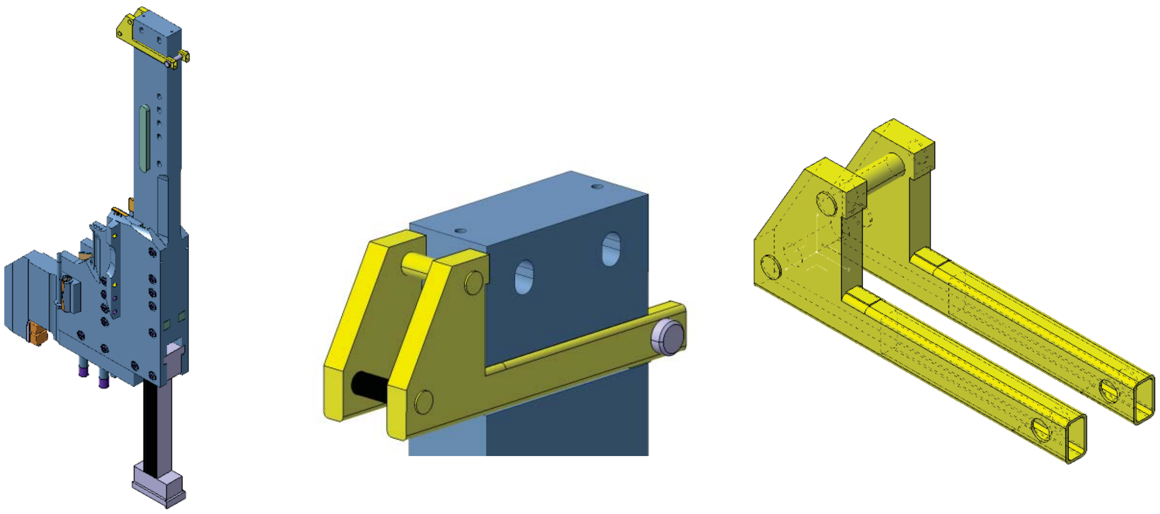

*Figure 5 Design of a possible form of the handling equipment for the lower subassembly of the C-frame.*

**[4.1.7]**
For the handling of the upper C-frame assembly, it is assumed that the upper M80 bolts can be gripped using the handling equipment with a load capacity of at least 4 tonnes. The Supplier is responsible for the actual design and delivery of this tool.

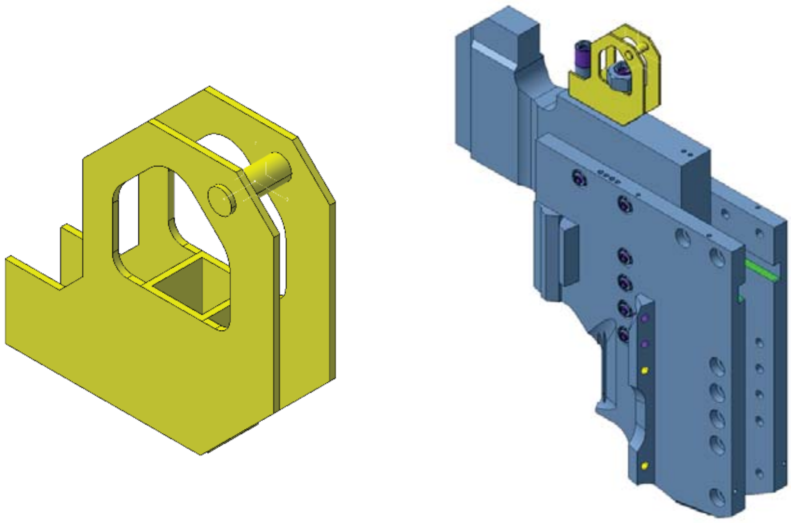

*Figure 6 Design of a possible form of the handling equipment for the upper subassembly of the C-frame.*

# 5 INSPECTION AND TEST REQUIREMENTS

## 5.1 Proof of the chemical composition of the steel

**[5.1.1]**
The Supplier shall carry out a chemical composition analysis for each batch of materials intended for the manufacture of the support structure according to the applicable standards. The choice of the appropriate method is at the Supplier's discretion; however, the Supplier shall document the method used in the report. Depending on the production method and the source of the raw material, it is appropriate to determine the chemical composition either on test wedges which will be part of the ingot or casting from each melting batch of the material or, if stock material is used, on a suitable sample obtained by the cutting method.

**[5.1.2]**
The chemical composition analysis must be evaluated before further processing of the material. If the identified material properties do not meet the requirements set forth in this specification and the approved production documentation, the material shall not be used for the production of the work.

**[5.1.3]**
For each test, the Contractor shall issue a report assessing the compliance of the tested batch of material with the requirements specified in [2.1.4] of this specification. The protocol shall be handed over to the Contracting Authority.

**[5.1.4]**
The protocols are subject to approval by the Contracting Authority.

## 5.2 Demonstration of mechanical properties of materials

**[5.2.1]**
The Supplier shall carry out a test of mechanical properties in a certified laboratory for each batch of materials to be used in the manufacture of the support structure. Depending on the production method and the source of the raw material, the mechanical properties (tensile test and Charpy notch impact test) shall be measured either on test wedges which will be part of the forging, casting or castings treated by HIP from each melting batch of the material or, in the case of stock material, on a suitable sample obtained by the cutting method.

**[5.2.2]**
The tensile test will be carried out according to EN ISO 6892-1 at room temperature and according to EN ISO 6892-3 at liquid nitrogen temperature (77 K).

**[5.2.3]**
The Charpy impact test will be carried out at 77 K according to EN ISO 148-1 and related standards.

**[5.2.4]**
In addition, the Supplier shall provide the Contracting Authority with 10 test bodies for the tensile test and 5 V-notched test bars for Charpy impact test from each batch of material for possible control testing.

**[5.2.5]**
The test must be evaluated before further processing of the material. If the identified material properties do not meet the requirements set forth in this specification and the approved production documentation, the material shall not be used for the production of the work.

**[5.2.6]**
For each test, the Supplier shall issue a report assessing the compliance of the tested batch of material with the requirements specified in [2.1.5] of this specification.

**[5.2.7]**
The protocols are subject to approval by the Contracting Authority.

## 5.3 Demonstration of magnetic properties of materials

**[5.3.1]**
The supplier shall carry out a test of the magnetic properties, namely a measurement of the relative magnetic permeability, for each batch of materials intended for the manufacture of the support structure. Depending on the production method and the source of the raw material, the magnetic permeability should be measured either on test wedges that will be part of the forging, casting or casting treated by HIP from each melting batch of the material, or, if stock material is used, on a suitable sample obtained by the cutting method that does not affect the magnetic permeability. Measurements will be made at room temperature (approximately 293 K) and possibly at liquid nitrogen temperature (approximately 77 K).

**[5.3.2]**
The relative magnetic permeability of the material at room temperature shall comply with the requirements given in [2.1.10]. Alternatively, a test at liquid nitrogen temperature can be performed and if the material meets the requirements of [2.1.10] at this temperature, it can be used for the manufacture of the Work.

**[5.3.3]**
The measurements will be carried out according to EN 60404-15, preferably using a magnetic permeability meter (chap. 6 of that standard).

**[5.3.4]**
The test must be evaluated before further processing of the material. If the identified material properties do not meet the requirements set forth in this specification and the approved production documentation, the material shall not be used for the production of the work.

**[5.3.5]**
For each test, the Supplier shall issue a report assessing the compliance of the tested batch of material with the requirements specified in [2.1.10] of this specification.

**[5.3.6]**
The protocols are subject to approval by the Contracting Authority.

## 5.4 Proof of dimensional conformity

**[5.4.1]**
For each manufactured part, the Supplier shall prove the dimensional conformity with the approved production documentation.

**[5.4.2]**
The Supplier shall prove the dimensional conformity with the approved production documentation for the completely assembled support structure.

**[5.4.3]**
The dimensional conformity check shall be performed by measuring instruments with a valid metrological confirmation according to EN ISO 10012. The Contracting Authority can request the Supplier to provide valid calibration certificates.
Measurement protocols are subject to approval by the Contracting Authority.

**[5.4.4]**
The Supplier shall, upon request and without undue delay, allow the Contracting Authority to inspect the dimensions of any part by its own measuring instruments.

## 5.5 Proof of quality of semi-finished steel products

**[5.5.1]**
The Supplier shall prove the volume quality of the steel semi-finished products of the main support structure components (i.e. except of fasteners, cooling tubes etc.) by a non-destructive testing (NDT): by the radiographic method (X-ray) or ultrasonic method. For forgings the tests are governed by EN 10228-4, for castings by EN 12681-1 or equivalent. For selected components (see Specification of components of the support structure) a full volume inspection (100% testing) is required. For any castings and castings processed by HIP, the Supplier shall propose a suitable procedure.

**[5.5.2]**
Special attention should be given to highly stressed areas (see CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A4-FEManalysis) and areas with increased risk of coolant leakage (e.g. areas with a small distance between the cooling channel and surface of the part, bolt holes or grooves for keys).

**[5.5.3]**
On the basis of the made NDT, the Supplier shall draw up a report to document the compliance of the steel with the requirements set out in chapter 2.3.

**[5.5.4]**
The Supplier shall perform a local test of all welds. The Supplier shall design a suitable non-destructive testing method for each weld and describe it in the Production Documentation.

**[5.5.5]**
The Supplier shall demonstrate in a protocol that the quality of all welds conforms to the requirements set out in chapter 2.4. Each weld report will include a photograph of the weld and the result of the examination.

## 5.6 Demonstration of cooling channel cleanliness

**[5.6.1]**
The Supplier shall provide a protocol to demonstrate that all cooling channels are clean.

**[5.6.2]**
The passability of all cooling channels will be demonstrated during the channel cleaning procedure by photographs or video recording of the endoscopic check of channel cleanliness .

## 5.7 Demonstration of leak tightness of cooling channels

**[5.7.1]**
The Supplier shall prove the leak tightness of the cooling channels by first a nitrogen pressure test and then a helium leak test, according to the standards EN ISO 20485 and EN 1779 and the following provisions.

**[5.7.2]**
No condensation or moisture shall be present on the component being tested upon starting the test.

**[5.7.3]**

Each cooling channel shall be tested separately

**[5.7.4]**

The Supplier shall perform the pressure test with nitrogen at a pressure of 2.5 MPa for 10 minutes. A cooling channel is considered tight if there is no more than a 1 % drop in test pressure during the test, or if the observed difference between the test pressure values at the beginning and at the end of the measurement can be clearly attributed to changes in the temperature of the test medium or atmospheric pressure and ambient temperature during the test.

**[5.7.5]**

The helium leak test shall be performed by the Supplier using a calibrated mass spectrometer leak detector and helium tracer gas using the method A.2 or A.3 according to EN 1779. The helium inflow into the tested channel must not exceed $1\times10^{-10}$ Pa.m$^3$/s.

**[5.7.6]**

On the basis of the performed measurements, the Supplier shall draw up a test report proving the tightness of all cooling channels. In the protocol, the Supplier shall state, among other things:

- the vacuum achieved in the test,
- detected background signal before the actual helium spraying begins,
- the purity of the test helium used,
- the approximate pressure in the helium pressure bottle at the start of the spray.

## 5.8 Assembly of the support structure at the production site

**[5.8.1]**

The Supplier shall carry out the final test of the manufactured support structure on the production site. The test consists of complete assembly of the support structure, photodocumentation of all assembly steps and protocol proof of the conformity of the assembled support structure with the approved production documentation.

**[5.8.2]**

The Supplier assembles the complete support structure on the production site.

**[5.8.3]**

The Supplier will provide detailed photo documentation of all assembly steps with illustrations of important details.

**[5.8.4]**

The Supplier shall provide a time-lapse recording of the entire build procedure from at least one fixed position so that the recording can be used for promotional purposes of the project and to check the entire build process. The frame rate of the time-lapse recording shall be at least 1 frame per minute.

**[5.8.5]**

The Supplier shall allow the participation of the Contracting Authority's representatives throughout the assembly process. The Supplier shall invite the Contracting Authority to participate in writing sufficiently in advance of the start of the assembly to enable the Contracting Authority to participate in the assembly.

**[5.8.6]**

The Supplier shall allow the Contracting Authority to perform a metrological measurement of the assembled support structure.

**[5.8.7]**
The Supplier shall prove the conformity of the support structure with the approved production documentation on the basis of a measurement report of the complete assembled support structure.

**[5.8.8]**
The Supplier shall record the order in which the individual parts were machined in the case of larger batches so that the development of machining accuracy can be evaluated and, if necessary, the positioning of individual parts in the assembly can be adjusted to take this into account in order to minimise overall inaccuracies in the assembly.

**[5.8.9]**
The Supplier shall provide the Contracting Authority with assembly documentation that is modified and supplemented according to the actual course of assembly of the support structure. The assembly documentation will include detailed photo documentation.

**[5.8.10]**
On the basis of the above points, the Contracting Authority and the Supplier shall certify the **Protocol of the support structure assembly at the production site**, provided that no deficiencies were found during the test.

**[5.8.11]**
In the event that deficiencies are found, a **Record of defects and deficiencies in the support structure assembly at the production site** will be made, including a deadline for their correction. The successful performance of the test assembly will then be confirmed by the **Protocol of the support structure assembly at the production site** signed by both parties after all deficiencies have been eliminated.

**[5.8.12]**
To assemble the support structure at the production site, the Supplier will manufacture a temporary support fixture (legs) and ensure its anchoring to the surface on which the assembly will take place. This fixture must be sufficiently dimensioned to support the full weight of the support structure.

**[5.8.13]**
This fixture must be anchored to the support structure in the same way as the flexible legs that will anchor the support structure to the base—the bottom lid of the cryostat at the construction site. The connection interface on the side of the support structure is defined on each c-frame by a gap between the side plates and a pair of 80 mm wide slots for keys, see Figure 7.

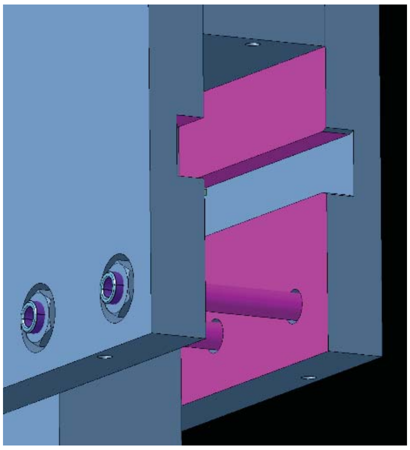

*Figure 7 connection point of the leg of the support structure.*

**[5.8.14]**
As some parts of the support structure will have been given a final clean during the test of assembly,

it is very important to ensure cleanliness when handling these parts. All operations must be carried out in accordance with the instructions in the chapter 8.3.

## 5.9 Tests of fasteners

**[5.9.1]**

Testing of chemical composition and mechanical properties of fasteners shall be secured and documented or certificates 3.1 according to EN 10204 proving conformity with prescribed material and strength class shall be provided.

**[5.9.2]**
Conformity of magnetic permeability of fasteners with requirements stated in chapter [2.1.10] shall be demonstrated for randomly selected fasteners in the amount of 10% from each fastener type.

# 6 TRAINING OF THE CONTRACTING AUTHORITY'S EMPLOYEES

**[6.1.1]**
The Supplier shall allow the participation of at least 2 persons designated by the Contracting Authority in the assembly of the structure and ensure that they are trained to assemble the structure.

**[6.1.2]**
The Supplier shall keep the trainees informed of the assembly procedure and all rules that must be observed during assembly.

**[6.1.3]**
The aim of the training is for the trained personnel to be able to manage the final assembly of the support structure at the construction site.

# 7 CLEANING

## 7.1 Cleaning the parts before assembling them

**[7.1.1]**
To minimize cross-contamination of parts and to avoid damage during assembly, parts must be cleaned of sawdust, scale, grease and other contaminants before assembly. The threads must be thoroughly cleaned.

**[7.1.2]**
Parts that will be transported to the construction site in assembled condition must be carefully cleaned and completely degreased before assembly (as this cannot be done afterwards without the need to disassemble and reassemble them). Cleaning of parts must be carried out in accordance with the rules for the use of parts in high vacuum.

## 7.2 Cleaning of parts before packing

**[7.2.1]**
All parts must be thoroughly cleaned and completely degreased before packing. Cleaning of parts must be carried out in accordance with the rules for the use of parts in high vacuum and the document CU_ORD_VacuumRequirements.

**[7.2.2]**
After cleaning, the Supplier shall limit the handling of parts as much as possible. All subsequent

operations, especially packing and placing on transport frames, must take place in a clean environment.

**[7.2.3]**
The parts that will be delivered to the site in assembled condition will be cleaned before assembly and can only be lightly cleaned before packing - for example, blowing off dust with dry nitrogen or cleaning individual areas with solvents (wash with acetone and then with pure ethanol or pure isopropanol). The assembly as a whole can no longer be washed with the recommended cleaning procedure due to possible fluid deposits in inaccessible areas.

## 7.3 Cleaning procedure

**[7.3.1]**
Cleaning of the components of the support structure is a multi-step process to remove any contaminants (grease, oils, etc.) that would restrict the evacuation of the cryostat in which the support structure will be installed in. The source of contamination by impurities is usually the material production process (scale, dirt, etc.), machining (cutting fluids, etc.) and handling (hand grease, sweat, contamination of handling equipment, etc.).

**[7.3.2]**
All processes used for cleaning or handling parts of the support structure shall be vacuum compatible.

**[7.3.3]**
The cleaning procedure must not disturb the surface finish of the parts.

**[7.3.4]**
Recommended cleaning procedure:
- Step 1 - Mechanical cleaning: Removal of coarse dirt by suitable means - brushes, compressed air, vacuum cleaner.
- Step 2 - Washing: Wash with a suitable detergent (for example Elma Clean 115c or Tickopur R33) diluted in deionised water at the appropriate temperature.
- Step 3 - Cleaning: Cleaning in an ultrasonic cleaner or high-pressure cleaner.
- Step 4 - Rinsing: Remove detergent and remaining dirt with deionised water. A high-pressure cleaner can be used.
- Step 5 - Drying: Drying in a low-dust, hydrocarbon-free atmosphere. Dry nitrogen or a clean air stream can be used.
- Step 6 - Cleanliness check

**[7.3.5]**
The Supplier shall clean all smaller parts of the structure, up to a minimum of 1300 mm x 600 mm x 600 mm, in an ultrasonic cleaner.

**[7.3.6]**
For cleaning larger parts where ultrasonic cleaning cannot be used, the Supplier shall use a high pressure cleaner.

**[7.3.7]**
The cleanliness check must pass three tests:
- Test 1: UV light verification. The entire surface of the parts must be illuminated in the dark with a sufficiently strong UV-A source and all surfaces must be visually inspected. No contamination (layers, splashes, droplets, spills, etc.) must be visible under UV light.
- Test 2: Verify cleanliness with a clean cotton cloth. After wiping the surface, there must be no visible contamination of dirt on the cloth.

- Test 3: Verification of purity with deionised water. When spraying with deionised water, a continuous layer of water must be formed on a flat surface (no beading up of water).

The recommended procedure for performing the tests is given in ASTM F21.
If the cleanliness verification fails, the cleaning process must be repeated.

**[7.3.8]**
The Supplier shall clean all cooling channels.

**[7.3.9]**
The recommended procedure for cleaning the cooling channels is the same as the above procedure with the following clarification:

- Cleaning of the channels shall be carried out just before the welding of fittings.
- The cleanliness check will only be performed with UV light and an endoscope.

The Supplier shall draw up a report on the inspection of the cleanliness of the channels, which shall include photographs (or a video recording) from the endoscope from the inspection of all channels. The photographs must also demonstrate the clear passage of the entire cooling channel.

**[7.3.10]**
The details of planned processes for cleaning or handling shall be described in the production documentation and shall be approved by the Contracting Authority as part of the approval of the entire documentation. If these processes are changed or new processes are selected during the course of the work, these processes must be approved in writing prior to their application.

**[7.3.11]**
The proposed cleaning procedures must be appropriate to the type of contamination. If cutting fluid is used for machining, it must be verified that it is cleanable by the proposed procedure.

**[7.3.12]**
After cleaning, all parts must be handled in such a way that their cleanliness is not compromised. The use of clean gloves (powder-free latex or nitrile gloves, cotton gloves) is mandatory. Gloves must be changed regularly to prevent cross-contamination.

# 8 HANDOVER OF THE WORK, STORAGE OF PARTS AND TRANSPORT TO THE SITE

## 8.1 Dismantling of the support structure

**[8.1.1]**
Upon confirmation of successful completion of the final test according to 5.8 by the Contracting Authority, the Supplier shall disassemble the assembly into sub-assemblies and individual parts, clean them and then pack them so that they are not damaged during storage and transport. The Supplier shall mark and place the packed parts on the marked transport frames.

**[8.1.2]**
The C-frame assembly will be split into a lower and upper section only. These parts shall be packed, stored and transported in a position corresponding to the position of the part in the assembly, or the Supplier shall provide handling equipment for turning the subassembly from the assembly position to the transport position and back.
The lower part includes parts:

- C-frame bottom rib 100061_V12_PRT
- Lower left side plate100065_V14_PRT
- Lower right side plate 100066_V14_PRT
- Column 100060_V12_PRT (or 100060_V13_PRT or 100060_V14_PRT)

- Connection accessories (including tight keys)
- Related cooling tubes etc.

The upper part includes parts:

- Top rib of C-frame 100062_V12_PRT
- Upper left side plate 100064_V14_PRT
- Upper right side plate 100063_V14_PRT
- Connection accessories (including tight keys)
- Related cooling tubes etc.

## 8.2 Marking of parts and transport frames

**[8.2.1]**
All parts shall be marked electrochemically or by stamping or a similar method with the part number according to the BOM and the serial number of the part in a series of identical parts. The "_PRT" ending of the part number is not necessary, the marking will then have the format of "XXXXXX_VYY ZZ", where "XXXXXX" is the unique 6-digit part number, "VYY" is the variant designation and "ZZ" is the serial number of the part. The way of marking connection elements shall be agreed with the Contracting Authority.

**[8.2.2]**
The position of the marking in relation to the part must be the same for all pieces of one part.

**[8.2.3]**
All parts shall be clearly identified by easily removable labels attached to the parts packaging.

**[8.2.4]**
All transport frames must be clearly marked with a label on the frame. The marking must be resistant to damage.

**[8.2.5]**
The label shall indicate the part identification, the nomenclature of the part, the part number and the weight of the part. If there is more than one part placed on the transport frame, then the frame label must show the details for all parts.

## 8.3 Packaging and handling

**[8.3.1]**
Cleaned parts must be carefully packaged to prevent contamination during handling, storage and transport. Preferred materials used for packaging are polyethylene, aluminium foil, cellulose-based fabric/paper, or a combination thereof. All materials used must be low in volatile substances (dyes, plasticizers, anti-corrosives, hydrocarbons, etc.)

**[8.3.2]**
All surfaces must be protected against accidental damage (during handling, storage, etc.). The packaging must be able to withstand all planned operations, e.g. lifting by crane, lifting by forklift, attachment to truck trailer, etc.

**[8.3.3]**
The packaging must protect the surface finish of the parts from being damaged during transport.

**[8.3.4]**
Pipe openings must be tightly sealed. The fittings fitted according to [2.6.1] must be sealed with a cap provided by the fitting manufacturer to prevent damage to the edge of the fitting.

**[8.3.5]**
For smaller parts it is recommended to use a plastic box covered with polyethylene. For large parts it

is recommended to wrap the parts in polyethylene film, which will be fixed with stretch wrapping and plastic binding tape.

**[8.3.6]**
The use of adhesive tape to protect and package parts is limited to packaging where steel will not be contaminated by the tape. The adhesive tape must not come into contact with the surface of the parts.

**[8.3.7]**
The packaging must take into account fixation to transport frames.

**[8.3.8]**
Parts must be packed dry internally and externally.

**[8.3.9]**
The packaging must be designed to keep volume to a minimum without reducing the effectiveness of its protection.

**[8.3.10]**
The packaging must be provided with a label of the packaged part according to [8.2.3] and handling instructions.

**[8.3.11]**
The Supplier shall allow the presence of a representative of the Contracting Authority during packing. After inspection, the packaging must be sealed so that the part(s) cannot be unpacked without breaking the seal.

**[8.3.12]**
Persons handling parts must wear clean powder-free latex, nitrile or cotton gloves and be dressed in clean work overalls. All such protective equipment must be changed frequently enough to prevent cross-contamination.

**[8.3.13]**
For storage and transport, the packaged parts must be placed on transport frames that allow the parts to be handled, placed in storage and their final transportation. Each transport frame will hold one or more parts depending on the size of the parts. The size of the frames must allow the road transport of frames with parts.

**[8.3.14]**
If multiple parts (or assemblies of parts) are placed on one frame, each part (assembly of parts) must be mounted on the frame separately, independent of the other parts.

**[8.3.15]**
The design of the frames must ensure that the parts are fixed so that they are not loosened or damaged when the frames and parts are transported to the site.

**[8.3.16]**
After placement on the transport frames, the Supplier and the Contracting Authority shall check the seals of the stored parts and confirm by signature that the transport frame packing slip corresponds to the contents of the frame and that the parts are sufficiently protected against damage during storage and transport.

**[8.3.17]**
During transport, all transport frames must be adequately protected against thermal or mechanical stresses that may adversely affect the parts. The attachment of the frames must prevent potential impact loads on the parts due to sudden movements or accidental drops. Shock absorbing material must be used.

**[8.3.18]**
The handling equipment used must not cause contamination of clean parts. Care should be taken especially (but not exclusively) with tie-downs (e.g. oil curtains, ropes or hooks) and crane hoists / crane tracks/ forklifts (dripping lubricant).

## 8.4 Handing over the work

**[8.4.1]**
The Contracting Authority shall take over the properly packed and labelled parts placed on the transport frames from the Supplier at the production site (or at the storage site) on the basis of an inspection and approved Shipping documents.

**[8.4.2]**
The acceptance of the work is conditional on the successful completion of the final test of the manufactured support structure by assembling it on the production site according to chapter 5.8, the removal of any defects found and the submission of complete documentation according to 10.4 - 10.6.

**[8.4.3]**
The handover of the work shall be confirmed by both parties in the **Handover protocol**.

## 8.5 Storage of packaged parts

**[8.5.1]**
Upon acceptance of the work by the Contracting Authority, the Supplier shall store all packaged and sealed parts on transport frames in temporary storage. The storage period will be a maximum of 2 years from the date of handover to the Contracting Authority.

**[8.5.2]**
The Supplier shall store the parts inside the building in a place where they will be fully protected from climatic influences, especially humidity, and from damage of any kind.

**[8.5.3]**
The Supplier shall ensure that the parts are not tampered with and that the sealed packaging of the parts is not damaged.

**[8.5.4]**
The Supplier is fully responsible for any damage to the stored parts.

**[8.5.5]**
Upon request, the Supplier shall allow the Contracting Authority to inspect the storage of individual parts without undue delay.

## 8.6 Transport, Oversized transport to location

**[8.6.1]**
Upon a request from the Contracting Authority, the Supplier shall transport the packaged parts on transport frames to the site of the equipment. Each delivery will be made at the request of the Contracting Authority upon an agreement with the Supplier.

**[8.6.2]**
The Contracting Authority anticipates a maximum of 12 hauls and 2 oversize hauls. The Supplier shall propose the transport of parts in this range of shipments.

**[8.6.3]**
The particular order of transports of the individual frames will be agreed upon with the Contracting

Authority to allow for optimal construction process. The lower half of the structure will be loaded first, followed by the upper half of the structure, with certain delay.

**[8.6.4]**
In the event of damage to the seal or packaging of the parts, representatives of the Supplier and the Contracting Authority shall unpack the parts and assess whether the parts are in good condition or they might be damaged. The Contracting Authority has the right to refuse to accept parts with a broken seal or damaged packaging and to demand their replacement from the Supplier.

# 9 TECHNICAL SUPPORT DURING ASSEMBLY

**[9.1.1]**
The work shall include technical assistance of the Supplier during the assembly of the support structure at the site during the assembly of the equipment.

**[9.1.2]**
The scope of technical assistance is set at a maximum of 1000 hours.

**[9.1.3]**
The place of technical assistance is the place of construction of the COMPASS-U tokamak: Institute of Plasma Physics of the CAS, Fusion Plasma division, U Slovanky 2525/1a, 182 00 Prague 8, Czech Republic.

**[9.1.4]**
Technical support during assembly will be provided exclusively by the Supplier's professionally qualified technical staff who have personally participated in the assembly test at the production site and meet the requirements defined in the contract.

# 10 DOCUMENTATION

## 10.1 General requirements on documentation

**[10.1.1]**
The Supplier shall prepare a **Quality Plan**, **Production and Assembly Documentation**, **As-built Documentation**, **Manual** and **Photodocumentation**.

**[10.1.2]**
The documentation referred to in [10.1.1] shall be prepared either in Czech or in English language. The Contracting Authority may request any of the documentation to be prepared in both Czech and English language versions. The documentation is subject to the approval of the Contracting Authority as well as any revision of the documentation.

**[10.1.3]**
The Supplier shall submit the **Quality Plan** to the Contracting Authority for approval no later than **2 months after the effective date of the contract**.

**[10.1.4]**
The Supplier shall submit the **Production and Assembly Documentation** to the Contracting Authority for approval no later than **5 months after the effective date of the contract**.

**[10.1.5]**
The Supplier shall submit the **As-built Documentation**, the **Manual** and the **Photodocumentation** to the Contracting Authority for approval prior to the acceptance of the work by the Contracting Authority.

**[10.1.6]**
The Supplier shall submit the documentation according to [10.1.1] to the Contracting Authority in 4 (four) copies and digitally in 2 (two) copies on two USB media.

**[10.1.7]**
The digital version will include the complete documentation including drawings in PDF format and complete source files of the 3D model and construction drawings in DWG, CATIA or STEP format.

**[10.1.8]**
The contracting authority will review the documentation and issue a decision on the documentation within 30 days of receipt for approval.

**[10.1.9]**
The Contracting Authority shall issue one of the following decisions on the **Production and Assembly Documentation** based on its review of the documentation:

A. The Contracting Authority approves the documentation. The documentation is in full compliance with the assignment and the Supplier may proceed with the work without restriction.
B. The Contracting Authority does not approve the documentation, but the Supplier may order materials for the manufacture of the support structure. The solutions proposed in the documentation need to be checked and the Contracting Authority must therefore carry out additional analysis to verify their impact.
C. The Contracting Authority does not approve the documentation and shall return the documentation to the Supplier for completion or redrafting.

**[10.1.10]**
In the case of decision B, the Contracting Authority shall secure a computer analysis of the Supplier's designed support structure at its own expense. The results of the analysis shall be forwarded to the Supplier without undue delay within 2 months of the decision. The Supplier undertakes to

incorporate the results of the analysis into the documentation within 30 days of receipt of the results or within a period agreed with the Contracting Authority. The Supplier shall again submit the corrected documentation to the Contracting Authority for approval.

**[10.1.11]**
In the case of decision C, the Supplier shall incorporate the Contracting Authority's comments no later than 30 days after receipt of the decision or within a time period as agreed with the Contracting Authority. The Supplier shall again submit the corrected documentation to the Contracting Authority for approval.

**[10.1.12]**
Ordering the material prior to the approval of the Production and Assembly documentation is on the own risk of the Supplier as this might by incompatible with the final approved documentation.

## 10.2 Quality documentation

**[10.2.1]**
The Supplier shall prepare a **Quality Plan** covering at least:

- Responsibility of management (responsible persons) for contract performance.
- Document and records management.
- Resource management.
- Processes of contract implementation.
- Equipment/Material Identification and Status management.
- Inspection, surveillance and audit procedures.
- Management of non-conforming products and corrective actions.

**[10.2.2]**
The Quality Plan shall include certificates and attestations related to the performance of the work (certification of the Supplier, qualification of welders, …) or plan of their acquisition.

**[10.2.3]**
On the basis of the inspections and tests carried out, the Supplier shall without undue delay issue

1. certificates of the chemical composition of the structural material,
2. measurement protocols of the magnetic properties of the structural material,
3. measurement protocols of the mechanical properties of the structural material,
4. protocols of NDT of the volume quality of semi-finished products,
5. metrological protocols for the manufactured parts,
6. weld inspection protocols,
7. protocols of cooling channels cleanliness check,
8. protocols for the helium leak test of the cooling channels
9. protocols for the pressure test of the cooling channels,
10. metrological protocol confirming the conformity of the assembled support structure with the production documentation and
11. the Protocol of the support structure assembly at the production site.

The protocols shall contain identification and calibration status of the equipment used, and identification of the inspector/tester. All protocols are subject to the approval of the Contracting Authority.

**[10.2.4]**
The Supplier shall issue all inspection documents related to the chemical composition, mechanical and magnetic properties of the structural material as Inspection Certificates 3.2 according to EN 10204 on its own expenses. Inspection Certificates 3.2 shall be approved by a third-party certified inspection authority selected based on prior approval by the Contracting Authority (e.g. TÜV SÜD,

TÜV NORD, TÜV Rheinland or other).

## 10.3 Production and Assembly Documentation

**[10.3.1]**
The Supplier shall prepare **Production Documentation** that shall, among other things, describe in detail all the production processes and technologies the Supplier plans to use for the manufacture of the parts of the support structure and its assembly and the design of the individual parts of the support structure. The documentation shall also contain detailed **Inspection and Test Plan** in accordance with chapter 5.

**[10.3.2]**
The Supplier shall prepare **Assembly Documentation** describing in detail the procedure of assembling the entire support structure. The documentation will include a detailed diagram of the assembly of the individual manufactured parts for easy orientation and instructions for the safe, smooth and logical assembly of the entire support structure.

**[10.3.3]**
The Production and Assembly Documentation must include a detailed **List of production materials**: i.e. the list of semi-finished products (forgings, castings, castings + HIP, rolled plates, ...) for the manufacture of individual parts of the support structure, assembly fixtures and connection elements.

**[10.3.4]**
The List of production materials shall include following information for individual items:

- material,
- dimensions,
- weight,
- manufacturing method (forging, casting, casting + HIP, cold rolling, hot rolling etc.),
- heat treatment,
- already after rough machining (yes/no).

**[10.3.5]**
The Contracting Authority reserves the right to designate selected manufacturing, inspection, test and/or assembly operations as mandatory Witness or Hold points. The Supplier shall provide the Contracting Authority with notice five working days in advance of such points.

## 10.4 As-built Documentation

**[10.4.1]**
The Supplier shall prepare the **As-built Documentation** to document all changes made to the support structure components and procedures compared to the approved Production and Assembly Documents.

**[10.4.2]**
In the case of small changes, the As-built Documentation may be in the form of an annex to the Production and Assembly Documentation, upon agreement with the Contracting Authority.

## 10.5 Manual

**[10.5.1]**
In the **Manual**, the Supplier shall specify the operation and maintenance rules for the support structure to ensure the long-term durability and functionality of the structure. It shall also provide a

description of the recommended service inspections and the recommended frequency of these inspections. Furthermore, the documentation shall describe the process of final disassembly and disposal of the structure at the end of the operation.

### 10.6 Photodocumentation

**[10.6.1]**
The Supplier will provide continuous photodocumentation of the entire production process. The aim of the photodocumentation is to document the methods of machining and handling of individual manufactured parts.

**[10.6.2]**
The Supplier shall provide detailed photographic documentation of the assembly of the support structure at the production site. The aim of the photodocumentation is to create a visual manual of the assembly of the support structure.

**[10.6.3]**
The Supplier shall provide a time-lapse recording from a fixed position of the entire process of assembling the support structure.

## 11 OTHER

**[11.1.1]**
If the Contracting Authority requests the Supplier to make a geometric change to a component of the support structure, the production of which has not yet started, and if this change does not require a change in the quantity of input raw materials or processing technology, the Supplier shall make this change without this affecting the time and price of the Work.

**[11.1.2]**
The Supplier shall allow presence of representatives of the Contracting Authority during all stages of the manufacturing process. The Contracting Authority should be granted the right to make photo and video documentation of the work in progress. Traveling of these representatives to the production site is on the expenses of the Contracting Authority.

**[11.1.3]**
The Contracting Authority and the Supplier shall meet at least once per two weeks to discuss the progress of the realization of the extent of delivery. The form of the Regular Progress Meetings (online or in person) is to be agreed between both sides and shall be organized by the Supplier. In exceptional cases, the meeting could be postponed by one week. The Supplier shall summarize the discussion that took place in Regular Progress Reports. The Regular Progress Report of the meeting shall be submitted one week after the meeting took place at the latest.

## 12 ACCOMPANYING DOCUMENTS

### 12.1 Bill of materials of the support structure

Bill of materials of the support structure is provided in the document *CU_CUPG-02_PTD_Annex3-Price Schedule and Deliverables*

### 12.2 Specification of components of the support structure

Specification of individual components of the support structure is provided in the document *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A1- SpecificationOfComponents*

## 12.3 Drawing documentation

Technical drawings are provided in the archive *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A2-DrawingDocumentation.zip*

## 12.4 CAD data

CAD 3D models are provided in the archive *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A3-CATIA.zip* and in the file *CU_CUPG-02-102530_V01_ASM_B02_CAD.stp*

## 12.5 Vacuum requirements

See the document *CU_ORD_VacuumRequirements* for detailed requirements on vacuum compatibility of used materials and for cleaning procedure specifications.

## 12.6 Shipment unloading area

See the document *CU_DOC_ShipmentUnloadingArea* for details on the delivery site and shipment unloading area.

## 12.7 FEM analysis summary

Summary of ANSYS finite element analysis of the support structure is provided in the document *CU_CUPG-02_PTD_Annex1-TechnicalSpecification-A4-FEManalysis.*