MARKET SURVEY TECHNICAL NOTE

HEATING NEUTRAL BEAM MAGNETIC SHIELDING SUPPLY

Tables

Figures

ABBREVIATIONS AND ACRONYMS

ACCC	Active Correction and Compensation Coil
BtP	Build to Print
DNB	Diagnostic Neutral Beam
HNB	Heating Neutral Beam
HVB	High Voltage Bushing
NA	Not Applicable
NDT	Non Destructive Testing
NB	Neutral Beam
PIA	Protection Important Activity
PIC	Protection Important Component
PMS	Passive Magnetic Shield
QC	Quality Control
RCC-MR	Regles de Conception et de Construction des Materiels Mecaniques des ilots nucleaires réacteur à neutrons rapides
RPOM	Rear PMS Opening Mechanism
RPS	Reference Procurement Specifications

RT	Radiography Testing
SDC-IC	Iter structural design criteria for in-vessel components
SIC	Safety Important Component
SS	Stainless Steel
TC	Thermocouple
VPI	Vacuum Pressure Impregnation

1 Scope

Fusion for Energy (F4E) is publishing a Market Survey in preparation of the signature of the Procurement Arrangement (PA) with IO for the supply of the Heating Neutral Beam Magnetic Shielding. This Technical Note provides supporting information so that interested companies can answer to the F4E market survey with a minimum of background. The information on the tender procedure provided with this document is only preliminary and only for the purpose of this Market Survey.

2 Introduction to the Heating Neutral Beam Injector

The ITER project aims to build a fusion device, twice the size of the largest current devices, with the goal of demonstrating the scientific and technical feasibility of fusion power. It is a joint project between the European Union, China, India, Japan, South Korea, the Russian Federation and the USA. ITER is currently under construction at Cadarache site, in the south of France. The fusion reactor is expected to be ready for first operation by end of 2035.

Most of the components that make up the ITER project are to be manufactured by each of the participating countries and contributed in kind through so-called Domestic Agencies. Fusion for Energy is the European Domestic Agency (EUDA).

There are two Heating Neutral Beam (HNB) Injectors and one Diagnostic Neutral Beam (DNB) injector inside the ITER Neutral Beam Cell (Figure 1). A third HNB Injector may be added at a later stage.

The ITER Heating Neutral Beam system injects high-energy neutrals into the tokamak plasma. This beam interacts with the tokamak plasma and heats the plasma. The global heating power of Neutral beam heating system of ITER is 33 MW with two NB Injectors (HNB1 and HNB2). A third injector (HNB 3) is optional and may be added in the future in order to provide an additional 16.5MW heating power to the plasma.

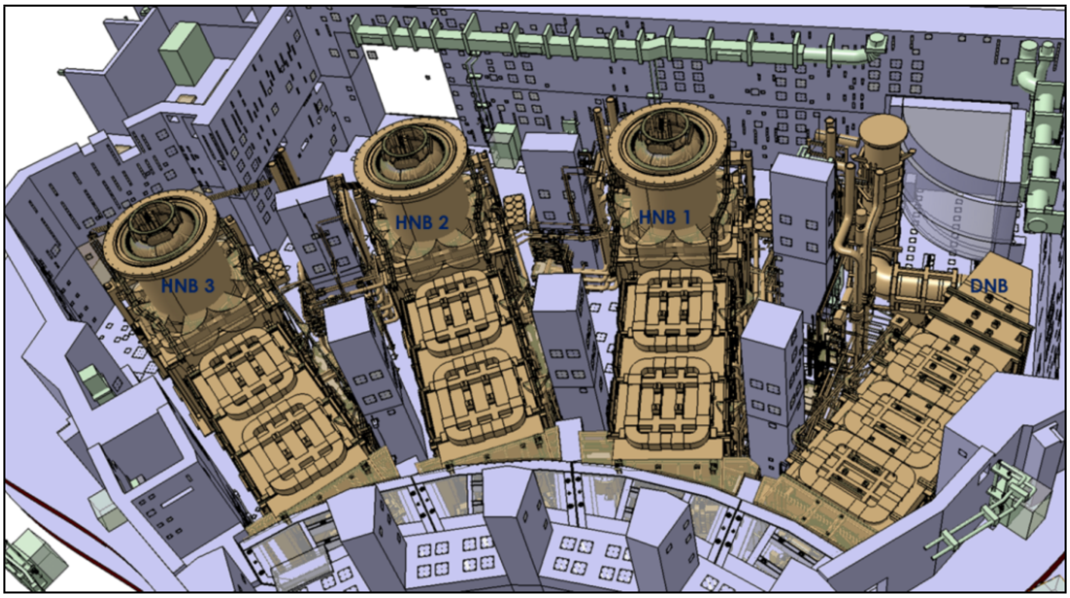

Figure 1: Three HNB injectors and DNB vessels (Diagnostic NB) inside NB cell

The cross section of the NB Injector connected to the ITER Tokamak is represented in Figure 2.

The Magnetic Shielding is composed by PMS (Passive Magnetic Shield) and ACCC (Active Correction and Compensation Coil) surrounding the NB Vessel and the HVB (High Voltage Bushing). It shields the beam from the stray field of the ITER Tokamak, and it is not a vacuum barrier.

One Magnetic Shielding is needed for each of the three HNBs and one DNB.

The HNB1 & 2 Magnetic Shieldings are part of the scope of supply of F4E. The DNB magnetic Shielding is part of the scope of supply of the Indian Domestic Agency.

Magnetic Shielding for the HNB3 or part of it may be in scope of the F4E procurement.

Indicatively each unit of the Magnetic Shielding is 15 meter long, with a weight of 600 tons.

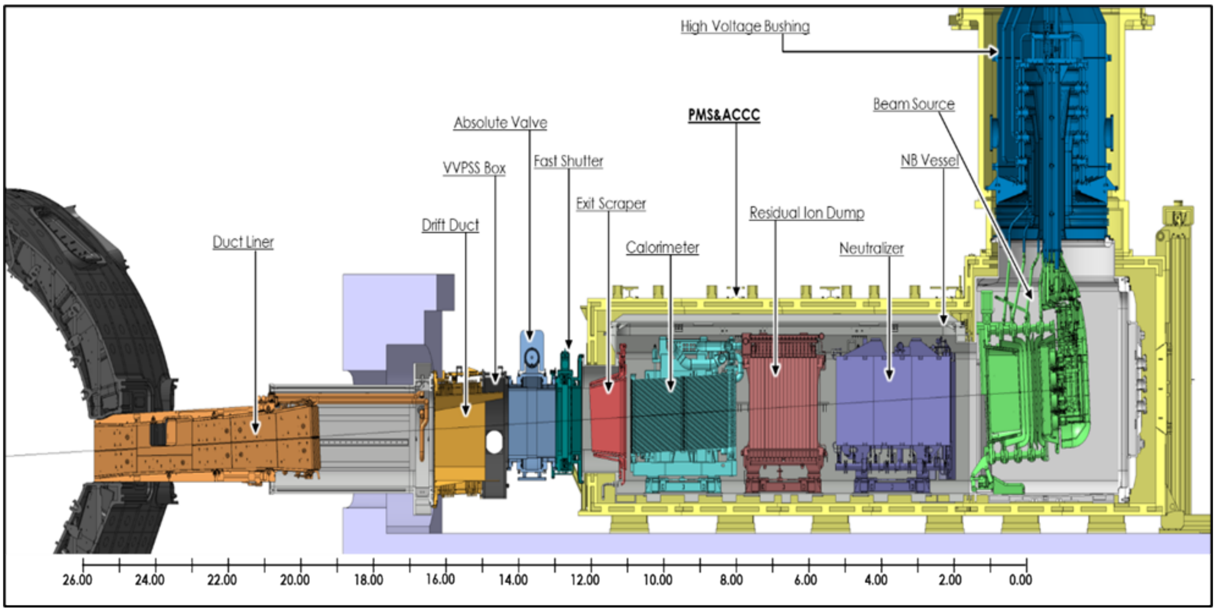

Figure 2: Cross section of the NB Injector

3 Description of the Magnetic Shielding

3.1 Overview

The HNB Magnetic Shielding is made from the following main sub-components:

- Vessel PMS and RPOM (Rear PMS Opening Mechanism) (see Figure 4,Figure 6 and Figure 11)

  It is a box structure made of carbon steel enclosing the NB Vessel (see Figure 6)

  The rear part is a door also made of carbon steel with an opening mechanism (RPOM) (see Figure 12)

- High Voltage Bushing PMS (see Figure 5)

  It is a carbon steel cylinder enclosing the High Voltage Bushing (this latter not part of the supply)

- Active Correction Compensation Coils (ACCC) (see Figure 3)

  It is a set of 8 coils (ACCC1 to ACCC8) located inside the top and bottom Vessel PMS

  Plus a coil (ACCC9) winded around the NB vessel

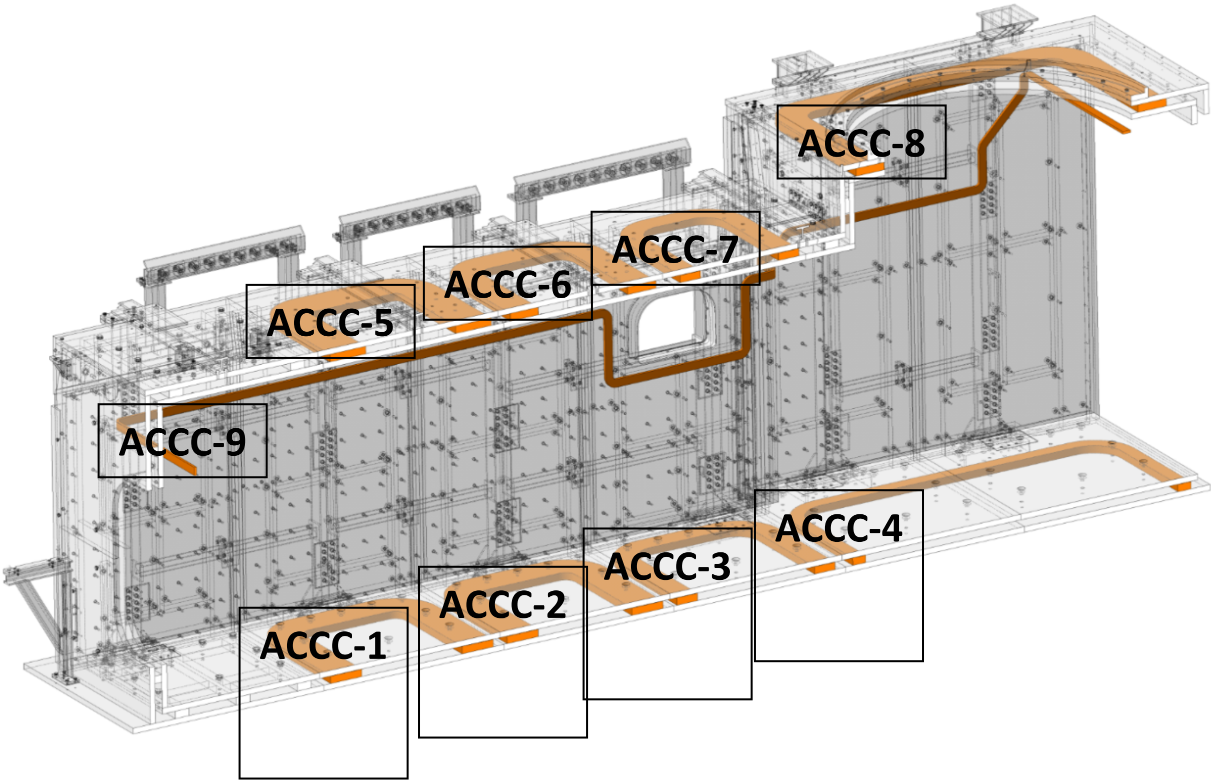

Figure 3 ACCC

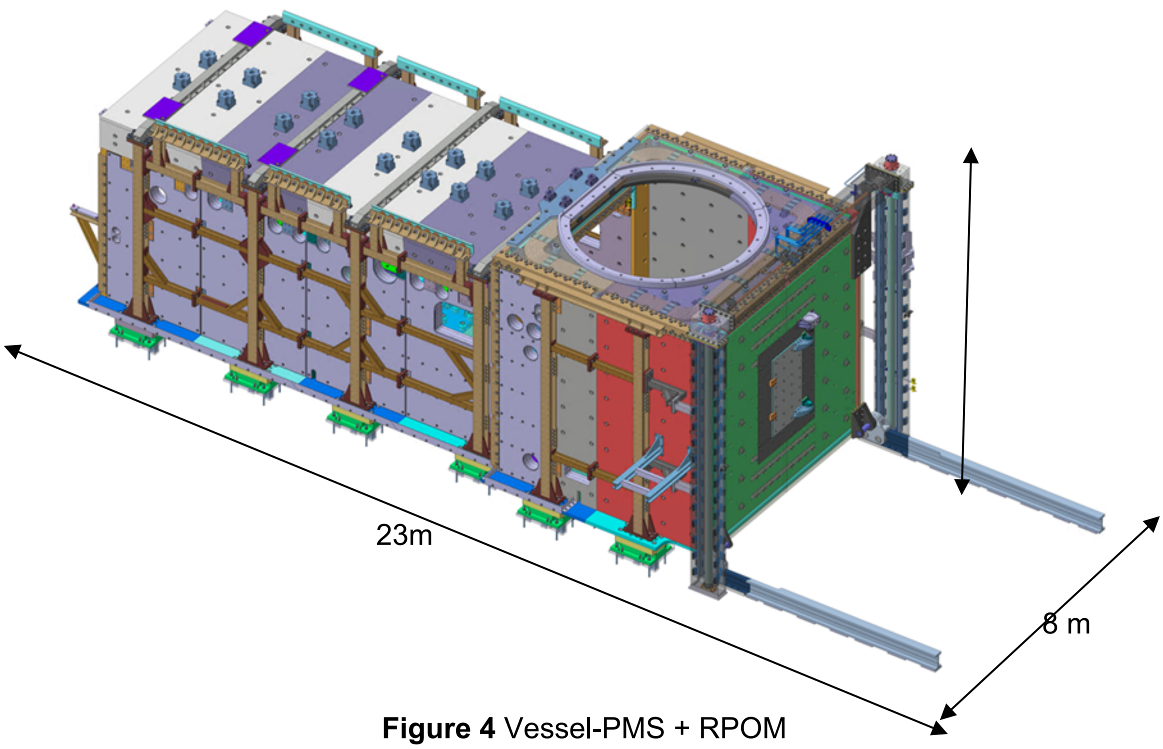

Figure 4 Vessel-PMS + RPOM

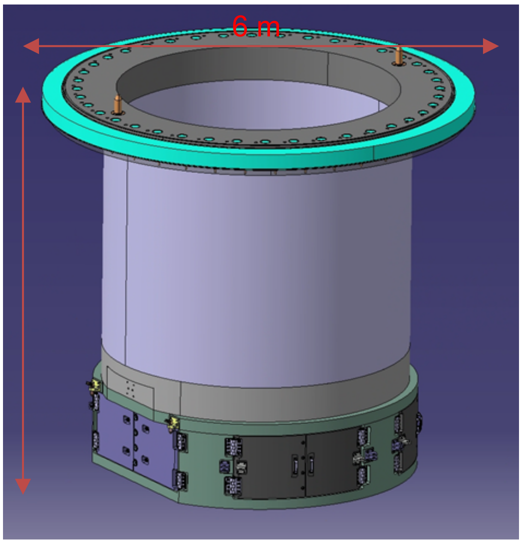

Figure 5 High Voltage Bushing PMS

The main functions of the Magnetic Shielding are:

- Reducing the magnetic field inside the HNB to allow correct operation of the components.

  This is performed by thick carbon steel plates all around the vessel and coils located at the top and bottom part.

- Shielding the Neutral Beam Cell from radiations coming from inside the tokamak.

  This is achieved with polyethylene and lead plates.

- Supporting the NB Vacuum Vessel.

  Performed by the bottom plates and the supports anchored to the floor.

- Providing Secondary confinement barrier from the NB Cell area to the upper floor,

  Performed by the High Voltage Bushing PMS.

3.2 Vessel PMS

The vessel PMS is a modular structure composed by 6 bottom parts (Bottom PMS), 6 top parts (Top PMS), 12 side parts (Side PMS) and 2 front parts (Front PMS), as illustrated in Figure 6.

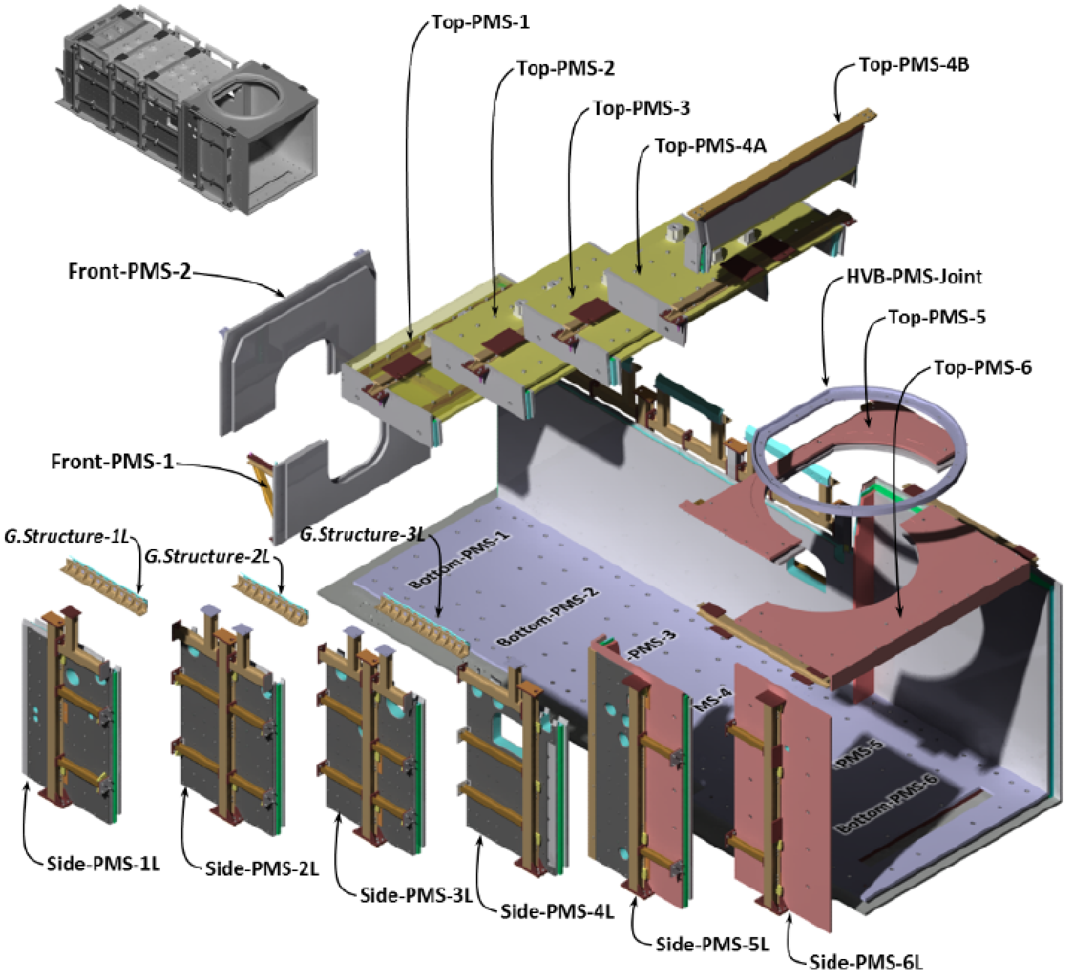

Figure 6 Vessel PMS exploded view

Each part is a sandwich composed by two plates 75mm thick in carbon steel (S235), separated by 100mm long spacers.

The Side PMS contains internally a 100mm thick Polyethylene plate, and externally a 24mm thick lead plate, encapsulated in stainless steel sheet. The H beam structure fixed to the external plate is used for the mechanical connection (see Figure 7). Internal plates are made from pure iron to improve the magnetic performance.

Bottom and Top PMS contain internally, in sandwich, the coils (see Figure 8 and Figure 9).

Top PMS (with the embedded coils) have been designed to be removed to have maintenance (using Remote Handling) access to the NB Vessel from the top.

Maximum dimension of the plates is 6.4m x 2.7m x 75mm (Side-PMS-6R). The weight of each assembled plate sandwich is approx. 20 tons.

The largest part to be handled (Bottom-PMS 5 + Bottom-PMS 6 + ACCC 4) is 6.4m x 5.3m and weights approx. 42 tons.

The overall assembly weight is around 500 tons, and it is supported by 12 base plates 1m x 0.75m wide (see Figure 10).

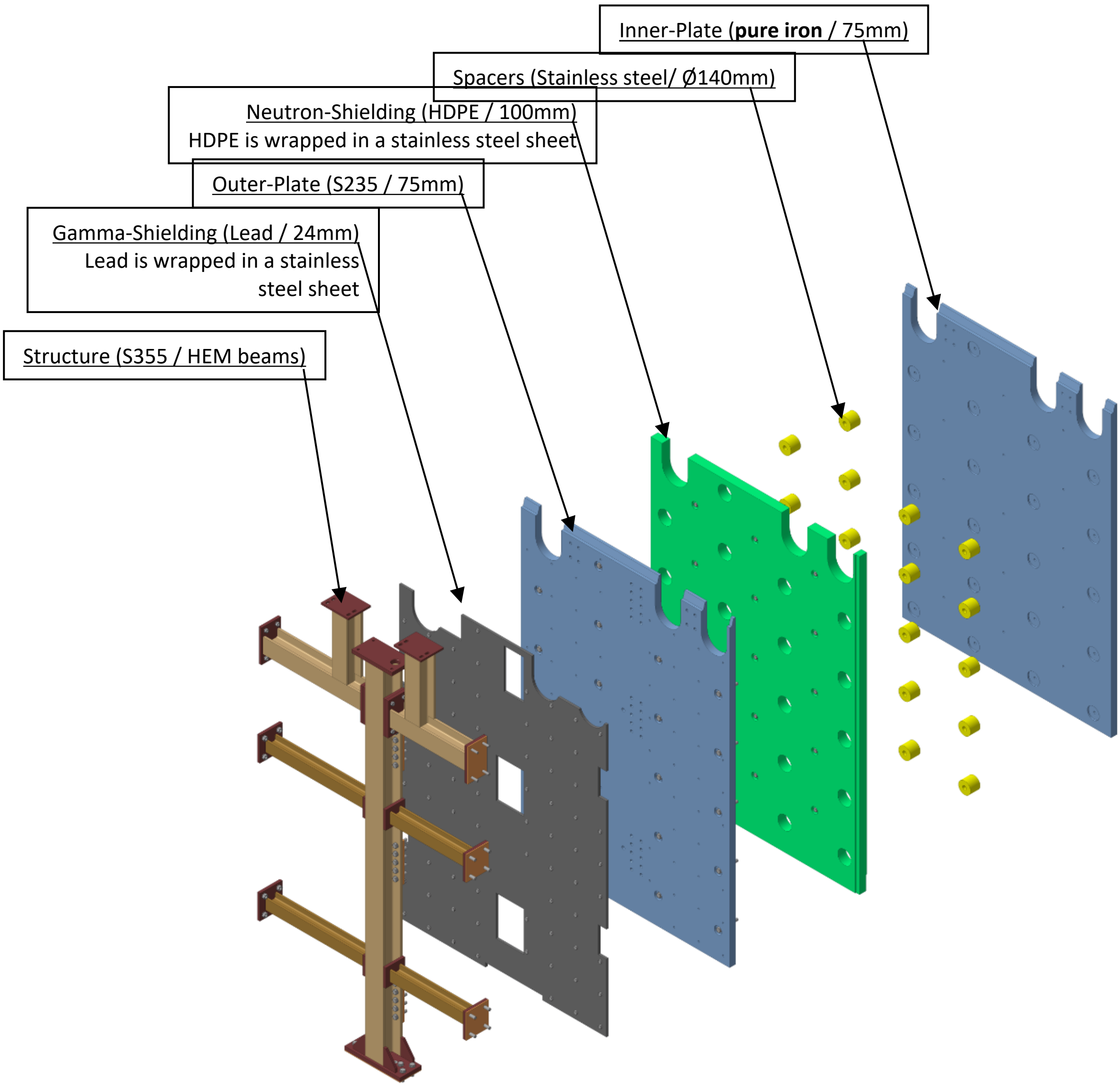

Figure 7 Side PMS exploded view

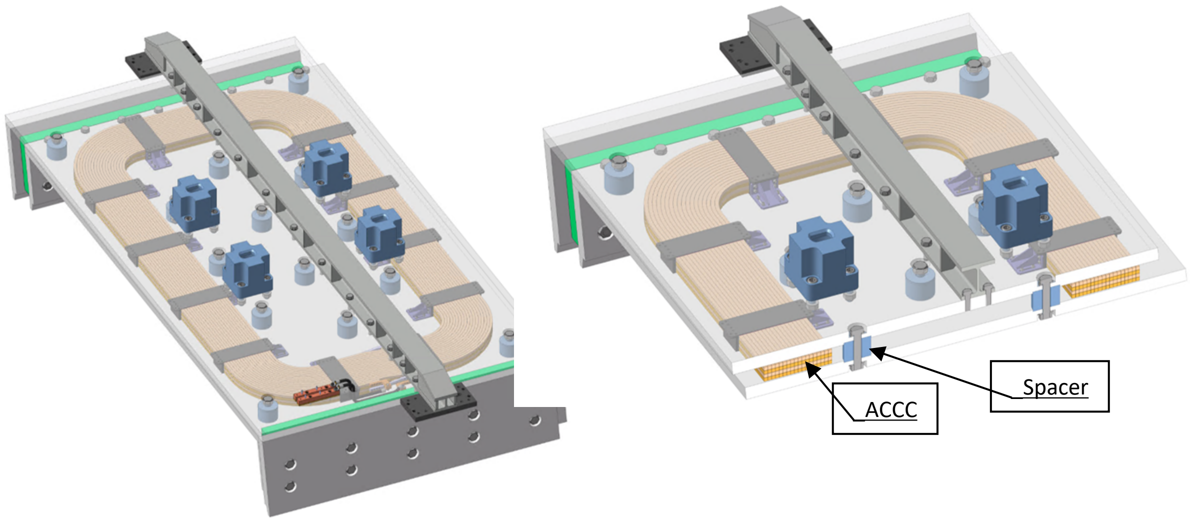

Figure 8 Top PMS

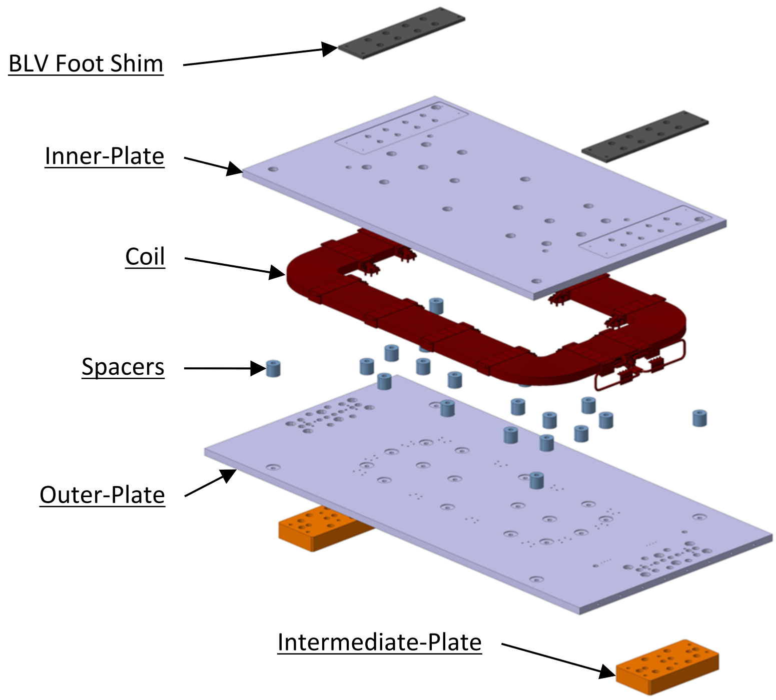

Figure 9 Bottom PMS

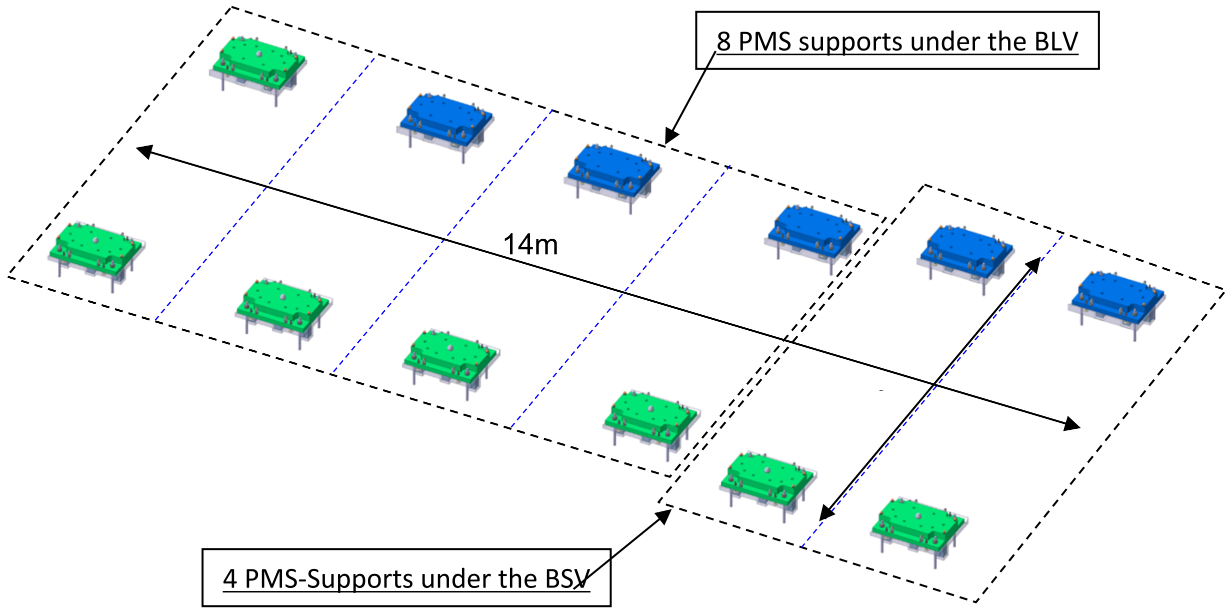

Figure 10 Vessel PMS base plates

3.3 RPOM

The rear part has the same sandwich construction than the side panels. It is composed of 2 sandwich panels joined by internal beams. It can be opened to have maintenance access to the NB vessel.

Trapezoidal screw actuated by water hydraulic motors and a rail system allow to open it (see Figure 11 and Figure 12). The hydraulic power pack is also included in the scope.

It has a weight of 55 tons and a dimension approx. 7m x 7m.

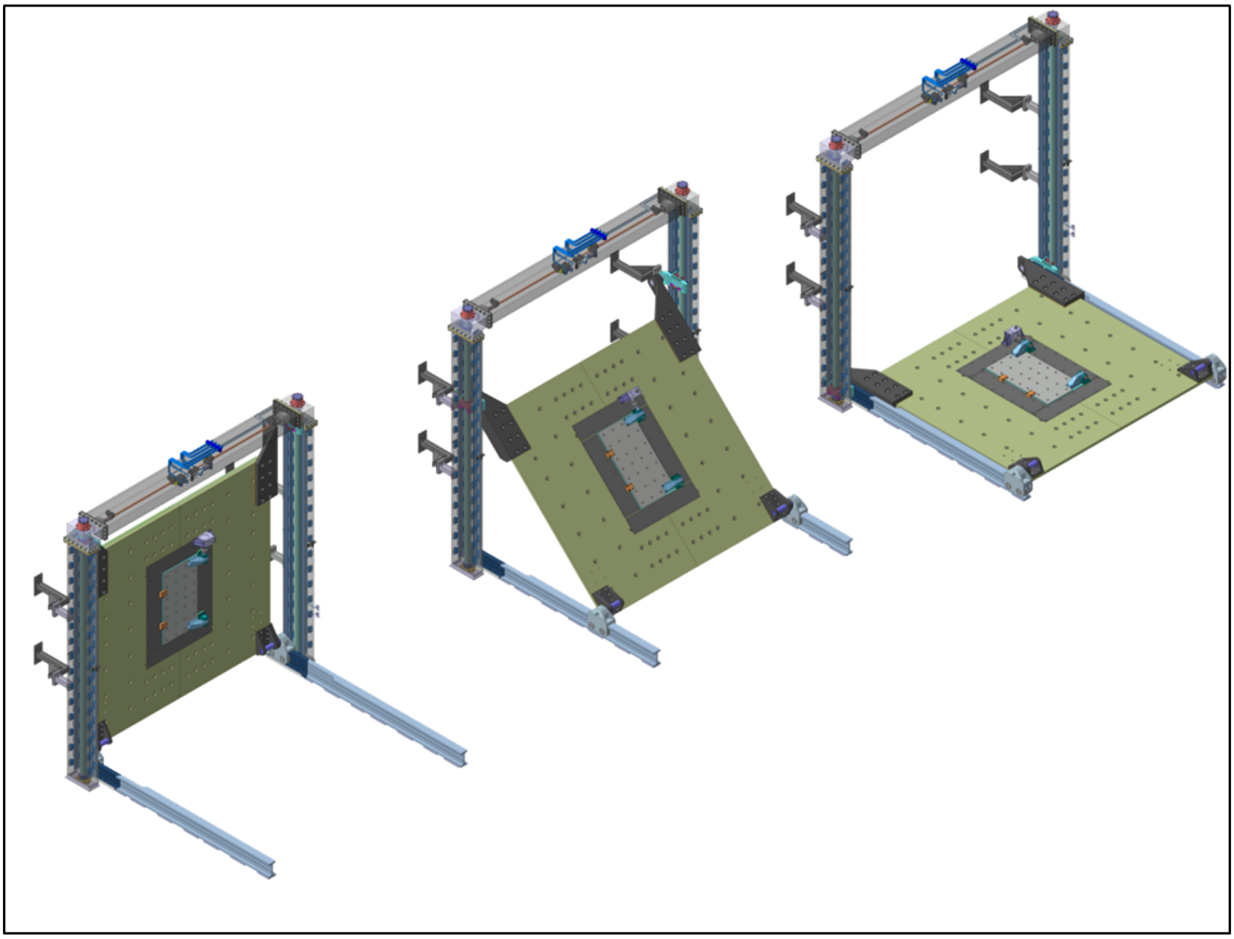

Figure 11 RPOM opening

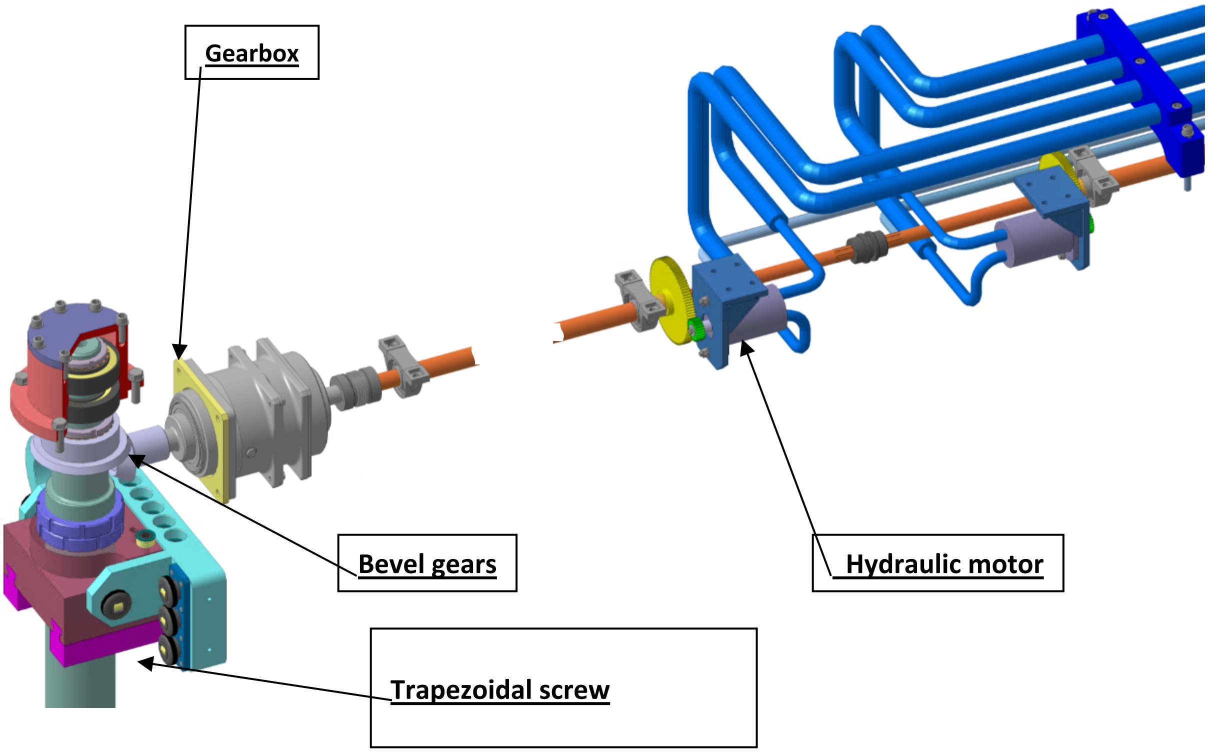

Figure 12 RPOM mechanism

3.4 HVB PMS

It is composed of a carbon steel (S235) cylinder, 150 mm thick, 4m diameter and 5m height, overall weight approx. 70 tons. When installed it is supported from the ceiling, not in contact with the Vessel PMS.

The lower part, demountable, has ports and doors to access the HVB that will be hosted inside.

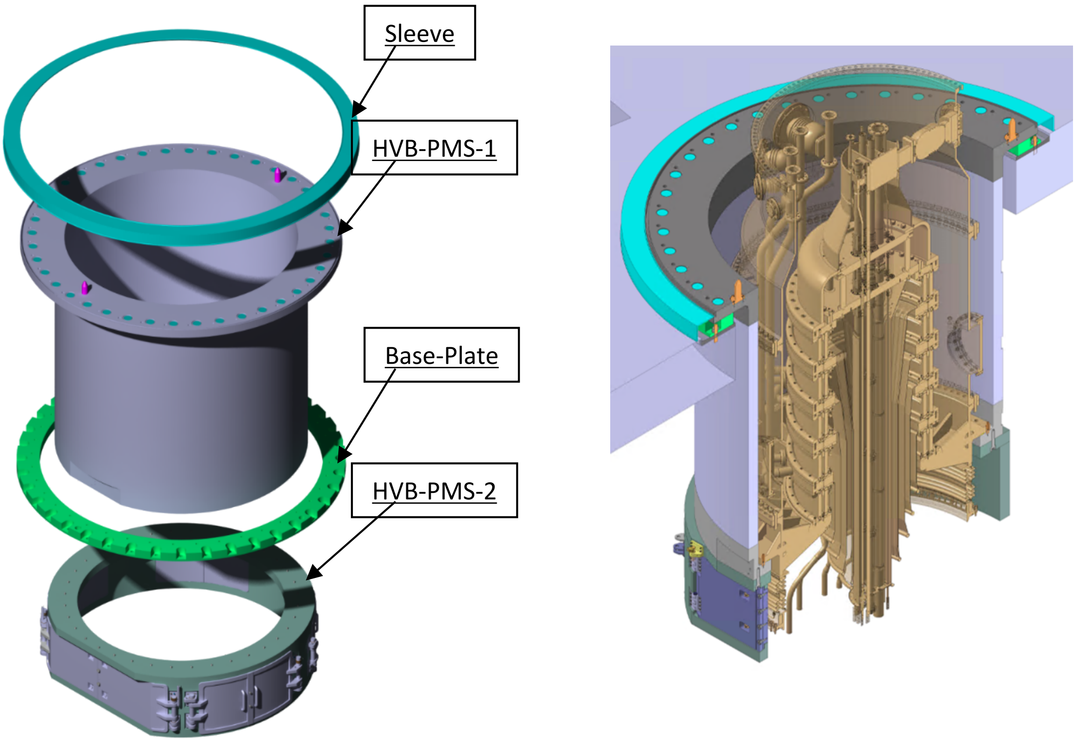

Figure 13 HVB PMS

3.5 Main PMS requirements

Requirements are driven by the magnetic shielding functions, by the support function and by the radiological protection. They have impact on the material characteristics, on the manufacturing and on the assembly.

3.5.1 Nuclear Safety classification

ITER components are classified according to their contribution to the nuclear safety functions. Components classified SIC-1 and SIC-2 are considered Safety Important and follows strict quality and technical requirement. For the case of the PMS they are designed and shall be manufactured according to RCC-MR code. Components classified Safety Relevant (SR) or Non-SIC follows more conventional requirements.

Figure 14 shows the classification of the PMS components:

- Red and orange parts are SIC-1 and Sic-2 (Bottom PMS, Side PMS, HVB PMS, TL PMS)
- Yellow parts and grey parts are SR or Non-SIC (Top PMS, RPOM, ACCCs)

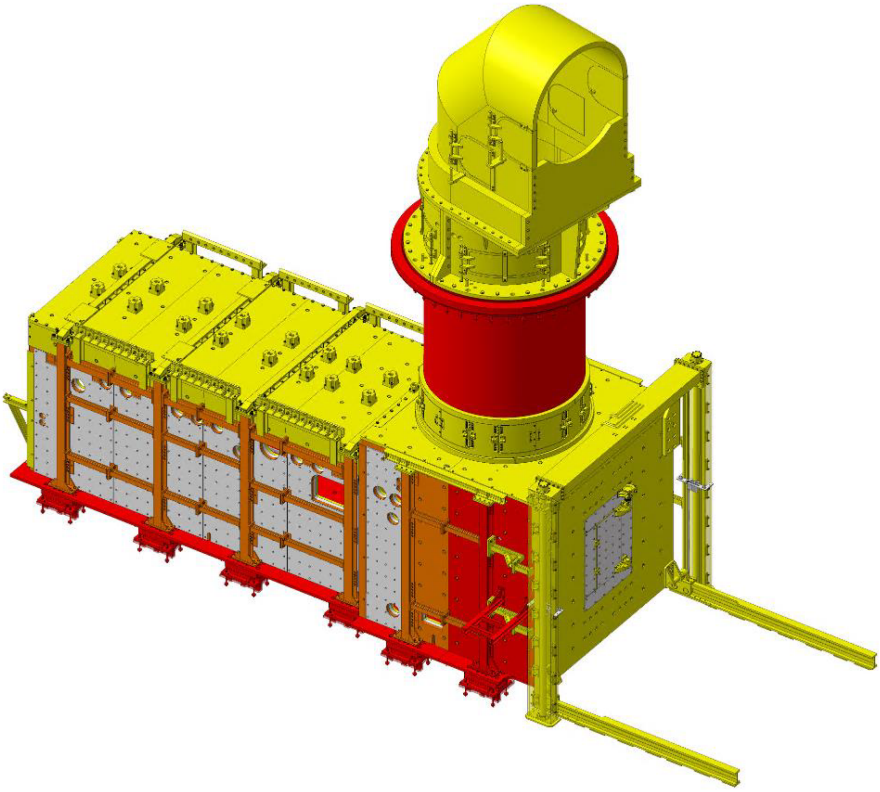

Figure 14 SIC Classification

3.5.2 Material requirements

3.5.2.1 Impurities requirements

To minimize activation, rad waste and radiation doses on the workers material shall respect ITER impurities requirements listed in

Material	Examples	Co %	Ta %	Nb %	Ni %
Aluminium alloy	Al alloy 6061-T6	0.025	NA	NA	0.025
Carbon steel	16MND5	0.01	NA	NA	0.05
	20CrMnTi				
	25CrMo4				
	42CrMo4				
	7CrMo9-10				
	Iron				
	S235				
	S295				
	S355				
Copper alloy	Cu	0.05	0.01	0.1	NA
	CuAl10Ni5Fe4				
	CuCrZr				

Austenitic steel	AISI 316, AISI 304	0.05	0.01	0.1	NA
	X2CrNi18-9				
	X2CrNiMo17-12-2				
	X5CrNiMo17-12-2				
	X6CRNIMOTI17				
	X7CrNiAl17-7				
Austenitic steel	X6NiCrTiMoVB25-15-2 (660)	0.05	0.01	0.1	NA
Austenitic steel	Filler material	0.2	NA	NA	NA
Ni Alloy	Inconel 625	0.1	0.01	NA	NA
	Inconel 718				

Table 1.

Material	Examples	Co %	Ta %	Nb %	Ni %
Aluminium alloy	Al alloy 6061-T6	0.025	NA	NA	0.025
Carbon steel	16MND5	0.01	NA	NA	0.05
	20CrMnTi				
	25CrMo4				
	42CrMo4				
	7CrMo9-10				
	Iron				
	S235				
	S295				
	S355				
Copper alloy	Cu	0.05	0.01	0.1	NA
	CuAl10Ni5Fe4				
	CuCrZr				
Austenitic steel	AISI 316, AISI 304	0.05	0.01	0.1	NA
	X2CrNi18-9				
	X2CrNiMo17-12-2				
	X5CrNiMo17-12-2				
	X6CRNIMOTI17				
	X7CrNiAl17-7				
Austenitic steel	X6NiCrTiMoVB25-15-2 (660)	0.05	0.01	0.1	NA
Austenitic steel	Filler material	0.2	NA	NA	NA
Ni Alloy	Inconel 625	0.1	0.01	NA	NA
	Inconel 718				

Table 1 Impurities requirements

On commercial off the shelf items (e.g. bolts) do not have impurities requirement but a chemical analysis is requested.

3.5.2.2 Plates and HVB material (magnetic material)

Material of the majority of the plates and for the HVB PMS is low carbon steel type S235 according to EN 10025-2. The material needs to fulfil the additional requirement, listed in RPS RM 1135 of the RCC-MR-2007 code, like additional inspections (e.g. ultrasound).

To achieve the magnetic performance of S235 a limitation in the Carbon contain is specified in

Element	Max. contain (%)	Note
C	0.10	For magnetic performance
CEV	0.29	For magnetic performance CEV=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15

Table 2.

Table 2 shows the chemical requirements for the pure iron plates.

F4E has the intention to launch a specific procurement for the raw plates and material requirement are still subject to changes. Raw plate thickness is expected 90 mm (15 mm over material), 20mm over material on width and length.

Element	Max. contain (%)	Note
C	0.10	For magnetic performance
CEV	0.29	For magnetic performance CEV=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15

Table 2 Chemical composition for S235 with magnetic requirements

To perform the foreseen magnetic shielding function the steel magnetic properties need to be guaranteed. **Error! Reference source not found.** and

Element	Max. contain (%)	Note
C	0.006	For magnetic performance
Si	0.020	
Mn	0.060	
P	0.010	
S	0.008	
N	-	
Cu	0.030	
Cr	0.030	
Al	0.005	

Table 3 show the reference magnetic characteristics. F4E is currently performing measurements on a series of S235 samples with different chemistry and thermal treatments to establish the minimum acceptable characteristics.

Element	Max. contain (%)	Note
C	0.006	For magnetic performance
Si	0.020	
Mn	0.060	
P	0.010	
S	0.008	

N	-	
Cu	0.030	
Cr	0.030	
Al	0.005	

Table 3 Pure Iron chemical requirements

3.5.2.3 Other structural material

	Mass T	%	N. of parts	%	RPS in RCCMR 2007 (or EN for Non-SIC)
S235					
Total	**378**	**63%**	**149**	**3%**	
SIC 1 and 2	232	39%	28	-	RM1135 (EN10025-2) except for Forged EN10250
Non-SIC	146	24%	121	2.7%	
Forged SIC1 for HVB PMS 01: Dext 5m / Dint 3,5m / Th 0.4m Dext 4m / Dint 3,1m / Th 0.4m	46	8%	1	-	
Pure Iron					
Total (Non-SIC)	**72**	**12%**	**17**	**-**	N/A
S355					
Total	**52**	**9%**	**965**	**22%**	
SIC1 and 2	26	4%	113	3%	RM1135
Non-SIC	26	4%	852	19%	EN 10025-2
H beam SIC1 and 2 (≈ 100m)	14.6	2%	14	-	RM1135
Copper					
Total Non-SIC	**30**	**5%**	**120**	**3%**	
Only for coils	23	4%	8	-	N/A
Lead					
Total (Non-SIC)	**21**	**3%**	**17**	**-**	N/A
316L					
Total	**17**	**3%**	**1655**	**37%**	
SIC1 and 2	2	0%	129	3%	RM 3332
Non-SIC	15	2%	1526	34%	EN 10088 +AT
PE					
Total (Non-SIC)	**13**	**2%**	**28**	**1%**	N/A
Other Materials : X7CrNiAl17-7, Al alloy 6061-T6, Inconel 718, 16MND5, X2CrNi18-9, Rubber, CuAl10Ni5Fe4….					
Total	**15**	**2%**	**1520**	**34%**	
SIC1 and 2	4.8	1%	444	10%	/
Non-SIC	10.2	2%	1076	24%	/

Table 5 indicate the quantity of material (mass and number of parts) expected for each unit

	Mass T	**N. of parts**
Total for one Unit	608	26204

Fasteners	7	21767
Manufactured parts	601	4437

Table 4 Component quantity

Table 5 list the materials used in the project for manufactured parts.

Material for components classified SIC shall follow applicable RPS, otherwise EN standard are applicable.

As a reminder, F4E supplies a large part of the raw material for S235 plates. The raw plates supplied directly by F4E represents 77% of the S235.

	Mass T	%	**N. of parts**	%	**RPS in RCCMR 2007 (or EN for Non-SIC)**
S235					
Total	**378**	**63%**	**149**	**3%**	RM1135 (EN10025-2) except for Forged EN10250
SIC 1 and 2	232	39%	28	-	
Non-SIC	146	24%	121	2.7%	
Forged SIC1 for HVB PMS 01: Dext 5m / Dint 3,5m / Th 0.4m Dext 4m / Dint 3,1m / Th 0.4m	46	8%	1	-	
Pure Iron					
Total (Non-SIC)	**72**	**12%**	**17**	**-**	N/A
S355					
Total	**52**	**9%**	**965**	**22%**	
SIC1 and 2	26	4%	113	3%	RM1135
Non-SIC	26	4%	852	19%	EN 10025-2
H beam SIC1 and 2 (≈ 100m)	14.6	2%	14	-	RM1135
Copper					
Total Non-SIC	**30**	**5%**	**120**	**3%**	
Only for coils	23	4%	8	-	N/A
Lead					
Total (Non-SIC)	**21**	**3%**	**17**	**-**	N/A
316L					
Total	**17**	**3%**	**1655**	**37%**	
SIC1 and 2	2	0%	129	3%	RM 3332
Non-SIC	15	2%	1526	34%	EN 10088 +AT
PE					
Total (Non-SIC)	**13**	**2%**	**28**	**1%**	N/A

Other Materials : X7CrNiAl17-7, Al alloy 6061-T6, Inconel 718, 16MND5, X2CrNi18-9, Rubber, CuAl10Ni5Fe4….					
Total	**15**	**2%**	**1520**	**34%**	
SIC1 and 2	4.8	1%	444	10%	/
Non-SIC	10.2	2%	1076	24%	/

Table 5 Material quantities for manufactured parts

3.5.2.4 Fasteners

The construction need a large quantity of fasteners. Their quantity and main characteristics are shown in Table 6

	Mass T	%	N. of parts	%	RPS in RCCMR 2007 (or EN for Non-SIC)
Total	**7**		**21767**		
Total 42CrMo4	3.8	54%	16603	76%	
SIC1 and 2	2.1	30%	4242	19%	RM5151
Non-SIC	1.7	24%	12361	57%	ISO 898 class 10.9
Total BUMAX Nitro	3.1	44%	3042	14%	
SIC1 and 2	0.6	9%	657	3%	Strength class 109
Non-SIC	2.5	36%	2385	11%	Strength class 109
Total in others materials : Inconel 625, 316L…	0.15	2%	2122	10%	/

Table 6 Fasteners

3.5.2.5 Polyethylene

Polyethylene shall have a minimum density of 0.95 g/cm³ at 35°C and halogen-free. No special shielding characteristics (Boron additive) or fire reaction is prescribed.

3.5.2.6 Lead

The Lead shall have a minimum density of 11.34 g/cm³ at 35°C, and incapsulated in a stainless-steel case.

3.5.3 Manufacturing requirements

Manufacturing of SIC component shall follow RCC-MR, and activities are classified as PIA, requesting technical supervision. Anyhow there are not pressure equipments, so the supervision by a notified body is not needed. All components are classified Support Class S1 (for the SIC-1) / Class S2 (for the SIC-2).

RCC-MR prescription according to the selected class applies mainly to fabrication (welding and its examination, forming).

Manufacturing of non-SIC components follows applicable EN/ASME standards.

3.5.4 Carbon steel corrosion protection

Due to the radiation dose (1MGy) and RCC-MR prescription the following surface treatment are allowed:

- Paint according to RF 5300, class PIG, resistant to 1MGy and halogen-free. Surface of the bolted joints shall not be painted
- Manganese Phosphate Coating following section RF 5200
- Zinc or Aluminium spray metallization following section RF 5700

3.5.5 Factory assembly requirements

A factory assembly of the Vessel PMS plus RPOM and of the HVB PMS is required (separately).

Components shall be cleaned before factory assembly according to Class B from RF 6000. After cleaning they will be assembled in a clean area according to RF 6242 (Level II).

A typical assembly sequence of a subassembly (bottom PMS containing an ACCC) is represented in Figure 15.

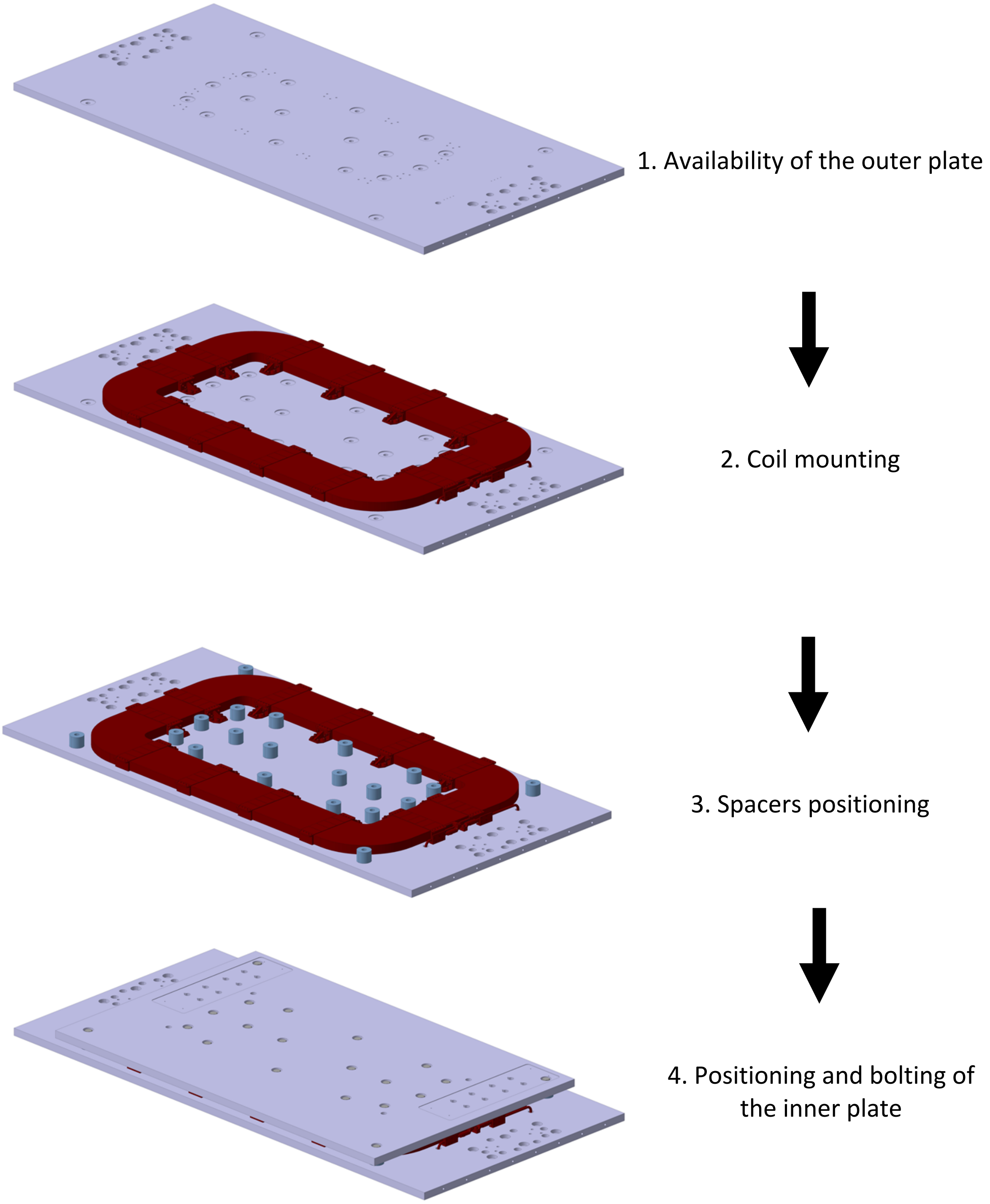

Figure 15 Typical assembly sequence (PMS with coil)

During the final assembly the gap between subassemblies (e.g. see Figure 16) need to be controlled to assure mechanical contact and good magnetic performance. Average gap shall be less than 1 mm.

Custom machining of plates to adapt the interfaces with the adjacent ones is allowed, if deemed necessary due to the machining tolerances of the plates and the assembly tolerances of the subassembly.

After custom machining the related surfaces will be corrosion protected.

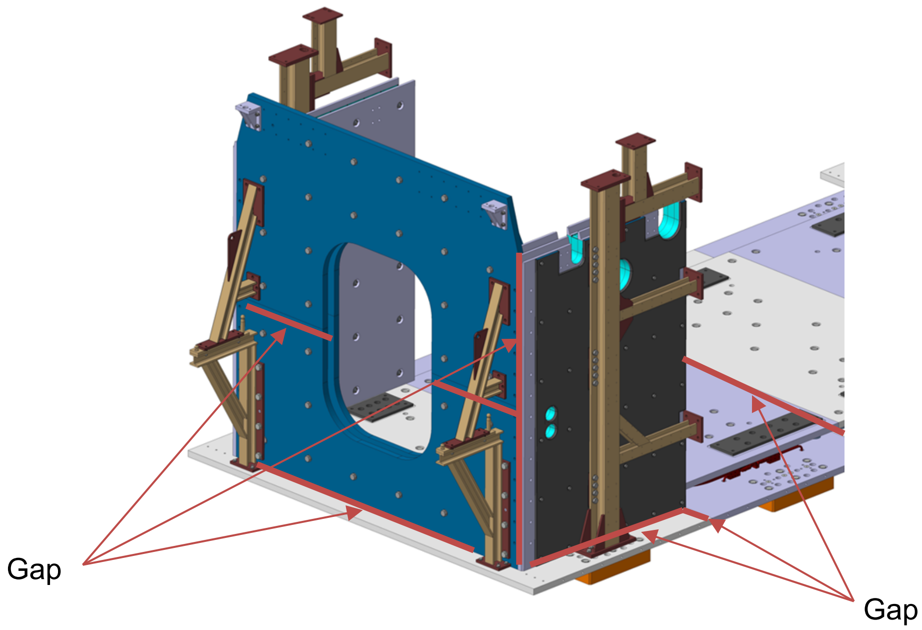

Figure 16 Assembly gaps

Shims are foreseen at the connection of the H structures. Once the correct alignment is reached the structures will be counter drilled and pinned before disassembly to create references to be used at on-site assembly in ITER site.

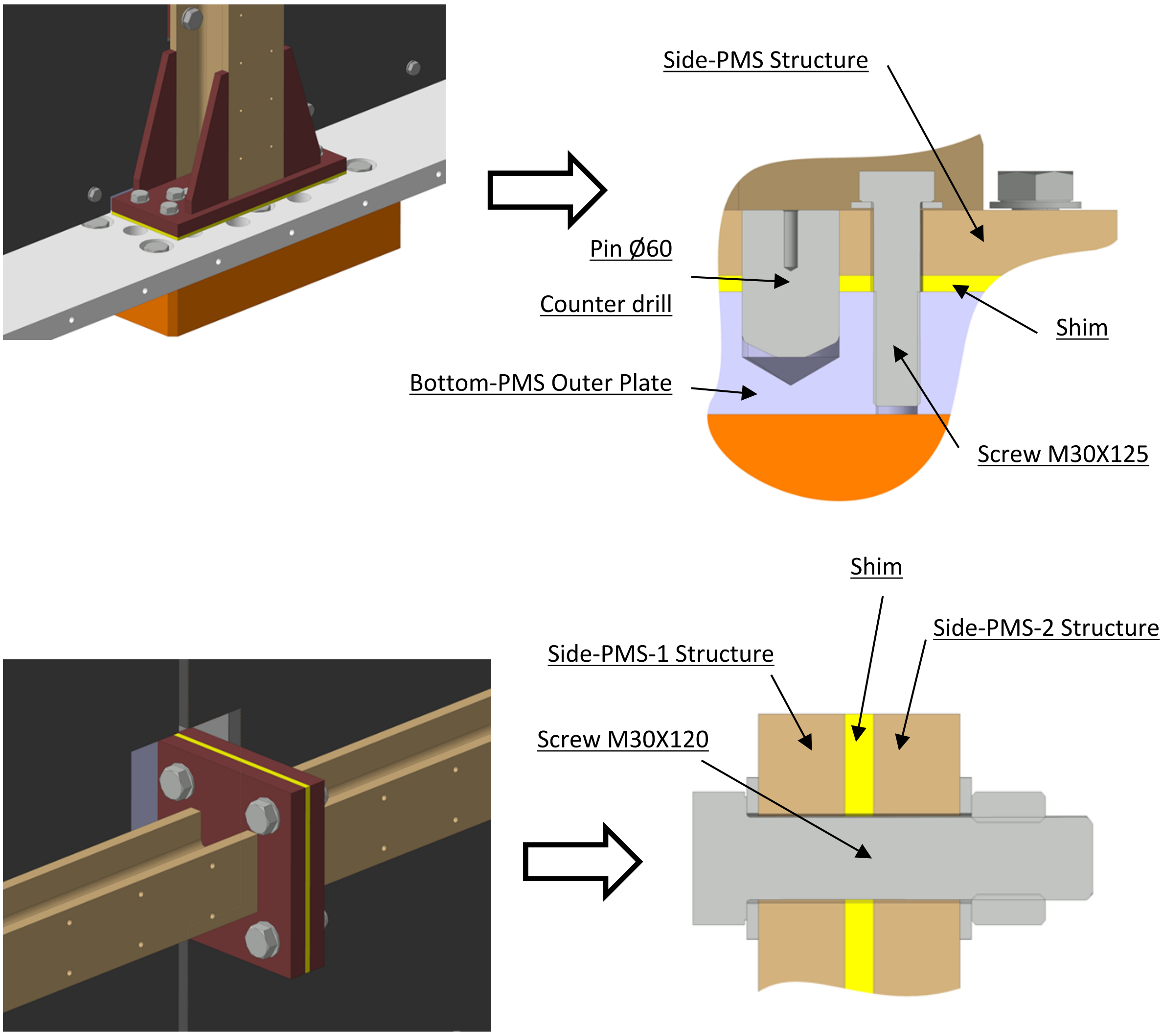

Figure 17 Shims and pin

The rails and the structure of the RPOM (see Figure 18) will be installed on temporary supports simulating the real position of the embedded plates installed in ITER. Also for this structure the shims will be adjusted and parts pinned for reference.

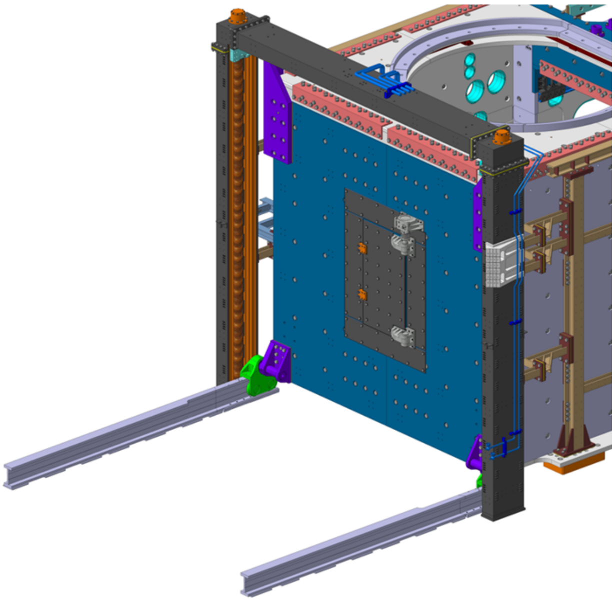

Figure 18 RPOM assembly

After the complete assembly, in addition to the metrology survey on gaps and other external interfaces (e.g. the NB Vessel interfaces), some functional tests will be required, the main are:

- Electrical measurements of the coil, to check that they did not suffer any damage
- Opening and closing of the rear door, to check correct operation
- Dismounting and re-assembly of the Top-PMS plates
- Opening and closing of the maintenance windows in the RPOM and HVB-PMS

3.5.6 Disassembly and shipping

After successful completion of the Factory Acceptance Tests the PMS shall be disassembled in individual sandwich panes (see Figure 6).

The biggest components will be the HVB–PMS1, the Rear Door, the Top PMS-5/6 and the Bottom PMS-5/6. These two last components need temporary supports and stiffeners for handling to avoid damages to the coils, see Figure 19 and Figure 20.

The maximum size of packaged items that can be transported on normal French roads to the ITER Site is;

- for HEL - Highly Exceptional Load: (9m wide × 9.1m high and 19m long with a weight limit of 600 tonnes)
- for CEL - Conventional Exceptional Load: (5m wide × 5m high and 19m long with a weight limit of 60 tonnes).

Except for the biggest components listed above, for which the supplier should assess the applicable category, the rest of the components can be shipped as CEL.

Delivery of first and second unit may be done in two different period, in some months' time.

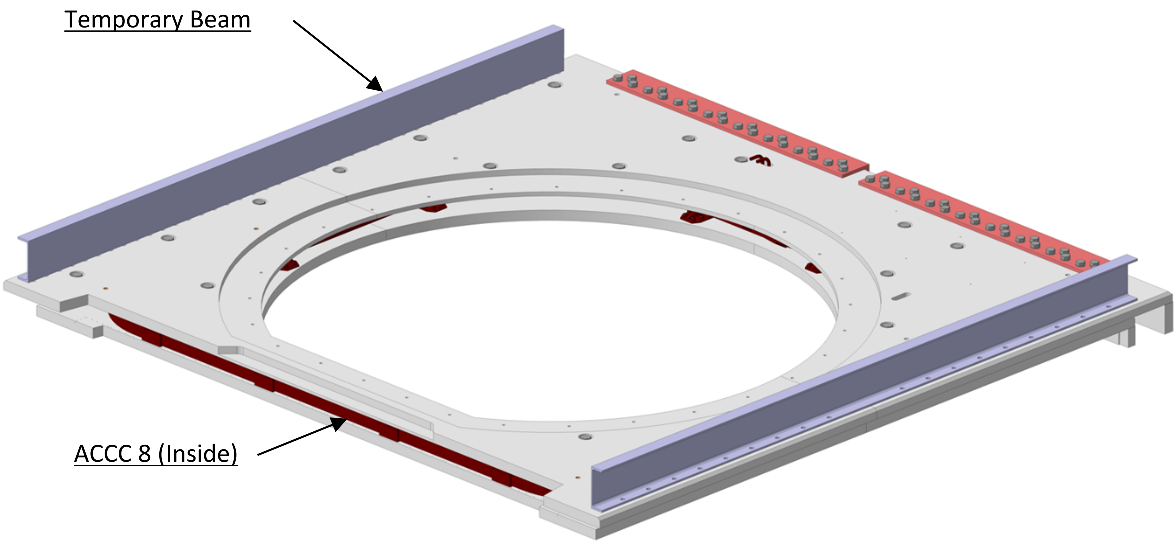

Figure 19 Top PMS 5/6 with temporary supports

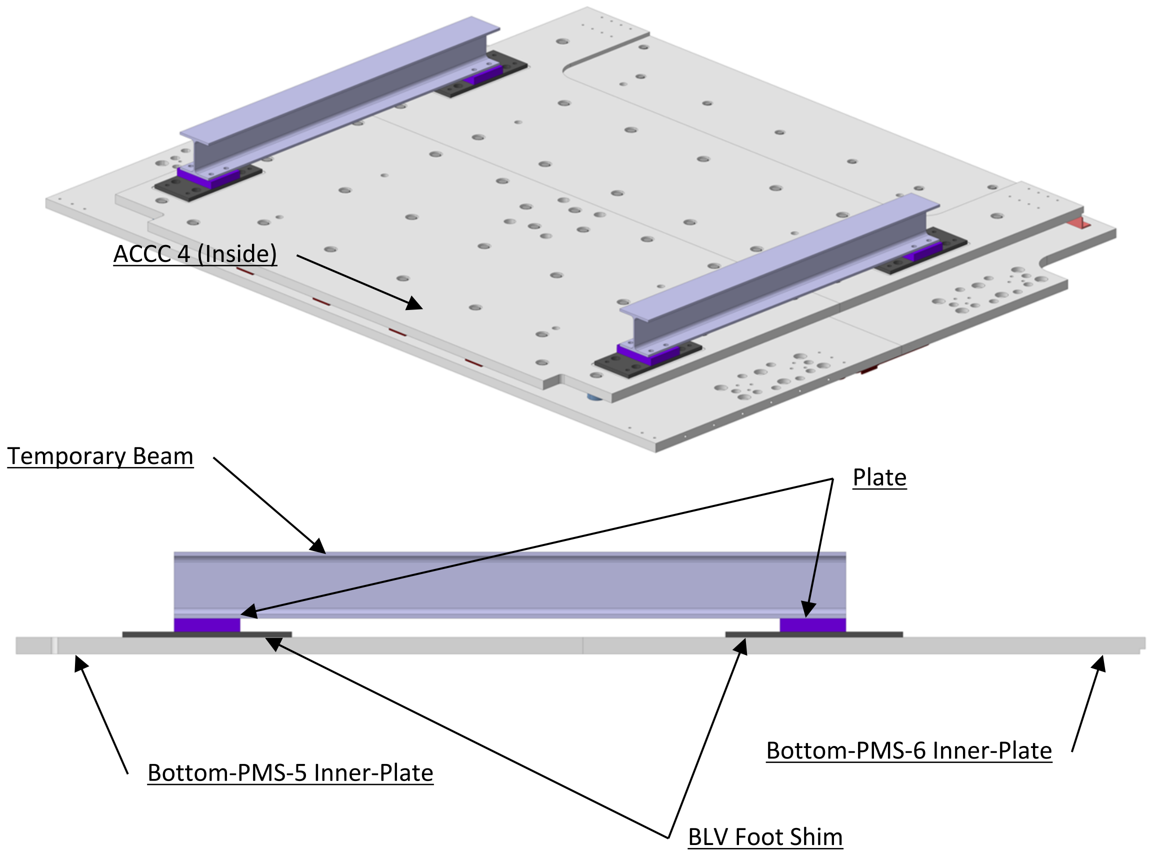

Figure 20 Bottom PMS 5/6 with temporary supports

3.5.7 Site Acceptance Test

The site acceptance tests will be limited to check that no component has been damaged during the shipping.

It will consist in check of the package, of the cleanliness condition and electrical tests of the ACCC insulation.

3.6 ACC Coils

The coil conductor material is copper. They are cooled by natural convection, and through (thermal) contact with the PMS plates. Main characteristics and dimensions are listed in Table 7.

		ACCC1	ACCC2	ACCC3	ACCC4	ACCC5	ACCC6	ACCC7	ACCC8	ACCC9
Geometry / Coil construction	**Nb of turn**	92	92	92	64	96	72	52	72	24
	Nb of pancake	4	4	4	4	4	4	4	4	12
	Nbturn/pancake	23	23	23	16	24	18	13	18	2
	Conductor total length (m)	~816	~800	~547	~513	~921	~687	~473	~1174	~1081
	Conductor size (mm)	□20	□20	□20	□20	□20	□20	□20	□20	Ø15*
	Coil Mass (kg)	~3029	~2970	~2031	~1904	~3419	~2550	~1756	~4358	~1702

Table 7 ACCC Characteristics

ACCC 1 to 8 insulation is made with vacuum-pressure impregnation, while ACCC 9 is made by a standard cable winded around the NB Vessel.

Rated currents are 380A for coil ACCC1-ACCC8, 100A for ACCC9.

3.6.1 ACCC 1 to 8

Overall and cross section dimension of ACCC1 to 8 are listed in Figure 21 and Figure 22.

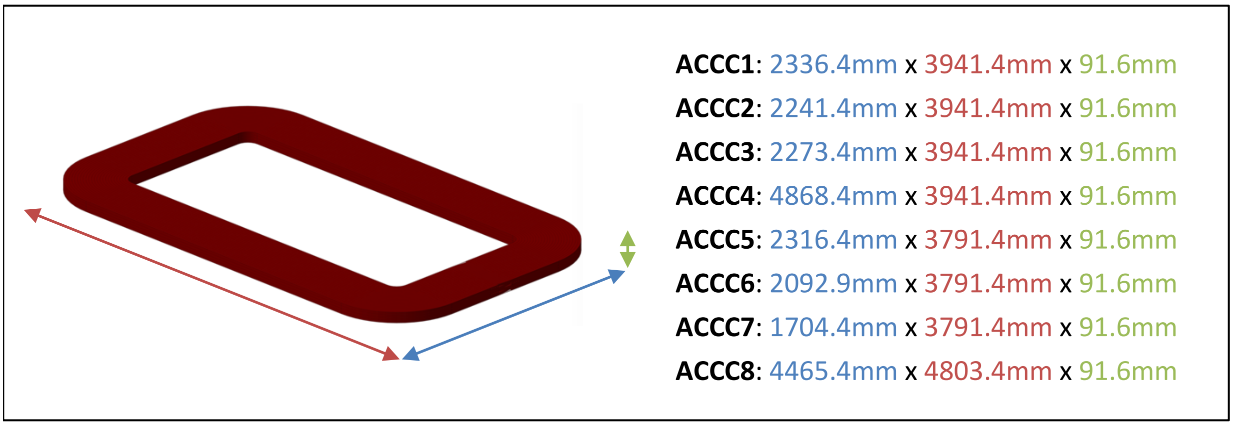

Figure 21 Coil 1-8 overall dimensions

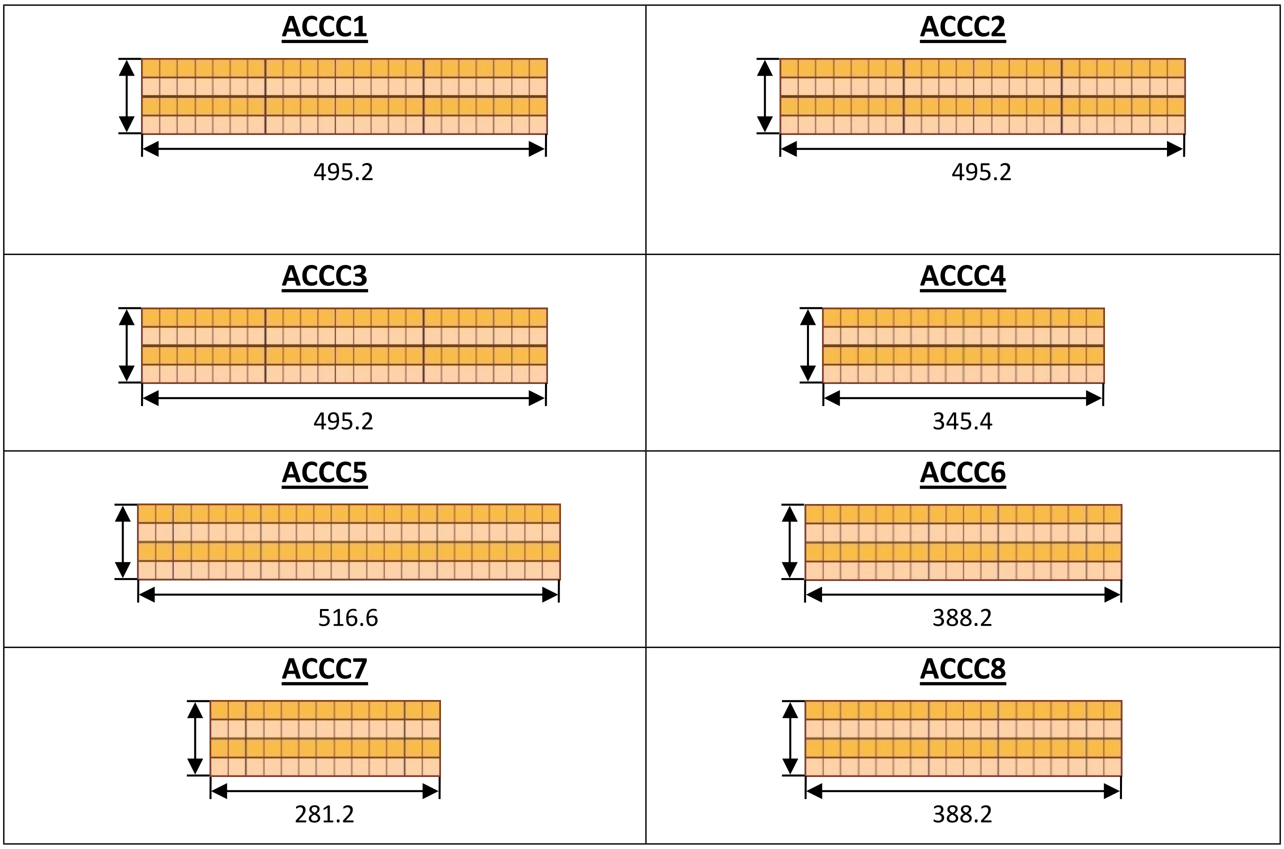

Figure 22 Coil 1-8 cross sections

The conductor is square, 20mm x 20mm, with rounded edges. Indicative dimensions for the insulation are shown in Figure 23. Changes in conductor dimension up to 19x19 mm is allowed to facilitate coil integration.

It is the manufacturer responsibility to choose the final composition and thickness of the insulation layers, and to respect the insulation voltage requirement listed in 3.7. Indicative dimensions are shown in Figure 23.

The coil is provided with three insulations: conductor insulation (inter-turn), pancake insulation (inter-layer) and overall coil insulation (to earth insulation) (see Figure 24). The insulation shall provide also for the required coil mechanical stiffness before impregnation and mechanical strength after the impregnation.

The external surface shall be painted with a conductive varnish.

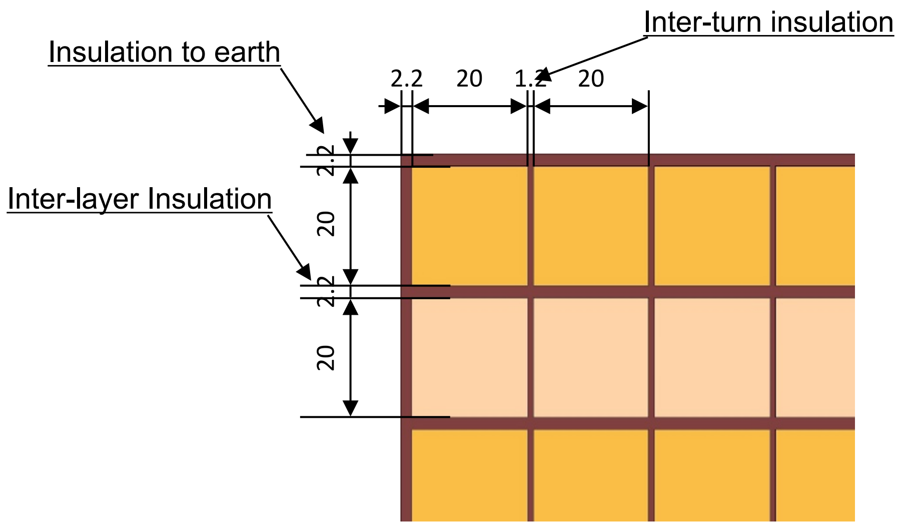

Figure 23 Indicative insulation dimensions

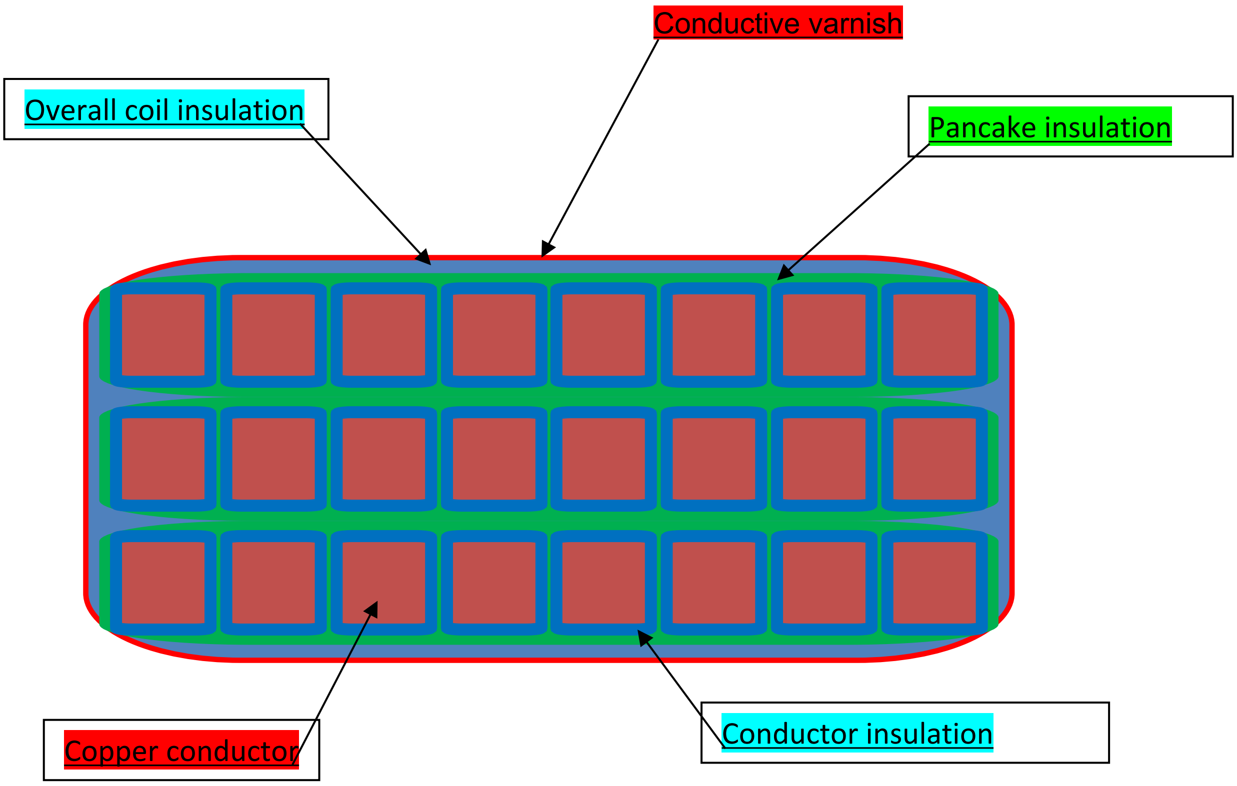

Figure 24 Coil insulation structure

Figure 25 shows a coil installed over a PMS plate before the closure of the sandwich with the top plate. The design foresees an electrical connection between pancakes made with bolted busbars.

F4E will evaluate alternative design that can improve the reliability and/or the easiness of manufacturing, reducing the number of joints (e.g. double pancakes).

After its impregnation and before being painted with the conductive varnish, each coil shall be equipped with four thermocouples that shall be placed in a good thermal contact with the coil insulation surface.

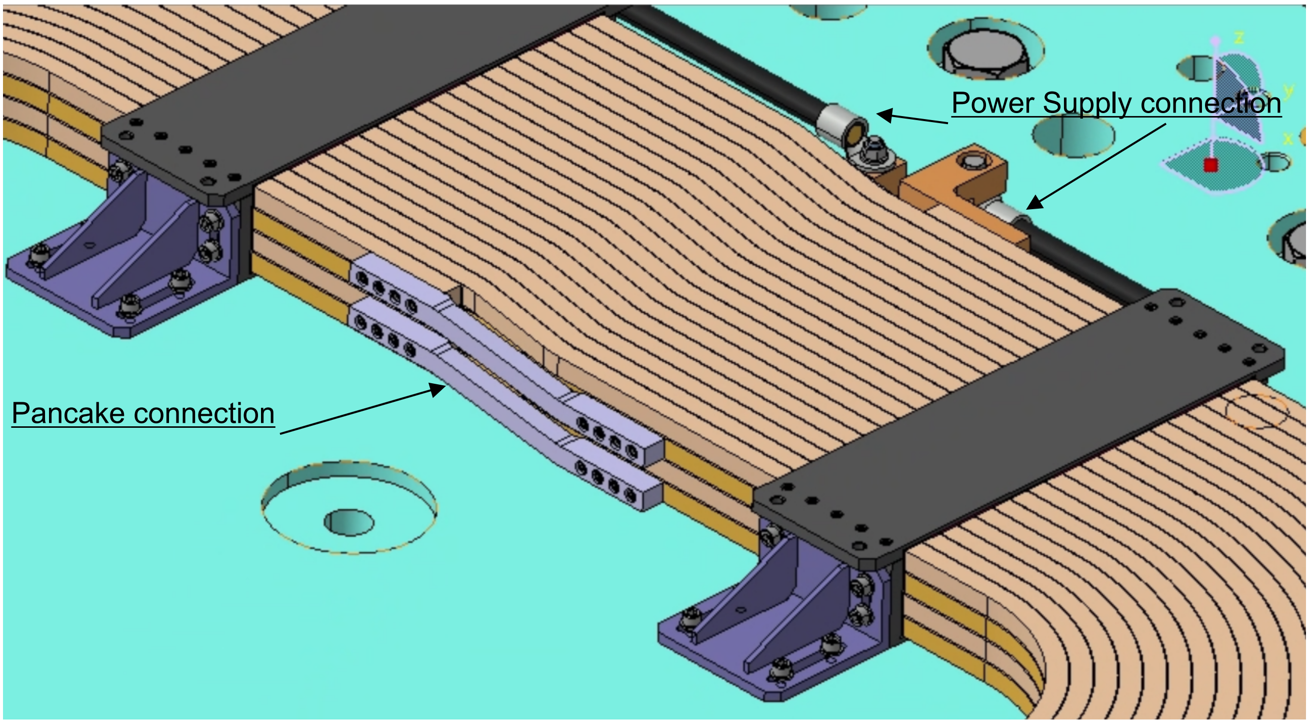

Figure 25 Coil electrical connections

3.6.2 Integration of the ACCC 1-8 with the PMS

Figure 25, Figure 27 and Figure 27 show the electrical connections to the power supply with a flexible cable arriving inside the PMS sandwich. This connection is part of the scope of the supply.

F4E will evaluate alternative design that can improve the reliability and/or the easiness of manufacturing (e.g. extending the coil conductor outside the plate to connect it externally).

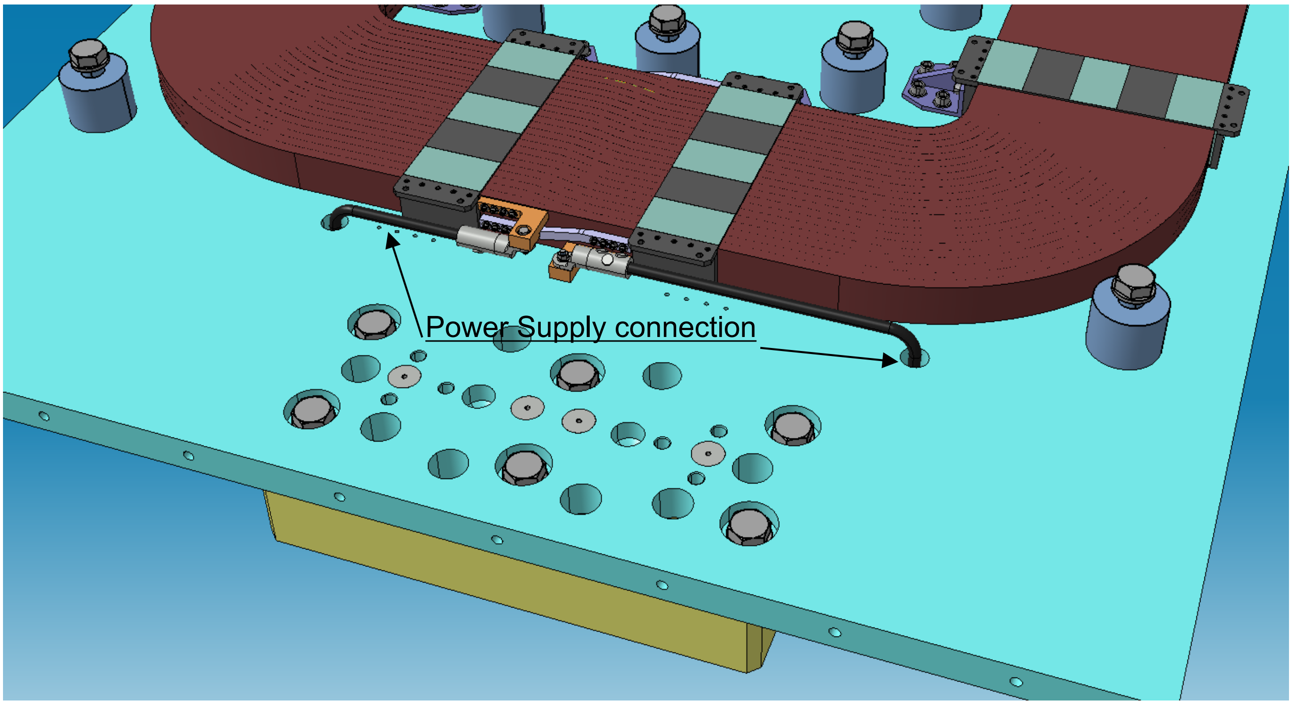

Figure 26 Power supply connection (above Bottom PMS plate)

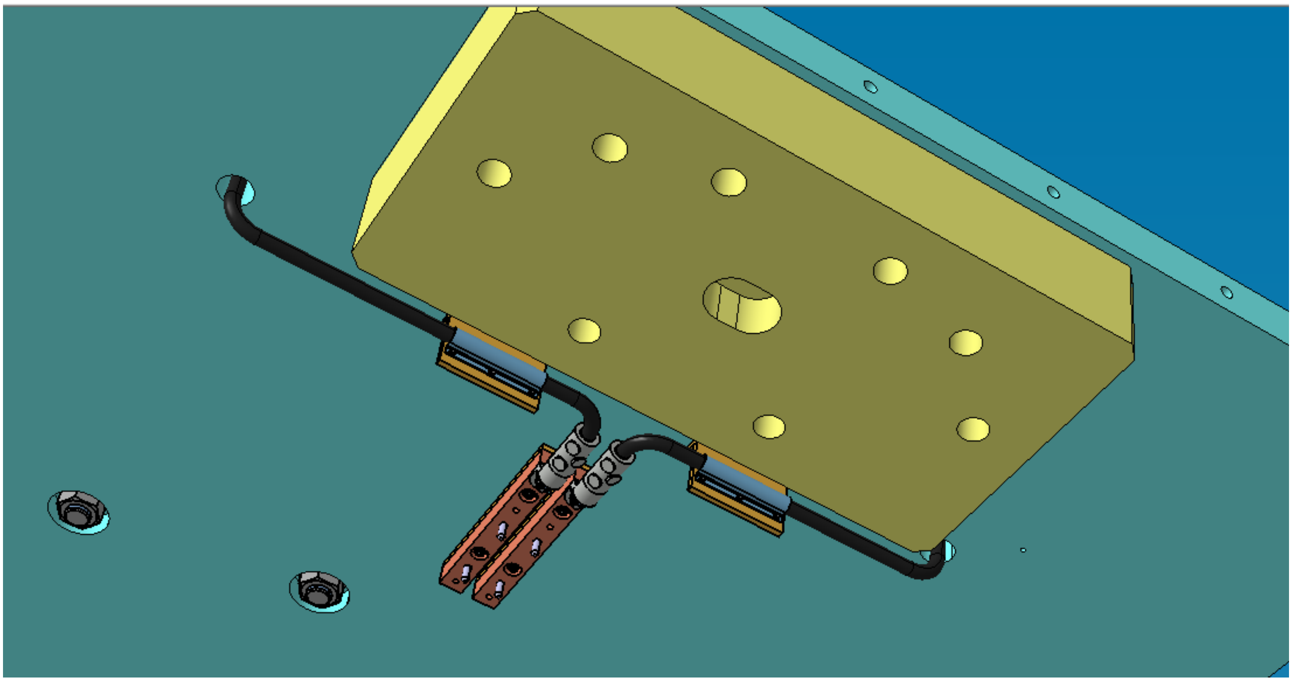

Figure 27 Power supply connection (below Bottom PMS)

The coils are mechanically and thermically connected to the PMS plate with the supports shown in Figure 28 and Figure 29. They are made of two parts clamped around the coils. Supports have elastic shims (radiation resistant rubber) to accommodate coil thermal expansion and manufacturing tolerances.

It is foreseen that supports are installed on the coils during their manufacturing and their planarity are checked to guarantee uniform contact between PMS and ACCC. They can be custom machined, or epoxy grouting can be used to compensate coil tolerances.

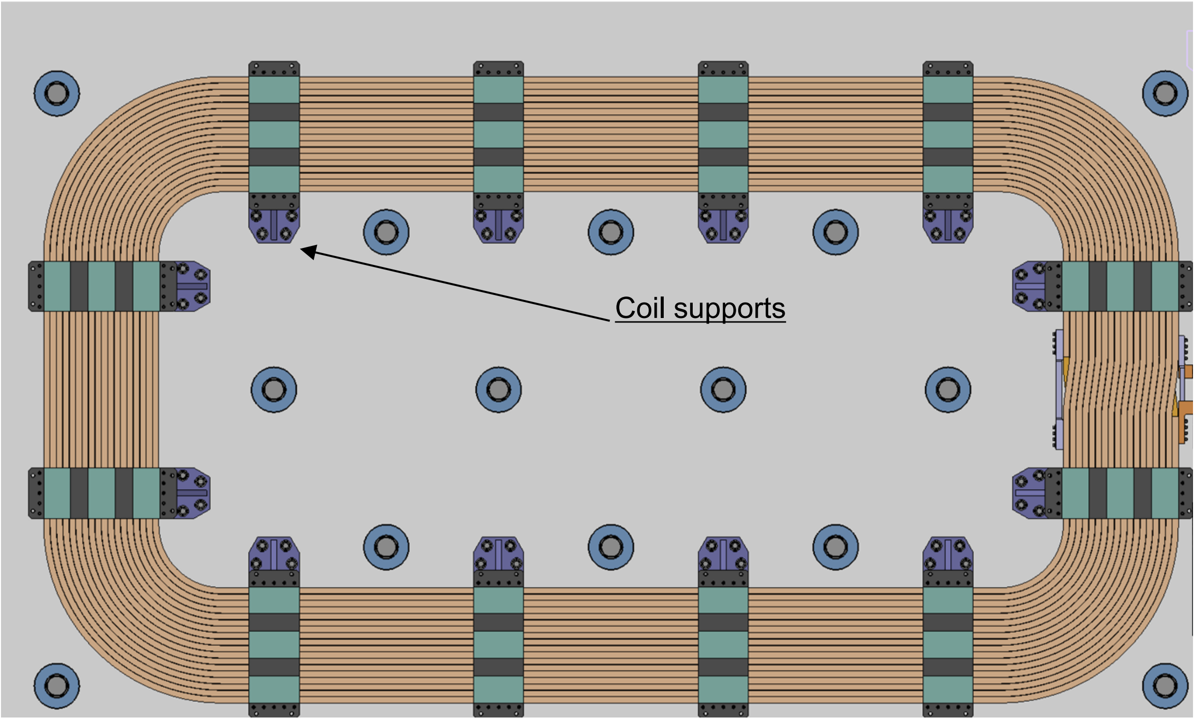

Figure 28 Coil installed over PMS Plate

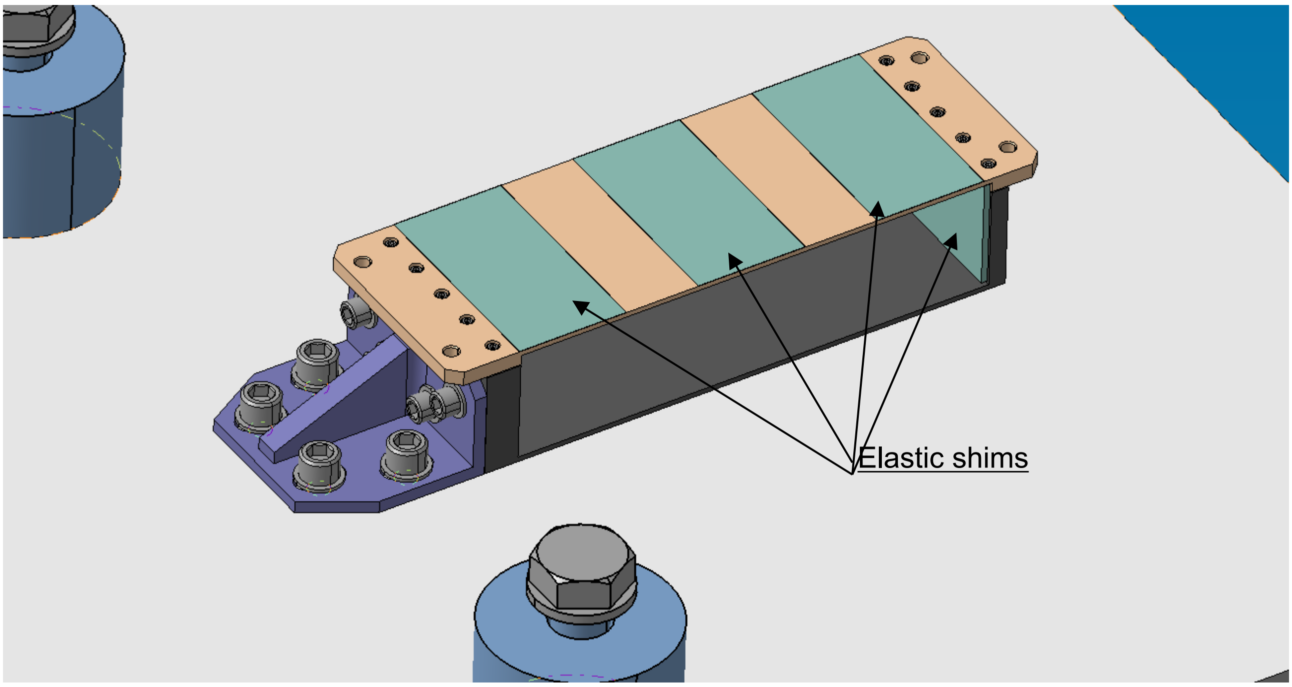

Figure 29 Coil support

3.6.3 ACCC 9

ACCC9 is an insulated conductor that will be wound around the HNB Vessel (see Figure 30).

The scope of supply consists of the cable and of the supports that hold it on the vessel.

The cable shall comply with the following requirements:

- Radiation resistance 1MGy as per: IEEE 383 (radiation resistance only) or IEC 60544-2;
- Fire retardancy as per: NFC 32070 C1, IEC 60332-1 and/or IEC 60332-3;
- Low Smoke as per: IEC 61034;
- Zero Halogen as per: IEC 60754-1;
- Non Toxicity as per: IEC 60754-2;

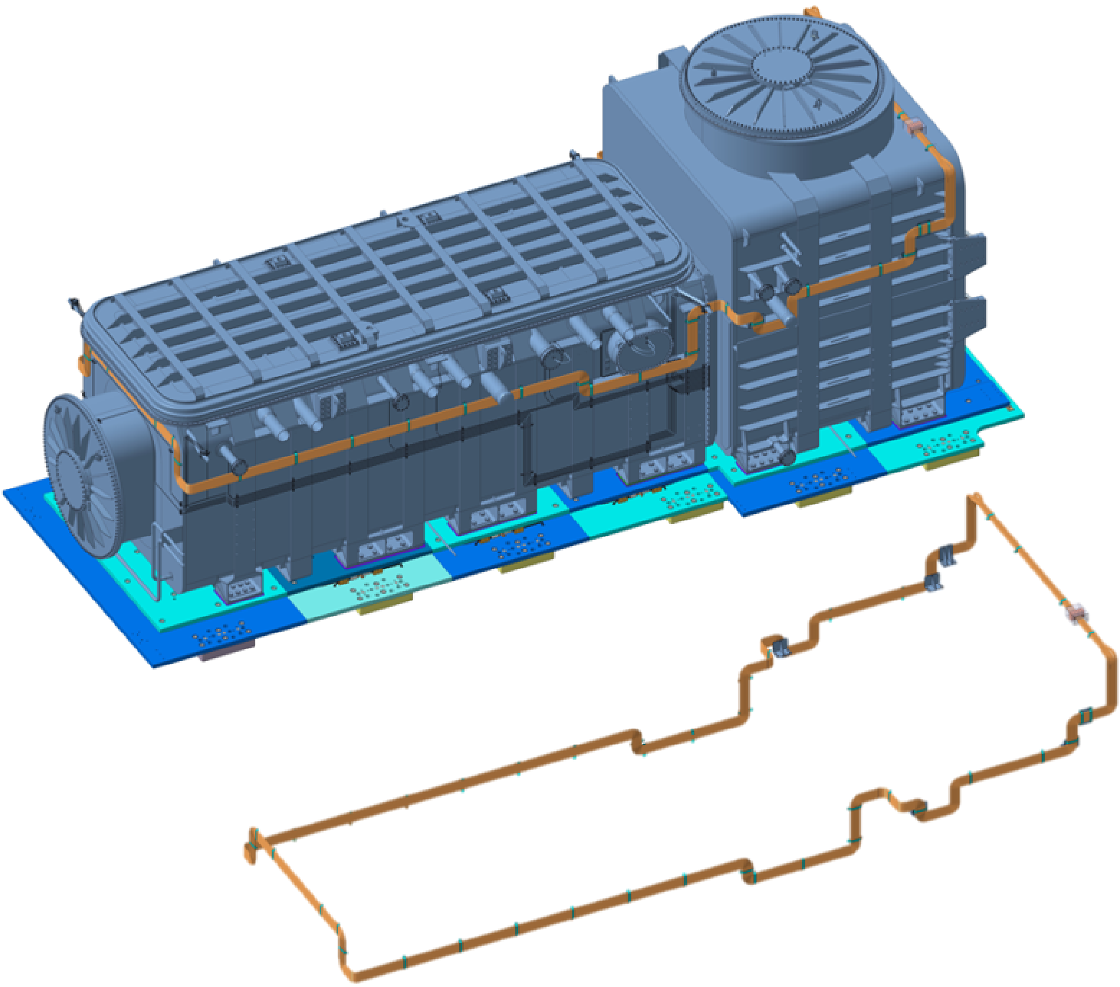

Figure 30 ACCC 9

3.7 ACCC main requirements

The inter-turn coil nominal voltage is 40 V, the inter-layer nominal voltage is 1.8 kV and the voltage to ground is 3.6 kV. It is manufacturer responsibility to choose the final composition and thickness of the insulation layers.

3.7.1 Material requirements

For the conductor the material shall be Copper OFXLP UNS C10300 or C10200 in half-hard conditions and in compliance with the requirements listed in

Chemical composition		
Copper + Silver %	min 99.95	
Silver %		max 0.0025
Oxygen %		max 0.001
Phosphorous %		max 0.004
Cobalt %		max 0.05
Niobium %		max 0.01
Tantalum %		max 0.01
Other characteristics		
Electrical resistivity at 20 Deg (W.m).	max 1.76E-08 (98% IACS)	
Yield strength 0.2% (MPa)	min 50	
Elongation at fracture [%]	min 15%	

Table 8.

Chemical composition		
Copper + Silver %	min 99.95	
Silver %		max 0.0025
Oxygen %		max 0.001
Phosphorous %		max 0.004
Cobalt %		max 0.05

Niobium %		max 0.01
Tantalum %		max 0.01
Other characteristics		
Electrical resistivity at 20 Deg (W.m).	max 1.76E-08 (98% IACS)	
Yield strength 0.2% (MPa)	min 50	
Elongation at fracture [%]	min 15%	

Table 8 Copper requirements

DGEBA or DGEBF resin according to Table 9 are proposed as the impregnation resin for the ACCC, since already qualified for ITER application.

If alternative resins than DGEBA or DGEBF are to be used, the resin shall be qualified, and its mechanical and electrical performance after irradiation at 1MGy shall be at least as good as the one proposed.

Type	Epoxy Resin	Hardener (all anhydride)	Additives
DGEBF	Ciba Geigy GY282 (100pbw)	Ciba Geigy HY918 (MTHPA)	Ciba Geigy DY073 (0.25pbw)
DGEBA	MY745	HY905	DY072 DY073
DGEBA	LY1025/CH	HY905	Orlitherm44

Table 9 Resin types

3.7.2 Manufacturing requirements

Even if the performance of the coil in term of voltage and current are low, quality and testing requirements are driven by the fact that no repair or replacement will be possible during ITER life.

The insulation system and the Vacuum Pressure Impregnation (VPI) shall be qualified with a linear model of the coil structure.

All parameters of the process (pressures and temperature curves, characteristics of the resin) shall be controlled.

The following tests are foreseen on the linear model:

- Inter-turn insulation (250 V).
- Inter-layer insulation (12 kV).
- Insulation to earth (15 kV).
- Breakdown voltage measurement.
- Insulation glass content (> 75%).
- Insulation visual inspection and dimensional check.
- Insulation shear strength on samples extracted from the model (20 MPa).

The joint method between turns (bolting or brazing) shall be qualified with mechanical and electrical tests.

Before proceeding with the series production the first coil needs to complete the full dimensional and electrical tests.

3.7.3 Testing requirements

For each coil the following series of tests (for acceptance) and measurement (for information) are foreseen after manufacturing:

- Dimensional tests and visual inspection (compliance with drawings).
- Insulation to earth test (10 kV).
- Insulation loss factor measurement.
- Temperature rise measurement (and thermocouple test).
- Inter-turn insulation test (transformer or capacitor method).
- Insulation to earth test (10 kV AC, 20kV impulse).
- Insulation resistance to earth test (100 MΩ).
- Insulation loss factor measurement.
- Capacitance to earth measurement.
- Electrical resistance measurement.
- Impedance with frequency measurement.

After installation inside the PMS the following tests will be repeated:

- Insulation resistance to ground test (100 MΩ).
- Insulation resistance to earth test (10 kV).
- Insulation resistance to ground test (100 MΩ).
- Impedance with frequency measurement.

3.7.4 Assembly and shipping

ACCC-1 to 8 shall be installed inside the Top and Bottom PMS plates. Supplier shall be responsible for the transportation to the factory where the PMS will be assembled. Design and manufacturing of lifting and transportation are also included in the scope.

Transportation of the coils to ITER site will be done together with the PMS, without disassembling.

4 SCOPE OF SUPPLY

The expected scope of Supply is based on Build-to-Print (B-t-P) specification provided by F4E to the Supplier(s)*.

The scope of the contract is expected to include

- Production of manufacturing drawings and plans,
- Execution of the Manufacturing Readiness Review (MRR) with the participation of experts from F4E, ITER Organization and external experts.
- Manufacturing.
- Factory testing
- Disassembly and shipping
- Delivery to ITER at Cadarache and SAT.
- Reassembly on site or its supervision if required

On the basis of the B-t-P design provided by F4E, the supplier shall produce the manufacturing drawings and consequently shall procure materials, and shall manufacture and deliver the components in line with the required delivery schedule for installation in Cadarache.

Build-to-Print Specification means that F4E provides the final specification from IO to the Supplier(s), namely:

- Bill of Materials
- 2D Drawings (Build-to-Print) including the contractual dimensions and tolerances;
- CATIA 3D model;
- Equipment specification including:
  - Reference Procurement specifications for material procurement;
  - B-t-P Welds tables with proposed welds configuration compliant (including NDT control) with the applicable manufacturing codes (RCC-MR) and requirements and in accordance with the Build-To-Print drawings;
  - Factory testing and delivery requirements.

2D Drawings are provided for the single parts, with tolerances that will guarantee correct operation. Some of the surfaces will be identified as "custom machined surfaces after metrology survey during factory assembly).
It is the responsibility of the supplier to guarantee the factory assembly and to pass the factory tests. Tolerances affecting the assembly can be adjusted, in agreement with F4E, according to the chosen manufacturing and assembly route.
It is expected that during the manufacturing design minor adaptation will be needed (e.g. on the final geometry of the ACCC). Those adaptations are part of the scope but will need F4E/IO authorization.

Based on this Build-to-Print specification, the scope of work of the Supplier includes, mainly:

1. Manufacturing Engineering:
   - ✓ Manufacturing plan;
   - ✓ Material procurement specification;
   - ✓ 2D drawings for manufacturing and testing;
   - ✓ Procedural baselines for manufacturing sequence, welding, NDE, and factory assembly;
   - ✓ A Manufacturing Readiness Review (MMR) that authorizes start of procurement and manufacturing activities after successful demonstration by the Supplier. Earlier procurement of raw materials is accepted but subjected to the approval by F4E/IO of the material technical specification.
2. Procurement:
   - ✓ Base Materials;
   - ✓ Bolts;
   - ✓ Off-the-shelf products.
3. Manufacturing:

- ✓ Machining;
- ✓ Forming;
- ✓ Metrology;
- ✓ Welding;
- ✓ NDT of the welded joints such as VT, PT, RT, UT;
- ✓ Marking and identification of components;
- ✓ Final cleaning.

4. Factory testing:
   - ✓ Factory assembly;
   - ✓ Metrology and gap inspection;
   - ✓ Functional tests as described in 3.5.5;
5. Packaging and shipment to ITER Cadarache:
   - ✓ The PMS will be disassembled in individual subassemblies.
6. Documentation:
   - ✓ Quality documentation;
   - ✓ Manufacturing documentation;
   - ✓ End of Manufacturing Report (EMR) dossier.

In addition, the Supplier will design and procure the specific jigs, fixtures and frames that are needed for the construction and testing of the equipment. These items are not specified by F4E.

* The procurement strategy is not yet defined; the possible options are described in section 6.

5 TECHNICAL AND INDUSTRIAL CAPACITY

The potential Supplier(s) is expected to be experienced in the following fields:

Table 10: Expected industrial capacity (*)

	Vessel PMS	RPOM	HVB PMS	ACCC
Manufacturing of large component	No	Yes	Yes	Yes
Precise assembly of large components (at factory)	Yes	Yes	No	No
Manufacturing according to RCCM or similar codes	Yes	No	Yes	No
Quality system suitable for management of safety relevant activities	Yes	No	Yes	No
Manufacturing of large parts in plastic material	Yes	No	Yes	No
Lead shields fabrication	Yes	No	No	No
Manufacturing engineering	Yes	Yes	Yes	Yes
Copper magnet manufacturing	No	No	No	Yes
Magnetic tests of carbon steel	Yes	No	No	No
Non-destructive examination such as RT and UT	Yes	No	Yes	No
Machinery manufacturing	No	Yes	No	No
Water hydraulics	No	Yes	No	No
High Vacuum component manufacturing	No	No	No	No
Clean environment	Yes	No	Yes	Yes

manufacturing				

* The procurement strategy is not yet defined; the possible options are described in section 6.

One of the main challenges will be to fabricate SIC parts compliant with the French nuclear code: RCC-MR 2007 especially for what concern material procurement, welding and the Non Destructive Testing, even though the components are not pressure bearing nor primary confinement.

The second main challenge concerns the precision of the overall assembly, that consists of individual elements up to 6 m long and 20 tons weight, with tolerance of the order of 1 mm in some interfaces.

The potential Supplier(s) is expected to have the industrial capacity for procuring and manufacturing up to two magnetic shielding to the requested schedule, in particular:

- Manufacturing engineering;
- Management team for the engineering, procurement and construction contract as well as effective activity execution management;
- Quality assurance and quality control activities;
- Machining, dimensional inspection, and non-destructive examination for large components;
- Manufacturing documentation management;
- Factory with suitable capacity (floor space and load capacity, cranes, cleanliness) for assembly of equipment suitable for the manufacturing scope execution;
- Adequate management system for Safety Relevant Activities to be performed.

With this market survey, the Supplier(s) is invited to provide information on the parts of the contract which are intended to be subcontracted. Among the activities which may be considered subcontracted or insourced, where applicable, are:

- cutting and machining activities;
- forming;
- surface treatments (painting, phosphate coating);
- welding, NDT;
- dimensional inspection;
- lead and polyethylene shields;
- machinery (RPOM) manufacturing and water hydraulics;
- factory assembly.

6 PROCUREMENT STRATEGY

A framework contract with reopening of competition will be launched to select 3 Suppliers.

The first task order, awarded to the 3 Suppliers will foresee the manufacturing engineering and prototyping activities.

The competition will be reopened for the award of the manufacturing of the two units. If necessary for schedule reason two contracts may be awarded for one unit each.

7 SCHEDULE

The main tentative dates of the current planning are indicated below:

- F4E plans to publish a Call for Tender (CFT) by July 2025. The contract is planned to be signed within 1 year from the CFT publication.

- The expected delivery date is Q1 2031.