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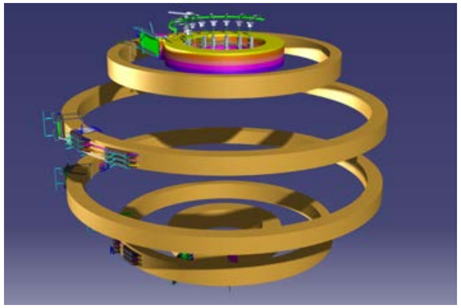
26 Apr 2021

PFC tender: technical issues, planning and logistics

Andrea Augieri

ENEA and DTT S.c.a r.l.



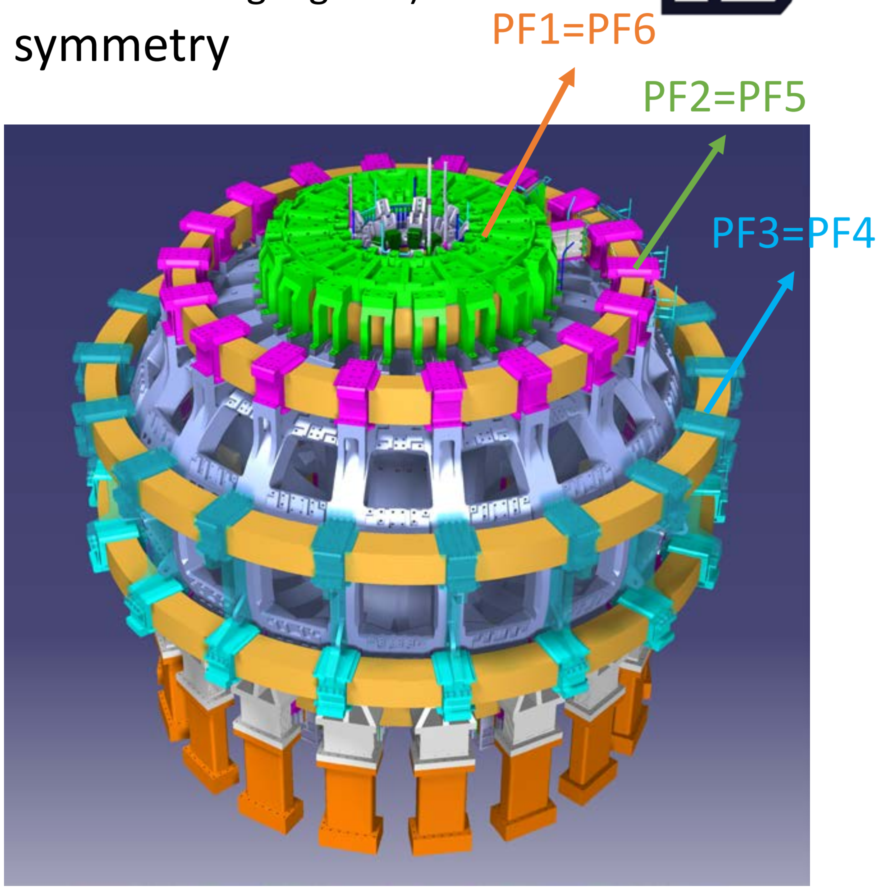
DTT INFO DAY – Superconducting Poloidal Field Coils Procurement

- Introduction to DTT Poloidal Field Coils
- Focus on some critical aspects of the procurement:
  - Internal Joints
  - He inlet and outlet
  - Nb_3Sn thermal treatment
  - Nb_3Sn turn insulation after thermal treatment
  - Provisions for coils integration in DTT
  - Process Qualification
  - Acceptance tests
  - Transportation and logistic
- Delivery and payment Schedule

DTT Poloidal Field Coils

6 coils

almost identical in pairs (small deviations will be highlighted)
to fulfil the full top-down symmetry



All coils relying on pancake winding technique

PF1-PF6: Nb_3Sn

PF2-PF5 and PF3-PF4: NbTi

The procurement will be for:

Impregnated winding packs with:

- He inlet and outlets (with related breakers and pipelines);
- Insulations (turn, pancake, winding pack);
- Internal joints and terminations;
- Instrumentation.

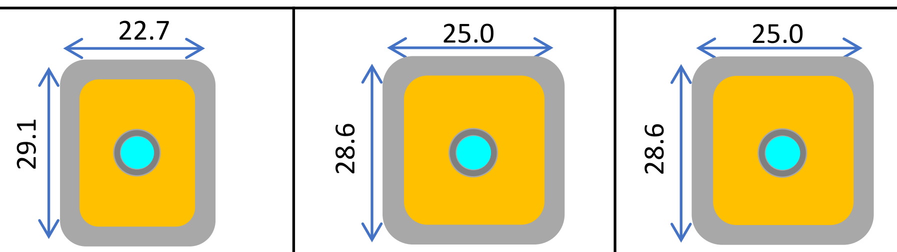
Temporary mechanical structures for handling and transportation and provisions for coils integration in the DTT machine will be also part of the procurement (more details in the next slides)

COILS main Features and parameters

Coil	PF1/6	PF2/5	PF3/4
B_{max} (T) (input data)	**9.1**	**4.2**	**5.3**
MA turns max (input data)	10.19	4.34	5.61
Inter-Pancake Insulation	1mm		
R_{in} (mm, @RT)	**1140**	**2940**	**4150**
R_{out} (mm, @RT)	**1660**	**3220**	**4550**
Z_{mean} (mm, @RT) (0 = eq. plane)	±2760	±2534	±1015
ΔZ_{tot} (mm, @RT)	582.4	516.8	452.2
Ground Insulation (to be added to ΔR & ΔZ)	5mm		
# Quadri/Double pancakes	**4 QP + 1 DP**	**8 DP**	**7 DP**
# turns (radial)	20	10	14
# turns (vertical)	18	16	14
Unit length (m, @RT)	723/361	394	769
N turns totali	**360**	**160**	**196**
I_{op} max (kA)	**28.3**	**27.1**	**28.6**
ΔT_{margin} (T_{op}: 4.5K)	**1.8**	**1.9**	**1.7**
L (H)	**0.454**	**0.298**	**0.690**
Weight (ton)	**15**	**16**	**28**
Safety discharge (delay time)	**1.5 s**		
Safety discharge (tau)	**6 s**		

Conductor main Features and parameters

Conductor	PF1/6	PF2/5	PF3/4
Radial Ext. Dim. (mm, at RT)	22.7	25.0	25.0
Vertical Ext. Dim. (mm, at RT)	29.1	28.6	28.6
Jacket thickness (mm)	3.0	3.0	3.0
Inner Corner Radius (mm)	3.5	3.5	3.5
Central Channel (OD/ID; mm)	7/5	7/5	7/5
Turn insulation (mm)	1.4	1.4	1.4
# SC strands (0.82mm)	180 (Nb_3Sn)	162 (NbTi)	324 (NbTi)
Strand Cu no-Cu ratio	1	1.9	1.9
# Cu strands (0.82mm)	216	324	162
Total strand number	396	486	486
Cabling sequence	[2x(2sc+Cu)+(sc+2Cu)x (6+Cucore)x6] Cu core: 12 strand	(2Cu+1SC)x3x3x3x6	(1Cu+2SC)x3x3x3x6
Void fraction	29.8%	27.9%	27.9%
LBO wrapping	(0.05 ± 0.01) mm x 12 mm, open area 50%, SS		
external wrapping	(0.05 ± 0.01) mm x 40mm, 50% overlapping, SS		



The tolerances for the cross section dimensions (±0.1mm) apply to the conductor after compaction and prior to spooling. No attempt will be made by the conductor manufacturer to correct any key-stoning or other effect which may result from the spooling process.

INTERNAL JOINTS AND TERMINATIONS

4 internal joints for PF1-PF6, 7 for PF2-PF5 and 6 for PF3-PF4

+

2 half terminations for each coil

Detailed design is left to supplier

It **must** be compliant with requirements in terms of:

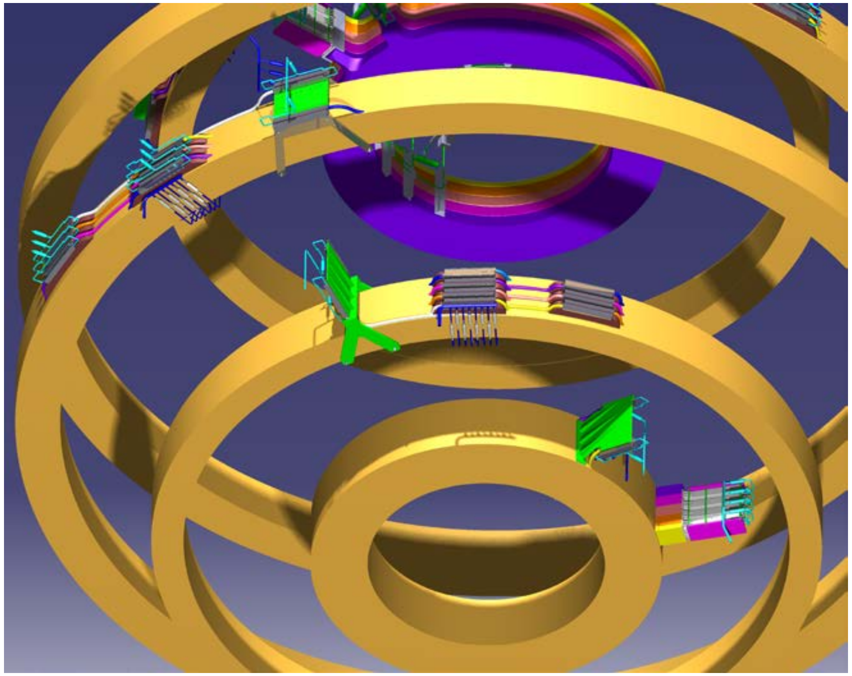
- Maximum allowable resistance
- Geometrical constraints

Each coils internal joints concept MUST pass the following qualification test:

- @RT
  - welds mechanically tested
  - He leak test at 3 MPa for 3 hours
- @4.5 K
  - electrical test (maximum resistance specification)

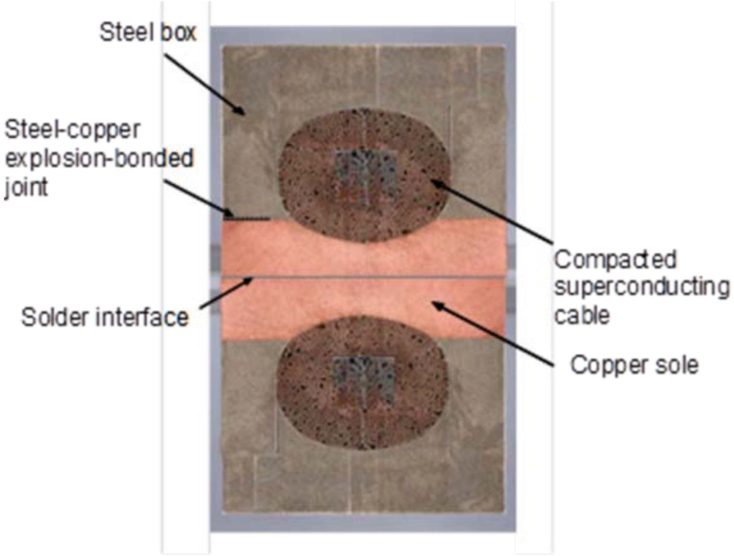
INTERNAL JOINTS AND TERMINATIONS

PF1 - PF6 + PF5



Internal Joints and half terminations **MUST** be in radial direction (interference with other structures)

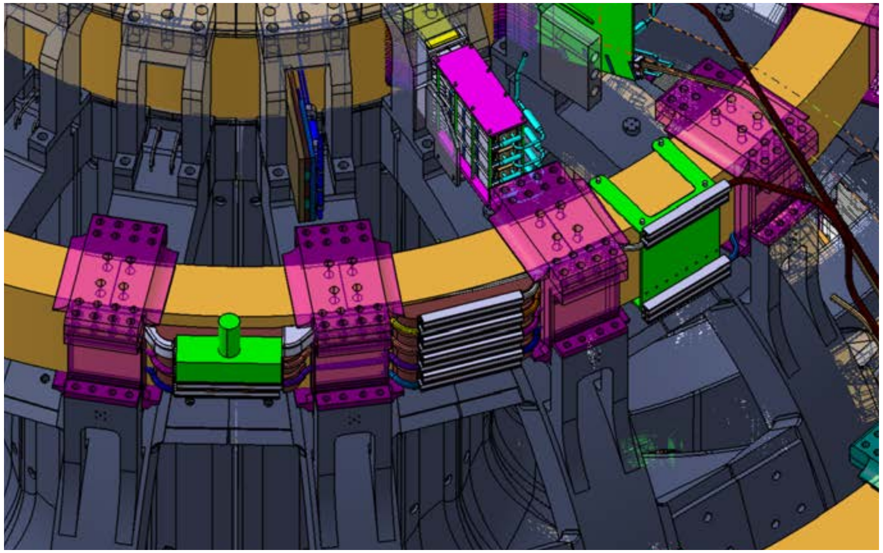
Possible method: twin box – praying hands



A supporting structure (G10) embedded in the WP body **MUST** be designed and realized to ensure mechanical stability of the joints and termination structures

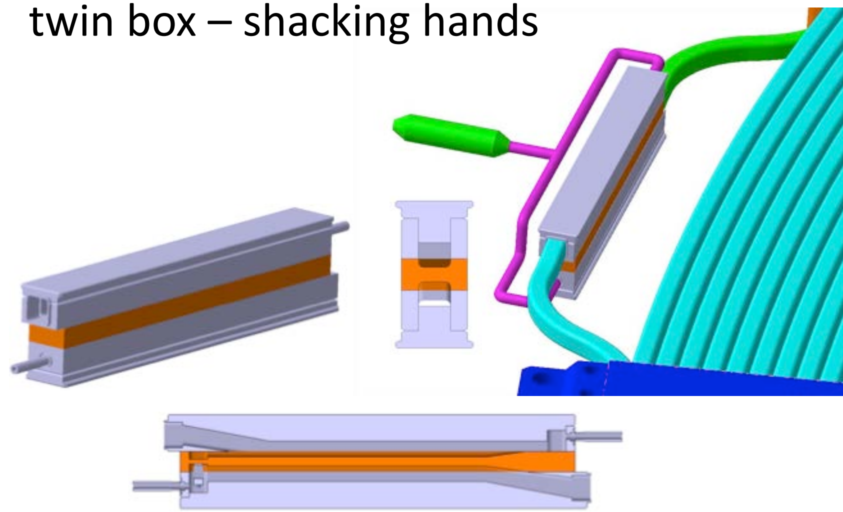
In PF1-PF6, half joint should be prepared before heat treatment
Joint finalized after heat treatment

PF2 – PF3 – PF4



Internal Joints and half terminations **MUST** be in tangential direction

Possible method:
twin box – shacking hands



A supporting structure (G10) embedded in the coil body **MUST** be designed and realized to ensure mechanical stability of the joints and termination structures

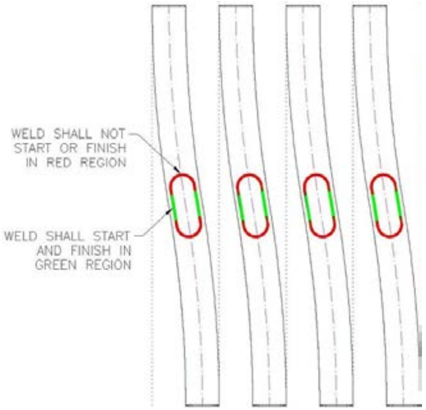
Reduced space between joints could be an issue:
joint process must be possible with all the DP stacked

He inlet and outlet

He inlets must be located always in the inner surface of the coils.

In DPs, the inlets will be welded in the inter-pancake transition region

In QPs, the inlets will be welded in the 1->2 and 3->4 inter-pancake transition region



He outlets must be located always in the joint or half termination region

In QPs, outlets will be welded in the 2->3 inter-pancake transition region

The He inlet and outlet manufacture could be critical with respect to:

- strand integrity
- pipeline complexity

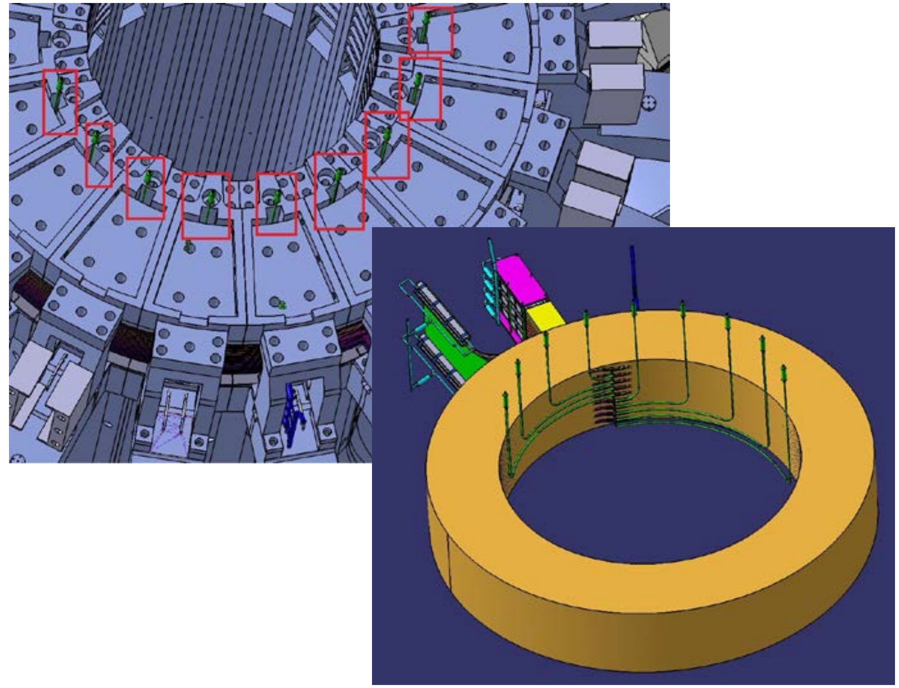
The proposed manufacturing process MUST be approved by DTT and MUST be qualified (He leak, pressure test and strands properties)

He Inlet and Outlet

PF1 - PF6

Complex pipeline structure
(due to geometrical constraints)

Electrical isolators on He line will be re-installed after integration with mechanical supports



PF1 - PF6 coils will be tested in the DTT Cold Test Facility

Coil acceptance after test results

after the test

connection with He circuit will be removed (step 1)
during the assembly, connection with He circuit will be restored (step 2)

Supplier **MUST** define a proper procedure to perform step 1 and step 2 to be sure that insulation and He circuit will be safe (warranty still valid)

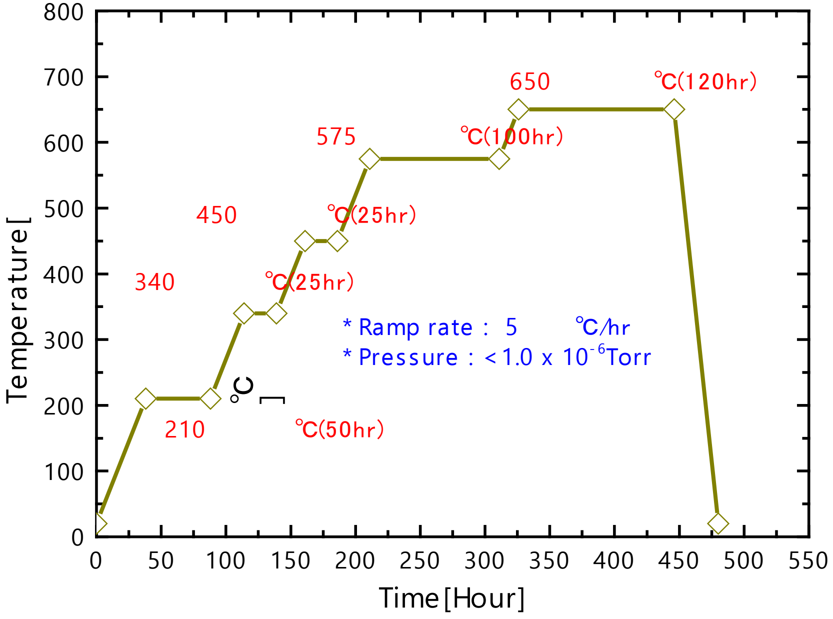
Nb_3Sn thermal treatment

The temperature and Ar gas pressure MUST be accurately monitored and their readings recorded during the entire cycle

The correctness of the heat treatment will be proved on one or more strand (provided by DTT) witnesses placed inside the furnace

The required temperature uniformity inside the working volume (including the thermal load mass) is ± 5 °C

Example of Nb_3Sn thermal treatment



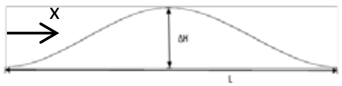
Nb_3Sn insulation (after thermal treatment)

TURN INSULATION include :
the positioning of the co-wound tape for the QDS, and the insulation of the He Inlet region
and
does not include the inter-pancake insulation (additional step)

NbTi coils (PF2-PF3-PF4-PF5): turn insulation can be performed during the winding process (supplier can choose to perform this step in a different stage)

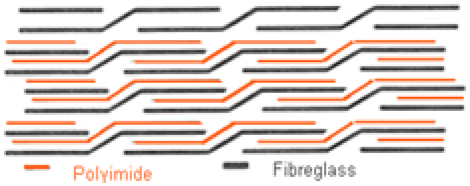
Nb_3Sn coils (PF1-PF6): turn insulation **MUST** be performed after the thermal treatment

Lifting each turn of DP and QP



Longitudinal and transverse strain on the conductor must be considered

Wrapping the complete conductor length (hybrid Polymide and Fiber glass)



ITER PF like turn insulation layout

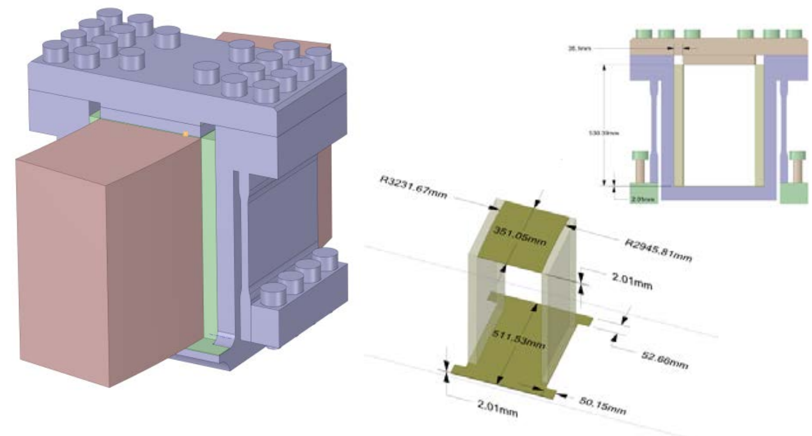
Provisions for coils integrations in DTT

Each PF winding pack will be integrated with 18 mechanical supports

Mechanical support purpose:
pre-compression of the coil
mounting of PF coils on TF structures

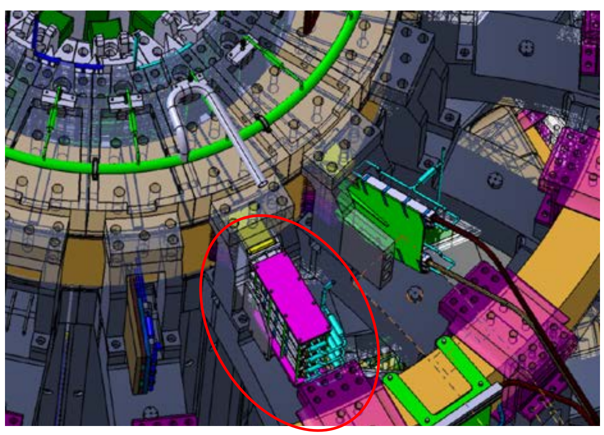
The integration will be made by DTT but…

G10 filler and **SS sheets** for finer spacing must be provided by the supplier



DTT will provide detailed information on this topic

In
PF1 - PF6 + PF5
joints and
term.
are in radial
direction



Coils are expected to move in radial direction
(cooldown and energization)

↓

Slides to allow joints and termination radial movement

Qualification of the Manufacturing process

The definition of most of the manufacturing processes are left to supplier

BUT

All the special processes **MUST be qualified** and approved by DTT

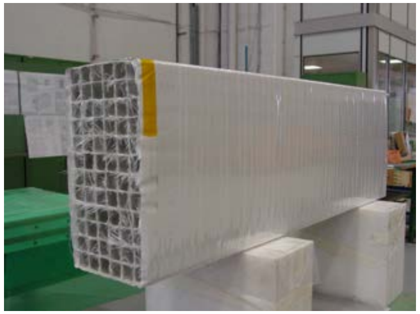
Internal joints and half terminations

Geometrical: 3D modelling
Electrical: test on mock-up (@ op. cond)

He inlets and outlets

Strand integrity
He leak and pressure tests
Insulation

Winding + Impregnation → **SUB-size or Mock-up Straight beam Sample**


Courtesy of JT-60SA

Geometrical survey
Sizes check
Impregnation quality
Electrical test

minimum set of the QUALIFICATION TESTS will be defined by DTT

Qualification of Insulation

A dedicated procedure, to be submitted and approved by DTT has to be prepared and qualified by testing a **significant WP mock up**

HIGH VOLTAGE TESTING

D.C.

V_{dc} = 1.2 kV (turn insulation)

V_{dc} = 10 kV (insulation to ground)

A.C.

V_{ac} (RMS) = $0.1/\sqrt{2}$ kV (turn insulation)

V_{ac} (RMS) = $3/\sqrt{2}$ kV (insulation to ground)

Example values. Exact voltage values will be provided with technical specifications

Simplified PASCHEN test (@RT)

High Voltage testing in Vacuum and selected step of He pressure

Qualification of the Manufacturing processes

Conductor lengths provisions

Item	Length (m)	Quantity
PF1-PF6 Cu Dummy	368	1
PF1-PF6 SuperDummy	200	1
PF1-PF6 DP	368	8
PF1-PF6 QP	730	2
PF2-PF5 Cu Dummy	401	1
PF2-PF5 SuperDummy	200	1
PF2-PF5 DP	401	16
PF3-PF4 Cu Dummy	776	1
PF3-PF4 Cu SuperDummy	200	1
PF3-PF4 DP	776	14

Any other material required for the qualification of the manufacturing processes must be purchased by the supplier

Acceptance Tests

There will be acceptance tests during **each** manufacture step of a single coil

- He inlets
- Winding
- Internal Half joints and terminations
- Heat treatment
- Insulation of DP and/or QP
- Internal joints
- Impregnation
- Instrumentation
- WP grounding

Mechanical tests of welding
Pressure tests
He leak test

Geometrical measurements
Strands witnesses verification

Prior to:
He leak and pressure test
Flow measurement
After:
Geometrical and visual check
HV tests

Final Acceptance tests: COIL

Tests at Room Temperature

Visual checks (integrity of wiring and hydraulic circuit, geometrical survey)

Electrical tests (RT resistance, HV tests, V taps connections, turn insulation tests)

Simplified PASCHEN test

Leak test

Pressure test

Pressure drop test

Courtesy of ITER

Tests at Cryogenic Temperature

Hydraulic tests

Evaluation of joint resistance

PF1-PF6

will be tested in the COLD TEST FACILITY

I_c test

QDS test

(final acceptance released only after tests)

Transportation and logistics

Transportation of the coils could be an issue

- Total weight (> 15 tons)
- Total dimensions (~10 m)

Coil	PF1/6	PF2/5	PF3/4
R_{in} (mm, @RT)	1140	2940	4150
R_{out} (mm, @RT)	1660	3220	4550
Weight of WP (tons)	15	16	28

The transportation strategy is left to the supplier

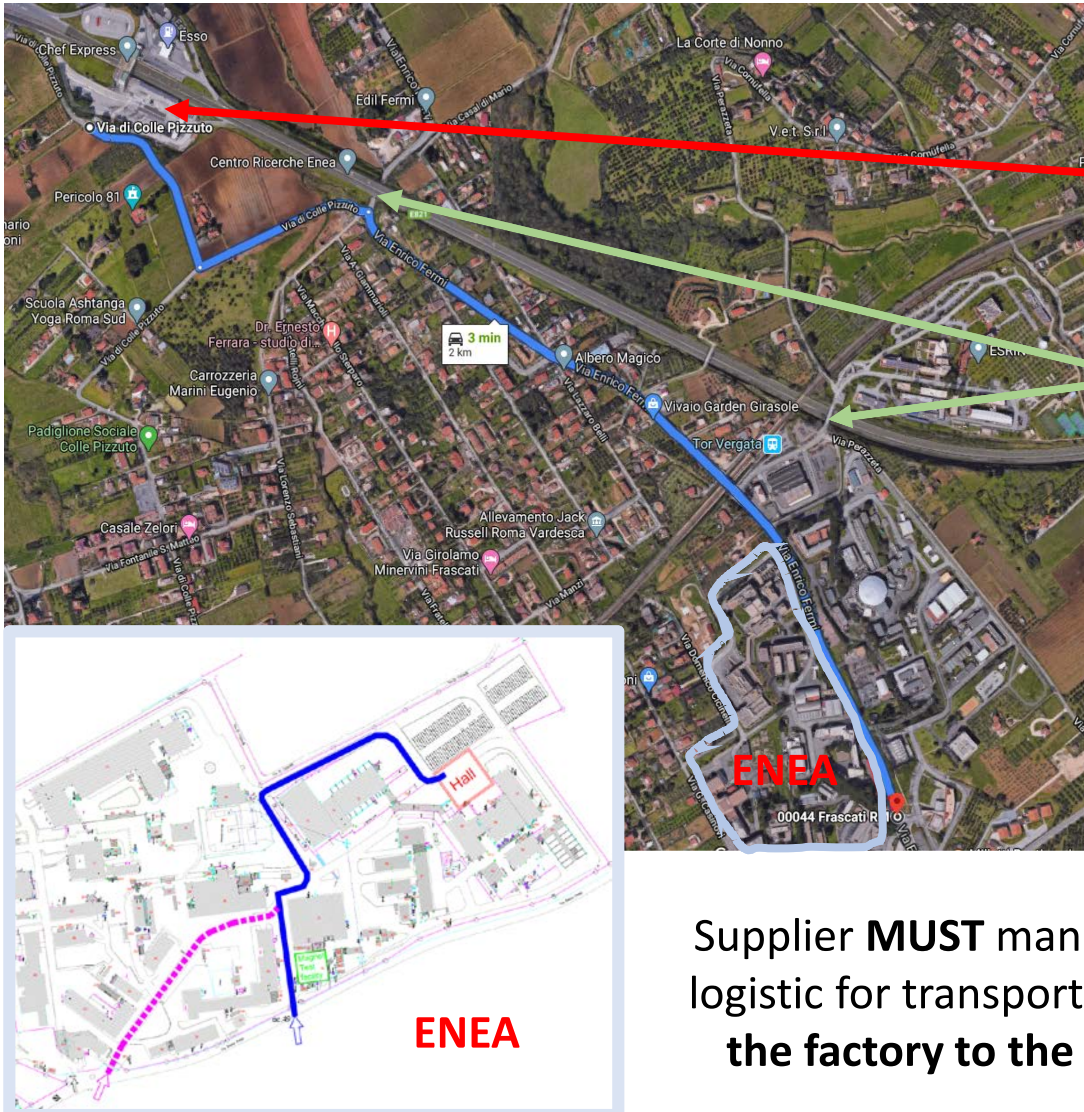
For **all the 6 coils** a **transportation structure** **<u>must</u>** be designed and realized

Courtesy of JT-60SA

Courtesy of ITER

For PF1-PF6 the transportation structure **<u>must</u>** be designed to work in the **Cold Test Facility**

Some possible hypotheses



Hp-1: A1 (E35 Highway) Frascati Service Station

Hp-2: Bridge over the A1 (E35 highway)

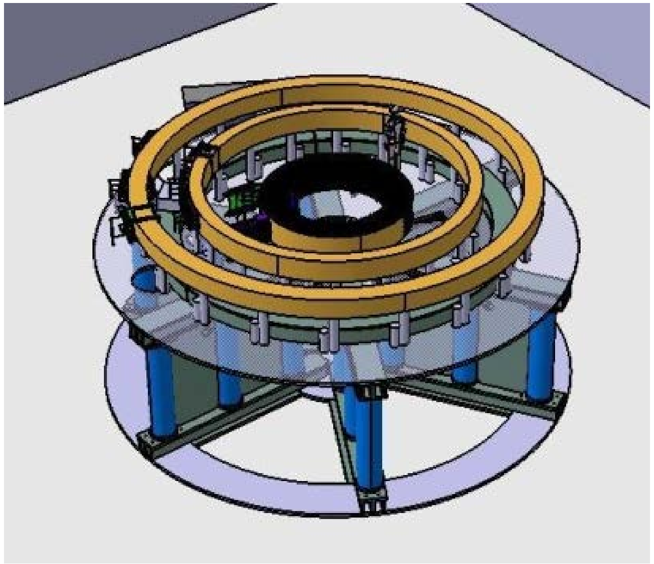
Hp-3: Mil Mi-26 from A1 (E35 Highway)

Supplier **MUST** manage all the logistic for transportation from **the factory to the DTT Hall**

Delivery and Payment Schedule

There are two main constraint:

1. PF6, PF5 and PF4 MUST be delivered, tested (PF6 only) and ready to be assembled before September 23;
2. Conductor delivery schedule already defined.



Main consequences

Although coils are identical in pairs, the production plan MUST proceed in this order:
PF6 – PF5 – PF4 – PF3 – PF2 – PF1

Due to conductor production schedule (fixed by other magnets requirements): there could be a pause in the PF coils production (some months)

About payments: a 20% of the total amount can be pre-paid

THE END

Thanks to:
S. Turtù, G.M. Polli, A. Di Zenobio