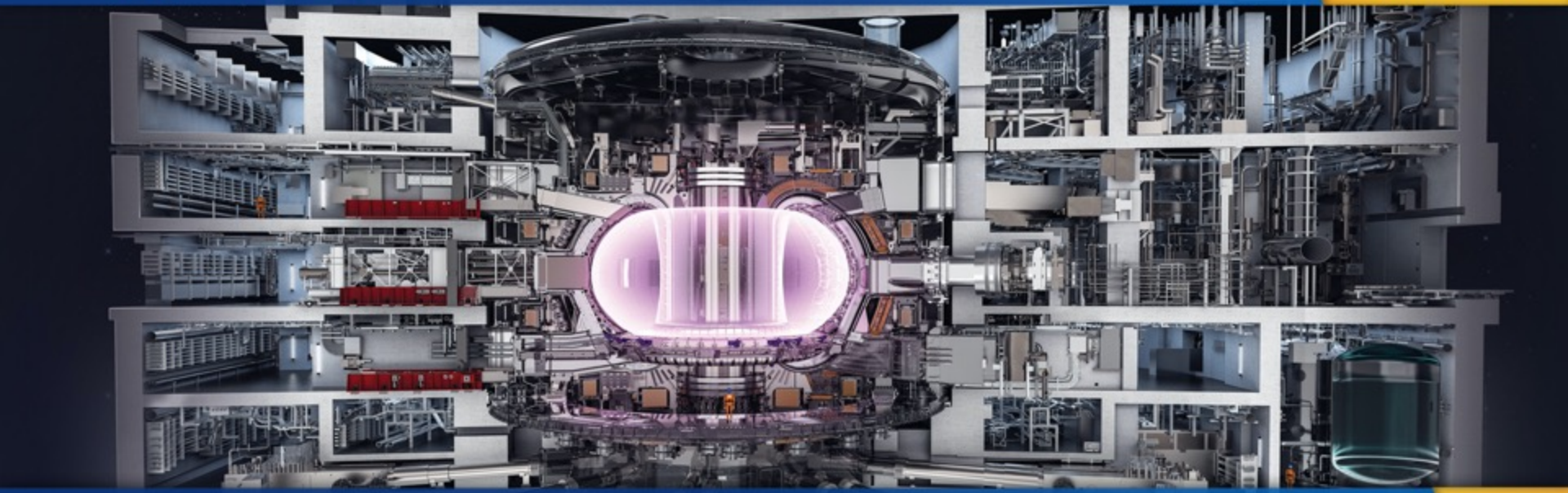
FUSION FOR ENERGY

BRINGING THE POWER OF THE SUN TO EARTH



The ITER Magnet System and the European Contribution

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Technical Procurement Officer @ Magnets Unit

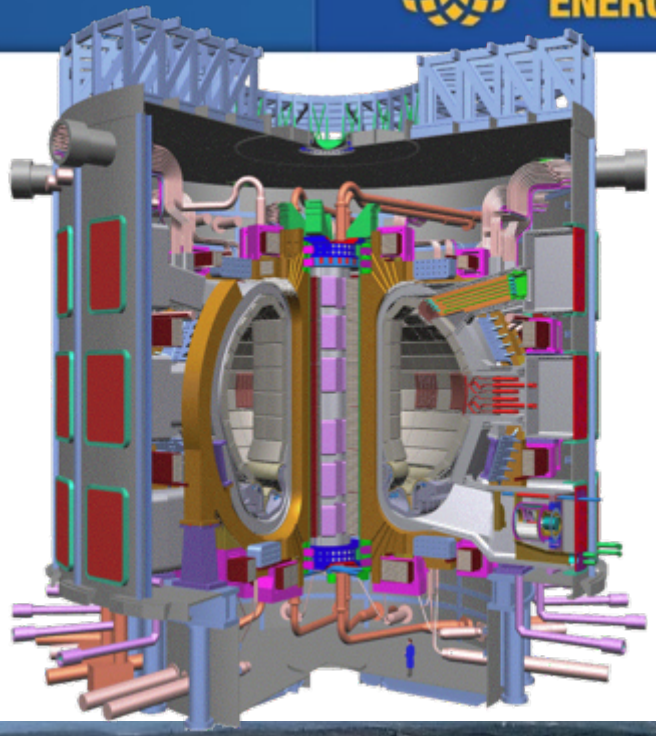
Big Science Sweden Conference 2020 - 24 November 2020

ITER

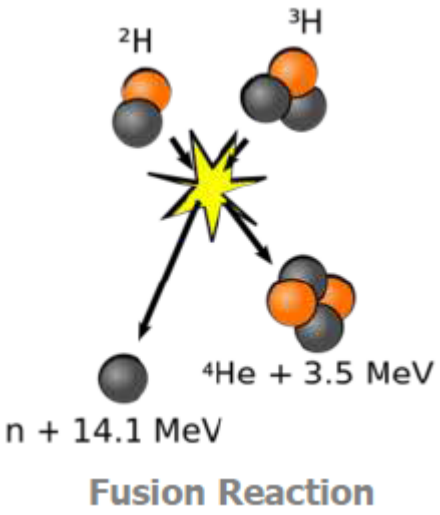
- ITER will be the first fusion device to generate more heat than used to start the fusion reaction.
- ITER is under construction in Cadarache, south of France.
- The members are Europe, China, Japan, India, the Republic of Korea, the Russian Federation and the United States.

Advantages:

- No Greenhouse gas emissions
- No ‘long-lived’ radioactive waste
- No risk of critical safety events
- The fuels are abundant and there is no geographical localisation.



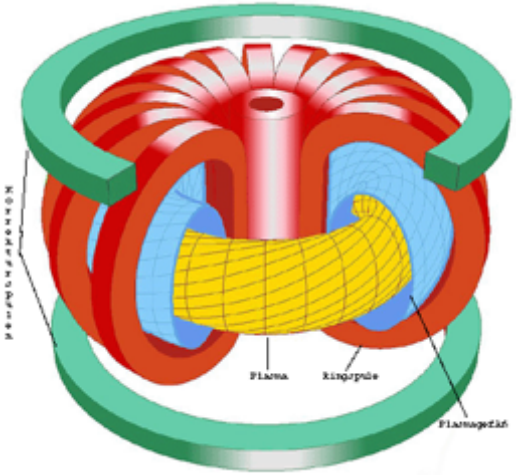
ITER Magnets: why?



Fusion Reaction

- To get the fusion reaction very drastic conditions of density and temperature (~ 150 millions of ^{o}C!!) needed.
- In such conditions the matter state is called plasma and it needs to be confined to keep conditions.

In ITER Tokamak:



- **CS** creates and drives the plasma current,
- **TF** for the magnetic confinement of the plasma
- **PF** coils shapes and stabilizes the plasma.
- In order to minimize power consumption and magnets dimensions by maximizing current density, superconducting magnets used at -269 ^{o}C.

The ITER Magnets System

48 Superconducting Coils

18 TF coils (Nb_3Sn):

- 9 JADA,
- 10EUDA
- 18 Installed, 1 Spare

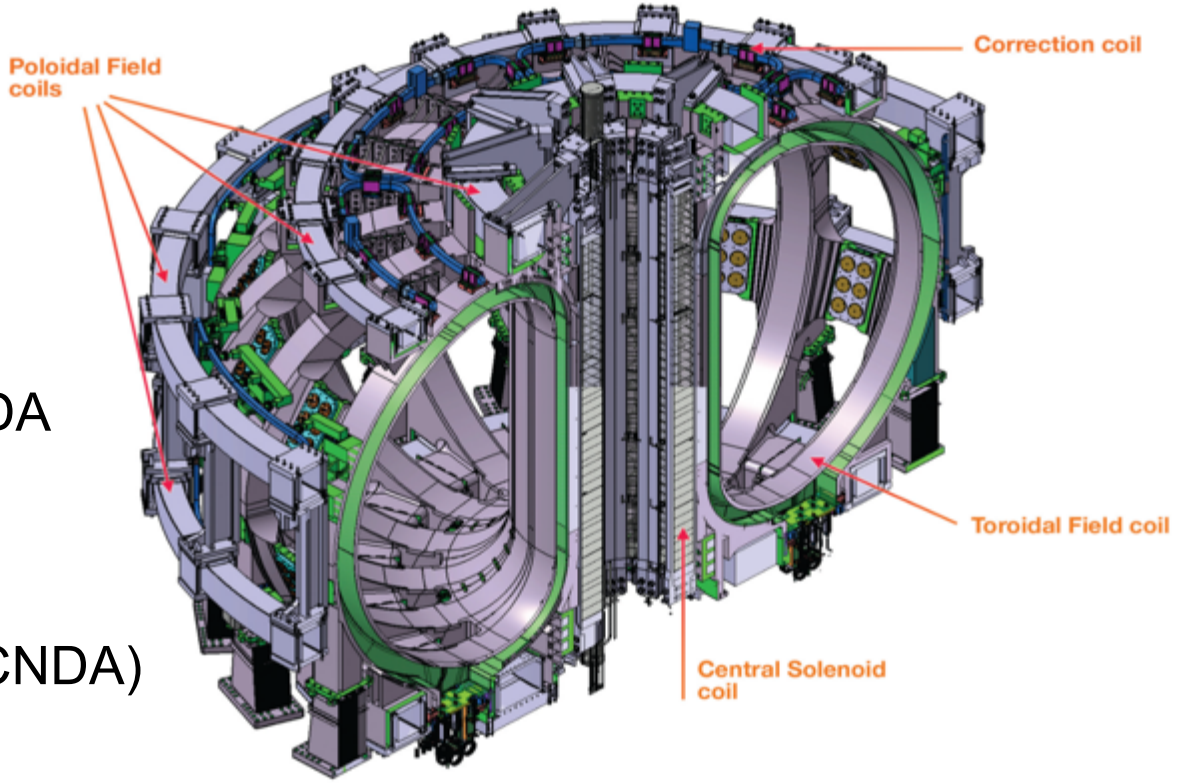
6 CS modules (Nb_3Sn): USDA

6 PF coils (Nb-Ti):

- 1 RFDA
- 5 EUDA (1 supplied by CNDA)

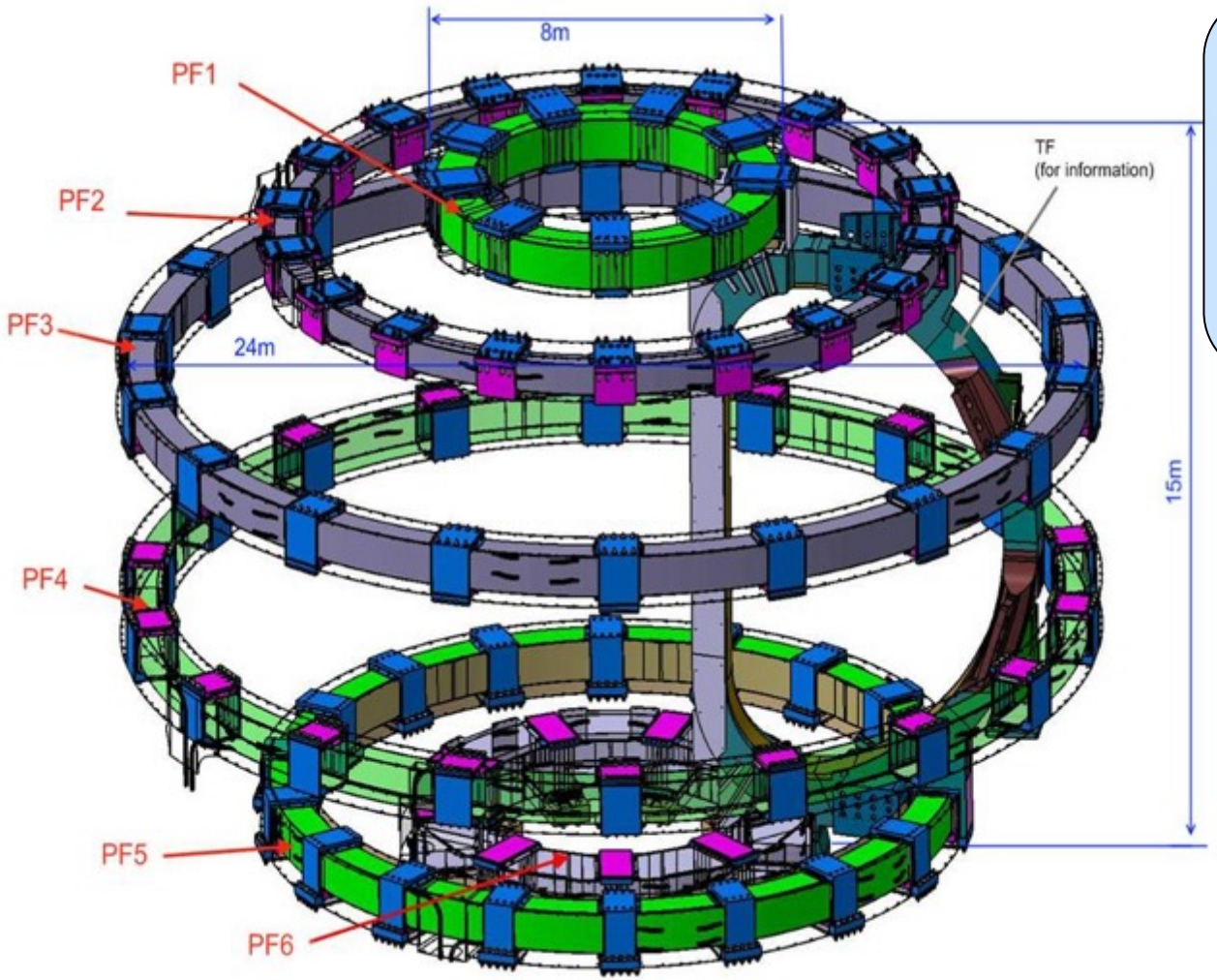
18 CC (Nb-Ti): CNDA

Magnet Systems: 10,150 t



For comparison:*ITER Toroidal Field 41 GJ → 10.5 GJ magnetic energy in the 27 km tunnel of the Large Hadron Collider at CERN)*

ITER PF Coils, NbTi Magnets



Russia 1 coil

PF1

EU 5 coils

PF2-PF5 in Cadarache

PF6 in China (ASIPP)

	OD (m)	H (m)	W(t)
PF6	10.3	1.1	399
PF5	17.6	1.0	342
PF2	17.2	0.7	208
PF4	24.6	1.0	349
PF3	24.8	1.0	384

PF Procurement Strategy

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Driving factors

- PF3 & PF4 too large to be transported: to be built in Cadarache
- PF5 & PF6 to be delivered simultaneously: 2 production lines
- Not enough space in Cadarache to install 2 production lines

Key decisions

- Production line built in Cadarache
- Manufacture of PF6, the PF with smallest diameter, outsourced
- PF2-PF5 built in Cadarache

Procurement configuration

- PF2-PF5 Procurement split in 6 smaller contract: Engineering Integrator, Manufacturer, Tooling suppliers, Service and logistic contract
- PF6 Procurement assigned on 2013 through international agreement to:

Chinese Academy of Science (CAS) Institute ASIPP, located in Hefei (China)

The PF Factory in Cadarache

Winding

DP Impregnation 1

DP stacking

PF coil cold test

Electrical Jointing

DP impregnation 2

PF coil impregnation

PF coil final assembly

PF Manufacturing Status

PF6 status

- Cold test, Leak and Electrical test completed.
- Delivery to ITER January 2021.

PF5 status

- Positioned in the cryostat, final assembly on going.
- Cold test, Leak and Electrical test on going starting in December.
- Delivery to ITER March 2021.

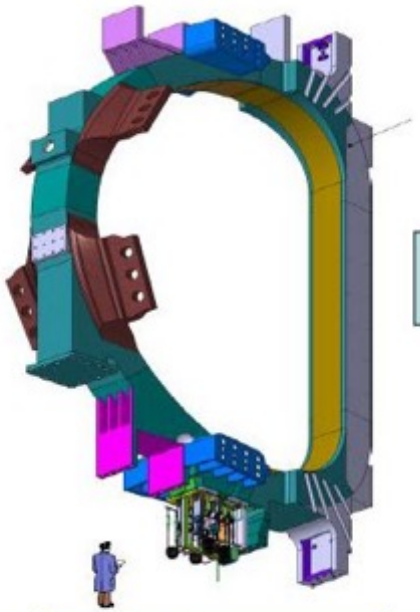
PF2 status

- WP in Impregnation to start in December.
- Delivery to ITER July 2021.

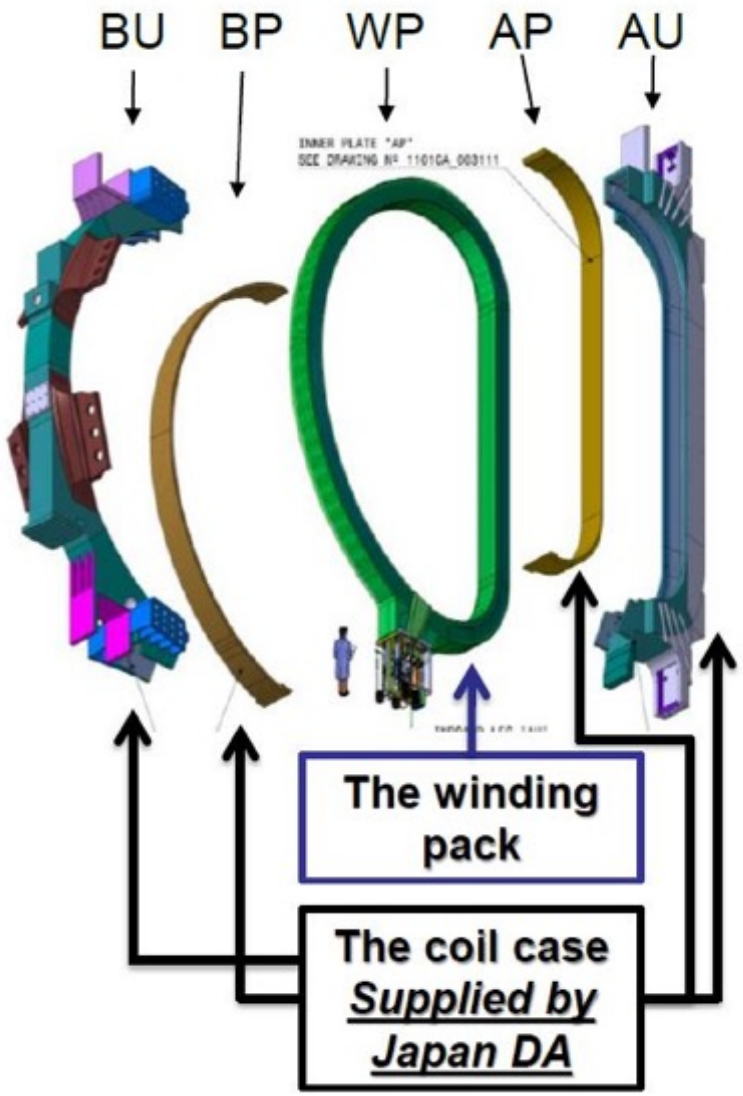
PF3-4 status

- PF4 2.5 DPs wounded and 1 DP ready for impregnation.
- PF4 deliver to ITER March 2023.
- PF3 deliver to ITER beginning 2024.

The ITER TF Coils

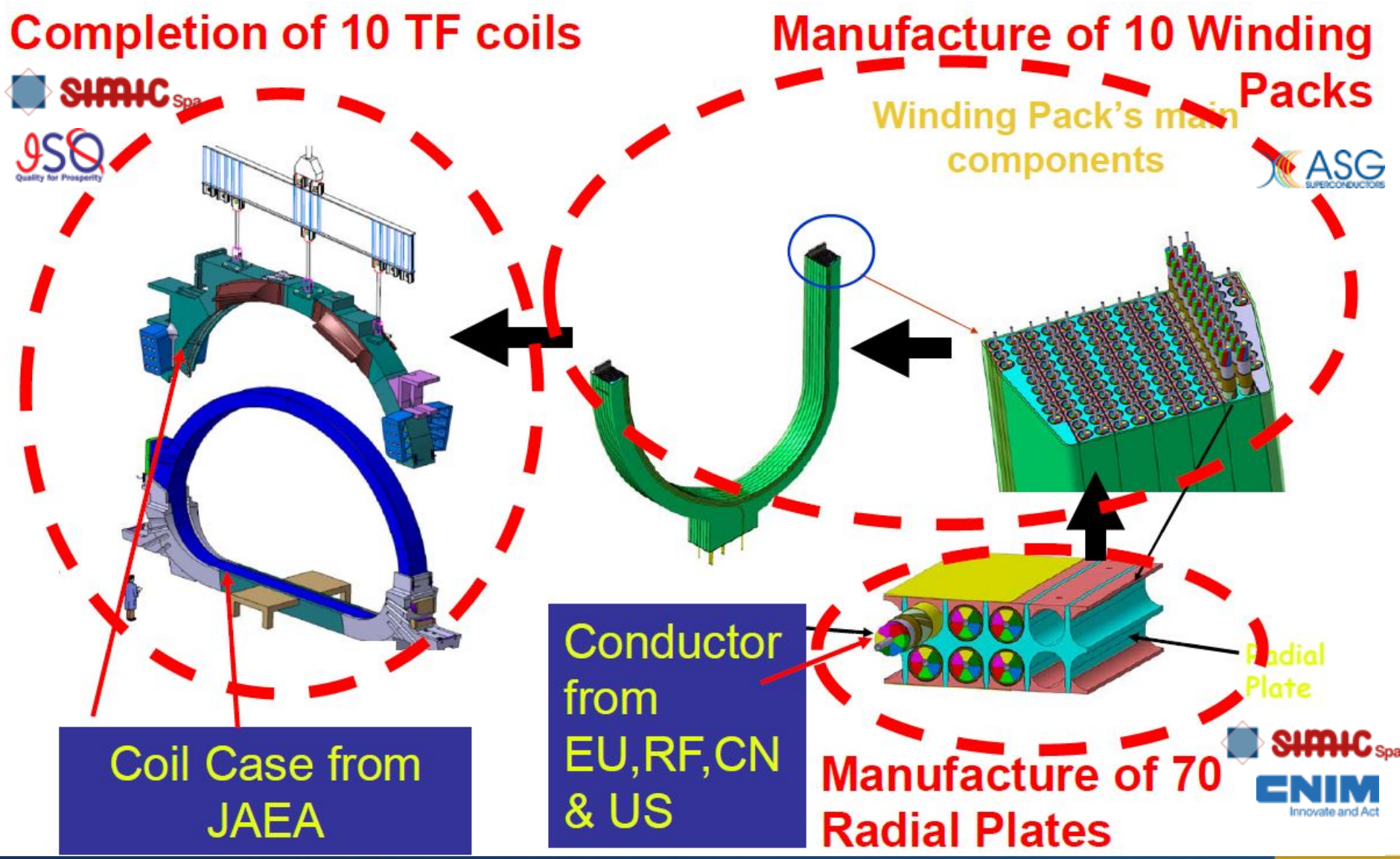


The ITER TF coil



	OD(m)	H (m)	W(t)
TF Coil	16.5	9	300

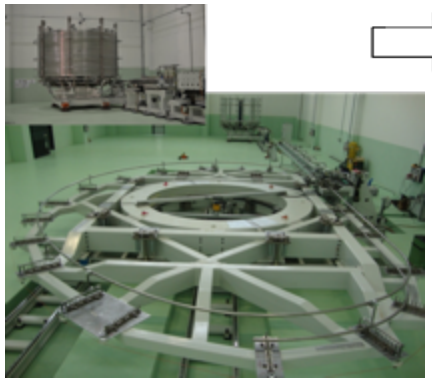
TF Coils Procurement Strategy



TF Coils: WP fabrication process

Each TF coil: 16.5 m high, 9m wide and around 300 tons (~ weight of Boeing 747!)
The biggest Nb_3Sn magnets ever produced. 11.8 T magnetic field. (~2.10^5 times that of Earth)

Conductor Spool



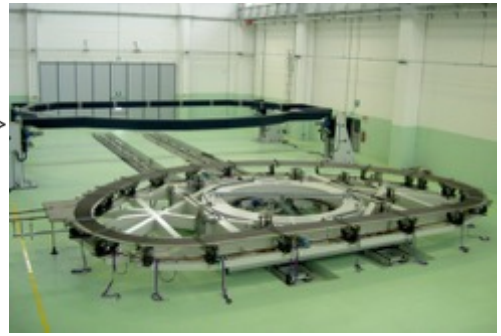
DP Winding
(14 m x 9 m)

He Inlet

DP Heat Treatment

Radial Plate Section Welding

Radial Plate
Assembly



Transfer of HTd DP into
Radial Plate

TF Coils: WP Fabrication process (2)

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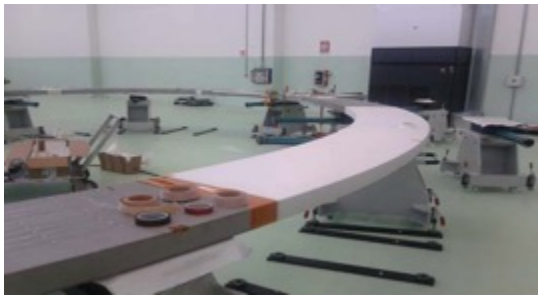
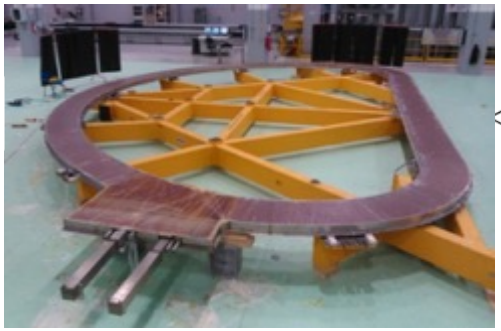
DP Turn Insulation inside Radial Plate

Cover Plate Welding



DP Ground Insulation

DP Loading into Vacuum Impregnation Mold (radiation-hard cyanate ester resin)

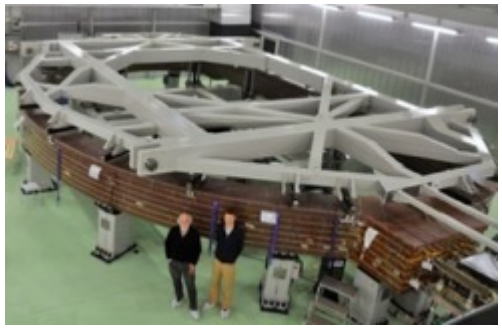


Impregnated DP

Hi-Pot Test on Impregnated DP

TF Coils: WP fabrication process (3)

Winding Pack (WP) made of 7 Double Pancakes (DPs)



7 DP Stacking

WP Insulation

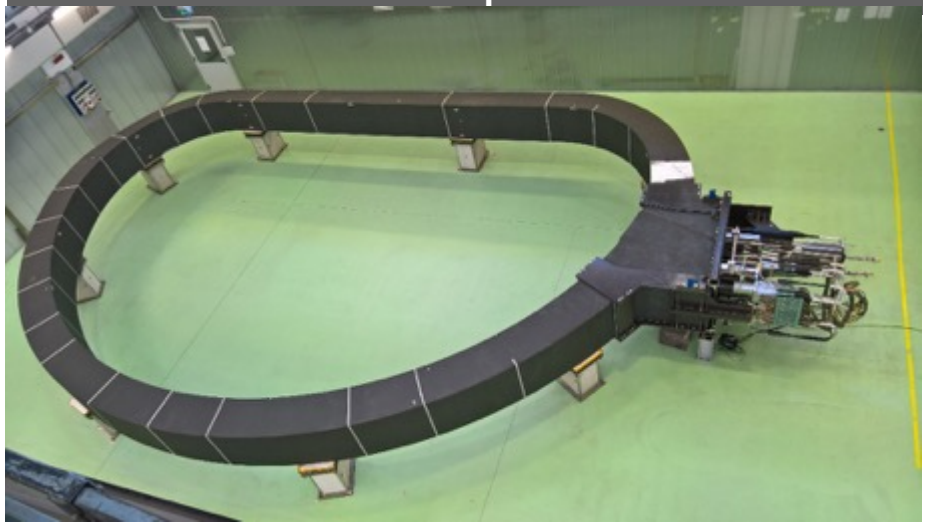
Terminal Preparation

Vacuum Pressure Impregnation

Completed WP

TF Coils WP Procurement Status

WP completed



70 Double Pancakes (DP) to build: completed !

- ☑ Winding of 70 DP completed ⇨**100%**
- ☑ 70 Radial Plates completed ⇨**100%**
- ☑ 70 DPs impregnated & completed ⇨**100%**

10 Winding Packs (WP) to build:

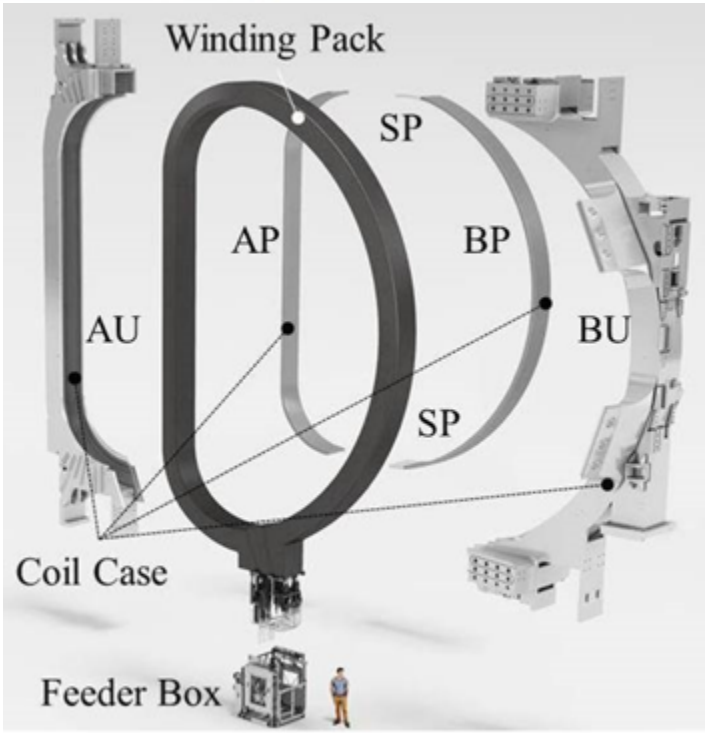
- ☑ Stacking of 10WPs completed ⇨**100%**
- ☑ Ground insulation of 10 WPs completed ⇨**100%**
- ☑ VPI of 10 WPs completed ⇨**100%**
- ☑ Final assembly of 9 WPs completed ⇨90%
- ☑ Delivery of 7 WPs completed ⇨70%

Production slowed down to match the delivery of TFCS by JA-DA

TF Coils: Insertion Process

Cold Test & Acceptance Tests

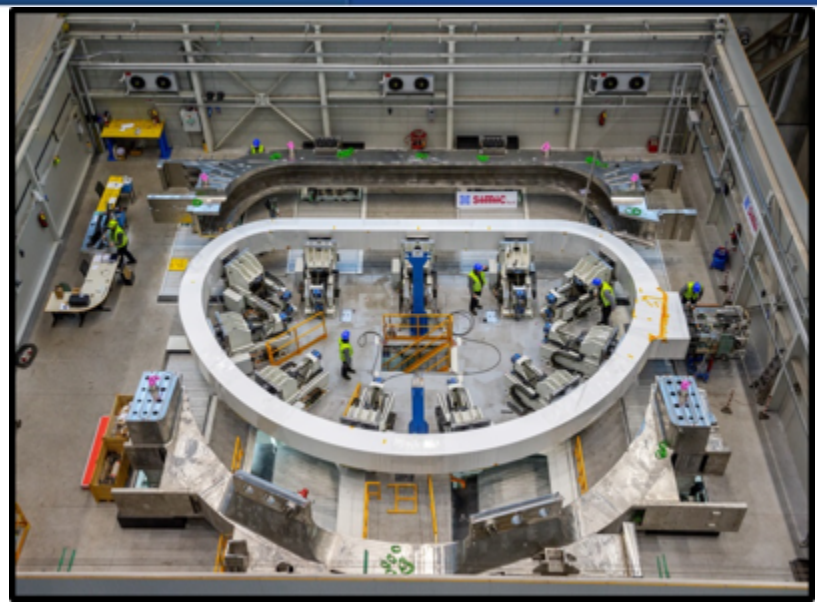
- Before to start the insertion the magnet is thermally cycled between R.T. & 80 K.
- Electrical and leak tightness tests are performed at each stage (the WP has to withstand up to 19.5kV to ground and the max acceptable leak rate is 5*10^7 mbar l/s)
- The aim is to check that the electrical insulation and leak tightness of the WP are not compromised after the thermal cycle.



TF Coils: Insertion Process (2)

Insertion

- Horizontal Insertion
- WP is kept still while CC moves (approaching speed of about 1mm/s)
- The WP has an “Optimal Position” defined as the position minimizing the Current Center Line deviation from its Nominal Position.
- On the first four WPs after insertion the WP was within 0.3/0.4mm from the “optimal position” (tol. ±1.3 mm)



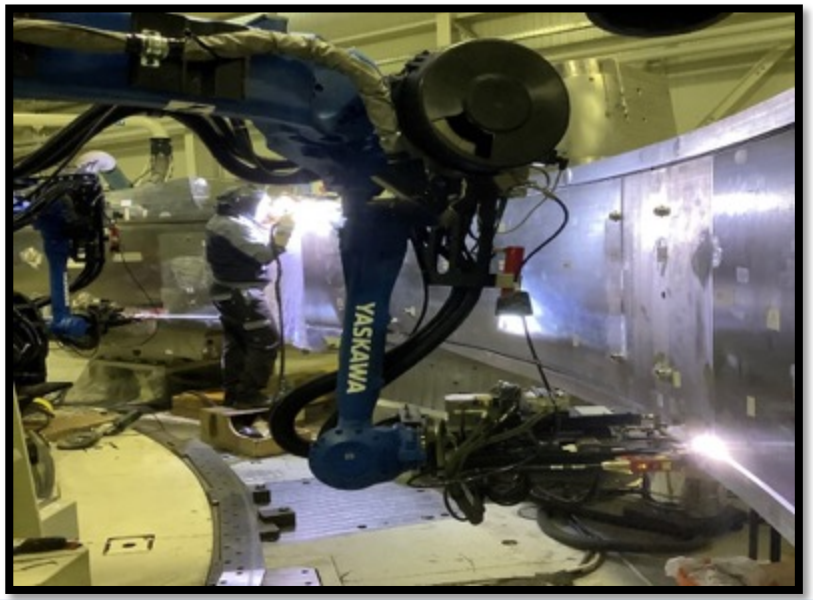
TF Coils: Insertion Process (3)

Closure Welding

- Welding is partially done with Manual GTAW process and partially using an Automatic Narrow-Gap-Pulsed GTAW process with two welding heads work simultaneously

Gap Filling

- Aim: to create a mechanical continuity engagement between WP and CC
- Filling with Epoxilic resin charged with Dolomite



TF Coils: Insertion Process (4)

Final Machining

Machining is done in a Portal Milling Machine where the TF coil fit entirely and the extra material of the TFC interfaces will be removed.

TF Coils Manufacturing Status

10 TF Coils to deliver to ITER:

- ☑ Cold test of 6 WPs ⇨60%
- ☑ Insertion of 5 WP in CC ⇨50%
- ☑ Welding of 4 TFC completed ⇨40%
- ☑ Gap Filling of 3 TFC ⇨30%
- ☑ Final machining of 3 TFC ⇨30%
- ☑ Delivery of 3 TFCs completed ⇨30%

Conclusions

- ITER project reached 70% completion for first plasma;
- EU production and delivery of Magnets on schedule;
- The Industry and Fusion Laboratories Portal is your point of entry for F4E's and ITER's business opportunities:

https://industryportal.f4e.europa.eu

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