ITER: Opening the way to a new energy future

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ITER International Organization

CHATS on Applied Superconductivity 2021

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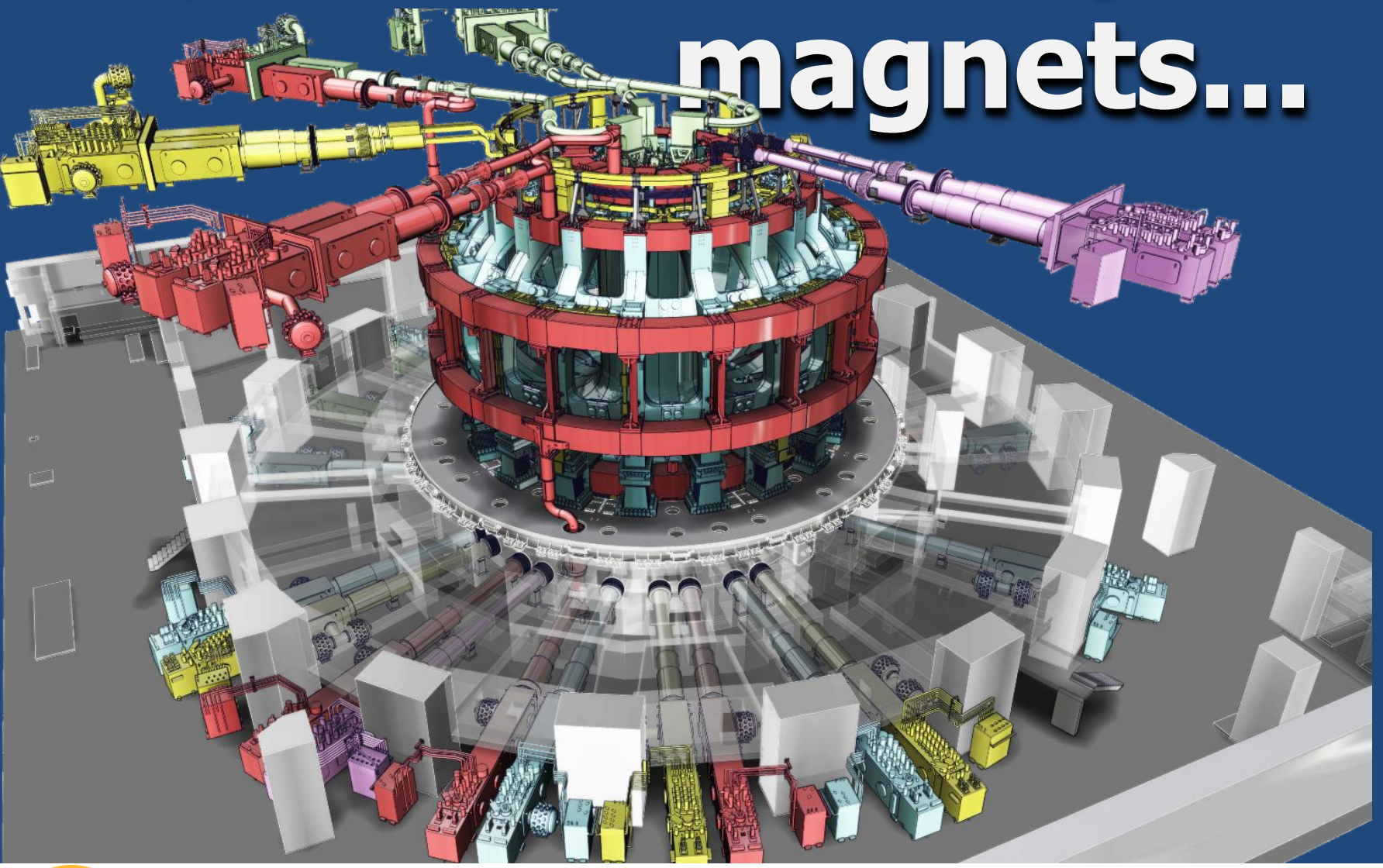
Part 1

ITER superconducting(SC)magnets

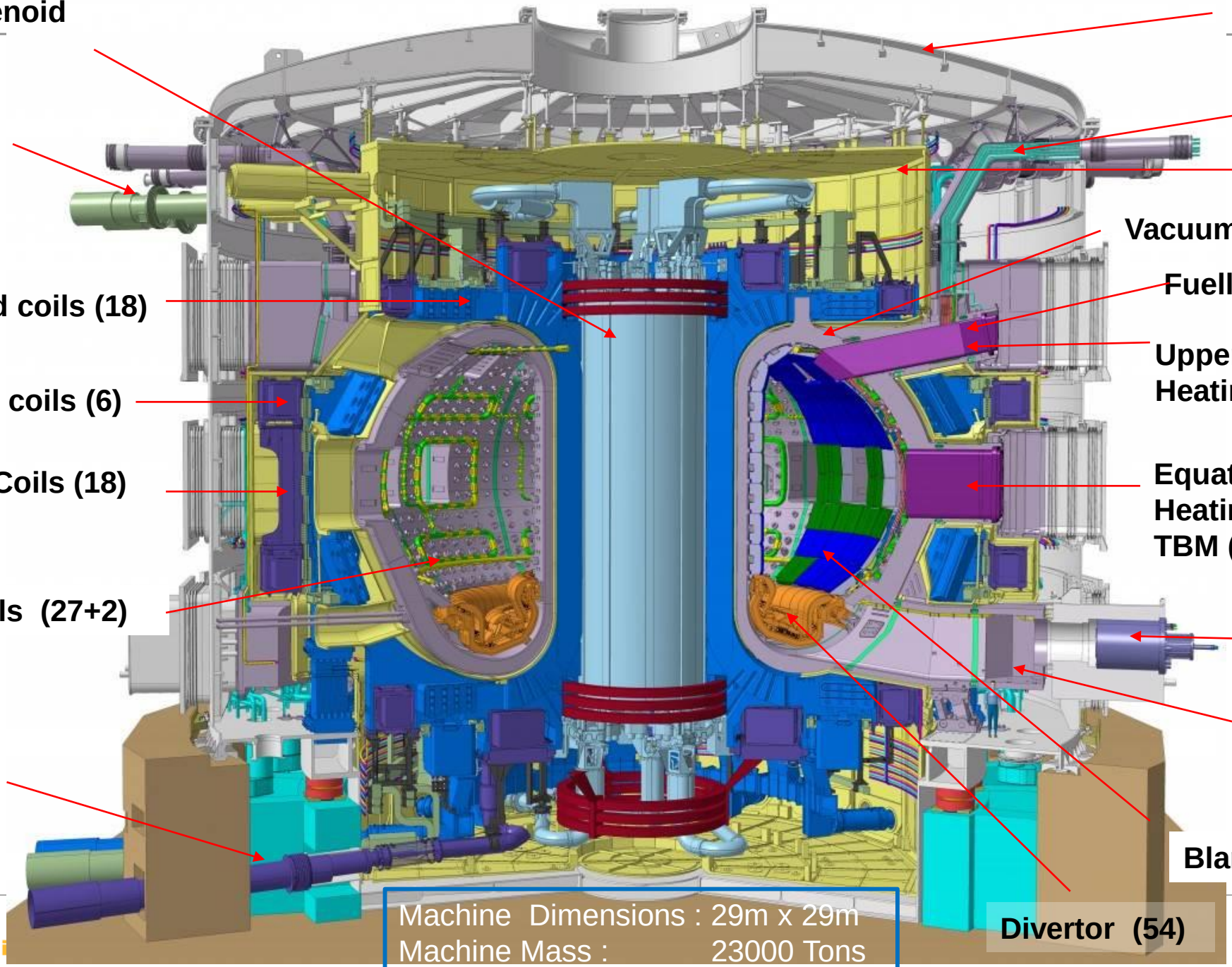
10,000 tons of superconducting magnets...



Manufactured from niobium-tin (Nb3Sn) or niobium-titanium (Nb-Ti), the magnets become superconducting when cooled with supercritical helium in the range of 4 K (– 269 °C).

10,000 tons of magnets, with a combined stored magnetic energy of 51 Gigajoules (GJ), produce the magnetic fields that initiates, confines, shapes and controls the ITER plasma.

ITER Tokamak



Central solenoid (6 modules)

Feeders (10)

Toroidal Field coils (18)

Poloidal field coils (6)

Correction Coils (18)

In Vessel Coils (27+2)

Feeders (21)

Cryostat

Cooling Water

Thermal shield

Vacuum vessel

Fuelling: Gas (4)

Upper Port Plugs : 18
Heating (4), Diagnostics (10)

Equatorial Port Plugs: 14
Heating (3) , Diagnostics (8), TBM (3)

Cryopumps (6)

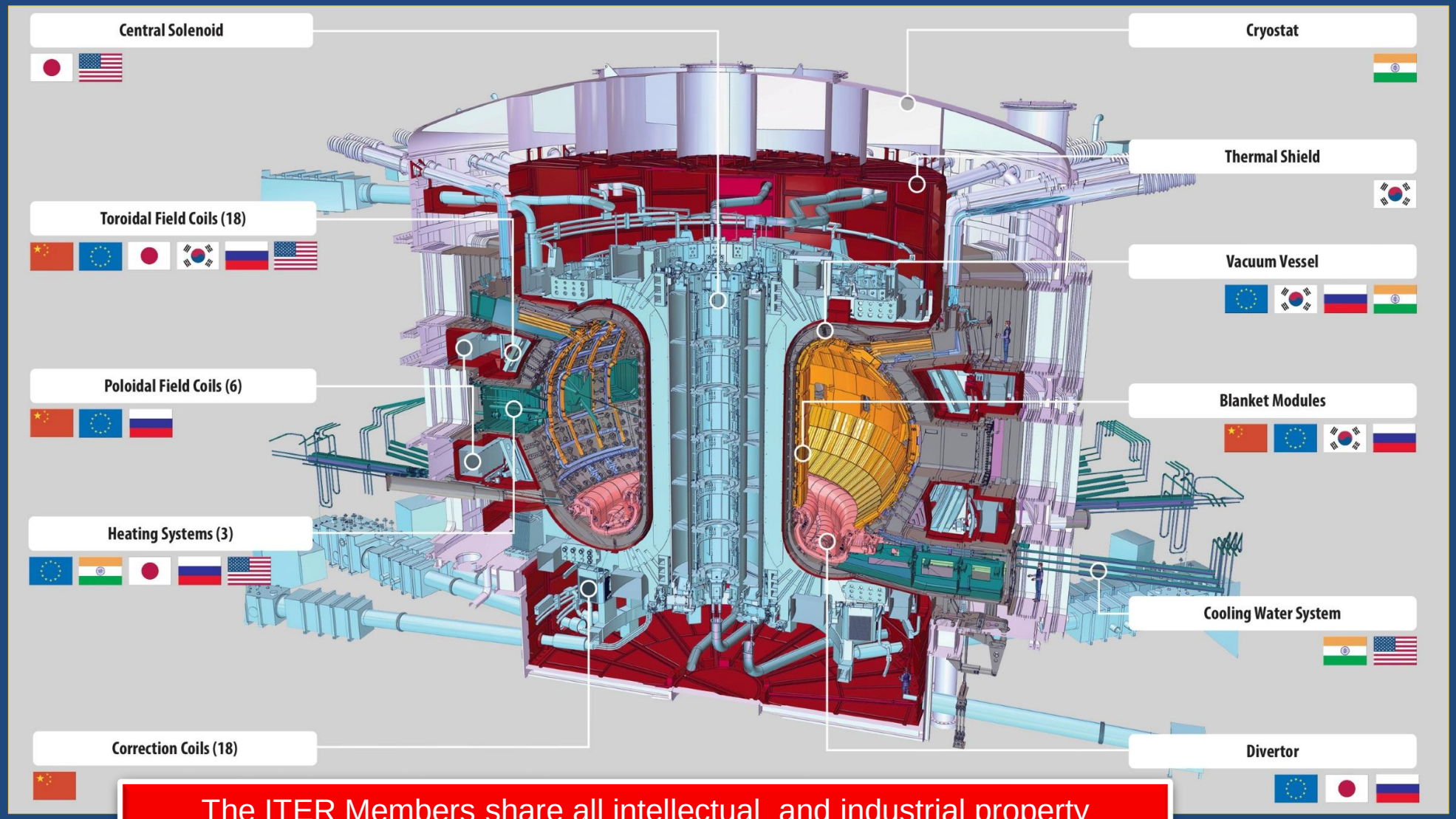
Fuelling: Gas (3), Pellet Injection (3)

Blankets (440)

Divertor (54)

Machine Dimensions : 29m x 29m
Machine Mass : 23000 Tons

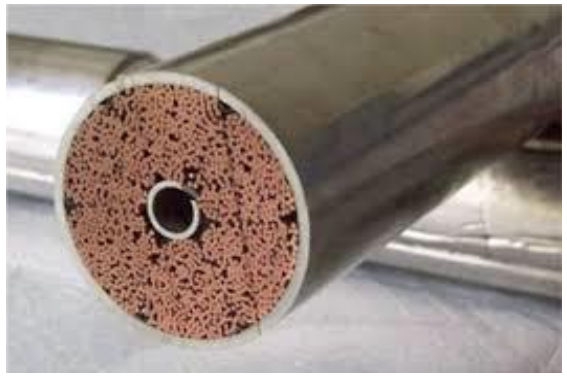
Who manufactures what?



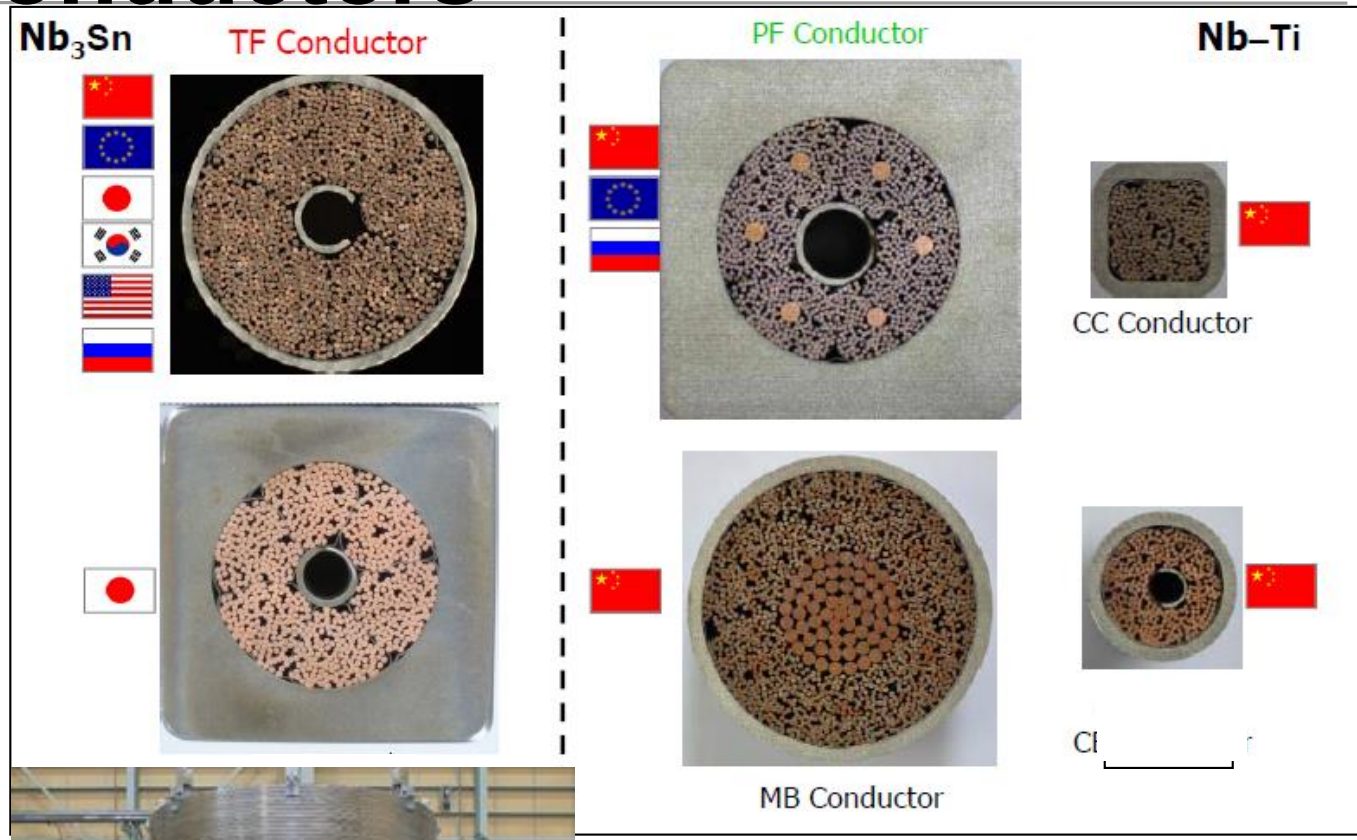
The ITER Members share all intellectual and industrial property

ITER Conductors

ITER coils are wound from Cable-In-Conduit Conductors (CICC's), relying on superconducting multifilament composite strands mixed with pure Cu strands/cores. The strands are assembled in a multistage rope-type cable around an open central cooling spiral. The cable and its spiral are inserted inside a stainless steel conduit which provides helium confinement.



-200 km, 2.800 tons of super
total required) have been manufactured and validated
-Largest superconductor procurement in industrial history
-Largest Nb3Sn strand production ever – pre-ITER world production was ~15 t/year

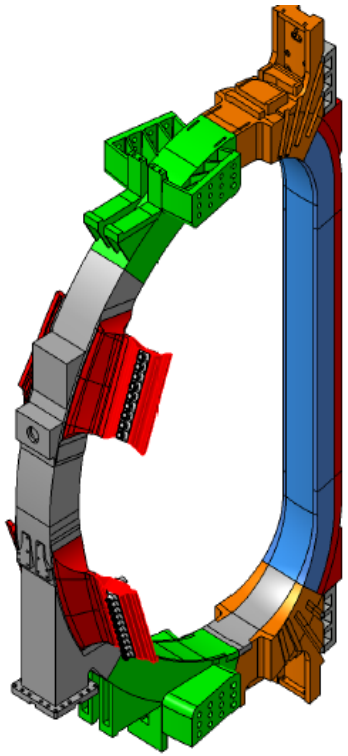


Completion of the procurement of 43 kilometres (700 tonnes) of niobium-tin cable-in-conduit superconductor for ITER's CS in December 2017

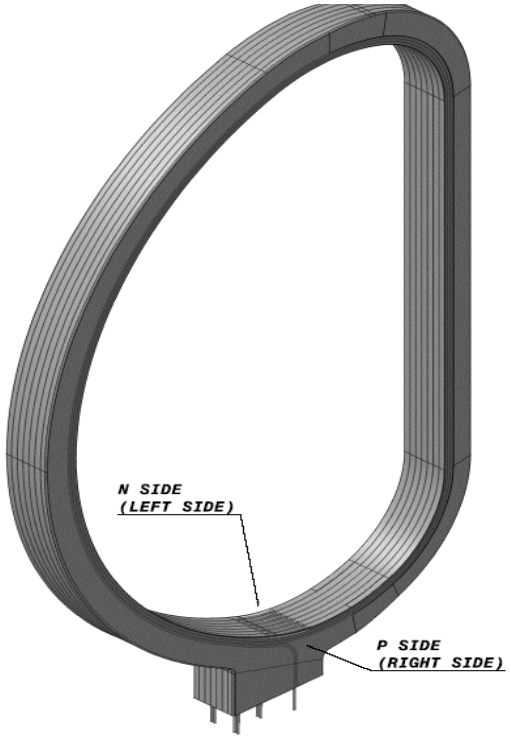
Toroidal Field Coils

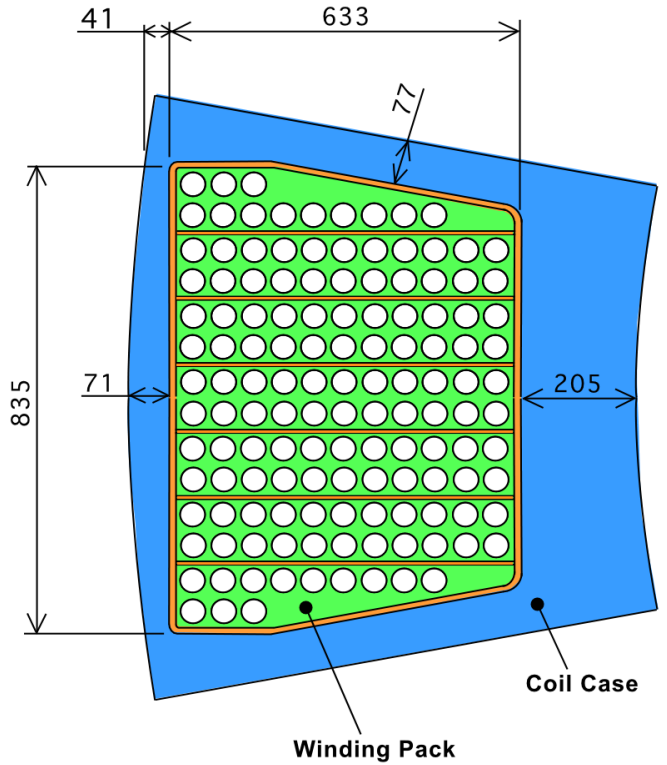
18 Toroidal Field Coils. (1) TF Coil: ~360 t. 16 m Tall x 9 m Wide . Each TF Coil consists of casing housing the winding pack

TF Casing : D–shaped 195 t rigid structure of stainless steel 316L(N)

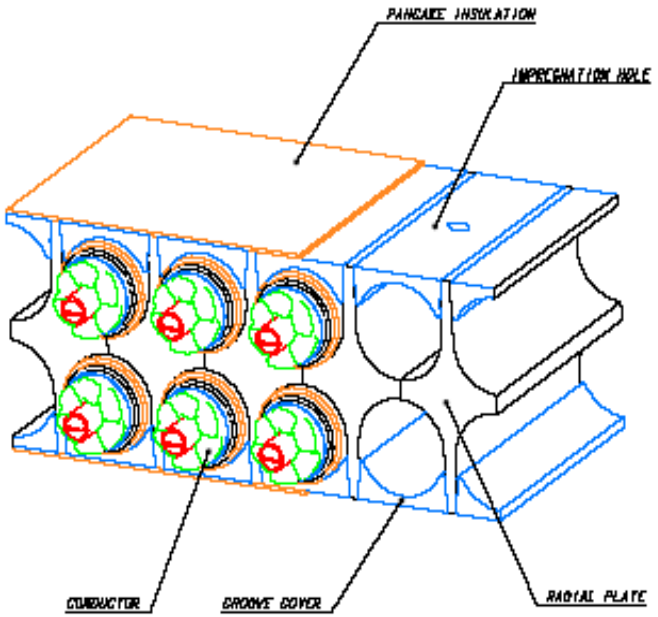


Winding pack : 110t
Cable-in-conduit conductor embedded in seven radial plates that builds seven double pancakes inter-connected through lap joints.





Double pancake: one radial plate, a D-shaped special grade stainless steel plate , in which the conductor is embedded

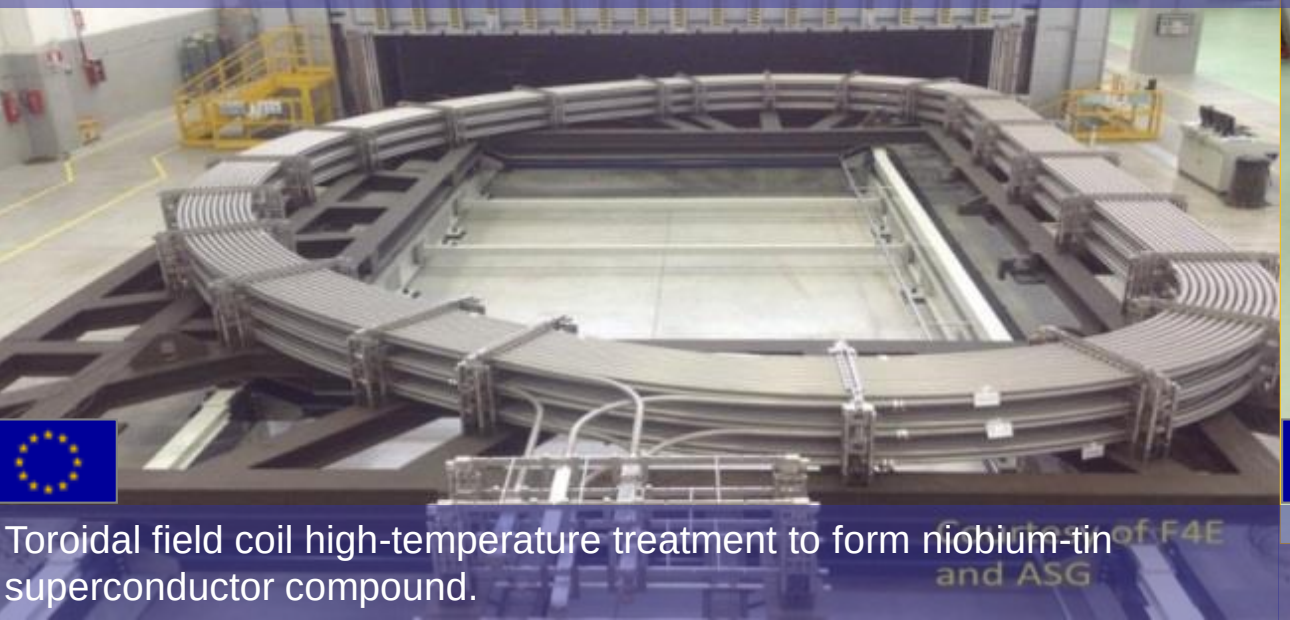


TF Winding Pack

9 provided by EU (+1)
9 provided by JA

The radial plates that hold the conductor of the toroidal field coil: D-shaped stainless steel structures with grooves machined on both sides along a spiral trajectory.

TF Coil Winding Line



Toroidal field coil high-temperature treatment to form niobium-tin superconductor compound.

The first toroidal field coil winding pack – the 110-ton inner core of ITER's TF Coils was completed in April 2017

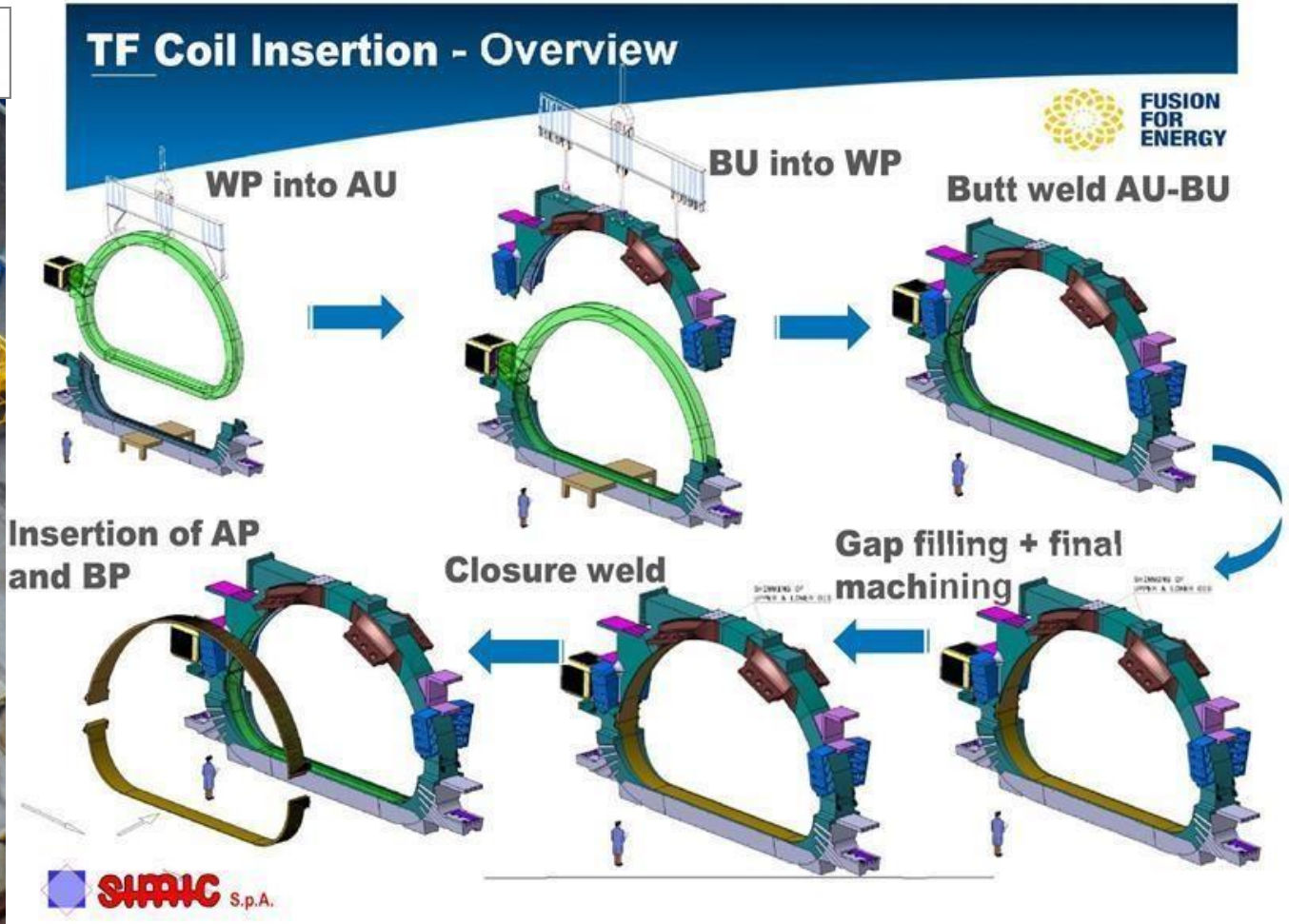
TF Casing

19 by JA-KO

First Toroidal Field Coil Casing Fitting Completed - December 2017

TF Coil

9 provided by EU (+1)
9 provided by JA



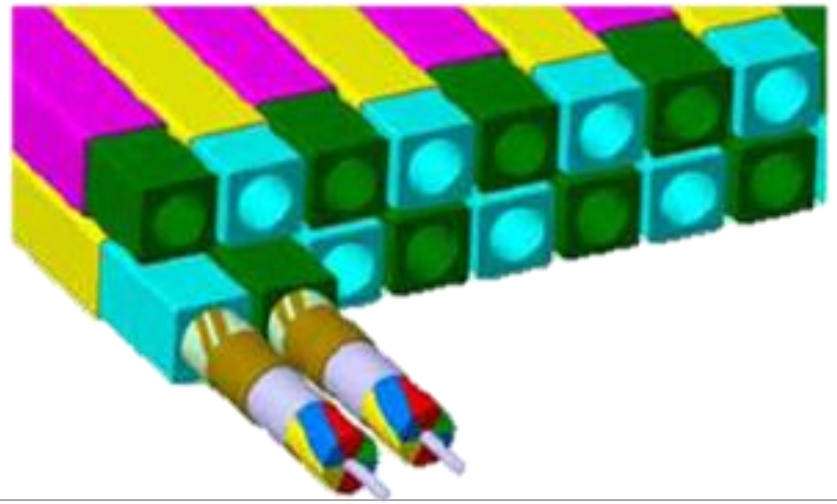
The winding pack will be inserted into the TF casing, where it will be laser welded, wrapped in insulating material, impregnated with resin and then machined

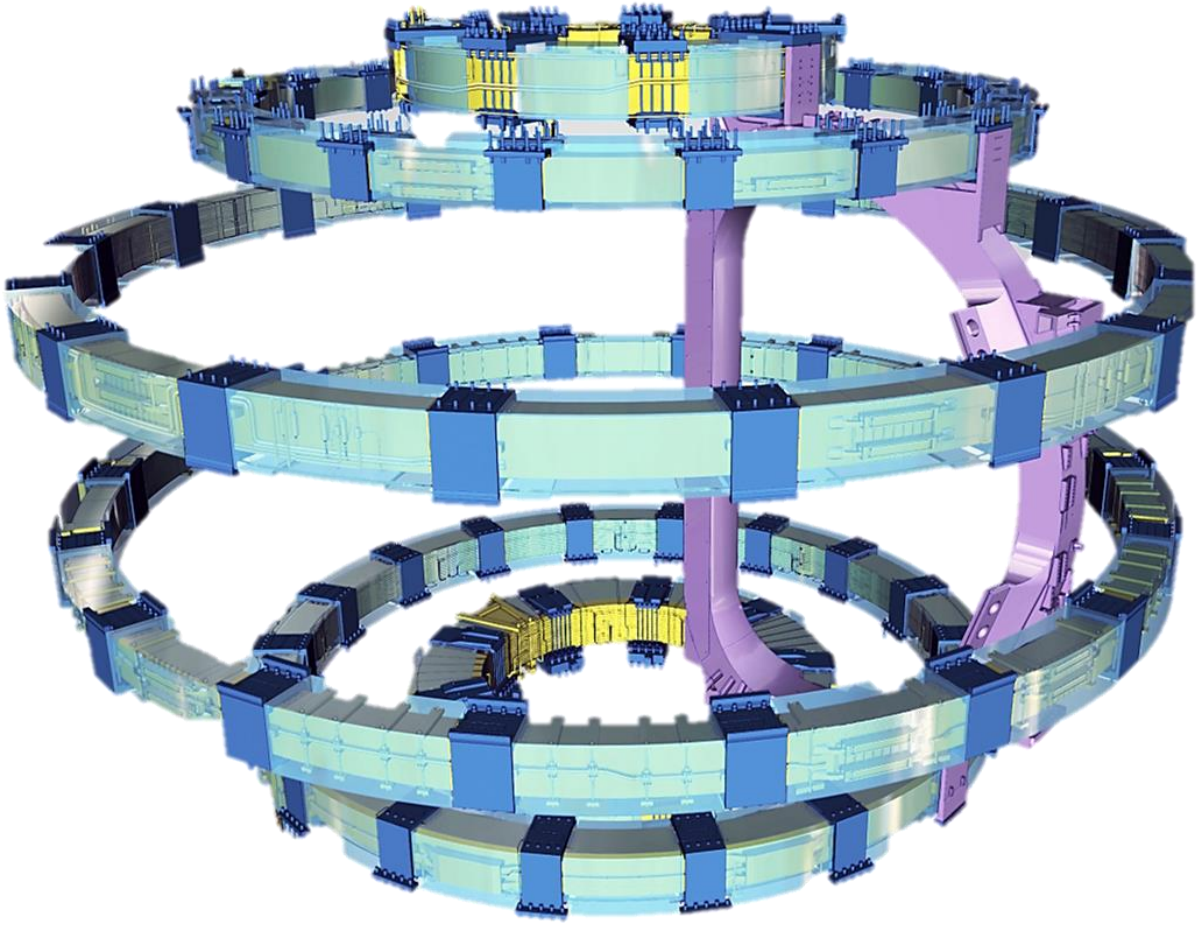
Poloidal Field Coils

Six ring circular coils , independently powered, ranging from 8 to 24 metres in diameter and weighing between 200 and 400 tonnes.

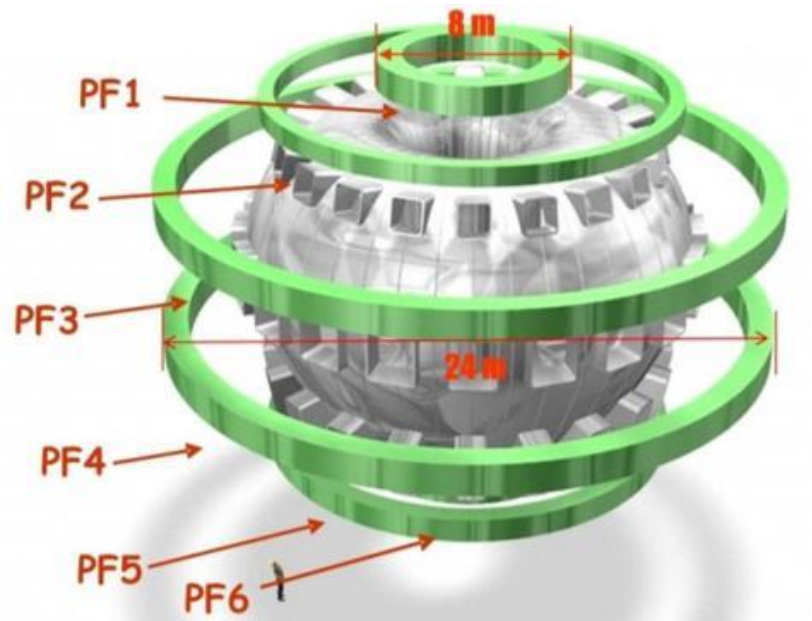
Poloidal field coils are made of six to nine circular conductor arrangements (called "double pancakes") that are insulated, resin-impregnated, stacked together and compressed

Poloidal Field Coil Conductor





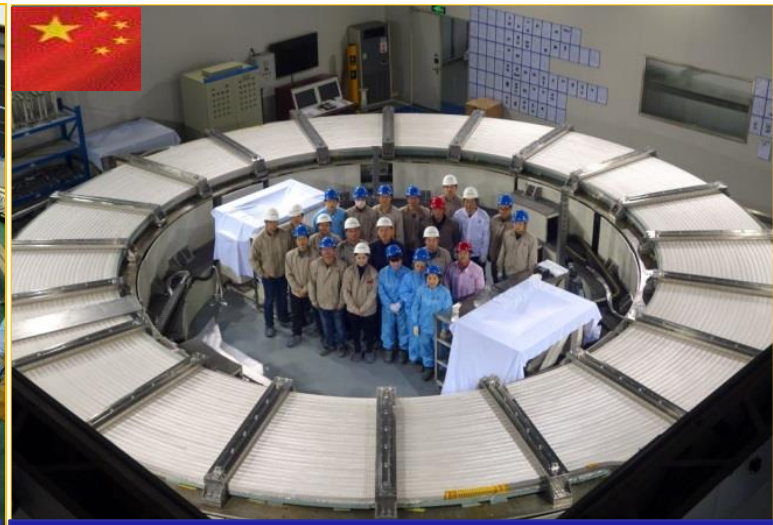
Poloidal Field Coils



PF Coils #2, #3, #4, # 5:
Too large components to be transported . PF3 24.5 m dia & 386 ton.
Manufactured at Cadarache at the PF Coil Winding Facility
PF Coil #1:
Manufactured in Russia
PF Coil #6:
Manufactured in China

Winding of Poloidal Field Coil # 5 began in April 2017. Second pancake started by August 2017

First-completed double pancake of PF1 after vacuum pressure impregnation with epoxy resin



Fabrication and qualification tests of PF6 winding pack stack sample were successfully completed.

PF Coil winding facility

Too large to be transported by road, four of ITER's six ring-shaped magnets (the poloidal field coils, 8 to 24 m in diametre) will be assembled by Europe in this 12,000 m² facility.

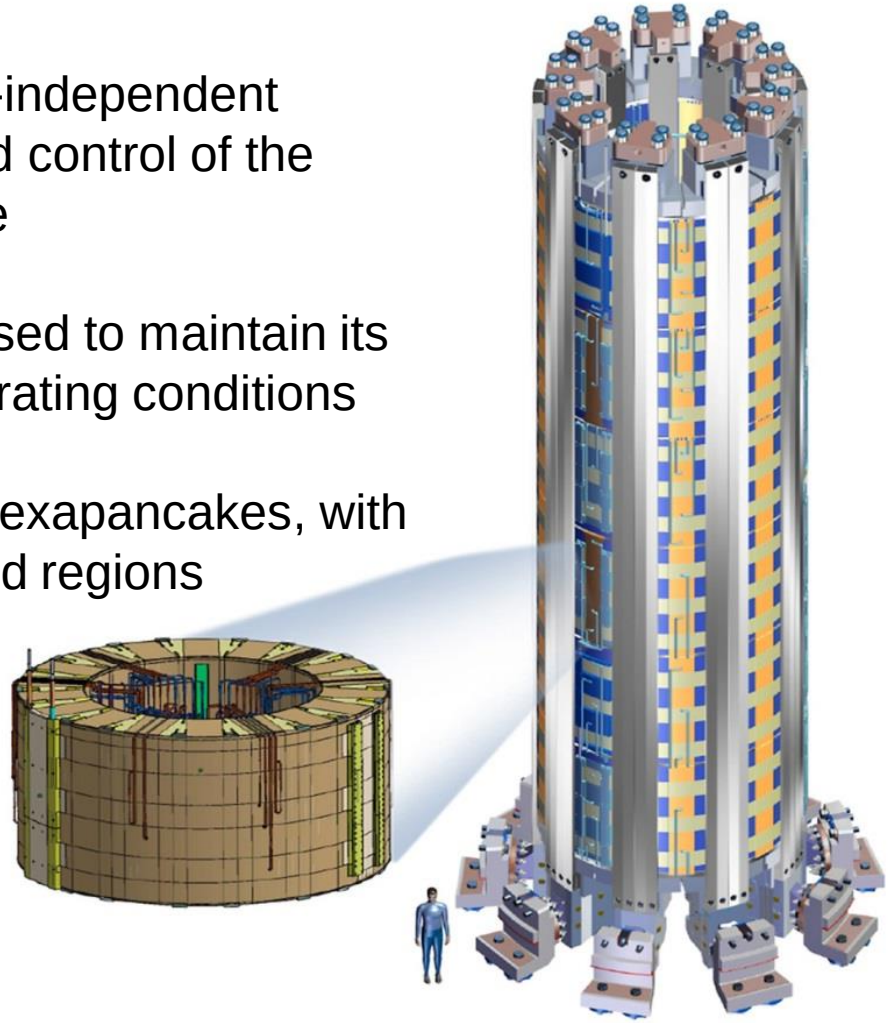
Central Solenoid

CS coil weights about 974 t, and is about 13 m high and 4 m in diameter

Stack of 6 electrically-independent modules to allow good control of the inboard plasma shape

The stack is compressed to maintain its integrity under all operating conditions

The coil is wound in hexapancakes, with all the joints in low field regions

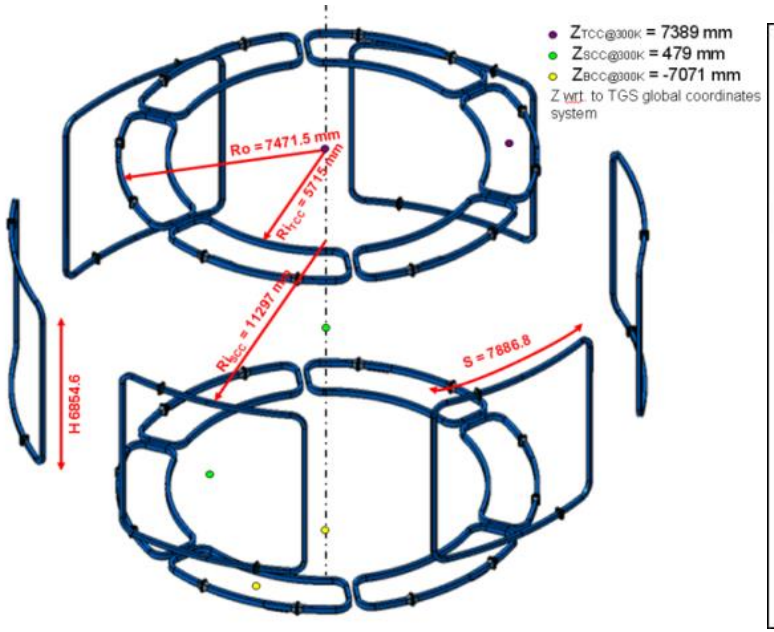


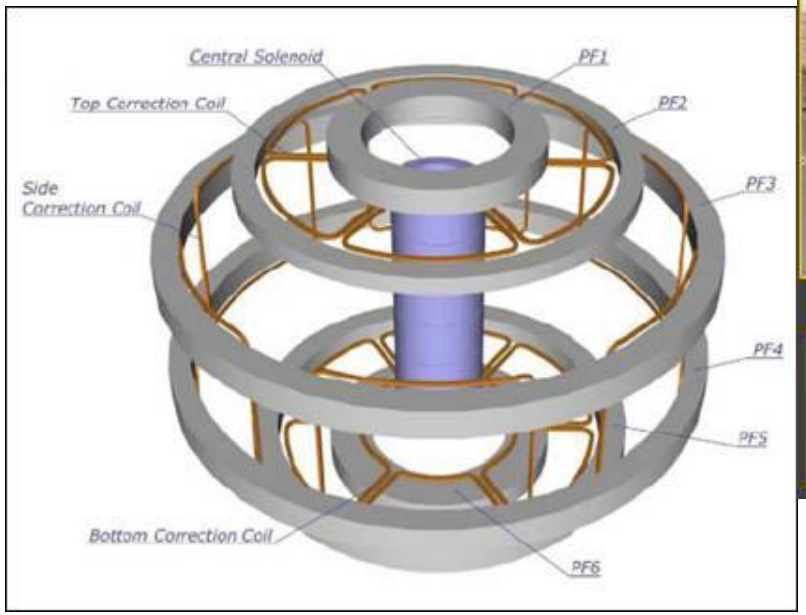
General Atomics is fabricating the 1000-ton Central Solenoid (CS). Winding of the first CS module was completed. January 2018: Completion of ground insulation for the first module

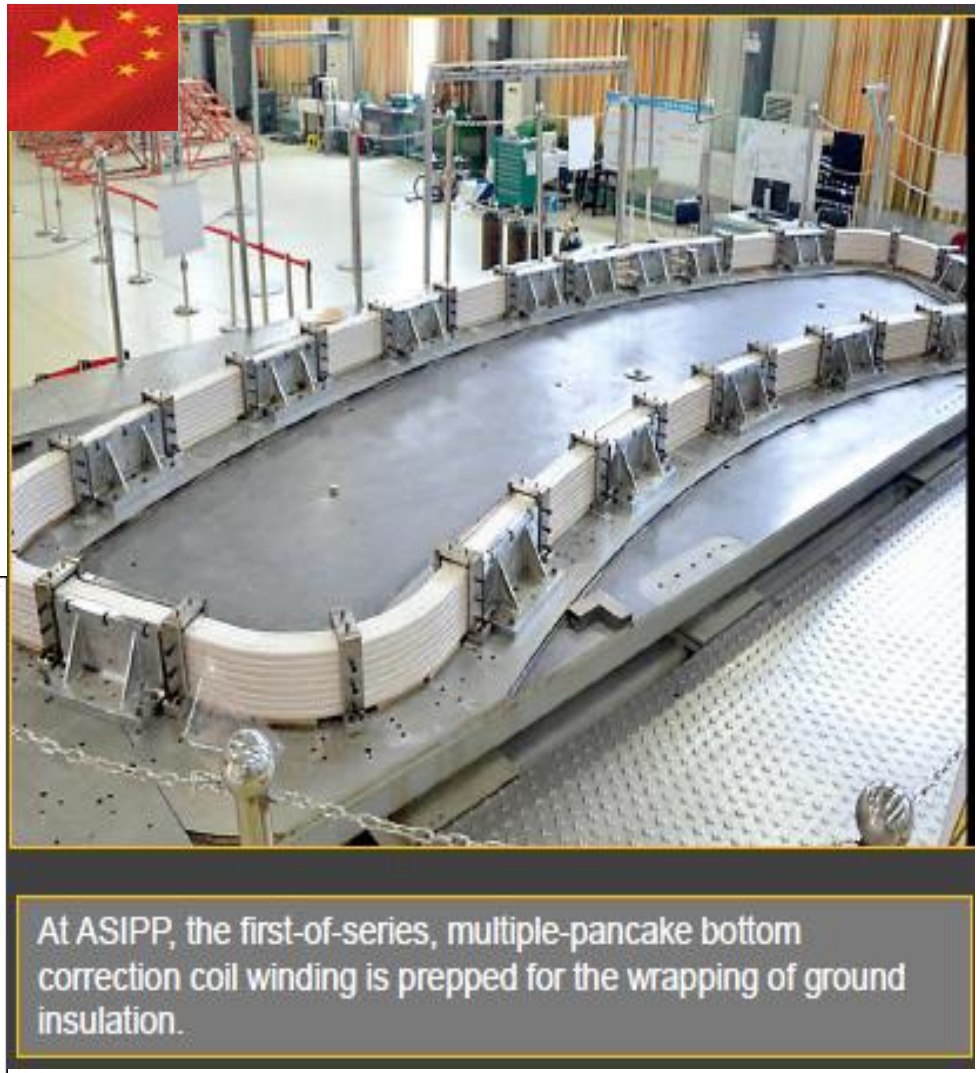
Correction Coils

Eighteen superconducting correction coils inserted between the toroidal and poloidal field coils will compensate for field errors caused by geometrical deviations due to manufacturing and assembly tolerances.

The correction coils will be arranged in groups of six around the toroidal circumference above, at and below the mid-plane of the vacuum vessel.

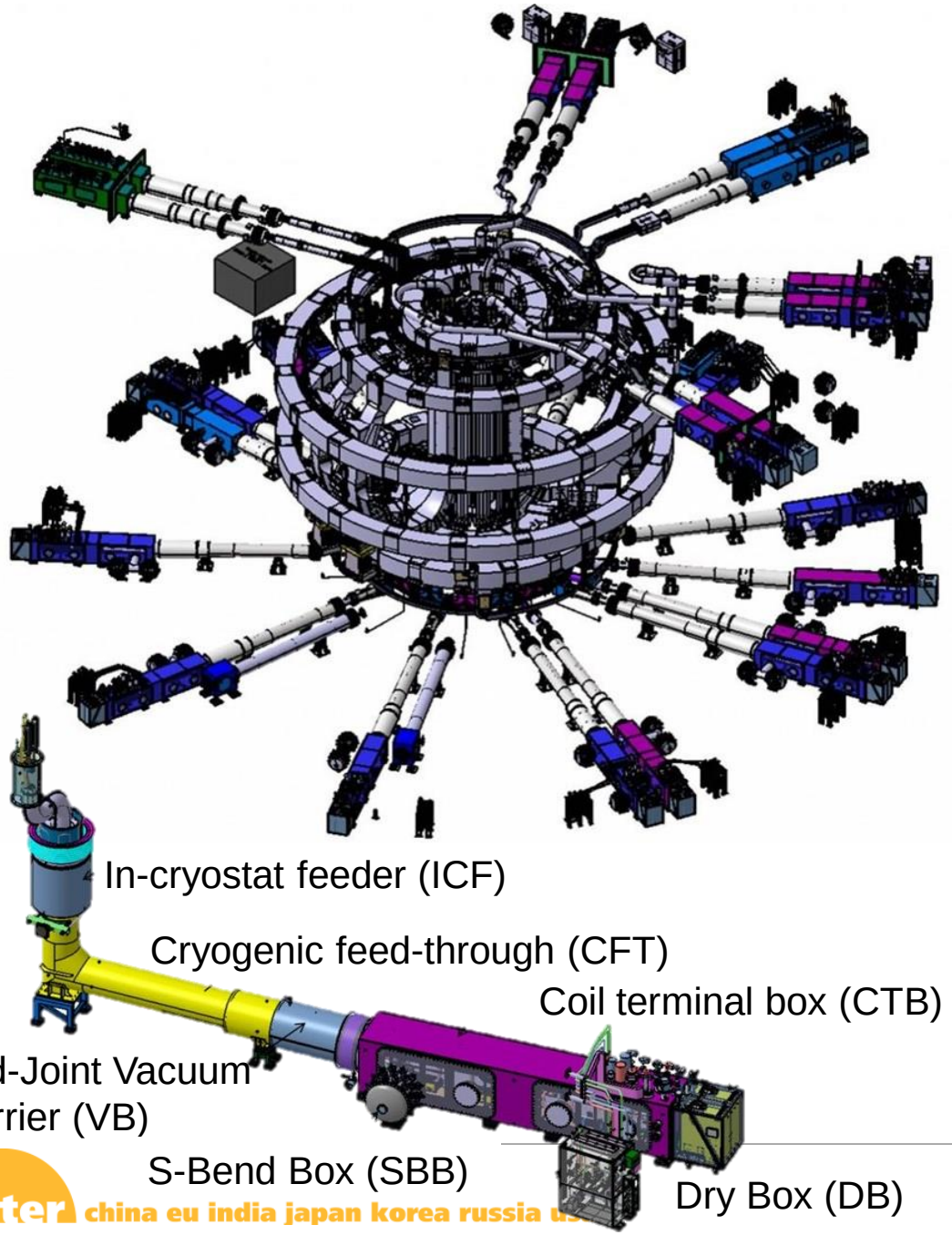






At ASIPP, the first-of-series, multiple-pancake bottom correction coil winding is prepped for the wrapping of ground insulation.

Feeders



31 superconducting feeders:

- ✓ Provide He to cool and control the temperature of the magnets coils and structures
- ✓ Connect the magnets to their power supplies : superconducting busbars that interface to room temperature busbars
- ✓ Provide cables for instrumentation signals

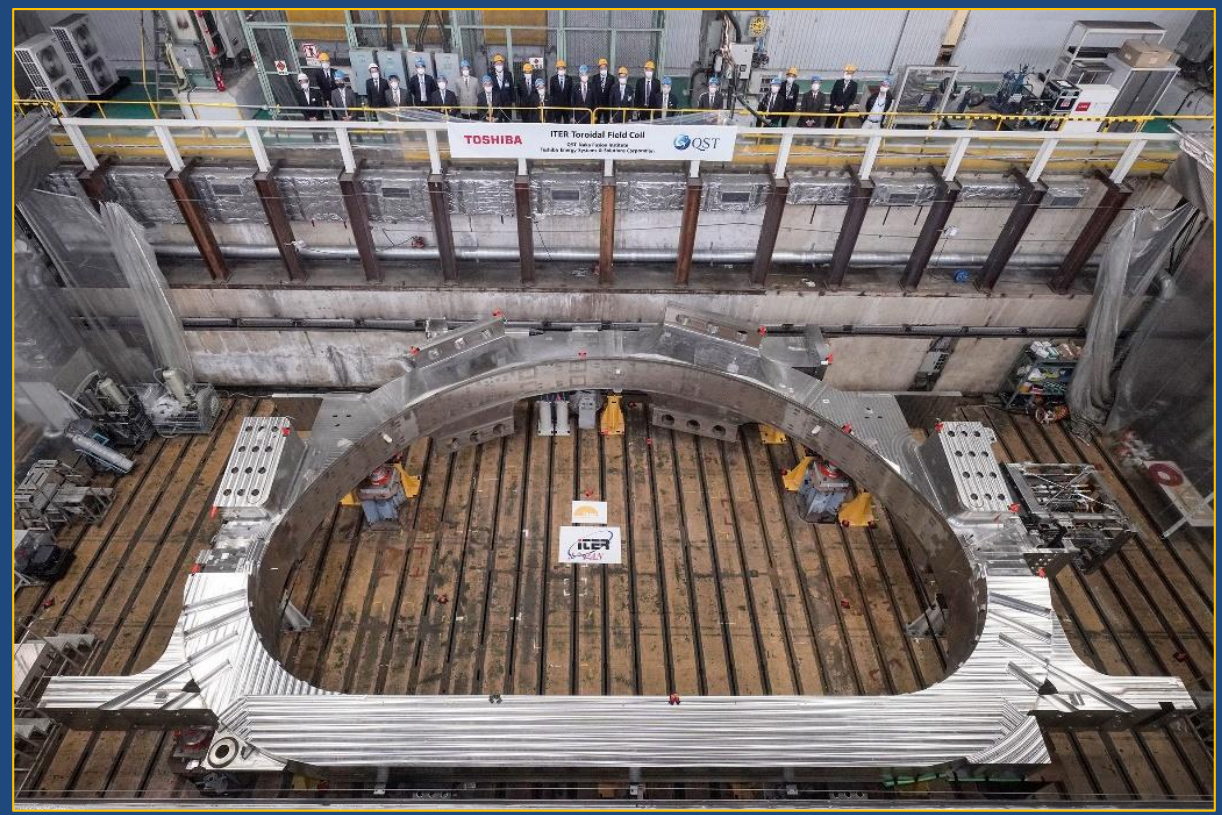
Cryogenic feedthrough for poloidal field coil #4 delivered to IO from ASIIP in October 2017,
First of 31 cryostat feedthroughs to be delivered.

Part 2

84% of total manufacturing finalized

Delivery of more than 1,600 tonnes of equipment for the magnet feeders system is ongoing.

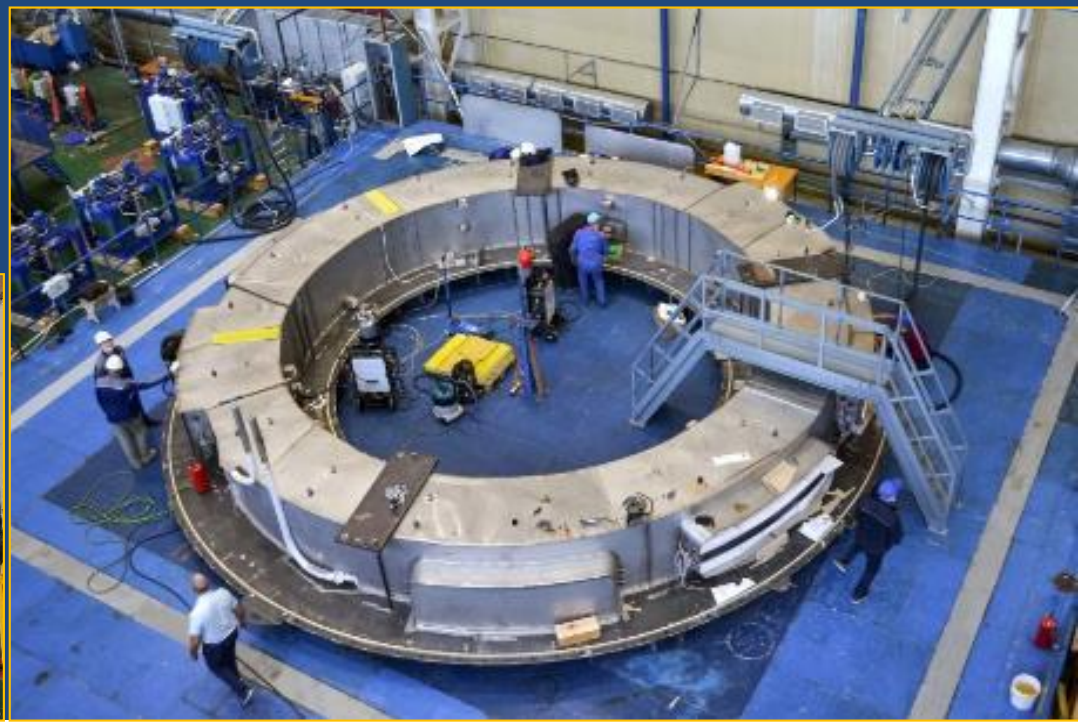
Japan has already delivered 4 toroidal field coils. A 5th (photo) shipped in July. Fabrication is being finalized for the remaining 4.



84% of total manufacturing finalized

Out of the 9 required vacuum vessel sectors (VVS), Korea procures 4. VVS#6 was delivered in July last year and is now in place in one of the sub-assembly tools; VVS#1 arrived on site two weeks ago. Completion rate of the remaining two : 95% and 88%

Poloidal field coil #1 is entering the final stages of fabrication in Saint-Petersburg.



84% of total manufacturing finalized

The first of the seven central solenoid modules (6 + 1 spare) procured by the United States was delivered to ITER.
The six others are in the late stages of fabrication at the General Atomics facility in Poway.

84% of total manufacturing finalized

Five vacuum vessel sectors are under fabrication in Italy. Completion rates range from 70 to 93%

Europe manufactures the 4 largest poloidal field coils (17 & 24 m in diametre) in a dedicated onsite facility. PF#5 and #2 are finalized. PF#3/4 ongoing. (Here, PF#5 moved to temporary storage on 16 April 2021)

Of the 10 toroidal field coils that Europe is procuring (out of a total 19, four have been delivered to the ITER site.

Part 3

Seven years of steady progress

April 2014 – May 2021

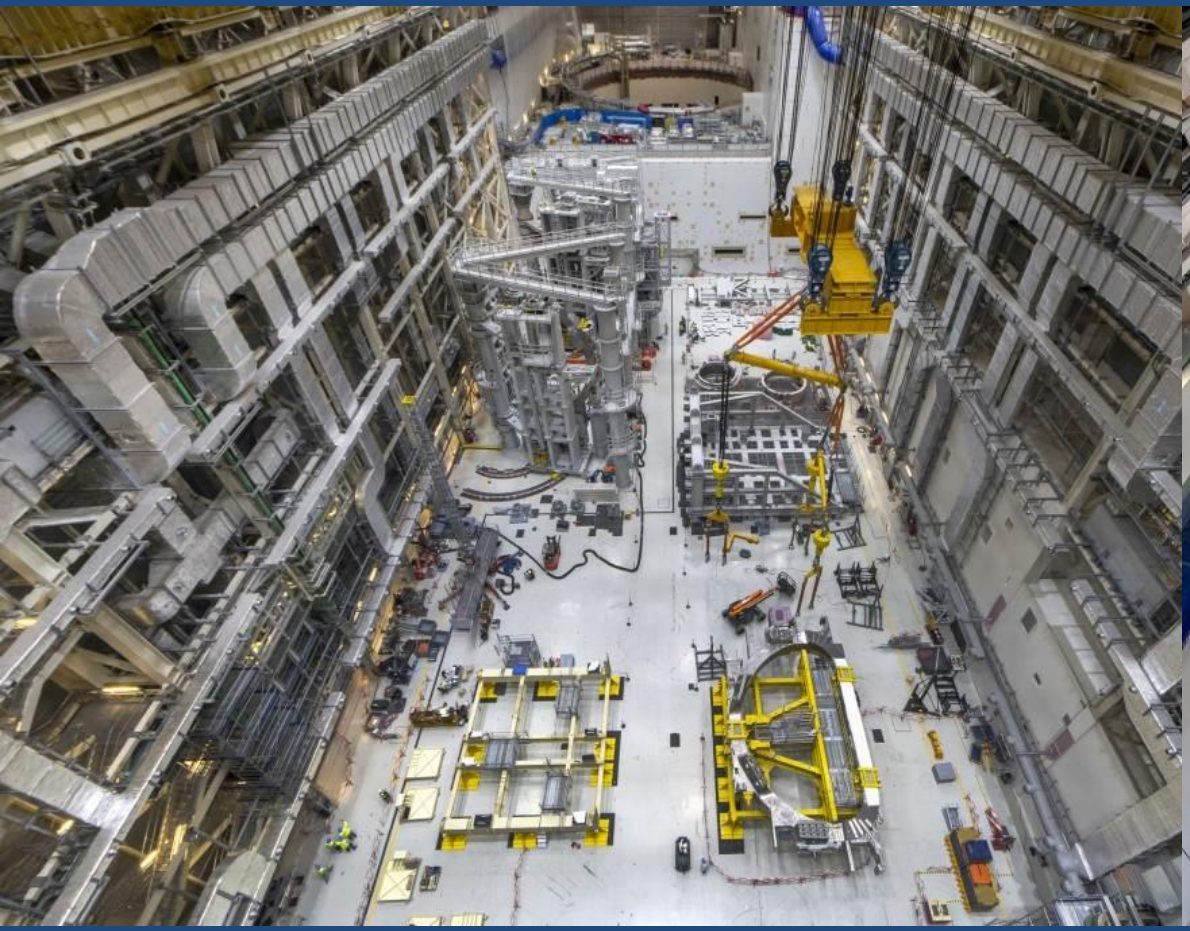
More than 80% of the installation's civil works is now completed.

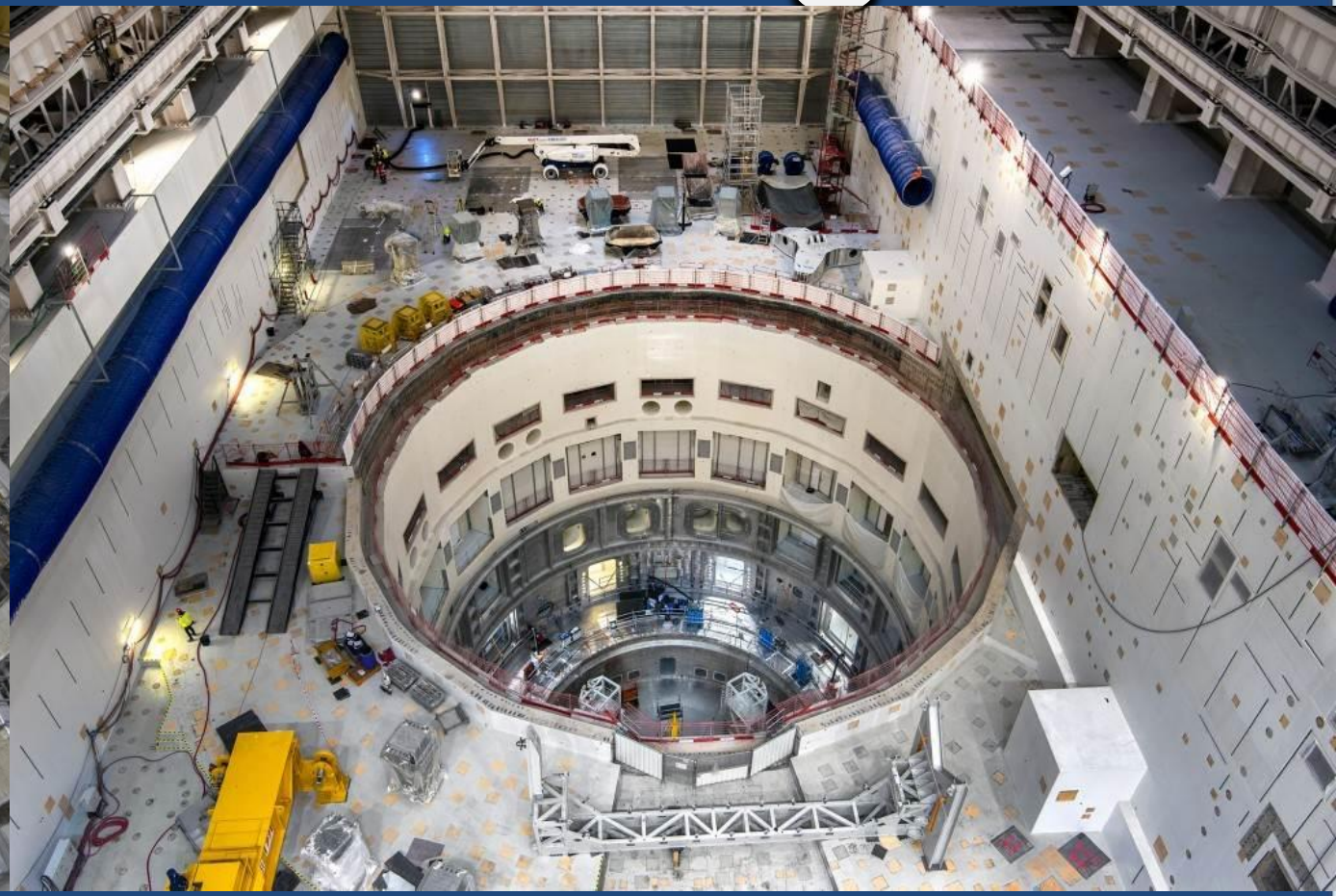
Work scope towards First Plasma
> 74% complete

According to the stringent metrics that measure project performance, > 74 % of the "*total construction work scope through First Plasma*" is now complete.

Worksite progress

Tokamak Building





Extending from the Assembly Hall, the SSAT and overhead cranes are available. Every zone is being used for busy assembly work. The Pit is becoming more and more crowded.

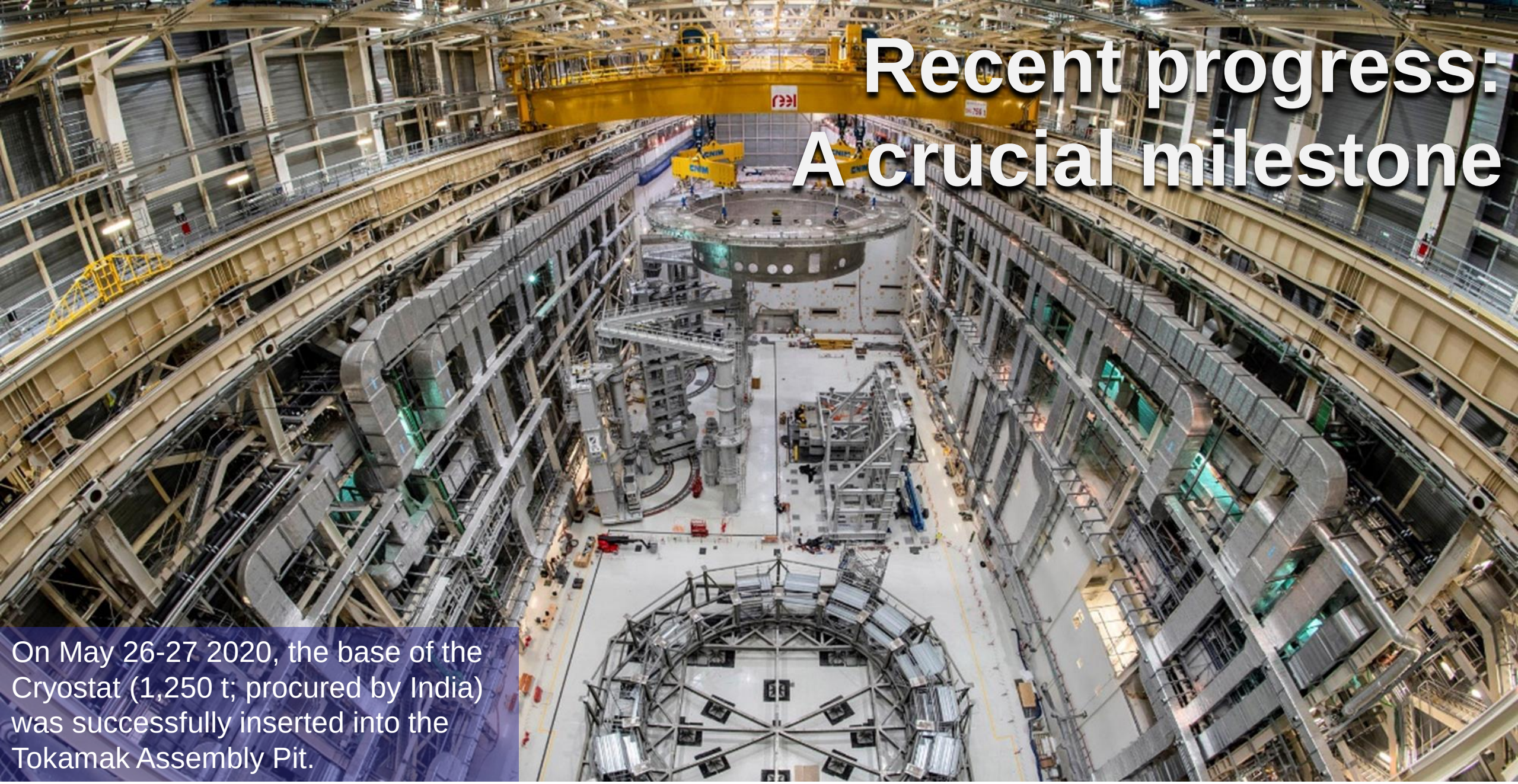
Two major assembly contracts

CNPE Consortium

Two international consortia have been selected to carry out the thousands of complex lifting, positioning, joining, and inspection activities behind the assembly of the ITER core.
The five-year Assembly phase is set to begin in the spring of 2020.

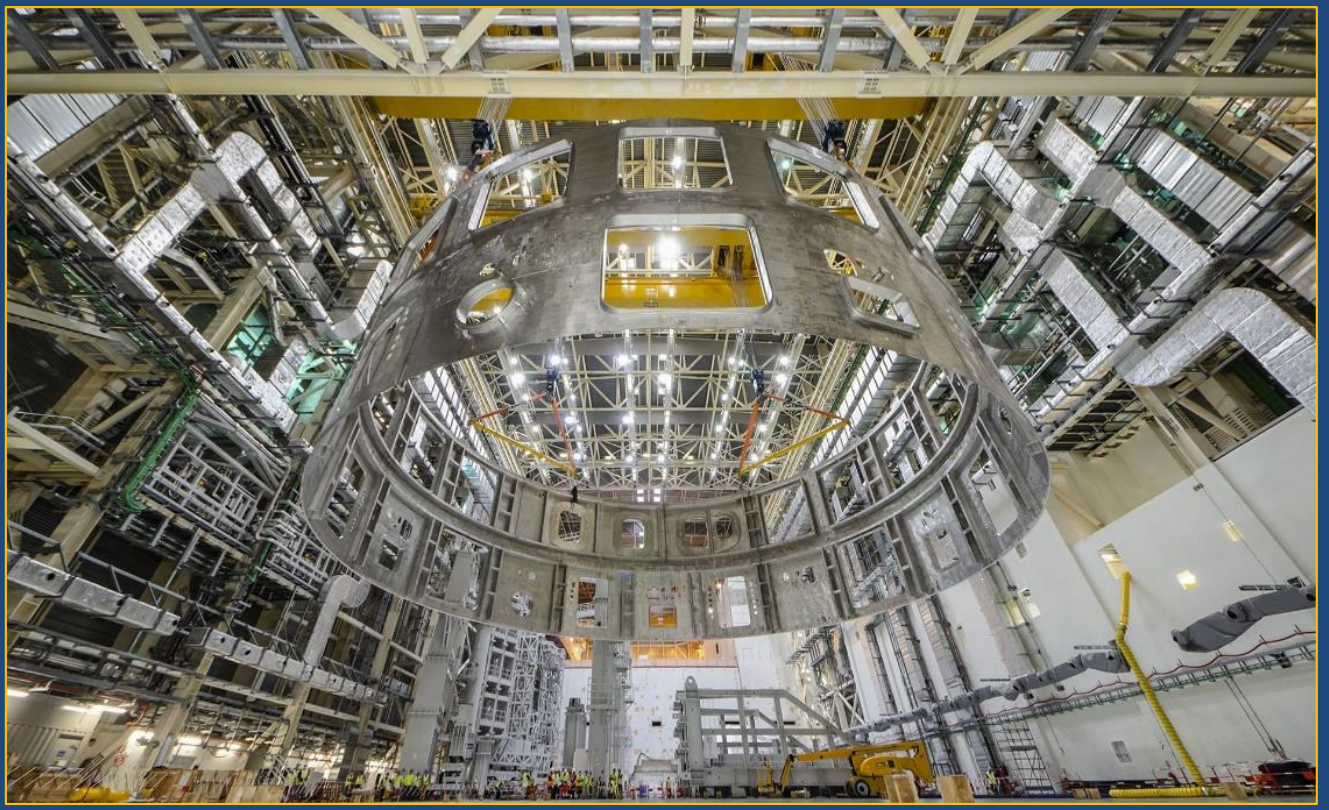
DYNAMIC SNC Consortium

Recent progress: A crucial milestone



On May 26-27 2020, the base of the Cryostat (1,250 t; procured by India) was successfully inserted into the Tokamak Assembly Pit.

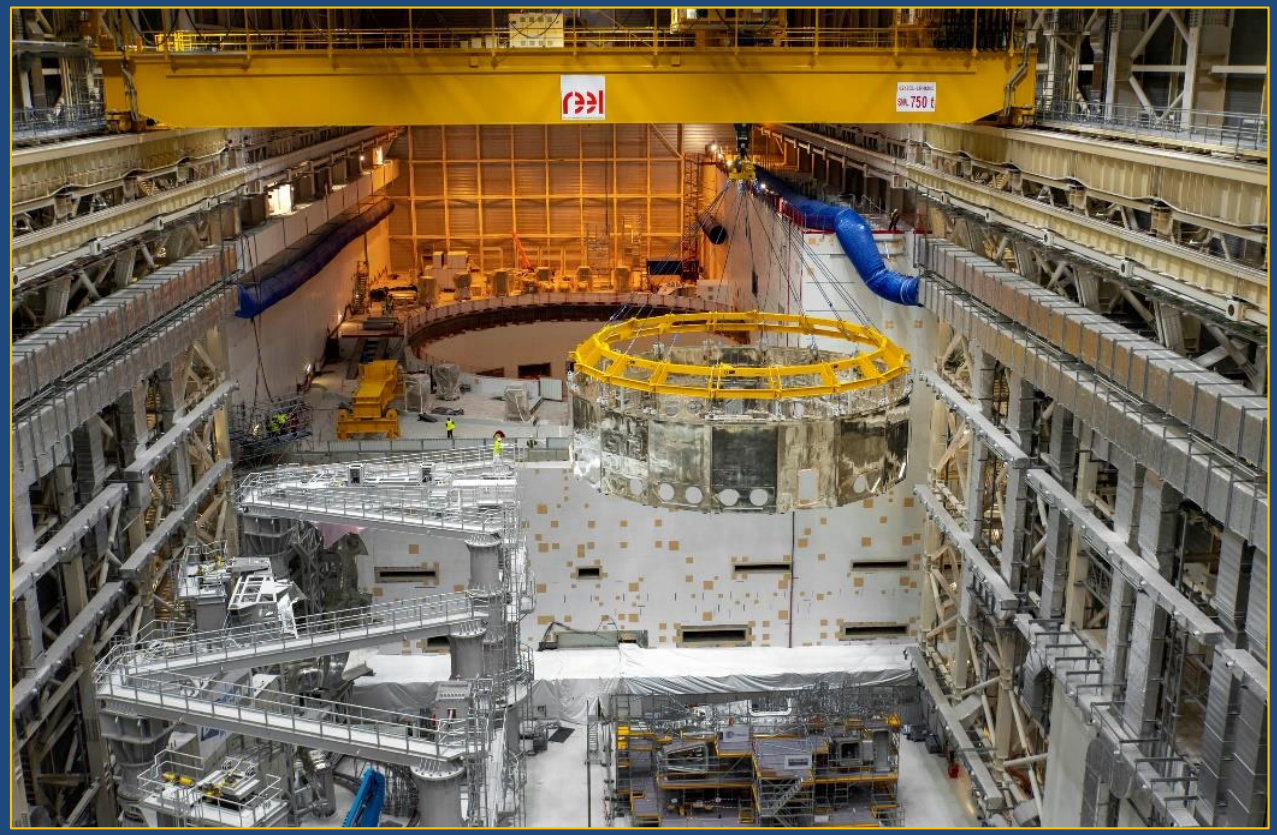
Recent progress: Lower cylinder insertion

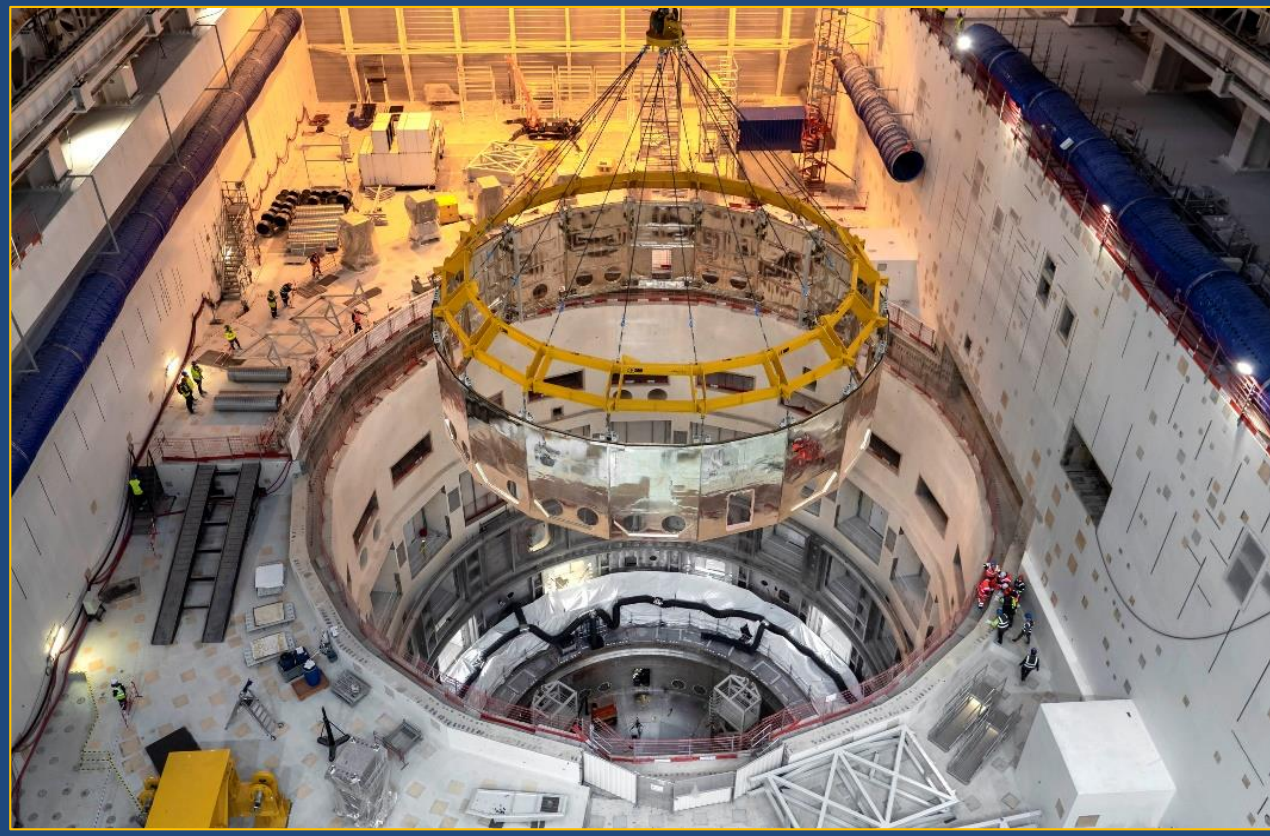


Cryostat Lower Cylinder lift,
31 August 2020

Inserting the Cryostat Lower Cylinder into the Tokamak Pit.
Perfect fit with the Base
31 August 2020

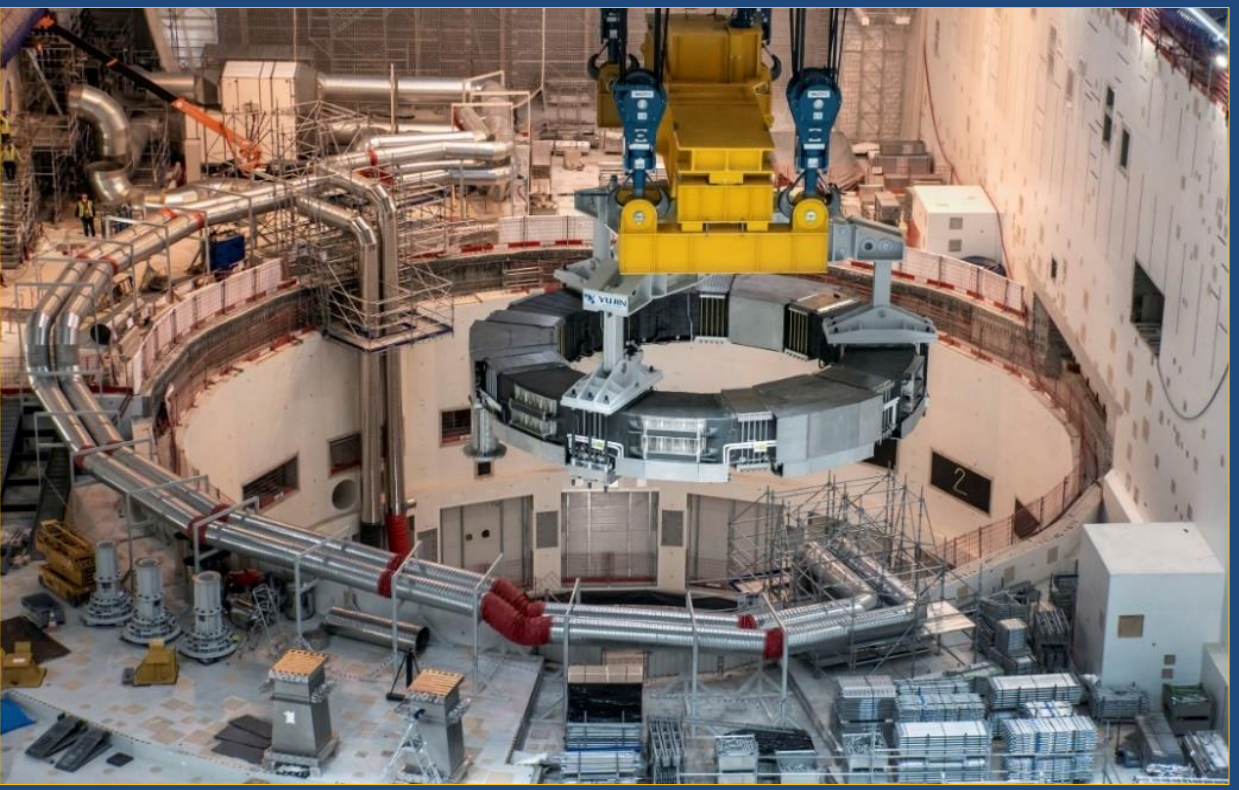
Recent progress: Thermal shield insertion

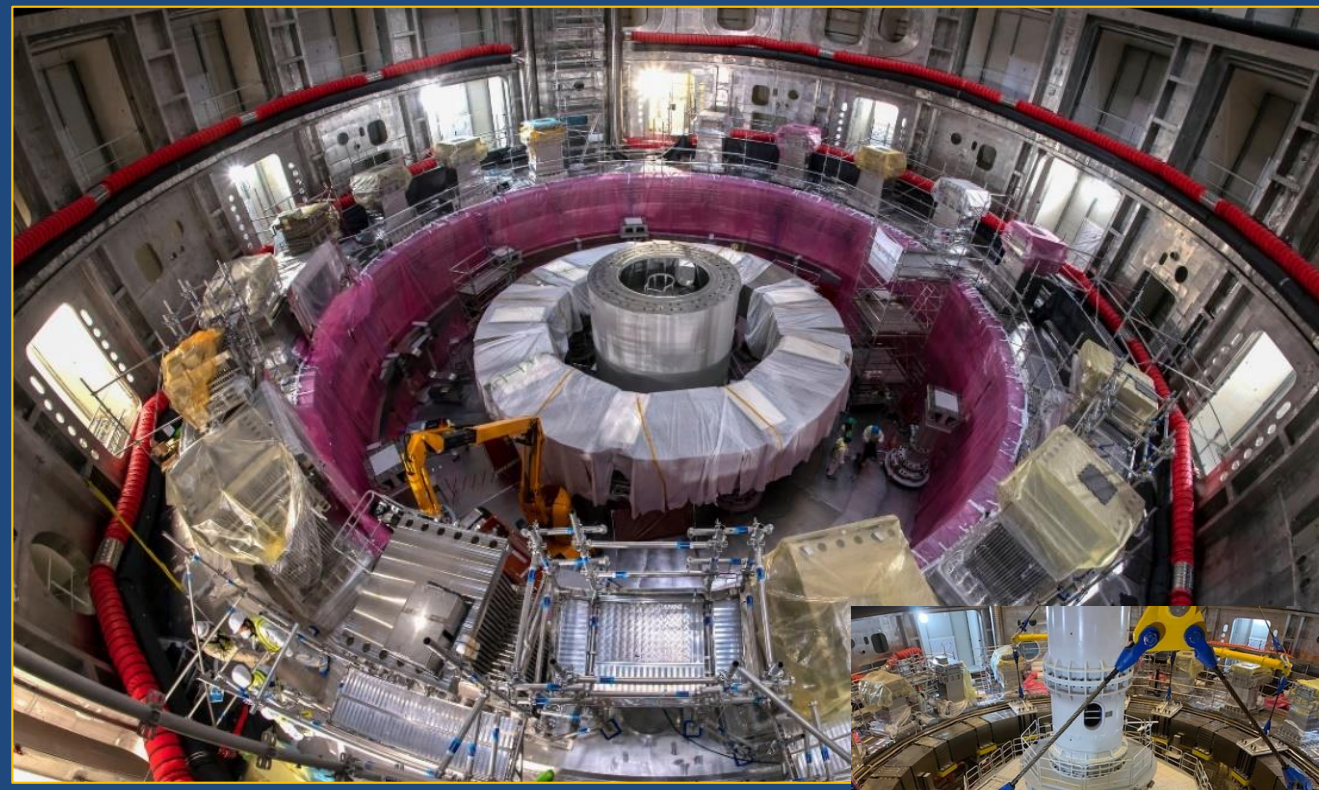




The lower cylinder thermal shield (LCTS) was installed on 14 January 2021. A silver-plated component, the LCTS stands between the lower section of the Cryostat and the machine to act as an obstacle to thermal radiations.

Recent progress: First 2 PF coils inserted

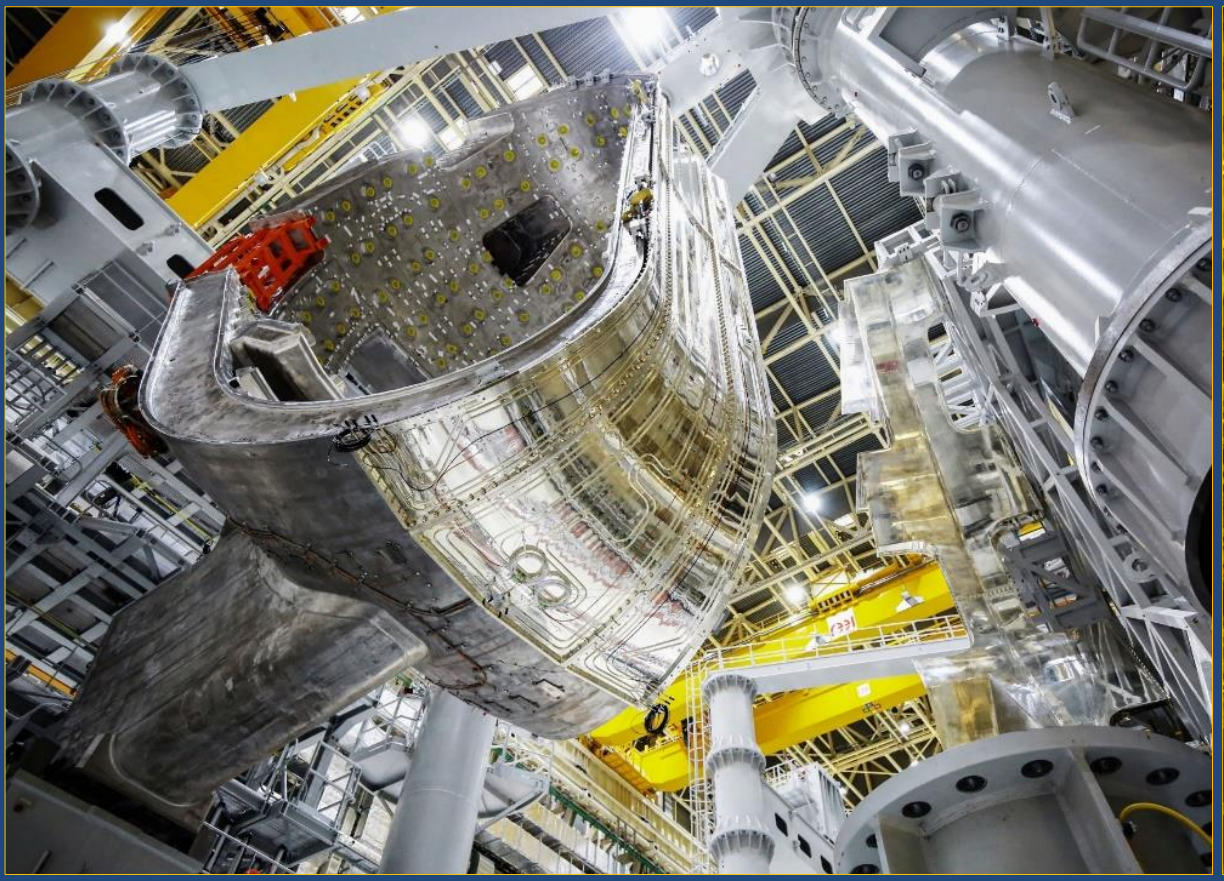


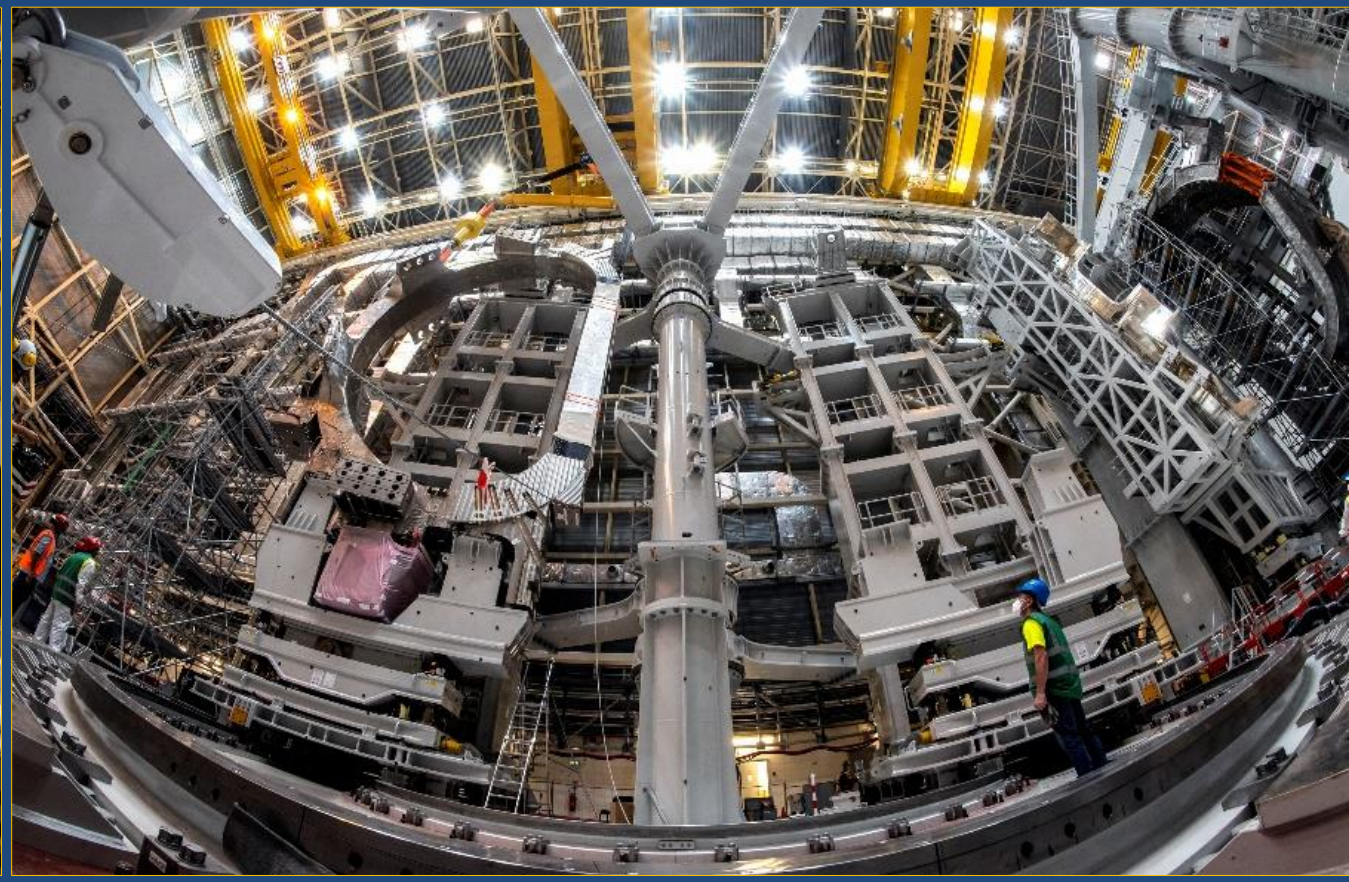


Poloidal field coil # 6 was inserted in the assembly pit on 21 April 2021

Poloidal field coil # 5 was inserted in the assembly pit on 15 September 2021

Toward the first « pre-assembly »





« Pre-assemblies » are the building bricks of the Tokamak's torus. They comprise one 40° vacuum vessel (left) sector, two toroidal field coils (one, right) and the corresponding thermal shield panels (left, partially installed) and weigh close to 1,500 tonnes.

Nine pre-assemblies are required to close the torus. First one scheduled in September 2021.

Part 4

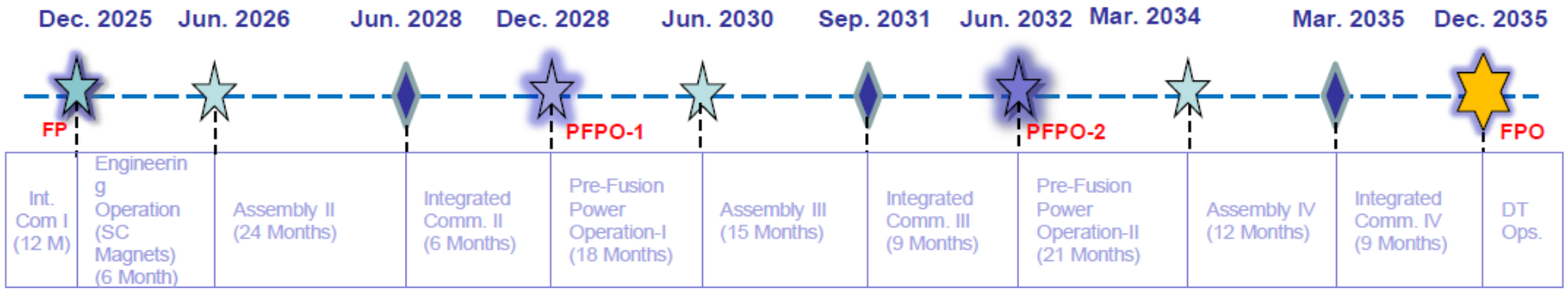
Objective

System Commissiong

Integrated Commissioning

Engnieering operation

Timeline(Theoretical)



FP & EC priorities for magnet control.

Evaluation of FP/EC data magnet technical characteristics without plasma Iterate on control models.

Evaluation of magnet behaviour with plasma. Real impact of VS control and disruptions. Iterate on control models

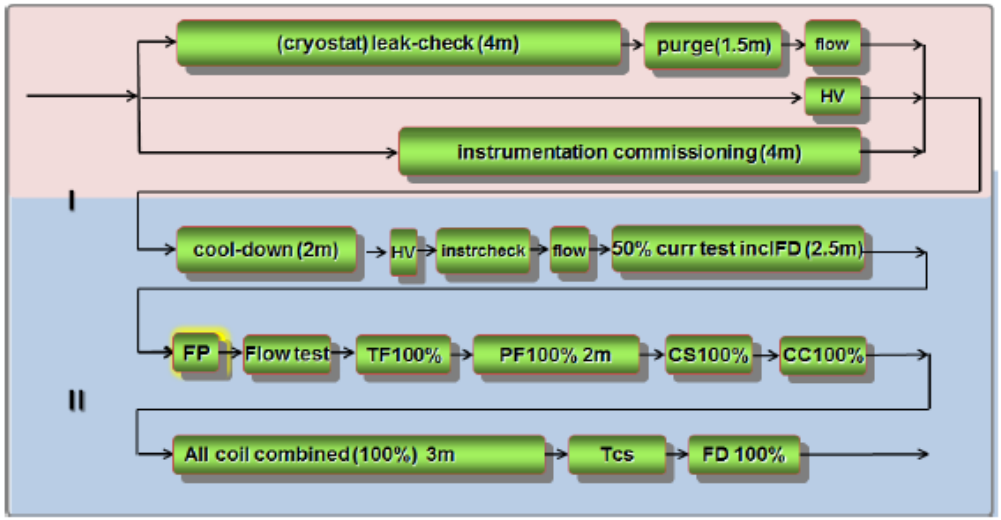
Nuclear licensing

Modelling for Commissioning

- Instrumentation and its Interface to Control;
- Cool down control with model;
- Quench detection modelling and thresholds

Bottom Up Schedule from Magnets : 'integrated' commissioning as developed by magnets

- 5 months pre-FP after cooldown
- 12 months engineering commissioning post-FP (11 months without CC)



Specific thanks to

CEA, EPFL, Udine University, ASSYSTEM, West Pomeranian University of Technology, PoliTo, KIT, UniBo, NFRI, ENEA, NHMFL, CERN, TWENTE, and Tampere University.

Thank you for your attention!