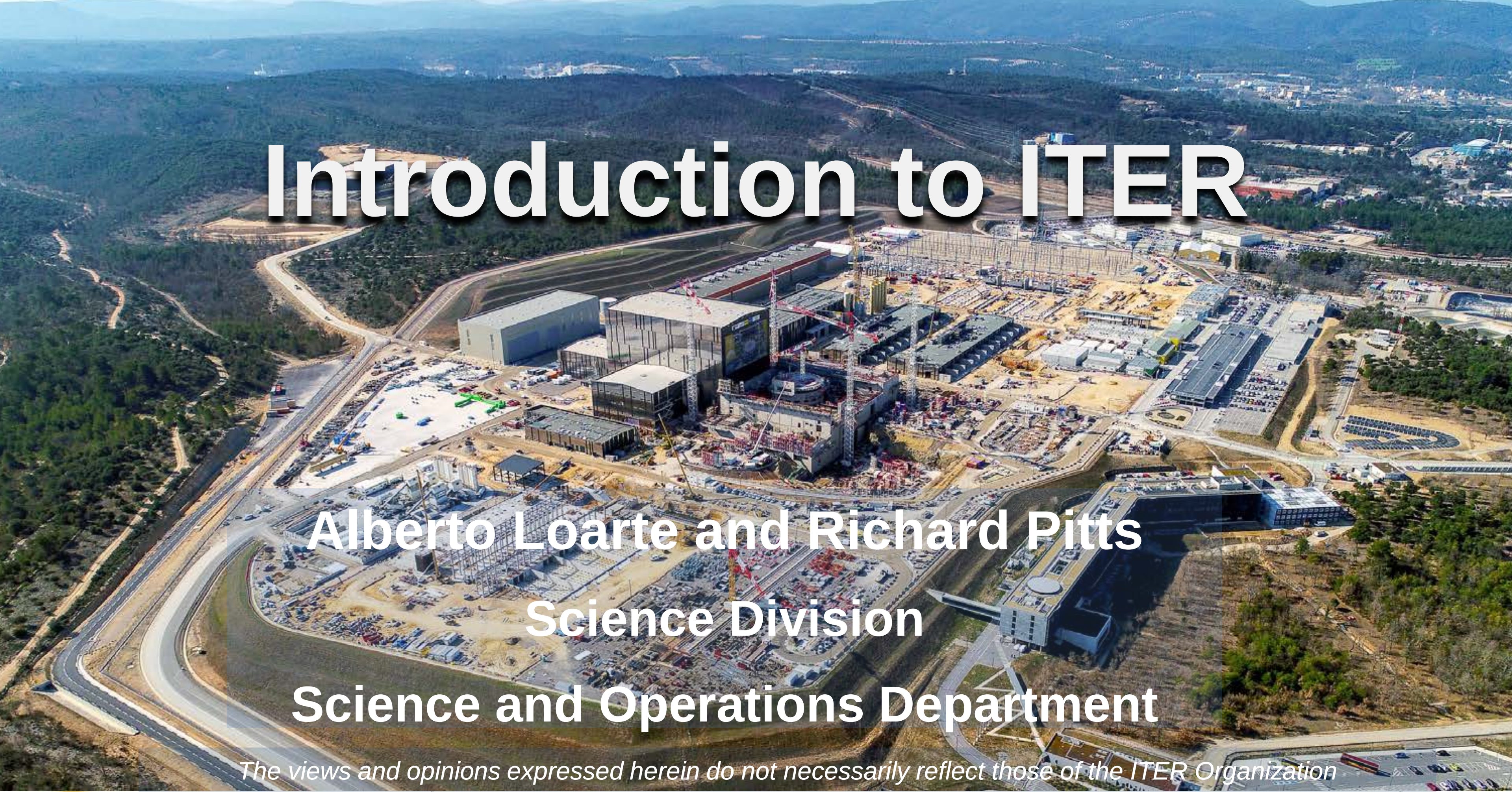


Introduction to ITER

Alberto Loarte and Richard Pitts

Science Division

Science and Operations Department

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Outline

- Description of ITER Project

- Scientific ITER exploitation
  - Power Flux Issues

- Progress on ITER construction

- Conclusions

Description of ITER Project

ITER – Objectives

- ITER's overall programmatic objective:
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes
  - to design, construct and operate a tokamak experiment at a scale which satisfies this objective

- ITER is a tokamak designed to confine a DT plasma in which α-particle heating dominates all other forms of plasma heating
  $\Rightarrow$ an experimental nuclear fusion reactor
  - ✓ Designed to achieve P_{fusion} = 500 MW with gain Q ≥ 10 for 300-500 s
  - ✓ Aims to achieve P_{fusion} ≥ 350 MW with Q ≥ 5 for 1000-3000 s
  - ✓ Aims at exploring "controlled ignition" (Q ≥ 30)

$$D + T \rightarrow \alpha + n \qquad Q = P_{fusion}/P_{add} \rightarrow P_{\alpha}/P_{add} = Q/5$$

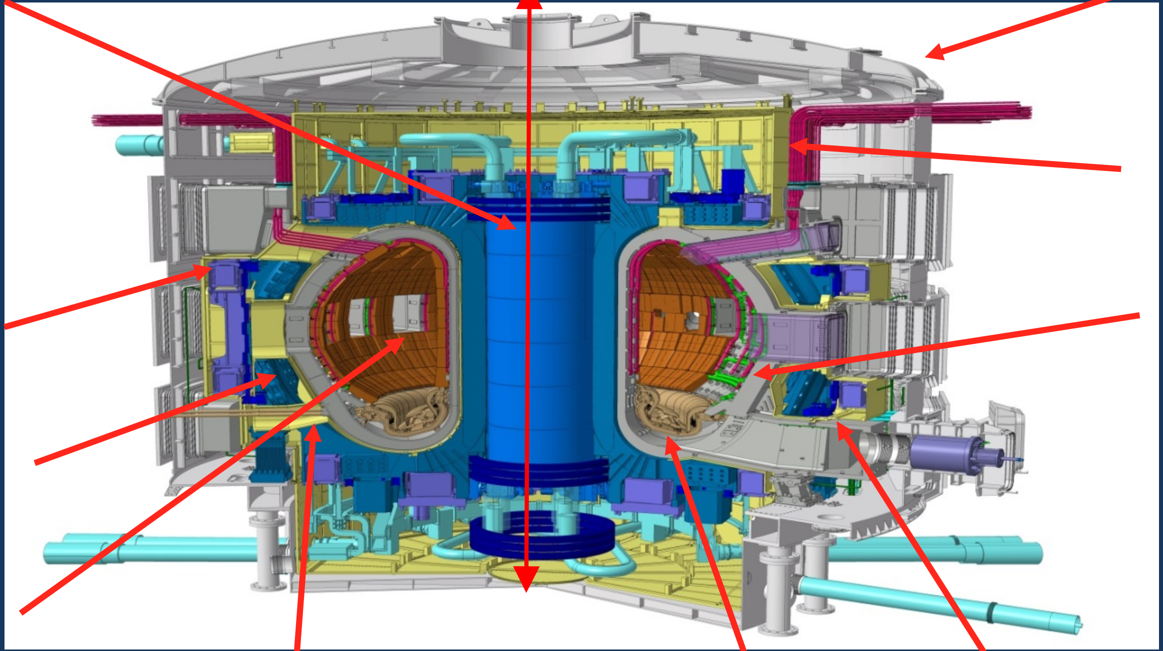
ITER – Tokamak Core Components

d ~ 30 m

Central Solenoid

(6) (Nb_3Sn)

Cryostat
(SS)



Thermal Shield
(SS)

Poloidal Field Coils

(6) (NbTi)

Internal Coils
(Cu)

Toroidal Field Coils

(18) (Nb_3Sn)

Shielding Blanket Modules
(SS/ Be)

Vacuum Vessel
(SS)

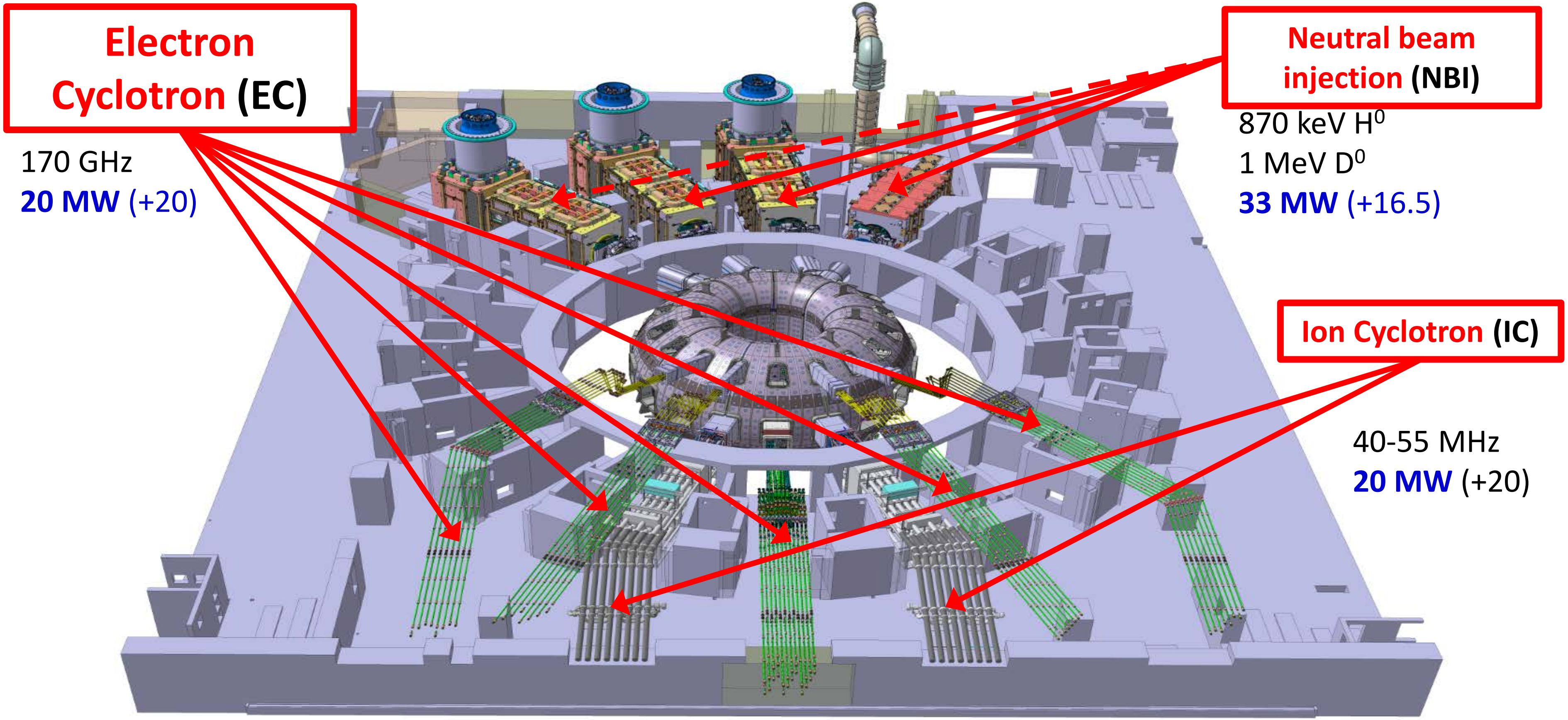
h ~ 29 m

Divertor
(SS/ W)

Correction Coils

(18) (NbTi)

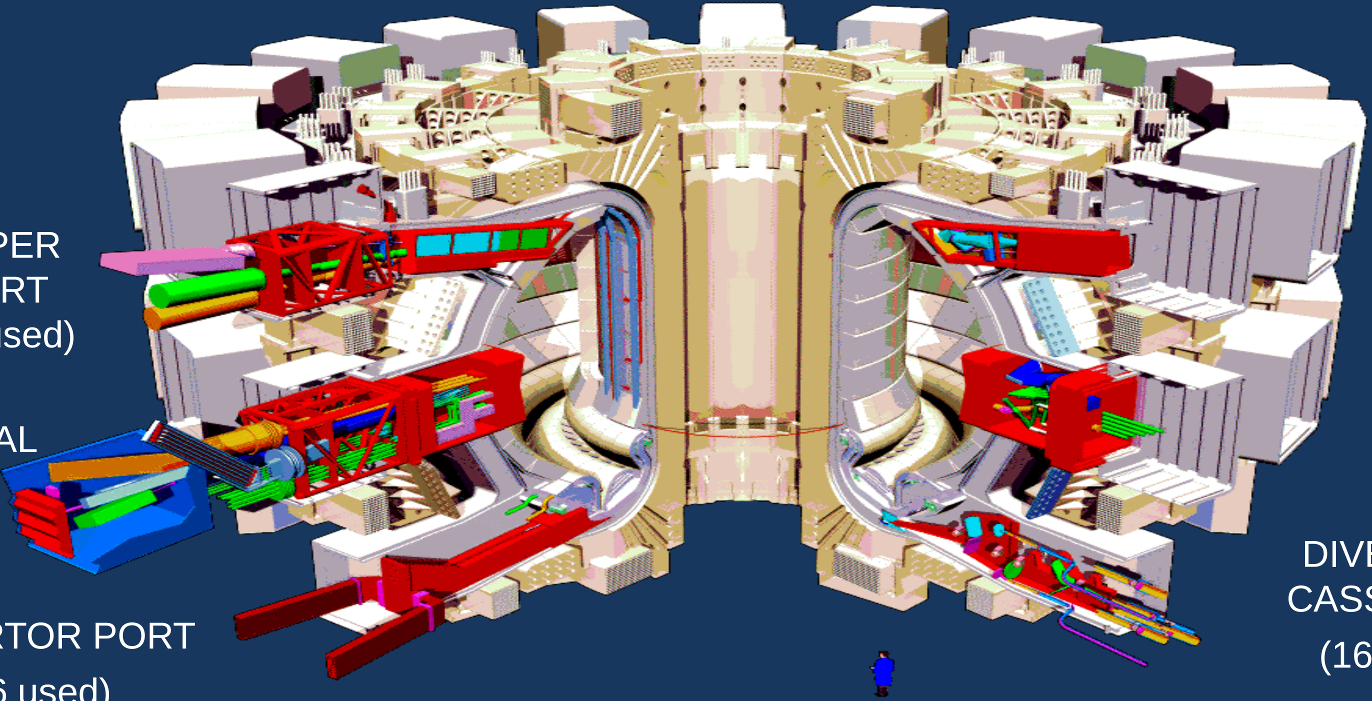
Plasma heating and current drive systems



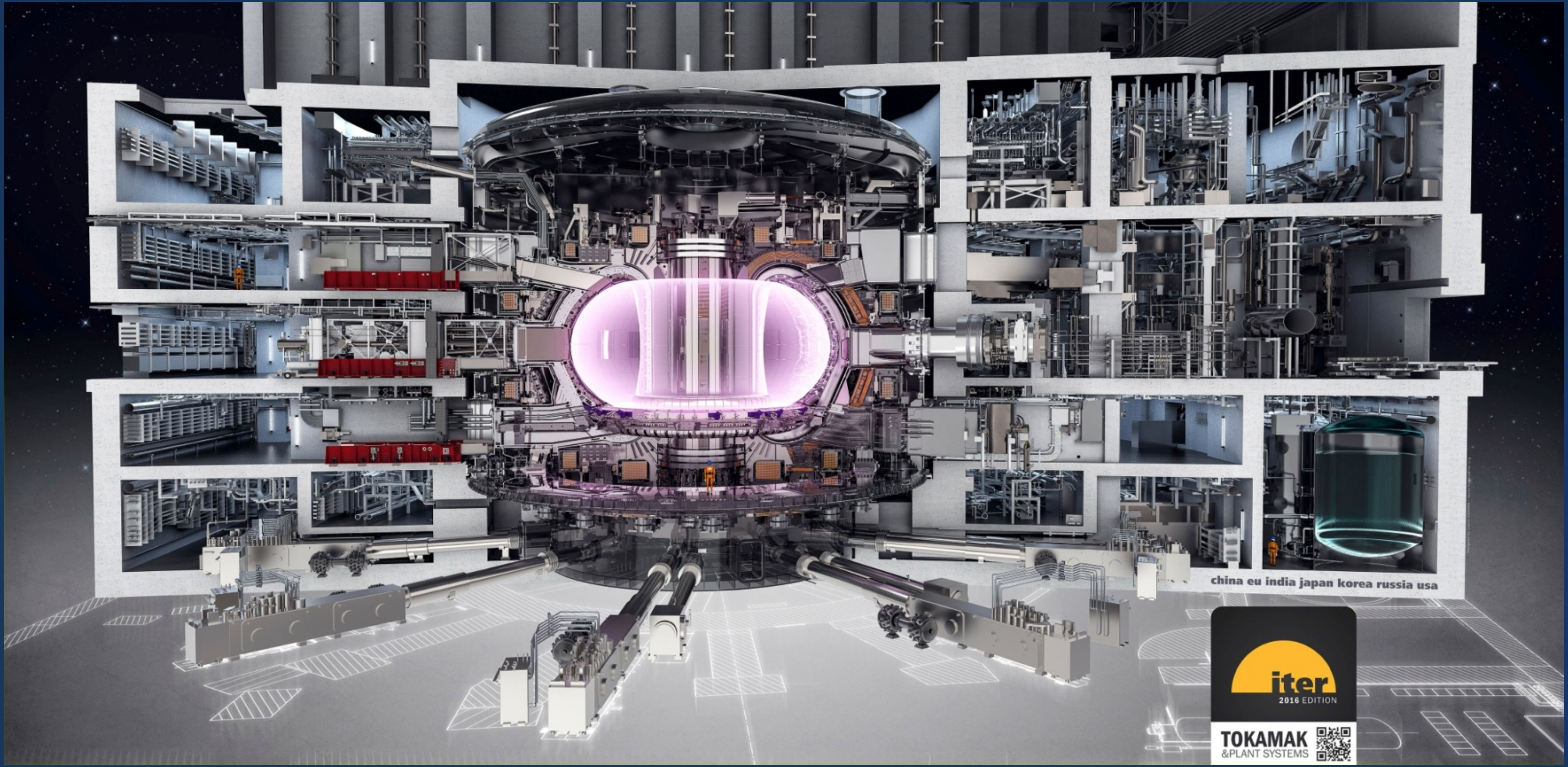
Plasma Measurements (Diagnostics)

About 40 major diagnostic systems (= very well diagnosed)

- For machine protection, control and physics studies
- Can reach peta-bytes of raw data → intelligent filtering will be required



ITER into tokamak building

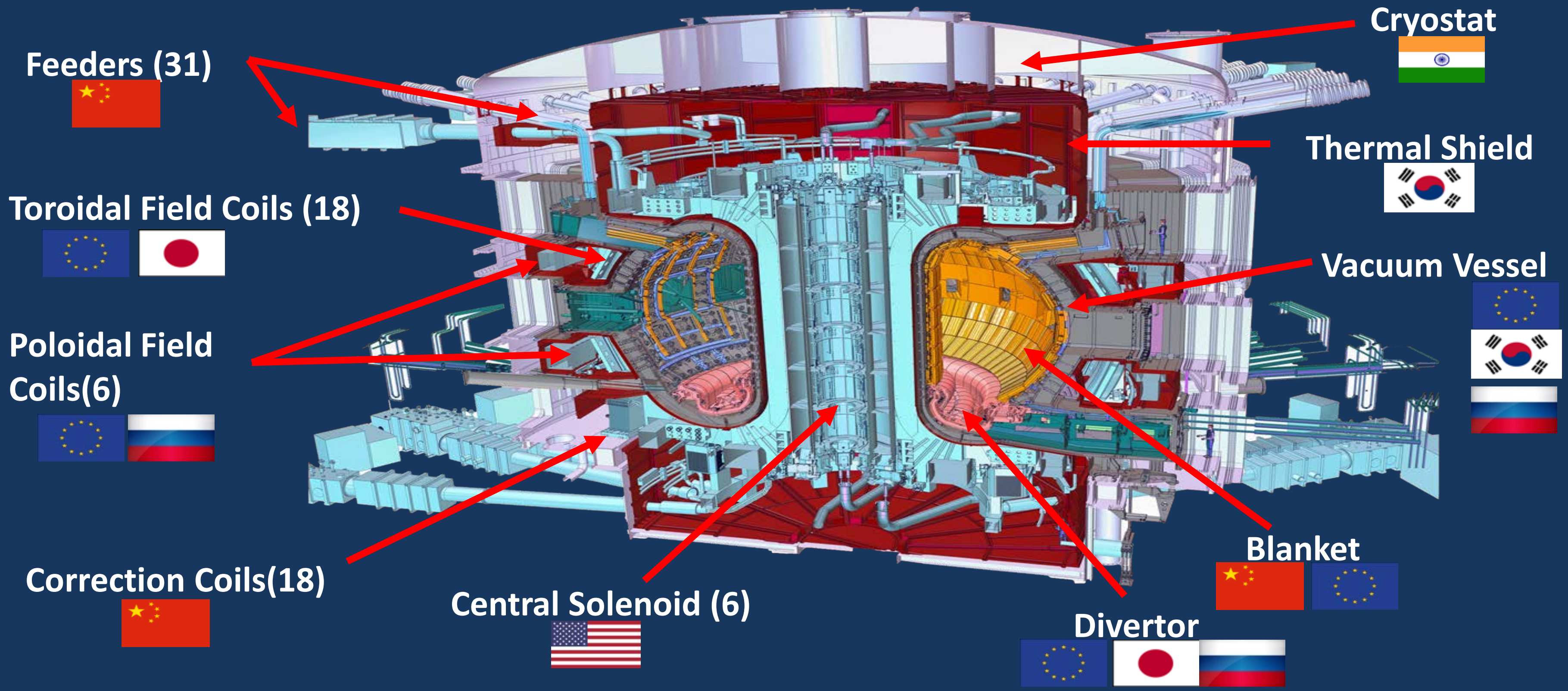


ITER – A Major International Collaboration

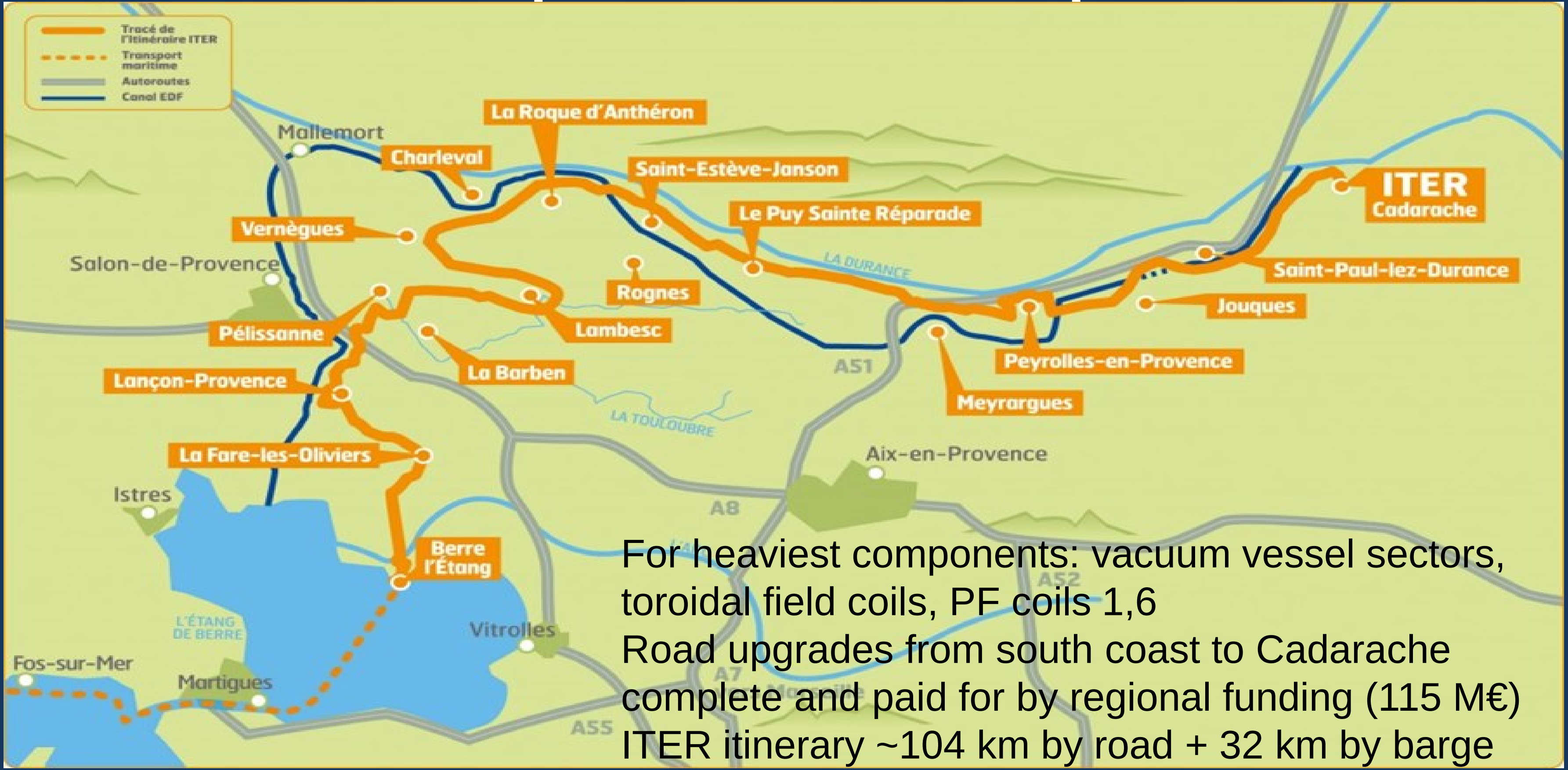
- **90% of ITER components are supplied "in-kind" by the Members through their Domestic Agencies**

- **This approach necessitates the integration of ITER management, design and manufacturing activities across the globe**

Who manufactures what?



Component transport



For heaviest components: vacuum vessel sectors, toroidal field coils, PF coils 1,6

Road upgrades from south coast to Cadarache complete and paid for by regional funding (115 M€)

ITER itinerary ~104 km by road + 32 km by barge

Components arriving regularly

Double convoy bringing two of the four 47-ton girders for the Assembly Hall cranes along the roads from the Mediterranean Sea to the ITER site: 5 km/hour

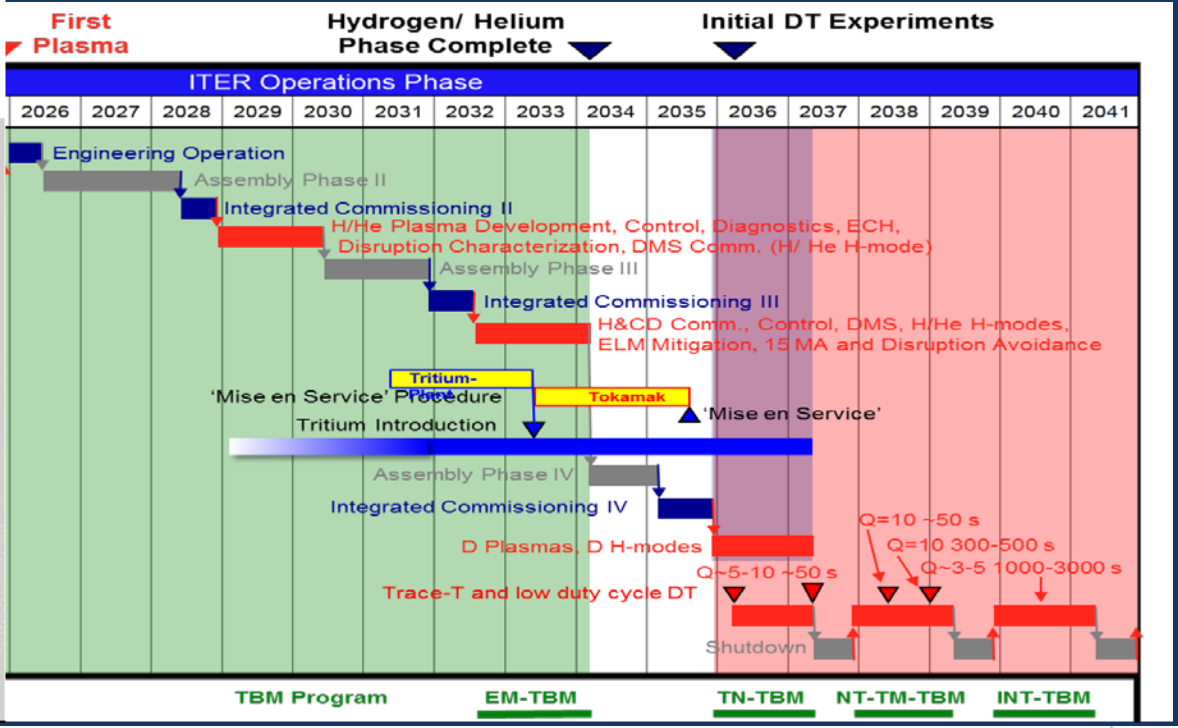
ITER Scientific Exploitation

ITER Scientific Exploitation

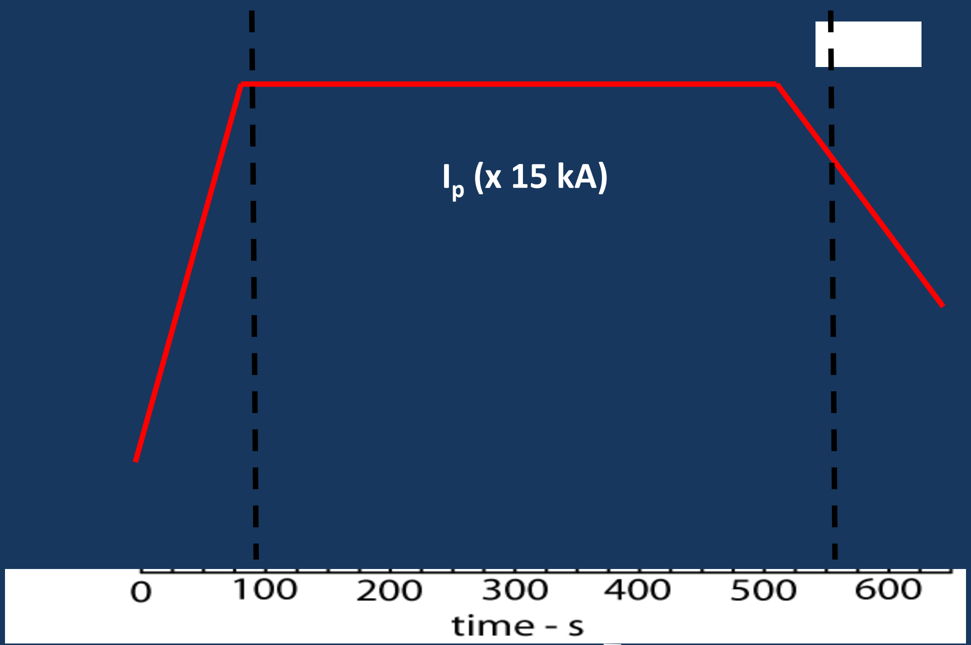
- ITER scientific exploitation will demonstrate fusion energy project's objectives
- Plans for scientific exploitation are described in ITER Research Plan
  - Pre-Fusion Operation Phase with H and He plasmas
    - ✓ Commissioning of tokamak systems
    - ✓ First ITER plasmas with high confinement
  - Fusion Operation Phase with DT plasmas
    - ✓ Demonstration of project's objectives

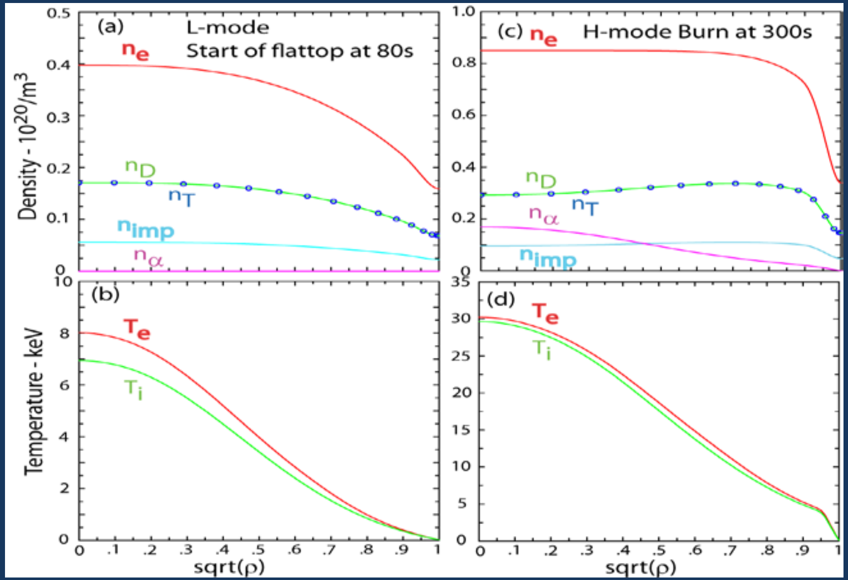
ITER Research Plan (IRP)

- IRP → strategy for R&D to achieve Project goals : Q = 10 (300-500 s), Q = 5 (1000 s) & Q = 5 steady-state starting from First Plasma



An ITER high Q discharge





L-H transition

H-L transition

ITER Power Exhaust Issues

ITER – Power exhaust

P_{fusion} = 500 MW with gain Q ≥ 10 for 300-500 s

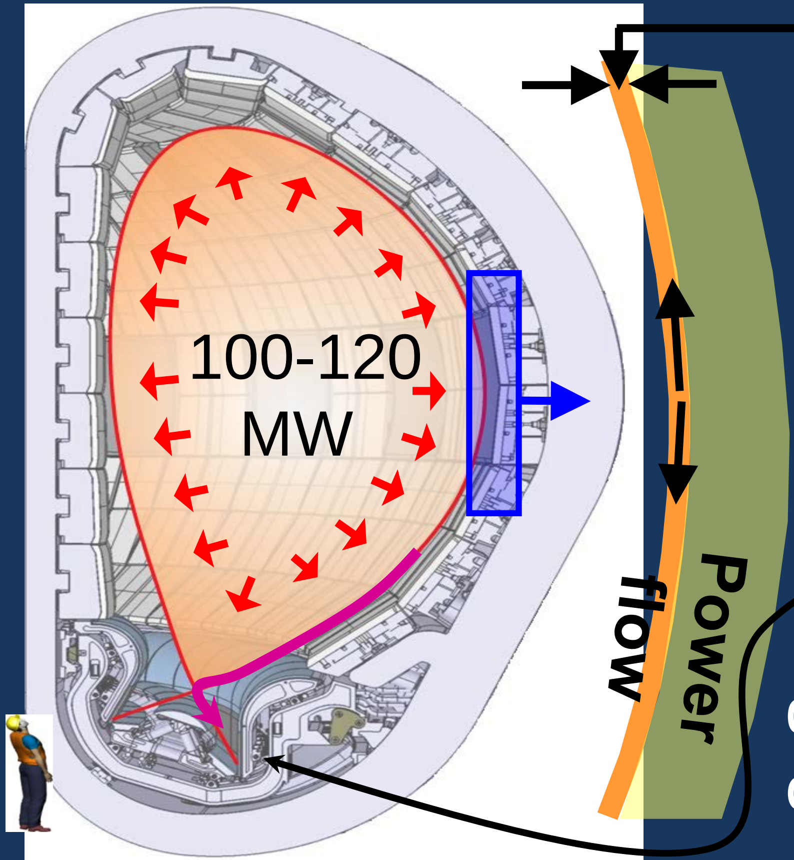
D + T → α + n $Q = P_{fusion}/P_{add}$ → $P_\alpha/P_{add} = Q/5$

P_{add} ~ 50 MW → direct heating of e + i → charged particles in $\vec{B}$

P_α ~ 100 MW → a slowing down → heating of e + i → charged particles in $\vec{B}$

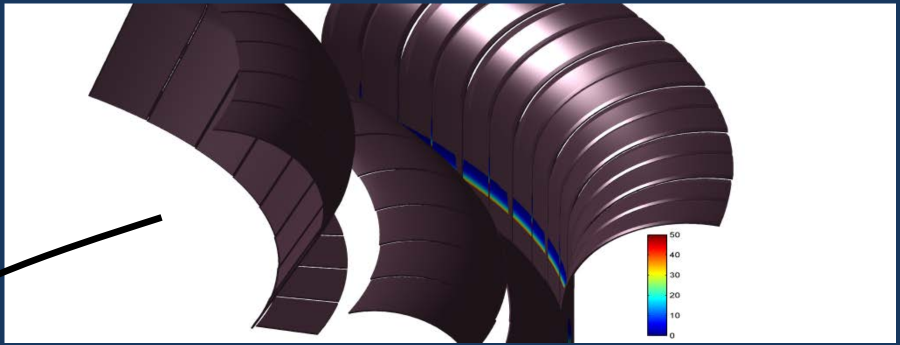
P_n ~ 400 MW → 14 MeV neutral particles (not affected by $\vec{B}$) → well spread over tokamak inner components in space & depth

ITER – Power Exhaust – The problem



We expect the "thickness" (λ_q) for SOL power flow will be only a **few mm** on ITER

$A_{effective}$ ~ 1-2 m²



q_{div} ~ 50 MWm^{-2} → similar to heat flux on sun's surface (60 MWm^{-2})

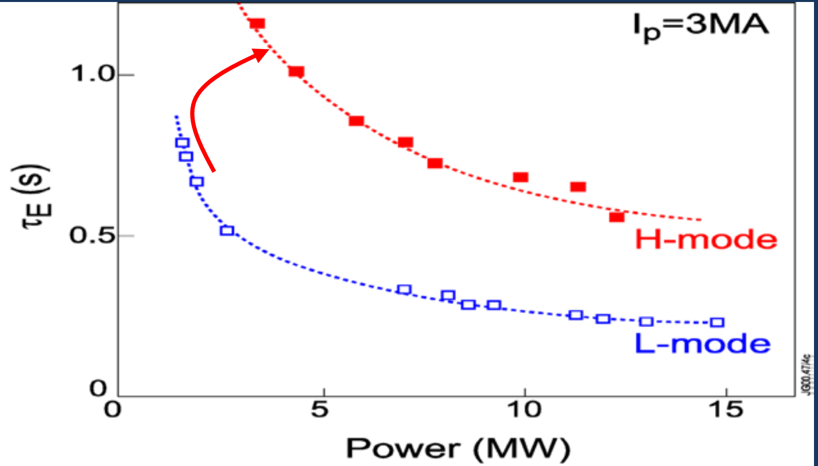
Energy Confinement : L-mode and H-mode

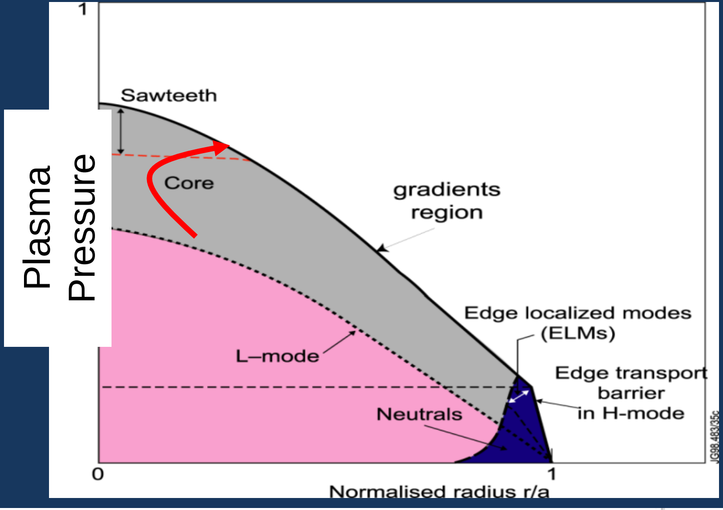
Energy confinement → $\tau_E = W_{plasma}/P_{input}$

Energy Confinement in Tokamaks and Stellarators : L *(low)* and H *(high)* Confinement Modes

H-mode ←→ Edge Transport Barrier (➔ Pedestal)

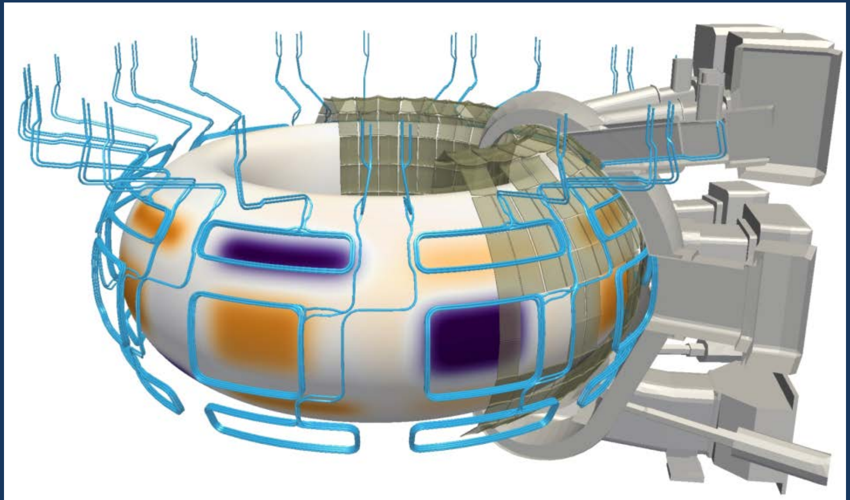
- H-mode confinement is "naturally" achieved when $P_{input} > P_{L\text{-}H}^{threshold}$
- $P_{fusion}^{H\text{-mode}} > 5\ P_{fusion}^{L\text{-mode}}$ → ITER requires H-mode for high Q





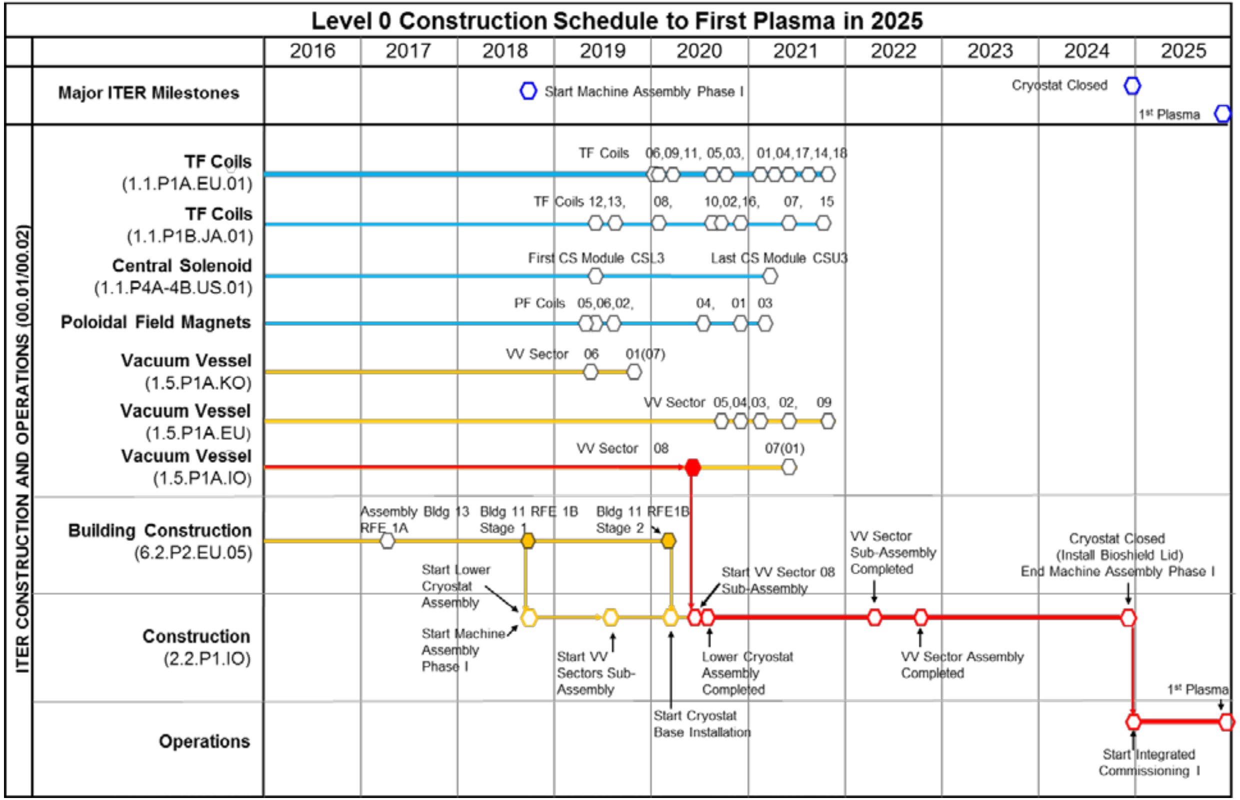
H-mode and ELMs

- Reduced transport at edge leads to large ∇p and j → local MHD instability develops (Edge Localized Modes)
- ELMs expel few % of W_{plasma} in sub ms timescales → large power fluxes ($q_{div}^{uncontrolled\text{-}ELM}$ ~ 100 GWm^{-2}) to plasma facing components
- ELMs need to be controlled to ensure acceptable power fluxes to PFCs

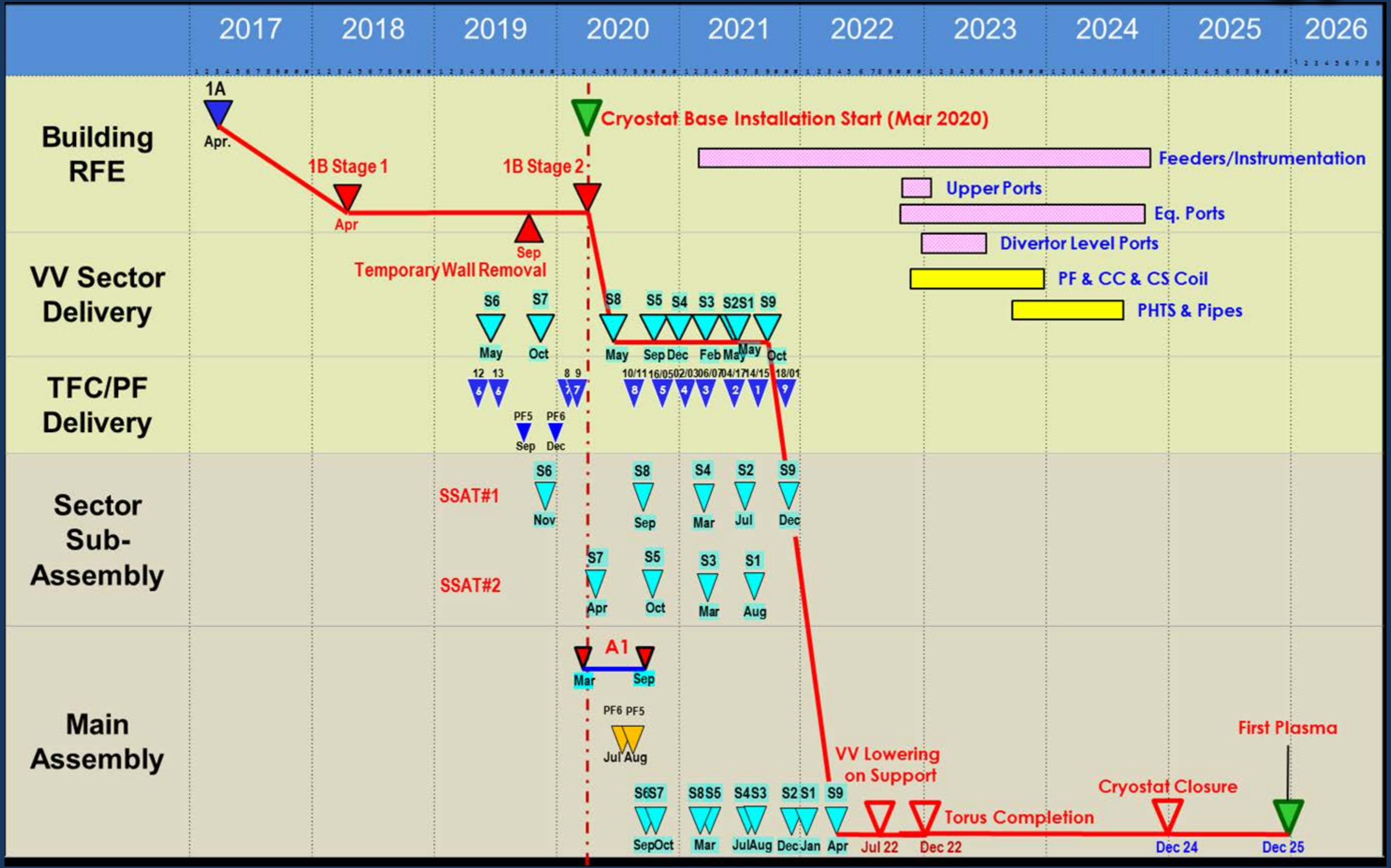


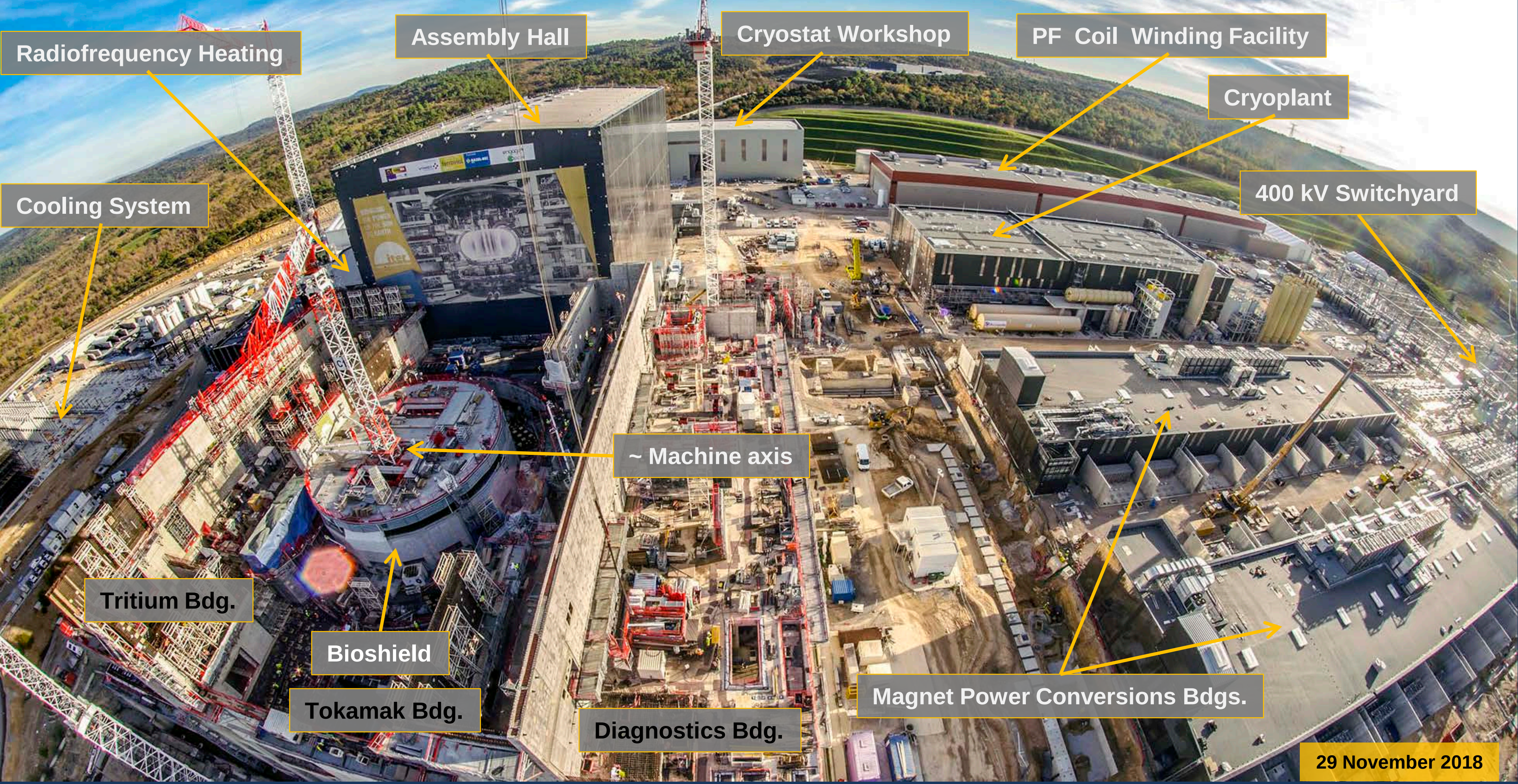
Progress on ITER Construction

Major milestones

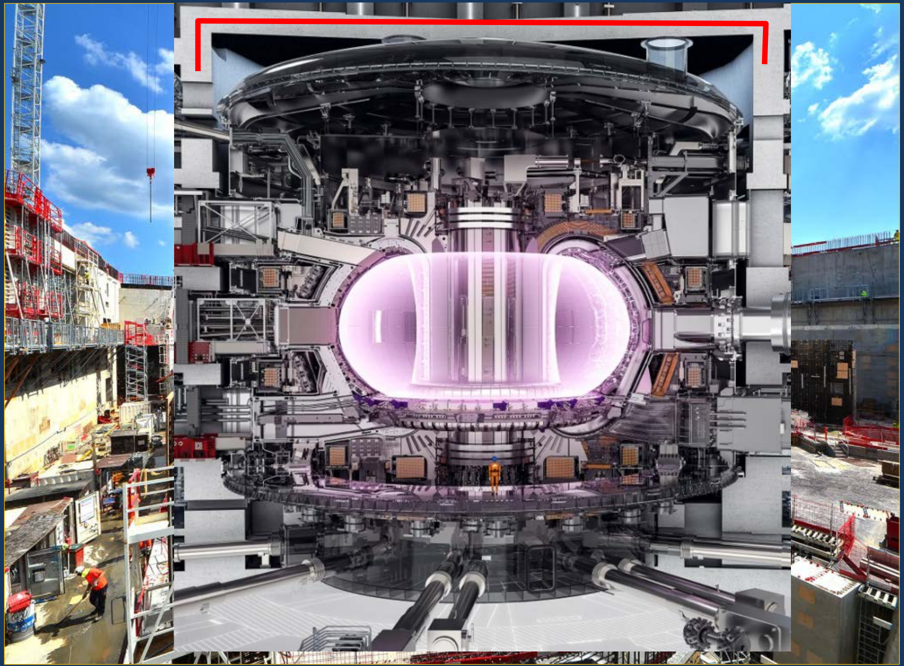


Details of Construction Strategy



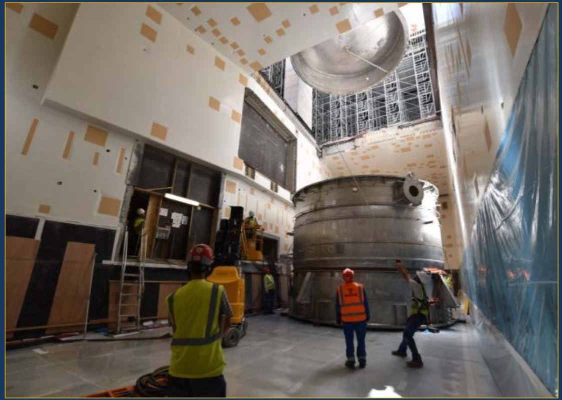

Radiofrequency Heating
Assembly Hall
Cryostat Workshop
PF Coil Winding Facility
Cryoplant
Cooling System
400 kV Switchyard
~ Machine axis
Tritium Bdg.
Bioshield
Tokamak Bdg.
Diagnostics Bdg.
Magnet Power Conversions Bdgs.
29 November 2018

Tokamak Complex



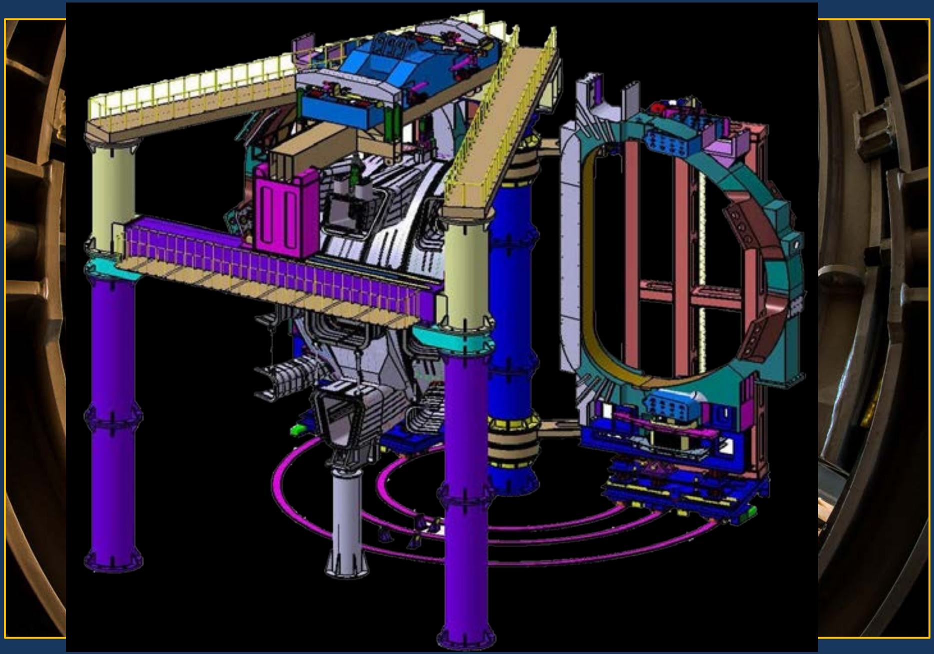
The bioshield is now finalized. Openings in the wall are for the cryostat bellows that will connect the machine to the port cells designed to give access to systems such as remote handling, heating and diagnostics. The crown (right) that will support the machine (23,000 tonnes) was finalized in August 2018

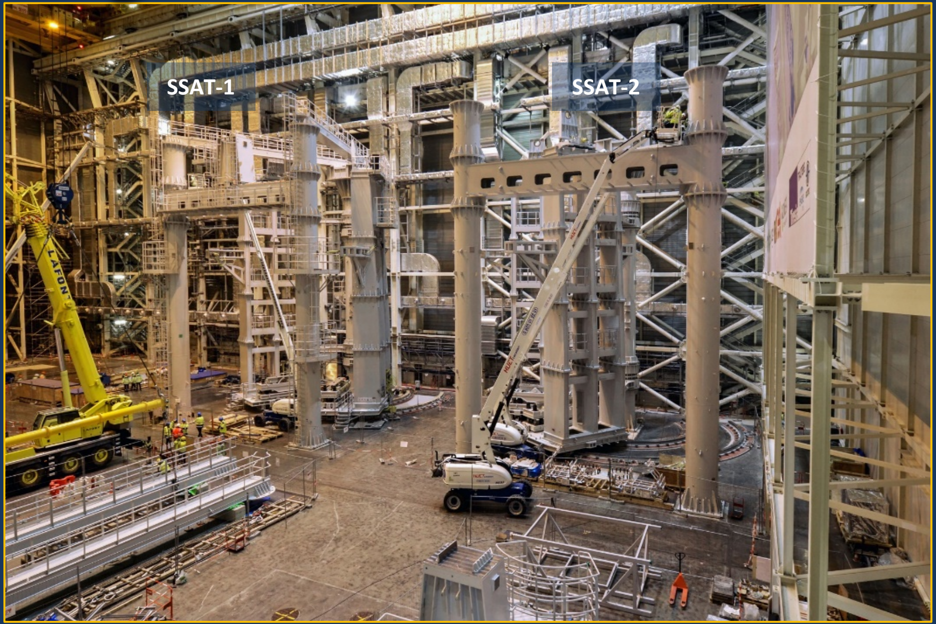
Tokamak Complex



Seven water storage tanks for the machine's cooling water and vacuum vessel pressure suppression systems were installed in less than one week in mid-August 2018,

Assembly Hall

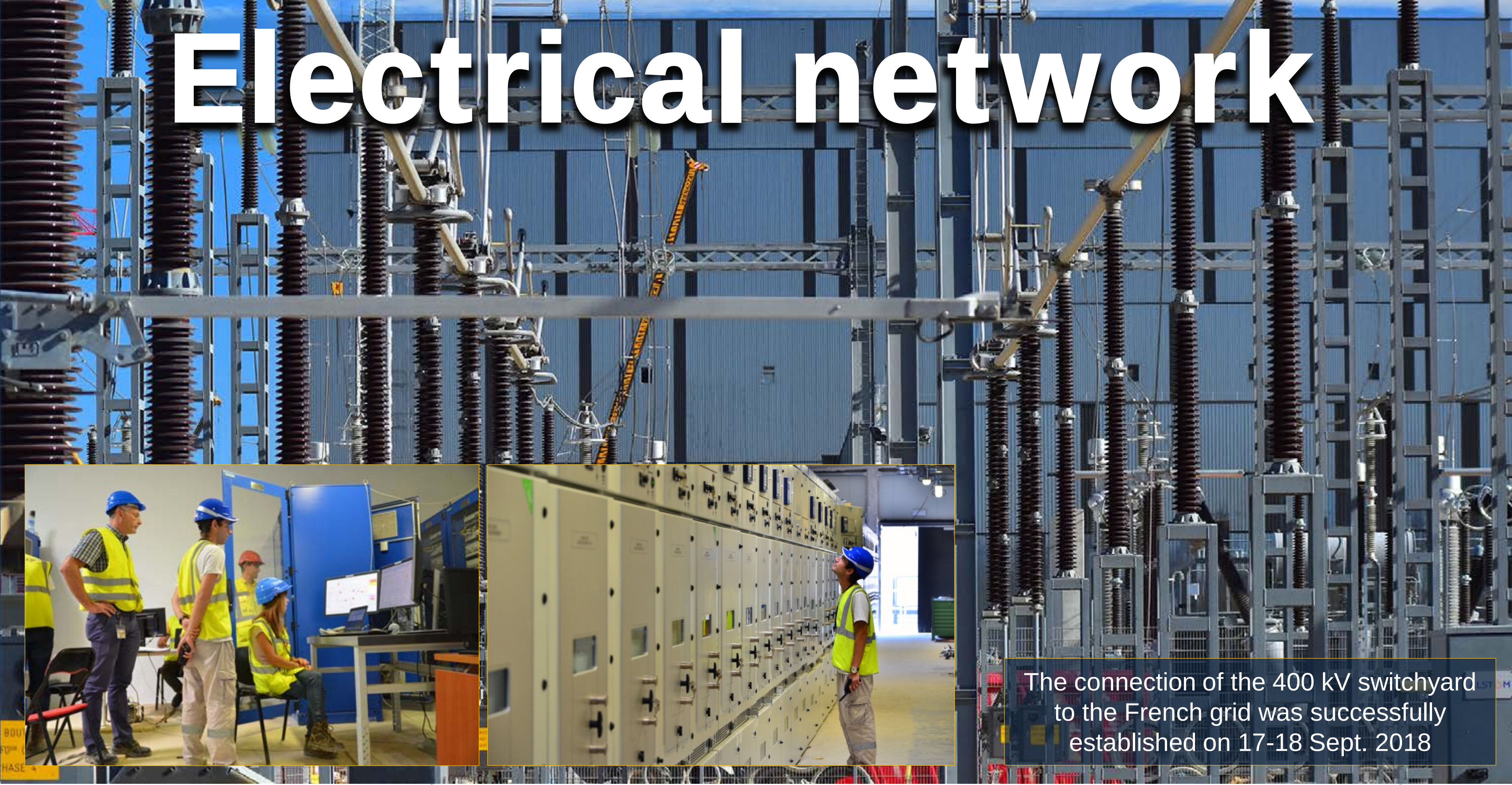




Before being integrated in the machine, the components will be prepared and pre-assembled in this 6,000 m2, 60-metre high building. The Assembly Hall is equipped with a double overhead travelling crane with a total lifting capacity of 1,500 tons.
All mechanical elements of sub-assembly tool # 1 (SSAT-1) are assembled, and work is progressing on the installation of SSAT-2.

Cryoplant

Equipment installation for what will be the largest cryogenic unit in the world is now approximately half-complete.



Electrical network

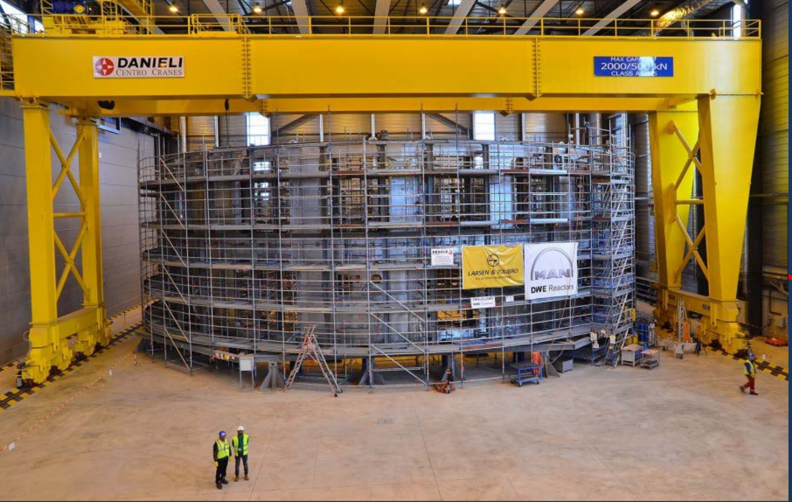
The connection of the 400 kV switchyard to the French grid was successfully established on 17-18 Sept. 2018

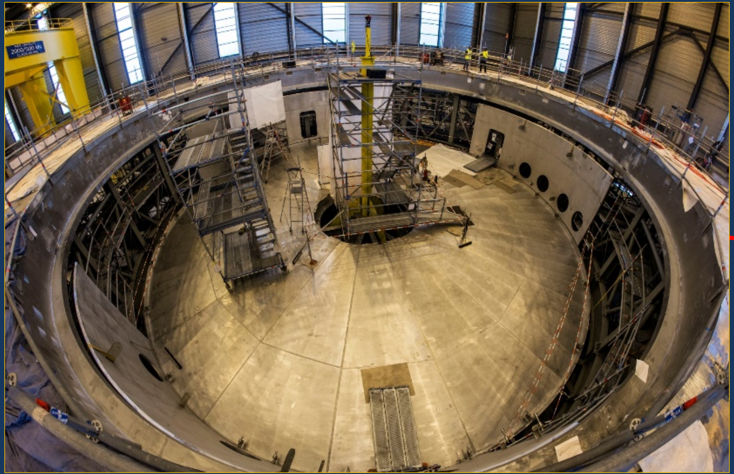
Electrical conversion

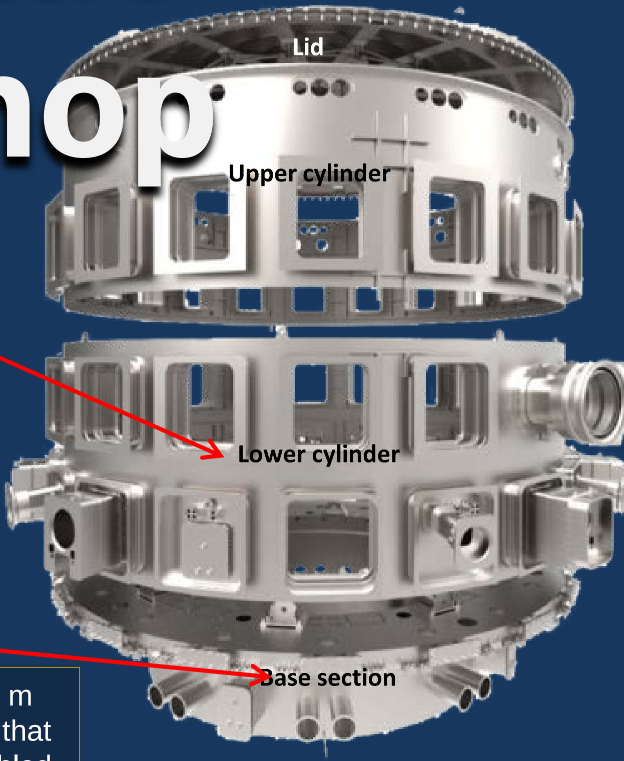
Two large Magnet Power Conversion buildings will host the transformers and converters (AC ► DC) feeding power to the ITER magnets.

The twin buildings are now ready for equipment. Electrical components from China, Korea and Russia will be progressively installed inside of the building as well as in the exterior bays.

Cryostat workshop

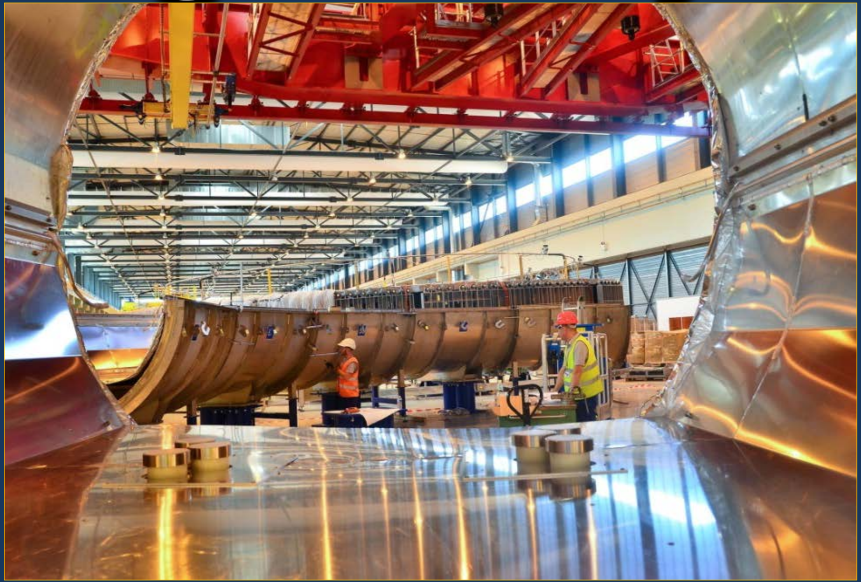


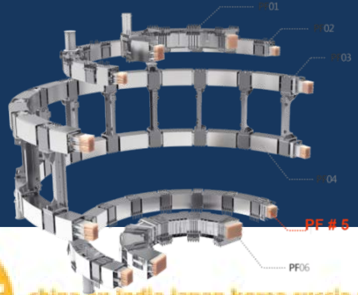




Manufactured in India, the 30 m x 30 m cryostat (the insulating vacuum vessel that encloses the machine) is being assembled and welded on site.

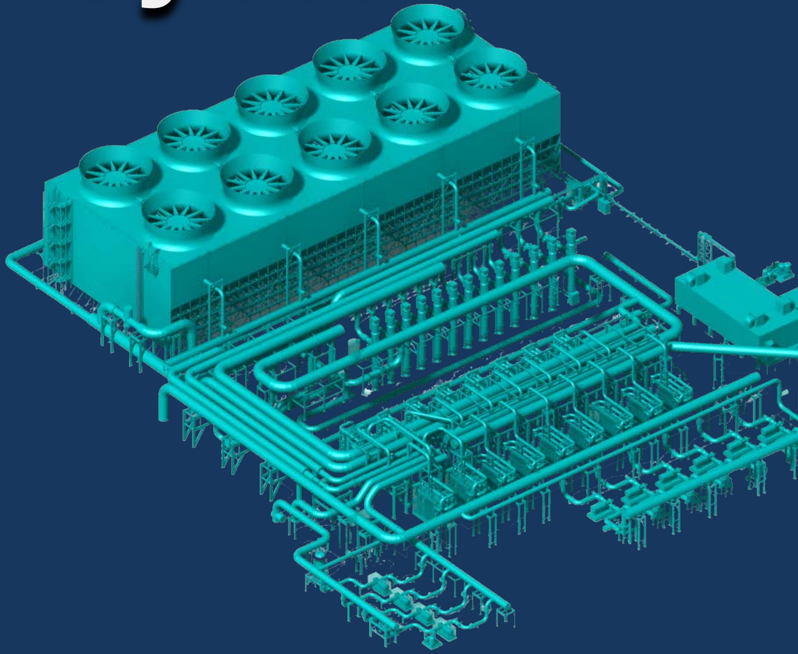
PF Coil winding facility





Too large to be transported by road, four of ITER's six ring-shaped magnets (the poloidal field coils, 17 to 24 m, in diametre) will be assembled on site by Europe in this 12,000 m² facility. Resin impregnation ongoing for PF Coil # 5 (17 m. diametre, ~ 350 tonnes). Superconducting cables are procured by China.

Heat rejection system



ITER power will be partly evacuated by cooling towers (procured by India).

Worksite Progress: Feb. 2015 – Dec. 2018

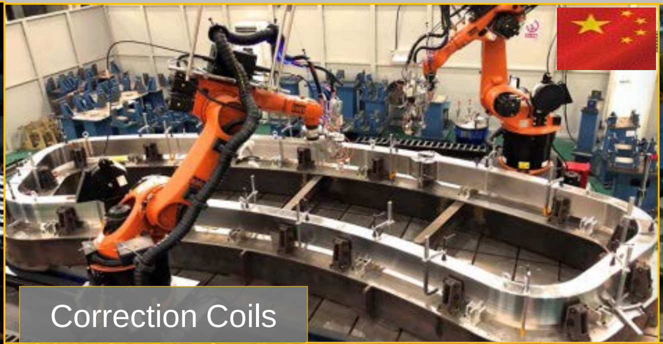
60% of completion to First Plasma by end 2018:

According to the stringent metrics that measure ITER project performance, as of the end of October 2018 the project reached 58.7%of the "total construction work scope through First Plasma.” *[approximately 0.8% per month since Nov. 2017]*

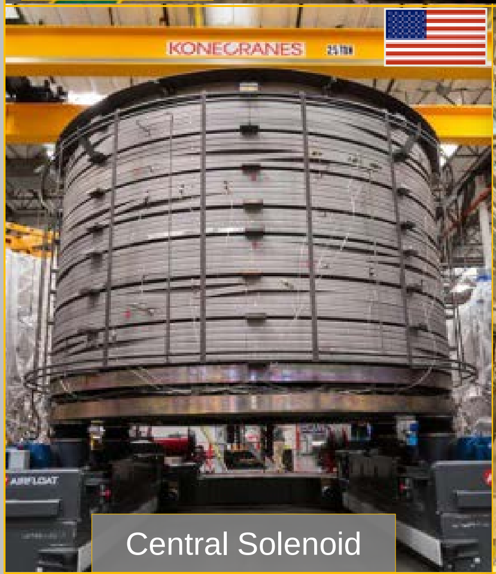
Manufacturing Progress

Total average component manufacturing through First Plasma is >65% complete.

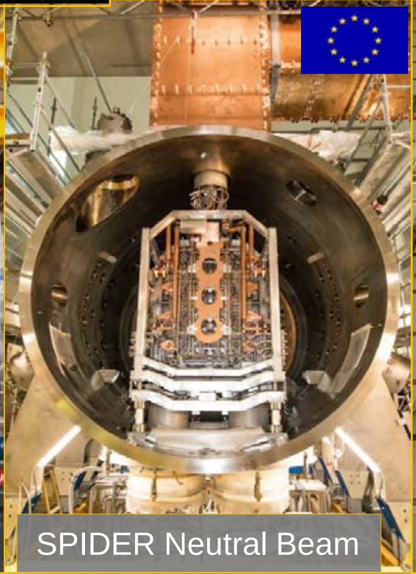

Cryostat


Correction Coils

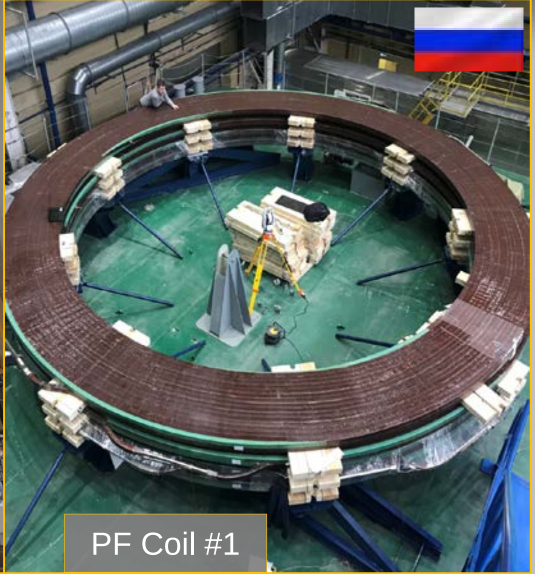

Vacuum Vessel



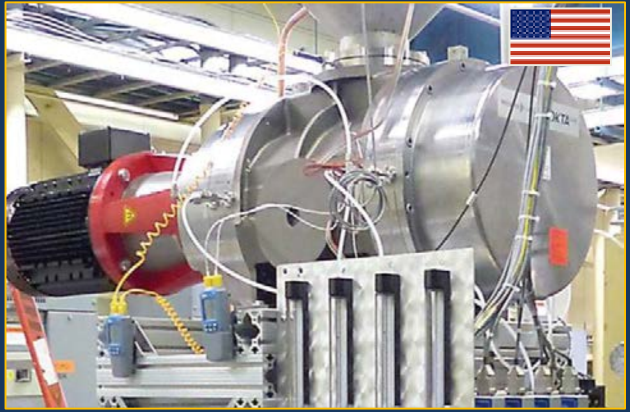
Central Solenoid


SPIDER Neutral Beam

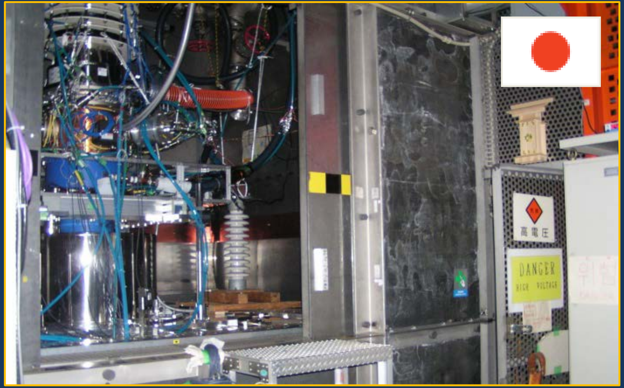
TF Coil Winding Pack


PF Coil #1

Manufacturing progress…



Thermal Shield, Vacuum Systems, Gyrotrons, Divertor, Electrical Systems



From fabrication…

Manufacturing of ITER components is taking place all around the world at the cutting edge of technology:

- **Geometrical tolerances measured in millimetres for steel pieces up to 20 m tall weighing several hundred tons**
- **Superconducting power lines cooled to *minus* 270 degrees Celsius**
- **Plasma facing components to withstand heat flux as large as 20 MW per m^2**
- **Cryoplant cooling capacity of 110 kW at 4.5 K; maximum cumulated He liquefaction rate of 12,300 l/hr**
- **…**

...to assembly preparation

In Spain, welding procedures and techniques are being tested on a real-size vacuum vessel mockup.

On the night of 26 November 2018, the first machine component *(cryostat feedthrough)* was lowered into the Tokamak Pit.

Conclusions

The ITER device integrates many advanced technologies and is driving major R&D programmes within the ITER Members

- **The ITER project is now fully into the manufacturing and construction phase**
  - on-site construction is advancing rapidly
  - ITER Member's Domestic Agencies are carrying out large scale manufacturing for the major tokamak and plant components

- **First Plasma will be demonstrated in late-2025 and first fusion power experiments will take place in 2036**

Successful exploitation of ITER will not only realize the limitless possibilities of fusion energy, but open new areas of fusion plasma research and fusion technology

ITER is moving forward!

http://www.iter.org