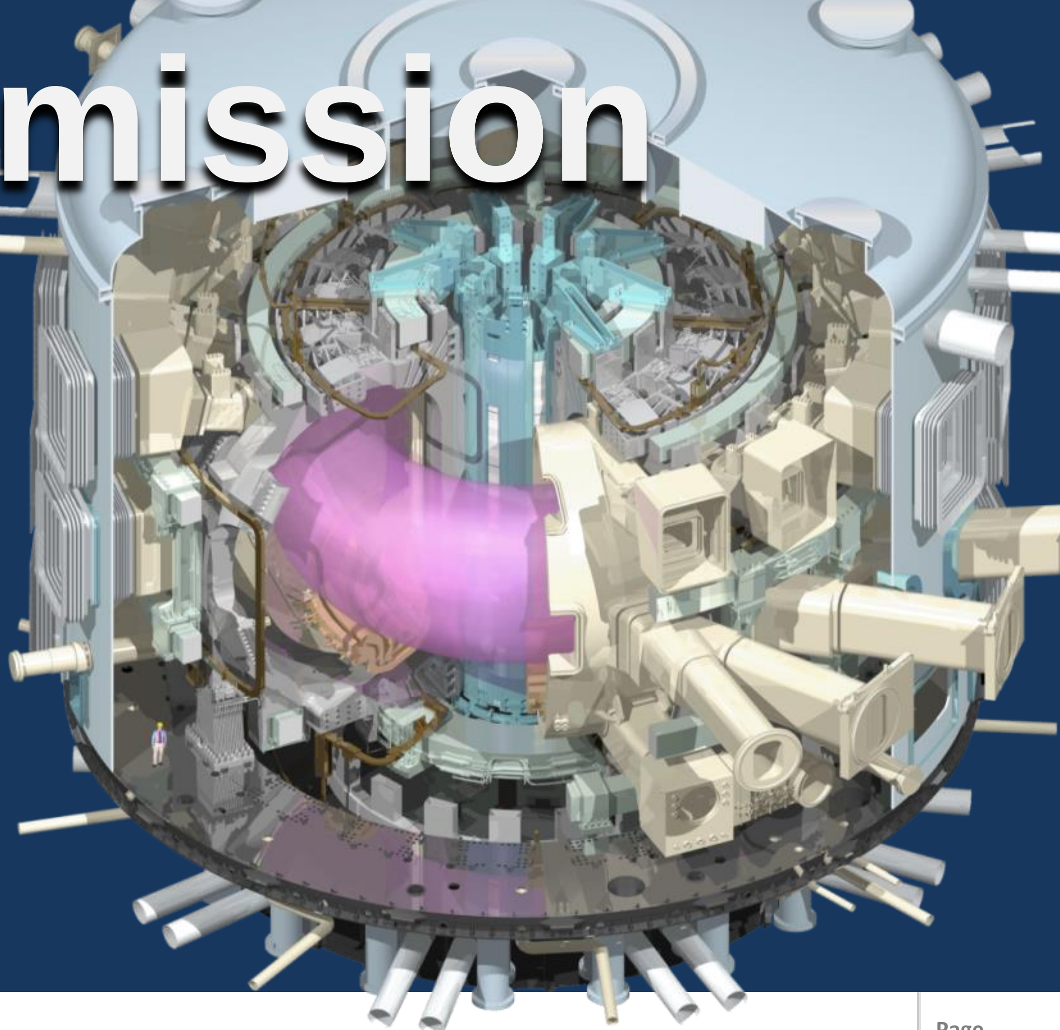
The ITER Project

Construction and Manufacturing Progress Toward First Plasma

Bernard BIGOT, Director-General, ITER Organization

ITER mission



To demonstrate the scientific and technological feasibility of fusion power for peaceful purposes

ITER is the only magnetic fusion device under construction aimed to produce a burning plasma.

Input (heating power): 50 MW

Output (fusion power): 500 MW

ITER

A multinational scientific collaboration without equivalent in history

A large-scale experiment to demonstrate the feasibility of fusion energy

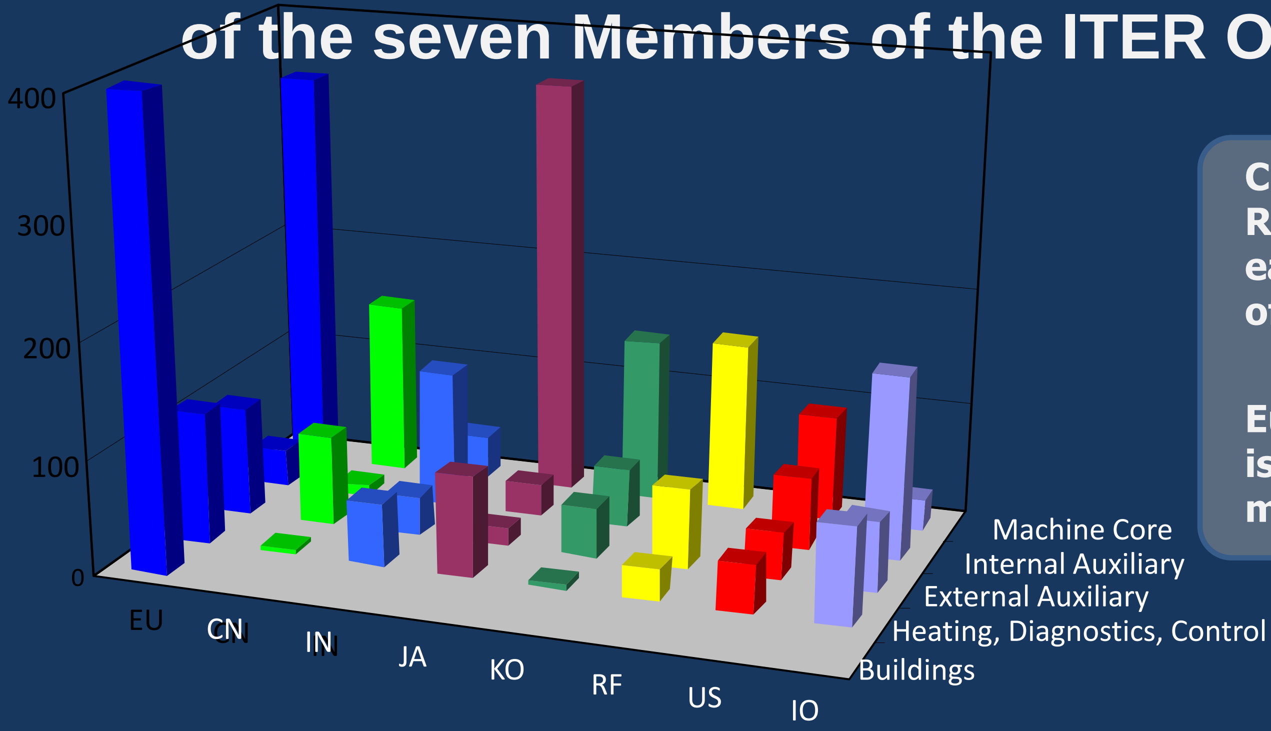
An integrated project:

Central Team & Seven Domestic Agencies

- **The 7 ITER Members make cash and in-kind contributions (90%) to the ITER Project. They have established Domestic Agencies to handle the contracts to industry.**
- **The ITER Organization Central Team manages the ITER Project in close collaboration with the 7 Domestic Agencies.**
- **The ITER Members share all intellectual Property generated by the Project.**

A unique formula

ITER is being built through the in-kind contributions of the seven Members of the ITER Organization.



China, India, Japan, Korea, Russia and the United States each have responsibility for ~ 9% of procurement packages.

Europe's share, as Host Member, is ~ 45% (construction and manufacturing).

ITER Council Milestones

2016-2017: 29 technological and organizational milestones set

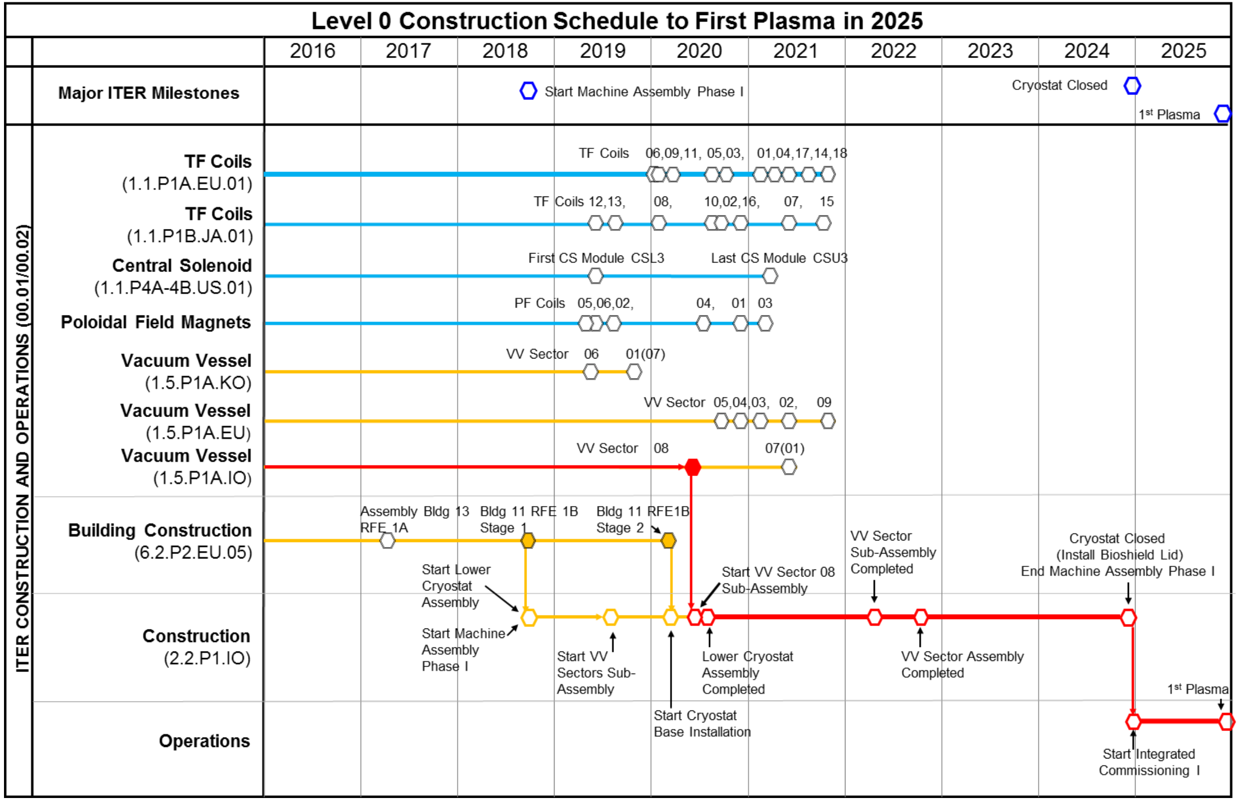
- Monitoring mechanism to show that the project remains on track
- Additional milestones added through First Plasma

36 milestones met so far: many challenges and potential delays mitigated

  – Demonstrates enhanced risk anticipation and management

- Two milestones postponed, with mitigation in place
- Critical path remains on schedule for First Plasma in 2025

Major assembly milestones



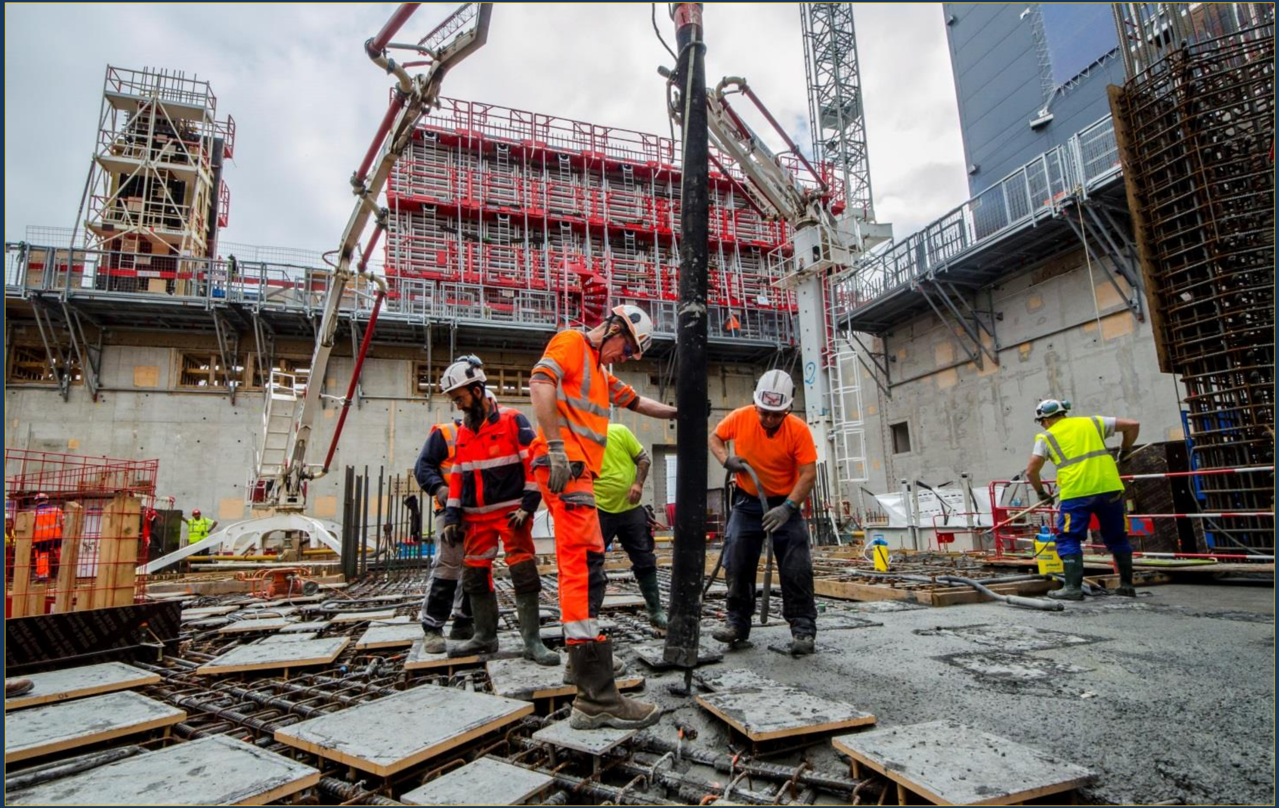
Worksite progress

Worksite Progress: Feb. 2015 – Oct. 2018

More Than Halfway to First Plasma:

According to the stringent metrics that measure ITER project performance, in November 2017 the project reached 50%of the "total construction work scope through First Plasma." ***[August 2018: ~57.4%]***

The ITER worksite

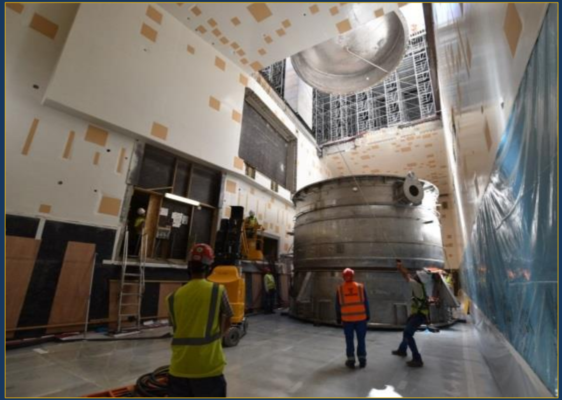


- *2,300 workers, technicians and engineers today, up to 3,000 in the coming years;*
- *ITER construction represents 18 million working hours (2010-2020).*

Tokamak Complex

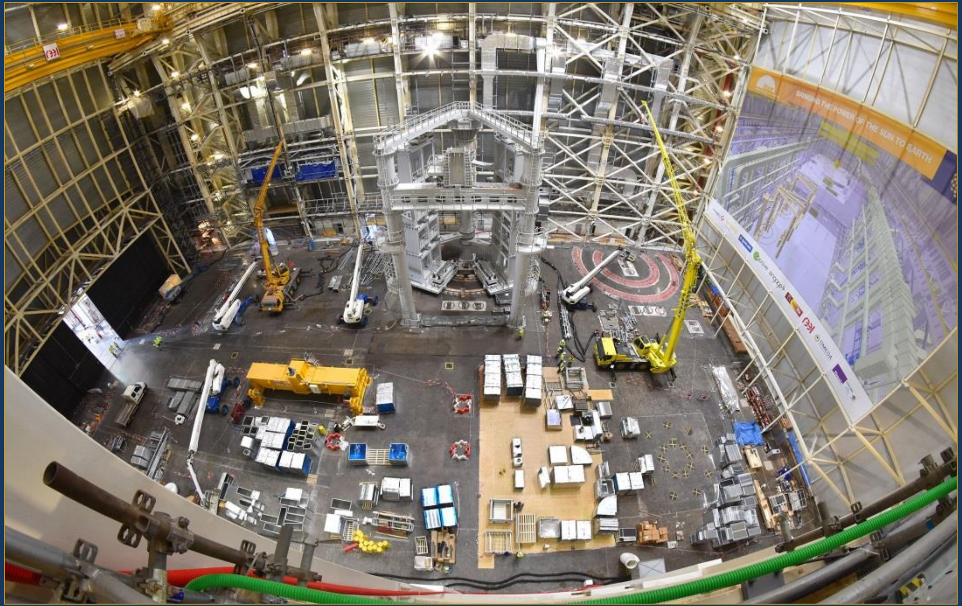
The bioshield is now finalized. Openings in the wall are for the cryostat bellows connecting the machine to the port cells designed to give access to systems such as remote handling, heating and diagnostics. The high-resistance concrete-and-steel structure (the “Crown”) that will support the combined mass of tokamak + cryostat (23 000 tonnes) is in the last stages of completion.

Tokamak Complex



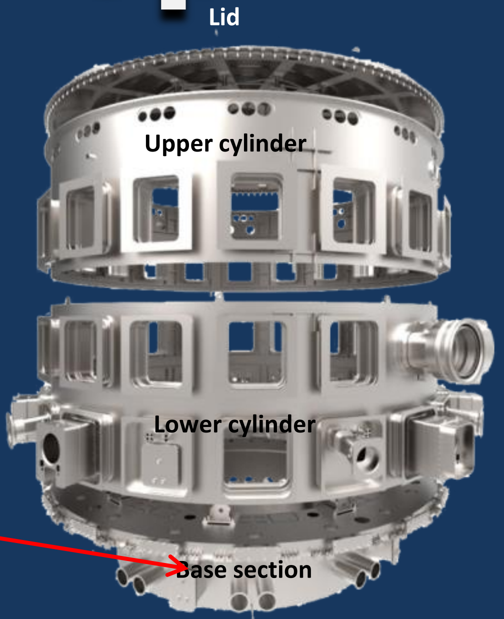
Seven water storage tanks (four of them from China) for the the machine's cooling water and vacuum vessel pressure suppression systems were installed in less than one week in mid-August 2018,

Assembly Hall



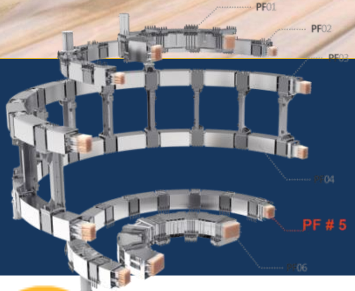
Before being integrated in the machine, the components will be prepared and pre-assembled in this 6,000 m2, 60-metre high building. The Assembly Hall is equipped with a double overhead travelling crane with a total lifting capacity of 1,500 tons.
To the right, the installation of the sub-assembly tool (SSAT-1) is almost finalized.

Cryostat workshop



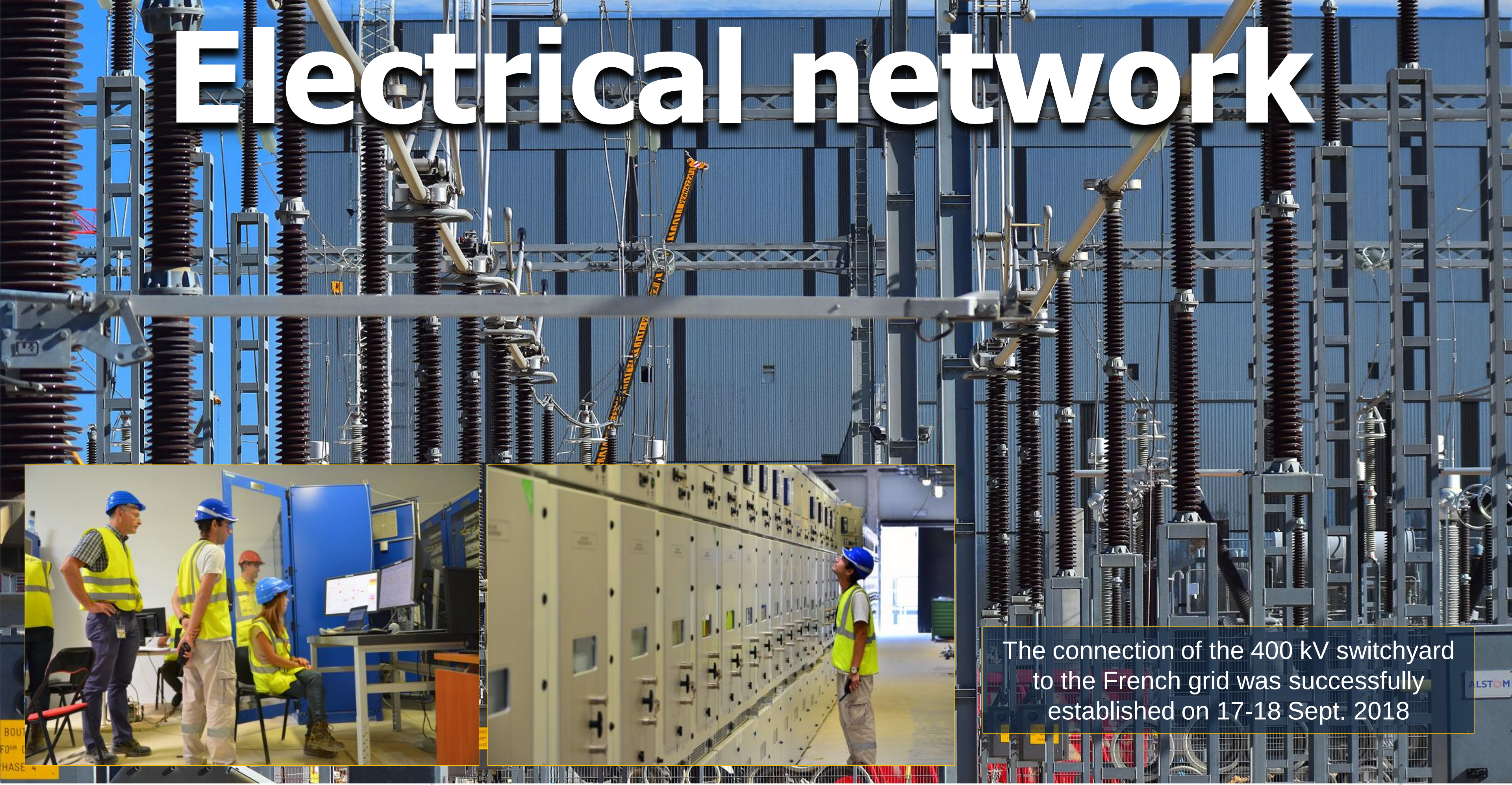
Manufactured in India, the 30 m x 30 m cryostat (the insulating vacuum vessel that encloses the machine) is being assembled and welded on site.

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 operations have begun for PF Coil # 5 (17 m. diametre, ~ 350 tonnes).

Electrical network



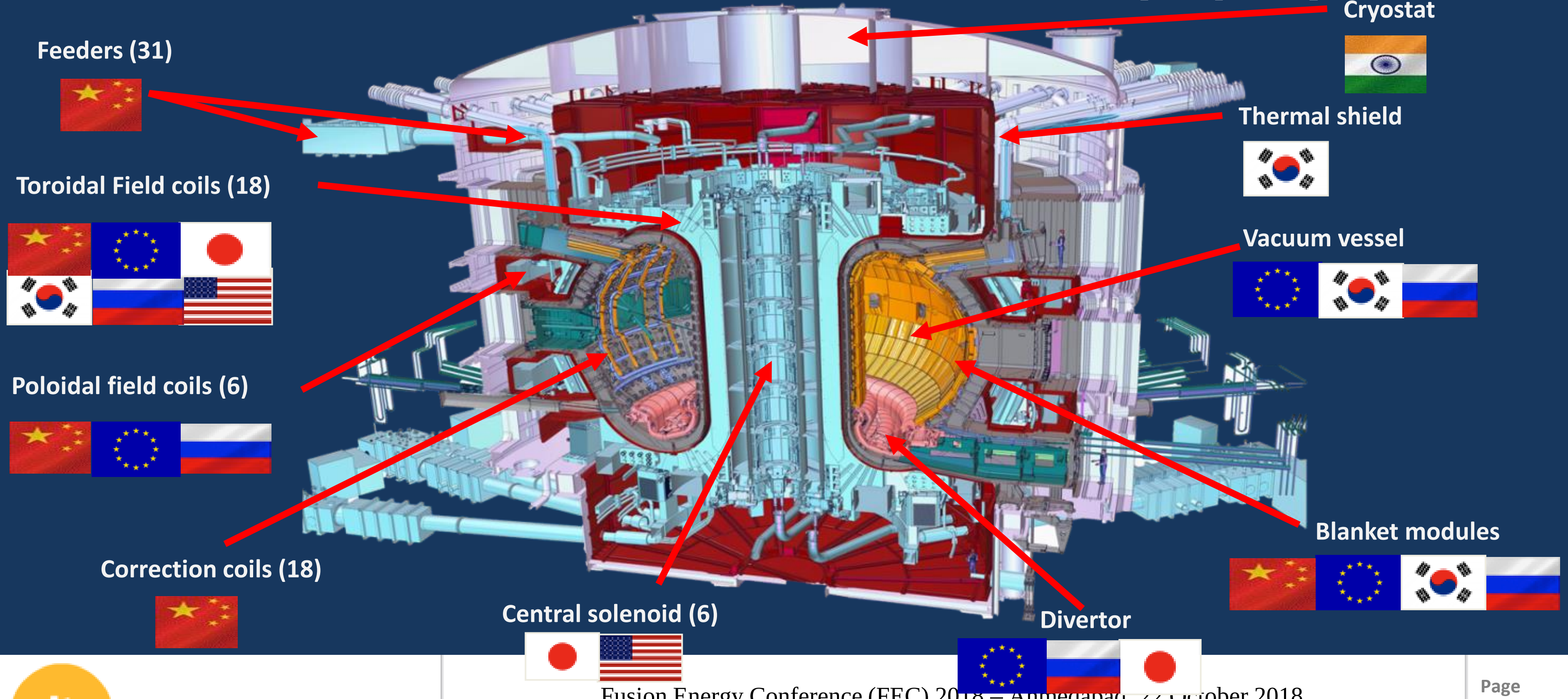
The connection of the 400 kV switchyard to the French grid was successfully established on 17-18 Sept. 2018

Cryoplant

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

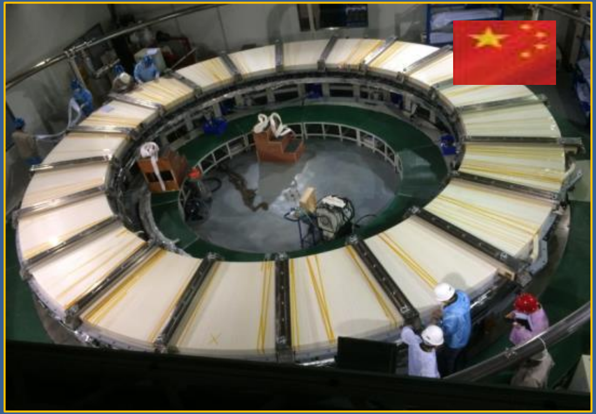
Who manufactures what?

The ITER Members share all intellectual property

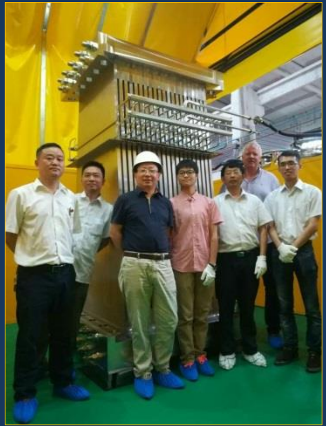


Manufacturing Progress

Vacuum Vessel, Magnets, Cryostat, Thermal Shields, Cryopumps, etc.



Manufacturing progress



The first production unit gravity support has been realized in China. Its design is based on years of prototyping, load analyses and testing

Welding operations for the cryostat's lower cylinder are finalized. Weld verification is ongoing.

Two out of ten toroidal field coils to be procured by Europe are finalized.

Fabrication of Japan's share of superconducting cables (43 km, 745 t.) is finalized.

Manufacturing progress

4 out of 9 segments for the vacuum vessel are being manufactured at Hyundai Heavy Industries shipyard in Ulsan.

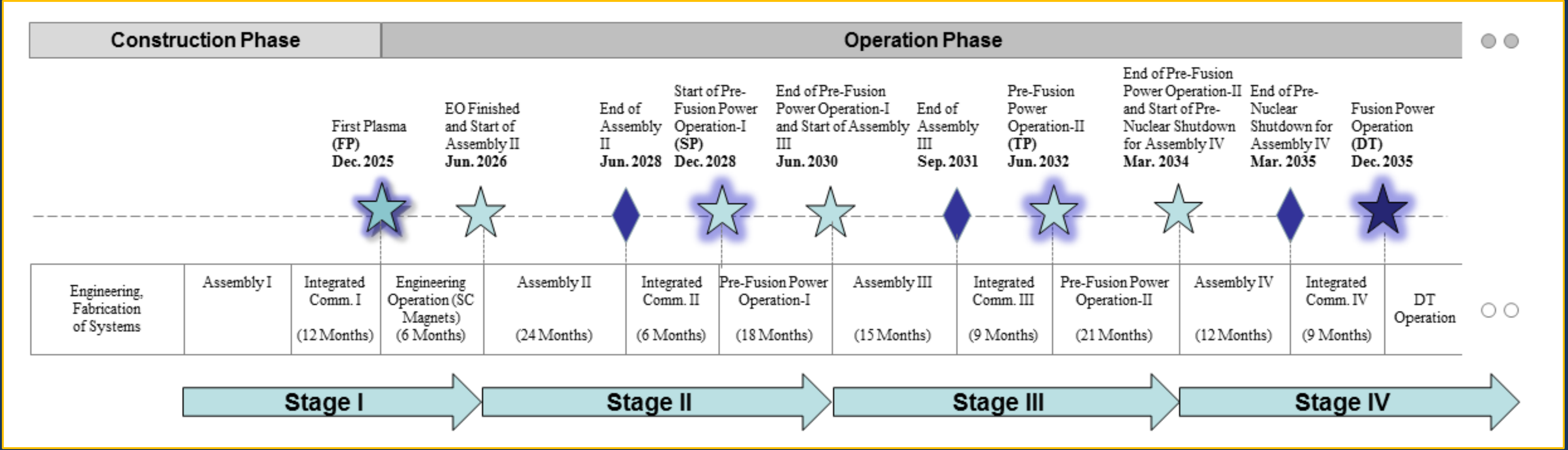
In San Diego, General Atomics is completing the high-temperature treatment for the Central Solenoid modules.

The fitting test for the first Toroidal Field Coil Structure, manufactured partly in Korea, partly in Japan, was completed at Hyundai Heavy Industry in Ulsan. Tolerance requirements of 0.5mm +- 0.25mm were successfully met!

A staged approach to DT plasma

Extensive interactions among IO and DAs to finalize revised baseline schedule proposal

- ✓ Schedule and resource estimates through First Plasma (2025) consistent with Members' budget constraints
- ✓ Proposed use of 4-stage approach through Deuterium-Tritium (2035) consistent with Members' financial and technical constraints

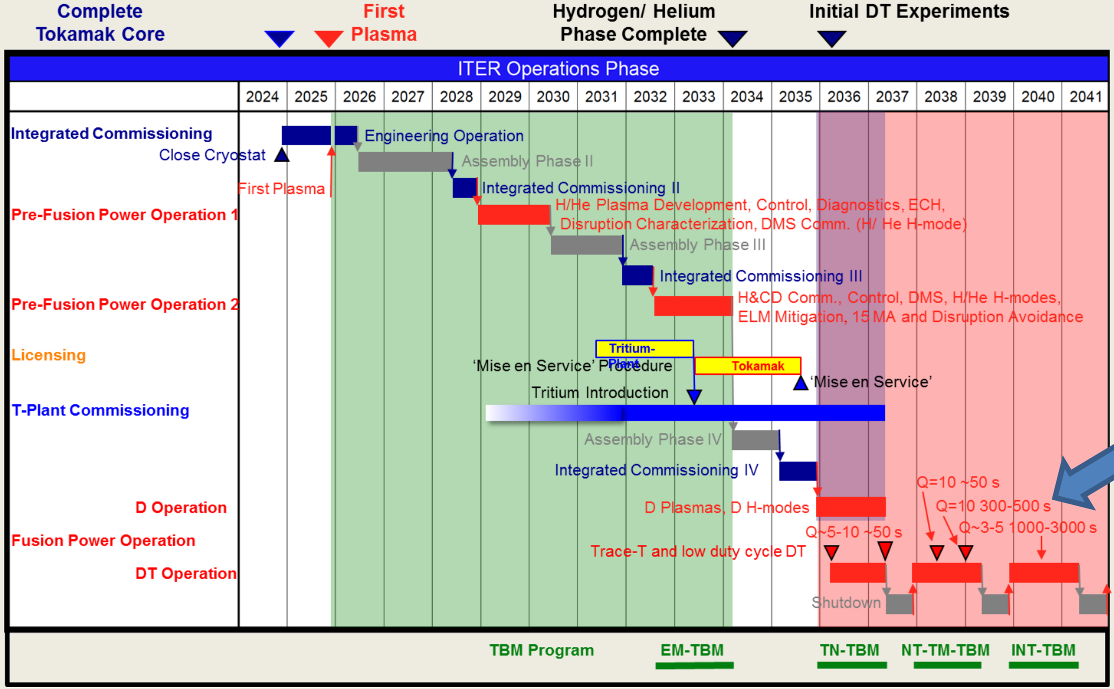


Progress on ITER Fusion Science since IAEA-FEC 2016

- ❑ Elaboration of ITER Research Plan within Staged Approach
- ❑ Revised strategy for development of Disruption Mitigation System
- ❑ Progress on R&D to support planning of ITER operations
  - ➢ 5 MA / 1.8 T H-mode plasma operation in PFPO-1
  - ➢ Development of Integrated Modelling & Analysis Suite (IMAS) and creation of Scenario Database
  - ➢ Optimization of ELM control in ITER scenarios
  - ➢ Revision of Divertor heat flux limits
  - ➢ Development of First Wall heat flux control schemes

ITER Research Plan (IRP) within Staged Approach

- ❑ IRP developed from First Plasma through to achievement of Project’s goals: Q = 10 (300-500 s), Q = 5 (1000 s) & Q = 5 steady-state
- ❑ R&D supported by available systems in each phase of Staged Approach



Full fusion power

Release of ITER Research Plan as ITER Technical Report

- ❑ Elaboration of ITER Research Plan (IRP) → supported by experts from ITER Members' fusion R&D institutions and DAs → recommendation by IC-STAC

- ❑ IRP made publicly available as ITER Technical Report ITR-18-003 for first time since ITER Organization established

- ❑ IRP informs fusion community on details of experimental plans to achieve project's goals → definition of required supporting R&D programmes


ITER TECHNICAL REPORT

iter
china eu india japan korea russia usa

REPORT NO.
ITR-18-003

TITLE
ITER Research Plan within the Staged Approach (Level III – Provisional Version)

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DATE
17th September 2018

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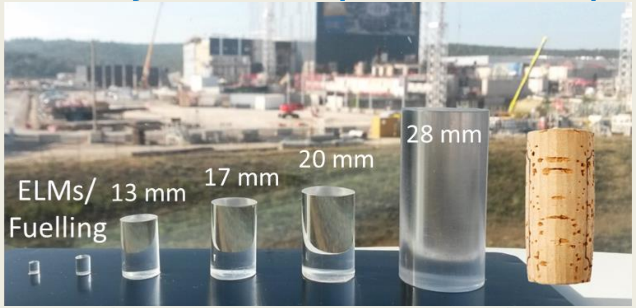
Disruption Mitigation System (DMS)

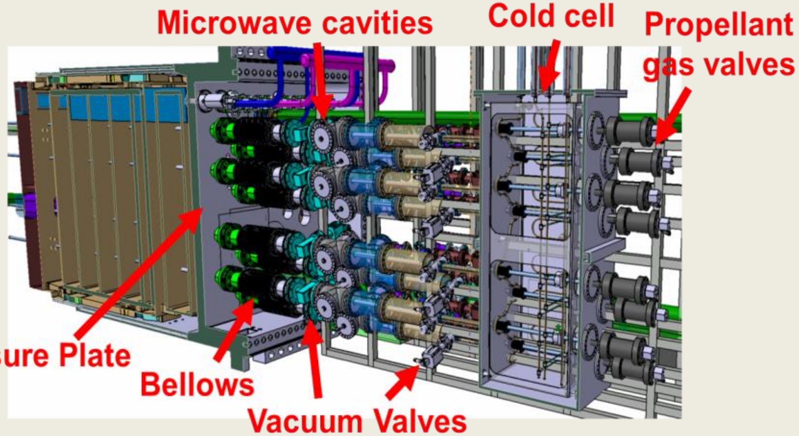
The DMS is a key plant system for ITER to achieve its goals

Increase of injection capabilities in preparation:



Ne, Ar, D_2

Lehnen
EX/P7-12



≤ 32 x 28 mm pellets in 3 equatorial ports
3 x 13-20 mm pellets in 3 upper ports

ITER DMS Task Force – Implementation of <u>design validation</u> and <u>engineering studies</u>

- Scientific validation (experiment and theory) of DMS requirements → in progress
- Technology development to ensure required DMS reliability → in progress
- Studies to address future upgrades or alternative approaches

Scientific validation of DMS requirements

Baseline concept:

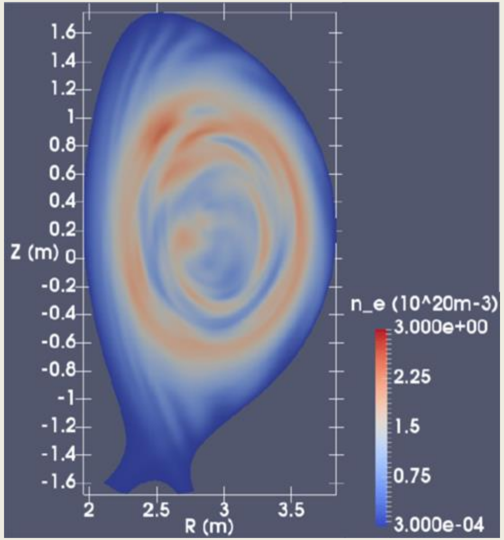
- ***dissipating thermal and magnetic energy*** → radiation
- ***preventing runaway electron formation*** → increasing plasma density

Baseline technique:

- *injection of* ***Ne***, ***Ar*** *and* ***D_2*** *through* ***Shattered Pellet Injection***

Most urgent issues to be addressed:

- Confirm concept of multiple injections by experiment (needed to inject material in ITER)
- Identify most effective pellet fragment sizes
- Assess concept of runaway electron avoidance and runaway energy dissipation



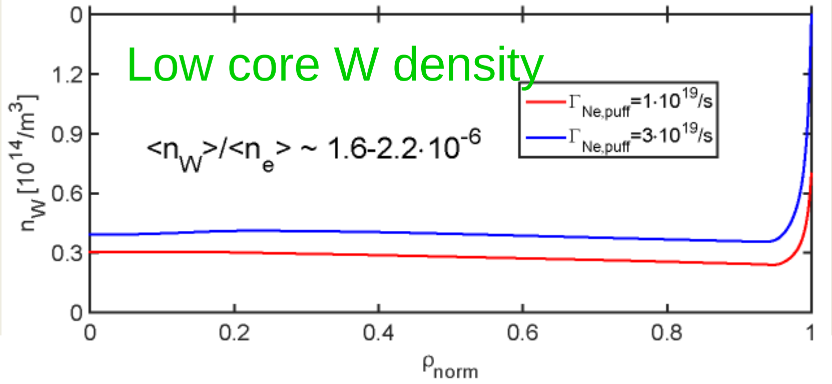
3D MHD JOREK SPI simulation of JET :

Density distribution at thermal quench is critical for runaway electron avoidance

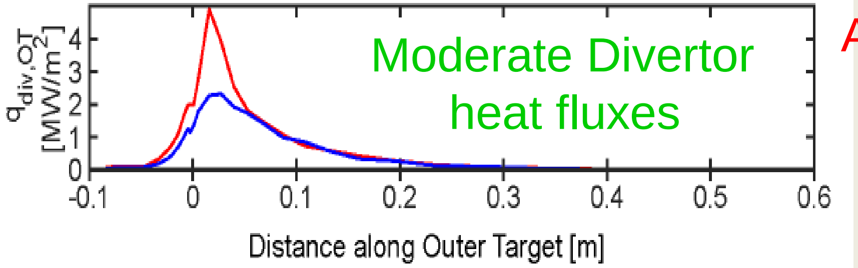
Hu, Nucl. Fusion 2018 (accepted)

Assessment of 5 MA / 1.8 T H-mode plasma operation in PFPO-1

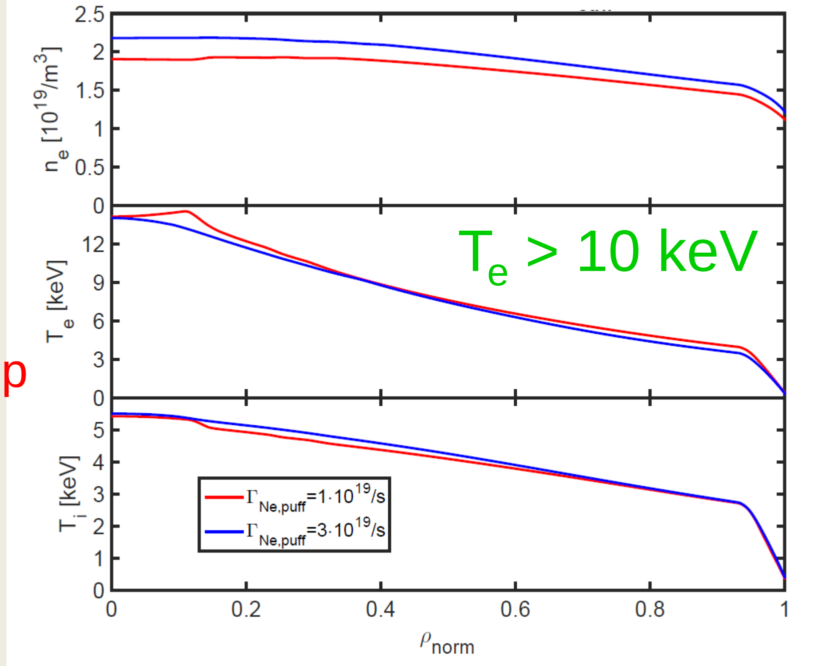
- 5 MA / 1.8 T allows H-mode access in PFPO-1 → risk reduction for later operation
- No outstanding physics/operational issues for 5 MA/1.8T plasmas:
  - ECH heating with good absorption (3rd harmonic)
  - Electron temperatures > 10 keV with low plasma tungsten content



Schneider TH/6-1

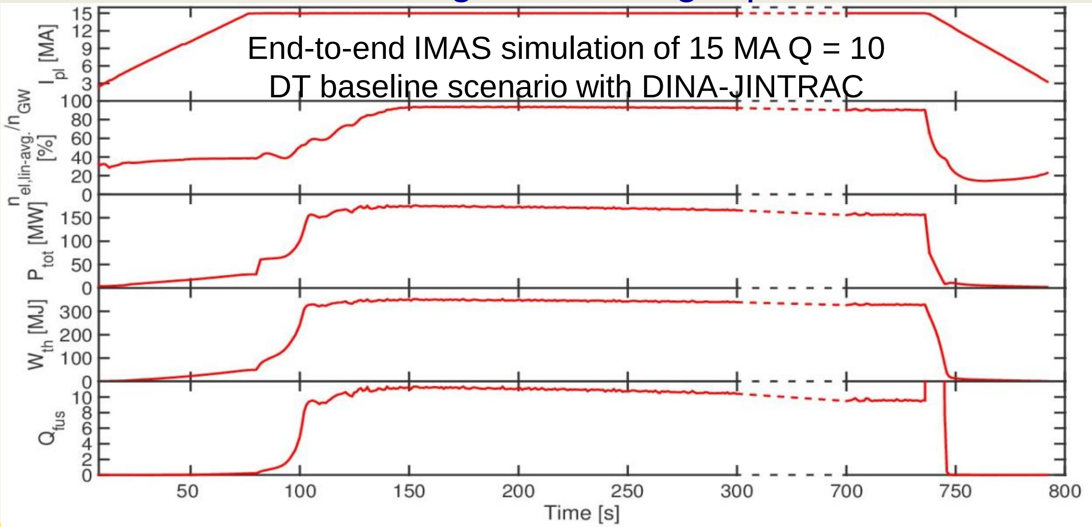


Militello-Asp APS 2018



Development of Integrated Modelling & Analysis Suite (IMAS) and Scenario Database

- First high fidelity IMAS simulations of 15 MA / 5.3 T Q = 10 DT baseline scenarios including core – edge - divertor evolution respecting principal engineering limitations
  - Optimization of scenario and control schemes for plasma shape control, current induction, heating, fuelling and seeding actuators
- IMAS Scenario Database set up and populated with simulations representing all stages of the ITER Research Plan (currently over 110 entries)
  - Support to joint activities such as diagnostic design, performance assessments, etc.



Köchl EX/P7-25
Pinches TH/P6-7

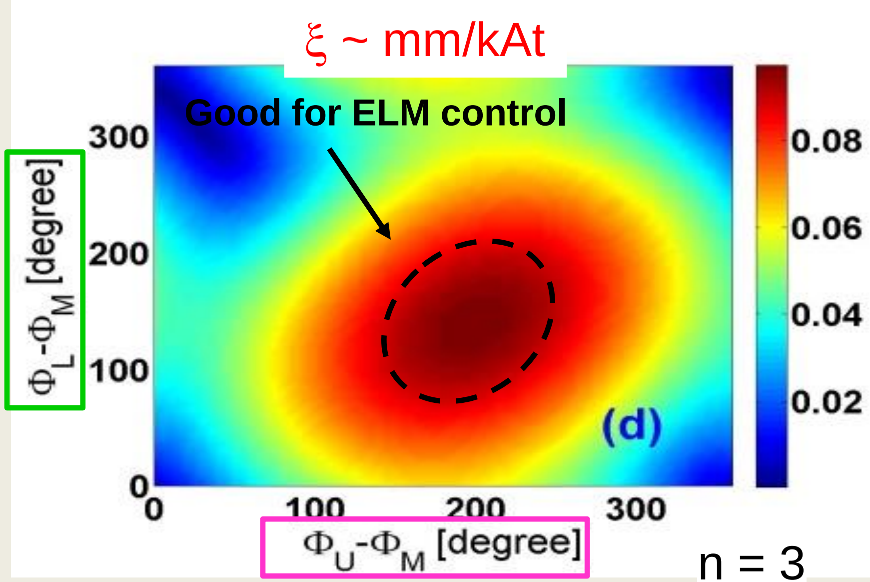
Optimization of ELM control in ITER

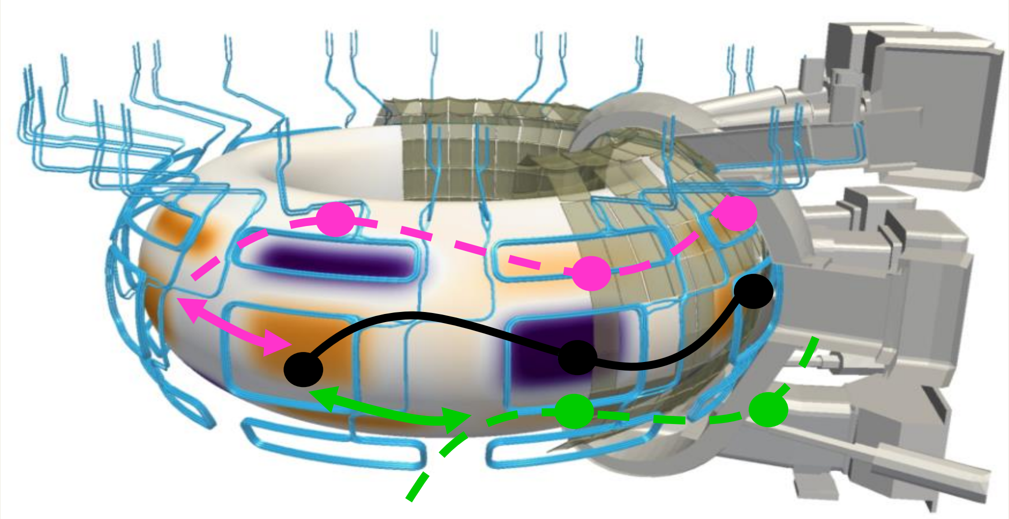
- MagnetoHydroDynamic simulations → optimization of current waveforms in ELM control coils performed under ITER Scientist Fellow Network (ISFN) work programme
- Optimization → maximum ELM control potential (X-point deformation, ξ) with minimum detrimental effects (slowing down of plasma rotation)

Li & Liu TH/P1-7

ITER ELM control coils

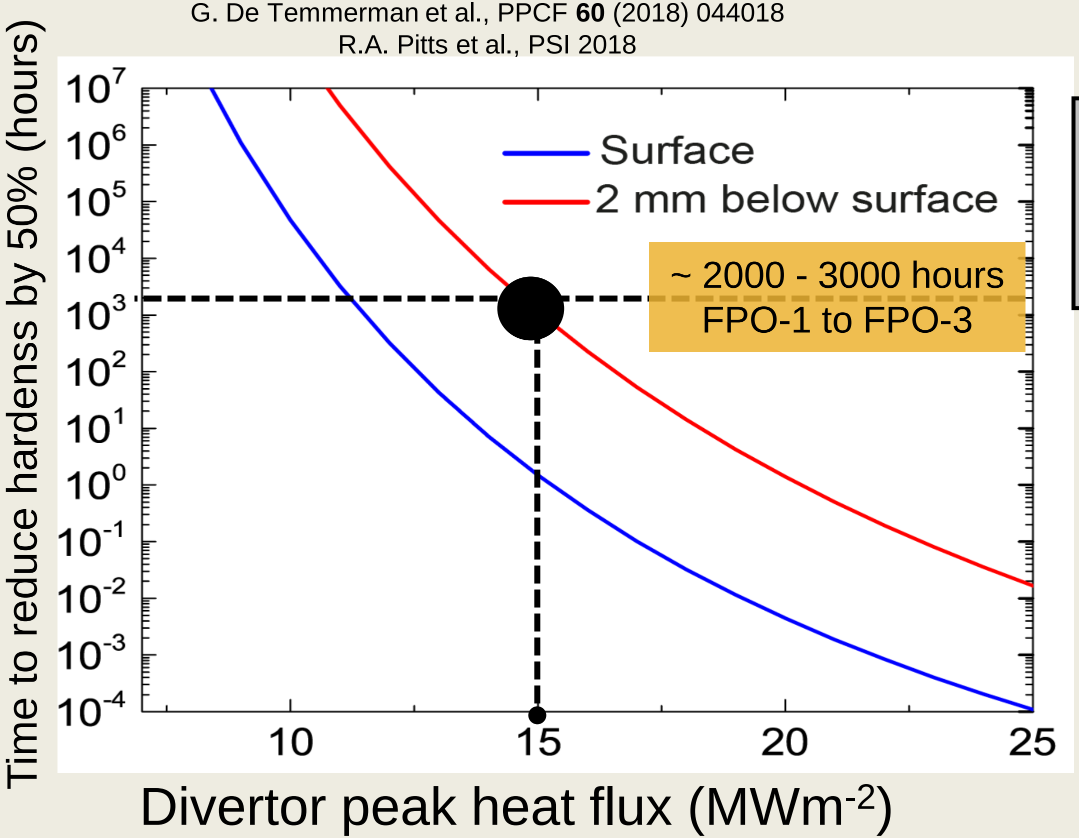
I_{coil}^{max} = 90 kAt

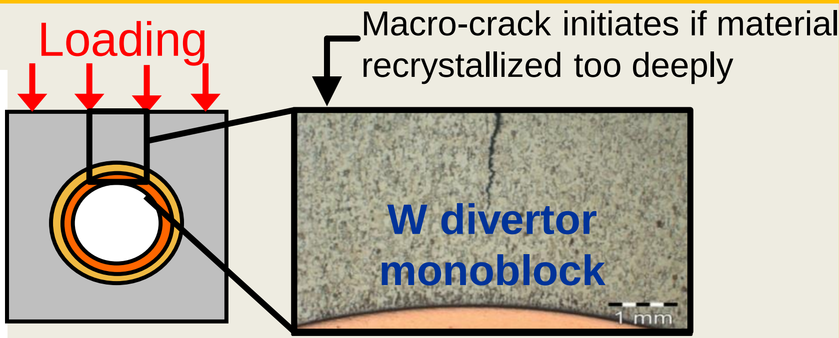




Revised divertor steady state heat flux limit

G. De Temmerman et al., PPCF **60** (2018) 044018
R.A. Pitts et al., PSI 2018



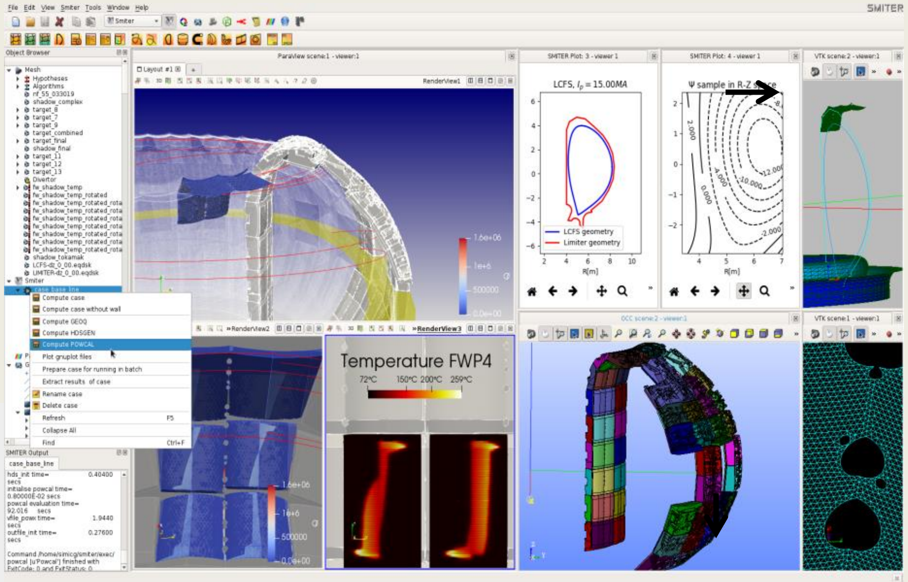


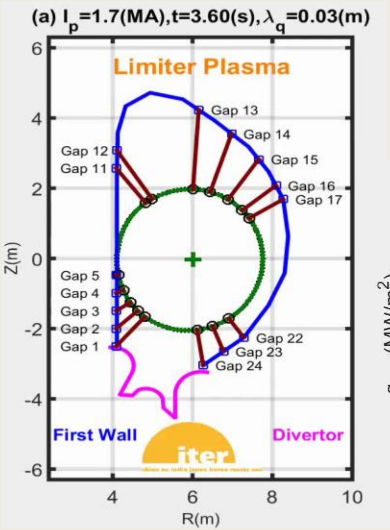
- New "Operational Budget" for peak divertor heat flux → time for hardness to drop (due to recrystallization) by 50% at given depth below W surface
  - Gives $q_{peak,target}$ ≲ **15 MWm^{-2}** for first ITER divertor up to end of FPO-3
  - Increased margin wrt. the previous limit of 10 MWm^{-2}

ITER First Wall heat flux control development

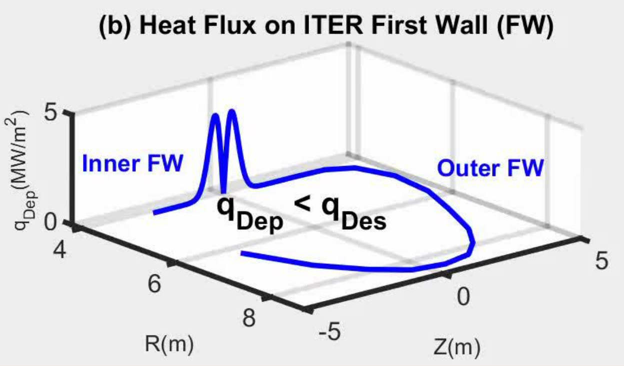
- Heat flux on first wall panels needs to be controlled from early IRP phases
- New algorithm combines **off-line 3D field line tracing** and **2D real-time heat flux estimation** for control system

SMITER incorporated in IMAS





ITER Start-up
Heat fluxes



Cross-calibration using SMITER

Work performed under Monaco postdoctoral programme

Anand EX/P7-24

Challenges ahead for ITER until construction completion

- ITER Organization, Domestic Agencies and suppliers working as "**One-ITER Team**" with a strong project culture
- Strict respect by suppliers for **quality and safety** requirements
- Strict respect by all stakeholders for the **schedule requirements**, in particular for the **required delivery dates** for materials and equipment on the ITER site
- Reliable and fully **integrated assembly/construction sequences** on ITER site
- Contracting with high performing and experienced companies for the **assembly activities** in the Tokamak Complex
- Setting in place a well-suited organization in charge of **commissioning**
- Setting in place a well-suited organization to conceive and execute the **progressive take-over of the machine**, ultimately for its operation and maintenance
- **Timely, reliable availability of the planned and committed resources from the seven ITER Members**

ITER is moving forward!

http://www.iter.org