ITER: progress toward Assembly and Commissioning

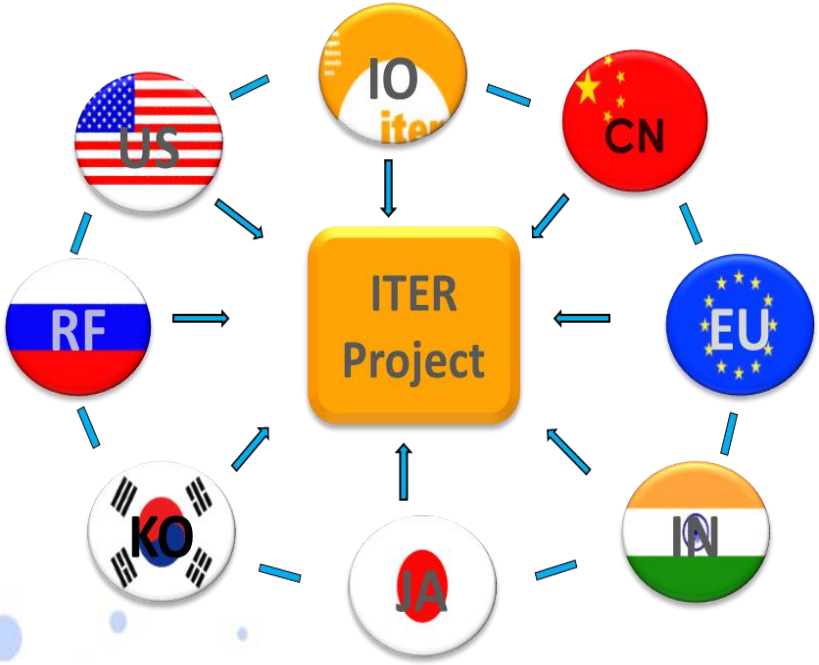
Bernard Bigot
Director General
ITER Organization

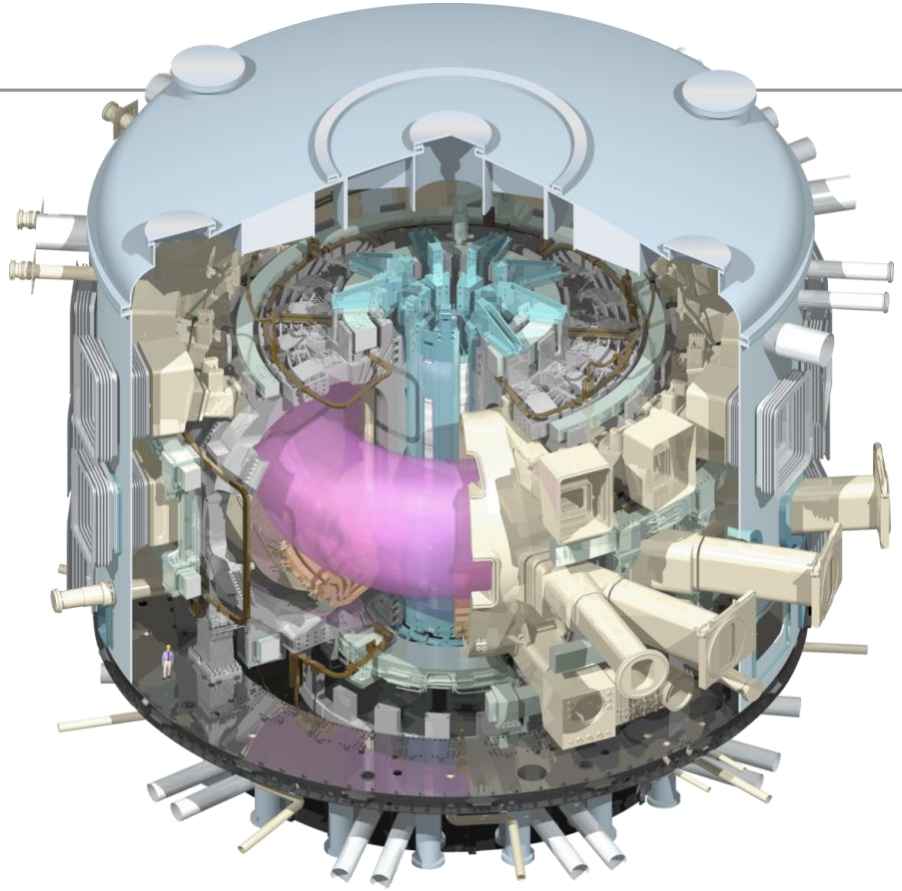
Outline

- Update on Project Status since IAEA FEC 2018
- Progress on Machine Assembly
- Progress Infrastructure Plant Systems and Commissioning
- Progress on construction of remaining ITER components and systems for First Plasma
- Consolidation of ITER Research Plan
- Steps ahead for First Plasma
- Conclusions

ITER mission

- To demonstrate the scientific and technological feasibility of fusion power for peaceful purposes
- ITER is a tokamak that will demonstrate conditions required to produce a burning plasma





Project specifications:

- ✓ Q ≥10 at 500 MW, 400 seconds
- ✓ Q = 5 in principle at steady state
- ✓ Demonstrate the technologies needed for a fusion power plant

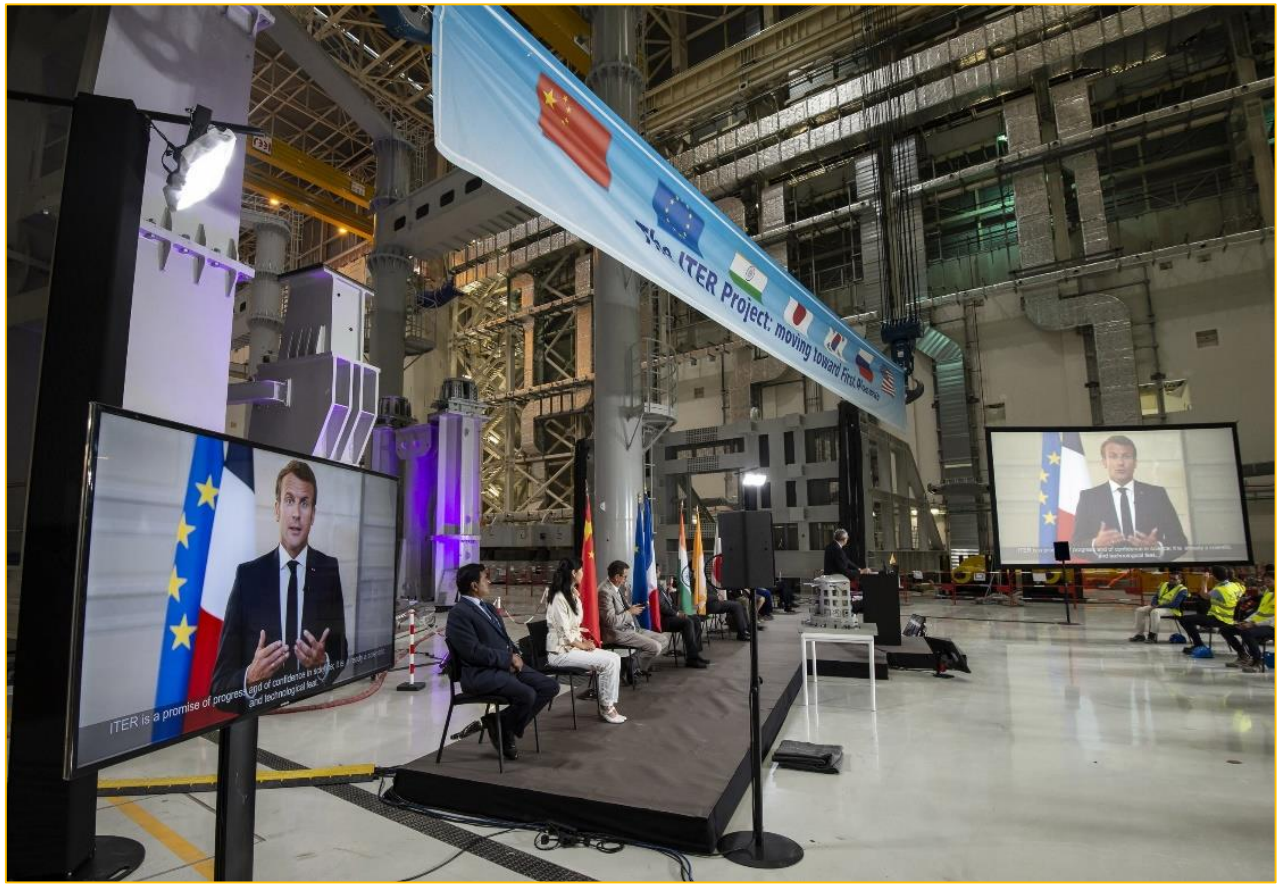
Update on Project Status since FEC 2018

- Many First-of-a-Kind core tokamak components successfully manufactured and delivered
  - Magnets: 7 Toroidal Field coils, 2 Poloidal Field coils
  - First vacuum vessel sector; 3 Cryostat sections; 10 VV Thermal Shield sections; 12 Feeders,…
- Many major aspects of progress on Buildings & Plant Systems

October 2018

November 2020

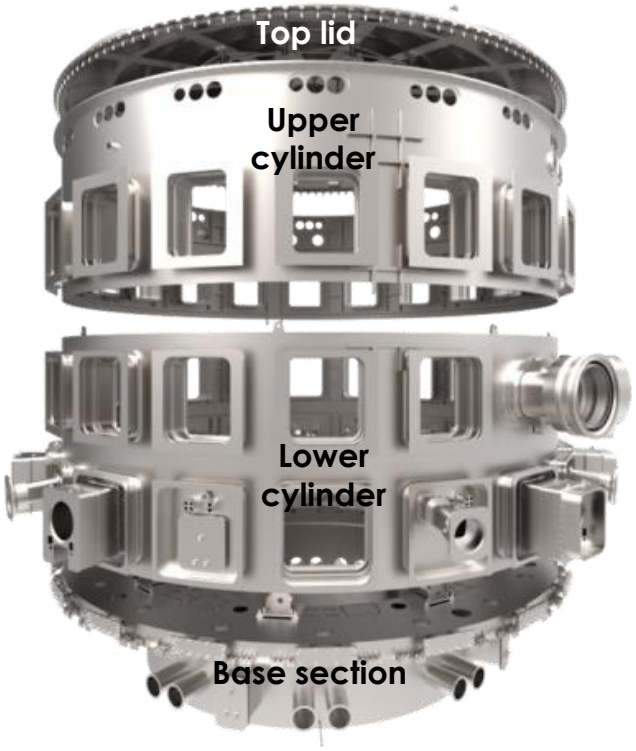
Progress on Machine Assembly

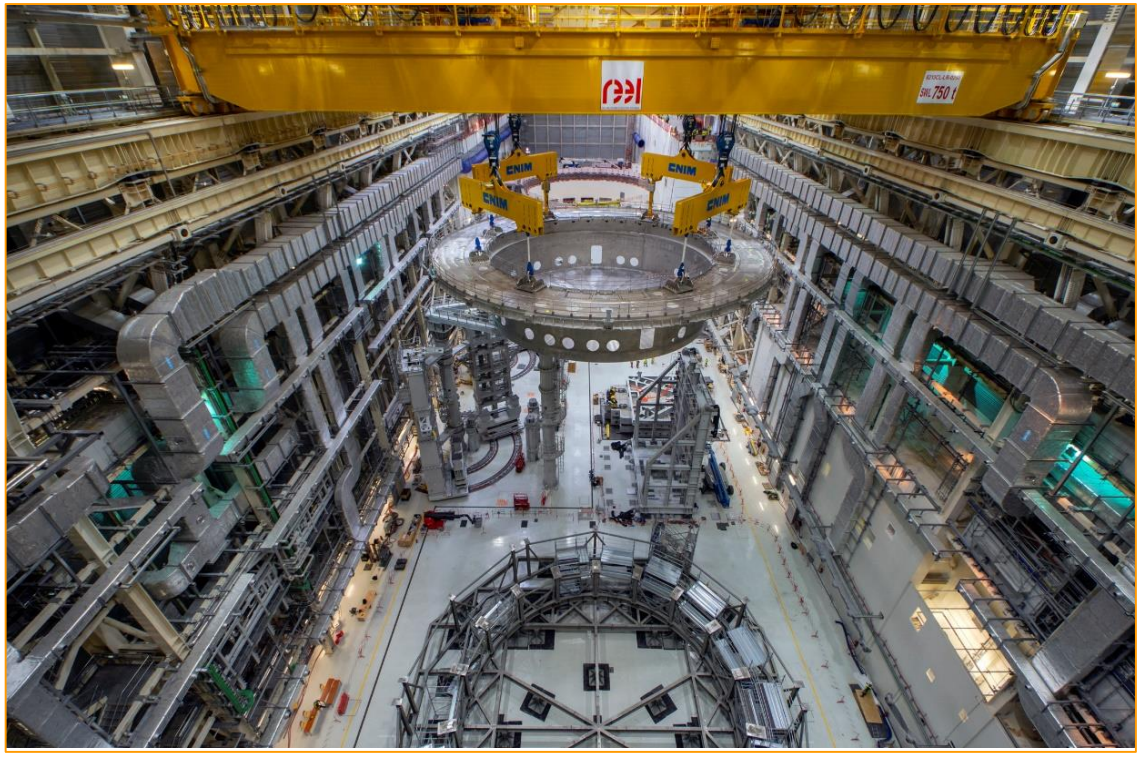


28 July 2020: remote celebration by 7 ITER Members Heads of State and French President Macron

Cryostat base

- 3 out of 4 cryostat sections manufactured and two already installed in the tokamak pit; top lid under assembly on site
- Cryostat base (~ 1250 tonnes, 30 metres diameter) → heaviest ITER component rests on 18 bearings

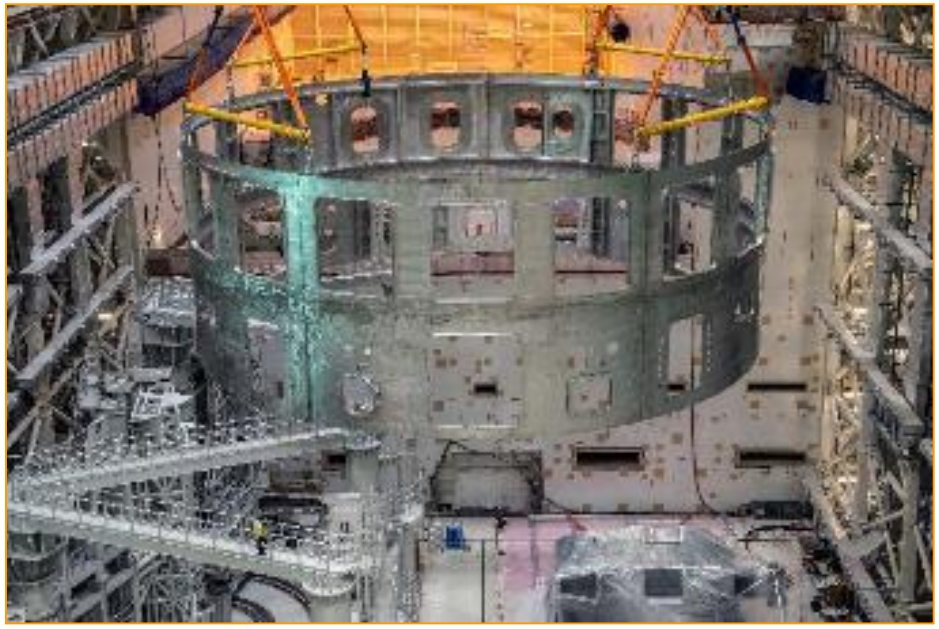




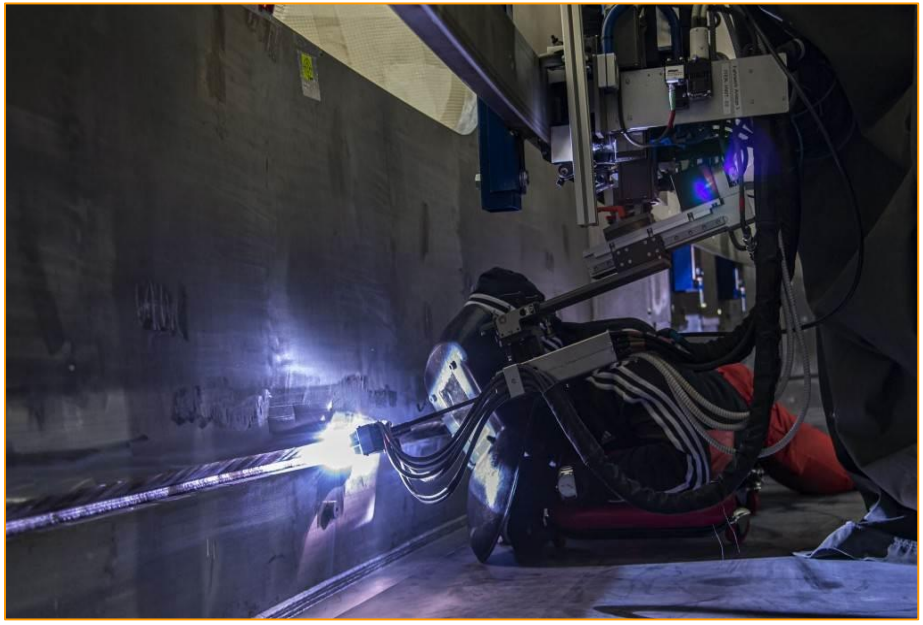
May 2020: lift and installation of Cryostat Base

Cryostat lower cylinder

- Cryostat lower cylinder (10 metres high, 30 metres in diameter) installed
- In-pit welding of lower cryostat lower cylinder to base is completed



September 2020: Lower Cylinder lift and installation



Q4 2020 – Q1 2021: welding base to lower cylinder

Vacuum Vessel delivery and pre-assembly

- Vacuum Vessel Sector 6 completed in April 2020, arrived at ITER site in August 2020

VVS6 ready to ship: June 2020

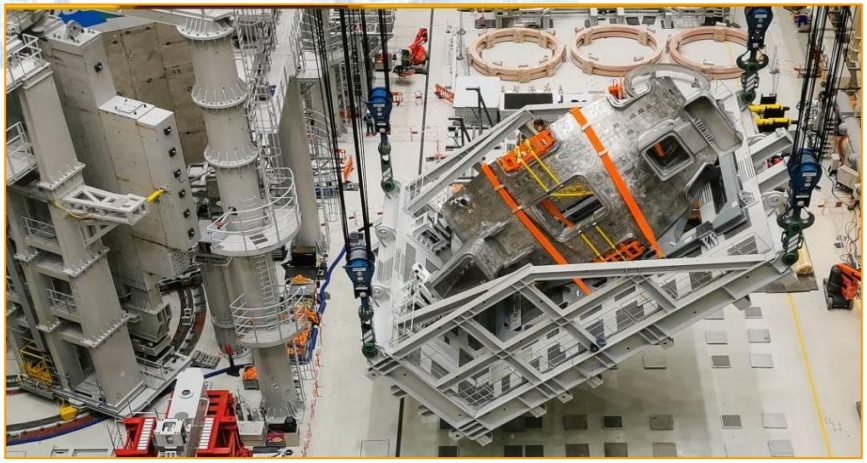
Arrival at ITER site: August 2020

Helium Leak Test: September 2020

Installation of threaded inserts: November 2020

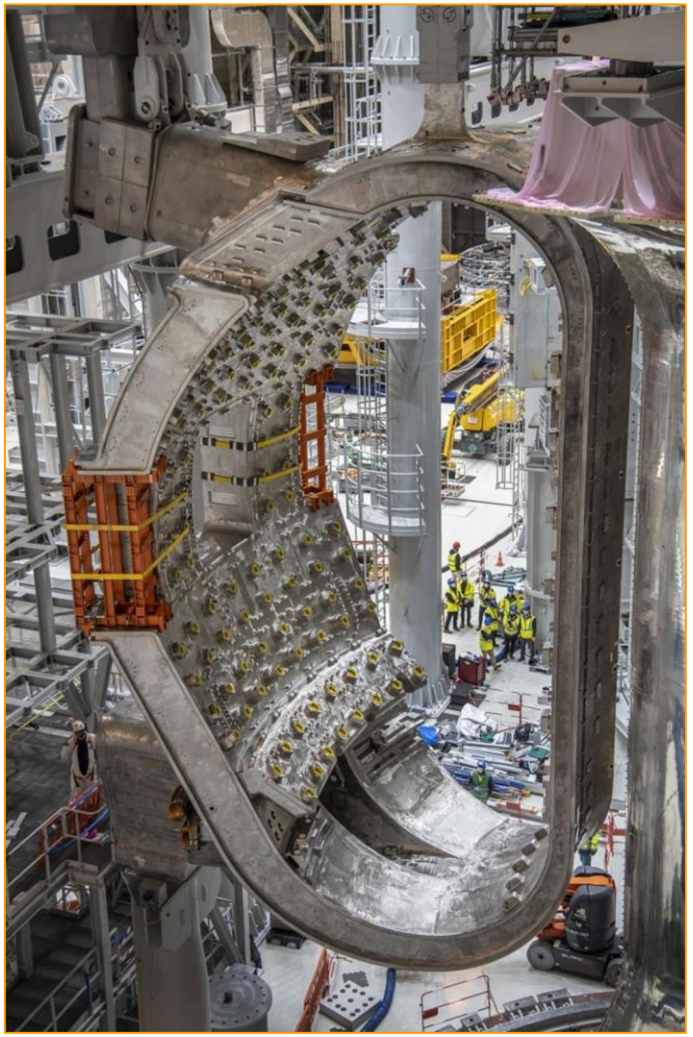
Beginning first sub-sector assembly

- VV Sector 6 positioned in SSAT (March-April 2021)



Up-ending VV Sector 6 with special tool

VVS6 lifted into the sector sub-assembly tool (SSAT)



Final position in the SSAT

Toroidal Field Coils – 1

- Seven Toroidal Field coils delivered between April 2020 and May 2021, from Japan and Europe (Italy)

TF09 – April 2020

TF12 – April 2020

TF13 – July 2020

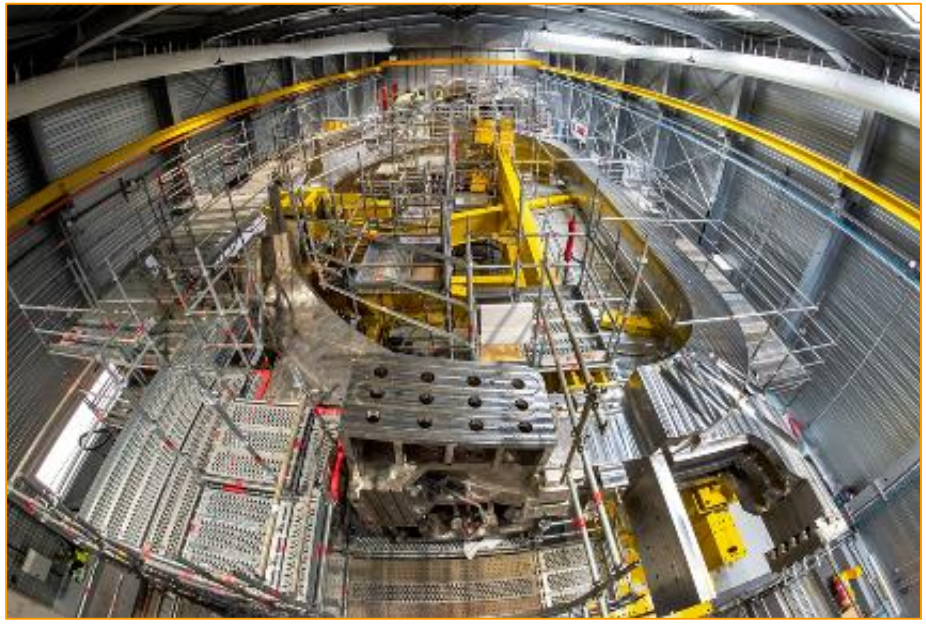
TF11 – September 2020

TF05 – December 2020

TF08 – March 2021

Toroidal Field Coils – 2

- Work to prepare first 2 TF coils for incorporation into pre-assembly is completed: includes local machining, assembly of external cooling piping, and instrumentation interfaces



TF12 and TF13 under preparation for pre-assembly

Preparation for Instrumentation of terminal region

Poloidal Field Coils

- Two Poloidal Field coils completed and cold tested

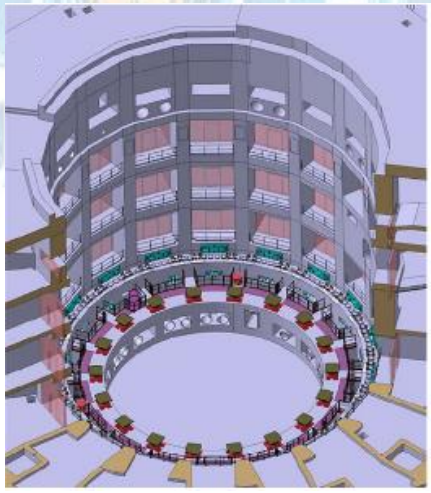
PF6 arrival June 2020

PF5 in final fabrication onsite

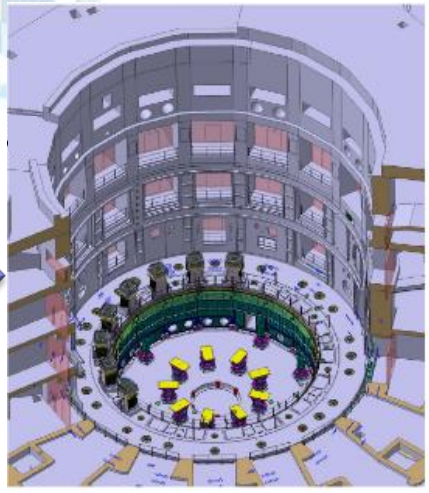
PF6 cold test November 2020

PF5 cold test February 2021

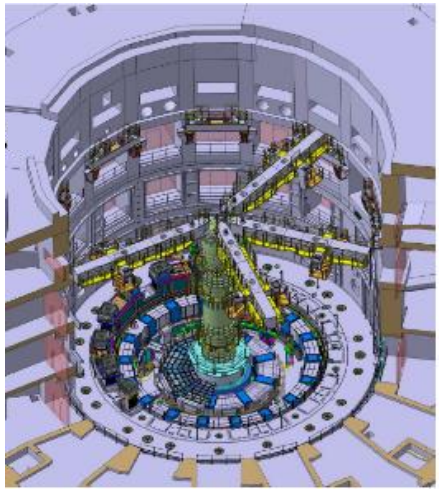
In-pit installation work - 1



May 2020



March 2021



Summer 2021

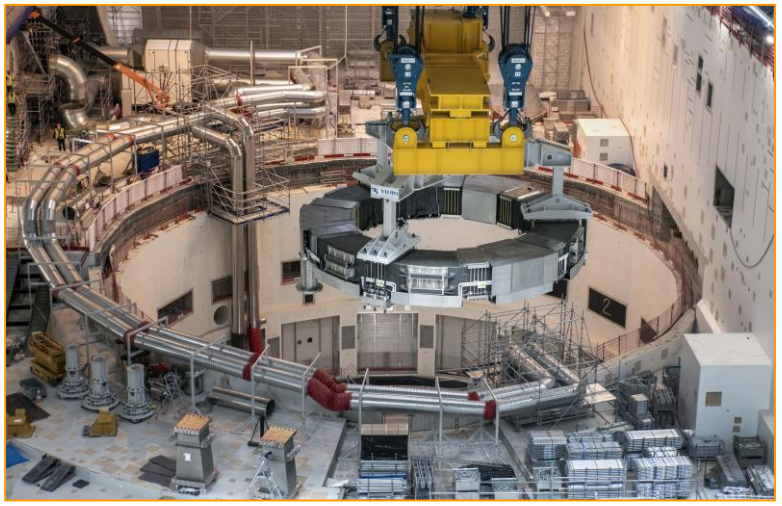
Pit Ready for VV Sector6

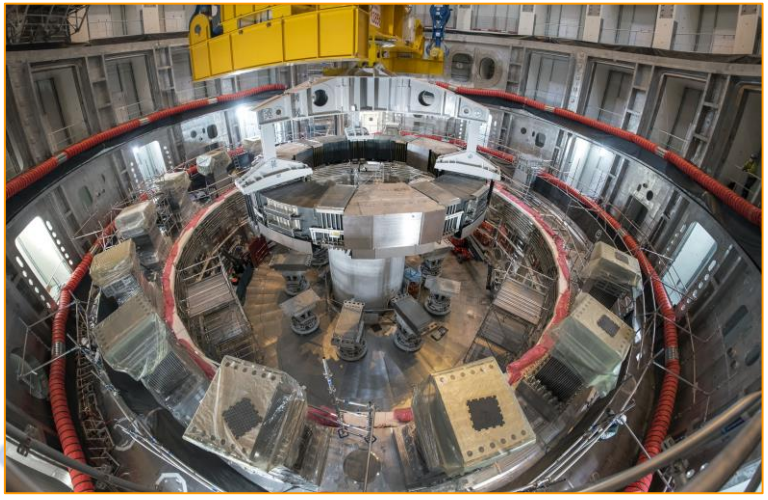
Completed as of 4/21

- ✓ Cryostat Base
- ✓ Lower Cryostat Cylinder
- ✓ Welding of base to cylinder
- ✓ Neutron Flux Monitor Tubes
- ✓ Lower Cylinder Thermal Shield
- ✓ 9 Toroidal Field Coil Gravity Supports
- ✓ PF6 on Temporary Supports

In-pit installation work - 2

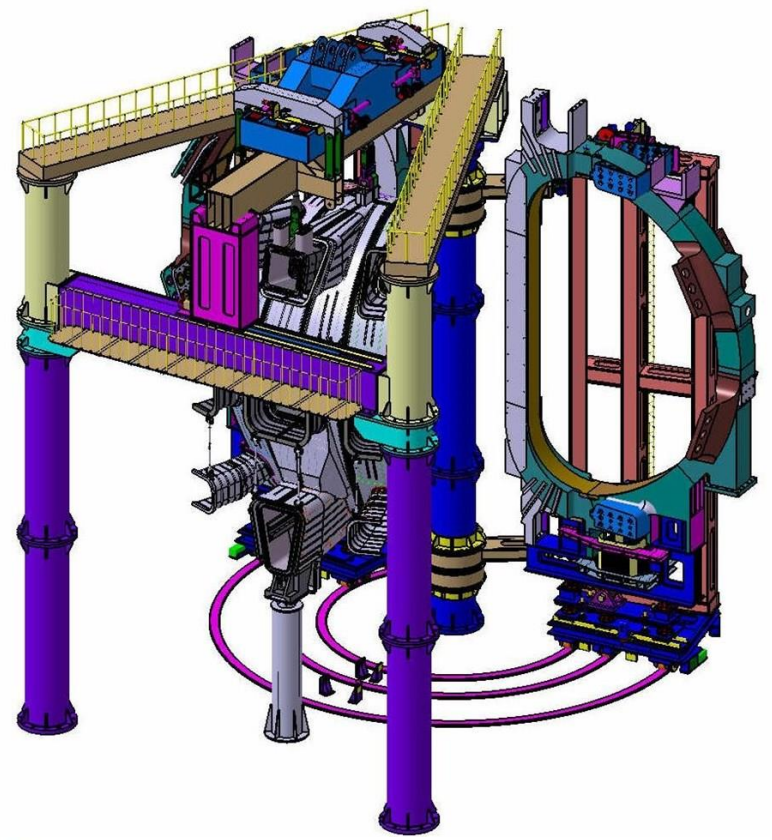
- April 2021: lift and installation of Poloidal Field Coil #6, ITER's first installed superconducting magnet



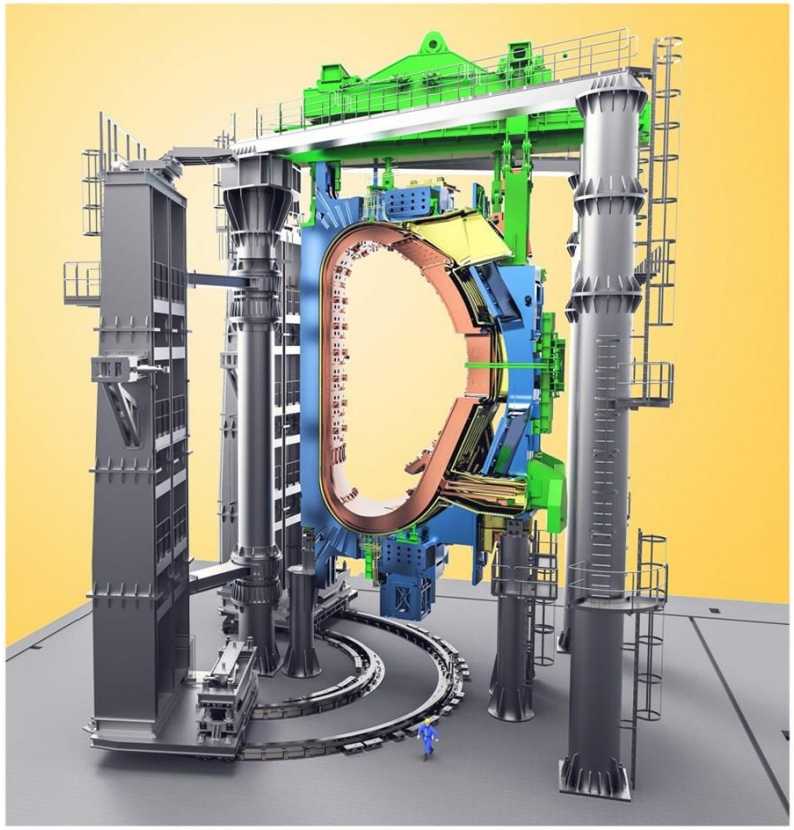


Near-term plans for first sub-sector assembly

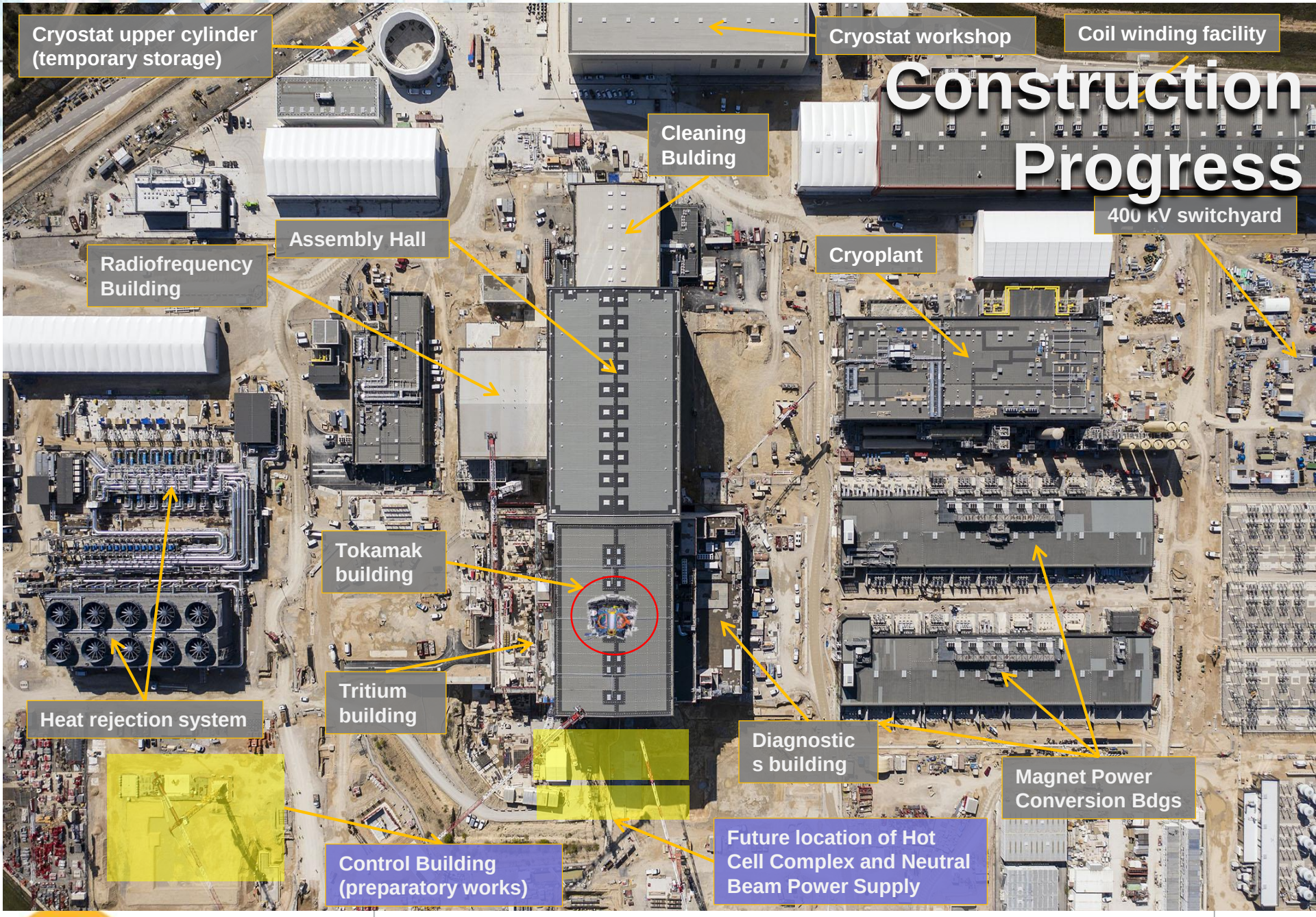
- Assembly of Thermal Shield and Toroidal Field coils
- First finalized sector to be transferred to tokamak pit by October 2021



TF Coil Assembly



Finalized Sector Assembly before transfer to pit


Cryostat upper cylinder (temporary storage)
Cryostat workshop
Coil winding facility
Construction Progress
Cleaning Bulding
400 kV switchyard
Assembly Hall
Radiofrequency Building
Cryoplant
Tokamak building
Tritium building
Heat rejection system
Diagnostic s building
Magnet Power Conversion Bdgs
Control Building (preparatory works)
Future location of Hot Cell Complex and Neutral Beam Power Supply

Completion of tokamak building

- Tokamak building completed and crane hall joined in March 2020: key milestone enabling start of assembly

IAEA FEC 2018

March 2020

Progress on Infrastructure, Plant Systems and Commissioning

October 2020: installation of equipment continues inside and outside of the Magnet Power Conversion Buildings

Infrastructure installation in tokamak building

- Finalization of penetrations and installation of piping networks
- Feeders for superconducting coils transferred to final position

Finalizing penetrations and installing piping networks

TF Coil feeder – part 1
Transferred to gallery Dec 2020

TF Coil feeder – part 2
Transferred to gallery Jan 2021

Plant Systems – Cooling Plant

- Cooling plant commissioning ongoing – began in 2020
  - Chilled water system turned over to Operations
  - Cooling water system turned over to Operations
  - Cooling tower turnover in progress

Plant Systems – Cryogenics plant

- Largest concentrated cryoplant in the world: installed cooling power of 75 kW at 4.5 K (He) and 1300 kW at 80 K (N_2).
- Cryoplant functional tests beginning in 2021

External view of cryogenics plant with storage tanks

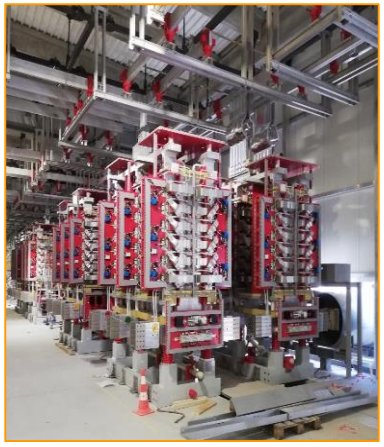
Crypolant compressors

Helium Cold Boxes and Cryoplant Termination Cold Box

Plant systems – Electricity Supply

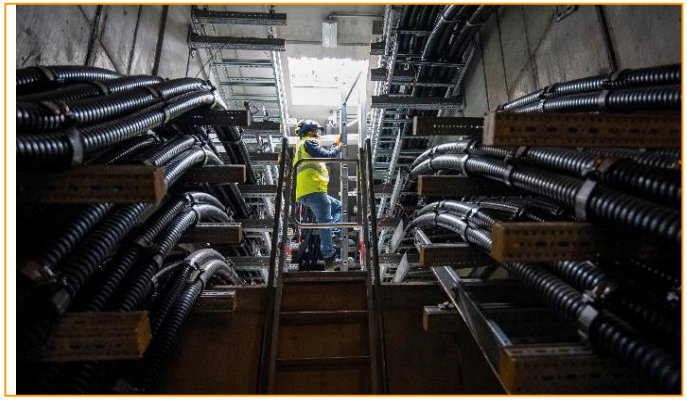
- Direct connection to French 400 kV network – January 2019
- Low and medium voltage load centers completed – end 2020
- 400 kV transformers for pulsed systems connected in 2020
- AC/DC converters and reactive power compensation system functional tests begin in 2022

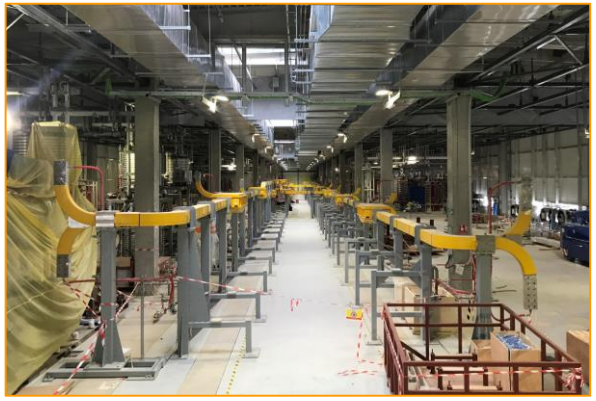
Reactive Power Compensation installation January 2021



Converter bridge of PF3 and AC/DC Converter January 2021

Pulling of 66 kV cables February 2021





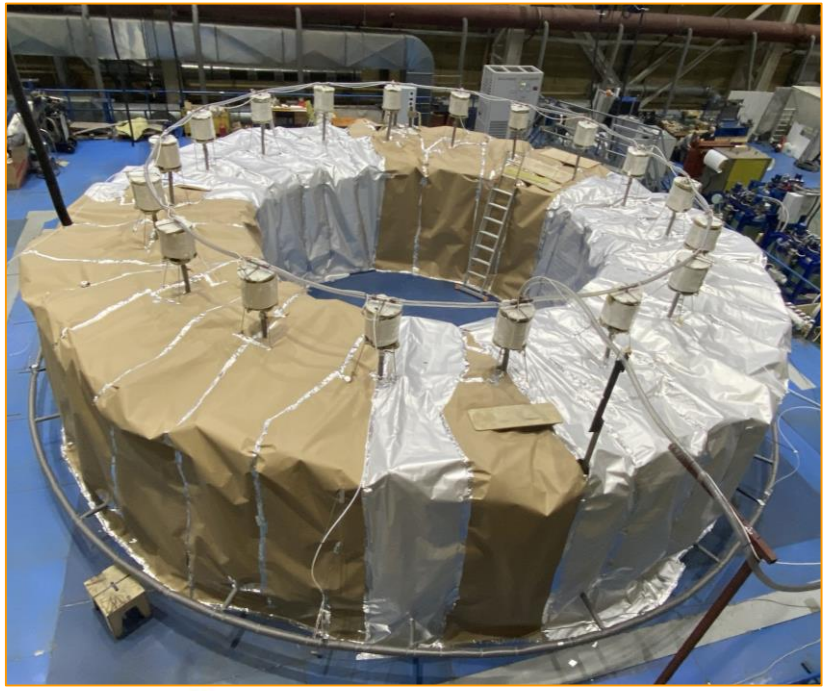
Busbars in power conversion building January 2021

Manufacturing progress on remaining ITER components and systems for First Plasma

Celebration of completed fabrication of all Cryostat Lid elements, June 2020

Toroidal and Poloidal Field coils

- TF coils continuing in series production
- PF1 coil winding pack resin impregnation completed → shipment to ITER site in 2022
- PF2 prepared for testing; PF3 & 4 manufacturing started onsite



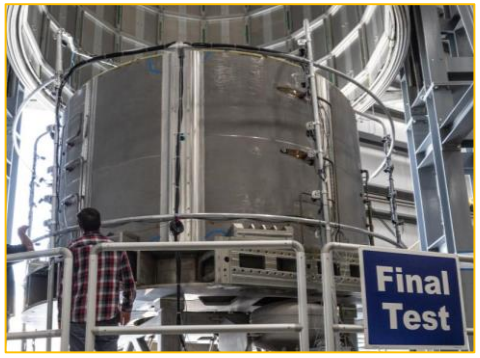
PF1 vacuum impregnation March 2021

Size comparison: PF5 completed (17m) next to PF4 pancake (24m)

Central Solenoid

- CS modules manufacturing now in series production
- CS Module1 has passed acceptance test; CSM2 undergoing tests → both to be shipped to ITER later in 2021
- Preparation for CS assembly tools on-going

CS modules in manufacturing

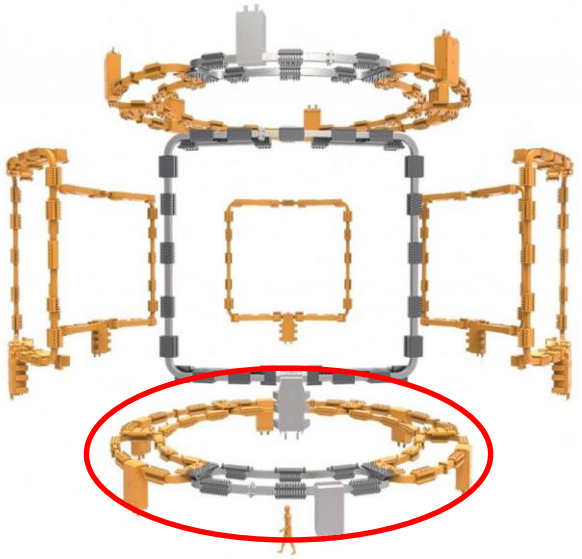


CS Module 1 January 2021

CS Module Lifting fixture

Correction Coils

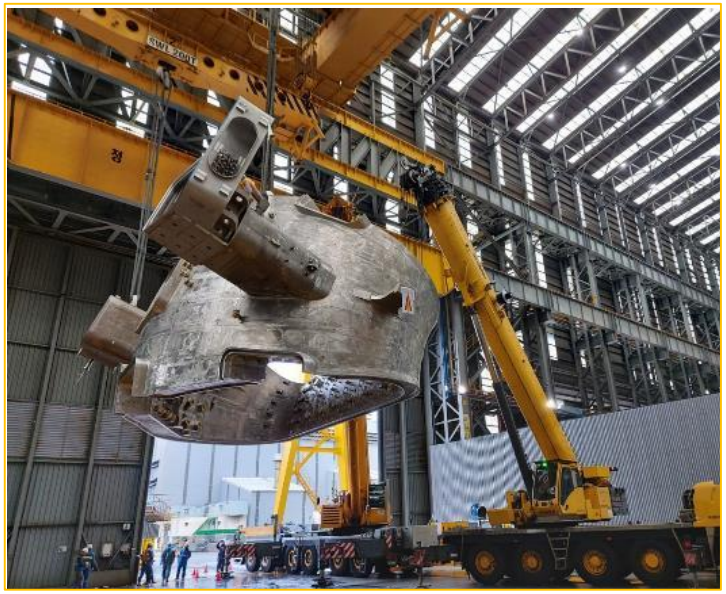
- Six bottom correction coils completed in September 2020
- Manufacturing of remaining 12 correction coils proceeding on schedule



Bottom correction coils completed, September 2020

Vacuum Vessel manufacturing

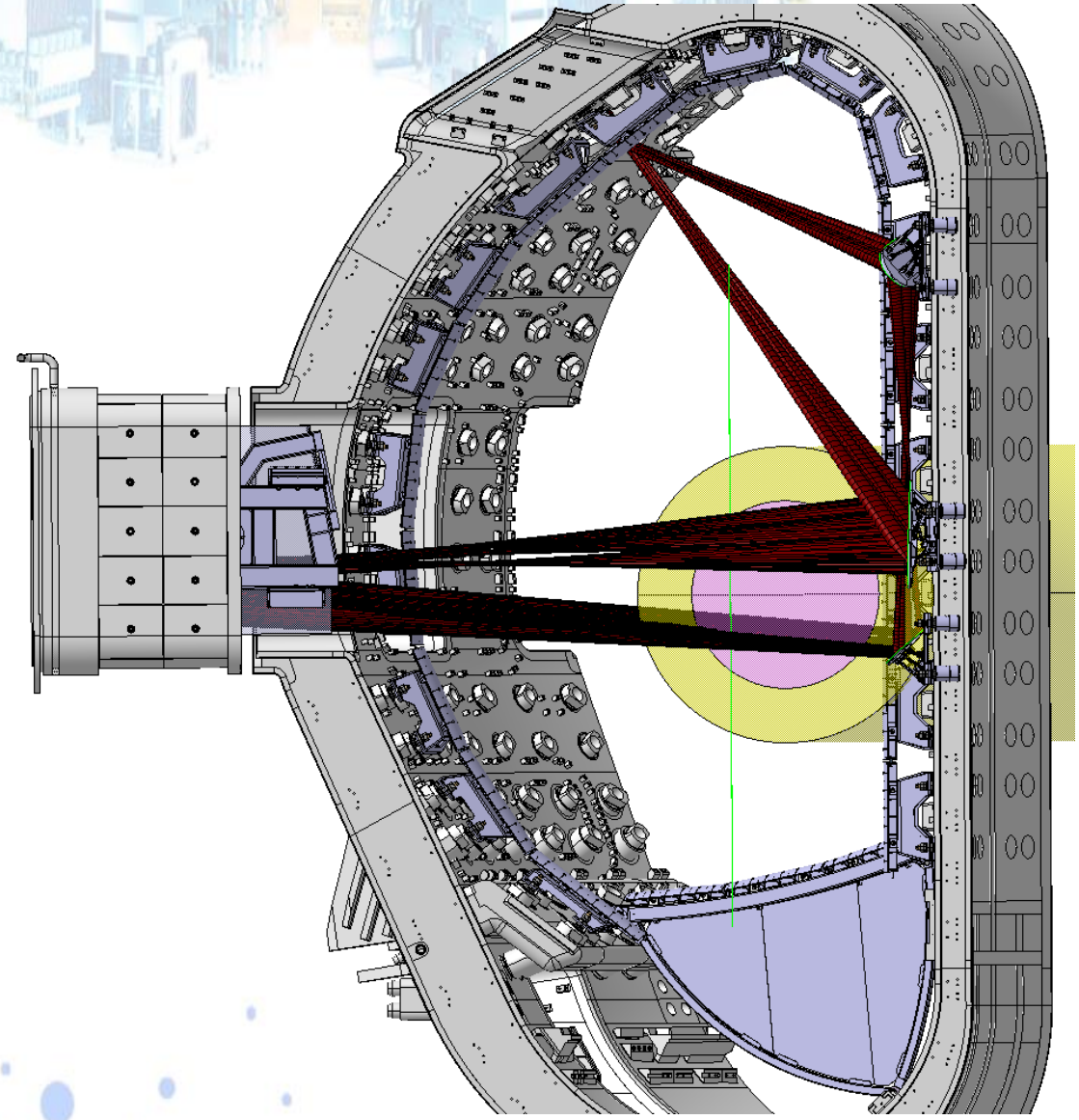
- VV sector 7 completed, to arrive at ITER in coming weeks
- VV sector 5 in final stages of completion (welding of four sections)
- All remaining sectors in advanced stages of manufacturing, but on critical path for First Plasma end of 2025



VV Sector 7
April 2021

Section of VV Sector 5
February 2021

Electron Cyclotron Heating for FP



- Electron Cyclotron Heating system for First Plasma includes 8 gyrotrons at 170 GHz launched from one upper launcher.
- Each gyrotron can inject 0.83 MW.
- To protect in-vessel components before Beryllium blanket and Tungsten divertor are installed, ECH power will be reflected off inner wall mirrors into ECH absorbing beam dump in the opposite equatorial port.

Consolidation of ITER Research Plan

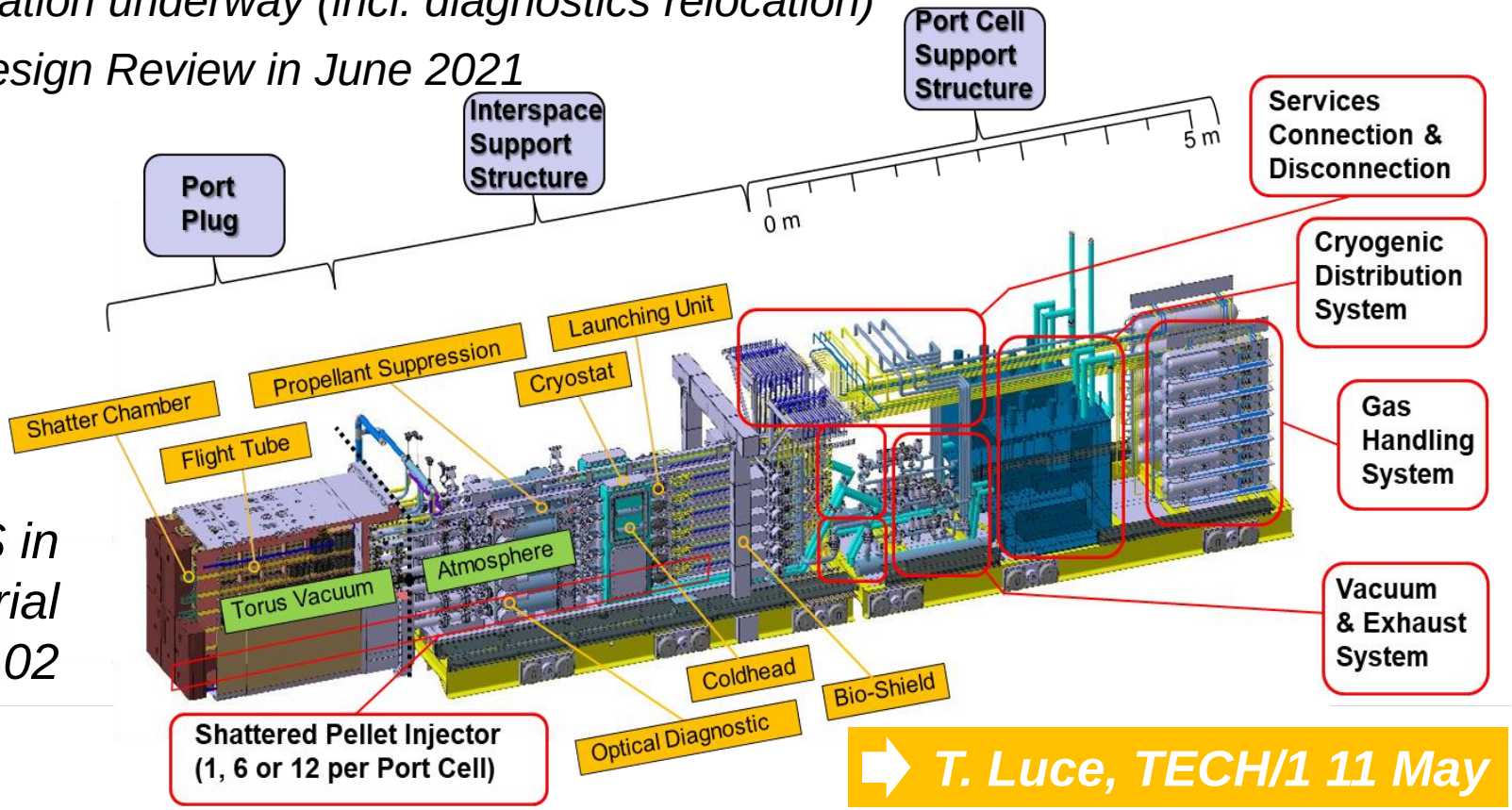
Using augmented reality to visualize complex installation and maintenance operations

ITER Research Plan and Supporting R&D

- ITER Research Plan presented at IAEA FEC 2018 (available as Tech Report (ITR-18-003) → now ITER baseline document
- R&D topics to support effective execution of Research Plan made accessible to fusion community (ITR-20-008) → used to focus R&D programmes (e.g. ITPA)

Disruption Mitigation: *essential for execution of ITER Research Plan*

- In 2018, design solution changed from Massive Gas Injection to Shattered Pellet Injection → significant impact
- Design and integration of Disruption Mitigation System into ITER tokamak and ancillary systems has progressed:
  - *Configuration established with 24 equatorial port injectors + 3 upper port injectors*
  - *Supply network will be installed in 2021*
  - *Port integration underway (incl. diagnostics relocation)*
  - *System Design Review in June 2021*

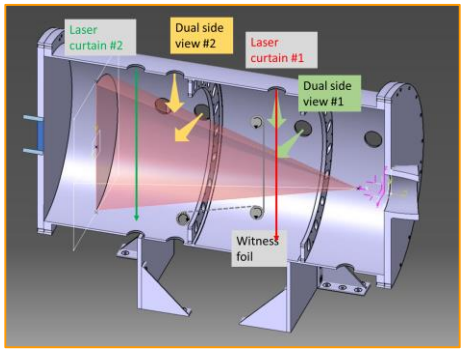


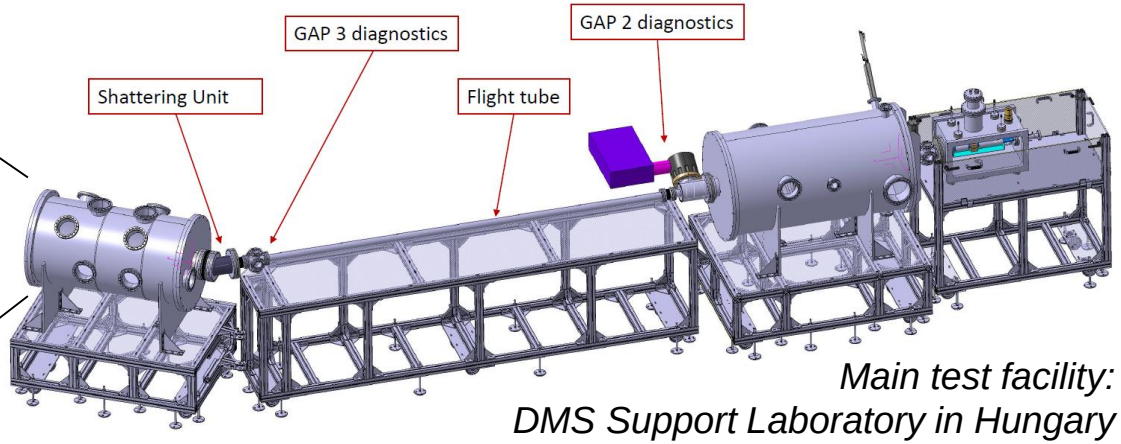
DMS in equatorial port 02

➡ *T. Luce, TECH/1 11 May*

ITER Disruption Mitigation Task Force

- International programme with extensive support from ITER Member institutes
- Engineering studies to develop Shattered Pellet Injection (SPI)
  - Develop, test, and optimize DMS components to ensure reliability in ITER's challenging environment.





Main test facility:
DMS Support Laboratory in Hungary

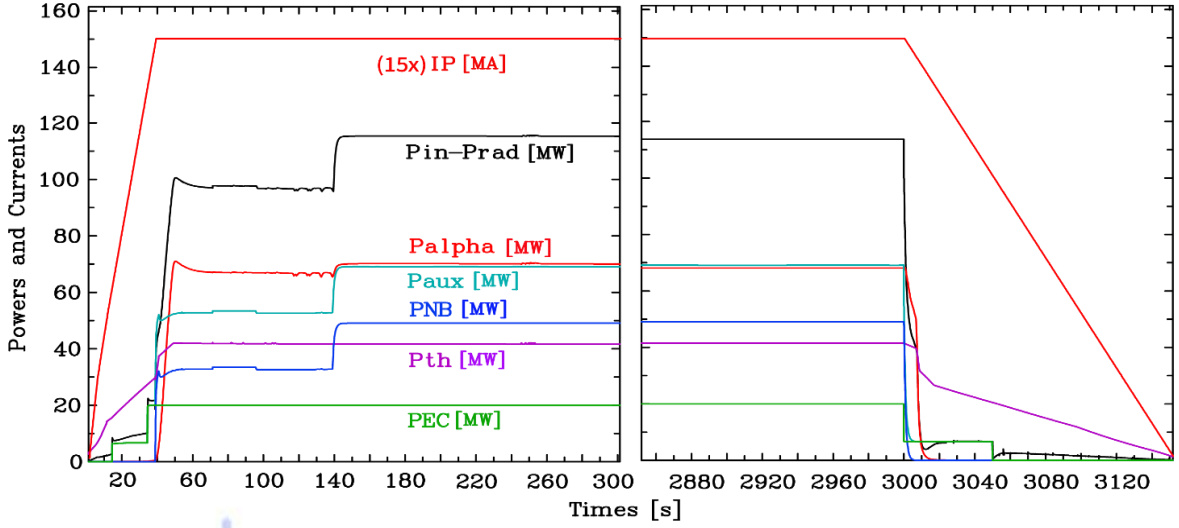
- Design Specification through experiments and modelling
  - SPI experiments are key for model validation and extrapolation to ITER.
  - 5 tokamaks will be providing data by end of 2021 to support modelling.

➡ ***S. Jachmich (JET), E. Nardon (Theory & Modelling), 14 May + 10 contributions related to the ITER DMS R&D***

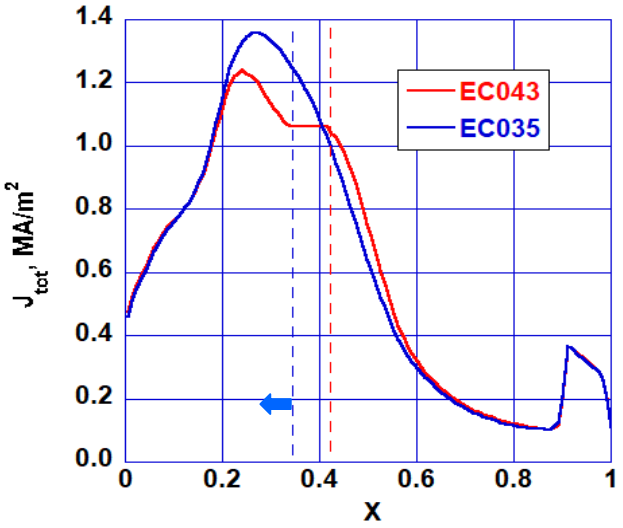
Re-assessment of ITER Q = 5 steady-state

- Q = 5 fully non-inductive steady-state plasmas with NBI and ECH (including upgrades) identified that operate within ideal MHD stability and PF coil system limits
- No advantage provided by Lower Hybrid for such scenarios → Lower Hybrid removed from H&CD upgrade options

➢ **Candidate operation scenario with 3000s of flat-top (10MA/5.3T)**



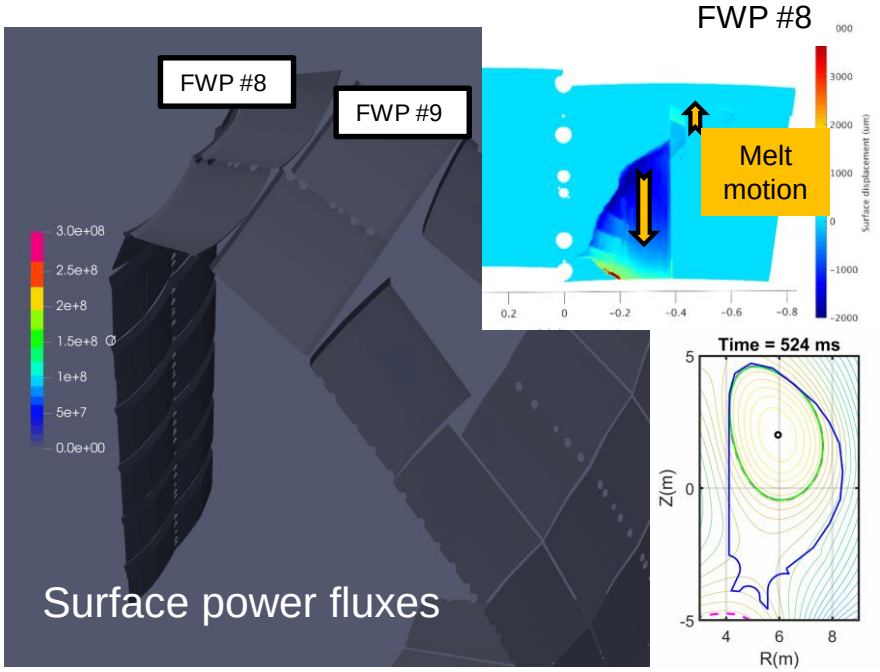
[NF61, S.H. Kim]

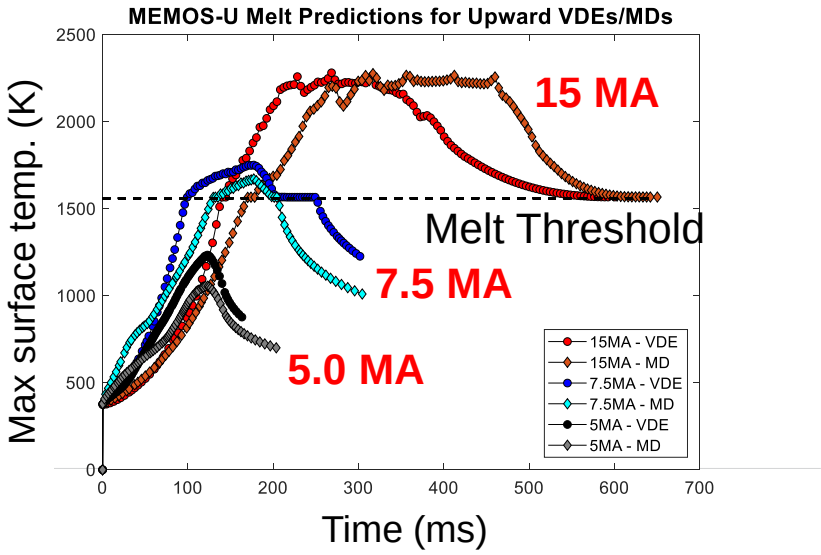


[NF60, A.R. Polevoi]

Improved constraints on DMS for PFC lifetime

- Disruption can melt main chamber ITER's Beryllium First Wall Panels (FWP) above a given magnetic energy
  - Already seen on JET's ITER-Like Wall
- New simulation workflow developed at IO to quantify this for ITER
  - Includes production of extensive new DINA disruption database
- Threshold for FWP melting ~7.0 MA → provide margin to gain DMS operational experience in PFPO-1



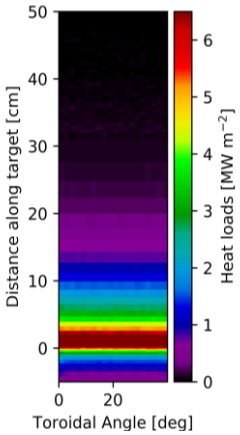


J. Coburn (Monaco Postdoc) TH/7 15 May

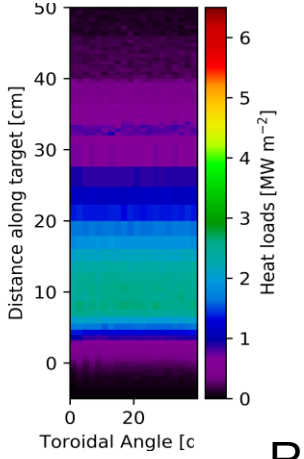
Control of divertor heat flux with RMPs

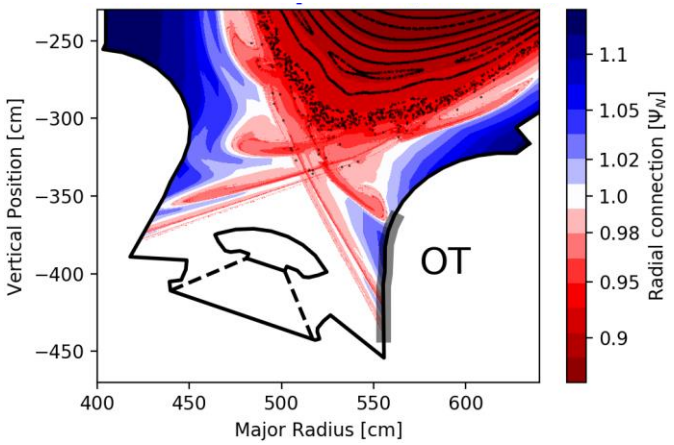
- Transient heat loads from ELMs can damage the divertor if not mitigated
- 3-D magnetic field structure (RMPs) impacts access to high recycling/radiative divertor conditions for off-separatrix lobes → Study by ITER Scientist Fellows
- Optimization of ELM control (e.g. perturbation rotation) and guidance to experiments

Low n_e

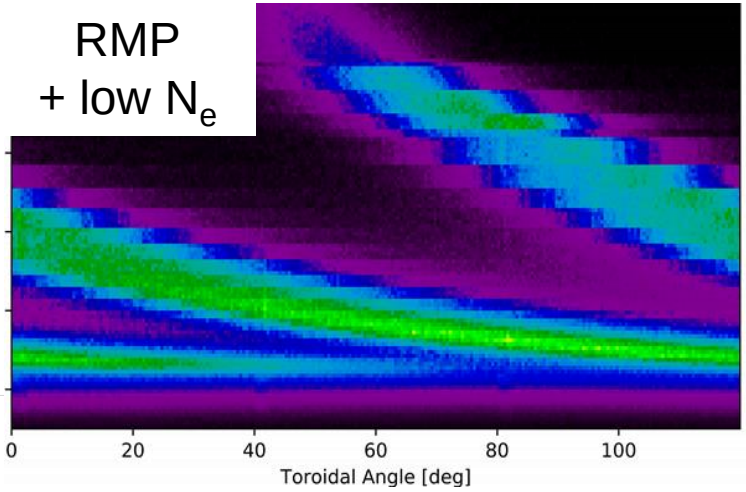


high N_e





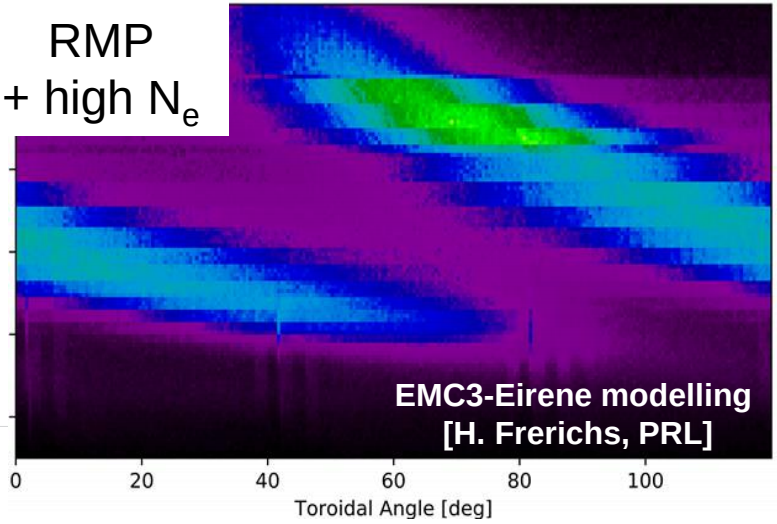
RMP
+ low N_e



H. Frerichs ITER Scientist Fellow

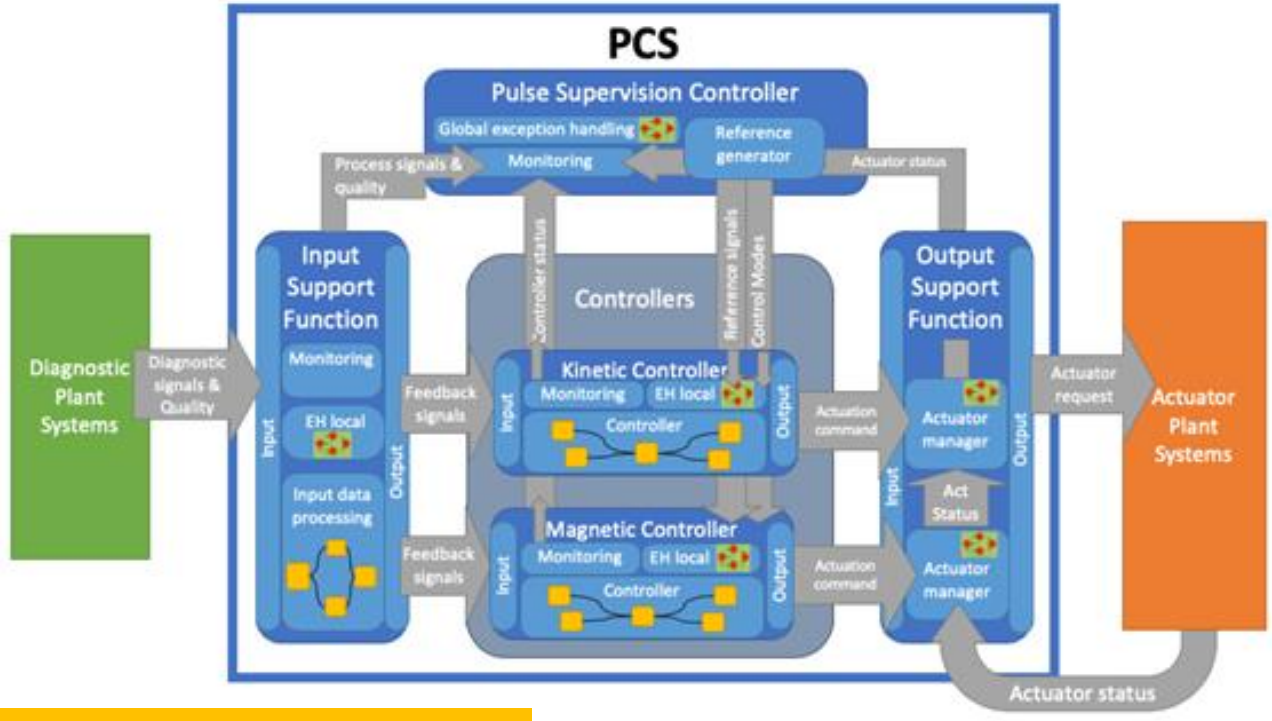
TH/P6 13 May

RMP
+ high N_e



Plasma Control System Design

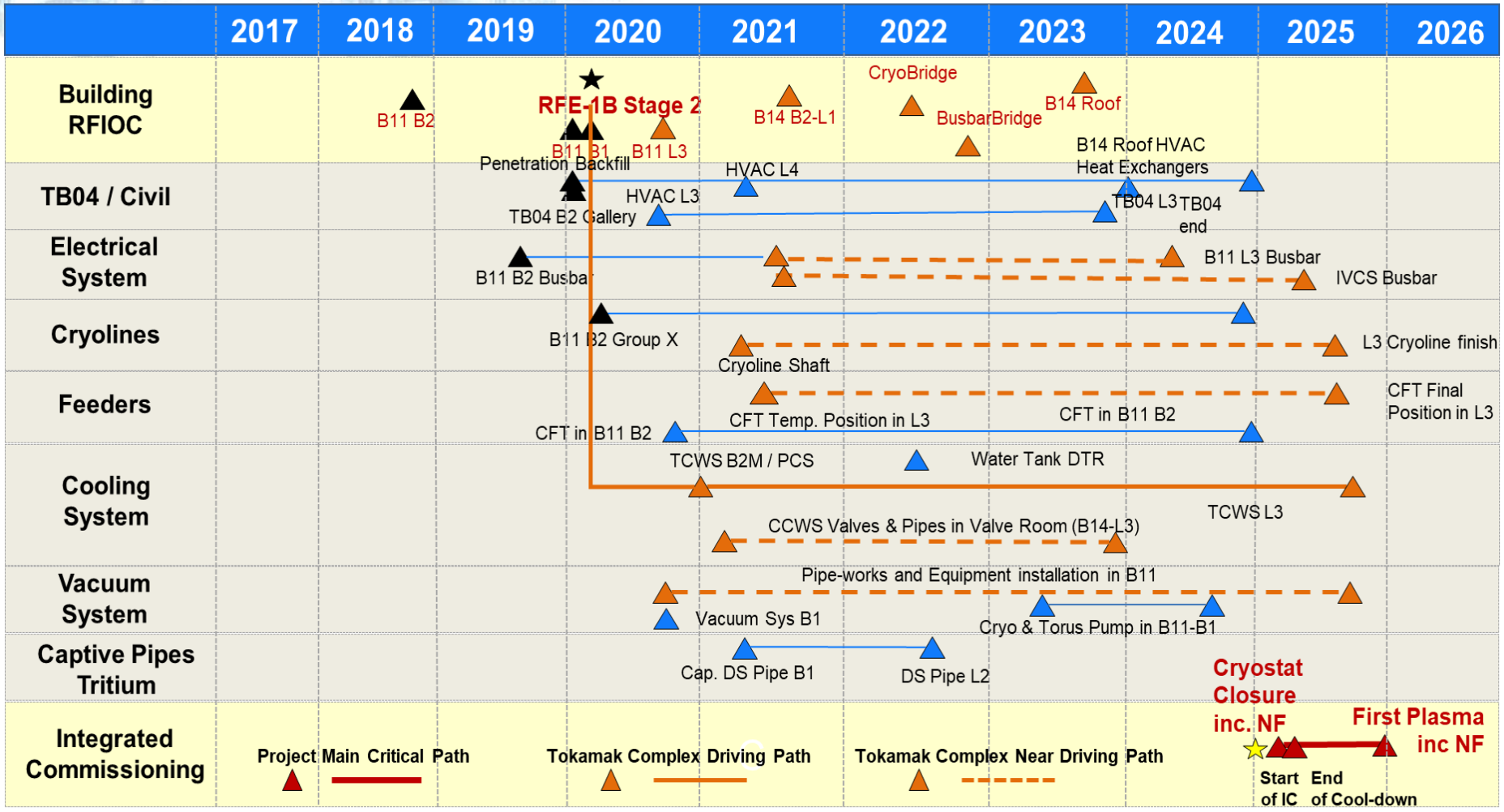
- An effective Plasma Control System (PCS) is essential for the execution of the Research Plan
- PCS Final Design for First Plasma approved in July 2020 and being implemented for Integrated Commissioning, FP, & EO
- Start of PCS PFPO-1 design in 2021 for implementation before FP



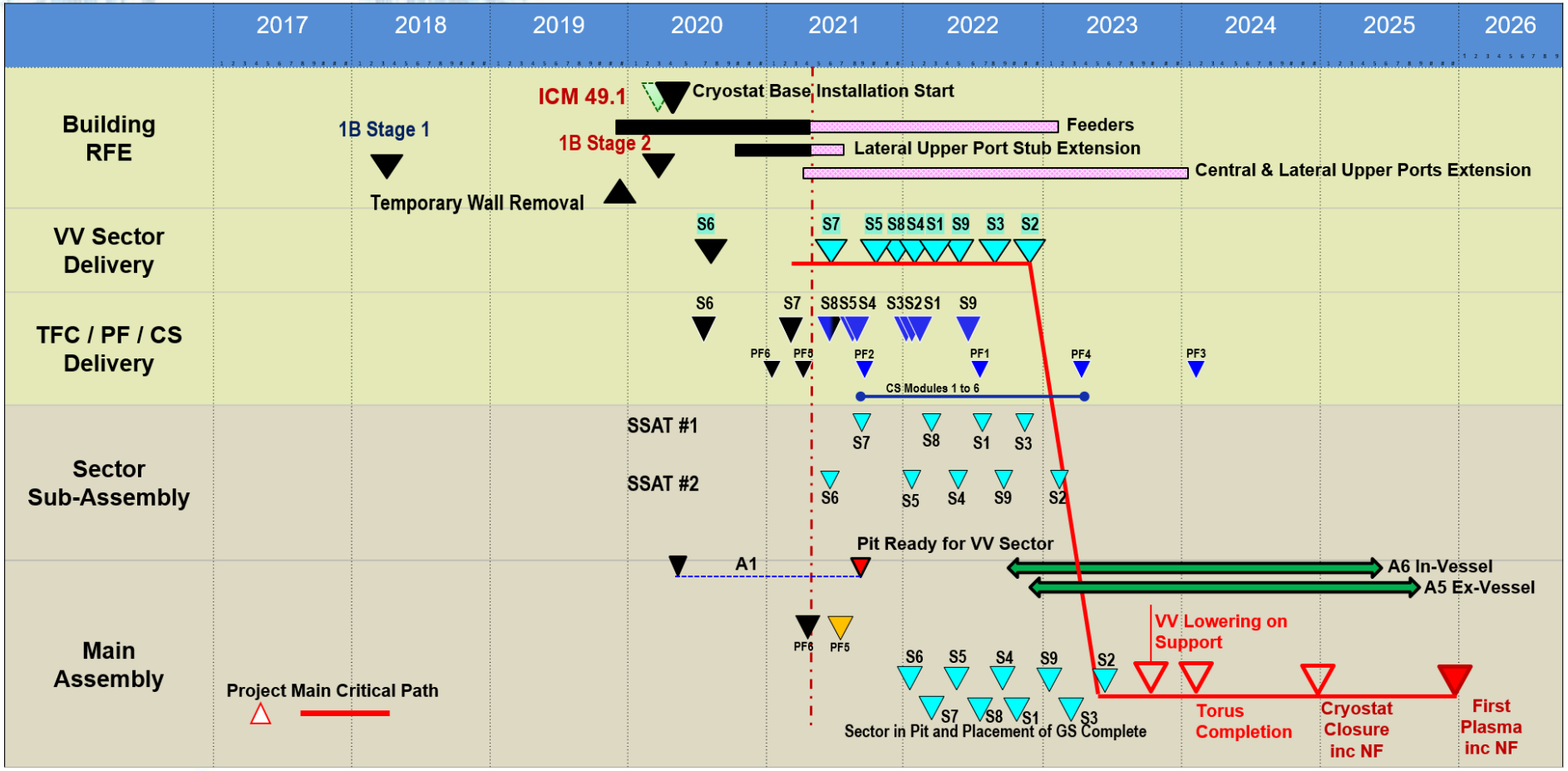
➡ *J. Snipes TECH/1 11 May*

Looking ahead to First Plasma

Worksite Phase 1 Assembly Schedule



Machine Assembly

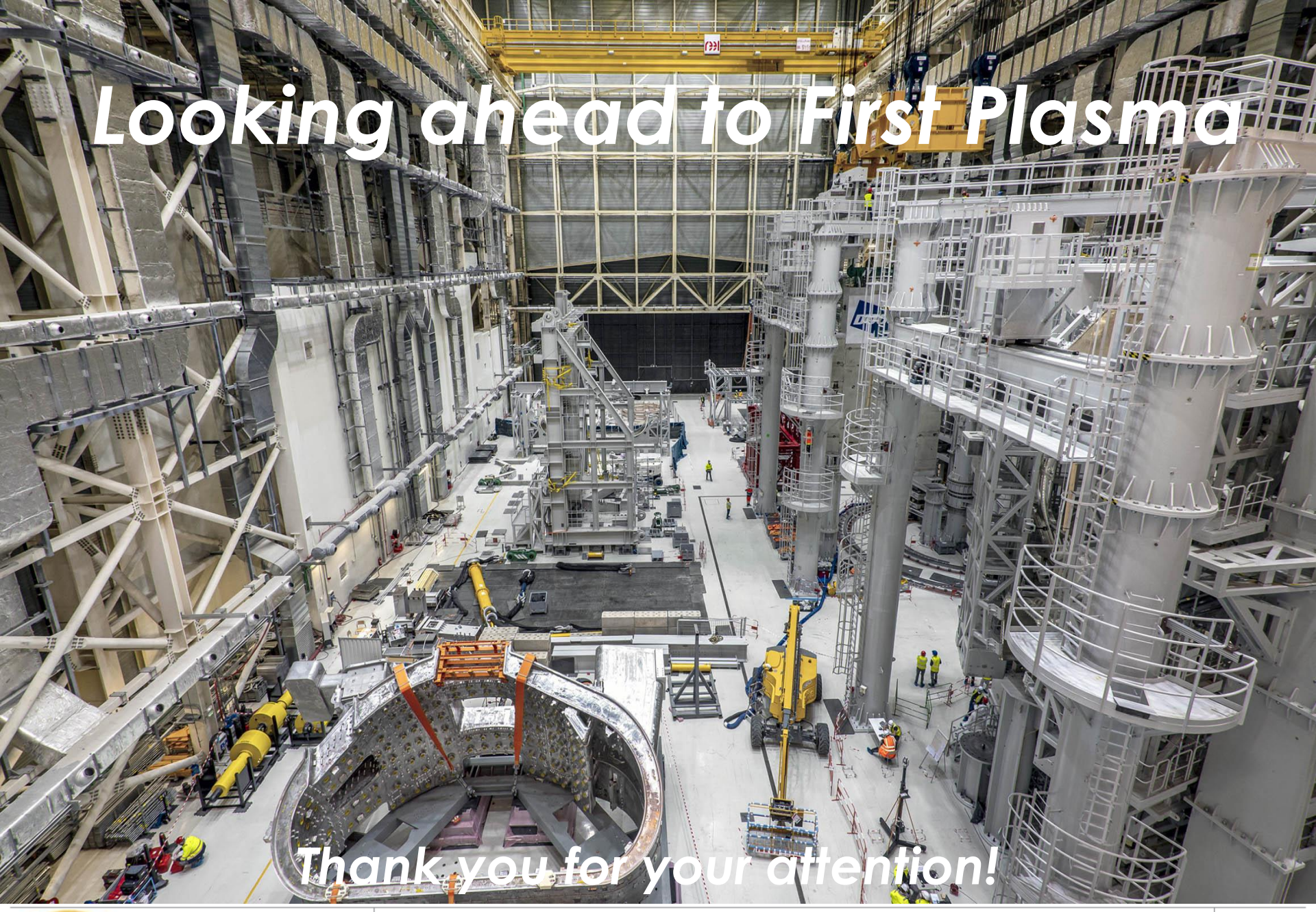


Summary and Conclusions

- ITER construction has made enormous progress since IAEA FEC 2018 despite the challenges due to the pandemic and many FoAK:
  - First sets of major tokamak components have been successfully completed and delivered to ITER site allowing start of machine assembly: Cryostat base, lower cylinder, upper cylinder, Vacuum Vessel sector, Toroidal Field Coils, Poloidal Field Coils, Correction Coils, with additional components (2 Central Solenoid Modules) to arrive soon.
  - First Sector Sub-Assembly with TF Coils and thermal Shielding has started after commissioning of Sector Sub-Assembly tools
  - Tokamak pit works to install supports for TF coils, Central Column, first PF coil, and other components for machine assembly are well advanced
  - Key infrastructure and plant systems have been completed: 400 kV connection, Tokamak Building, Cooling Plant, Cryoplant, etc., with substantial progress on all other balance of plant systems.
  - Research is progressing as foreseen with some important results
- Challenges remain ahead to complete assembly, commissioning, demonstrate First Plasma and go on executing the Research Plan

Support of ITER Members fusion communities is essential to success

Looking ahead to First Plasma



Thank you for your attention!