ITER Status and Research Plan

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15th ITER International School, 20th July 2026, Chengdu, China

iter
china eu india japan korea russia usa

Outline

- **ITER : Design Basis**
  - ITER objective
  - ITER design features to achieve objective
- **ITER's Origin and Status**
  - Project's origin and implementation
  - New baseline and construction status
  - ITER Research Plan

ITER : Design Basis

ITER objective

ITER design features to achieve objective

china eu india japan korea russia usa

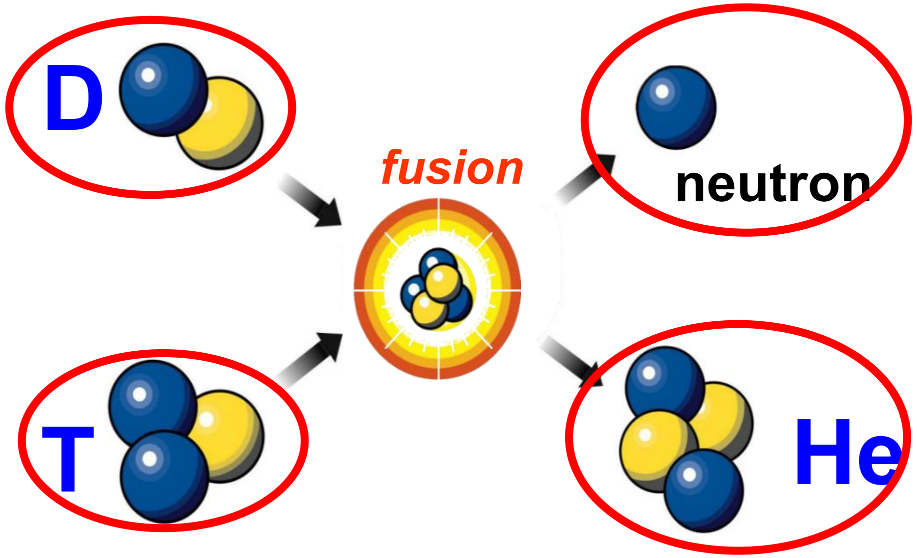
ITER Objective

Demonstrate the scientific and technical viability of fusion energy as a energy source for humankind

Present in 1 part in 6500 in water (H_2O) – easy to extract

Escapes from plasma and deposits energy on the wall of the reactor

P_{heat} = 50 MW



P_{fusion} = 500 MW

Does not exist in nature. Produced in the reactor (from Lithium) n + Li → T + ^{4}He

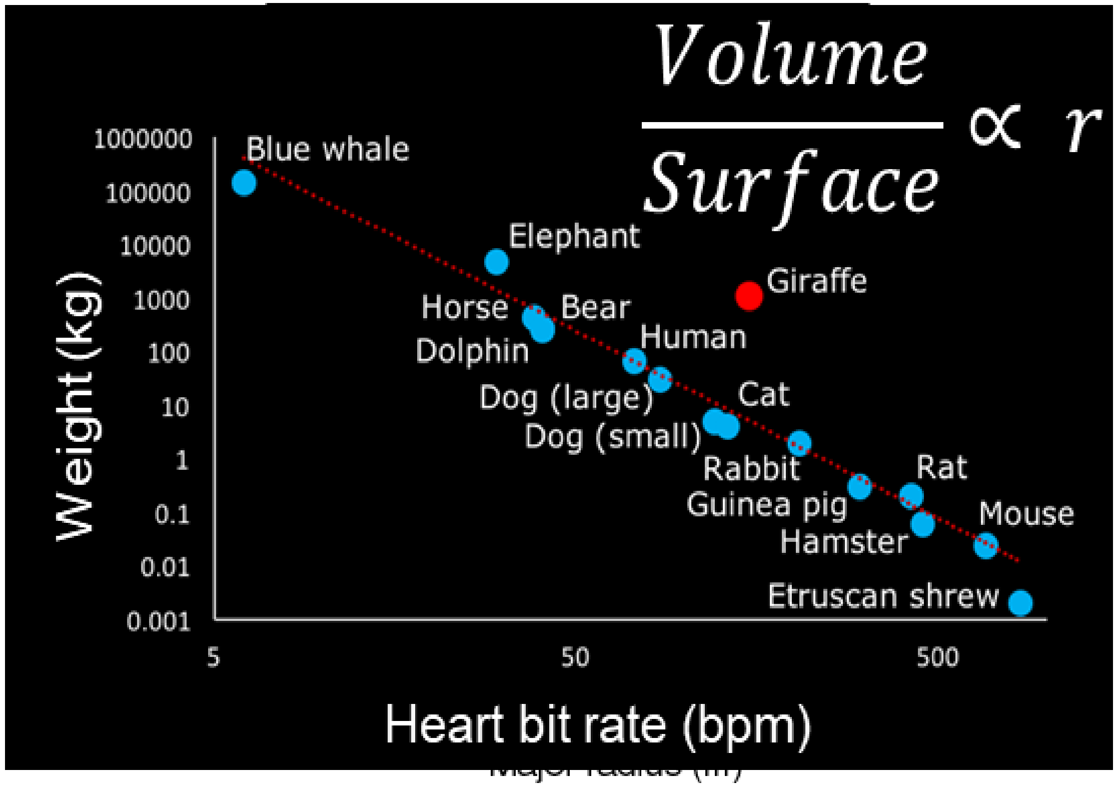
Charged Particle → trapped in magnetic fields re-heats DT

ITER design basis : Size

Fusion energy production

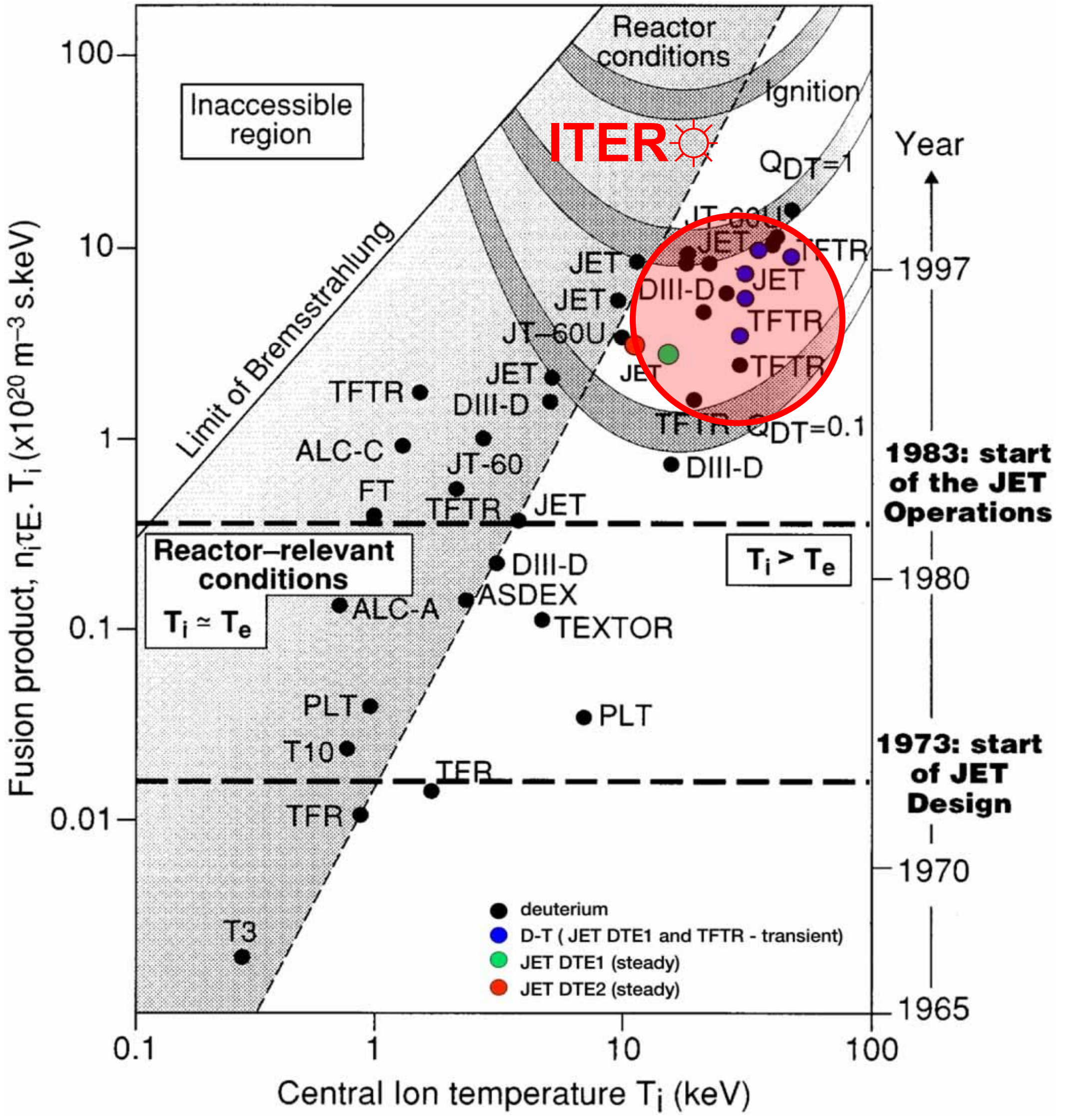
$Q = P_{fusion}\ ({}^4He + n)/P_{external\text{-}heat}$

Q = 10 with P_{fusion} = 500 MW in ITER



I_p = 15 MA

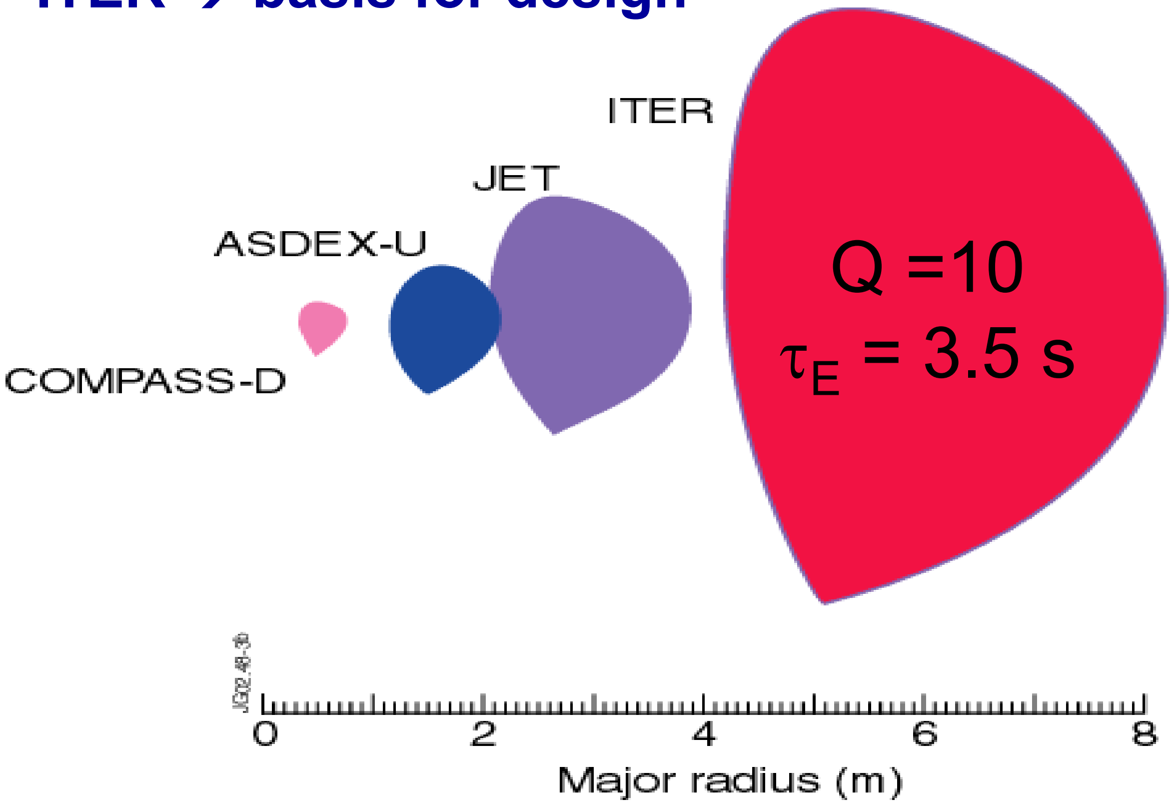
B_t = 5.3T

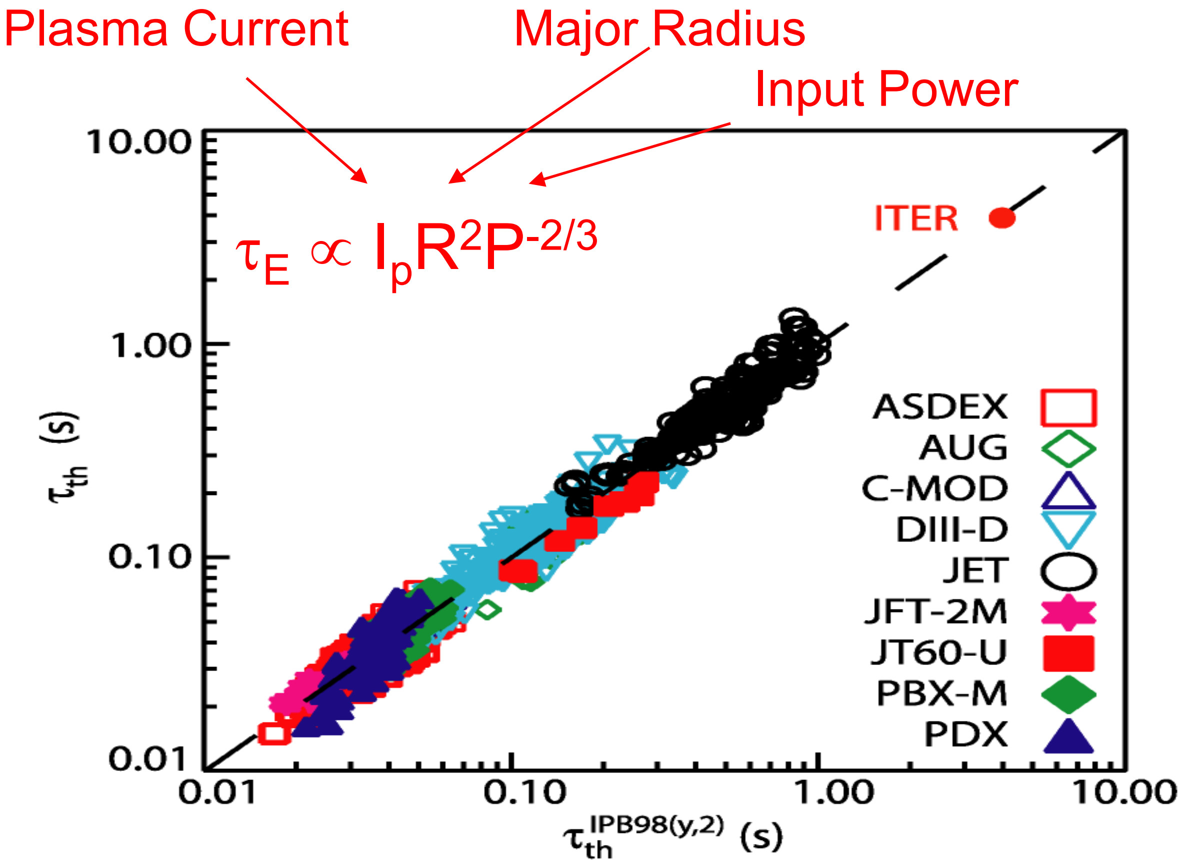


ITER design basis : Energy Confinement (τ_E)

➢ Turbulent transport is difficult to predict quantitatively:

✓ Use scaling experiments ("wind-tunnel") to predict the level of energy confinement in ITER → basis for design



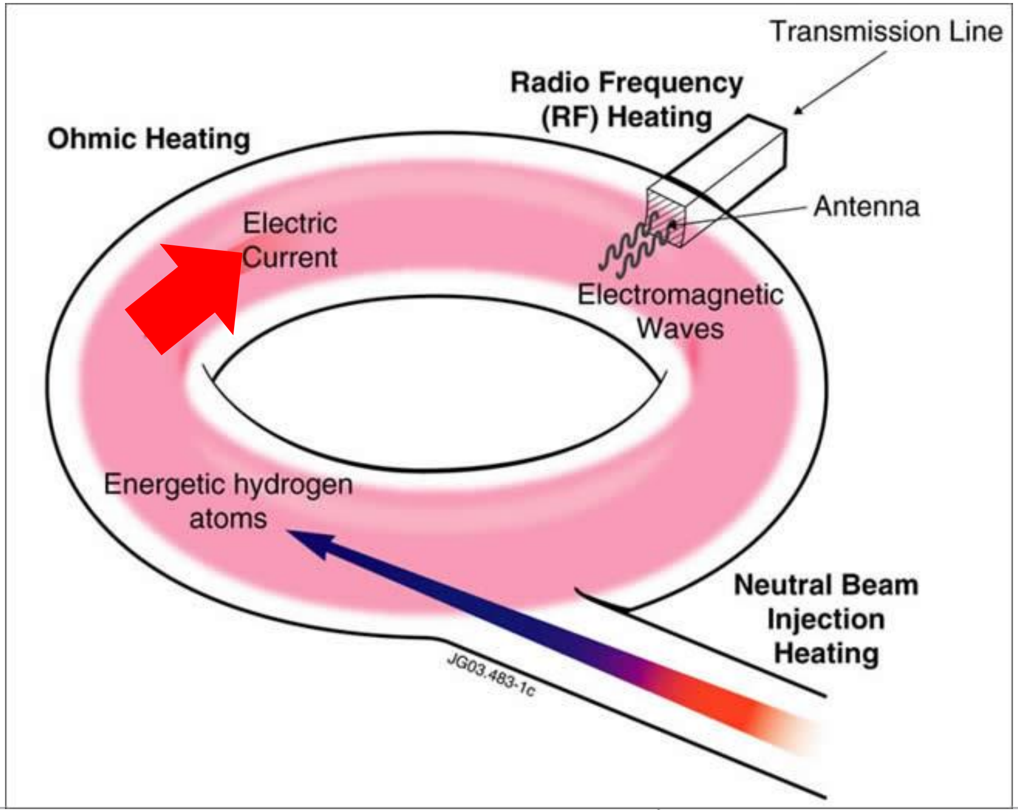


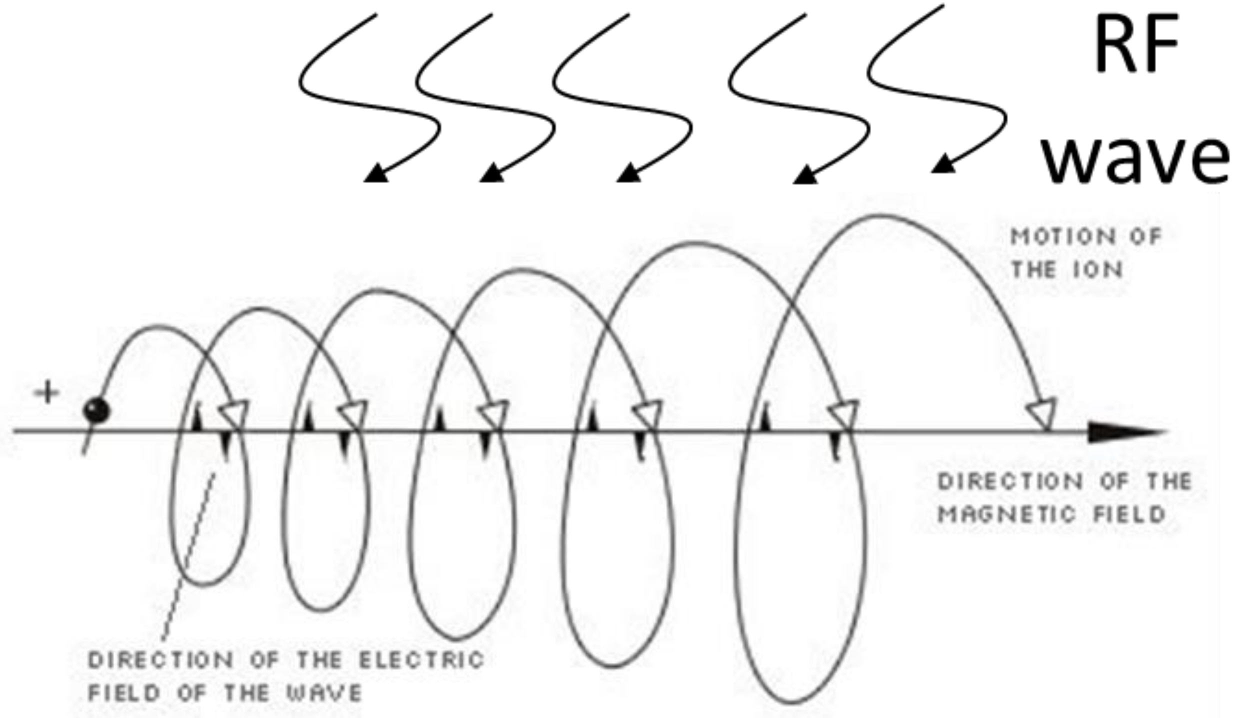
ITER design basis : Plasma heating

To reach temperatures of 150 M°C so that the fusion reaction "burns" we have to create and heat a plasma first :

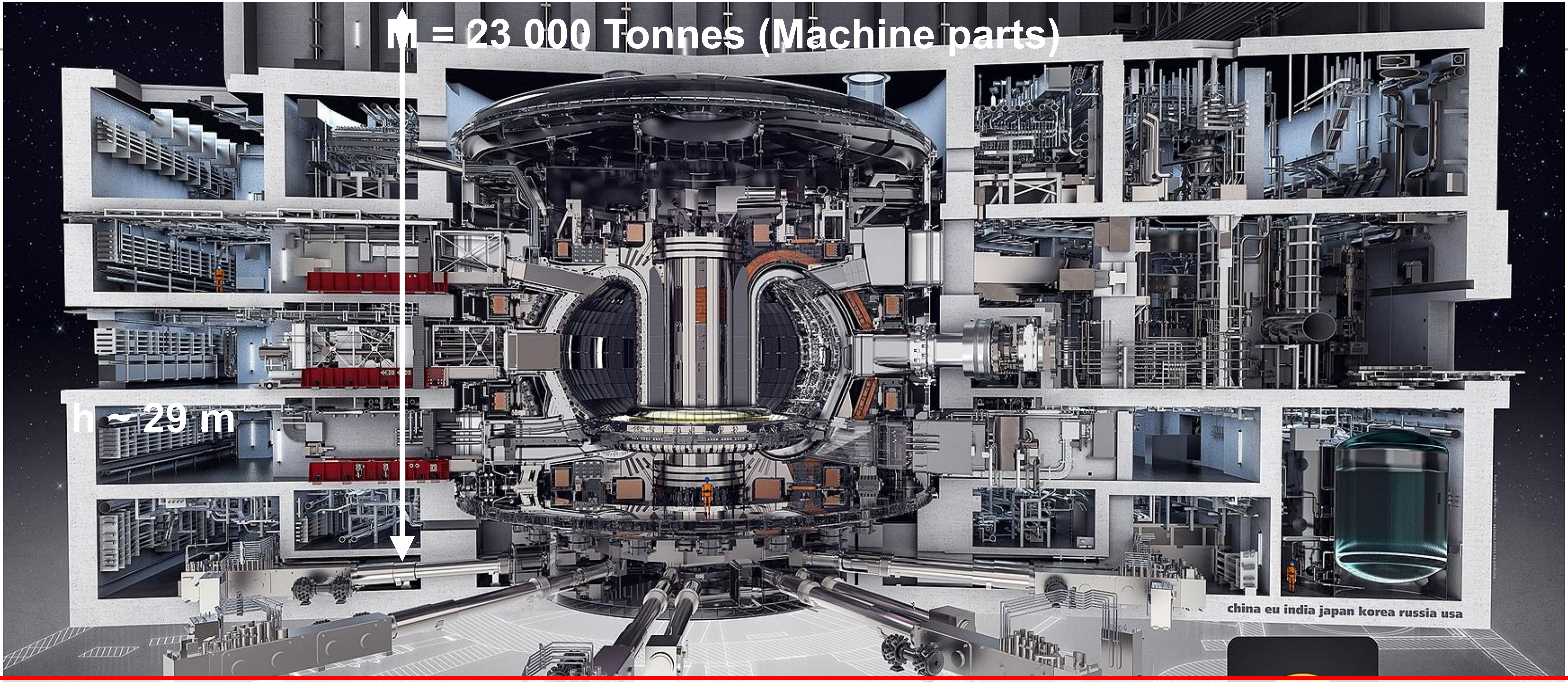
- **Radiofrequency (~ microwave oven)**
- **Injection of energetic atoms (~ particle accelerator to ~ MV)**

ω_e ~ 150 GHz
ω_i ~ 50 MHz



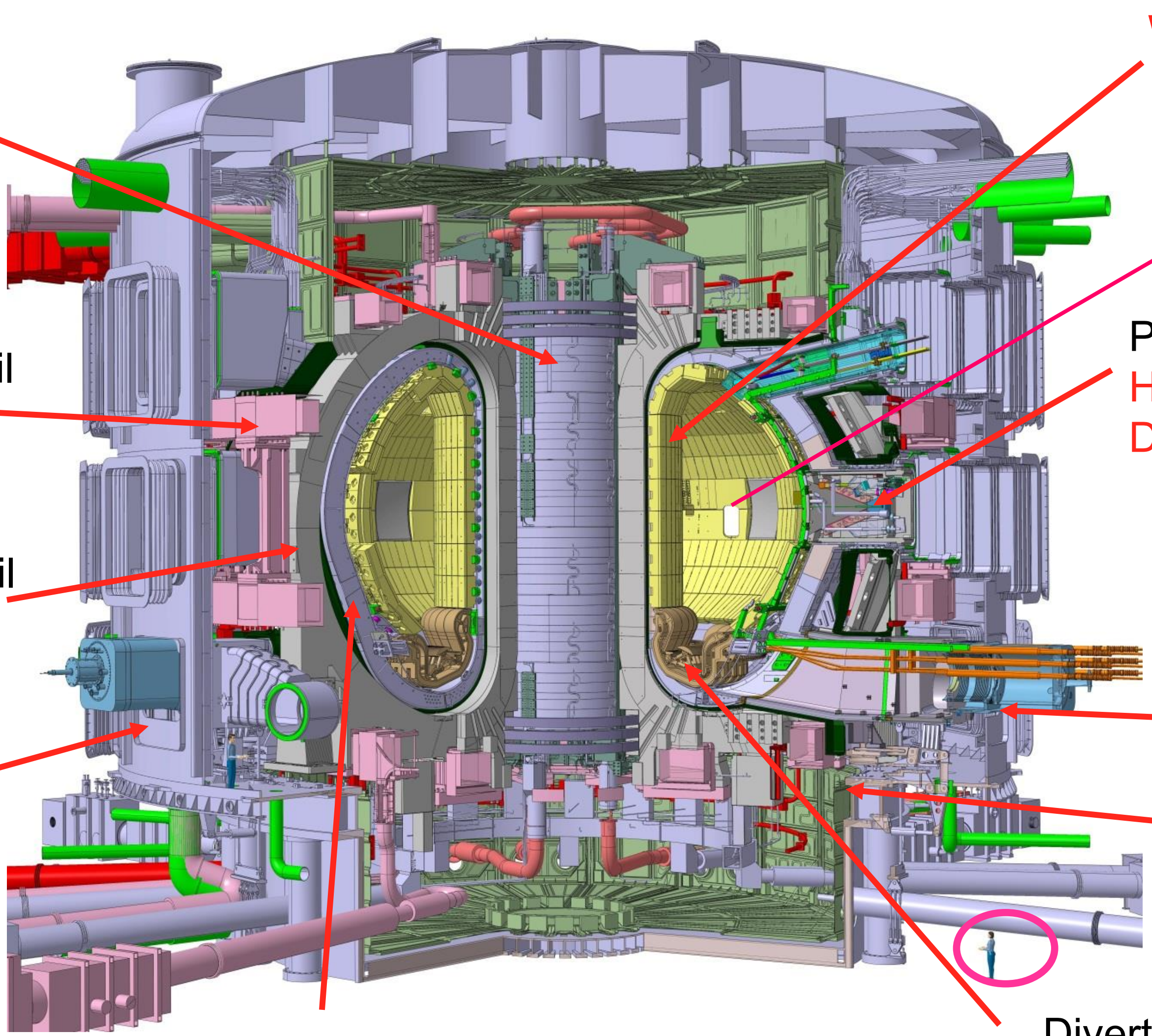


Design features and systems to achive ITER objectives



ITER will maintain self-heated DT plasmas by the fusion reaction for durations of 10 minutes to 1 hour. ITER will demonstrate in an integrated way the technology, materials and physics needed to produce electricity in commercial fusion reactors

Main ITER Components



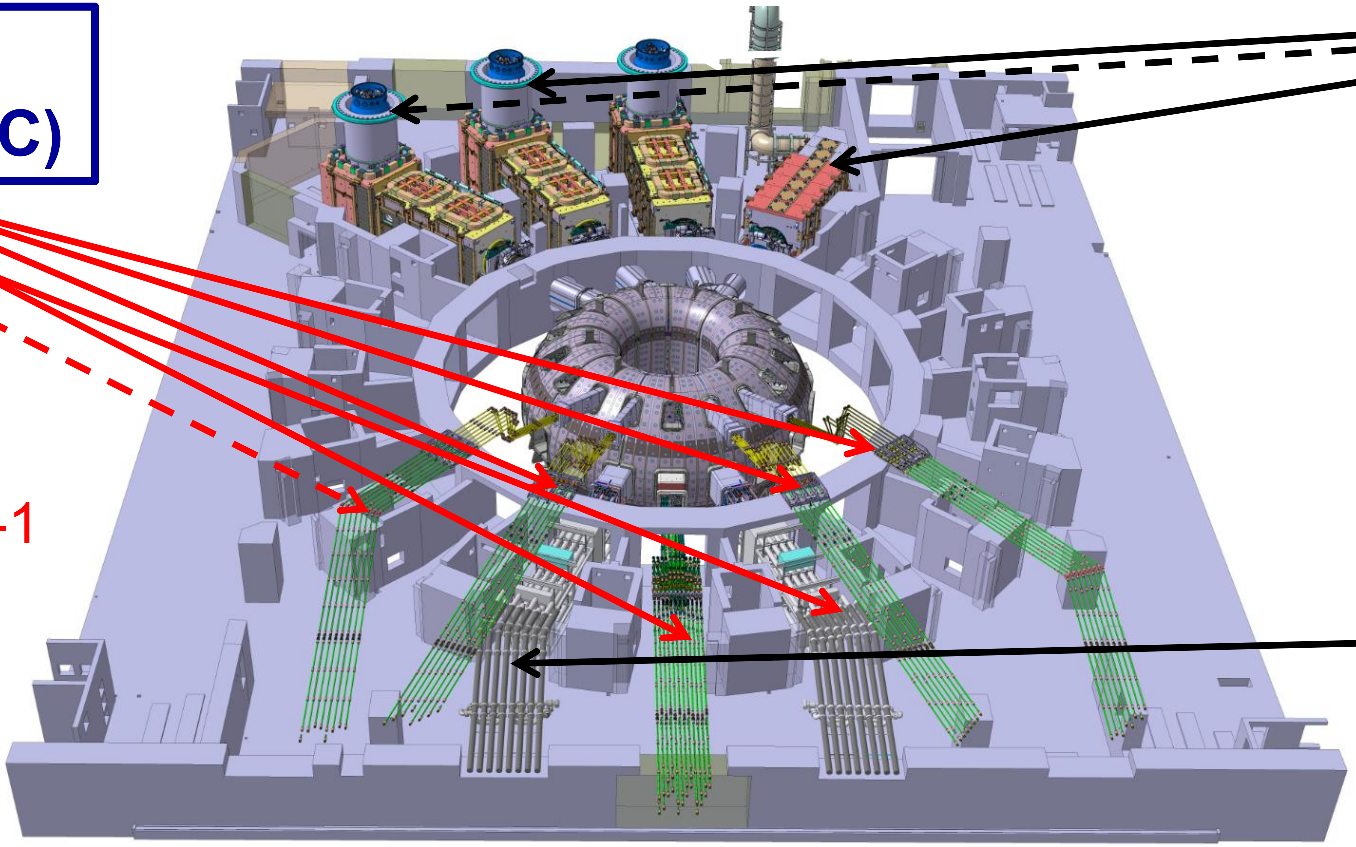
Heating and Current Drive

Large H&CD power and optimized power mix for operation with W PFCs

High flexibility for experimental programme, reduction of risks to achieve Q = 10

Electron Cyclotron (EC)

170 GHz
40 MW - SRO
+
20 MW (+7) – DT-1



Neutral beam injection (NBI)

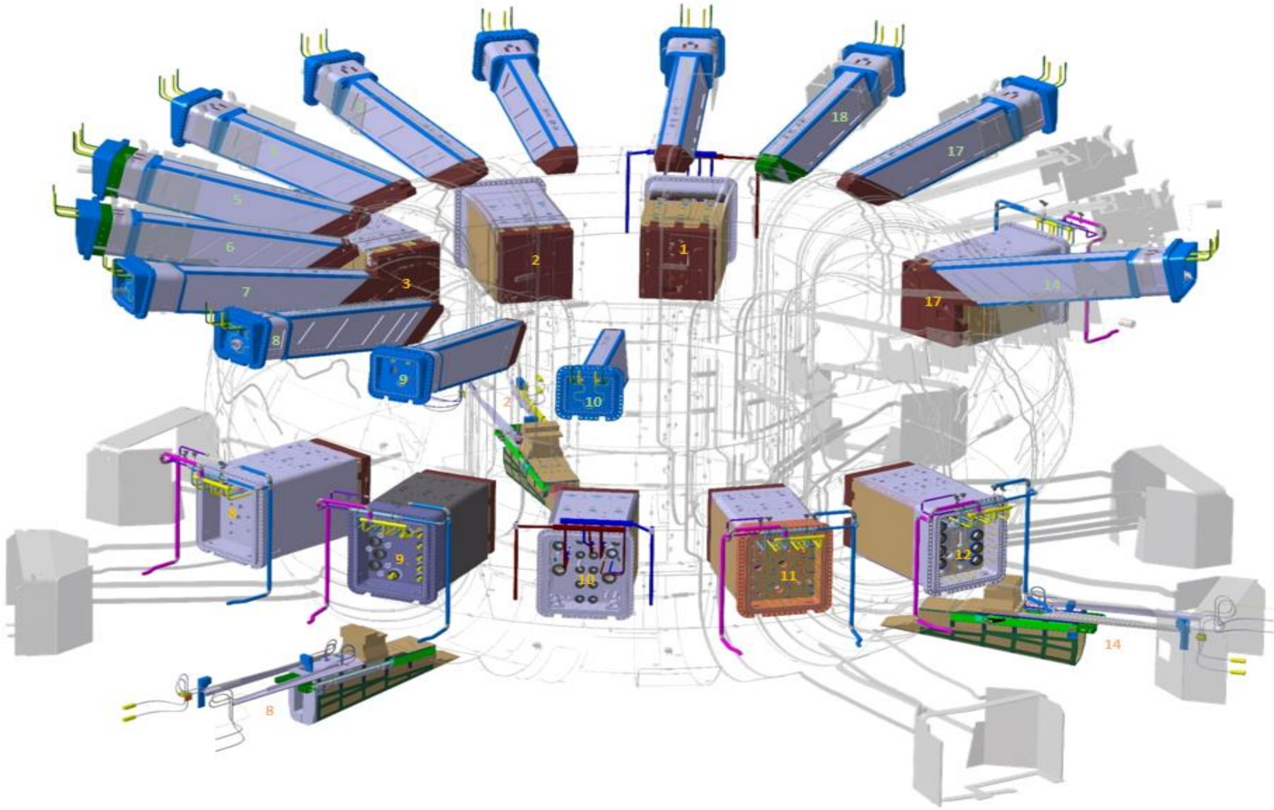
870 keV H^0
1 MeV D^0
33 MW (+16.5)

Ion Cyclotron (IC)

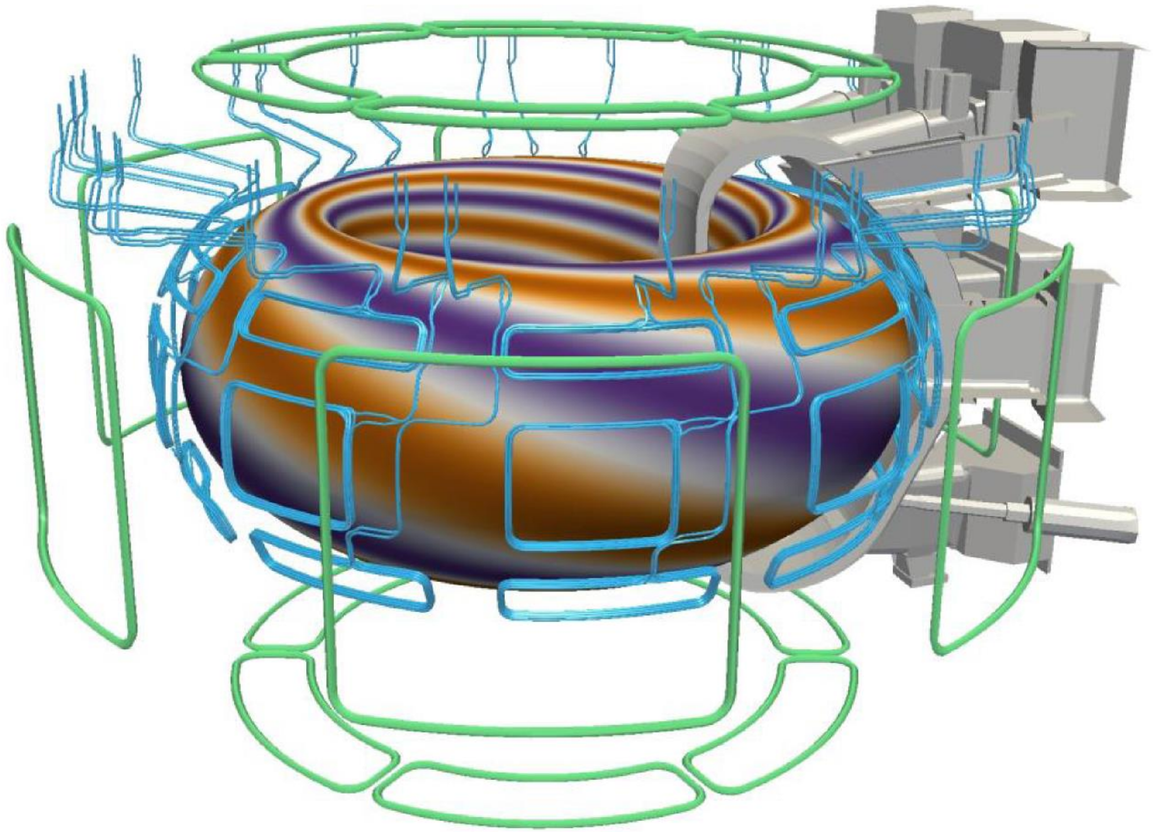
50 MHz
10 MW – SRO
10 MW (+10) **– DT-1**

ITER Diagnostics and 3-D coils (Error Field, ELM control)

- Diagnostics: ~ 60 instruments measuring ~ 100 parameters



- External error field correction coils + internal ELM control coils

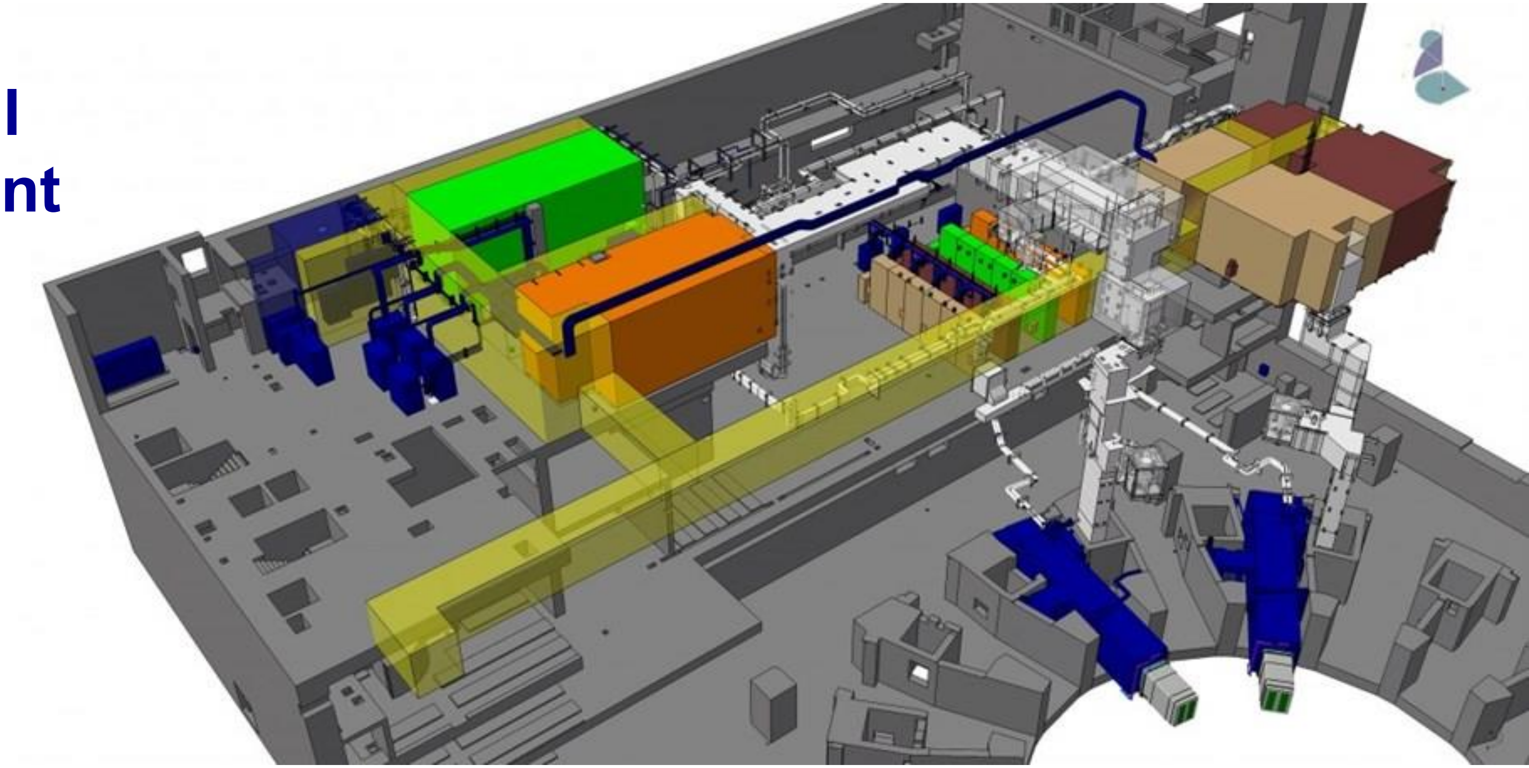


Tritium Breeding : Test Blanket Systems

Tritium not available in sufficient amounts for large scale nuclear fusion energy production → Tritium needs to be produced in-situ (n + Li → T + He)
T production schemes will de demonstrated in ITER (at small scale)

Different test blanket systems will be installed in ITER to test different combinations of design options:

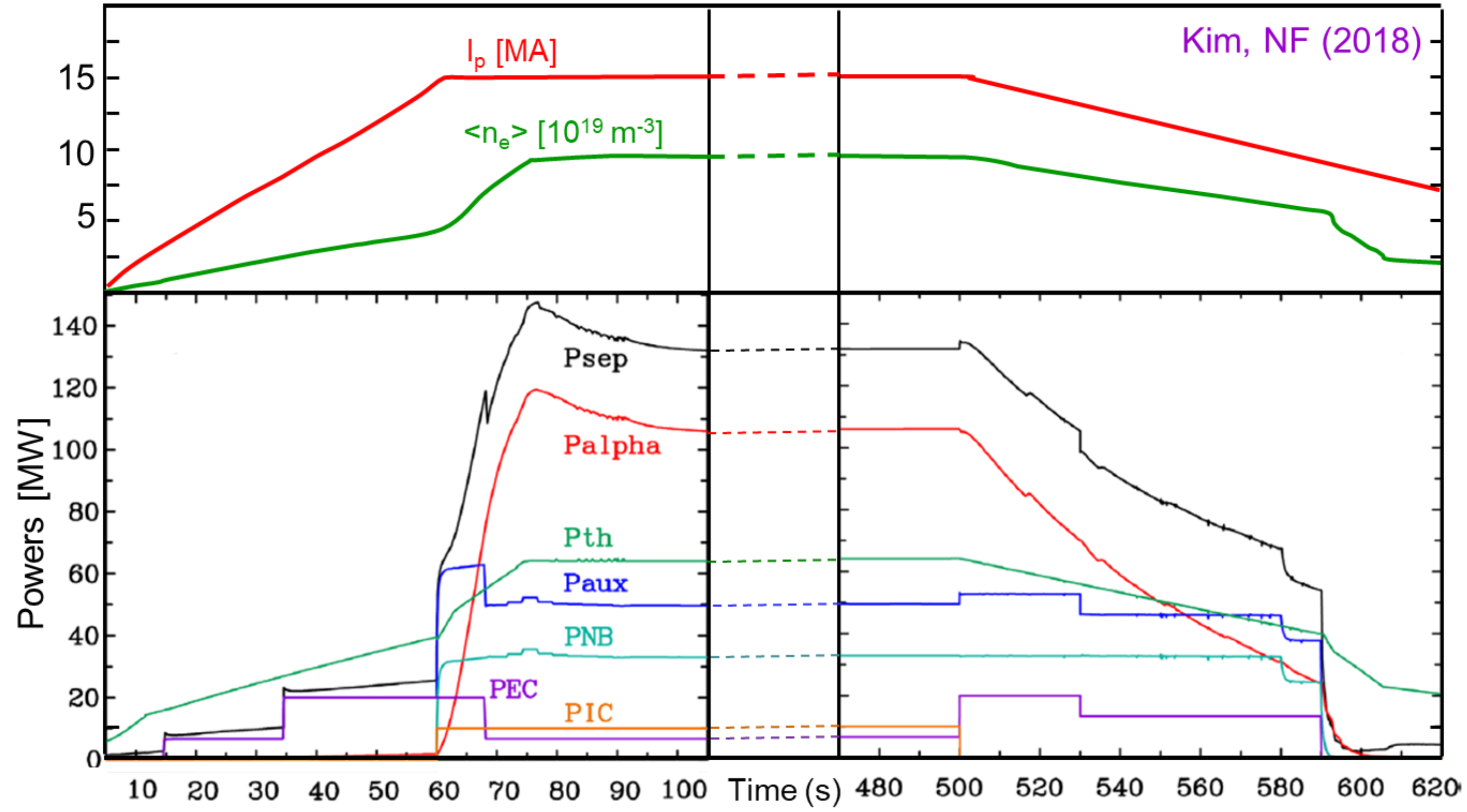
- **Liquid metal breeder**
- **Solid breeder**
- **Helium coolant**
- **Water coolant**

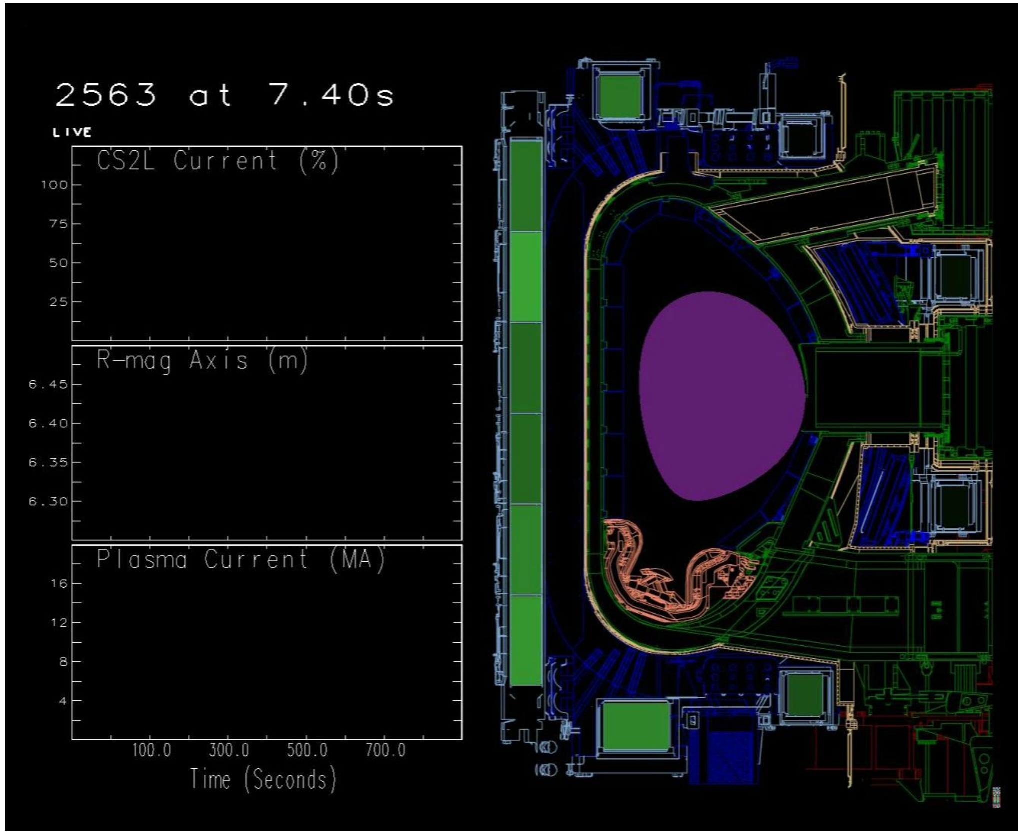


Demonstration of the achievement of coolant thermo-hydraulics conditions (both water-coolant and Helium-coolant) relevant for high-efficiency electricity production

ITER Q = 10 scenario (300 – 500 s burn)

- Scenario used for design of magnets and components (15 MA/5.3 T)
- P_{aux} ~ 50 MW → Alpha-heating dominant scenario P_{fusion} = 500 MW





ITER’S ORIGINS AND STATUS

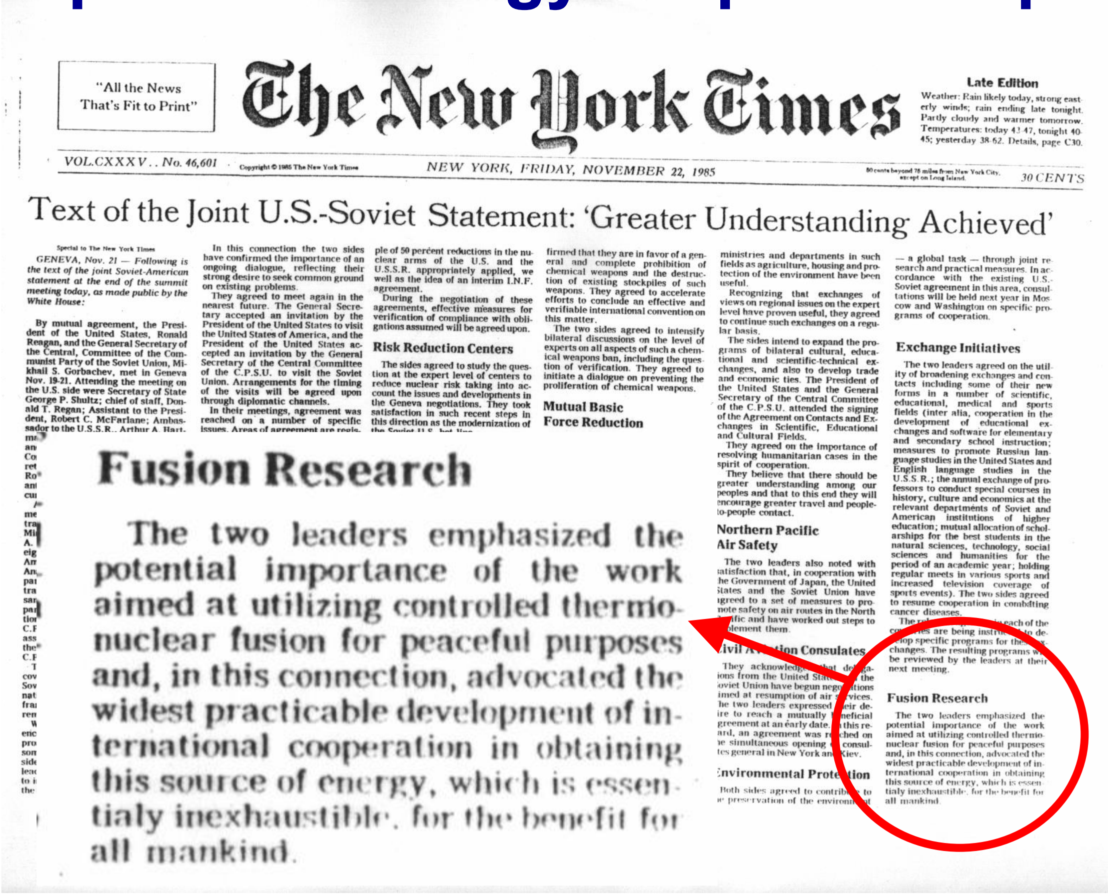
- Project’s origins and implementation
- New baseline and construction status
- ITER Research Plan

iter
china eu india japan korea russia usa

ITER's History

The origin of the idea is the meeting in Geneva on 1 November 1985:

Mr. Gorbachev and Mr Reagan signed an agreement to create an international project to develop fusion energy for peaceful purposes.



"All the News That's Fit to Print"

The New York Times

Late Edition

VOL. CXXXV.. No. 46,601 — NEW YORK, FRIDAY, NOVEMBER 22, 1985 — 30 CENTS

Text of the Joint U.S.-Soviet Statement: 'Greater Understanding Achieved'

Fusion Research

The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermo-nuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible, for the benefit for all mankind.

ITER

Global Challenge, Global Answer

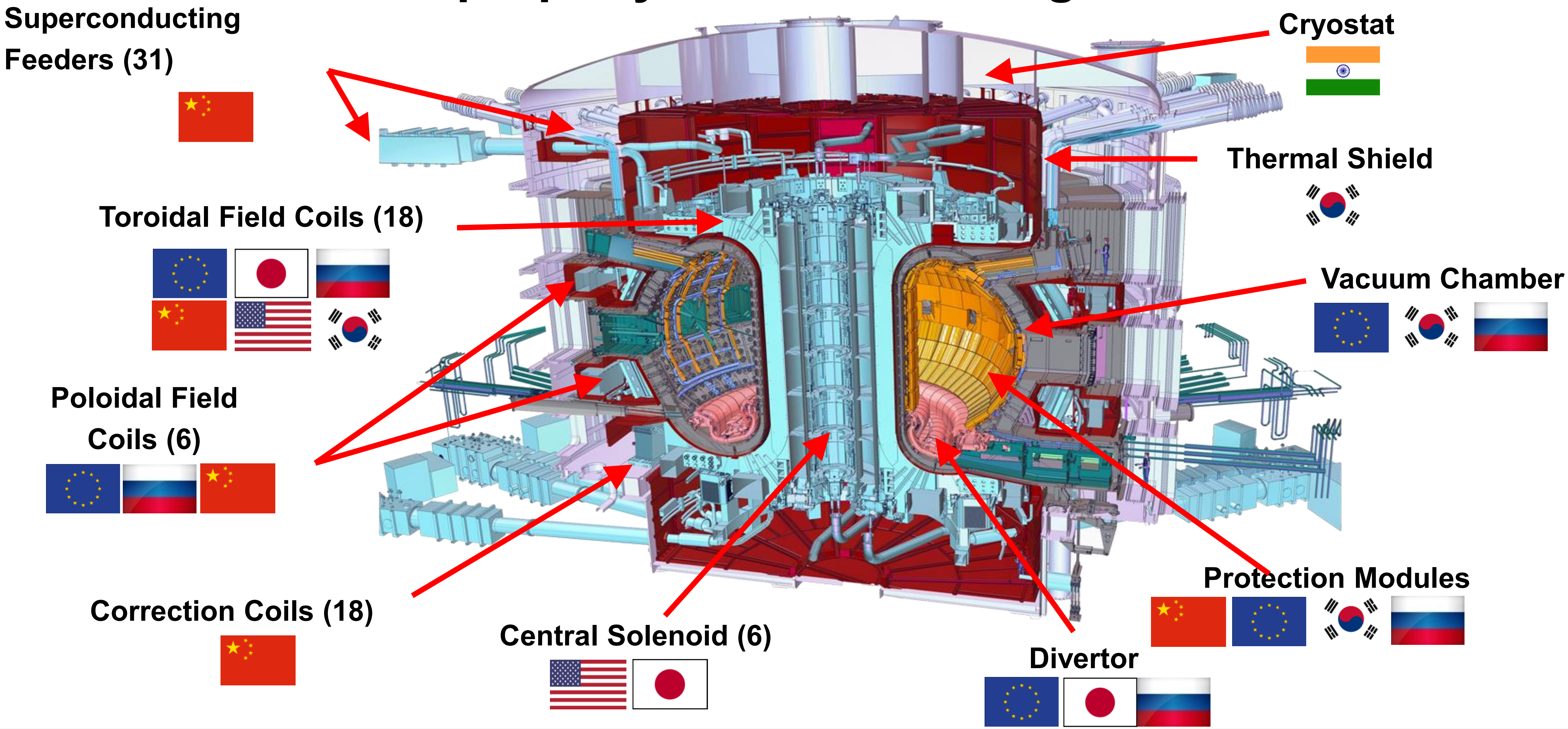
- **28 June 2005: The ITER Members unanimously agree to construct ITER at the site proposed by the European Union**
- **21 November 2006: Signature of the ITER Treaty at the Élysée Palace in Paris**

The ITER Members represent more than 50% of the world population and 85% of the global GDP

China EU India Japan Korea Russia USA

Who makes what?

All intellectual property is shared among the seven Members



ITER Toroidal Field Coil Construction

New Baseline and construction Status

New Baseline Rationale

- In 2022 issues were identified in some tokamak components → repairs were carried out and tokamak assembly re-started in 2024
- A new baseline was developed to ensure a robust achievement of Projects’ goals
  - New and reliable strategy for assembly
  - Minimization of technical risks in first operational phase
  - Early achievement of H-mode operation in D plasmas
  - Stepwise Safety Demonstration (DT-1 & DT-2)
    - ✓ DT-1 focuses on the achievement of specific Project goal(s) → Q = 10, 300-500s
    - ✓ Limited neutron fluence (1/100 of present end-of-life) → ~ 3.5 10^{25} neutrons
    - ✓ DT-2 → Full achievement of Project goal(s): safety demonstration based on DT-1
- New baseline also included changes to first wall material for reactor relevance (Be → W) and to H&CD (increased of ECH power)

TOROIDAL FIELD COILS

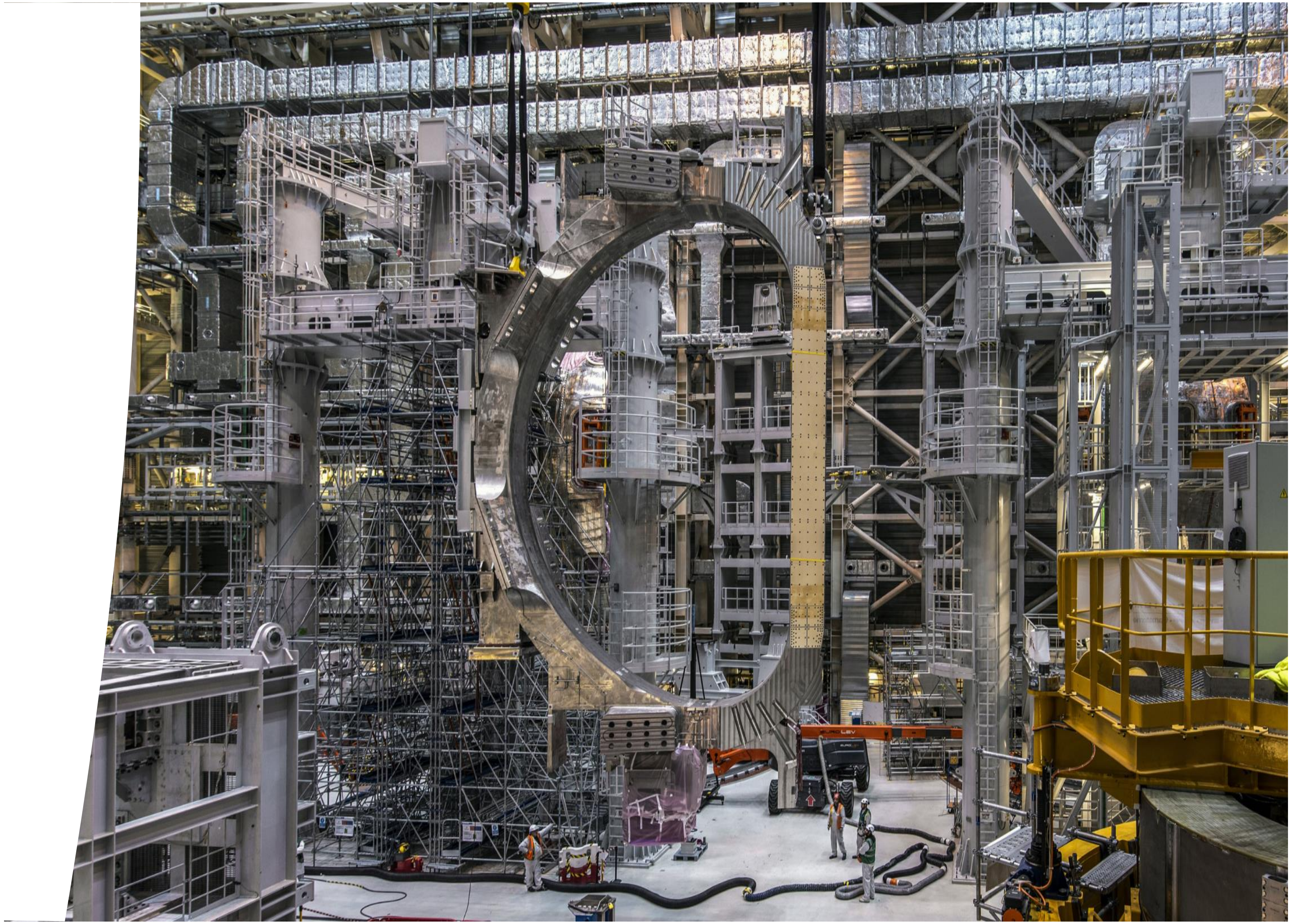
- 18 (+1) coils
- 41 gigajoules
- 11.8 Tesla

Each coil:

- 360 tonnes
- 9 x 17 metres

Status:

All TF coils onsite



POLOIDAL FIELD COILS

Six coils, the largest with a diameter of 24 metres, weighing 400 tonnes.

Total magnetic energy: 4 gigajoules

Maximum magnetic field: 6 Tesla

Status:

All PF delivered on-site

CENTRAL SOLENOID

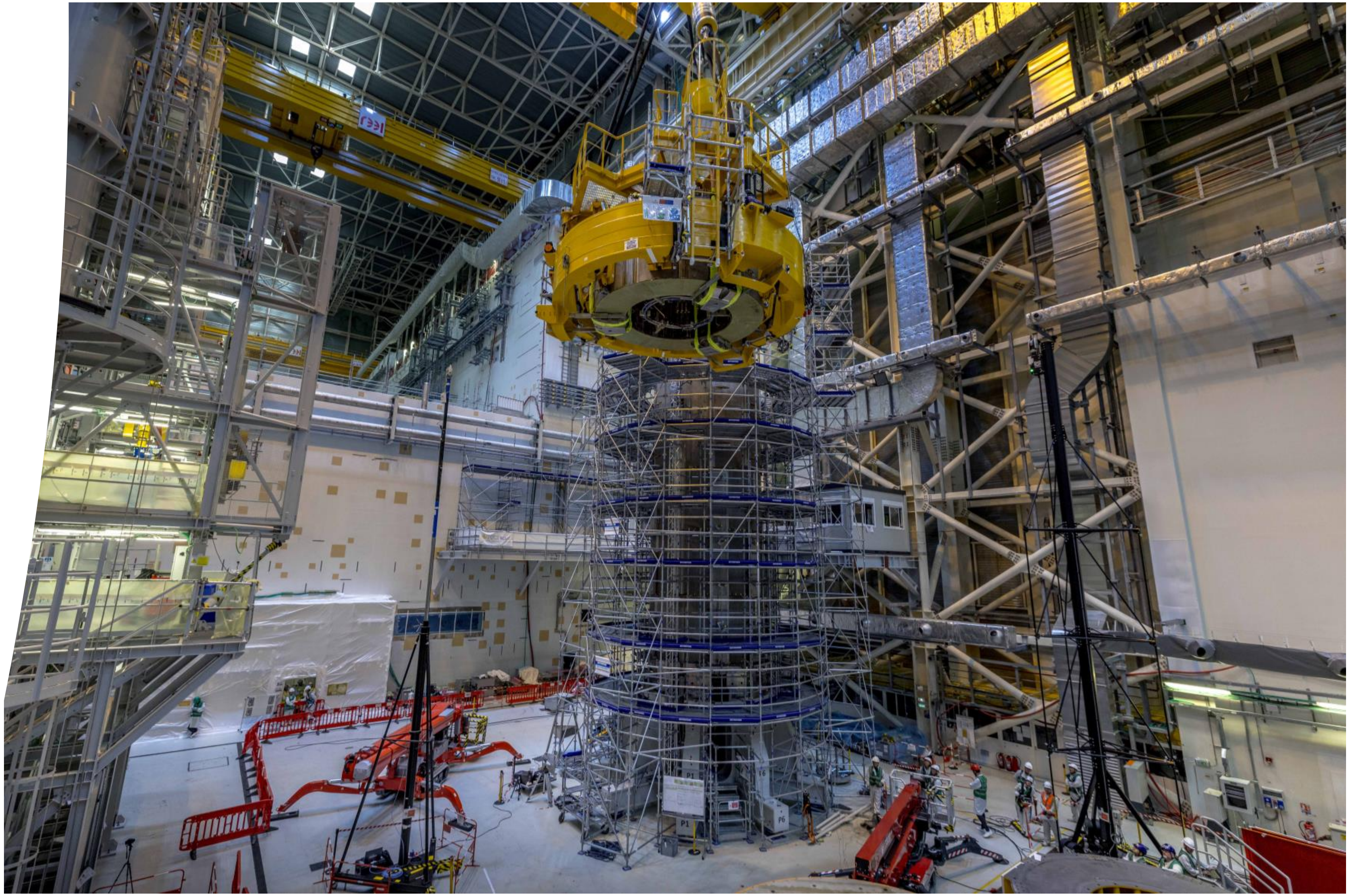
Height: 18 metres
Diameter: 4.13 metres
Total weight: 1000 tonnes
Peak field strength: 13.1 Tesla
Operating voltage: 14 kV
Operating current: 45 kA
Stored energy: 5.5 gigajoules

Status:

All Modules manufactured and delivered

All modules of the Central Solenoid installed on the assembly platform.

#3 module will be used as a spare.



CRYOSTAT

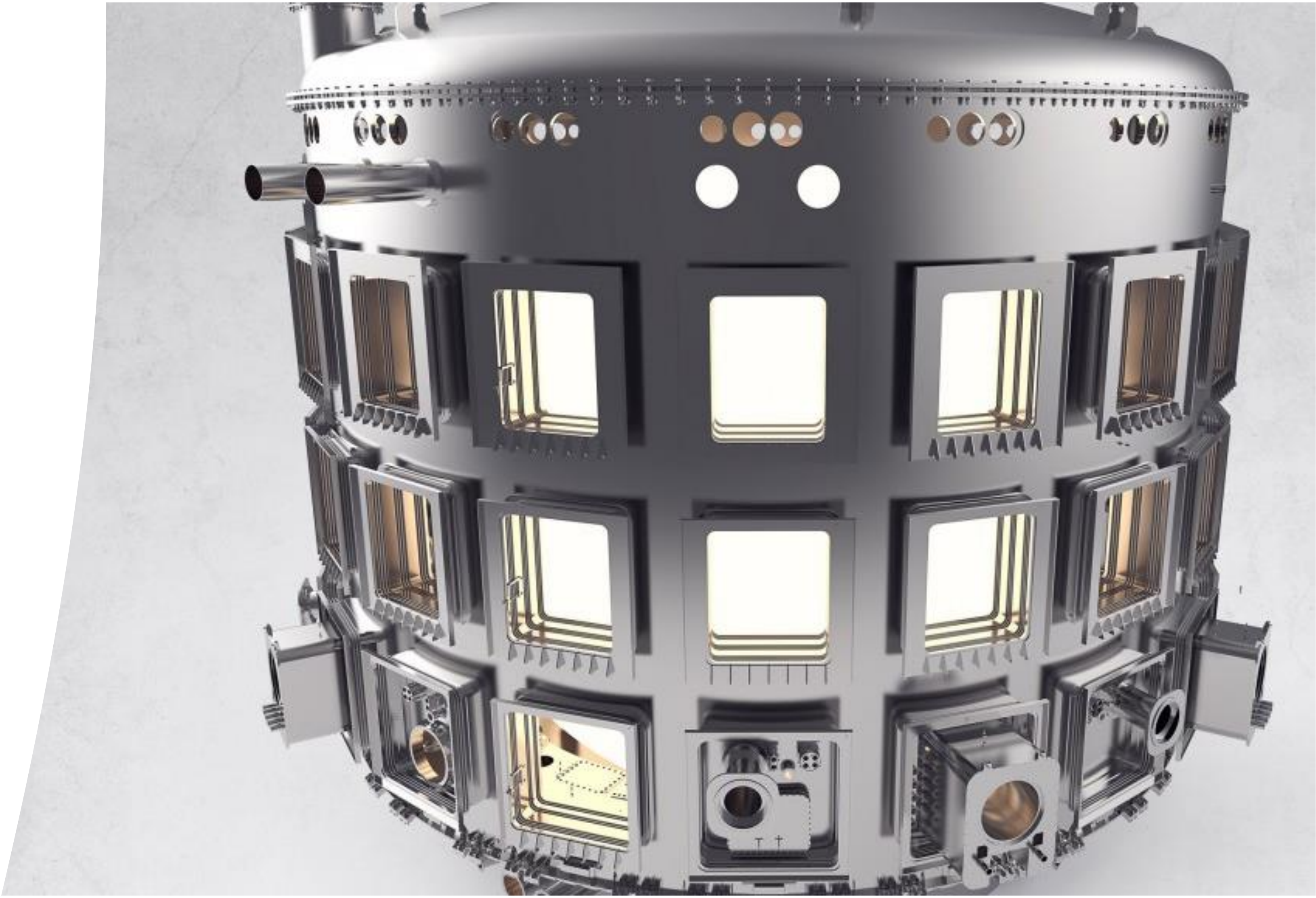
The largest stainless-steel vacuum chamber ever constructed

Total weight: 3,850 tonnes1 base (1,250 tonnes); 2 half-cylinders, 1 lid

Equipment operating underultra high vacuum

Manufacturing and assembly completed

The base and the lower half-cylinders are in place.



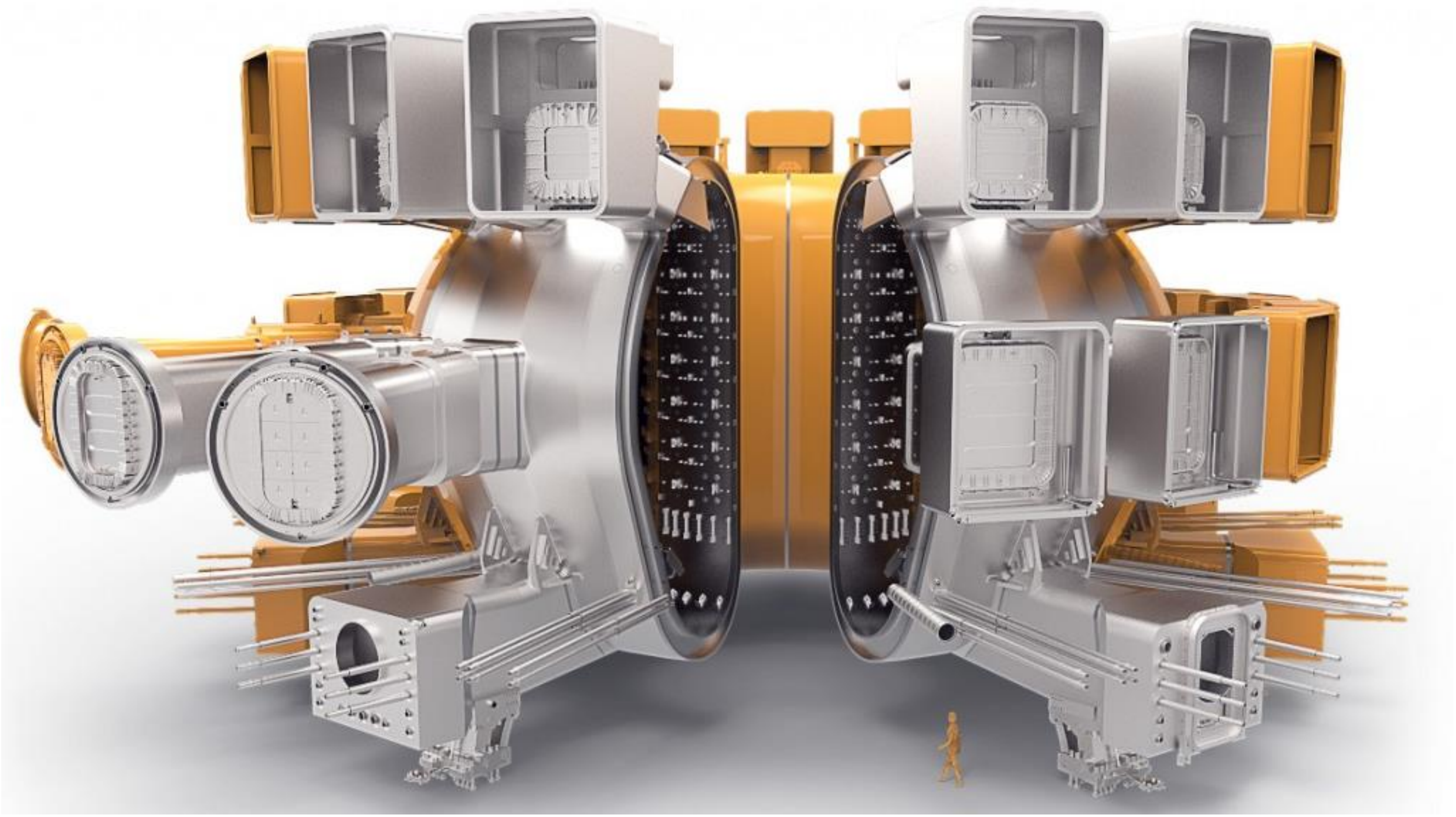
VACCUUM VESSEL

9 sectors

Total weight: 5200 tons

Nuclear equipment operating under ultra high vaccuum

44 “penetrations” (“ports”) dedicated to services: H&CD, diagnostics, plasma facing components, etc) and to remote handling
Preassembled with 2 PF coils and Thermal shields: ~1350 Tons/each



VACCUUM VESSEL

Height: 17 meters
Individual weight: 600 tons

Status :

8 modules (over 9) delivered

5 modules assembled with toroidal field coils and thermal shields (1350 tons); **positioned in pit.**

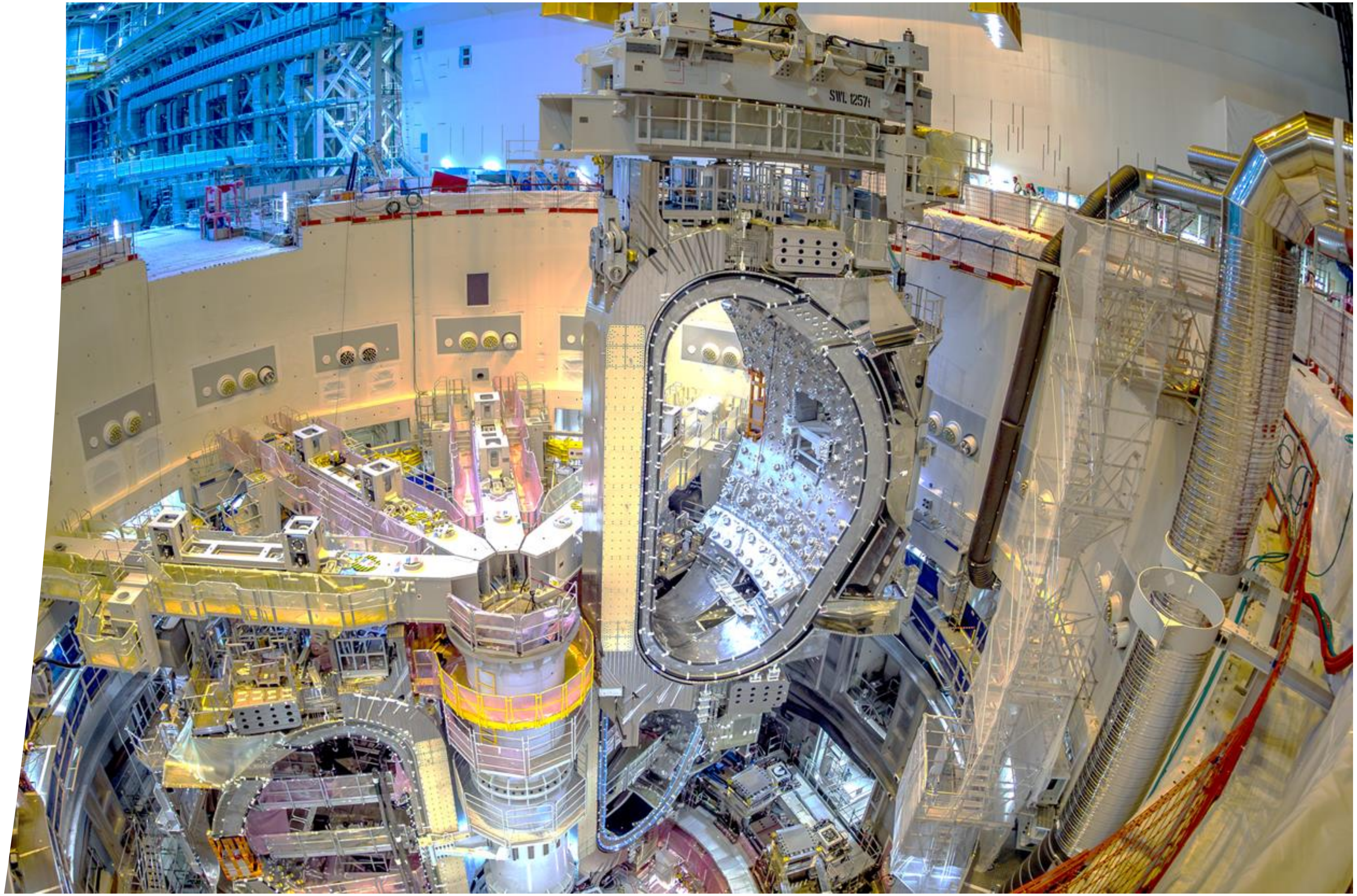
6th module planned next week!

ITER ASSEMBLY AT FULL SPEED

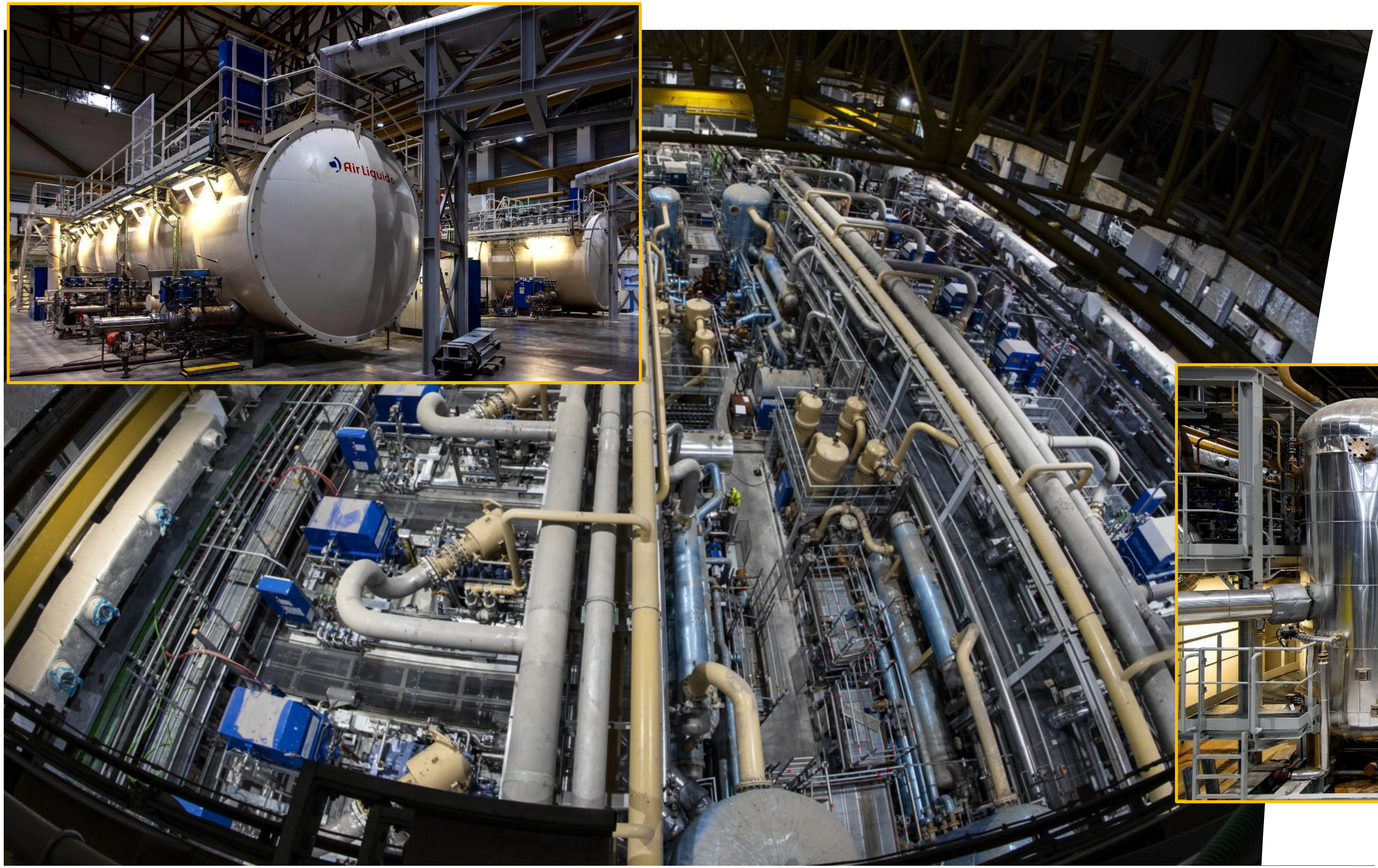
5th sector installed May 27th, 2026

Jan-2024 – May-2026

- Schedule Performance Index=1.06
- Cost Performance Index=1.12 (1.22)



CRYOGENIC PLANT



75kW @ 4 Kelvin

Equipment installation is complete, and is being commissioned.

Plant Systems in Tokamak Building

Delivery of equipment and installation of all plant systems is ongoing at full speed:

- Tokamak cooling water system.
- Vacuum systems.
- Electrical distribution.
- Fueling systems.

Main auxiliary buildings and plants are completed and in commissioning or operation.

POWER CONVERSION AND SUPPLY

Main magnet system power conversion installed.

CN supplied the PF coils converters

Commissioning started and High Voltage tests ongoing by IO team in cooperation with suppliers.

ELM power supplies to be delivered by SWIP

From assembly to commissioning (I)

Progressive hand over of packages with documentation (test records, engineering dossiers, As builts)

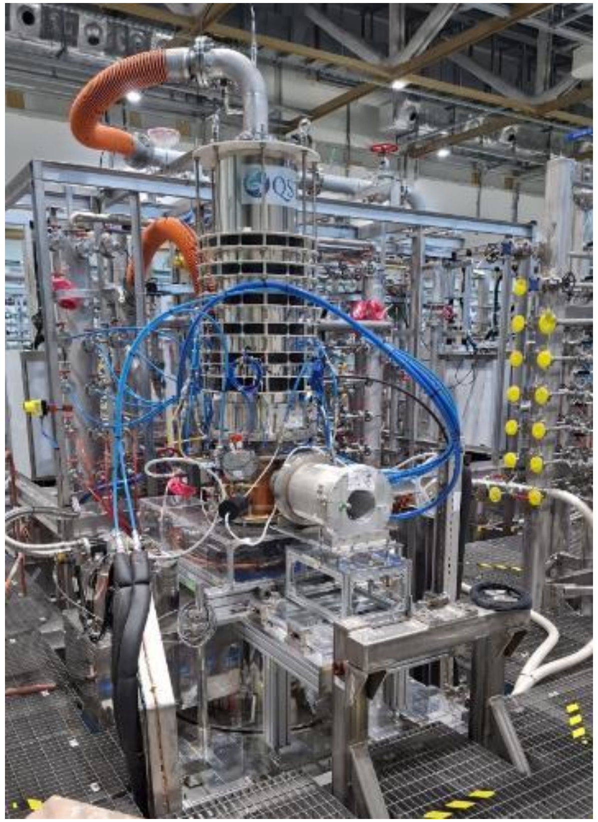
Initially supporting auxiliary systems (LV power distribution, compressed air, liquid, gas)

Then larger plant systems: Cryogenic system, cooling water, vacuum system, PPEN, etc

Integrated commissioning of larger parts and machine components.

From assembly…

To operation:



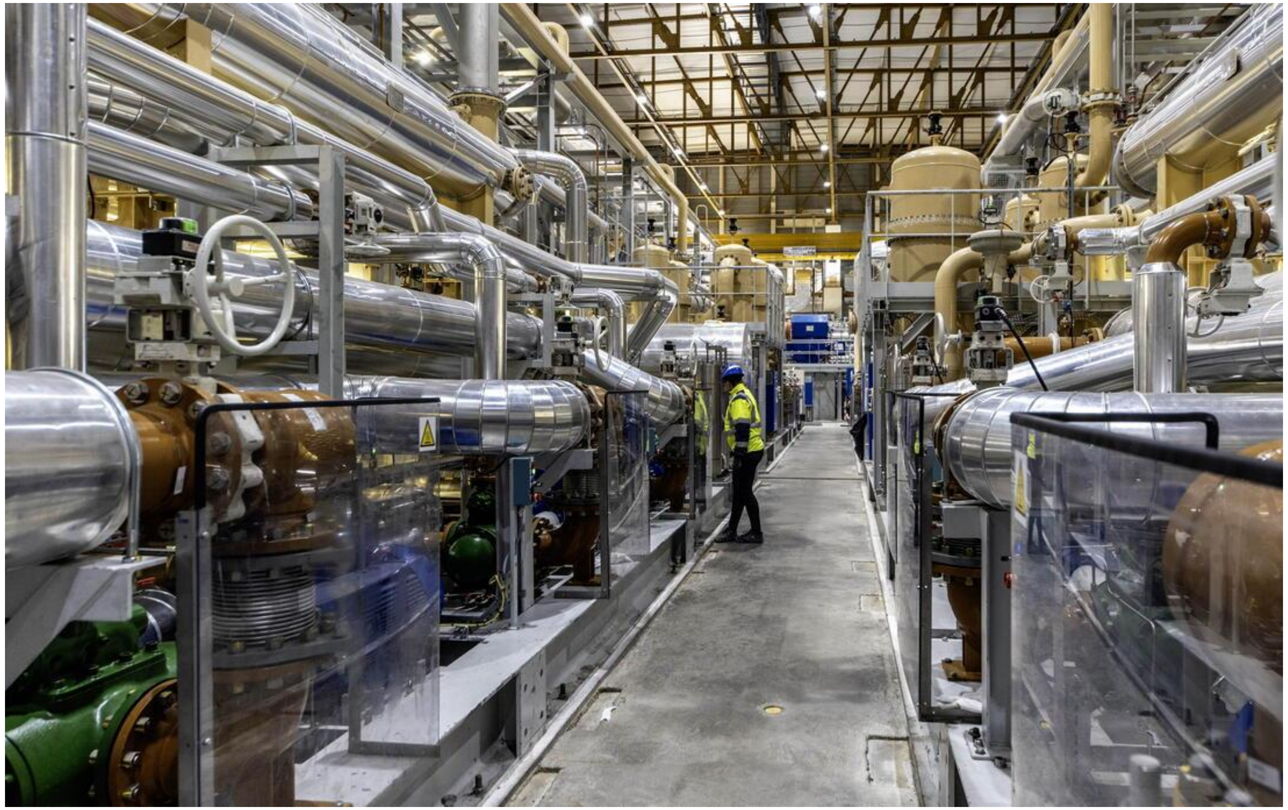
Vertical Pumps for HRS in assembly

Vertical Pumps for HRS in Operation

Gyrotrons ready for commissioning

From assembly to commissioning (II)

Cryoplant during civil works execution



Cryoplant during commissioning

From assembly to commissioning (&III)

Heat rejection system during assembly

Heat rejection system in operation

Testing facilities. Cryopumps

All of the ITER Cryopumps and its cryodistribution are delivered.

IO has set up a cryopump test bench that allows testing at operational conditions (4K).

The first Cryopumps was tested successfully and next is being prepared.

Testing facilities. SMF

Static Magnetic field facility.

Helping for qualification of components under SMF

Magnetic Cold Test Facility

18th May 2026

The first ITER TF coil was cooled to 4 K (-269 °C) over a 12-day period.

The conductor transitioned to its **superconducting** state.

Two weeks after high-current testing was conducted.

AT present next TF is in preparation

Updated ITER Research Plan

Updated ITER Research Plan

Machine configuration and research plan have been defined to gradually retire risks and provide robust path to objectives with intermediate milestones

Now		~18 months	~27 months (start autumn 2034)		~10 months
Engineering fabrication of system	Pre-SRO assembly	Integrated Commissioning I	Start of Research Operation (SRO)	Post SRO Assembly	Integrated Commissioning II

Install:
- Actively cooled W divertor
- Blanket shield blocks
- Inertial W First Wall panels
- 40 MW ECH
- 10 MW ICH

- Commission PCS and Protection Systems to reduce risks in DT-1
- Hydrogen L-mode to 15 MA/5.3T
- Demonstrate H-mode DD plasmas
- First assessment of boronization, fuel retention/recovery, ICWC

- Final, actively cooled W First Wall
- NBI: 33 MW
- ECH: 40 → 60-67 MW
- ICH: 10 → 20 MW
- Final diagnostics set

DT-2, ~3 x 10^{27} neutrons

FPO-y	FPO-(...)	FPO-x
DT (Q=10), high duty ≥ 500 s Q ≥ 5, 1000, 3000 s		

DT-1 ~ 6-7 years, ~3 x 10^{25} neutrons

FPO-5	FPO-4	FPO-3	FPO-2	FPO-1
D, DT (Q=10) ≥500 s High duty, 250 MW, ≥300 s	D, DT (Q=10) 500 MW, ≥300 s	D, DT (Q=10) 500 MW, ~50 s	D, DT, 100 MW, ~50 s	H, H+T, D

(start autumn 2039)

SRO objectives

- Demonstration of superconducting coils capability to operate plasma scenarios up to 15 MA/5.3 T → Full Magnetic Energy operation
- Identification and correction of error fields due to machine assembly and intrinsic toroidal asymmetric features of ITER
- Routine operation with shape/vertical position control up to 15 MA/5.3 T in L-mode (H)
- Exploration of H-mode operational space up to 7.5 MA/2.65 T in D plasmas (inc. P_{ECH} required for stationary H-mode operation) including ELM control demonstration
- Characterization of disruption loads (potentially up to 15 MA/5.3 T, if electromagnetic forces allow) → in-vessel component verification
- Commissioning and demonstration of effective disruption mitigation up to 15 MA/5.3 T in L-mode and 7.5 MA/2.65 T in H-mode
- Commissioning of ECH and ICH systems up to their nominal SRO power levels (40 MW and 10 MW) including compatibility of ICH with W wall
- Demonstration/optimization of wall conditioning (GDC, Boronization, ICWC, ECWC)

DT-1 Objectives (5 FPO campaigns = 80 months)

- Demonstration of reproducible operation with P_{fusion} = 500 MW with Q ≥ 10, t_{burn} ≥ 300s
- Demonstration of high-duty operation with P_{fusion} = 250 MW, t_{burn} ≥ 300s
- Qualification of all tokamak components and systems in nominal Q ≥ 10 operation
- Assessment of neutron effects and nuclear heating at nominal power levels on diagnostics and SC magnets in nominal Q ≥ 10 operation
- Characterization of burning plasmas physics and associated control and load mitigation challenges in nominal Q ≥ 10 operation
- Validation of radiation maps, demonstration of in-vessel tritium management, measurement of dust production rates, etc., in nominal Q ≥ 10 operation → Input to DT-2 licencing
- First operation of the TBM in nominal Q ≥ 10 operation and in high-duty operation with P_{fusion} = 250 MW
    - Coolant thermo-hydraulics conditions relevant for high-efficiency electricity production
    - Tritium breeding to confirm Tritium Breeding Ratio (TBR) in fusion power reactors

DT-2 Objectives (3 FPO campaigns)

- Demonstration of high-duty operation with $Q \geq 10$, P_{fusion} = 500 MW for t_{burn} = 300 – 500;
- Demonstration of long pulse operation with $Q \geq 5$, P_{fusion} = 400 MW for t_{burn} = 1000 s;
- Demonstration of steady-state operation with $Q \geq 5$ and P_{fusion} = 400 MW for t_{burn} = 3000 s;
- Exploration of $Q \geq 10$ scenarios for a wide range of $P_{fusion} \leq 700$ MW;
- Exploration of burning plasma physics, scenario integration and integrated controls at high Q, high P_{fusion} operation;
- Assessment of fusion reactor physics and operational issues: Optimization of H&CD mix, minimum set of diagnostics and actuators, achievement of high Q plasmas with integrated control, and exhaust of power and particles;
- Consolidation of the tritium breeding efficiency evaluations, tritium management, conditions for high-efficiency electricity production, etc., for reactors breeding blankets, etc. up to the total neutron fluence of, at least, $3x10^{27}$

Concluding remarks

ITER is a challenging project, that turned a corner in 2023

Repairs of components has been carried out and assembly work is being performed at a record rate with sound Project Management indicators SPI=1.06, CPI=1.12

A new and robust ITER Baseline has been developed with many improvements and new concepts; however, it will take a few years for ITER to reach Q=10

Further R&D on a very wide range of topics is needed to prepare and optimize the exploitation of ITER in its path to achieve Q = 10 so that this is achieved in the shortest possible time

Thanks you for your attention !


27 May 2026
5th Module in pit
YUJIN