Il Progetto ITER e la fusione nucleare

Pietro Barabaschi, Director-General
27 March 2025

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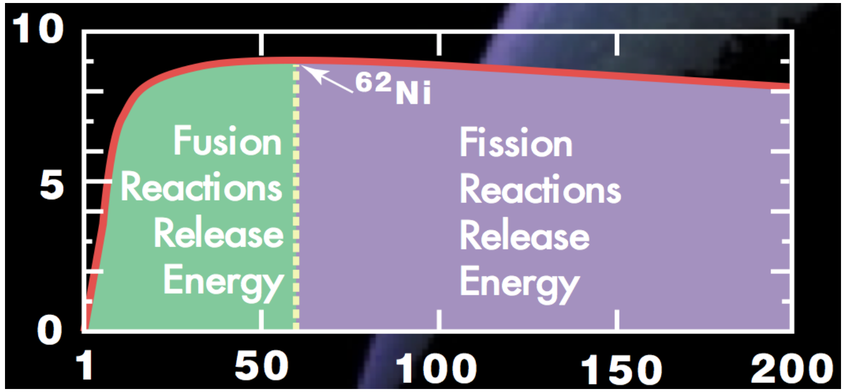
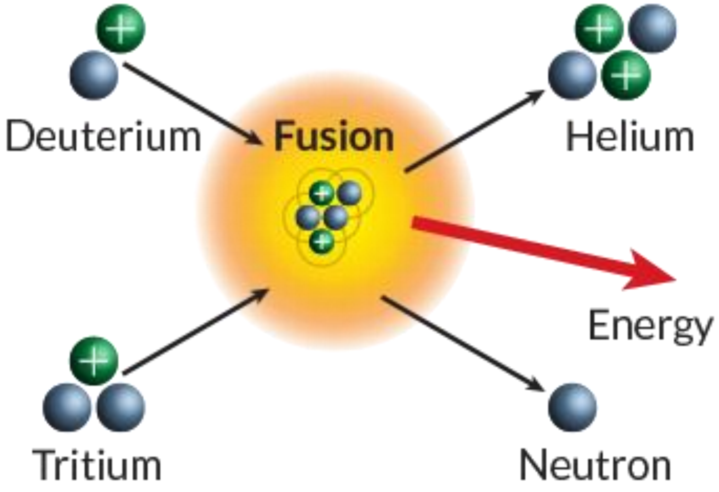
china eu india japan korea russia usa

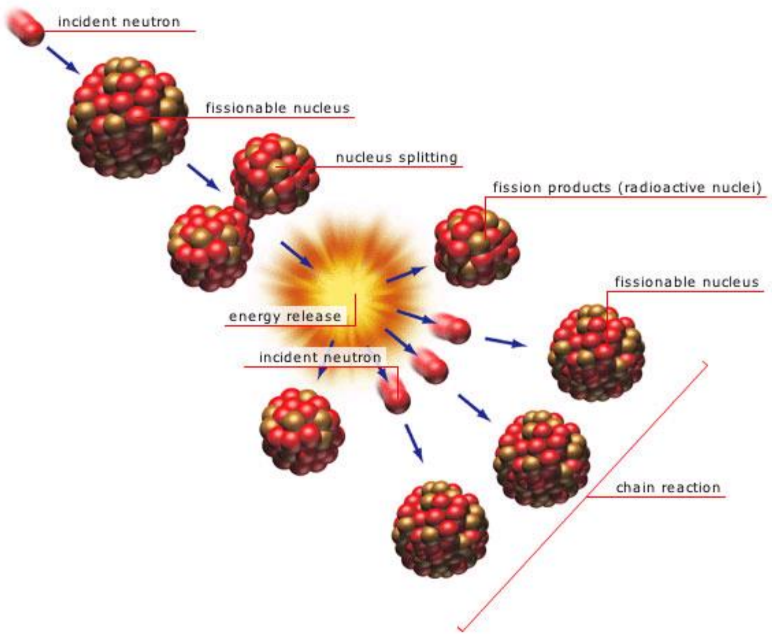
Fusion and Fission



Nuclear Fusion



Nuclear Fission



Fusion powers our sun

Solar radius ~100 Earth radii

Solar mass = 333,000 Earth masses

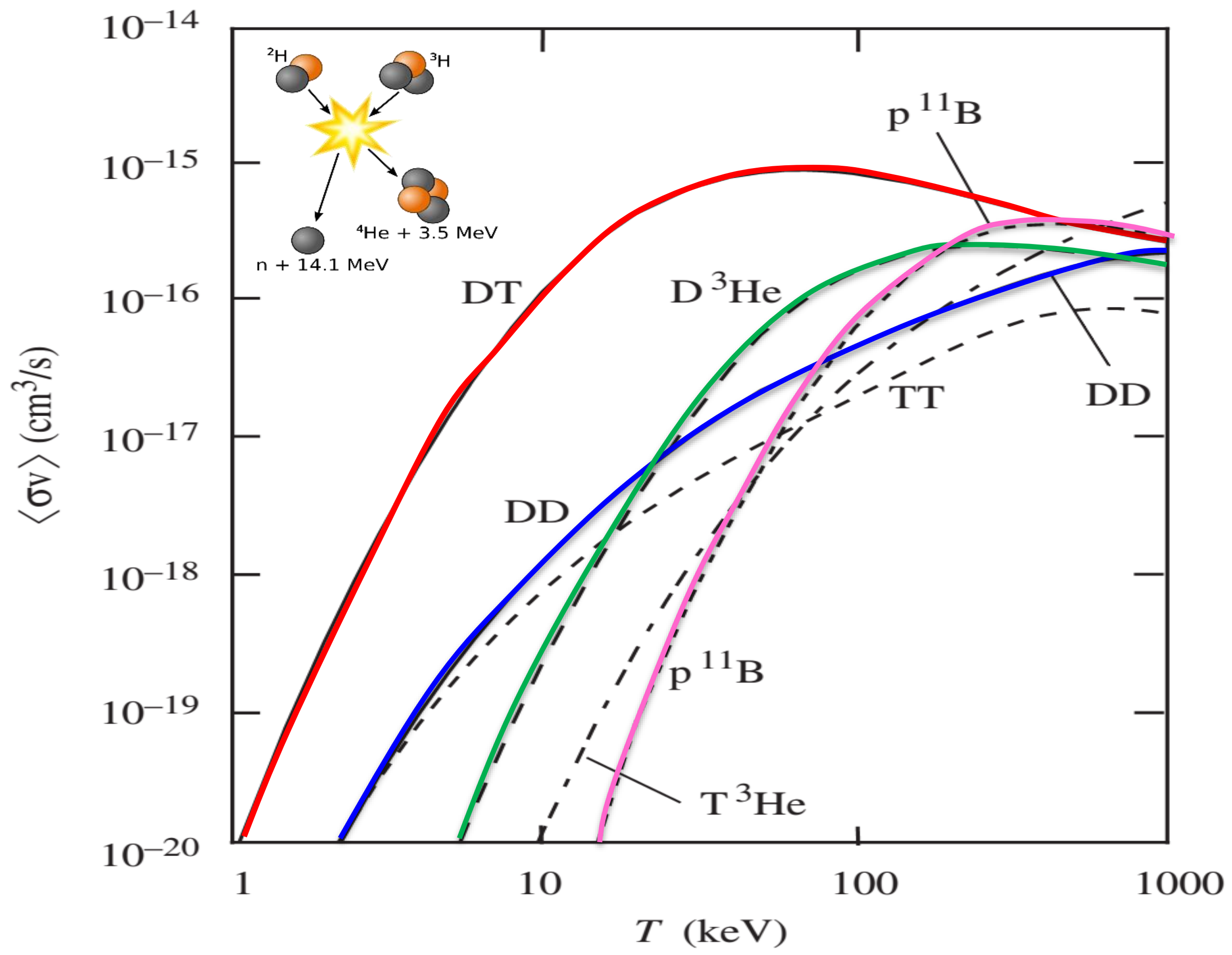
Surface temperature = 5500 C

Central temperature ~ 15 millionC

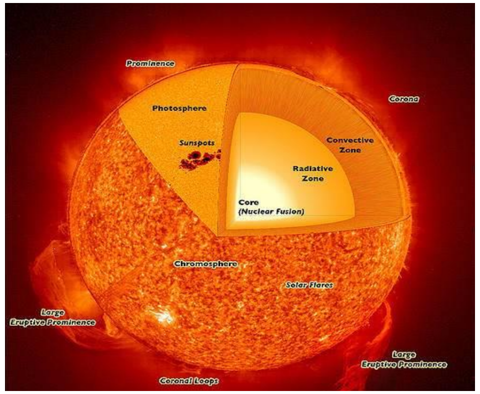
Central density ~ 150’000Kg/m^3

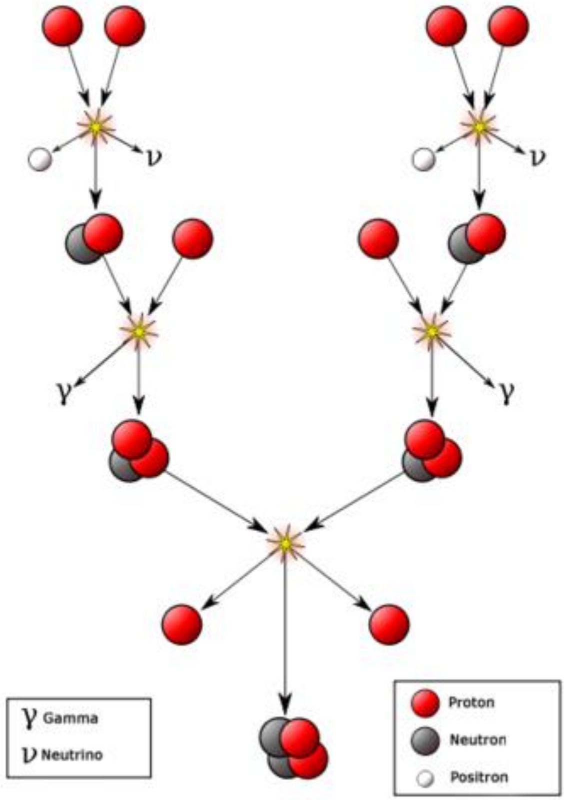
Time for fusion reaction energy in the core of the sun to reach us: ~1M years + 8 minutes

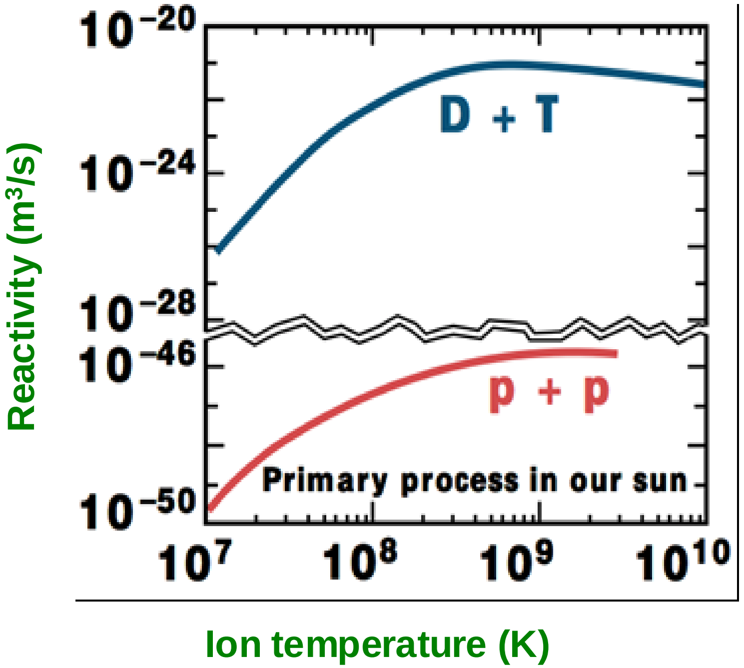
DT is by far the easiest fusion reaction to achieve

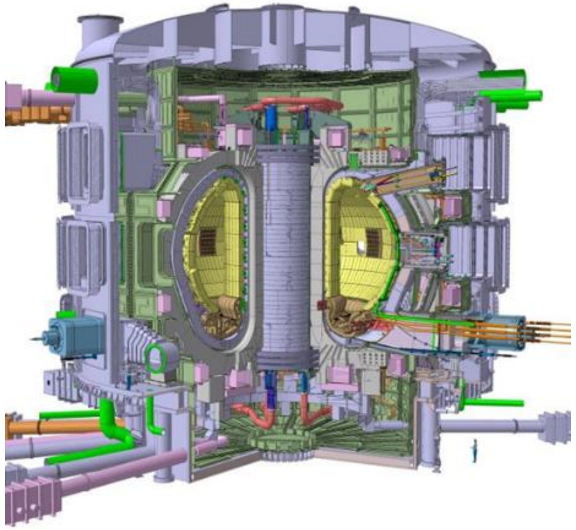


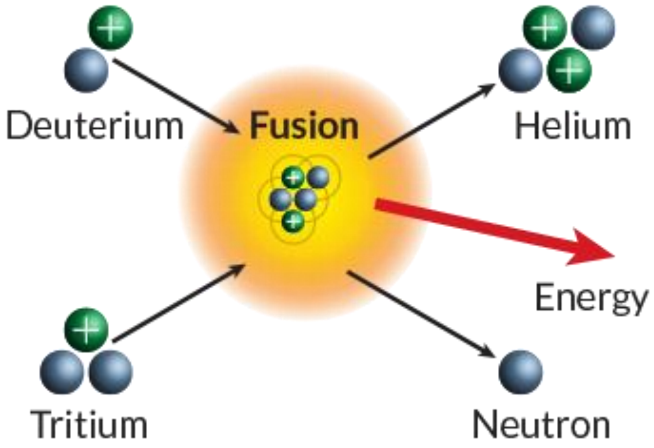
p-p and DT fusion











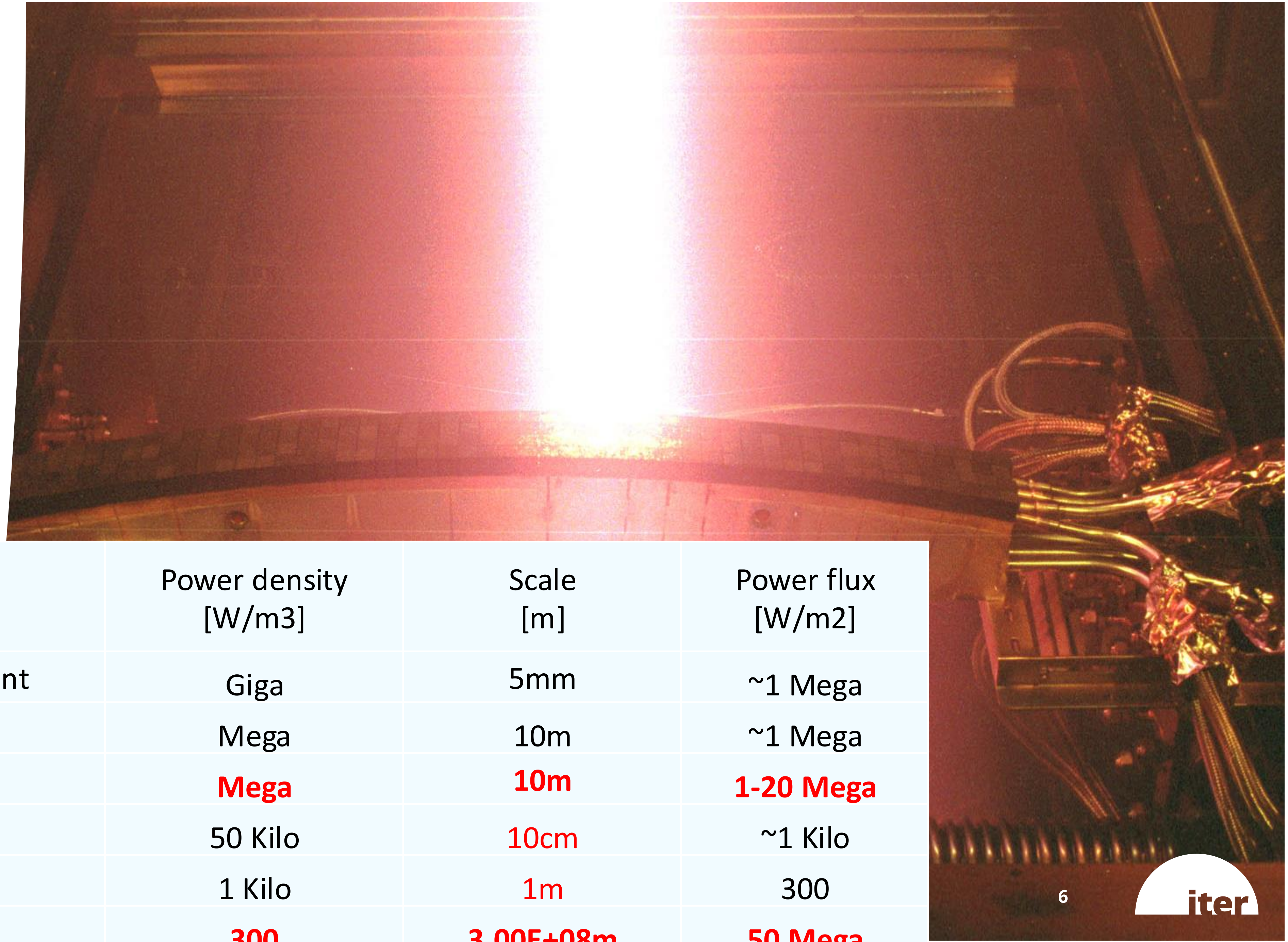
THE TECHNOLOGY

Fusion requires hot plasma

Has inherent safety features; however:

- **Heat source and sink cannot be intermingled**
- **Neutron rich (80% of energy)**

⟶ Surface heat flux and neutron damage resilience, is a key technological barrier



	Power density [W/m3]	Scale [m]	Power flux [W/m2]
Light Water Reactor fuel element	Giga	5mm	~1 Mega
Burning coal	Mega	10m	~1 Mega
DT fusion reaction in ITER	**Mega**	**10m**	**1-20 Mega**
Humming bird body	50 Kilo	10cm	~1 Kilo
Human body	1 Kilo	1m	300
Sun	**300**	**3.00E+08m**	**50 Mega**

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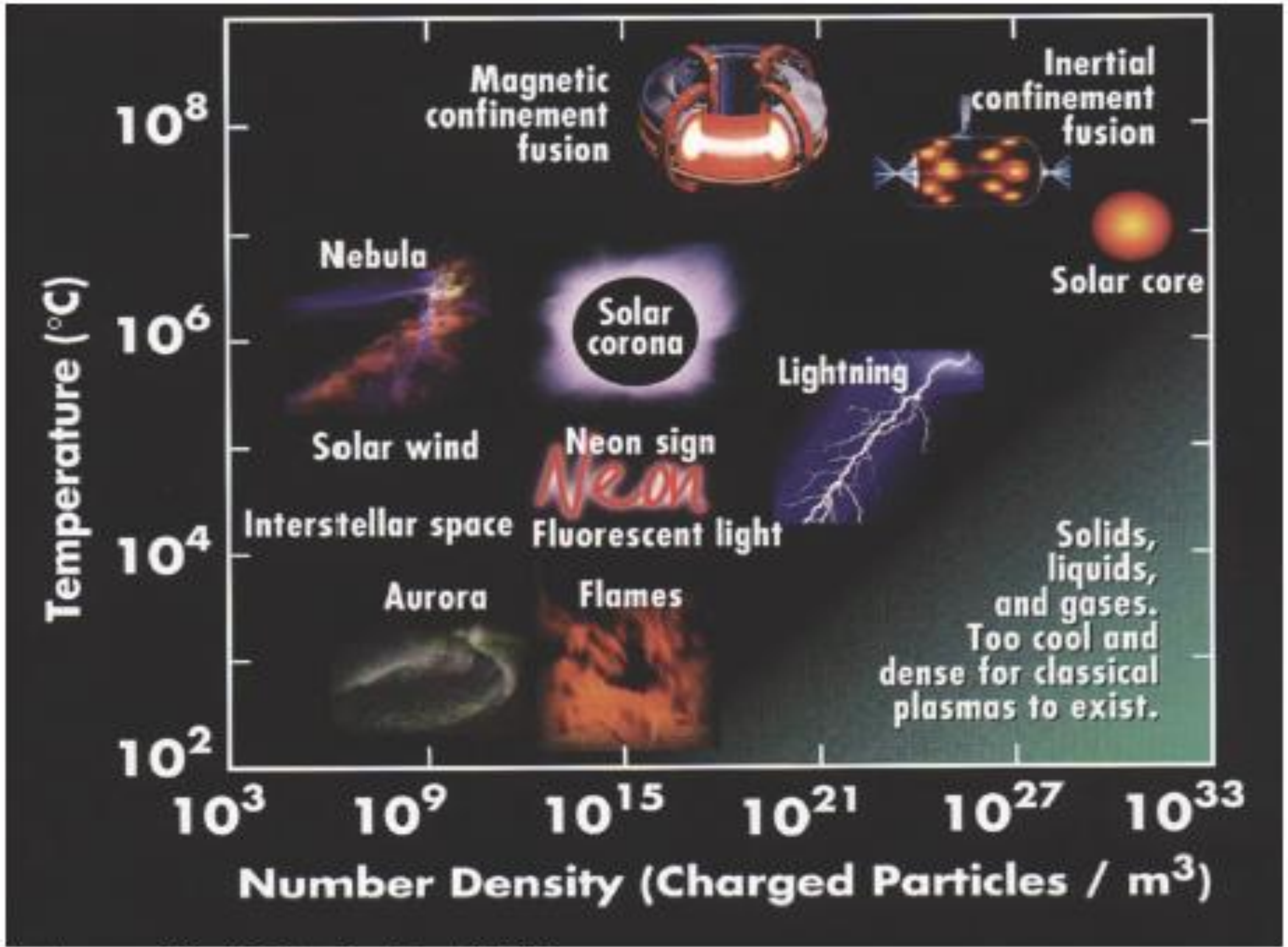
Plasmas

99% of the visible universe – which BTW is estimated to be ~5% of the total energy+mass of the universe, the rest guessed to be dark matter and dark energy.



Confinement

In the sun confinement is achieved by gravitational forces, cannot be replicated on earth

Mankind has been able to create significant quantities of nuclear fusion by two main confinement methods:

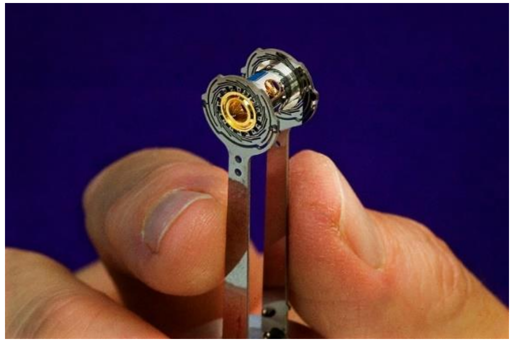
Magnetic Confinement – Inertial Confinement

In inertial confinement tiny pellets of DT fuel are rapidly compressed and heated by powerful lasers or ion beams. The outer layer of the pellet explodes outward, creating an inward shock wave that compresses the core to the point where fusion occurs.

In **magnetic confinement** the fusion fuel is in plasma state (high temperature ionized gas) and is kept confined in a closed space by using **magnetic fields**.

Inertial Confinement

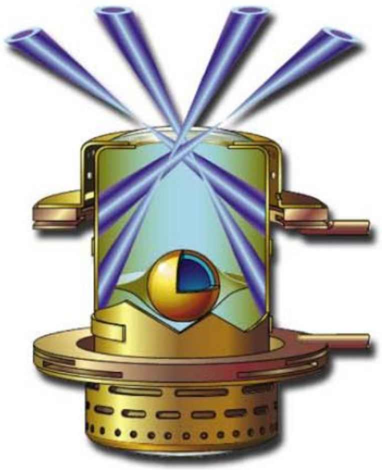
Laser implosion of small (3mm diameter) solid deuterium–tritium pellets produces fusion conditions,

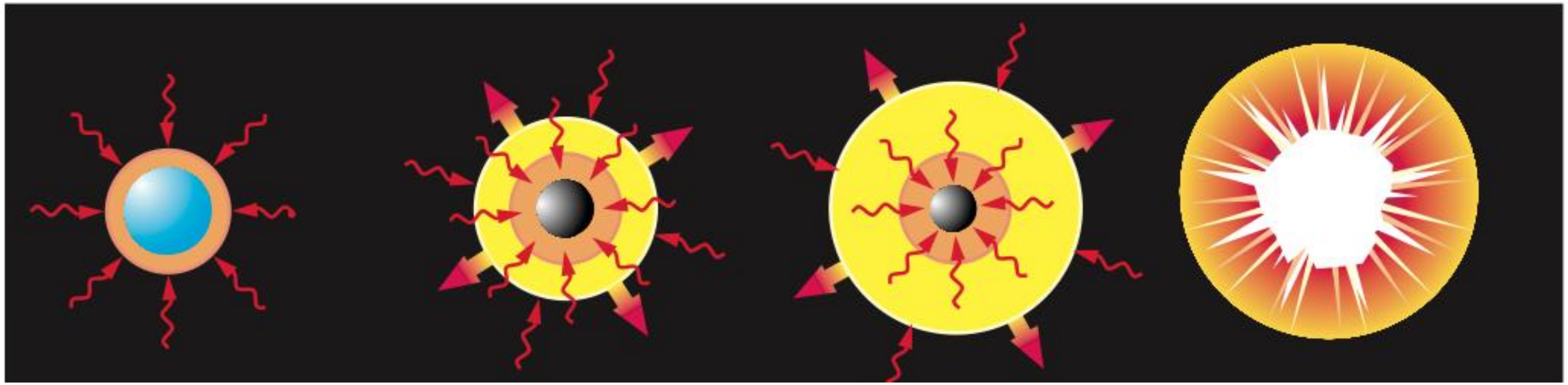


Pressure generation

Compression

Ignition and burn: Peak compression fuel reaches ~1000 x times density for ~10^{-11} s. Core is heated and 'spark ignition' occurs.





Surface Heating | **Compression** | **Ignition** | **Burn**

Magnetic Confinement – basics

We can create the conditions suitable for nuclear fusion by **heating** and **confining** our fuel long enough in a limited portion of space. In a confined space, with a high average energy, the particles in the high tail of the energy spectrum will eventually fuse together

But we need to increase the temperature of the fuel up to > 100 MK. The fuel will be in the **plasma** state, and due to its temperature it cannot be contained with a "solid" container.

Max plasma pressure in ITER will be in the order of 10 bar

pressure, p ~ 10bar, in ITER as in tire of a race/road bike

p ∝ density * temperature

$p \propto n * T$

~6 orders of magnitude, up in T, and down in n

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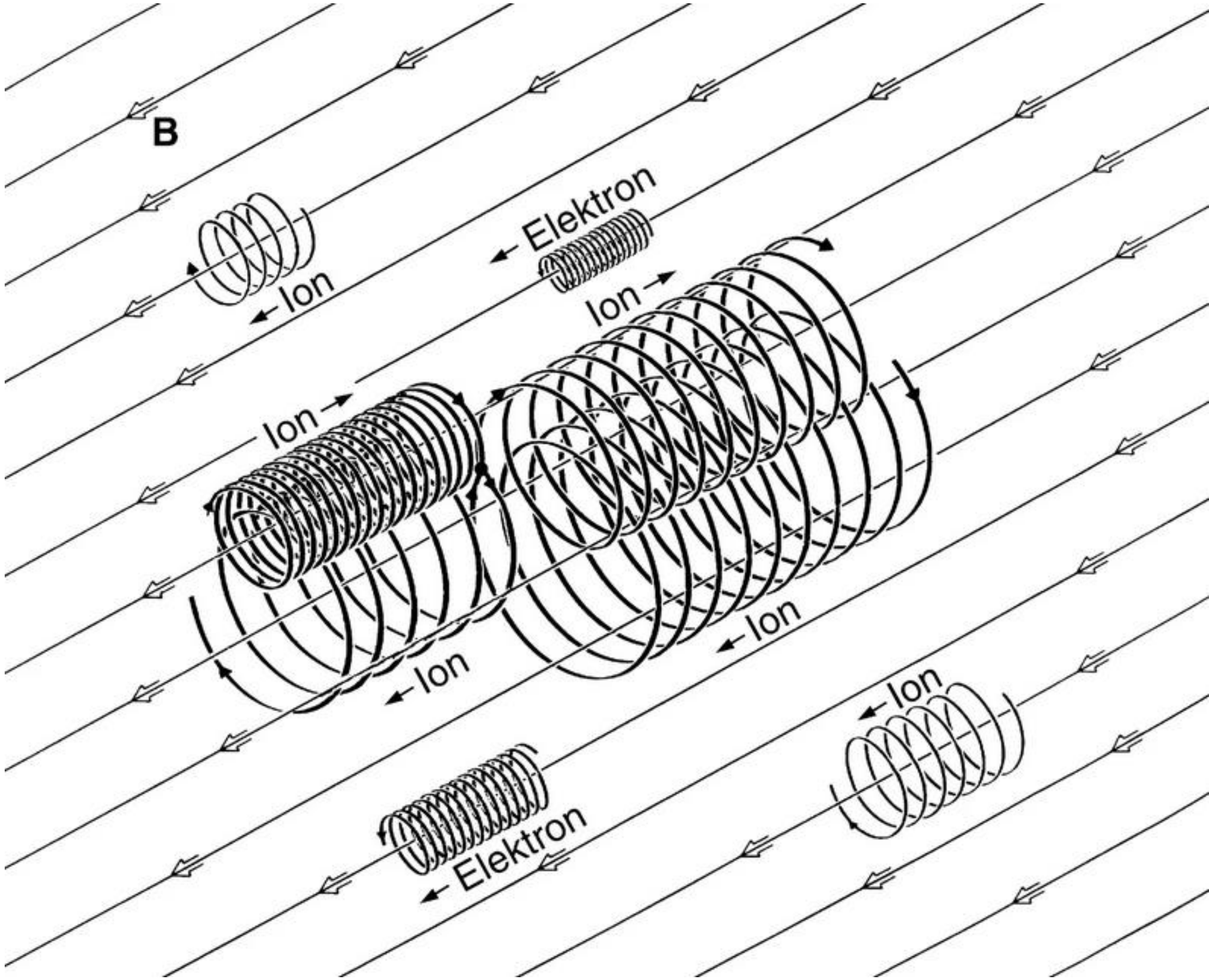
Magnetic Confinement – basics

Magnetic confinement devices use magnetic fields to confine the fusion fuel in the form of a hot plasma, avoiding the direct contact of the hot part of the plasma with the surrounding walls

Ions and electrons are forced into **circular and helical orbits** around the magnetic field lines.

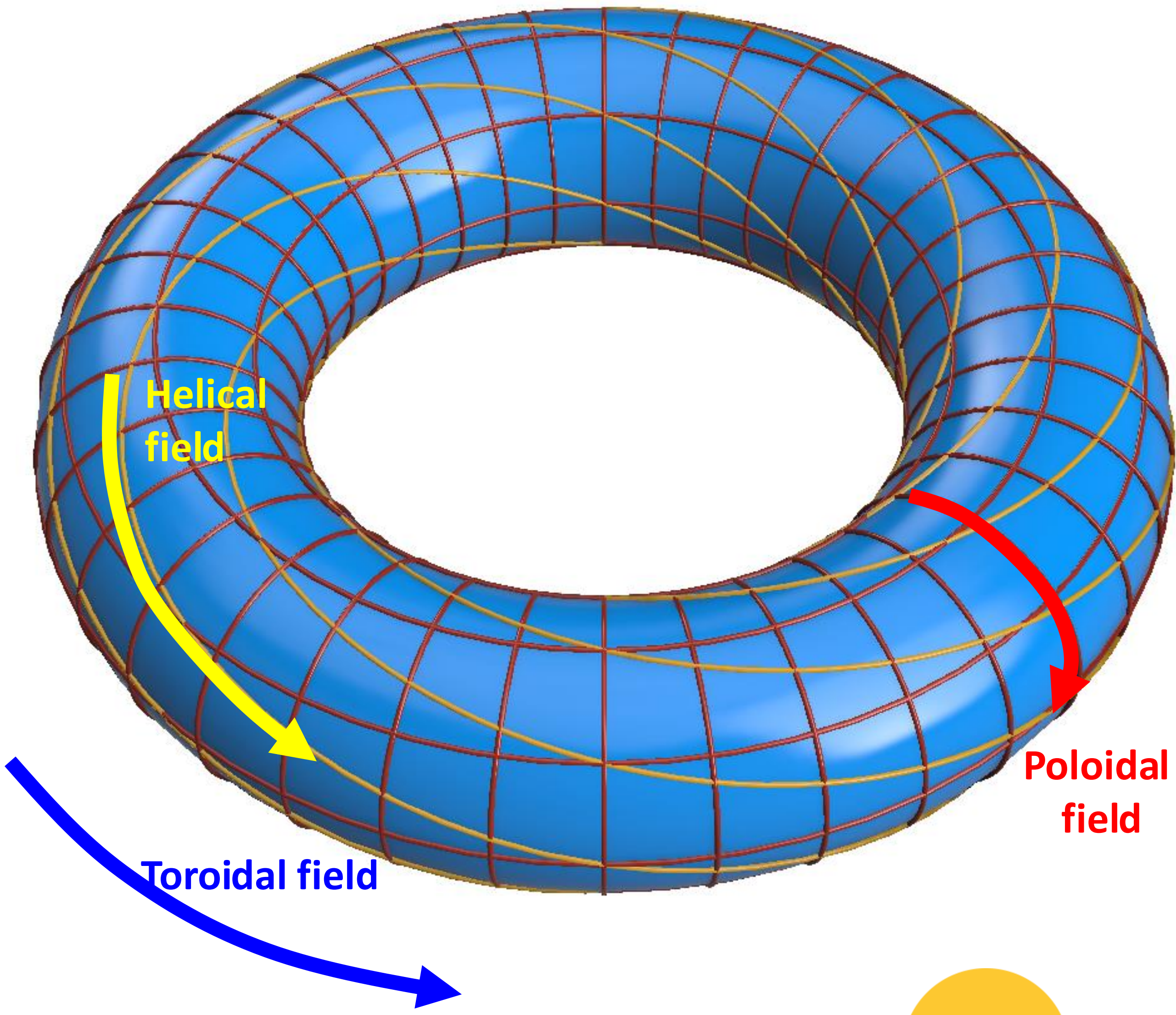
The particles are thus ‘tied’ to the field lines, but they can **move freely in the longitudinal direction** along the field lines.

In a suitably shaped magnetic field cage it is therefore possible to **confine a plasma** and keep it away from material walls.



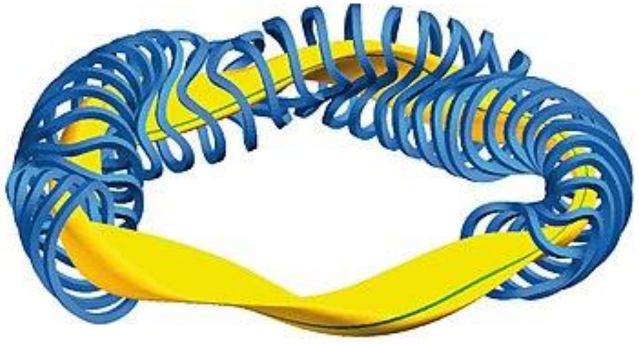
The Helical Field

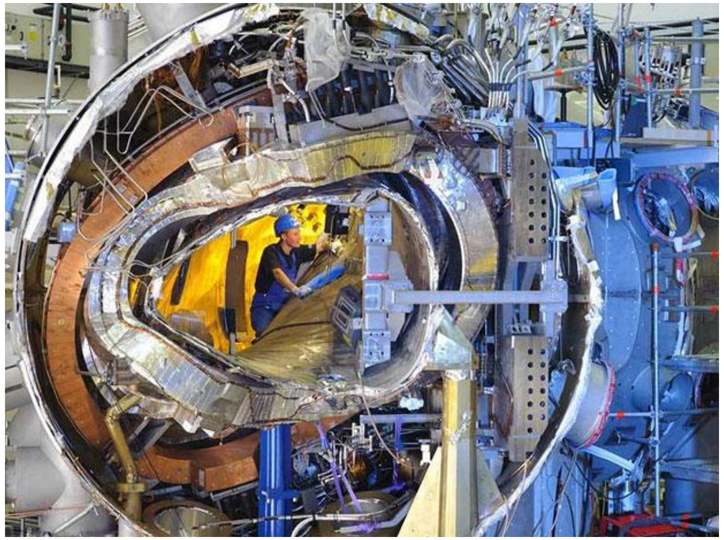
In this way the particles will move along the helical field lines around the torus, and no charge accumulation will occur.



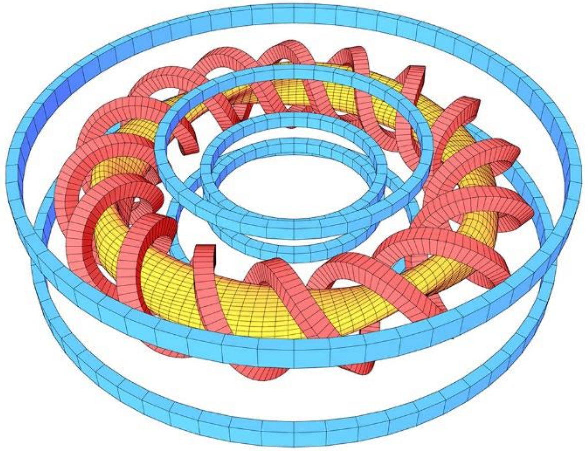
Stellarators

Helias : Modular stellarator using special crooked coils to create a twisted magnetic field ribbon with a variable bean-shaped cross-section. Consists of several (about 3 to 5) repeating sections. Wendelstein 7-X stellarator





Heliotron: A stellarator that uses one or two helical coils and several poloidal coils to confine particles. The LHD Large Helical Device stellarato



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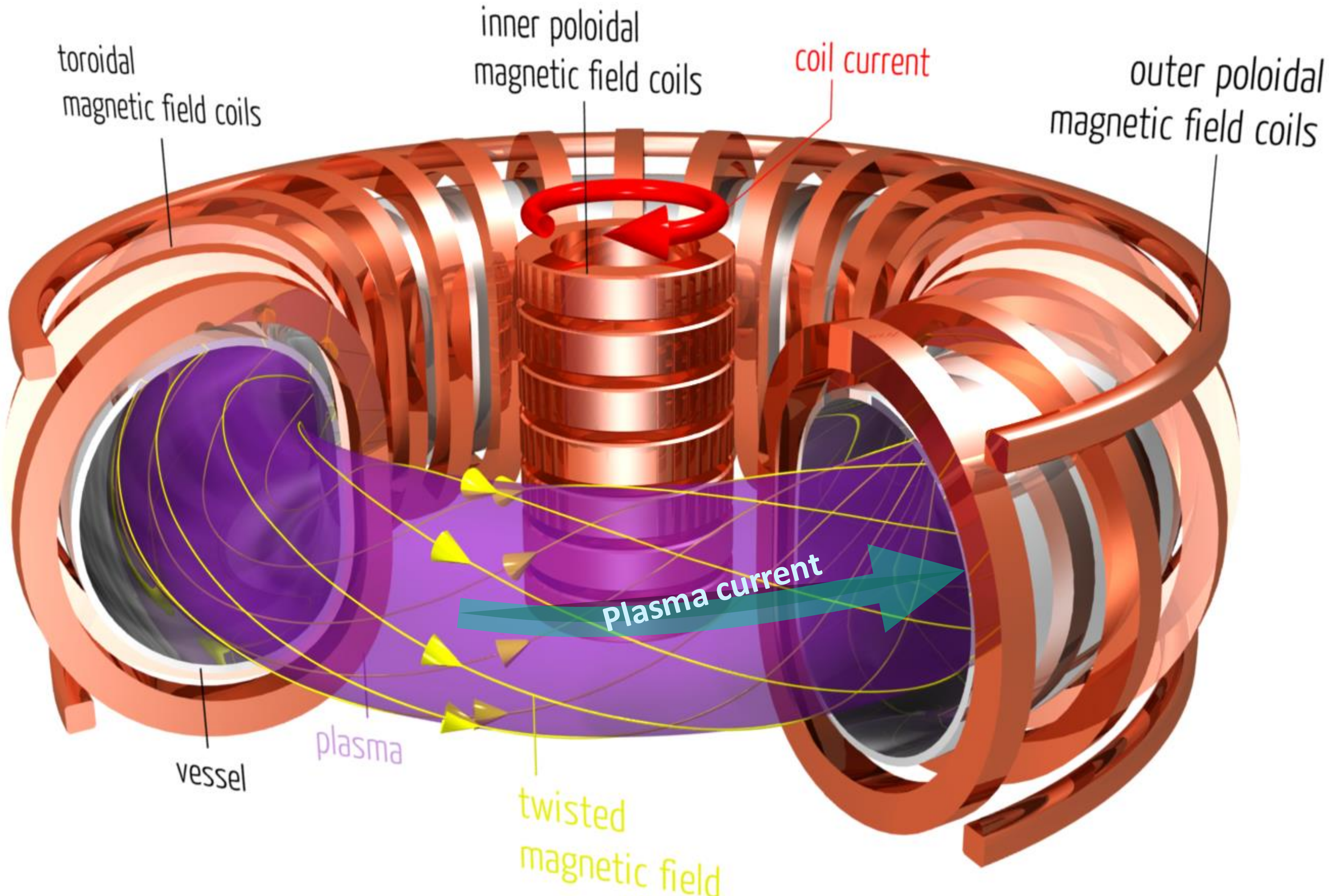
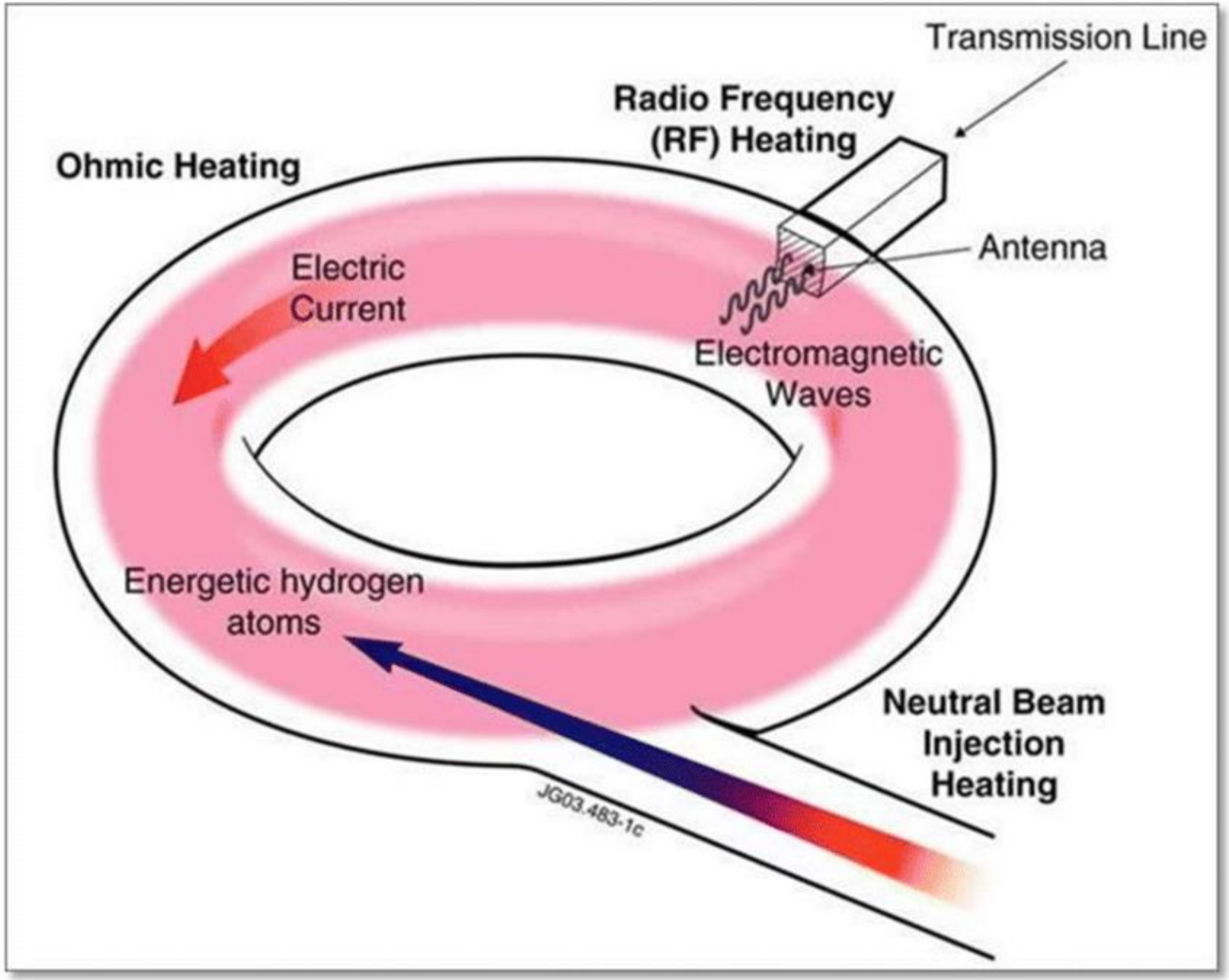
The Tokamak

- The Tokamak was Invented by : A Sakharov and I. Tamm at the Kurchatov Institute in Moscow in 1950



Heating systems



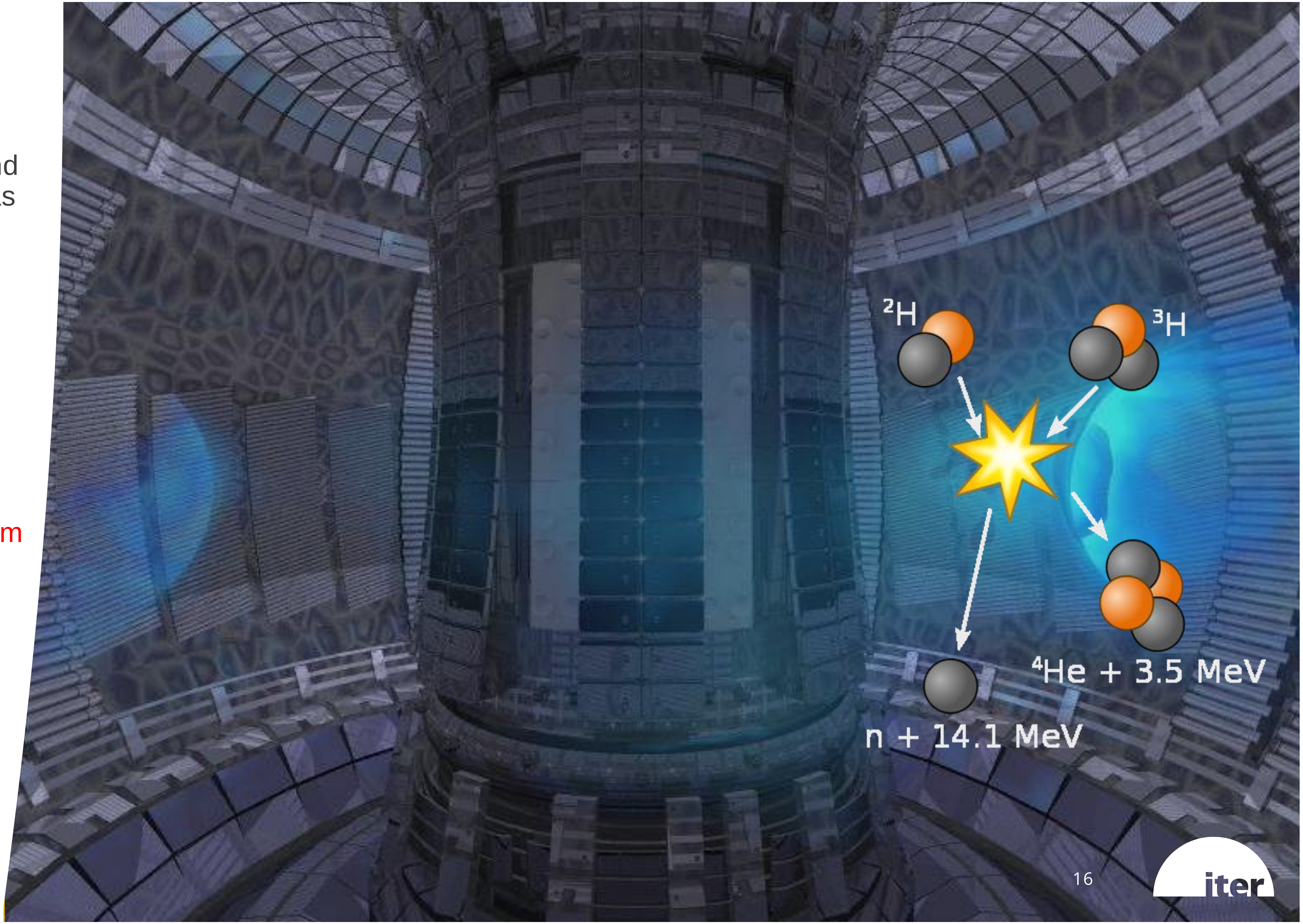
f_{EC}~100GHz

f_{IC}~10MHz

WHY ITER?

"Demonstrate the scientific and technical feasibility of fusion as a source of energy":

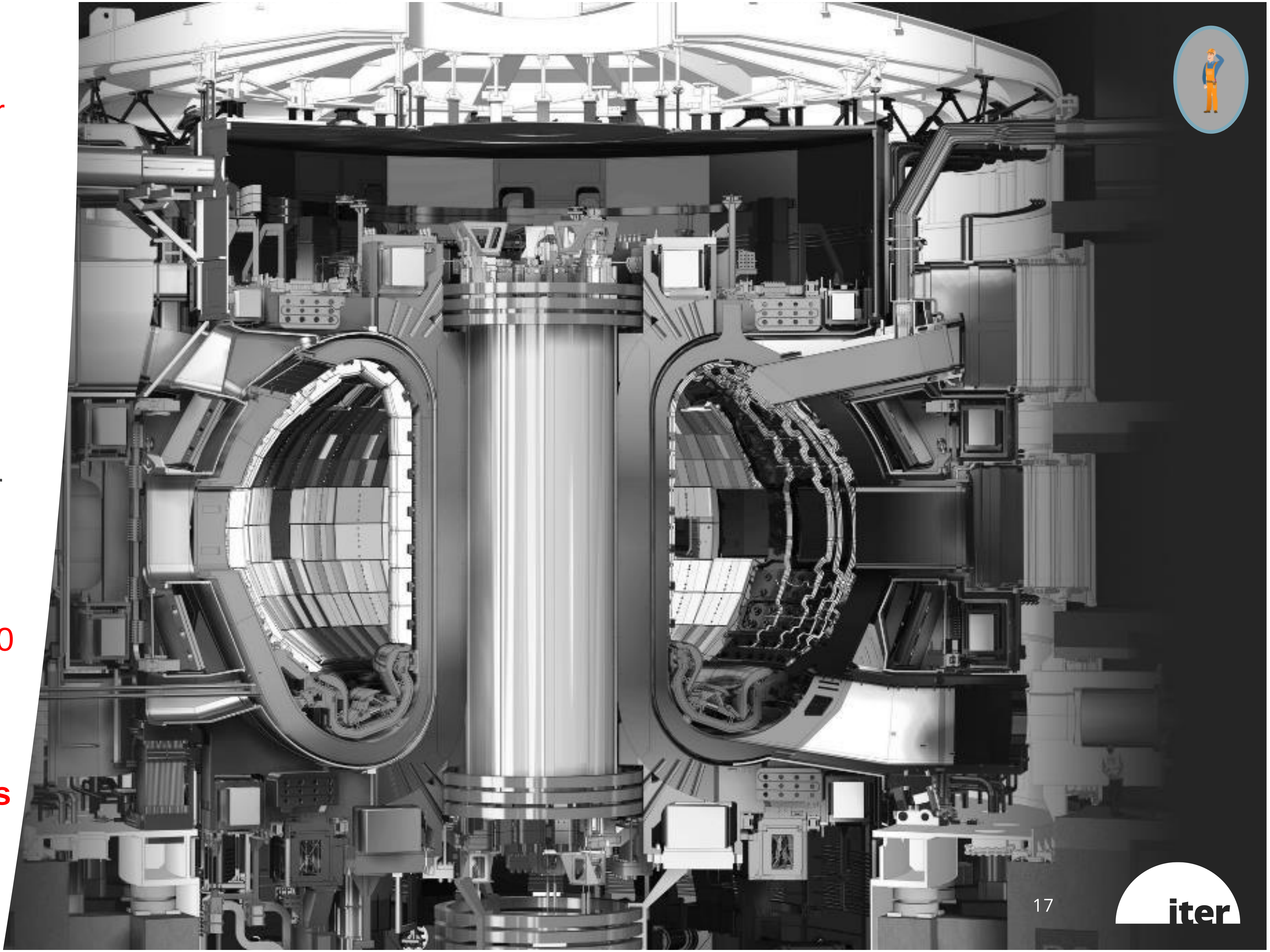
- Q>10 in D-T plasmas
- In Thermal Equilibrium (400s->3600s)
- Nuclear licensing experience
- Proof(s) of concept of tritium breeding
- Knowledge management and transfer to future reactors, including technology breakthroughs, codes & standards, etc.



WHAT IS ITER?

A tokamak designed for power & duration performance

- A 830m^3 toroidal vacuum chamber, the first confinement barrier
- A "magnetic bottle" with a 10,000 tons of superconducting magnets, cooled to -269^{o}C, enclosed in a 30mx30m cryostat, the second confinement barrier
- A plasma of deuterium and tritium, confined and controlled by the magnetic field, and heated to 100-150 million degrees
- **Size largely determined by confinement and power flux considerations**



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FROM INTENTION… TO REALIZATION

November 1985

November 2006

Aug 2010

2024

50% of the world's population.

80% of the world's industrial capacity

EU, as Host, contributes with 45%. Others with ~9%

Of:

1) **Cash contributions**
2) **In-Kind contributions**

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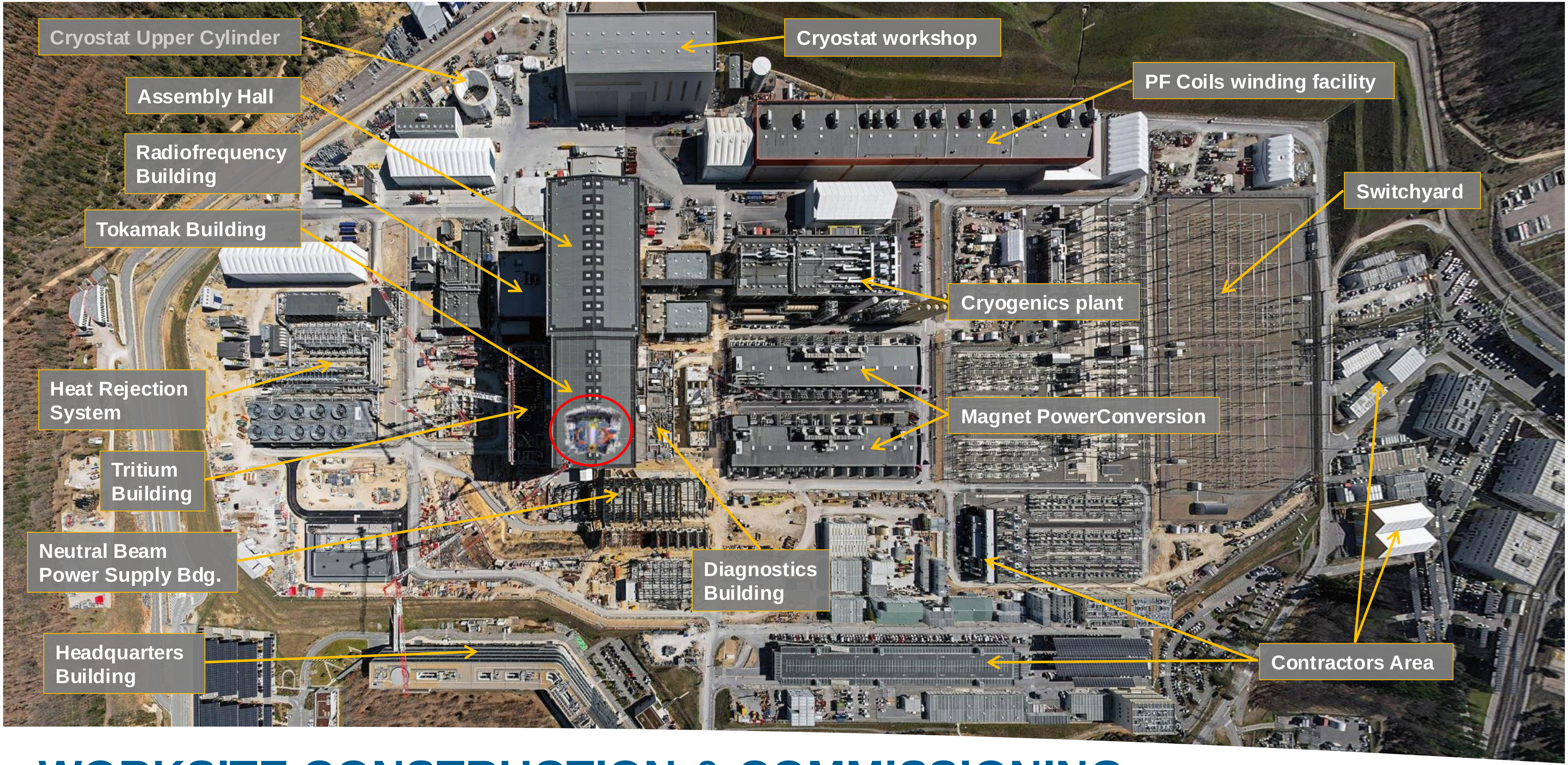


WORKSITE CONSTRUCTION & COMMISSIONING

~ 5000 staff every day enters the worksite

TOROIDAL FIELD COILS

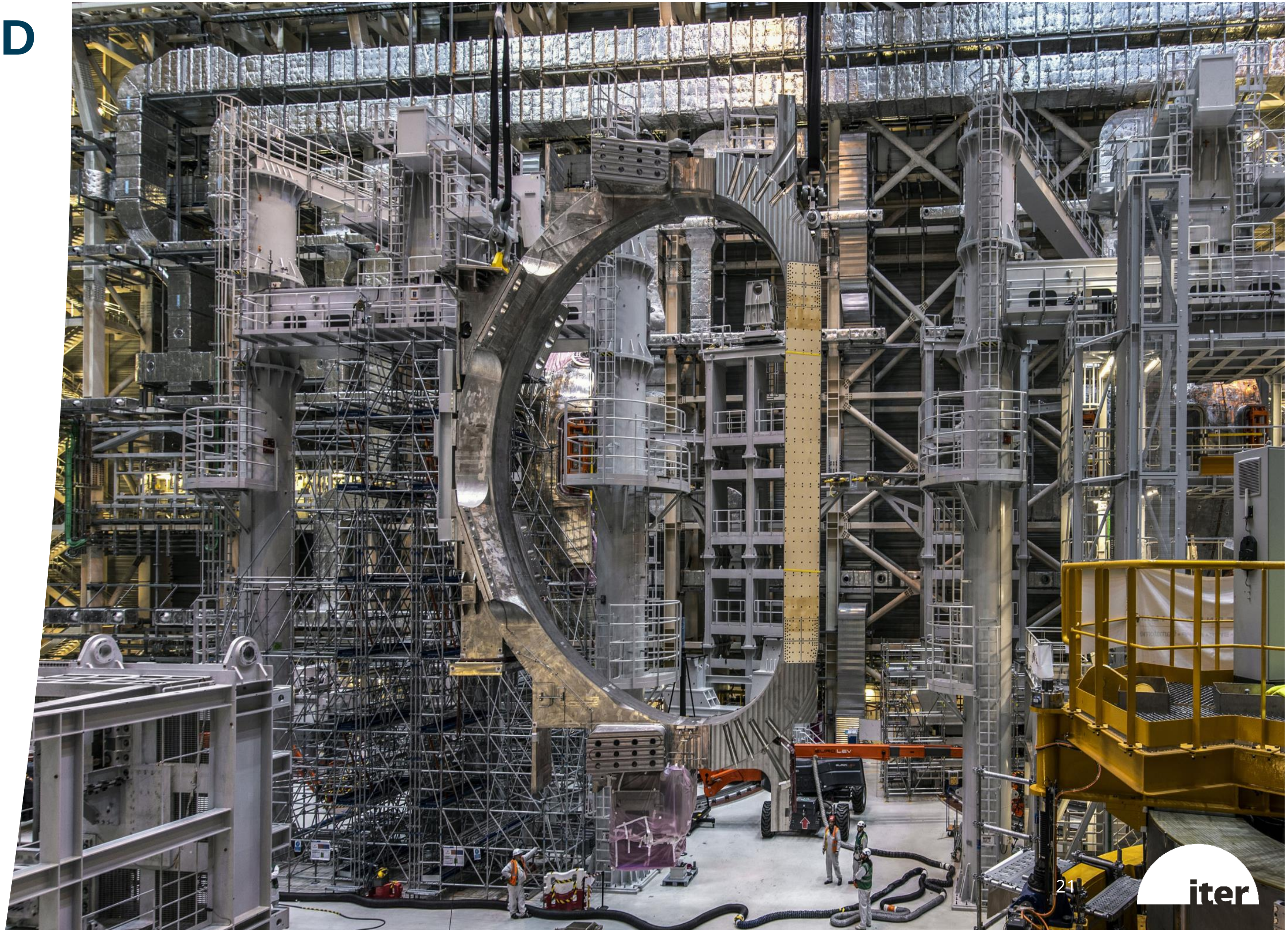
- 18 coils
- 41 gigajoules
- 11.8 Tesla

Each coil:
- 360 tonnes
- 9 x 17 metres

Status:

Manufacturing of all 19 coils completed.

All coils already onsite



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POLOIDAL FIELD COILS

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

Total magnetic energy: 4 gigajoules

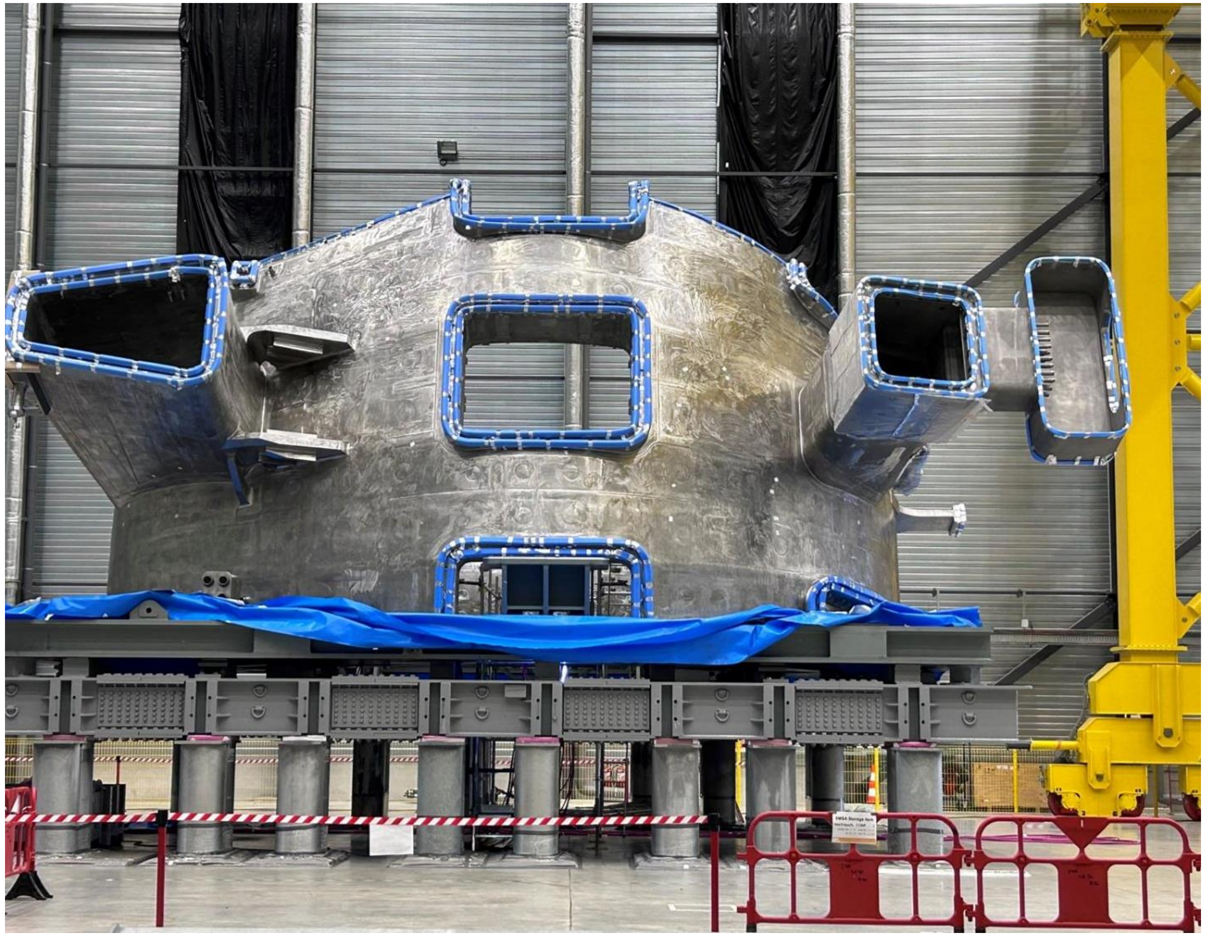
Maximum magnetic field: 6 Tesla

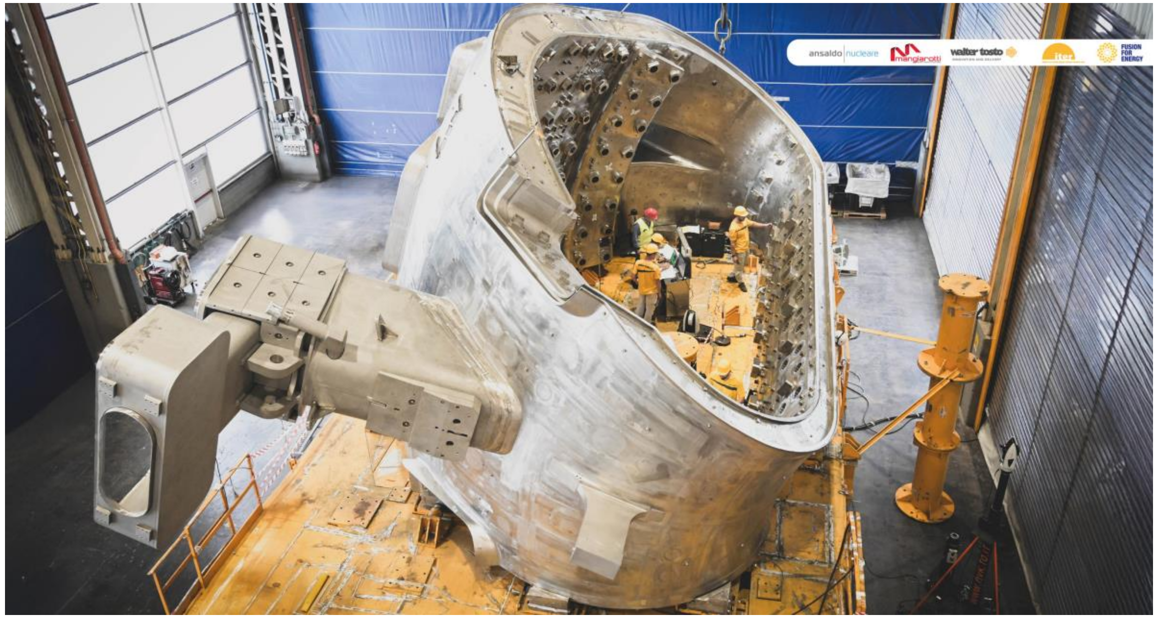
Status:

All PF delivered on-site

VACUUM VESSEL SECTORS

Korea has delivered all its four sectors.

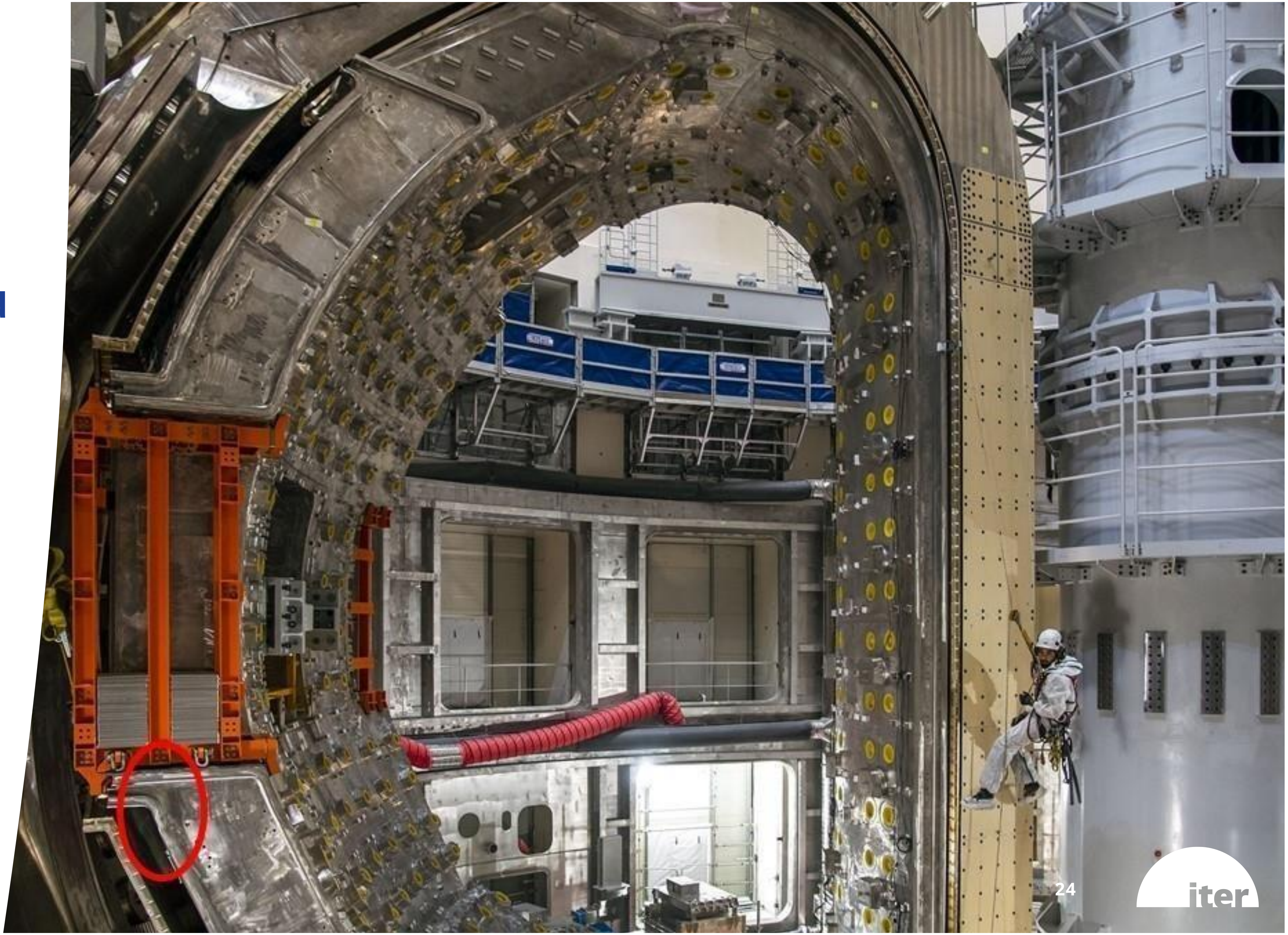


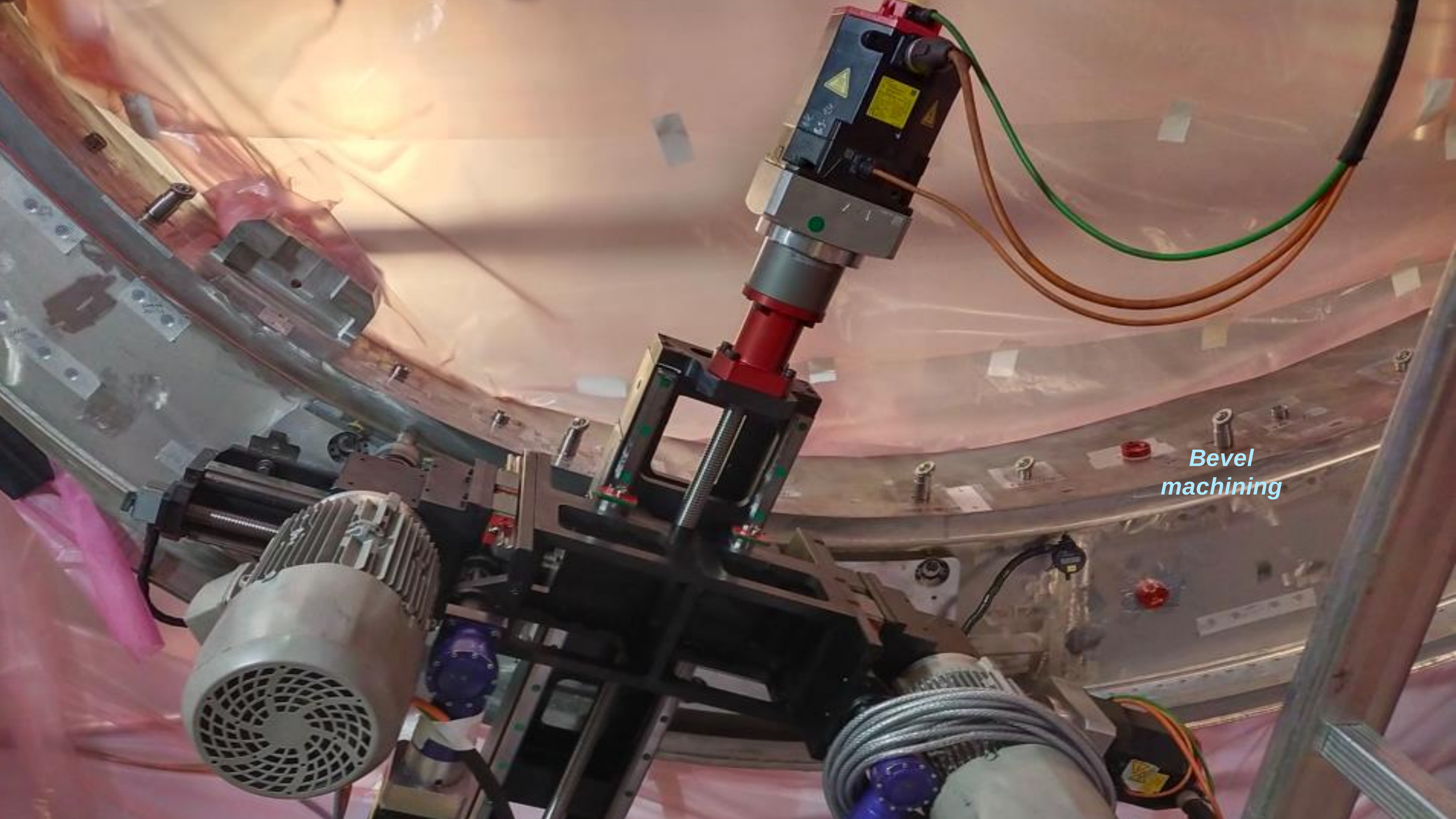


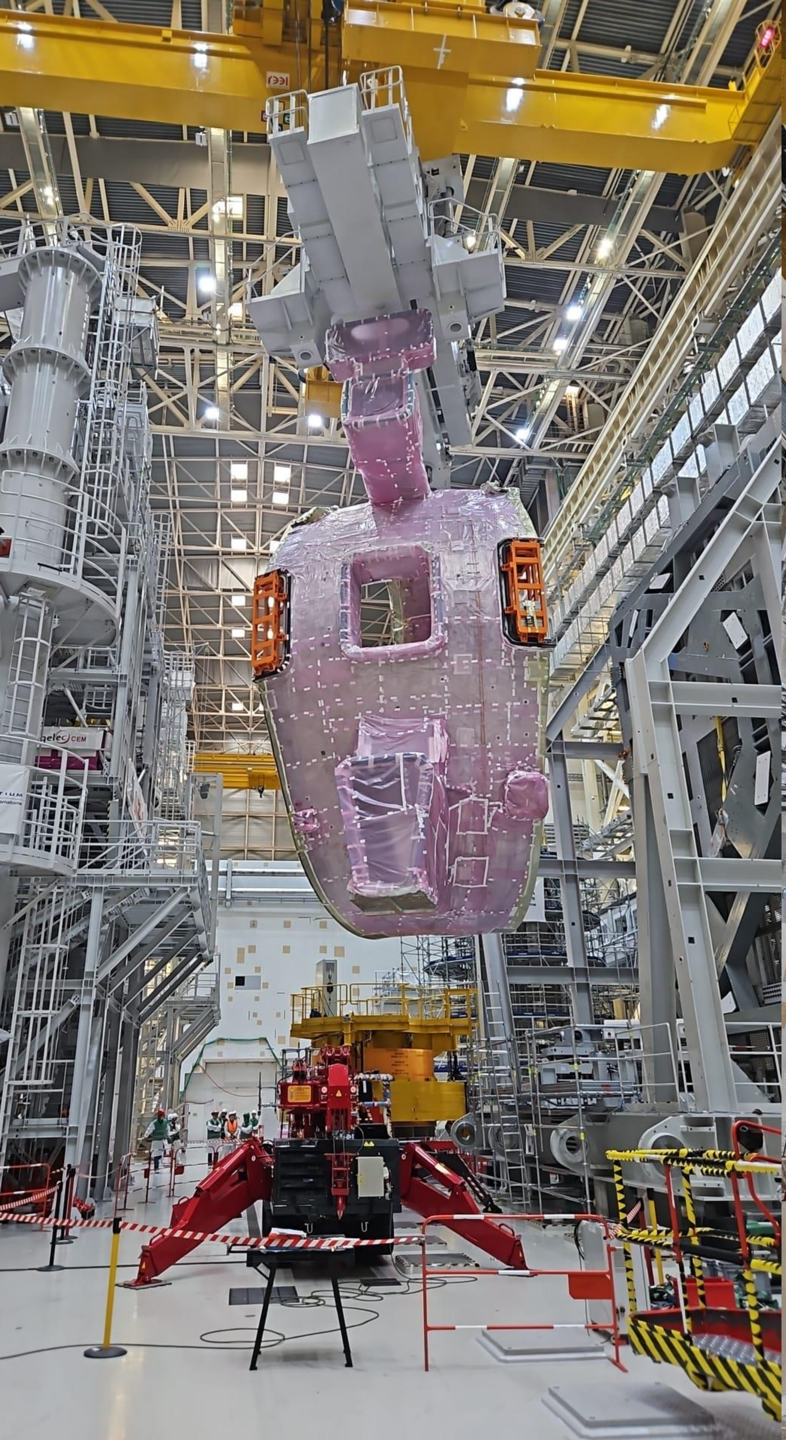
Europe delivered its first vacuum vessel sector in October 2024. Second was completed in March 2025 – being now shipped

CHALLENGES OF FIRST-OF-A-KIND COMPONENTS

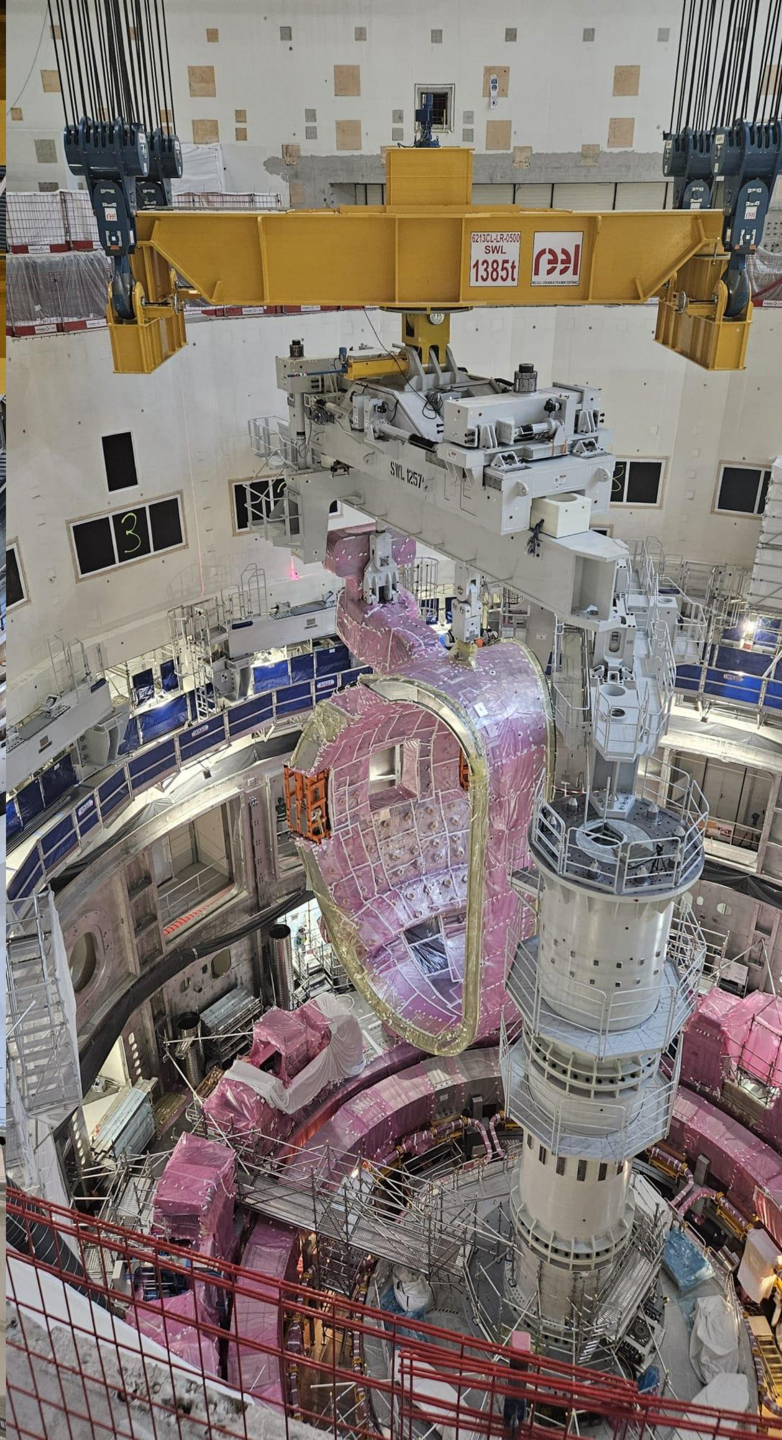
Vacuum Vessel sectors have geometric non-conformities in the field bevel joints.




Bevel
machining




SWL 1257t


SWL
1385t

TWO POWER SUPPLY SYSTEMS

- Steady-state electrical network
- Pulsed-power electrical network (sometimes called “reactive power compensation”)

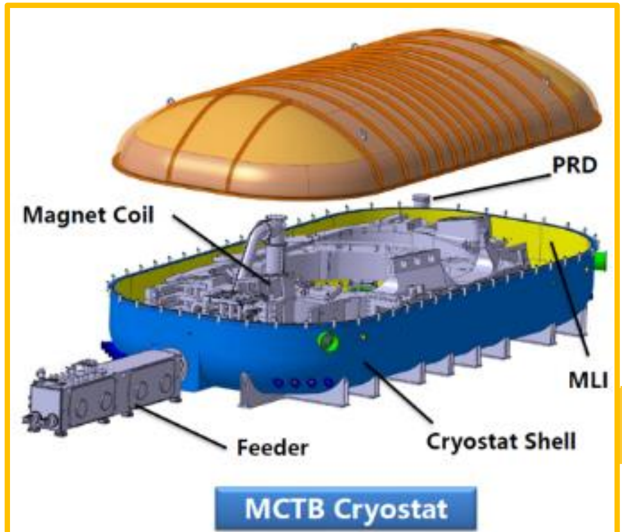
MAGNET CONVERSION
Equipment largely installed and commissioned

CRYOGENICS PLANT COMMISSIONING

Helium gas compressor and gas distribution network has completed functional testing in July 2024.

This completes the performance test of the first compressor train.

Liquid Helium production has started in December 2024, with the near-term goal to support operation of a Magnet Cold Test Bench (MCTB) under construction.

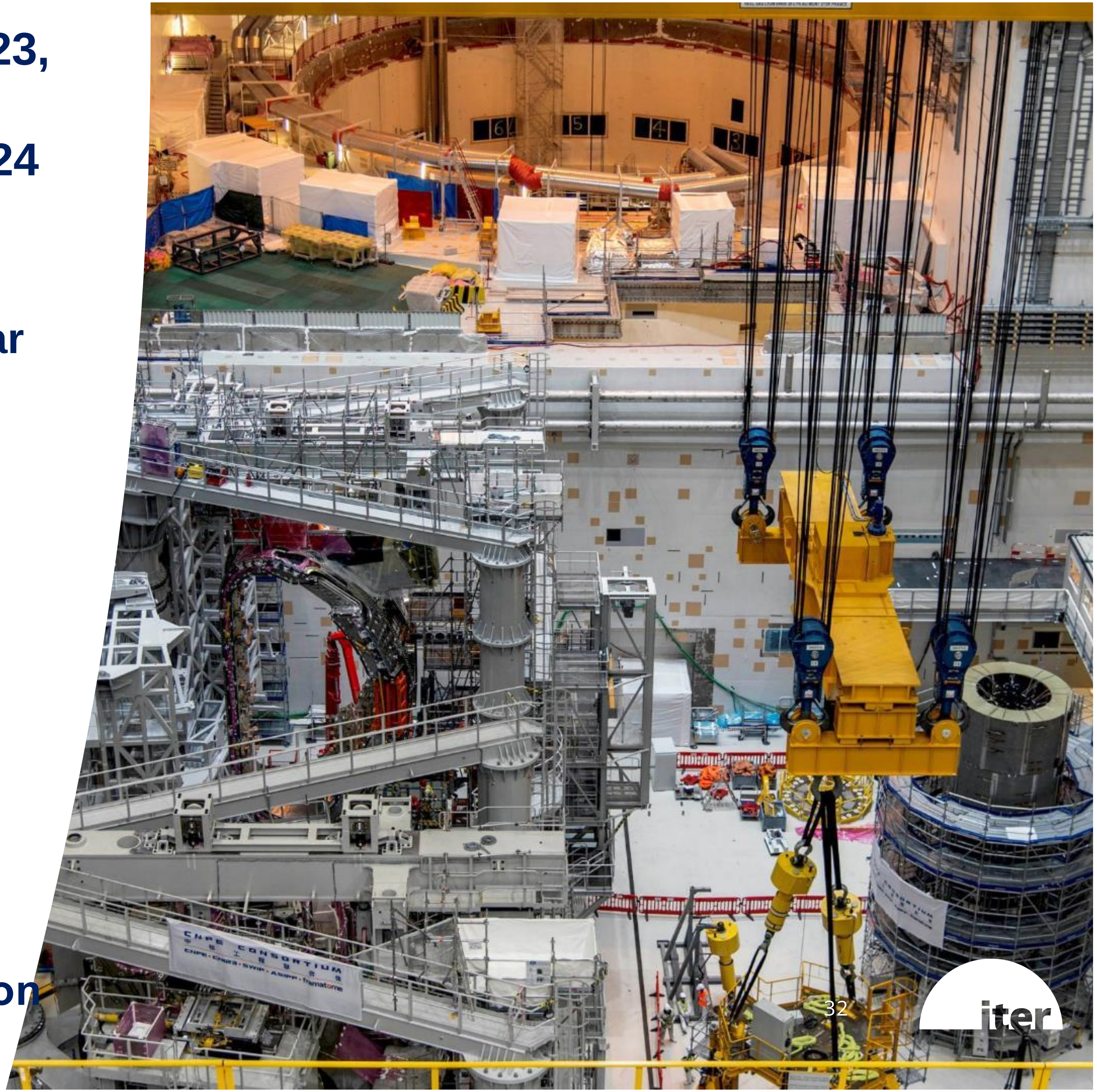


COOLING WATER SYSTEM

Heat Rejection System: ITER's cooling water system is capable of removing 1.2 gigawatts of heat. Equipment installation and system commissioning are complete, and the system is operational.

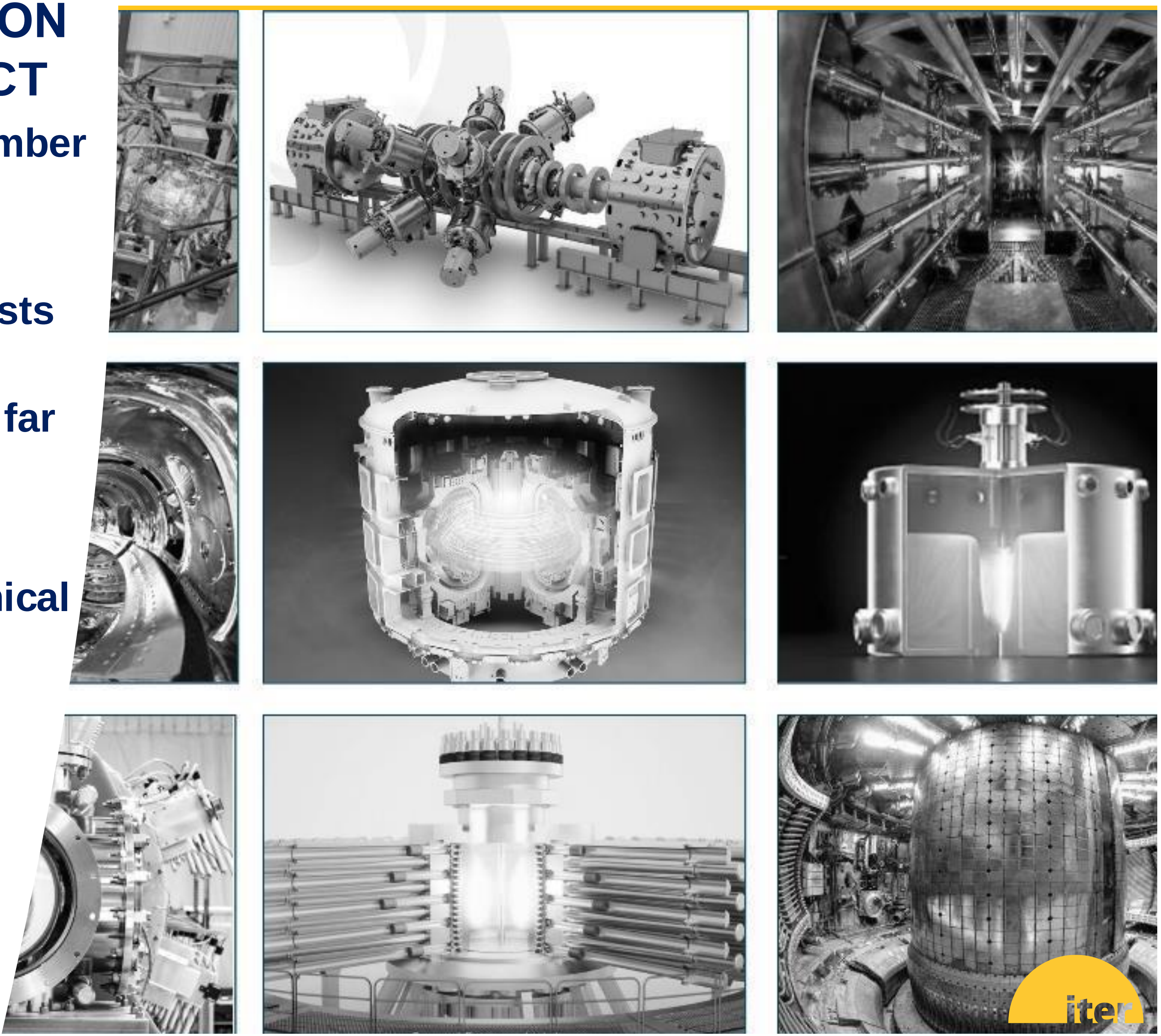
FROM THE TURNAROUND YEAR IN 2023, THE ITER PROJECT PERFORMED AT RECORD RATES OF EXECUTION IN 2024

- **Major restructuring of organisation**
- **Recovery of trust with the French Nuclear Regulator, and initiation of important simplifications ;**
- **Restructuring of assembly contracts**
- **Repair of components;**
- **Development of the new Baseline, with many new concepts therein;**
- **Improvement of project and design control processes;**
- **…while achieving record (100%) execution (with CPI=1.05) in ITER construction.**



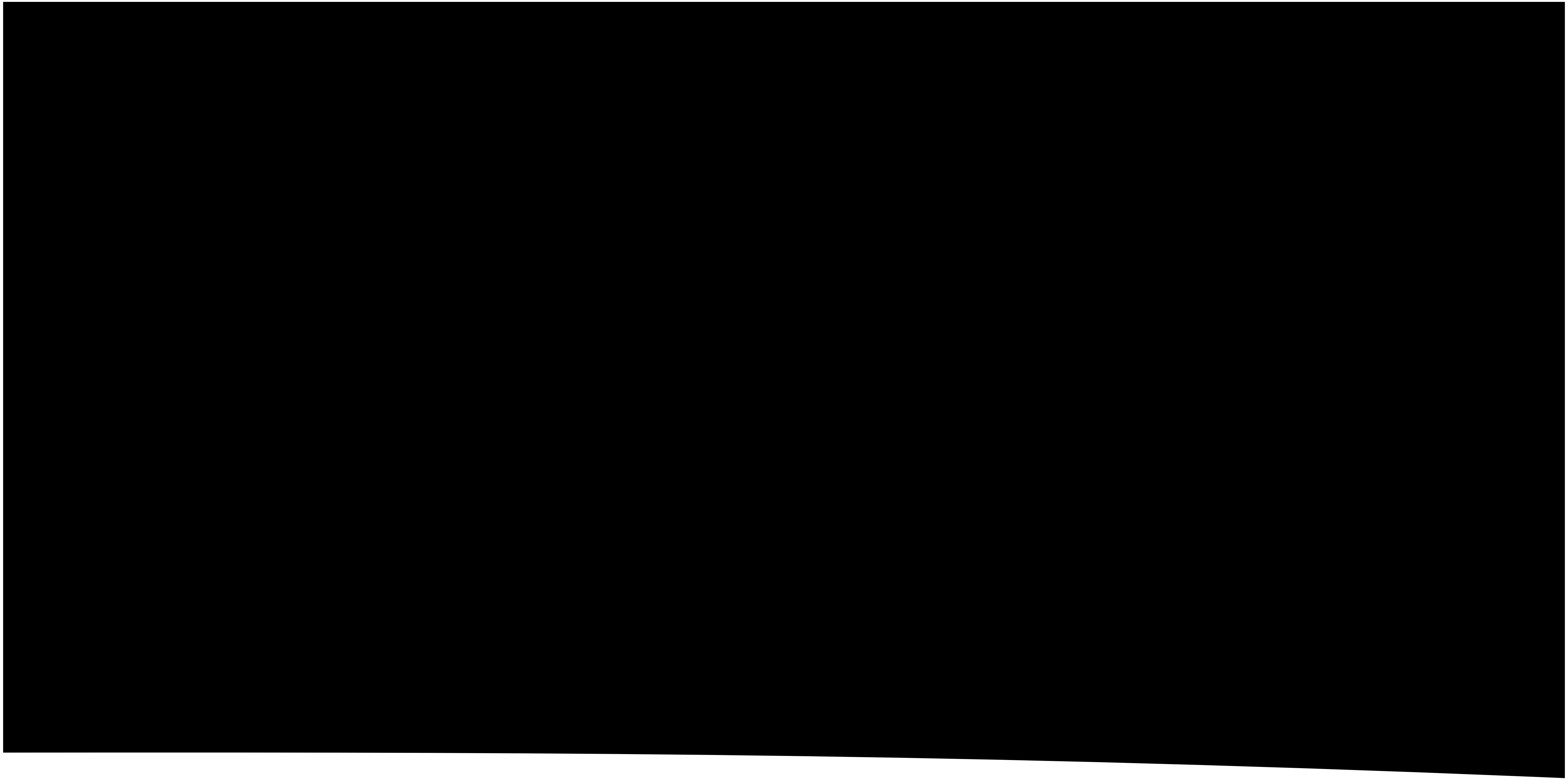
ITER'S PRIVATE SECTOR FUSION ENGAGEMENT (PSFE) PROJECT

- Requested by ITER Council, November 2023
- Design Handbook
- Access to ITER documents Requests from 13 private companies
  - ~500 documents requested so far
- "Open-sourcing IMAS
- Agreements
- Fusion resource catalogues Technical visits
- Access to ITER experts
- Access to technical committees
- Private sector secondees
- Help desk



FUSION'S REMAINING CHALLENGES

- Materials resistant to extreme conditions (intense flux of high-energy neutrons)
- Heat exhaust management in the divertor region
- Remote handling for maintenance
- Tritium fuel cycle (breeding tritium at scale)
- Efficient heat removal for electricity generation



Thanks for your attention