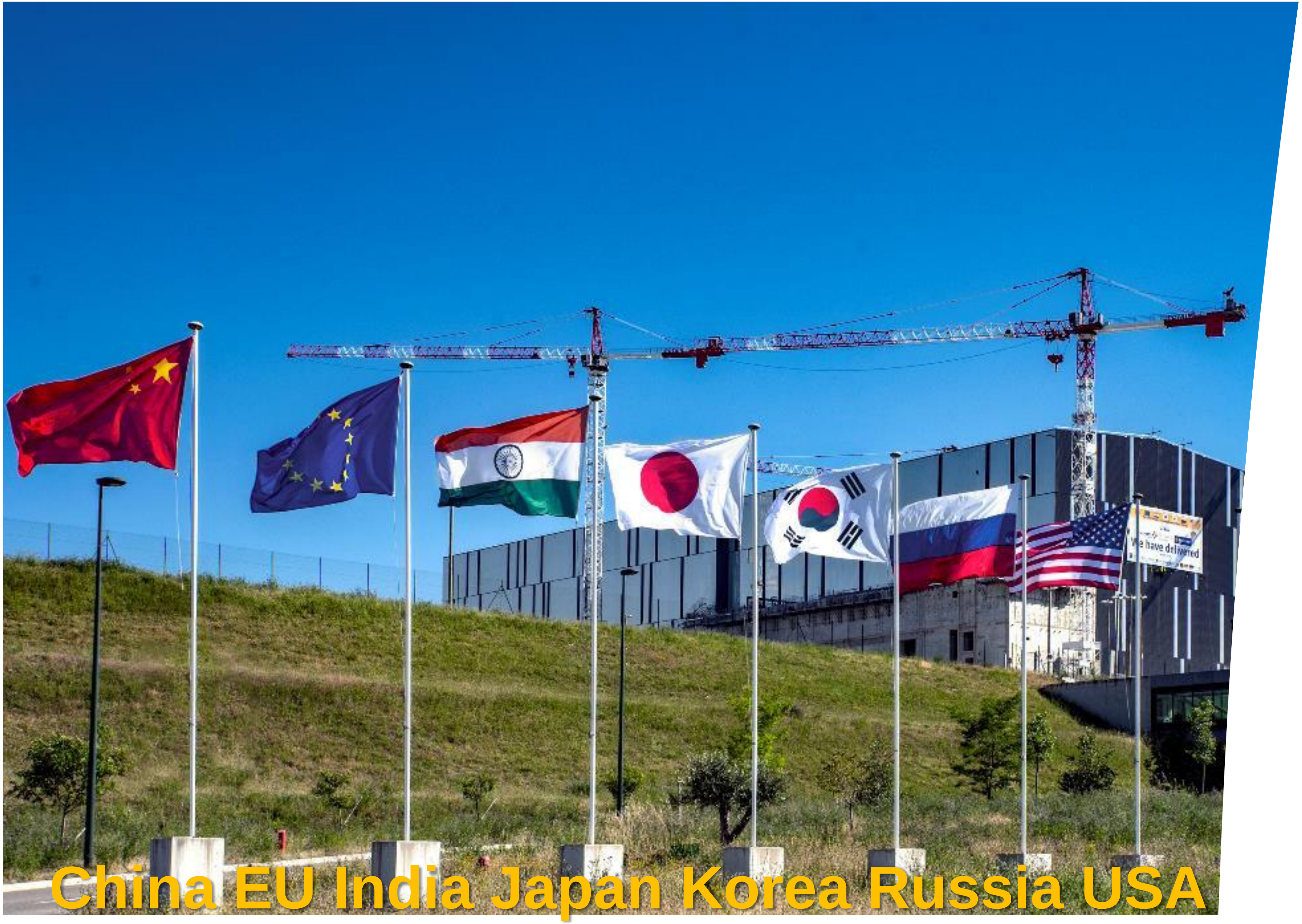
THE ITER PROJECT
PROGRESS AMID CHALLENGES

Dario Carloni on behalf of Radiation, Safety and Environment group (RSE)
Nuclear Division (ND) – Safety and Quality Department (SQD)

IAEA TM on compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission reactors

30 October-03 November 2023, Vienna

iter
china eu india japan korea russia usa



A GENERATIONAL CHALLENGE

United in a common cause: to transform our energy legacy.

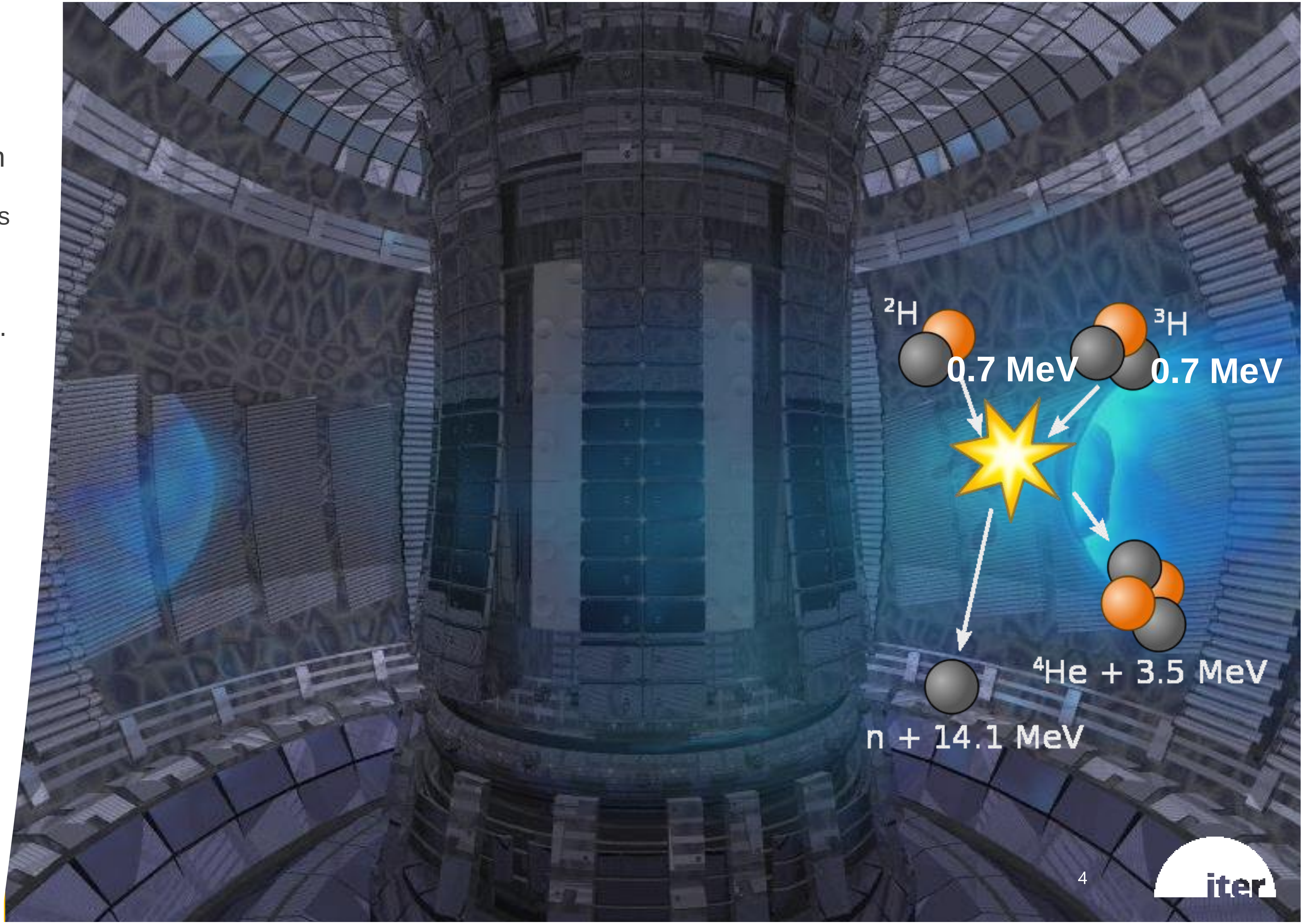
FUSION IN THE UNIVERSE

- Solar power (the energy of the sun and the stars)
- Source of light, heat, and life on Earth
- Produced by gravitational force

FUSION ON EARTH

Magnetic confinement fusion

- Deuterium + Tritium produces Helium + a neutron
- Requires a precisely shaped and controlled magnetic field.
- Temperature: ~150 million C
- Desired outcome: a ”burning” (largely self-heating) plasma



HYDROGEN FUSION

- Baseload power
- Carbon-free
- Abundant fuel supply
- No long-lived, highly radioactive waste*
- Safe
- Difficult engineering challenges

**Depends on successful identification of appropriate first-wall materials.*

HOW DOES IT WORK?

Inject DT gas.

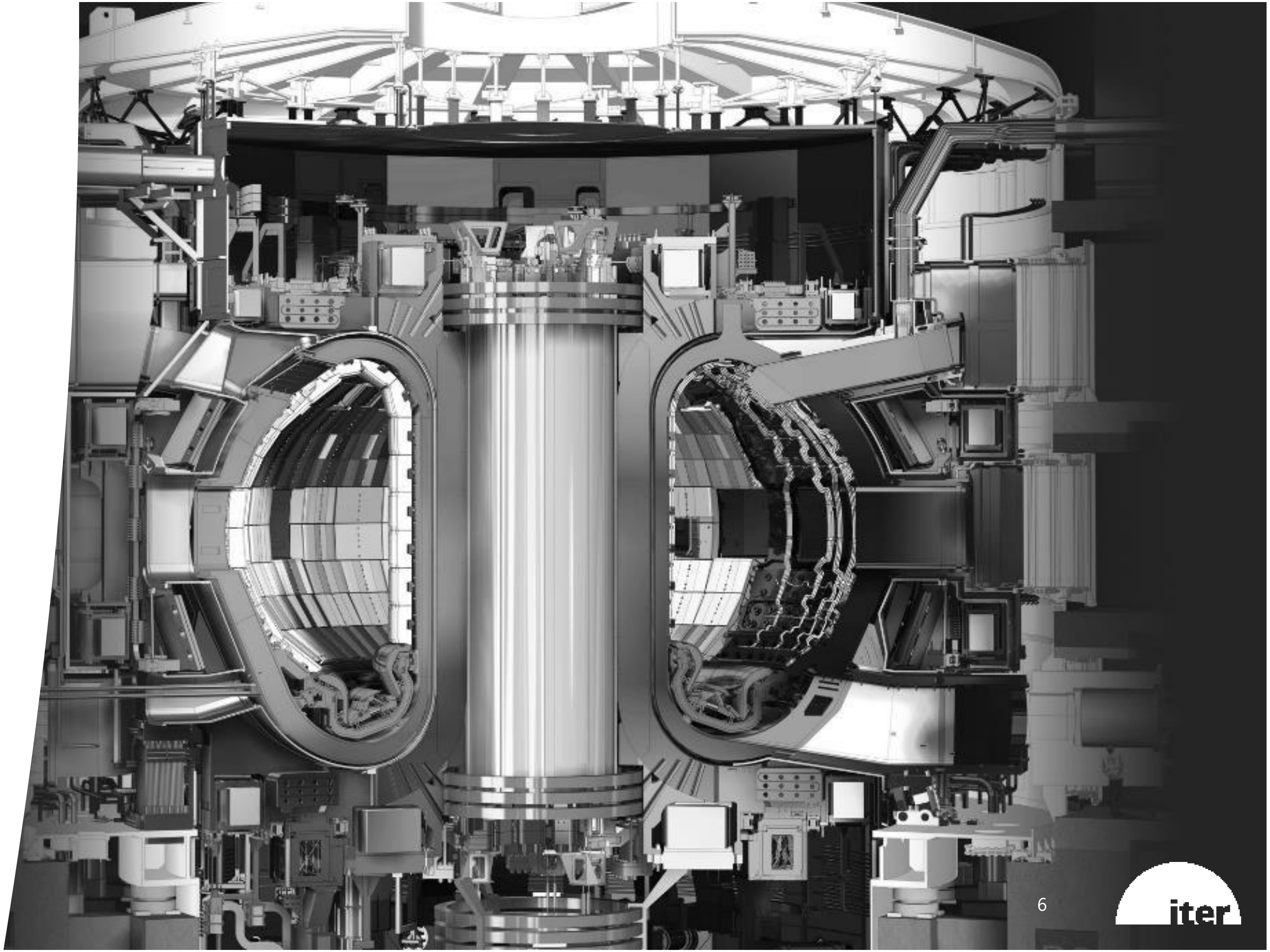
Inject electric current to convert the gas to plasma.

Inject electromagnetic waves.

Inject high-energy neutral particles.

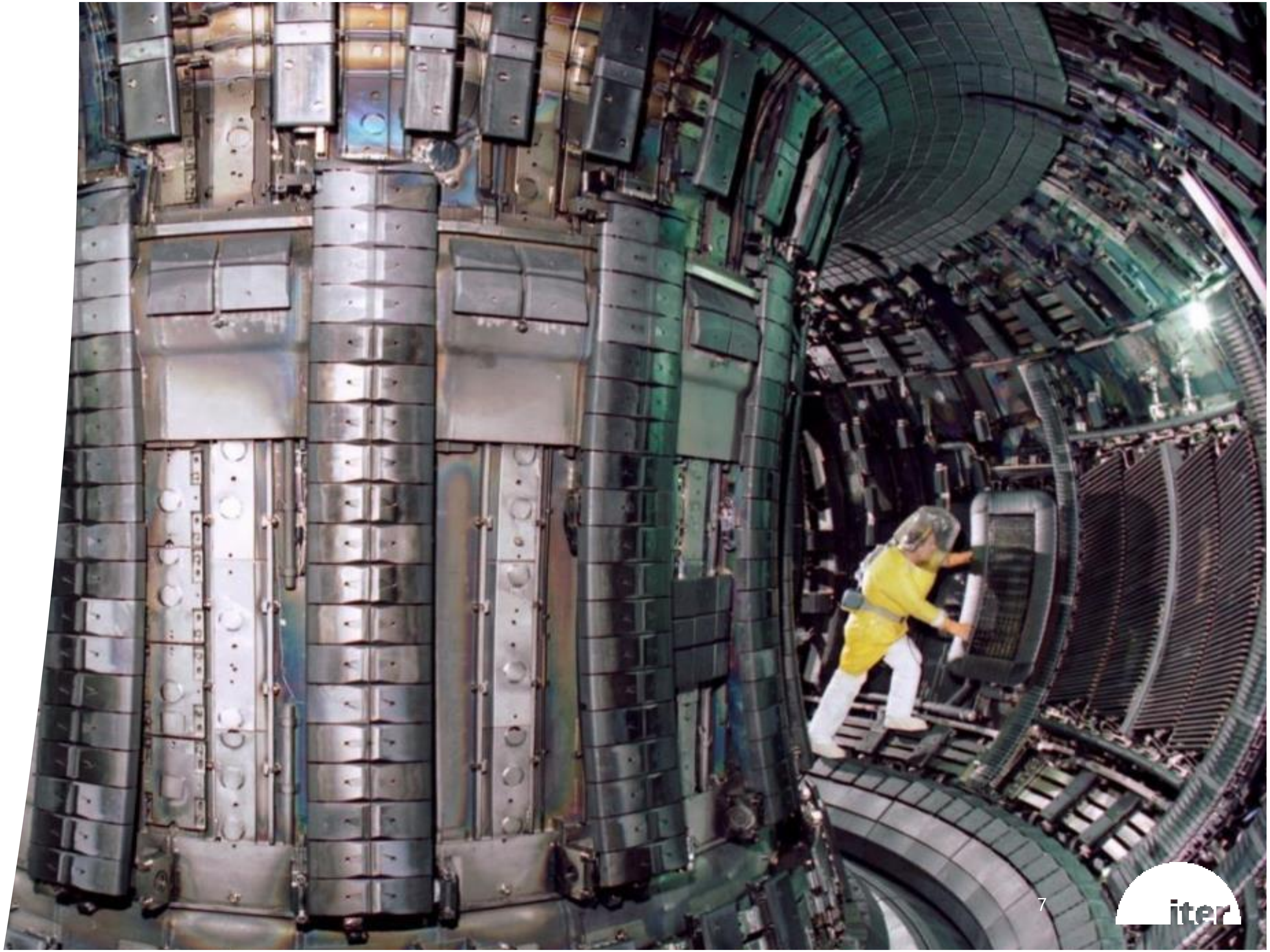
Combine these techniques to reach 150-million degrees.

THE CHALLENGE: TO CONTAIN AND SHAPE THE PLASMA.



60 YEARS OF PROGRESS

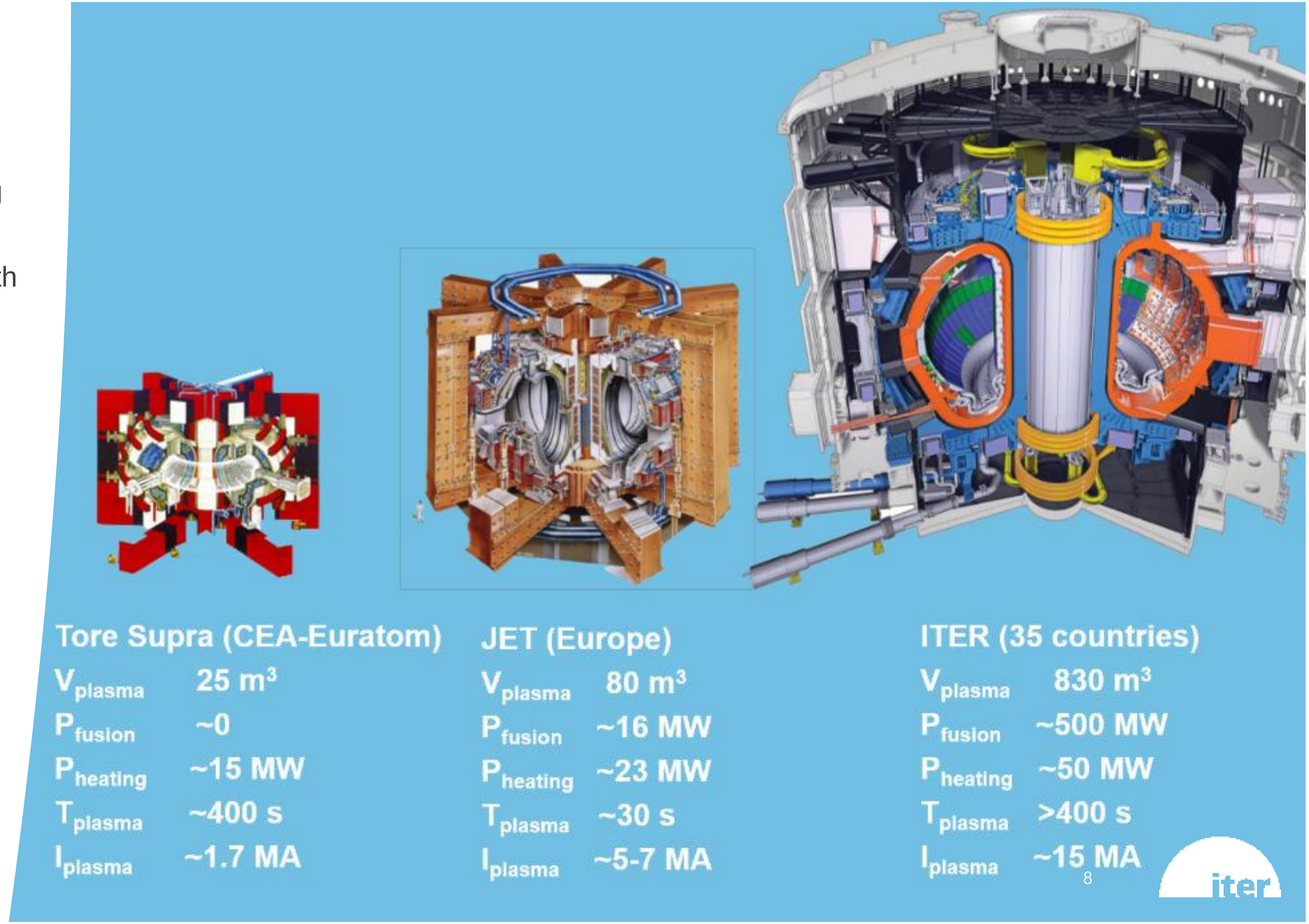
JET (Joint European Torus), Culham, United Kingdom.



SIZE MATTERS

Ratio of output thermal power over input heating power (Q) depends on:

- Magnetic field strength
- Plasma density
- Plasma volume



THE ITER NARRATIVE:

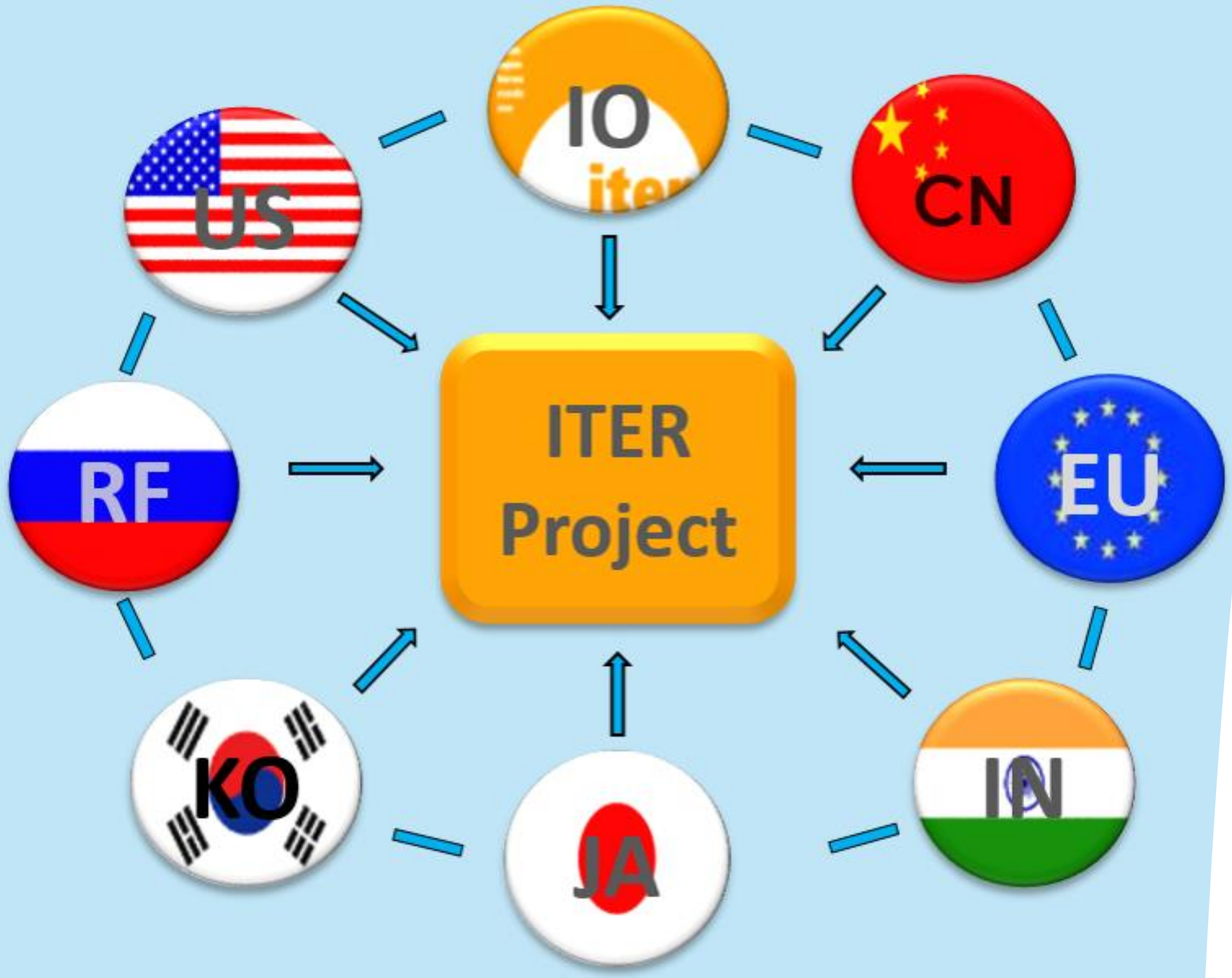
FROM IDEA TO REALITY

November 1985

November 2006

August 2010

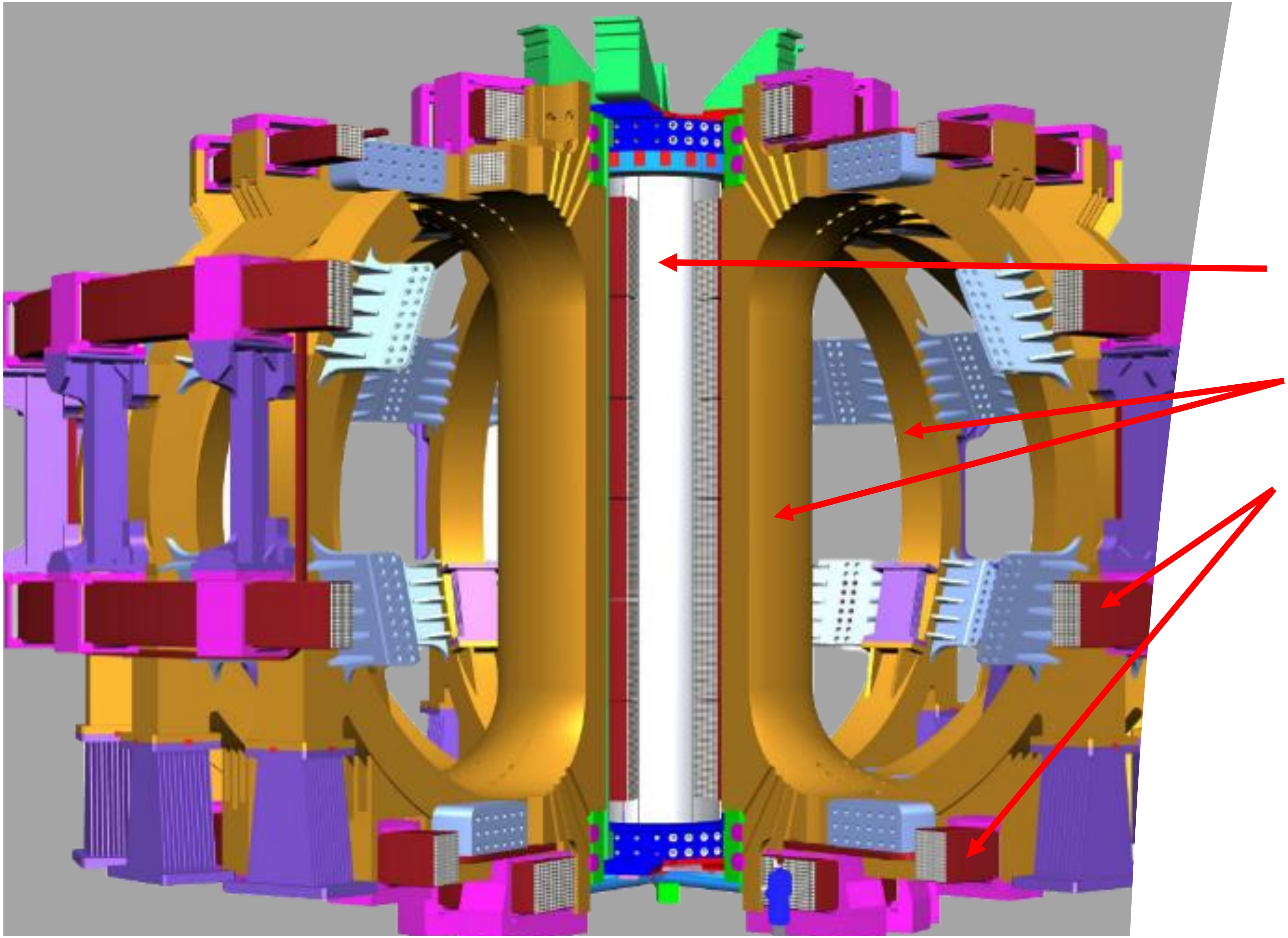
Today



AN INTEGRATED PROJECT

ITER Organization and Domestic Agencies

- Members contribute “in-kind” (80-90%)
- Domestic Agencies procure these in-kind contributions
- Europe, as host, contributes ~45%
- Non-EU members contribute ~9% each

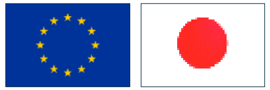


A MAGNETIC CAGE

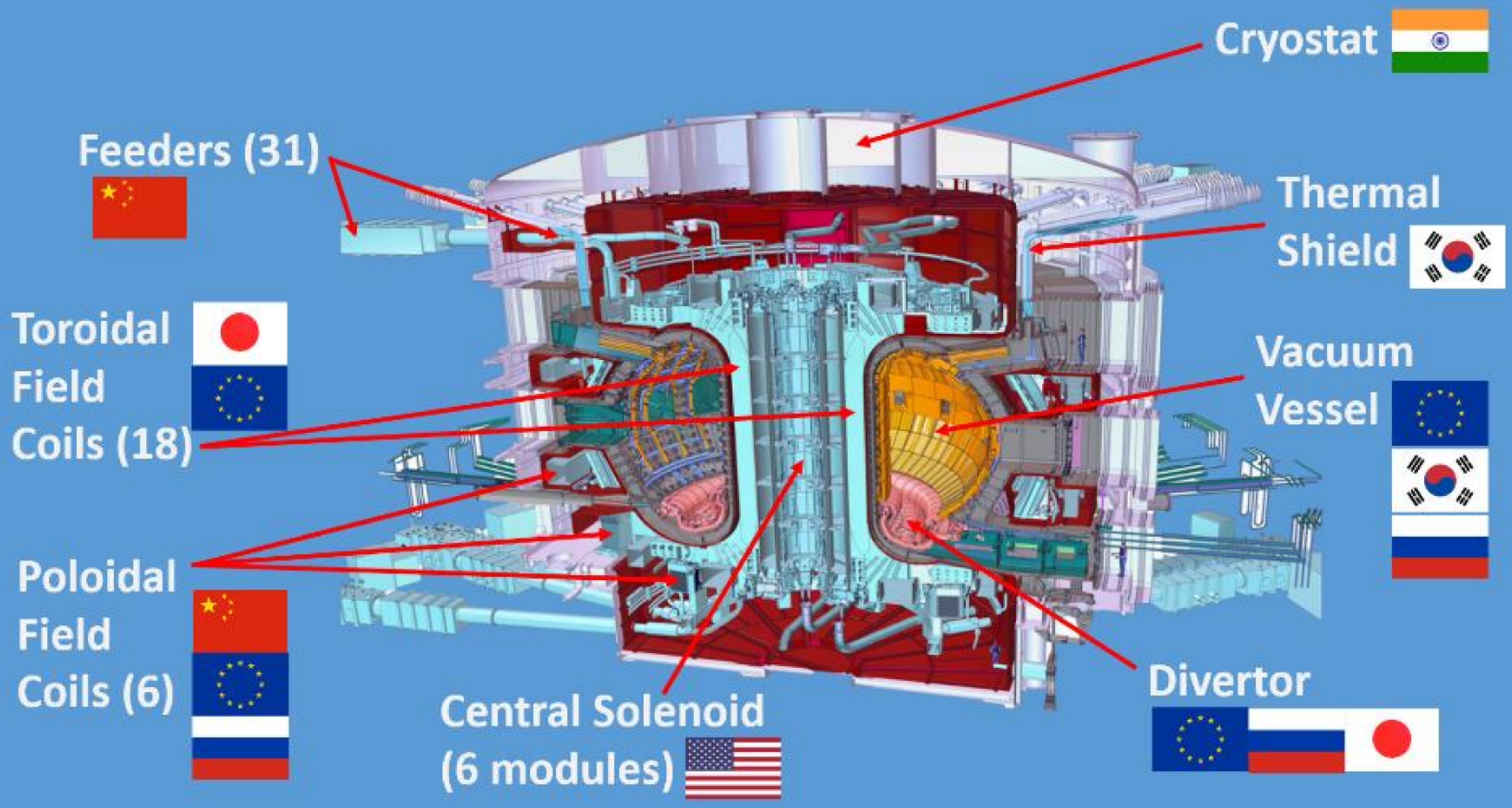
Three main magnet systems:

- 1 Central solenoid

- 18 Toroidal Field Magnets



- 6 Poloidal Field Magnets



WHO MANUFACTURES WHAT?

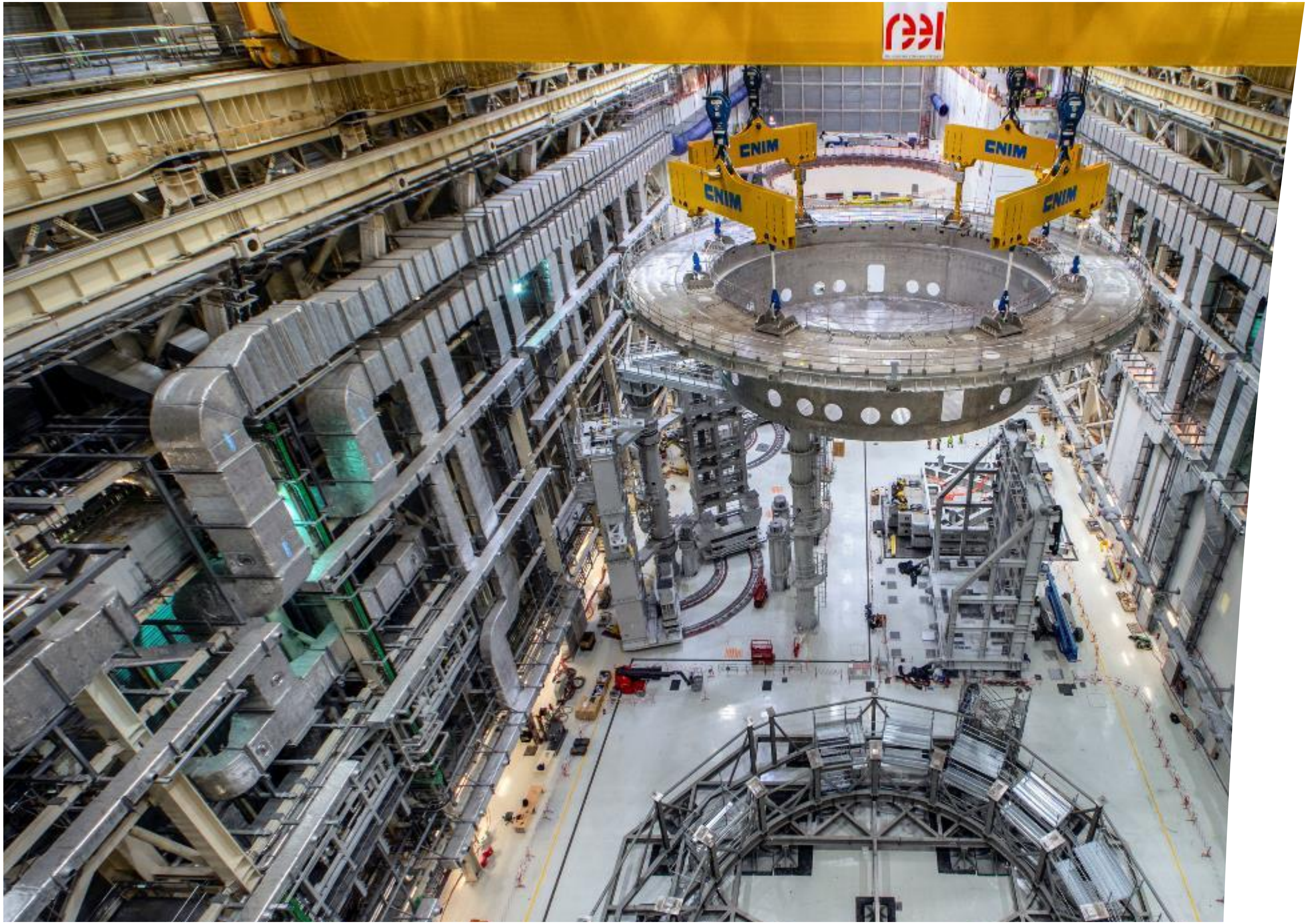
The ITER Tokamak is comprised of more than 1 million components. This shows a simplified breakdown of ITER Member contributions.

ITER Members share all intellectual property.

WORKSITE CONSTRUCTION

Aerial perspective, September 2023

iter



ASSEMBLING THE MACHINE

Cryostat Base installation (1350 tonnes), traversing the Assembly Hall.

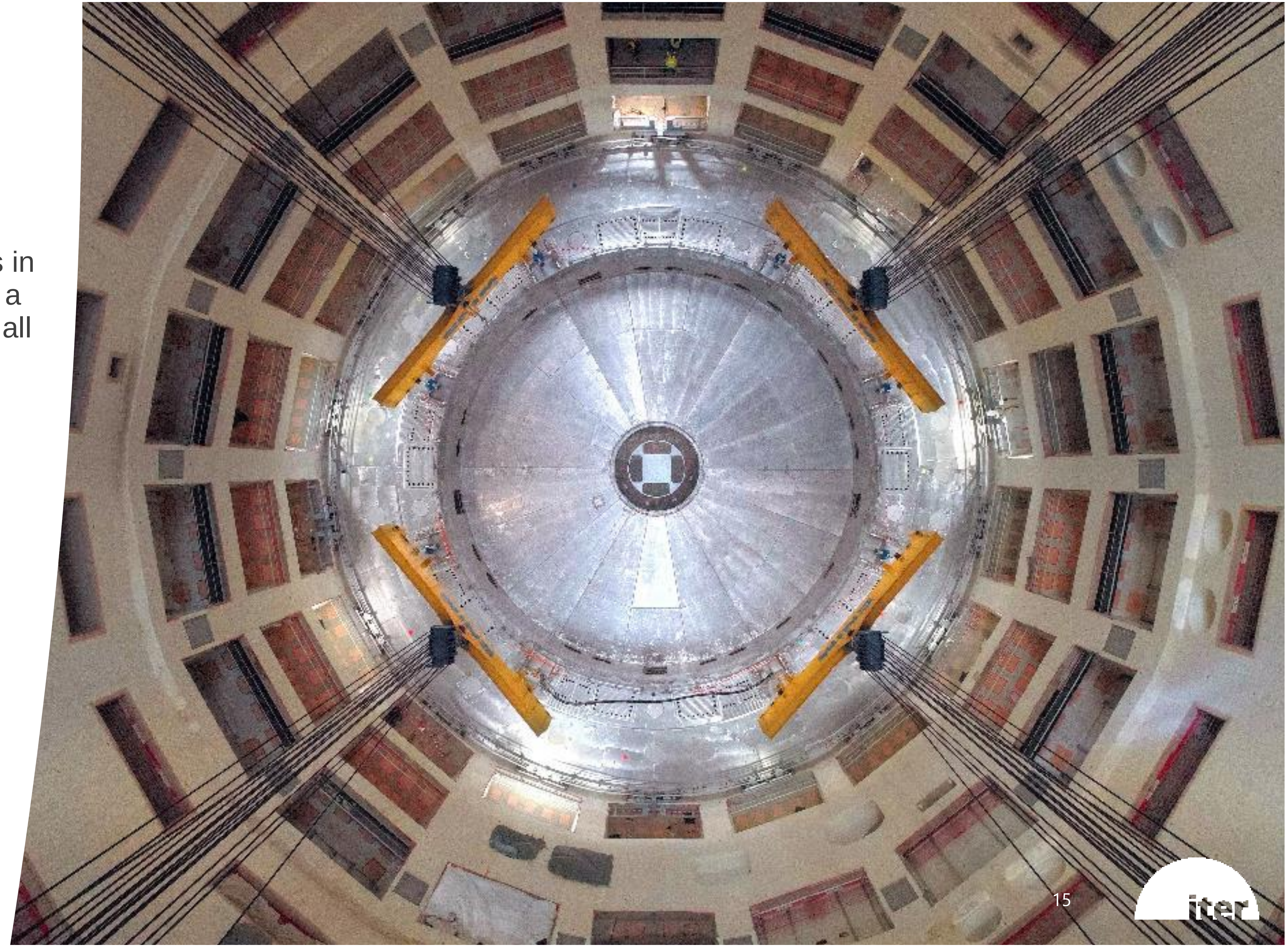
May 2020

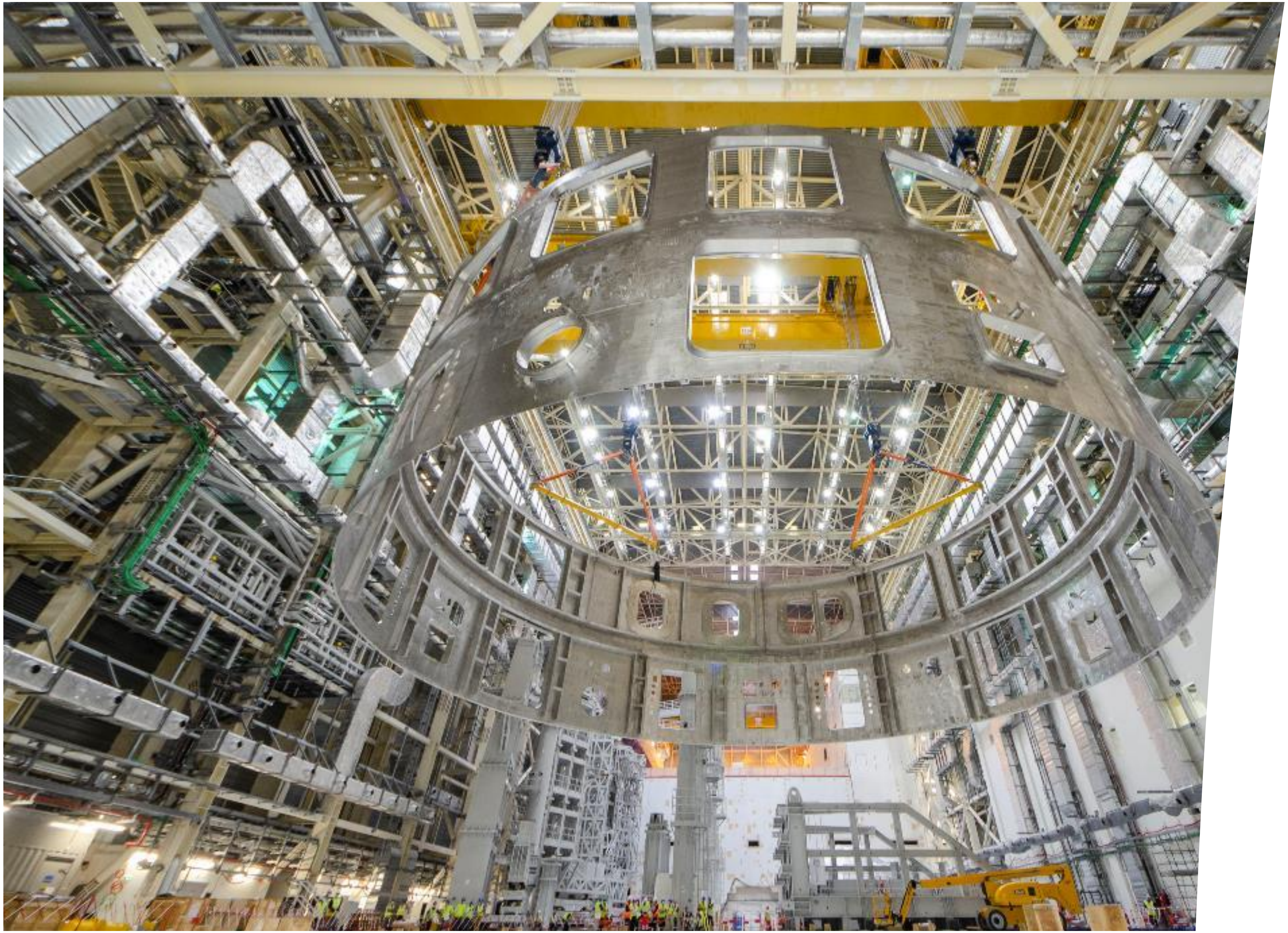
ASSEMBLING THE MACHINE

[Tokamak Pit, top-down view]

The Cryostat Base, 30 metres in diameter, was positioned with a final tolerance under 3 mm at all metrology points.

May 2020





ASSEMBLING THE MACHINE

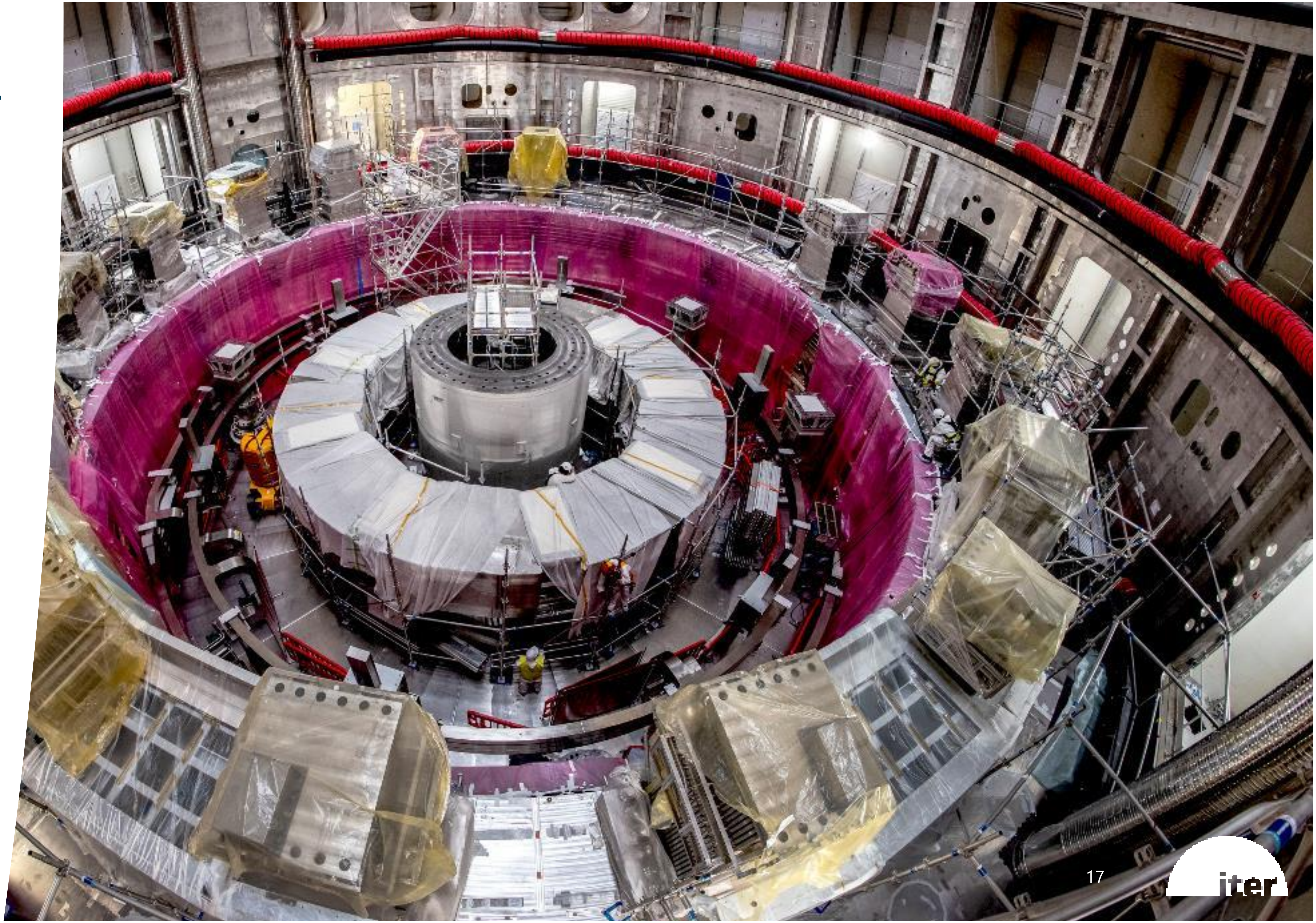
Cryostat Lower Cylinder installation

August 2020

ASSEMBLING THE MACHINE

Poloidal Field Coil #6 installation

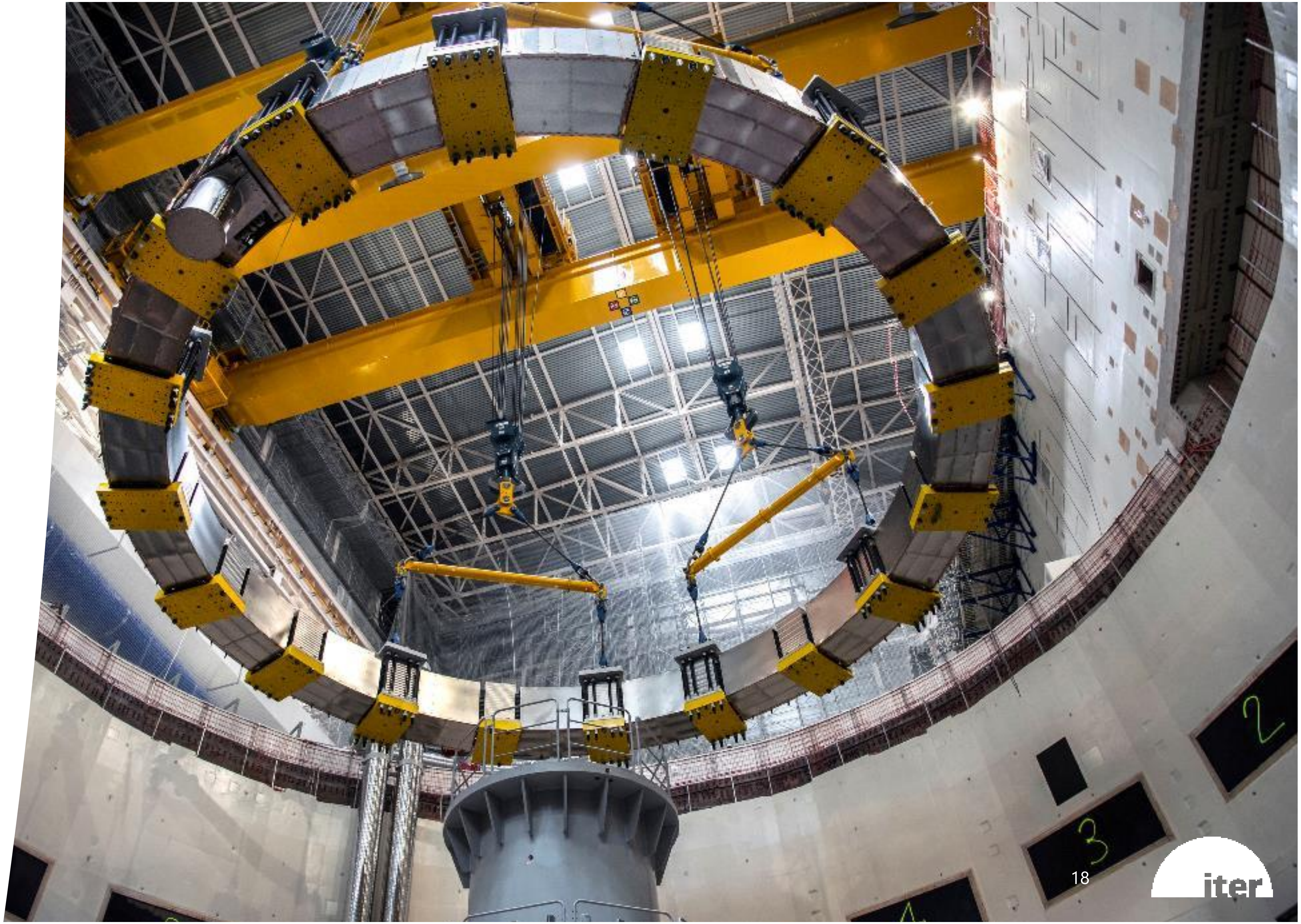
April 2021



ASSEMBLING THE MACHINE

Poloidal Field Coil #5 installation

September 2021



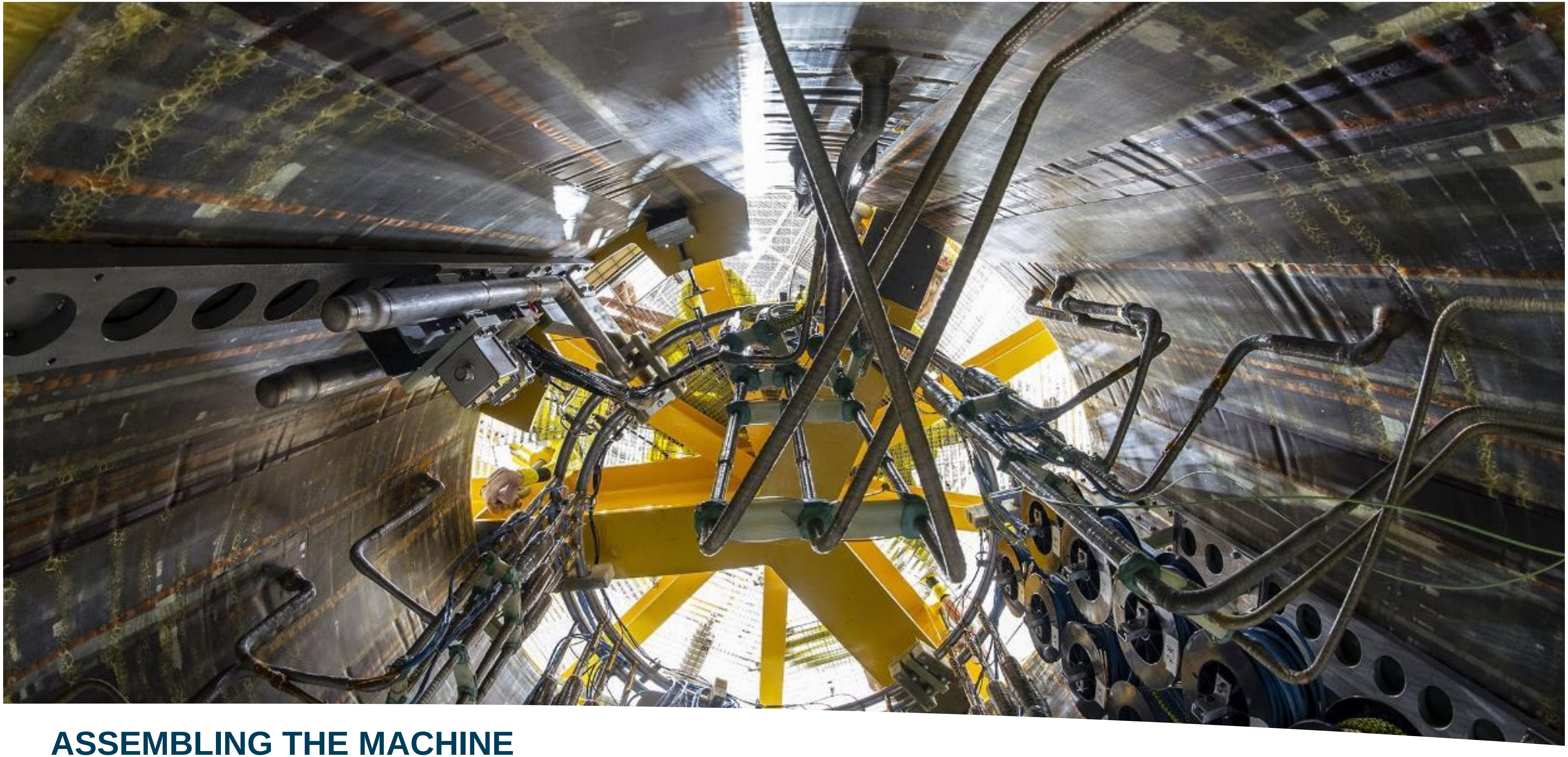
ASSEMBLING THE MACHINE

Central Solenoid sub-assembly has begun.

- The first module delivered to ITER sits atop nine lower key blocks on a dedicated platform.
- The second module waits at right.

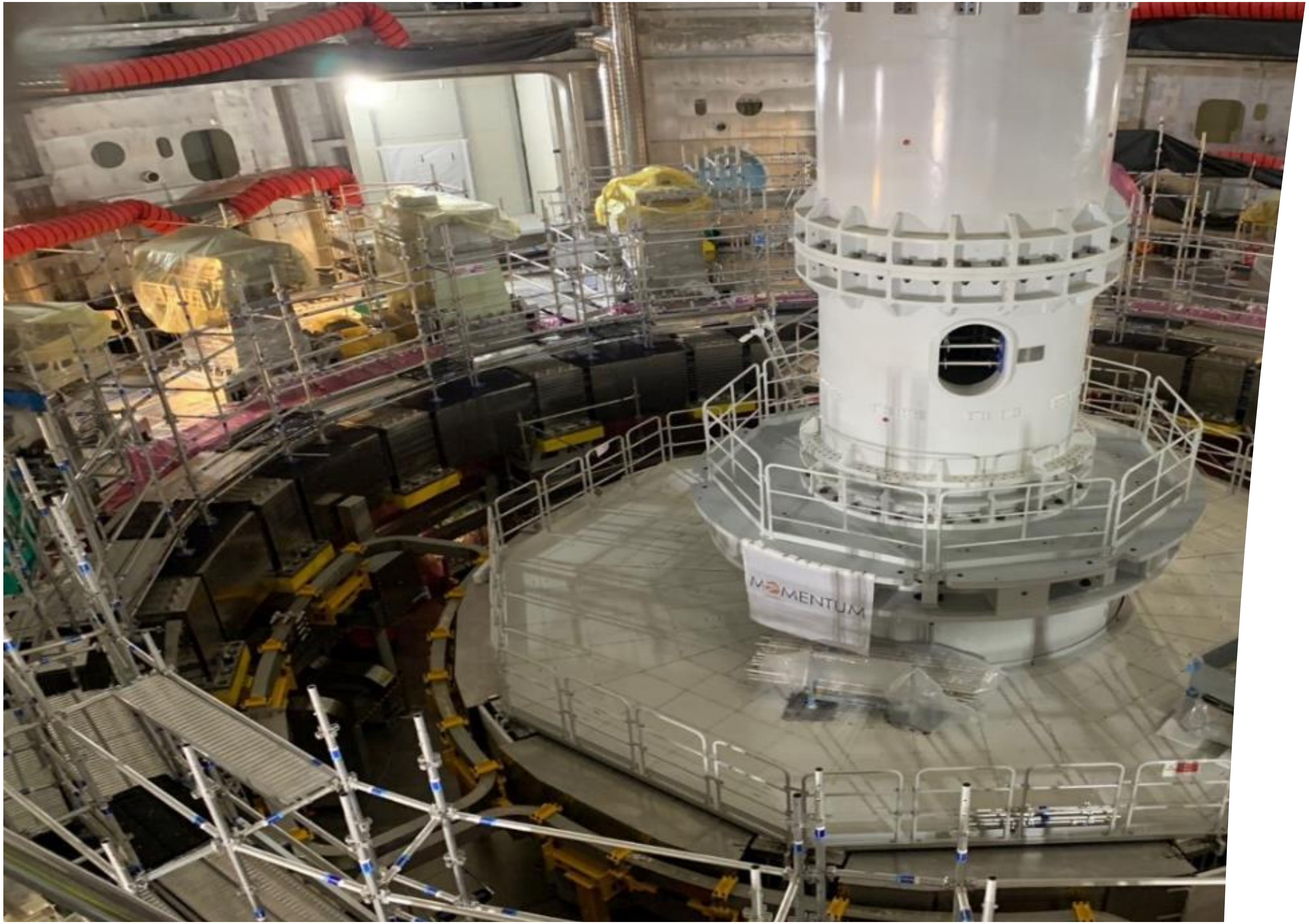
A total of six modules will bring the tower to well over 20 metres (platform included).

January 2023



ASSEMBLING THE MACHINE

The first of six cylindrical superconducting magnets for the central solenoid is positioned on a dedicated assembly platform at ITER. Pictured (inside the cylinder): helium input pipes and electrical connections. *January 2023*



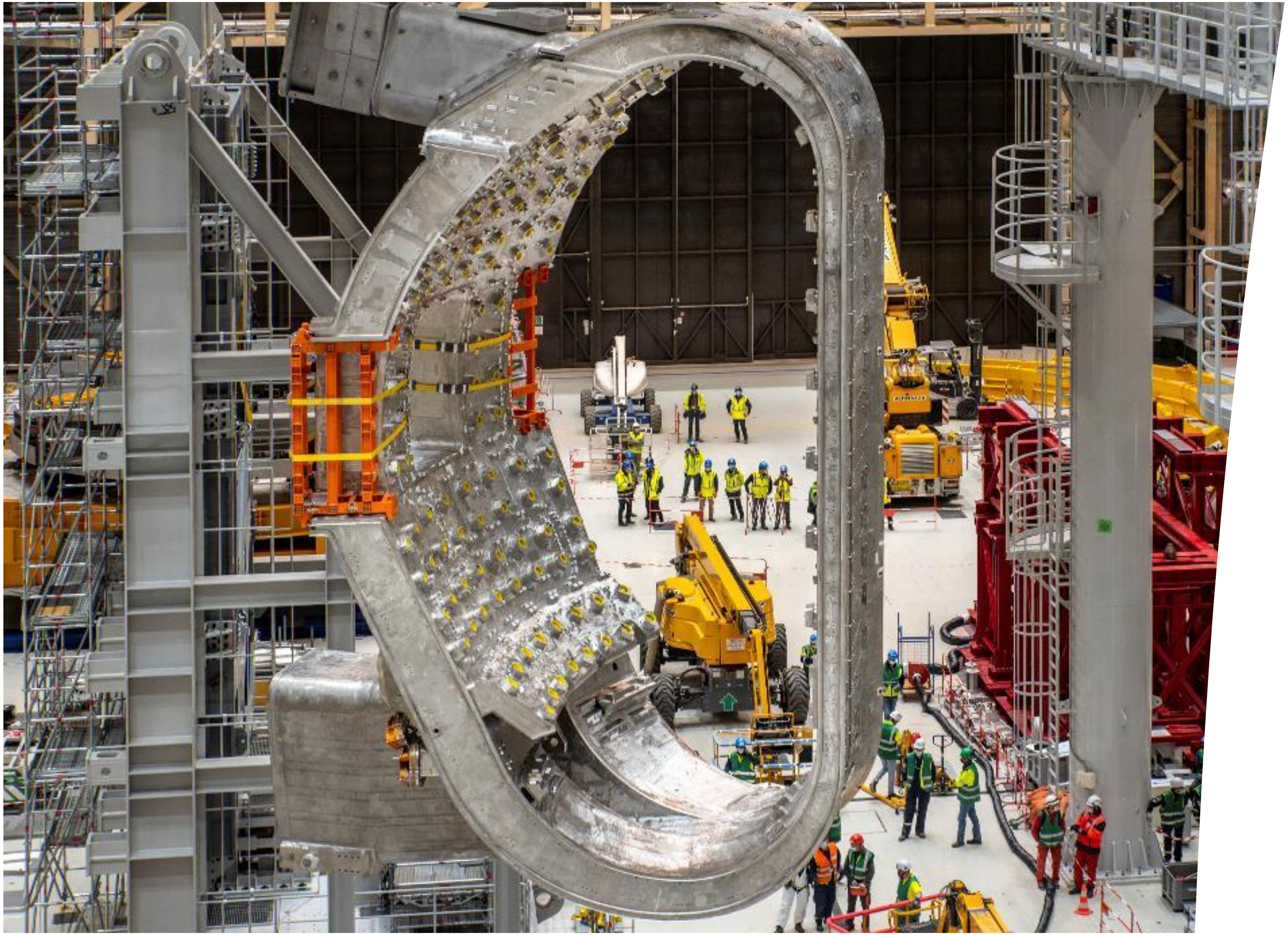
ASSEMBLING THE MACHINE

Tokamak Pit shown ready to receive the first Vacuum Sector Module

- Cryostat Base and lower Cylinder
- 2x Poloidal Field coils, 6x Correction Coils
- Lower Cryostat Thermal Shield
- Central Column as assembly tool
- Gravity supports & Instrumentation

November 2021

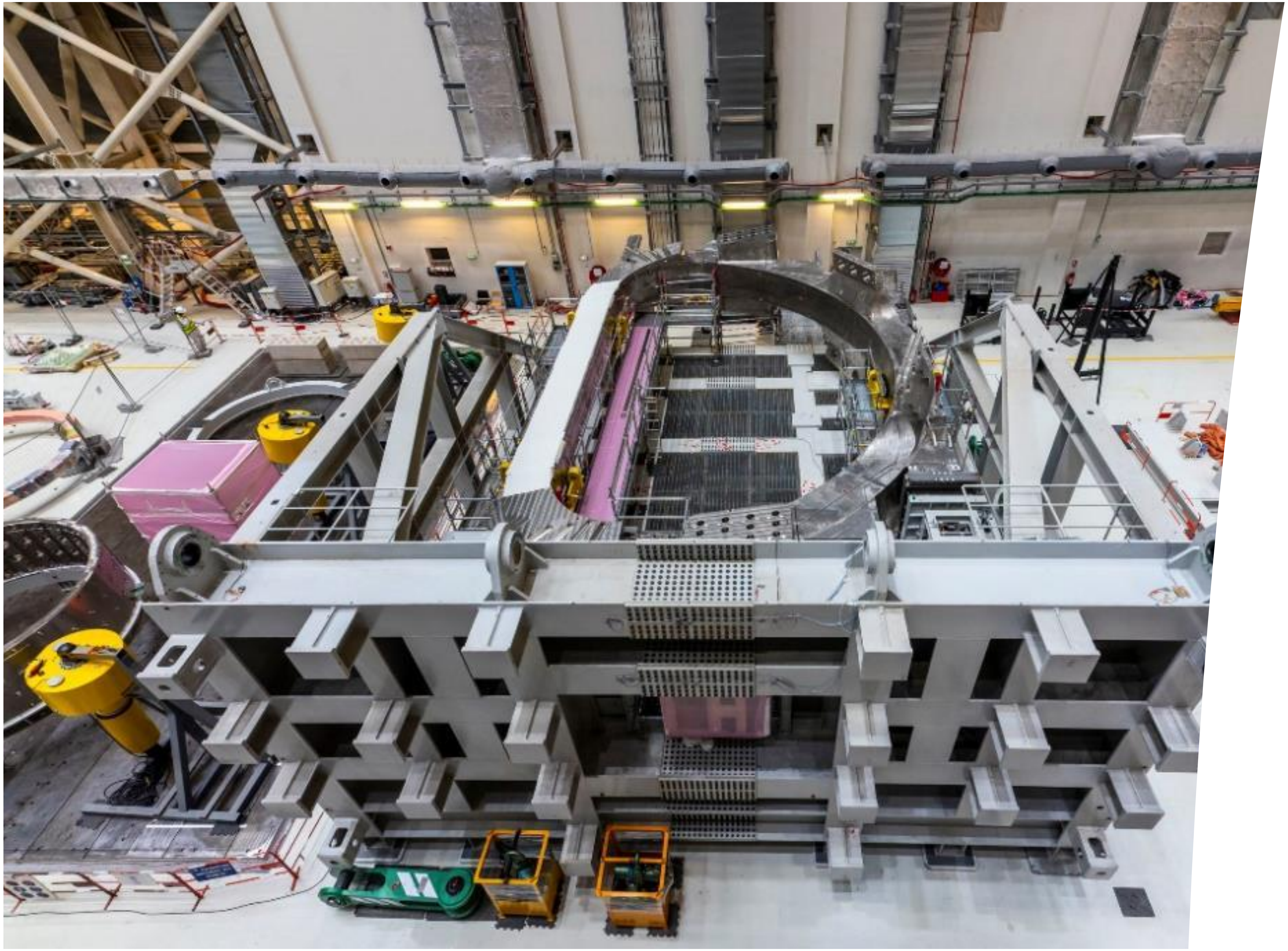
iter



FIRST SECTOR SUBASSEMBLY

Vacuum Vessel Sector 6 placed on the Sector Sub-Assembly Tool

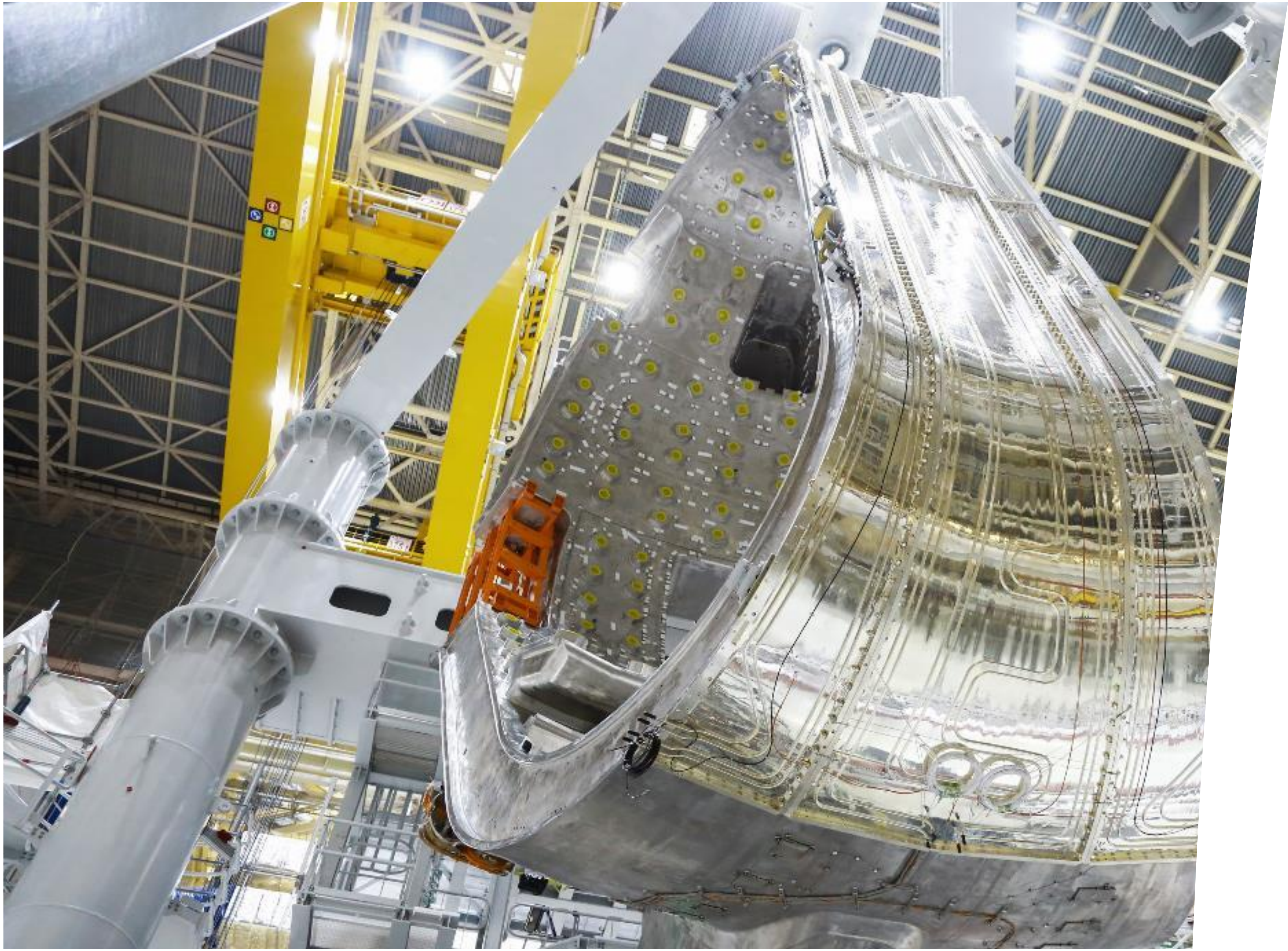
May-June 2021



FIRST SECTOR SUBASSEMBLY

Toroidal Field Coil #12 placed on the "upending" tool.

May-June 2021



FIRST SECTOR SUBASSEMBLY

Thermal Shield added to the Vacuum Vessel sector

May-June 2021

ASSEMBLING THE MACHINE

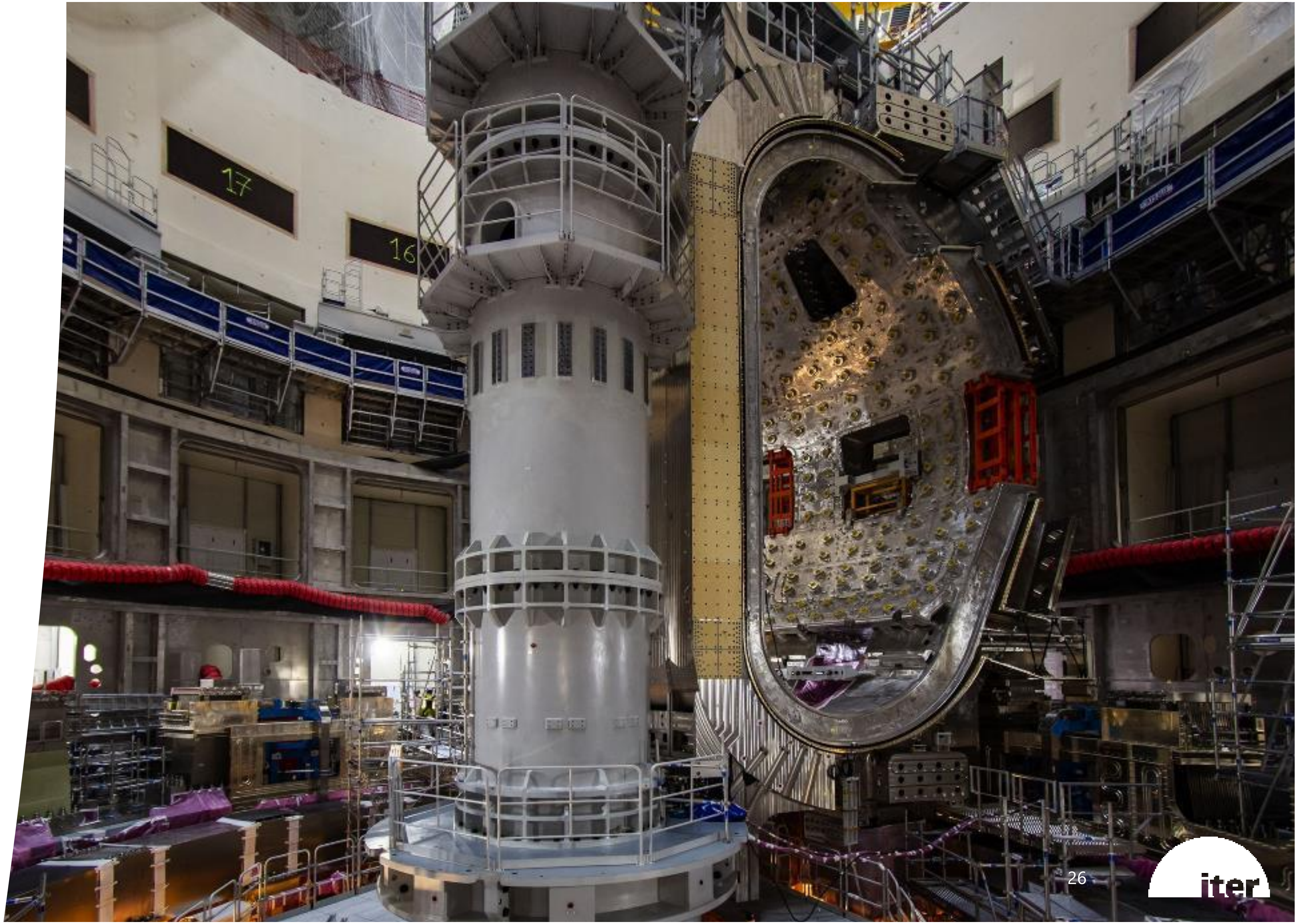
First complete Vacuum Vessel Sector Module lifted

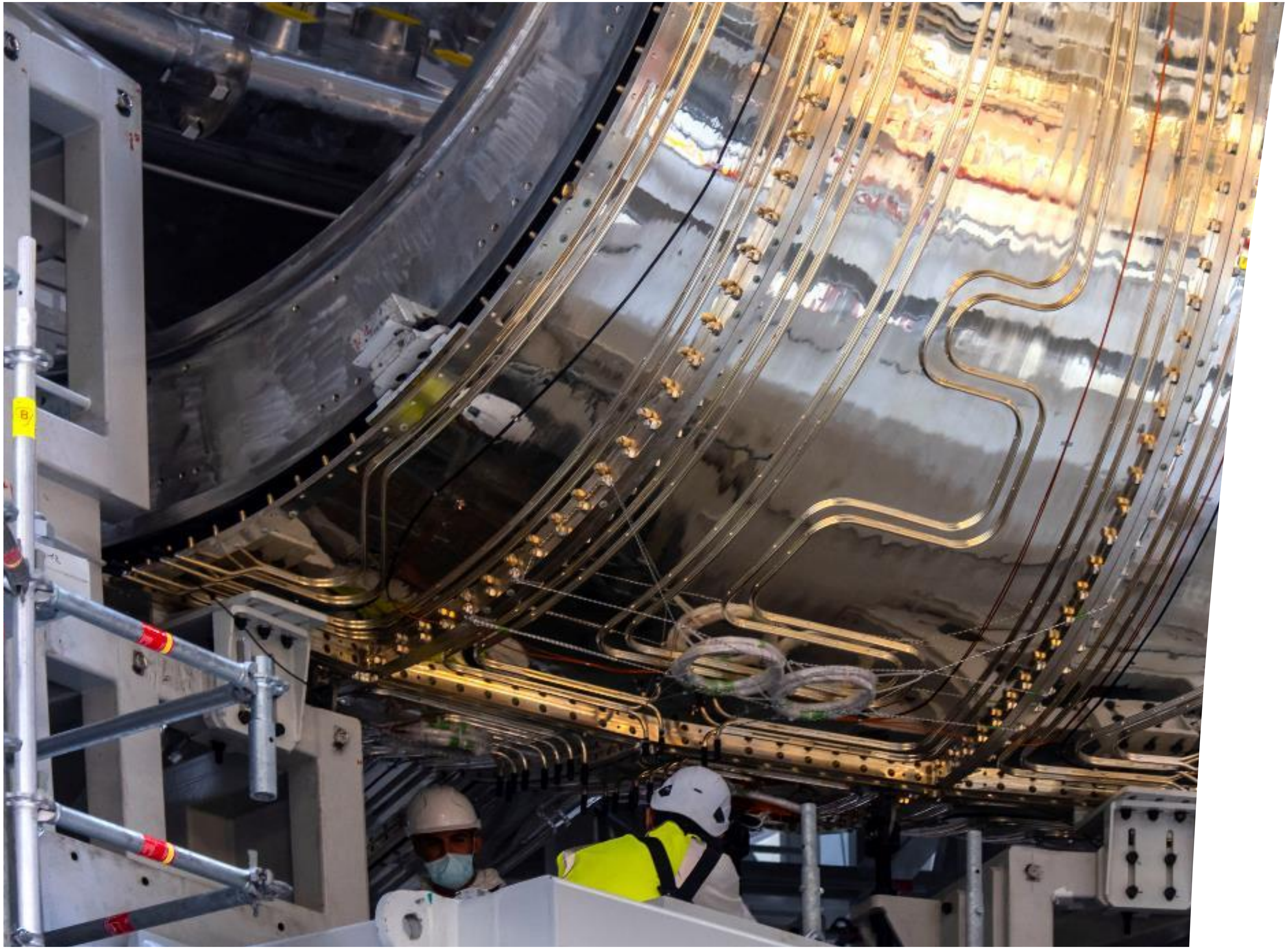
May 2022

ASSEMBLING THE MACHINE

First complete Vacuum Vessel Sector Module installation

May 2022





CHALLENGES OF FIRST-OF-A-KIND COMPONENTS

Leakage identified in thermal shield cooling piping due to chloride stress corrosion.

Repair strategy defined. Accelerated procedure underway to select specialize subcontractors for the repairs.

CHALLENGES OF FIRST-OF-A-KIND COMPONENTS

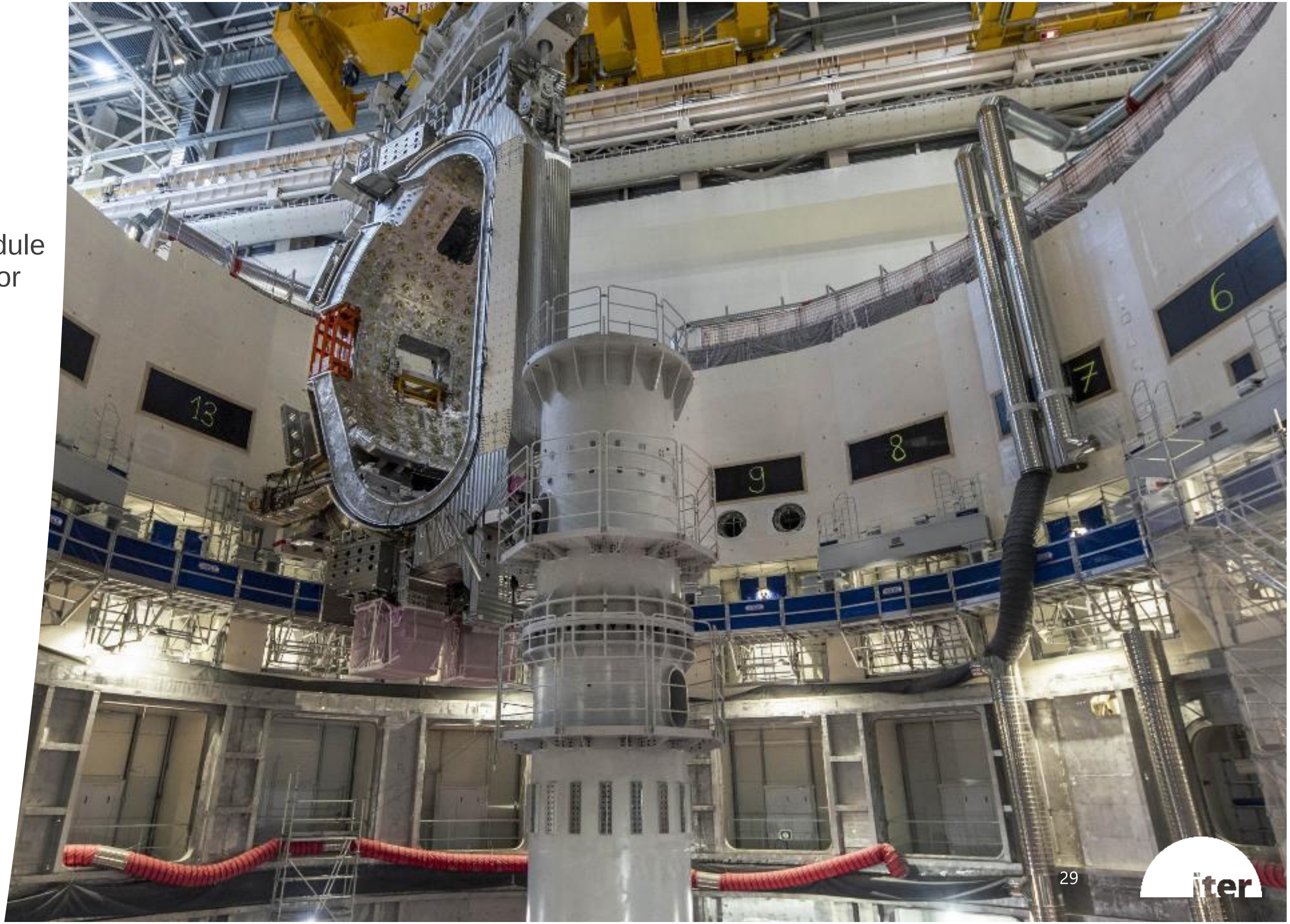
Geometric non-conformities found in Vacuum Vessel sector field joints.

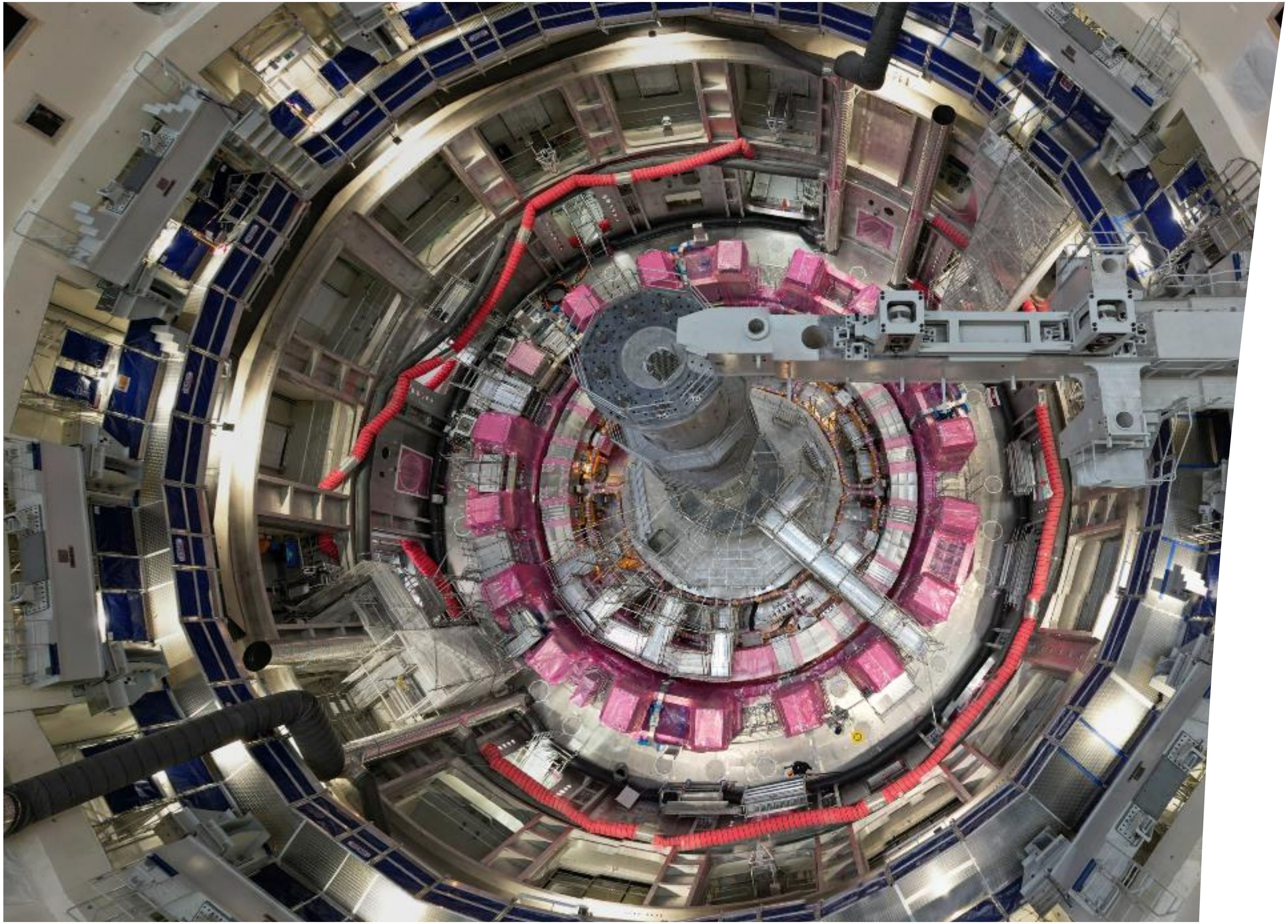
Repair strategy defined. Accelerated procedure underway to select specialize subcontractors for the repairs.

CHALLENGES OF FIRST-OF-A-KIND COMPONENTS

Vacuum Vessel Sector Module 6 has now been removed for repairs

July 2023





TOKAMAK PIT: *top-down view*

September 2023

REPAIRS TO VV BEVEL JOINTS & THERMAL SHIELD COOLING PIPES

Photo shows "musical chairs" in the Assembly Hall, as components are removed from the SSATs, "down-ended," and transported as needed to the repair location.

- Repair contracts have largely been finalized.
- Photo from June 2023

REPAIRS TO VV BEVEL JOINTS & THERMAL SHIELD COOLING PIPES

Photo shows thermal shield components in the re-purposed PF Coils building.

- Photo from Setember 2023

DIRECTOR-GENERAL PIETRO BARABASCHI

[took office in October 2022]

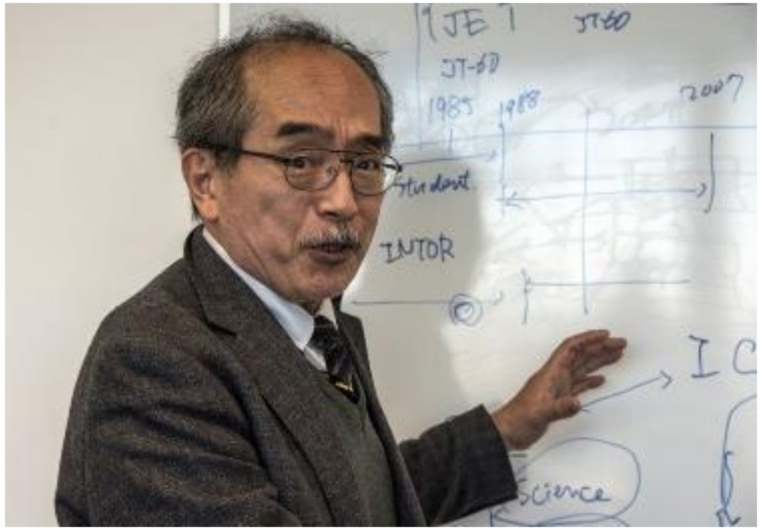
Key points of emphasis

- Accuracy and transparency in communication
- Improved integration of IO and DAs
- Strong, positive relationship with French safety regulator
- Reliable solutions to technical FOAK challenges
- Enhanced quality culture
- Review and adjustment of Project Baseline
- Reliable measurements of progress

LEADERSHIP APPOINTMENTS

The ITER Council has approved the recommendations of the Director-General for the appointment of four DDGs, as shown.

The search for a Chief Engineer is being re-formulated.



Yutaka Kamada, DDG, Science & Technology

Luo Delong, DDG Corporate

Sergio Orlandi, Construction Project Leader

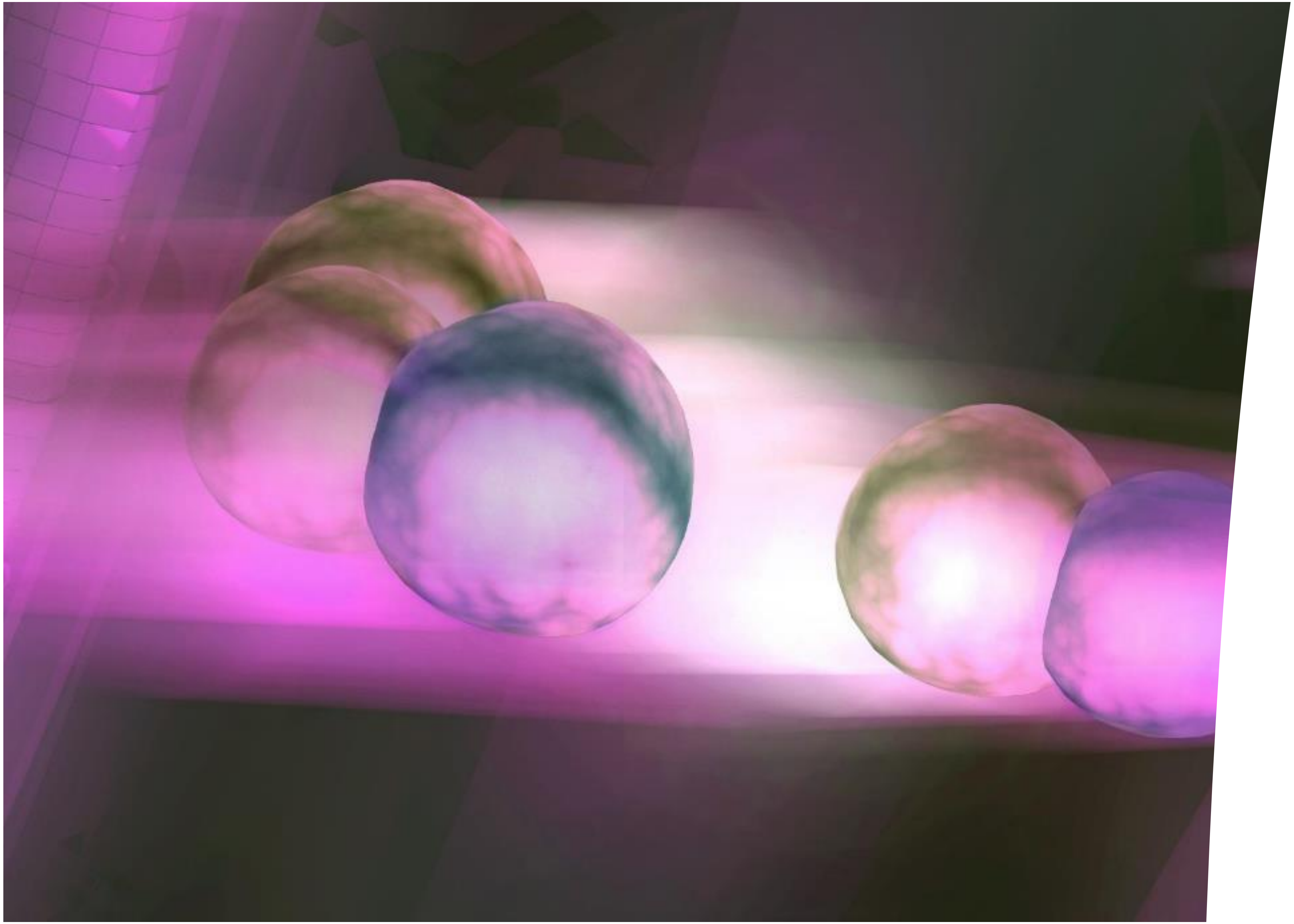
Alain Bécoulet, Chief Scientist

Tim Luce, Deputy Construction Project Leader

IC-32 OUTCOME

Council "noted the IO's intention" to change the Blanket First Wall armour material from **Beryllium to Tungsten**

- Logic: Is ITER's mission to reach Q≥10 and a set of experiments? Or to serve as precursor to DEMO?
- Answer: **both**
- This is why we are moving to Tungsten.
- STAC asked to perform additional evaluation



IC-32 OUTCOME

Council support for **two-phase DT operations**

- Essentially a 2-stage safety demonstration
- Goal: early achievement of nuclear operations

PLANT SUPPORT SYSTEMS

ITER has two overall power supply systems: the steady-state electrical network, commissioned in January 2019; and the pulsed-power electrical system (sometimes called “reactive power compensation”), for which the equipment is largely installed.

PLANT SUPPORT SYSTEMS

Heat Rejection System: ITER’s cooling water systems will be capable of removing ~1.2 gigawatts of heat. Equipment installation is complete, and the system is now in pre-commissioning phase.

PLANT SUPPORT SYSTEMS

The Cryogenics Plant equipment installation is complete, and has entered pre-commissioning phase.

Largest portion of cryogenic pipes are installed.

PLANT SUPPORT SYSTEMS

Control Building construction is largely complete and is now “ready for installation.”

December 2022

MANUFACTURING PROGRESS: *Europe leading a global effort*

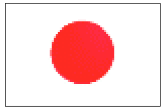
Vacuum Vessel sector

Cryostat Lid

Poloidal Field coil in cold testing

Central Solenoid modules

MANUFACTURING PROGRESS: *Europe leading a global effort*




Toroidal Field coil


Vacuum Vessel sector


Bottom correction coil


Poloidal Field coil in delivery

COMPONENT DELIVERIES

Main components delivered since 2020:

- 18 TF coils (1 spare will arrive soon)
- 2 PF coils (plus 3 manufactured onsite, with 1 more in final stages)
- 3 vacuum vessel sectors (out of 9)
- 3 Central solenoid modules (out of 6+1 spare)

PROJECT PROGRESS

The third Central Solenoid module has left the factory near San Diego and arrived at ITER (shown here in transit).

July 2023

PREPARING AN UPDATED BASELINE

To be presented to Council in mid-2024, for approval by end-2024.

Key challenges and considerations make this a complex exercise:

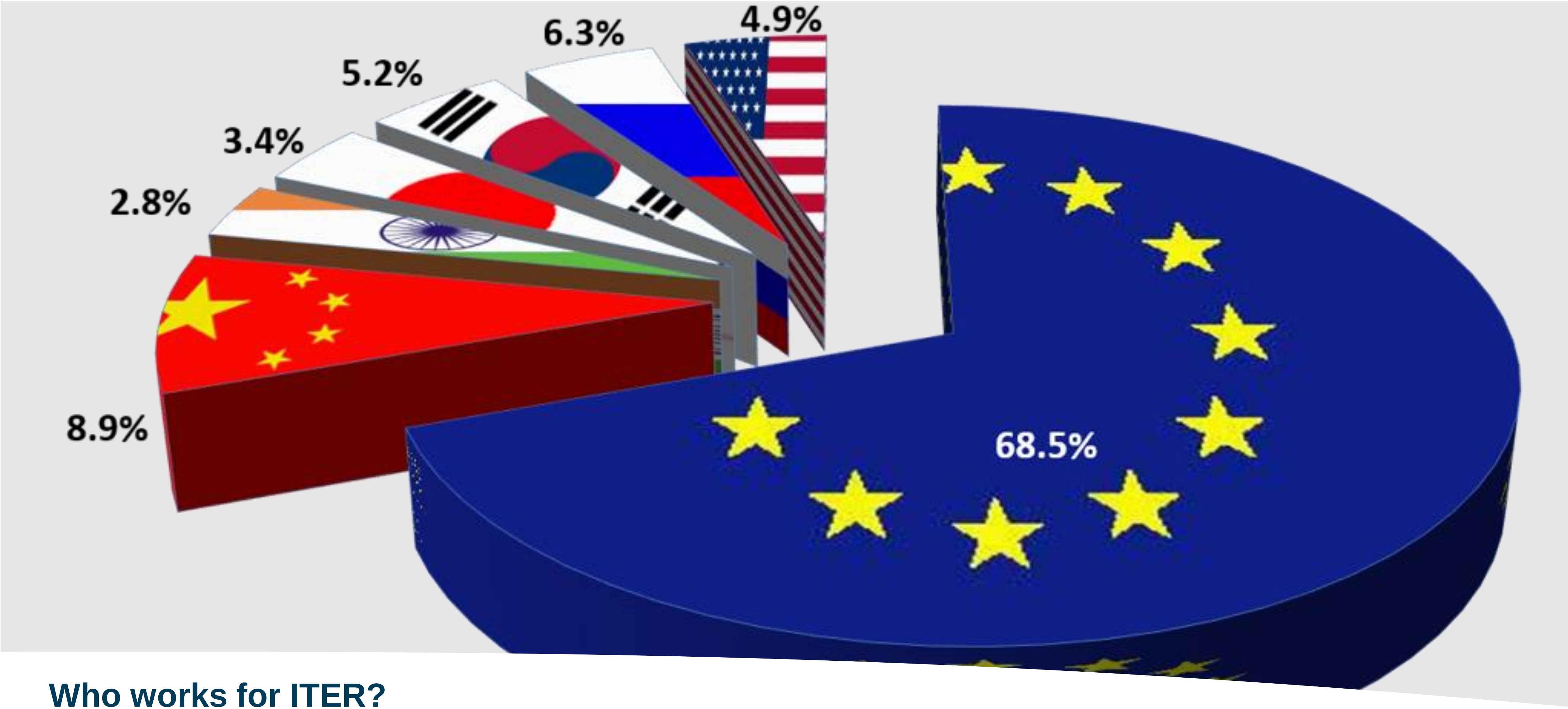
- Recovering from past delays incurred due to the Covid-19 pandemic and technical challenges in completing First-of-a-Kind components;
- Finalizing strategies and supplier contracts for repairs to key components;
- Considering strategies to offset future risks, including in particular the use of ITER's completed cryogenics plant, following commissioning, for additional testing of toroidal field coils prior to installation;
- Proposing the change from beryllium to tungsten "first-wall";
- Planning for an "Augmented First Plasma," to enhance the scope and scientific value of ITER's first experimental campaign;
- Setting clear, scientifically and technically meaningful milestones along the way to full nuclear operation that effectively and transparently communicate the progress of the ITER Project; and
- Close and effective engagement with the ASN, regarding their questions related to the machine assembly "hold point," and ensuring mutual alignment on the way forward.

> *To be presented to Council in mid-2024, for approval by end-2024.*

SUMMARY

5 factors to a reliable baseline

1. Address Covid and tech delays
2. Complete repairs
3. Resolve ASN issues
4. Offset future risks
5. Compress "stages"



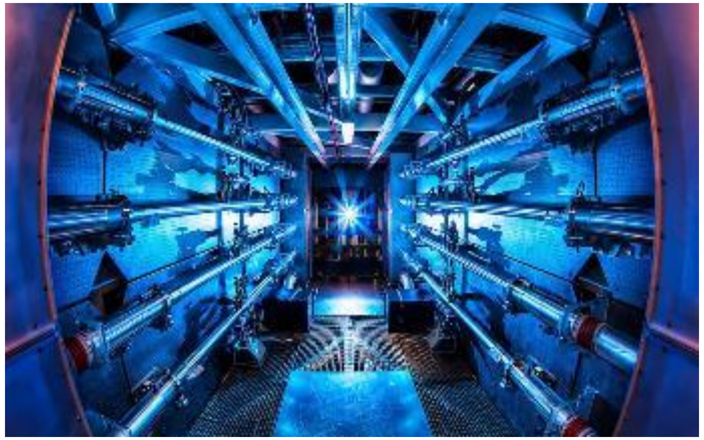
Who works for ITER?

The ITER Organization employs ~1250 staff from 35 countries, plus about 500 experts and subcontractors.
ITER Domestic Agencies (mostly Fusion for Energy, the EU-DA) has about 350 employees in France.
On the construction site, we also have about 2500 additional workers.
Globally, ITER partners also employ more than 3000 scientists, engineers, technicians, and support staff.

GLOBAL FUSION R&D: A SHARED GOAL

90+ PUBLIC & PRIVATE PROJECTS

National Ignition Facility, USA:
Inertial confinement



Wendelstein 7-X, Germany:
Stellarator

Commonwealth Fusion, SPARC, USA:
Smaller tokamak

Tokamak Energy, UK:
Spherical tokamak

THE “JOINT NARRATIVE”: re-articulating ITER’s mission

…in the context of the global fusion innovation program

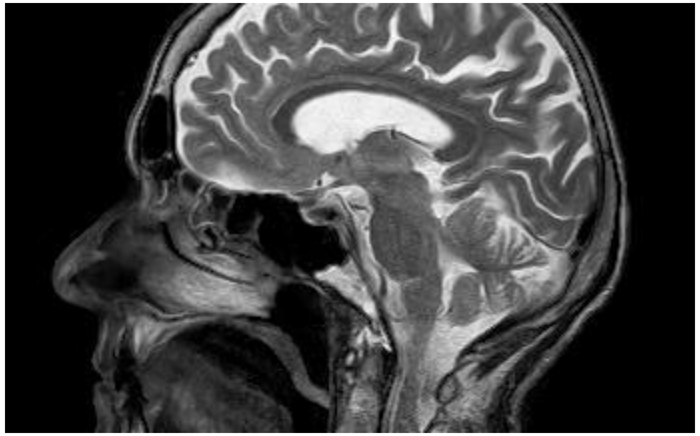
- Many characterize the current state of fusion as a “competition” between public fusion R&D (e.g., ITER) and the emerging private sector initiatives.
- In reality, fusion development requires an innovation program – which, optimally, is a public-private collaboration.
- ITER remains essential at this program’s core: the convergent “national lab” for all involved, enabling repeatable experiments, long-term testing.
- The private sector offers small scale, agile, initiatives:
  - Enabling technologies (e.g., better Magnets)
  - Understanding of plasma physics (e.g., shape effects, burning plasma)
  - New materials resistant to 15MeV neutron irradiation
  - Foster innovation and exploration of new concept ideas (often with higher risk of failure)
- The need (extremely valuable): a platform for cross-fertilization.
- Our ambition is for ITER to serve as an “information hub” for global fusion R&D, breaking down research “silos” and consolidating knowledge to drive faster fusion success.

> *Fusion development requires an innovation program – which, optimally, is a public-private collaboration.*

INNOVATION AND SPIN-OFFS FROM ITER

ADVANCING MEDICINE, MANUFACTURING, AND MORE

Superconductor magnet advances →
Enhanced mapping of the human brain



Complex aluminum structures →
Enhanced electric train bodies

Explosive forming →
High-strength components such as aircraft

High-precision diagnostics →
Enhancements for geothermal energy, laser welding, cancer treatment, etc.

Thank you!

iter

china eu india japan korea russia usa