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# ITER ORGANIZATION
# PROGRESS IN PICTURES 2018

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# A star is born

A star will soon be born, a star unlike any other ... a man-made star. ITER - the Latin word for "The Way" - will light up in the middle of the coming decade.

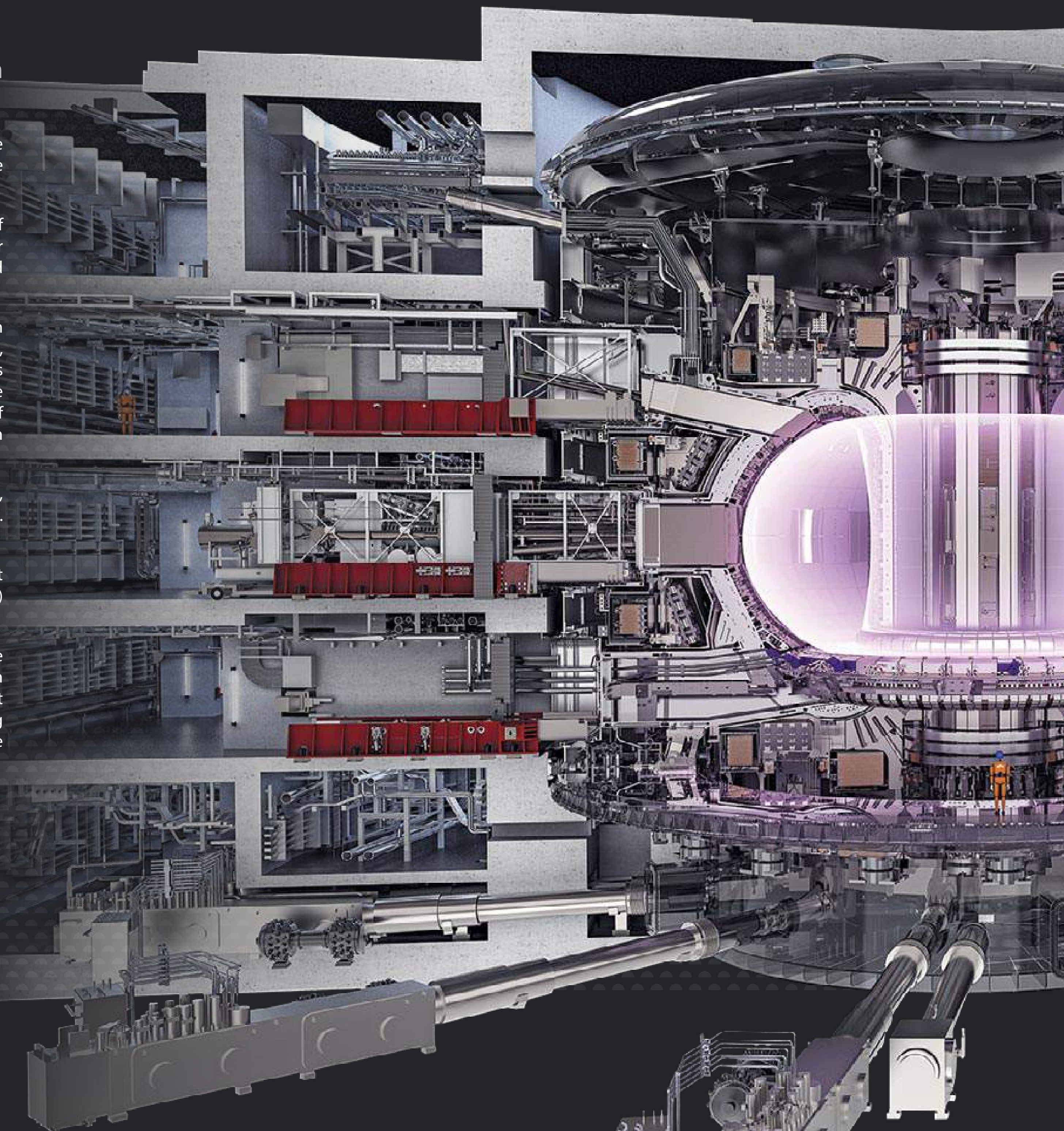
From a scientific and technological point of view, it will be one of humankind's historic achievements. The creation of an artificial star and the tapping of the tremendous amounts of energy produced could forever alter the course of civilization.

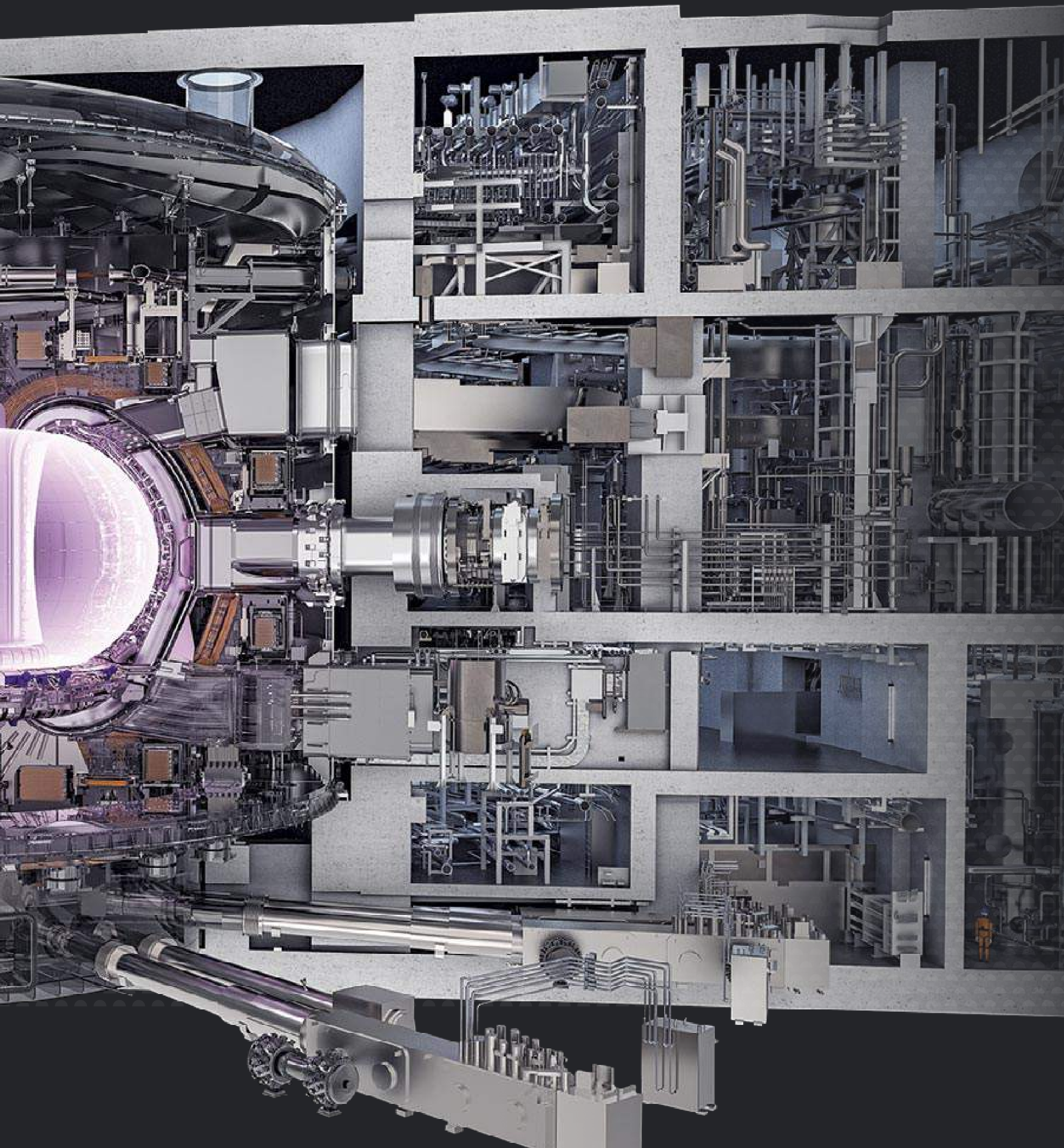
The ITER Project, an unprecedented international collaboration that brings together China, the European Union, India, Japan, Korea, Russia and the United States, is the culmination of decades of research and years of diplomatic negotiation. It has been the aspiration of three generations of physicists; it is now the reality of hundreds of scientists, engineers, and labourers involved in ITER in France and throughout the world.

The seven ITER Members, representing half the world's population, share the responsibility for building the ITER machine and facilities. Every Member, essentially, is involved in every system.

As buildings rise on the ITER platform (pages 5 to 27), component manufacturing advances in ITER Member factories (pages 33 to 53) and preparations are underway for the machine assembly phase.

This fifth edition of the ITER photobook aims to take you into the heart of ITER – from the rolling hills of Provence to factories on three continents, where men and women from 35 nations are bent on realizing one of mankind's most enduring dreams: capturing the fire of the stars and making it available to humanity for the millennia to come.





## The ITER Tokamak

The ITER machine is a *tokamak*, the Russian acronym for Toroidal Chamber, Magnetic Coils. Tokamaks were developed in the 1960s at a time when nations were experimenting with all kinds of different systems to reproduce the nuclear reactions at work in the core of the Sun and stars.

A tokamak, like a star, is designed to fuse light atoms into heavier ones. A tokamak is a magnificent tribute to Albert Einstein's $E=mc^2$: the tiny loss of mass that results from the fusion process translates into a huge quantity of energy. One gramme of fusion fuel (the hydrogen isotopes deuterium and tritium) generates as much energy as eight tonnes of oil.

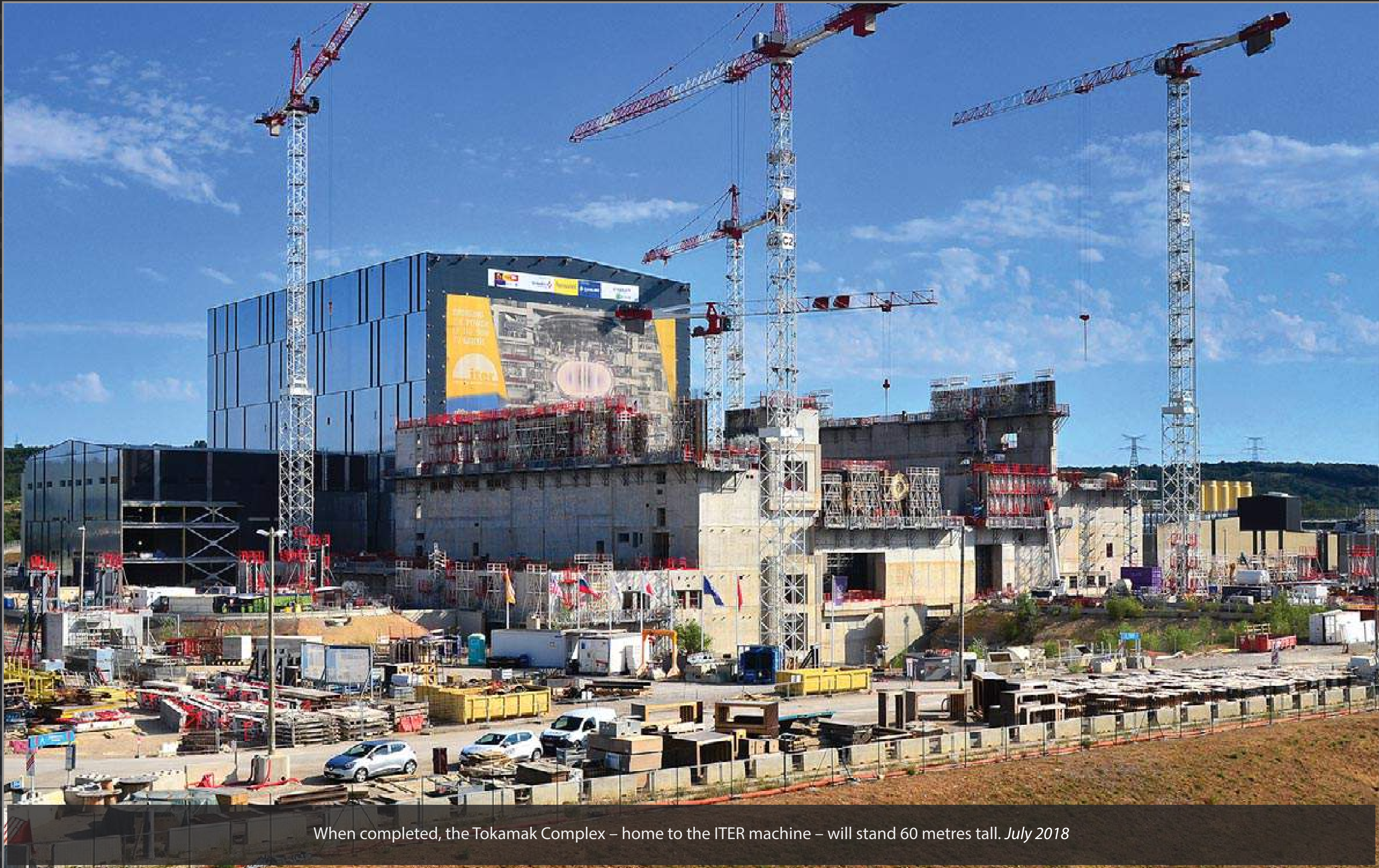
ITER will be by far the largest and most complex tokamak ever built. Designed from the experience accumulated in hundreds of fusion machines throughout the world, it will demonstrate that fusion energy is scientifically and technologically feasible.

| | |
|---|---|
| Weight | **23,000 Tonnes** |
| Height | **~ 30 Metres** |
| Diameter | **~ 30 Metres** |
| Plasma volume | **840 $M^3$** |
| Temperature at plasma core | **150,000,000 °C** |
| Fusion power | **500 MW** |

As signatories to the ITER Agreement, ITER Members China, the European Union, India, Japan, Korea, Russia and the United States share in the cost of construction, the planning for operation and the overall governance of the ITER Organization. *June 2018*

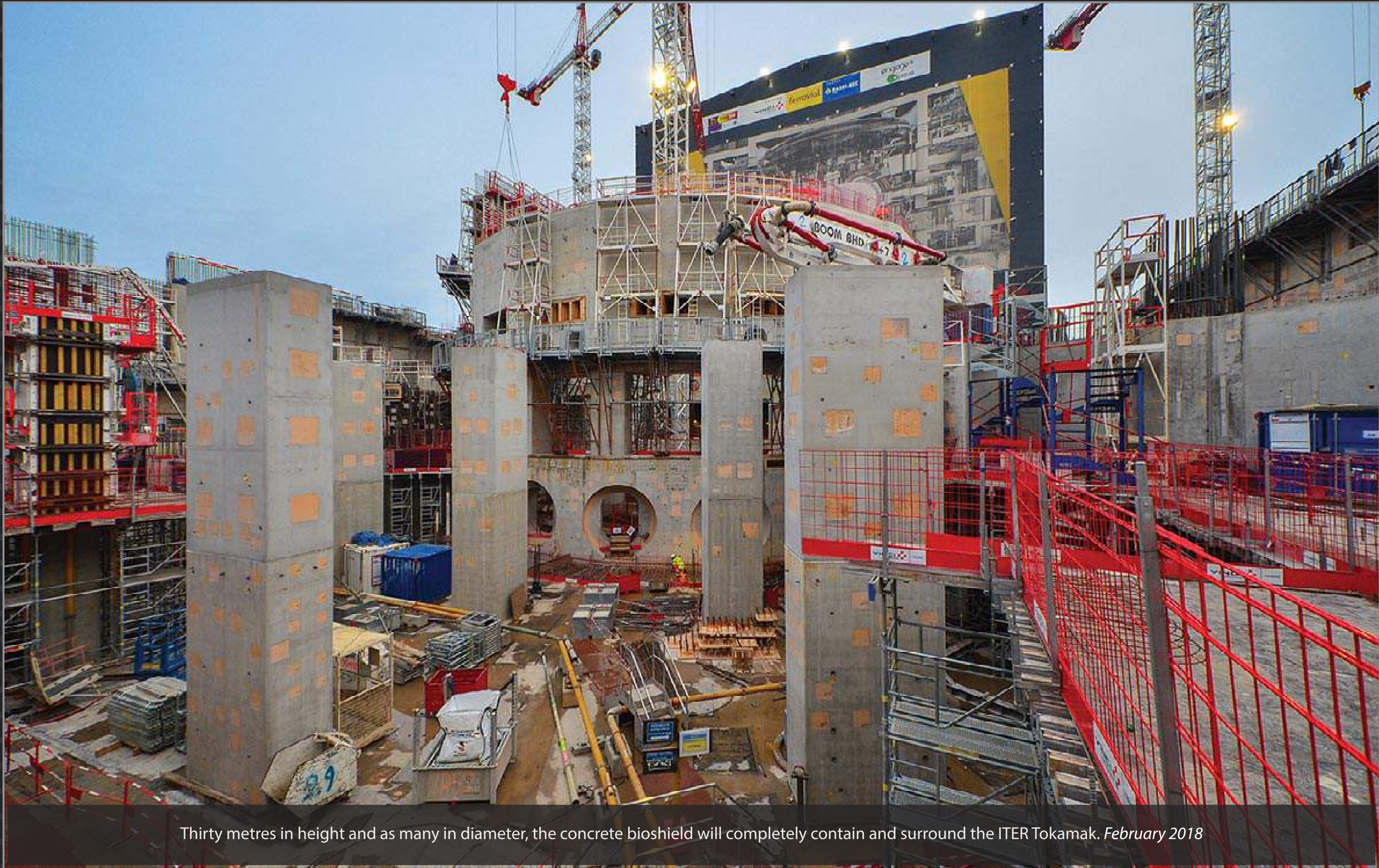
# The ITER construction platform

Building started on the 180-hectare site in southern France in 2010. Seven years remain until First Plasma. *July 2018*



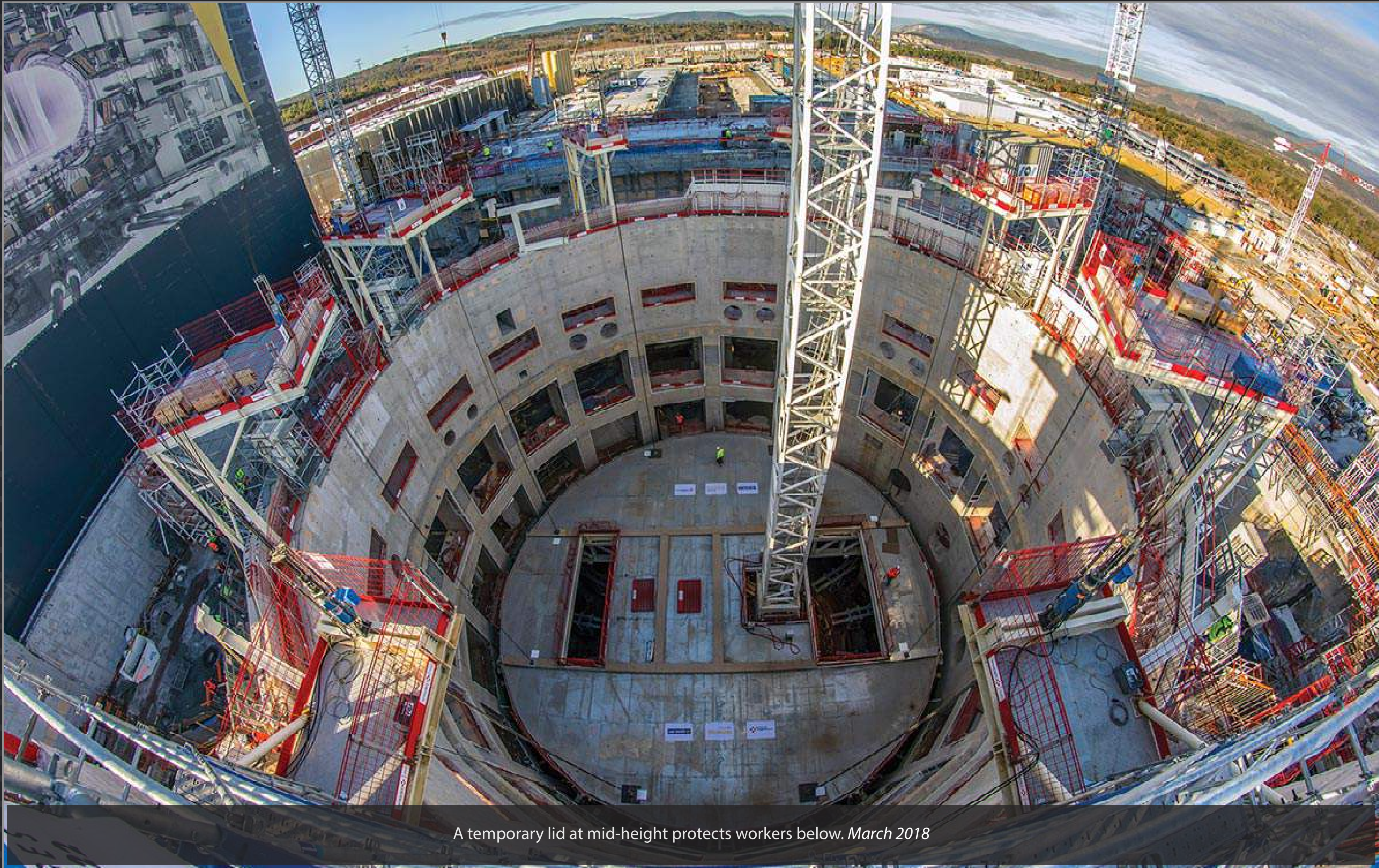
When completed, the Tokamak Complex – home to the ITER machine – will stand 60 metres tall. *July 2018*

# ITER jewel box



Thirty metres in height and as many in diameter, the concrete bioshield will completely contain and surround the ITER Tokamak. *February 2018*

# Temporary lid

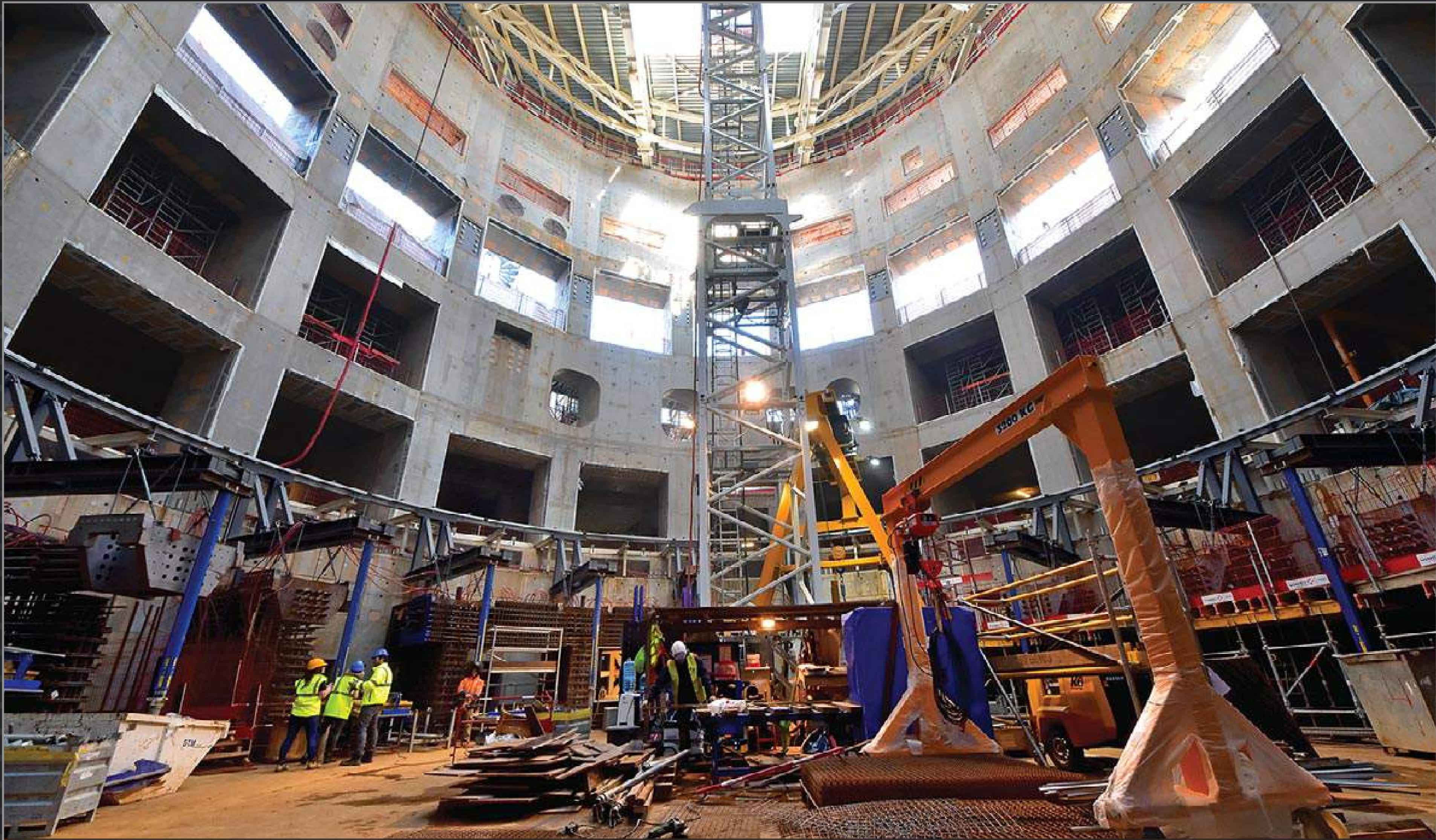


A temporary lid at mid-height protects workers below. *March 2018*

# Under a protective roof


The last scaffolding is removed, the lid is raised to the top, and teams now have a 30-metre-deep "well" to prepare for machine assembly. *April 2018*

# A crown under the machine

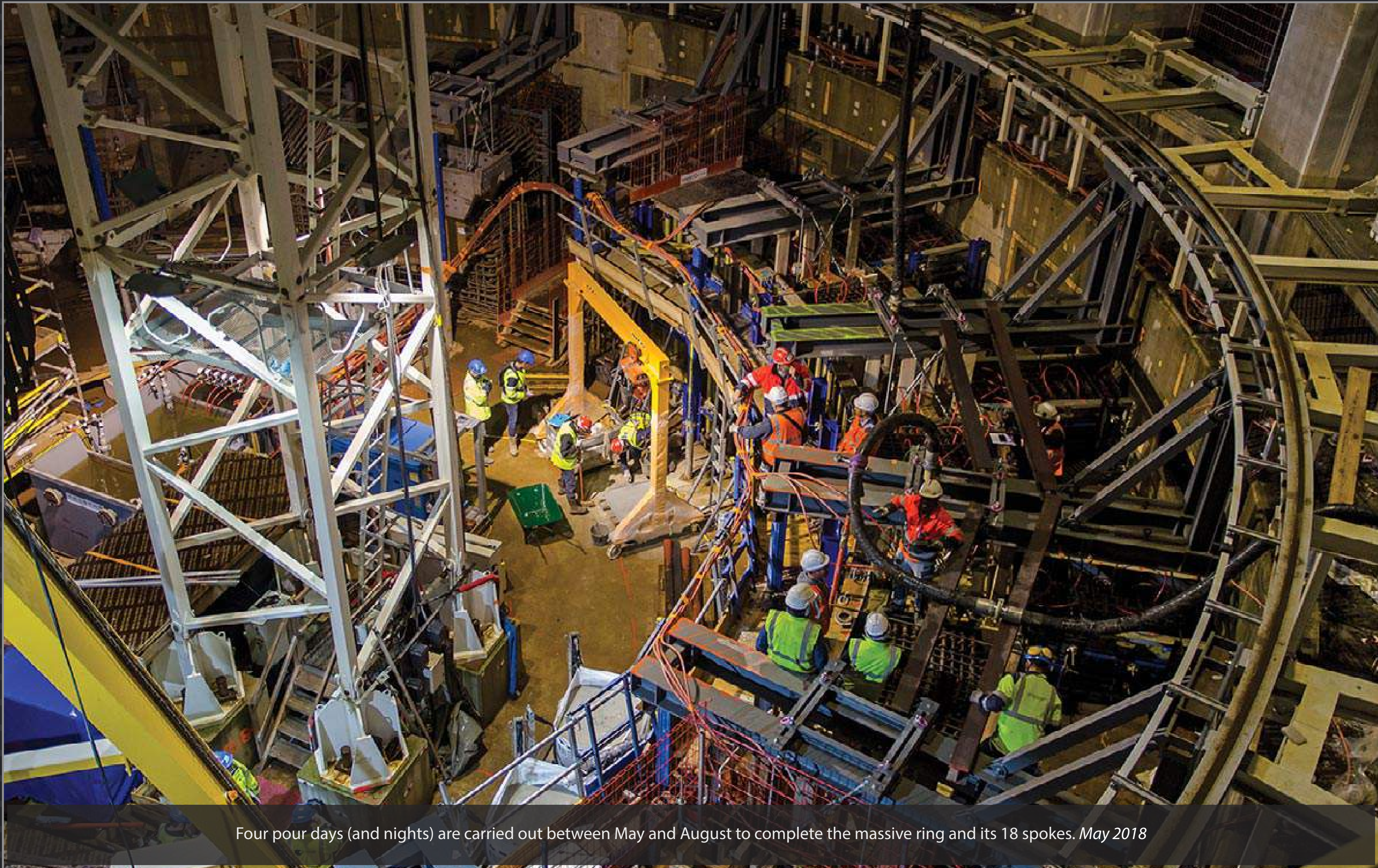



On the floor of the Tokamak Pit, European contractors prepare to pour the concrete crown – the ring wall foundation that will support the full weight of the machine. *April 2018*

# Supporting 23,000 tonnes

The crown and its 18 radial walls are the most heavily reinforced areas of the Tokamak Complex. *April 2018*

# Working into the night

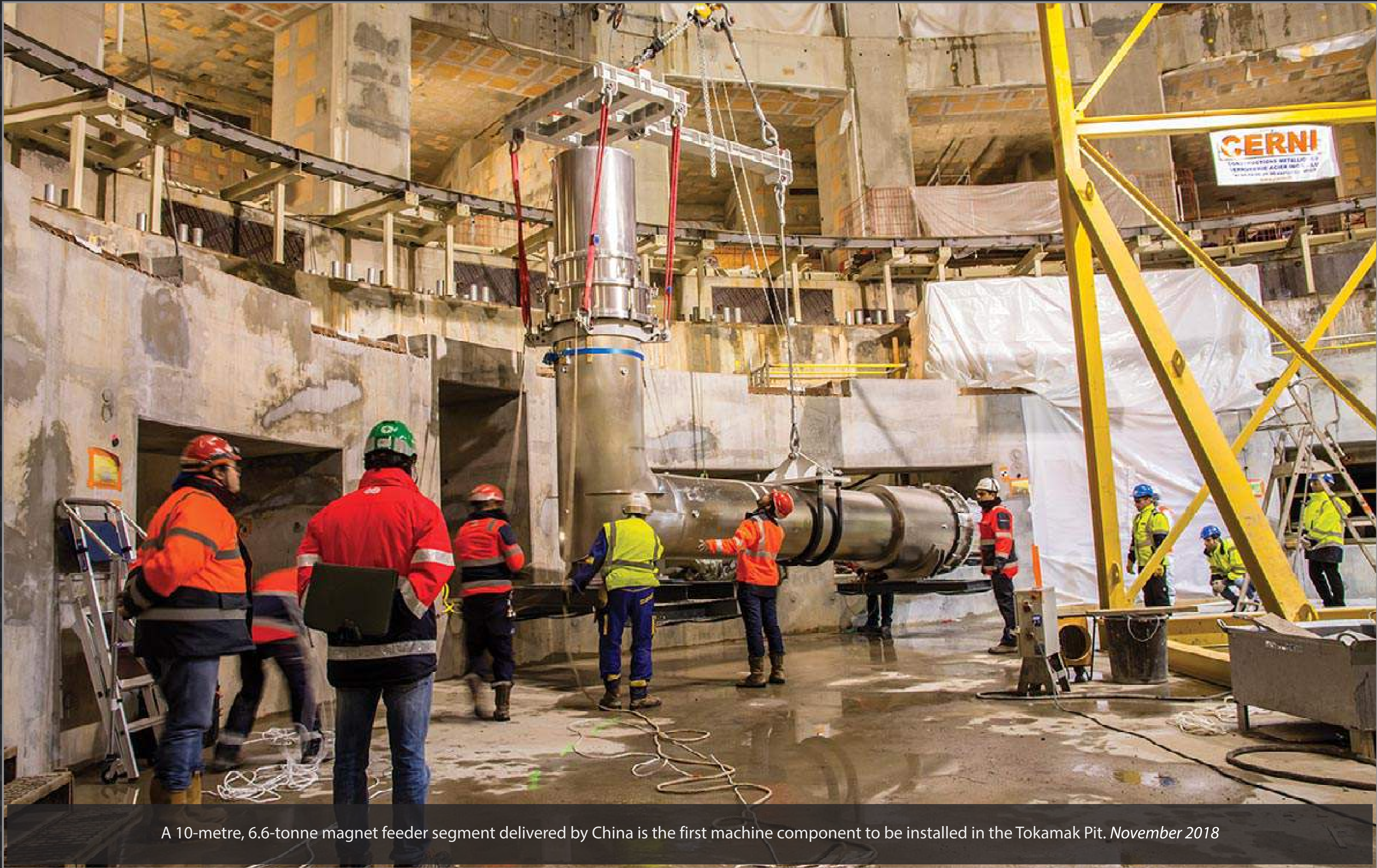


Four pour days (and nights) are carried out between May and August to complete the massive ring and its 18 spokes. *May 2018*

# 18-point crown

Only one small opening (lower right) remains in the concrete crown for the installation of the first metal component – a magnet feeder. *September 2018*

# Metal joins concrete




A 10-metre, 6.6-tonne magnet feeder segment delivered by China is the first machine component to be installed in the Tokamak Pit. *November 2018*


Contractors prepare to install heavy nuclear doors on each of the port cells (left) that separates outlying galleries from the machine. *October 2018*

# Looking north

Looking from a worksite crane over the northern half of the construction platform. *December 2018*

# Cooling tower zone

In this 6,000 m² area, infrastructure for the installation's heat rejection system is emerging. *December 2018*

## Storing helium


The first of six tall storage tanks for gaseous helium is installed near the ITER cryoplant. *February 2018*

# Powered up

Four transformers supplied by US ITER for the steady state electrical network have been "energized" and ITER is officially connected to the French grid. *September 2018*

# The cold factory

Nearly all the equipment for the ITER cryoplant has been delivered and installation is underway. *July 2018*

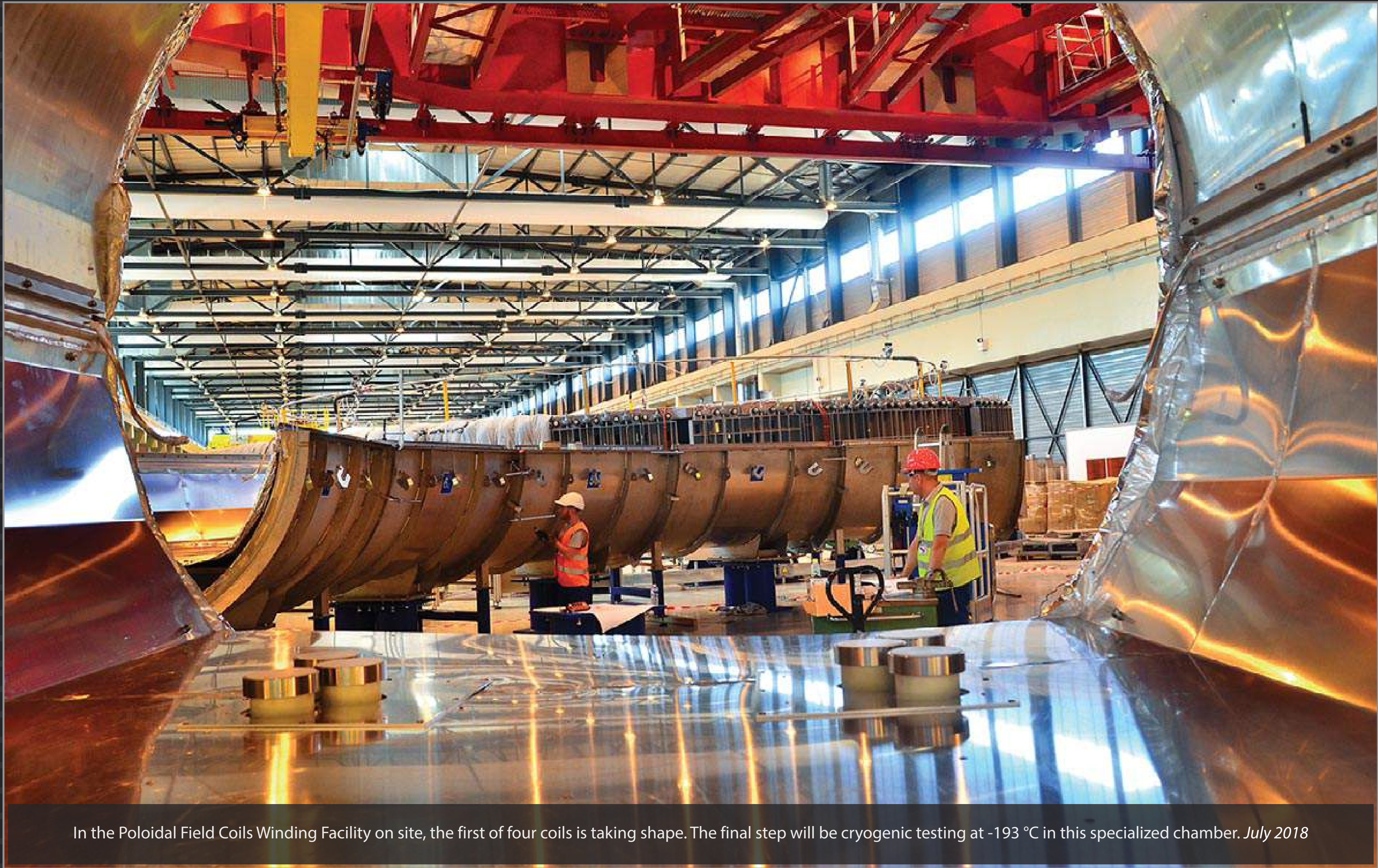
## Giant thermos taking shape


Indian contractors are close to finalizing two major sections of the cryostat – the lower cylinder (far end) and the base (next page). *July 2018*

## Heaviest single component

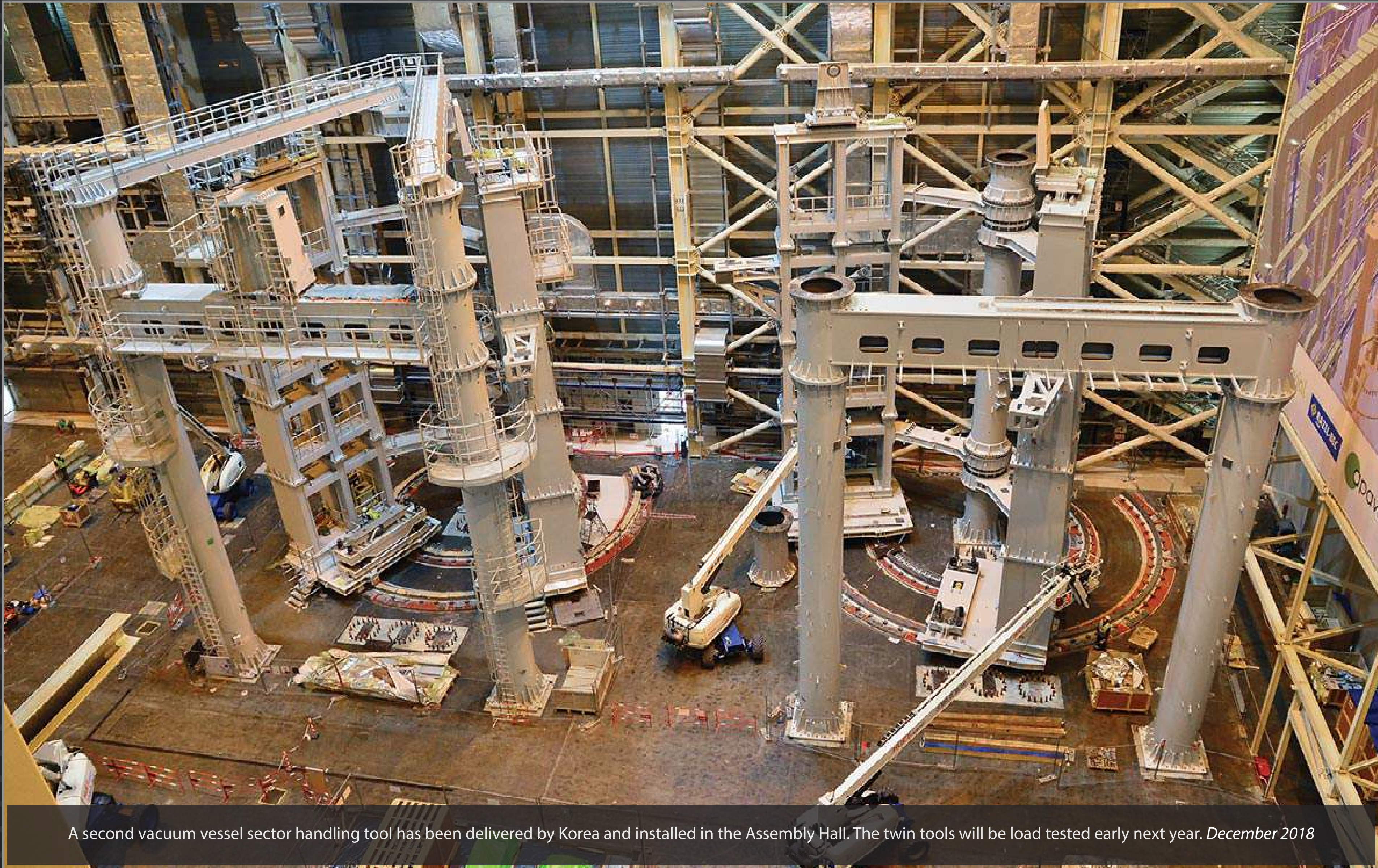
At 1,250 tonnes, the cryostat base tops the list of heaviest ITER components. *December 2018*

## Ring magnet #5



In the Poloidal Field Coils Winding Facility on site, the first of four coils is taking shape. The final step will be cryogenic testing at -193 °C in this specialized chamber. *July 2018*

# Twin Titans



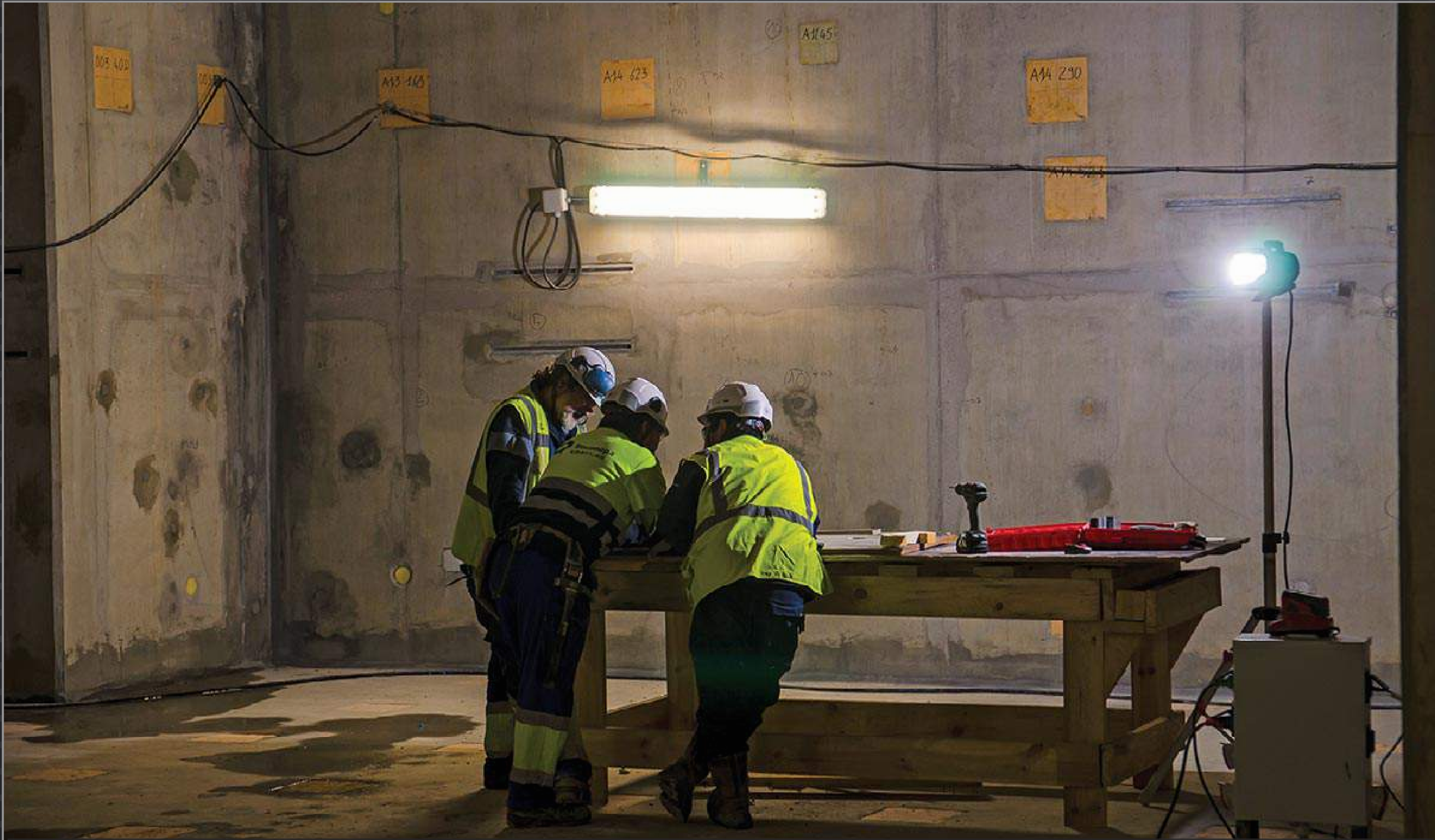
A second vacuum vessel sector handling tool has been delivered by Korea and installed in the Assembly Hall. The twin tools will be load tested early next year. *December 2018*

# Narrow access to a large room

Three tanks for the Tokamak cooling water system (procured by US ITER) and four tanks for the vacuum vessel's vapour suppression system (procured by the ITER Organization) have been installed in the Tokamak Building's drain tank room. *August 2018*

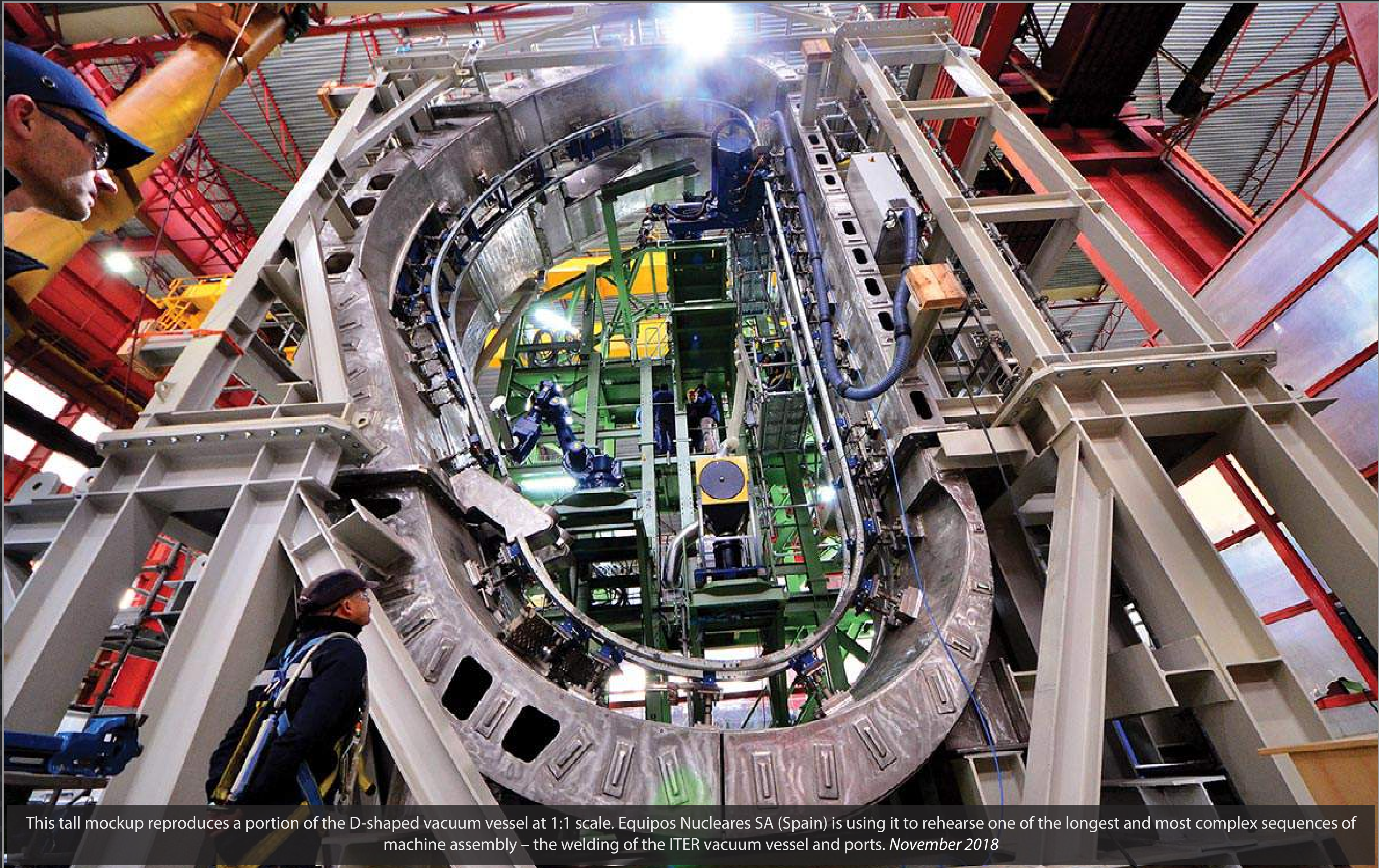
## White world

Now painted in white, the lowest basement level of the Diagnostic Building is ready for handover to contractors for systems installation. Embedded plates – for the attachment of system supports – are visible on all surfaces. *December 2018*




In one of the galleries deep inside the Tokamak Complex, contractors review the day's plans. More than 2,000 people are involved in ITER construction – 1,600 workers and 400 engineers and supervisors. *March 2018*

# Rehearsing a grand production



This tall mockup reproduces a portion of the D-shaped vacuum vessel at 1:1 scale. Equipos Nucleares SA (Spain) is using it to rehearse one of the longest and most complex sequences of machine assembly – the welding of the ITER vacuum vessel and ports. *November 2018*


Science at the ITER Neutral Beam Test Facility in Padua, Italy, is officially launched as the SPIDER negative ion source produces its first plasma. The Domestic Agencies of Europe and India have contributed components. *June 2018*


KEMPPI

ITER ORGANIZATION
# MANUFACTURING

A unique aspect of ITER implementation is the in-kind procurement system that was established at the onset of the project. Instead of contributing purely financial resources, China, the European Union, India, Japan, Korea, Russia and the United States provide 90% of their contributions in the form of machine components, systems and – in the case of Europe – buildings.

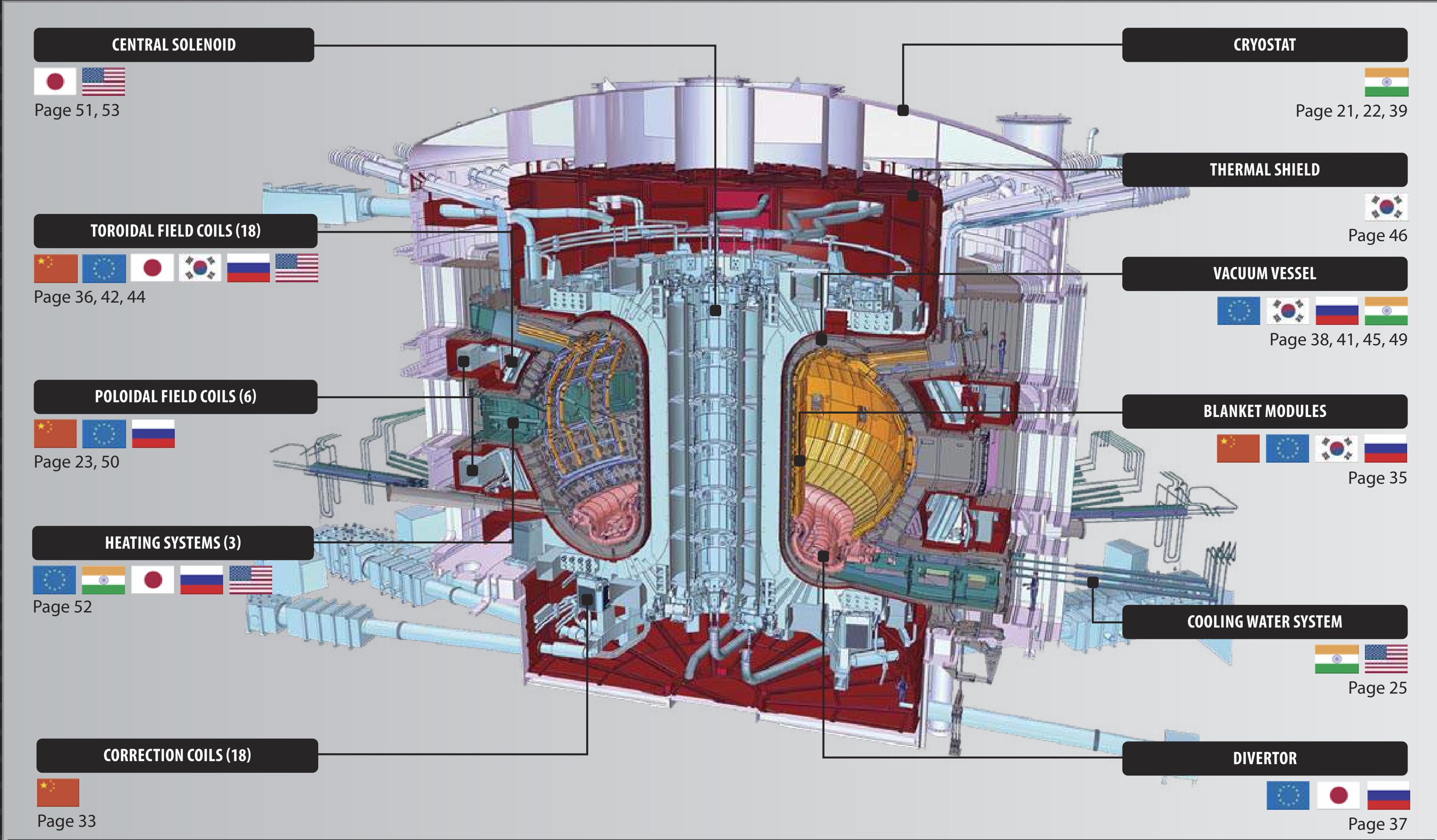
Procurement packages are shared equally (~ 9% of the total value) between China, India, Japan, Korea, Russia and the United States; Europe's share, as Host Member, is ~ 45%.

The in-kind procurement arrangement is at the core of ITER's founding philosophy, offering the ITER Members invaluable experience in the manufacturing of components for a fusion installation.

By contributing to the construction of the experimental machine, the ITER Members are creating the technological and industrial basis for the commercial fusion reactors of the future.

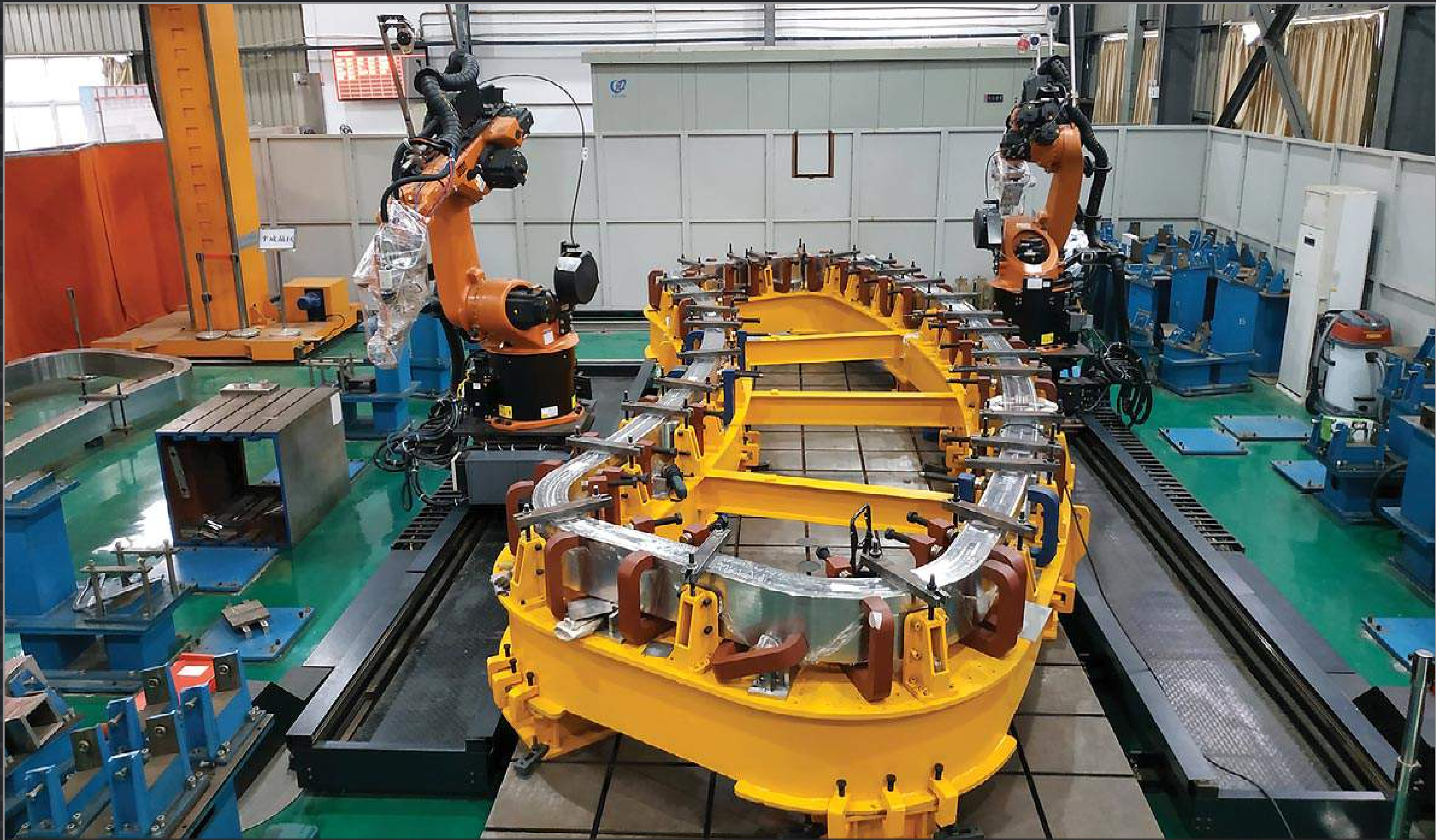
The project is also spurring developments in other fields, as companies apply the expertise acquired in the fabrication of ITER's cutting-edge components and systems to other applications and technologies.

# Who manufactures what?




Not all systems (or contributions) are represented in this illustration.

# Case closed



Six bottom, six side, and six top correction coils will be installed around the Tokamak to correct field errors. At the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), final closure welding has been carried out on the first bottom production unit.

# A box for cold components


Coil termination boxes provide the thermal insulation for the cryogenic components at the very end of each magnet feeder. This production unit is about to pass factory acceptance tests at ASIPP.

# Helium test passed

Hot helium leak tests on this 2.8-tonne blanket shield block prototype have successfully confirmed its suitability for ITER's ultra-high vacuum environment.

# 20 days in the cold

The first toroidal field winding pack manufactured in Europe is lowered into a specially designed cryostat for cold testing, where it will spend 20 days at minus 193 ˚C to confirm the robustness of coil insulation.

# Trial by fire

This plasma-facing component of the ITER divertor – a full-scale prototype of the inner vertical target manufactured by Ansaldo Nucleare and ENEA – is about to be tested at the ITER Divertor Test Facility at the Efremov Institute in Russia.

## Five out of nine


Fusion for Energy (F4E), the European Domestic Agency, is delivering five of ITER's nine vacuum vessel sectors. The first to come off the production line in 2020 will be Sector #5. (Pictured, a poloidal segment mounted on assembly tooling at Mangiarotti SpA.)

# Nearing the end

At the Larsen & Toubro manufacturing complex in Hazira, work is underway on the last two orders the company is filling for the ITER cryostat: segments of the 490-tonne upper cylinder (pictured) and 665-tonne top lid.

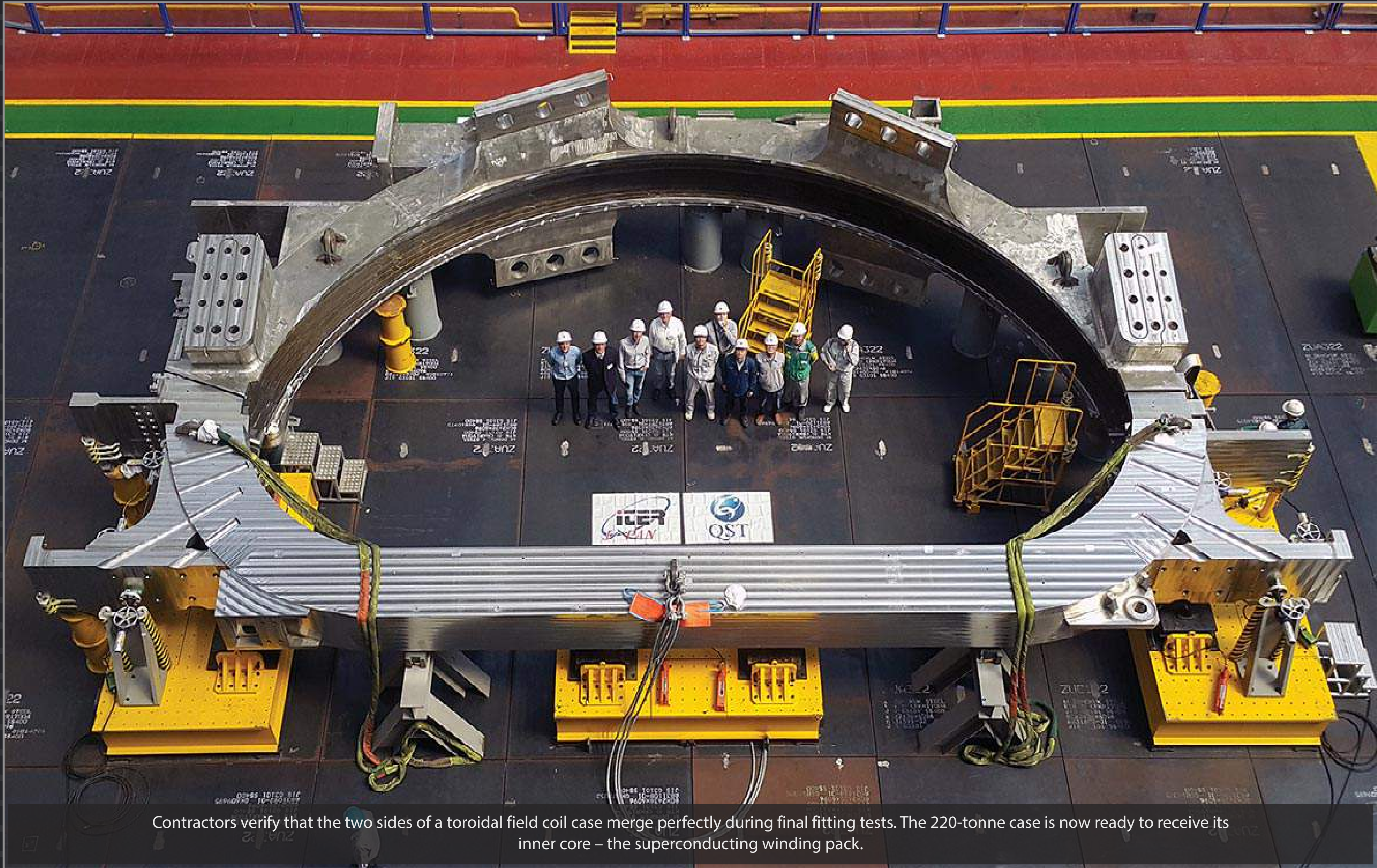
# All angles, bends and turns

Cryogenic fluids at ITER will be circulated between the cryoplant and the Tokamak Building through a complex, five-kilometre network of industrial cryolines. INOXCVA is manufacturing approximately 50% of these high-tech components at its factory in Vadodara.

# Thousands of plates, thousands of shapes

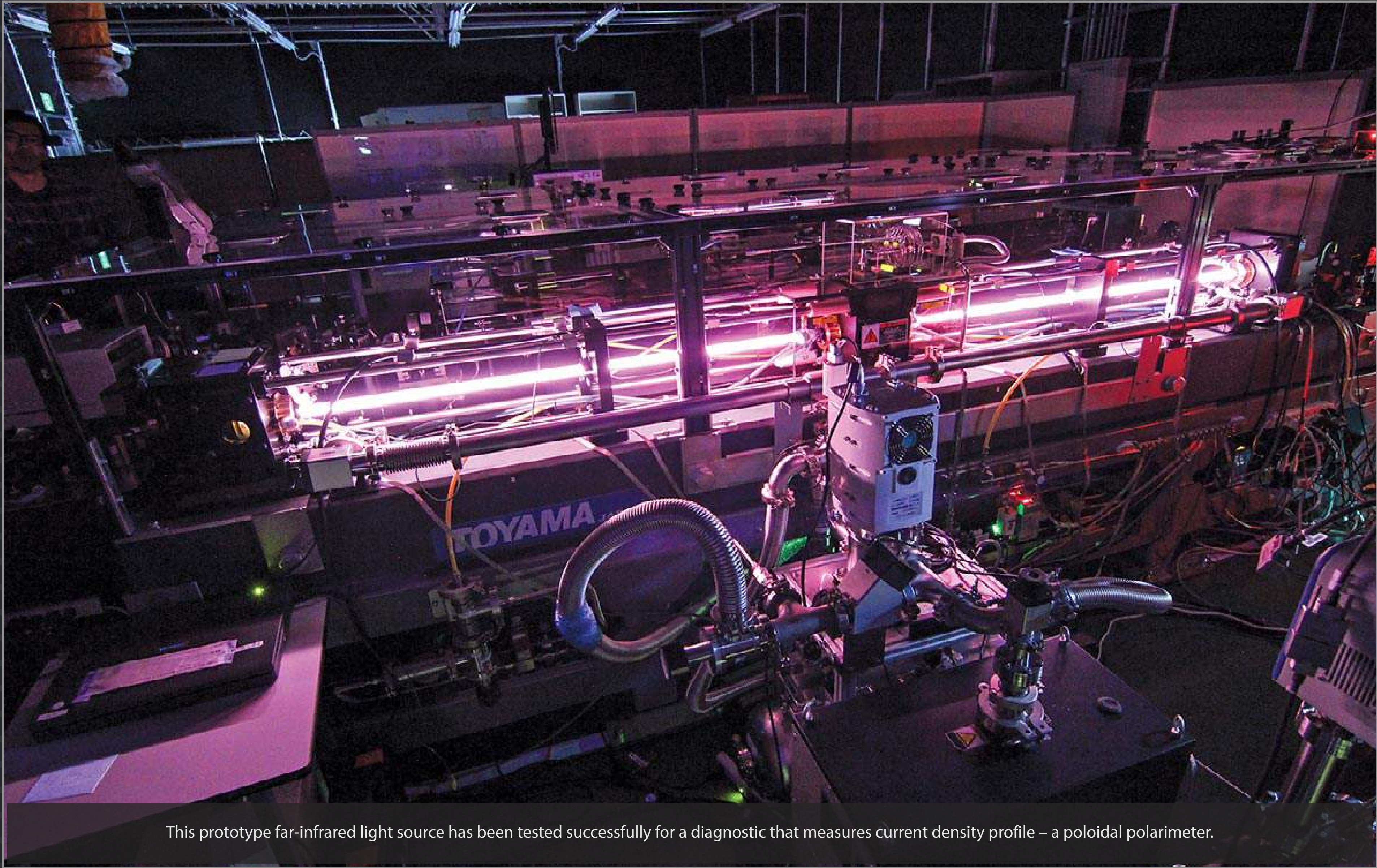
In-wall shielding plates – assembled into blocks – will fill 55% of the space between the walls of the vacuum vessel to provide radiation shielding for the superconducting coils. India is procuring approximately 50,000 plates, and each one is unique in shape, size and weight.

# Final fit



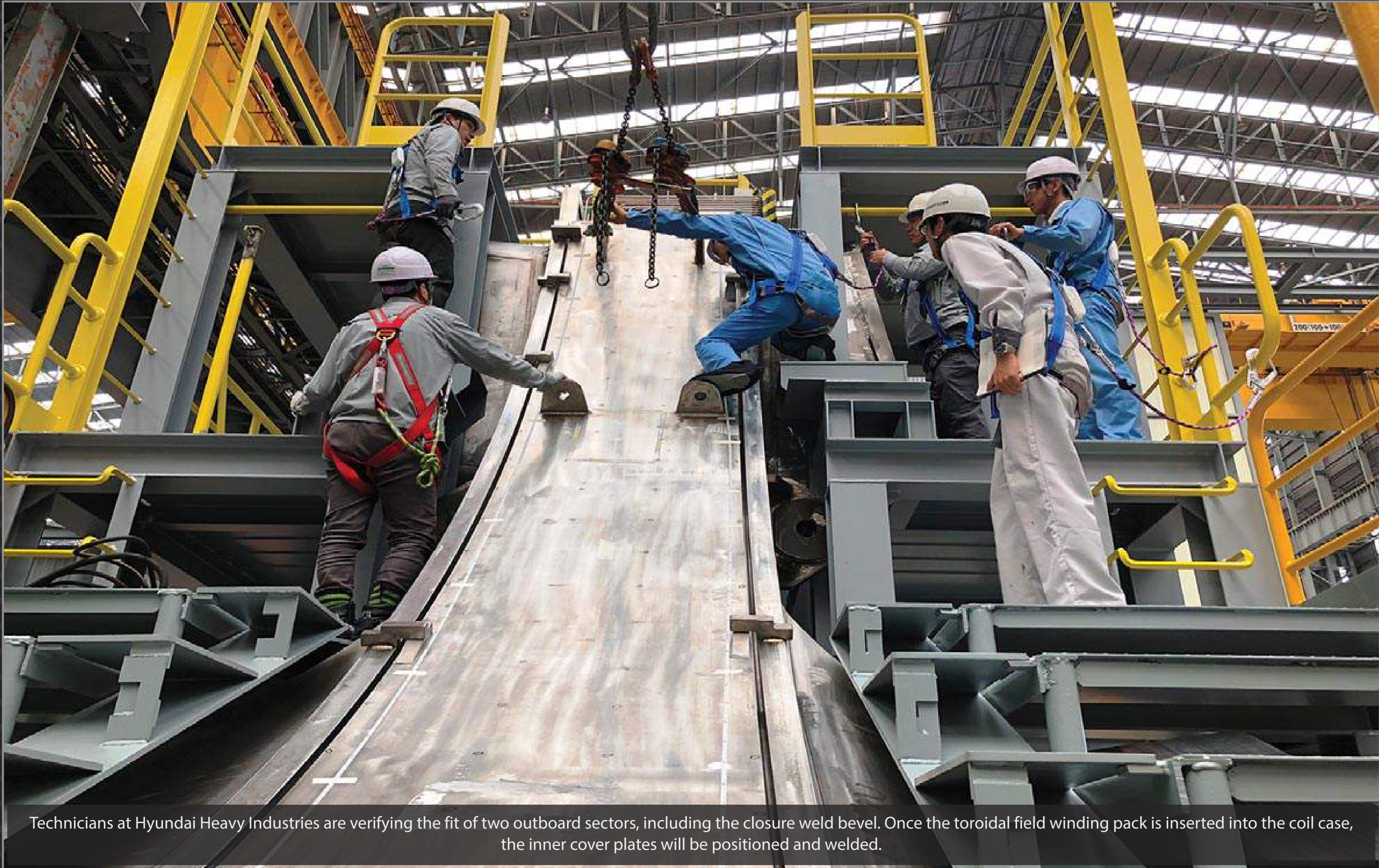
Contractors verify that the two sides of a toroidal field coil case merge perfectly during final fitting tests. The 220-tonne case is now ready to receive its inner core – the superconducting winding pack.

# Prototype diagnostic




This prototype far-infrared light source has been tested successfully for a diagnostic that measures current density profile – a poloidal polarimeter.

# Coil cases in mass production




Technicians at Hyundai Heavy Industries are verifying the fit of two outboard sectors, including the closure weld bevel. Once the toroidal field winding pack is inserted into the coil case, the inner cover plates will be positioned and welded.

# Four out of nine

Hyundai Heavy Industries is manufacturing four of ITER's nine vacuum vessel sectors. The first to come off the production line in 2019 will be Sector #6. (Pictured, technicians are inserting in-wall shielding blocks into one of four Sector #6 segments.)

# Like clockwork

The first 23 panels of the vacuum vessel thermal shield have been successfully pre-assembled for fitting tests. After silver coating, the panels will be shipped to ITER to be installed on the first vacuum vessel sector.

# Solid feet

Korea is procuring a large array of assembly tooling ranging from the tall (see page 24) to the very small. These units will support vacuum vessel sectors and magnet coils from below while they are pre-assembled at ITER.

# High-tech power cables

Russia is procuring 5.4 km (500 tonnes) of high-current, water-cooled busbars for the superconducting magnets; the largest will carry close to 70 kiloamps of current.

## Port extensions

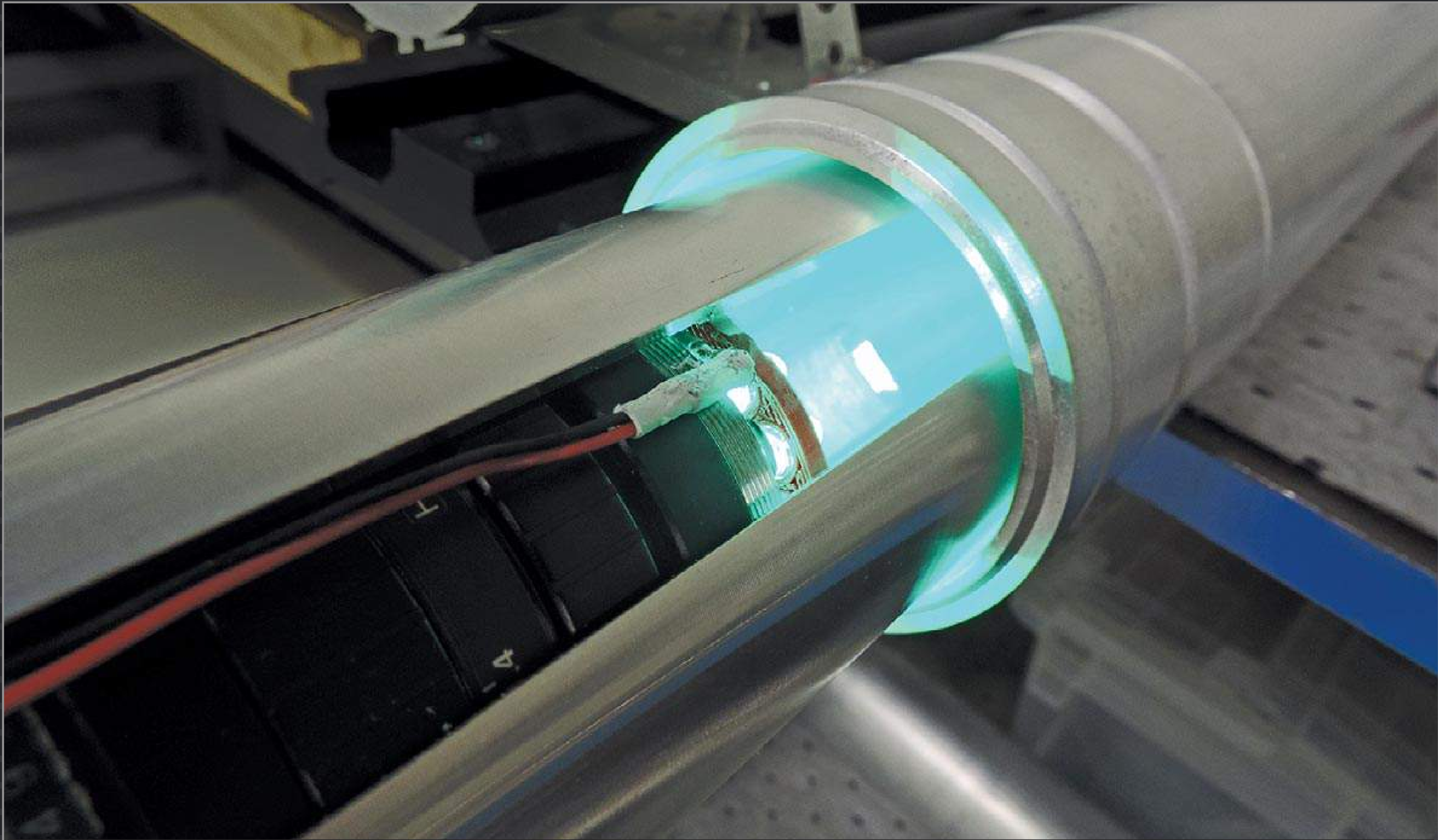
Extending out from the openings in the vacuum vessel are port stub extensions that must be welded to the sectors before the assembly of the main vessel in the pit. Series production is underway.

## Completely wound

All eight double pancake windings have been completed for poloidal field coil #1; now they must undergo vacuum pressure impregnation (pictured).

# Central solenoid modules at different stages

In the General Atomics workshop, one central solenoid module is about to undergo vacuum pressure impregnation (left) and another has been successfully heat treated.




US ITER is procuring the transmission lines that will provide efficient power transfer from the ion and electron cyclotron wave sources to the plasma. This waveguide inspection camera has been developed to assist manufacturing quality assurance.

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# Layer upon layer

A central solenoid mockup coil was produced to confirm the readiness of all manufacturing steps. One wedge of the mockup, showing layer upon layer of niobium-tin superconductor, is on its way to ITER for future display.

# ITER ORGANIZATION
# **HIGHLIGHTS**

The ITER Project has begun its countdown to First Plasma – only seven years remain until the button is pushed to initiate the first operational event of the ITER scientific program.

Until then, many complex challenges lie ahead as construction is concluded on site, major one-of-a-kind components are finalized and delivered by the Domestic Agencies, and the ITER Organization team plus contractors implement a carefully sequenced assembly, installation and commissioning program.

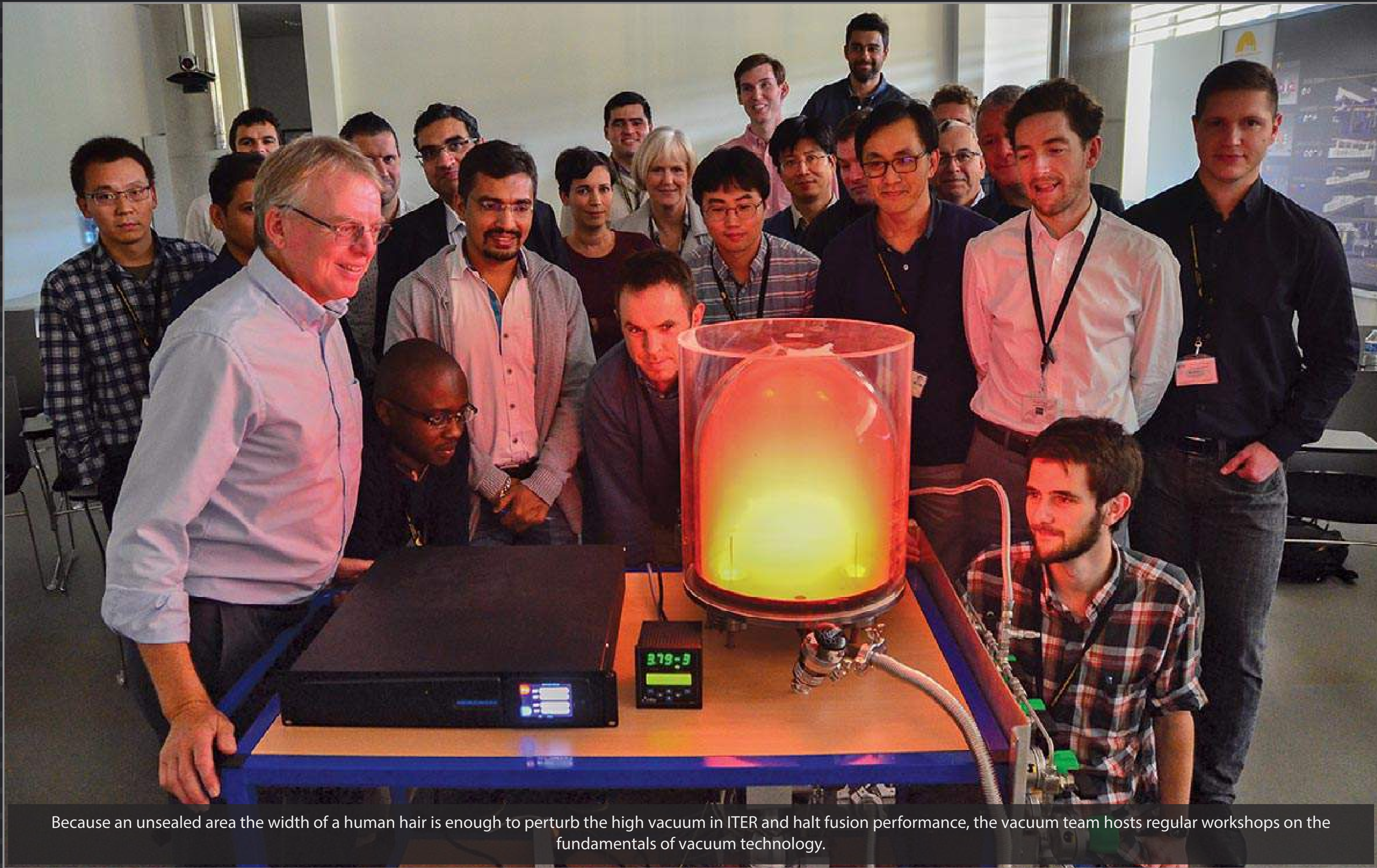
Based on the stringent metrics that measure overall project performance, 60 percent of the "total construction work scope through First Plasma" (a category that includes all design work; construction and manufacturing; delivery; assembly, installation and commissioning) was completed at the end of 2018.

First Plasma will be a decisive step in the making of the man-made star that will demonstrate that fusion energy can produce power on an industrial scale.

# Where are we at?

The ITER Project Control Office tracks progress monthly against the schedule. "At any moment, we can answer the question of where we stand in regard to the objective of First Plasma in 2025," says Deputy Head Colette Ricketts.

# The light in the vacuum



Because an unsealed area the width of a human hair is enough to perturb the high vacuum in ITER and halt fusion performance, the vacuum team hosts regular workshops on the fundamentals of vacuum technology.


Media teams from the seven Members are invited for an annual project update - the perfect occasion to film on site, interview specialists, and learn more about the world's largest collaborative effort in science.

# Always a hit

Held twice a year, Open Doors events take members of the public into the very heart of ITER construction.

# Mr Secretary, Ms Ambassador


As part of a US review of ITER Project progress, the Secretary of the US Department of Energy, Rick Perry, and the US Ambassador to France, Jamie McCourt, visit ITER in July.

# A princess with a passion for science


A large delegation of scientists, diplomats and high-level officials from Thailand, including Her Royal Highness Maha Chakri Sirindhorn, travel to ITER for the signature of a Cooperation Agreement with the Thailand Institute of Nuclear Technology.

# Witnessing the birth of a star

When asked why he chose to visit the ITER construction site, Microsoft co-founder Paul Allen replied, "A visit to ITER was my chance to see preparations for the birth of a star on Earth."

# Team work, just like at ITER

Six hundred students take part in the annual ITER Robots challenge, competing with Lego robots that they have designed and programmed to perform ITER-like remote handling tasks.

## PHOTO CREDITS

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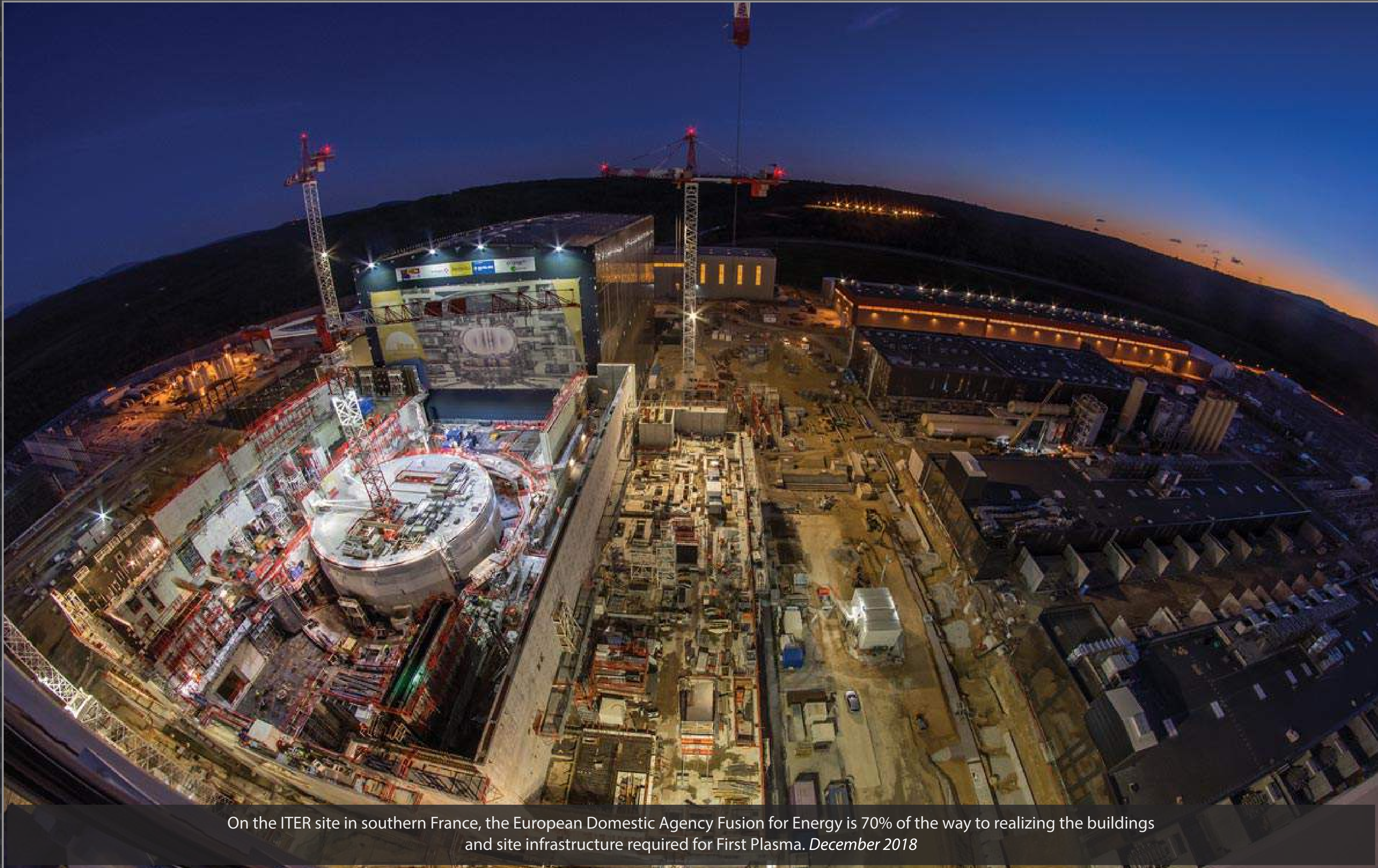
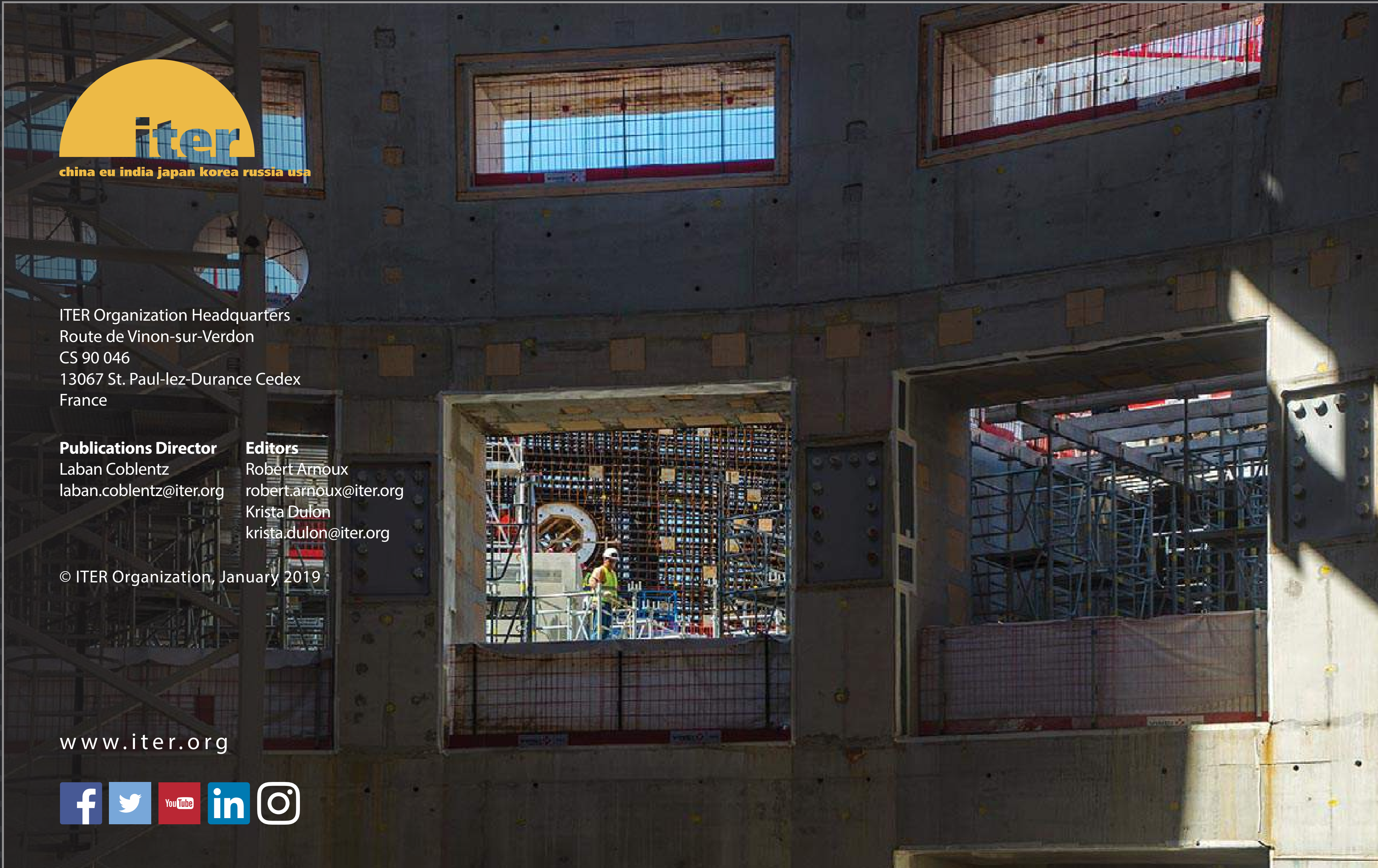


On the ITER site in southern France, the European Domestic Agency Fusion for Energy is 70% of the way to realizing the buildings and site infrastructure required for First Plasma. *December 2018*



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