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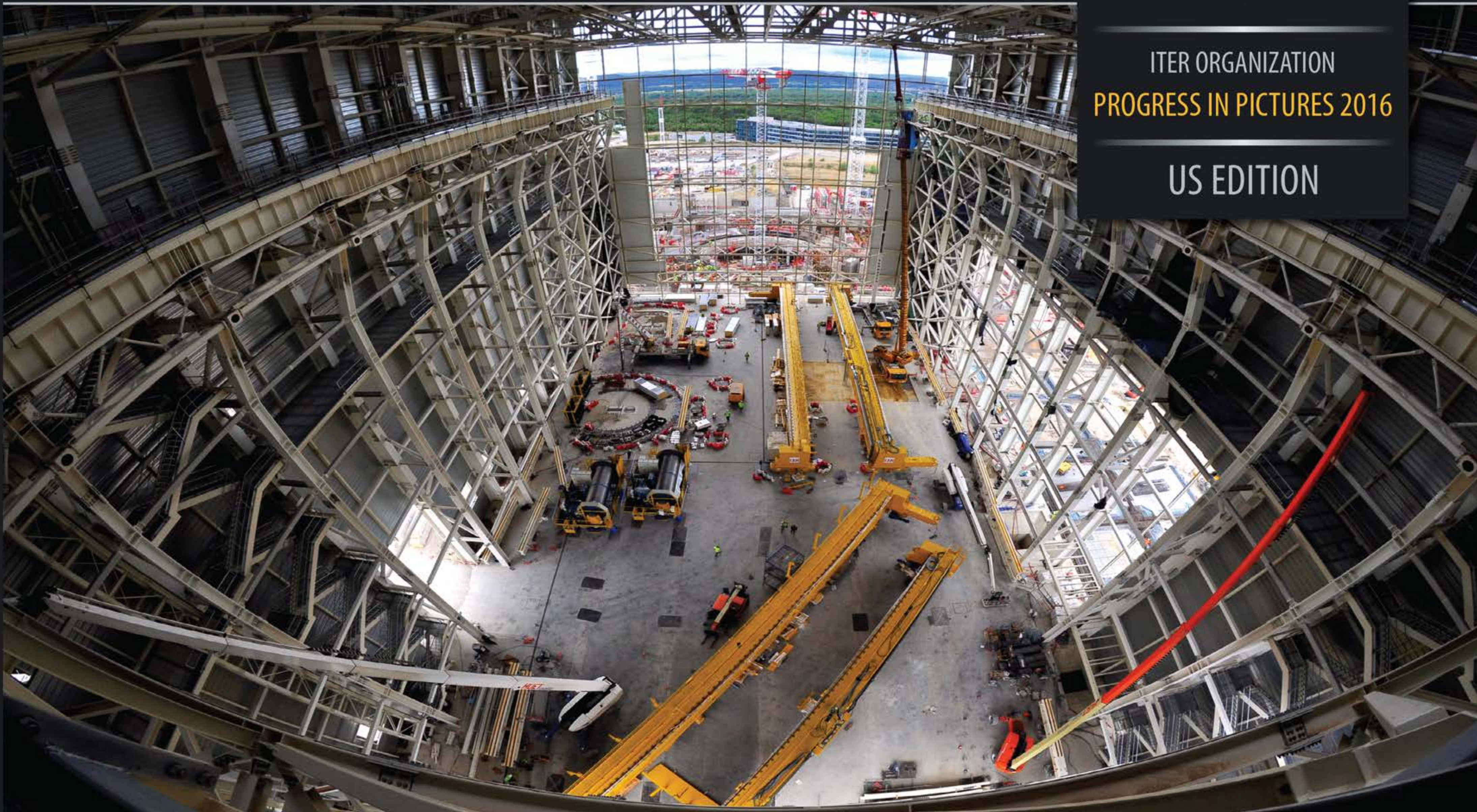
ITER ORGANIZATION

PROGRESS IN PICTURES 2016

US EDITION




BRINGING THE POWER OF THE SUN TO EARTH
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The ITER Project

PROGRESS IN PICTURES 2016

November 2016

A star will be 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.

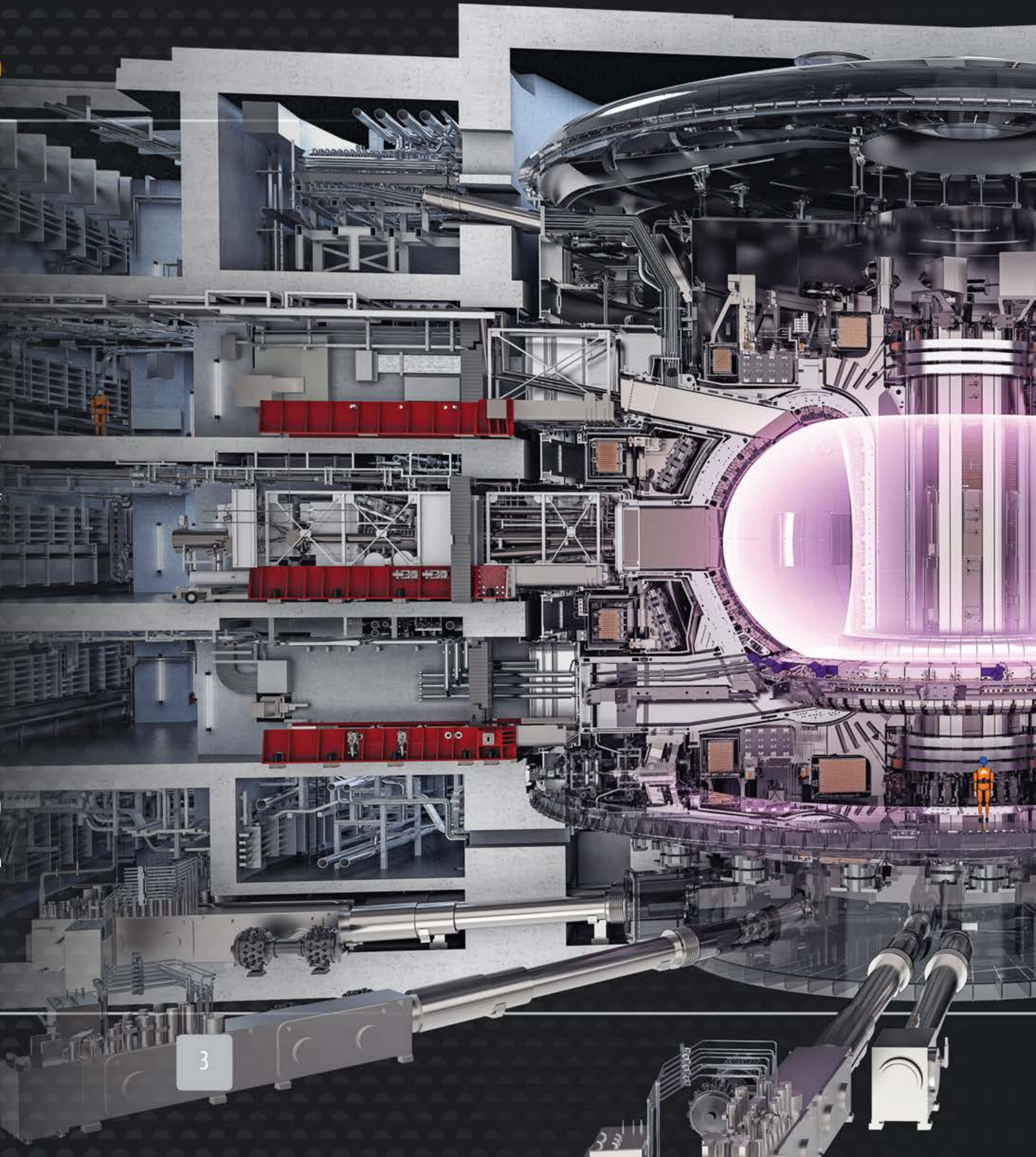
From a scientific and technological point of view, it will be one of humankind's historic achievements. The creation of an artificial star and the tapping of the tremendous amounts of energy produced could forever alter the course of civilization.

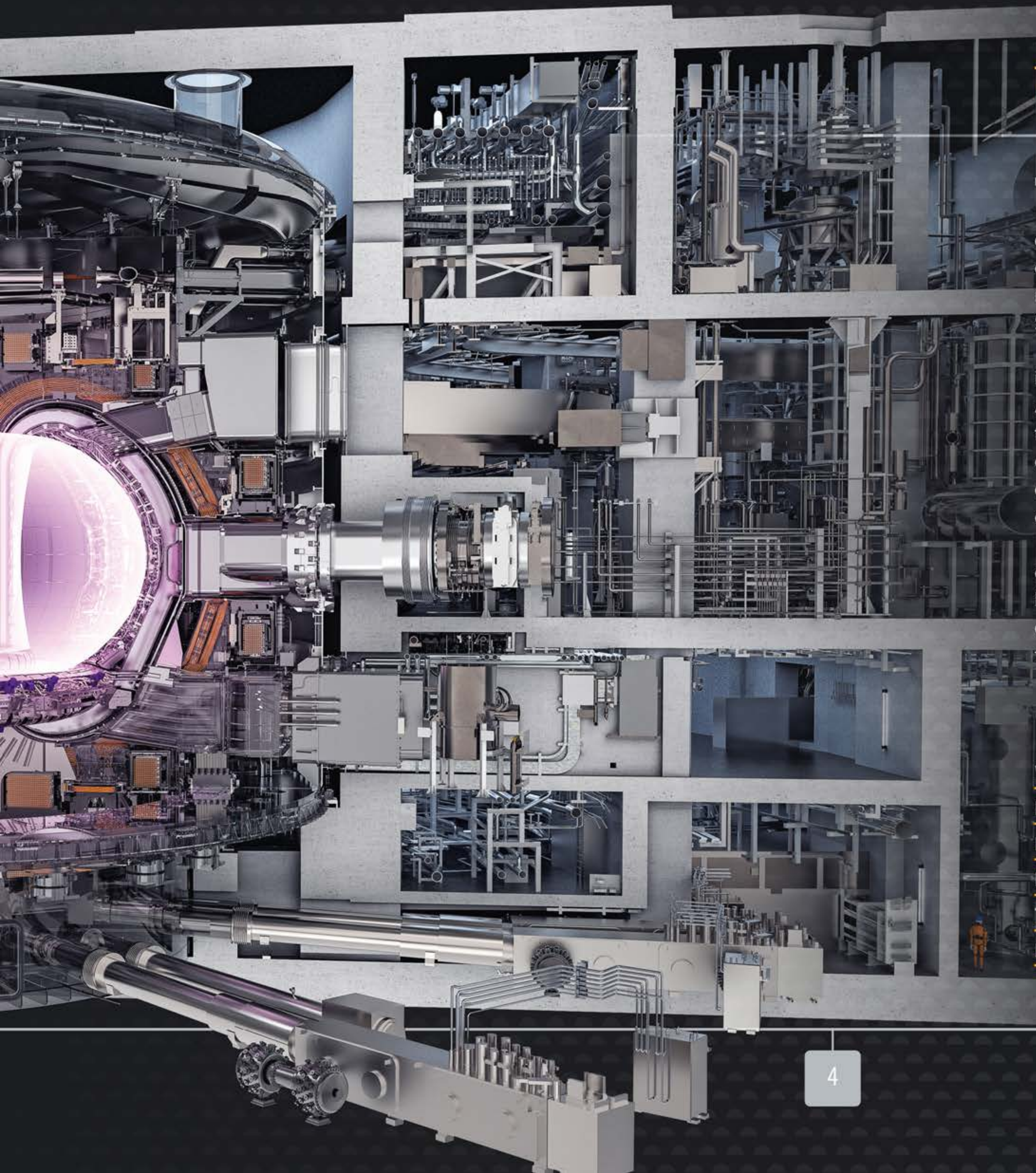
The ITER Project, an unprecedented international collaboration that brings together China, the European Union, India, Japan, Korea, Russia and the United States, is the culmination of decades of research and years of diplomatic negotiation. It has been the aspiration of three generations of physicists;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

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 15), component manufacturing advances in ITER Member factories (pages 16 to 51).

This third 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

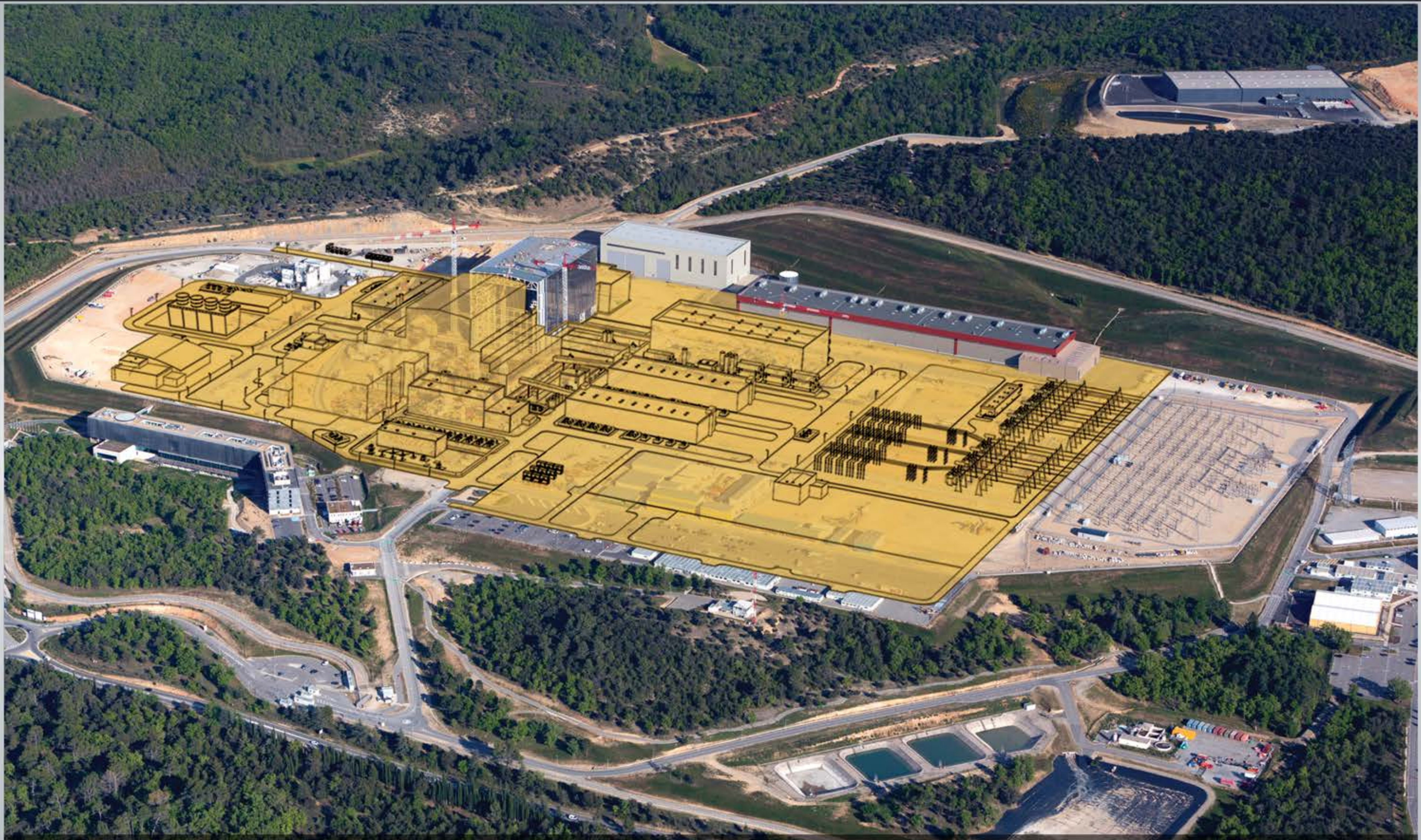
The ITER machine is a *tokamak*, the Russian acronym for Toroidal Chamber, Magnetic Coils. Tokamaks were developed in the 1960s at a time when nations were experimenting with all kinds of different systems to reproduce the nuclear reactions at work in the core of the Sun and stars.

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 gram 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 by 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**

Site map



The ITER Project is located about 45 miles north of Marseille, France, on a 444 acre parcel of land in the Durance River Valley. Building construction began in 2010.

The heart of ITER

It took four years (2010-2014) to create the foundations of the Tokamak Complex, including the excavation, first-level basemat, retaining walls, seismic pillars and bearings, and second-level basemat. Now, the lowest levels of the Tokamak Complex are taking shape with – at their center – a perfectly round "well" reserved for machine assembly. *April 2016*

The ITER site, looking northwest

Industrial activity has kicked off in both of ITER's on-site manufacturing facilities: the vast winding facility for poloidal field coils (red trim) where European contractors have installed equipment and begun qualification winding activities; and the Cryostat Workshop (lower right), where Indian contractors have begun welding the cryostat base. *October 2016*

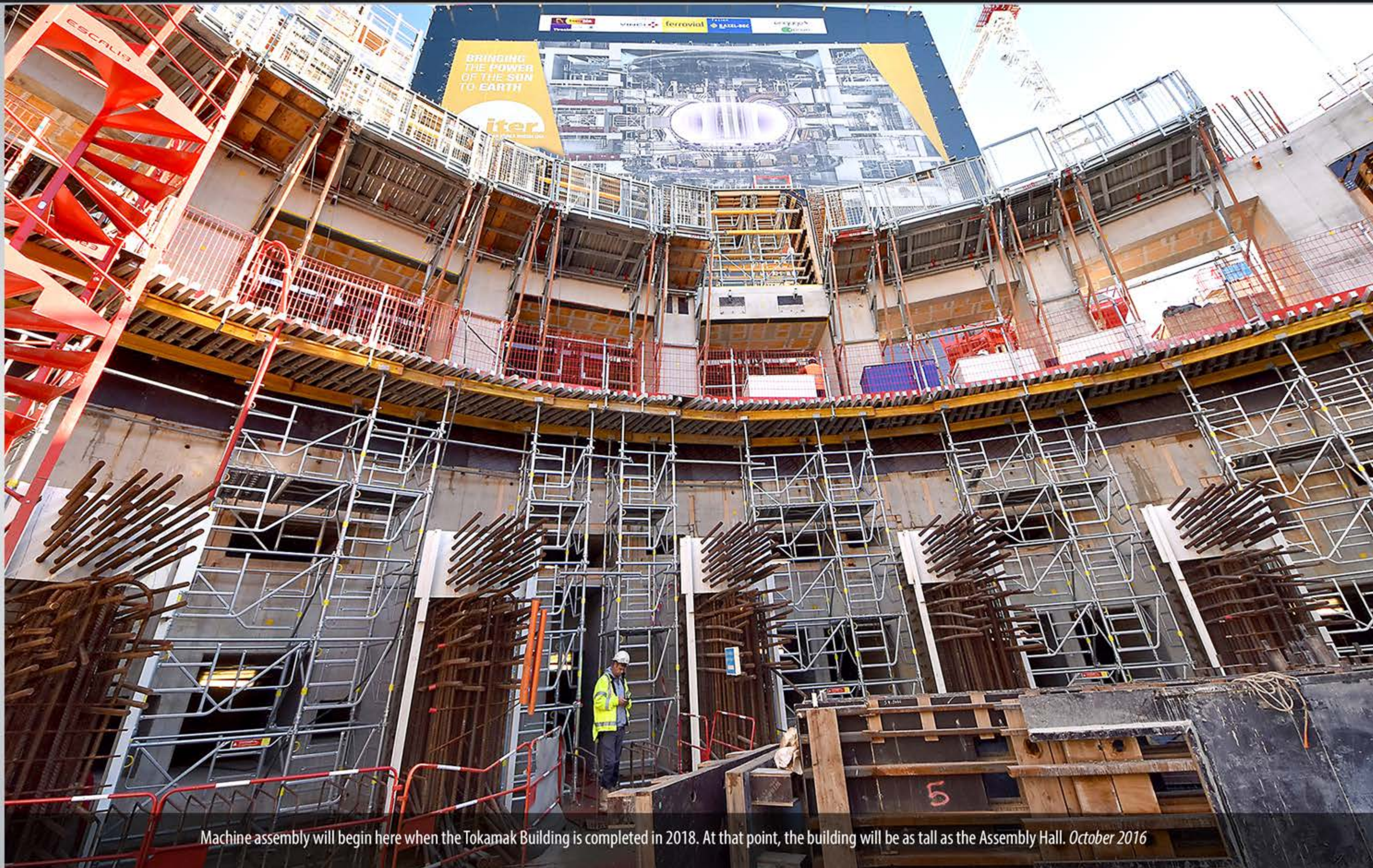
A spectacular backdrop

The ITER Assembly Building is now the most visible feature of the ITER site. This photo captures cranes on the ITER worksite as well as outlying buildings belonging to the CEA Cadarache research center. *March 2016*

A perfect circle

The three-meter-thick ITER bioshield creates an inner circle, with spoke-like reinforcement set in place for the radial walls that will connect it to the cryostat crown. A wider circle is formed by 18 giant columns that will rise 30 meters to provide structural support to the Tokamak Building. *January 2016*

Deep in the Tokamak Pit



Machine assembly will begin here when the Tokamak Building is completed in 2018. At that point, the building will be as tall as the Assembly Hall. *October 2016*

Cathedral-like place

The cavernous area in the basement of the Tokamak Building will be competely filled up with pipes, cables, feeders and busbars as the Tokamak systems are installed. The equipment will be anchored to the embedded plates that can be seen in the floor, walls and ceiling. *October 2016*

Winding qualification activities begin

Four of ITER's six ring-shaped poloidal field coils will be manufactured by Europe in this on-site facility. In 2016, activities to qualify tooling and processes were successfully launched. *November 2016*

Cryoplant Building progressing

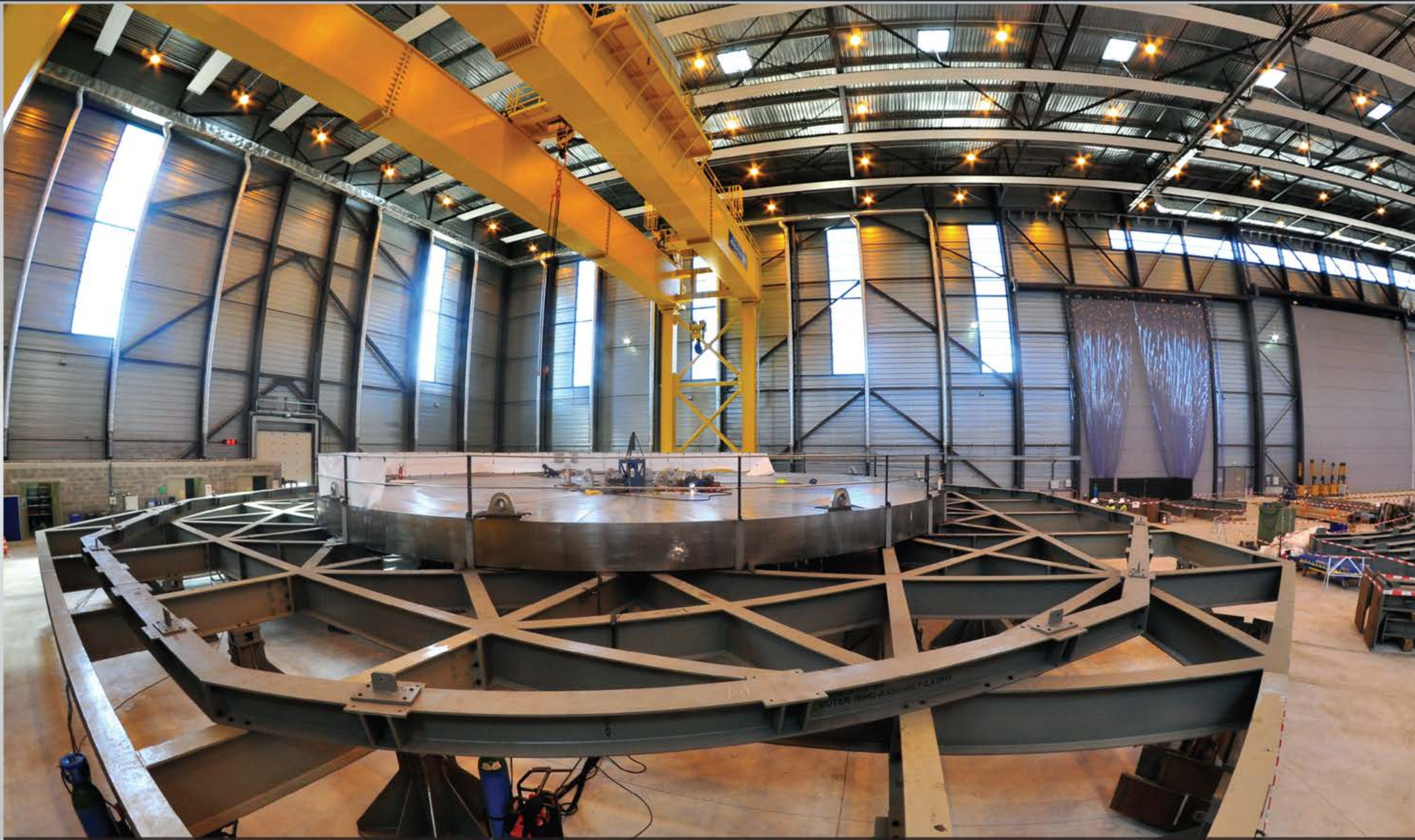
The ITER Cryoplant Building is under construction now on the southeast portion of the platform. In parallel, cryogenic components (cold boxes, turbines, compressors . . .) have begun arriving on site. *July 2016*

Large components like this cryoplant tank procured by Europe are shipped by sea to the Mediterranean port of Fos-sur-Mer before continuing along a specially adapted road itinerary to the ITER site. Approximately 10% of the "highly exceptional loads" scheduled to be delivered along the ITER Itinerary have already reached the site. *November 2016*

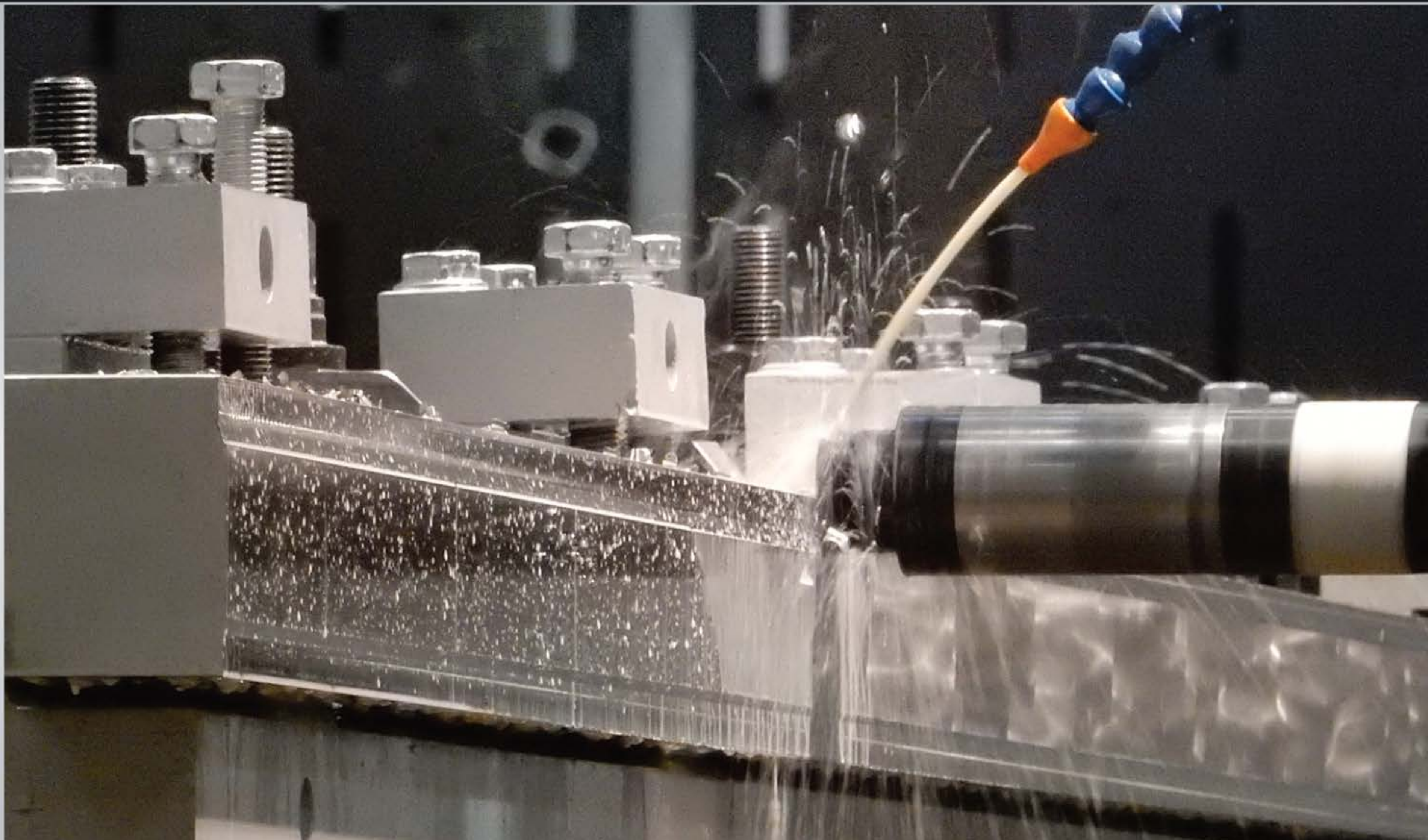
Night shift

Approximately 1,500 workers are involved in the construction of the ITER scientific installation. The last daily shift ends at 10 p.m. *November 2016*

Cryostat welding begins



Welding begins on tier 1 of the cryostat base. When assembled with second tier segments, the cryostat base will weigh 1,250 tonnes. *September 2016*



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.

ITER ORGANIZATION

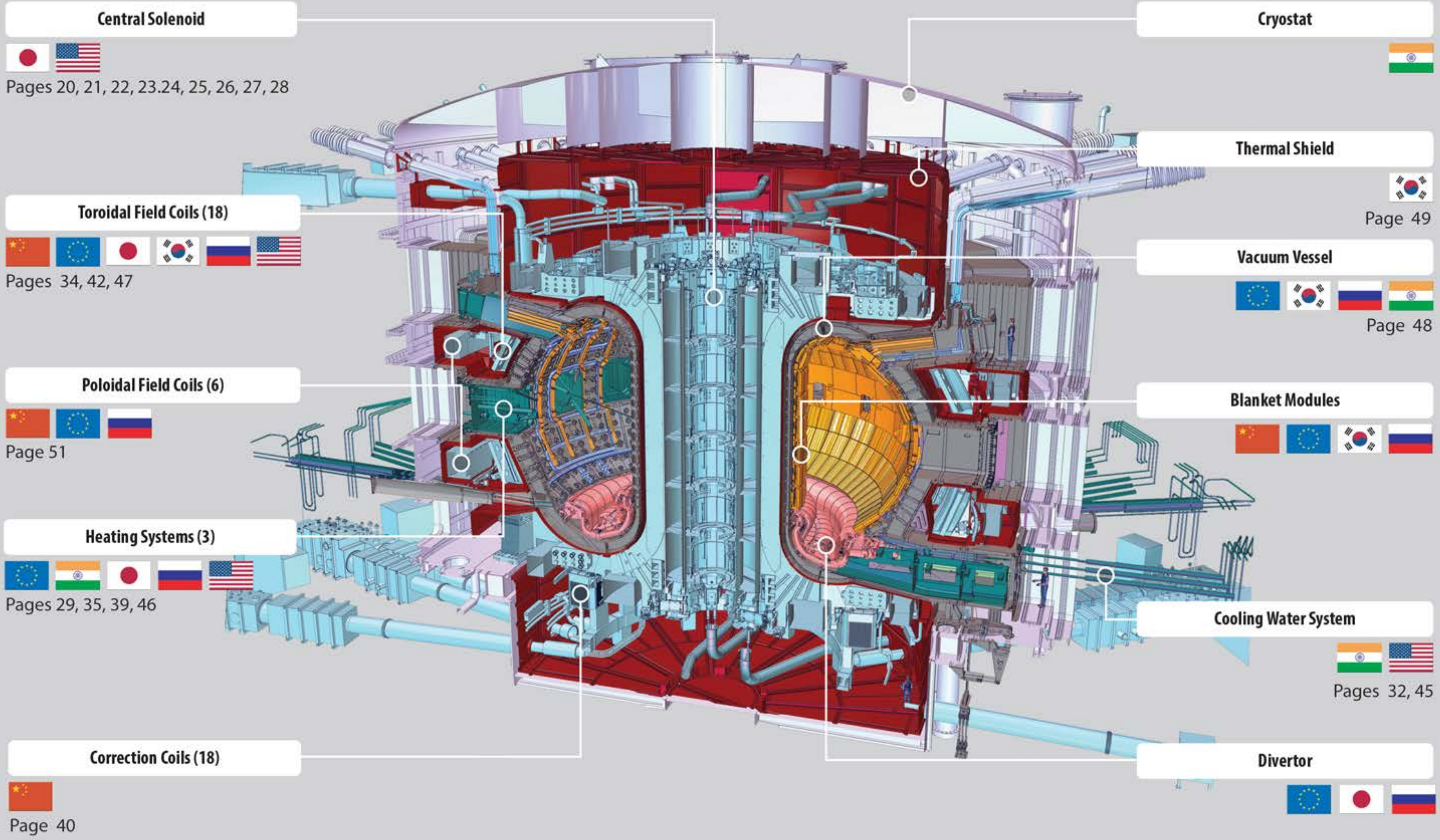
MANUFACTURING

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 will be providing 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.

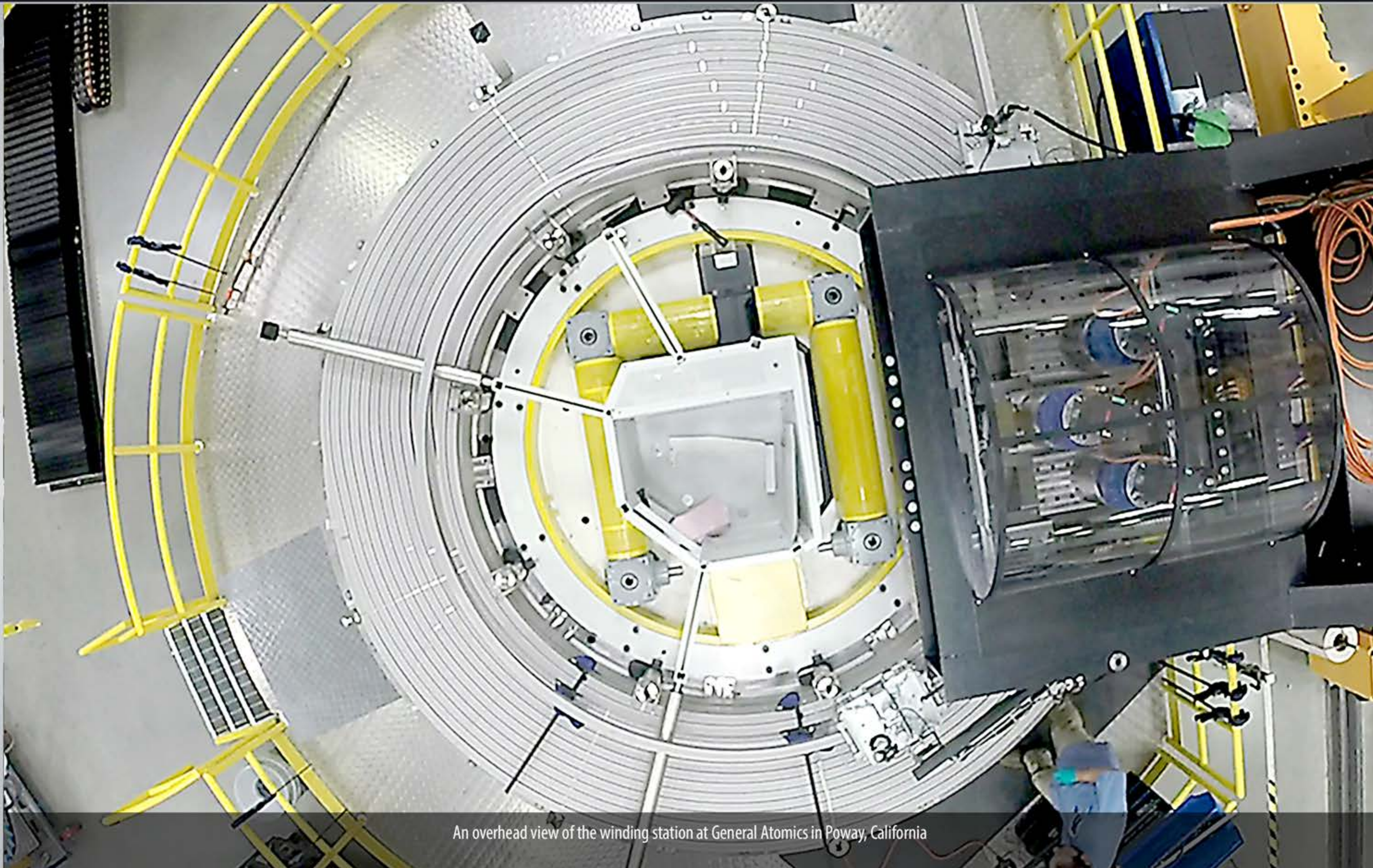
By contributing to the construction of the experimental machine, the ITER Members are creating the technological and industrial basis for the commercial fusion reactors of the future.

Who manufactures what?



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

Central solenoid module winding is underway



An overhead view of the winding station at General Atomics in Poway, California

Central solenoid fabrication milestone

General Atomics technicians completed the winding of the first central solenoid module in April. Six modules – each made from approximately 6,000 meters of niobium-tin (Nb_3Sn) superconductor supplied by Japan – will be stacked to form the 13-meter-tall central magnet.

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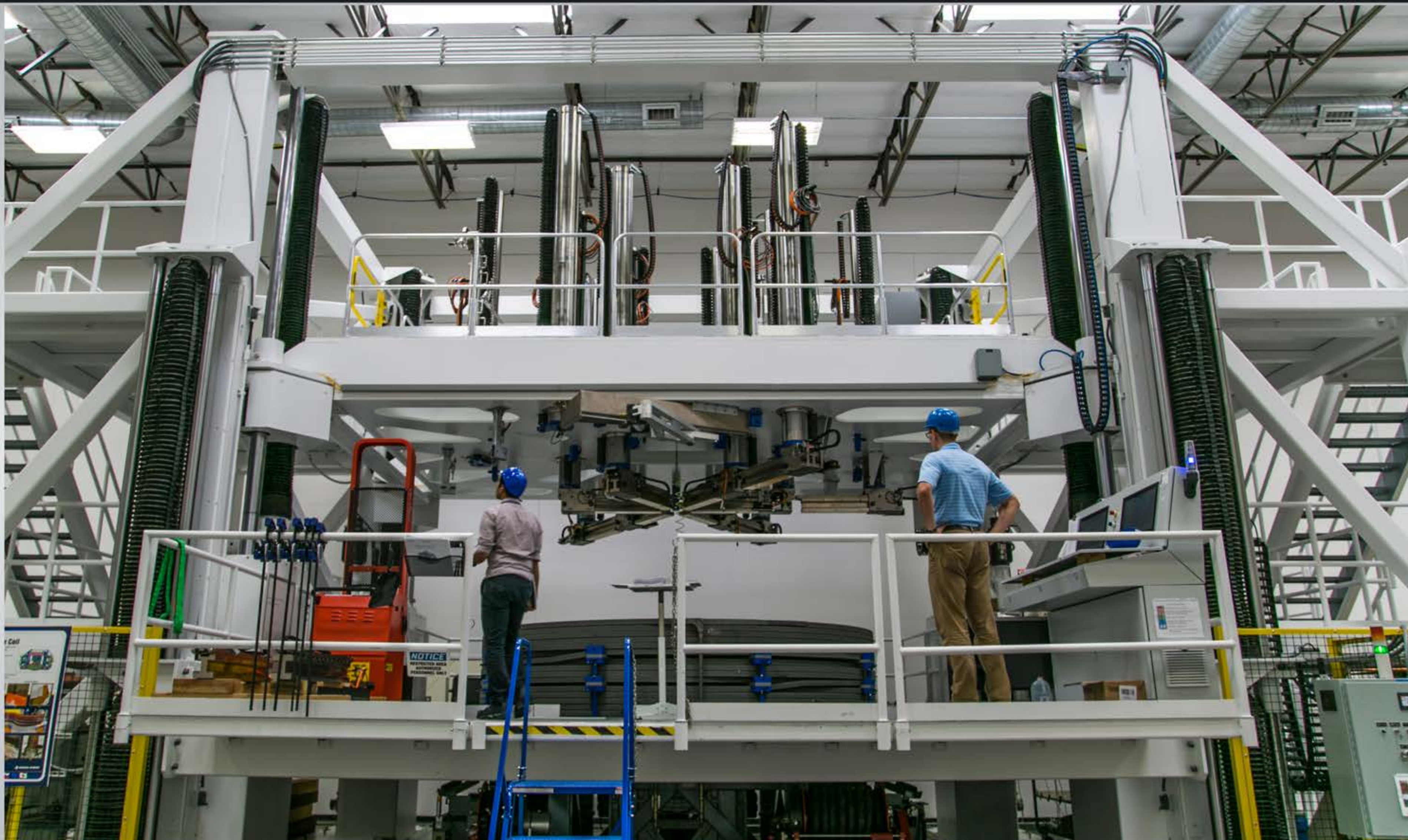
Heat treatment of mock-up coil completed

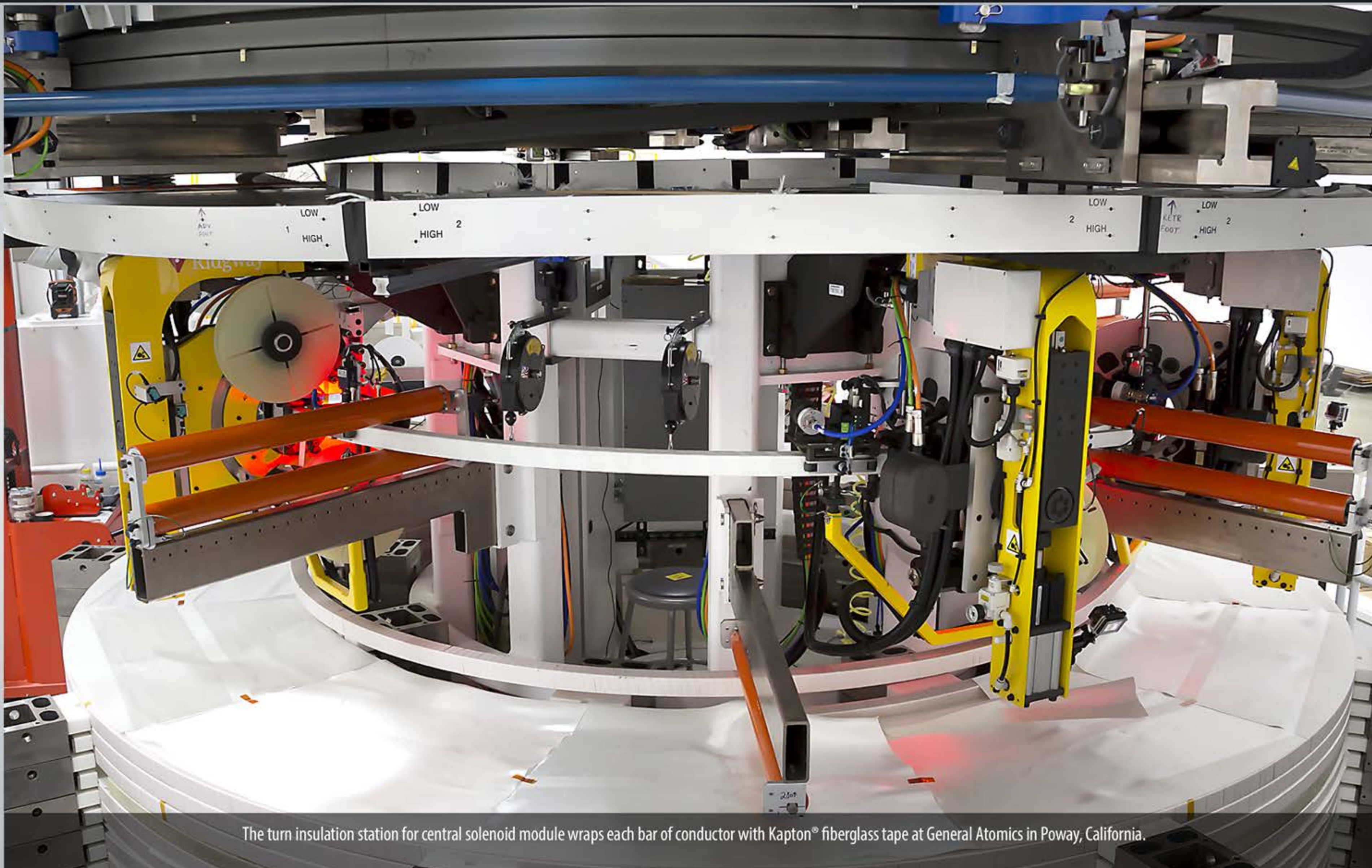
A mock-up coil composed of sample conductor plus spacers exits the heat treatment furnace at General Atomics in Poway, California.

Workstations are in operation for central solenoid modules



The size and complexity of the turn insulation station is evident at General Atomics' Magnet Development Facility in Poway, California.

Turn insulation for the heartbeat of ITER



The turn insulation station for central solenoid module wraps each bar of conductor with Kapton® fiberglass tape at General Atomics in Poway, California.

Forging magnet supports

Forging of a tie-plate first article at Scot Forge in Spring Grove, Illinois. The tie-plates are part of a substantial structural cage surrounding the central solenoid magnet.

Withstanding tremendous force

Tie plates for the central solenoid undergo machining at Major Tool and Machine in Indianapolis, Indiana. These plates are part of a specially designed support structure that will hold the central electromagnet in place during operation despite thousands of tonnes of force.

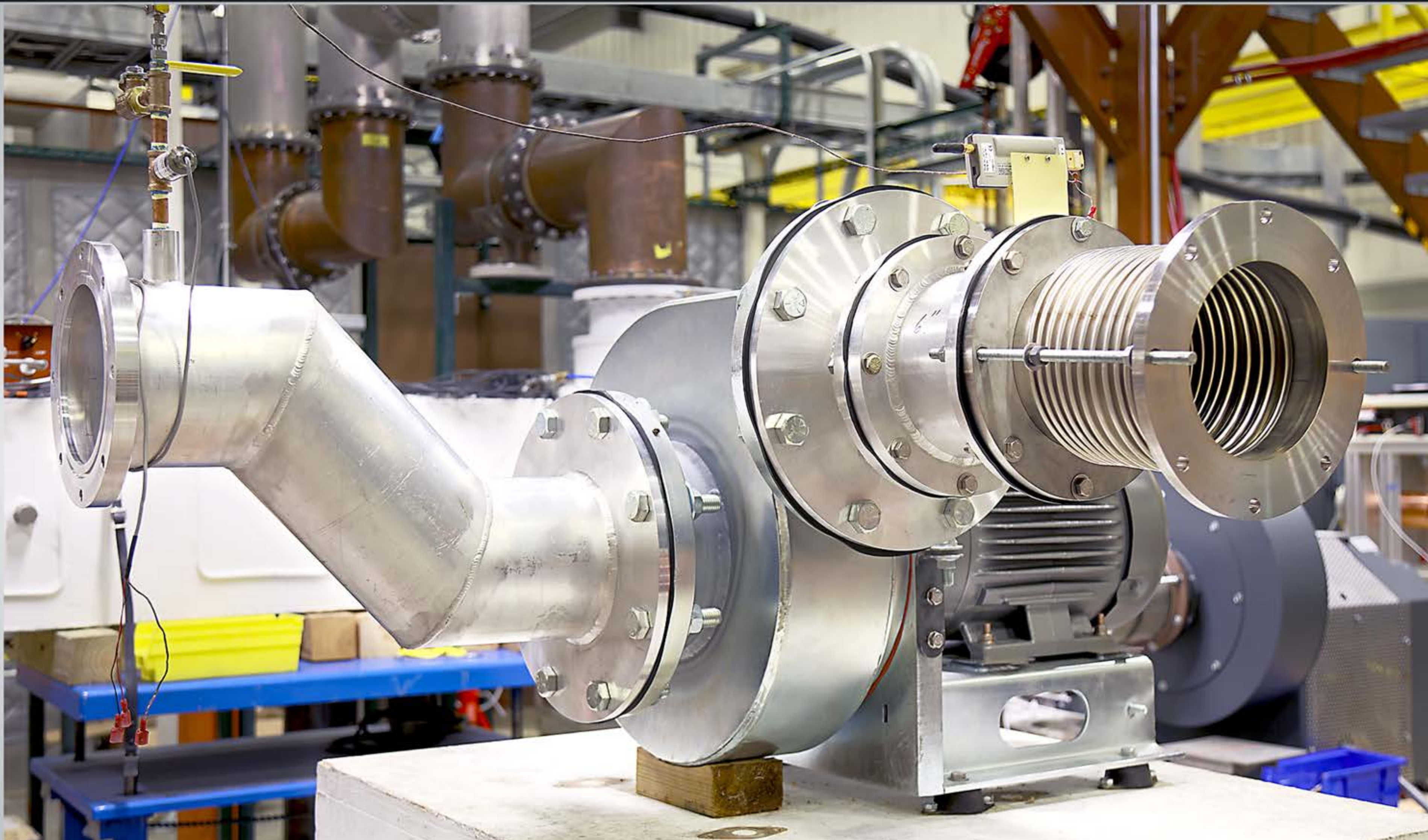
Key blocks to support the central solenoid

Lower key block final machining at Petersen, Inc. in Ogden, Utah. The central solenoid will be supported by nine lower key blocks, each weighing about 6 tons.

Central solenoid assembly platform is in fabrication

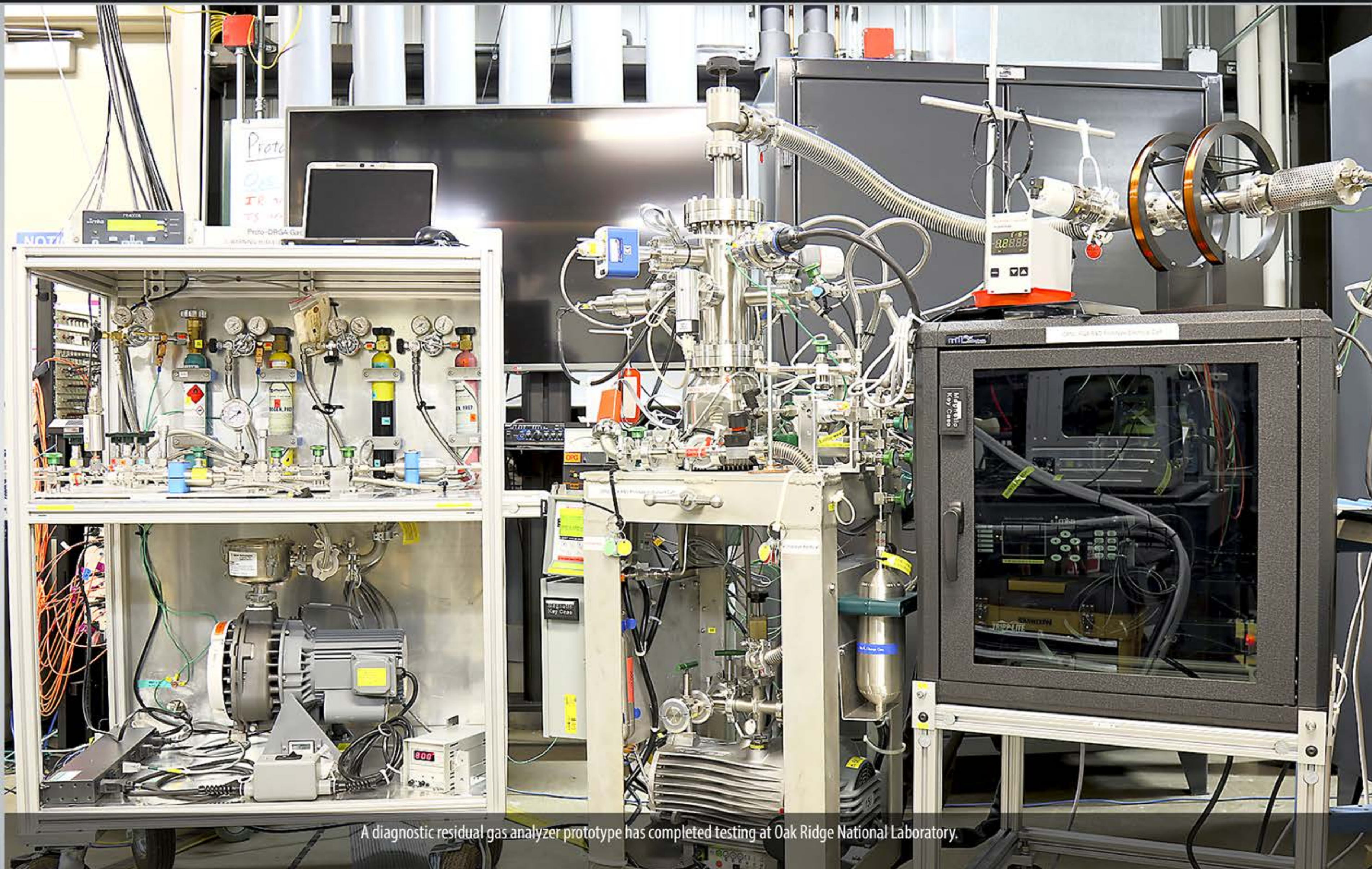
The top plate for the 4 meter diameter assembly platform is shown after machining.

Components ready for high-powered testing



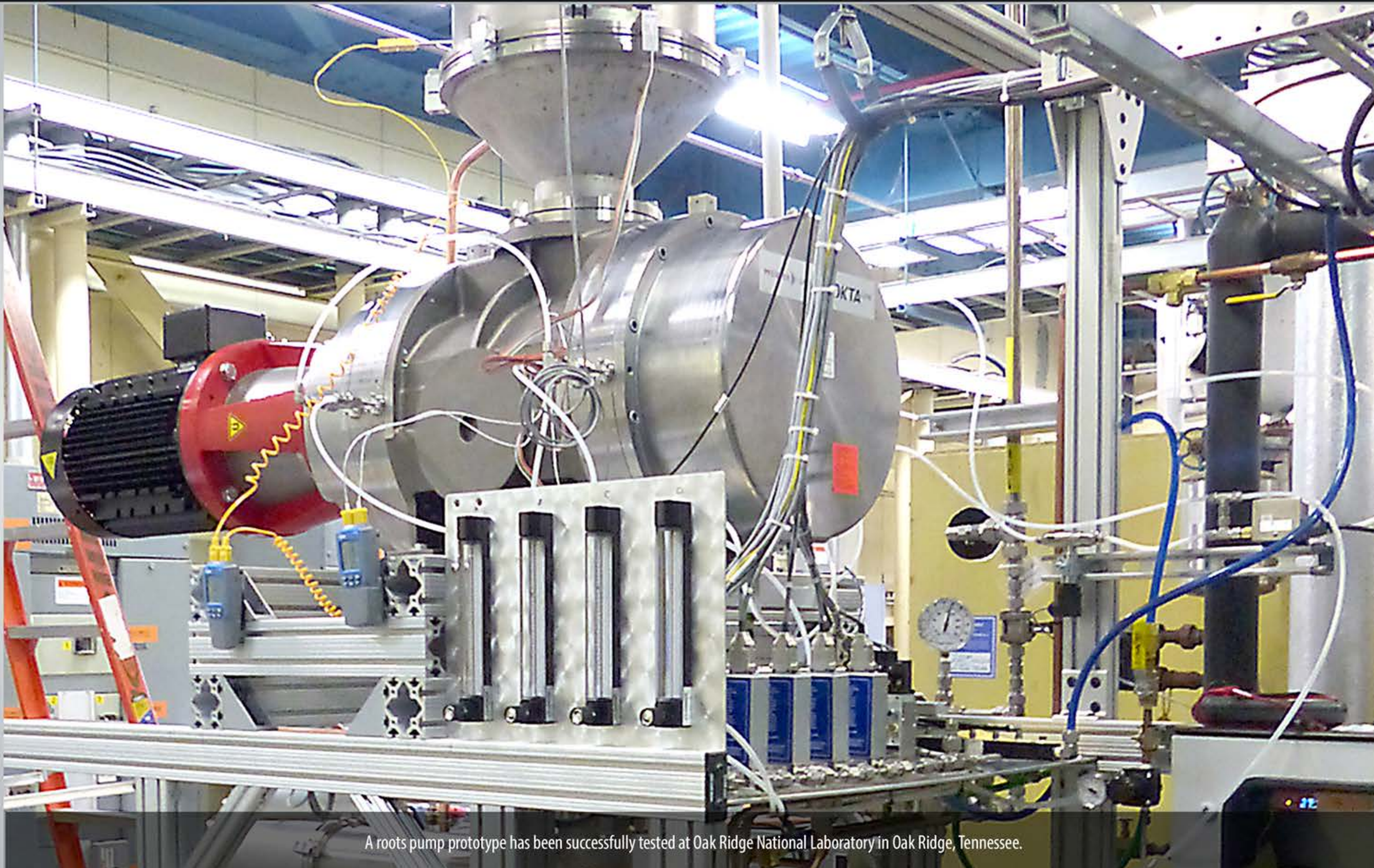
A blower for cooling transmission lines will be tested on the high-powered resonant test line at Oak Ridge National Laboratory.

Diagnostics development is underway



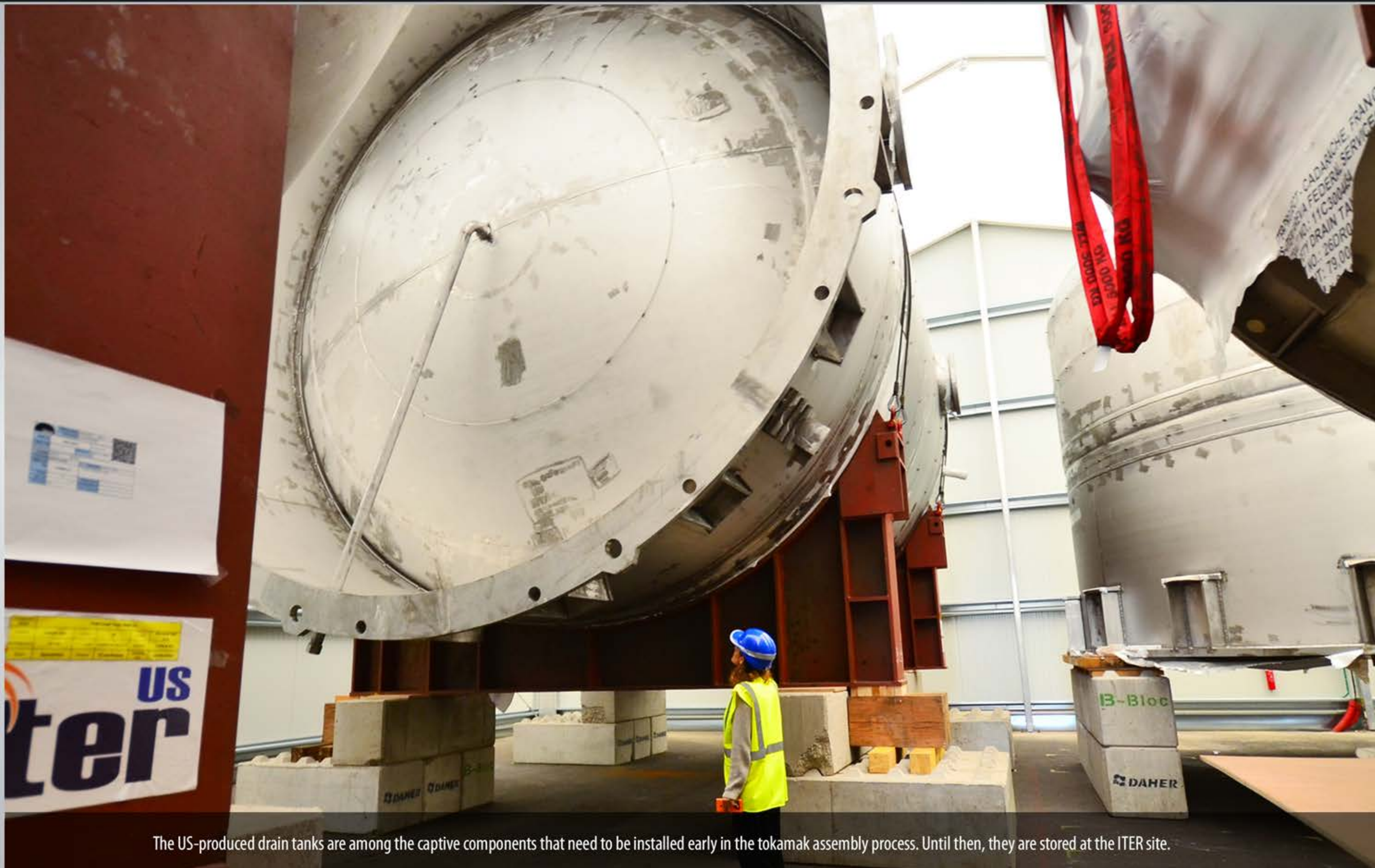
A diagnostic residual gas analyzer prototype has completed testing at Oak Ridge National Laboratory.

Vacuum system components are in testing



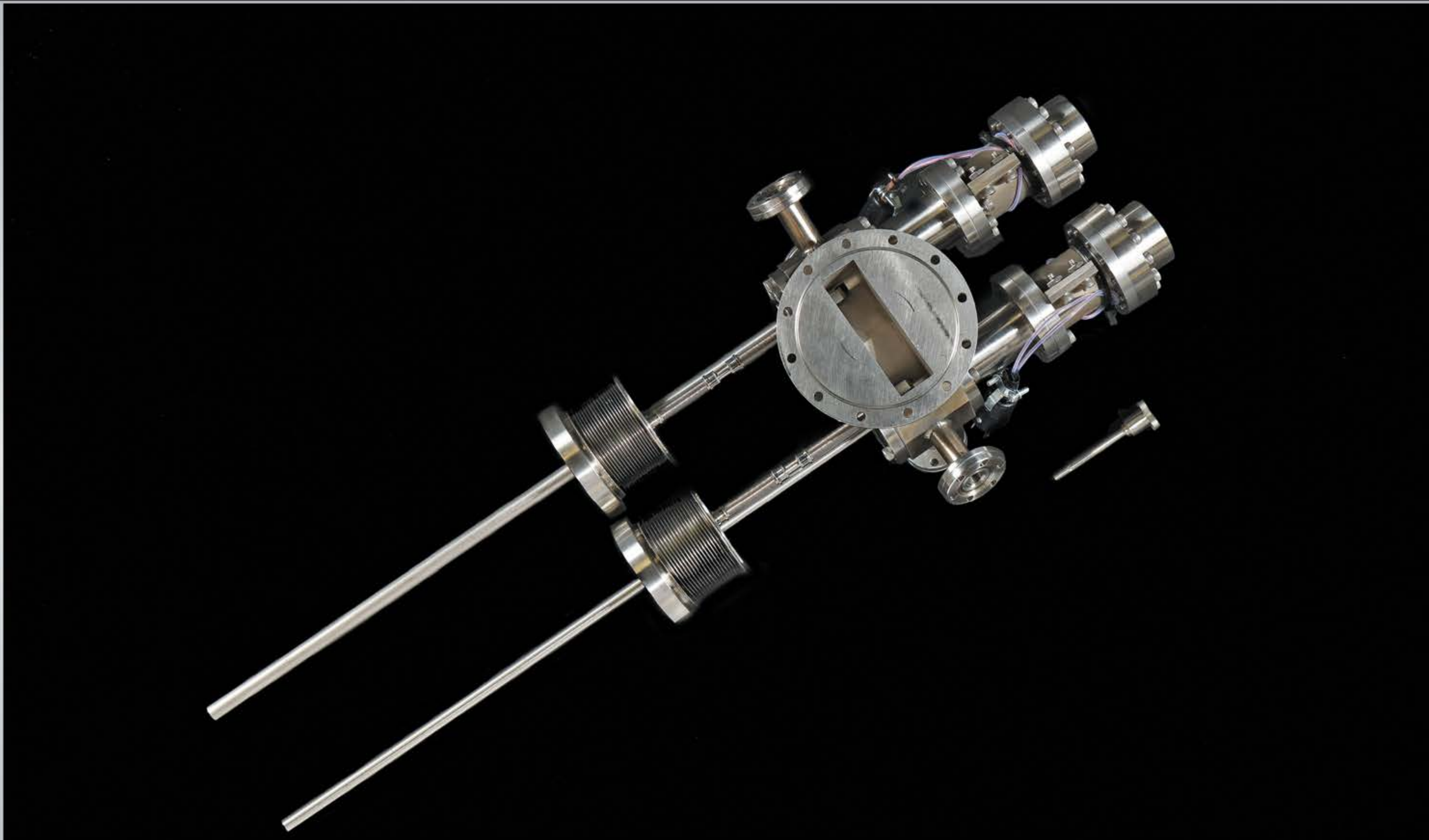
A roots pump prototype has been successfully tested at Oak Ridge National Laboratory in Oak Ridge, Tennessee.

Drain tanks await installation



The US-produced drain tanks are among the captive components that need to be installed early in the tokamak assembly process. Until then, they are stored at the ITER site.

Shooting selected pellets



A high-speed injection system will be used to deliver pellets of fuel to the core of the plasma and "pace" plasma instabilities that may form on the edge. This dual nozzle developed at Oak Ridge National Laboratory will deliver both – selecting differently sized pellets for either fueling or pacing.

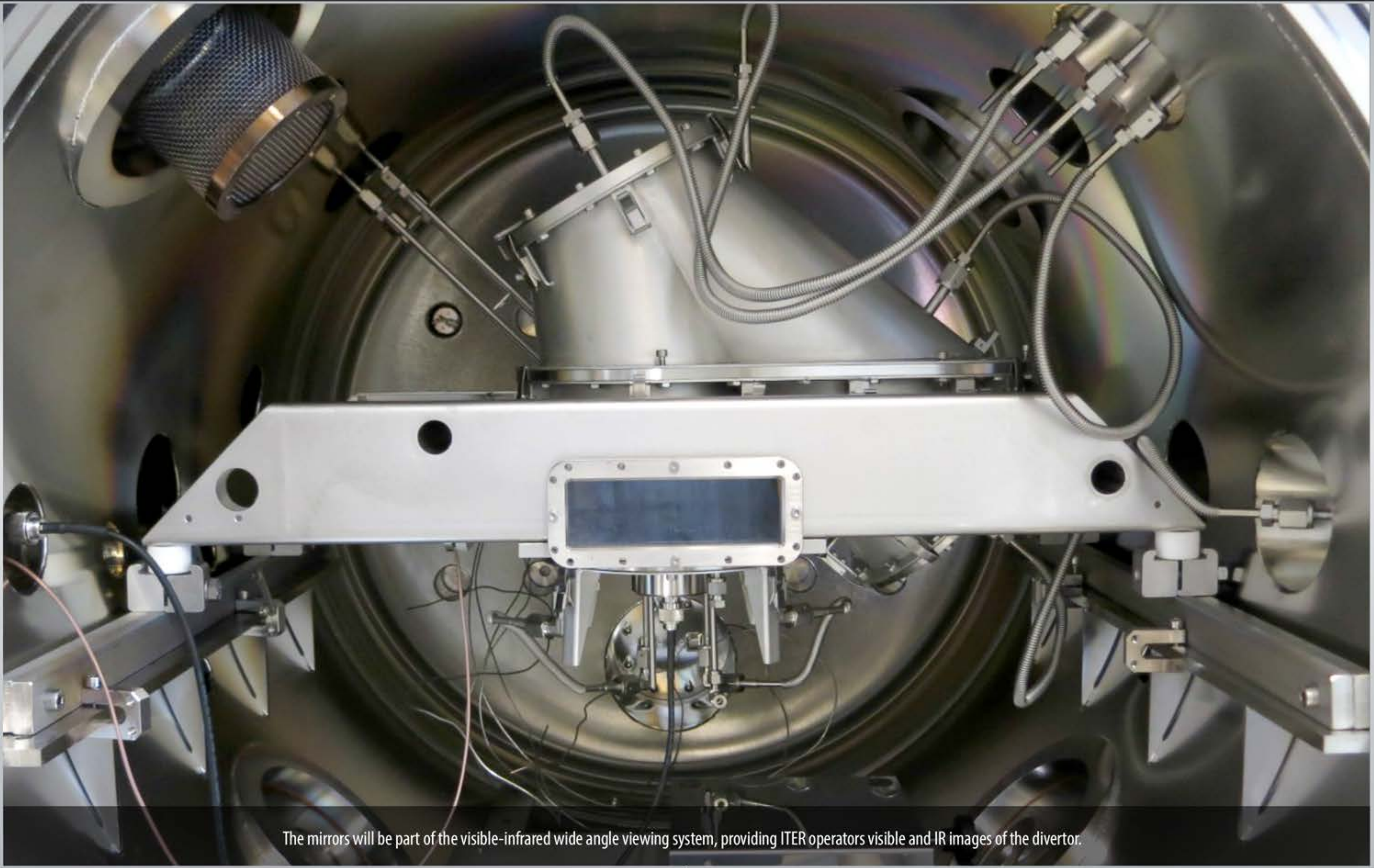
US will complete toroidal field coil conductor fabrication in 2017

Top Left: Conductor packaged and loaded for delivery at the Charleston Harbor, South Carolina. Right: Integrated conductor ready for acceptance processing at Criotec in Chivasso, Italy.
Background: Close-up of integrated conductor.

Transmission lines in fabrication

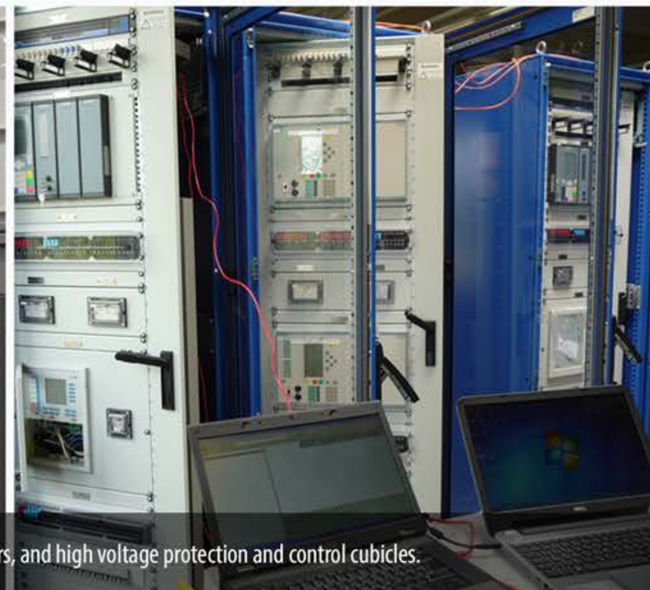
Finishing process of test articles for ion cyclotron transmission lines at Diversified Honing in Bolivar, Ohio.

Mirror equipment for the infrared viewing system



The mirrors will be part of the visible-infrared wide angle viewing system, providing ITER operators visible and IR images of the divertor.

US will complete steady state electrical network deliveries in 2017

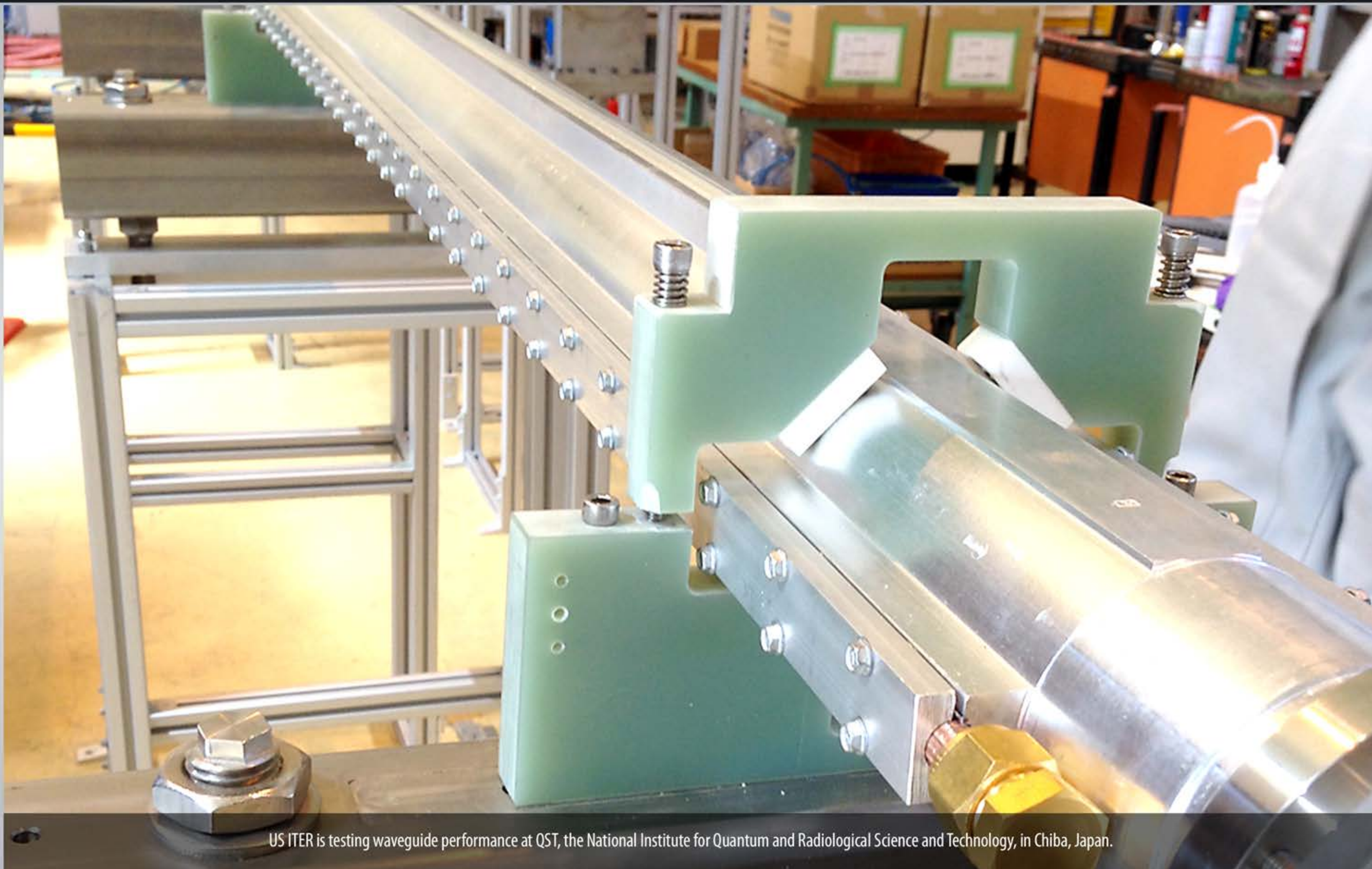


Many deliveries have already been completed, including 22 KV switchgear (top) and, from left, insulators , earthing resistors, and high voltage protection and control cubicles.

US-procured transformers are installed

Located next to the high voltage switchyard, these components for the steady state electrical network will step down the voltage to useable levels for ITER conventional facilities.

Electron cyclotron waveguide testing



US ITER is testing waveguide performance at QST, the National Institute for Quantum and Radiological Science and Technology, in Chiba, Japan.

Qualifying correction coil fabrication

Three sets of six correction coils will be distributed symmetrically around the tokamak to correct field errors. At the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), the first-of-series, multiple-pancake bottom correction coil winding is prepped for the wrapping of ground insulation.

Mega transformer

This 300 MVA step-down transformer is one of three that have successfully passed factory acceptance tests in China for ITER's pulsed power electrical network. The first transformer reached ITER in 2016; two others are expected next year.

First toroidal field winding pack

D-shaped toroidal field coils will create the magnetic field that confines the ITER plasma. In 2016, the first toroidal field "inner core" – called a winding pack – is successfully produced in Europe. Following testing, it will be inserted into a stainless steel coil case to form the final 310-tonne coil assembly.

Inner tank passes leak tests

A 23-metre storage tank for liquid helium, part of Europe's contribution to ITER's liquid nitrogen plant and auxiliary systems, has successfully passed leak tests. The 190 m^3 stainless-steel tank will store liquid helium at -269 °C.

Thousands of in-wall shielding components

Approximately 55 percent of the space between the double walls of the vacuum vessel will be occupied by in-wall shielding blocks that protect ex-vessel components from neutron radiation. India is manufacturing close to 9,000 of these blocks and sending them in batches to vacuum vessel manufacturers in Europe and Korea.

Cooling water pipes

Some 100 containers of piping are expected from India for ITER's component cooling water, chilled water and heat rejection systems. Deliveries are arriving regularly.

Contributing to the neutral beam test facility

Japan is supplying the high voltage power supplies and the high voltage bushing for MITICA, a full-scale ITER neutral beam injector under installation at the PRIMA neutral beam test facility in Italy. Pictured are assembly tests on the 1 MV bushing at Hitachi, before the component is shipped and installed in the 1 MV insulating transformer.

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Double pancake series production

Toroidal field coil windings are first insulated with glass and polyimide tape, then impregnated with cyanate-ester and epoxy resins to harden the assembly. Thirty-five double-pancakes – the building blocks of the toroidal field coils – have been insulated and impregnated at Mitsubishi Heavy Industry's Futami factory.

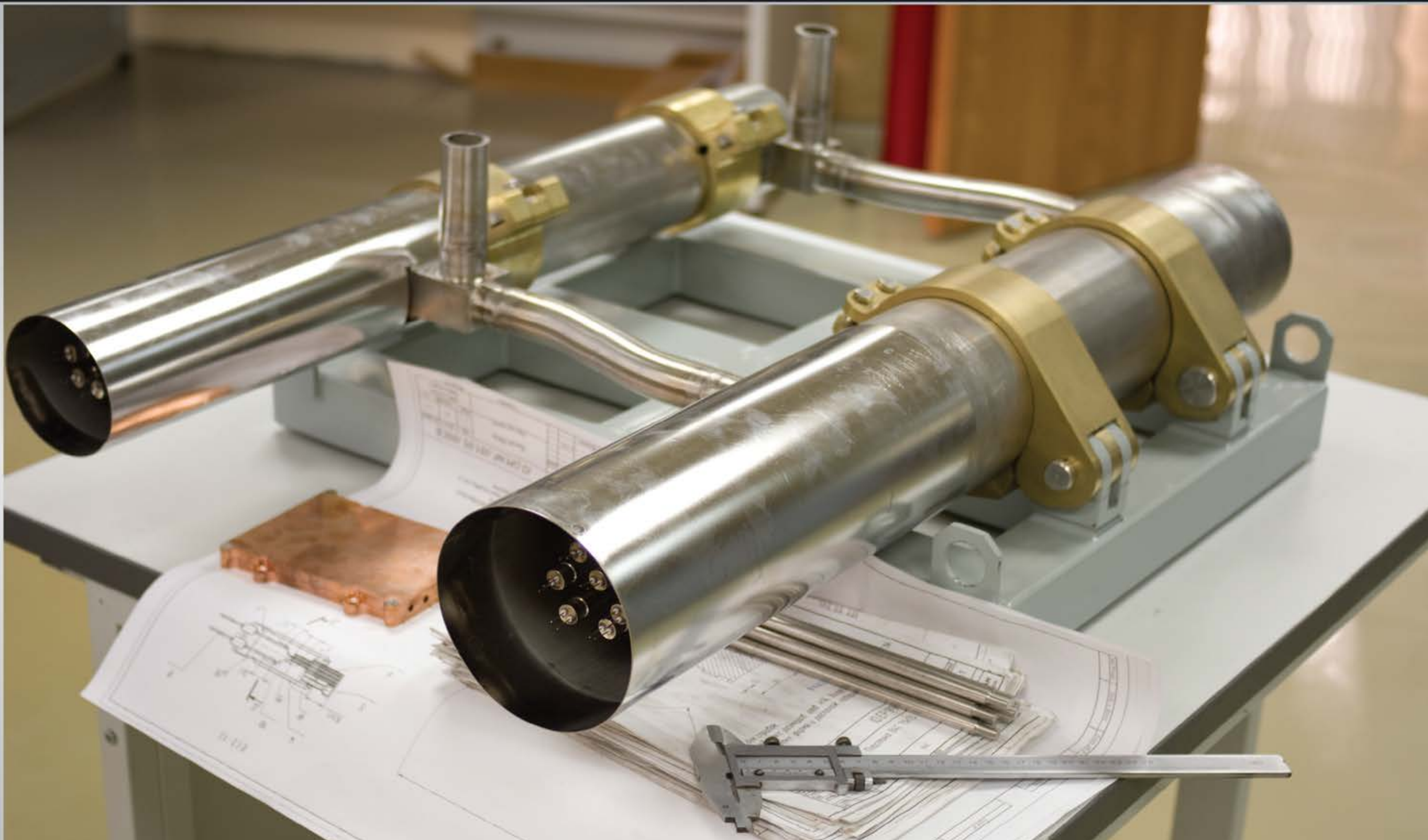
Vacuum vessel fabrication in Korea

Each of the nine vacuum vessel sectors will be assembled from four segments (upper, lower, inner and outer). At Hyundai Heavy Industries, technicians carry out 3D dimensional inspection on the upper segment of sector 6.

Thermal shielding

A thin barrier of stainless steel (10-20 mm), actively cooled and covered with a low-emissivity coating of silver, will protect the magnet coils from thermal radiation. At SFA Engineering in Changwon, welding is underway on an outboard sector of the vacuum vessel thermal shield.

“Seeing” the neutrons from the divertor



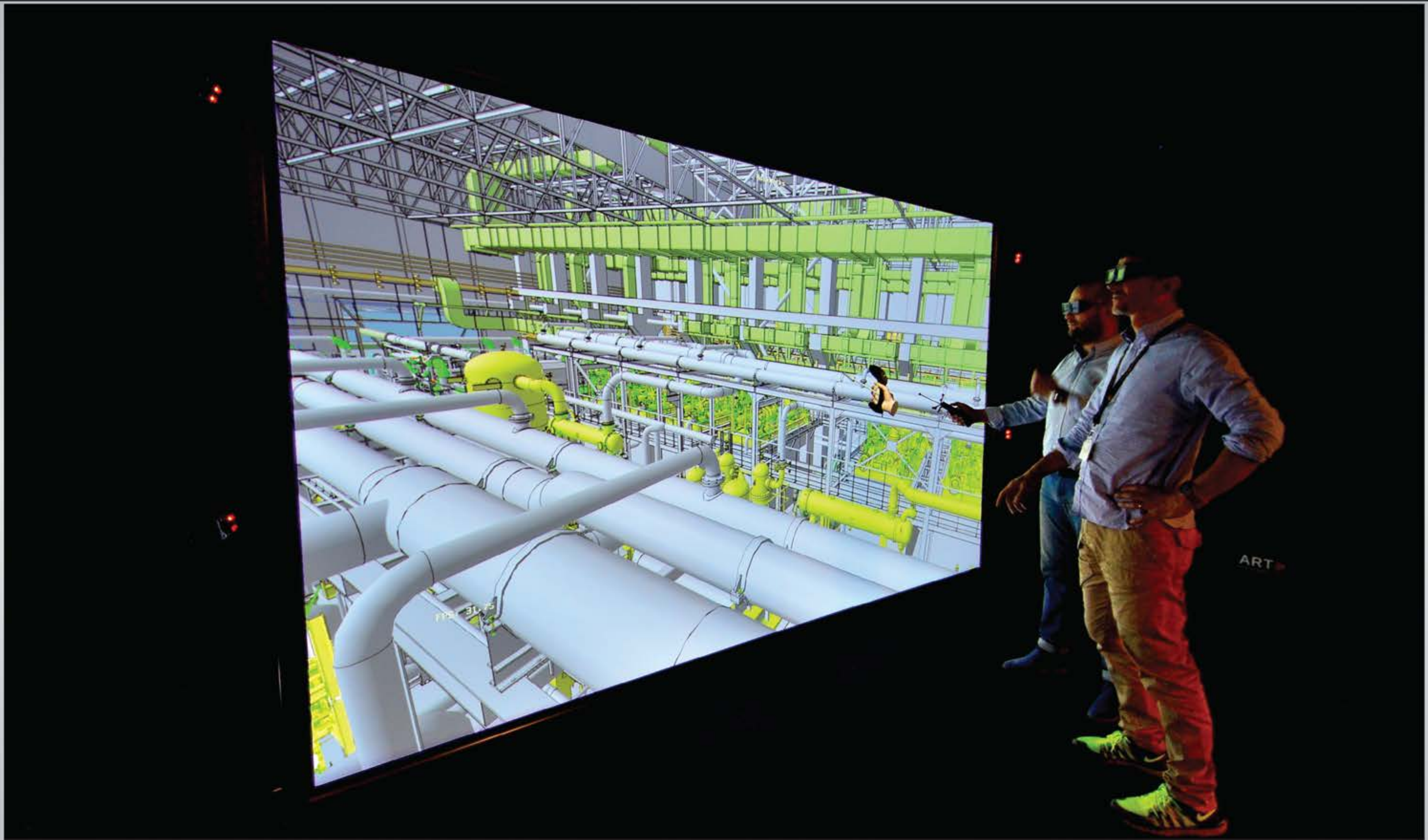
The divertor neutron flux monitoring system – under development in Russia – will provide routine measurements of neutron emissions from a location at the bottom of the vacuum vessel.

First of eight poloidal field coil windings

In St. Petersburg, specialists of the Efremov Institute and the Srednenevsky shipyard have completed the first poloidal field double pancake winding. Eight double pancakes will be stacked to form poloidal field coil 1, the smallest of ITER's ring-shaped magnets.

Senior representatives from the seven ITER Members convene twice a year as part of the ITER Council – the ITER Organization's top governing body.

3D rendering of ITER plant systems



The virtual reality room is used by technical responsible officers and configuration managers for design and engineering activities. The "immersion" experience (in this photo, the ITER cryoplant) facilitates the identification and resolution of integration challenges.

The men and women of ITER

Approximately 500 of the ITER Organization's 730 directly employed staff members take part in a team photo in January, before the installation of the first assembly platform in the Cryostat Workshop makes gathering impossible.

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