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iter magazine

#5 OCTOBER 2014

Superconductivity: it gets the current flowing...

Editorial

An important milestone was achieved when the concrete "floor" of the Tokamak Complex was finalized on 27 August 2014. Work is now underway on the walls of the seven-storey edifice that will house the ITER Tokamak and its systems – fully 400,000 tons of building, equipment and machinery. On the next page, you'll see what the ITER scientific installation will look like once it's completed…

A large number of specialized tools will be required for ITER assembly, including the six-storey, 800-ton tool that is featured in this issue. Two of these massive tools will work side by side in the Assembly Building to equip the nine sectors of the vacuum vessel before they are welded together to form the torus-shaped ITER vacuum chamber.

And finally, in this fifth issue of *ITER Mag* we'll take a close look at one of the wonders of physics – superconductivity – without which fusion power plants could never be economically viable.

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Mirror, mirror on the platform

By reflecting the hues of the passing seasons, the mirror-like stainless steel will express, according to ENIA, "the precision of the research work being performed inside of the buildings."

How much latitude does an architect have when considering how best to integrate the ITER buildings into the surrounding landscape?

Not a lot, says architect Simon Pallubicki – a partner at ENIA, the firm chosen in 2009 to work on the exterior architecture of the ITER installation. Changing the buildings' morphology was out of the question, since each building's height, footprint, volume and organization was already pre-determined by the processes it harbours. How about painting the buildings with colour? Possible, but risky: what blends nicely into the environment at noon under a bright summer sun may look dull and depressing under the cold November rain.

"We faced an interesting problem," admits Simon. "The buildings on the ITER platform are extremely heterogeneous in terms of functionality, size and construction mode; commonly used architectural parameters like regularity and alignment are absent."

The architects at ENIA, a Parisian firm specialized in multiple architectural domains, were presented with a double challenge – how to lend unity to apparent architectural disorder and how to integrate the project harmoniously into its surroundings.

The solution they chose was daring but restrained. All buildings, with the exception of the Control Building, will be covered in alternating cladding of mirror-like stainless steel and grey-lacquered metal. The proportion between the mirror-like and lacquered surfaces will vary according to facade orientation: 80 percent mirror on the east/west facades and 80 percent lacquer on the north/south facades. For the Control Building in the northwest corner of the platform – the "brain" of the installation – the choice was made to clad the building entirely in polished stainless steel.

The architectural choices made for the cladding materials will allow the scientific installation to "meld" into its natural environment, with the buildings picking up hues of the passing seasons and blending poetically into their surroundings. The polished, mirror-like stainless steel also expresses, according to ENIA, "the precision of the research work being performed inside of the buildings."

Because architecture is as much about functionality as it is about aesthetics, the metal cladding will also enhance the insulation qualities of the buildings' "skin."

While they were working on the architectural project, Simon Pallubicki and his colleagues spent a lot of time hiking and driving around the site. "We did a lot of reconnaissance work, sometimes nearby, sometimes as far as 40-50 kilometres from the platform to evaluate the visual impact of the installation that will reach 60 metres at its highest point."

The temptation to create a stand-alone work of architecture was high, according to the architects. But ITER isn't an isolated facility – it's part of the Durance River industrial landscape and, as such, should engage in a dialogue with its physical and human environment.

The ITER scientific facilities, say the ENIA architects, "should settle deep into the consciousness of the neighbourhood population and should leave a positive mark on local and regional history." Their choice of polished facades, reflecting the ever-changing shades of skylight and seasons, will express what is at stake in ITER: the perspective of harnessing an unlimited, universally available and environmentally respectful energy source.

Last pour, first delivery

Two milestones in ITER construction were achieved as summer 2014 drew to a close – the last pour of the Tokamak Complex basemat on 27 August and the delivery of the first completed components on 4 September.

It was the last of fifteen "segments" poured to complete the 9,300 m² concrete basemat that will support the Tokamak Complex and its 400,000 tons of building, machinery and equipment – a perfectly circular, central plot that will support the ITER machine.

14,000 m³ of concrete, 3,600 tons of rebar, 8 months of work – the "floor" of the Tokamak Complex was finalized on 27 August 2014.

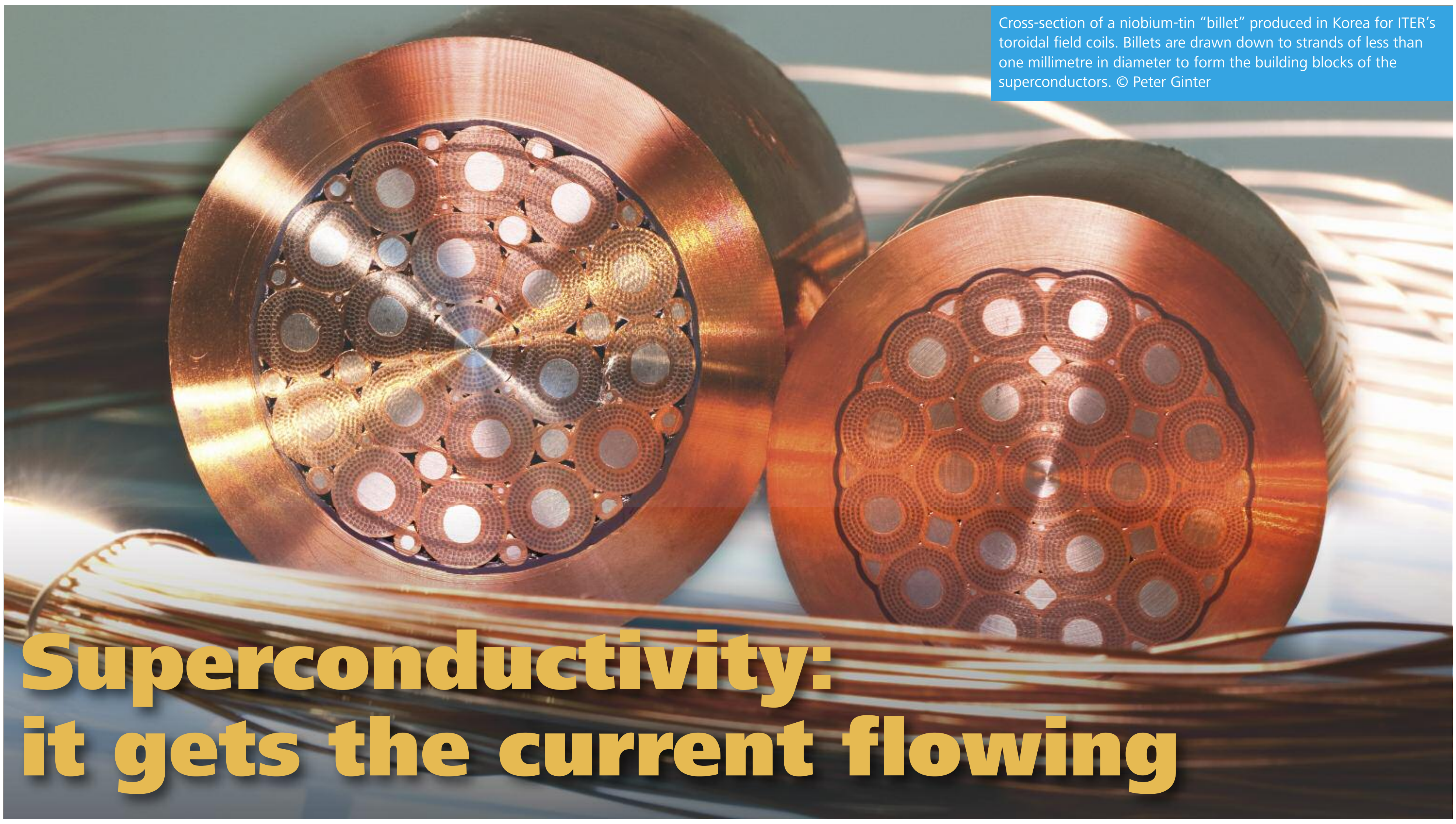
Well before dawn on 27 August, the team was in place to prepare the worksite and position the concrete pumps. Ahead was a 12-hour continuous pour – some 865 m³ of concrete formulated to penetrate in and around the tight weave of rebar, particularly dense in this area of the basemat.

The completion of the Tokamak Complex basemat has opened the way to a new phase of ITER construction: with the "floor" in place, work will now start on the walls. The 80 x 120 metre Complex, housing the Tokamak, Diagnostic and Tritium buildings, is a seven-storey structure that will reach 60 metres at its tallest point.

Early September, another ITER milestone was celebrated as the very first completed components – 12 high voltage surge arrestors shipped from the United States – were delivered to the site and stored. Destined for the installation's steady state electrical system, they'll take their place between the 400 kV switchyard and the transformers that will feed power to the ITER plant systems and components in order to provide protection from the type of major voltage surge that can be caused by lightning.

Shipped from New York on 5 August 2014, the 12 surge arrestors that were delivered to ITER on 4 September had a high symbolic value. As the first completed components to reach the site, they usher in a new phase on the road to building ITER.

One truck, just a few crates ... but a delivery with important symbolic value, as it kicks off a new phase for ITER. Over the next years thousands of components will be shipped from around the world for installation into the ITER Tokamak and plant. This first delivery was the opportunity to test the administrative, technical, industrial and regulatory procedures that will accompany the procurement of all of these machine and plant components.



Cross-section of a niobium-tin “billet” produced in Korea for ITER’s toroidal field coils. Billets are drawn down to strands of less than one millimetre in diameter to form the building blocks of the superconductors. © Peter Ginter

Superconductivity: it gets the current flowing

To create the optimal conditions for fusion in a tokamak, the hot gas (plasma) must be confined in the centre of the vessel. This is the job of powerful magnetic fields, which are created by large electromagnets.

At JET, the biggest operating tokamak in the world, the energy consumption of the electromagnets is on the order of 150 MW – one-sixth of the power delivered by a standard nuclear plant. Although acceptable for short periods in an experimental machine, this kind of consumption would disqualify, in economic terms, the type of large, commercial fusion reactor that is expected in the second half of this century.

For the economics of fusion to be viable, reducing the consumption of the magnets becomes absolutely necessary.

The amount of energy a magnet consumes is directly related to the notion of electrical resistance, or the collision between particles. Even in a conducting metal, like copper, collisions create resistance and resistance creates heat that must be evacuated; what’s more, the energy lost must continuously be replaced. Without resistance, electrical consumption would drop to zero and, as an added advantage, no heat would be created in the magnets.

It was in 1911 that Dutch particle physicist Heike Kamerlingh Onnes discovered, practically by accident, that once certain metals were cooled to very low temperatures, resistance dropped to zero.

Called “superconductivity,” this discovery remained without practical applications for decades. Following theoretical advances in the 1950s, as well as new discoveries in material science, superconductivity began to revolutionize medical imagery, profoundly change particle physics, and open the way to a viable industrial and commercial future for fusion energy.

All of the large fusion devices built since the late 1980s – the LHD stellarator (Japan) and the tokamaks Tore Supra (France), EAST (China), KSTAR (Korea) and SST-1 (India) – are equipped with superconducting magnets. And it goes without saying that projects under construction – such as the W7-X stellarator (Germany), the JT-60 SA (Japan) and, of course, ITER – will also rely on superconducting magnets to carry higher current and produce stronger magnetic field than conventional counterparts, while consuming less power.

“If ITER’s magnets were made from copper, like JET’s, we would need a 800 MW nuclear reactor just to feed them,” says Arnaud Devred, who is in charge of superconducting systems at ITER. “What’s more, they would heat up incredibly quickly. With superconducting technology, only the cryogenic plant responsible for cooling the magnets to superconducting temperatures will require energy (20 MW).”

The niobium-tin or niobium-titanium alloys used for the superconducting wire in ITER’s magnets become superconducting at temperatures on the order of -270 °C – the temperature of liquid helium. (That’s colder than the dark side of the Moon.)

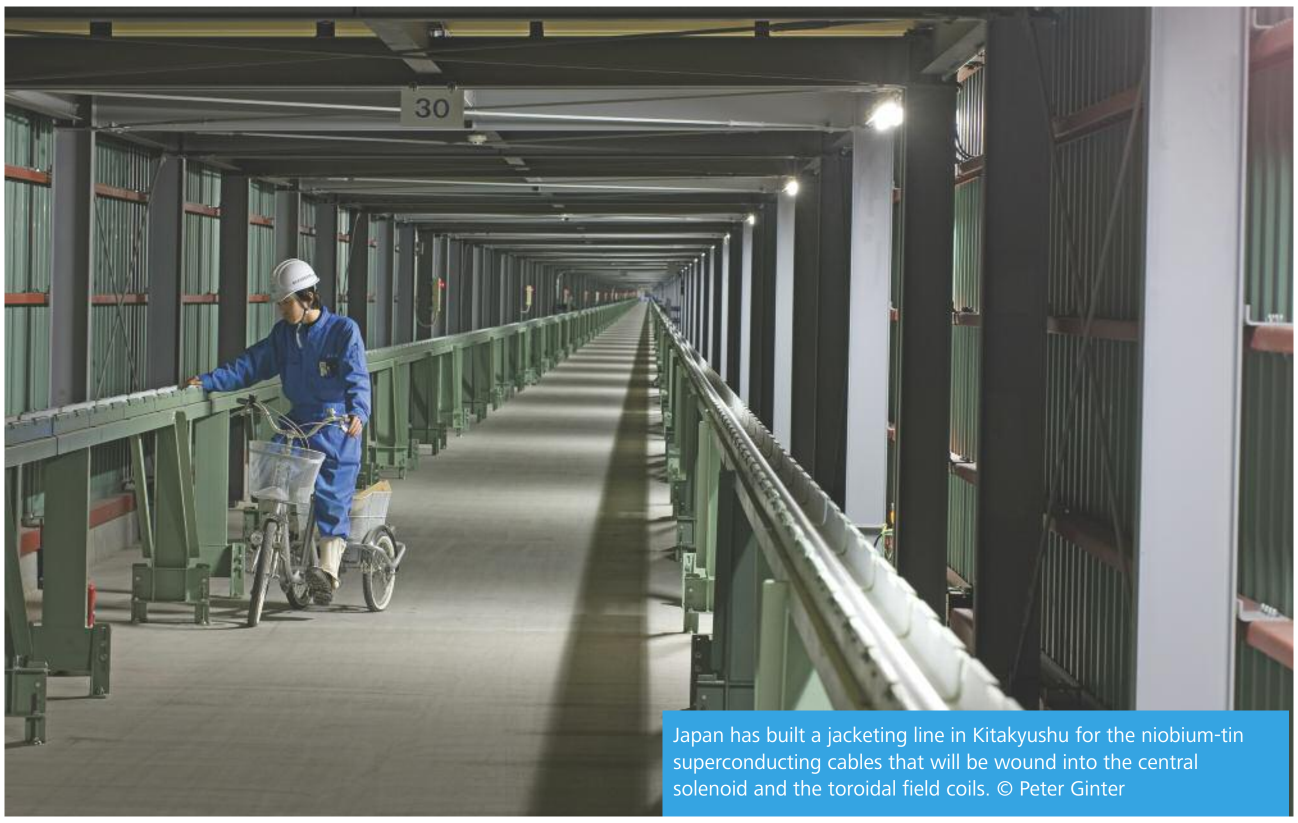
In a conventional superconducting magnet system, the magnets are immersed in the liquid that cools them. But ITER’s magnet systems will be far too large for that (24 m in diameter for the largest poloidal field magnet and 17 metres high for the toroidal field magnets).

To solve this dilemma, in the mid-1970s fusion scientists and engineers developed a new type of superconducting cable. Called “cable-in-conduit” conductors, the superconducting cable is enclosed in a metal jacket and a forced flow of liquid helium circulates in a central channel.

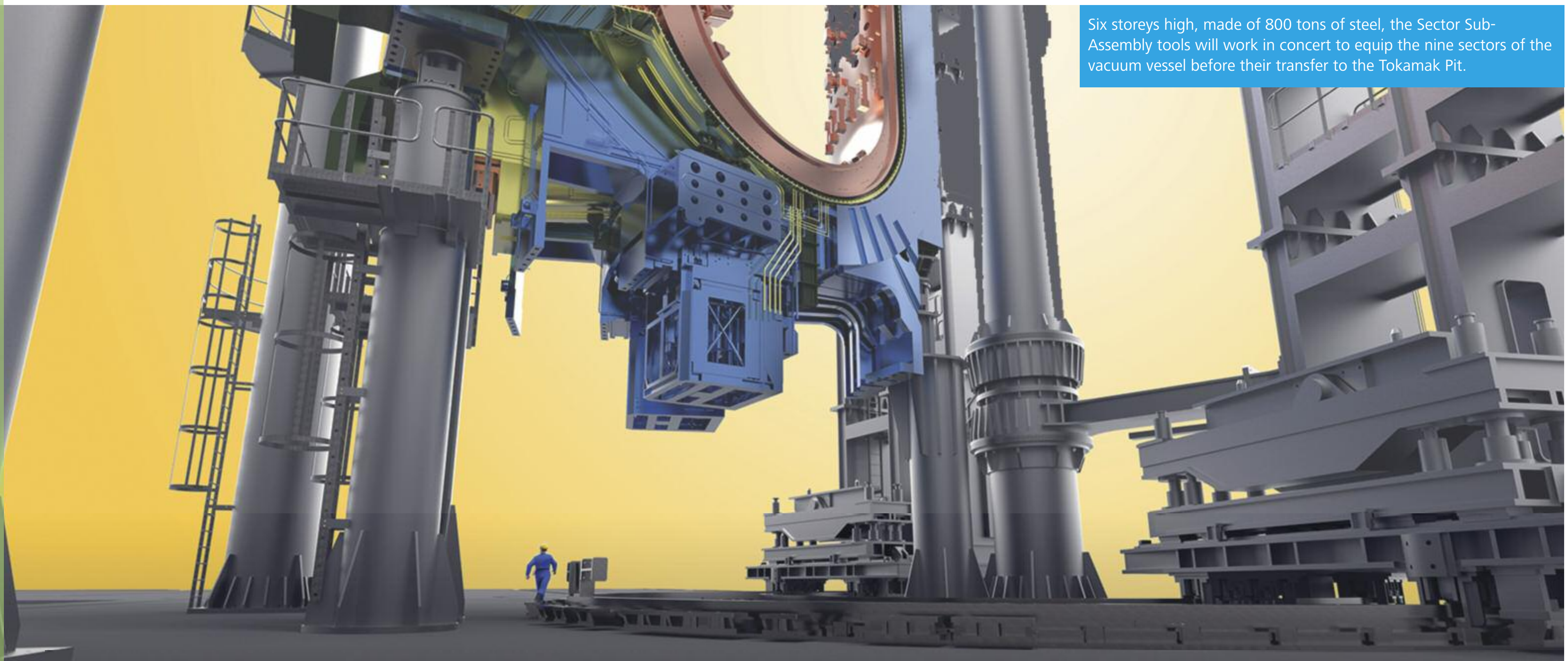
The sheer quantity of superconductors required for ITER has invigorated the world market. ITER will use more than one-fifth of the annual production of niobium-titanium strands (275 tons), and the global production of niobium-tin strands has been multiplied by six to meet ITER’s needs (on the order of 600 tons).

“Thanks to superconductivity,” says Arnaud, “physicists have been able to develop instruments that are exploring the limits of scientific knowledge.”

Applied to fusion, superconductivity – the “miracle of physics” – has enabled the construction of larger machines without costly electrical consumption. Without it, fusion would have remained a laboratory science …



Japan has built a jacketing line in Kitakyushu for the niobium-tin superconducting cables that will be wound into the central solenoid and the toroidal field coils. © Peter Ginter



Six storeys high, made of 800 tons of steel, the Sector Sub-Assembly tools will work in concert to equip the nine sectors of the vacuum vessel before their transfer to the Tokamak Pit.

Twin giants to pre-assemble the vacuum vessel

As the doors of the Assembly Building open to admit the first vacuum vessel sectors shipped from manufacturing sites in Europe or Korea, two imposing custom-built tools will stand ready to receive them.

Six storeys high, with wings spreading 20 metres, the Sector Sub-Assembly tools will work side by side to equip the nine sectors of the vacuum vessel before their transfer to the Tokamak Pit, where they will be welded together to form the torus-shaped ITER vacuum chamber.

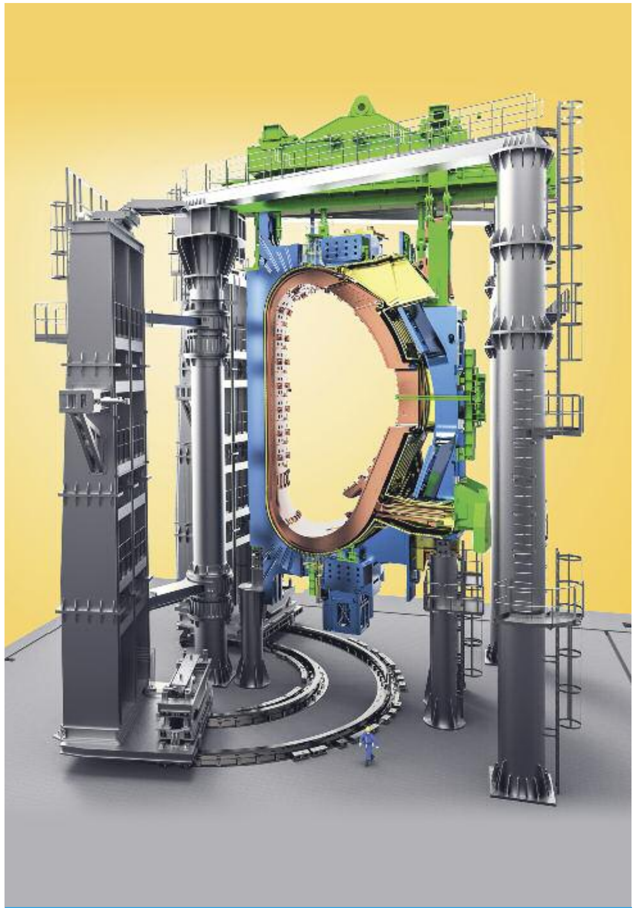
"It's far from a simple operation," says Emma Watson, an engineer who works within the Machine Assembly & Installation Section at ITER. "For each of the nine sectors, the complete sub-assembly operation will take five to six months." To optimize the overall schedule for the nine sectors, two identical tools are planned, each one capable of holding a sector on its end while positioning – and aligning – the associated components.

The sectors, which will travel from the factories in a horizontal position, will first have to be "upended" by a dedicated tool that is designed to lift the 440-ton (max) vacuum vessel sectors (7.6 x 6.5 x 13.7 metres) and the 310-ton toroidal field coils (9 x 3.7 x 17 metres) into their final, vertical orientation.

Then the Sector Sub-Assembly tools will take over, suspending each vacuum vessel sector from the top while carefully positioning and installing – via the rotary motion of the "wings" – the vacuum vessel thermal shields and two toroidal field coils. The sub-assemblies will be maintained in place as the remainder of the operations that must be completed on each 40° sector (such as the installation of some diagnostics, inter-connecting structures and cooling pipes) are carried out.

Made from 800 tons of steel, the 22-metre-tall tools will be capable of supporting, aligning, and stabilizing the vacuum vessel sectors and the toroidal field coils independently through a sophisticated array of precision actuators and sensors. "The assembly of the first sector will take the longest time, as assembly procedures based on the results of tests (involving partial component mockups) are honed via the experience gained as the sequences are performed for the first time on real components," says Emma. At different stages in the sub-assembly process, metrology surveys will be used to verify the components' positions. The final sub-assemblies, weighing a maximum of 1,200 tons, will be transferred by two overhead cranes operating in tandem to the Tokamak Pit.

As part of its procurement contributions to ITER, the Korean Domestic Agency is responsible for the design and fabrication of the Sector Sub-Assembly tool as well as 128 other purpose-built assembly tools.



Standing shoulder to shoulder, two Sector Sub-Assembly tools will suspend the vacuum vessel sectors from the top while carefully positioning and installing – via the rotary motion of the "wings" – the vacuum vessel thermal shielding and two toroidal field coils.

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