FUSION FOR ENERGY

HIGHLIGHTS 2017

THE MAIN ACHIEVEMENTS


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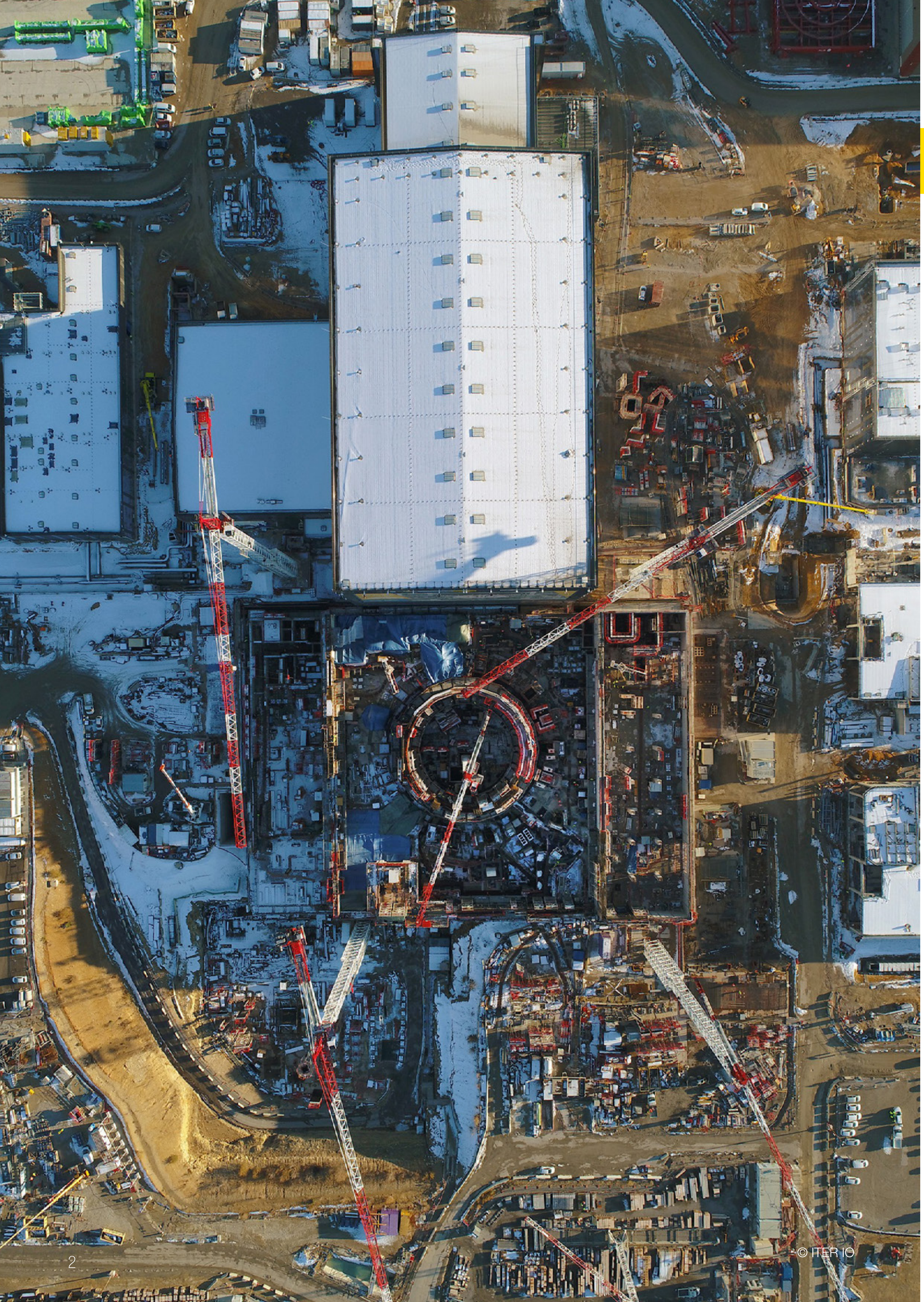


FOREWORD

2017 has been a year where the challenges of carbon emission reduction, in my personal perception, moved into the limelight of public discussion. I had the chance to attend a discussion at the world 2017 Expo in Astana, where UN representatives and ministers from major nations including EU, China and Russia discussed sustainable energy sources. A clear consensus emerged that new technologies are required, and several nations have mentioned fusion as a definite long-term goal. There has been little agreement about which bridge technologies should fill the gap until fusion becomes available to provide reliable and clean baseload energy that complements renewables. The COP23 conference in Bonn, the second “Conference of the Parties” since the Paris Climate Change Agreement of 2015, has highlighted again the challenges that most nations face to reach the carbon reduction goals, based only on a mix of traditional fossil fuels and renewables.

How can we become less reliant on fossil fuels for our energy and combat climate change? Just imagine if we could create a small sun on earth and connect it to the electricity grid to provide a virtually inexhaustible and clean energy source - this sounds like science fiction but it is the ultimate mission of our organisation - Fusion for Energy (“F4E” for short). Fusion can be an important part of a future sustainable and clean “energy mix” by complementing other energy sources such as renewables. Fusion fuels are widely available and plentiful, fusion does not produce greenhouse gases or long-lasting waste products, and fusion reactors will be intrinsically safe.

Making fusion happen in a laboratory is very challenging, but thanks to the progress made by scientists and engineers over the last fifty years, we are now one-step away from demonstrating fusion on the scale of a reactor. This is the objective of ITER – meaning “the way” in Latin - an international project of large scale and ambition to build and operate the largest fusion research machine ever. ITER is under construction in France; F4E is the European contributor, responsible for manufacturing about half of its components. F4E is also coordinating three joint EU-Japan fusion projects and, in the longer term, will prepare for the generation of fusion reactors to follow ITER.

2017 has been an important year – working together with the ITER International Organization and all the other ITER parties (China, India, Japan, Korea, Russia and the United States) - we have reached the halfway point of the total construction work to reach “First Plasma” in 2025, when ITER will be switched on for the first time. The contribution of F4E has been decisive, delivering all of our planned high-level milestones – a clear demonstration of Europe’s unwavering commitment to the project.

Europe’s participation in ITER continues to offer F4E’s industrial partners and research organisations unique opportunities to work together on diverse cutting-edge technologies, enhance their expertise, gain new knowledge and establish new commercial partnerships. Many industries have already developed “spin-off” innovations from work in fusion and we expect this to intensify in the future.

In 2017, we have signed almost 70 contracts for new work. Since 2007, we have placed almost €4bn of contracts with more than 500 companies and 70 research organisations.

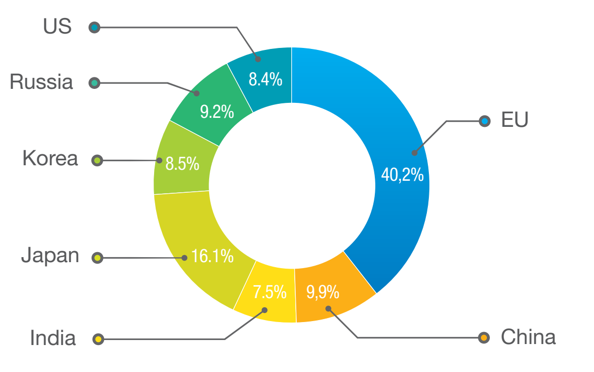
On the site of ITER in France, F4E’s progress on the buildings has been very visible, while manufacturing of many different ITER components continued across Europe. Of particular importance has been the completion, on time and in budget, of a Winding Pack – the first core of the 18 superconducting Toroidal Field magnets. In Japan, the assembly of the JT-60SA fusion device - which will be the biggest in the world until ITER comes to life - has continued throughout 2017, with the support of F4E and the EU voluntary contributors to the Broader Approach. As you will see in the following pages, there have been many more achievements during the year.

2017 marked the 10th anniversary of Fusion for Energy. Over the last decade, we have increased in numbers, broadened our expertise and continued to improve our ability to deliver. I would like to pay tribute to the unwavering commitment of all our staff, past and present - their enthusiasm, resilience and professionalism has been the driving force of F4E and its numerous achievements in these last ten years. I would also like to sincerely thank the European member states, represented in the F4E Governing Board, and our partners in industry and research organisations, for their continued support and trust.

Johannes P. Schwemmer
Director of Fusion for Energy

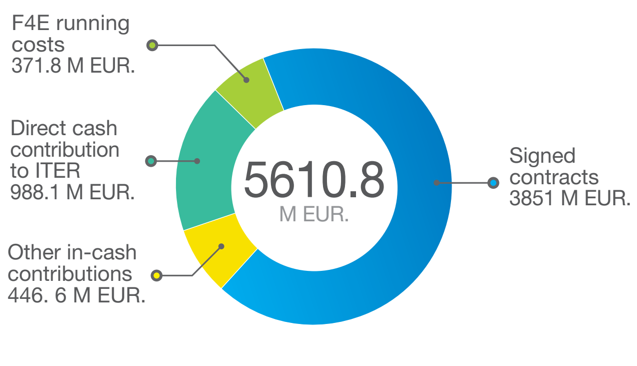
2017 KEY FIGURES

Contributions to ITER



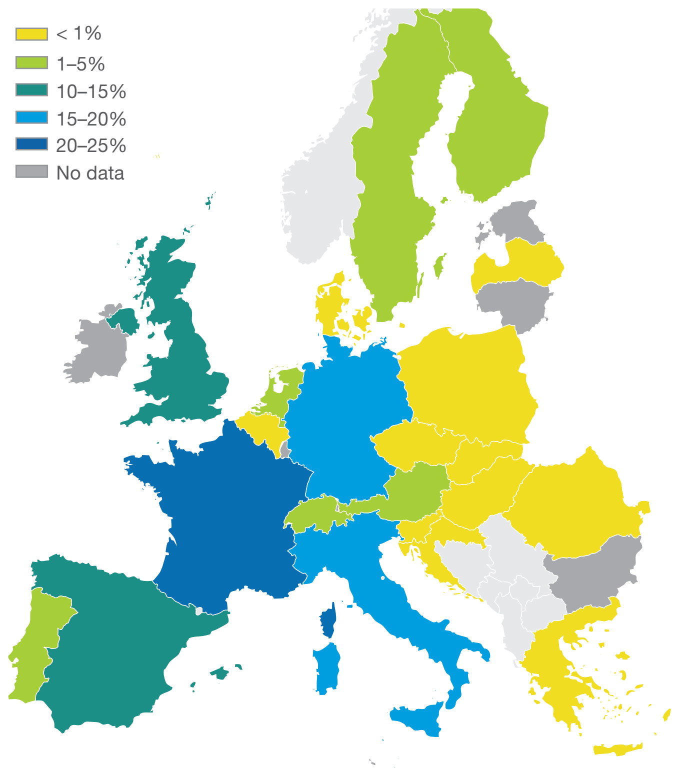
Total contributions between the different ITER parties 2008-2017

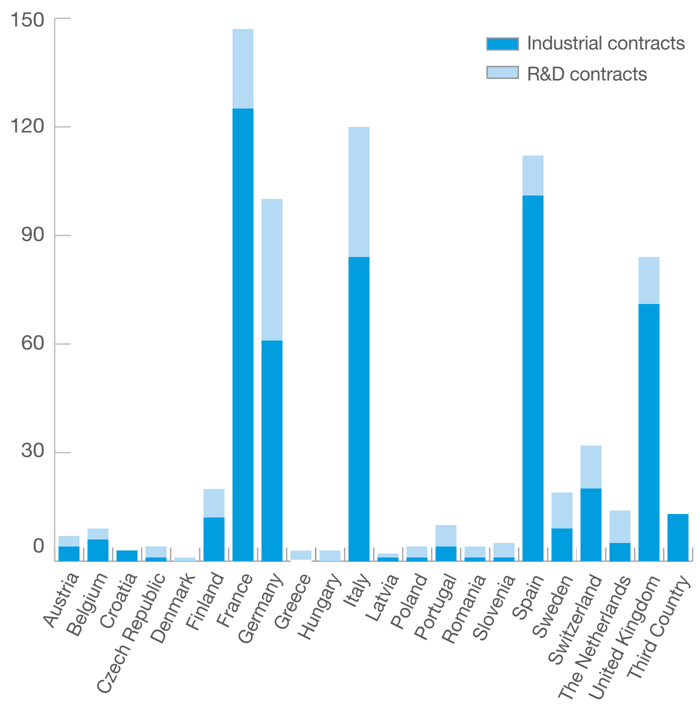
F4E budget breakdown



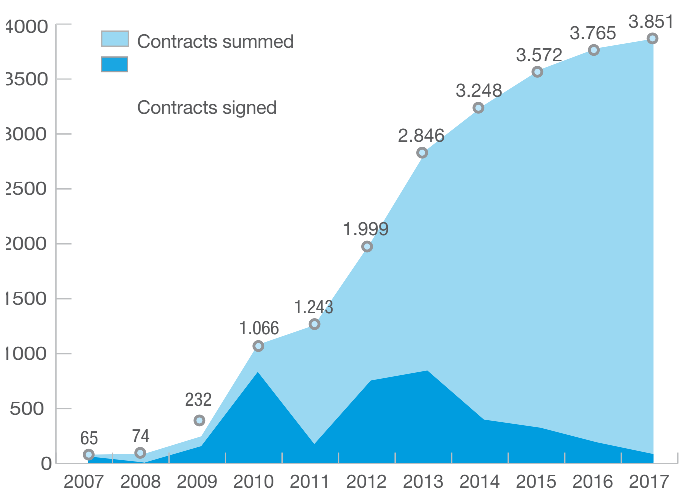
Budget breakdown of F4E main activities 2008-2017

Geographical distribution of contracts awarded by F4E 2008-2017

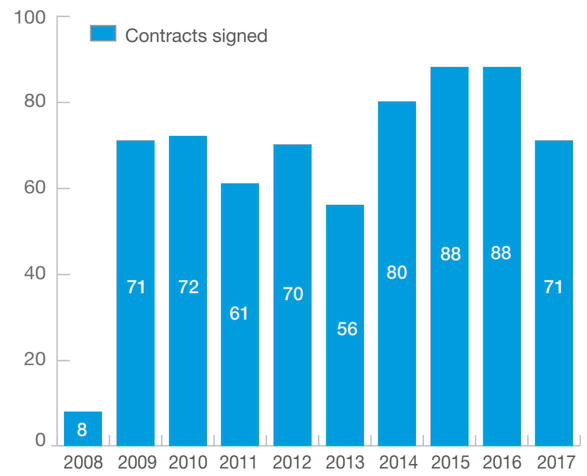




Value and quantity of signed contracts

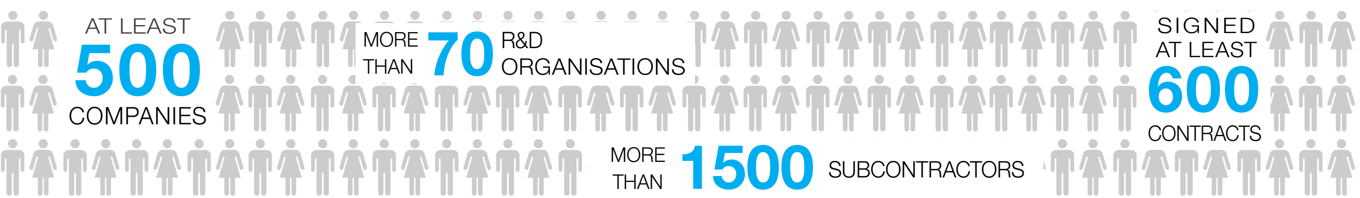


Annual and summed value of contracts signed

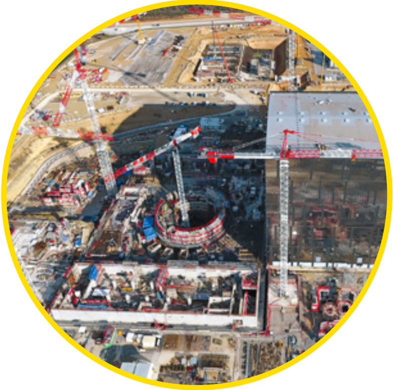


Number of contracts signed

Since 2008 F4E has been collaborating with:



Some of the F4E achievements during 2017



January

Works have advanced at the Tokamak Complex bioshield. Steel structures of the Cryoplant, and Radio Frequency buildings have started being erected. The Toroidal Field coils of JT-60SA have started being installed in the machine.

February

Full-scale Double Pancake mock-up of Poloidal Field coil six has been successfully wound. European Gyrotron prototype has produced impressive output power. EUROFER samples have undergone irradiation tests to test their performance.

March

Europe's first diagnostics equipment has been delivered to ITER. F4E has completed its power supplies contribution to the Neutral Beam Test Facility. The ITER site has been connected to the grid.

April

Vacuum Vessel segments have ben welded together to form the first sector. The manufacturing of the Poloidal Field coils has started. Broader Approach tests performed on materials have been successfully concluded at ENEA Brasimone. Europe has presented new business opportunities at the ITER Business Forum.

May

Europe has completed the first Toroidal Field coil winding pack, the production of all radial plates and the winding of the last conductor. The progress of Broader Approach projects has been presented to the King and Queen of Spain. Remote Handling cutting and welding techniques have been tested.

June

The potential of ITER and fusion energy have been presented at the World Expo in Astana. More cryogenic tanks for the ITER Cryoplant have arrived on-site. The manufacturing of the ITER Vacuum Vessel has advanced with new components delivered by ENSA. ITER has made a debut at the European Sustainable Energy Week.

July

Remote Handling camera tests have been successfully performed. Best welding techniques for Test Blanket Modules have been validated. Europe and Russia have reinforced their partnership in ITER.

August

The lid of the bioshield has been installed at the Tokamak building. Europe has delivered to ITER the first cryopump. Pre-qualification programme for In-Vessel components has moved to the next stage. Europe and China have held talks to strengthen collaboration in ITER.

September

The vessel of the JT-60SA Cryostat has been manufactured and pre-assembled. At the ITER construction site, the progress of the Cryoplant and the Magnets Power Conversion Buildings has been noticeable. A Delegation from China's Ministry of Science and Technology, and ITER's Domestic Agency, has visited F4E and European fusion laboratories to work closer.

October

Diagnostics sensors have successfully undergone neutron testing. The sixth Poloidal Field coil and the Pre-Compression Rings have advanced further. ITER's Architect Engineer's consortium has received "Industries and Technologies Consulting" award by the French Federation of Engineering Firms. Europe has delivered all of its cryogenic tanks to ITER. F4E has organised a companies' workshop to explore the manufacturing of the first wall panels.

November

F4E has celebrated its 10-year anniversary at a high-profile event gathering policy-makers, stakeholders, members of staff and industrial partners. Europe's first Toroidal Field coil winding pack has entered its last stage of production. Production of all European sectors for the vacuum vessel has started.

December

F4E has delivered the SPIDER beam source to the ITER Neutral Beam Test Facility. JT-60SA Cryostat has been manufactured and has left to Japan. Test Blanket Systems safety assessment has been delivered to ITER IO. Poland has hosted a big science projects event to unveil their business opportunities.

SOME OF THE ITER ACHIEVEMENTS DURING 2017

FIRST QUARTER

- Japan has completed the insulation of its first ITER Toroidal Field winding pack [1].
- The power-up of the first transformer of the 400kV switchyard has been successfully achieved to supply the 22kV network on site.
- China has completed the prototype of the first correction coil [2].
- US has started the fabrication of the pipe which will be part of the tokamak cooling water system [3].
- US has completed its share of production of the conductor for the Toroidal Field coils.
- Korea has completed 70% of sub-assembly tool that will be used to support the sectors of the vacuum vessel [4].
- China has produced approximately 65% of the niobium-titanium (NbTi) strand needed for ITER's Poloidal Field coils and 7.5 % of the niobium-tin (Nb3Sn) strand needed for its Toroidal Field coils.
- Manufacturing has started in China on the first of the heavy steel cases of the bottom correction coils.
- Japan has delivered to ITER's Neutral Beam Test Facility the bushing for the insulator transformer.
- India has started working on the cryostat upper cylinder at Larsen & Toubro [5].

SECOND QUARTER

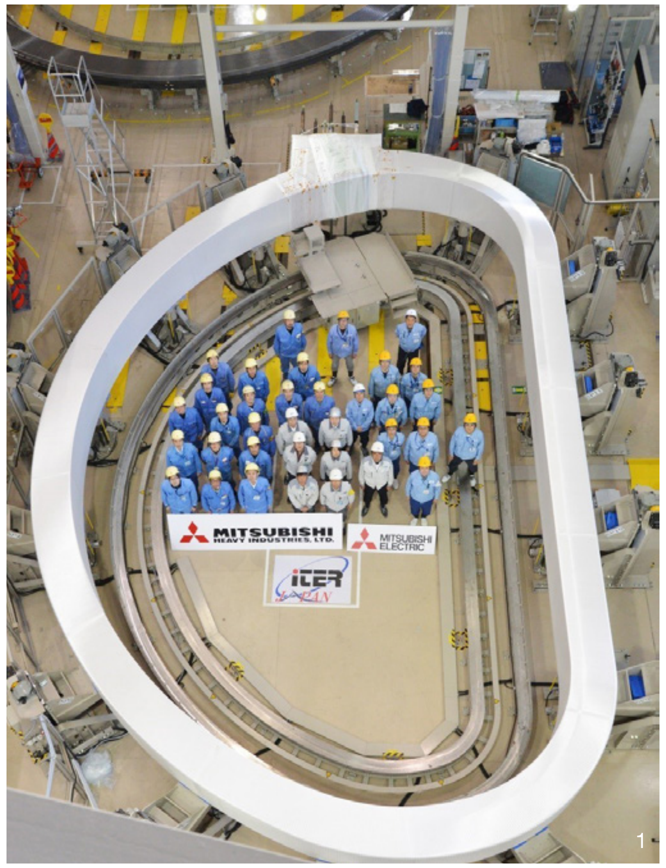
- Korea has shipped to the ITER site the first of two vacuum vessel sector sub-assembly tools which will be assembled on-site.
- US has made progress with the first of six independent magnets for ITER's central solenoid, having successfully passed the heat treatment phase.
- China has reached the last stages of machining of a full-scale prototype of a blanket shield block [6].
- In India, the large-capacity chiller (one of eight required for the chilled water system) has successfully passed pre-shipment inspection at Kirloskar Chillers in Pune.
- Korea has manufactured electrical converters which will be installed in the Magnet Power Conversion buildings on the ITER site.
- Japan has manufactured the High Voltage bushing for ITER Neutral Beam Test Facility [7].
- India has shipped to ITER the first batch of cryolines which will deliver liquid helium to the actively cooled magnets, thermal shield and cryopumps

THIRD QUARTER

- China has completed the first magnet feeder component. The 10 m, 6.6 t component has left for ITER.
- Korea has advanced with the machining of one segment (PSE 2) of ITER's Vacuum Vessel sector 6.
- Japan has manufactured the niobium-tin (Nb3Sn) superconductor required for the central solenoid and has shipped the material to the US.
- Korea has successfully tested a 130 t transformer and the 4 m long busbar that connects it to the AC/DC converter. The equipment will be installed in the Magnet Power Conversion building.
- Russia has made progress with the vacuum, heat and functional testing of the port plugs.
- Japan has finished the resin impregnation phase of the first Toroidal Field coil winding pack.
- Technical Cooperation Agreement signed between ITER Organization and Australia.

FOURTH QUARTER

- US has started developing the waveguide prototypes.
- US has completed its contribution to the steady state electrical network (SSEN) which will power the lights, pumps, computers, heating and ventilation of the ITER facility.
- China has delivered the first magnet feeder.
- Korea has completed the manufacturing of the first segment of ITER's Vacuum Vessel sector six with ribs and in-wall shielding elements.
- India has delivered a High Voltage rack to the ITER Neutral Beam Test Facility.
- Russia has completed the first Poloidal Field coil double pancake after vacuum pressure impregnation with epoxy resin.
- Korea has completed the fabrication of the first poloidal segment of sector 6 of the Vacuum Vessel [8].
- Japan has successfully conducted fitting tests for the first Toroidal Field coil cases.
- Russia has completed the first port stub extension [9].
- US has completed the ground insulation on the first module of the Central Solenoid.
- ITER has completed 50% of the construction work linked to first plasma.



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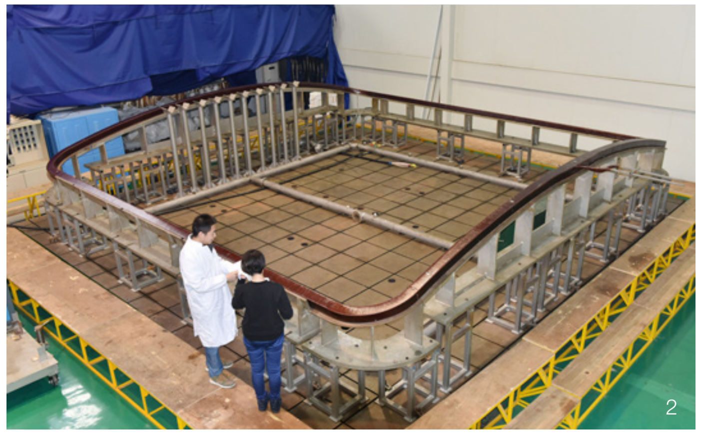
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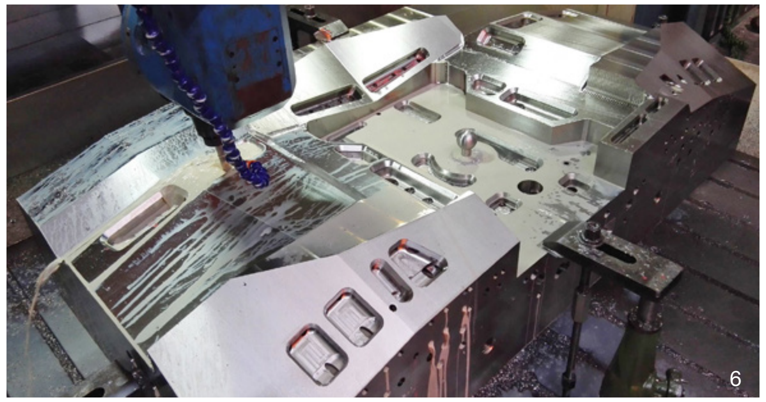
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01

Building ITER

The ITER platform is located in Cadarache, south of France. It measures 42 hectares and is considered as one of the largest man-made levelled surfaces in the world.
Europe is responsible for the construction of the 39 buildings, the infrastructure and power supplies on-site which will be needed to operate the world's biggest fusion machine.
Currently, more than 2000 people are contributing to ITER's civil engineering works. As more buildings get erected and a growing number of components is being delivered from all over the world, workforces on the ground are planning carefully the various stages of construction and installation.

THE ITER SITE

Building the infrastructure that will deliver the energy of the future.
It has been a year of steady progress during which the ITER site has been connected to the grid; the impressive Assembly Hall has been completed in order to welcome the first tooling, and more components have started being installed. The construction of the Tokamak Complex, the main edifice of the project where the fusion device will be installed, has advanced boasting more floors and a massive cylinder made of concrete, known as the bioshield, which will act as a safety barrier between the machine and the building. The teams of F4E, ITER International Organization and the companies involved in civil engineering, have accelerated the pace of works at the Cryoplant, Magnet Power Conversion buildings, and the Cooling Towers. Below the ground, workforces have carried on digging the vast galleries, where a network of pipes will be installed to connect different facilities. Discover this year's key moments on the ITER construction site.

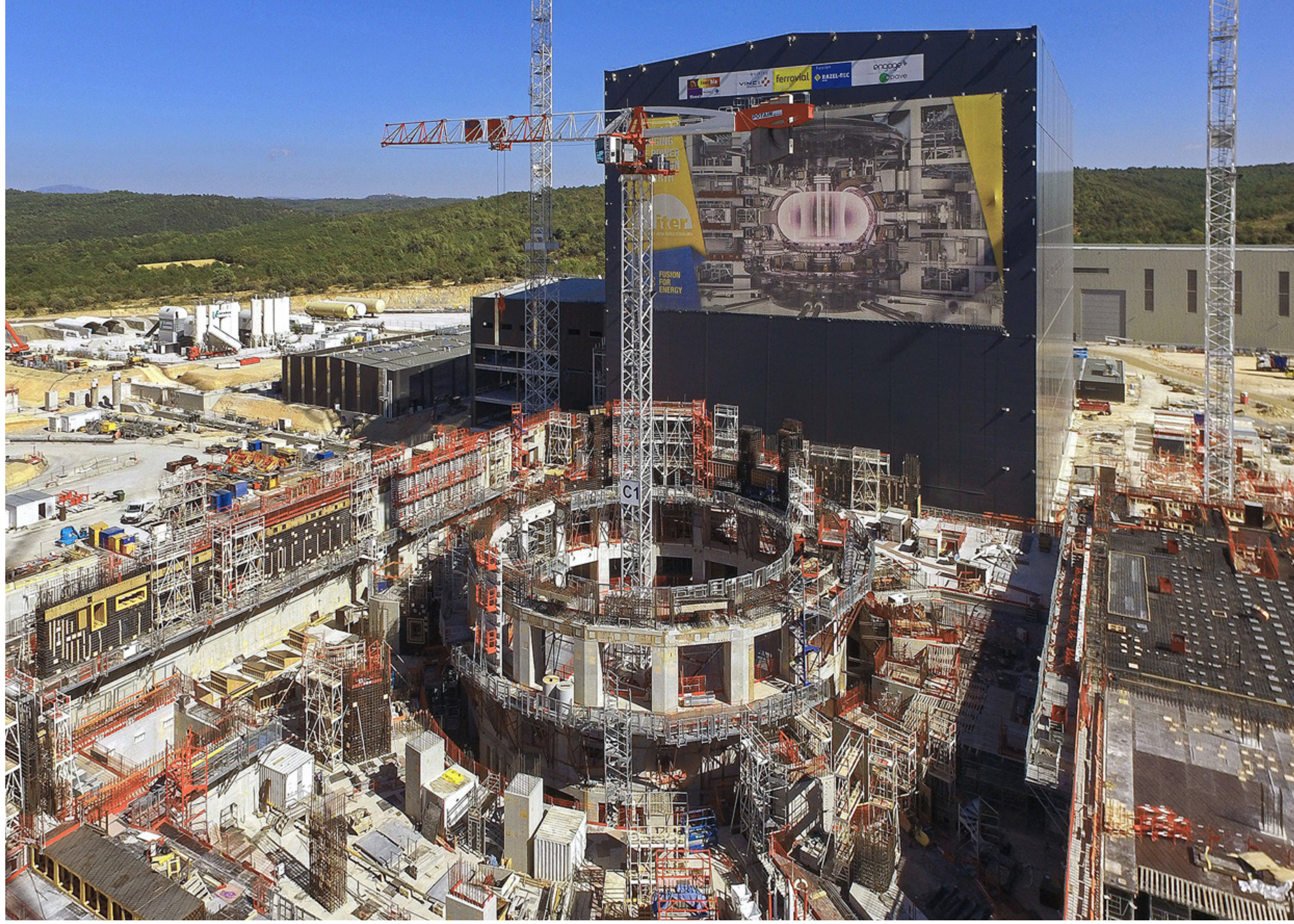
Technical teams on-site cross-checking cabling before the ITER site is connected to the grid © SNC Engage

Construction in progress

Contracts signed	73%
Construction completed	40%
Tokamak	39%
Assembly bldg.	84%
Site Service bldg.	70%
Cryoplant bldg.	75%
Power Supply	40%
Magnet Power Conv. bldg.	50%
Cooling Towers bldg.	75%

Connecting ITER to the grid

F4E and ITER International Organization have hailed a historic moment connecting the construction site of the biggest fusion device to France's grid (RTE). Until then, a connection had been supplied by France's CEA, offering 15 MW. From this moment, the direct connection will be offering a supply of 75MVA at 400kV. Thanks to the ITER transformers provided by China and the US, the 400kV will be converted to 22 KV and 66 KV for the needs of the ITER site and components.



Aerial view of the Tokamak Complex and Assembly Hall, ITER construction site, September 2017, Cadarache © ITER IO

Feel the heartbeat of the project at the Tokamak Complex

The second floor of the Tokamak building has been completed and works on the third floor are expected to come to an end in spring 2018. Below the concrete and rebars, 40 000 out of the 150 000 embedded plates have been installed. These thick pieces of steel have been anchored deep into the concrete to match the location of equipment with 98% accuracy. At the Diagnostics building, the third floor has been completed and works have started on the fourth floor. Meanwhile at the Tritium building, the slab of its third floor has been steadily advancing.

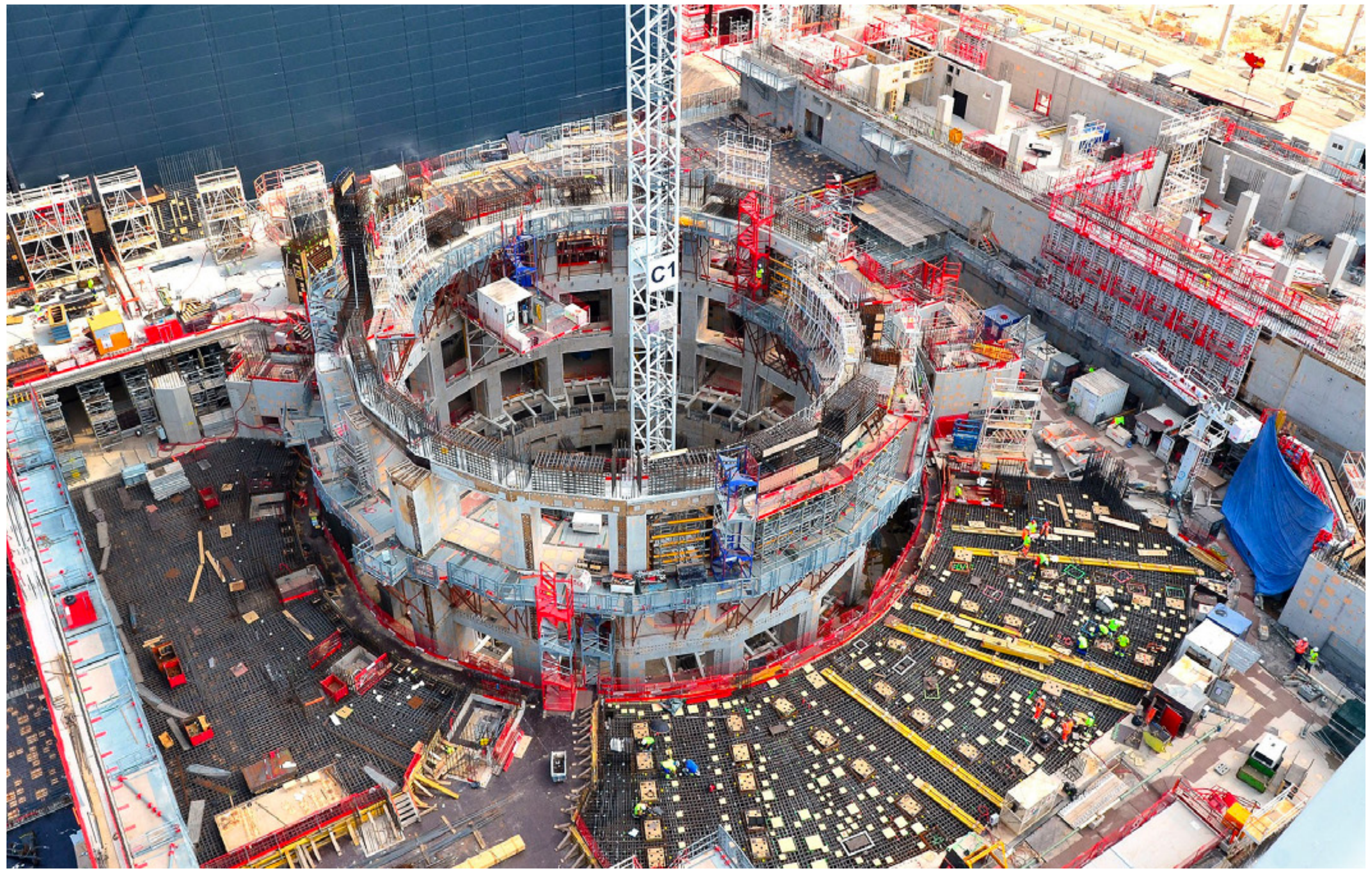
Various embedded plates installed on the level above, Tokamak building © ITER IO

TOKAMAK COMPLEX

Diagnostics, Tokamak and Tritium buildings

Dimensions: 120 x 80 m, 60 m high, 17 m deep

Weight: 360 000 t (the equivalent of the Empire State building)



Scaffolding surrounds the ITER Bioshield as workers advance on the L2 level © ITER IO

Below the lid of the ITER Bioshield © ITER IO

The ITER Bioshield- a rising tower on-site

The shield acting as a safety barrier between the ITER machine and the edifice that will house it has come a long way. Its construction started on the ground floor (level B2) of the Tokamak building and has accelerated all the way to the fourth floor (level L3). It will be 30 m high and its walls will be 3.5 m thick. It is made of concrete with steel bars, embedded plates and heavy anchoring equipment. In August, a 30 m lid has been installed to allow works to start on the “crown” located on the ground floor. It will consist of 18 massive blocks of steel that will support the equipment of the ITER machine, which is in the range of 23 000 t.

01

02

03

First tooling has been delivered to the Assembly Hall

The civil engineering works at the Assembly Hall have been completed. The two cranes have been fully tested and the sliding doors, from where the ITER components will be delivered, have been fitted. The installation of the heating and ventilation infrastructure has been completed on time for the first tooling arriving from Korea.

The construction works of the Site Services building and Cleaning Facility have finished, paving the installation of cabling, heating ventilation and air conditioning works.

The cladding at the Radio Frequency building has been filling in while the internal partitions and floors have been advancing as planned.

01 – Installing the first pieces of equipment inside the ITER Assembly Hall, September 2017 © LNM-Engage

02 – The ITER Assembly Hall (dark anthracite building) and the Site Services buildings (adjacent to the right), April 2017 © Engage

03 – Cladding advancing at the Radio Frequency Heating building, located at the right, of the Assembly Hall © ITER IO

ASSEMBLY HALL

100 m long, 60 m wide, 60 m high.

Cladding operations starting early in the year at the ITER Cryoplant, April 2017 © LNM

ITER Cryoplant ready to receive equipment

Europe is one of the ITER Parties with a big stake in the cryogenics of the machine. The cryoplant can be described as a massive refrigerator which is going to generate extremely cold temperatures for some of the ITER components. For instance, to confine the super-hot plasma, expected to reach 150 million ˚C, the magnets will need to be cooled with liquid helium to reach a superconducting state at 4.5 K, close to absolute zero.

The main facility that will house Europe's share of components for the cryoplant has been completed paving the way for the installation of equipment (cold boxes, tanks, etc).

Final works at the ITER Cryoplant before the first tanks get installed, December 2017 ©Engage

CRYOPLANT

Total area: 8 000 m^2
Building dimensions:
20 m high, 120 m long, 45 m wide.

(L-R) Aerial view of the two ITER Magnet Power Conversion buildings and the ITER Cryoplnat, December 2017 © SNC Engage

Magnet Power Conversion Buildings

The construction of both buildings started early in the year and has advanced to the extent that 60% of the slabs have been completed. The 150 m in length facilities will house electrical converters, switches and fast discharge units which will act as an AC/DC converter for the current of the ITER magnets.

Installing the steel structure of the Magnet Power Conversion Buildings, ITER construction site, July 2017 © ITER IO

Aerial view of the works in progress at the area of the water basin and cooling towers, ITER construction site, September 2017 © LNM-Engage

Cooling the heat of the ITER machine

In a 6 000 m^2 area, hot and cold cooling water basins, powerful pumps, heat exchangers, and an induced-draft cooling tower with ten individual cells will be located. Its construction has already advanced significantly. The lower slabs and walls have been completed together with the top slab. Cooling water, circulating under pressure through the ITER device, will remove the heat load from the ITER vacuum vessel, its plasma-facing components, and plant systems such as heating and power systems.

A network of galleries below the ground

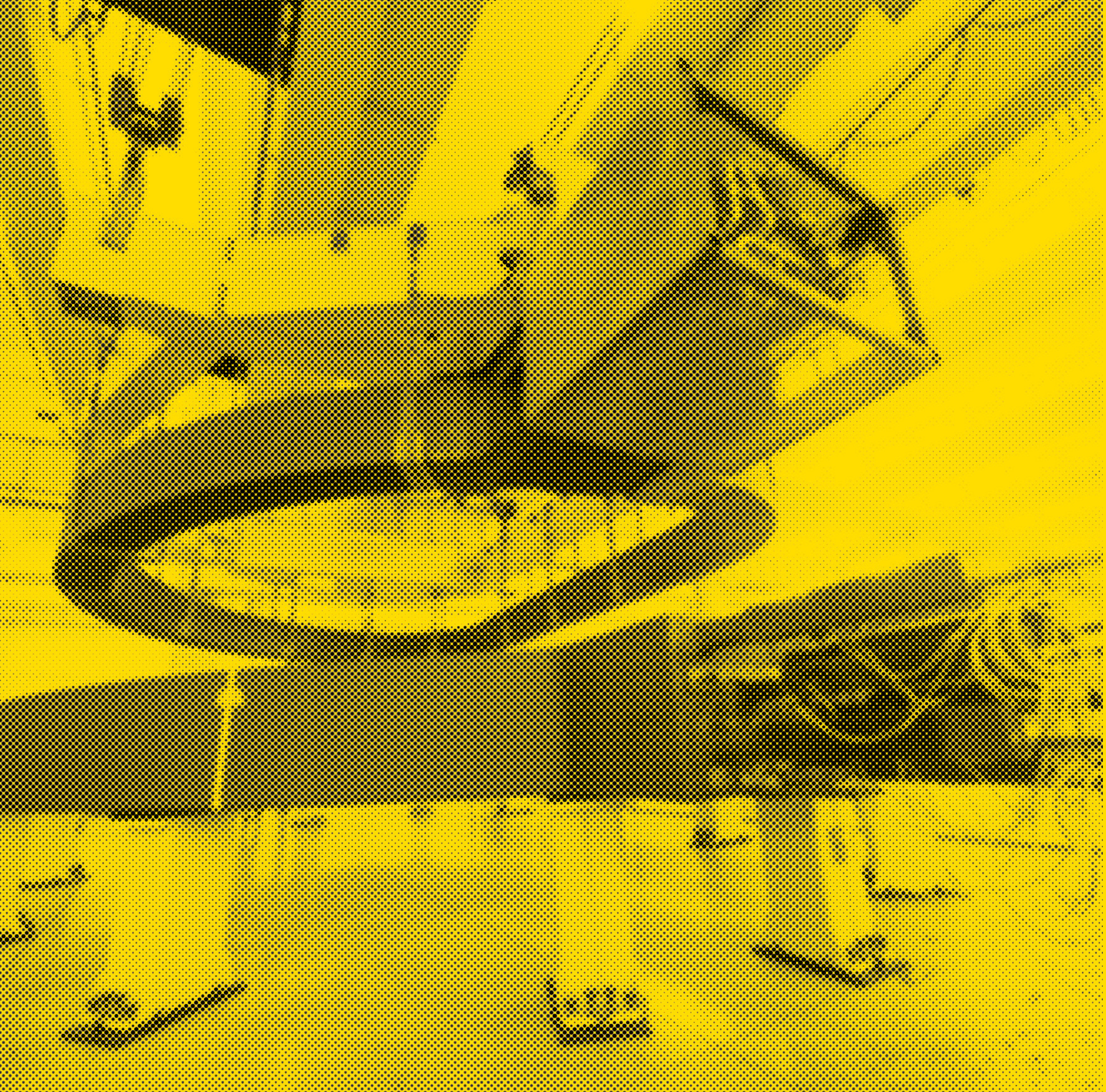
ITER construction is also unfolding below the ground in order to dig the deep trenches, comparable to the size of humans, to house the piping network that will crosscut the entire field. Nearly 30% of the concrete galleries and associated infrastructure works have been completed.

01 – Five kilometres of piping will be installed in the underground galleries of the cooling tower area © LNM/SNC

02 – A labyrinth of pipes installed below the ground at the ITER construction site, August 2017 © ITER IO

01

02

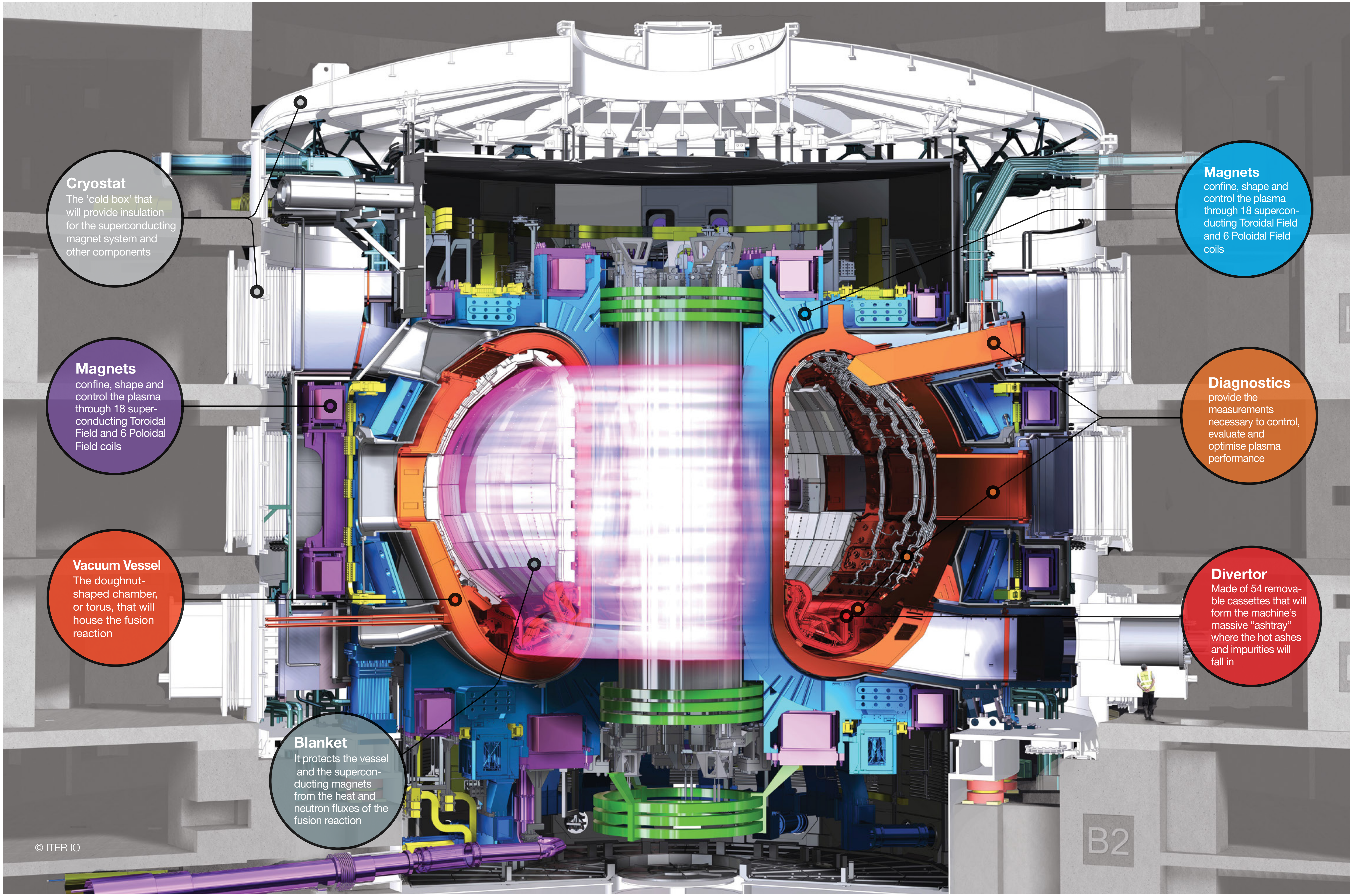


02

Manufacturing the ITER components

ITER is the next important step to fusion energy, relying on massive, complex and impressive high-tech components. They have undergone rigorous manufacturing tests and are underpinned by extreme accuracy. Components of such size have never been manufactured before!

Europe's in-kind contribution to ITER amounts to roughly 50% of the total. Its share offers an unprecedented opportunity to industry, SMEs and fusion laboratories to get involved and contribute to the largest international collaboration in the field of energy.


Cryostat
The 'cold box' that will provide insulation for the superconducting magnet system and other components
Magnets
confine, shape and control the plasma through 18 super-conducting Toroidal Field and 6 Poloidal Field coils
Vacuum Vessel
The doughnut-shaped chamber, or torus, that will house the fusion reaction
Blanket
It protects the vessel and the supercon-ducting magnets from the heat and neutron fluxes of the fusion reaction
Magnets
confine, shape and control the plasma through 18 supercon-ducting Toroidal Field and 6 Poloidal Field coils
Diagnostics
provide the measurements necessary to control, evaluate and optimise plasma performance
Divertor
Made of 54 remova-ble cassettes that will form the machine's massive "ashtray" where the hot ashes and impurities will fall in
B2
© ITER IO

DIAGNOSTICS

The Diagnostics system will help scientists to study and control the plasma behaviour, measure its properties and extend our understanding of plasma physics. This system will act as “the eyes and ears” of the experts offering them insight thanks to a vast range of cutting edge technologies.

ITER will rely on approximately 50 diagnostic instruments that will offer an unparalleled view of the entire plasma and ensure the smooth operation of the machine. Given the duration of the plasma pulse, which will be 100 times longer than any fusion device currently in operation, the strong fluctuation levels, and the extreme environment in the vessel, the diagnostic system will act as the guardian of the safe and sound operation of the machine. Europe is responsible for roughly 25% of all Diagnostics in ITER.

Work in progress

Contracts signed	42%
Design	48%
Manufacturing	1.7%

01

Europe delivers its first diagnostic component

The five Continuous External Rogowski (CER) coils have become Europe’s first diagnostic equipment delivered to the ITER site. Each coil is a flexible, cylindrical structure, measuring approximately 40 m in length and 12 mm in diameter. The CER coils will be installed within the cases of three Toroidal Field (TF) coils and their purpose is to measure the total electric current flowing in the ITER plasma. The CER coils have been manufactured by Axon (France), which provided the electrical parts of the system, and Sgenia (Spain), which supplied the mechanical parts.

02

01 – One of the Continuous External Rogowski (CER) coils undergoing acceptance tests

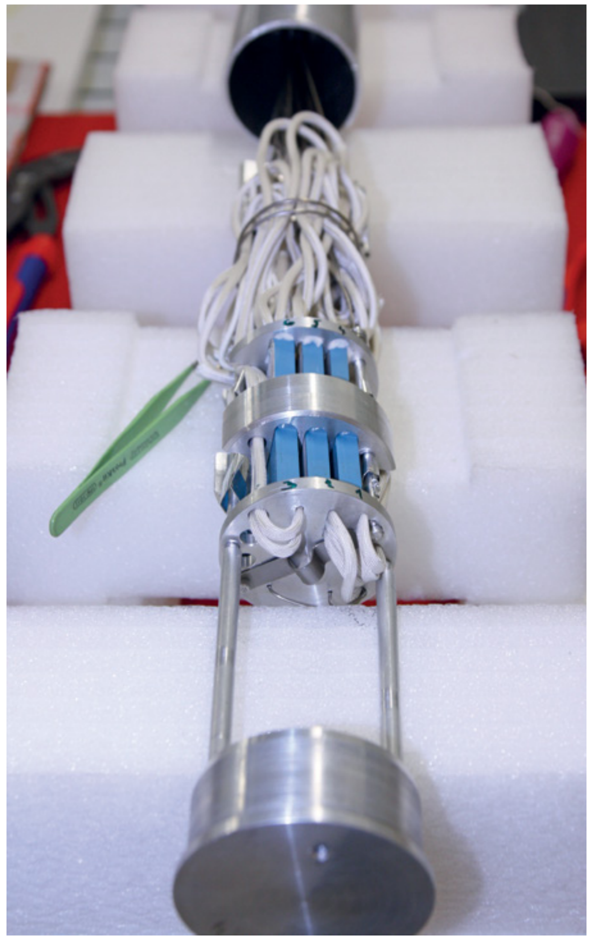
02 – Delivering the Continuous External Rogowski (CER) coils to the ITER site

Europe to manufacture 400 coils to measure ITER’s magnetic field strength

F4E has signed a contract worth 2 million EUR with Elytt Energy (Spain), to produce more than 400 coils which will be installed on the outer surface of the ITER Vacuum Vessel. These coils will measure the magnetic field strength focusing on key parameters such as the shape and position of the plasma during operation.

“This is a technically challenging task, as these coils must last the entire lifetime of ITER without maintenance, after their installation on the machine.”

Glenn Counsel
Project Team Manager
Diagnostics



The LTCC sensor prototypes (in blue), installed on a supporting structure and fully connected, in final preparation for testing

Neutron testing of the diagnostic sensor prototypes successfully completed

The tests have been carried out on behalf of F4E by Belgian (SCK-CEN) and Czech (REZ) laboratories, focusing on assessing whether the diagnostic Low-Temperature Co-fired Ceramic (LTCC) sensors will be able to withstand the exposure to neutrons which will be created during the fusion process in ITER. Prototypes of these sensors subjected to neutron testing were manufactured by EPFL (Switzerland), Via Electronic (Germany) and VTT (Finland).

The sensors can be likened to eyes of the ITER machine, measuring the magnetic field around the plasma core and this giving information regarding its position and shape. In total the ITER machine will house more than 1500 magnetic field sensors of various different types.

MAGNETS

Powerful superconducting magnets will help us confine ITER's super-hot plasma which is expected to reach 150 million ˚C. The first layer of magnets will consist of the Toroidal Field (TF) coils that will entrap the hot gas and keep it away from the walls of the Vacuum Vessel. The second layer will consist of the Poloidal Field (PF) coils that will embrace the TF coils from top to bottom to maintain the plasma's shape and stability. Europe is responsible for five out of the six PF coils, of which one will be manufactured in China. The remaining coil will be produced in Russia.

Inside the facility where Europe's ITER TF coils are being manufactured, ASG Superconductors, La Spezia, Italy

Toroidal Field coils

Europe has manufactured the most high-tech magnet in history!

The first of the winding packs— the inner core of the TF coil magnet—has been completed and in parallel the production of the remaining ones has been advancing. F4E together with ASG Superconductors, Iberdrola Ingeniería y Construcción, Elytt Energy, CNIM, SIMIC and the ICAS consortium, have achieved this important milestone. More than 600 people from 26 companies have collaborated to produce this component. Towards the end of the year, it left from the factory of ASG Superconductors, La Spezia (Italy), where Europe is manufacturing the TF coils, to be delivered to the port of Marghera, Venice (Italy) where SIMIC will perform a series of cryogenic tests and insert it into its metallic case.

Work in progress

Toroidal Field coils	
Contracts signed	100%
Tooling	95%
Qualification	96%
Manufacturing	75%

01

TOROIDAL FIELD COILS

The gigantic "D" shaped coils will be the biggest Niobium-tin (Nb3Sn) magnets ever produced, which once powered with 68000 A will generate a magnetic field that will reach 11.8 Tesla – about 1 million times stronger the magnetic fields of the Earth. Each coil is approximately 14 m high, 9 m wide and weighs 110 t. When inserted into its metallic case its total load will exceed 300 t, which compares to that of a Boeing 747.

02

01 – Europe's Toroidal Field Coils winding pack, ASG Superconductors, La Spezia, Italy

02 – The case containing Europe's first TF coil winding pack departing from the ASG factory, La Spezia, Italy © ASG Superconductors

Representatives of F4E, CMIN and SIMIC standing inside the final radial plate to be used in the manufacturing of the 10 Toroidal Field coils procured by Europe.

All of Europe's Radial Plates have been produced

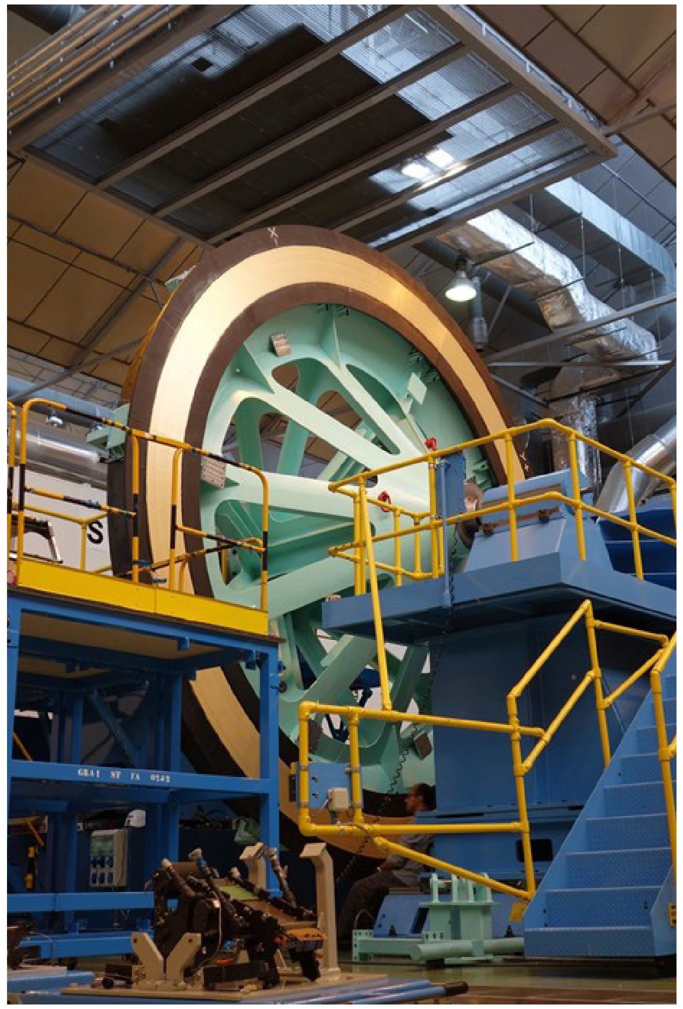
The final radial plate which will house in its finely machined grooves the superconducting conductor of the ITER Toroidal Field coils (TF) has been manufactured. The contract signed between F4E and the consortium of SIMIC and CNIM for a value of 150 million EUR has been successfully concluded.

> *"Europe has proudly concluded one of its main contracts in the area of magnets."*
>
> **Alessandro Bonito-Oliva**
> Project Team Manager
> Magnets

Developing nine rings to cope with ITER's powerful magnetic fields

Airbus Defence and Space (Airbus D&S) has been working to complete a full-scale prototype of a Pre-Compression Ring so that "real" production can begin. To reach this stage, three full-scale ring slices of fiberglass epoxy resin have been cured. Previously, one additional full-scale slice has been produced and has undergone the first stage of the qualification phase.

In parallel, CNIM has been involved in the production of three spare Pre-Compression Rings. They have been building on the work performed by companies such as Exel (FI), Solvay (UK), CMF (IT), CMC (FR) and test laboratories such as Rescoll (FR), Etim (FR) and KIT (DE). They have started with the fabrication of a mock-up, which is roughly 1005 mm in diameter, almost 1/5 of the real size of the component.



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PRE-COMPRESSION RINGS

The fiberglass composite rings, consisting of more than a billion miniscule glass fibers, will be glued together by a high performance epoxy resin. The rings will have a diameter of approximately 5 m, a cross-section of nearly 300 mm x 300 mm and will weigh roughly 3 t.

01 – Installing the Pre-Compression Ring prototype in order to perform checks © CNIM

02 – Technician examining the lay-up of the full-scale prototype of the Pre-Compression Ring's slice © AIRBUS D&S Spain

European contractors have completed winding a full-size dummy double pancake for the fifth Poloidal Field coil, Cadarache © ITER IO

CNIM technicians supervising the manufacturing of the European Poloidal Field coils in F4E's facility, Cadarache

Poloidal Field coils

The production of the massive magnets has started

The engineers from F4E, ASG and CNIM, working in Europe's industrial facility on the ITER site, and their colleagues in ASIPP, the Institute of Plasma Physics of China's Academy of Sciences, have officially started manufacturing the Poloidal Field (PF) coils assigned to Europe. After having successfully completed the winding tests using lengths of dummy conductor, the technicians have started working with the "real" conductor.

Work in progress

Poloidal Field coils

Contracts signed	100%
Tooling	90%
Qualification	80%
Manufacturing	8%

Representatives of F4E and ASIPP in front of the first layer of the dummy double pancake

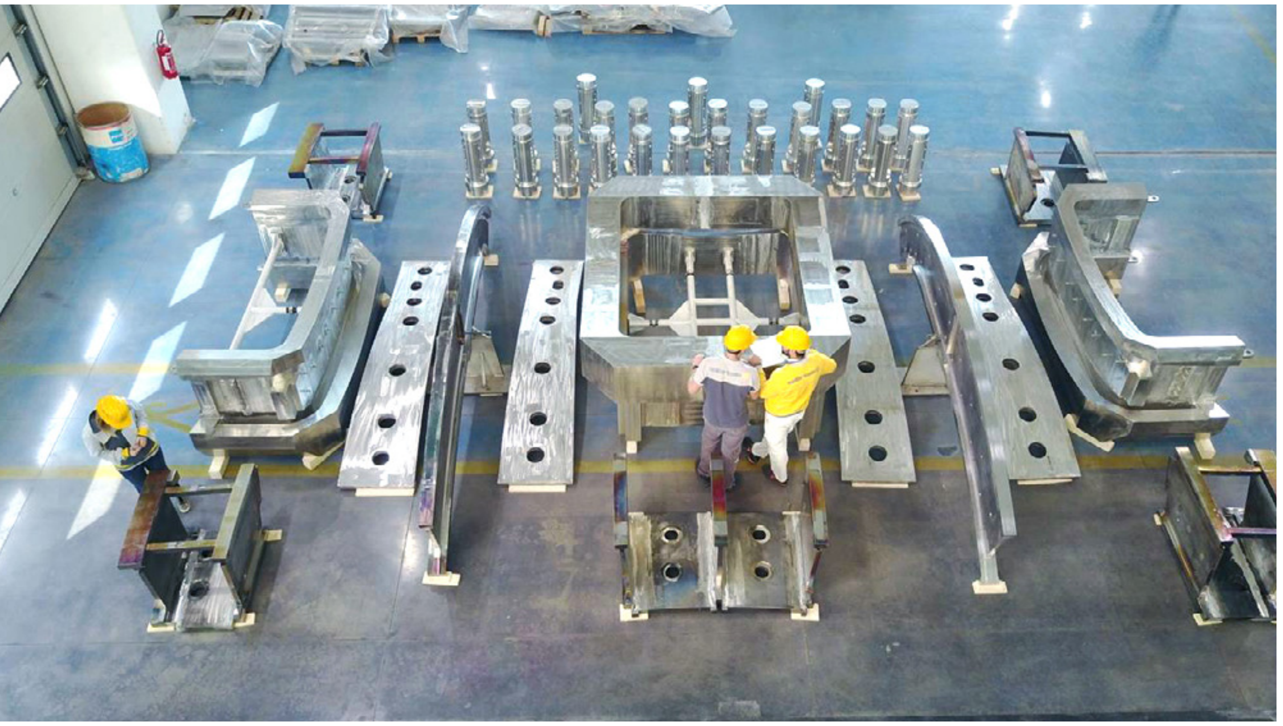
Working on the terminations of one Double Pancake of Poloidal Field coil 6, ASIPP, China

POLOIDAL FIELD COILS

The construction of the PF coils facility has been financed and delivered by F4E through a contract signed with the consortium of Spie batignolles, Omega Concept and Setec. The facility is approximately 250 m long, 45 m wide and 17 m high. It includes regular services (HVAC, electrical, piping), two overhead cranes (one standard crane with a capacity of 25 t and another crane especially adapted with a capacity of 40 t), one gantry crane to lift 400 t, offices, technical rooms and workshop space. The facility is operated by Dalkia-Veolia.

VACUUM VESSEL

The ITER Vacuum Vessel is located inside the cryostat of the ITER machine. Its basic function is to operate as the chamber that will host the fusion reaction. Within this torus-shaped vessel, plasma particles collide and release energy without touching any of its walls due to the process of magnetic confinement.



Parts placed together before assembly of segment PS3 for vacuum vessel sector 5, Walter Tosto

Fabrication has started for all European vacuum vessel sectors

The vacuum vessel consortium collaborating with F4E has increased in size and capacity by bringing together CNIM (France), ENSA (Spain), MAN (Germany), ProBeam (Germany), Belleli (Italy), Mangiarotti (IT), Walter Tosto (IT), and Ansaldo Nucleare (IT). The additional resources and expertise have helped all partners to move forward with the production of all five European sectors in parallel.

Fabrication consists of the following main steps: qualification, manufacturing design, material procurement, machining into the correct shapes, welding of the parts to form bigger the sectors for the vacuum vessel. Notable in terms of qualification, is that in part due to the past experience, CNIM has been able to qualify its welding techniques according to the nuclear code in less than two months, a record in comparison to earlier welding qualification times. The acceleration in the speed of production has also been due to better quality welding techniques used to join the various pieces of the sectors.

Work in progress

Sector 5	
Delivered material	100%
Design	100%
Manufacturing	51%
Sector 4	
Delivered material	100%
Design	74%
Manufacturing	44%
Sector 3	
Delivered material	100%
Design	63%
Manufacturing	19%
Sector 2	
Delivered material	86%
Design	58%
Manufacturing	8%
Sector 9	
Delivered material	83%
Design	60%
Manufacturing	5%

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01 – One of the two inner shell plates – the first pieces to be manufactured at ENSA

02 – Smaller parts of a poloidal segment have been welded together for the first time to form a bigger piece ©Walter Tosto

03 – Preparation of parts by Belleli for Electron Beam welding of Poloidal Segment 2 sector 3

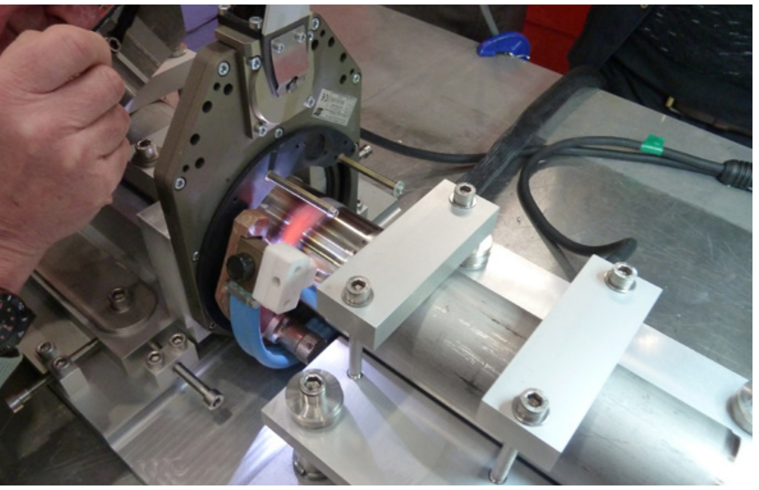
04 – Vacuum Vessel staff checks the welding of T-rib, Mangiarotti

VACUUM VESSEL

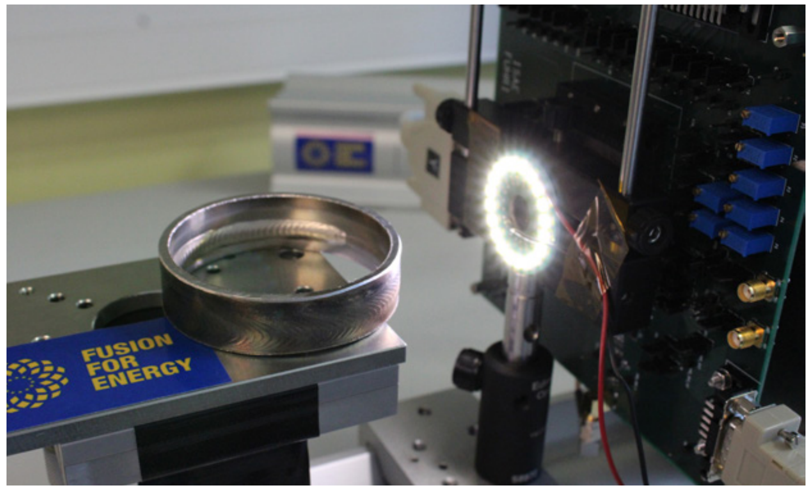
The vacuum vessel is composed of nine sectors made of thick special grade stainless steel. Europe is responsible for five of them. Each sector is 12 m high, 6.5 m wide and 6.3 m deep. The weight of each sector is approximately 500 t and the weight of the entire component, when welded together, will reach an impressive total of 5 000 t which is equivalent to the weight of the Eiffel Tower.

REMOTE HANDLING

Remote handling helps us to perform a task without being physically present where it is being carried out. For example, it is widely used in space exploration missions, underwater repairs or challenging maintenance works. The limited space inside the ITER machine together with the weight of the tooling and the exposure of some components to radioactivity will require the use of remote handling systems during maintenance. This area combines manufacturing and R&D in order to develop the appropriate tooling to operate with extreme dexterity and millimetric precision.



Testing welding technologies at RACE, UK



Test set-up to validate the performance of the camera using a real-size ITER weld

Developing new tooling for Remote Handling systems

To carry out various maintenance activities and move the bulky ITER components, F4E in collaboration with its industrial partners have been working together to develop and test new tooling. RACE (Remote Applications in Challenging Environments), the new centre of the UKAEA for robotics development, is participating in the contract signed between F4E and Assystem UK for the remote handling system of the ITER Divertor. A team of experts has been working to identify key technologies to perform the cutting and welding operations required for the pipes of the divertor cassettes. Due to the fact that no liquids can enter in the vacuum vessel, dry cutting techniques will need to be deployed.

Some of the ITER components will be exposed to radioactivity and as a consequence, engineers will not be allowed to physically carry out any maintenance tasks in the machine. Therefore, a system to help them do repairs remotely is under preparation counting at least 100 cameras. For this reason F4E in collaboration with Oxford Technology Limited (OTL) have been working together to develop different sub-system mock-ups in collaboration with ISAE, Toulouse, for the image sensors; CEA for the illumination system and the Jean Monnet University Saint Etienne for the optic system. After having concluded the development and validation of these subsystems, their resistance has been tested for almost a year in Belgium's SCK-CEN, a nuclear facility, and the results have been extremely good.

Assystem UK and the Technical University of Tampere (TUT) have been testing a water-hydraulics system replicating ITER conditions by monitoring its performance during a 2 000 hours test. The performance of the prototype and wear of components have been satisfactory but engineers have spotted that they lack robustness and wear off easily. Consequently, F4E has started looking for alternatives and has signed a contract with Tamlink and Hytar Ltd., part of Fluiconneto by Manuli, to explore the potential of digital water hydraulics replacing the servo valves. Tamlink and TUT have invested in digital hydraulics for almost 20 years and Bosch Rexroth has licensed this technology. In fact, the digital oil valves of such kind are being used in some of Finland's high speed trains. The team of engineers will draw its conclusions when testing is concluded considering even the commercialisation of water digital hydraulic valves.

Work in progress

Divertor RH	
Contract signed	22%
Design	60%
Cask & Plug RH	
Contract signed	6%
Design	37%
Neutral Beam RH	
Contract signed	8%
Design	40%
In Vessel Viewing System	
Contract signed	10%
Design	37%

IN-VESSEL

The extremely hot temperature of the fusion reaction will be mostly felt by the in-vessel components, otherwise known as plasma facing components, due to their direct exposure to high heat and neutron fluxes. The divertor consisting of 54 cassettes, located at the lower part of the machine, and the blanket consisting of the 440 modules, resembling to tiles covering the walls of the vacuum vessel, are the key components to be tested and manufactured in this area. Europe is responsible for the production of 54 divertor cassettes and 215 blanket modules.

Moving forward with the full-scale manufacturing of in-vessel prototypes

The first stage of the divertor Inner Vertical Target pre-qualification programme has been completed with the successful manufacturing and testing of small-scale mock-ups by ATMOSTAT-ALCEN (France), CNIM (France) and Research Instruments (Germany). Together with the already approved contractor Ansaldo Nucleare, all companies will now move forward to the second stage of the pre-qualification programme to manufacture and test full-scale Inner Vertical Target prototypes. F4E is responsible for providing the inner vertical target and the cassette bodies. The Japanese and Russian ITER Domestic Agencies are responsible for providing the outer vertical target and the dome respectively.

F4E has taken the initiative to help its contractors currently working on first wall panel prototypes to network with companies specialised in automation. AREVA N.P, ATMOSTAT (group ALCEN), and a consortium consisting of IBERDROLA, Wood (formerly AMEC Foster Wheeler) and LEADING Enterprises were introduced to six European companies, identified through an F4E market survey, in order to learn more about their skills and expertise. The F4E contractors have completed the testing of materials and bonding techniques, and produced semi-scale prototypes which have successfully undergone high heat flux tests. Since then, they have moved on to produce full-scale prototypes.

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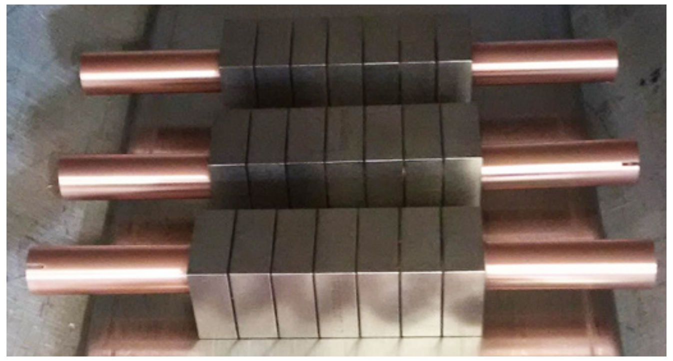

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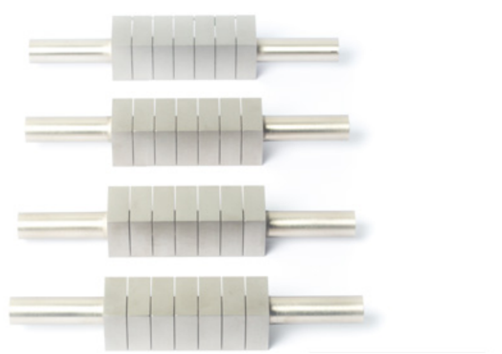

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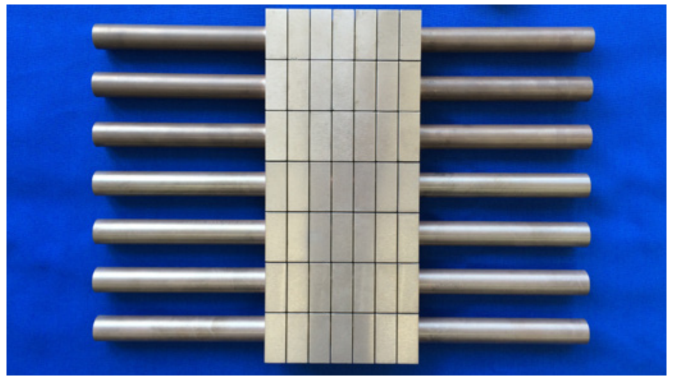


01 – The divertor inner vertical target prototypes from CNIM

02 – The divertor inner vertical target prototypes from ATMOSTAT-ALCEN

03 – The divertor inner vertical target prototypes from Research Instruments

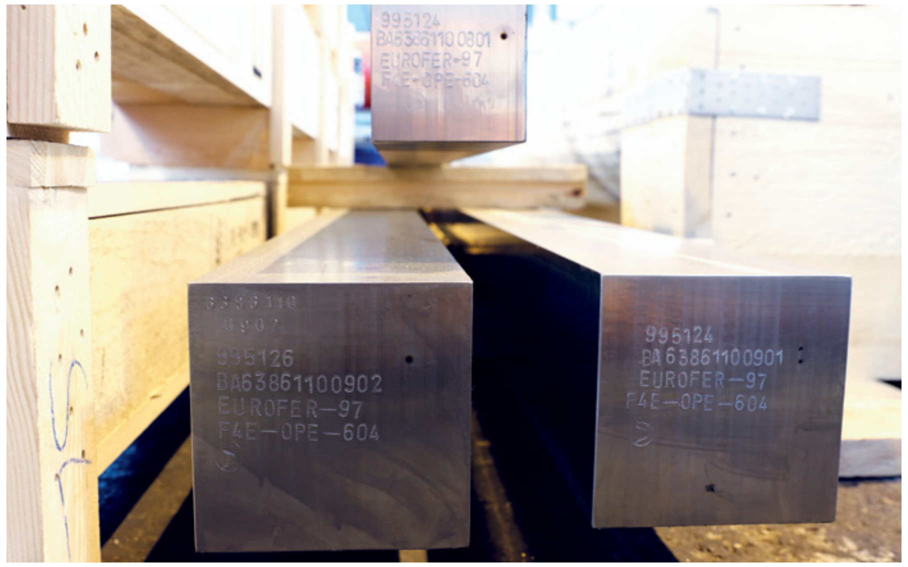
TEST BLANKET MODULES

Experts working in the area of Test Blanket Modules Systems (TBMS) are among those who will use ITER to understand how tritium can be continuously bred in order to keep the fusion reaction going. Without a doubt, the lessons drawn will have significant implications towards the design of future fusion reactors like DEMO. In essence, they will be generating a new nuclear system and licensing using advanced materials and top fabrication techniques.

Completing the production of EUROFER97 and starting testing

The production of EUROFER97, a low-activation steel to be used in Europe's first wall of ITER's Test Blanket Modules (TBMs), has been completed. Saarschmiede GmbH Freiformschmiede, has produced approximately 27 t in the form of special plates and bars of various thicknesses ranging from 1.2 to 45 mm. In parallel, F4E has signed a contract with Studsvik, a company based in Sweden, to perform tests on EUROFER97. With the help of NRG, Netherlands, a subcontractor of Studsvik, the teams will study the performance of the steel after being irradiated to similar conditions as in ITER. The home of these tests is the High Flux Reactor, Petten, Netherlands, one of the most powerful multi-purpose materials testing reactors in the world.

01



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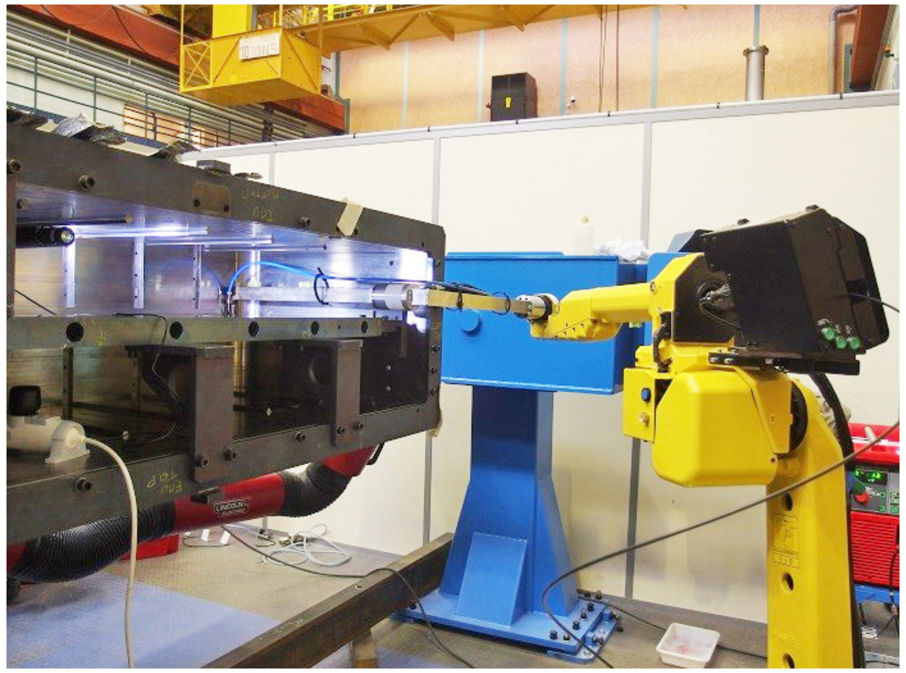
01 – Samples of EUROFER97 material produced by Saarschmiede GmbH Freiformschmiede on behalf of F4E

02 – Representatives of Saarschmiede GmbH Freiformschmiede (L-R) A. Neumann, V. Wagner and N. Lang next to EUROFER97 boxes



TIG welding robot performing preliminary welding procedures on a full size mock-up of the Test Blanket Modules box

Validating the best welding techniques

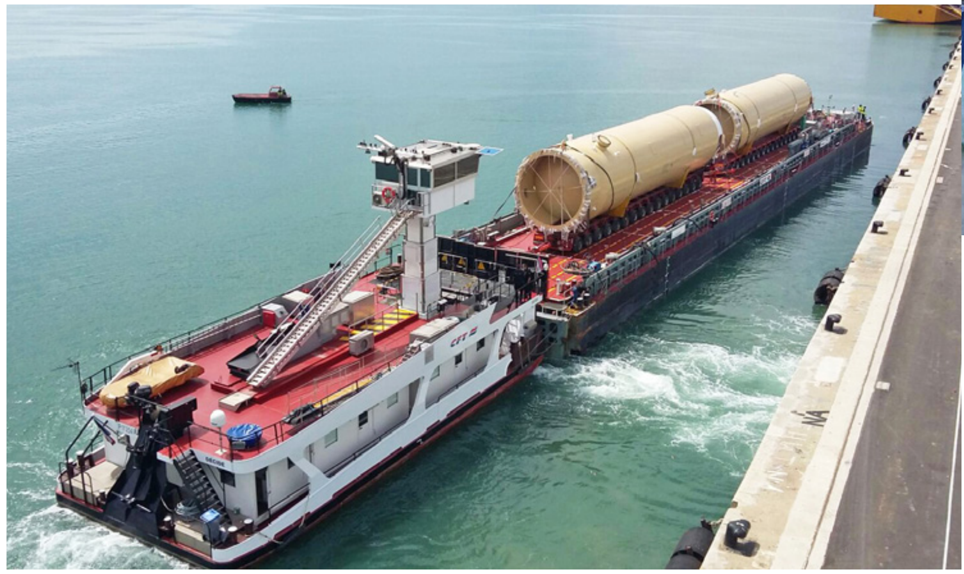
Europe has developed two types of TBMs that will be located at the 16th equatorial port of ITER. The last two years, technicians had to manufacture mock-ups of these boxes in various sizes in order to identify the best welding techniques to be applied at the time of production. F4E together with a large group of partners consisting of Atmostat, CEA Saclay/Grenoble, Alsyom, Commercy, Airbus, Bodycote and CETIM have successfully developed a preliminary welding procedure on a full size mock-up of the TBM box measuring 1.7 x 0.5 x 0.7 m. A Tungsten Inert Gas (TIG) welding robot has been used to carry out the operations in the tight and limited space of the box. In order to cope with any distortions resulting from the operation, and keep the surface of the box intact without damaging any of its internal channels, special clamping tools were designed and used during tests.

CRYOPLANT AND FUEL CYCLE

The ITER machine will have to cope with extreme temperature fluctuations. Cold helium will circulate inside the magnets to bring their temperature down to -269 ˚C in order to confine the hot plasma. The magnets, thermal shields and cryopumps will have to be cooled down and maintained with the help of one of the most advanced cryogenic systems to date. The cryoplant can be described as a massive refrigerator that will generate the freezing cold temperatures required for the fusion machine. Europe is responsible for the Liquid Nitrogen (LN2) Plant and its auxiliary systems. F4E has awarded to Air Liquide the contract for Europe's contribution to ITER's cryogenic system.

Work in progress

LN2 Plant	
Contracts signed	93%
Design	100%
Manufacturing	98%
Vacuum Pumping	
Contracts signed	6%
Design	7%
Manufacturing	13%
Tritium Plant	
Contracts signed	32%
Design	35%
Manufacturing	5%



Two of the six gaseous helium (GHe) tanks arriving at the industrial port of Marseille, May 2017 © DAHER

Europe delivers all of its cryogenic tanks to ITER

The 11 tanks that Europe is responsible to provide, as part of its contribution to ITER's Cryoplant, have arrived to the ITER site. The delivery of the gigantic pieces of equipment has been considered an important milestone for F4E's team working in the fields of cryogenics and transport logistics. Europe's first tank was delivered to ITER in November 2016 and almost a year later all other tanks followed departing from different countries (Sweden, Czech Republic, China, and Turkey). The manufacturing of all components was undertaken by Air Liquide, and its subcontractors, while the logistics were handled by DAHER.

An army of gaseous helium (GHe) tanks heading towards the ITER construction site, June 2017 ©ITER IO

The LHe tank, considered as the "jewel" of the ITER Cryoplant, has finally reached the construction site, Cadarache, October 2017 © DAHER

LN2 PLANT

Europe is responsible for the Liquid Nitrogen (LN2) Plant and the auxiliary systems that will cool down, process, store, transfer and recover the cryogenic fluids of the machine. Two nitrogen refrigerators have been manufactured along with two 80 K helium loop boxes, warm and cold helium storage tanks, dryers, heaters and the helium purification system. One liquid nitrogen (LN2) tank manufactured by Aritas (Turkey) has been delivered, which weighs 115 t and when it stores the gas it will be able to sustain a load of 340 t. The GN2 buffer tank has also been delivered. This vessel has been manufactured in China by FURUI.

ITER HELIUM PLANT

ITER's Helium (He) plant will handle an inventory of approximately 24 t of He, which corresponds to the gas needed to fill up 14 million helium balloons. The plant consists of six warm Gaseous Helium (GHe) tanks, measuring 24.0 x 5.0 m, with a capacity of 400 m3 each, manufactured by Zhangjiagang Furui Special Equipment Co., LTD (China); one Liquid Helium (LHe) storage tank measuring 25.5 x 3.8 m, with a capacity of 188 m³ at 4.5K (-268.5 °C), manufactured by CryoAB (Sweden) able to store up to 70% of the helium that the plant will need; two quench tanks produced by Air Liquide and their subcontractor Chart Ferox, which measure 35 m x 4.5 m and weigh 160 t each.
Europe is providing all GHe tanks, the LHe tank and the two quench tanks.

The GN2 buffer tank, part of ITER's Cryogenic system, has been delivered on-site, Cadarache, October 2017

First ITER cryopump has been manufactured

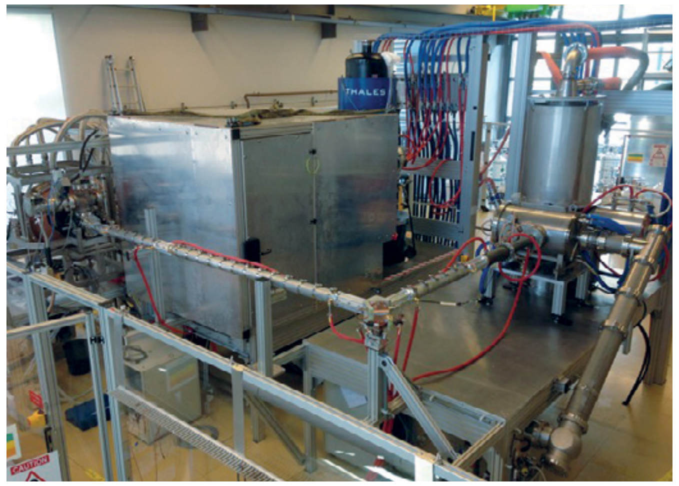
When ITER is operational the gases resulting from the fusion reaction will be pumped with the help of the six cryopumps from the lower part of the torus to the roughing system, where they will be processed and treated in a closed loop as part of the fuel cycle. Europe is the only Party responsible for the production of the cryopumps. Research Instruments, Alsyom, SDMS and their subcontractors have manufactured this piece of equipment, which measures 3.4 x 1.8 m and weighs nearly 8 t. After its performance testing is completed, eight more cryopumps will be manufactured under the supervision of F4E. Six of them will be installed in the torus of the ITER device and two in the cryostat.

Delivery of cryopump to ITER site, Cadarache © F4E

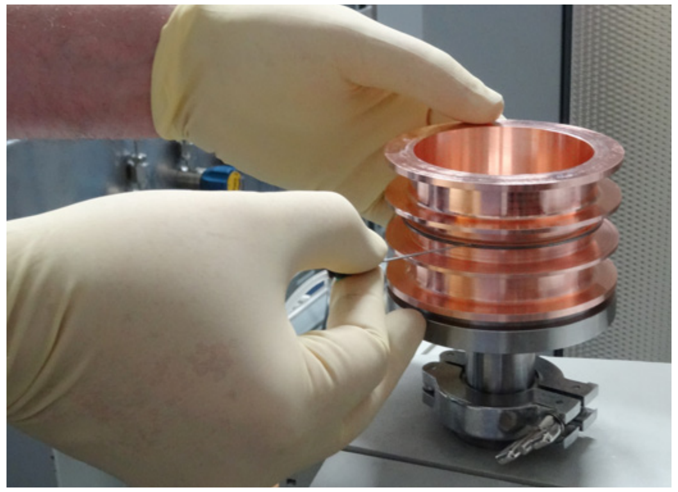
Representatives of the Vacuum Teams of F4E and ITER IO © ITER IO

ANTENNAS AND PLASMA ENGINEERING

Large antennas will channel the electromagnetic waves generated by two heating systems—the Electron Cyclotron and the Ion Cyclotron—to heat ITER's plasma. Electron Cyclotron Launchers will help scientists to target specific parts of the plasma by guiding the waves with the help of mirrors. In parallel, in order to optimise ITER's design and to achieve high plasma performance, a great degree of engineering is carried out in collaboration with companies and European fusion laboratories.



FALCON Facility in Lausanne



A mock-up of the diamond disk being tested.

Welding, prototyping and testing

For the Ion Cyclotron (IC) Antennae, a special welding procedure was developed in 2017 to join the required grades of titanium and stainless steel together by an interlayer of pure zirconium with a tensile strength in excess of 300 MPa. In addition, F4E signed a contract with a group of European fusion laboratories to simplify the IC antenna manufacturing and assembly.

For the Electron Cyclotron (EC) system, some of the main achievements include the prototyping and final design review of the diamond window design. Other prototyping activities include the fabrication of a full-scale prototype Blanket Shield Module and 50 mm waveguide mock-ups. The final design of the port plug cooling also started in 2017. In parallel, engineering support activities progressed for requirements management and verification, nuclear engineering and analysis.

The setting-up of the "Falcon" facility at the Swiss Plasma Centre for testing the EC launcher components was completed and the operation of the 1 MW gyrotron has started. The operation of the facility has allowed the design of the plant control system to be improved.

Commissioning and factory acceptance tests for the first power EC power supplies have been successfully completed, exceeding specifications. The cryogenic free magnet has been delivered to the Swiss Plasma Centre and site acceptance tests have been successfully concluded. It is first time such a magnet using 'cryogen-free' technology is built in Europe.

Work in progress

EC Launcher	
Design	60%
Manufacturing	5%
IC Antenna	
Design	48%
Manufacturing	0%
EC Control System	
Design	44%
Manufacturing	0%

NEUTRAL BEAM AND ELECTRON CYCLOTRON POWER SUPPLIES AND SOURCES

To heat up ITER's plasma at 150 million ˚ C, roughly ten times the temperature at the core of the sun, we will need powerful heating systems using high-energy beams. This requires the fabrication and testing of new equipment before manufacturing the components for ITER. For this reason an ITER test facility has been set up to develop and test a Neutral Beam Injector (NBI) prototype.

It consists of two test beds: i) SPIDER (Source for Production of Ion of Deuterium Extracted from Radio Frequency plasma), which will help engineers to finalise the development of the ion sources required for the ITER Neutral Beam Injectors (NBI), and to test the essential aspects of the diagnostic neutral beam accelerator; ii) MITICA (Megavolt ITER Injector and Concept Advancement), which will develop and test a full-size prototype of a Neutral Beam Injector.

The Neutral Beam Test Facility, receives contributions from F4E, ITER International Organization, India's and Japan's ITER Domestic Agencies, and Italy's Consorzio RFX, the host of the infrastructure.

SPIDER

Europe delivers to the most powerful negative ion source to date

The recent delivery of Europe's beam source to the SPIDER experiment has been a major achievement for F4E, the ITER Organization, ITER India, Consorzio RFX and the companies involved. This is the first full-scale ITER ion source, capable of running pulses of up to 3 600 seconds at maximum power with hydrogen or deuterium. The 6 MW generated by this beam source in one hour are equivalent to the energy required by roughly 1 000 medium apartments in one day. A European consortium consisting of Thales, CECOM Srl, Galvano-T GmbH, and E.Zanon SpA has been responsible for the manufacturing of the equipment. The SPIDER beam source, weighing about 5 t and measuring 3 x 3 x 2 m, will be installed inside its vacuum vessel with the help of a sophisticated handling tool.

Representatives of F4E, Thales and RFX posing in front of the SPIDER beam source © Thales

"Thales is very proud to have delivered the SPIDER beam source to F4E. Thales is very thankful to its partners Galvano-T, Cecom and Zanon and to F4E, RFX and ITER Organization for the great collaborative spirit making SPIDER a success."

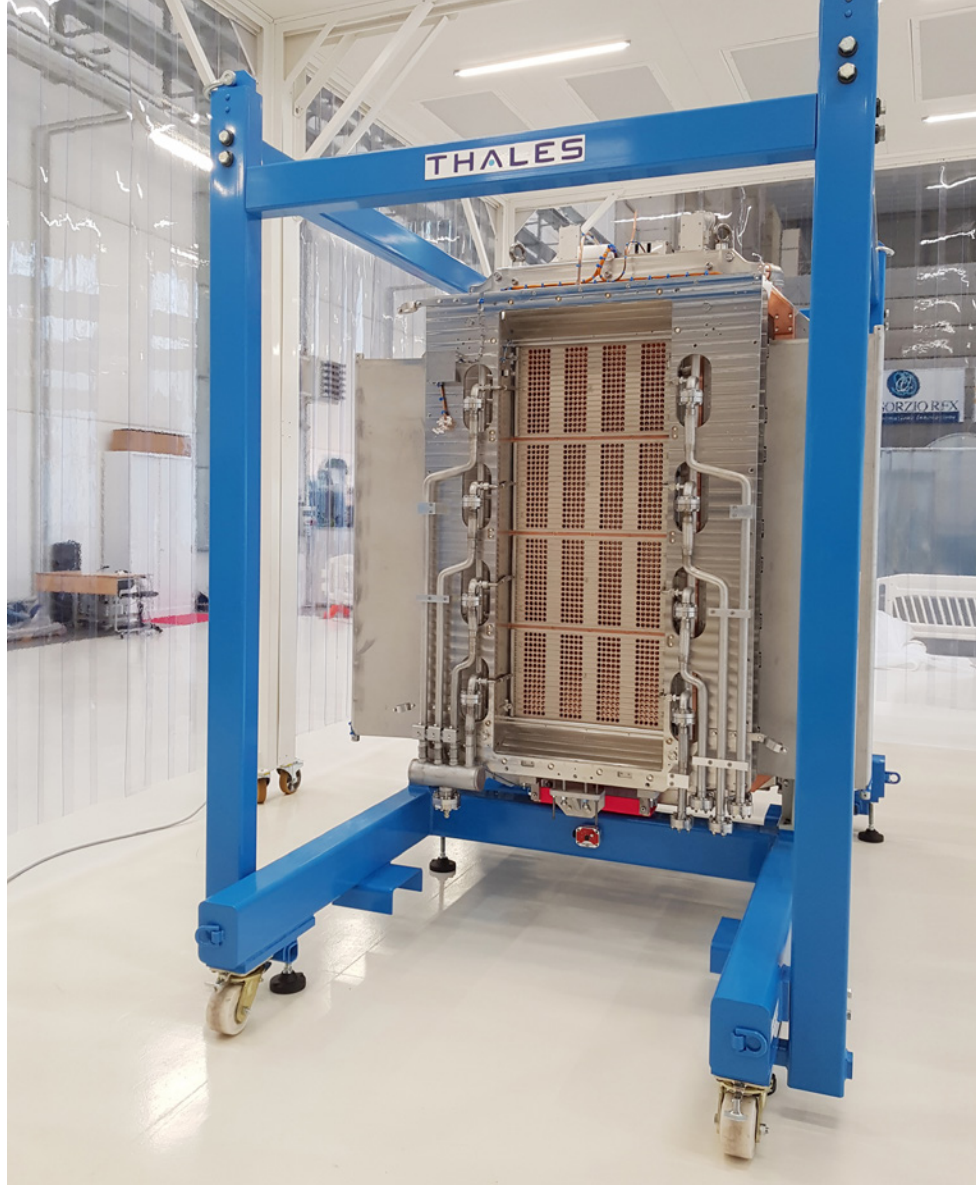
Charles-Antoine Goffin
DefSI and Transformation Director of Thales

"It's an R&D equipment counting 2 000 parts in total, which all had to fit together during the final assembly. During the various phases of the project, a lot of planning was required involving more than 30 companies from all over Europe counting on the contribution of at least 50 professionals."

Antonio Masiello
Technical Responsible Officer

Work in progress

Electron Cyclotron Power Supplies	
Contracts signed	100%
Design	100%
Manufacturing	25%
Delivery	0%
SPIDER	
Contracts signed	99%
Design	97%
Manufacturing	94%
Delivery	91%
MITICA	
Contracts signed	56%
Design	52%
Manufacturing	43%
Delivery	27%



01

02

01 – The SPIDER beam source delivered to the ITER Neutral Beam Test Facility, RFX Consorzio, Padua, Italy © Thales

02 – A section of the SPIDER beam source vacuum vessel arriving at the ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy

> *"The delivery of the European components is the outcome of the strong collaboration between F4E, its industrial suppliers and the other ITER Parties contributing to this project."*

Muriel Simon
Technical Responsible Officer

Installing the High Voltage Deck inside the MITICA High Voltage hall, October 2017 © Consorzio RFX

MITICA

Bringing mythical power to MITICA

The European equipment that will help us reach "mythical" levels of beam energy and electrical power has been delivered to the MITICA test facility. F4E and Siemens have started working together three years ago in order to develop three units that will be part of the power supplies for the Neutral Beam Injection system. Each unit is made of: i) an electrically insulated box, so-called "High Voltage Deck", that hosts the power supplies for the ion source of the injector, ii) a gas-insulated bushing, called "High Voltage Bushing Assembly", bringing the electrical power through the transmission line all the way to the ion source. To reach the required high voltage insulation levels of 1 MV they are using SF6, a potent greenhouse gas, as electric insulator.

HIGH VOLTAGE DECK

The insulated box is distributed over two floors covering a surface of 150 m². Think of it as a Faraday cage that can maintain a level of voltage of 1 MV isolating the power supplies of the ion source from the ground. It contains transformers, power distribution systems, converters and control cubicles weighing approximately 50 t. The box rests on eight insulated "columns" which are more than 6 m high above the floor. The installation of the High Voltage Deck has now been completed. It has successfully passed the electrical acceptance tests in a factory, and has concluded the mechanical, structural and seismic tests at the MITICA facility.

BUSHING

The equipment provided by Siemens and its subcontractor HSP GmbH has been fully installed and all tests required have been properly completed. It is now ready to be connected to the transmission line supplied by Japan and then to proceed with the final tests of the entire system. The bushing assembly has a height of 12 m and weighs approximately 19 t. It will be connected to the transmission line which has been designed and built by Japan.

> *"The involvement of Siemens in this project offered us the opportunity to bring in our experience in global business together with our excellent technical expertise. Thanks to our collaboration with F4E, we have become familiar with the ITER project and fusion energy."*

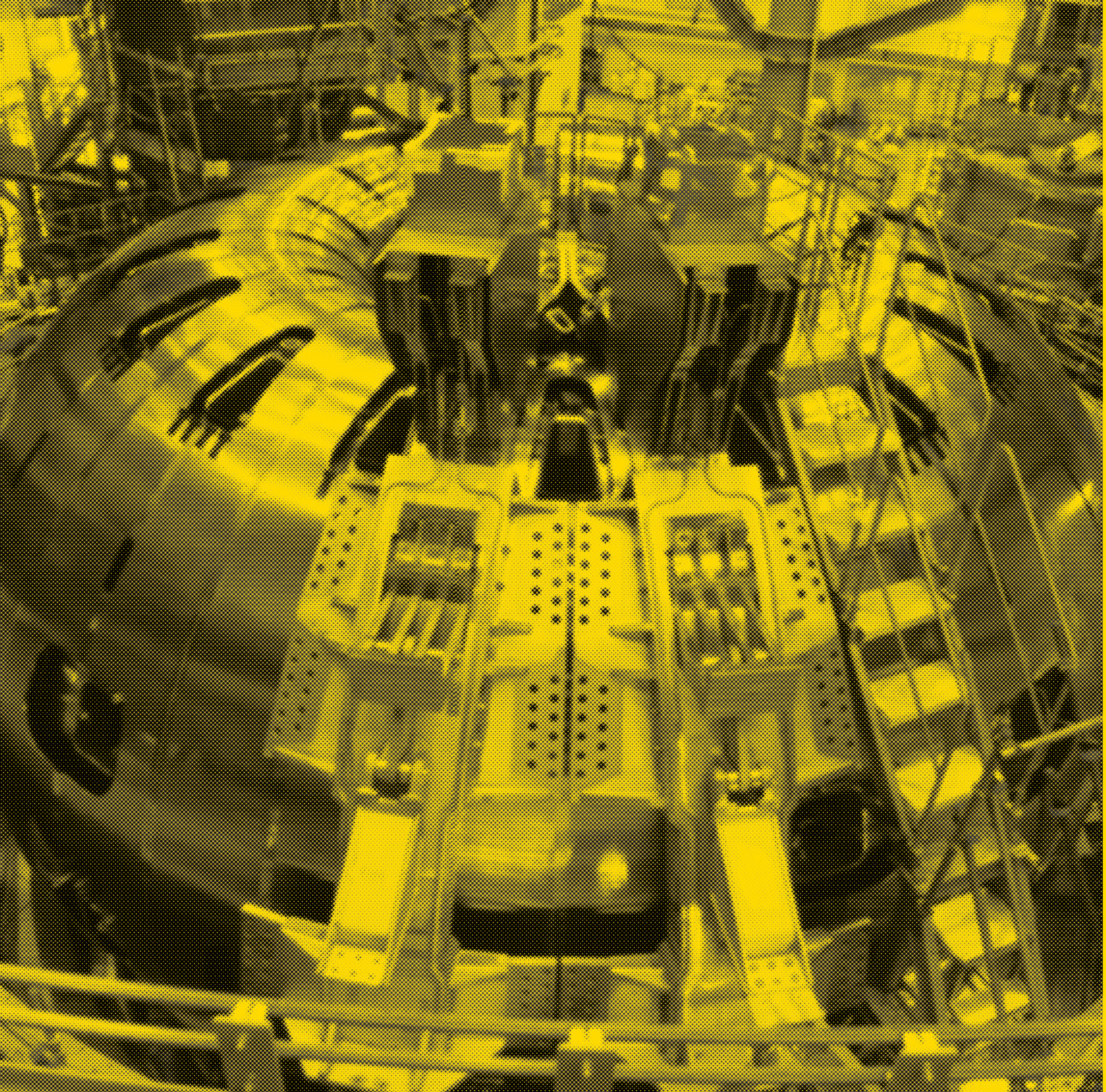
Michael Krohn
Siemens Project Manager

Installing the High Voltage Bushing inside the pit of the MITICA facility with the help of a remote control rolling platform and several cranes © F4E

High Voltage Bushing during electrical tests, HSP GmbH high voltage facility, Germany. © SIEMENS

> *"The operation of such extensive system at 1 MV is not only challenging but will also be unprecedented. The fusion community will be looking at us for answers in order to take the next step towards the fabrication of the ITER Neutral Beam components."*

Tullio Bonicelli
Project Team Manager
Neutral Beam & Electron Cyclotron, Power Supplies and Sources



03

The Broader Approach

Boosting fusion know how through Research & Development

Uniting broad vision and precision to address short and long term fusion research challenges, summarises the spirit of collaboration between Europe and Japan in this area. In February 2007, an Agreement was signed between the two Parties complementing the ITER project in order to accelerate the realisation of fusion energy through R&D and the development of key technologies.

The Broader Approach consists of three main projects:

- The Satellite Tokamak Programme (STP) JT-60SA "satellite" facility of ITER in order to model proposals for optimising plasma (in progress);
- The International Fusion Materials Irradiation Facility - Engineering Validation and Engineering Design Activities (IFMIF-EVEDA) to carry out testing and qualification of advanced materials in an environment similar to that of a future fusion power plant (in progress);
- The International Fusion Energy Research Centre (IFERC) through the DEMO Design Research and Development Coordination Centre (on-going), the Computational Simulation Centre and the Remote Experimentation Centre (concluded).

JT-60SA

JT-60SA Cryostat has been manufactured and delivered to Japan

JT-60SA is not only the fruit of the collaboration between Europe and Japan, it is also a precursor to ITER. The know-how that will be obtained about optimising plasma operation will be used to develop and benefit ITER. The cryostat of the "satellite" tokamak has been successfully manufactured and delivered to Japan. It took roughly four years to fabricate and test all of its 12 sectors, a task undertaken by Asturfeito S.A. As a voluntary contributor to the Broader Approach Agreement, Spain, through the national fusion research centre CIEMAT, has delivered this component in collaboration with F4E. The equipment reached Naka towards the end of 2017, one year ahead of the required assembly date.

The F4E/CIEMAT/Asturfeito S.A. team in front of the JT-60SA cryostat vessel body.

36 packages and the two lifting devices weighing a total of 322 t have been loaded on the ship © DAHER

JT-60SA CRYOSTAT

The component works as a large containment vessel which will enclose all core JT-60SA components. It consists of 4 individual upper sectors (4 m high) and 8 individual lower sectors (7 m high) which have each been separately positioned and precisely adjusted to form a cylindrical shape which measures about 14 m in diameter. The cryostat vessel body will provide a thermal insulation and vacuum around the magnet components within the machine in order to ensure that they stay at the cryogenic temperature necessary (at 4 K) for their superconducting functions.

The JT-60SA Cryostat vessel body from above

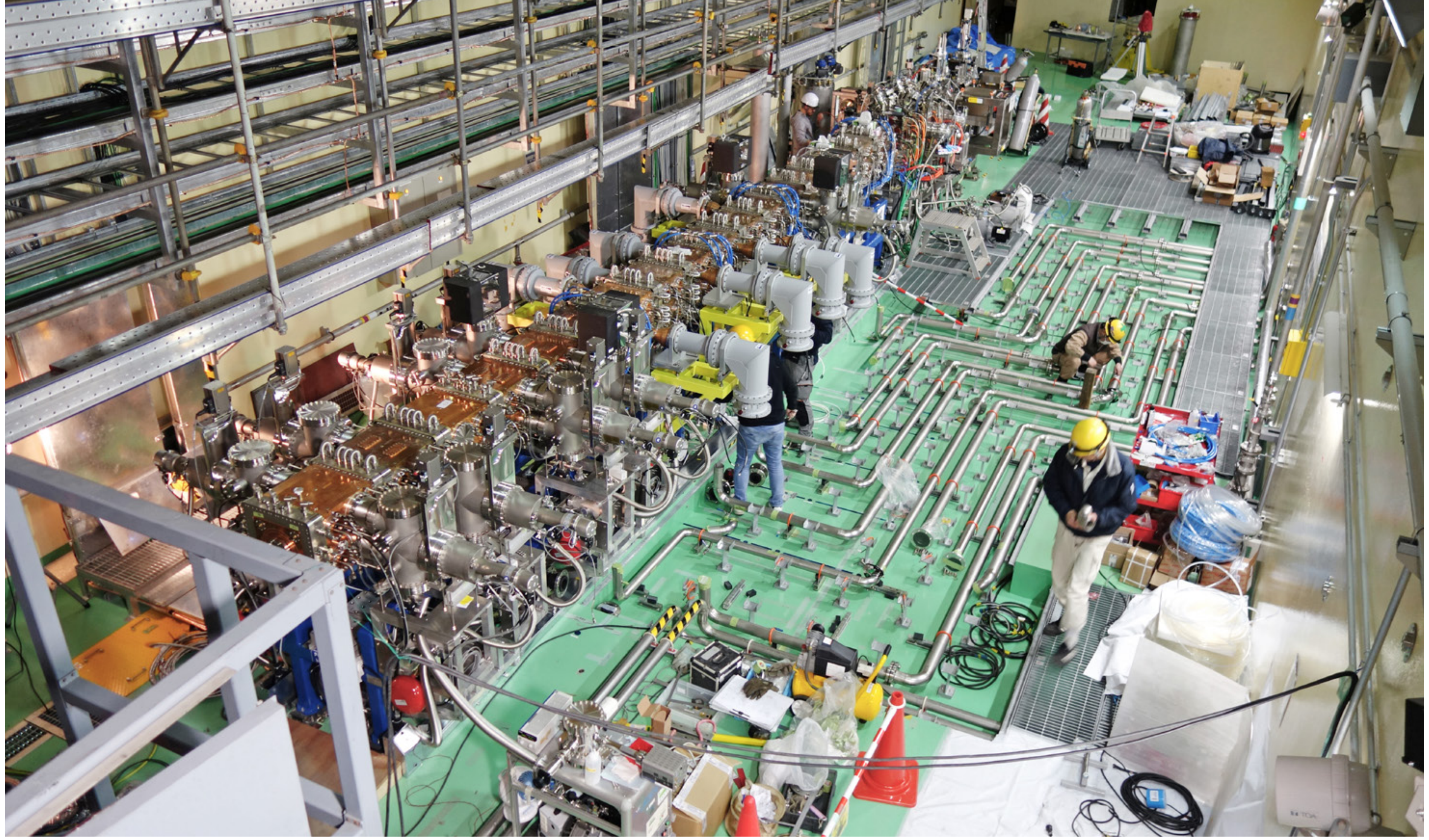
IFMIF

Progress at LIPAc accelerator helps us get closer to fusion energy

The Linear IFMIF Prototype Accelerator (LIPAc), located at the International Fusion Energy Research Center has been under assembly and commissioning at the Broader Approach site in Rokkasho. LIPAc is a prototype accelerator going through validation in order to be used in a future fusion neutron source, like IFMIF-DONES. The assembly of the equipment has been completed for its intermediate phase, where proton and deuteron beams of will be accelerated to 5 MeV in 2018, using a normal conducting accelerator element known as "RF Quadrupole".

This linear accelerator, small in size yet powerful, is expected to turn a new page for those working in the field of ion accelerators with major spin-offs for Accelerator Driven Systems (ADS) heading for waste treatment of fission power plant by transforming long lived radioisotopes or producing them for medical treatments.

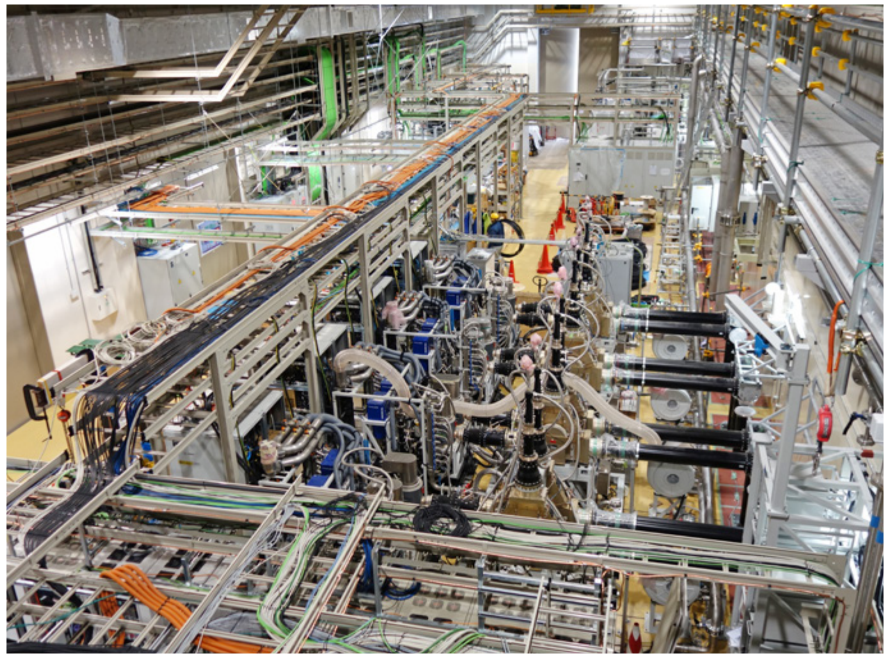
During the BA Steering Committee held in December in Mol (Belgium), the teams of IFMIF/EVEDA were congratulated for their work contributing to the concept of a fusion neutron source to be put into operation during the next decade; an essential step in the world fusion roadmap. The years ahead promise to be exciting with LIPAc providing breakthroughs in accelerators technologies by operating both proton and deuteron beams in unprecedented conditions.



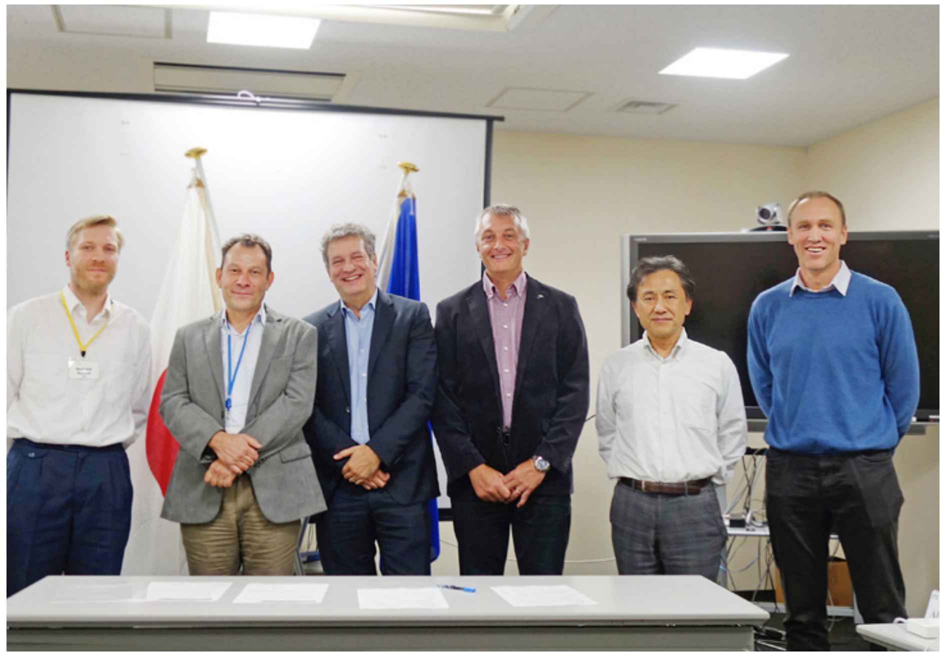
Top view into the LIPAc accelerator vault during the installation of the cooling loops for the "Radiofrequency Quadrupole", Rokkasho, Japan

"Leading IFMIF/EVEDA these last five years has been a unique experience. We have demonstrated how organisational and technical difficulties in an international context can be overcome fostering communication and mutual trust among stakeholders. The on-going success of LIPAc is having a positive impact on the credibility of the fusion programme since we are achieving unprecedented operational conditions in accelerators technologies."

Juan Knaster
IFMIF-EVEDA Project Leader



Top view of the Radiofrequency Area of the LIPAc facility, Rokkasho, Japan



(L-R): Bertrand Renard (CEA), Stéphane Chel (CEA), Juan Knaster (F4E) IFMIF/EVEDA Project Leader, Philippe Cara (F4E), Keishi Sakamoto (QST), Guy Phillips (F4E)

04

Working together with stakeholders

F4E has been actively engaging with European and national policy-makers giving them periodic updates on the progress of Europe's contribution to ITER, and explaining the direct and indirect benefits of the project. ITER is a motor of economic growth, innovation and competitiveness, ultimately making a contribution to a sustainable energy mix for the future.

With the help of various committees and the network of ITER Industrial Liaison Officers (ILOs), F4E has been reaching out to industry, SMEs and R&D organisations to get them involved in the biggest energy project and unleash their potential.

To strengthen the spirit of collaboration between the ITER Parties, F4E has taken the commitment to build stronger ties and improve the information flow. For this reason, an effort has been made to visit most of the ITER Domestic Agencies, and various production facilities, in order to have a complete overview of the project.

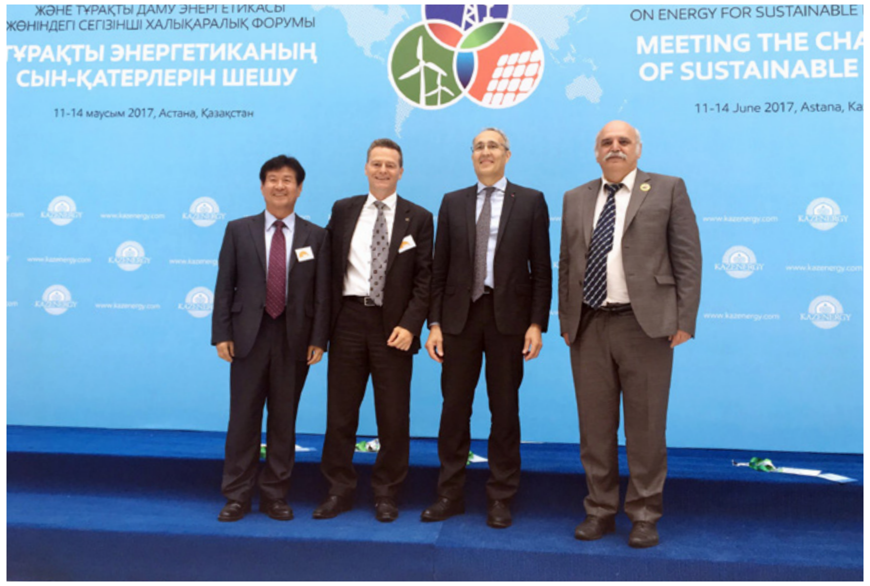
From left to right clockwise: European Commissioner for Climate Action and Energy, Miguel Arias Cañete; Spain's Secretary of State for Research, Development and Innovation, Carmen Vela; Johannes Schwemmer, Director of Fusion for Energy; The Mayor of Barcelona, Ada Colau.

Celebrating 10 years of F4E

F4E's ten year anniversary brought together the main stakeholders, policy-makers, representatives from industry, laboratories and companies contributing actively to the main achievements of the Europe's contribution to ITER. Since its establishment, F4E has invested in Europe's economy close to 4 billion EUR by signing more than 900 contracts with 500 companies, research organisations, and involving 1500 of their subcontractors, in the ITER project.

ITER shines bright as a future energy at the World EXPO 2017

"Future Energy" has been the theme of this year's World EXPO hosted in Astana, Kazakhstan. Stands from at least 100 countries and exhibits from ten international organisations have been designed to welcome over two million people. In keeping with France's role as Host to the ITER project, the ITER international Organization has showcased the project at the French Pavilion.



01

02

01 – (L-R) Head of the ITER Domestic Agency in Korea K. Jung, the F4E Director J. Schwemmer, the ITER Director-General B. Bigot, and the Head of the ITER Domestic Agency in Russia A. Krasilnikov at the Ministerial meeting.

02 – The F4E Director, the ITER Director-General and the Heads of the ITER Domestic Agencies in China, Korea and Russia at the fusion exhibition at the 2017 World EXPO.

King and Queen of Spain learn more about the JT-60SA and IFMIF/EVEDA projects

Their Majesties King Felipe VI and Queen Letizia of Spain have been introduced to various bilateral scientific and technological projects in progress between Spain and Japan. Amongst them, JT-60SA and IFMIF/EVEDA – part of the Broader Approach Agreement in which Spain through Laboratorio Nacional de Fusion - CIEMAT plays an important role.

The King and Queen of Spain together with Dr J. Sanchez, Prof. M. Mori, Secretary of State C. Vela, Foreign Affairs Minister A. Dastis, and Ambassador G. de Benito.

ITER Business Forum 2017: the road to first plasma is paved with commercial opportunities

F4E has highlighted Europe's contribution to ITER by presenting the progress of the project and by thanking its business partners for their dedication and collaboration. The largest business event for the fusion community has welcomed 1000 participants from more than 400 companies operating in at least 25 countries. This has been the most successful IITER Business Forum in terms of attendance, offering the fusion community an unprecedented opportunity to network, exchange information and establish new business partnerships.

▲ Johannes Schwemmer, Director of F4E, welcomes Bernard Bigot, Director-General of ITER Organization, and representatives from the regional and local authorities of the Provence-Alpes-Côte d'Azur region ©AIF. C21

◂ Participants exchanging ideas during the B2B meetings © AIF.C21

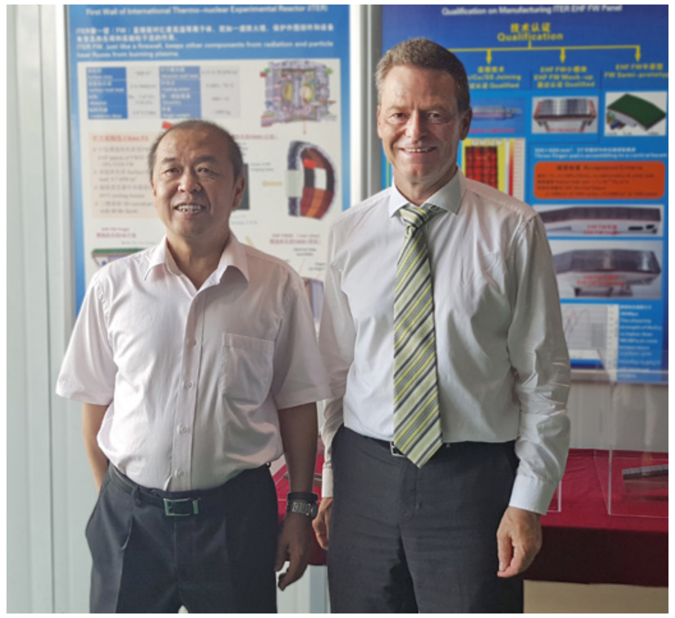
Fusion takes the stage at the EU Sustainable Energy Week

The EU Sustainable Energy Week is Europe's most important policy conference on energy. The 2017 edition featured more than 60 conference sessions exploring the latest thinking on sustainable energy policy, led by representatives of the European Commission, industry organisations, local authorities and NGOs. For the very first time, fusion energy was included in the programme of the conference. F4E representatives organised a policy seminar on "Fusion: Clean, Safe, Unlimited Energy for the Future" to explain the merits of this energy source and its potential.

Green MEP visits the ITER site

Indrek Tarand, Member of the European Parliament's Group of the Greens/ European Free Alliance, and Vice-Chair of the Budgetary Control Committee, visited the ITER project to witness its progress.

01



02

03

F4E Director strengthens ties with Russian and Chinese ITER partners

The success of ITER depends on the strong partnership between Europe and the six other parties involved in the project. A visit was planned at the Budker Institute of Nuclear Physics (BINP), in the company of the Head of Russia's ITER Domestic Agency, Anatoly Krasilnikov. BINP is developing some key ITER components including the "port plugs" which house diagnostic systems to measure ITER's performance. The Director of F4E has been invited by China's ITER Domestic Agency and two major fusion research organisations— the Institute of Plasma Physics of the Chinese Academy of Sciences (ASIPP) and the Southwestern Institute of Physics (SWIP). The shared ITER work and the status of the work performed by CNDA for F4E, were discussed. Last but not least, a visit at the EAST Tokamak was planned. In September 2017, a Chinese delegation visited F4E in Barcelona and Garching.

04

01 – F4E Director J. Schwemmer with Chinese ITER Domestic Agency Director General Prof. D. Luo

02 – The F4E Director visiting the ITER PF6 coil manufacture workshop

03 – The Chinese ITER Domestic Agency delegation during their visit to F4E and EUROfusion in Garching. From left to right Q. Xiaoyong, MOST; M. Wang, ITER China; D. McDonald, EUROfusion; L. Delong, ITER China; P. Barabaschi, F4E; T. Donné, EUROfusion; J. Schwemmer, F4E; G. Federici EUROfusion/F4E; B. Zhang, MOST; C. Chunyu, MOST; and Y. Zhu, ITER China

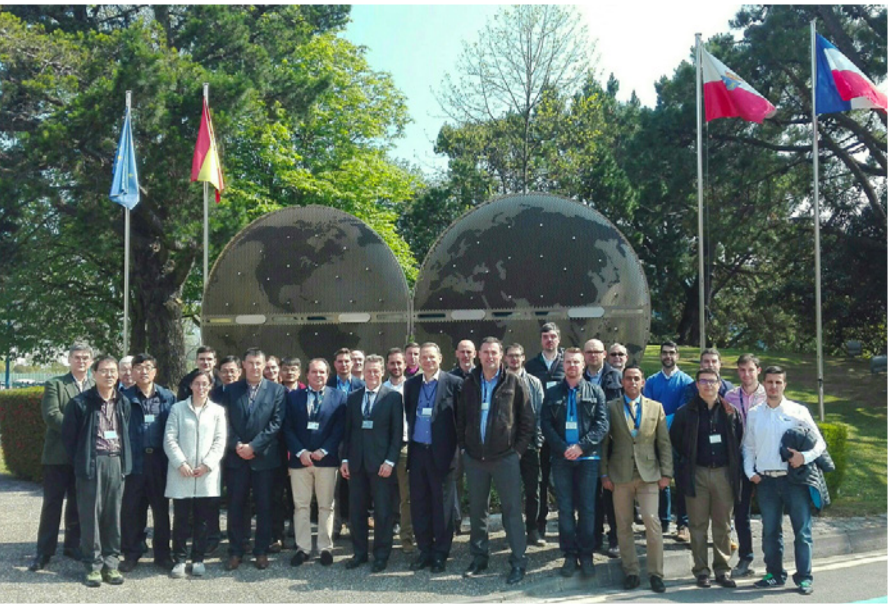
04 – Inspecting the full-size mock-up of the Diagnostic Module recently fabricated at BINP (L-R: Aleksandr Burdakov, (BINP Deputy Director); Anatoly Krasilnikov, (ITER Russia DA Head), and Johannes Schwemmer, Director of F4E

05

EVENTS

Spreading the word on Europe's contribution to ITER

F4E has participated in different events to promote various aspects of its work. Our members of staff have been targeting science and business communities, technology and innovation clusters and audiences interested in fusion research. In this section we look back at some of the key events that marked the year.



The participants shared technology and fabrication experiences in relation to the ITER Vacuum Vessel and are committed to ensuring its deliver

ITER Vacuum Vessel partners share know-how and discuss fabrication issues

Over 30 experts from F4E, ITER IO, the Indian, Korean and Russian ITER Domestic Agencies, and European, Russian and Korean industrial partners have come together in a Vacuum Vessel collaboration meeting held at the Spanish headquarters of Equipos Nucleares SA (ENSA) – a company working both for ITER IO and the AMW consortium (the European consortium consists of companies Ansaldo Nucleare S.p.A, Mangiarotti S.p.A and Walter Tosto S.p.A). Industry partners attending also included Hyundai Heavy Industries and MAN Diesel and Turbo, as subcontractors for the Korean and Russian ITER Domestic Agencies respectively.

Europe reaches out to Japan to strengthen collaboration in ITER Remote Handling systems

At the margins of the International Fusion Technology Symposium celebrated in Kyoto, F4E's Carlo Damiani, heading the team of Remote Handling, took the initiative to meet with counterparts from Japan's ITER Domestic Agency and some of its suppliers working in this field. A visit to Toshiba, entrusted with ITER's blanket wall remote handling system, was planned to receive an update on the progress of the works and exchange information on the procurement of the European components.

(L-R): Kiyokazu Sato, Senior Fellow at Toshiba Keihin Products Operation, Carlo Damiani, F4E Remote Handling Project Manager, Dr. Nobukazu Takeda, Group Leader, Remote Handling Technology Group, Naka Fusion Institute, National Institutes for Quantum and Radiological Science and Technology, Takahito Maruyama, Naka Fusion Institute, National Institutes for Quantum and Radiological Science and Technology

Europe celebrates its leadership in magnets technology

The completion of Europe's first completed Toroidal Field coil winding pack, the core of the ITER magnets which will confine the super-hot ITER plasma, represents eight years of hard work performed by F4E in collaboration with 26 industrial partners and at least 600 people all over Europe. On the premises of ASG Superconductors, La Spezia, Italy, a small ceremony has been organised bringing together 80 representatives from the various European companies contributing to this achievement, together with various stakeholders and journalists.

Representatives of F4E and ITER Organization together with Europe's industrial partners (ASG Superconductors, CNIM, Elytt, Iberdrola Ingenieria y Construcción, ICAS, SIMIC)

The Engage team on stage receiving the "Industry and Technologies Consulting" award © Assystem

ITER's Architect Engineer consortium receives "Industry and Technologies Consulting" award

The groundbreaking nature of ITER, referred to as the most ambitious energy project in history, and its potential to influence the way we produce and consume power, were some of the elements that convinced the jury of the 11th edition of France's National Engineering awards to hand over the prestigious "Industry and Technologies Consulting" award to Alain Baudry and his team from the Engage consortium, counting 230 people from 15 countries, working for Egis, Assystem, Atkins, and Empresarios Agrupados. F4E has to the Engage consortium the Architect Engineer contract.

Film on fusion energy wins praise

“Let there be light” has been called a wakeup call of internationalism and the need to collaborate in order to solve global issues like energy. The film directed by Van Royko and Milan Aung-Thwin, based on a screenplay by the latter, asks: how much will it take to bring the power of the sun to Earth? To portray the complexity of the project, they followed the lives of those involved in it, directed together and conducted interviews with many engineers, followed technical reviews, were given access to senior policy meetings and travelled to many locations to witness the manufacturing of different components. The film has already received its first award for Artistic Vision at the Big Sky Documentary Film Festival and has been screened at SXSW, the Copenhagen CHP:DOX, DocsBarcelona, Sarasota film festival.

(L-R) Van Royko (Cinematographer and Co-Director), Alessandro Bonito-Oliva (F4E Project Team Manager for Magnets), Milan Aung-Thwin (Director and Screenwriter), Mark Henderson (ITER International Organization Electron Cyclotron Section Leader) at the “Let there be light” screening in Barcelona.

(L-R) Moderator: Paweł Wojtkiewicz, Polish Space Industry Association; Lucio Rossi, CERN; Arnout Tromp, European South Observatory ESO, Meredith Shirey, European Spallation Source ESS, Leonardo Biagioni, F4E.

F4E helps Poland to unleash its potential in big science projects

Members of the big science community coming from F4E, CERN, the European Space Observatory (ESO) and the European Spalation Source (ESS) contributed to a two day-event, organised by the Wrocław Technology Park, to explain the state of play of the various scientific collaborations and the business opportunities in each of them. A fine mix of keynote speeches, workshops, presentations, and business to business (B2B) meetings gave the possibility to at least 400 participants to receive updates and get in touch with those running the projects.

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Fusion for Energy
The European Joint Undertaking for ITER
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