FUSION
FOR
ENERGY

HIGHLIGHTS 2019

THE MAIN ACHIEVEMENTS

2019
Table of contents


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FOREWORD

Imagine if we could create a small Sun on Earth to make a virtually inexhaustible and clean energy source - this sounds like science fiction but it is the ultimate mission of Fusion for Energy ("F4E").

We are the main contributor to ITER – an international project to build and operate the largest research machine to create solar fusion. We also have three fusion projects with Japan.

I am very proud to be the Director of F4E and will use this report to tell you about some exciting developments in 2019.

ITER has been 'the project that takes one year longer every year' but I am sure if you look through the following pages you will see that it is really going full speed ahead.

2019 has been the year where everyone could see and feel the very big components we build for ITER taking shape!

Working with ITER Organization and our international partners (China, India, Japan, Korea, Russia and US) we are 70% on the way to switch on ITER in 2025 in its first configuration.

A key achievement of European industry was the successful insertion and welding of the first of the ten European superconducting Toroidal Field coil magnets, please see the impressive pictures on page 23.

As this report shows, we also made important progress in many other areas of ITER works including the assembly of one of the largest cryoplants in the world. If you see the pictures (page 41), I hope you agree with me that we are delivering, no doubt.

We are also close to completing the assembly of a smaller fusion experiment in Japan called JT60-SA so that European scientists bridge the gap until ITER starts operating, see page 54.

I appreciate that this is a tremendous investment of public money and thank you to entrust it to us.

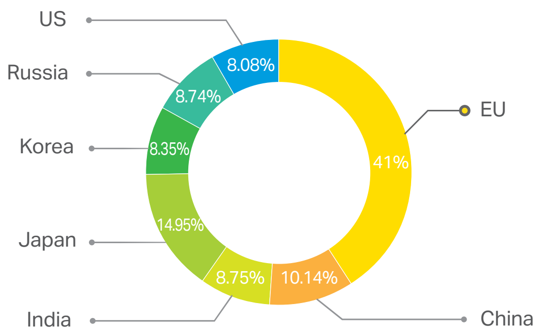
F4E partners with more than 500 European companies and 70 research organisations through 1 000 contracts for a value of €4.4bn. This investment has produced benefits of around €4.8 billion, 34 000 job years to Europe's economy as well as high-tech expertise and spin-offs.

I invite you to look through this publication and discover many more of our achievements during 2019 and if you are curious, I encourage you to visit our website and to follow us on social media.

Johannes P. Schwemmer
Director

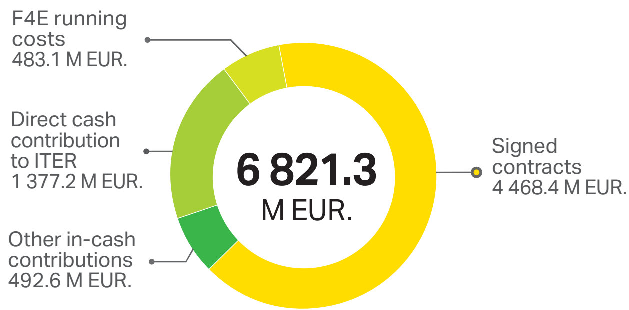
2019 KEY FIGURES

Contributions to ITER



Total contributions in percentages, between the different ITER parties 2008-2017

F4E budget breakdown



Budget breakdown of F4E main activities 2007-2019

Contracts with Industry and Laboratories

€229m

Value of contracts signed in 2019

€4.4bn

Total value of contracts signed from 2007-2019

833

Contracts signed since 2008

557

Companies

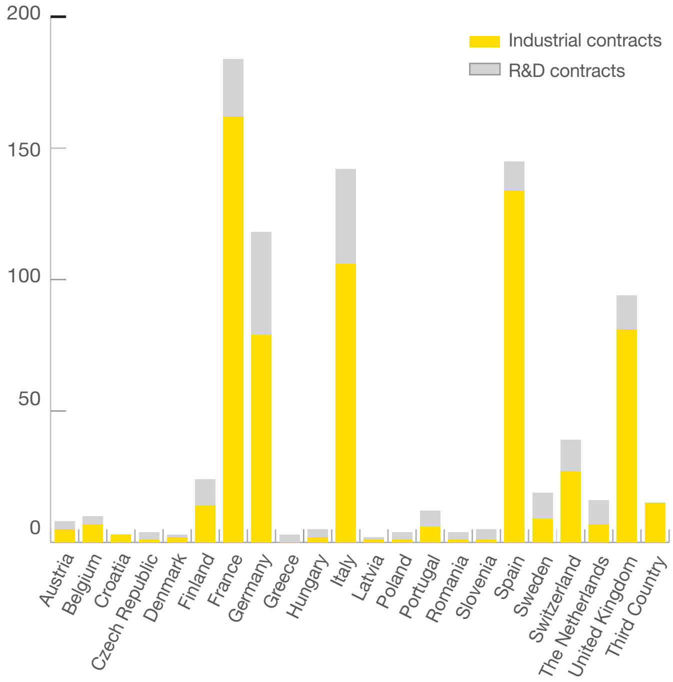
1670

Subcontractors

>70

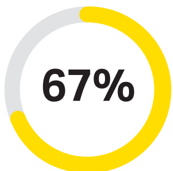
Research Organisations

Geographical distribution

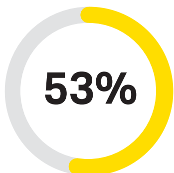


Contracts and grants awarded by F4E 2008-2019

ITER Project Progress



Progress towards ITER First Plasma in 2025



Progress towards ITER construction

Some of the F4E achievements during 2019

January

Europe's suppliers start working on the first series of ITER Divertor Cassettes. Progress made in designing a leak detection system for ITER. The 40-degree crown mockup on the construction site celebrated for serving a learning purpose.

February

Chairman of European Parliament Budget Committee visited ITER site. Winding concluded for Europe's second Poloidal Field coil. Tokamak building crown and bioshield completed.

March

ITER Pre-Compression Rings manufacturing started. Spin-off unveiled in the field of accelerators developed by Seven Solutions through involvement in IFMIF-EVEDA. Commercial partnerships explored during 1100 B2B meetings at ITER Business Forum-2019.

April

F4E handed over to ITER Organization Magnet Power Conversion buildings. Designs for Diagnostics feedthroughs approved. Blanket Cooling Manifold prototype structures approved.

May

JT-60SA central solenoid installed. Massive steel roof pillars of Tokamak building delivered on-site. Sixth Poloidal Field coil entered final production phase. F4E and European Fusion Laboratories test Test Blanket Modules technology and equipment.

June

MITICA beam source vessel installed. SPIDER delivered its first hydrogen beam. First Pre-Compression Ring completed by CNIM. Fusion and ITER project discussed at EU Sustainable Energy Week.

July

Qualification procedure for the Blanket Shield Module successfully concluded. MITICA High Voltage Deck and High Voltage Bushing Assembly tests performed successfully.

August

Vacuum vessel manufacturing progressed with all electron beam welding completed for sector 5 assemblies. F4E in collaboration with Air Liquide successfully completed the installation of the MITICA cryoplant.

September

Testing started for the combined operation of JT-60SA power supplies. F4E and ASIPP completed manufacturing process of the sixth Poloidal Field coil. ITER presented at European Research and Innovation Days.

October

Insertion of Toroidal Field coils in cases and welding operations accelerated. Europe delivered its first Electron Cyclotron Power Supply unit to ITER.

November

Final concrete poured at Tokamak building. Lower segment of ITER Vacuum Vessel sector 5 completed and ready to go through radiographic tests.

December

Notable progress in Poloidal Field coils manufacturing. Europe signed last major contract for the ITER Neutral Beam Test Facility. F4E Director presented ITER progress at European Parliament's Budgetary Control Committee.

SOME OF THE ITER ACHIEVEMENTS DURING 2019

ITER Organization

- On Coil Power Supply, the first unit of Filter Reactors and Thyristor Controlled Reactors (TCRs) was successfully installed.

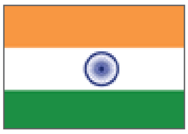
China

- Alternative Current / Direct Current production close to an end conducted were delivered to Europe in September.
- On the Correction Coils (CC):
  - Series production of the Bottom Correction Coil (BCC) is ongoing: two are finished and one have been tested.
  - Series production started for the Side Correction coil after successful qualification.
- The first two In-Cryostat Feeders were delivered in early August, and the following two are under assembly.
- 4 Cold Terminal Boxes have been integrated. The following two are underway.
- 4 Cryostat Feedthroughs have been integrated and tested.
- On the Shield Blanket, 91 series production forgoing have been complete and 63 are on-going.

Korea

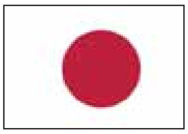
- On the Vacuum Vessel sectors 6, 7, 8 and 1, the manufacturing is ongoing in order to ensure First Plasma.
- Regarding the Vacuum Vessel ports, the first Lower Port Stub Extension (LPSE) were delivered.
- On the AC/DC Converters, Factory Acceptance Tests were completed on the first batch of converters in July 2019.
- On the thermal shield, silver coating was completed on sector 6 of the Vacuum Vessel and shipped.





India

- The Cryostat is over 60% complete. The Cryostat base section was handed over to IO in June 2019. Upper Cylinder Tier-1 & Tier-2 sectors have been delivered.
- The Cooling Water System manufacturing and shipment is reaching completion: 93% for the piping and 90% for the equipment.
- On the In-Wall Shielding, 66% of the blocks have been manufactured and shipped.
- 80% of cryolines and cryodistribution have been manufactured, and about 20% of it have been installed on-site.
- Ion-Cyclotron RF Power Sources (ICRF) were successfully tested in IN-DA Test Facility at 1.5 MW power level.

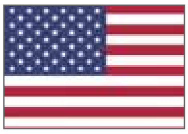


Japan

- For the Toroidal Field (TF) coil 1, the case closure welding as well as the gap filling impregnation was completed
- For TF 2, the case closure welding is completed and gap-filling impregnation has started.
- The casing of TF 4 was delivered to the EU
- Factory Acceptance Test were completed on the second Gyrotron.

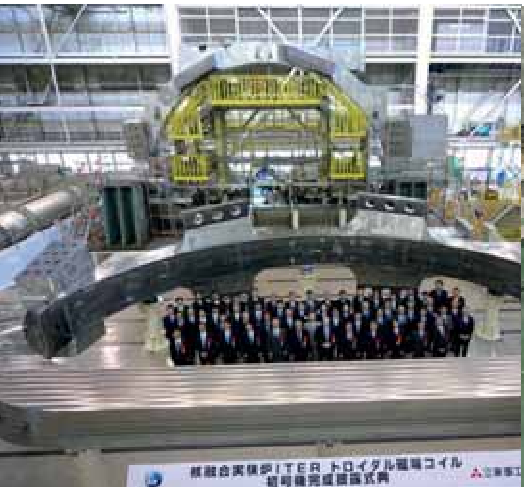
Russia

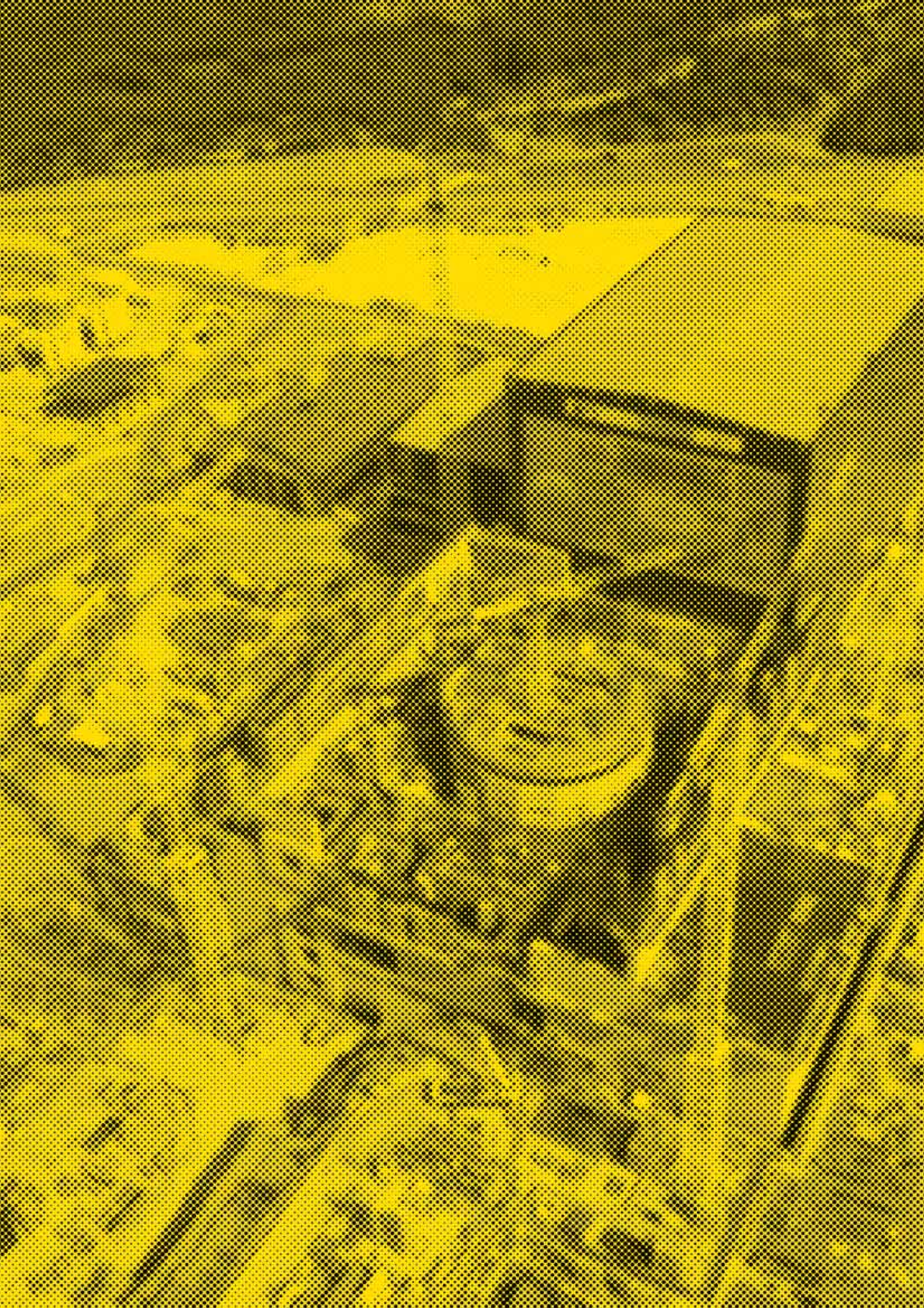
- On PF 1, the eighth and final double pancake has been successfully impregnated.
- On the Vacuum Vessel upper ports, the central upper port No. 16 was manufactured.
- On the Blanket First Wall panels, a plan for inspection of the First Wall full-scale prototype panel has been developed
- On the Dome Divertor, the manufacturing of a full-scale prototype is in progress.
- On the Plasma Facing Component Test, the operational capability of the new hypervapotron design has been verified.



United States

- Central Solenoid Module 1 testing is underway. Two rounds of Paschen and hipot testing were successfully completed.
- The fabrication of the Central Solenoid Lower Key Block is completed.





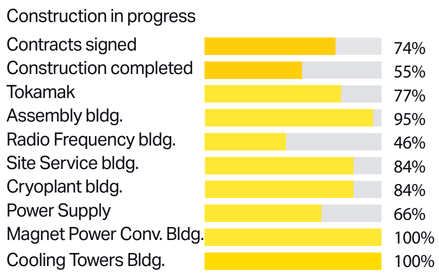
01

Building ITER

The ITER platform measures 42 hectares and is located in Cadarache, south of France. It is one of the largest man-made levelled surfaces in the world.
Europe is responsible for the construction of 39 buildings, as well as of the infrastructure and power supplies on-site required to operate the world's biggest fusion machine.
More than 2 000 people working for European companies are involved in ITER's civil engineering works. Architects, engineers, technicians, planners, inspectors are some of the professionals contributing to the project. They are building the facilities where the components arriving from all over the world will be delivered, assembled and installed.
Day by day the workforces on the ground are transforming the platform into the "home" of one of the most impressive technology projects.

THE ITER SITE

Europe has mobilised its workforces on the ground to transform the Tokamak building, the house of the ITER device, so that the first pieces of equipment get installed according to schedule. The pouring of the last concrete was an important milestone towards the completion of the civil engineering works which started in 2014. The first massive steel pillars, placed on the top floor of the building, offered a sense of how impressive its rooftop will be like. There were also important activities unfolding on the lower floors of the building. For instance, F4E handed over to ITER Organization the ground and first floors to move forward with the next wave of works; the bioshield was completed and further progress was made with the installation of the port cell doors. The Magnet Power Conversion buildings and that of Electrical Power Supplies were also delivered. Works in the galleries advanced rapidly forming a maze below the ground in order to install the piping and cabling of the project. Here are some of this year's main achievements on the ITER construction site.



Final pouring of concrete at the Tokamak building

The VFR consortium (VINCI, Ferrovial, Razel-Bec) poured the final concrete at the Tokamak building marking an important moment on-site. The first excavation works began in 2010 - a turning point in the history of the project. Four years later the first pouring of concrete took place. The tight schedule, the precision required, the complex design of the machine and need to comply with the high standards set by the French Nuclear Safety Authority, were some of the challenges we had to face.

Approximately ten types of concrete were developed for the construction of different parts of the edifice.

Almost like a fortress, the Tokamak Complex comprises the Tritium, Tokamak and Diagnostics buildings. It is 120 m long, 80 m high and 80 m wide. In order to build its foundation slab, 150 000 m^3 of concrete had to poured, and only for the Tokamak building 19 000 t of steel reinforcement bars had to be used.

" Europe is the party responsible for building ITER's infrastructure. Our close collaboration with VINCI, its partners, and more than 700 workers, has enabled us to finalise successfully this phase in compliance with the safety, security and quality requirements. "

Laurent Schmieder
F4E Programme Manager for Site, Buildings and Power Supplies

ITER Tokamak Complex during final pouring of concrete, Cadarache, France, November 2019 © ITER Organization/EJF Riche

"VINCI undertook to write a new chapter in one of the most ambitious and promising research experiments ever undertaken. We warmly thank them for having been a highly capable, reliable partner sharing our objectives, standards and determination. The success of ITER will be theirs."

Bernard Bigot
Director-General of ITER Organization

"VINCI Construction and its partners Razel-Bec and Ferrovial are extremely proud of carrying out the ITER civil engineering works. This is an extraordinary human undertaking, posing a huge technical challenge, and we were constantly called on to innovate and expand our expertise. With ITER, we are humbly helping to implement one of the greatest and most ambitious energy projects of our time, designed to make electricity available without CO_2 emissions."

Jérôme Stubler
Chairman of VINCI Construction

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)

A massive rooftop for the Tokamak building

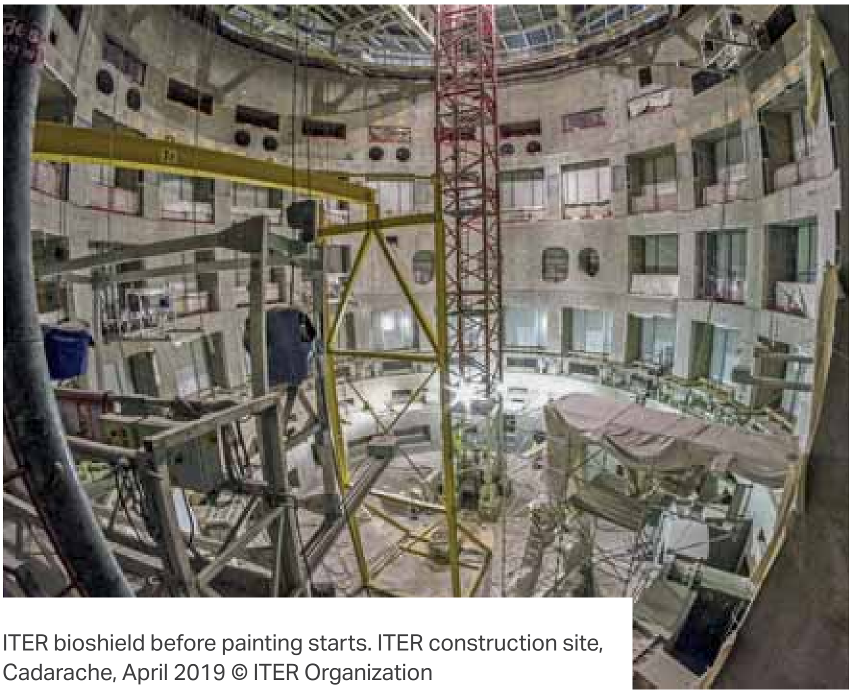
An impressive 2 000 t rooftop structure of the Tokamak building started to get erected. It will cover the crane coming from the Assembly Hall to the Tokamak Building, which will transport the exceptionally heavy components directly into the central pit. F4E installed all the steel structure columns and beams needed to support the roof.

Tokamak building rooftop fully installed, December 2019

Bioshield and port cell doors to protect ITER

The bioshield, a massive cylinder made of concrete around the ITER device will act as a safety barrier between the ITER device and the rest of building, keeping the radiation inside the machine. Another measure of shielding is offered by the port cell doors weighing more than 50 t each. F4E in collaboration with its contractors installed 28 out of a total of 40 heavy doors.

To ensure the best clean-up in the case of an incident, the floors, walls and ceiling of the Tokamak building must have a smooth surface. The first and second basement floors of the Tokamak Complex were painted. ITER Organization moved ahead with the installation of the first components in the Diagnostics and Tokamak buildings.



ITER bioshield before painting starts. ITER construction site, Cadarache, April 2019 © ITER Organization

Power to the magnets

In order to power the giant ITER superconducting magnets and thus confine the plasma, a strong electrical current is needed. This will be managed by electrical converters, switches, as well as fast discharge units delivered by China, Korea and Russia, all housed inside two 150 m long Magnet Power Conversion buildings. F4E provides these buildings which measure 4 900 m^2.

In March, the Magnet Power Conversion buildings were officially handed over by F4E to the ITER Organization signalling another major delivery from Europe to the ITER project. This was the culmination of nearly two years of design and three of construction counting on the support of 150 people at peak time. It will be now up to ITER Organization and China to supervise the installation of the equipment.

View of the equipment installed in the Power Supplies building. The works have been financed by F4E and carried out by Ferrovial, ITER construction site, Cadarache, France, October 2019 © F4E

Johannes Schwemmer, Director of F4E; Joaquín G. Vidal, Ferrovial; Bernard Bigot, Director of ITER Organization; cutting the ribbon at the handover ceremony held on the ITER construction site, Cadarache, France.

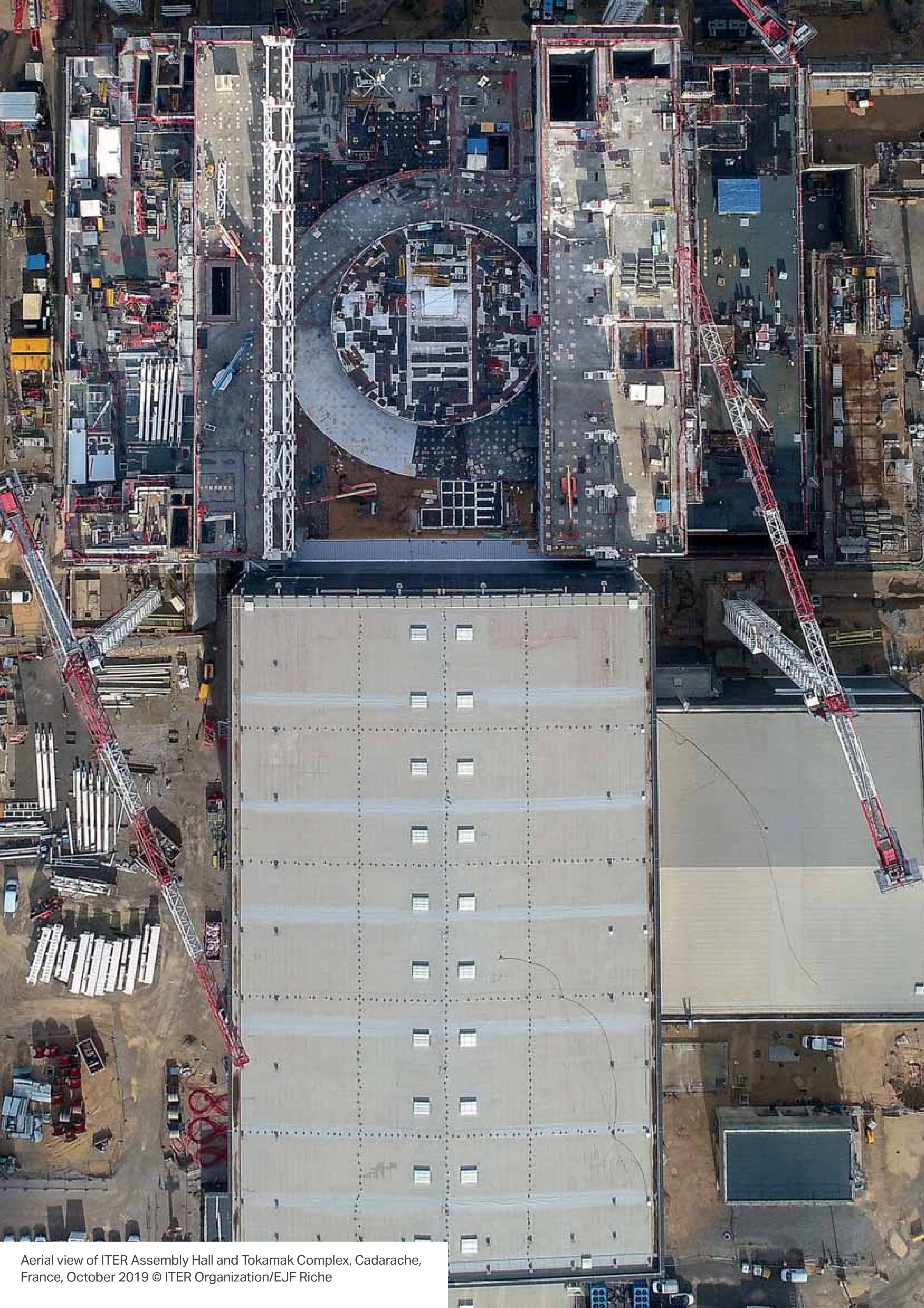
First phase of infrastructure works and galleries completed

Works on the site unfolded both above and below ground. In the maze below the ground, the piping and cabling of the project crossed the site. In December 2019, the site infrastructure works on deep buried networks, and galleries, connecting the ITER buildings came to completion.

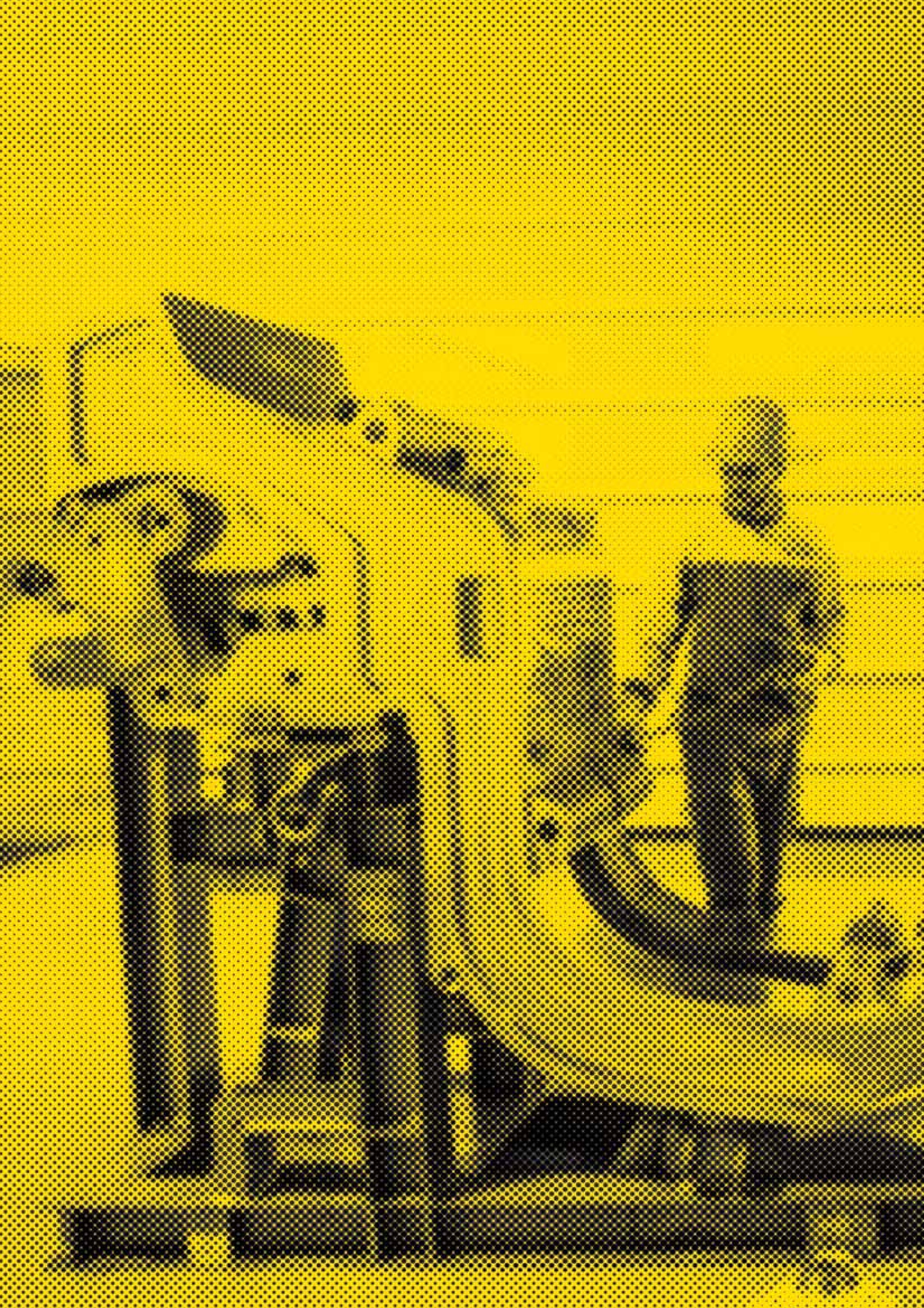
Getting ready for Assembly

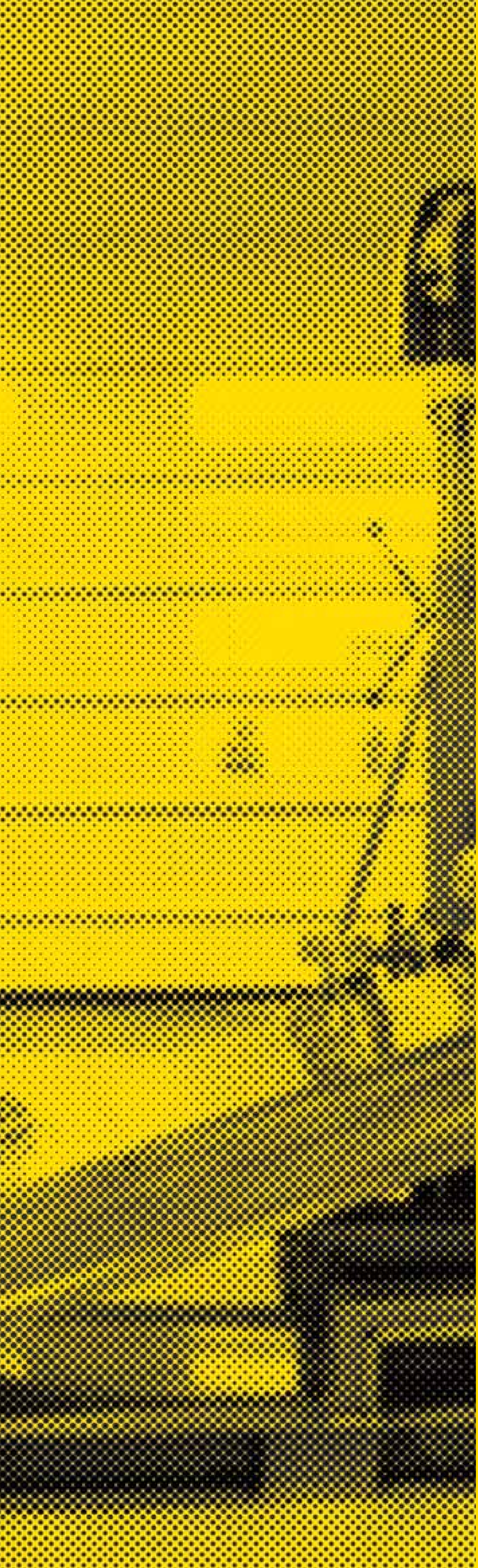
F4E gave the ITER Organization access to the 60 m-tall Assembly Hall to start assembly activities, with full building testing and commissioning progressing, and takeover planned for the following year. A major milestone was reached with the successful energisation of the first bay of the Pulsed Power Electrical Network. Electrical works continued with the progressive energisation of the ITER buildings and areas.

Inside the Assembly Hall, pipping and HVAC testing are performed whilst other contractors are coating its 6 500 m² floor with epoxy resin, Cadarache, France, October 2019 © ITER Organization



Aerial view of ITER Assembly Hall and Tokamak Complex, Cadarache, France, October 2019 © ITER Organization/EJF Riche



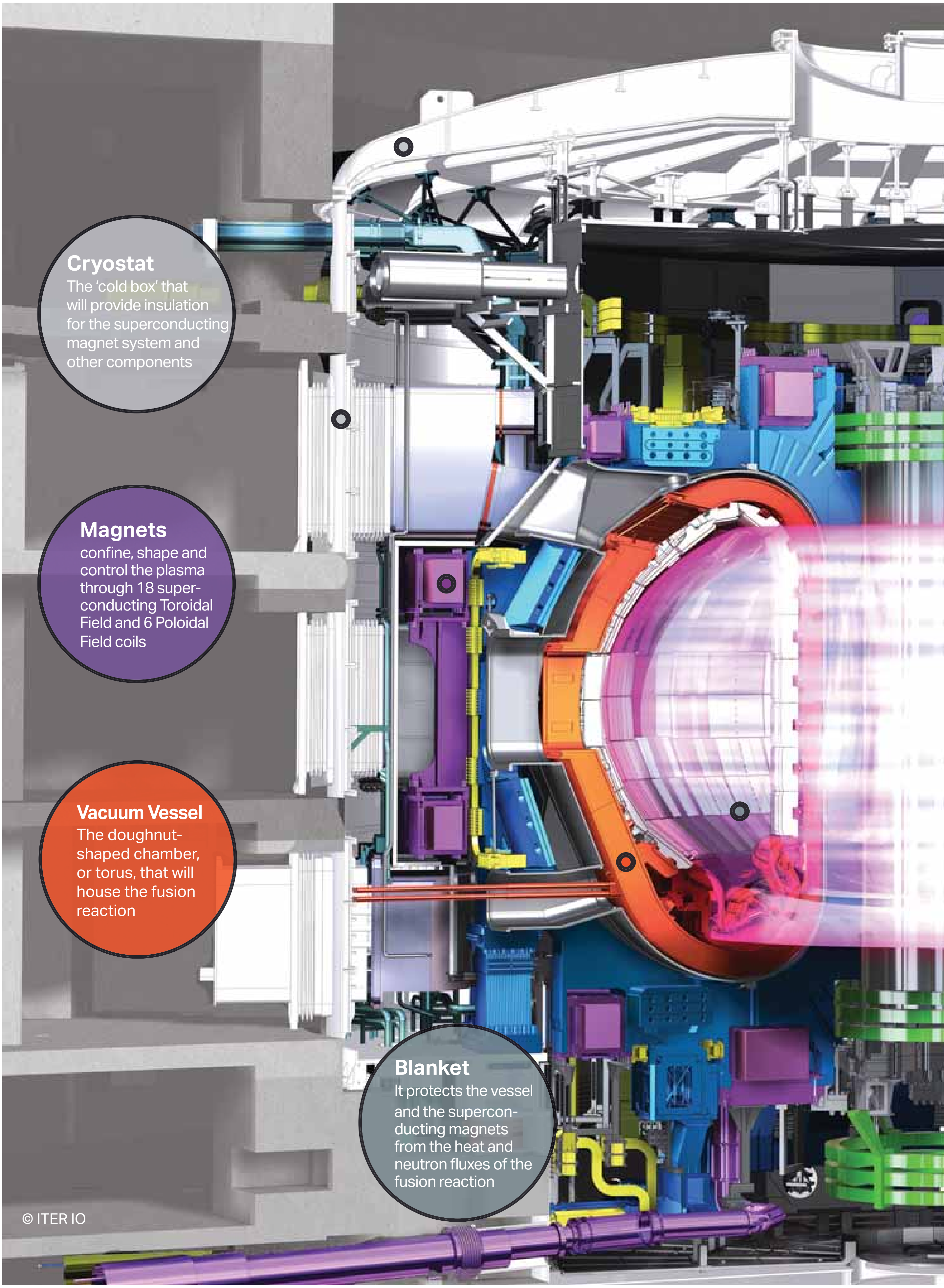


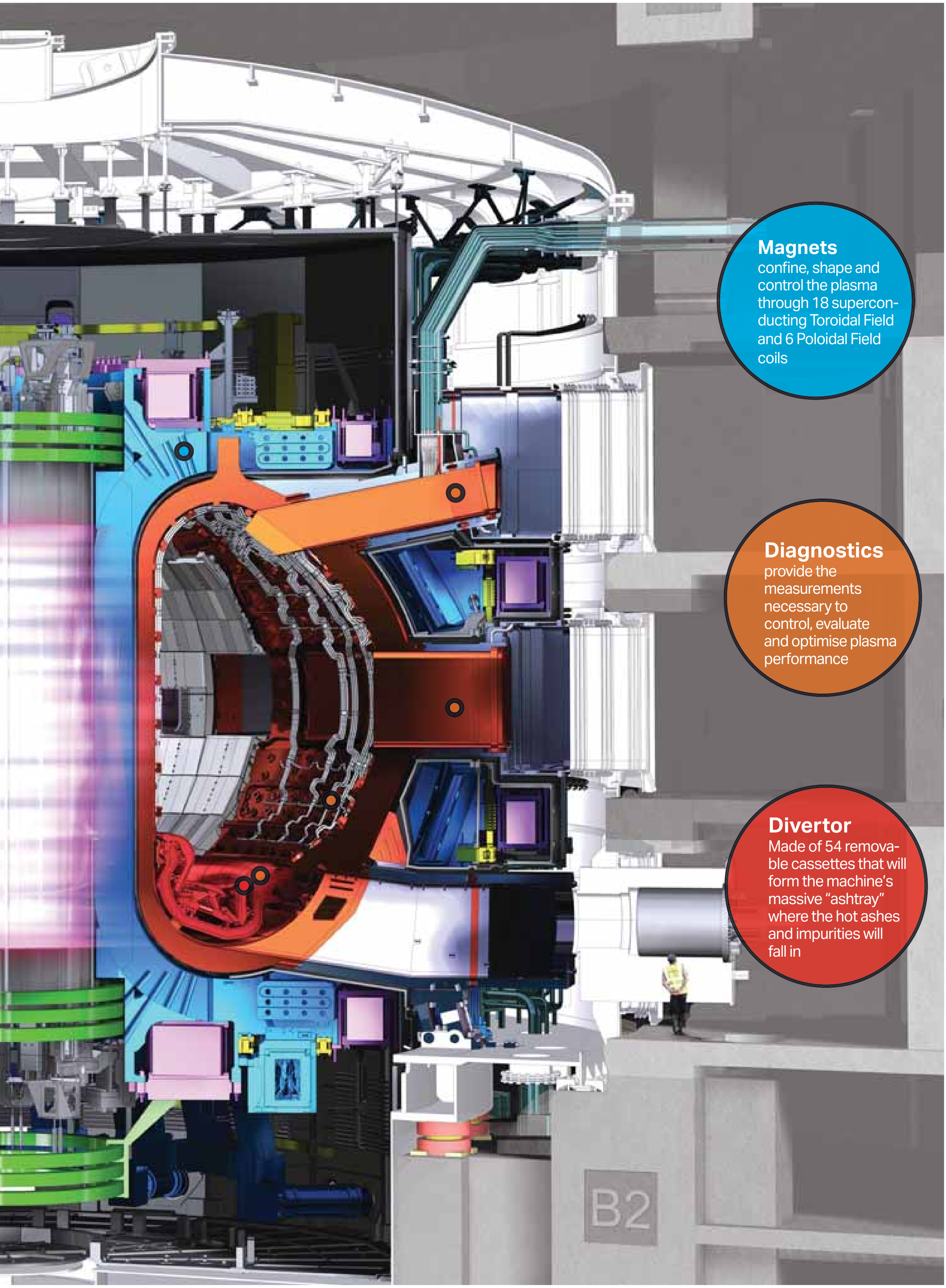
02

Manufacturing the ITER components

ITER is the biggest international scientific partnership to test the potential of fusion energy. It's an impressive technology puzzle that will generate new knowledge and stimulate industrial expertise to manufacture its components.

Europe's contribution to ITER, financed by the EU budget, amounts to roughly 50% making it the biggest of all Parties. It is a one-of-a-kind opportunity for industry, SMEs and fusion laboratories to get involved and be part of an emerging energy market. The manufacturing of components spreads all over Europe encompassing an impressive supply chain of at least 550 main contractors and approximately 1670 subcontractors.


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

MAGNETS

ITER will rely on a sophisticated system of superconducting magnets. Think of the central solenoid as its backbone. The correction coils will act as guards to reduce any magnetic errors resulting from the position and geometry of other coils.

To confine ITER's 150 million ˚C plasma, and keep it away from the walls of the Vacuum Vessel, a first layer of magnets consisting of the Toroidal Field (TF) coils is used. Europe is manufacturing ten out of the 18 TF coils for ITER, involving more than 700 people from 40 industrial partners.

To cope with the tremendous forces due to the powerful magnetic fields, six Pre-Compression Rings (PCRs) will tightly hold the TF Coils in place. An extra set of three will be manufactured as spares in case there is a need in future to replace the lower set. Europe is providing all nine Pre-Compression Rings (PCR) using a cutting-edge fiberglass technology.

Finally, six Poloidal Field (PF) coils embrace the TF coils from top to bottom in order to maintain the plasma's shape and stability. Europe is responsible for five of them. Four must be built on-site because of their size while one is being manufactured in China under contract with F4E.

Work in progress Toroidal Field coils

Contracts signed	100%
Tooling	100%
Qualification	100%
Manufacturing	91%

Work in progress Poloidal Field coils

Contracts signed	100%
Tooling	93%
Qualification	85%
Manufacturing	32%

Work in progress Pre-Compression Rings

Contracts signed	100%
Tooling	100%
Qualification	100%
Manufacturing	55%

" The results we have obtained so far represent ten years of hard work and careful planning. Our strategic thinking helped us to analyse upfront, and to define the proper implementation strategy. "

Alessandro Bonito-Oliva
F4E Magnets Programme Manager

One of Europe's Toroidal Field (TF) coils on the assembly rig where gap filling operations are performed. Thermal mats cover the entire coil to raise the temperature of the component so that the resin injected hardens as it fills in the space between the coil and its case. The work is performed at the SIMIC factory, Port of Marghera, Venice, Italy. Ten of the 18 TF coils will be delivered by F4E and its suppliers

Toroidal Field coils

First European TF coil on the verge of completion

F4E achieved a major milestone with the successful insertion and welding of the first of the ten European TF coils into its case. This is the proof that F4E has been able to conduct all first of a kind and complex operations needed for the fabrication of one coil and ready to replicate them for the remaining nine.

Technical staff following the welding of the ITER Toroidal Field (TF) coil cases. The work is performed by automated robots at the SIMIC factory, Port of Marghera, Venice, Italy.

"We are very satisfied with the results obtained during the welding operation. The second TF coil is almost welded. We were able to build on the expertise from the first TF and replicate the good results."

Paolo Barbero
SIMIC Project Manager

How is Europe producing its share of TF coils?

The fabrication of Europe's TF coils kicked off in ASG Superconductors (La Spezia, Italy), where technicians rolled out the entire fabrication process starting with the spooling of the conductor until the production of the inner-structure of the magnet, known as Winding Pack. This stage also counts on the contribution, either by means of components or expertise, of Iberdrola Ingeniería y Construcción, ICAS consortium, Elytt, SIMIC, CNIM.

Then, to become a fully-fledged ITER magnet, the massive component needs to go through a series of cryogenic and electrical tests and to be inserted into its coil case, which is welded, gap-filled with epoxy resin, and machined to make sure its steel panoply is tight and well fitted. These final steps take place in SIMIC (Marghera, Italy).

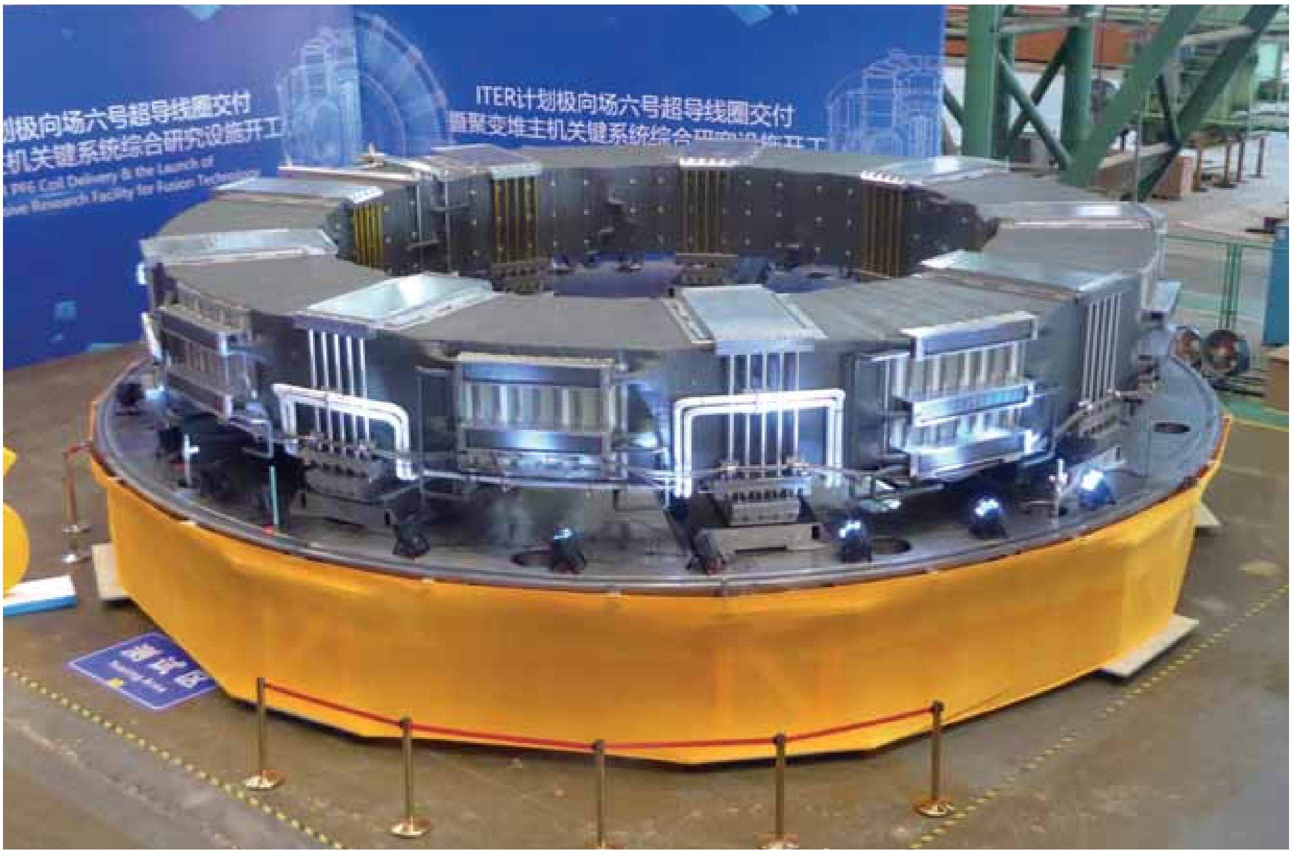
TOROIDAL FIELD COILS

The gigantic "D" shaped coils will be the biggest Niobium-tin (Nb_3Sn) magnets ever produced, which once powered with 68 000 A will generate a magnetic field of 11.8 Tesla—about 250 000 times the magnetic field 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 Airbus 350.

Poloidal Field coils

First of the six ITER PF coils manufactured

In China, at the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), the final assembly of the sixth PF coil (PF6) manufactured under contract by F4E was also completed. This achievement brought an end to three years of qualification stages plus another three of fabrication. In autumn, the coil entered the phase of final acceptance tests.



Poloidal Field coil 6 completed in China before final testing.

Manufacturing thrill for ITER magnetic rings

F4E introduced important changes in collaboration with industrial suppliers to stabilise the production of the Poloidal Field (PF) Coils. For the four coils manufactured on the ITER site, the winding pack assembly was completed leading to the final stage of manufacturing of one coil. The production of the Double Pancakes for another coil also progressed. F4E took measures to adapt the planning and tooling of larger coils.

"I recall when the winding operations started, during which we had to learn how to work as one team, and to become familiar with the tooling. The number of people involved has gradually increased and in parallel, we mastered the fabrication techniques. Now we have solid know-how and this also explains why the speed of production has accelerated."

Pierluigi Valente
F4E Senior Technical Officer

Poloidal Field coil 5 positioned to the impregnation table, in the PF coils factory, November 2019, Cadarache, France © F4E

"We revised our working method, improved the training of personnel, and restructured the work between various parties to meet our tight deadlines. We are already installing an additional crane and will erect an annex to carry out the demolding process and some of the manufacturing steps of PF3 and PF4."

Thierry Boutboul
F4E Project Manager

ITER Poloidal Field coils factory on-site, where four of the five coils that Europe is responsible for will be manufactured.

PF COILS FACTORY IN FRANCE

The construction of the PF coils factory was undertaken by F4E together with a number of industrial partners. The factory is about the size of two football pitches: approximately 250 m long, 45 m wide and 17 m high. It includes regular services (heating, ventilation and air conditioning, 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.

Pre-Compression Rings

Production on the roll for ITER Pre-Compression Rings

F4E started the series production of the Pre-Compression Rings (PCRs) using a pultrusion-based technology. By the end of the year, six of the nine rings had been manufactured and five of them successfully proof-tested.

Technicians carrying out checks on the first ITER Pre-Compression Rings undergoing production. F4E is collaborating with CNIM for the manufacturing of the nine rings which will absorb the fatigue and deformation felt by the ITER Toroidal Field (TF) coils.

"The time invested in prototyping and qualification has paid off. After having validated all processes, and carefully examined the production techniques, the fabrication of the nine PCRs became more straightforward."

Eva Boter
F4E Project Manager, responsible for the contract with CNIM

Technician at the CNIM production facility where the ITER Pre-Compression Rings are being manufactured. © CNIM

"Initially, we started working with one supplier using a specific technology. To maximize the probability of success, we explored in parallel an alternative technology, relying on a distinct supply chain using different materials. The latter has proven to be successful. Thanks to the excellent collaboration with our suppliers and the close monitoring of the development and production phases, we have managed to meet the quality standards and to meet the time schedule for the delivery of the PCRs."

Alessandro Bonito-Oliva
F4E Programme Manager for Magnets

"The materials we have opted for respond well to the different tolerance tests performed. Consequently, we are continuing production as planned."

Angela Hernandez
F4E Technical Support Officer, responsible for the contract with EXEL Composites

A prototype of the ITER Pre-Compression Ring being inserted in the CNIM Pre-Compression Rings Facility, La Seyne sur Mer, France © CNIM

PRE-COMPRESSION RINGS

The fiberglass composite rings, consisting of more than a billion miniscule glass fibers, are glued together with a high performance epoxy resin. The rings will have a diameter of approximately 5.5 m, a cross-section of nearly 300 mm x 300 mm and will weigh roughly 3 t. These will be among the largest composite structures ever manufactured as a single piece and are capable of withstanding tremendous forces to keep the TF coils in place (radial force of 7 000 t/coil).

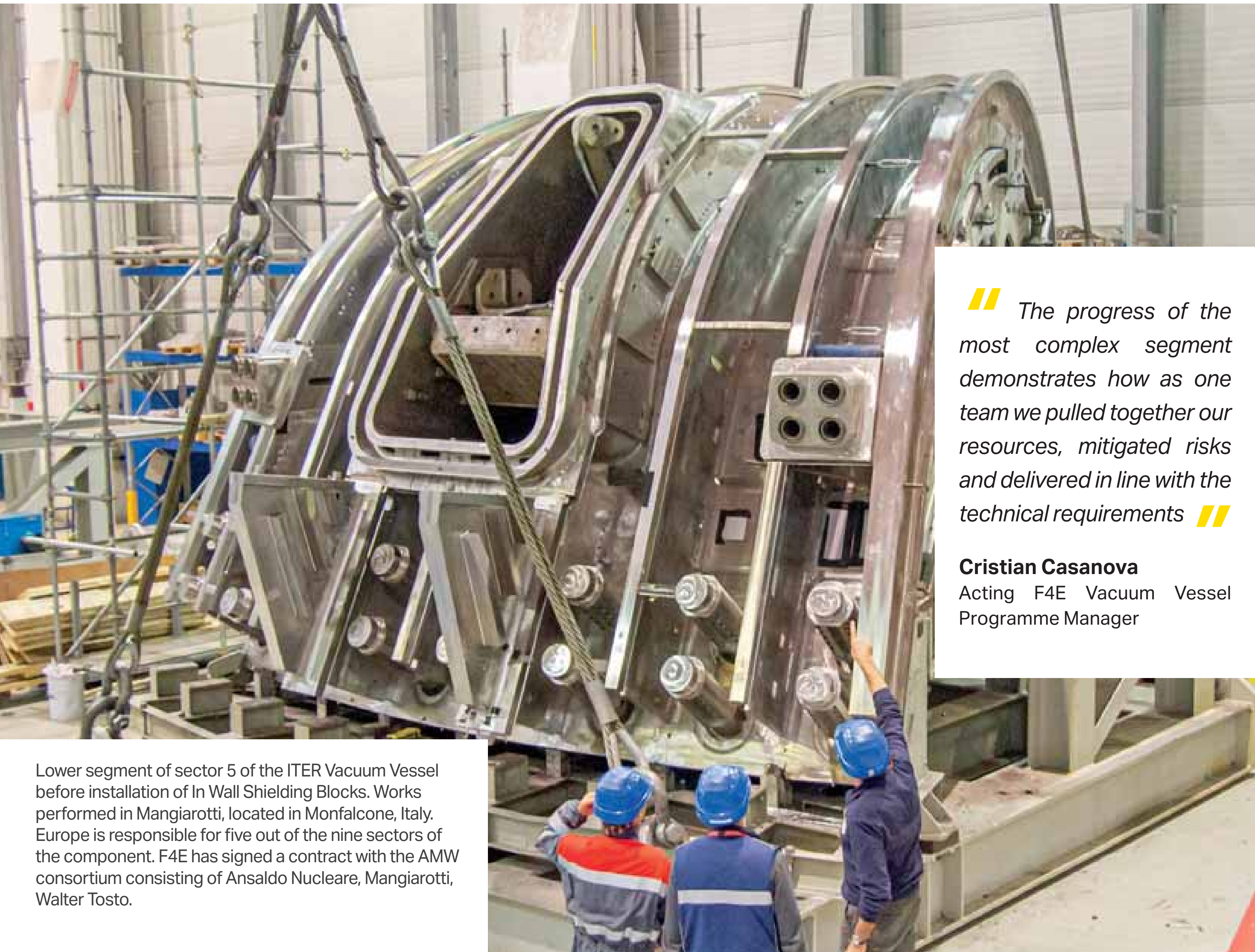
VACUUM VESSEL

The ITER plasma, where the fusion reactions will take place, will be under vacuum inside a special double-walled container, the Vacuum Vessel. Within this doughnut-shaped vessel, plasma particles collide and release energy without touching its walls thanks to magnetic confinement.

Europe is providing five of the nine vacuum vessel sectors of thick special grade stainless steel. Manufacturing these first of a kind components is very challenging due to the strict technical requirements, application of new techniques, and sheer size of the components as each sector is 12 m high, 6.5 m wide and 6.3 m deep. The sectors weigh approximately 500 t each. Nine European companies are involved in their fabrication.

Work in progress

Sector 5	
Delivered material	100%
Design	100%
Manufacturing	73%
Sector 4	
Delivered material	100%
Design	98%
Manufacturing	68%
Sector 3	
Delivered material	100%
Design	90%
Manufacturing	64%
Sector 2	
Delivered material	100%
Design	90%
Manufacturing	64%
Sector 9	
Delivered material	100%
Design	90%
Manufacturing	63%



" The progress of the most complex segment demonstrates how as one team we pulled together our resources, mitigated risks and delivered in line with the technical requirements "

Cristian Casanova
Acting F4E Vacuum Vessel Programme Manager

Lower segment of sector 5 of the ITER Vacuum Vessel before installation of In Wall Shielding Blocks. Works performed in Mangiarotti, located in Monfalcone, Italy. Europe is responsible for five out of the nine sectors of the component. F4E has signed a contract with the AMW consortium consisting of Ansaldo Nucleare, Mangiarotti, Walter Tosto.

Important milestone in the manufacturing of sector 5

F4E has entrusted the manufacturing of the five sectors to the consortium of Ansaldo Nucleare, Mangiarotti S.p.A and Walter Tosto S.p.A , plus an extensive chain of sub-suppliers. After nearly two years, some of the most challenging manufacturing tasks were completed. The consortium achieved the installation of the poloidal ribs that connect from top to bottom the inner-shell with the outer-shell of the vacuum vessel. On the segments of sector 5, works kicked off for the outer-shell welding stage, the last operation before final segment machining and assembly of the four segments into sectors.

Lower segment of sector 5 of the ITER Vacuum Vessel loaded on a trailer to go through radiographic tests. Works performed in Mangiarotti, located in Monfalcone, Italy.

"The manufacturing approach that we opted for in the production of the sectors is reverse engineering. Any distortions resulting from fabrication are taken into account and compensated in the fabrication of the other parts. It is a time-consuming exercise, but necessary, so that the end result is in compliance with the tight tolerances requested. For the size of such component and of such geometry this is no easy task."

Andres Dans Alvarez De Sotomayor
F4E Senior Technical Officer

"Significant progress has been achieved during the last months, and in the case of the poloidal ribs they were completed earlier than initially foreseen. The good collaboration between suppliers, F4E, ITER Organization and the other ITER Parties played an important role."

Fabio Ceccanti
F4E Project Manager

F4E STAFF EXPLAINS THEIR WORK ON THE VACUUM VESSEL

Scan the code to watch the video

Overcoming technical challenges in welding

Using electron beam welding on the huge pieces of the vacuum vessel was challenging. F4E reached an agreement with the suppliers to increase the resources on the project on condition that certain schedule performance indicators were met. The first positive results were witnessed by the end of the year.

Before welding: Inspection at ProBeam of the last sector 5 assembly with a central port arriving from Walter Tosto.

REMOTE HANDLING

Remote handling helps us to carry out tasks without being physically present. It is widely used in space exploration missions, underwater repairs or challenging maintenance works. The limited space inside ITER together with the weight and exposure of some of the components to radiation will require the use of remote handling systems during maintenance. Europe is responsible for four of the six-major remote handling systems of ITER. For each of them it carries out design activities, R&D and manufacturing in order to deliver the appropriate tooling.

Work in progress Divertor RH

Contract signed	33%
Design	66%

Cask & Plug RH

Contract signed	12%
Design	42%

Neutral Beam RH

Contract signed	19%
Design	50%

In Vessel Viewing System

Contract signed	16%
Design	65%

ITER Divertor Remote Handling Preliminary Design Review concluded

The design of the Divertor Remote Handling System (DRHS) has been reviewed by a panel of experts from F4E, ITER Organization and industries. Based on the conclusions of the panel, a specifically appointed Steering Committee chaired by the F4E Director gave its green light to the launch of the final design activities that include also advanced laboratory tests. The DRHS will be used in ITER to replace the divertor cassettes which will be damaged when receiving very high heat loads during plasma operations. Around 10 000 elementary tasks will need to be carried out in order to replace the full divertor - composed of 54 cassettes- over six months. Man in the loop robotics, a specially developed hydraulic system, advanced pipe welding and cutting tools, new radiation resistant electronics cameras, innovative software and powerful computers will be among the technologies deployed to perform the tasks.

"We want to learn from this exercise and draw lessons for the other Remote Handling packages that will go through their respective Preliminary Design Reviews in 2019."

Carlo Damiani
F4E Remote Handling Programme Manager

Members of staff of F4E, ITER Organization, experts and companies participating in the Preliminary Design Review of the ITER Divertor Cassette Remote Handling system procured by Europe.

Operating remotely a 180 m monorail crane system

The Preliminary Design Review of the monorail crane system was successfully completed. A panel of experts from F4E, responsible for the Neutral Beam Remote Handling System (NBRHS), ITER Organization, and independent experts from laboratories and other companies, contributed to the review of this system which will be part of the NBRHS. The design of such crane has been developed by Jacobs (former Wood), F4E's main contractor for the design and manufacturing of the system, and its specialised subcontractor Reel.

The 180-m long monorail system hosts the transfer trolley picking up and transporting components in the Neutral Beam Cell. Such crane is meant to work in combination with other NBRHS devices like the so-called beam source maintenance equipment, the beam line transporter, two manipulator arms and a variety of tools for component bolting and unbolting for pipe cutting and welding etc. To understand the complexity the crane designers are dealing with, try to imagine a train positioned upside down running on a rail mounted to the roof in a limited space full of equipment and following a complex and reconfigurable railway. The bulky equipment also needs a high level of operational flexibility and must act in perfect coordination with the tooling and manipulators.

The monorail system, able to carry payloads up to 40 t, will need to comply with the anti-seismic requirements applying to the Tokamak building, where the ITER device will operate, and will have to be perfectly aligned the Neutral Beam Injectors when these have to be repaired. It is estimated that every 18 months maintenance works would need to be conducted which may take up to six months.

" The completion of the Preliminary Design Review of the monorail leads us towards the Final Design Review scheduled to take place in early 2022. From this moment on, we will have two years to complete the fabrication of the system in order to be installed in the ITER machine for first plasma operations. "

Marco Van Uffelen
F4E Project Manager for the Neutral Beam Remote Handling System

Experts contributing to the partial Preliminary Design Review of the Neutral Beam Remote Handling system on the ITER site

Collecting information from one billion points in the vessel

ITER will require a sophisticated and agile inspection system to perform a series of checks inside the machine. Cutting-edge technologies bringing together metrology instruments, high-tech vision and robotics will be deployed to create a one billion pixel 3D map of the plasma-facing surfaces inside the ITER device. The In-Vessel Viewing System (IVVS) will help scientists inspect changes, such as erosion, on In-Vessel components. With the help of six probes, located in different ports inside the lower part of the machine, the IVVS will measure nearly 100% of the surface of the In-Vessel components with at least one measurement per mm^2 offering an excellent image.

Members of a panel composed of F4E, ITER Organization, and independent experts gathered for the Preliminary Design Review (PDR) of the IVVS. More than 35 participants attended the meeting during which it was discussed if the proposed design fully met the requirements, and whether the design process was robust enough for the complexity, quality, and safety of the system. Representatives from big and small-medium sized companies contributed to the IVVS design (and presented it to the panel), such as Veolia Nuclear Solutions (UK), ASE Optics Europe (Spain), Optima Systems Consultancy (UK), 3D Scanners UK (UK), Cedrat Technologies (France), IDOM (Spain), Micronor (Switzerland), Bridger Photonics Inc. (US).

"The completion of the Preliminary Design Review is an important step towards the fabrication of the ITER In-Vessel Viewing System. What was until recently considered a conceptual design is gradually starting to resemble to a proper system."

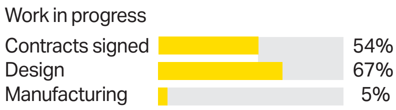
Gregory Dubus
F4E Project Manager for In-Vessel Viewing System

Participants from F4E, ITER Organization, independent experts and company representatives at the Preliminary Design Review Meeting held at ITER Organization, December 2019, Cadarache, France

DIAGNOSTICS

The Diagnostics systems 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 scientists and engineers offering them insight thanks to a wide range of cutting edge technologies.

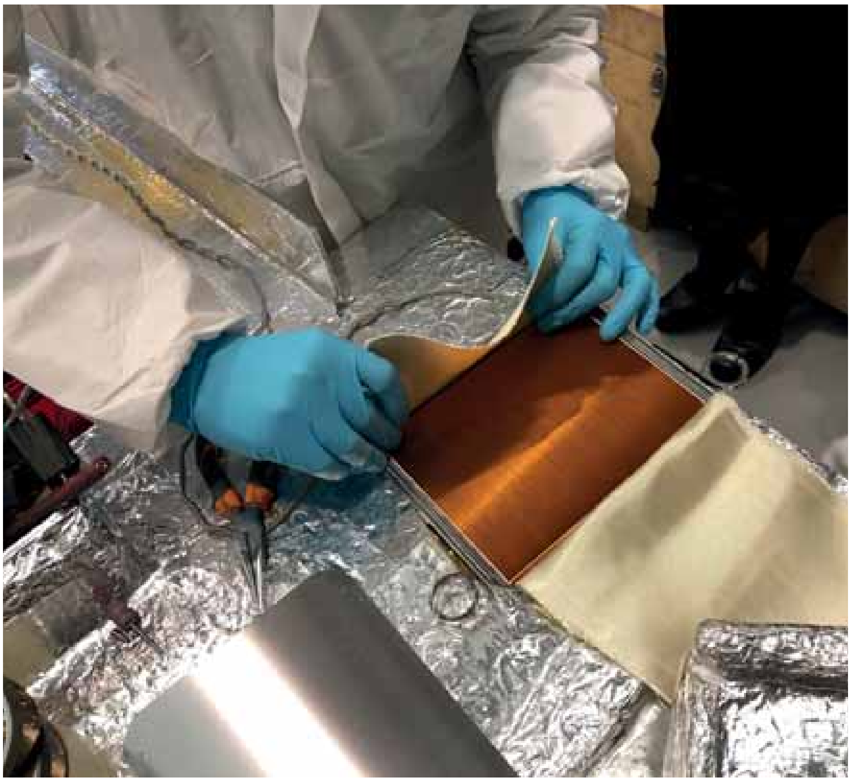
ITER will offer an unparalleled view of the entire plasma and the duration of the plasma pulse is 100 times longer than any fusion device currently in operation. With the extreme environment in the vessel and large energy inside the plasma, the diagnostic systems will also help to ensure the safe operation of the machine. Europe is responsible for roughly 25% of all Diagnostics in ITER, involving more than 60 companies and research laboratories.



Europe's first Diagnostic installed

The installation of the Continuous External Rogowski (CER) coils marked the installation of the first diagnostic provided by Europe. The CER coils are to be located outside the ITER vacuum vessel, within the cases of three Toroidal Field (TF) coils. They measure the total electric current flowing in the ITER plasma.

F4E also delivered a second set of 270 magnetic coils, known as Outer Vessel Coils, which will measure the magnetic field strength surrounding the ITER machine core. Finally progress was made with the manufacturing of the diagnostics magnetics Inner Vessel Coils (IVC). F4E signed contracts for three distinct types of IVC sensors, and manufacturing started. Located in a high vacuum environment, IVC will measure local magnetic field in various frequency ranges.



Manufacturing activities on one of the Outer Vessel Coil sensors

F4E signs Diagnostics Engineering Services contract

F4E signed a contract for manufacturing engineering support for the Diagnostics systems with AVS (Spain). This engineering company will assess F4E's on-going Diagnostics design works in terms of manufacturing feasibility, cost and risks and provide expert guidance to F4E and European fusion laboratories.

"As we are now approaching the finalisation of the preliminary design phase for most of the Diagnostics systems it makes sense to bring on-board European industrial companies to complement the work done by the European fusion labortaories."

Sandra Julià Torres
F4E Project Manager

"After having successfully delivered countless turnkey projects such as accelerators, astrophysics, neutron sources, space and synchrotron main facilities, AVS is excited to help F4E and the EFLs to bring fusion a step closer."

José Miguel Carmona
Head of Fusion and Beams Area at AVS

First design of Diagnostics "cable gatekeeper" approved

Several Diagnostics systems, which will be connected to the exterior through high-tech cabling, will study the plasma inside the vacuum vessel. F4E started developing cable 'gatekeepers' or feedthroughs to guarantee the integrity of the vacuum inside the chamber. In total, F4E is supplying 75 feedthroughs to ITER, of five different design variants.

F4E worked closely with IDOM to develop a preliminary design which was approved by ITER in April. On this basis, a final design will be developed, and manufacturing is planned to start in 2021.

F4E has worked closely with IDOM to develop the design which will be the basis for the production of these feedthroughs.

"We have been positively surprised by IDOM's capability of producing an innovative design solution for the feedthroughs that meets all our stringent and numerous requirements whilst remaining simple to manufacture."

Miguel Pérez Lasala
F4E Project Manager

"We carried out a great deal of R&D in order to find the optimal technical solution. Our next challenge will be to deliver a final design to F4E, fully qualified, on a constrained schedule."

Amaya Martínez Jiménez
IDOM Project Engineer

TEST BLANKET MODULES

Experts working in the area of Test Blanket Modules (TBM) systems 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.

F4E strengthened its collaboration with EUROfusion

F4E and EUROfusion – the European consortium of fusion research laboratories – formalised the joint organisation of their resources in research programmes for tritium breeding technology. In September 2019, they signed a Memorandum of Understanding as well as a multi-annual programme plan for the joint execution of the TBM systems programme. To cement this relationship, EUROfusion laboratories seconded four engineers to the joint TBM Project Team at F4E Cadarache.

Steel for Fusion

Joint efforts by F4E and EUROfusion were made on EUROFER97 – the European steel chosen for the TBM – to demonstrate its weldability as well as its resistance to neutron irradiation. EUROFER97 is less susceptible to radioactivity than other types of steel when experiencing the neutrons produced in fusion devices. The objective is to make EUROFER97 the standard for longer-term programmes such as DEMO.

Promising developments on Preliminary Design Activities

EUROfusion laboratories brought the conceptual design of the Water-Cooled TBM System close to its final stage. For the Helium-Cooled system, F4E prepared the next phase of engineering design and signed five contracts with industrial partners. This work will bring it to the level required for preliminary or final design reviews.

Experimental activities being carried out in European Fusion Laboratories in order to test TBM technology

Experimental activities being carried out in European Fusion Laboratories in order to test TBM technology

IN-VESSEL

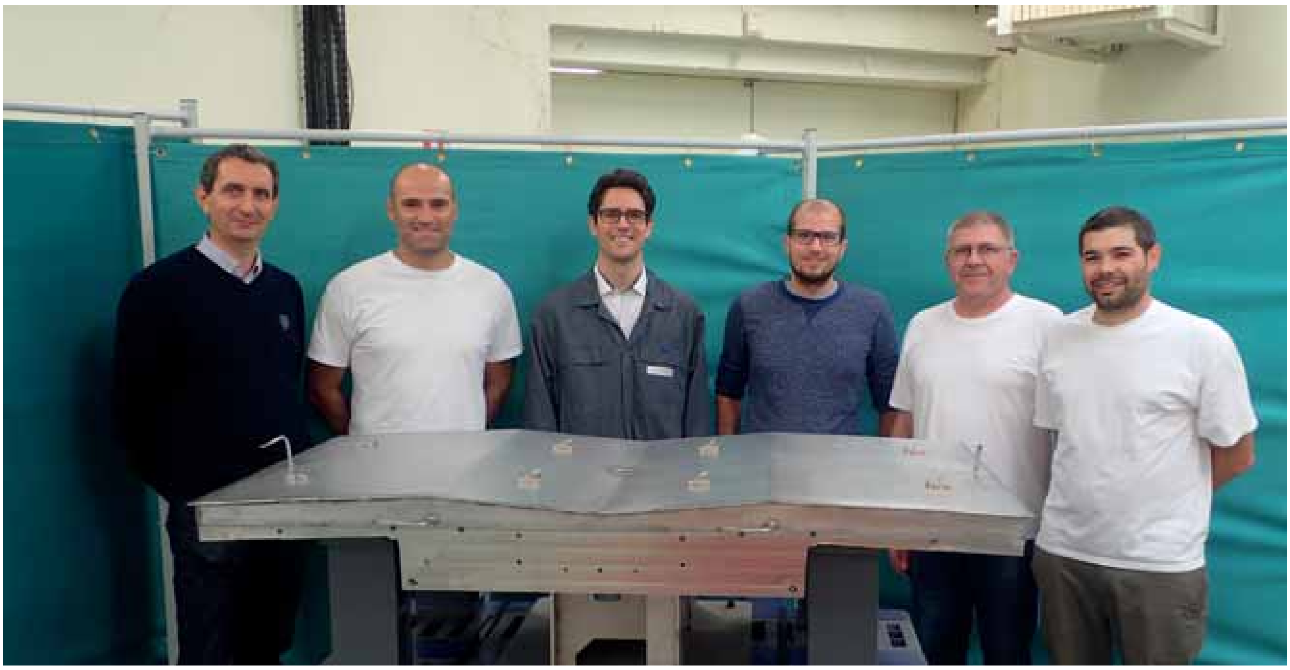
The extremely hot temperature of the fusion plasma will be mostly felt by the In-Vessel components, otherwise known as plasma-facing components, due to their direct exposure to high heat and neutron fluxes. The divertor, likened to a massive 'ashtray" where the plasma ashes and impurities are diverted to, consists of 54 cassettes, all to be manufactured by Europe, and is located at the lower part of the machine. The blanket is made of the 440 modules, resembling to blocks, covering the walls of the vacuum vessel. Europe is responsible for the production of 215 of them.

Work in progress

Blanket Cooling Manifold	
Design & Qualification	95%
Blanket & First Wall Panels	
Qualification	100%
Divertor Vertical Target	
Qualification	45%
Divertor Cassette Body	
Qualification	100%
Design and Engineering	60%

Great progress on the First Wall Panels

The vacuum vessel will be covered on the inside by a layer of 440 First Wall Panels. Covering a surface of 600 m^2, these 1 x 1.5 m thick metallic blocks shield the vacuum vessel and the external machine components. As a first-of-a-kind component, much effort was put in developing conceptual designs, starting will smaller mock-ups leading to full-size prototypes. F4E has been working with three companies in the prototyping phase: Framatome, Atmostat and a consortium consisting of Iberdrola, Wood and Leading. All three companies completed their first wall panel full-scale prototype and announced their willingness to participate in the coming call for tender.



Members of the Atmostat team involved in the manufacturing of a full-scale prototype of the ITER first wall panel, financed by F4E.

ITER first wall panel full scale prototype manufactured by Iberdrola, Leading and Wood, financed by F4E.

"Due to the fact that we scaled up our prototypes, there was a direct impact on the manufacturing process. Next, we will perform a series of strict quality tests to check the performance of the equipment in high temperatures."

Stefano Banetta
F4E Project Manager

"Better insight and more know-how have been acquired after years of work in this area. The successful manufacturing of the three full-scale prototypes has paved the way for the launch of the F4E call for the production of the first-wall panels"

Patrick Lorenzetto
F4E Programme Manager

ITER first wall panel full-scale prototype manufactured by Framatome, financed by F4E.

Prototyping the Blanket cooling system

To cool down the First Wall panels, a network of pipes branching into several openings (Blanket Cooling Manifold) will deliver pressurised water to cool them down. Inside this structure, measuring roughly 9 m, water will flow to remove up to 736 MW of thermal power. A simpler and more practical design is under preparation due to the limited availble space in the vacuum vessel.

" Space, vacuum conditions and high temperatures are important factors that come to play at the stage of fabrication. But above all, we need to be practical, reasonable and creative so that we end up with a piece of equipment that fits and works well with the ITER environment. "

Georges Dellopoulos
F4E Project Manager

Technician applying three levels of torque to test the restrain of the support equipment manufactured by TCPP. The tests have been performed by Tecnalia. The works are financed by F4E, responsible for the ITER Cooling Blanket Manifold.

Getting ready to perform thermal tests in order to calculate the heat conductance between the pipe and the support. The equipment has been manufactured by TCCP and the tests have been carried out by Tecnalia.

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.

Work in progress

LN2 Plant	
Contracts signed	95%
Design	100%
Manufacturing	100%
Installation & Commissioning	45%
Vacuum Pumping	
Contracts signed	31%
Design	13%
Manufacturing	20%
Tritium Plant	
Contracts signed	32%
Design	35%
Manufacturing	18%
REMS and Rad Waste	
Contracts signed	1%
Design	9%

LN2 Plant on the verge of completion

The Liquid Nitrogen (LN2) Plant and its auxiliary systems will cool down, process, store, transfer and recover the cryogenic fluids of the machine. F4E completed the installation of all remaining equipment, conducted most of on-site pipe fitting and welding, and carried out the first pressure acceptance tests. Also, the manufacturing of the quench line header components was launched.

Integration of the 80 K loop cold boxes

Design validation and component qualification for ITER vacuum systems

Europe provides the cryopumps needed to obtain a high vacuum in the vacuum vessel and the cryostat. F4E made progress in designing the front end cryodistribution system, qualifying technologies used in MITICA cryopumps (ITER Neutral Beam Test Facility), and the successful manufacturing and acceptance tests of the double-walled warm regeneration lines. F4E also signed the contract for the eight Torus and cryostat cryopumps.

Delivery of the supports of the warm regeneration lines

How to spot leaks in the vacuum systems?

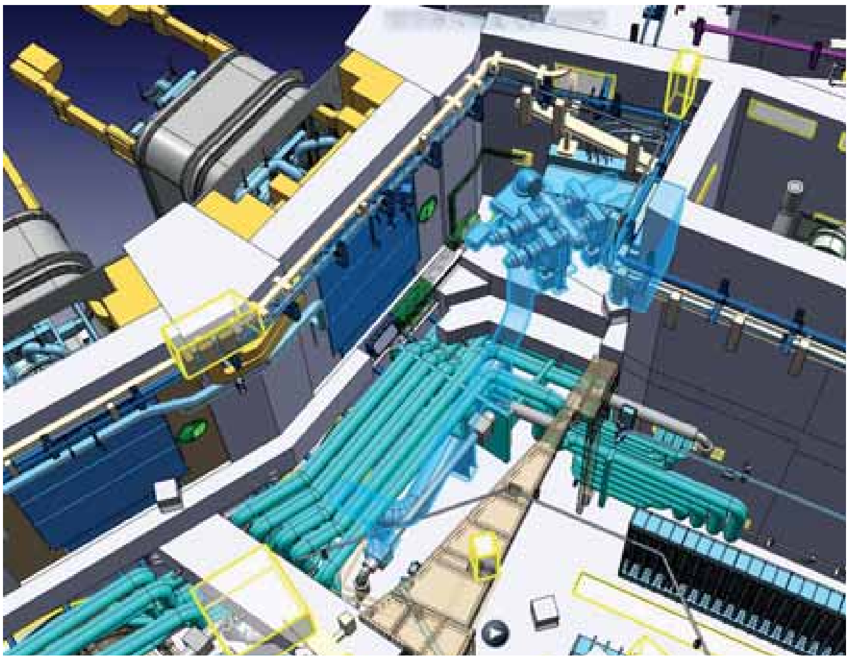


Illustration of the leak detection equipment for the ITER Vacuum Vessel

Vacuum systems will have an important role to play in ITER. The sheer size of the machine poses a challenge in delivering the right level of vacuum to its different components: The vessel, the neutral beam front components, and the massive cryostat will need to remain leak-tight and operate in vacuum. F4E launched a call for tender for the procurement of those systems.

NEUTRAL BEAM AND ELECTRON CYCLOTRON POWER SUPPLIES AND SOURCES

To heat up the ITER 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 ITER components.

For this reason the ITER Neutral Beam Test Facility (NBTF), located in Padua, Italy, has been set up consisting of two test beds:

- SPIDER (Source for Production of Ion of Deuterium Extracted from Radio Frequency plasma), will help scientists to develop the ion source, one of the critical elements needed for the operation of the ITER Neutral Beam Injectors.
- MITICA (Megavolt ITER Injector and Concept Advancement) will develop and test a full-size prototype of a Neutral Beam Injector.

The NBTF receives contributions from F4E, ITER Organization, India’s and Japan’s ITER Domestic Agencies, and Italy’s Consorzio RFX, the host of the infrastructure.

Work in progress

Electron Cyclotron Power Supplies
1st to 8th unit

Contracts signed	100%
Design	100%
Manufacturing	45%
Delivery	5%

SPIDER

Contracts signed	99%
Design	99%
Manufacturing	99%
Delivery	97%

MITICA

Contracts signed	92%
Design	83%
Manufacturing	59%
Delivery	52%

Aerial View of the Neutral Beam Test Facility in Padua, Italy

SPIDER

One year of experiments for SPIDER

In May 2019, SPIDER, the world's most powerful negative ion source, produced its first hydrogen beam marking one year of operation, fixing of technical issues and fine-tuning of equipment. Thanks to the commissioning of its diagnostics, scientists can now see the footprint of the beam source with infrared cameras and thus confirm its operation. With SPIDER now reaching its full potential, a promising future awaits the fusion community.

"All the systems are now up and running as part of the same equipment. They are no longer parts of a sum. Soon we will have some data to share and compare with other experiments around the world."

Francesco Paolucci
F4E Project Manager

Members of Consorzio RFX installing diagnostics equipment, the STRIKE calorimeter, in SPIDER so as to monitor the operation of the beam source, March 2019, Padua, ITER Neutral Beam Test Facility.

BUILDING SPIDER

SPIDER was constructed between 2012 and 2018. F4E, Consorzio RFX, ITER India, ITER Organization, together with approximately 120 companies, have contributed to this experiment by means of components, infrastructure and know-how. The value of components paid by F4E is in the range of 34 million EUR, while India invested roughly 3 million EUR. Consorzio RFX financed the construction paying approximately 25 million EUR.

MITICA

Europe is one of the main contributors to MITICA and provides a large part of the equipment such as power supplies, the cryoplant, cooling, vacuum and gas introduction systems, the SF6 plant, and all main injector components (beam source, vacuum vessel, etc.).

MITICA beam source vacuum vessel successfully installed and tested

In June, the vacuum vessel of the MITICA beam source was successfully installed, and later tested. The metallic box weighing 57 t will house the components of the beam source. One of the most delicate parts of the installation was the alignment of the vacuum vessel to its high voltage bushing, provided by Japan, to which the components of the beam source vessel will be connected.

MITICA beam source vacuum vessel delivered to ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy. The component has been manufactured by De Pretto Industrie and financed by F4E.

Cryoplant installation completed

Important progress was made on the equipment of the MITICA cryoplant that will maintain the vacuum in the vessel as well as cool down its cryogenic pump. F4E, in collaboration with Air Liquide, successfully completed its installation in spite of the complex technical environment and multiple interfaces.

Cryolines connecting the main cold box with the auxiliary cold box, ITER Neutral Beam Test Facility, MITICA, Padua, Italy

Success for high voltage tests

High voltage insulating tests were successfully carried out on the power supplies which resulted in the acceptance and the hand over to to ITER Organization (IO) of most of EU components. Likewise, the SF6 Handling System was also finally accepted and handed over to IO.

Engineers from F4E, Consorzio RFX, ITER Japan, ITER Organization, and the companies involved in fabrication of the MITICA High Voltage Deck and High Voltage Bushing Assembling, standing inside the High Voltage Hall of MITICA below the connection between the Insulating Transformer from Japan (to the left) and the High Voltage Deck (to the right), ITER Neutral Beam Test Facility, Padua, Italy, July 2019

MITICA

MITICA's beam source will measure 3 x 3 x 4.5 m and will weigh 15 t and produces negative ions. Thanks to a powerful accelerator, they will travel at high energy through 8960 holes and eventually land on a calorimeter, which measures the beam power based on the level of the heat produced. Given the fact that MITICA mimics the ITER Neutral Beam Injectors, scientists will be able to have good estimates of the heating power that will be transmitted to the ITER plasma.

F4E signed last major contract for MITICA

The contract for the production and delivery of MITICA's beam line components was signed with the AVS-Tecnalia consortium. It took two years for the design and prototyping to address critical technologies and refine industrial and manufacturing specifications. This was the last main contract for the NBTF under F4E responsibility.

" The signature of the final procurement provides the final in-kind and financial contribution of the EU to this international experiment. In the years to come F4E will have to concentrate on the follow up of these contracts and the delivery of the ITER equipment. "

Tullio Bonicelli
F4E Programme Manager

Swirl tube element prototype produced by the AVS-TECNALIA consortium

" The size and characteristics [of the Neutral Beam] make it a-first-of-a-kind negative ion injector. The calorimeter will be able to absorb as much thermal energy as that produced by half a million light bulbs of 35 W. "

Gonzalo Micó
F4E Project Manager

Representatives of F4E, Consorzio RFX, ITER Organization, AVS-TECNALIA consortium checking prototypes produced by AVS-TECNALIA consortium

ELECTRON CYCLOTRON

The Electron Cyclotron (EC) is one of the power supplies that will be used to raise the temperature of the ITER plasma. It will convert electricity from the grid and supply it to the gyrotrons, the devices that generate strong electromagnetic waves, which in turn, will transfer their energy to the electrons of the ITER plasma to heat it up and confine it better. Gyrotrons will require high and stable voltages.The EC power supplies need to guarantee the accurate amount of power, and ensure that its supply is in line with ITER's operation. It takes expertise to develop a piece of equipment that can provide this amount of power and switch it off in less than 10 micro-seconds!

First EC Power Supplies delivered to ITER

F4E delivered to Cadarache the first of the eight EC power supplies under its responsibility, as well as testing equipment. Factory testing of power supplies modules was successfully completed.
Meanwhile, in Falcon, an F4E test facility hosted by the Swiss Plasma Center, tests were completed on the 1MW European gyrotron prototype for ITER. After further inspections, further improvements were identified.

F. Albajar, F4E Technical Responsible Officer, Darshan Parmar, ITER Organization Technical Responsible Officer, Paco Sanchez Arcos, F4E Project Manager, supervising the delivery of Europe's first High Voltage Power supply unit delivered to ITER.

High Voltage Power supply unit procured by F4E and manufactured by Ampegon © Fusion for Energy

European gyrotron, Falcon facility, Swiss Plasma Centre

EC / BEAM SOURCE

The Electron Cyclotron (EC) power supplies convert electricity from the grid and supply high and stable voltages to the gyrotrons. These complex devices generate strong electromagnetic waves, which in turn, transfer their energy to the ITER plasma to heat it up.

The EC power supplies need to guarantee the accurate amount of power (20 MW), and ensure that its supply is in line with ITER's operation. It takes expertise to develop a piece of equipment that can provide this amount of power and switch it off in less than 10 microseconds!

ANTENNAS AND PLASMA ENGINEERING

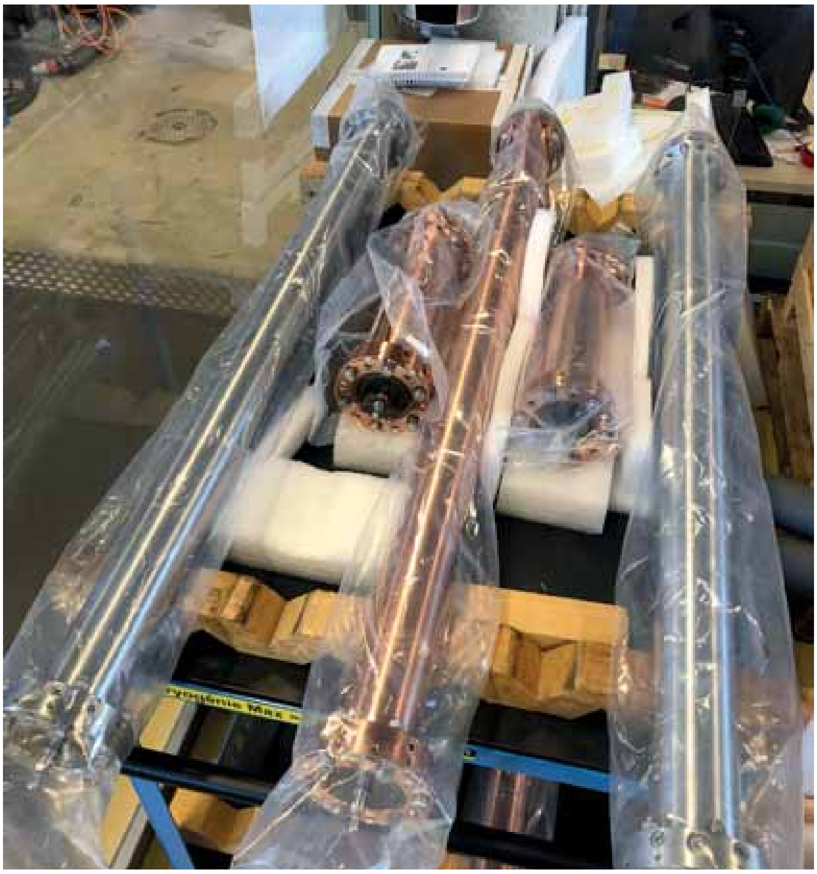
Large antennas will channel the electromagnetic waves generated by two heating systems – the Electron Cyclotron (EC) and the Ion Cyclotron (IC) – to heat ITER's plasma to the temperatures required for fusion to happen. EC Launchers will help scientists to target specific parts of the plasma by guiding the waves with the help of mirrors. F4E is working on these projects with support on engineering from companies and European fusion laboratories.

Work in progress

EC Launcher	
In-vessel Design	90%
Ex-vessel Design	65%
Manufacturing	8%
IC Antenna	
Design	48%
Manufacturing	0%
EC Control System	
Design	80%
Manufacturing	0%

Testing activities at FALCON

At the FALCON facility, Swiss Plasma Center, interesting results were produced in testing the first mock-ups of the ex-vessel waveguides and a prototype of miter-bend with a 50 mm diameter. F4E's collaboration with General Atomics (GA) has also been fruitful allowing a direct comparison between components of different manufacturers and a more flexible facility thanks to the components provided by GA.

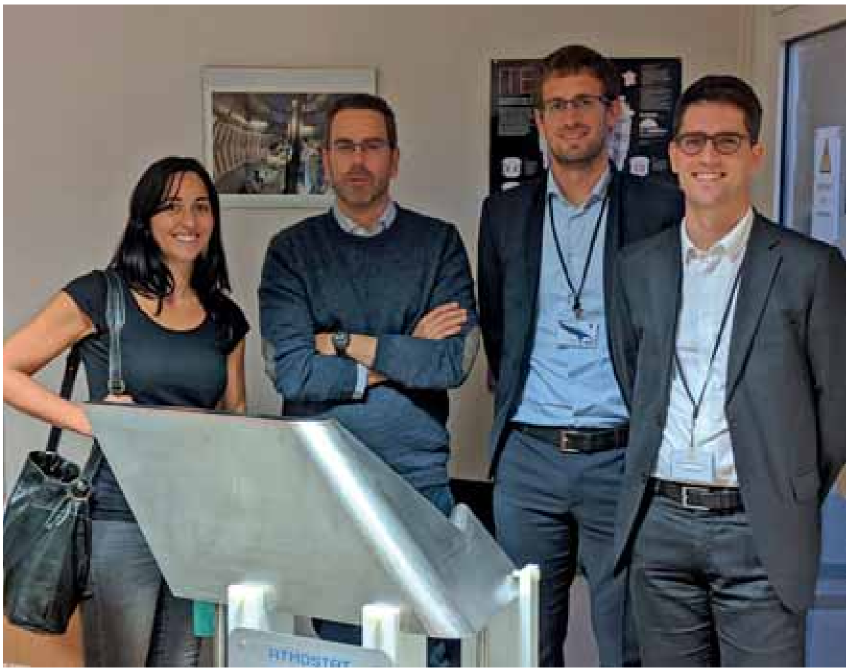


Short waveguide mock-ups (CuCrZr) and three 1.2 m waveguide mock-ups, in Stainless Steel, CuCrZr and Aluminium, manufactured by TBB under F4E contract.

Final Design Review completed for the EC Upper Launcher

Four ITER EC Upper Launchers will each inject up to 8 MW of microwave power into ITER in order to help start-up the plasma and counteract any instabilities. After an intense activity of design integration and finalisation performed by F4E and industrial partners, the Upper Launcher successfully passed its Final Design Review.

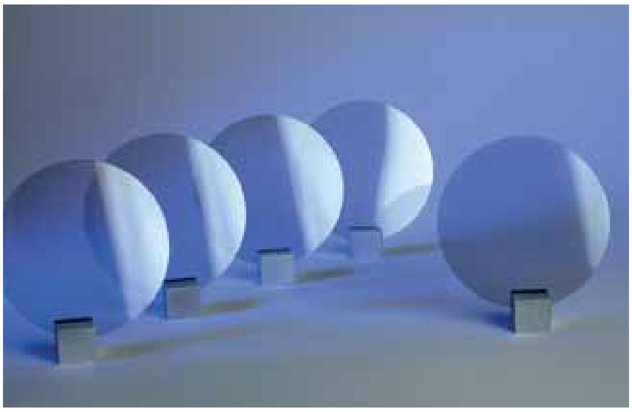
This positive outcome is the result of efficient prototyping with qualified suppliers. For instance, in October, F4E and ATMOSTAT presented to ITER Organization a prototype of the Blanket Shield Module (BSM). This plasma-facing part of the Upper Launchers will be able to withstand temperatures up to approximately 350 °C during ITER operation, thanks to a state of the art cooling system, as well as ultra-vacuum environment of the vacuum vessel, through metal joints of the highest quality.



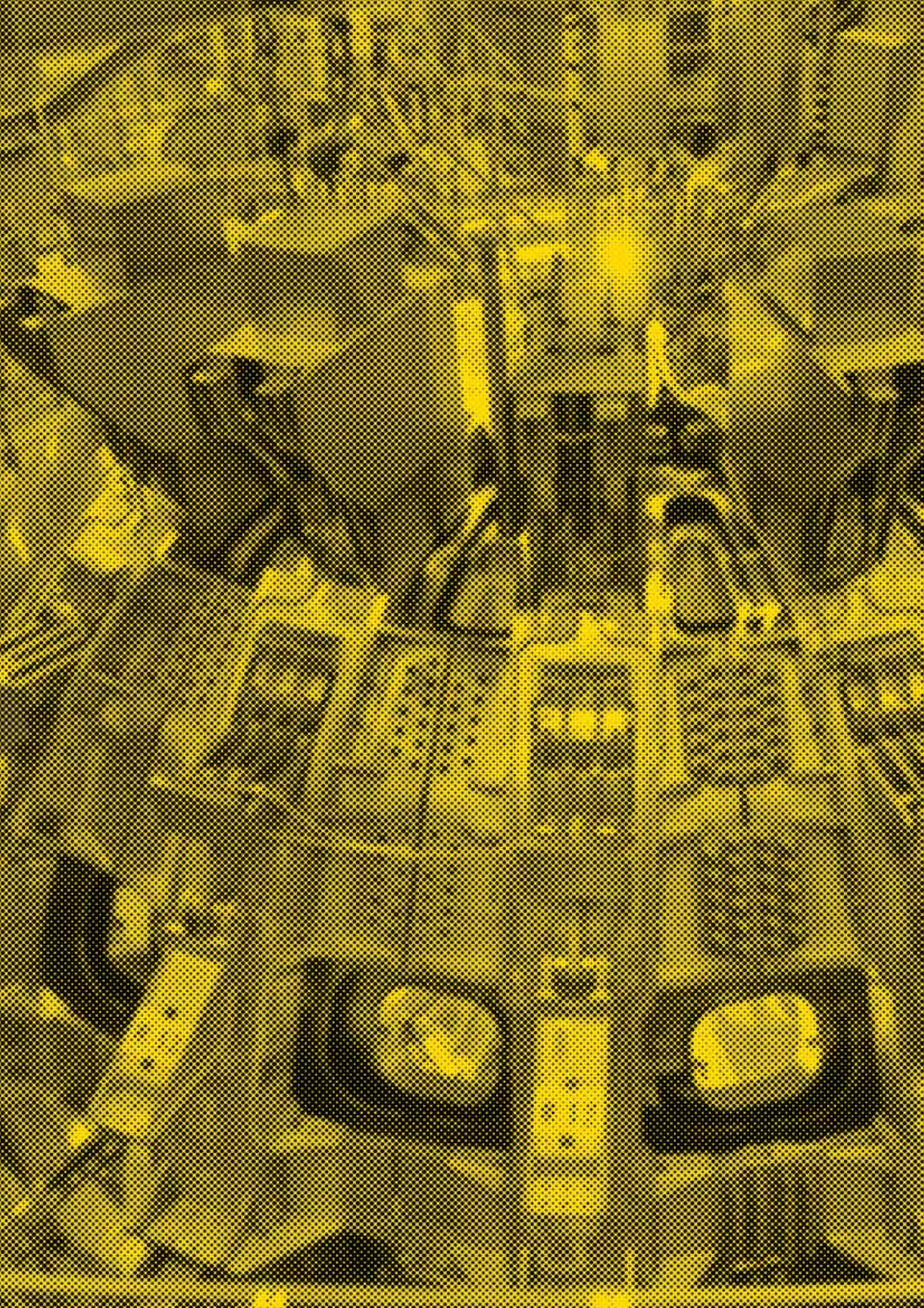
Europe's Blanket Shield Module corner mockup, produced by ATMOSTAT

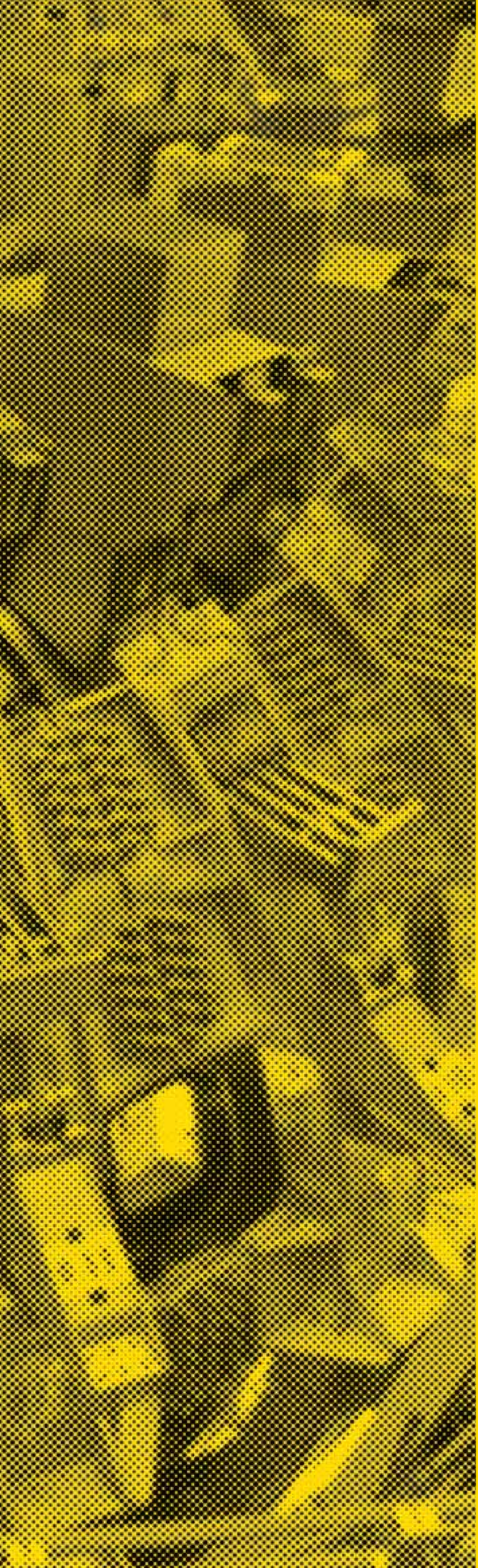
Production started for 60 diamond discs

Unbreakable, transparent and able to dissipate heat five times better than that of copper, diamonds are particularly useful for ITER's tokamak Electron Cyclotron (EC) heating system. The EC System will heat the plasma by transferring the energy of electromagnetic waves into the electrons of the plasma. Gyrotrons will generate those electromagnetic waves that will be guided into the vacuum vessel by 56 beam-lines. Both the gyrotrons and the chamber have to remain vacuum-tight. Radiofrequency waves propagate in a manner similar to light, therefore, the only way to get them from the gyrotrons into the chamber is through a diamond window. Situated at the core of the window, those 80 mm diameter discs will ensure the safe and efficient transmission of the waves' very high power for durations of up to 50 minutes. The production of 60 diamond discs started towards the end of the year with Diamond Material, a German SME.



Powerful microwaves will travel through these transparent and resilient diamond windows produced by Chemical Vapour Deposition (CVD). F4E has signed a contract for the production of 60 diamond discs with Diamond Materials. © Diamond Materials





03

The Broader Approach

Taking a step closer to fusion energy 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;
- 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;
- The International Fusion Energy Research Centre (IFERC) through the DEMO Design Research and Development Coordination Centre, the Computational Simulation Centre and the Remote Experimentation Centre.

JT60-SA

When completed, the JT-60SA tokamak will the second largest tokamak in the world after ITER. Located in Naka, Japan, this device is the upgrade of an existing tokamak into capable of long pulse operation. The upgrade involved the complete dismantling of the old device, the refurbishing of the buildings, the upgrade of power supply and heating systems. When completed, this facility will support the operation of ITER through complementary experiments to improve the design of the future DEMO reactor.

Getting closer to first plasma

F4E and its Japanese counterpart (QST) made steady progress. The assembly of the torus was almost completed as well as the cryostat and thermal shields. This is great step towards the target of First Plasma in 2020. F4E has delivered all of the components under its responsibility.

The presence of F4E personnel at the Naka site in Japan contributed to the implementation of complex on-site assembly and commissioning operations, as well as successfully integrating EU suppliers in the Japanese safety and management environment.

View of the JT60-SA as operation insertion of the central solenoid advances, Naka, Japan, May 2019

IFMIF/EVEDA

Reproducing the conditions of the future fusion reactors is the challenge of the International Fusion Materials Irradiation Facility (IFMIF). This accelerator-based facility aims to test materials under the conditions of the DEMO fusion device, which will follow ITER. This should allow us to improve the durability of such materials and minimise their activation. The Engineering Validation and Design Activities (EVEDA) for IFMIF are being conducted in Rokkasho, Japan.

Europe and Japan celebrate major milestone in validating LIPAc

To validate the design of the IFMIF neutron source, scientists are building LIPAc (Linear IFMIF Prototype Accelerator). This initiative brings together QST (Japan) and F4E, co-ordinating the contributions to IFMIF from INFN (Italy), CIEMAT (Spain), CEA Saclay (France) and SCK•CEN (Belgium). To accelerate the beam of charged particles with the highest efficiency, LIPAc relies on the world's longest Radio Frequency Quadruple (RFQ): 9.8 m.

After successful commissioning and tests, the scientists managed to accelerate a 125 mA-deuterium beam at 5 MeV at 90% efficiency. It's the first time a beam is accelerated at such intensity and energy. In parallel, further activities for the preparation of the commission phase were conducted to improve the reliability, the control system and the radio frequency power systems.

"We have proof that we can transport the high-energy beam with minimal losses. This is not only a breakthrough for the project, it is a fantastic achievement for those in the field of physics."

Philippe Cara
IFMIF-EVEDA Project Leader

"The IFMIF accelerator will become the most powerful Linear accelerator (Linac) in the world working in continuous wave."

Hervé Dzitko
F4E Project Manager for IFMIF/EVEDA

The team of engineers from the Broader Approach parties involved in the LIPAc tests performed in July, Rokkasho, Japan. They managed to accelerate a beam of deuterium with 125 mA at 5 MeV reaching nearly 90% of transmission.

IFERC

The International Fusion Energy Research Centre (IFERC) Project is hosted in Rokkasho, Japan and comprises three sub-projects:

- The Computational Simulation Centre (CSC) hosted "Helios", a supercomputer which offered the fusion community the possibility to run simulations. In 2019 the CSC prepared the framework for an exchange of computer time between Europe and Japan to allow joint projects in their respective supercomputers.
- The Demonstration Reactor (DEMO) activities aim at reinforcing collaboration with EUROfusion in the area of materials, design and planning. This year, the DEMO Activity Integrated Project Team continued working on pre-conceptual DEMO designs.
- ITER Remote Experimentation Centre (REC) started working on offering Europeans remote access to JT-60SA and the LIPAc accelerator, after having successfully demonstrated remote participation in experiments.

Members of the ITER Organization CODAC group visited REC to agree on a programme of collaboration between the two projects. The programme will help them to test and develop applications proposed by ITER Organization; give ITER Parties access to ITER data and to follow remotely the experiments.

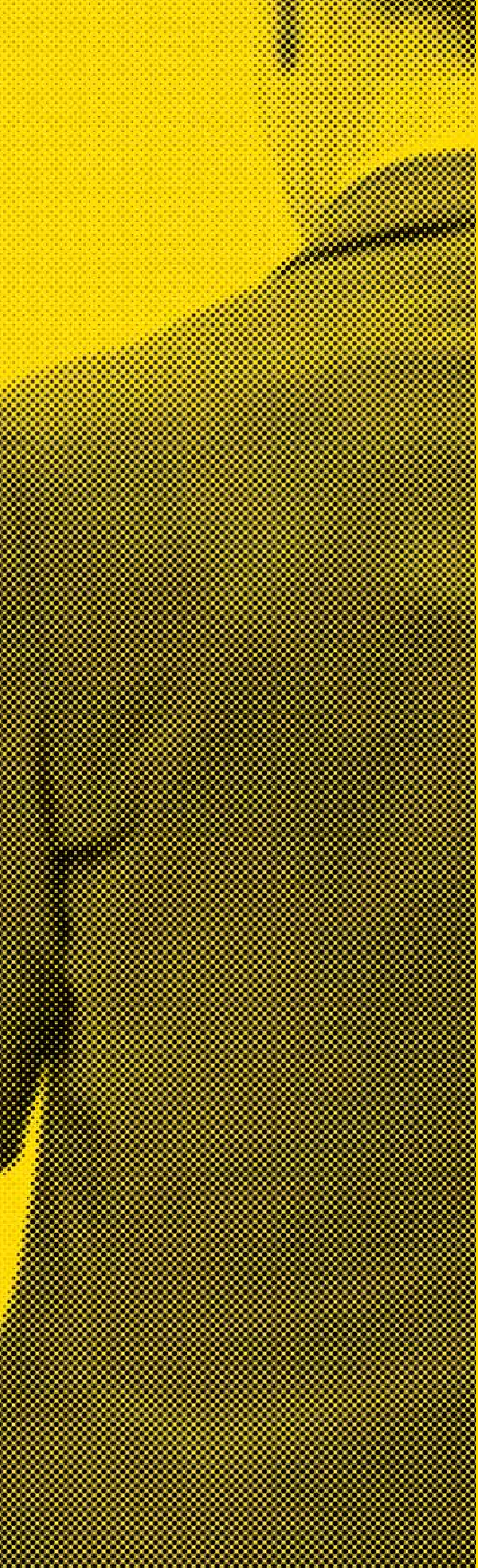
ITER Organization CODAC Group and REC members at the kick-off meeting of the joint programme. The meeting was held in the REC control room, Rokkasho, Japan.

“In phase II of the Broader Approach, we are giving high priority to IFERC in supporting ITER, JT-60SA and IFMIF EVEDA projects. We are also preparing a control room at REC for the Lipac accelerator with remote participation capabilities”

Susana Clement Lorenzo
Deputy Head of Department
F4E Broader Approach Programme and Delivery

Representatives from Europe, Japan, ITER Organization during the kick-off meeting between REC and ITER Organization CODAC Group, Rokkasho, Japan

(L-R) Takahisa Ozeki, QST, Hideya Nakanishi, NIFS, Yasumoto Ishii, QST, Shinsuke Tokunaga, QST, Mi-Kyung Parc, ITER Organization, Denis Stepanov, ITER Organization, Susana Clement Lorenzo, F4E, Noriyoshi Nakajima, IFERC Project Leader



04

Working together with stakeholders

F4E actively engaged with European and national policy-makers through periodic updates and the communication of success stories highlighting 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 support of various F4E committees and the network of ITER Industrial Liaison Officers (ILOs), various initiatives were undertaken to reach out to industry, SMEs and research organisations in order to get involved.

To strengthen the spirit of partnership between ITER Parties, Europe maintained its firm commitment to building stronger ties by improving the flow of information and the exchange of good practice.

F4E Director strengthens ties with Japanese partners

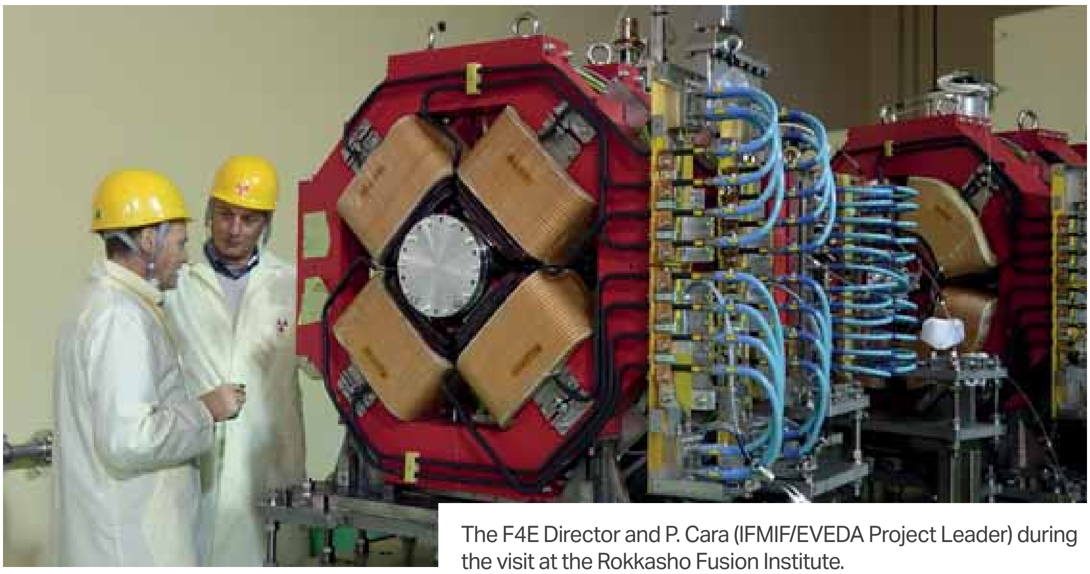
F4E has strong collaborations with Japan through the Broader Approach agreement as well as on the shared ITER projects in areas such as magnets, remote handling and neutral beam heating systems. To deepen working relationships with our Japanese colleagues, F4E Director Johannes Schwemmer visited Japan.

The F4E Director first visited Rokkasho where the sites for the International Fusion Energy Centre (IFERC) and the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) are located. Travelling on to Naka, the F4E Director visited the JT-60SA Satellite Tokamak under construction and met with the top management. Finally, he then visited the main industrial supplier for the cases that will be used for the Toroidal Field Coils being manufactured by F4E.

"I am very impressed by the professionalism and dedication of our Japanese partners which in practice translates to fruitful collaboration and progress concerning Broader Approach and work related to ITER."

Johannes Schwemmer
F4E Director

From left to right: S. Ohira (QST), J. Schwemmer (F4E), P. Cara (IFMIF/EVEDA), K. Sakamoto (QST) and S. Ishida (QST) standing right in front of the LIPAc.



The F4E Director and P. Cara (IFMIF/EVEDA Project Leader) during the visit at the Rokkasho Fusion Institute.

European Parliament sets ITER as an example of European added value

The Budgetary Control Committee of the European Parliament organised a public hearing on the added value of EU funding. The hearing was moderated by its Vice-Chair, MEP Martina Dlabajova. The F4E Director reported on the collaboration of companies and research centres generating success stories and spin-offs thanks to their involvement in ITER. For example, progress made in the field of robotics was successfully used in healthcare, improvements in the fabrication process of superconducting magnets proved conducive to upgrades in MRI.

From left to right: Giovanni Grasso (ASG Superconductors), C.J.M. Heemskerk (HiT), Massimmo Garribba (DGENER Director), Johannes Schwemmer (F4E Director)

Chairman of European Parliament Budget Committee visits the ITER site

In the PF Coil Facility, from left to right: Bernard Bigot (ITER Organization Director-General), Jean Arthuis (Chairman of the Budget Committee, European Parliament), Johannes Schwemmer (F4E Director)

Jean Arthuis, Chairman of the Budget Committee of the European Parliament visited the ITER site on February 2019. The MEP, and former Minister of National Economy and Finance, was welcomed on the site by Bernard Bigot, ITER Organization Director-General, Johannes Schwemmer, F4E Director, and Jan Panek, Head of the ITER Unit at European Commission´s Directorate-General for Energy.

F4E Director showcases ITER contribution and visits U.S. fusion R&D hubs

The success of ITER depends on a strong partnership between Europe and the six other countries involved in the project. To this end, F4E Director, Johannes Schwemmer, visited the United States in order to develop relationships, and exchange knowledge related to ITER with key U.S. contacts within the Department of Energy, U.S. ITER and U.S. fusion laboratories. F4E's Director held a keynote speech at the plenary session of the 28th IEEE Symposium on Fusion Engineering (SOFE).

He also visited General Atomics in California – the company building the ITER Central Solenoid – as well as the Oak Ridge National Laboratory (ORNL) in Tennessee where he had the opportunity to see SUMMIT, the most powerful supercomputer in the world and Proto-MPEX, a plasma material testing prototype. In addition, the F4E Director shared experience on procurement during meetings with the U.S. ITER Domestic Agency.

F4E Director J. Schwemmer in front of the SUMMIT supercomputer together with Director J. Wells.

General Atomics' Central Solenoid Fabrication Facility

F4E strengthens cooperation with FAIR Scientific Research facility

F4E signed a cooperation agreement with the international accelerator facility FAIR (Facility for Antiproton and Ion Research in Europe). This is the largest research project under construction in Darmstadt, Germany. When it becomes operational in 2025, FAIR will provide scientists from all over the world new insights into the structure of matter and the evolution of the universe from the Big Bang to the present. The cooperation agreement will support scientific and administrative collaboration to exploit synergies for industrial activities, including industrial policies, market intelligence, contracts management, standardisation of quality criteria and procurement practices.

From left to right: Jörg Blaurock (FAIR's Technical Director), Ursula Weyrich (FAIR's administrative director), Gebhard Leidenfrost (F4E CFO and Head of Commercial Department), Leonardo Biagioni (F4E Deputy Head of Commercial Department), Paolo Giubellino (FAIR Scientific Director).

Member of the European Court of Auditors visits ITER

Jean-Marc Filhol, F4E Head of ITER Programme Department, and Ms Gall-Pelcz in the in the PF Coil Facility, at ITER site.

Ms Gall-Pelcz, member of the European Court of Auditors (ECA) visited the ITER site. Every year, the ECA publishes a report on the annual accounts of F4E that forms the basis for the European Parliament's procedure known as the "discharge" and confirms that F4E has used its annual budget appropriately.

" I am very impressed with the ITER construction site and the considerable progress achieved. It is useful to look beyond the figures as the money spent here is invested in knowledge, jobs and most importantly in our future. "

Ildikó Gáll-Pelcz
member of the European Court of Auditors

05

EVENTS

Spreading the word on fusion energy and Europe's contribution to ITER

F4E participated in various events to communicate how ITER and fusion power are part of the European Union's long-term strategy in delivering sustainable energy and smart growth.

Our members of staff reached out to science and business communities, technology and innovation clusters and different audiences interested in fusion research.

In this section we look back at some of the key events which marked the year.

ITER Business Forum 2019 – 1100 business speed dates in search of commercial romance

Celebrating innovation and its commercial benefits, was the objective of the bi-annual ITER Business Forum. This year's edition brought together nearly 500 companies from all over the world, keen to unleash their business potential, among which a total of 80 companies and laboratories. Their objective was to showcase their expertise and identify potential partners to seal lucrative deals.

Organised by Agence ITER France in Antibes, in the South of France, this event combined intense networking, B2B meetings, speeches by key ITER personalities and social events. Among them, F4E Director Johannes Schwemmer, summed up the win-win relationship between ITER and Europe's economy, while Gerassimos Thomas, the European Commission's Deputy Director-General for Energy, explained how fusion could be in the long run part of the sustainable energy mix and encouraged attendees to "paint a new future and sustain this level of progress."

A delegation of politicians from the regional French authorities; J. Vayron (Director of Agence ITER France), G. Thomas (Deputy Director-General, DG Energy, European Commission), J. Schwemmer (F4E Director), B. Bigot (ITER Organization Director-General) welcomed by B. Blanc, (Assystem).

" Everyone stands a chance! IBF gives you the keys to understanding and better preparing your case for the project. "

Jacques Vayron
Director of Agence ITER France

L. Schmieder, F4E's Project Manager for Buildings, Infrastructure and Power Supplies, during a B2B meeting with companies

F4E representatives at the corporate stand, (L-R): B. Perier, V. Saez, G. Saibene, L. Biagioni, G. Leidenfrost, N. Van de Ven.

Fusion shaping Europe's energy future

The Barcelona Energy Days took place on 6 June 2019 and focused on "Shaping Europe's Energy Future". The event, co-organised by UPC BarcelonaTech University, the Government of Catalonia, the City Halls of Barcelona and Sant Adrià de Besòs, and Fusion for Energy (F4E), highlighted different paths to our energy future with key interventions from Megan Richards, Director of Energy Policy in the European Commission, and Jesús Izquierdo, F4E Associate Chief Engineer The need to develop sustainable energy mix for the future, was one of the key messages together with the long-term contribution f fusion power.

(L-R): Adriana Farran (Dean at the Barcelona East School of Engineering), Ruth Soto (Member of Municipal Council of the City of Sant Adrià de Besòs), Gemma Fargas (Vice-Rector of Social Responsibility and Equality, UPC BarcelonaTech), Stavros Chatzipanagiotou (F4E Head of Communication).

Sweden gets organised to strengthen industrial participation in ITER

Leonard Biagioni, Deputy Head of F4E Commercial Department, presenting business opportunities.

On 6 June 2019, Big Science Sweden and Vinnova, Sweden's governmental agency supporting innovation, organised an industrial day on ITER. More than 60 representatives from government, academia and industry (such as Sandvik, Skanska, ABB AB Energy Industries, and Smarter Electronic Systems), attended the event, many of which already contribute to the European Spallation Source (ESS) located in Lund. The conference was opened by Stina Billinger, State Secretary for Enterprise and Innovation, emphasizing the importance of increased international cooperation on research and innovation, for a sustainable world, and reiterating Swedish commitment to large science projects such as ITER and ESS, as part of the vision to make Sweden the first nation free of fossil fuels.

The key messages from the seminar underlined the progress of the ITER project and highlighted the upcoming business opportunities. Special attention was given to the transfer of experience from the ESS construction (which is close to completion) to the ITER construction: this aspect was mentioned as a priority by both government and industry representatives.

ITER captivates audiences at EU Sustainable Energy Week

The EU Sustainable Energy Week (EUSEW), organised by the European Commission, has celebrated its 14th edition. Over time the event has grown in size, popularity and has become a reference to several policy communities, companies, laboratories, activists. By bringing together more than 4 000 participants, 380 speakers contributing to more than 90 policy sessions, it has become the ideal setting to network, make political declarations, launch new projects highlighting our commitment to cutting down greenhouse gas emissions by making Europe a pioneer in the production of sustainable, clean and efficient energy. A session on fusion explained its merits, the investment undertaken by the EU, and its contribution to ITER- the biggest scientific collaboration aiming to bring us a step closer to this abundant energy.

(L-R) P.Nieckchen, Eurofusion; S. Tabachnikoff, ITER Organization; E. Righi, European Commission, Directorate General for Research; S. Loupasis, European Commission, Directorate General for Energy at the European Union Sustainability Energy Week 2019, Belgium, Brussels , June 2019 © European Union

ITER builds up momentum at the European Research and Innovation Days

In its first edition, the European Research and Innovation Days exceeded all expectations by attracting more than 3000 participants. During the three day event, held in Brussels on 24-26 September under the auspices of the European Commission's Directorate General (DG) for Research and Innovation, policy-makers, industry, laboratories and the science community stressed the importance of investing in those areas, building networks and bridges with other continents.

The ITER exhibit, in the format of a compact movie theatre, travelled to Brussels offering a gripping visual narrative of the progress so far. Aerial views and the testimonies of key personalities involved in the ITER project were projected. To complement the cinematic visuals with persuasive hard talk, Dr. Bernard Bigot, ITER Organization Director-General, was one of the guest speakers at the "Euratom - research for all" session making the case for fusion research. He explained the principles of fusion energy, the technology involved and the significance of the ITER project.

(L-R) Katja Rauhansalo, ITER Organization; Aris Apollonatos, F4E, standing in front of the ITER exhibit and making the case for EU research at the European Research and Innovation Days, Brussels, September 2019.

(L-R) Concluding remarks by Elena Righi-Steele, Head of Euratom Research, DG Research and Innovation; Patrick Child, Deputy Director-General of DG Research and Innovation; Eric Van Walle, Director-General of SCK CEN; Bernard Bigot, Director-General of ITER Organization; Nathan Paterson, Foratom, at the European Research and Innovation Days, Brussels, September 2019.

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