FUSION FOR ENERGY

HIGHLIGHTS 2018

THE MAIN ACHIEVEMENTS

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FOREWORD

It's all about perception: my personal perception is that 2018 has been a pivotal year for ITER and F4E in the public perception. ITER had been 'the project that takes one year longer every year'. Now it is more like, 'it has taken a long time, but it looks like now they're really building it. Let's have the patience to see it working; it may end up really providing the abundant clean base load energy that we so badly need'.

In the key publication for 2018 Conference of the United Nations on Climate Change (COP24) - I advocated **solar fusion as an *"abundant, safe and sustainable base load energy for the future"*** and the **ITER project as the next major milestone to solar fusion energy.** Two years ago, the COP committee would not have perceived this contribution as credible – now they do.

F4E is delivering half of ITER's components, including all of the buildings. In 2018, F4E collaborated even more trustfully with the global ITER partners China, India, Japan, Korea, Russia and the US. Together we passed the halfway mark to switching on ITER in the first configuration in 2025.

Since 2007, F4E has partnered with more than **500 companies and 70 research organisations** through more than **740 contracts**. The investment in ITER has already produced **benefits in the order of 4.8 billion Eur and 34 000 job years to the European economy**. High tech ITER work generates innovation and spin-offs.

On ITER's construction site in France **2000 people are working around the clock**. What is different from before? You can see not just the buildings rise, but also the subsystems of ITER nearing completion. Most of them on their own would be considered noteworthy large research infrastructures (such as the largest Cryoplant in the world, for example), costing many hundreds of millions, and upping the ante of the technologically feasible.

Through this publication you will see the highlights of F4E's contribution to ITER, and I encourage you to view the videos on our website.

However, ITER is not the only fusion programme at F4E. Japan partners with Europe on the so-called **Broader Approach** fusion projects:

The **IFMIF/EVEDA accelerator** started operating for the first time in 2018, entering its commissioning phase.

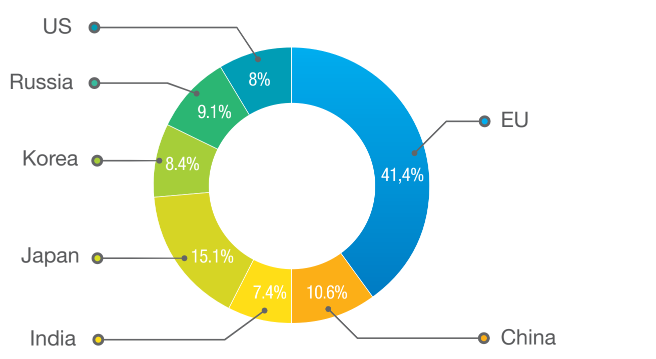
The Tokamak **JT-60SA**, will be the world's largest fusion experiment by the end of 2020, until ITER comes on line. In 2018, F4E provided and installed the final two superconducting magnets together with the European labs. Stay posted.

I invite you to look through this publication and discover many more of our achievements during 2018.

Johannes P. Schwemmer
Director of Fusion for Energy

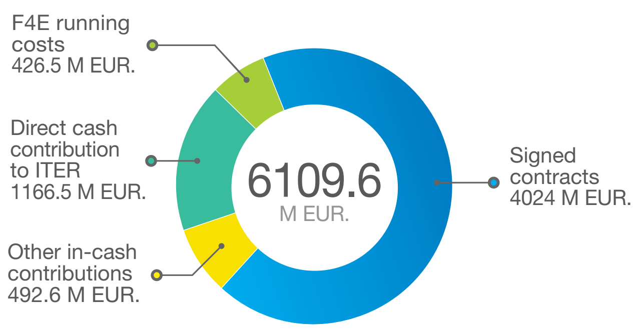
2018 KEY FIGURES

Contributions to ITER



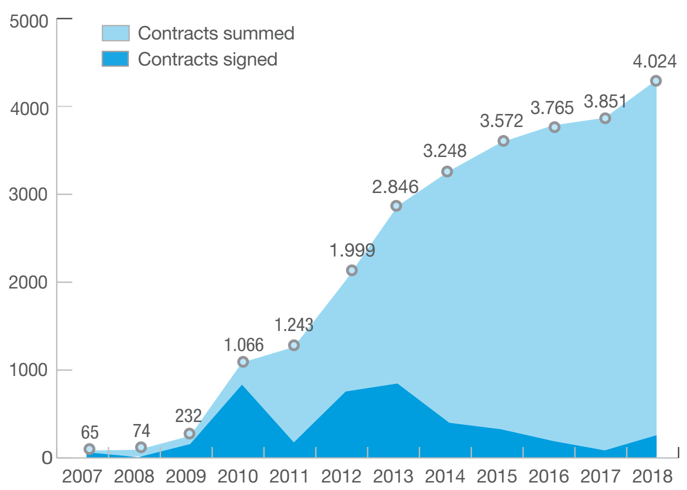
Total contributions between the different ITER parties 2008-2018

F4E budget breakdown

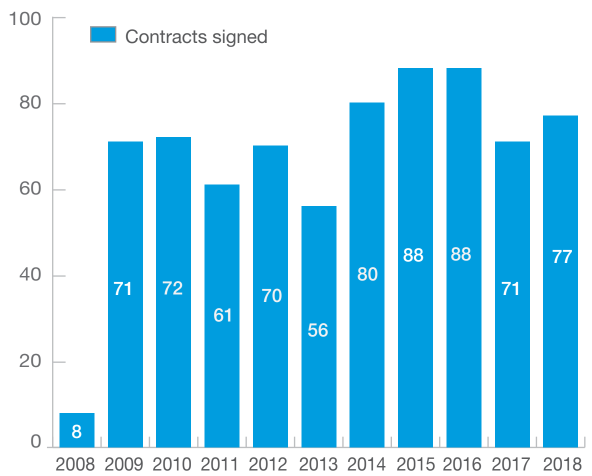


Budget breakdown of F4E main activities 2008-2018

Value and quantity of signed contracts

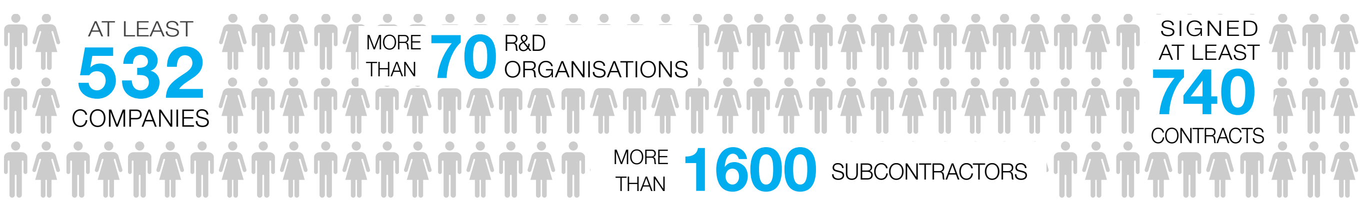


Annual and summed value of contracts signed

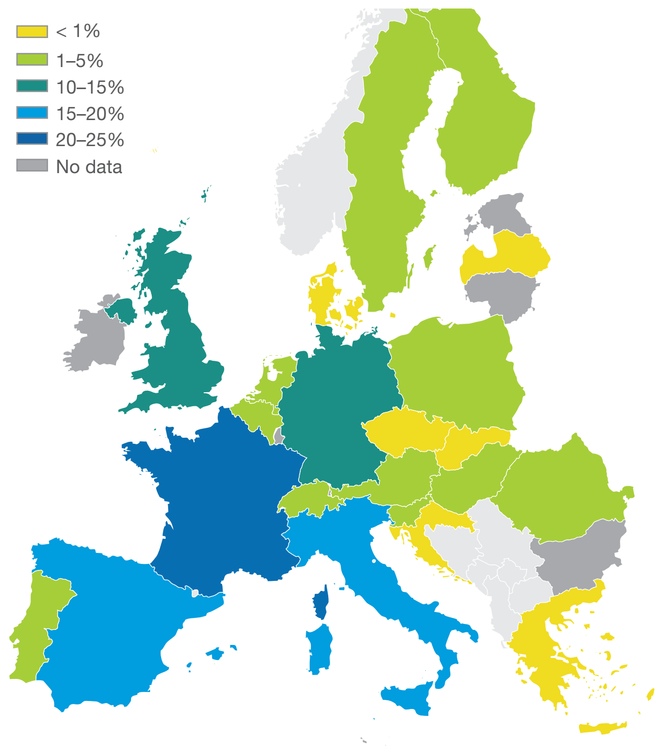


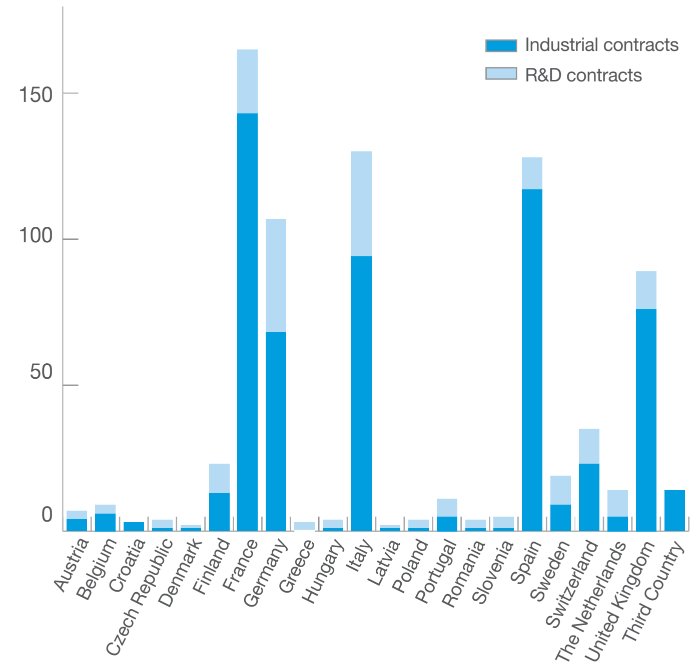
Number of contracts signed

Since 2008 F4E has been collaborating with:



Geographical distribution of contracts awarded by F4E 2008-2018





Geographical Distribution of contracts signed by F4E 2008-2018

2018 Highlights

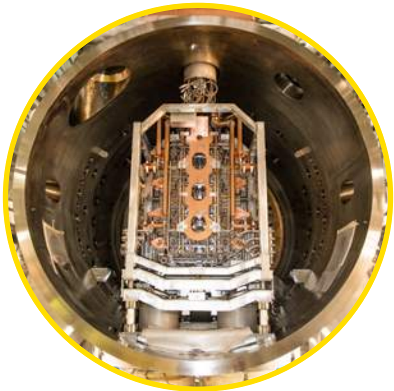
Some of the F4E achievements during 2018

January

After the final pouring of concrete for the ITER bioshield, workforces started building the crown upon which the machine will be installed. More components for JT-60SA arrived in Naka, Japan.

February

Europe's first tanks installed in ITER Cryoplant. Spain's Secretary of State for European Affairs paid official visit to the F4E headquarters. Last JT-60SA Toroidal Field coils, manufactured in Europe, reached Japan.



March

SPIDER beam source installed in its vacuum vessel. Lid placed over ITER bioshield. Europe's first Electron Cyclotron power supply unit tested successfully. F4E and ASIIP completed halfway the winding and impregnation of sixth Poloidal Field coil. Fusion opportunities presented in Big Science Business Forum.

April

Industry produced and delivered all forgings and plates for ITER Vacuum Vessel sectors. Final JT-60SA Toroidal Field coil installed. F4E developed simulation of tritium transport for Test Blanket System. First cold tests performed successfully for Europe's ITER Toroidal Field coils.

May

European prototypes for ITER Divertor Cassette completed. All of Europe's cryogenic tanks and cold boxes of ITER Cryoplant installed. Inner-Vertical Target prototype unveiled. Diagnostics Information session organised by F4E. INCOSE South European Systems Engineering workshop held at F4E.

June

SPIDER beam source switched on to produce first plasma. More water detritiation tanks delivered to the ITER site. F4E presented ITER in Barcelona Energy Days. The merits of fusion energy discussed during the EU Sustainable Energy Week. ITER Council Delegates visited one of Europe's factories for Toroidal Field coils.

July

Europe and Japan operated IFMIF/EVEDA accelerator to deliver its first beam. Winding completed for Europe's sixth Poloidal Field coil. MITICA Neutral Beam Test Facility test facility received equipment for its cryoplant. F4E and ITER IO raised awareness on fusion technology at World Nuclear Exhibition.

August

Crown of ITER machine completed. First port cell doors started being installed in Tokamak building. Pre-compression Rings Test Facility received first tooling.

September

Further subassemblies for ITER Vacuum Vessel sectors completed. F4E reported on progress of European contribution at SOFT. Potential of fusion energy presented at Global Power & Energy Exhibition.

October

MEP Martina Dlabajova, Vice-Chair of the Budgetary Control Committee, visited ITER. First fiducial nests installed in the Tokamak building. F4E launched e-tenders platform. Finnish consortium successfully tested the potential of digital hydraulic valves for ITER Remote Handling. F4E hosted European Physical Society energy meeting.

November

Europe and Russia started testing ITER Inner-Vertical Target prototype. European power supplies equipment installed in MITICA. Design of Remote Handling for Diagnostics port plugs successfully validated. All European double pancakes for ITER Toroidal Field coils manufactured. Fusion energy presented as future alternative at COP24.

December

Europe inserted the first ITER Toroidal Field coil in its case. F4E signed contract for MITICA beam source. Pre-Compression Rings facility completed. Europe signed deal for the production of Divertor Cassettes. Preliminary design review launched for Divertor Cassette Remote Handling system.

SOME OF THE ITER ACHIEVEMENTS DURING 2018

FIRST QUARTER

- India made progress with the third section of the ITER Cryostat. The 10 m tall cylindrical component weighs 430 t.
- The first two out of a set of 18 transformers manufactured by Korea were delivered for installation outside the Magnet Power Conversion buildings.
- First Russian gyrotron unit underwent factory acceptance testing at GYCOM. Then, the units were stored in order to be installed in the Radio Frequency Building at a later stage.
- Korean manufacturer Taekyung Heavy Industries manufactured and assembled the second sector sub-assembly tool plus installed all actuators.
- The first of 18 supports for the ITER Toroidal Field coils underwent testing in China. The magnet supports will sustain a dead weight of 10 000 t and have the flexibility to withstand the displacement of the coils during cooldown and operation.
- Japan manufactured the first two out of the eight gyrotron units. They were tested at The National Institutes for Quantum and Radiological Science and Technology (QST).
- A full-scale prototype of a blanket shield block manufactured in China successfully passed acceptance tests, including the challenging hot helium leak testing. China is responsible for half of the blanket shield blocks required by ITER (220 units).

THIRD QUARTER

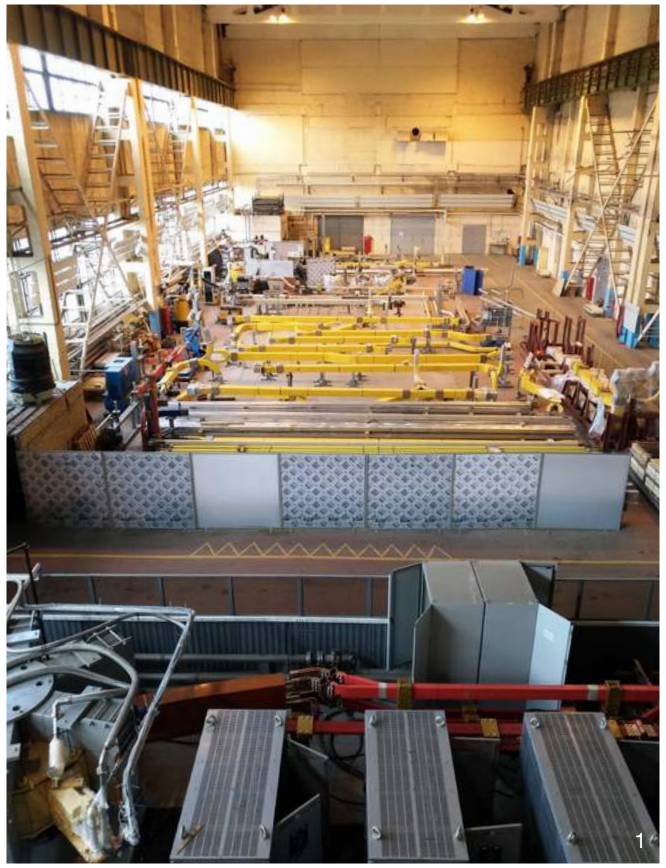
- Qualification activities performed to seal the correction coil case in China. High-power laser weld system specially developed by ASIPP. [4]
- General Atomics, contracted by US ITER, completed testing of the mockup coil to confirm the readiness of all module manufacturing processes. Fabrication started for five out of the of the seven central solenoid modules.
- First Japanese Toroidal Field coil winding pack was cold tested this bespoke cryogenic chamber at Mitsubishi. Before shipment to ITER, the winding pack will be inserted in its structural case.
- The first 12 m tall sector of the ITER Vacuum Vessel thermal shielding was successfully assembled from 23 stainless steel panels. Nine of these sectors will be installed between the vacuum vessel and the magnets.

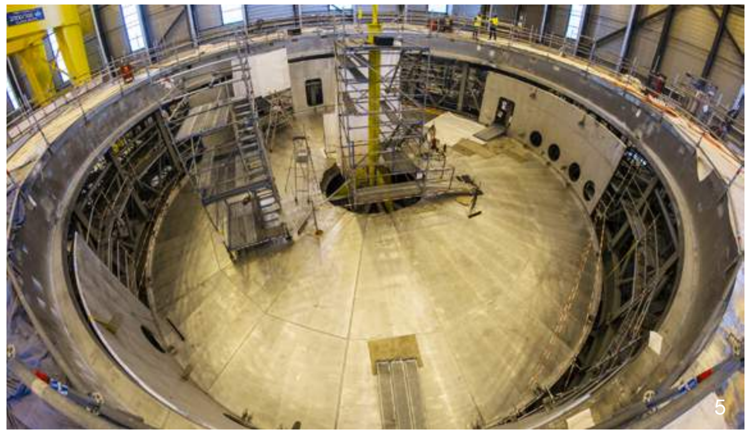
SECOND QUARTER

- Series production of busbars advanced. Russia is supplying the massively rigid cables that will connect the main ITER coils to their power supplies. [1]
- India made progress with the production of cooling water valves. This large valve (DN 1600) has been manufactured for the ITER cooling water system.
- The second of the 19 Toroidal Field coil case was completed. Part of the manufacturing, procured by Japan, is carried out by Hyundai Heavy Industries, Korea, and part of it by Mitsubishi Heavy Industries. The two halves matched perfectly to form the coil case. [2]
- General Atomics, US contractor for the manufacturing and assembling of the ITER Central Solenoid, received the last crate of conductor from Japan. [3]
- Russia's second gyrotron successfully passed acceptance tests at the Institute of Applied Physics and GYCOM Ltd.
- The first magnet supports were shipped. China finalised a first lot of 18 clamps for ITER's fifth Poloidal Filed coil. More than 1 600 t of forged steel supports will be required by the superconducting magnets to resist thermal and electromagnet loads during operation.
- Last steps for the qualification of the bottom/top correction coil performed in China. At ASIPP, a "dummy" superconducting winding pack was inserted into a prototype steel case.
- Russia completed its share of production for the Poloidal Field coils conductor. More than 120 t of niobium-titanium superconducting strands have been produced at the Chepetsky Mechanical Plant in Glazov.

FOURTH QUARTER

- Cryostat fabrication in India reached final stages placing two last orders with Larsen & Tourbo Hazira. Work focused on the 490 t upper cylinder and 665t top lid. Subsequently, contractors executed the final assembly tasks on the two lower sections of the cryostat— the base and the lower cylinder. [5]
- Four transformers delivered to the site ITER—one Poloidal Field coil rectifier from China and three central solenoid converters (89 t each) procured by Korea.
- Manufacturing the port stub extensions procured by Russia for each of the vacuum vessel's upper ports. [6]
- Korea delivered more components of the sub sector Assembly tool to the ITER site. This 800 t tool is 22 m high and can handle a 1200 t subassembly. [7]
- ITER IO in collaboration with Ensa developed a mockup to test its equipment reproducing the joint between two sectors of the ITER Vacuum Vessel. [8]
- A magnet feeder component procured by the Chinese Domestic Agency became the first machine component to be installed in the Tokamak pit.
- Specialists of the Sredne-Nevsky Shipyard and the Efremov Institute in Russia completed the eight double pancake windings required for the first Poloidal Field coil




01

Building ITER

The ITER platform measures 42 hectares and is located in Cadarache, south of France.
It is considered as one of the largest man-made levelled surfaces in the world.
Europe is responsible for the construction of 39 buildings, the infrastructure and power supplies on-site required to operate the world's biggest fusion machine.
More than 2000 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

A platform in fast motion

This year's focus was put on the Tokamak building – the emblematic edifice where the ITER device will be installed. Works on the walls of its final floor started and in parallel finishing works on its first floor kicked off. The bioshield, a massive cylinder made of concrete, acting as a safety barrier between the machine and the rest of building, was built. A large lid was installed to cover the bioshield allowing for works to advance in its interior. The construction of the crown, the concrete foundation upon which the ITER machine will rely on, was also finalised. The arrival of six port cell doors together with that of a poloidal field coil feeder marked the beginning of installation activities in the Tokamak building. Regarding ITER's connection to France's national grid, the final tests were successfully carried out leading to a permanent and steady supply of power.

Europe and its contractors handed over to ITER Organization the infrastructure of the Cooling Towers so that the installation of equipment begins. Civil engineering and finishing works advanced in the Assembly Hall and the Radio Frequency building. Finally, there was more progress with the construction of galleries covering the pipes of the various buildings.

Here are some of this year's main achievements on the ITER construction site.

Construction in progress

Contracts signed	73%
Construction completed	47%
Tokamak	52%
Assembly bldg.	87%
Site Service bldg.	82%
Cryoplant bldg.	78%
Power Supplies	50%
Magnet Power Conv. bldg.	85%
Cooling Towers bldg.	95%
Radio Frequency Heating building	45%

Putting a lid on the bioshield

F4E and its contractors, together with ITER Organization, took positions to lift the 30 m diameter lid of the bioshield. The VFR consortium (consisting of Vinci, Ferrovial, Razel), responsible for the civil works of this building, put its trust on VSL Heavy Lifting, a company specialised in heavy-load lifting operations, to perform this task.

The technical teams placed eight hydraulic jacks on eight metallic structures to lift with cables the 150 t lid that will cover the inner-tower of the Tokamak building. It was fixed on beams and will remain on top until April 2020 when the first assembly operations begin.

View of the ITER Bioshield lid positioned 30 m high ©ITER IO

Bioshield and crown ready

The construction of the bioshield, a safety barrier between the ITER machine and the rest of the Tokamak building, was concluded. The 30 m high tower with 3.5 m thick walls is made of concrete with steel bars, embedded plates and heavy anchoring equipment.

The civil engineering works of the crown also came to an end. The solid base ring of the bioshield consists of 18 massive blocks of steel that will support the equipment of the ITER machine (weighing approximately 23 000 t).

Top down view of a fully-formed crown © ITER IO

Tokamak complex reaching for the sky

Civil engineering works in the Tokamak complex accelerated. Europe's contractors started constructing Level 5 (sixth floor) of the Tokamak building and began to perform finishing works on Level B1. At the Diagnostics building, Level 5 (sixth floor) walls started to be raised. Towards the end of 2018, the first piece of equipment was installed in the Tokamak building.

TOKAMAK COMPLEX

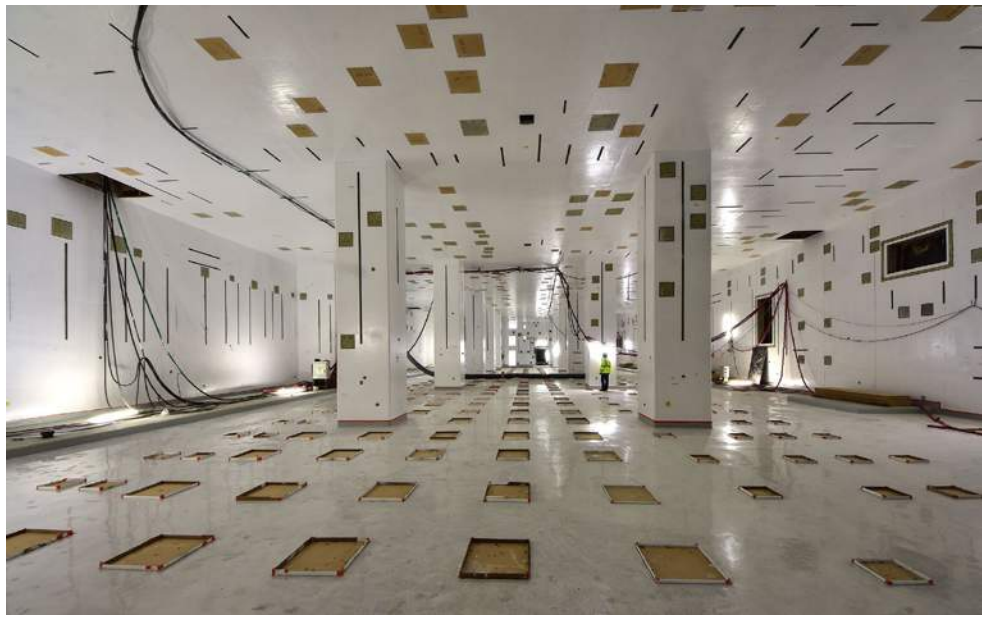
Diagnostics, Tokamak and Tritium buildings

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

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

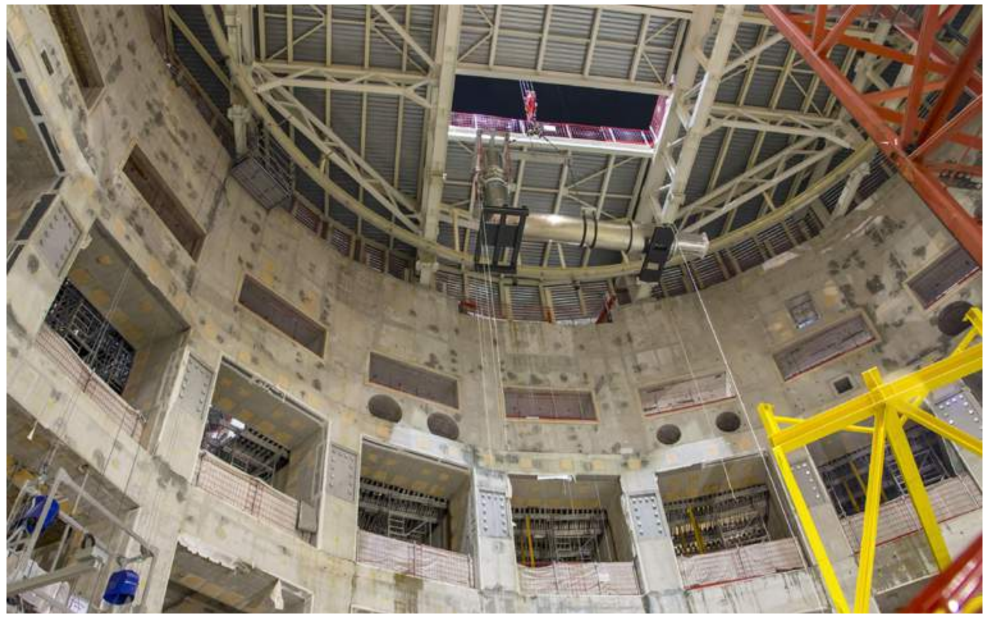
Aerial view of the Tokamak Complex © ITER IO

Pouring of borated heavy concrete in the area of the cooling water exchangers in the Tokamak building © ITER IO



The first level of the Diagnostics building ready for handover to contractors for the beginning of systems installation.

The embedded plates visible on all surfaces will allow contractors to attach the supports required to install various systems. © ITER IO

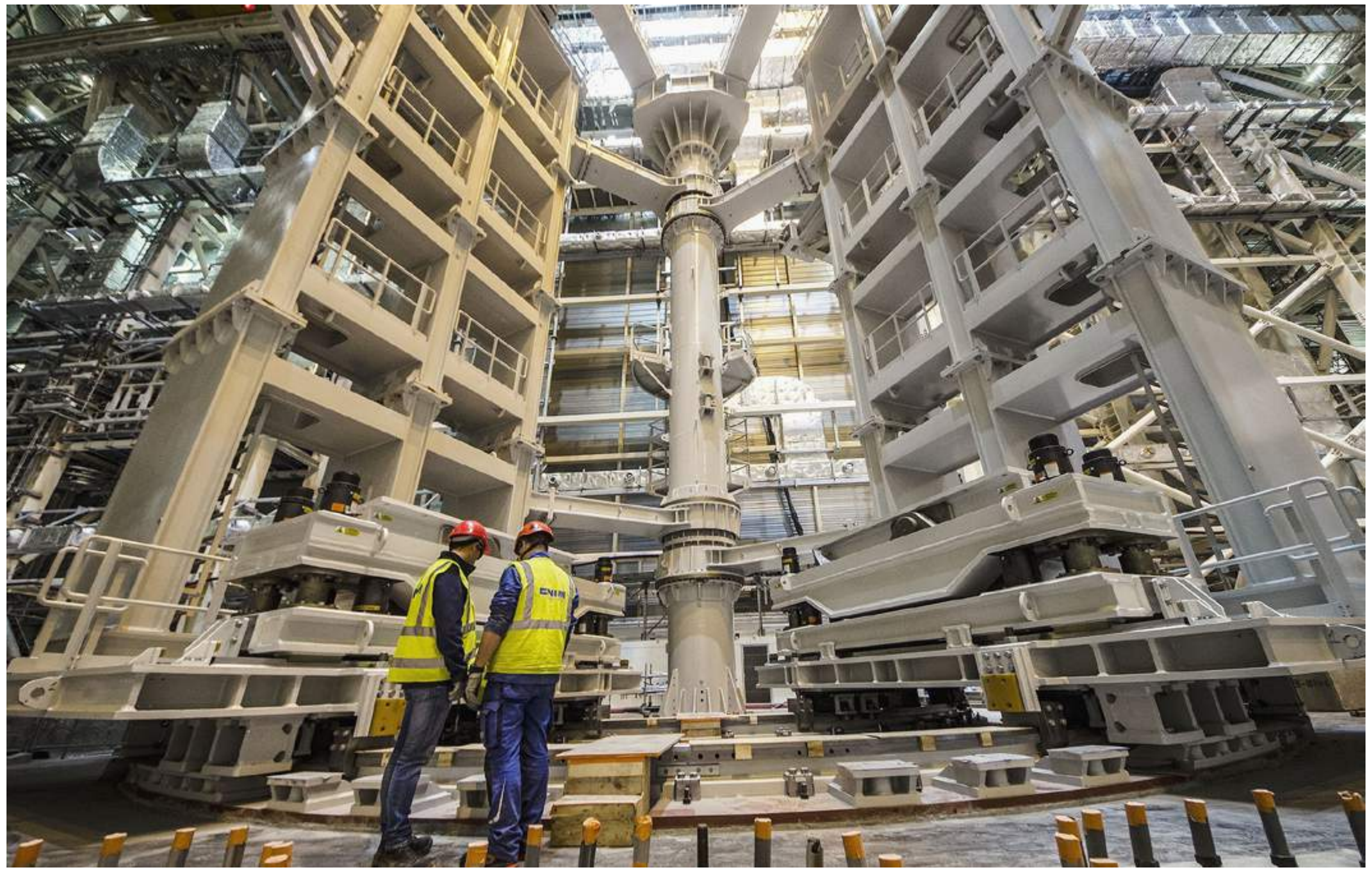


The first metal piece of the Tokamak installed in the bioshield (a 10 m, 6.6-t feeder component delivered by China). ITER's logistics provider DAHER, together with the VFR consortium, and ITER engineers from the In-Cryostat Assembly Section were all involved in the operation. © ITER IO

2000 eyes to oversee the works in the Tokamak Complex

The Metrology groups of F4E and ITER Organization set up a network to increase the level of precision in the works performed on-site. With the help of special software, fiducial nests were installed to help engineers identify the exact position of each component in the Tokamak complex. So far, 1 000 of these nests are keeping an eye on the site and another 1 000 will follow. Thanks to the installation and the measurements provided by the fiducial nests, 10 000 embedded plates were scanned.

Giacomo Calchi, F4E Metrology, holding a fiducial nest before it gets installed in the Tokamak building



First tool in place missing only hydraulic and electrical connections © ITER IO

More tooling delivered to the Assembly Hall

Electrical works together with heating, ventilation and air conditioning installation were nearly completed for the entire facility. Technical teams fully assembled the first sub-assembly tool for the vacuum vessel sectors, procured by ITER Korea. The installation of a second tooling has been in progress.

ASSEMBLY HALL

100 m long
60 m wide
60 m high
Two 750 t cranes to lift 1 500 t

Aerial view of the ITER Cryoplant during installation © SNC Engage

Equipment installed in ITER Cryoplant

Europe's tanks and cryogenic boxes were installed. Think of the cryoplant as a massive refrigerator which is going to cool down the components of the ITER device. Magnets, for instance, will need to reach a superconducting state at 4.5 K (close to absolute zero) in order to confine the hot plasma.

CRYOPLANT

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

Construction completed for Magnet Power Conversion buildings

Civil engineering works for the two buildings came to an end. The twin 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.

(L-R) Cryoplant, Magnet Power Conversion buildings © ITER IO

The handover of the cooling tower zone from F4E to the ITER Organization © ITER IO

Handing over to ITER Organization the Cooling Water Towers zone

Hot and cold cooling water basins, powerful pumps, heat exchangers, and an induced-draft cooling tower with ten individual cells will be located in a 6 000 m^2 area. 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.
Following the completion of the infrastructure works, Europe handed over the Cooling Water Towers area to ITER Organization so as to start erecting the towers. Next, the ITER team will supervise the installation of equipment sent by India.

A labyrinth of galleries underground

A big part of the construction activity also unfolded a few metres underground. The workforces and machine operators were drilling and digging to create an entire network. Tunnels and trenches are part of the galleries that will house the pipes of the ITER platform. Works advanced reaching a 74% completion rate.

Technician checking the equipment before it is moved on-site © SNC Engage

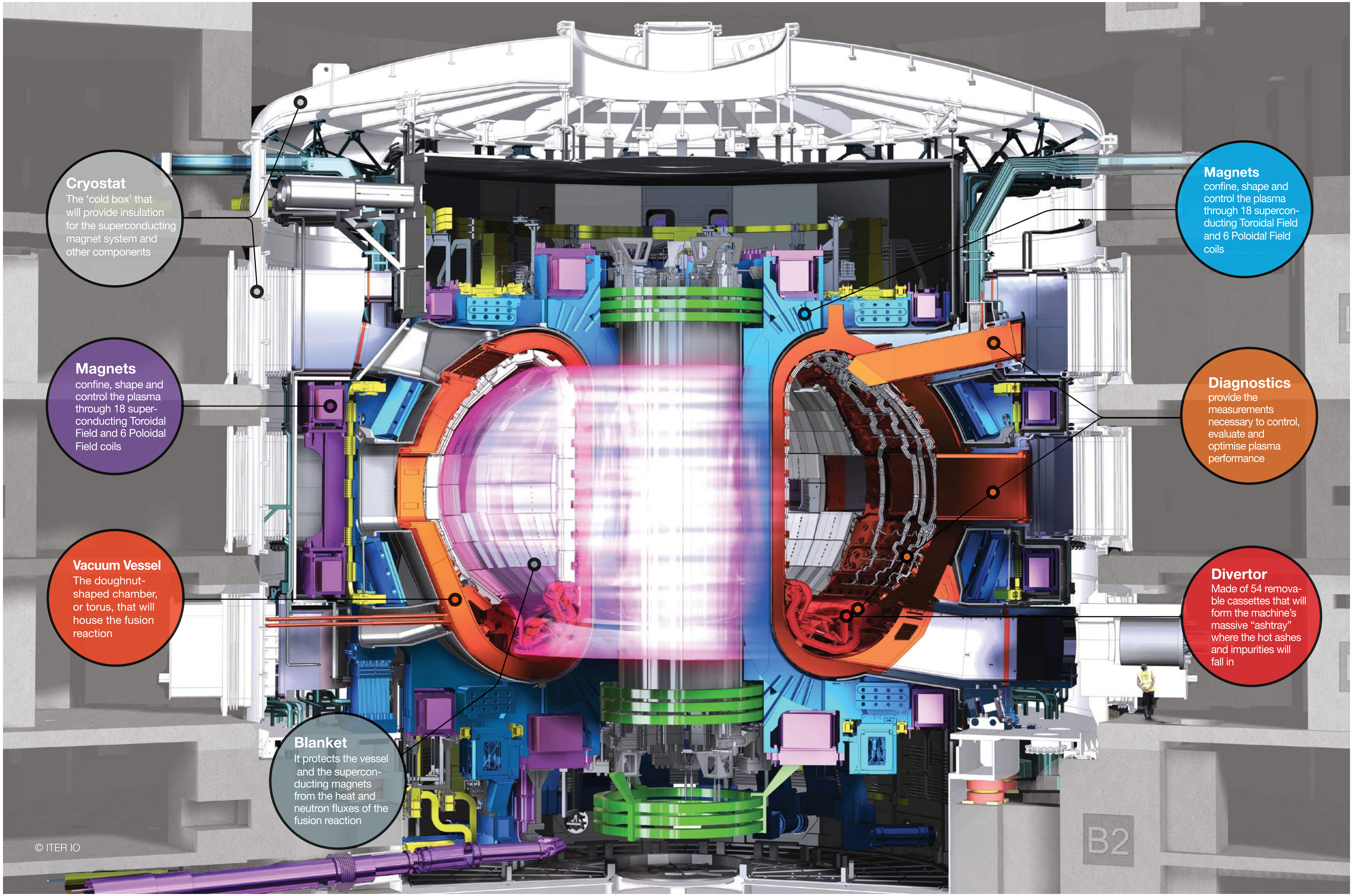
Works advancing in galleries © SNC Engage

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 500 main contractors and approximately 1600 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
© 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	44%
Design	58%
Manufacturing	3%

Information Day on manufacturing engineering support for the Diagnostics systems

Around 28 companies from all over Europe such as AVS (Spain), Alsyom (France), Thales Alenia Space (Italy), KT Optics (Germany) and ISQ (Portugal) attended the meeting which sought to present the main points of F4E's requirements for the tender in the area of Diagnostics.

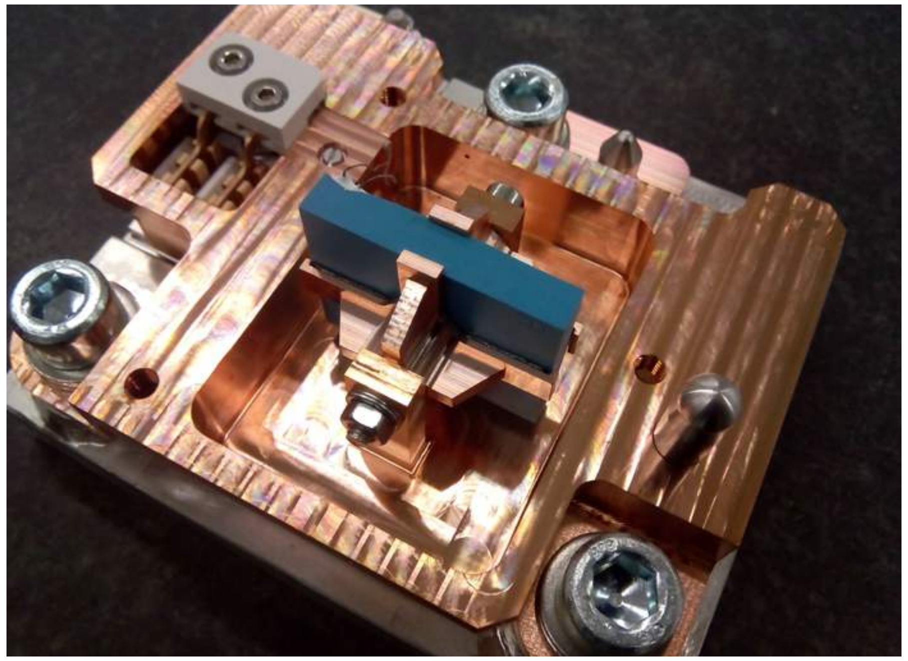
While the design of F4E's Diagnostics contribution is being conducted under Framework Partnership Agreements by European Fusion Laboratories (EFLs) most of the Diagnostics are currently under preparatory design stage. Support will be required during the design phases in order to make sure that Diagnostics systems can be manufactured within cost and schedule.

Participants of the information meeting about the Diagnostics Engineering Services Call for tender.

Remote Handling design for ITER Diagnostics port plugs successfully validated

Shielding modules will be manufactured to support and protect various Diagnostics systems from neutrons. These steel structures weigh up to 3 t each and will be mounted in many of ITER's port plugs. F4E will supply nine such modules, which will be installed in the five Diagnostics port plugs provided by Europe to ITER. Due to the fact that their maintenance and repair must be done remotely, experts from the UK's Remote Applications in Challenging Environments (RACE) facility led a series of tests. Representatives of F4E, ITER Organization, IDOM, and ITER Japan were there to follow them and to certify their success.

Members of UKAEA's RACE facility, leading the tests, together with representatives of F4E, ITER IO, ITER Japan and IDOM ADA, responsible for the design of the DSM.



The upper part of the mock-up of the platform that will be manufactured by Sgenia © ITER IO

Manufacturing the Inner-Vessel coil mechanical platforms

F4E signed a contract worth 1.3 million EUR with Spanish company Sgenia to produce 450 platforms into which diagnostic sensors will be integrated. The purpose of these platforms is to provide mechanical support, protection and electrical connectivity for the sensors. This is the largest manufacturing contract placed to date by the F4E Diagnostics Project Team.

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 super-hot plasma, which is expected to reach 150 million °C, a first layer of magnets consisting of the Toroidal Field (TF) coils will entrap the hot gas and keep it away from the walls of the vacuum vessel. Out of the 18 TF coils in ITER, Europe will manufacture ten, involving more than 600 people from 26 companies. Japan will manufacture eight of them plus one spare.

To cope with the fatigue exercised on the TFs, and with the deformation resulting from the powerful magnetic fields, three pre-compression rings will be placed on top of them and three below them. An extra set of three will be manufactured as spare in case there is a need in future to replace the lower set.

Finally, six Poloidal Field (PF) coils will be used to 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, of which one will be manufactured in China. The remaining coil will be produced in Russia.

Work in progress
Toroidal Field coils

Contracts signed	100%
Tooling	96%
Qualification	98%
Manufacturing	86%

Work in progress
Poloidal Field coils

Contracts signed	100%
Tooling	90%
Qualification	85%
Manufacturing	27%

Toroidal Field coils

Europe finalised the production of all Double Pancakes

The completion of the 70 Double Pancakes, was an important milestone for F4E and its suppliers – ASG Superconductors, Iberdrola Ingeniería y Construcción, CNIM, SIMIC, Elytt, and ICAS.

In each Toroidal Field coil there are seven Double Pancakes. In two of them the cable-in-conduit conductor measures 450 m in length, while in the remaining five it measures approximately 750 m.

Technician lifting a Double Pancake, ASG Superconductors, La Spezia (Italy) © Andrea Botto

TOROIDAL FIELD COILS

The gigantic "D" shaped coils will be the biggest Niobium-tin (Nb3Sn) magnets ever produced, which once powered with 68 000 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.

European Toroidal Field coil cold tests started

Three Toroidal Field coil winding packs left from ASG Superconductors (La Spezia) and were delivered to SIMIC (Port of Marghera) to go through the final steps of manufacturing. The cold tests were successfully completed for all them.

Simple guide to tests:
Upon arrival, the coil goes through dimensional and electrical checks.

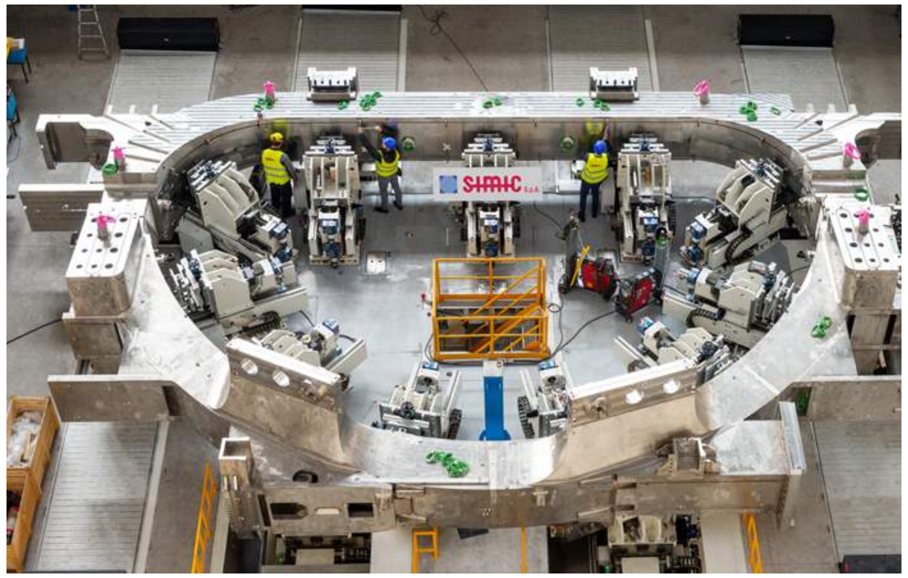
Next, the coil enters into the cryostat to be cooled down at 80 K (-200 °C) for nearly 20 days using a combined cycle of nitrogen and helium. Meanwhile, its electrical connections are placed at the exits of the cryostat to be tested with a current of 1000 A.

Afterwards, dimensional and electrical checks are performed to inspect the state of the coil.

Then, the coil is moved to the assembly rig to be inserted into its case using state-of-the-art tooling and laser dimensional technology. 110 t will need to fit in the cases with millimetric precision.

Finally, the cases will need to be welded in order to be fixed firmly around the coil.

Europe's first Toroidal Field coil winding pack to undergo cold tests, SIMIC, port of Marghera, Italy © SIMIC



Europe's winding pack inserted into its case coil, SIMIC, Port of Marghera, Italy. It is the first time that this operation is performed in the history of the ITER project © SIMIC

"We need to acknowledge the years of R&D that we have capitalised on to get where we are. We started more than 20 years ago developing the concepts of this component."

Paolo Barbero
Project Manager - SIMIC

Operation insertion accomplished

F4E in collaboration with SIMIC successfully inserted the inner-core of a Toroidal Field coil, known as "winding pack", in its case. The achievement was not only recorded as a first for Europe but also for the ITER project. The winding pack was enclosed in its heavy stainless steel panoply of approximately 150 t. The TF coil cases, under the responsibility of ITER Japan, were produced by Mitsubishi Heavy Industries (Japan), and Hyundai Heavy Industries (Korea). They measure no less than 17 x 10 m and will protect the magnets almost like an "overcoat".

"We have entered the final production stage of the TF coils and it is the first time that we are performing these manufacturing steps."

Alessandro Bonito-Oliva
Project Team Manager - F4E Magnets

Technicians checking the tooling, performance of material and the method to produce the ITER Pre-Compression Rings © CNIM

Europe approved the technology, tooling and materials

After various tests, F4E agreed to use pultruded laminate for the production of the pre-compression rings. The material will be wound along the trajectory of the ring. As the tooling will be slowly bending the material, a bonding tape will be applied on its layer.

This helical movement is repeated several times until the pre-compression ring consists of multiple layers which will then be cured. Then, the ring will be placed on an equipment to be machined to the final dimensions and to remove excessive material.

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.

ITER Organization, CNIM and F4E deliver the Pre-Compression Rings Facility

CNIM in collaboration with Douce Hydro delivered the facility where the ITER Pre-Compression Rings tests will be performed. The contract was awarded to the consortium by ITER Organization, while the conceptual designs of the facility and its technical progress were followed by F4E.

The tests will assess the fabrication of the components by checking their resilience to high loads. When positioned on the tool, the 36 actuators will start to operate simultaneously, maintaining an accuracy of 0.1 mm while releasing a total force of 36 000 t — similar to the pressure exercised by 6 000 African elephants, the biggest mammals living on land, when they walk. The stress tests will last a few hours and will be complemented by other tests to confirm that the creep and fatigue performances are also adequate.

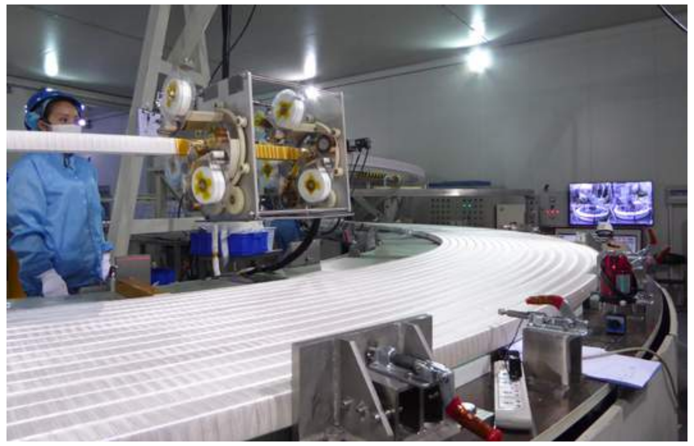
The tooling which will be releasing a force of 36 000 t to test the quality of the ITER Pre-Compression Rings, CNIM, La Seyne-sur-Mer, France.

Poloidal Field coils

Stepping up the production of the massive magnets

The engineers from F4E, ASG Superconductors, and CNIM, working in the magnets factory on the ITER site, and the team in ASIPP, the Institute of Plasma Physics of China's Academy of Sciences, made further progress with the manufacturing of the Poloidal Field (PF) coils assigned to Europe.

Group photo of ASIPP team celebrating the completion of the conductor winding for PF6.



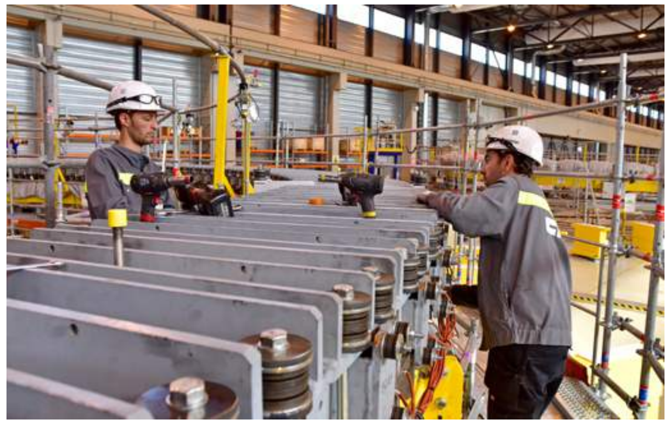
Wrapping and insulating with Kapton and fiber and glass tapes the conductor of the sixth Poloidal Field coil

PF6 Winding Pack on its way

The sixth Poloidal Field (PF6) coil consists of nine pairs of windings, known as Double Pancakes (DPs). ASIPP concluded the winding of the conductor and the impregnation of all DPs. After stacking of the DPs, the internal electrical connections were checked to form the Winding Pack.

Half of PF 5 completed

Six out of the eight Double Pancakes were wound. Five of them were terminated, passing successfully electrical tests, and four of them were impregnated, making them resistant to the extreme forces inside the ITER machine. A mock-up of a winding pack, consisting of multiple layers of impregnated conductor lengths, was assembled to identify any production glitches before real manufacturing kicks in at this level. The next stage is to commission the cryostat and the cryoplant.



Technicians checking the equipment to be used for the impregnation of the Poloidal Field coils.

POLOIDAL FIELD COILS

The construction of the PF coils factory has been financed and delivered by F4E through a contract signed with the consortium of Spie batignolles, Omega Concept and Setec. The factory 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 PF coils factory 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 house 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.

All forgings and plates for European vacuum vessel sectors delivered

Five of F4E's sub-contractors, namely Acciaierie Valbruna (Italy), Forgiatura A. Vienna (Italy), Industeel (France), Rolf Kind GmbH (Germany) and ThyssenKrupp (Germany), produced and delivered all the remaining forgings and plates which will be used on the five vacuum vessel sectors which are under Europe's responsibility. Around 1100 forgings and 150 plates were delivered at Mangiarotti S.p.A and Walter Tosto S.p.A for cutting and machining into desired shapes and sizes.

Work in progress

Sector 5		
Delivered material	100%
Design	100%
Manufacturing	63%
Sector 4	
Delivered material	100%
Design	98%
Manufacturing	62%
Sector 3	
Delivered material	100%
Design	85%
Manufacturing	56%
Sector 2	
Delivered material	100%
Design	82%
Manufacturing	55%
Sector 9	
Delivered material	100%
Design	84%
Manufacturing	52%

Workers at Mangiarotti S.p.A installing the forgings (in the foreground) in one of the plates (in the background).

The triangular support subassembly for the fourth segment for sector 5, manufactured by Mangiarotti and electron-beam welded at Pro-beam.

The top sub-assembly for the second segment for sector 4 manufactured by Walter Tosto for the Vacuum Vessel ready for electron-beam welding at Pro-beam.

Further segment subassemblies for ITER's vacuum vessel completed

Ansaldo Nucleare, Mangiarotti and Walter Tosto, together with their sub-suppliers ENSA and Pro-beam, produced these segment subassemblies marking a big step towards reaching the final assemblies of the segments. The completed subassemblies, ranging between 14 000 to 11 000 kg, form part of three of the five sectors which make up Europe's contribution to ITER.

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.

REMOTE HANDLING

Remote handling helps us to perform a task without being physically present where it is 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 high precision.

Work in progress

Divertor RH	
Contract signed	23%
Design	65%
Cask & Plug RH	
Contract signed	8%
Design	39%
Neutral Beam RH	
Contract signed	13%
Design	45%
In Vessel Viewing System	
Contract signed	13%
Design	50%

Preliminary Design Review launched for ITER Divertor Remote Handling system

During a two day meeting at ITER organization, F4E's Remote Handling team organised the Preliminary Design Review (PDR) of the ITER Divertor Remote Handling system. Experts gathered to learn, ask and assess the work carried out by F4E and its partners. Europe had signed a contract with Assystem Energy & Infrastructure Ltd, UK's RACE centre (Remote Applications in Challenging Environments), Soil Machine Dynamics Ltd (SMD), (VTT) Finland's Technical Research Centre and the Tampere University of Technology (TUT) to work on this equipment. It is estimated that 10 000 tasks and 4 000 unique functions are required to be carried out in order to replace the component over six months.

"This is the first European system in the area of Remote Handling reaching such level of maturity. The community is eager to learn more about its design and fabrication because something like this has never been tried before."

Carine Van Hille
F4E Technical Responsible Officer

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.

ITER Remote Handling poised to transform the future of digital hydraulics

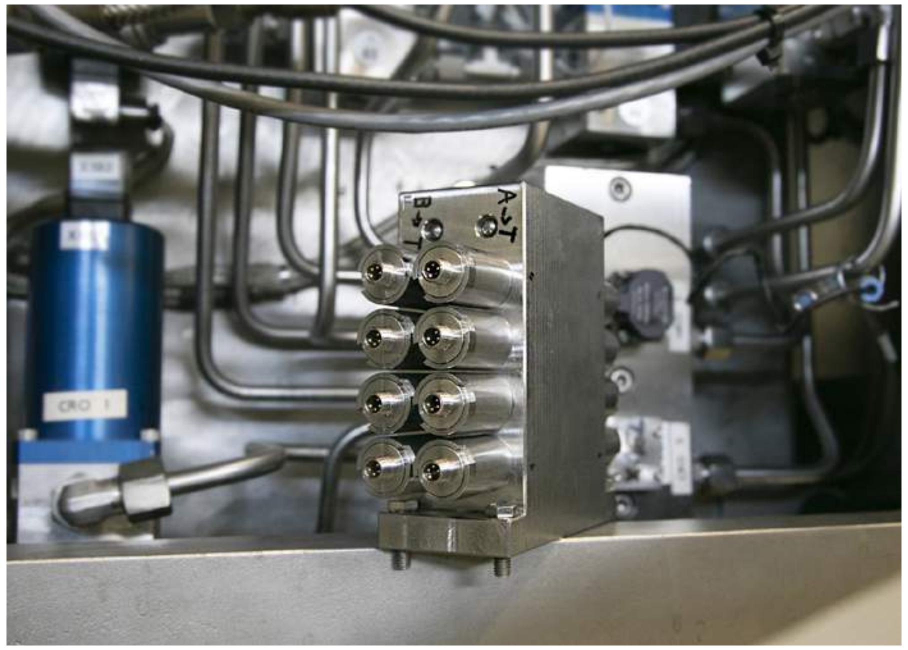
F4E signed a contract with Tampere University of Technology (TUT), Fluiconnecto Oy and Tamlink Oy to explore the possibility of using digital hydraulic valves as part of the remote handling system. After months of trials, the engineers concluded that the digital valves present several merits. First, they are more resilient; second, they offer a combination of various valves and in the event of failure there is a back up to ensure continuity; third, the digital valve system demonstrated a new state-of-the-art control performance.

The successful results motivated TUT, Fluiconnecto and Tamlink to explore the commercial potential of this technology. Digital water hydraulic valves could be used in the fields of transport, aeronautics, construction, industry and machining. Tamlink and TUT have been working the last 20 years in this field. For example, Bosch Rexroth licensed this technology operating with oil. In fact, digital oil valves of such kind are used in some of Finland's high speed trains.

Finnish engineers involved in this technical achievement, (L-R) Harri Sairiala (Fluiconnecto Oy, responsible of the valve design and manufacturing), Miika Paloniitty (TUT, researcher and special water valve advisor), Lauri Siivonen (Tamlink Oy, project coordinator), Matti Linjama (TUT Adjunct Professor) ©TUT

"This is a success story that could yield commercial benefits. The collaboration of R&D centres and companies, making the transition from fusion to other areas of work, shows the diverse mix of technologies we use and their far-reaching application."

Carlo Damiani
F4E Project Manager for Remote Handling



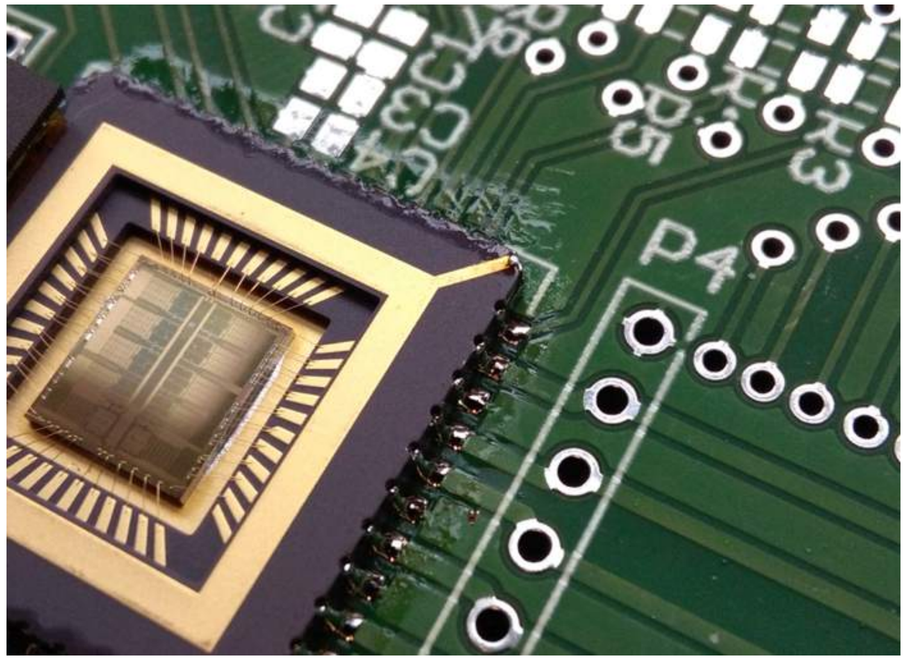
"ITER is probably the most demanding environment we can imagine for a hydraulic system. If we successfully address this challenge, then we will have many possibilities in more traditional industrial applications in future."

Harri Sairiala
Fluiconnecto Technical Responsible

The digital hydraulic valve is the result of collaboration between the Tampere University of Technology, Fluiconnecto and Tamlink. The EU has financially supported this initiative.

Experts discuss mix of technologies to cope with radiation

Europe took the initiative to plan the third ITER Remote Handling workshop during which close to 60 participants met virtually to discuss the latest progress in radiation tolerant technologies. The progress in the field of rad-hard CMOS cameras was presented. The electronics required was the other subject addressed. F4E has been pushing for a smart solution given the fact that cabling must be kept to a minimum. How can the "brain" of the movers and its circuit be neatly installed? Magics and Oxford Technologies, part of Veolia, have been collaborating to develop a multiplexer — a compact box of electronics — which is able to reduce the number of cables needed for the movers to carry out maintenance works in the machine.



Prototype of an electronics integrated circuit chip designed by Magics, contributing to the body of work financed by F4E in the field of rad-hard multiplexers.

GENROBOT – the software that Europe will use in its Remote Handling systems

The successful tests performed at the seat of GTD (Madrid) indicate that this software will allow engineers to install a sense of harmony in the operating system and to rigorously control all ITER Remote Handling machines that Europe has to manufacture. Also, it can be adapted and configured to operate various robotics equipment. Further fine-tuning is expected to be carried out during the first semester of 2019. Then, it will travel to ITER's Remote Handling Facility, Tampere, Finland, where experts will receive training to perform various tests at the Divertor Test Platform (DTP2).

Representatives of GTD and F4E around the test bench of GENROBOT, GTD offices, Madrid, Spain.

"We made time and cost savings. But above all, developed an industrial software system of outstanding quality, complying with SIL-2 IEC 61508 standards, which is a novelty for the market."

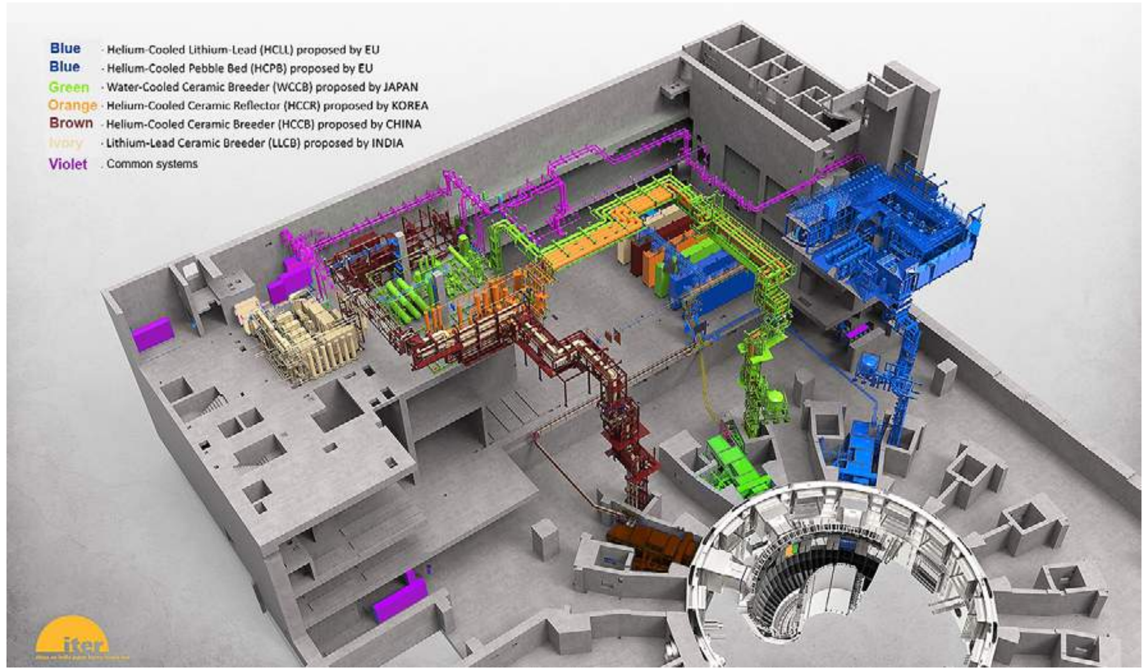
Ruiz Morales
F4E Technical Responsible Officer

"GENROBOT allowed us to enter the robotics market by contributing through our expertise in safety-critical software. For us it has been an interesting journey which helped us acquire new capabilities and made us step out of our comfort zone."

Alejandro Cantos
GTD Robotics Manager

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.



F4E will be able to predict the tritium transport along the different components and materials of the European TBS sub-systems (in blue) ©ITER IO

Simulation platform predicting the transport of tritium in progress

In close collaboration with CIEMAT (Spain) and Empresarios Agrupados (Spain), F4E started developing a computer code based on the EcosimPro simulation platform, able to predict the transport of tritium, through different components and materials of the two European Test Blanket Systems (TBS). Tritium atoms are very small and may easily diffuse and permeate through all types of materials to which they are in contact. For this reason, tritium confinement is essential in order to recover it and to control it from spreading within ITER.

"The outcomes of the computer code are data of tritium concentration and flux in the form of tables and graphs which can be used not only to support the design of the two European TBS but also to comply with the nuclear safety requirements imposed by the Nuclear Operator (ITER Organization)."

Italo Ricapito
F4E Group Leader
Test Blanket Modules Project Team

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 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.

Manufacturing Europe's first ITER Divertor Casettes

After having successfully completed the stage of prototyping, Europe moved forward with the phase of manufacturing. F4E signed two deals for the production of 19 cassette bodies out of the 58 (54 + 4 spare) which must be delivered. One contract was signed with Walter Tosto and another with the CNIM-SIMIC consortium. The works are expected to last approximately five years and once completed, the equipment will be handed over to ITER Organization to assemble the rest of the components (the Outer-Vertical Target, the dome and the Inner-Vertical Target). In line with F4E's phased-production approach, the remaining 39 cassette bodies will be manufactured at a later stage. These pieces of equipment are not required for ITER's first plasma, hence, the calendar applying to them is a bit different.

"This is the outcome of the very good collaboration between various teams in F4E, ITER Organization and the companies involved. The signature of the two contracts shows that Europe is now ready to proceed with the manufacturing of the first series of the ITER Divertor's Cassette body."

Patrick Lorenzetto
Project Team Manager
F4E In-Vessel

European real-size prototype of ITER Divertor Cassette manufactured by Walter Tosto © Walter Tosto

European real-size prototype of ITER Divertor Cassette manufactured by CNIM – SIMIC © CNIM

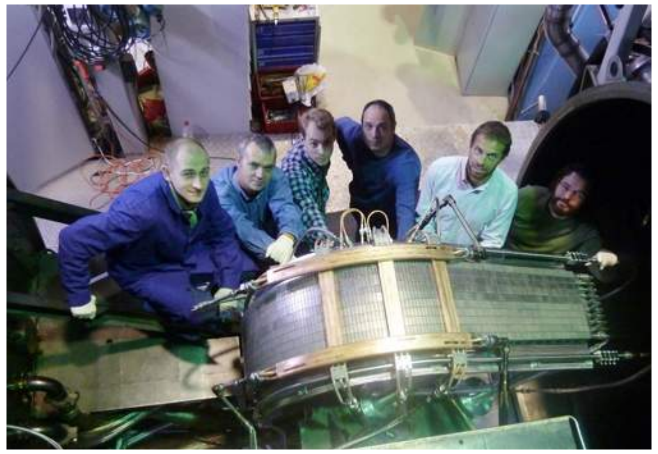
DIVERTOR CASSETTE

The ITER Divertor, consisting of 54 cassettes, covers the lower part of the machine. It is one of components that will experience part of the high plasma temperature. It is estimated that the highest heat deposition on the surface of the cassette could be in the range of 20MW/m^2. The plasma impurities will be diverted to fall on this massive "ashtray" covering an area of 142 m2. Each ITER Divertor Cassette measures 0.8 x 2.3 x 3.5 m and weighs roughly 8 t with all components installed.

Inner-Vertical Target prototype completed

F4E has to deliver the Inner-Vertical Target for each of the 54 ITER Divertor Cassettes. With the help of Ansaldo Nucleare, and its main subcontractors Ansaldo Energia, ENEA and Walter Tosto, Europe's first-ever full-scale Inner-Vertical Target prototype was completed. The component was unveiled at the workshop of the manufacturer in Genoa, Italy. Its manufacturing has been considered rather challenging because Europe's industry has not previously produced it at such scale and with these specifications.

Europe's first ITER Inner-Vertical Target prototype manufactured by Ansaldo Nucleare.



Efremov Institute members of staff - V. Kuznetsov, A. Volodin, A. Komarov, A. Malyshev, N. Stepanov, together with the representative of F4E, P. Gavila (second on the right), and M. Palermo from Ansaldo Nucleare (first on the right), standing in front of F4E's first full-scale ITER Inner-Vertical Target prototype before it is inserted in the vacuum vessel. The tests will be performed at the Efremov Institute, Saint Petersburg, Russia.

"We need to acknowledge the years of R&D that we have capitalised on to get where we are. We started more than 20 years ago developing the concepts of this component."

Bruno Riccardi
Technical Co-ordinator
F4E Divertor

Setting in motion Inner-Vertical prototype tests

At the Efremov Institute, the host of the ITER Divertor Test Facility, Europe's first Inner-Vertical Prototype, manufactured by Ansaldo Nucleare, was delivered to go through tests. The surface of the prototype will be "divided" into three test areas which will experience distinct temperatures. Each area will be tested at a certain heat flux and for a given number of cycles.

"We are proud of the fabrication of the Inner Vertical Target component achieving the challenging assembly tolerances."

Gian Paolo Sanguinetti
Ansaldo Nucleare
Fusion Business Leader

"It is the first time that an In-Vessel full-scale prototype, produced in line with the ITER requirement, will be tested at such length. We will get to validate the materials, the machining and decide the route of manufacturing of the real component to be used in ITER."

Pierre Gavila
Technical Responsible Officer
F4E Divertor

INNER-VERTICAL TARGET

The Inner-Vertical Target (IVT), located on the upper part of the cassette, is one of these components that will be exposed to the high temperature of the ITER plasma. It will receive a maximum of about 1 000 °C in normal operating conditions and about 2 000 °C in off normal conditions, the so-called slow transient event. The IVT prototype is weighing 0.5 t, measuring approximately 1.5 m, and is covered by 1 104 tungsten blocks.

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	94%
Design	100%
Manufacturing	100%
Installation & Commissioning	20%
Vacuum Pumping	
Contracts signed	13%
Design	11%
Manufacturing	16%
Tritium Plant	
Contracts signed	32%
Design	35%
Manufacturing	18%

All of Europe's tanks, cold boxes and auxiliary equipment installed

The 11 tanks that Europe has to provide as part of its contribution to the ITER Cryoplant were successfully installed. The manufacturing of all components was undertaken by Air Liquide, and its subcontractors, while the logistics were handled by DAHER.

Europe's contribution to the ITER Helium (He) plant consists of six warm Gaseous Helium (GHe) tanks manufactured by Zhangjiagang Furui Special Equipment Co. LTD (China); one Liquid Helium (LHe) storage tank manufactured by CryoAB (Sweden), able to store up to 70% of the helium that the plant will need; and two quench tanks produced by Chart Ferox (Czech Republic).

Europe is also responsible for the Liquid Nitrogen (LN2) plant. One Liquid Nitrogen (LN2) tank, manufactured by Aritas (Turkey), and the Gaseous Nitrogen (GN2) buffer tank, manufactured in China by Furui. The cold boxes, manufactured by Nuclear Industry 23 (China), and the LN2 compressors, produced by Atlas Copco Energas (Germany/Belgium), were successfully installed.

"The installation of the equipment on-site is the culmination of years of work. We followed the full manufacturing cycle; travelled to different facilities around the world to check their progress and put in place the logistics for their arrival and installation on-site."

Alain Teissier
F4E Project Manager for Cryoplant and Fuel Cycle

"Reaching this milestone would not have been possible without the effective collaboration of all F4E industrial partners and ITER parties."

Marc Simon
F4E Deputy Project Leader for Cryogenics

"The main pieces of equipment of the cryogenic plant are now delivered on site. This important milestone is the result of more than 100 members of staff from Air Liquide working in engineering activities, 80 main suppliers and up to 150 people on site."

Didier Magnet
Large Projects Director of Air Liquide Advanced Technologies.

Finalising the installation of Europe's cryogenic tanks on-site, ITER Cryoplant © SNC Engage

Technicians checking the installation of compressors in the ITER Cryoplant

Fuel cycle equipment delivered

Four additional water detritiation tanks reached the ITER site to be part of its fuel cycle system. The components resulted from a contract signed between F4E and Equipos Nucleares SA (Ensa). Works for their fabrication lasted approximately two years reaching a value of approximately 1 M EUR. Two tanks will be used to store water and the other two will feed the fuel cycle system with tritiated water.

Representatives of F4E, Ensa, ITER IO welcoming on the ITER site the additional four water detritiation tanks that will be part of the fuel cycle system © ITER IO

(L-R) J. Schwemmer, F4E Director, and B.Bigot, ITER Organization Director-General, sealing the agreement for the cryopump systems.

Getting ready to manufacture more equipment

A Procurement Agreement (PA) has been signed between F4E and ITER Organization (IO), according to which Europe will have to deliver six cryopumps for the torus of the ITER device, two for the cryostat, and their respective auxiliary systems. The PA foresees a number of tasks for both parties, among which, Europe with its suppliers will have to manufacture the equipment, and IO will then take care of the installation, testing and commissioning. The two Parties signed another PA agreeing that F4E will develop a final design which will be used to manufacture the leak detection system for primary vacuum of the neutral beam and vacuum vessel, as well as the leak detection system for the cryostat.

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.

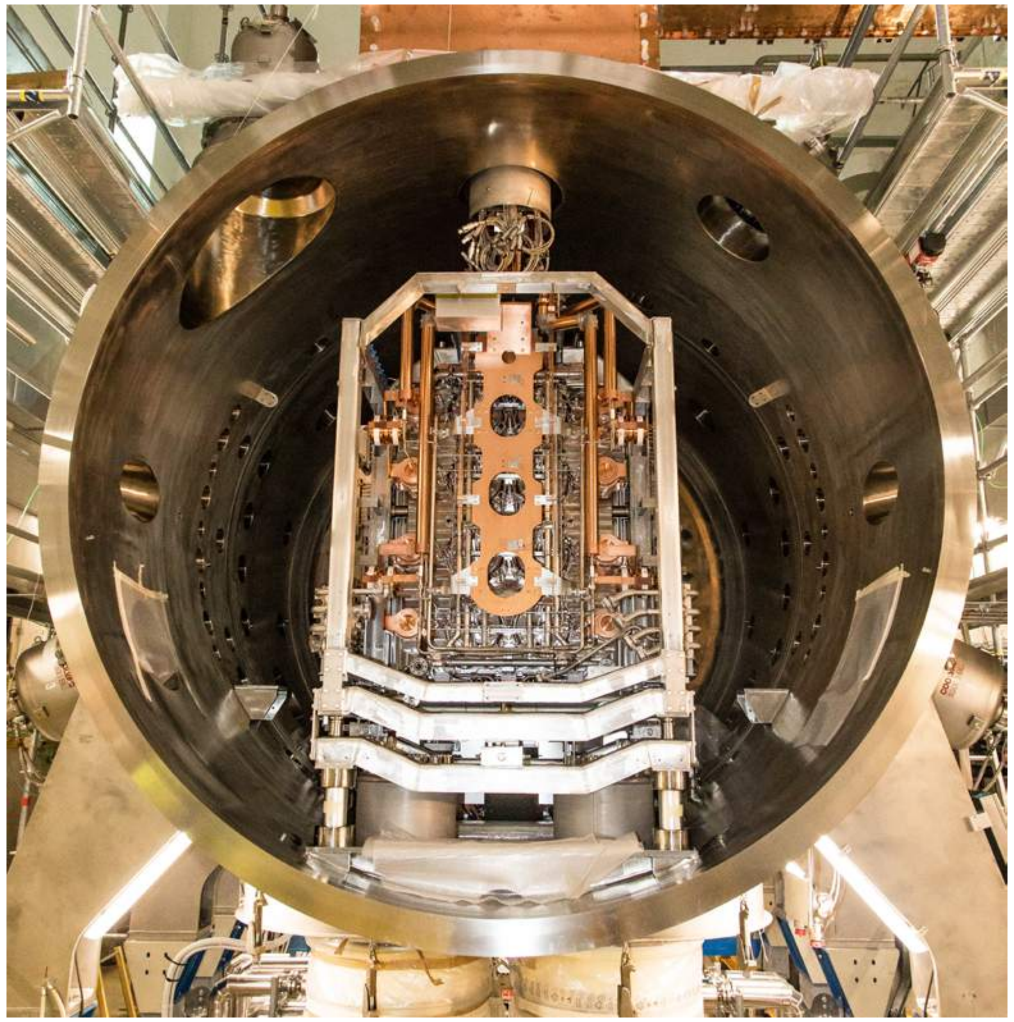
For this reason the ITER Neutral Beam Test Facility (NBTF), located in Padua, Italy, has been set up consisting of two test beds:

- **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	
Contracts signed	100%
Design	100%
Manufacturing	40%
Delivery	0%
SPIDER	
Contracts signed	99%
Design	99%
Manufacturing	97%
Delivery	96%
MITICA	
Contracts signed	76%
Design	58%
Manufacturing	52%
Delivery	39%



The SPIDER beam source installed in the vacuum vessel © RFX

SPIDER

Switching on the most powerful negative ion source to date

The first full-scale ITER ion source produced its first plasma during a ceremony gathering all parties contributing to this experiment. It is capable of running pulses of up to 3 600 sec at maximum power with hydrogen or deuterium. The 6 MW beam generated for one hour by 1280 powerful beamlets are equivalent to the energy required by roughly 1 000 medium apartments in one day.

F4E worked together with suppliers and subcontractors to produce various SPIDER components. A European consortium consisting of Thales Electron Devices SA, CECOM Srl, Galvano-T GmbH, and E.Zanon SpA manufactured the beam source and its vacuum vessel. OCEM Power Electronics and COELME provided the power supplies. The cooling plant was delivered by Delta Ti Impianti, and the vacuum and gas injection plant system by Angelantoni Test Technologies. URS and NIER offered valuable engineering support. ITER India collaborated with PVA Tepla for the beam dump and with ECIL for the accelerator grid power supplies. Consorzio RFX in collaboration with the Italian authorities undertook the construction costs of the buildings, and procured diagnostics and control systems.

Representatives of Consorzio RFX, F4E, ITER Organization, ITER India, European and Italian authorities getting ready to launch the first SPIDER plasma.

Discussing with company representatives the benefits of their involvement in SPIDER

(L-R) Giuseppe Taddia (OCEM PE), Charles-Antoine Goffin (Thales), Aris Apollonatos (F4E), Fabien Siroti (Angelantoni Test Technologies), Christian Eckardt (PVA Tepla), Michele Tamagnone (Delta Ti impianti)

> *SPIDER is the result of collaboration between technical teams, companies and laboratories that worked for years to get here. It felt like putting together a mini ITER. Europe has made important technical and financial contributions to SPIDER because it will help us develop the powerful heating systems to achieve the hot plasma of the biggest fusion device.*

Tullio Bonicelli
F4E Project Manager
Neutral Beam & Electron Cyclotron Power Supplies and Sources

MITICA

Ions to travel through 8960 holes at top energy

F4E signed a contract with ALSYOM-SEIV to provide the MITICA beam source.
After years of background work, consultations, and technical meetings bringing together experts from the Neutral Beam community, it was time to convert the specifications into equipment.
The beam source consists of two main parts: a radio frequency ion source and an accelerator of seven grids.

(L-R) Representatives of F4E, ITER Organization, Consorzio RFX, ALSYOM-SEIV at the kick-off meeting of all parties held in Barcelona, Spain.

“In mid-2015 we started putting on paper the specifications of the beam source and then worked our way through the tender. The time has come to convert the specifications into equipment.”

Antonio Masiello
F4E Technical Responsible Officer

“We are very proud and excited to reinforce our long term partnership with F4E, ITER Organization and Consorzio RFX through this challenging project where quality and timing are of pivotal importance.”

Eric Giguet
Head of Sales and Marketing
ALSYOM

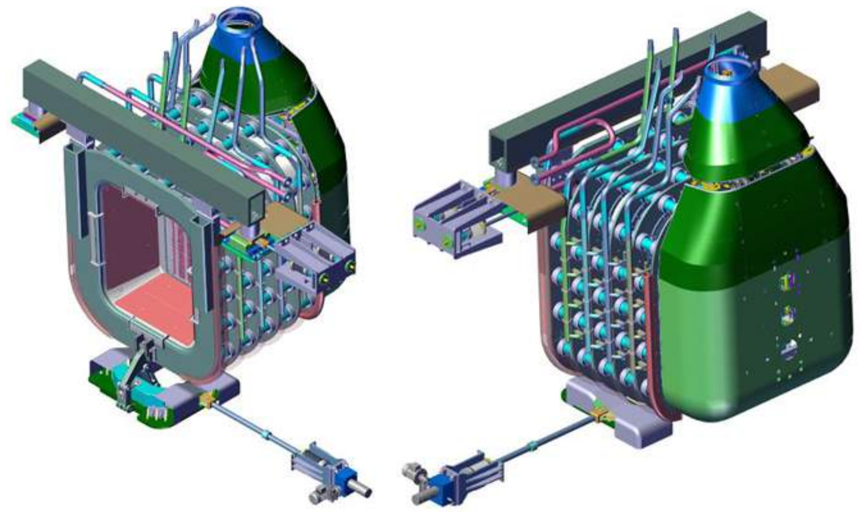


Illustration of MITICA beam source

“The signature of the contract for the MITICA beam source marks the beginning for a key prototype component of ITER – Heating Neutral Beam Injectors.”

Pierluigi Zaccaria
Project Leader for the Neutral Beam Test Facility (NBTF) Thermo-mechanics, Consorzio RFX

BEAM SOURCE

This component will measure 3 x 3 x 4.5 m and will weigh in total 15 t. In this piece of equipment negative ions will be produced. Thanks to a powerful accelerator they will travel at top energy through 8960 holes and eventually will crush on the calorimeter, which measures 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 make several calculations. For instance, they will be able to have good estimates of the heating power that will be transmitted to the ITER plasma.

Power supplies installed

Although neutral beam injection is routinely used for heating gas in fusion devices, MITICA will reach some “mythical” levels of power compared to the existing test beds. Therefore, it will require power supplies proportionate to the task. The European equipment was delivered and installed, whose value is in the range of 22 million EUR. NIDEC, OCEM PE and Siemens are the three companies directly involved.

“I feel that the completion of the MITICA power supplies is an outstanding achievement. It is an important step towards the first-ever neutral beam injector for ITER.”

Loris Zanotto
Consorzio RFX
Deputy Programme Manager for the NBTF

“Our involvement in the project has boosted our competitiveness and our ability to produce equipment fit for a very demanding environment.”

Giuseppe Taddia
OCEM PE General Manager

“Our contribution to ITER is of strategic importance because it allows us to work in an international environment which promotes cutting-edge technology.”

Ettore Merli
NIDEC ASI Project Manager

“Our company is very proud to be part of this project.”

Michael Krohn
Siemens Project Manager

Installing in MITICA’s High Voltage Deck, produced by Siemems, the ion source power supply equipment manufactured by OCEM PE.

Connecting the main cold box, on the left, with the auxiliary cold box, on the far right, with the help of cryolines, ITER Neutral Beam Test Facility, MITICA, Padua, Italy

Cryoplant equipment delivered and installation kicked off

F4E in collaboration with Air Liquide, have been working together to manufacture the components of the MITICA Cryoplant. More than 90% of the equipment was completed. The overall budget of the contract is in the range of 6 million EUR. Works are expected to be completed by mid-2019.

Electron Cyclotron Power Supplies

First Electron Cyclotron power supplies unit pass tests

Europe has to manufacture 8 of the 12 main high voltage power supplies (55kV/110A) and 16 body power supplies (35kV/100mA). To put things into perspective, the eight high voltage main power supplies can generate enough household electricity for 270 000 people, which is the population of a medium-sized city in Europe.

The first main high voltage power supply and two of the body power supplies successfully passed the Factory Acceptance Tests, reaching the operational benchmark set for ITER. This technical achievement resulted from the superb collaboration between F4E, Ampegon and ITER International Organization, with contributions from the Swiss Plasma Centre, and experts, where teams had to work hand in hand to manage the various interfaces.

“The results prove that we are on the right track. The performance of the equipment exceeds the demanding specifications set by the contract and makes us confident that we can generate additional heating for ITER’s plasma.”

Ferran Albajar
F4E Technical Responsible Officer

“Ampegon has been proud to contribute to the ITER project by pushing forward the boundaries of knowledge, both directly through our novel power supply design, and indirectly by being part of the largest scientific experiment in history— ITER.”

Josef Troxler
Ampegon CEO

BEAM SOURCE

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!

Representatives from F4E, Ampegon, ITER IO and Swiss Plasma Centre during the tests of the first High Voltage Power supply unit

Tests on-going in Falcon facility, Swiss Plasma Centre, where the European gyrotron is located

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. Electro 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 achieve high plasma performance, a great degree of engineering is carried out in collaboration with companies and European fusion laboratories.

Work in progress

EC Launcher	
In-vessel Design	80%
Ex-vessel Design	60%
Manufacturing	5%
IC Antenna	
Design	48%
Manufacturing	0%
EC Control System	
Design	80%
Manufacturing	0%

The F4E-ATMOSTAT team which has ensured the qualification for the fabrication of the Electron Cyclotron (EC) Upper Launcher Blanket Shield Module.

“The qualification approval is the culmination of six months of intense testing in order to ensure that the BSM prototype will be of the highest quality and will function well. We are happy that the results of the testing were so successful. This means that we are on track for the manufacturing of the full-scale BSM prototype.”

Jose Pacheco
F4E Technical Responsaible Officer

Enhancing the cooling performance of the Blanket Shield Module

F4E and French company ATMOSTAT, collaborated to improve the cooling performance of this component which is part of the Upper Launcher. This was ensured using Hot Isostatic Pressing technologies (HIP - a method that involves pressure used to compress the metals together homogenously from every direction), with a more uniform repartition of the water channel within the flange and the definition of a manufacturing route suited for the new water channel geometry.

To ensure the quality of their HIP process, ATMOSTAT completed a successful qualification process which included mechanical tests, ultrasonic testing and macrophotography on numerous specimens. In addition, the stamp of approval from a “Notified body” accredited by the French Nuclear Safety Authority (ASN), was received. It was also confirmed that the BSM internal geometry was not deformed after HIP achieving one of the main goals of this development programme: to develop a manufacturing route to build the complex cooling geometry of the BSM.

BLANKET SHIELD MODULE

The four ITER EC Upper Launchers will each inject up to 8 MW microwave power into the ITER machine in order to help with plasma initiation and counteract any instabilities. The plasma-facing part of the Upper Launchers is called the Blanket Shield Module (BSM) and will be heated up to approximately 350°C during ITER operation. Therefore, it will require a state of the art cooling system. In addition, since the BSM will be fully immersed in ITER’s Vacuum Vessel, which is an ultra-high vacuum environment, its metal joints must be of the highest quality.

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:

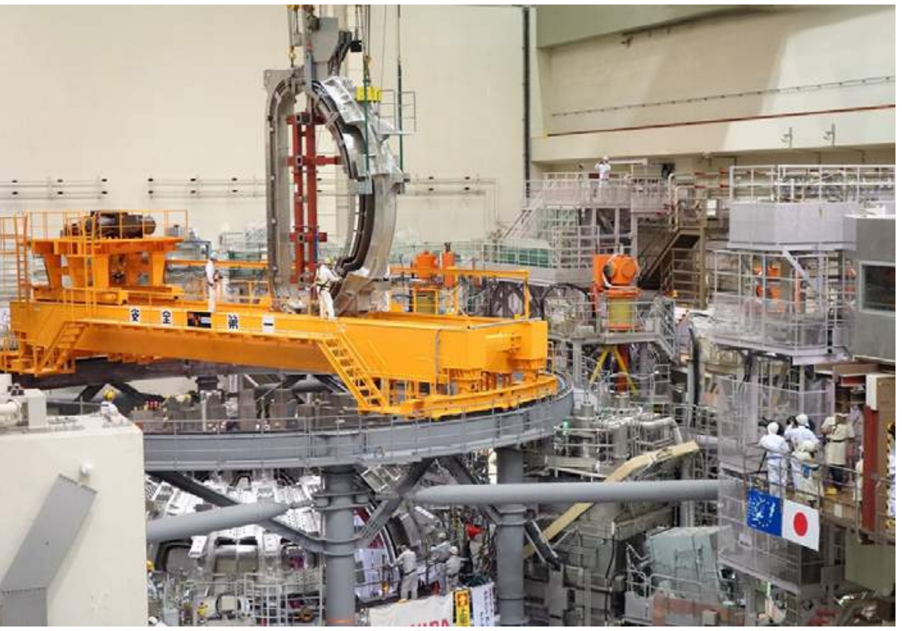
- The Satellite Tokamak Programme (STP) JT-60SA "satellite" facility of ITER in order to model proposals for optimising plasma;
- The International Fusion Materials Irradiation Facility - Engineering Validation and Engineering Design Activities (IFMIF-EVEDA) to carry out testing and qualification of 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.

JT-60SA

Installation of JT-60SA Toroidal Field coils completed

The eighteenth and final Toroidal Field (TF) coil was successfully inserted in JT-60SA. Pre-assembled together with the final sector of the vacuum vessel and its thermal shield, it was lifted high over the tokamak assembly frame and lowered into the waiting space on the cryostat base.

The F4E Team and the CEA Technical Coordinator after the loading of the TF coils on the plane ©CEA



The last TF coil being installed in JT-60SA (Photo courtesy of QST).

The pre-assembled sector comprising TF coil, final vacuum vessel sector and its thermal shield being lifted for installation © QST

“The first 17 coils have been aligned with high accuracy and their positions have been ‘frozen’ by bolting and pinning them together. But only with all the coils acting together does the structure function as intended.”

Valerio Tomarchio
F4E Technical Officer

IFMIF/EVEDA

Engineering and validation of equipment in progress

After having successfully launched the first beam campaign, additional components like the high energy beam transport line and the high energy beam dump, manufactured by CIEMAT, started being installed. The testing phase of diagnostics also kicked-off.

The French Ambassador to Japan, accompanied by various attachés, visited the facility to receive information on the overall progress and the involvement of laboratories and companies from different countries. Some significant developments for the fusion community include, the transfer of ownership of the equipment from Europe (F4E) to Japan (QST) and the first Commissioning and Beam Operation LIPAc workshop, bringing together more than 30 experts from Europe and Japan, to exchange views on the first beam operation campaign.

Representatives from Europe and Japan witnessing the first beam of the accelerator at the LIPAc facility, Rokkasho, Japan.

Wide angle of the LIPAc prototype accelerator, Rokkasho, Japan.

The transfer of ownership of key LIPAc equipment was signed between F4E and QST. Contributors from CEA (Saclay) , CIEMAT (Madrid) and INFN (Legnaro) were also present.

“The facility is up and running and we are working together to build an attractive device. We can all be proud of this collaboration between Europe and Japan particularly when one looks back on what we have jointly developed since 2007 together with esteemed colleagues like P. Garin, H. Matsumoto and J. Knaster.”

Philippe Cara
IFMIF/EVEDA - Project Leader

“The performance of LIPAc is key to the development and operation of the fusion neutron source. In this respect, the LIPAc team has taken a major step ahead.”

Roland Heidinger
IFMIF/EVEDA
F4E European Project Manager

LIPAC

LIPAc is prototype accelerator that will help scientists validate the design of a neutron source which will be used to qualify materials for DEMO, the fusion machine after ITER. QST (Japan) is working together with F4E, coordinating the European contributions of INFN (Italy), CIEMAT (Spain), CEA Saclay (France) and SCK-CEN (Belgium), house in this facility the world’s longest Radio Frequency Quadrupole (RFQ) accelerator, measuring 9.8 m, and its eight radio frequency lines supplying a total of 1.6 MW.

Spanish SME sets new benchmark through its involvement in IFMIF/EVEDA

Seven Solutions counts its track record contributions to Big Science projects such as CERN and ESA added on its list IFMIF. One of their success stories is radiofrequency equipment for accelerators, software and firmware which will enhance their operation by measuring with high precision the beam energy and its position.

A license agreement was signed between the company and F4E. Seven Solutions will be allowed to explore the commercial potential of the hardware and software used in LIPAc. The results of this project will feed into DONES, the DEMO Oriented Neutron Source, which is planned to operate in Granada.

(L-R) Miguel Mendez, Head of High Energy Physics, and Gebhart Leidenfrost, F4E's Chief Financial Officer in charge of commercial activities, on the day of the signature of the license agreement.

The team of Seven Solutions involved in the IFMIF-EVEDA project

"LIPAc is state-of-the-art equipment and we had the privilege to run the software there for the first time. In essence we have a new and innovative product in the market. The development of this software has opened us the door to high-energy physics and to projects such as ITER, the ESS or experiments using RF control systems. It may also be of relevance in medicine, where accelerators are also being used for cancer therapy."

Miguel Mendez
Seven Solutions
Head of High Energy Physics

Experts gathering in the WEST control room (Cadarache, France) during the WEST-REC tests, financed by F4E, as part of the Broader Approach Agreement signed between Europe and Japan © CEA

IFERC

WEST invited East to its control room

Scientists from CEA's WEST (Tungsten Environment in Steady-State Tokamak) fusion experiment, Cadarache, France, "hosted" virtually in their control room several of the colleagues siting in the Remote Experimentation Centre (REC), Rokkasho, Japan, to follow an experiment unfolding in real-time. The 8 h time difference and the 9620 km of distance were not an obstacle. In fact, we will see more of these encounters in future given the fact that scientists working in REC will be allowed to follow remotely ITER experiments. A total of 70 scientists from both institutes, representatives from F4E, EUROfusion, local policy-makers, journalists and students took positions in the two control rooms to witness the experiment carried out in the south of France. The test was financed by F4E.

"Such initiatives help scientists to exchange know-how by sharing data, and train them to perform more of these tests in future. Next year, for instance, we plan to carry out a similar exercise with JET."

Susana Clement Lorenzo
F4E Broader Approach Programme and Delivery Deputy

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.

(L-R) Jorge Toledo, the then Spanish Secretary of State for European Affairs, with the Director of F4E, Johannes Schwemmer.

Visit of Spanish Secretary of State for European Affairs

Jorge Toledo, the then Spanish Secretary of State for European Affairs, visited F4E in order to learn more about the progress of ITER, its project management model and the potential of fusion as an abundant and sustainable energy for the future. The Director of F4E provided details on the ITER baseline, and offered examples of Spain's involvement.

Inside the Cryostat Assembly Hall, (L-R) Jan Panek (European Commission), Laurent Schmieder (F4E Project Team Manager for Buildings Site Power Supplies & Infrastructure), Johannes Schwemmer (F4E Director), Martina Dlabajová (MEP ALDE), Vincenzo Esposito (Head of F4E Processes and Organisational Improvement)

MEP Martina Dlabajová offers her support to ITER project

Martina Dlabajová, MEP of the Group of the Alliance of Liberals and Democrats for Europe and Vice-Chair of the Budgetary Control Committee of the European Parliament, visited the ITER site, Cadarache.

F4E's Director, Johannes Schwemmer, offered an overview of the state of play and provided a guided tour to the main on-site construction and manufacturing facilities.

"[I am] truly impressed by the significant progress of the ITER construction since my last visit in August 2015. I am now more convinced than ever that the project will meet its targets and I would be happy to report the progress of ITER to my colleagues in the Budgetary Control Committee, as rapporteur of the 2017 discharge report."

MEP Martina Dlabajová
(ALDE)

F4E and ASG Superconductors unveil to the ITER Coucil delegates the manufacturing steps of the most complex superconducting magnets © Andrea Bolto

ITER Council delegates visit European factory for Toroidal Field coils

F4E welcomed the ITER Council delegates at ASG Superconductors, La Spezia, Italy, in order to get a close look at the fabrication of the winding packs, the inner of the Toroidal Field coils.
Davide Malacalza, President and Shareholder of ASG Superconductors; Andrea Benveduti, Regional Counselor for Economic Development; Sergio Frattini, CEO of ASG Superconductors; Johannes Schwemmer, F4E Director; Alessandro Bonito-Oliva, F4E Magnets Project Team Manager, gave background information on the state of play, the tangible benefits and lessons drawn. The delegates of the ITER Council received a guided tour in the factory to view closely the different machines and tooling.

ITER Council delegates discussing the various manufacturing steps in the room, ASG Superconductors, La Spezia (Italy) © Andrea Botto

(L-R first row) Ki Jung Jung, Director-General of ITER Korea, NFRI, Alessandro Bonito-Oliva, F4E Magnets Project Team Manager, Stefano Pittaluga, ASG Superconductors Project Manager, discussing the impregnation process of TF coils winding packs © Andrea Botto

F4E shows its strong commitment delivering ITER at SOFT

The Symposium on Fusion Technology (SOFT) brought together scientists, engineers, laboratories, industry and SMEs, policy-makers as well as the future generation of Europe's fusion community. It is the event to find out more about the state of play of current fusion experiments, technology breakthroughs and the progress of big projects like ITER. The 30th edition took place in Sicily under the auspices of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), gathering over 1000 international participants.

F4E Director, Johannes Schwemmer, opened the plenary session with a presentation of the status of Europe's contribution to ITER. Additionally, he highlighted F4E's close partnership with the European Fusion Laboratories (EFLs), European industry and ITER partners.

F4E Director, Johannes Schwemmer during his keynote speech.


The participants of various organisations at the EIROforum Council meeting.

F4E joins EIROforum Council meeting

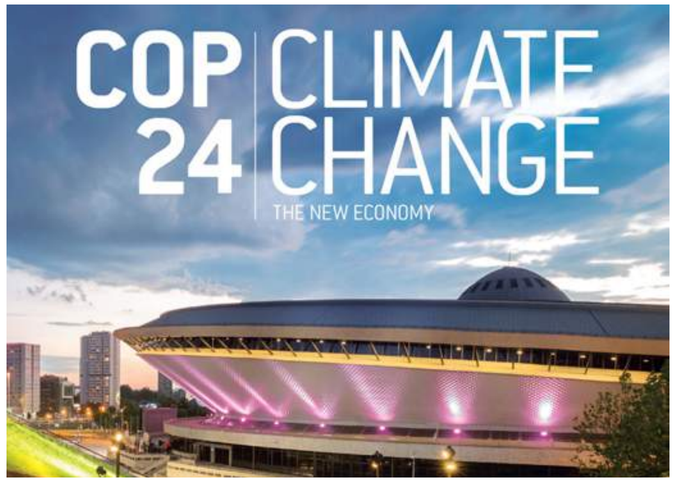
Together with EIROforum science research members such as CERN and ESA, F4E was represented by Director, Johannes Schwemmer, at the EIROforum Council meeting. Chaired by EUROfusion and hosted by the ITER Organization, the meeting took place at the ITER Headquarters in Cadarache.

EIROforum is the unified platform for CERN, EMBL, ESA, ESO, ESRF, European XFEL, EUROfusion and the Institut Laue-Langevin – eight European organisations that form the backbone of fundamental science research in Europe. These organisations have extensive expertise in the areas of basic research and the management of large, international infrastructures, facilities and research programmes.

Visit of British Ambassador

F4E welcomed the British Ambassador to Spain, Simon Manley, to its headquarters in Barcelona. Together with a group of British Foreign Office colleagues, the Ambassador met with F4E Senior Management and attended presentations about the work of F4E and the ITER project. The Ambassador also took the opportunity to meet with F4E's British members of staff.


(second from the right) British Ambassador to Spain, Simon Manley, with a group of British Foreign Office colleagues.



Cover of COP24 "Climate Change – The New Economy" publication


COP24 Opening plenary session © UN Climate Change

Fusion energy introduced in COP24

COP24 is the informal name for the 24th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) which commenced in 1994 and has near-universal membership today. This year's edition took place in Katowice, Poland, from 2-14 December 2018.

"Climate Change – The New Economy" is the key publication for COP providing the stage for world leaders, government and NGO representatives to present their vision, as well as for scientists, experts and companies to offer technological solutions for the future. The publication, released a few weeks before the conference, featured Johannes Schwemmer, F4E Director, advocating in favour of fusion as an "abundant, safe and sustainable energy for the future." In his piece he stressed the importance of ITER as "an essential step to bringing the power of the sun to Earth", and highlighted the role of the EU in the quest for fusion energy.

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.

F4E takes fusion to the Big Science Business Forum

Nine of Europe's largest Big Science organisations – CERN, EMBL, ESA, ESO, ESRF, ESS, European XFEL, F4E, and ILL – came together to create the Big Science Business Forum (BSBF2018). Their aim is a stronger, more transparent and consolidated Big Science market in Europe for the benefit of both business and science. BSBF2018 became Europe's new one-stop-shop in the Big Science market, offering industry a wide range of business opportunities worth 12 billion EUR for the next five years. More than 1000 delegates from at least 500 companies coming from 30 countries attended this first edition.

Participants following the opening session of BSBF2018.

Richard Cobben, Head of ITER Delivery Department, explaining the progress of ITER.

(L-R) Oriol Ribas (Ferrovial), María Teresa Rodriguez García (Empresarios Agrupados), José Mª García Casasnovas (AEIC), Alfonso Carpio Riva (Applus Laboratories), Luis Sedano (FUS_ ALIANZ Science, Engineering & Consulting).

Catalan Association of Engineers learns about ITER's potential

Members of the Catalan engineering community, companies interested in possible business opportunities, as well as graduate and postgraduate students were amongst those who attended the ITER Information Day. Four of F4E's industrial partners – Ferrovial, Empresarios Agrupados, APPlus + Laboratories, and FUS_ALLIANZ Science, Engineering & Consulting – provided testimonies of their involvement in the project.

INCOSE South European Systems Engineering tour stops by F4E

F4E hosted the South European Systems Engineering (SESE) tour for the Spanish chapter of INCOSE (International Council on Systems Engineering) in Barcelona. The objective of the event was the promotion of Systems Engineering among practitioners and other interested participants. It comprised talks on Systems Engineering by, amongst others, representatives from INCOSE, F4E, Navantia, SENER, The Reuse Company, Thales and ISDEFE.

The meeting participants of the South European Systems Engineering (SESE) tour for the Spanish chapter of INCOSE (International Council on Systems Engineering).

(L-R) Eloi Badia (Adviser at Water and Energy, Barcelona Municipality), Joan Callau (Mayor of Sant Adrià de Besòs), Fransesc Torres (Rector UPC BarcelonaTech University), Francesc Subirada (Director-General for Research, Generalitat of Catalonia), Stavros Chatzipanagiotou (F4E Head of Communication).

F4E presents ITER at Barcelona Energy Days

The first Barcelona Energy Days, organised by UPC BarcelonaTech University, the Generalitat of Catalonia, the city halls of Barcelona and Sant Adrià de Besòs, and F4E, highlighted different ways to achieving a sustainable energy mix for the future. Europe's energy roadmap and involvement in fusion energy experiments were amongst the topics addressed.

Fusion and ITER take the stage at the EU Sustainable Energy Week

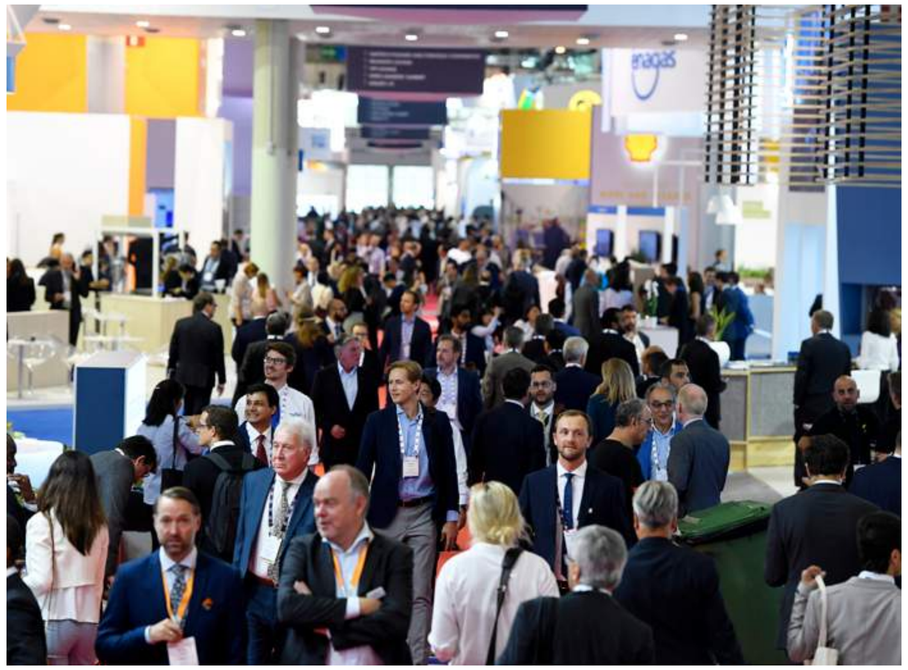
The EU Sustainable Energy Week is Europe's most important policy conference on energy. Fusion and ITER featured in the programme of the conference, highlighting the growing recognition of the important role it would be called upon to play in the sustainable energy mix of the future. The 2018 edition featured more than 60 conference sessions exploring the latest thinking on sustainable energy policy, led by representatives of the European Commission, industry, local authorities and NGOs. It offered the opportunity to more than 3 000 participants to learn more about innovative policies and projects for clean, secure, sustainable energy.

Speaking at the Fusion session (from left to right): Juan Knaster (F4E), Tony Donne (EUROfusion), Jan Panek (European Commission) and Shira Tabachnikoff (ITER IO).

ITER at the core of the World Nuclear Exhibition

F4E and ITER IO joined forces to showcase the continuous progress of the biggest fusion experiment at the World Nuclear Exhibition (WNE), the leading event for the global civil nuclear energy community. This record-breaking third edition with almost 1 000 exhibitors, gathered 20 000 visitors from all over the world. A specific F4E workshop on "ITER: the way to fusion energy" attracted a lot of interest from industry and government representatives.

WNE 2016 - Opening Ceremony - Photos Bruno des Gayets / Christian Bamale. Bruno Le Maire, France's Minister of the Economy and Finance, delivering a keynote speech.



Participants at the GPEX Exhibition © GPEX

F4E promotes ITER at the Global Power & Energy Exhibition

The Global Power and Energy Exhibition (GPEX) took place in Barcelona together with Gastech, the major event of the global gas industry. Strategies and technologies that need to adapt to the global energy transition was the main theme of the event. More than 30 000 participants joined from the global power and energy community, including government, commercial and industrial power users.

F4E participated for the first time in the conference and exhibition, officially opened by His Majesty King Felipe VI of Spain, and Teresa Ribera, Spain's Minister for Ecological Transition.

F4E hosts meeting of the European Physical Society energy

With an obvious and keen interest for European and global energy production issues, F4E hosted the annual Energy Group Meeting of the European Physical Society (EPS) at its Barcelona headquarters. Gathering 25 participants from 15 countries all over the world, the purpose of the meeting was to exchange knowledge and give an overview of energy-related topics.

Presentations about wind energy, nuclear power, integrated energy systems and sustainable development were held by members of the European Physical Society.

Participants of the European Physical Society energy meeting.

Poland presents ITER at Big Science projects Info Day

The Institute of Nuclear Physics in Krakow, Poland, welcomed 40 representatives from startups and SMEs interested in Big Science business opportunities. F4E, CERN and the ESS were there to brief them on the progress of the projects and most importantly on upcoming tenders, and contractors looking for sub-contractors.

Representatives from various SMEs and startups at the Big Science Partner & Industry Day, Institute of Nuclear Physics, Krakow, Poland.

Getting in touch with the EU

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