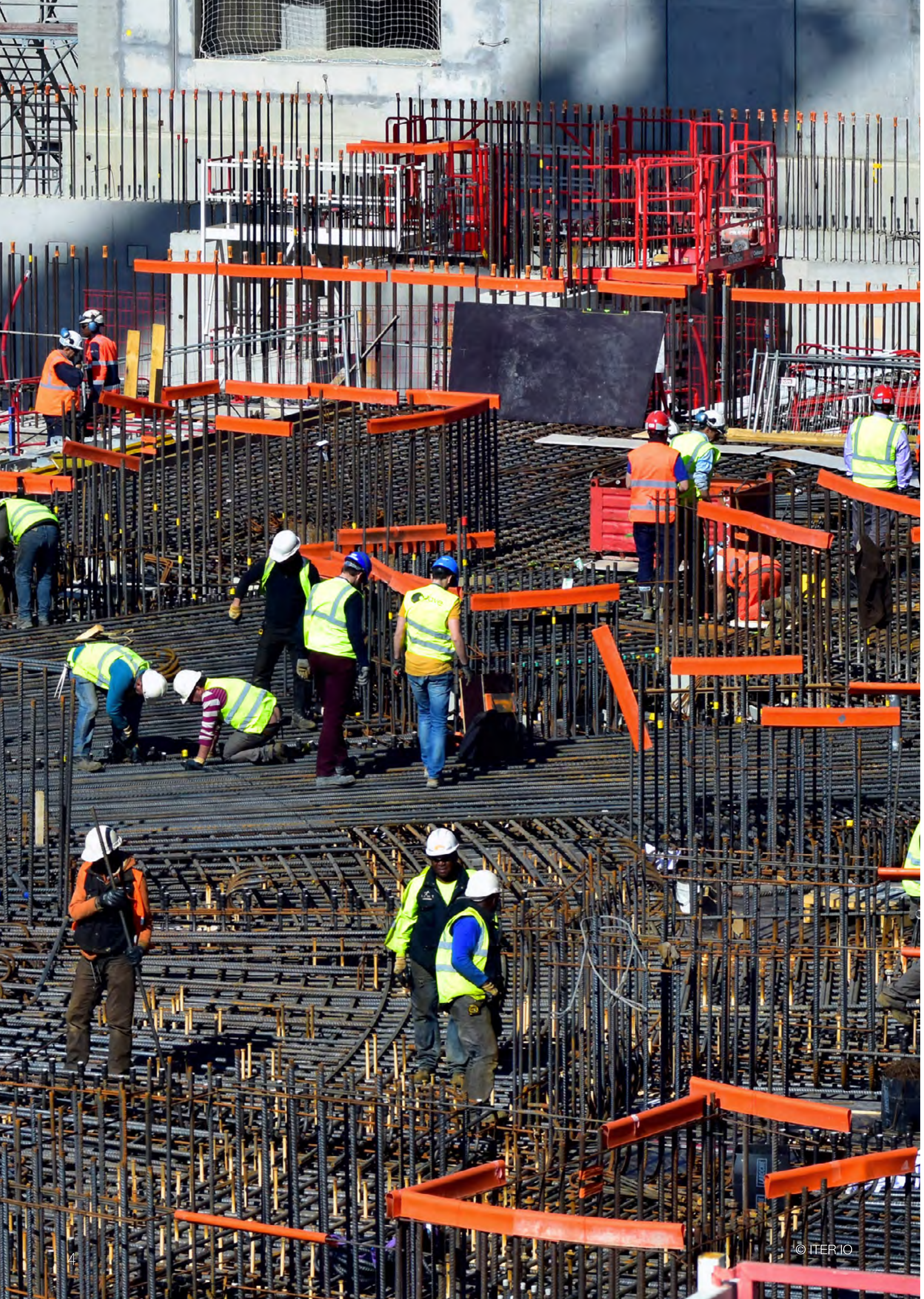
FUSION FOR ENERGY

HIGHLIGHTS 2015

THE MAIN ACHIEVEMENTS

See PDF page 10

Table of contents



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Background

The Paris Climate Conference (COP21) reminded the 195 countries adopting the first-ever universal legally binding deal of the need to reduce greenhouse emissions and strive towards a diversified, sustainable and reliable energy mix. Fusion energy can play a meaningful role in the decades to come.

The countries of the European Union form the largest trading bloc in modern history. They consume one fifth of the word's energy but have very few reserves of their own. Europe's energy dependence poses an important challenge to the prosperity and well-being of its people. The appetite for more economic competitiveness, manufacturing and excellence in services and innovation will need to be matched with the firm commitment to fight climate change. Ultimately, the power that Europe requires to produce, export and thrive will influence the delicate balance of power with its global partners. Six member states depend for their entire gas imports on a single supplier and it has been estimated that every additional 1% increase in energy savings would cut gas imports by 2.6%. When it comes to transport, 94% of the sector relies on oil, of which 90% is imported with severe implications on global warming.

For the first time-ever, 195 countries adopted at the Paris Climate Conference (COP21) a universal legally binding deal to reduce greenhouse emissions and strive towards a diversified, sustainable energy mix. Fusion energy can play a meaningful role in the decades to come. The fuels needed for fusion are widely available and virtually inexhaustible. With fusion there are neither greenhouse gas emissions nor long-lasting radioactive waste. Furthermore, fusion reactors are intrinsically safe with no risk of a chain reaction.

Fusion for Energy (F4E) is the European Union organisation managing Europe's contribution to ITER, the biggest international collaboration in the field of energy that will demonstrate the viability of fusion. The project brings together half of the world's population (China, Europe, Japan, India, the Republic of Korea, the Russian Federation and US) and represents 80% of the global GDP. The host party of this one-of-a-kind scientific endeavour is Europe and it contributes close to one-half of the ITER components. F4E is also responsible for the coordination of the European contributions to three joint fusion projects carried out in collaboration with Japan, known as the "Broader Approach", which will offer us better insight in this field.

To develop a better understanding of the ITER project we report on a number of strategic improvements introduced in 2015, which have been introduced to strengthen cooperation between the seven parties and helped them to capitalise on their financial and human resources. For instance, the creation of joint teams have cut down duplication of tasks; independent experts have been asked to assess the time, cost and delivery of components in order to develop an updated project plan in different stages; the adoption of key milestones cross-cutting the entire project have set common objectives.

In 2015 F4E signed contracts with European companies and laboratories for a value of approximately 330 million EUR, bringing the total value of contracts signed since 2008 to 3 572 billion EUR. In parallel, 88 new contracts were signed in order to proceed with the ITER construction and the manufacturing of Europe's components.

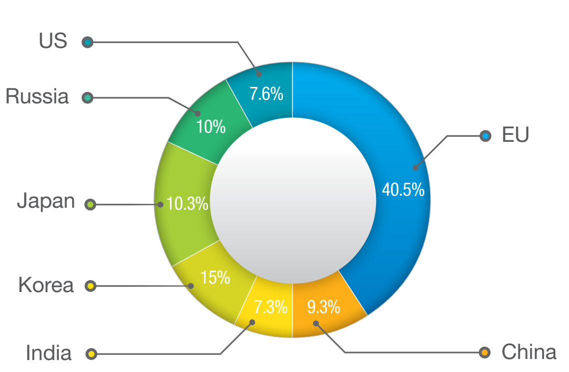
In terms of construction, the erection of the Assembly Hall and the lifting of its roof have been without a doubt the most symbolic milestones on the ITER site together with the progress of the Tokamak complex, the building where the fusion device will be located. Meanwhile, the arrival of the first tooling for the manufacturing of the Poloidal Field coils, has converted the site to an industrial hub. Similarly, the successful production of a key component of the Toroidal Field coils, has been viewed as an major achievement.

The delivery of the six water detritiation tanks, part of the ITER fuel cycle system, has been considered as a significant milestone, given the fact that it has been the first European component delivered on-site. In the area of Diagnostics, Europe has started manufacturing its first piece of equipment and in parallel, testing and fabrication of heat exchangers and other auxiliary systems have marked this year's contribution to the cryoplant which will cool down the machine to temperatures as low as -269°C. Major contracts have been signed and tests on prototypes have been carried out in the areas of Remote Handling, Neutral Beam Systems and Power Supplies. There has been progress in tooling and testing of materials for the ITER Vacuum Vessel and the development of Test Blanket Modules.

Last but not least, we have liaised with stakeholders at different levels to keep them abreast of the latest developments through conferences and briefings. To convey the main achievements that Europe has celebrated in 2015, we take you through some of the most interesting moments of one of the most fascinating projects in the field of energy-ITER.

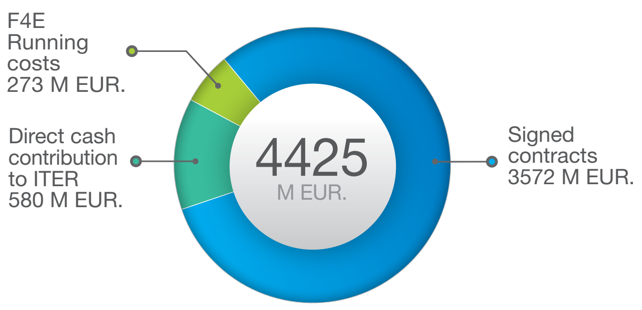
2015 Key figures

Contributions to ITER



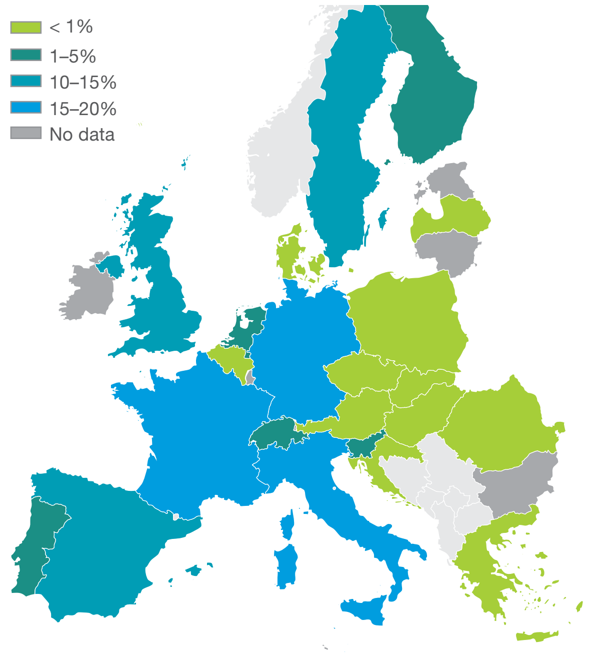
Total contributions between the different ITER parties 2008- 2015

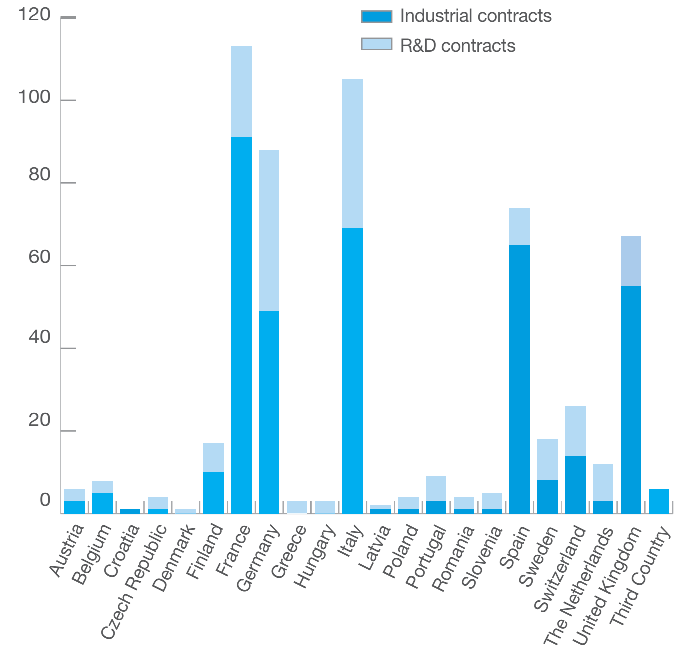
F4E budget breakdown



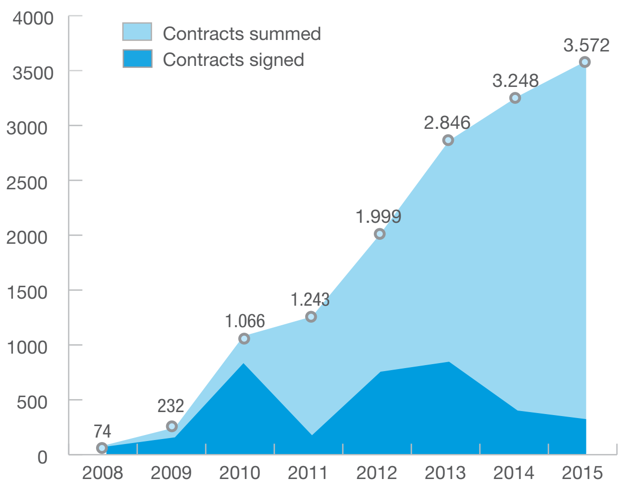
Budget breakdown of F4E main activities 2008-2015

Geographical distribution of contracts awarded by F4E 2008-2015

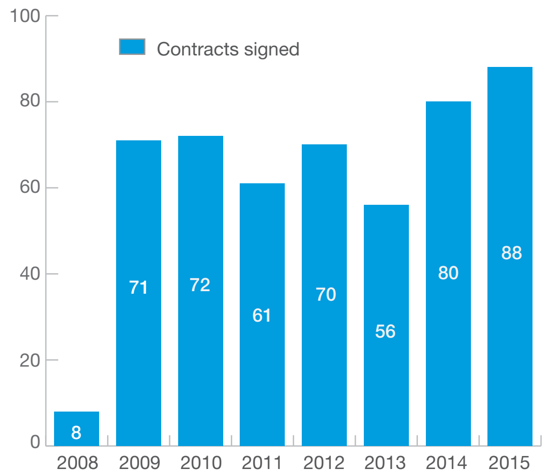




Value and quantity of signed contracts

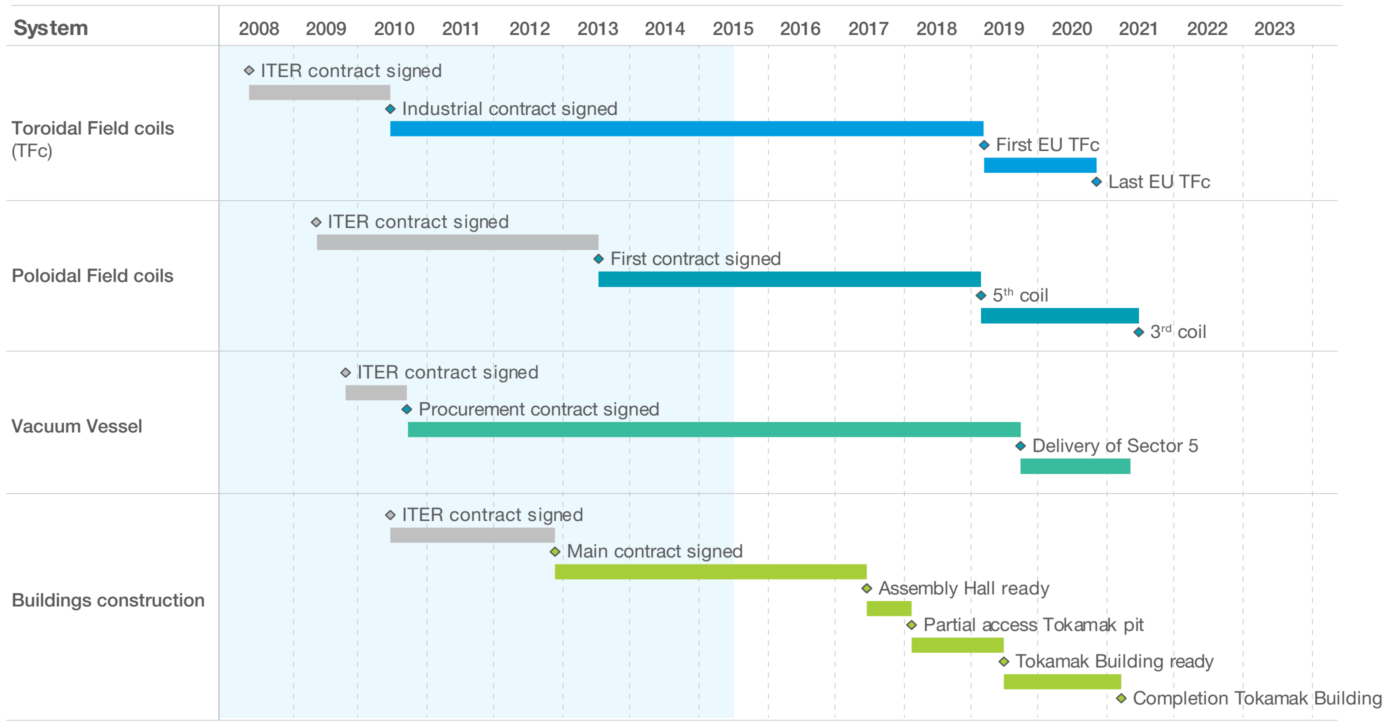


Annual and summed value of contracts signed

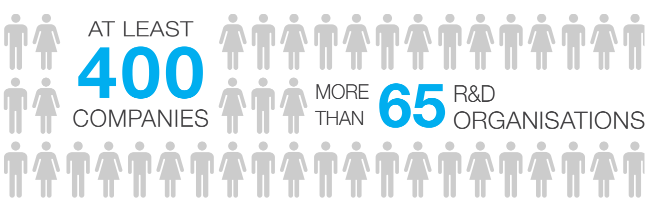


Number of contracts signed

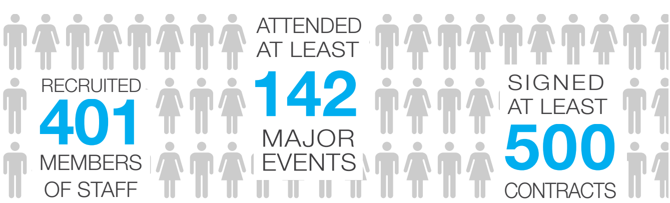
Progress of the work for some of the main components provided by F4E



Since 2008 F4E has been collaborating with:



Since 2008 F4E has:



F4E progress in figures

Overview of the construction on-site and the manufacturing of some key components.

ITER construction site

Europe is responsible for the construction of 39 buildings and facilities on the ITER site.
We have highlighted the overall progress of works and focused on some of the main facilities.

Contracts signed	Construction completed	Tokamak Complex construction	Assembly Hall construction	Construction of Poloidal Field coils facility
73%	22%	10%	52%	100%

Magnets

Europe will deliver 10 out of the 18 Toroidal Field coils and 5 out of the 6 Poloidal Field coils. The lifecycle of these components mainly consists of contract signature, the development of infrastructure and tooling, qualification of materials/prototypes and manufacturing.

	Contracts signed	Infrastructure and Tooling	Qualification	Manufacturing
TF COILS	100%	63%	77%	33%
PF COILS	86%	33%	4%	0%

Vacuum Vessel

Europe is responsible for the production of a significant number of sectors that make up ITER's vacuum vessel. We have concentrated our efforts on sectors 4 and 5. The lifecycle of this component mainly consists of contract signature, the delivery of materials, the finalisation of the design and manufacturing.

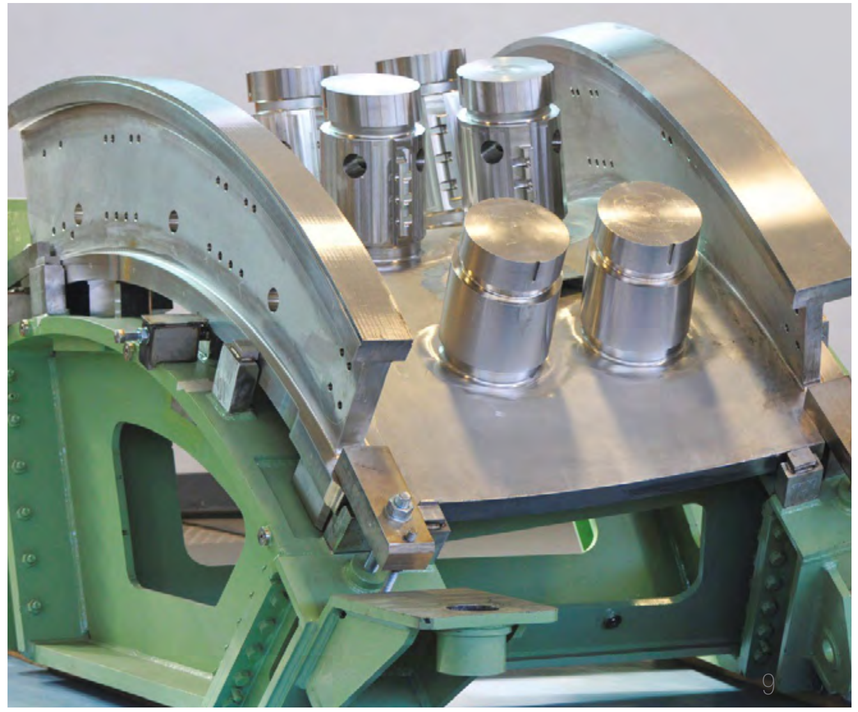
	Contracts signed	Delivered material	Final design	Manufacturing
SECTOR 4	100%	48%	20%	0%
SECTOR 5	100%	100%	98%	10%


Aerial view of ITER construction site, September 2015, ©MatthieuColin.com


Wrapping and insulation of conductor for the ITER Toroidal Field coils, ASG, November 2015


Installation of winding tooling, Poloidal Field coils facility, December 2015


ITER Vacuum Vessel manufacturing - Mangiarotti - November 2015


Vacuum Vessel port mock-up , ©Walter Tosto

2015 at a glance

January

An 87- tonne high voltage transformer arrived at the ITER site, the first component to travel via the specific route for the delivery of heavy equipment.

February

Six helium storage tanks of the JT-60 SA cryogenic system passed the final acceptance tests. Demonstration activities in the field of Remote Handling proved successful at ITER's Divertor Test Platform (DTP2), Finland.

March

The first European components - six water detritiation tanks manufactured by ENSA- were delivered to ITER. F4E presented to companies and laboratories the different business opportunities at IBF and signed a multi-million deal with DAHER for global logistics.

April

Key milestone achieved in the field of magnets. Electricity infrastructure contract signed with Ferrovial for the installation of two new high voltage substation networks and seven transformers to supply the ITER machine and some of its systems with power.

May

One of the biggest robotics contracts in the field of fusion energy awarded to Amec Foster Wheeler. The manufacturing of two diamond disc prototypes that will transmit electro-magnetic waves into the vacuum vessel was signed with Diamond Materials.

June

Collaboration between F4E and Cryogenic Limited kicked off for the production of a superconducting magnet prototype for the ITER gyrotron. Two high voltage electricity transformers installed on the ITER site. Remote Handling experts held a meeting to exchange technical know-how.

July

Work in the field of Test Blanket Modules received recognition at the Conceptual Design Review meeting. First heat exchangers for ITER Liquid Nitrogen plant manufactured. F4E hosted the first Diagnostics meeting bringing together 20 laboratories and companies from 12 different countries.

August

Europe delivered its first component to the Neutral Beam Test Facility in Italy. F4E signed three contracts for the manufacturing of prototypes for the divertor inner vertical target (IVT).

September

The roof of the Assembly Hall, weighing 800 tonnes, was lifted 60 metres high and fixed on the steel structure of the building. The propping works of the Tokamak complex B2 slab started and more embedded plates were installed.

October

Johannes Schwemmer appointed as F4E's new Director. The construction of the bioshield, the wall between the ITER machine and the rest of the Tokamak building, advanced. F4E signed a contract with DALKIA-Veolia to equip the Poloidal Field coils facility.

November

F4E and CCFE developed new equipment for Remote Handling. Collaboration launched between Studsvik, NRG and F4E to test EUROFER97 in the field of Test Blanket Modules. European Continuous-wave gyrotron prototype successfully passed final factory acceptance tests.

December

JT-60 SA cryogenic installation completed together with the assembly of nine sectors of its vacuum vessel. ITER Diagnostic sensor prototypes manufactured by Via Electronic. F4E and Nidec Asi Sp.A started collaborating for the acceleration power supply grid of the Neutral Beam Test Facility.

01

Building the ITER facility

Landmark contracts have been signed and major woks have started.
The ITER platform is one of the largest man-made levelled surfaces in the world and is considered as one of the biggest building sites in Europe measuring 42 hectares.
The party responsible for the construction of 39 buildings on the site, is Europe.
Currently, the personnel directly involved in construction counts at least 1 400 people.
One of the key challenges will be to accommodate the rapidly growing workforce and to guarantee an optimal use of space by the different companies operating on the ground, in order to carry out the construction of all infrastructures in parallel and on time.

The ITER site

How has the ITER construction site evolved?

The progress of the civil engineering works in the Tokamak complex and the adjacent facilities demonstrates that the pace of construction has accelerated. Since the arrival of the first components, the installation of power supplies and the erection of the Assembly Hall, the ITER site has entered a new phase. Furthermore, the creation of one integrated team overviewing the construction has introduced a new style of collaboration described as “one project-one team”. To help you grasp the progress on-site we look back at some of the most memorable achievements.

Assembly Hall

The lifting of the Assembly Hall’s roof has been without a doubt the most symbolic milestone of the year. This impressive operation has given rise to a giant made of steel overlooking the Tokamak complex and has permanently changed the landscape of the ITER platform. It has taken approximately seven months to erect the 22 columns that weigh 6 000 tonnes upon which the 800 tonne roof relies. The operation had to be carefully planned to cope with the wind and position the roof exactly.

The teams of F4E, ITER International Organization, Vinci, Ferrovial and Razel (VFR) consortium, Martifer, VSL and Apave have been preparing for this moment for some time which took nearly 36 hours to be completed. Under the watchful eye of 25 engineers and support staff, 22 hydraulic jacks all connected to six hydraulic pumps, carefully lifted the roof from the ground. The cladding of this impressive facility has officially started paving the way for the installation of its impressive cranes and rails.

“This is a building of fundamental importance for ITER. It is here that we will assemble the components of the biggest fusion device.”

Bernard Bigot
Director-General
ITER International Organization

The Assembly Hall in figures

100 m long, 60 m wide, 60 m high.
50 people working during 7 months to erect its steel structure.
65 000 bolts had to be fixed during days and nights before the operation.
The task has been completed three months earlier than planned.

The ITER Assembly Hall - 2015

Tokamak complex

This complex of buildings is of critical importance because it holds the key to the project's success. Without a doubt it is the construction site's most emblematic area. It consists of the Tokamak building, where the ITER machine will be located with two adjacent buildings where the fusion fuel will be stored and treated known as the Tritium building, and the Diagnostics building, where the information received by the instruments acting as "the eyes and ears" inside the machine will be interpreted, analysed and processed. The works carried out result from the contract signed between F4E and the Vinci Ferrovial Razel (VFR) consortium.

Works in the Diagnostics building have further advanced and the propping works for the level above, which measures 9 300 m², have started. Approximately 800 m³ of concrete and 110 tonnes of steel have been used for the construction of its slab. It has taken roughly three months for the 40 workers mobilised for this activity to cover with concrete its 1 600 m² surface.

There has also been progress with the installation of the embedded plates. They are thick steel plates onto which several steel studs with rounded heads have been welded. They have to be anchored deep into the concrete and positioned with accuracy to match the location of the ITER equipment that will be installed. More than 80 000 embedded plates will be installed in the Tokamak complex. They will have to be placed with an accuracy of 20 mm, which is remarkably tight considering that they weigh approximately 3 tonnes each.

In the middle of the Tokamak building a new 3.5 metre thick wall has started to emerge that will shield the ITER machine inside its building- the bioshield. When completed, it will be more than 30 metres high and will protect the cryostat, responsible for generating the freezing temperatures surrounding the machine. The works for the bioshield have started and 620 m³ of concrete have been poured for the first half of wall in basement 2 with a high density of reinforcement.

"The concrete that will be used for the Tokamak bioshield is a type of concrete that doesn't need to be vibrated. The density of the metallic framework, the thousands embedded plates weighing several tonnes and the concrete for the bioshield make this shield one of the most complex elements of the ITER buildings."

Luis Aspilcueta
Energhia

The Tokamak Building seen from the south of the Tritium Building – November 2015

The two transformers being installed on the ITER site

Setting the foundations of ITER's electricity grid

To produce 500 MW of power from an input of 50 MW - a "gain factor" of 10 - ITER will need to be connected to the grid. The installation of the powerful transformers on their pits is the first step towards in this direction. Each of them will connect the 400 kV substation on site from the French operator RTE to the ITER distribution system.

The transformers that have been designed by F4E, procured by the US Domestic Agency (DA) for ITER and manufactured by Hyundai Heavy Industry. The design process started in 2009 in close collaboration with ITER International Organization, the US DA, F4E and its contractors- Energhia, Engage and Apave.

Ferrovial, responsible for the works of the electricity infrastructure, has constructed four oil retention pits measuring 100 m² and 70 m³ each to collect any possible leakage of the oil from the transformers. Three additional transformers coming from China will be installed in the northern part of this area and all of them will be connected to the grid.

A series of studies will be carried out regarding the works for the foundations of the electrical components, the precipitation drainage systems and the earthing grid system – The lighting and fences will also need to be installed. When the electrical assembly of the other components is in place the works for the entire high voltage electrical substation will be considered completed.

The installation of all other components in order to connect the transformers to the 400 kV network, and the construction of the building that will house the 22 kV switchgear on the site, have been planned for 2016.

"Thanks to this contract Ferrovial Agroman has the opportunity to be further involved in ITER and establish itself as one of the most committed contractors. We are extremely proud to be part of the most ambitious international energy project."

Alejandro de la Joya
CEO of Ferrovial Agroman

Key facts and figures

A power of 1200 MVA will run through the ITER electrical system using a Pulsed Power Electrical Network (PPEN) and a Steady-State Electrical Network (SSEN).

The PPEN will supply with power the AC/DC converters, the Heating and Current Drive systems, and the Reactive Power Compensation. Thanks to this electrical network, the ITER plasma will be heated and the powerful superconductive magnets will be able to confine it.

The SSEN will supply with power the cryogenic and cooling water systems, the tritium plant and the general infrastructures. This network will provide the power needed to generate the low temperatures for some of the components in the machine.

Scope of the contract

The development of infrastructure that will supply ITER and its different systems with electricity will be delivered through a contract signed between F4E and Ferrovial Agroman. Its duration will be for six years and its overall value will be approximately 30 million EUR. The design, installation, commissioning and maintenance of the electrical networks, combined with civil engineering works of the buildings that will host the electrical devices, will also materialise through this contract.

Poloidal Field coils facility

View of the Poloidal Field coils facility, October 2015, Cadarache

The Poloidal Field (PF) coils facility will be one of the most sophisticated engineering hubs in Europe. It is where some of the most powerful magnets deployed in a fusion device will be manufactured. The PF coils will help us confine and maintain the plasma's shape and stability. Due to their impressive diameter and weight, four out of the six PF coils will be manufactured on-site. A range of bespoke equipment, heavy cranes, vacuum chambers and assembly stations will operate.

F4E has signed a contract with a consortium formed by Dalkia, part of the EDF Group which is one of the world's leading electric utilities, together with Veolia, through its subsidiaries Propreté Industries Services (VPIS) and the Water activity of Veolia in France, to equip the ITER magnets facility on-site.

Dalkia-Veolia will furnish the PF coils facility with the appropriate infrastructure: clean areas, additional workshop rooms, electrical and other utility distribution systems as well as the construction of an external building where superconductor spools will be stored in. Furthermore, the contractor will have to maintain and operate the infrastructure, train manufacturers and suppliers' personnel to operate the two cranes, supervise loading and unloading operations, offer surveillance and be in charge of waste management. The contract will run for at least five years and has a value of approximately 12 million EUR.

“Thanks to this contract Dalkia has the opportunity to bring its energy services expertise to the table and contribute to a major international energy project. Together with Veolia we count ourselves among the most committed and ambitious contractors of the ITER project. We are proud to cooperate on this project and we are sure of its success.”

Jean-Michel Mazalérat
CEO and General Manager of Dalkia

Key facts and figures
The ITER Poloidal Field coils facility

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

The building is approximately 250 m long, 45 m wide and 17 m high. It includes regular services (Heating Ventilation Air Conditioning, electrical, piping), two large cranes (one standard crane with a capacity of 25 tonnes and another crane especially adapted with a capacity of 40 tonnes), offices, technical rooms and workshop space.

The building offers adequate space to carry out all the steps of coil manufacturing: winding, impregnation, stacking and cold testing. It has the capacity to host maximum 80 people.

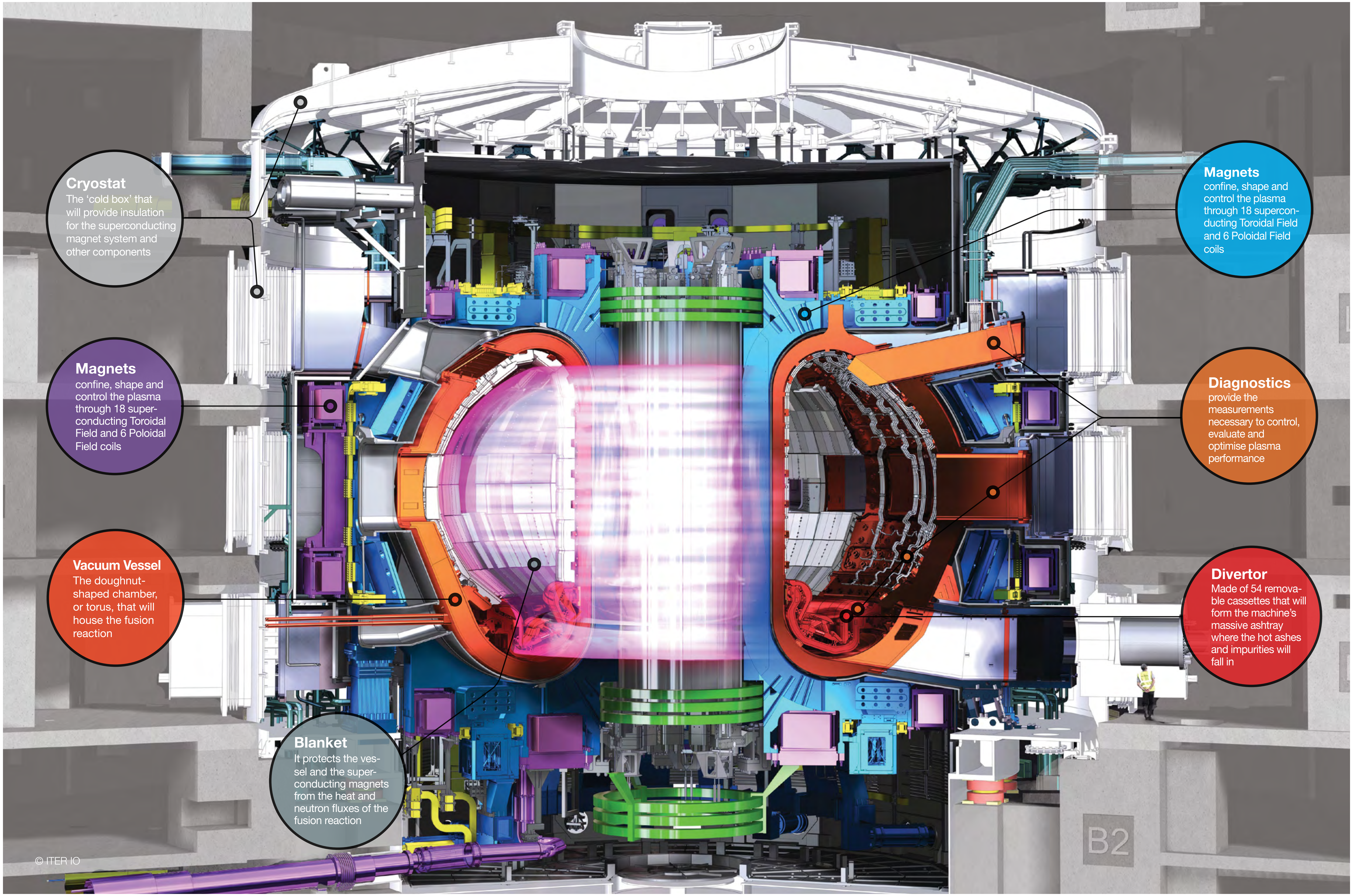
Aerial view of the ITER Assembly Hall, Tokamak complex and Poloidal Field coils building, November 2015

02

Manufacturing the ITER components

The biggest-ever fusion device that will demonstrate the viability of fusion energy is relying on massive, complex and impressive high-tech components that have undergone rigorous manufacturing tests and are underpinned by extreme accuracy. Components of such size have never been manufactured before!

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


Cryostat
The ‘cold box’ that will provide insulation for the superconducting magnet system and other components
Magnets
confine, shape and control the plasma through 18 super-conducting Toroidal Field and 6 Poloidal Field coils
Vacuum Vessel
The doughnut-shaped chamber, or torus, that will house the fusion reaction
Blanket
It protects the vessel and the super-conducting 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

DIAGNOSTICS

The Diagnostics system will help scientists to study and control the plasma behaviour, measure its properties and extend their understanding of plasma physics. In simple words, 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 ITER. Europe is responsible for roughly 25% of all Diagnostics in ITER.

Manufacturing the first European equipment for ITER diagnostics

The signature of the contract for the Continuous External Rogowski (CER) coil system has marked an important milestone for F4E's contribution to ITER diagnostics, being the first European equipment going to production.

Two companies: Axon, France and Sgenia, Spain, have been entrusted with the manufacturing of this piece of equipment.

The CER coils will be located outside the vacuum vessel, within the cases of three Toroidal Field (TF) coils. Their purpose is to measure the toroidal current flowing within the contour of the TF coils, which approximates to the plasma current under steady conditions, a key measurement with relevance for safety and plasma control. The coils are formed by two layers of concentric windings insulated by fibreglass and enclosed in a copper-nickel braided sheath. Each coil measures approximately 50 metres in length. By contrast to other common methods of measuring the plasma current, the Rogowski method provides the measurement with a single sensor, resulting in very high reliability.

Cross section of the prototype CER coil

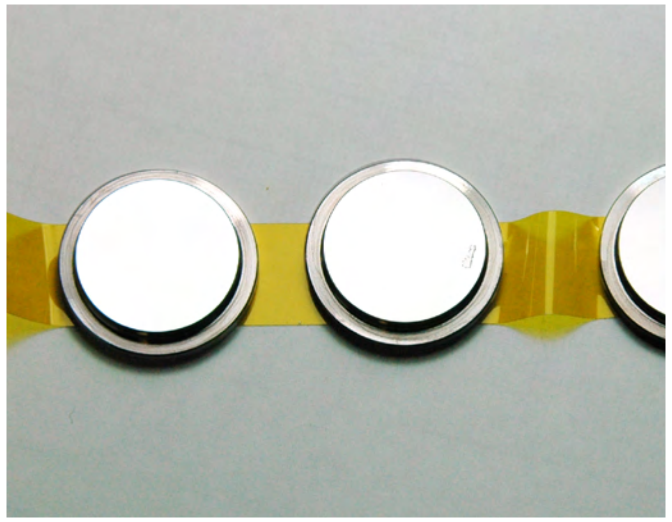
Monitoring ITER's plasma through mirrors

More than 100 mirrors in various different shapes and sizes, measuring up to 250 x 200 mm, will be used to reflect light from the plasma towards detectors and cameras.

F4E together with experts from Basel University, Switzerland, and ITER IO, have been collaborating to find out what materials make the best mirrors for the ITER environment in conjunction with a Radio Frequency cleaning system to be used on the mirrors' surface.

The conditions that the mirrors will be subjected to are not well known. The inner walls of the machine contain tungsten and beryllium, two metals which can withstand the high temperatures, but are likely to create deposits on the mirrors when ITER will be operating. Consequently, the mirrors may lose their reflectivity and the overall performance of the Diagnostic system may decrease.

Tests have also been carried out on how to clean them and to determine the best mirror surface. For these tests, small mirror samples, with deposits of tungsten and aluminium, have been placed in a small vacuum chamber into which a low pressure gas has been added. Each mirror sample is going to be tested many times in an environment mimicking ITER conditions, where cleaning may be required frequently to keep the mirrors shiny and bright.



Samples of the mirrors currently being tested

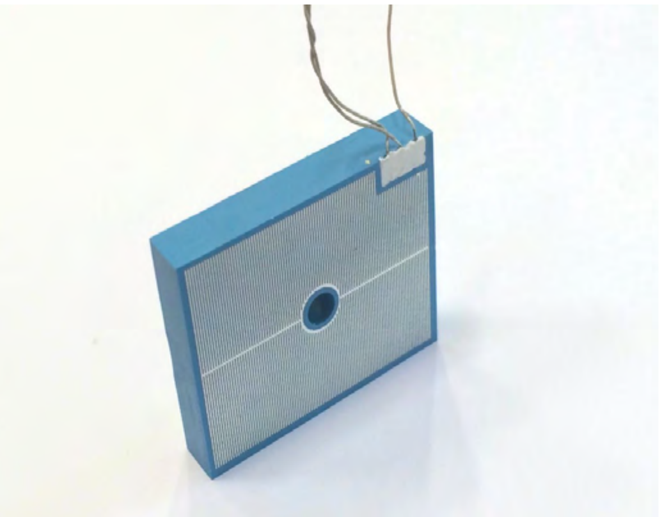
Developing sensor prototypes to measure ITER magnetic field

Via Electronic, Germany, has been entrusted with the manufacturing of sensor prototypes to be installed inside the vacuum vessel.

More than 200 of these sensors will measure the local magnetic field in ITER during operation, and transmit vital information regarding the plasma.

Each prototype consists of 34 layers of ceramic, 30 of which contain a screen-printed spiral coil circuit made out of pure silver. The remaining layers of ceramic provide external protection and electrical screening in the form of a printed grid on the external faces of the device. The collaboration between F4E and Via Electronic covers the production of 40 prototypes.

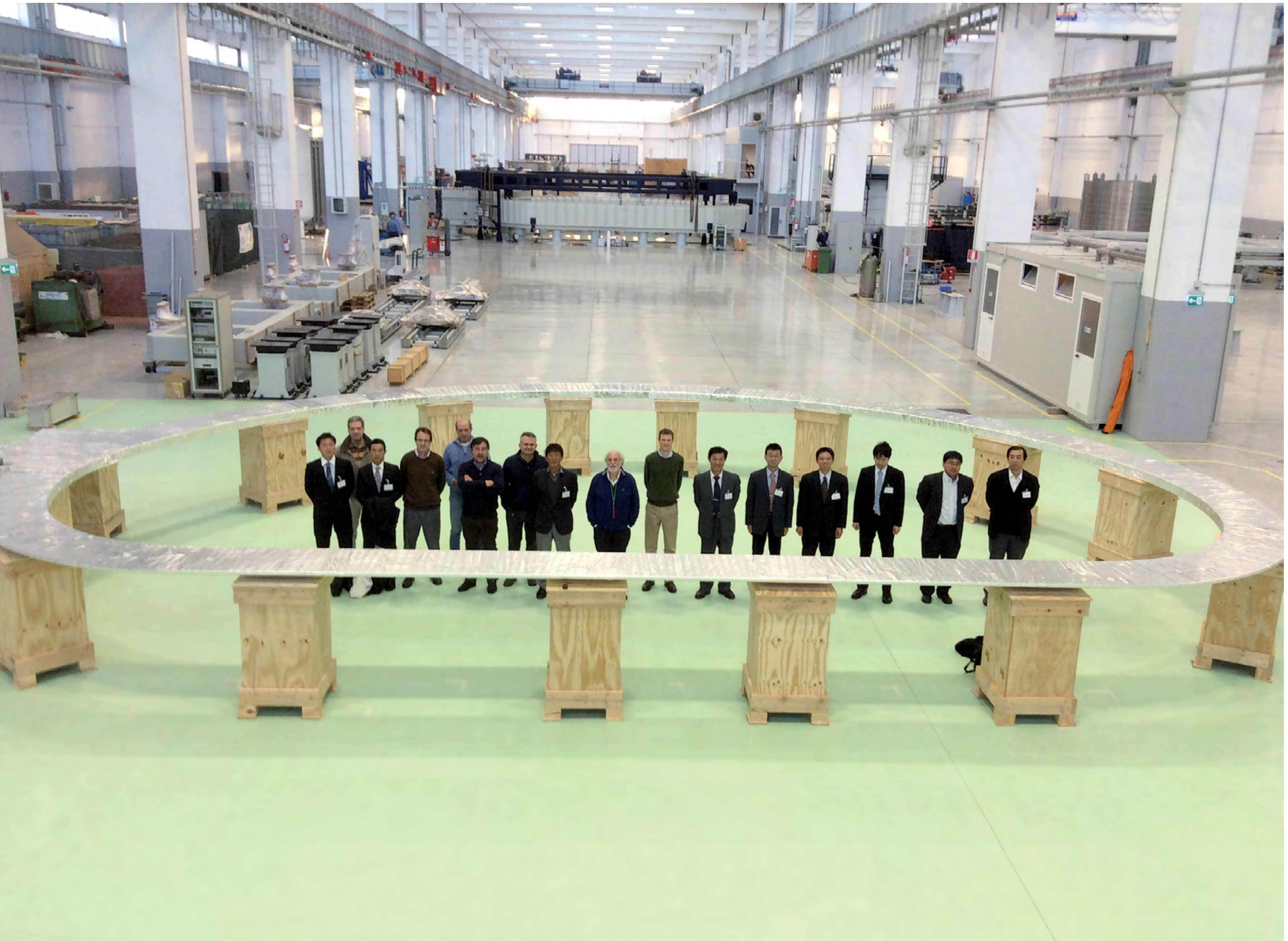
Two additional contracts for manufacture of similar prototypes by other suppliers have been in preparation. The sensor prototypes will be tested in a fission reactor to establish their performance in an ITER-like environment. Nuclear Research and Consultancy Group (NRG), Netherlands, and the Centrum výzkumu Řež s.r.o. (CVŘ), Czech Republic, have been given asked to overview this task. A computer model, developed by the Belgian Nuclear Research Centre (SCK-CEN), will be used to help with interpretation of the irradiation tests.



One of the Low-Temperature Co-fired Ceramic (LTCC) sensor prototypes manufactured by Via Electronic

MAGNETS

Powerful superconducting magnets will help us confine ITER's super-hot plasma which is expected to reach 150 million ˚C. The first layer of magnets will consist of the Toroidal Field (TF) coils that will entrap the hot gas and keep it away from the walls of the vacuum vessel. The second layer will consist of the Poloidal Field (PF) coils that will embrace the TF coils from top to bottom to maintain the plasma's shape and stability.



Representatives of F4E, JADA, Toshiba, Mitsubishi, ASG Super Conductors, Iberdrola Ingeneria and Elytt Energy pose inside the first-ever completed double pancake

TF coil component prototype passes all tests

In the ASG Facilities, Italy, F4E and its team of contractors have celebrated an important milestone: the first major prototype has successfully passed a series of technically demanding tests.
The excellent results have validated the manufacturing procedures.

The main processes unfolding in the facility are: winding, heat treatment, insertion of the superconductor inside the radial plate and laser welding of the radial plates-produced by SIMIC and CNIM. These are extremely delicate steps and require an exceptional degree of precision.

The good collaboration between F4E, the ITER International Organization TF coil Central Team, ITER's Japanese Domestic Agency and F4E has also played an important role towards the successful completion of this task.

In order to check the capability of the prototype to withstand the cryogenic temperatures of ITER, the double pancake has been first cooled down to liquid nitrogen temperature at -196 ˚C and then, it has been brought back to room temperature.

Afterwards, the prototype has gone through a series of tests to check its response to High Voltage above 2 kV in air, and has also been tested in Paschen conditions, considered as the most demanding electrical conditions due to the fact that even a tiny insulation defect would cause failure.

Last, but not least, the prototype has passed a leak test. It is also worth highlighting the impressive dimensional tolerances that have been achieved which indicated only a minute deformation of less than 1mm in the prototype, in spite the 900 m long laser welding applied to the radial plate.

“This is an important technological step towards the manufacturing of one of the biggest and most complex superconducting coils ever produced. It is the result of the partnership established between F4E and ASG Superconductors, Iberdrola Ingeneria, Elytt Energy, CNIM and SIMIC.”

Alessandro Bonito-Oliva
F4E Project Manager for Magnets

What is inside a TF coil?

Europe is responsible for 10 out of the 18 Toroidal Field (TF) coils of the ITER machine.

In the core of a TF coil the lengths of conductor are protected inside seven double pancakes, large D-shaped disks that are 13 m long, 9 m wide and 0.1 m thick. They are made of a stainless steel plate, known as the radial plate, with grooves machined on both sides where a 450 m long insulated superconductor is located and impregnated.

Poloidal Field coils tooling has arrived at the ITER site

This has been a development of symbolic importance because the ITER construction site has started to become a manufacturing site. The first equipment has been delivered to the Poloidal Field coils facility.

The erection of the clean areas, where the coils will be manufactured, along with the building of the new office space and the fitting out of the building maintenance works have started to transform its space and convert it into a workshop.

The conductor winding table and the associated auxiliary tooling have been assembled in the PF coils facility, where the winding, impregnation, stacking and cold testing will be carried out.

The equipment has been produced under the contract signed between F4E and the SEA ALP Engineering Consortium responsible for the detailed design, manufacturing, installation onsite and commissioning onsite of the tooling needed for the winding of the PF coils. The value of the contract is in the range of 14 million EUR and will run for approximately six years, during which time the consortium will also train personnel, maintain the equipment and decommission when all winding is completed.

"The engineering process to be used will be brand new. This is the first time that the "two in hand" technique will be applied for the winding and wrapping of such a large conductor. We will be winding two conductors together in a concentric spiral and eventually connecting them at the end to form a double pancake coil."

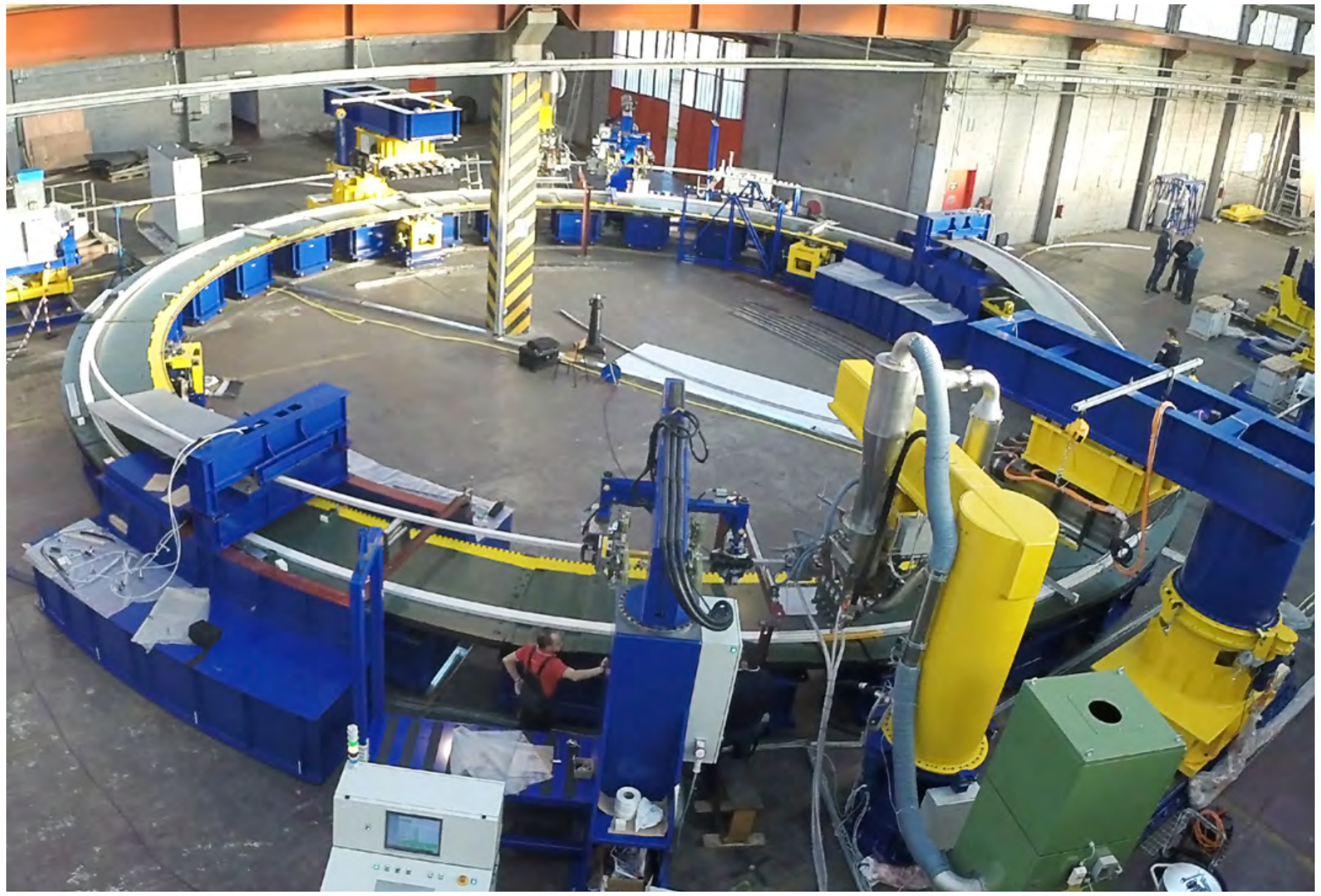
Gian Battista Fachin
F4E Technical Officer

PF Coils Facts and Figures

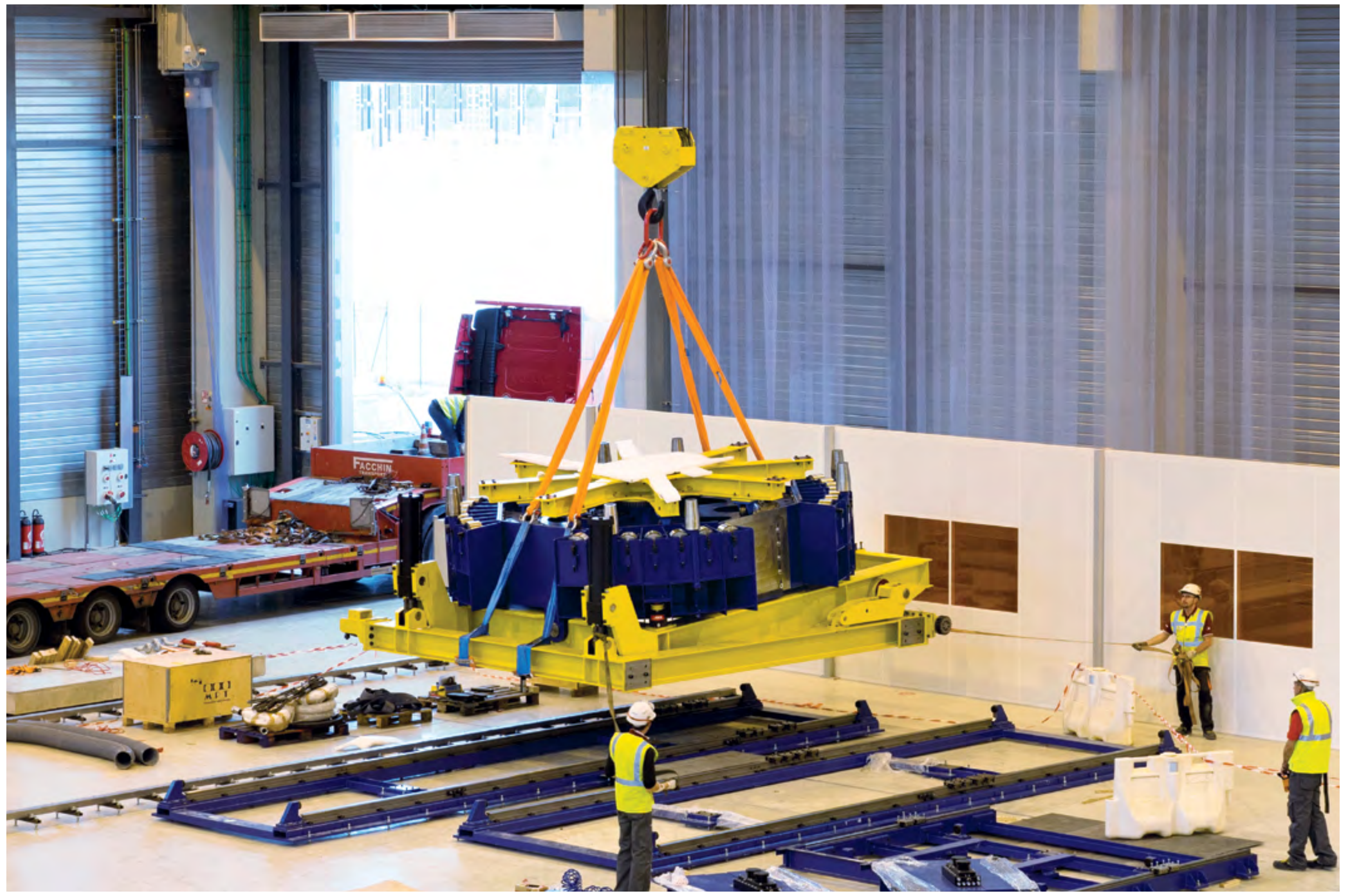
ITER will have six PF coils that together create a magnetic cage to maintain the plasma's shape and stability. Due to their impressive diameter and weight, four out of the six coils will be manufactured in the PF coils building facility on the ITER site.

Europe is responsible for five out of the six PF coils and the fifth of its coil is being manufactured through a collaboration agreement between F4E and the ASIPP laboratory in Hefei, China.

The diameter of the largest PF coil is around 25 metres and the weight of the coils varies between 200 and 400 tonnes. All five European coils will be cold tested in the PF coils' facility whilst for the sixth coil, manufactured by Russia, it is currently being considered if it will also be tested in the facility.



The Poloidal Field coils winding tooling table, SEA ALP workshop, Turin (Italy)



The Poloidal Field coils winding tooling equipment delivered to Cadarache

VACUUM VESSEL

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

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

A giant to mill the ITER vacuum vessel has been inaugurated

To manufacture this large component the engineers will need to work with considerable volumes of materials, operate big machines and perform tasks with extreme precision.

The production of the large stainless steel sectors for the ITER Vacuum Vessel requires milling – a material removal process which can create a variety of features on a part by cutting away the unwanted material. For this purpose the “PowerTec”, one of the world’s largest high precision portal milling machines ever built has been inaugurated at the Walter Tosto facility in Ortona, Italy. Especially designed and built by the German large tooling manufacturer Waldrich Coburg, the “PowerTec” weighs 1 300 tonnes and measures 50 m in length, 18 m in height and is 22 m wide.

However, it is not only the sheer size that is impressive about this machine; it is also its precision. The manufacturing of the ITER Vacuum Vessel requires extreme accuracy in the order of 1- 3 mm to accommodate for components such as the 440 blanket modules, the 54 divertor cassettes, the in-vessel coils and the blanket manifolds which will act as a first barrier and protect the vacuum vessel from the neutrons and other energetic particles that are produced by the plasma.

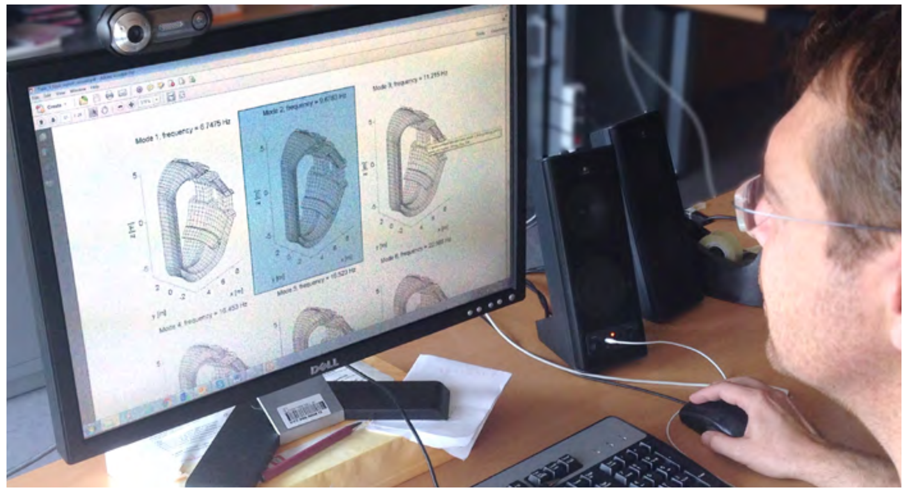
The milling machine inaugurated at the Water Tosto facility for the manufacturing of the ITER vacuum vessel sectors (image courtesy of Waldrich Coburg)

New numerical model to calculate the powerful electromagnetic forces

When the ITER plasma starts moving it will produce powerful electromagnetic forces of 100 MN, equivalent to the weight of the entire Eiffel Tower.
These loads are created by electrical currents interacting with the magnetic fields which are necessary to confine the plasma in the vacuum vessel.

F4E has been collaborating with Guglielmo Rubinacci, an expert from the University of Naples Federico II, to develop a mathematical model using a computer programme which will simulate the behaviour of the ITER Vacuum Vessel, during the fusion process. It is the first time such tool has been developed and the objective is to check and test how the vacuum vessel, or other ITER components, may deform during the operation. The model has focused on improving the existing numerical analysis by increasing the information available from the simulations. It has now been possible to obtain the full history of the deformation of the vacuum vessel and its movement during the plasma instability.

The application of this numerical model to the analysis of the ITER Vacuum Vessel has been greatly praised by the scientific community. It will also be used in the work of developing the next generation fusion machines, such as DEMO.



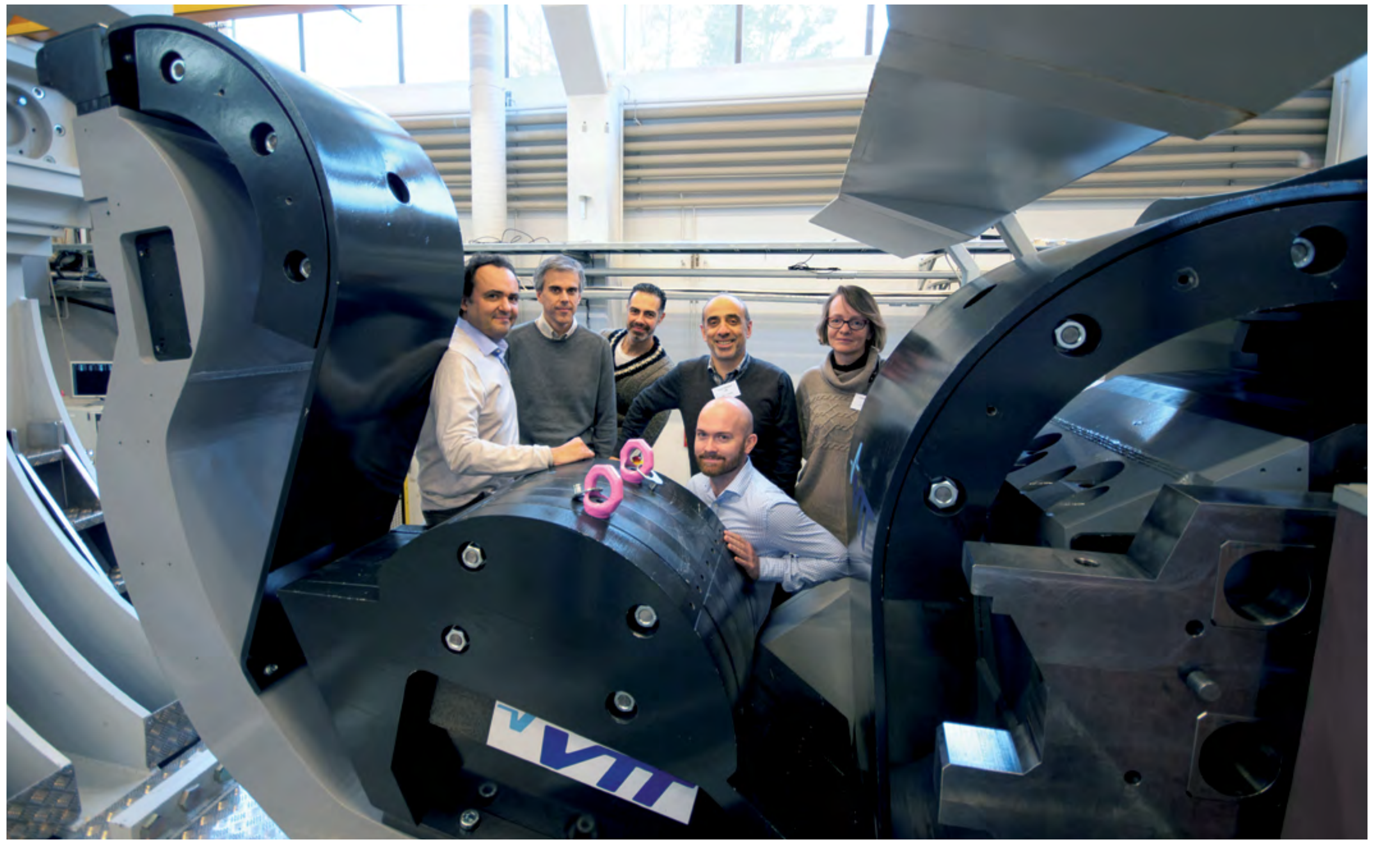
Pietro Testoni using the new numerical model in order to carry out calculations of electromagnetic loads in the ITER Vacuum Vessel

“We have managed to fine-tune the design of the supporting structure of the vacuum vessel and improve the safety margin during the operation of the machine.”

Pietro Testoni
F4E Technical Officer

REMOTE HANDLING

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



The F4E team behind the ITER Divertor cassette mock-up before the final tests begin

Real size prototype of the ITER Divertor Cassette in the Divertor Test Platform (DTP2) facility, VTT, Finland

Successful demonstration of remote handling prototype performed at Divertor Test Platform (DTP2) facility

Testing prototypes before manufacturing components and thoroughly examining the technical systems before deploying them are essential practices so as to minimise risks and contain costs. VTT, Finland's Technical Research Centre, in collaboration with the University of Tampere, have been hosting during the last six years the Divertor Test Platform (DTP2), a facility where teams of experts have been testing the movement and transportation of an ITER Divertor cassette mock-up.

The component weighs roughly 10 tonnes and measures 3.3 m x 2.3 m x 0.8 m. The ITER machine will have 54 cassettes in total and they will form the divertor. This component will absorb a significant amount of the heat during operation and shield the lower part of the vacuum vessel and magnets from the neutrons.

How will this work? In practice, the powerful magnets will divert part of the hot plasma together with the "ashes" and impurities from the walls of the vessel and direct them to the massive "ashtray" formed by the divertor cassettes.

The demonstration of the tooling moving the ITER Cassette Divertor mock-up has been successfully carried out giving confidence to F4E and its suppliers that the research and the tooling designed is on the right path.

The R&D that started in the DTP2 facility has successfully found a niche in the partnership of companies and laboratories led by Assystem UK, a leader in innovation and engineering, for the manufacturing of the ITER Divertor Remote Handling system. The value of the contract, awarded by F4E, in the range of 40 million EUR, has brought together some of the pioneers from this area such as the UK's Culham Centre of Fusion Energy, TUT, VTT and Soil Machine Dynamics Ltd (SMD).

"A brand new chapter is being written in Remote handling technology thanks to ITER. We need to design and manufacture systems that are resistant, agile and precise. It's an opportunity for industry, SMEs and laboratories to think outside of the box, innovate in engineering and shape future fusion reactors."

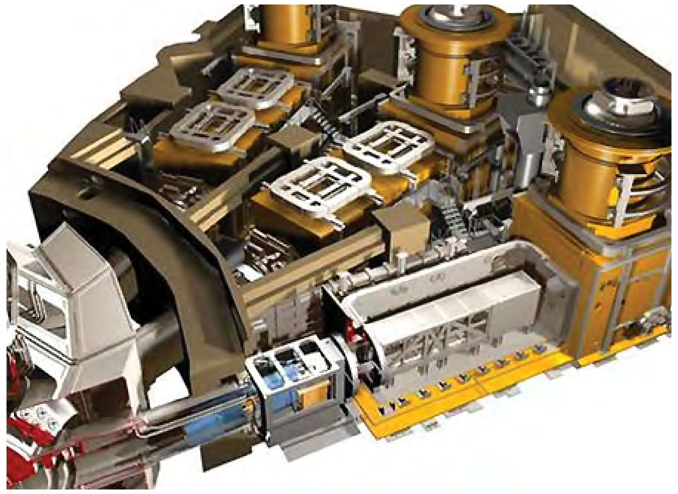
Carlo Damiani
F4E Remote Handling Project Manager

"Playing a role in ITER has helped us to generate new know-how. We have developed new expertise in areas like mechanical engineering, manipulator arms, special tooling, control system software, virtual reality and so on… The possible industrial applications are widespread in the field of industry, such as in off-shore movable machine manufacturers, power plants or the manufacturing industry."

Jouko Suokas
VTT Executive Vice President for Smart Industry and Energy Systems

One of the largest robotics contracts in the field of fusion energy awarded to Amec Foster Wheeler

F4E has signed a contract with Amec Foster Wheeler, a UK innovation leader with a proven track record in energy, to manufacture ITER's Neutral's Beam remote handling system. The contract reaching a value of 70 million EUR, will unfold progressively during at least seven years.



Artistic impression of the ITER Neutral Beam Remote Handling system. Copyright: Amec Wheeler Foster

(L-R) Carlo Damiani, F4E Project Manager for ITER Remote Handling Systems congratulating Ian Grayson, Boiler Spine Programme Director of AMEC Foster Wheeler

A sophisticated repair hub will use a 90 m monorail that will spread over the neutral beam cell, and will consist of transfer trolleys, beam line transporters and a variety of supporting beams that will operate in perfect coordination with tooling and manipulators. Some of the key tasks performed will include the maintenance work of the neutral beam injectors, with the cutting and welding of myriads of pipes, and the transportation of heavy components to the neutral beam cell storage area or to its main entrance for refurbishment and disposal.

Under the leadership of Amec Foster Wheeler, a group of laboratories and companies such as CCFE - the Culham Centre for Fusion, the UK's national fusion laboratory, Reel SAS of France, Wallischmiller Engineering GmbH of Germany, Hyde Group of UK, Capula of UK, "KU Leuven-MaGyICs" of Belgium, VTT - the Technical Research Centre of Finland, and the Technical University of Tampere will share their expertise in robotics and contribute to the works.

"This contract reinforces our company's strong expertise in remote handling and robotics, and more generally in taking a key role in the design and development of future fusion energy reactors."

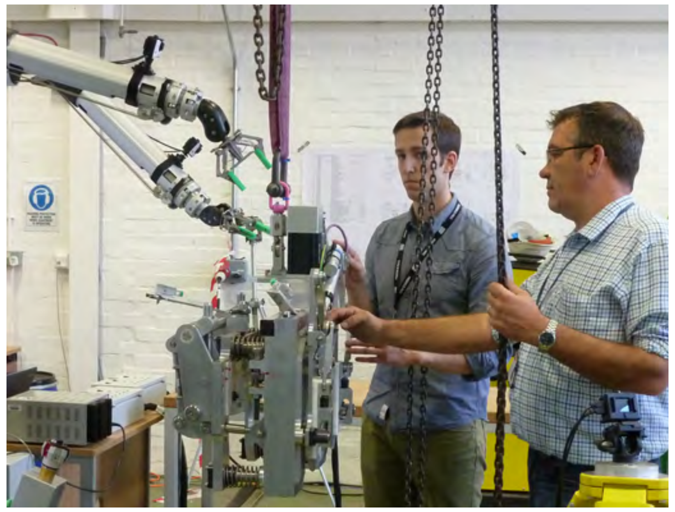
Clive White
President of Amec Foster Wheeler's Clean Energy Business

F4E collaborates with Culham Centre for Fusion Energy to develop tomorrow's remote handling equipment

ITER will be the first fusion device where welding and cutting of pipes will be routinely performed through remote handling. Similar equipment has also been used in the Joint European Torus (JET) but conditions were such that manual deployment was permitted. The need for R&D activity in this domain and its potential spill-over as part of ITER's remote handling system has led to a collaboration between F4E and the Culham Centre for Fusion Energy (CCFE).

The main objective has been to assess the current state of play and the development of future remote handling equipment for the alignment, cutting and welding of pipes taking as a case study the ITER Neutral Beam Injectors. The works carried out under this contract have started almost two years ago and F4E's contribution has amounted to 187 000 EUR.

CCFE has been assigned to develop prototype proof of principle pipe maintenance tools and has evaluated the tools and welded samples produced through parametric testing. During a series of demonstrations, the CCFE and F4E teams have witnessed the performance of different mock-ups and have acknowledged the progress of the tooling. The mock-ups will feed in two contracts managed by F4E in the fields of the divertor and neutral beam remote handling systems. The advances stemming from this R&D activity will generate savings in the two contracts and decrease technical risks.



Manipulator working with a crane to get the tool to its final position

Demonstration of a manipulator master arm performing an alignment.

ANTENNAS AND PLASMA ENGINEERING

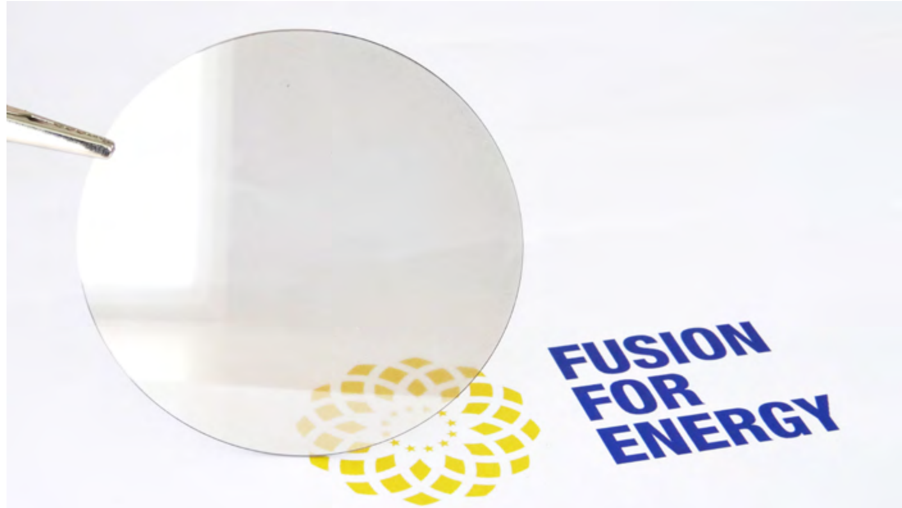
Large antennas will channel the electromagnetic waves generated by two heating systems- the electron cyclotron and the ion cyclotron - to heat ITER's plasma. Electro cyclotron launchers will help scientists to target specific plasma properties by guiding the waves with the help of mirrors. In parallel, 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.

Diamonds for fusion

Electromagnetic waves will travel through a diamond window to raise the plasma temperature inside ITER's Vacuum Vessel. Prototyping has started for two diamond discs.

One of ITER's heating systems that will help to raise the plasma temperature to 150 million ˚C is the Electron Cyclotron (EC). It will transfer the energy from electromagnetic waves into the electrons of the hot gas by injecting an unprecedented amount of power between 1 to 2 MW. Given the fact that the ITER vessel and the gyrotrons, responsible for generating the electromagnetic waves, have to remain vacuum tight, the only way to get the waves into the vessel will be through a diamond window. Across its 80 mm diameter and for up to 3 000 seconds, this impressive amount of power will be transmitted.

F4E is responsible for procuring 60 such diamond windows. In collaboration with ITER IO and Karlsruhe Institute of Technology (KIT), F4E has entrusted the manufacturing of two diamond discs prototypes to Diamond Material, a German SME. The manufacturing of the 1.1 mm thick diamond disc has started and has been the result of some 10 years of development at KIT and the Fraunhofer Institute (IAF).



An example of the diamond disc prototype currently being produced

"The diamond disc will be integrated into a mechanical structure which needs to withstand the harsh ITER environment and ensure that the diamond window does not fail. Vacuum-tightness is also important since the window will confine the tritium gas used for fuelling the ITER plasma and thus the disc is a key element for the confinement."

Gabriella Saibene
F4E Project Team Manager for Antennas and Plasma Engineering

IN-VESSEL

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

Pre-qualification for the Divertor Inner Vertical Target has started

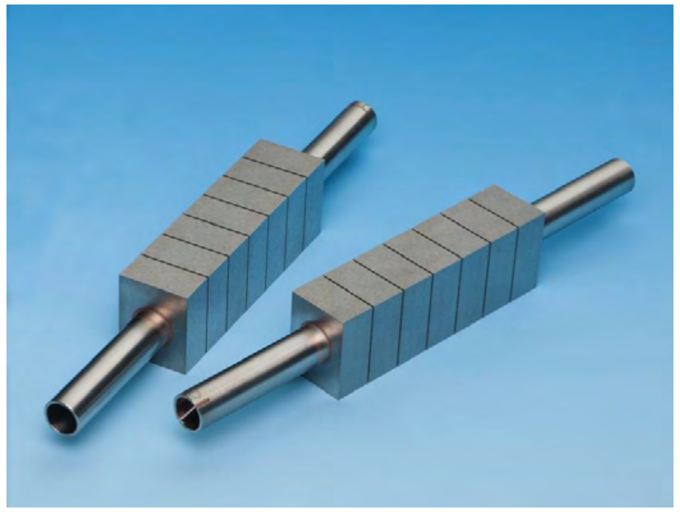
With the objective of fostering competition, F4E has signed framework contracts for the manufacturing of divertor inner vertical target (IVT) prototypes with the German company Research Instruments as well as two French consortiums ALCEN-ATMOSTAT and CNIM-TPI.

These three contractors have joined the already existing approved contractor Ansaldo Nucleare in their bid to pre-qualify as F4E suppliers. There is merit in working with different contractors in parallel because F4E will be able to test different technologies and mitigate technical risks.

F4E is responsible for providing the inner vertical target, the cassette bodies and the mounting of all the plasma-facing components, together with the required diagnostics and instrumentation, on the cassette body. The Japanese and Russian ITER Domestic Agencies are responsible for providing the outer vertical target and the dome respectively.

Each divertor cassette has three plasma-facing components (namely, the inner and outer vertical targets and the dome). The technical design will enable the targets, in their lower part, to intercept the magnetic field lines, and divert the high particle heat flux load coming from the plasma.

Companies will have approximately 18 months for the manufacturing of the IVT small-scale mock-ups. The second stage of the competition, the manufacturing of the full-scale prototypes, has been scheduled to be launched by early 2017. This latter stage should last about two and a half years after which the Call for tender for the series production will be launched.



Examples of how the small-scale mock-ups of the Inner Vertical Target (IVT) could look when completed

"We need a number of different companies for the pre-qualification stage in order to have enough competition when we then get to the qualification stage."

Patrick Lorenzetto
F4E Project Manager for In-Vessel

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. In essence, they will be generating a new nuclear system and licensing it using advanced materials and top fabrication techniques. Without a doubt, the lessons drawn will have significant implications towards the design of future fusion reactors like DEMO.

Conceptual Design Review concluded for European Test Blanket Module System

Under the leadership of F4E, companies like IDOM, Atmostat, AMEC Foster Wheeler, Empresarios Agrupados, Assystem, Iberdrola, and European fusion laboratories such as KIT, CEA, ENEA, CIEMAT, UJV, KFKI and NRG, have been collaborating extensively to push the R&D frontiers further.

Experts and representatives from F4E and ITER IO during the Conceptual Design Review of the European Test Blanket Module Systems

Years of hard work and a documentation exceeding 1 500 pages of engineering reports have come to crunch during the Conceptual Design Review (CDR) meeting, organised jointly by F4E and ITER International Organization, gathering 30 distinguished experts from the field to review the progress so far.

The assessment of the CDR panel has been overall positive praising the high quality of work and making some recommendations.

“This has been a turning point in the field. Years of R&D work have evolved into an engineering design that will be a system in ITER.”

Yves Poitevin
F4E's Project Manager for European TBMS

Facts and Figures

Europe has developed two blanket concepts: the Helium-Cooled Pebble-Bed (HCPB) and the Helium-Cooled Lead Lithium (HCLL). The key difference lies in the type of materials used for the tritium breeder. In order to choose which way to go for DEMO, it has been decided to test both European concepts simultaneously in ITER by placing the TBMS in an equatorial port of the machine.

Europe has started testing steel materials for the fusion reactors of the future

F4E and its contractors have started testing the merits of EUROFER97. Amongst its many advantages, this steel responds well to neutron activation with a good resistance to neutron irradiation. It is compatible with liquid metal and ceramic breeders and can sustain high temperatures.

Technical staff measuring the thickness of the EUROFER plates

A contract has been signed between F4E and Studsvik, Sweden, to perform a series of tests to learn more about the physical and mechanical properties of this steel. Studsvik and their subcontractor, NRG, Netherlands, have signed a contract in October to carry out the work and come back with a detailed technical analysis. The works are expected to last five years and will cost approximately 3.7 million EUR. The successful partnership of the two SMEs is another example of the potential contribution made by companies that are small in size but big in innovation.

Parallel to these developments, F4E has signed a contract with Saarschmiede GmbH Freiformschmiede, Germany, to deliver various EUROFER97 finished products. A total of approximately 27 tonnes will be manufactured in the form of special plates and bars of various thicknesses from 1.2 to 45 mm. The completion of the manufacturing, testing operations and acceptance of the EUROFER97 finished products, storage and delivery is foreseen over 17 months.

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 the most advanced cryoplant to date.

Final design review for European contribution to ITER Cryoplant concluded

To ensure a thorough, in-depth and independent assessment of the final design of the European components to ITER's Cryogenic System, F4E has structured a review relying on two main bodies: the design review.

Experts reviewing the final design details of Europe's contribution to the ITER Cryoplant

The successful completion of the Final Design Review meeting paves the way to manufacturing. The meeting has gathered more than 50 participants, members of the review panel and staff from Air Liquide and GTD Sistemas, the ITER International Organization, India's ITER Domestic Agency and F4E.

F4E has signed a contract with Air Liquide to supply the Liquid Nitrogen Plant (LN2) and Auxiliary Systems which will cool down, process, store, transfer and recover the cryogenic fluids of the machine. Two nitrogen refrigerators will be delivered along with two 80 K helium loops, warm and cold helium storage tanks, dryers, heaters and the helium purification system.

First heat exchangers for the ITER Liquid Nitrogen plant have been manufactured

F4E, ITER International Organization and Air Liquide have celebrated a series of important milestones with the successful factory acceptance testing of heat exchangers for the 80 K loop boxes – the first manufactured equipment from the contract signed between F4E and Air Liquide.

The heat exchangers are "key components" for the refrigeration of the cryogenic system. Basically, they exchange heat between two circuits: one with helium gas and another with liquid nitrogen. They have been designed and produced meeting the highest quality requirements.

The first two have been manufactured in Amagasaki, Japan by Sumitomo Precision Products and they are on their way to Europe. Six additional heat exchangers are being produced by the same company. All will be subsequently integrated into their respective cold boxes.

At Heatric, UK, two additional heat exchangers have successfully passed a global helium leak test consisting of liquid nitrogen cold tests and a helium leak test to check the compliance of the equipment. Having concluded the tests successfully, the equipment will be packed and delivered to China. There they will join the two heat exchangers manufactured in Japan and will be integrated in the cold box that will be manufactured.

F4E's Roger Martín with representatives from Air Liquide and Sumitomo Precision Products standing next to the first 80 K loop heat exchangers

Heatric technical staff carrying out the liquid nitrogen test.

ITER's Fuel Cycle System has started to take shape

The six water detritiation tanks, part of ITER's Fuel Cycle System, have been recorded as the first European components to be delivered on-site.

The six large-sized tanks are part of ITER's Water Detritiation System. When ITER starts operating, these tanks will collect the water containing tritium in order to recover it and subsequently use it in future fusion reactions. Four tanks, weighing approximately 5 tonnes and measuring 20 m³ each, will be part of this system. Two bigger tanks, weighing approximately 20 tonnes and measuring 100 m³ each, will be used for the tritium recovery phase in exceptional circumstances.

The first 100 m³ emergency tank being delivered to ITER

> *"It has been a great honour to be the first European company supplying the first components."*

Rafael Triviño
Ensa Managing Director

Representatives of F4E, ITER IO and Ensa celebrating the arrival of the first water detritiation tank to ITER

The contract awarded by F4E to Ensa, the Spanish company specialising in nuclear equipment, for the final design and manufacturing of the six tanks, has also counted on the expertise of Empresarios Agrupados and GEA as subcontractors. It has taken roughly 20 months for the six vessels to be designed and manufactured in order to comply with the stringent safety requirements that apply to ITER components. Their overall cost has been in the range of 2 million EUR.

The role of the water detritiation system

The two hydrogen isotopes - deuterium and tritium - will be supplied in the machine through the Tritium Plant in order to reach the core of the machine and fuse to release energy. What is left from the fuel of the fusion reaction, together with other gases produced, will return through pumps to the Tritium Plant in order to recover the tritium and use it to start all over a new series of fusion reactions.

NEUTRAL BEAM, ELECTRON CYCLOTRON POWER SUPPLIES AND SOURCES

Powerful heating systems using high-energy beams will be needed to raise the plasma's temperature and trigger off a fusion reaction. The neutral beam injectors will fire uncharged (neutral) particles into the plasma and by colliding with other particles their energy will be transferred. The electro cyclotron power supplies and sources will use radiofrequency waves to heat electrons in order to transmit their energy to ions through collision. To test this technology a Neutral Beam Test Facility (NBTF) in Padua, financed by F4E, Japan's Domestic Agency for ITER and Italy's Consorzio RFX, has been set up.

First European component for Neutral Beam Test Facility delivered

The first F4E component – a High Voltage Deck – has successfully gone through the acceptance test and has been installed.

During the acceptance tests of the SPIDER High-Voltage Deck (HVD) at the Neutral Beam Test Facility (NBTF) at the Consorzio RFX site in Padua, Italy

F4E has collaborated with the Italian company COELME in order to design, manufacture and install the high voltage deck (HVD), a structure which will hold the set of power supply equipment weighing around 40 tonnes. The delivery and acceptance of the HVD has marked the end of a four-month installation period.

The HVD measuring approximately 13 m × 11 m has been installed 1 m below ground-floor level on supporting insulators so that it can withstand the high 100 kV voltage of the power supplies.

COELME has also produced a transmission line to connect the power supplies installed inside the HVD to the SPIDER ion source and beam acceleration.

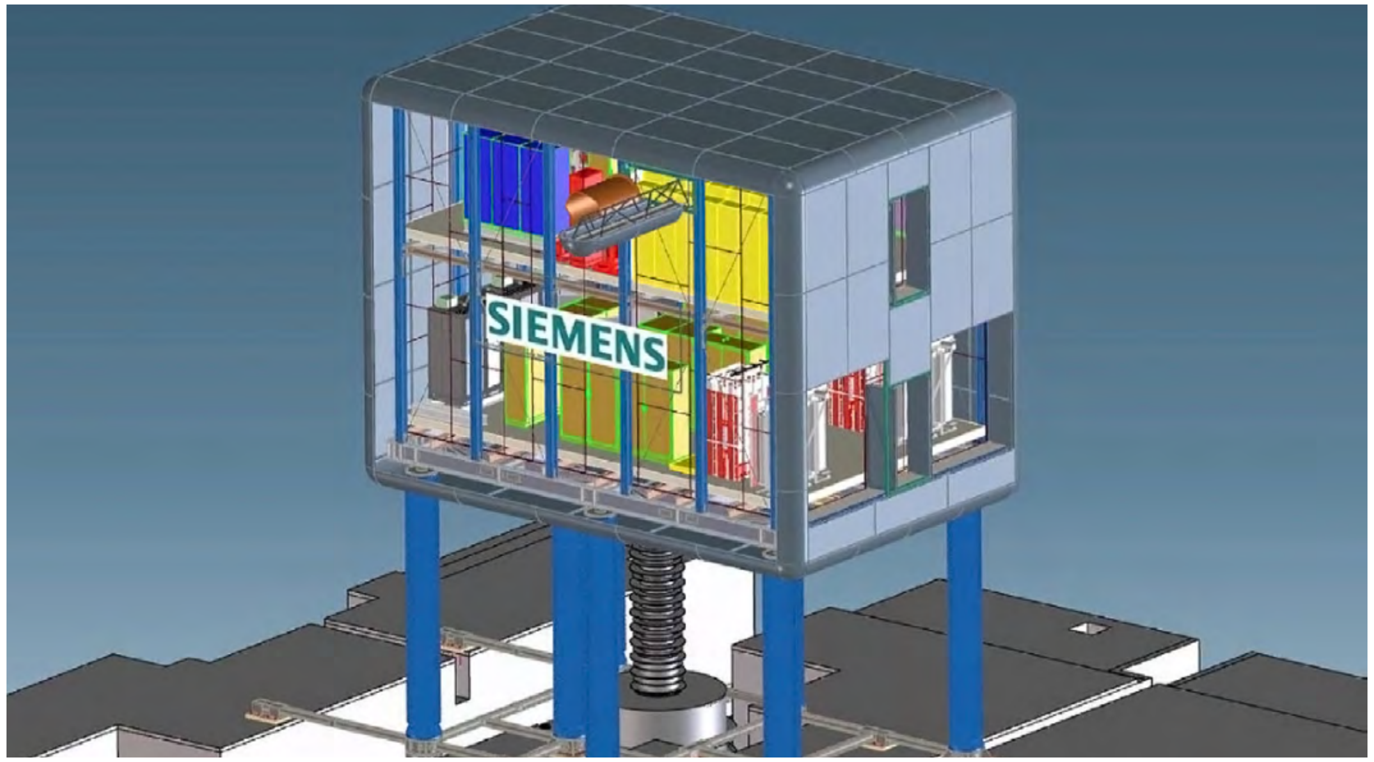
The Neutral Beam Test Facility, Padua, Italy

The Neutral Beam Test Facility (NBTF), located at the Consorzio RPX site, will house two independent test beds:

SPIDER (Source for Production of Ion of Deuterium Extracted from Radio frequency plasma), where the first full-scale ITER ion source will be tested and developed with an acceleration voltage up to 100 kV; and MITICA (Megavolt ITER Injector and Concept Advancement) which will be the first 1:1 full ITER injector aiming at operating up to the full acceleration voltage of 1 MV and at full power (16.5 MW).
F4E will supply the ITER machine with two neutral beam (NB) injectors similar to those in MITICA.

Siemens contributes to ITER's powerful heating system

Siemens has joined the ITER business family and through a contract signed with F4E it will deliver three units of equipment that will host power supplies as part of the ITER Neutral Beam Injectors (NBI).



One unit will be manufactured to be tested at the NBI facility (Italy) and other two units will be manufactured as part of the ITER powerful NBI system, designed to deliver 33 MW of power in order to inject neutral particles to the core of its super-hot plasma. The works are expected to last seven years and their overall value will be in the range of 18 million EUR.

"Siemens is proud to be part of this international research project and to play an active role in the construction of units for the ITER Neutral Beam Injectors. We look forward to a fruitful collaboration."

Michael Krohn
Project Manager for High Voltage Decks and High Voltage Bushings at Siemens

The scope of the contract:

Through this contract Siemens will design, manufacture and test three high voltage units to contain the power supplies of the NBI high energy beams that will heat up the ITER plasma. Similarly, the high voltage bushing assemblies, connecting the power supplies to the transmission lines, procured by Japan's Domestic Agency for ITER, will also be delivered through this contract. Following the successful completion of the factory acceptance tests, the components will be shipped and installed to different locations.

Gyrotron prototypes have been successfully completed

The successful tests of the gyrotron prototypes have stemmed from the fruitful collaboration between F4E, industry and European fusion laboratories.

F4E, TED and EGYC representatives with the CW gyrotron prototype that passed all Factory Acceptance Tests

Gyrotrons will generate high power microwaves that will transfer their energy to the plasma electrons and raise its temperature. ITER will have in total 24 gyrotrons and Europe is responsible for six of them.

F4E has been developing a short pulse and a long pulse Continuous Wave (CW) 1 MW gyrotron prototypes in close collaboration with the European Gyrotron Consortium (EGYC), which consists of several European Fusion Laboratories, namely KIT - Germany, CRPP - Switzerland, HELLAS - Greece, CNR - Italy, and USTUTT- Germany, and ISSP - Latvia as third parties, and Thales Electron Devices (TED), a French company.

The short pulse gyrotron experiments have been successfully carried out with an output performance exceeding ITER specifications. The CW gyrotron prototype has been manufactured and delivered to KIT where it will go through more testing. In parallel, a mock-up of a main gyrotron subsystem has been developed by TED and F4E and been tested. The results of all these tests have been evaluated as positive and have been shared with F4E, EGYC, TED and ITER IO.

More progress in the areas of power supplies and gyrotrons

The collaboration between F4E and Nidec Asi Sp.A has kicked off. The company is responsible for the manufacturing of three Acceleration Grid Power Supply Conversion systems (AGPS-CS): two for the ITER Neutral Beam Injector (NBI) and one for the Neutral Beam Test Facility.

F4E and Nidec Asi Sp.A are working together, with the support of RFX, to procure the acceleration grid power supply for the neutral beam injector

Representatives from F4E and British SME Cryogenic Limited at the kick-off meeting

The neutral beam injectors will fire uncharged (neutral) particles in ITER's burning plasma and by colliding with other particles they will transfer more energy and raise its temperature. The acceleration grid systems provided by Nidec Asi Sp.A will increase the energy of the uncharged particles to be injected.

F4E is responsible for the supply of the lower voltage part of the AGPS-CS, whereas the Japanese ITER Domestic Agency is responsible for the supply of its higher voltage part, the direct current generators. The design of the AGPS-CS for MITICA will be presented in summer 2016.

There has also been significant progress in the work carried out by Ampegon, a Swiss SME, collaborating with F4E for the European electro cyclotron (EC) high voltage power supply system for ITER. Following the successful completion of the final design review the fabrication of the first series of the units has started.

F4E and Cryogenic Limited, a British SME, have started working together to design and manufacture the first-of a-kind of a superconducting magnet (SCM) for the European 1 MW gyrotron prototype. The final design of the SCM has been completed.

In ITER, the superconducting magnets will form together with the gyrotrons the source of power of the electro cyclotron (EC) heating system. In order to produce this magnetic field, the coils of the SCM must be superconducting and work at cryogenic temperatures of around -269° C. F4E and Cryogenic Limited will use an innovative cryogen-free, 'dry' magnet technology which until now has never been used in Europe.

Facts and Figures:

The neutral particles injected by the two NBI will be accelerated in an acceleration grids system, with the required voltages and currents being provided by the acceleration grid power supply. F4E is responsible for supplying its lower voltage part, the conversion system, whereas the Japanese ITER Domestic Agency is responsible for supplying its higher voltage part, the DC generators.

Technical Support Services

F4E and DAHER have signed a multimillion contract for global logistics

The prestigious deal is in the range of 100 million EUR and foresees that for all future F4E contracts, DAHER will be Europe's exclusive logistics service provider for its impressive share of components.

Its mission will be to deliver them to the project's site, in Cadarache, from many different international locations. As host, Europe will pick up the bill for the services of DAHER used by the other ITER parties – China, Japan, India, the Republic of Korea, the Russian Federation and the US – to transfer their components from Marseille's Marignane airport or Fos-sur-Mer, its sea port, to Cadarache. The condition, however, is that the other ITER parties will have to use DAHER as logistics provider to ship their equipment to France.

The scope of the contract:

Approximately 4 000 European loads will be transported through this contract, which will be divided between exceptional loads, as it was the case for the delivery of the water detritiation tanks earlier this month, and conventional loads, such as pumps or more conventional equipment that could fit in containers.

In addition, 220 highly exceptional loads will also be transported through this contract. These are components that due to their exceptional weight and size will need to be transported at night, following a specific itinerary, and accompanied by representatives from the forces of the gendarmerie so as to minimise any disturbance that may be caused to locals. The arrival of the US transformer in January 2015 made history being registered as the first real highly exceptional load entering the ITER site.

The ITER test convoy on its way to Cadarache Copyright: S Benacer/400ASAn

03

The Broader Approach

Boosting fusion know how through Research & Development

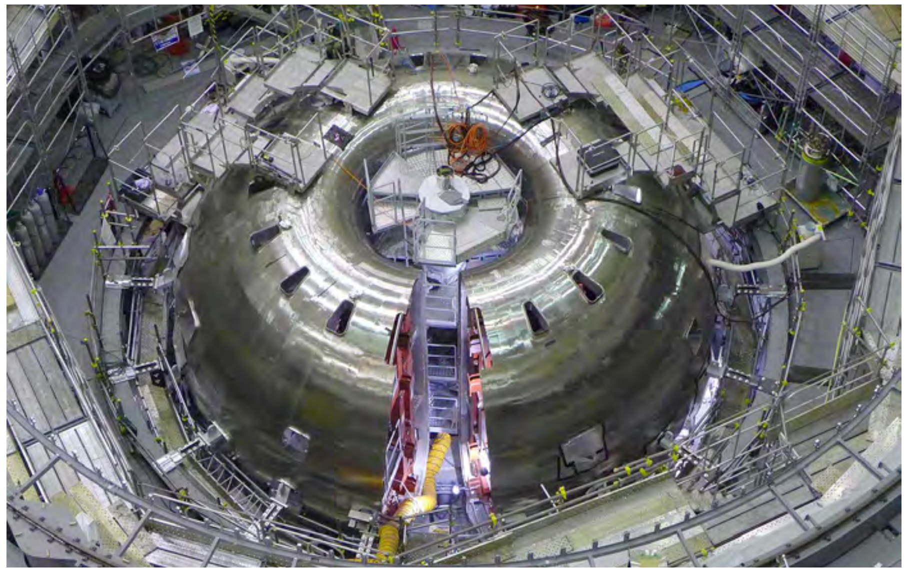
Thinking in broad terms and combining vision and precision in order to address short and long term challenges summarises the spirit of collaboration between Europe and Japan in the area of fusion research. In February 2007, an Agreement was signed between the two parties complementing the ITER project 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, namely:

- The Satellite Tokamak Programme (STP) JT-60SA “satellite” facility of ITER in order to model proposals for optimising plasma operation
- 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-60 SA vacuum vessel nearly assembled

The Japanese Atomic Energy Agency (JAEA), the Japanese Implementing Agency for Broader Approach activities and F4E partnership in the JT-60SA project, has completed the on-site assembly of nine out of the ten sectors of the JT-60SA tokamak vacuum vessel.



340 degrees (nine sectors) of the JT-60SA vacuum vessel assembled and ready for TF coils installation

"This important Japanese achievement is a fundamental milestone towards the challenging goal to complete the JT-60SA project on schedule, by March 2019. On behalf of F4E and the Broader Approach European voluntary contributors, I heartily congratulate JAEA and their suppliers."

Pietro Barabaschi
F4E's Head of Department for the Broader Approach

This major achievement has come after years of work – the JT-60SA tokamak assembly began in January 2013 and is expected to last six years, including a commissioning period which will enable the first plasma to be achieved in March 2019. Before the installation and welding of the last sector which is foreseen in 2017, the 18 Toroidal Field (TF) coils produced in Europe, the magnets which will keep the plasma in place during the fusion process, will be threaded over the vessel and fixed in place.

JT60-SA vacuum vessel

The vacuum vessel is the heart of the machine where the fusion reaction will take place. It consists of 10 sectors made of 316 L stainless steel, 6.6 m high and 3.5 m wide, each weighing around 17 tonnes. All sectors have been manufactured by Toshiba as part of JAEA's contribution to the project. The vacuum vessel, with a diameter of 10 m and a height of 6.6 m, has been assembled respecting maximum tolerances of the order of a few millimetres!

One of the 13 QPC units after installation in Naka, Japan

Successful acceptance test for the JT-60 SA Quench Protection Circuit (QPC)

A first for a circuit of such technology to be used in an industrial application for high currents and voltage ratings of 4.2 kV.

The Quench Protection Circuit (QPC) has an important safety function in the JT-60SA machine: superconducting coils confine the fusion plasma, but if, for whatever reason, the coils stop being superconducting, they need to be immediately discharged to avoid damage from overheating. This protective function will be performed by 13 QPC units that allow rapidly dissipating the huge magnetic energy stored in the coils into a set of discharge resistors.

The QPC, procured by the Italian Research Council (CNR) acting through Consorzio RFX in Padua, Italy have been successfully tested and completed.

The cryogenic system has been installed

The cryogenic system of JT-60SA tokamak installation has been successfully completed. The system, which will be the most advanced of the three largest helium refrigerators in Asia, can be described as a large plant for cooling helium to very low temperatures with an equivalent refrigeration capacity of 9 kW at 4.5 K (-269 °C). It will be used to cool the superconducting magnets, cold structures, thermal shields, current leads and divertor cryopumps of JT-60SA.

The team involved in the installation of the Auxiliary Cold Box (ACB) in front of the component itself

F4E, in collaboration with CEA (Commissariat à l'énergie atomique et aux énergies alternatives), have developed the preliminary design and specifications of the JT-60SA cryogenic system. CEA has contracted Air Liquide Advanced Technology, France. Most of the heavy-weighting components have been manufactured in Europe and therefore had to be transported to Japan where JT-60SA is being constructed.

F4E has also contributed to the hardware, with the supply of the gaseous helium storage vessels. In total, the six pressure vessels will store 3.6 tonnes of gaseous helium.

The contract for the supply and transport to Japan of the pressure vessels and their equipment has been awarded by F4E to A. Silva Matos Metalomecanica SA (ASMM) (Portugal).

The Japanese Atomic Energy Agency (JAEA) has also finalised the construction of a new compressor building, the refurbishment of the cryogenic hall, the preparation of the foundation for the helium storage vessels, and the installation of the high voltage transformers and water cooling towers.

The final Factory Acceptance Tests of the complete plant will have been concluded by August 2016.

"The fact that the demanding installation of this complex system has succeeded is indeed a very good example of what can be achieved by joint effort in the Broader Approach projects between Europe and Japan."

René Gondé
French Project Director within the European Home Team of JT-60SA

All HTS Current Leads for JT-60SA TF coils delivered

Europe has completed all six high-temperature superconductor current leads (HTS CLs), which will connect JT-60SA's superconducting Toroidal Field (TF) coils with the power supplies.

KIT (Karlsruhe Institute of Technology), the designated German contributor, in consultation with F4E and JAEA, has selected the most advanced high temperature superconductor current lead design which KIT has already previously developed for the Wendelstein 7-X experiment.

The electrical connection between the warm power cables of the power supplies and the cold superconducting electrical network of the coils is realised by special helium-cooled connectors, the so-called current leads. Apart from the six that have already been produced, twenty current leads will be used to connect the power supplies with the JT-60SA Poloidal Field (PF) coils and the central solenoid modules.

"This important EU contribution has been possible thanks to the extensive know-how, developed at KIT on high-temperature superconductors, coupled with the dedication of KIT researchers, engineers and professional personnel."

Prof. Dr. Joachim Knebel
Head of Mechanical and Electrical Engineering Division, KIT

F4E and JAEA representatives with Stefan Kaufmann, Member of German Parliament (sixth from the left) in front of the delivered HTS-CLs

04

Working together with stakeholders

In order to better serve the various communities that have a vested interest in the ITER project, we have developed different platforms to listen, understand and respond to their needs.

F4E explored together with the different committees and the network of ITER Industrial Liaison Officers (ILOs) and European Fusion Laboratories Officers (EFLOs) a series of measures that would stimulate further the participation of industry, SMEs and R&D organisations.

MEP Martina Dlabajová sees the progress of the ITER site

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, has visited the ITER site to receive an update on the overall progress of the project and in particular on Europe's contribution.

MEP Martina Dlabajová (third from the left) visiting the ITER site, Cadarache

A tour on the ITER site and a series of exchanges with representatives from F4E and the ITER International Organization have given the MEP the opportunity to familiarise herself further with the project. The manufacturing of components and the potential technological transfers stemming from ITER have highlighted the potential of this international endeavour in jobs, growth and competitiveness.

European and Japanese policy-makers celebrate JT-60 SA achievements

All the milestones of the JT-60SA project were celebrated by some 200 high-level European and Japanese guests visited the site of the project in Naka, Japan. Hosted by the Japanese Atomic Energy Agency (JAEA), the event showcased the excellent progress stemming from this collaboration.

To celebrate all the milestones of the JT-60SA project some 200 high-level European and Japanese guests visited the site of the project in Naka, Japan.

Addresses by high ranking representatives of the Japanese government, European Embassies and the European Commission have expressed satisfaction with the contributions of all parties involved, and have drawn attention to the mutual trust developed between them. After a tree planting ceremony, guided tours were given on the site so that visitors could view the state of technical achievements in the different areas.

Commercial partnerships and intense networking at the ITER Business Forum

The fourth edition of the ITER Business Forum (IBF) has taken place in Marseille, France.
The event has brought together more than 800 participants from 26 countries working in high-tech industry and R&D.

Jean-Marc Filhol, Head of F4E's ITER Department, delivering his welcome address at IBF2015. © AIF

Europe's commitment to deliver the lion's share to ITER has been highlighted by Jean-Marc Filhol, F4E's Head of ITER Department: " F4E through its contracts with industry, has already been creating over 15 000 person-years of employment and will create many more during the rest of the project's construction. ITER work is more labour-intensive than conventional industrial manufacturing due to the high content of R&D and engineering tasks. On average, around 50 % of F4E's funding to industry has gone directly to salaries, compared to around 15 %, which is the case for the conventional manufacturing industry."

The thematic sessions have served mainly two objectives: first, attendees have received information on the current state of progress and manufacturing of components, second, the future procurement opportunities and subcontracting have been discussed.

Members of the ILOs network have acted as conveners and led 14 parallel sessions addressing specific areas of procurement. The participation of specialiasts from the different ITER Domestic Agencies (DAs) together with companies being involved in ITER contracts boosted the business angle of the event.

Big science means big business opportunities

Leonardo Biagioni, F4E's Head of Contracts and Procurement, presenting the ITER business opportunities.

The capacity of big science projects to structure around them a community of skills that will evolve with time, and adapt according to emerging R&D needs, has been the topic of the event organised by Sweden's research match, the agency promoting business in big science projects. Representatives of ITER, CERN, Omnisys instruments, Examec and the Director General of Vinnova, Sweden's national innovation agency, met with an audience drawn from 80 companies, to share their experience and inform them of the various opportunities. F4E showcased the different ways that the ITER project has been able to stimulate business and spin-offs.

Franco-Spanish meeting addresses tomorrow's energy challenges

Representatives of French and Spanish companies following the F4E information session

The second Franco-Spanish industrial meeting has managed to attract the interest of more than 50 companies with a proven-track record in the field of nuclear energy. Building on the success of a similar event organised almost two years ago, Spain's Industrial Nuclear Forum and the Business Division of France's Embassy to Spain have collaborated again to gather different economic actors. Networking, establishing new partnerships, and discovering the different commercial opportunities stemming from energy projects, have been the main objectives of this event.

Italy's industry in Piedmont sees ITER's potential

Organisers and invited speakers explaining the ITER business opportunities for Italy's companies in Piedmont.

An information day highlighting the business prospects of ITER has been organised by Cofindustria Piemonte, the confederation of industry operating in Italy's northern region, in collaboration with AMMA, the Turin Association of Metal and Mechanical Industrialists, and ENEA: the Italian National Agency for New Technologies, Energy and Sustainable Economic Development.

The industry operating in Piedmont has been leading by example. The region has been ranking first in the country, managing nearly 30% of Italy's share of ITER contracts for a value of 300 million EUR, and has a solid track record in the field of mechanical engineering.

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05

Events

Spreading the word on Europe's contribution to ITER

F4E contributed to several events in order to promote different aspects of its work to diverse target groups such as companies, technology communities, scientists, policy-makers and younger audiences.

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

Participants discuss the latest developments in ITER Remote Handling systems

Remote Handling meeting gathers pioneers and fosters industrial culture in fusion reactors' maintenance

A two day workshop organised by F4E, ITER IO and Japan's ITER Domestic Agency, has brought together more than 50 experts working in the field of remote handling. Participants have met for the first time and reported on the current progress of their work; recent technology breakthroughs and areas of mutual collaboration.

This first-of-a-kind workshop has laid the foundations for a technology cluster consisting of pioneers working in a vast range of technologies.

Carlo Damiani, F4E's Project Manager for ITER Remote Handling Systems, and his team have been working hard to see this idea through.

Jim Palmer, Section Leader of ITER IO Remote Handling and Hot Cell Complex, has confirmed that "that the event gave participants a sense of the big picture and of the impressive industrial potential stemming from their design and R&D."

Part of the ITER Remote Handling system will be manufactured in Japan and for Nobuzaku Takeda, who represented Japan's ITER Domestic Agency to the workshop, and in his view, "there is a clear industrial potential that will mature with time."

"Now that we have a critical mass of big industries, SMEs and fusion laboratories contributing to ITER's Remote Handling system through contracts and grants, we have started to form an integrated team."

Carlo Damiani
F4E's Project Manager
ITER Remote Handling Systems

Fusion laboratories receive training on project management software

A training session has been organised by F4E to give the European Fusion Laboratories (EFLs) the opportunity to further develop their skills in project management platforms used in the ITER project.

The software used by F4E contains information on schedule activities, budget and work programme milestones. The focus of this training has been the Diagnostics systems as part of the Framework Partnership Agreement signed between F4E and EFLs.

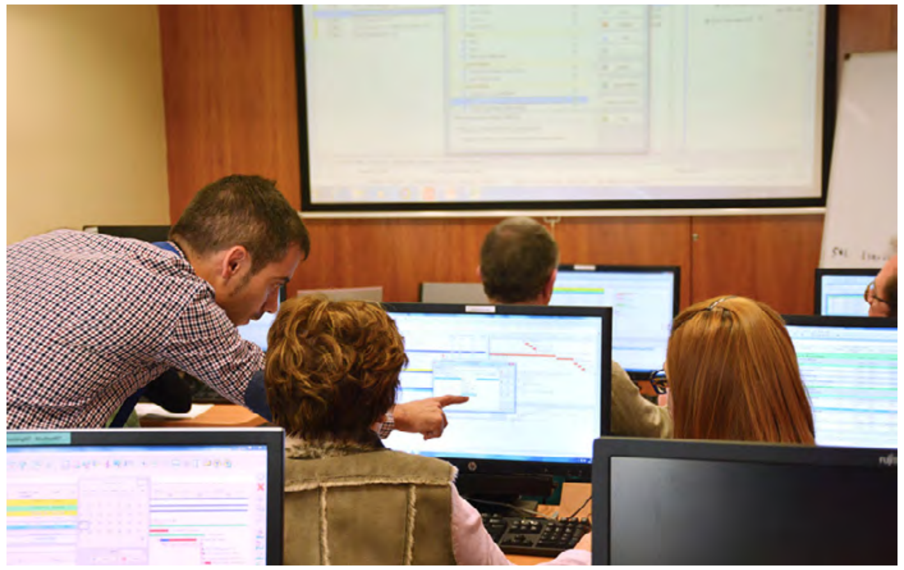
The training has covered subjects such as how to create a schedule and how to monitor the progress of the project as well as Earned Value Management (EVM). This has been a first of a kind training and feedback from the 11 EFL representatives coming from Denmark, Italy, Germany, Hungary, Spain and Portugal has been extremely positive.

"Primavera is the main planning tool we use at Forschungszentrum Jülich GmbH (FZJ) where we are building the CXRS diagnostic device for ITER. F4E's Primavera training incorporated clear examples and useful practical exercises in order to facilitate learning. I look forward to more of this type of trainings in the future."

Katarzyna Rasinska
FZJ Quality Manager (Germany)

"The F4E Primavera training managed to cover all relevant important areas and transmit knowledge for different background levels. I definitely recommend other F4E EFL partners to undergo this training."

Tamás Ilkei
Project Leader for the ITER and Fusion Diagnostic Development Research Group, WIGNER (Hungary)



During the Primavera training session for EFLs working under F4E Diagnostic FPAs

F4E hosts its first Diagnostics Workshop

Representatives from 20 fusion laboratories and companies from 12 different countries, presented their work and explored ways of closer collaboration.

Interventions given by ITER IO, US ITER Domestic Agency and F4E helped attendees to see how each party has a role to play in this echnical area.

F4E is responsible for contributing with 11 Diagnostic Systems, corresponding to approximately 25% of the ITER Diagnostics set. Large design teams made up of engineers and scientists from the European fusion laboratories and companies collaborate with F4E in order to develop and integrate the diagnostic systems.

Presentations by the fusion laboratories and companies have been complemented by specific interventions given by ITER IO, the US ITER Domestic Agency, and F4E. The workshop has proven to be a good forum for fostering closer collaboration and exchanging good practices

The participants of the Diagnostics Workshop at the F4E office

Learning more about metrology techniques

Metrology, the science of measurement, plays a vital role in procuring components for the ITER machine. In the case of Europe, this plays an even more important role with the increasing amount of components being produced. F4E has taken the initiative to train partners and suppliers with which it works, so that they use the same tools and the same procedures.

The participants of F4E's first-ever metrology training

This first metrology techniques training has consisted in theoretical sessions and a practical session which involved using the actual metrology equipment. Attendees came from European Fusion Laboratories and industry, as well as scientific organisations such as CERN. Led by the members of the F4E Metrology Group, the training was very much based on first-hand experience from working on the ITER project. "Our suppliers now have a better understanding of the importance of a correct metrology inspection. We now speak the same language and the documentation produced by them complies with the required standards and specifications, without any necessary additional intervention from F4E. Sharing a common metrology culture has greatly improved the efficiency of the acceptance process of ITER components", said Luigi Semeraro, Head of F4E's Metrology Group.

BEST innovators discover ITER and the merits of fusion power

The main objective of the Board of European Students of Technology (BEST) is to bring together European students with a healthy appetite for technology. With the help of more than 95 local networks, reaching out to 1 300 000 students from 33 countries, it has become a reference to those who believe in European research, mobility, knowledge transfer and aspire to innovate.

F4E has been invited to open the annual BEST seminar hosted by the Polytechnic University of Catalonia in Barcelona to explain the merits of fusion energy, the progress of the ITER project and the industrial and technological benefits that would stem from it.

A two-hour debate with the students attending the seminar has given innovators the opportunity to share views of multiple technical subjects.

Dr. Jesus Izquierdo, working in F4E's Technical Suport Services, has explained that "today's environmental awareness needs to be matched with intelligent energy choices. If we cannot consume less power then we have to empower tomorrow's innovators. We have to lay the foundations for the widest sustainable energy mix…and this is where fusion comes in."

Group of students attending the BEST seminar hosted by the Polytechnic University of Catalonia

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