FUSION
FOR
ENERGY

HIGHLIGHTS
2016

THE MAIN ACHIEVEMENTS


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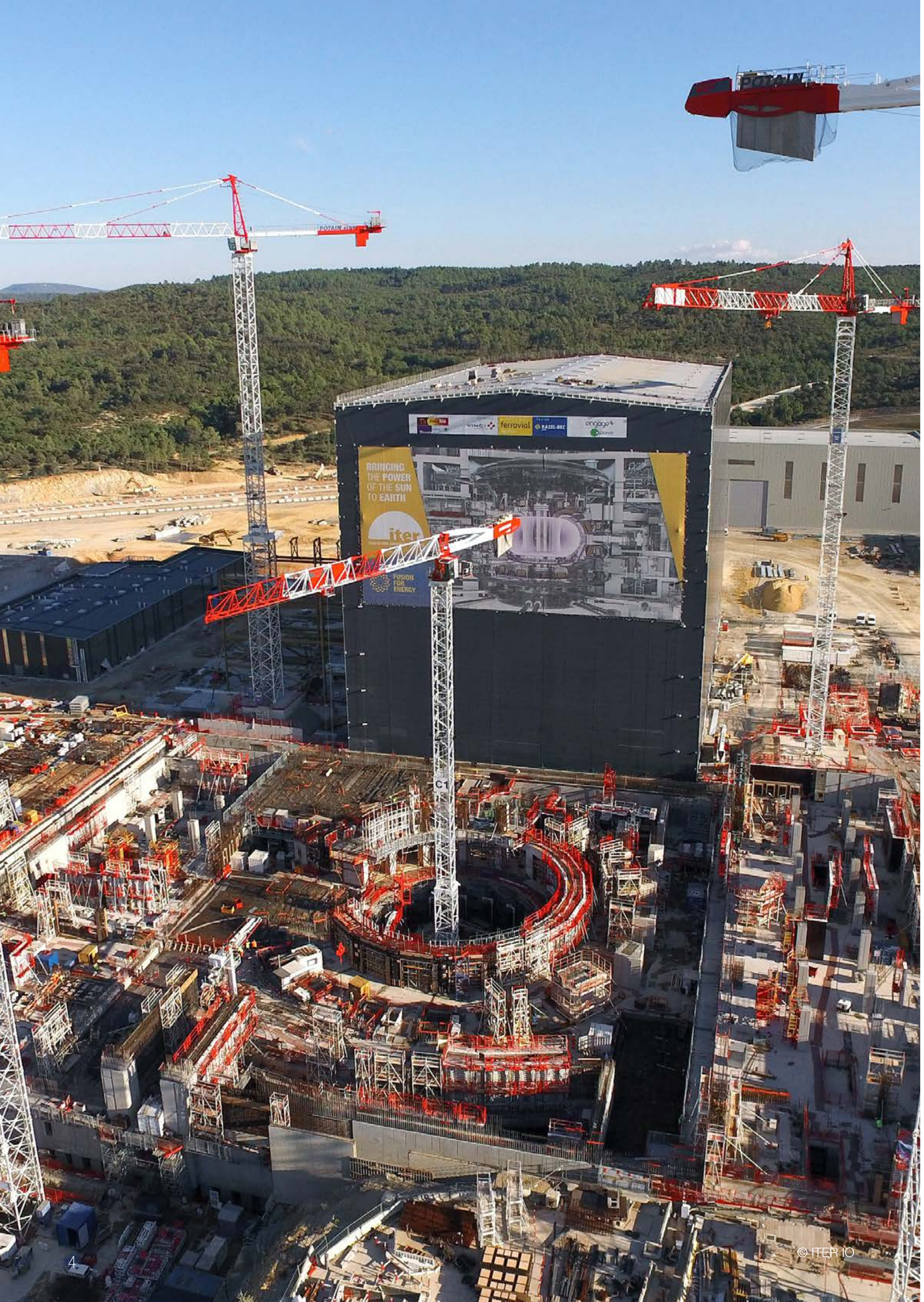
Table of contents



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Foreword

How can we foster growth and reduce CO_2 emissions? A sustainable energy mix is the answer and fusion energy has the potential to play a significant role in the decades to come.

Energy is the fuel for our economic prosperity; it has an impact on our social well-being and can influence world order. We rely on it to make progress, bridge inequalities and by having access to it we avoid conflict. Therefore, we need to take into consideration all of the above when we contemplate the level of investment in order to meet the future needs of our rising population. At the same time, fighting climate change remains one of the top challenges.

In the next 20 years countries must invest nearly 35 trillion EUR to meet their energy needs. Today, the EU imports 53% of the energy it consumes, at a cost of more than 1 billion EUR per day. In Europe alone, the total economic losses, caused by weather-related extremes during the last 25 years, amounted to 433 billion EUR.

How can we foster growth and reduce CO_2 emissions? A sustainable energy mix is the answer and fusion energy has the potential to play a significant role in the decades to come. Fusion is the power source of the sun and other stars. The fuels required are widely available and virtually inexhaustible. Fusion does not produce greenhouse gas emissions or long-lasting radioactive waste. Furthermore, fusion reactors will be intrinsically safe with no risk of a chain reaction whilst generating large amounts of electricity.

ITER is the biggest scientific international collaboration in the field of energy research and 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, US) and represents 80% of the global GDP. Europe is the host of this one-of-a-kind scientific endeavour and contributes more than the other six parties, reaching the range of nearly 50%. Fusion for Energy (F4E) is responsible for Europe's contribution to ITER and is also managing Europe's involvement in three fusion projects carried out in Japan, known as the “Broader Approach” (BA).

In this report, I would like to share some of our main achievements. In my first year as Director of F4E, my priority has been to consolidate the project's roadmap until 2025, leading to the so-called “first plasma”, when ITER will be switched on. This culminated in the agreement on an updated project schedule by the ITER Council in November 2016. At F4E, we have also laid the foundations of a stronger project management culture and further professionalised our processes. In collaboration with all ITER parties we have identified common milestones which underpin the progress of this challenging project. Cost containment remains our highest priority and by focussing our resources we are determined to continue to improve our performance.

Europe's participation in ITER offers industry, SMEs and research organisations unique opportunities to work together on diverse cutting-edge technologies and build commercial partnerships. Consequently, they will enhance their know-how, gain new knowledge which will trigger off spin-offs, and become familiar with an energy source that promises to pay dividends in the future. In 2016, we signed 88 new contracts involving additional economic operators, which since the start of the project count more than 440 companies and 65 R&D organisations.

In spite of the many challenges due to the complexity of the ITER project, in 2016 we witnessed much progress on the ITER site in France starting with the completion of the civil engineering works for the Assembly Hall and the installation of its cranes. The advancement of works at the Tokamak Complex and the rest of facilities has also been notable.

Several milestones for the manufacturing of key components have been achieved starting with the completion of the first Toroidal Field coil winding pack, one of the biggest and most technically complex superconducting magnets to date. The first manufacturing trials of the Poloidal Field magnets, performed in a facility on-site, have also kicked off successfully. The speed of the manufacturing of the huge sectors of the Vacuum Vessel increased in the second half of the year and F4E is supporting the suppliers to further improve. The installation of the Water Detritiation Tanks and the arrival of the more components of the Cryoplant, are major milestones for the one of the biggest ever cryogenic system. At the Neutral Beam Test Facility in Italy, more equipment has been installed converting this infrastructure gradually into an ITER test bed. There have been some excellent results from prototypes in the area of heating systems and a lot of good work has been carried out in the field of Diagnostics where the design of key components has been praised by independent experts.

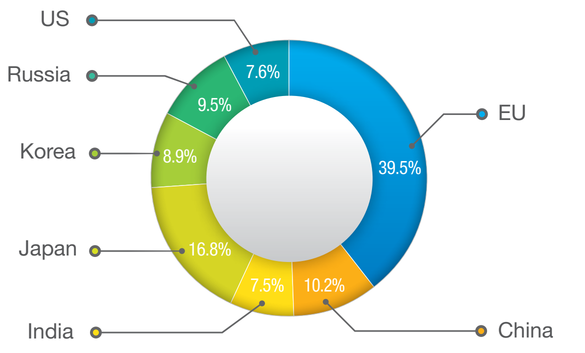
Major contracts have been signed in the field of Remote Handling with design and R&D making headway. The first prototypes of ITER's wall protection have been completed and in parallel, the testing of a steel material to be used for the manufacturing of Test Blanket Modules has advanced. For the Broader Approach projects, the year has been marked by the impressive assembly of the JT-60SA fusion machine, the successful completion of the IFERC project, and the execution of IFMIF activities on time and within budget.

To showcase some of the progress Europe has made in collaboration with its suppliers and other ITER parties, we have prepared this publication to guide you through some of the year's highlights.

Johannes Schwemmer
Director of Fusion for Energy

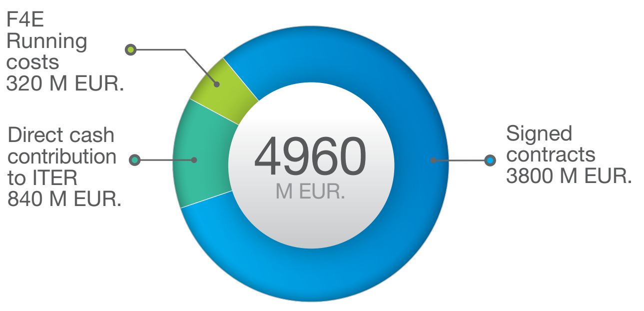
2016 Key figures

Contributions to ITER



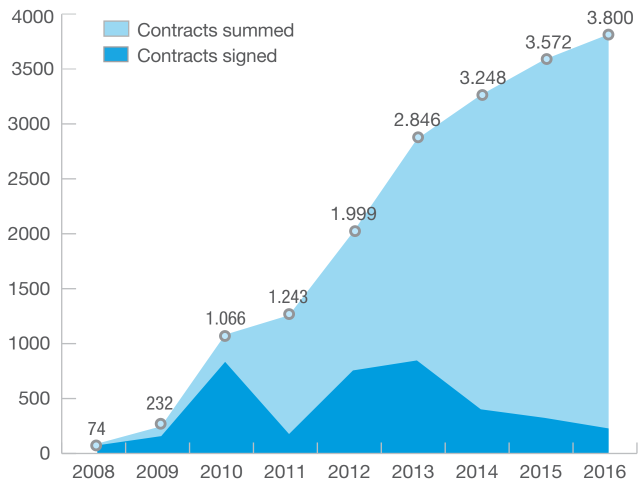
Total contributions between the different ITER parties 2008-2016

F4E budget breakdown

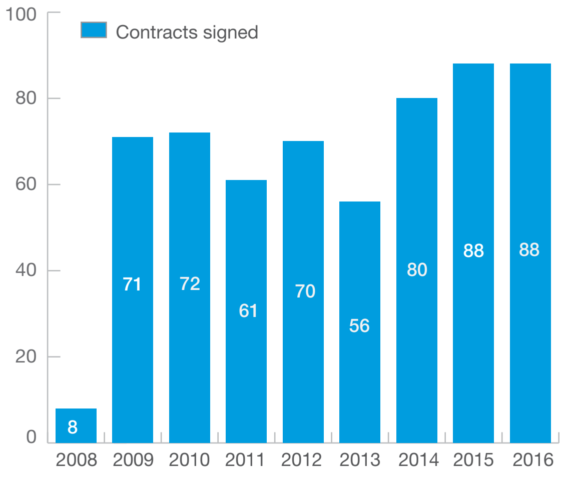


Budget breakdown of F4E main activities 2008-2016

Value and quantity of signed contracts



Annual and summed value of contracts signed



Number of contracts signed

Since 2008 F4E has been collaborating with:

AT LEAST **440** COMPANIES

MORE THAN **65** R&D ORGANISATIONS

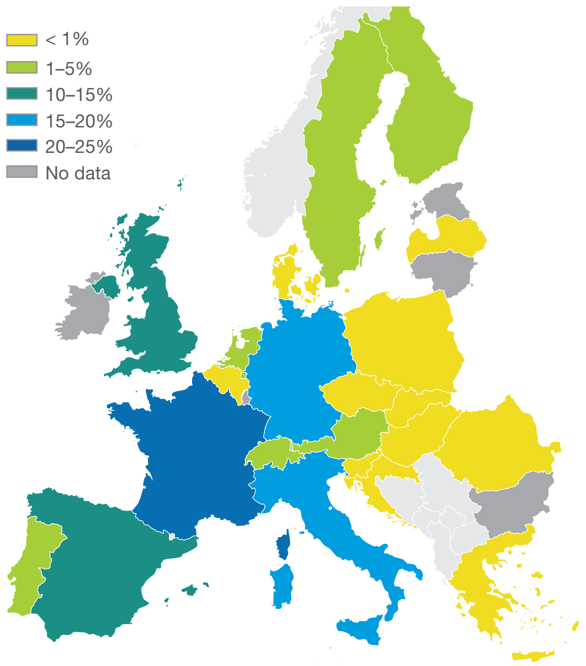
Since 2008 F4E has:

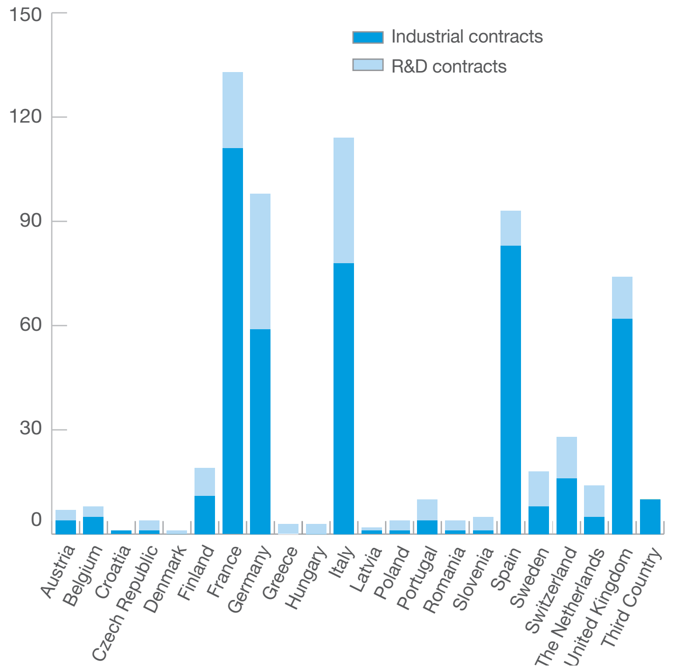
RECRUITED **415** MEMBERS OF STAFF

ATTENDED AT LEAST **150** MAJOR EVENTS

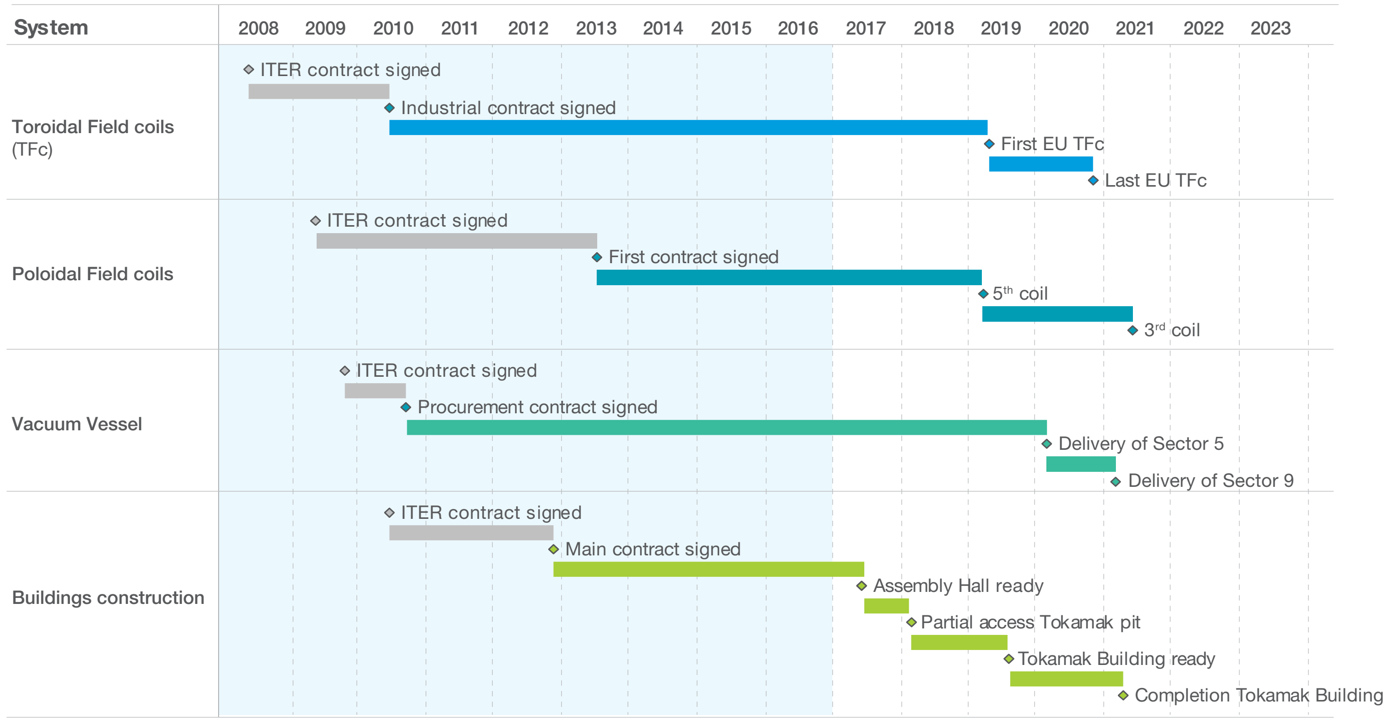
SIGNED AT LEAST **560** CONTRACTS

Geographical distribution of contracts awarded by F4E 2008-2016





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



Some of the F4E achievements during 2016

January

Europe and Japan have celebrated the delivery of the first JT-60SA Toroidal Field coil.
The development of electronic chips for the ITER sensors system have started.

February

More progress for the forgings of ITER's Vacuum Vessel. ITER roadmap and new business opportunities have been presented at MIIFED – IBF 2016.

March

Major component for ITER Cryoplant has been produced.
Tests for JT-60 SA Toroidal Field coil have been successfully completed.

April

Key components for IFMIF/EVEDA have been delivered and tested. Water Detritiation Tanks have been installed in ITER Tokamak Complex.

May

ITER Cryoplant Quench Tanks have been manufactured. Poloidal Field coils tooling and materials have been tested.

June

Massive girders have been installed in ITER Assembly Hall. Development of ITER Remote Handling cameras has progressed.

July

Transmission line has been installed and tested in ITER Neutral Beam Test Facility. JT-60SA Toroidal Field coil has been delivered to Japan.

August

Europe has completed production of its conductor for Poloidal Field coils.
Construction on ITER site has advanced.

September

High Voltage Box Deck has been delivered to Neutral Beam Test Facility. First ITER Cryoplant components have been delivered on-site. F4E has invested in Diagnostics equipment to improve plasma analysis.

October

Toroidal Field coil winding pack has been impregnated. Meetings have been organised with European Fusion Laboratories, ITER Parties and suppliers.

November

First layers of Poloidal Field coil prototypes have been produced.
Cryoplant Quench Tanks have been delivered on-site.

December

Tokamak Complex bioshield has been half-way completed. Alarm survey system for construction site has been developed.

Some of the ITER achievements during 2016

First Quarter

- Europe has begun the civil works of the first floor of the Tokamak Complex.
- India has delivered the Cryostat base section on-site and the first piping [1].
- ITER Scientist Fellow Network has been launched.

Second Quarter

- ITER Council Review Group has validated the progress of the project.
- Europe has completed the first of its Toroidal Field coils winding pack.
- Russia, China and Japan have completed the fabrication of their TF conductors.
- Three mega transformers have been manufactured in China for ITER's Pulsed Power ElectricalNetwork [2].
- ITER Council has endorsed updated schedule focused on first plasma.
- US has concluded winding of the Central Solenoid first module [3].

Third Quarter

- ITER Organization has awarded the ITER Assembly contract.
- Korea has made progress with the fabrication of the Vacuum Vessel [4].
- Japan has completed the Toroidal Field coil winding impregnation [5].
- China has started the fabrication of the correction coil series [6].
- Russia has produced major component of (PF1), the Poloidal Field coil [9].
- Three cold boxes have undergone final checks for ITER's Liquid Helium plant.
- Technical Cooperation Agreement signed between ITER Organization and Australia.

Fourth Quarter

- Toroidal Field coils case manufacturing has advanced in Japan.
- India has started the welding of the Cryostat on-site.
- ITER Council has endorsed overall project schedule [7].
- First Pulsed Power Electrical Network transformer, manufactured by China, has been installed on-site.
- Russia has shipped to ITER over 70 T of material, including busbars [10].
- Pressure equipment has been tested successfully for Russian port component [8].
- Central solenoid qualification coil has been fully insulated in US.
- Port stub extension manufactured in Russia has successfully passed pressure and helium leak tests.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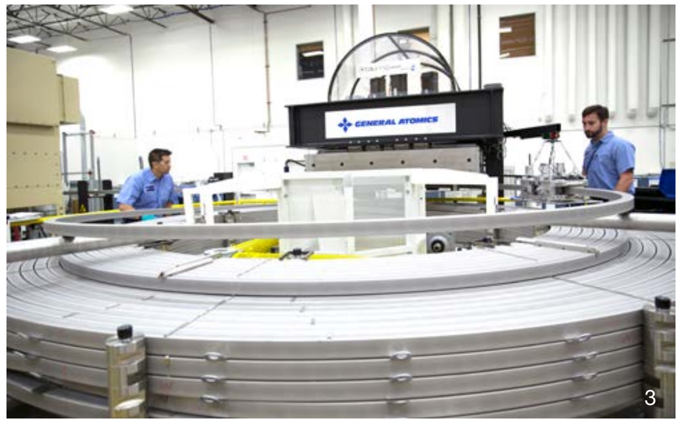
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01

Building the ITER facility

The ITER platform is one of the largest man-made levelled surfaces in the world. Measuring 42 hectares, it is considered as one of the biggest building sites in Europe.
The party responsible for the construction of 39 buildings on the site, is Europe.
Currently, the personnel directly involved in construction counts at least 1 500 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

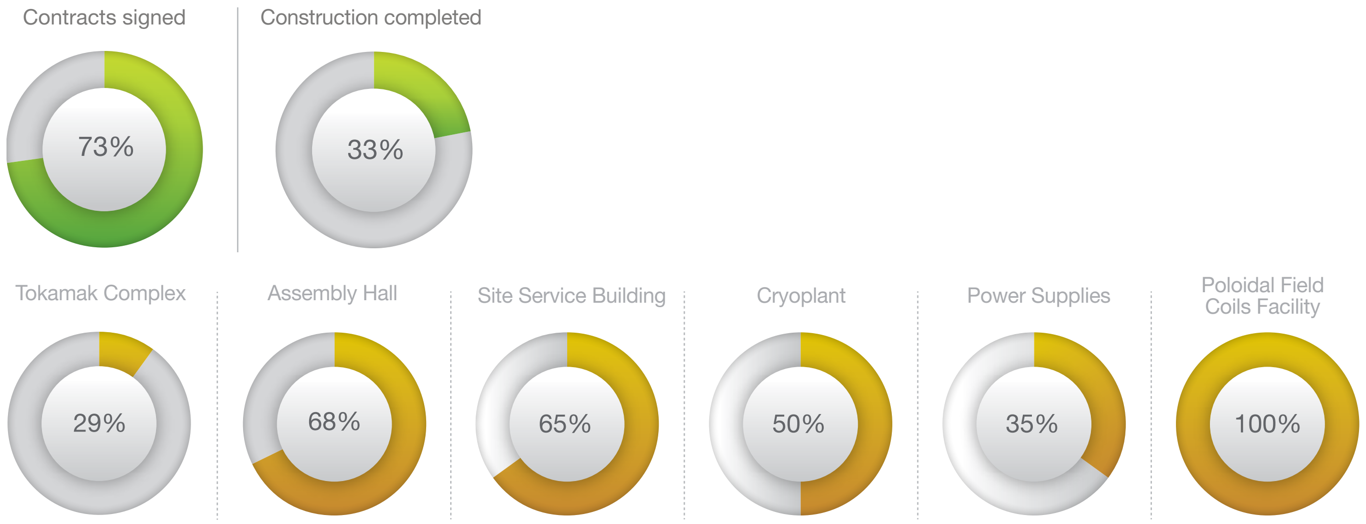
How has the ITER construction site evolved?

This year construction activities have reached a crescendo with more lifting, drilling and building across the entire platform. The ITER site has undergone a transformation, paving the way for the arrival of more equipment on-site, and the handover of facilities to assembly teams. Under the supervision of F4E, in collaboration with ITER International Organization (IO), and their contractors, more than 1 500 people have been working round the clock to meet the tight deadlines. Some of the most sophisticated civil engineering techniques have been applied on the site hosting the biggest energy project to date.

> *"By bringing together the staff of F4E and ITER IO working in the area of Buildings, Infrastructure and Power Supplies (BIPS), we have managed to structure the work in a more efficient way and to accelerate the pace of construction."*

Laurent Schmieder
Head of Buildings, Infrastructure and
Power Supplies Project Team

Construction in progress



Aerial view of the ITER construction site, October 2016, ITER IO ©

The Tokamak Complex

The Tokamak Complex, consisting of the Tritium, Tokamak and Diagnostics buildings, is where the heart of the ITER machine will beat one day. The construction and reinforcement works of the floors, walls and ceilings, have sufficiently advanced to get a glimpse of the inner-core of this emblematic edifice. F4E and ITER IO have been diligently co-ordinating a long list of contractors, counting more than 300 people from the Vinci Ferrovial Razel (VFR) consortium, who have been working exclusively on the complex. In parallel, workforces from the Engage consortium, Tiresia, Energhia and Apave have also been deployed, succeeding in accelerating the progress. The ground floor and walls of the first floor of the complex have been completed. And in the case of the Diagnostics building, the works on its second floor have commenced.

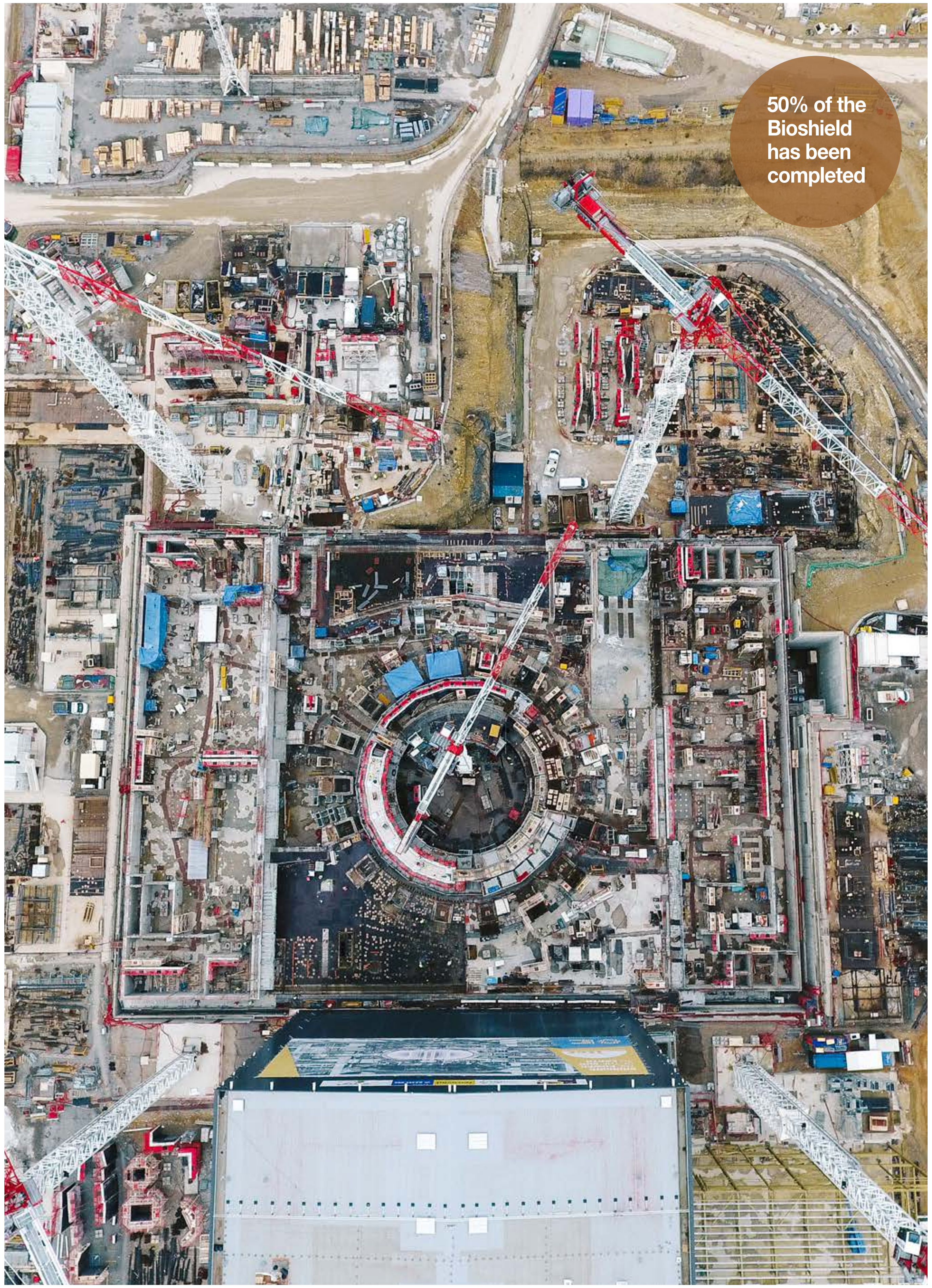
The Tokamak Complex will be 80 m tall, of which 20 m will be below the ground, 120 m long and 80 m wide. Given the fact that this building will host the ITER machine, and more than 30 systems required for its operation, its total load will reach 400 000 T. Under a thick mesh of rebars and concrete, the various pieces of equipment will gradually be installed. Already this year, six water detritiation tanks, Europe's first components delivered to ITER, have been fitted in the Tritium building.

The Bioshield

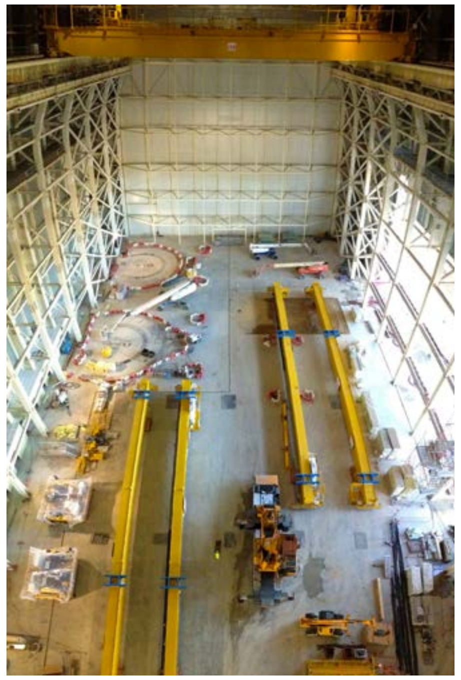
At the centre of Tokamak building a concrete ring has started to take shape. When completed, it will measure 30 x 30 m, and will shield the ITER Cryostat from top to bottom so as to offer radio protection. The works on the first floor have been completed using high density reinforcement and heavy embedded plates, robust metallic structures placed under the concrete upon which tooling will be welded. This cylindrical structure has risen with civil engineering works reaching the second and third floors. Nearly half of the Bioshield has been completed and the entry point for the Neutral Beam Injectors has become visible on the walls of the second floor.

> *“These exceptionally heavy embedded plates weigh approximately 3 T each and had to be placed with an accuracy of 20 mm. This delicate task has been successfully carried out with the help of our civil works contractors who developed specific tools.”*
>
> **Romaric Darbour**
> Deputy of Infrastructure and Power Supplies Project Team

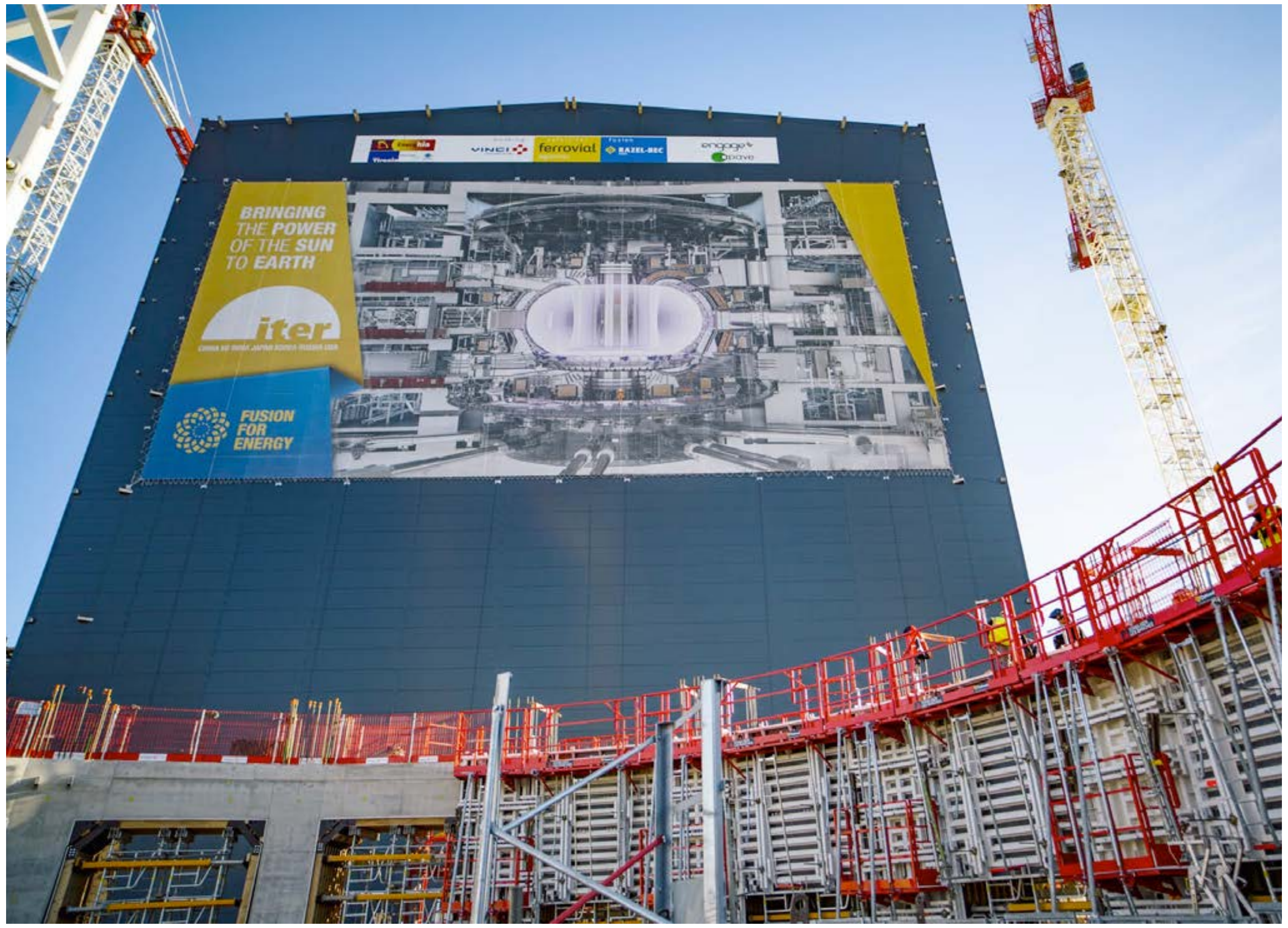
The entry points of the ITER Neutral Beam Injectors at the second floor of the Bioshield, Tokamak Complex, December 2016, © Engage



ITER Tokamak Complex aerial view, December 2016, © Engage



The second girder of the cranes operating in the Assembly Hall has arrived at the ITER site, March 2016
The four girders of the cranes that will lift the bulky ITER components have been installed in the Assembly Hall, July 2016, Cadarache © Engage
The impressive monster crawler crane that was used to help with the lifting operation, July 2016, Cadarache
The two auxiliary 50 T cranes at the Assembly Hall, November 2016, © Engage



An impressive illustration of the ITER machine decorating the façade of the Assembly Hall, October 2016, Cadarache © Engage

The Assembly Hall

The civil engineering works at the Assembly Hall have been successfully completed. The massive 60 m tall building overlooking the platform has attracted the attention of all on-site visitors. Some of the most high-tech components ever manufactured will be assembled in this vast workshop, and will then be transported to the Tokamak building to be fitted in the machine. Due to their impressive size, and extraordinary weight, a set of cranes has been manufactured to lift the ITER components.

Four electric overhead travelling cranes have been installed. They will be moving between the Assembly Hall and the Tokamak building, split in two areas housing the Tokamak machine and a crane hall above the machine. The heavy ITER components will be lifted by two 750 T cranes. Each of them will be equipped with two trolleys, each carrying a single 375 T hoist. All in all they will be able to lift 1500 T, approximately the weight of four Boeing 747 planes at take-off. The cranes will be synchronised to work in tandem, and for lighter assembly activities they will rely on two auxiliary cranes, able to lift 50 T each, which have also been fitted in the facility.

The two girders, each measuring more than 46 m length, are part of the tooling of the two cranes manufactured by the NKM NOELL-REEL consortium. They have been transported from Fos-sur-mer, the industrial port of Marseille, to the ITER site. The operation lasted two weeks and has been carried out by DAHER, the contractor for global logistics, using an exceptional convoy, considered to be the biggest in history.

Due to their impressive size and weight, a monster crawler crane came from Saudi Arabia to give a helping hand and lift them at 46 m high. This has been its first job in Europe and under the guidance of several technicians, and a team of 25 people on the ground, the various pieces of equipment were carefully positioned, balanced and loaded. It has taken roughly 3 hours to lift each girder and two weeks in total to complete this delicate operation.

> *“The reason why this complex operation seems quick and easy is because we have been working for months on its co-ordination and planning. We are delighted to see that all aspects have worked out smoothly.”*
>
> **Roberto Lanza**
> ITER IO Responsible Officer

Aerial view of the Site Services building, September 2016, © LNM

Technical teams checking the cabling where the ITER substation will be connected to France's grid to receive 400 kV, November 2016, © LNM

Auxiliary buildings

Cryoplant

Due to the delivery of the ITER Cryoplant compressors and the 35 m long quench tanks, there has been a growing momentum for the cryogenic system. Civil engineering works for the first columns have kicked off in November, and at a galloping pace 46 out of 50 have already been erected. The workforces have started installing the steel structure and by August 2017 this facility is expected to be ready for assembly operations.

Site Services

In the 60 metre-long Site Services facility, more than half of the internal doors have been fitted and the external doors are being manufactured. In this building, the chiller and demineralised water plants will be hosted, together with the air compressors, maintenance and instrumentation workshops. Lightning, Heating Ventilation and Air Condition (HVAC) installations have also started.

Transformers

The civil engineering works, where the ITER transformers are located, have almost finished. This is the area where the ITER substation will be connected to France's grid to receive 400 kV. Furthermore, there has been more progress vis `a vis the installation of the oil and drainage pipes.

Basin and cooling water stations

The areas of the ITER basin, which can store approximately 20 000 m^3 of water, and the cooling water stations have also closed the year with works on track. Almost 70% of the slab is ready, 12% of the columns have been installed and the first walls have started to be erected.

Magnet Conversion

For ITER to generate its 500 MW it will require power. The excavation and drainage works have progressed in the area of the Magnet Power Conversion building, which will host the equipment that will convert 66 kV alternating current to direct current in order to supply ITER's superconducting magnets with power. The slab of the fifth of the seven transformers to supply the ITER machine with power, and some of its systems, has been completed. This year, a transformer has arrived from China and has been installed.

Signing the contract for site infrastructure works

A consortium consisting of three subsidiaries of the Spie batignolles Group (Spie batignolles TPCI / Spie batignolles sud-est and Valérian) and ADF has signed a contract with F4E for a value of 60 million EUR to deliver the networks for the electricity and hydraulic services so that ITER facilities are operational. The road works connecting all buildings will also be delivered through this contract. The works will unfold to almost half of the platform covering a surface of more than 200 000 m^2.

> *“This contract demonstrates our expertise and our ability to design and build infrastructure for the biggest fusion facility. Spie batignolles Group together with Spie batignolles TPCI Valerian and ADF would like to thank F4E for its trust.”*

Guillaume Galant
Sales Director
Spie batignolles TPCI

Construction works in progress at the ITER Cryoplant, November 2016, © ITER IO

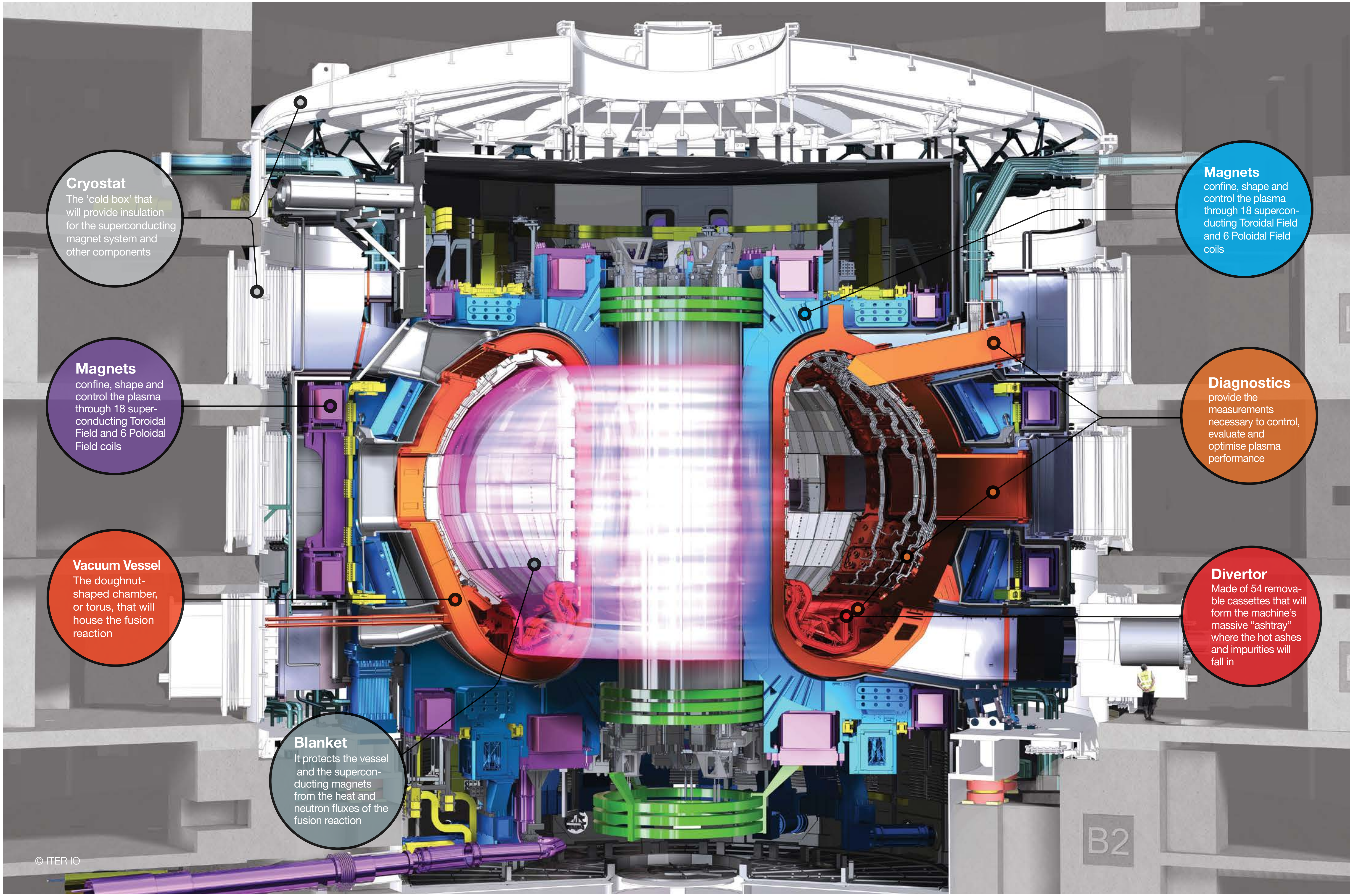
Civil engineering works progressing at the water basin and cooling water stations of the ITER device, November 2016, ITER IO ©

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 superconducting 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 superconducting magnets from the heat and neutron fluxes of the fusion reaction

Magnets
confine, shape and control the plasma through 18 superconducting Toroidal Field and 6 Poloidal Field coils

Diagnostics
provide the measurements necessary to control, evaluate and optimise plasma performance

Divertor
Made of 54 removable cassettes that will form the machine's massive "ashtray" where the hot ashes and impurities will fall in

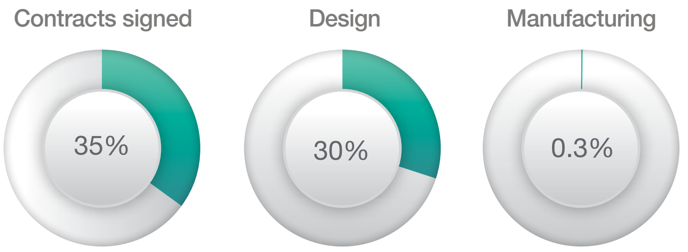
© ITER IO

DIAGNOSTICS

The Diagnostics system will help scientists to study and control the plasma behaviour, measure its properties and extend our understanding of plasma physics. In simple terms, 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.

Work in progress



The design of five ITER diagnostics ports is progressing

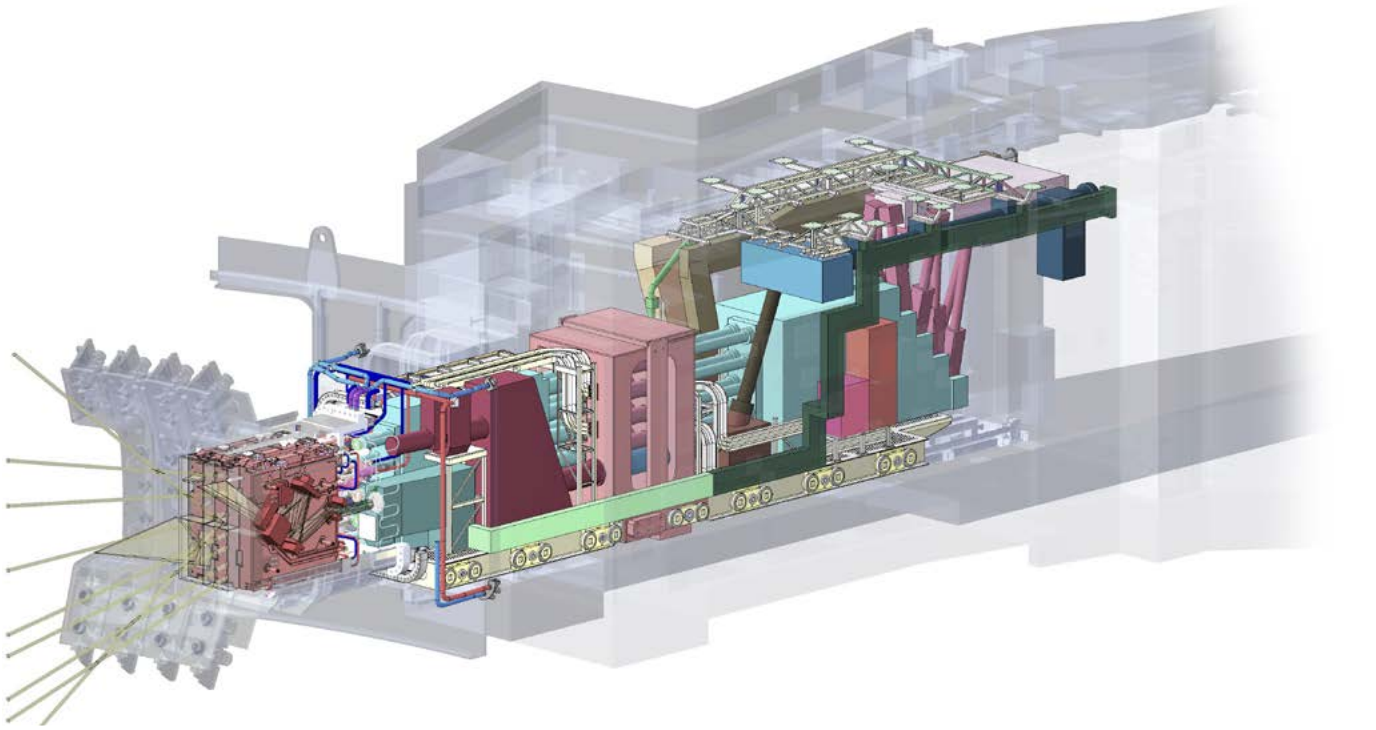
ITER diagnostics ports house large and sophisticated diagnostic systems to measure the conditions inside the machine. The ports must keep them protected from high-energy particles, hot temperatures and large electrical currents, whilst preventing the high-energy particles from escaping the machine. To achieve this, large shielding structures are needed inside the ports, weighing up to 45 T. These structures must be water-cooled and need to be manufactured with high precision. They provide access for services such as maintenance via remote handling tools, cooling and electrical connectivity – all of which need to be performed in very confined space.

F4E has made substantial progress with the design of five diagnostics ports, containing components of 20 diagnostic systems. A thorough assessment of the needs of these components has been conducted, a layout of the shielding structures has been developed and ways to manufacture them have been studied. In order to ensure compliance with the large number of ITER technical and safety requirements, running into hundreds per port, a rigorous systems-engineering approach was taken. This involved analysing the requirements and allocating them to particular components of the ports. Subsequently, they were registered together with their respective design activities. Use of systems-engineering allows for a more efficient design process, especially when large and dispersed teams are involved, and greatly facilitates obtaining the approval by all stakeholders (ITER IO, safety authorities etc.) because of the transparency it offers.

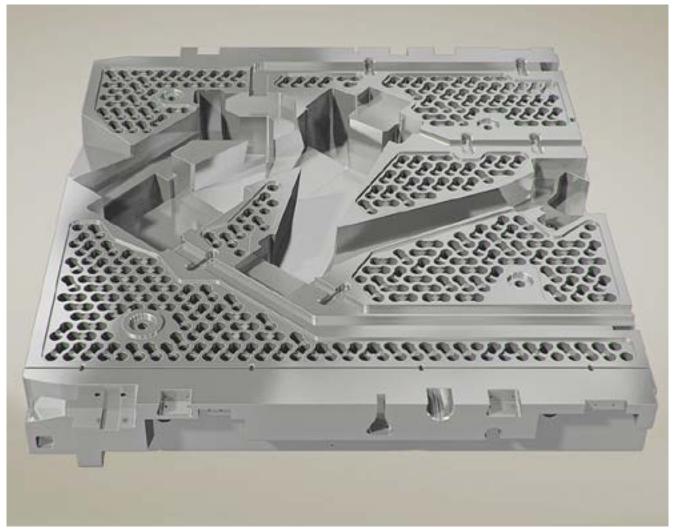
With diagnostics still evolving, a critical part of the work involved defining features that impacted both the component and port designs. For this reason, F4E worked closely with the Chinese, Japanese, Russian and US ITER Domestic Agencies, that are contributing diagnostics in these five ports. Where such early definition was not possible, F4E developed flexible port designs.

F4E’s progress has been assessed very positively by a panel of independent experts which confirmed that the state of the design was “well advanced” and that F4E was “more than ready” to proceed to the next design phase.

> *“F4E has made remarkable progress, given the immense challenges of the port design activity. We are now positioned very favourably to conclude this activity according to plan”*
>
> **Glenn Counsell**
> F4E Project Manager for Diagnostics



Schematic of one of the five ports showing shielding structures (in pink) housing some diagnostic components, and additional spaces allocated for diagnostics (in turquoise, dark pink, blue, green)



Schematic of a shielding module with space for diagnostic components

The Vector Network Analyser measuring device used to qualify ITER diagnostic components

F4E invests in Vector Network Analyser for ITER and European fusion research

F4E has invested 350 000 EUR in purchasing a Vector Network Analyser (VNA) through a Framework Partnership Agreement for R&D signed with Instituto Superior Técnico (IST, Portugal), Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT, Spain); and Consiglio Nazionale delle Ricerche, Istituto di Fisica del Plasma “Piero Caldirola” (IFP-CNR, Italy).

The Vector Network Analyser is a measuring device that will be used to qualify one of the diagnostics which will evaluate the position and shape of the plasma, namely the ITER Plasma Position Reflectometry (PPR) system. By sending radio frequency signals to the ITER plasma, and measuring the arrival time of the reflection of these signals from it, the PPR system will be able to give information on the location of the plasma, which needs to be controlled to avoid contact with the wall of the ITER vessel.

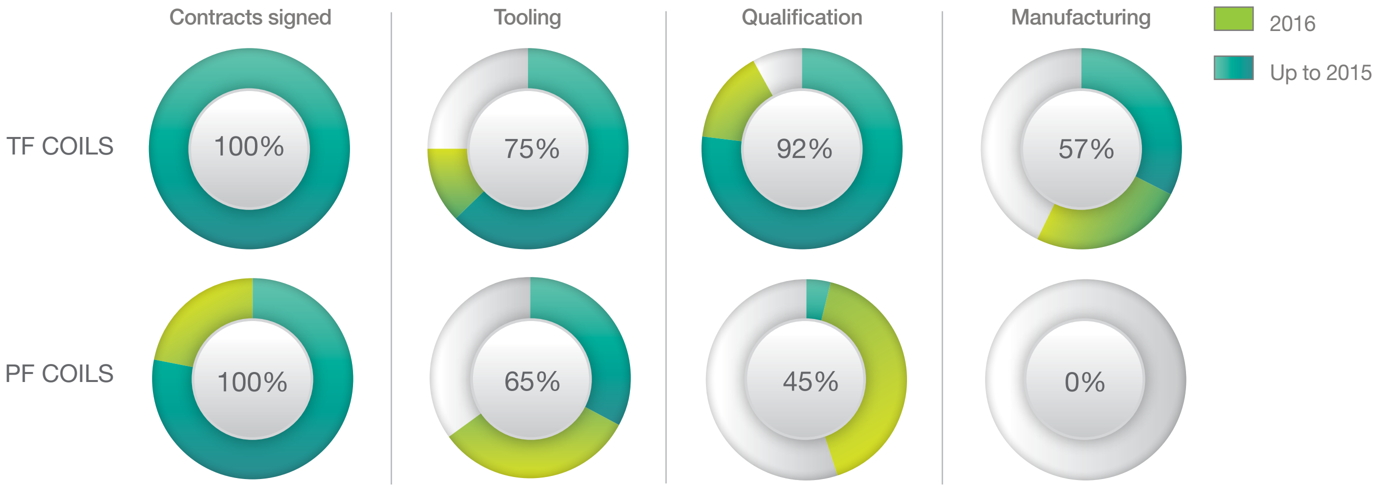
“The Vector Network Analyser is a one-of-a-kind tool which can measure a wide range of radio frequency signals, thus offering new capabilities to the European Fusion community”, says Paco Sánchez Arcos, F4E Technical Officer.

While the device will be kept at the IST premises, its acquisition will benefit fusion laboratories all over Europe and other ITER Parties.

MAGNETS

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

Work in progress



Manufacturing some of the biggest magnets in history

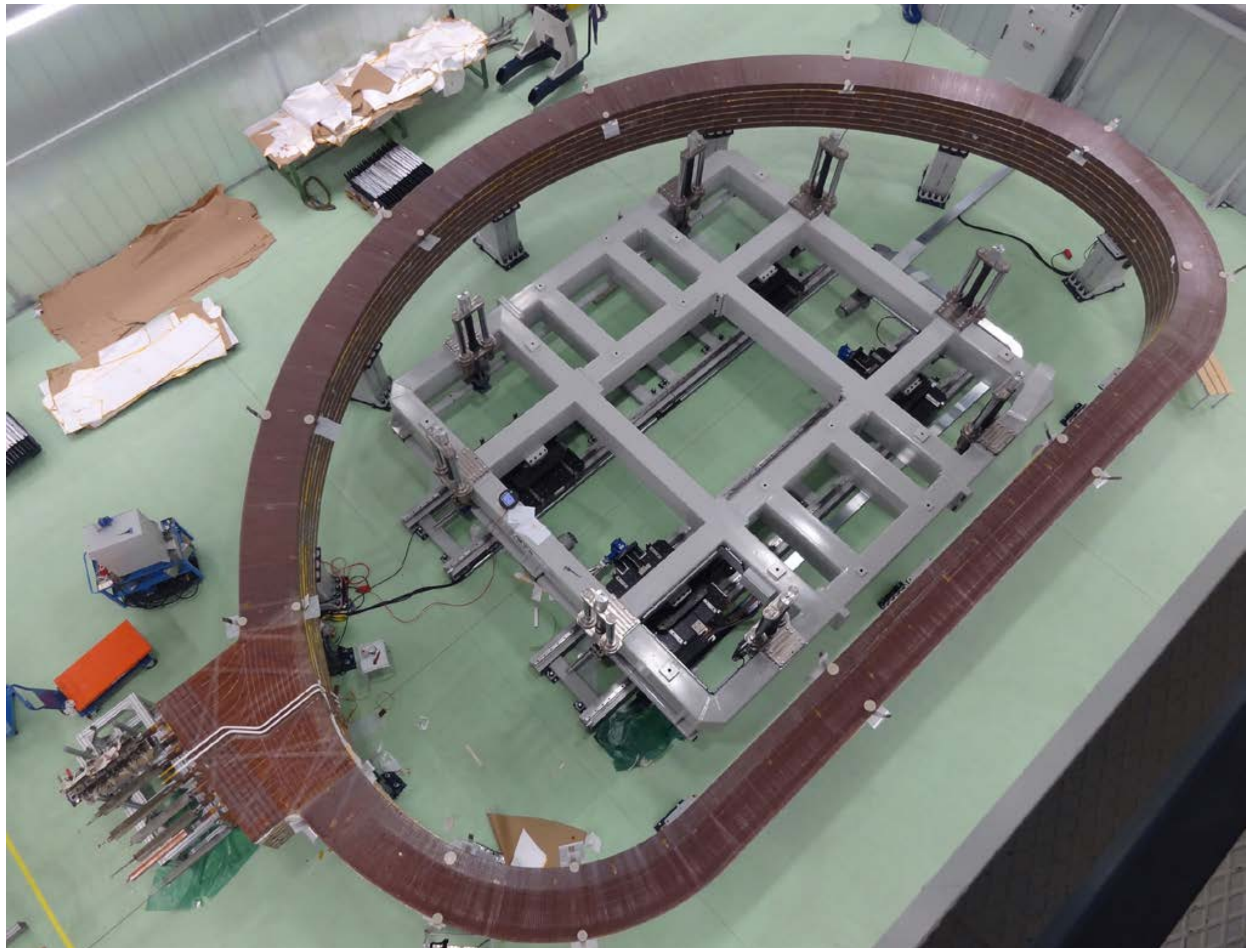
Toroidal Field coils

One of the biggest and most complex magnets in mankind has entered its final stages. The inner-core of the first ITER magnet, known as winding pack, has been manufactured. This landmark achievement has been supervised by F4E in close collaboration with ITER International Organization and other ITER parties. More than 600 people, from at least 26 companies, have contributed to this milestone during the last six years.

In order to grasp the scale of the various components used for the magnet, we start with the conductor, which has been tightly sealed in the impressive structure of the TF coil winding pack. F4E and its suppliers have successfully concluded the production of the European share of the conductor for 10 TF coils, which are under its responsibility. All in all, 20 km have been produced and the material has been progressively delivered to the ASG workshop, where Europe's TF coils are being manufactured. This has been the outcome of more than six years of work performed by Luvata, Oxford Instruments Superconducting Technology, Bruker European Advanced Superconductors, the ICAS consortium consisting of ENEA, Tratos and Criotec.

On the manufacturing front, Iberdrola, ASG and Elytt Energy, have been entrusted with the production of the inner-core of the TF coil. They used the conductor, which has been sandblasted, wound and heat treated to fit it into stainless steel plates, known as radial plates, manufactured by CNIM and SIMIC. Piece by piece the conductor has been lifted, wrapped, insulated and placed back in the grooves of the plates before it got covered. Then, the structure containing the conductor has been laser welded and wrapped with insulating material.

Next, a team of technicians has been in charge to get the magnet ready for impregnation, by all accounts the most delicate manufacturing step. An impregnation mould has been applied all over the surface of the magnet. Then, the magnet has been enclosed in a layer of stainless steel sheets and clamped by heating plates to create a solid shell. Approximately 100 clamps, tightened one by one, sandwiched the magnet to compact the electrical insulation at the right level. Stainless steel sheets have been welded and leak plus electrical tests have been carried out.



View of Europe's first winding pack, the inner-core of a Toroidal Field coil, which will magnetically confine ITER's plasma, ASG Facilities, February 2016

The successful completion of the works has paved the way for the impregnation process. What have been the main steps? First, the component needed to be heat-dried in vacuum at 110 °C to eliminate any vapour or humidity trapped in the insulation. Second, with the mould under vacuum, resin has been injected from the bottom of the magnet to fill in any gap, and pressure of approximately 3.5 atmospheres has been applied to ensure that the mould was completely filled. Finally, the winding pack has gone through a curing cycle, at temperatures reaching 155 °C during five days, before extracting the impregnated magnet from the mould.

After having completed this step, dimensional checks have been carried out together with laser scans to examine the state of the component. In order to protect the component in operation, a special conductive paint has been applied all over its surface.

Towards the end of the year, magnetic measurements, checking the geometrical compliance of the magnet, and final mechanical works have started to be performed. After the successful completion of the electrical insulation and leak tests, the component will be transported to SIMIC to go through a series of cold tests and be inserted in its coil case.

In terms of the progress of the other European TF coils components, the production of radial plates has accelerated reaching 62 out of a total of 70. Meanwhile, the manufacturing of the components of the second TF coil have been completed paving the way for its assembly.

Toroidal Field coil

Key facts and figures

Gigantic "D" shaped magnets, known as Toroidal Field (TF) coils, will form 10 of the 18 TF coils that Europe has to manufacture. These will be the biggest Niobium-tin (Nb3Sn) magnets ever produced, which once powered with 68000 A, they will generate a magnetic field that will reach 11.8 Tesla – about 1 million times stronger the magnetic fields of the Earth. The weight of each coil will be approximately 110 T which compares to that of a Boeing 747!

> *“This is a landmark achievement for the whole project. It is Europe’s first TF coil, which also happens to be a first for ITER. We have been working hard to meet the tight planning and manage all interfaces. The very good collaboration between the teams of F4E, ITER International Organization and Japan’s Domestic Agency for ITER, has helped us to reach this point and go beyond as production accelerates.”*
>
> **Alessandro Bonito-Oliva**
> F4E Project Team Manager for Magnets

First impregnated winding pack, the core of an ITER Toroidal Field coil, ASG Facility, La Spezia, Italy

Performing ground insulation on the winding pack prior to impregnation, ASG, La Spezia, Italy

Compacting the inner-core of the first Toroidal Field coil, ASG Facility, La Spezia, Italy

Main manufacturing steps of a Toroidal Field coil winding pack:

To create the inner-core of the TF coil, its components have to be stacked, electrically connected, insulated/wrapped and impregnated. Pipes have to be added, through which cold liquid helium will circulate inside the magnet to help it reach a superconducting state, and instruments to measure its performance. After the completion of all tests, the component is placed in a frame and shipped to another facility for the final step of manufacturing activities. Each winding pack is 14 m high, 9 m wide and 1 m thick.

Winding tooling at the Poloidal Field coils Facility where cleaning, sandblasting, bending, insulation and wrapping of the conductor will be performed, Cadarache. August 2016

Poloidal Field coils

Inside ITER's first industrial hub on-site where some of the most powerful magnets will be manufactured

Installation of tooling, testing of equipment and fabrication of prototypes briefly summarise the wave of change that the impressive Poloidal Field (PF) coils Facility has experienced this year. By all means, it has been considered a turning point.

In terms of F4E contracts, all have been signed. The construction of the PF coils facility has been financed by F4E and has been delivered by the consortium of Spie batignolles, Omega Concept and Setec. In this building, which has the capacity to host 80 people, all steps of manufacturing will be carried out such as winding, impregnation, stacking and cold testing. Dalkia and Veolia are responsible for the infrastructure supply, operation, maintenance and waste management in the facility.

A range of bespoke equipment, heavy cranes, a vacuum chamber and assembly stations are already in place to produce the coils that will maintain the shape and stability of the ITER plasma. Due to their impressive size and weight, four out of the six gigantic coils ranging between 17 and 25 m in diameter, weighing between 200 and 400 T, will be made in this facility. Sea Alp, Elytt Energy, Alsyom and Seiv will supply the tooling for the production of the coils. CNIM has been entrusted with the manufacturing of the coils, and Criotec with the production of equipment where coils will undergo cold tests.

> *“This contract is a milestone for our company supplying high technology components and services. Together with our collaborators, we feel very proud and honoured that our work is going to contribute to the development of a future inexhaustible energy source for all mankind.”*
>
> **Julio Lucas**
> Technical Director of ELYTT ENERGY

Poloidal Field coils Facility Facts and Figures

The ITER Poloidal Field coils Facility
The construction of the PF coils Facility has been financed and delivered by F4E through a contract signed with the consortium of Spie batignolles, Omega Concept and Setec. The facility is approximately 250 m long, 45 m wide and 17 m high. It includes regular services (HVAC, electrical, piping), two large cranes (one standard crane with a capacity of 25 T and another crane especially adapted with a capacity of 40 T), offices, technical rooms and workshop space.
Parking and two docking areas for the unloading and temporary placement of coils are also envisaged. The building offers sufficient space to carry out all the steps of coil manufacturing: winding, impregnation, stacking and cold testing. It has the capacity to host around 80 people.

> *“We have made great progress with both coils this year, a clear testament to the very good work and diligence of the teams in Cadarache and Hefei. As we go into 2017, we are excellently positioned for handing over the two coils to the ITER Assembly team in the first half of 2019!”*
>
> **Kevin Smith**
> F4E Poloidal Field coils Manager

Winding tooling at the Poloidal Field coils Facility where cleaning, sandblasting, bending, insulation and wrapping of the conductor will be performed, Cadarache, December 2016 ©ITER IO

Nearly 80% of the equipment, under the responsibility of Sea Alp, Elytt Energy, Alsyom and Seiv has been delivered. This development has led to the first fabrication tests which took place towards the end of the year. The completion of the first layer of the dummy coil, during which all main winding activities had to be carried out, opened a new chapter for the ITER magnets. The conductor had to be unspooled, straightened, cleaned with an ultrasound bath, bent to the correct radius and then sandblasted, washed and dried before being finally insulated with five layers of glass/polyimide.

“This is the result of the work which started almost three years ago. We have been collaborating with ASG to integrate all these steps of manufacturing, and seeing them in practice is extremely gratifying” Pierluigi Valente, F4E Technical Responsible Officer explains.

According to Pierre Gavouyere-Lasserre, F4E Technical Officer, “all these stages are essential and need to be carried out carefully in order to validate the manufacturing processes.”

F4E’s Materials and Fabrication group has also offered its expertise in the field of qualification testing of Poloidal Field Coils components manufactured by ASG and CNIM. The work consisted of overseeing the electrical and mechanical testing in conditions similar to ITER. Testing was carried out at Karlsruhe Institute of Technology KIT-ITEP, Cryogenic Mechanical Testing and High Voltage Testing Laboratories. The outcome of the testing was successful for each component, giving confidence that the designs and manufacturing processes can withstand the lifetime of ITER at its severe operating conditions.

A bit further away, at the ICAS/Criotec facility, another PF achievement has been celebrated. The share of conductor that Europe has been responsible to produce, as part of its contribution to ITER’s PF coils, has been completed. The conductor will be used for the sixth PF coil (PF6) which is being fabricated almost 8 000 km away from Europe’s PF coils facility, in China’s Hefei province.

PF 6, the sixth and one of the smallest coils, is being manufactured at ASIPP, China’s Institute for Plasma Physics. This PF coil will have a diameter of 10 m and will weigh approximately 350 T. The first full layer using a dummy conductor has been coming along nicely. The good collaboration between F4E and ASIPP, together with the high quality of work, summarise well this year. “We have managed to stick to our schedule and carry out the technical work with rigour and precision,” states Peter Readman, F4E Technical Officer.

Poloidal Field coils
Facts and Figures

How will the ITER PF coils be manufactured?

When the 1 100 T of the stainless steel clad niobium titanium conductor arrive on the ITER site, they will progressively move from the external storage area to the manufacturing hub, where the winding and vacuum impregnation processes will be carried out. During the moulding stage, epoxy resin will be uniformly applied to help the layers of the conductor to bond tightly in order to create a coil known as double pancake. Then, a second impregnation process will take place to bond the stack of the double pancakes to form one complete massive coil.

Top image: Team of technicians checking the manufacturing of the insulated dummy conductor, ITER Poloidal Field coils Facility, Cadarache, November 2016

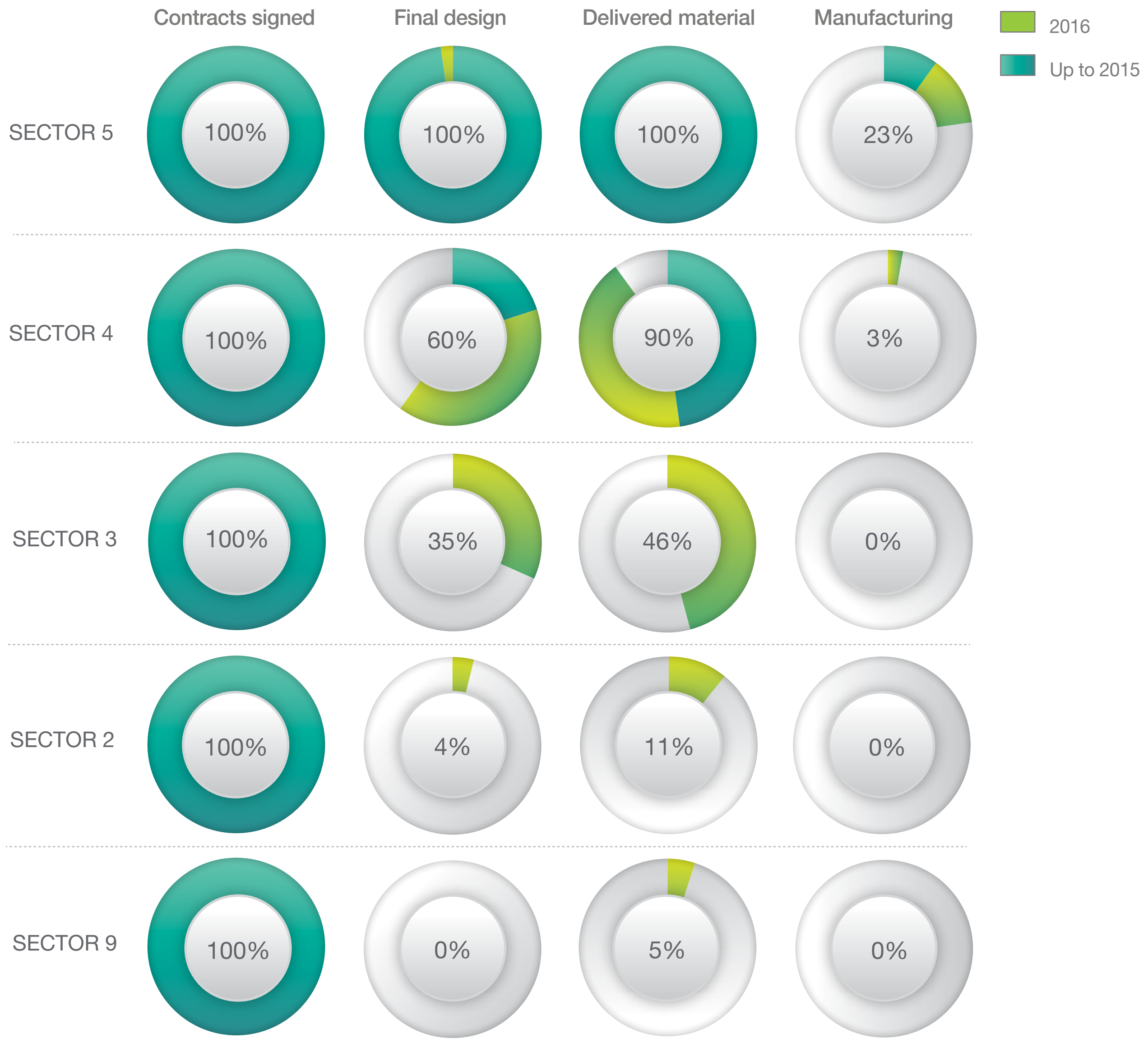
Bottom image: Technicians carrying out manually the insulation of the joggle, PF6 Coil Manufacturing Workshop, ASIPP China

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 T and the weight of the entire component, when welded together, will reach an impressive total of 5 000 T which is equivalent to the weight of the Eiffel Tower.

Work in progress



First sub-assembly of sector 5 ©Walter Tosto

During 2016, more progress has been made in the procurement of material, machining and welding of this impressive component. The years of preparatory work and the collaboration between F4E, ITER International Organization and the AMW consortium (Ansaldo Nucleare S.p.A , Walter Tosto S.p.A and Mangarotti S.p.A) are bearing fruit. The capacity of the group of companies has been further strengthened with Equipos Nucleares SA (ENSA), joining them this year.

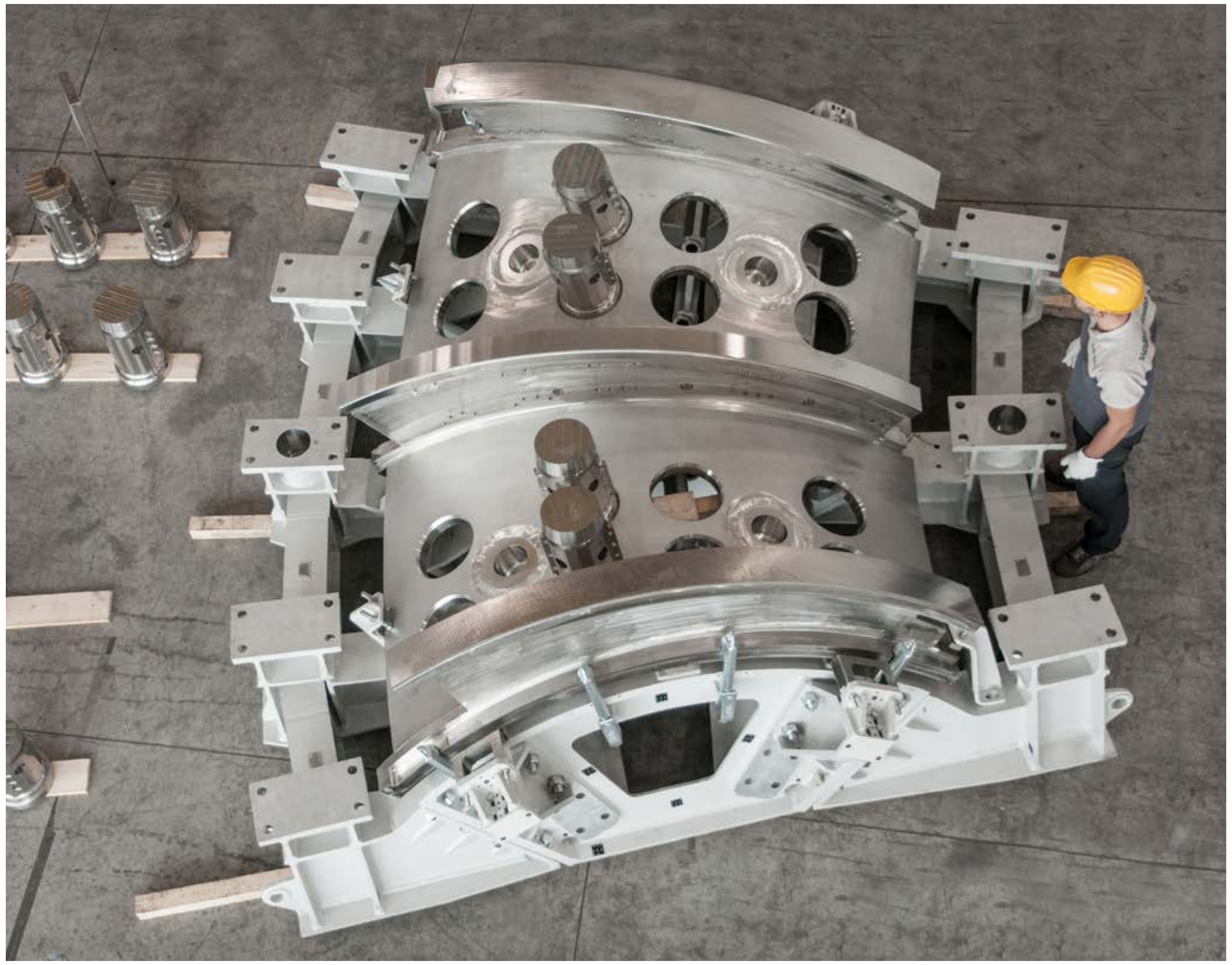
The production of material for the first two sectors has been notable. Approximately 400 stainless steel forgings (different shaped steel blocks) have been fabricated and over 20 plates (flat metal sheets which are then rolled and used to shape the VV segment) have been produced for each sector. The total of different forgings will weigh around 300 T per sector.

Parallel to these activities, machining to sculpture the shape of the forgings has also been advancing. 100% of machining for the largest forgings of sector 5 has been completed and 98% of the largest forgings for sector 4. This has been a remarkable achievement as machining some of these large forgings can take up to one month due to the complex geometry of the component. In addition, out of 38 plates, machining of 50% of them has been carried out.

Welding for all four segments for sector 5 has begun with over 20% completed. The quality of the welding has been optimised thanks to careful preparation by Mangiarotti S.p.A increasing the trials on mock-up segments.

The year concluded on a high note with the largest sub-assembly of sector 5 coming together. The good work performed by Walter Tosto S.p.A. and Probeam has been conducive to this important achievement.

> *“These positive results speak for themselves. Ramping up our activities in order to achieve over 20% of the welding during the course of one year, demonstrates that performance has definitely improved during 2016.”*
>
> **Francesco Zacchia**
> F4E Vacuum Vessel
> Project Team Manager



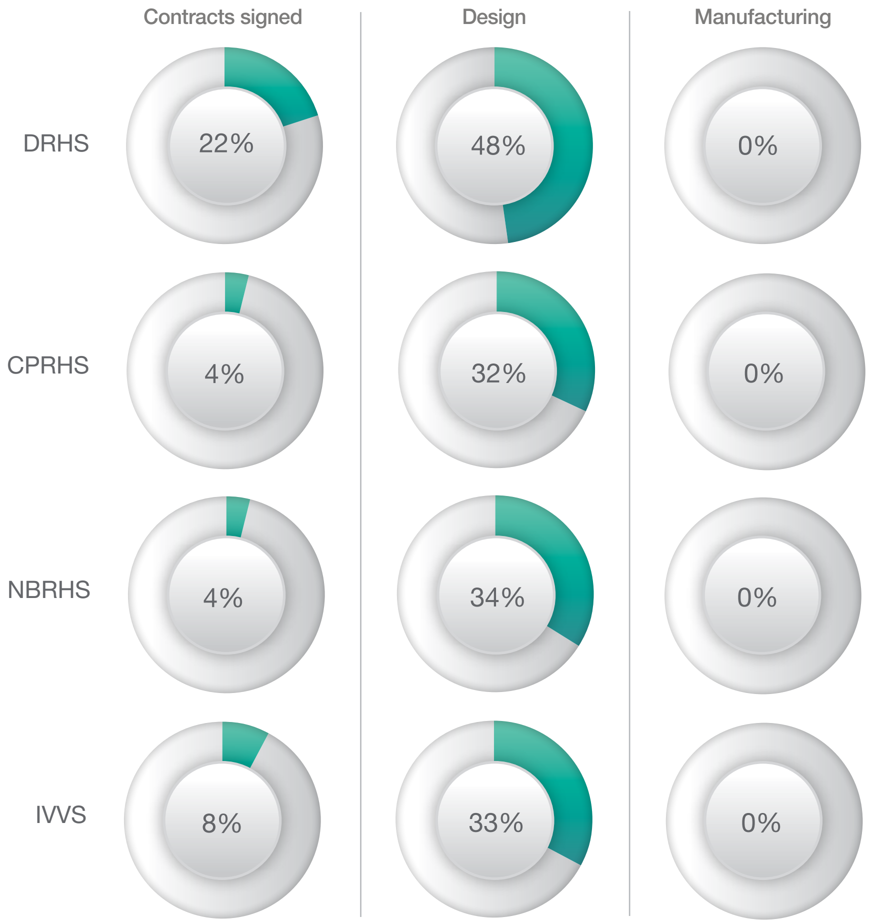
First sub-assembly of sector 5 ©Walter Tosto

Members of F4E’s Vacuum Vessel Project Team in front of a piece for one of the segments for sector 5

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.

Work in progress

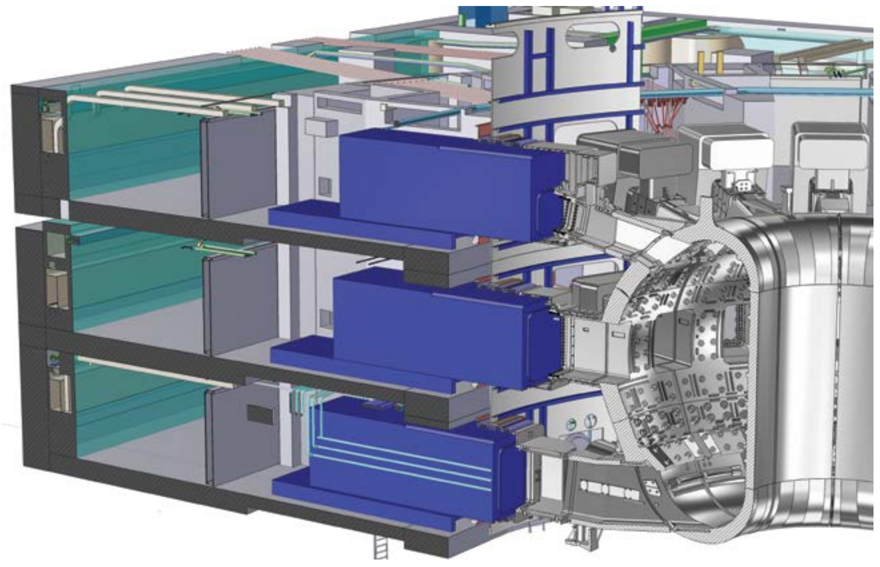


DRHS – Divertor Remote Handling System
CPRHS – Cask and Plug Remote Handling System
NBRHS – Neutral Beam Remote Handling System
IVVS – In-Vessel Viewing System

Developing the most sophisticated maintenance and inspection system for a fusion device

The signature of all framework contracts managed by F4E together with a series of successful R&D activities summarise the progress made in this area.

In 2016, F4E signed the single biggest robotics deal to date in the field of fusion energy reaching a value of nearly 100 million EUR. The collaboration between F4E and a consortium of companies consisting of Airbus Safran Launchers, Nuvia Limited and Cegelec CEM, two companies of the VINCI Group, will run for a period of seven years. The UK Atomic Energy Authority, Instituto Superior Tecnico, AVT Europe NV and Millennium will also be part of this deal which will deliver remotely operated systems for the transportation and confinement of components located in the ITER machine.



Cut-away image of the ITER machine showing the casks at the three levels of the ITER machine © ITER IO

The transfer of components from the ITER vacuum vessel to the Hot Cell building, where they will be deposited for maintenance, will need to be carried out with the help of massive double-door containers known as casks. According to current estimates, 15 of these casks will need to be manufactured and in their largest configuration they will measure 8.5 x 3.7 x 2.6 m approaching 100 T when transporting the heaviest components. These enormous "boxes", resembling to a conventional lorry container, will be remotely operated as they move between the different levels and buildings of the machine. Apart from the transportation and confinement of components, the ITER Cask and Plug Remote Handling System will also ensure the installation of the remote handling equipment entering into the vacuum vessel to pick up the components to be removed.

Cut-away image of the ITER machine showing the casks at the three levels of the ITER machine © ITER IO

Furthermore, through a contract that has been signed with CNIM for ITER's In-Vessel Viewing System, a cutting-edge inspection system will be delivered. High-tech vision equipment and robotics will join forces to carry out the delicate checks inside the ITER machine. It will take up to seven years for the company to manufacture the viewing system, which will perform the 3D mapping of the components inside the vessel and provide technical information about their state. The system will collect measurements and images with a resolution better than 1 mm at distances of 0.5 m – 4 m and better than 3 mm from up to 10 m away.

> *“F4E's stake in ITER offers an unparalleled opportunity to companies and laboratories to develop expertise and an industrial culture in fusion reactors' maintenance.”*

Carlo Damiani
F4E Project Manager for ITER Remote Handling Systems

On the R&D front, the community of experts working in this field has been extremely active preparing equipment that will be needed in the future.

To maintain and repair the ITER machine, many interconnected tools, manipulators and cranes will have to be routinely operated and inspected remotely. The information on the maintenance works performed will be supplied by sensors scattered in the machine to collect data on the temperature, pressure and position of all equipment. On top of that, sensors will need to speak the same language and be installed in the most ergonomic way, given the space limitations inside the tokamak.

F4E, Oxford Technologies Ltd (OTL) and the Katholieke Universiteit of Leuven (KU Leuven) have been collaborating for nearly five years to solve this conundrum by developing electronic chips that will be able to sustain the radiation environment; convert the analogue data picked up by sensors to a digital format and transmit the information through a single wire. A full-fledged design of a chip using Taiwanese technology has been designed and irradiated at the SCK-CEN facility. The results are promising and the know-how is expected to have an impact towards the development of other electronics to be deployed in the ITER device. The industrial potential of the chips is also ensured thanks to a cooperation agreement signed between F4E and KU Leuven, granting the university the possibility to make use of the foreground knowledge in future commercial activities.

Inspections and maintenance will need to be carried out in the limited space of the machine. The multiple inter-connected pieces of equipment and the exposure of some of them to radioactivity do not qualify human intervention as an option. Therefore, the search for ITER's compact Big Brother cameras system has already started.

A total of 100 cameras will be scattered in the machine and will consist of two types: oversight cameras giving engineers a broad angle inside the vacuum vessel and embedded cameras on tooling or robotics which will help us have vision inside tightly confined spaces of tooling.

The fruitful collaboration between F4E and Oxford Technology Limited (OTL) has generated different subsystem mock-ups that will soon be tested. OTL has successfully involved laboratories to develop different parts: ISAE, Toulouse, responsible for the image sensors; CEA for the illumination system and the Jean Monnet University Saint Etienne for the optic system. Currently, the mock-up measures 15 mm and fits inside a 1 EUR coin. In future, the camera prototype will measure 40 mm x 40 mm x 70 mm.

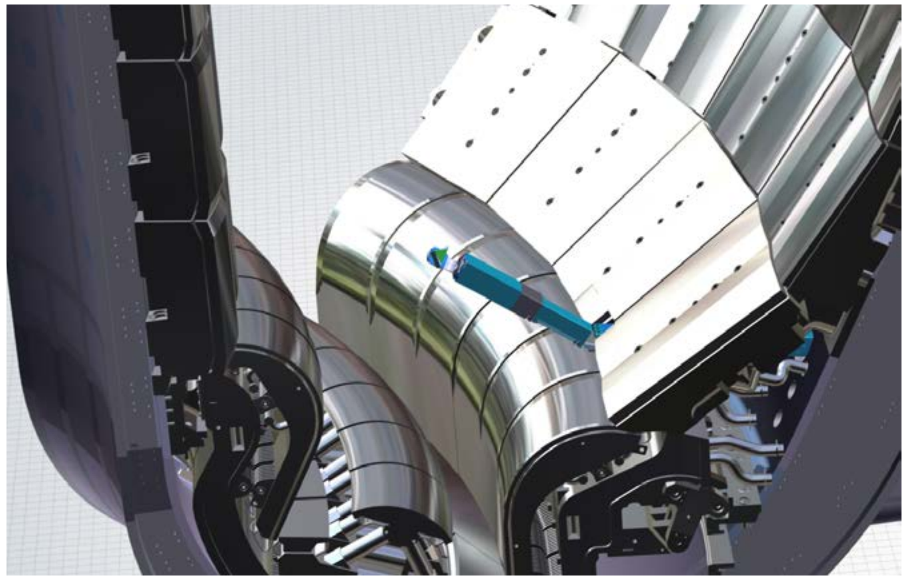


Illustration of a section of the ITER vacuum vessel with one probe forming part of the in-vessel viewing inspection system

> *“This contract highlights the expertise of CNIM in the field of Large Scientific Instruments and the quality of our industrial facilities, which are perfectly suited to large-scale projects.”*

Philippe Demigné
member of CNIM's Management Board and President of Bertin Technologies

Experts have been working on the development and validation of these subsystems for almost a year and a half and the next phase will be to test their resistance in a nuclear facility. In Belgium's SCK-CEN the subsystems will be exposed to Gamma radiations and after each irradiation step they will be analysed. The tests are expected to be concluded in March 2017 and on the basis of their findings the prototyping phase will begin.

> *“We are drawing lessons from space applications and fission technology to manufacture cameras that are small in size and strong enough to sustain the ITER In-Vessel environment.”*

Marco Van Uffelen
F4E Remote Handling Officer

Mock-up of the optical subsystem part of the FURHIS project (Fusion for Energy Radiation hard Imaging System) signed between F4E and OTL

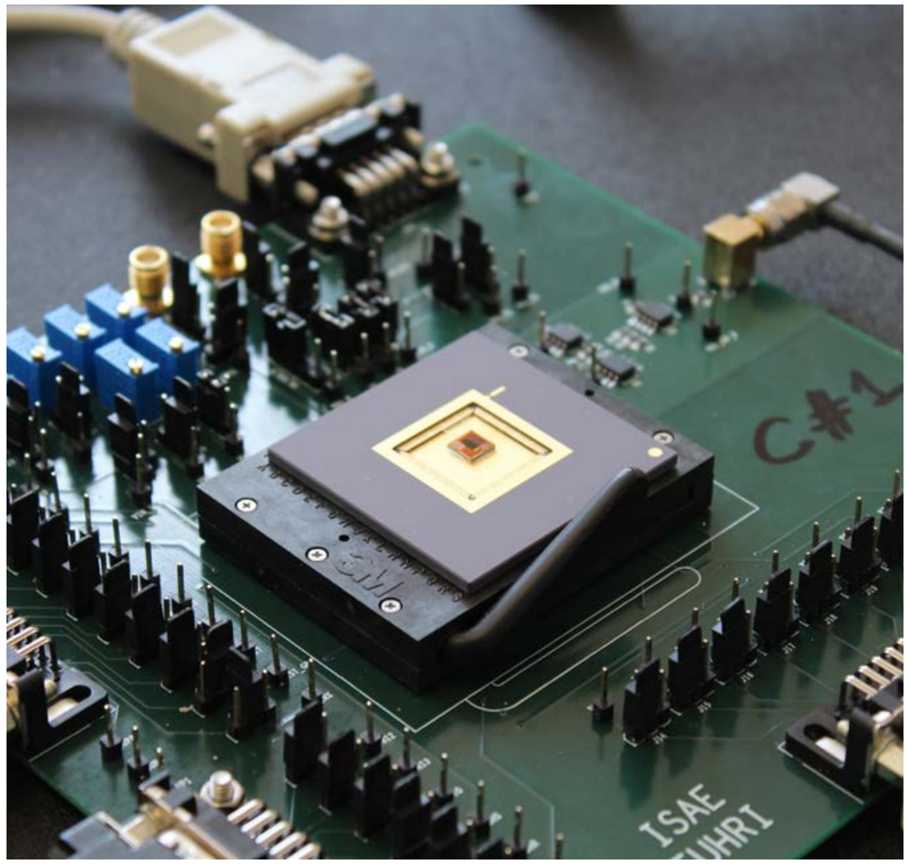


Image sensor mock-up on the test board part of the FURHIS project (Fusion for Energy Radiation Hard Imaging System) signed between F4E and OTL

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.

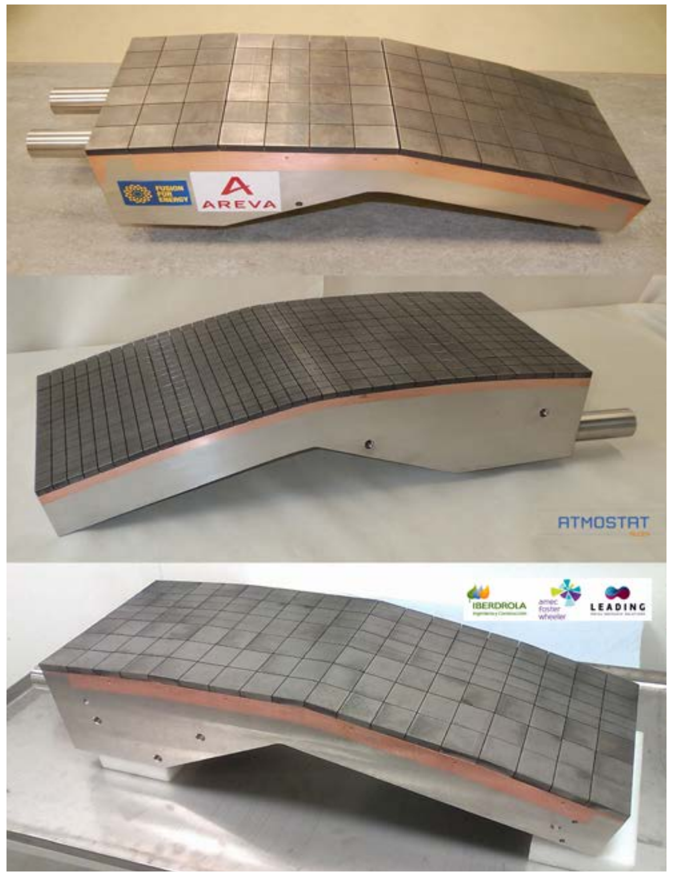
First stage of ITER Blanket First Wall qualification completed

F4E and its suppliers have been the first, out of all ITER Domestic Agencies, to complete the first of the two stages of the Blanket First Wall qualification. Four First Wall semi-prototypes (about 1/6 of the dimensions of a full-scale First Wall Panel) have been produced and have passed all acceptance tests. Two of the First Wall semi-prototypes have been produced by AREVA; one by a consortium which consists of Iberdrola, AMEC FW and Leading-MIB; and one by Atmostat.

F4E and its suppliers are now one step closer to obtaining qualification by ITER International Organization for the manufacturing of the machine's Blanket First Wall. Qualification is necessary for all ITER high-tech components and involves building and testing prototypes in order to validate the manufacturing of the actual components with the required quality. In the case of the ITER Blanket First Wall, two formal stages need to be passed prior to the manufacturing of a series. The second stage of the qualification, consisting in manufacturing and testing full-scale prototypes, is planned to be completed by the end of 2018.

Work on the Blanket First Wall is a technically-challenging project which requires new fabrication technology. In working with different suppliers to pass the ITER qualification, F4E will help them develop their know-how and prepare for the next stage which is the manufacturing of a full-scale prototype. Once this is achieved, the manufacturing of the actual ITER components will begin.

The First Wall consists of panels of about 1 x 1.5 m made from a bi-metallic copper alloy/stainless steel structure and beryllium tiles as armour material, which together with the shield block (a stainless steel block on which the first wall panels are fixed) form the Blanket modules. F4E will provide about half of the Blanket First Wall panels.



Three of the ITER Blanket First Wall semi-prototypes

> *“We mitigate risks and maintain competition until the series production by having selected three different suppliers from around Europe.”*
>
> **Patrick Lorenzetto**
> F4E In-Vessel Project Team Manager

TEST BLANKET MODULES

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

Laying the foundations for the fusion reactors of the future

F4E and its contractors have started testing the merits of EUROFER97, a steel which responds well to neutron irradiation. It is compatible with liquid metal and ceramic breeders and its properties seem to respond well at high temperatures.

Saarschmiede GmbH Freiformschmiede has signed a contract with F4E to deliver various products made of EUROFER97. In total, 27 T will be produced in the form of special bars and plates of various thickness ranging from 1.2 to 45 mm. Up to now, more than 40 T of raw material, in the form of billets, have been produced. The material has already been transferred to Boehler Bleche GmbH, a supplier of the contractor, to be rolled and heat treated. Approximately 80% of the material has already been processed with 71 plates already finely cut. Production is expected to be completed in May 2017 making way for the development of welding procedures and their qualification in order to develop a series of prototypes.

Rolling the EUROFER97 plates at Bohler Bleche

There has also been further progress from the contract signed between F4E and Studsvik to perform a series of tests so as to learn more about the physical and mechanical properties of EUROFER97. The total duration of the contract is five years and its cost in the range of 3.7 million EUR. In its first year, Studsvik and their subcontractor, NRG, have already completed the preparatory works comprising of the design and manufacturing of 478 samples to be tested. By the end of 2017, 371 samples will have been irradiated to be compared with non-irradiated ones. The work performed by the two SMEs will help us understand better the material that Europe plans to use for the fabrication of the TBMS.

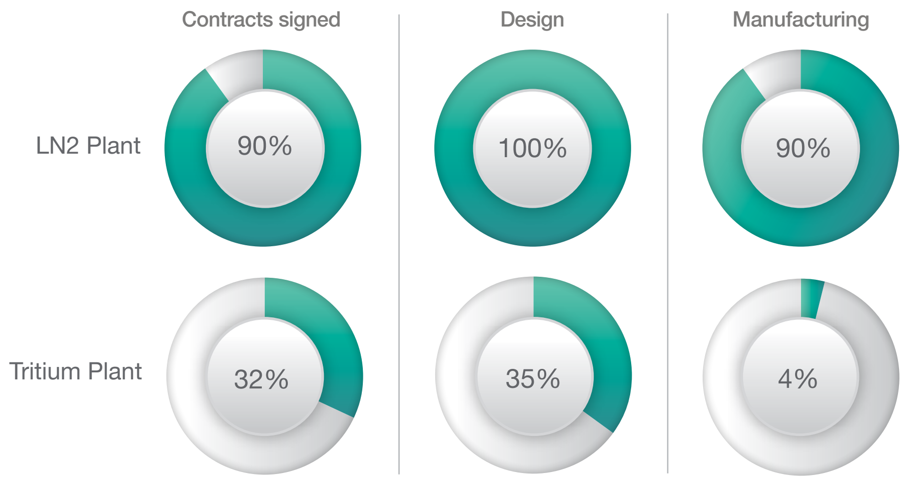
Last but not least, F4E has started preparing a preliminary maintenance plan of Europe's contribution to Test Blanket Systems. This work will help us assure the sound performance and safety of these systems during the operation of ITER. Through a contract signed with AMEC Foster Wheeler, for a value of approximately 1 million EUR, several studies have been carried out producing design recommendations in order to facilitate the maintenance of these systems.

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.

The cryoplant will generate the freezing cold temperatures required for the fusion machine. In simple words, it can be described as a massive refrigerator.
Europe is responsible for the Liquid Nitrogen - LN2 - Plant and auxiliary systems that will cool down, process, transfer and recover the cryogenic fluids of the ITER machine. Two nitrogen refrigerators will be manufactured along with two 80 K helium loop boxes, warm and cold helium storage tanks, dryers, heaters and a helium recovery and purification system. F4E has awarded to Air Liquide the contract for Europe's contribution to ITER's cryogenic system.

Work in progress

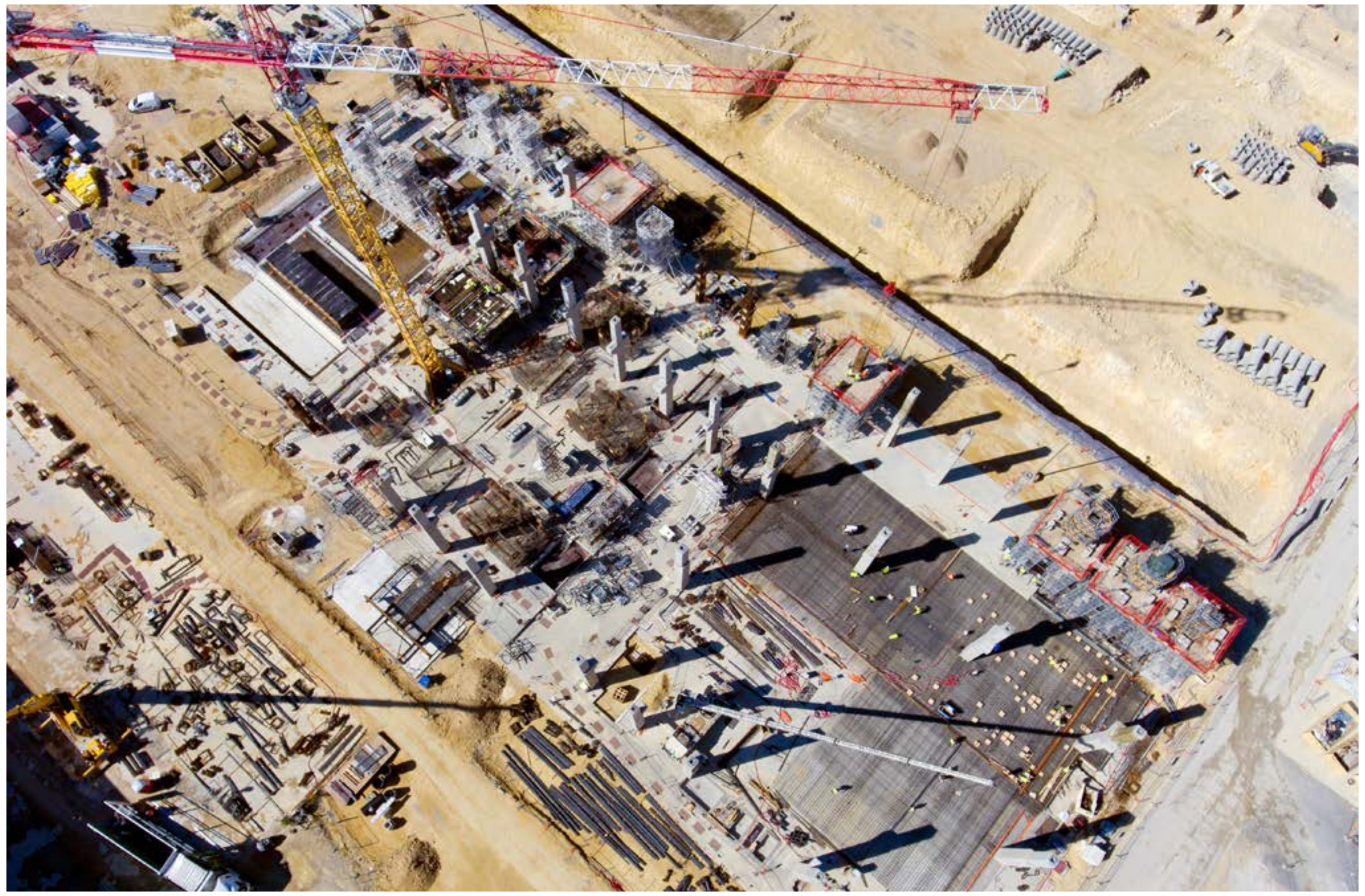


The creation of one team made of different ITER parties, the manufacturing of more equipment and the delivery of the first components on-site, describe some of the main achievements in this area.

The pace of manufacturing has increased and a stronger collaborative spirit has been introduced in the way the different ITER parties work. The installation of the cryoplant, cryodistribution components, and their supervision, have generated the need for the creation of the Cryogenic Project Team, which consists of staff from F4E, the ITER International Organization and ITER India. The team counts 40 members from the three organisations, and together with their contractors, they have been entrusted to deliver one of the biggest cryogenic facilities in the world. The sharing of resources and technical expertise has improved the supervision of the project and its risk management. Under the motto of "one project – one team", the follow up of the different pieces of equipment produced in the world has become more harmonised.

Two of the biggest tanks that will form part of ITER's Cryoplant have been manufactured and delivered on-site. The massive pieces of equipment, produced by Air Liquide and their subcontractor Chart Ferox, measure 35 m and have a 4.5 m diameter each. They weigh approximately 160 T each, which is the equivalent of a blue whale, our planet's heaviest mammal. A special convoy, managed by DAHER, ITER global logistics contractor, has transported the tanks from the industrial port of Marseille, Fos-sur-Mer, to the ITER construction site, Cadarache.

It has been an important milestone for the F4E colleagues who have been directly responsible for these components, working closely with ITER International Organization. After four years of solid work for the drafting of specifications, one year to conclude the contractual negotiations, two years of design, and a bit less than a year for manufacturing, we have a very visible result of F4E's contribution to ITER's cryogenic system.

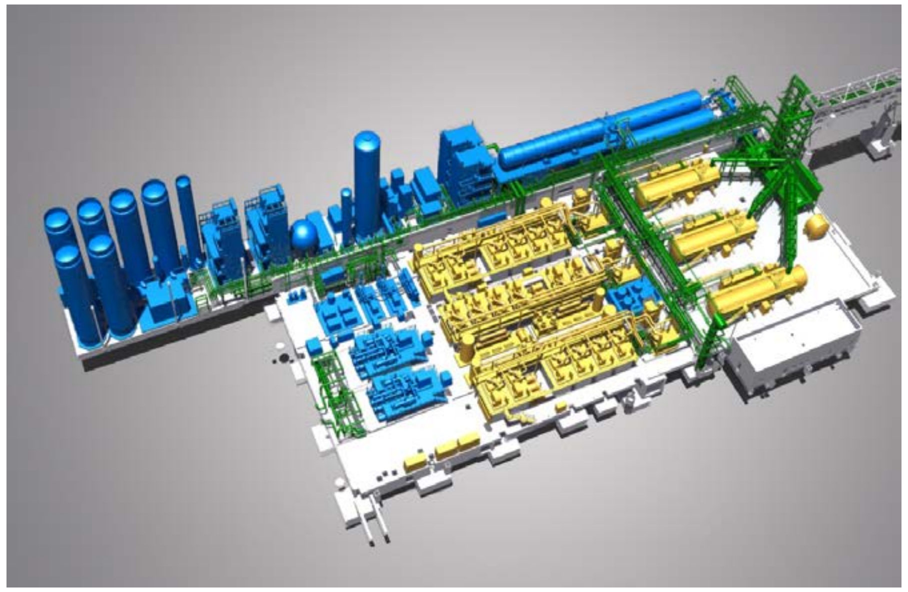


ITER Worksite - Cryoplant Building - October 2016

The ITER machine will use powerful superconductive magnets to entrap the hot plasma. From time to time, however, they may experience a so-called quench. Basically, they will stop being superconductive, start becoming resistant and their temperature will momentarily rise by 50 °C. Consequently, it will no longer be possible to confine the plasma. As the temperature rises, the helium circulating through the cryogenic system will start to expand and will need to be extracted from the machine. When this phenomenon occurs the helium will be directed to these tanks, where it will be stored at -196 °C.

The inner tank of ITER's liquid helium tank has also been completed. This massive piece of equipment, whose volume is 190 m^3 and measures 23 m in length by 3.5 m in diameter, will store part of ITER's liquid helium and will be assembled subsequently inside a bigger tank.

This equipment stems from the preliminary and final design reviews where F4E, Air Liquide, ITER International Organization, and ITER India, together with independent experts, critically assessed specifications before production started. The inner-tank, designed and manufactured by CryoAB, is made of stainless steel and has multi-layer insulation to minimise any thermal losses so that the temperature inside remains at -269 °C. Externally it will be covered by another component, known as a thermal shield, which is made of aluminum and its function is to minimise any thermal losses as well. When the tank is filled with liquid helium, its weight will reach 88 T, the equivalent of 58 mid-sized cars.



Layout of ITER Cryoplant. European contribution in blue.

Unloading the second quench tank at Fos-sur-Mer, the industrial port of Marseille, November 2016

One of the two quench tanks stored at the ITER worksite. Manufactured by Air Liquide and their subcontractor Chart Ferox, it is 35 m long and has a diameter of 4.5 m. It weighs approximately 160 T.

CryoAB technicians carrying out the liquid helium leak test on the inner-tank. It took almost half a day to inspect roughly 500 m of linear welds. February 2016

The liquid helium inner-tank, designed and manufactured by CryoAB, part of the contract signed between Air Liquide Global and EC Solutions and F4E, February 2016

Two nitrogen compressors of the LN2 plant, have also been delivered on-site. Atlas Copco Energas, Air Liquide's subcontractor, has been responsible for the engineering, manufacturing and testing of the compressors. Manufacturing started in April 2015 and almost a year and a half later the two compressors weighing 85 T each have been completed.

Four turbines, which will be inserted in the cold boxes of the LN2 plant, have also been manufactured. The role of the four turbines will be to generate vast amounts of cooling power by expanding the gas, previously processed, by the nitrogen compressors. Two of the turbines will generate a cooling power of 500 KW and two others of 150 KW. The four turbines have been manufactured by Cryostar, one of Air Liquide's subcontractors.

Six valves that will control the helium flow from the 80K loop boxes to the thermal shields and cryopumps of the machine, have been produced by Flowserve, a subcontractor of Air Liquide. The valves are almost five times bigger than the average cryogenic valves found on a standard helium liquefier and the maximum flow through these valves is over 4.4 kg/second which is more than twice what is normally released through a helium valve in the biggest helium liquefiers.


Nitrogen compressor of the ITER LN2 plant successfully tested at Atlas Copco


Turbo booster turbine able to generate 500 KW of cooling power fully assembled for testing at Cryostar

Fuel Cycle

Water detritiation tanks - the first European components to arrive on-site and to be installed in the Tokamak complex

The installation of the six large-sized tanks, part of ITER's Fuel Cycle system, has been considered a milestone of symbolic value. Thanks to them, the ribbon of European components delivered to ITER has been officially cut.

Giovanni Piazza and Josep Benet, F4E's Technical Officers following the manufacturing of these tanks, were present to witness history in the making and supervise this delicate operation. "The size of the tanks and the limited space where we had to fit them required good planning and a high level of precision. The installation required excellent co-ordination with ITER International Organization and F4E's Buildings team to perform the installation without any impact on the pace of construction" they explained.

In the meantime, F4E has signed a contract with Equipos Nucleares, SA (Ensa) to design, manufacture and deliver four additional tanks for ITER's Water Detritiation System. The value of the contract is the range of 1 million EUR and the works are expected to last approximately two years. Two tanks measuring 7 m^3, known as "holding tanks", will be used to store water. The additional two tanks, measuring 12 m^3, known as "feeding tanks", will be used to feed the fuel cycle system with tritiated water. All four tanks will be installed next to the six water detritiation tanks, also manufactured by Ensa, which have been on-site since March 2015, claiming the title of Europe's first-ever components delivered to ITER.

Water detritiation system

Why do we need a water detritiation system in ITER's Tritium plant?
To get a fusion reaction, nuclei of deuterium and tritium will need to collide at extremely high temperatures. The two hydrogen isotopes will be supplied through the Tritium plant. When the two isotopes reach the core of the machine they will fuse and release energy. What is left from the fuel of the fusion reaction, together with other gases, will return through pumps to the ITER Tritium plant and eventually to the water detritiation tanks in order to recover the tritium and use it in a future reaction.

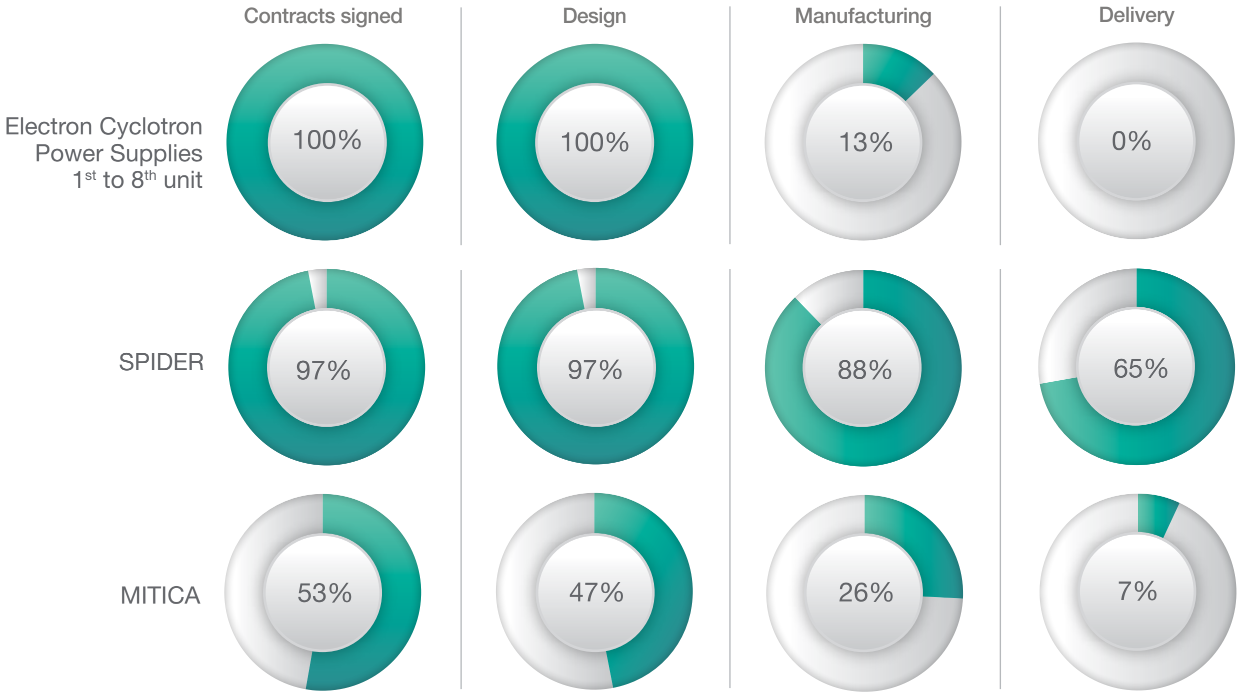

Transferring one of the bigger water detritiation tanks weighing approximately 20 T in ITER's Tritium building


Installing one of the smaller water detritiation tanks in ITER's Tritium building

NEUTRAL BEAM AND ELECTRON CYCLOTRON POWER SUPPLIES AND SOURCES

To develop and test the Neutral Beam Injectors, one of ITER's powerful heating systems, a test facility is being set up in Padua, Italy. The Neutral Beam Test Facility, receives contributions from F4E, ITER International Organization, India's and Japan's ITER Domestic Agencies, and Italy's Consorzio RFX, the host of the infrastructure where the tests will be carried out.

Work in progress



SPIDER facility: Source for Production of Ion Deuterium Extracted from Radio frequency plasma.
MITICA facility: Megavolt ITER Injector and Concept Advancement.

SPIDER

on its way to start operation

F4E, COELME and Consorzio RFX have celebrated the installation of the transmission line of the Neutral Beam Testing Facility (NBTF). F4E has collaborated with the Italian company COELME in order to design, manufacture and install the 35 m long transmission line. Its mission will be to connect the power supplies to the SPIDER beam source, installed inside a Vacuum Vessel (VV), so as to transfer the energy required for its operation. The transmission line itself is not straight but deliberately built in a winding manner within a concrete labyrinth to ensure the containment of the particles generated while SPIDER is operating.

F4E has also concluded the site acceptance tests of the High Voltage Deck (HVD), manufactured by COELME, which houses the SPIDER Ion Source and Extraction Power Supplies (ISEPS). The ISEPS are composed of a set of units, including four powerful radio frequency generators, which feed the ion source of the SPIDER experiment. They have been manufactured by OCEM ET and have passed successfully the final Site Acceptance tests.

The SPIDER VV has been installed and accepted at the NBTF and the assembly of the Beam Source (BS) has started at the factory. Both pieces of equipment have been manufactured by a consortium of European suppliers, namely Thales , Zanon, CECOM and Galvano-T.

The installation of the SPIDER vacuum and gas injection system has also been completed. This system will maintain the suitable operating conditions in terms of vacuum and cleanliness. It will also have to cope with the gas flow required for the operation of the full-size ITER beam source. Moreover, the SPIDER systems responsible for the control and protection of the components, and the acquisition of the data produced during the experimental campaigns, have been completed by Consorzio RFX in collaboration with F4E.

Finally, the installation of the large NBTF cooling system has progressed substantially. The cooling towers and heat exchangers were installed on the roof of the NBTF main building and the piping for the SPIDER experiment has been completed.

The SPIDER facility is now well underway to start its operation.

Part of the 35 m long transmission line which is connected to the SPIDER vessel

ISEPS of SPIDER equipment fully installed and tested inside the High-Voltage Deck

Cooling towers and heat exchangers on the roof of the Neutral Beam Test Facilitty, Padua, Italy

Neutral Beam Test Facility, Padua, Italy

Manufacturing the first components of MITICA's Acceleration Grids Power Supplies

Welding of the MITICA Vacuum Vessel in progress

MITICA

is making more progress

A mock-up box of MITICA's High Voltage Deck (HVD) has been subjected to high-voltage testing to validate the design of the supplier, SIEMENS AG. The tests have been carried out at the High-Voltage laboratory of Hochspannungsgeräte GmbH (HSP) in Troisdorf, Germany. The shiny metallic box measuring 4 x 4 x 4 m, resting 6 m above floor level on four large gas-insulated columns, located inside a futuristic-looking high-voltage laboratory, is impressive. Add the fact that this Faraday cage is subjected to voltages in excess of 1 MV (1 million V, compared to 230V for a typical electrical domestic appliance). Withstanding such high voltages is extremely challenging and similar examples are very rare worldwide. The completion of these tests constitutes an important step towards the full manufacturing of the HVD.

In addition, the MITICA bushing (a 13 m long container which holds all the power leads from the power supplies located in the HVD) has successfully been subjected to high-voltage testing to validate its design. F4E has signed a contract with DILO for a specialised plant to handle the gas needed for the insulation of the MITICA power supplies. The Factory Acceptance Tests have been successfully executed and the plant will be installed early 2017.

The manufacturing of the MITICA Vacuum Vessel has been progressing at the premises of De Pretto Industries (DPI). The vessel, which is 15 m long and 6 m high, has a weight of about 120 T and will house the core components of the MITICA Injector.

The Final Design Reviews for MITICA's Acceleration Grids Power Supplies (AGPS), procured by NIDEC, and Ground Related Power Supplies (GRPS), procured by OCEM ET, have been successfully performed, with the two power supply systems entering in the manufacturing phase. In addition, successful tests were also carried out on prototype modules of the AGPS.

There has also been progress with MITICA's cryogenic system, which will be needed to provide the necessary vacuum during the operation of its high-energy beams. F4E has signed a contract with Air Liquide for the design and manufacturing of the cryoplant.

The testing team at the High Voltage Laboratory at HSP GmbH © Siemens AG, 2016

Electron Cyclotron Power Supplies and Sources

Excellent results for Europe’s ITER gyrotron prototype

The magnet which will be joined to the gyrotron prototype and tested at Swiss Plasma Center

The 1 MW gyrotron prototype manufactured in Europe by French company TED on behalf of F4E

The tests of the long-pulse gyrotron prototype, manufactured by Thales and tested at the Karlsruhe Institute of Technology (KIT), have been carried out with success. The Expert Review Panel, set to to assess the results of the experimental phase, has concluded that “...the prototype gyrotron developed by F4E is close to meeting the ITER performance specifications. For a first 1MW long-pulse gyrotron prototype manufactured in Europe, the results obtained are quite impressive.”

In addition, a cryogen free superconductive magnet for the gyrotron operation has been manufactured by Cryogenics and has successfully passed all Factory Acceptance Tests. It is the first magnet of this type for high power gyrotrons to have been built in Europe and it fulfils all the specifications required for ITER.

Finally, the manufacturing of the first unit of the gyrotron high voltage power supplies needed for First Plasma has been completed at the Ampegon factory in Turgi, Switzerland.

> *“Achieving these excellent results is the result of the effective collaboration between F4E, European Fusion laboratories and industry.”*
>
> **Tullio Bonicelli**
> F4E Project Manager for Neutral Beam and Electron Cyclotron Power Supplies and Sources

TECHNICAL SUPPORT SERVICES

Developing systems and knowledge to improve the operation of all ITER systems

A new numerical model representing the entire ITER Toroidal Field (TF) coil system (18 coils in total) has been developed by F4E. For the first time we have a complete model of the entire ITER TF system with such a level of detail. “The level of complexity of the tool is outstanding. For example, there are more than 1 500 bolts connecting the different pieces of the TF magnet system and the model allows us to predict the behaviour of each one during operations”, explains Gabriele D’Amico, F4E Technical Support Officer

In short, this model will simulate how the TF coil system will function during the operation of the ITER machine and how the magnet system will deform during operation when the TF coil system will be cooled at the cryogenic temperature of -269 ° C.

The model, which took six months to develop, enables F4E and ITER IO to simulate different scenarios using a completely new approach. Its main advantage is related to the fact that the whole TF system is modelled. All the 18 coils and all the main subsystems are detailed which allows for a wider understanding and complete overview. The application of this numerical model received a great deal of praise when it was presented during the last Magnet Technology International Conference held in Seoul.

A network system in the ITER machine will be needed for the real-time communication between different ITER diagnostics, actuators and the plasma control system allowing scientists to monitor and control the operation of the machine. The real-time communication system has been developed by ITER IO and uses a cutting edge technology.

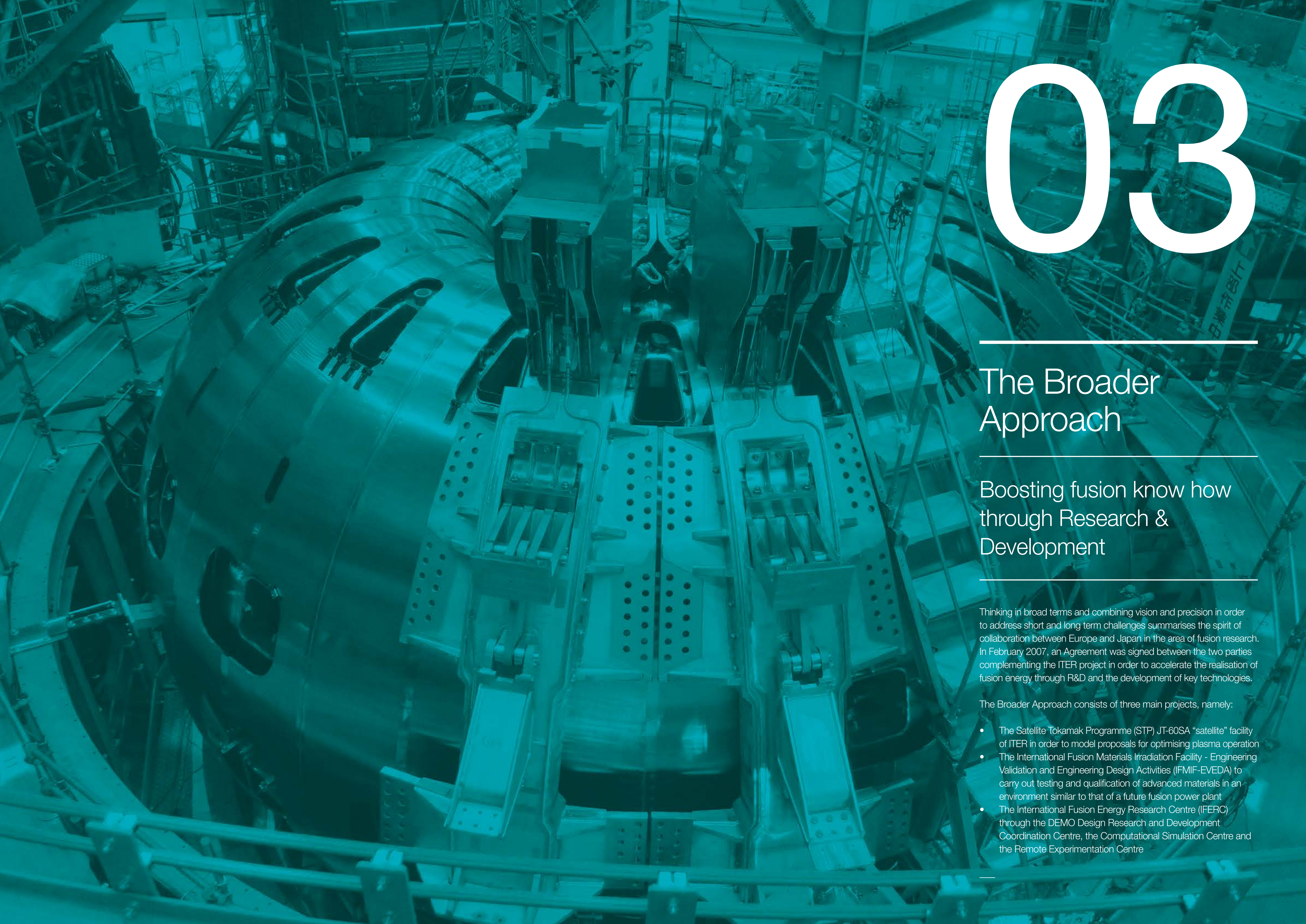
F4E has taken the use of this real-time communication platform one step further by adapting it to inter-connect in real-time different components that are being designed and integrated by F4E. For example, the Electron-cyclotron plant consists of 24 different gyrotrons and this network can be used to monitor and control the information coming from each individual gyrotron control systems.

The system is based on Gigabit Ethernet, the same technology that is used in offices and houses around the world to connect devices to the internet. ITER has developed a software stack that guarantees synchronisation with errors that are well below 0.0001 seconds.

The first alarm survey system to be used on the ITER site has been successfully installed. This is the result of a fruitful collaboration between F4E, ITER IO and the Spanish system and software engineering company GTD Sistemas who have integrated the F4E requirements into an efficient solution.

This alarm survey system aims to protect the people working on the ITER site and its facilities, for example by detecting a fire. It is an electrical system which processes information inputs received from sensors. The information received from the sensors and the programing of the software within the system allows it to transfer these alarms to a permanent alarm survey guard in order to undertake relevant actions.

Work has taken approximately one year but the alarm survey system is a tool which will be constantly developed. The system will be connected to other site systems such as the one which alerts about stormy weather and the system which monitors the distribution of electricity. At the moment, the alarm survey system is currently being used for ITER site’s contractor areas, as well as the Poloidal Field coil building, but the plan is that all the buildings on the ITER platform will be connected to this system within the next few years. Further upgrades will also incorporate alarms from the ITER Site Services building, Assembly Hall, Cryoplant and the electrical distribution system which is currently being installed.



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

Assembling JT-60SA

The first Toroidal Field (TF) coil has arrived from Europe to the JT-60SA site in Naka, Japan, where its assembly has began towards the end of the year. After the coil's successful fabrication and testing, even its transportation has been somewhat of an achievement, in consideration of the component size: second only to those currently being fabricated for ITER, they are 8 m high, 5 m wide, and 33 T heavy.

The TF coils are the backbone of the JT-60SA machine. The task of the 18 "D" shaped superconducting magnets will be to create the main magnetic field needed to confine the plasma. Each complete coil weights about 21 T, including structures, and is roughly 7 m tall and 5 m wide. The slender TF coils and the large space between them, available to diagnostics, heating, remote handling, etc. are one of the trademarks of JT-60SA.

The first two TF coils have been manufactured and tested during 2016. After the completion of the cold test, the outer intercoil structure was installed and in the month of May, the first TF coil was fully inspected before delivery to Japan. For the first time, F4E's Metrology Group has performed a full scan of the TF coil, the first TF coil of JT-60SA manufactured in Saclay, France.

The information gathered during the metrology scan process has allowed the team in Japan to have details about the shape of the coil and its virtual assembly before it actually arrived on-site.

When delivered on-site, colleagues at F4E, CEA, ENEA and JAEA celebrated this milestone.

> *"This outstanding achievement is the result of an intense, fruitful and efficient international collaboration between all parties involved in the JT-60SA project under the Broader Approach Agreement between Europe and Japan"*
>
> **Pietro Barabaschi**
> Home Team Project Manager for Europe's contribution to the Broader Approach project

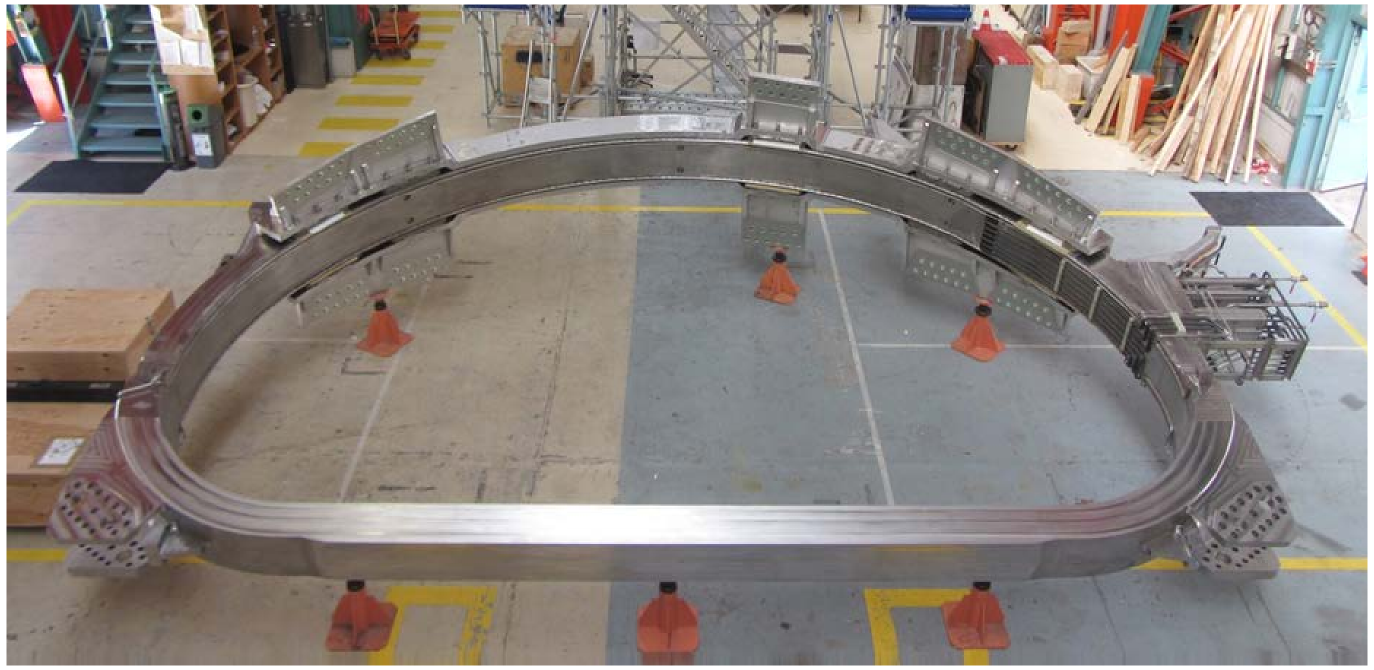
The design activities for the TF coils took place during 2007-2011 and were widely shared between European and Japan Institutions: JAEA, F4E, ENEA and CEA. The manufacturing and testing of the TF coils, defined as European contributions to JT-60SA in the framework of the Broader Approach Agreement, were split in several lots, each requiring a high level of skill and quality.

F4E procured the superconducting strands manufactured by the Furukawa Company in Japan (completed in May 2013) and their subsequent cabling and jacketing to produce Cable-In-Conduit conductor by the Italian consortium ICAS (completed in October 2015). ENEA procured the TF coil casings manufactured by Walter Tosto. Using these components, CEA and ENEA, who each have the duty to produce, with a high level of accuracy and reliability, nine coils plus one spare, have placed industrial contracts with renowned superconducting coil manufacturers: Alstom/GE for CEA and ASG for ENEA.

The news for the JT-60SA Cryoplant has also been good, having successfully passed the most demanding of its acceptance tests. The powerful refrigerator will be producing helium at temperatures close to absolute zero for some of the JT-60SA components. To confine the super-hot plasma, expected to reach over 100 million ˚C, for periods exceeding 100 seconds, the plasma-confining magnets need to be in a superconducting state so that the wire can conduct much larger electric currents than ordinary wire, and thus create intense magnetic fields. To reach this state, the magnets are cooled with helium to 4.4 K and protected from external radiation by thermal shield cooled by helium at 80 K. The JT-60SA cryoplant presently ranks among the largest helium refrigerators in the world.

The acceptance tests, which have been carried out by F4E's supplier company Air Liquide Advanced Technology (AL-AT), consisted in simulating how the cryoplant would behave during the operation of JT-60SA.

"This is a success for JT-60SA which has been achieved thanks to an almost perfect combination of design, manufacturing, installation, commissioning and management skills by AL-AT , and the EU Voluntary Contributor CEA, with important contributions by QST and F4E (both in terms of hardware and technical inputs)", explained Enrico Di Pietro, Head of F4E's Broader Approach JT-60SA Unit.

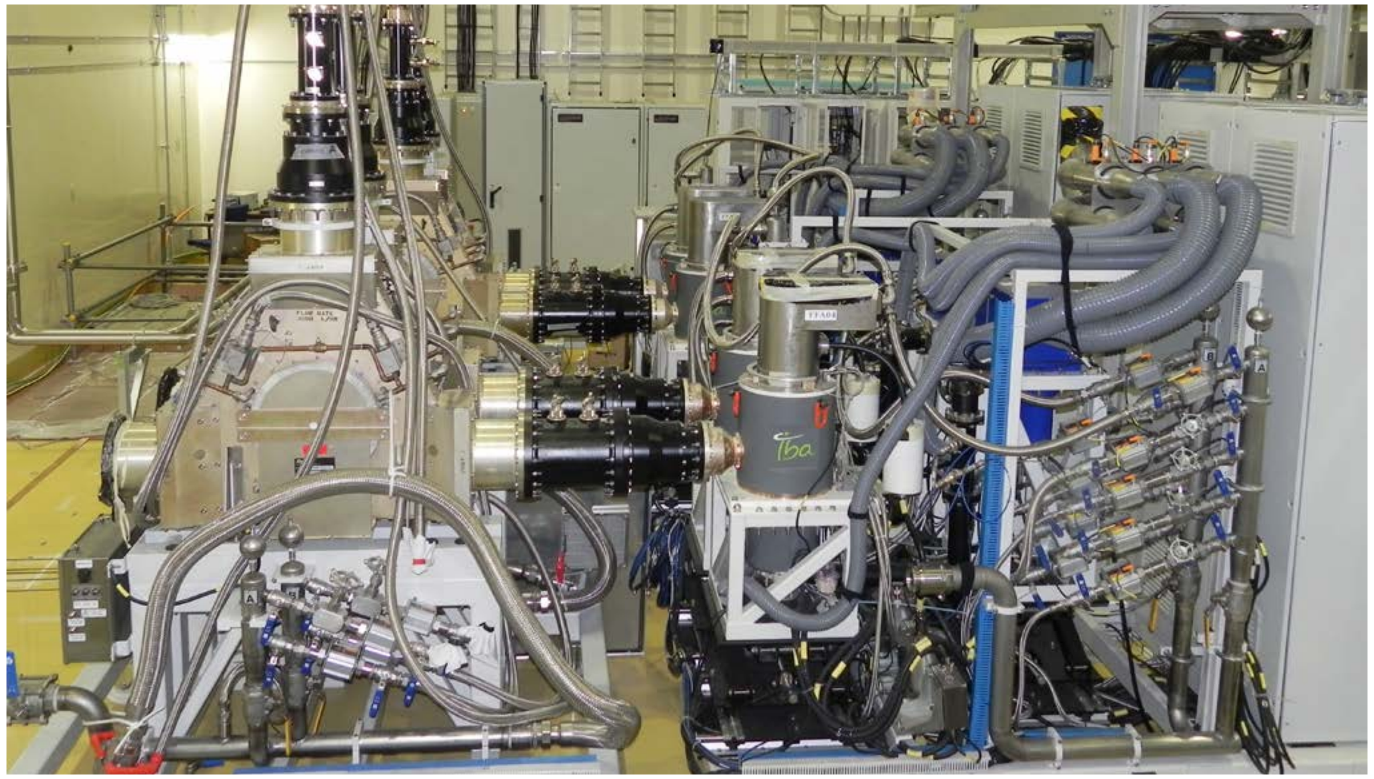


The first JT-60SA TF coil in Japan

The assembly has started: the first two of JT-60SA's TF coils are in place in the Tokamak

Advancing with more IFMIF activities

The International Fusion Materials Irradiation Facility (IFMIF), in its Engineering Validation and Engineering Design Activity (EVEDA) phase, has been evolving successfully celebrating important milestones in line with schedule and budget.

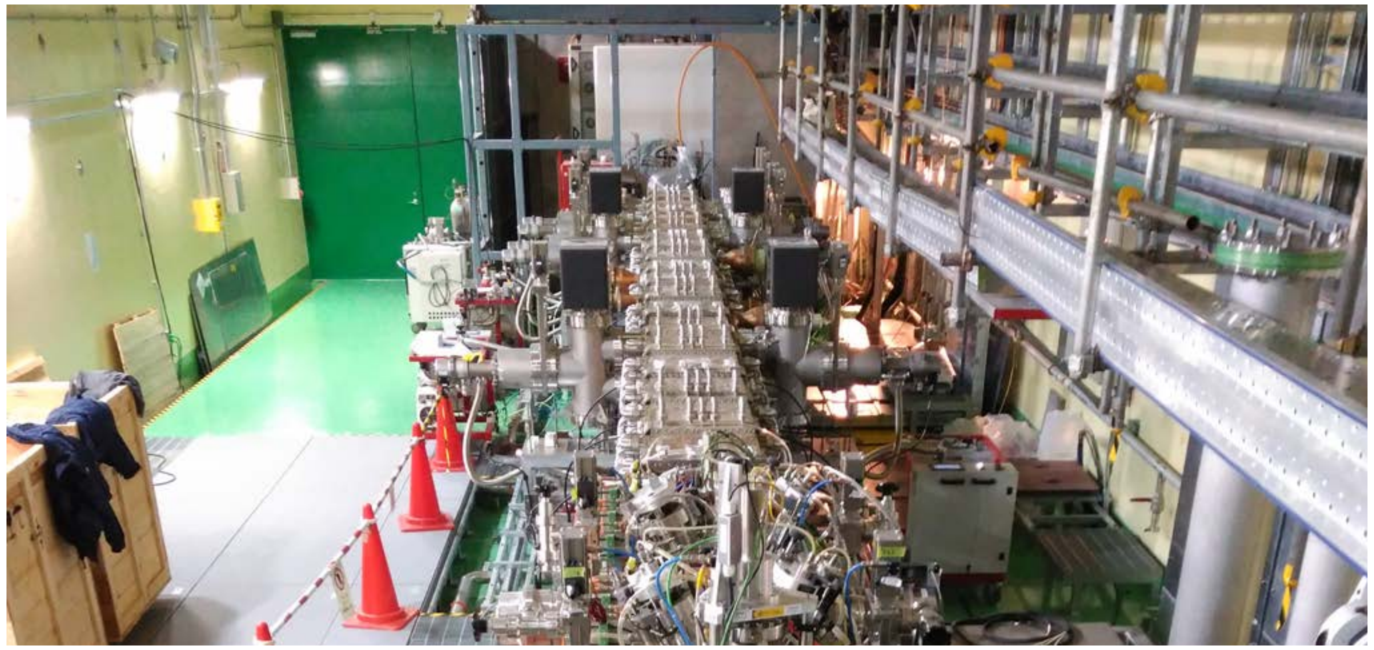


Two modules of the radio frequency power sources from CIEMAT installed at the LIPAc building of the International Fusion Energy Research Centre, Rokkasho, Japan

IFMIF will be a neutron source for the qualification of materials capable to withstand the impact of high energy neutron fluxes equivalent to those of deuterium-tritium reactions in a future fusion reactor. Validation activities have been successfully completed with the conclusion of the corrosion and erosion studies in the Lifus 6 facility, operated by ENEA, reaching 4000 h of exposure of Europe's EUROFER97, and Japan's equivalent F82H, to IFMIF lithium conditions.

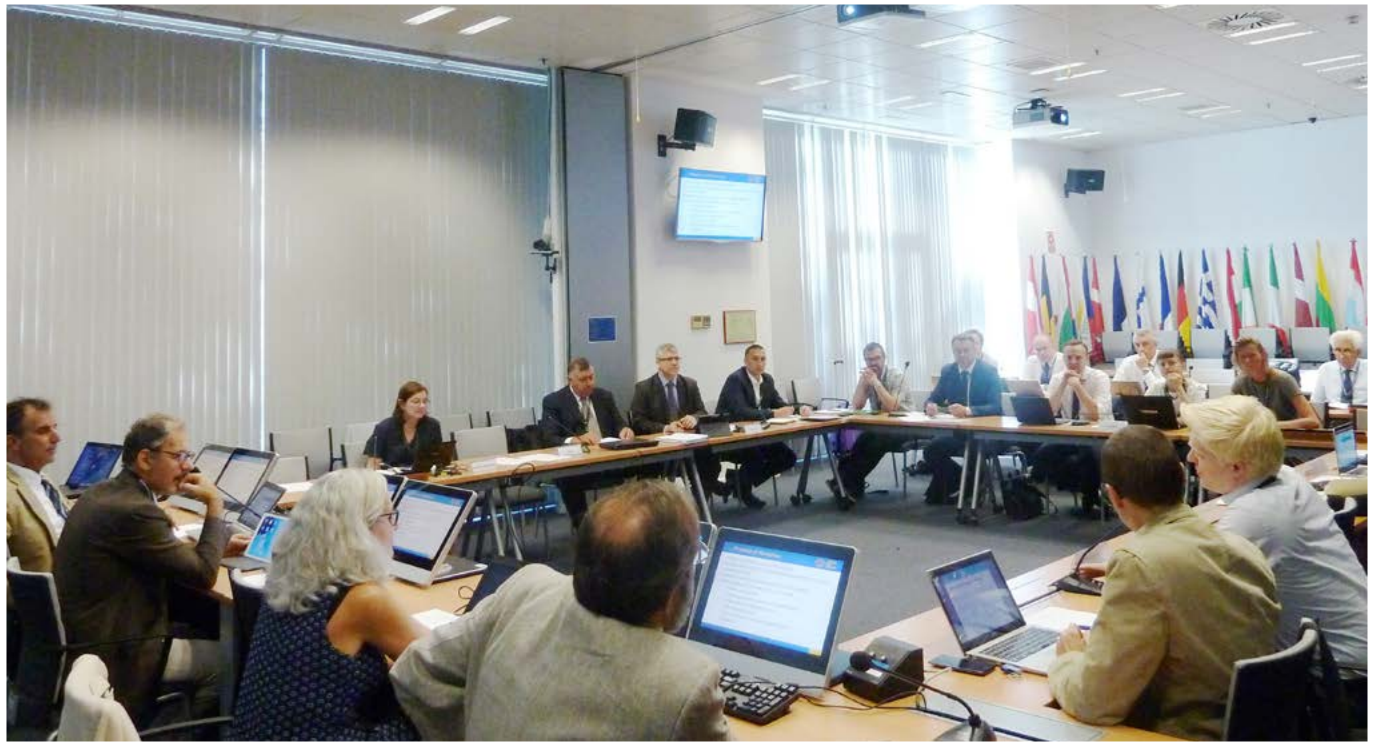
The only remaining activities are linked to the LIPAC accelerator, small in size but challenging in performance with its 1.1 MW beam power, being installed and commissioned in Rokkasho. The prototype accelerator will deploy cutting-edge technologies. Its injector, developed by CEA, has demonstrated that the deuterium beam can reach high levels of performance. With the help of the Radio Frequency Quadrupole (RFQ), developed by INFN, the beam energy will increase by a factor of 50. The RFQ is the longest one ever constructed, considered a jewel in the world of accelerator technologies. The Radio Frequency power chains, produced by INDRA, a contractor of CIEMAT, have been installed and are able to deliver 1.6 MW to operate the RFQ.

To celebrate the initial commissioning of the accelerator's injector, together with the first stages of installation of the RFQ and the Radio Frequency power sources, representatives from the policy, diplomatic and scientific communities from Europe and Japan visited the facility during a ceremony to witness the process on-site. Their presence has been read as an expression of their commitment to the project and as a token of appreciation for this technical milestone.



Installing the Radio Frequency Quadrupole and Injector already in position in IFMIF/EVEDA, Rokkasho, Japan

Policy-makers and scientists attending the installation ceremony of LIPAc, IFMIF/EVEDA, Rokkasho, Japan



DONES Technical information session, September 2016

Parallel to these technical milestones, the fusion community has started to plant the seeds for some of its future activities in the area of the Broader Approach. The DEMO Oriented Neutron Source (DONES) has been flagged as a new infrastructure which will help scientists test materials in an environment mimicking the conditions of DEMO, the fusion machine that will come after ITER.

Three European countries – Croatia, Poland and Spain – have expressed interest in hosting this prestigious facility and contribute to the fusion roadmap. Fusion for Energy (F4E), acting as co-ordinator for the European activities of the Broader Approach, has taken the initiative to invite representatives of the three countries at a technical information session in Barcelona to explain the scope of DONES, outline some first technical specifications and offer a tentative calendar for the different steps leading to the submission of their application.

In order to help all countries, during the preparatory stage, F4E has agreed to ask its Governing Board to nominate a group of experts to offer guidance. The activities will reach a crescendo in 2017 with the submission stage and the evaluation of proposals.

Helping scientists to generate new knowledge

The International Fusion Energy Research Centre (IFERC), hosted by the Japanese Atomic Energy Authority (JAEA), has been the home of one of the world's most powerful supercomputers known as "Helios". Considered as one of Europe's key contributions to the Broader Approach Agreement, it has been promoting R&D activities in the field of fusion, giving scientists the opportunity to perform complex calculations in plasma physics.

From the second quarter of 2012 and until the end of 2016, "Helios" has been up and running. Through its operation, the usage of the supercomputer has been very intense, exceeding at times a 90% capacity on average/week. This very good result was matched with the excellent management of time slots, accommodating most of the proposals submitted by the scientific community. For instance, there were reserved sessions for very large jobs or specific queues for longer jobs which did not fit in the normal queues.

Security has been a very important issue for the computer centre. Because of its high visibility, annual security audits had to be performed. They each praised the security status of the supercomputer while making recommendations which were duly implemented.

Due to the geographical position of the centre, almost all users have been accessing the supercomputer remotely.

To help users make the best use of it, training sessions were organised, both in Europe and in Japan from where scientists had the possibility to submit their proposals. For each submission cycle, a Standing Committee had to organise calls for proposals; select the projects from the proposals by peer review; allocate the computational resources to the selected projects; evaluate the performed projects; and make a written summary report of the calls.

According to user reports, 639 peer-reviewed papers have been prepared using the resources offered by "Helios". Main topics scoring high with the scientific community have been plasma physics, reactor technologies and materials.

Helios Supercomputer bullx ® series. © Bull

© istockphoto

04

Working together with stakeholders

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

With the help of different committees, the network of ITER Industrial Liaison Officers (ILOs) and the European Fusion Laboratories Officers (EFLOs), F4E has been tried to reach out to industry, SMEs and R&D organisations to get involved in the biggest international energy project.

In our attempt to report on the progress of the European contribution to ITER, explain the direct and indirect benefits of the project and its potential contribution to a sustainable energy policy, F4E has engaged with policy-makers at European and national levels.

Engaging with policy-makers

Early in the year, MEP Marian-Jean Marinescu, Budgetary Control Committee Rapporteur for European Joint Undertakings, made his first visit to the ITER construction site to learn more about the project and its progress.

A delegation of Members of the European Parliament during the guided tour at the Tokamak building where the ITER machine will be installed. October 2016.

F4E Director, Johannes Schwemmer, welcomed MEP Marinescu and accompanied him on a tour of the different buildings and facilities being constructed by F4E. Along the way they had the opportunity to meet several project managers and hear directly about the challenges of working on such a technically demanding international project. MEP Marinescu, an aerospace engineer himself, took the opportunity to find out more about the way in which the project has been managed and its cost.

"With the implementation of the ITER and F4E Action Plans, I am pleased to see that project management is being put at the heart of the ITER project". Marian-Jean Marinescu, Budgetary Control Committee Rapporteur for Fusion for Energy (F4E) and European Joint Undertakings

Towards the end of the year, F4E, in cooperation with the European Commission, has hosted a visit to the ITER with a first group of MEPs of the Industry, Research and Energy (ITRE) Committee. The visit has been attended by Clare Moody (Socialists & Democrats), Christian Ehler (European People's Party), Jakop Dalunde, (Greens), Flavio Zanonato (Socialists & Democrats), Eugen Freund (Socialists & Democrats), and Miroslav Poche (Socialists & Democrats), rapporteur of the Budgetary Control Committee for the 2015 accounts of the EU Joint Undertakings.

Apart from a guided tour on-site, where participants had the possibility to see the scale of the works, an information session was given by the F4E Director, and Bernard Bigot, ITER Director General, describing the benefits of fusion energy, the technical achievements and challenges, together with the important changes in the management of the project.

> *"It has been a very informative and interesting day and I was very pleased to have visited the construction site of this inspirational project."*
>
> **MEP Clare Moody**

Involving Fusion Laboratories

The scale and complexity of the ITER project has raised the benchmark for the fusion community in an unparalleled way. The involvement of industry to manufacture millions of high-technology components has offered a one-of-a-kind opportunity to fusion laboratories to export their know-how and contribute towards a culture of manufacturing. Years of expertise have found an ideal setting to be tested and directly applied. One of ITER's spillover effects has been its capacity to create a pool of excellence and nurture multiple innovation clusters.

Representatives of UKAE welcome Johannes Schwemmer, F4E Director (L-R): Tim Jones, Martin Cox, Steven Cowley, Johannes Schwemmer, Ian Chapman, William Morris

Representatives of IPP and Consorzio RFX meet Johannes Schwemmer, F4E Director (L-R) Ursel Fantz, IPP; Giorgio Rostagni, Consorzio RFX; Roberto Piovan, Consorzio RFX; Tullio Bonicelli, F4E; Francesco Gnesotto, Consorzio RFX; Sybille Günter, IPP; Johannes Schwemmer, F4E; Jean-Marc Filhol, F4E; Vanni Toigo, Consorzio RFX

With an open and collaborative spirit, exploring the role that fusion laboratories can play in future, Johannes Schwemmer, F4E Director, took the initiative to meet with some representatives of the European fusion community and visit their facilities. Given the fact that the seat of EUROfusion is split between the Max-Planck-Institut für Plasmaphysik, IPP, Garching and Culham Centre for Fusion Energy (CCFE), host to the Joint European Torus (JET), meetings were planned in both locations.

At Garching, Professor Sibylle Günter, Head of IPP, gave a warm welcome to the Director of F4E and showcased the latest achievements of the institute. Representatives of Consorzio RFX, were also invited to offer an update on the progress of the Neutral Beam Test Facility's progress, located in Padua, and explain future milestones. Next, a visit to the JET was organised, the world's largest operational magnetic confinement plasma physics experiment, and a series of meetings were planned with Professor Tony Donné, EUROfusion Programme Manager, Professor Steven Cowley, previously UKAE CEO and member of F4E's Governing Board, and Professor Ian Chapman, UKAE CEO.

Meeting with other ITER Parties and suppliers

Johannes Schwemmer with representatives of Huandai Heavy Industies (HHI)

The progress of the Broader Approach collaboration was discussed at the Rokkasho Fusion Institute

Johannes Schwemmer in front of the KSTAR machine

The F4E Director saw where the JT-60SA Toroidal Field magnets are currently being prepared for assembly

F4E Director, Johannes Schwemmer, on invitation by Ki-Jung Jung, Head of the Korean ITER Domestic Agency (KODA) visited the seat of the organisation and discussed joint F4E-KODA ITER. A visit was also planned to KSTAR, or Korea Superconducting Tokamak Advanced Research, the magnetic fusion device being built at the Korean National Fusion Research Institute. KSTAR is one of the first research tokamaks in the world to feature fully superconducting magnets, which has set a new record maintaining a temperature of over 100 ° million C for more than a minute. A visit was also paid to Hyundai Heavy Industries (HHI), headquartered in Ulsan, where the F4E Director travelled to witness the progress of the ITER Vacuum Vessel sectors.

To discuss issues related to ITER and to visit the JT-60SA site, the Director of F4E met with Drs Mori, Kurihara, Ishida and Kusama – the top management of the Japanese ITER Domestic Agency QST. Next, a meeting was organised at Toshiba, the company dealing with the assembly of JT-60SA's Vacuum Vessel, the ITER Toroidal Field coil cases, and the owner of Mangiarotti – the company which works on the ITER Vacuum Vessel for F4E.

Unveiling business opportunities

Company representatives meeting with F4E members of staff during business to business meetings (B2B), MIIFED-IBF 2016

Benjamin Perier, F4E Market Intelligence, presenting upcoming ITER business opportunities.

The Monaco International ITER Fusion Energy Days (MIIFED) has been the most important event of the year, gathering representatives from the seven parties of the biggest energy collaboration, together with multiple companies and laboratories currently involved. With the help of the ITER Business Forum (IBF) organisers, this three-day conference has transformed into a rendezvous of commercial deals.

The participation rate has been impressive bringing together 556 participants from 26 countries, representing 285 companies and fusion labs. To help attendees network and form future partnerships, 653 business to business (B2B) meetings were organised. Three technical tours were planned for 60 participants taking them to the ITER construction site, the facilities of CNIM and SIMIC, where some of Europe's components in the field of magnets are being manufactured.

To explain the procurement strategy of the Beam Source of MITICA and those of the Neutral Beam of ITER, F4E has organised a business Information Day gathering 30 representatives from different companies. A team of experts from F4E and Consorzio RFX elaborated on the overall rational and the different stages of the project. Through their interventions they covered technical, administrative and IPR aspects.

Similarly, at the Institute of Plasma Physics of the Czech Academy of Sciences, another information day has been organised to present a wide range of ITER business opportunities. More than 30 representatives, from at least 13 companies, attended the event which offered a progress report of the ITER project, a business forecast regarding contracts in the pipeline and a mapping of expertise and competences required. As a result, more than 50% of the participants registered on the portal and are actively seeking ways to contribute to the ITER project.

In an attempt to tease out the entrepreneurial angles of ITER, and future collaboration between Poland's Space Agency and the European Space Agency (ESA), Maciej Potocki, the President of the Wrocław Technology Park, and Sylwia Wójtowicz, the F4E Industry Liaison Officer for Poland, have organised an Info Day highlighting the business opportunities in international projects.

The event has brought together almost 50 representatives from 35 companies specialised in cutting edge technology with a proven track record in R&D. SMEs, managed by young and dynamic innovators, based at Wrocław Technology Park, which has become an incubator for talent in applied research. Because of their expertise in space technologies, they have expressed an interest in the manufacturing of cameras, sensors aand robotics in the field of Remote Handling, or even Cryogenics and Diagnostics.

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 groups such as companies, technology and science communities.
In this section we look back at some of the key events that marked the year.

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Participants at the Hollnad@CERN event, CERN ©

During the Dutch Presidency of the Council of the European Union, Europe's capacity to act as an innovator and job creator has been identified as one of the main challenges. Behind the vision of a prosperous, competitive and innovative Europe lie several questions: how can we stimulate innovative entrepreneurship and strengthen new services? What would be their societal impact? What kind of jobs and growth would they create?

The exhibition "Holland@CERN" tried to address some of these questions by discussing the challenges and opportunities of big science at CERN, one of most reputable facilities in the world promoting international scientific collaboration and excellence. The event, organised by the FOM Institute Nikhef, TU RID Delft, FOM Institute DIFFER, NWO and the ILO-net, managed to bring together more than 100 attendees from at least 38 Dutch high-tech companies and representatives of major scientific collaborations. Participants were there to network, showcase their expertise, focus on knowledge transfer and explore new business opportunities.

One of the popular myths suggesting that big science is only for big players was quickly debunked given the contribution of smaller companies to ITER. Contrary to what one would have expected, their adaptability has given them edge and helped them to be competitive. Furthermore, due to the complexity and the variety of skills required to respond to the technical needs of the projects, international partnerships and the creation of consortia have become more mainstream. As a result, larger and smaller companies have been working together and learning from one another.

The ITER project has been invited to the World Nuclear Exhibition (WNE) to demonstrate its contribution to the energy market in the decades to come. In spite of the fact that the event has only celebrated its second edition, it has already become a well-known reference in the energy community. This edition of WNE has attracted the interest of approximately 9000 participants from at least 27 countries.

F4E together with Assystem reported on the progress of ITER and the complexities that underpin it. A summary of the ITER project was given focussing on aspects of civil engineering and construction. Assystem, is part of the Engage consortium, managing the Architect Engineer contract which also consists of Iosis, Atkins and Empresarios Agrupados. The contract awarded by F4E to the consortium is considered as one of the biggest civil engineering deals in Europe.

Remote Handling experts from companies, laboratories and ITER Domestic Agencies gathering at the headquarters of ITER IO, November 2016

The participants of the Blanket Integrated Project Team meeting.

During 2016, a series of technical meetings were either hosted by F4E or were organised with its strong involvement.

Europe is responsible for the supply of 48% of the ITER first wall panels of the blanket, while Russia contributes 40% and China the remaining 12%. Representatives from all ITER Domestic Agencies, as well as the ITER International Organization Central Team, met at the F4E offices in Barcelona in order to exchange information on the design and procurement activities of the ITER Blanket project. The purpose of the meeting was to share information, receive industrial feedback experience from on-going manufacture of components and improve collaboration amongst all the relevant parties by face-to-face interaction. Later in the year, the ITER International Organization (IO) in collaboration with F4E, and Japan's ITER Domestic Agency, hosted in Cadarache the second Remote Handling workshop gathering more than 90 representatives from companies and laboratories, mainly from Europe. Amongst the list of objectives set for this meeting, the main focus was on the progress of the procurement packages, with attention to design, interfaces, cross cutting technologies and, where applicable, regulatory issues. Furthermore, the standardisation and the promotion of a common industrial culture, underpinning all suppliers, was another theme widely discussed during the three day event.

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