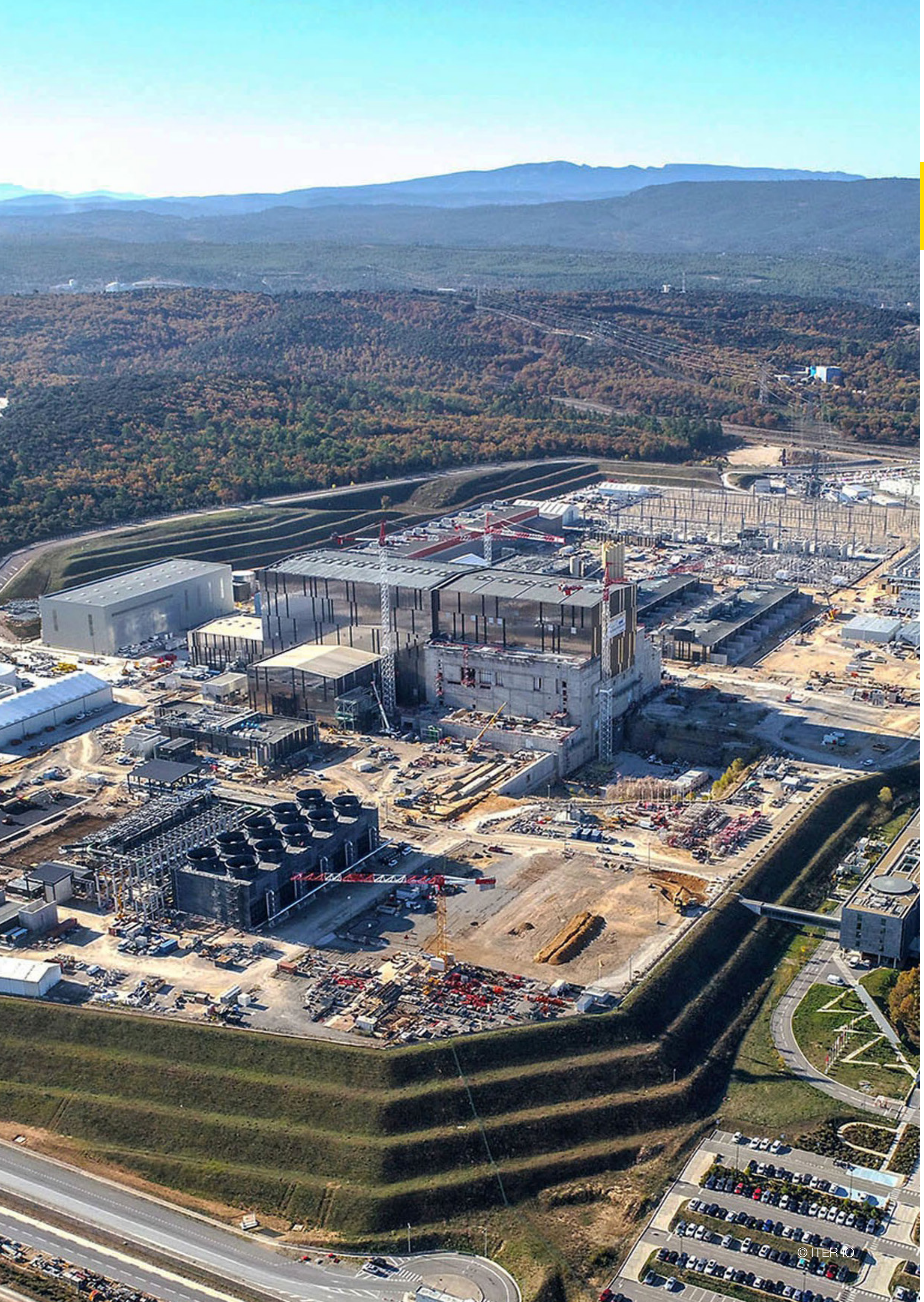
FUSION FOR ENERGY

HIGHLIGHTS 2020

The main achievements

To Mario Gagliardi
To Marco Van Uffelen

2020
Table of contents


© ITER IO

FOREWORD

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

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

I am very proud to be F4E's Director and to tell you about our achievements in 2020. You often hear in such reports that the year was special but I can assure you that 2020 was a year like no other.

We had to face the unprecedented challenges of the Covid-19 pandemic. We put safety first and switched to full teleworking while maintaining business continuity. I am proud to say that we had no cases of an infection in the workplace during the whole year.

Our industrial partners, especially those in Italy and Spain, adapted quickly and took protective measures to keep working. As a result, the additional cost and delays of the Covid-19 pandemic were limited to approximately €50m and 4 months respectively.

Let me take this opportunity to thank both our staff and our industrial partners for the way in which they have coped with this challenging situation and kept on delivering as this report shows. In particular, you will see that among the many highlights of the year:

- We brought construction work on the Assembly Hall and Tokamak Building to the point where ITER assembly could begin and this was celebrated in an event hosted by President Macron
- We delivered three superconducting Toroidal Field magnets - the result of several complex technical operations involving more than 30 EU companies
- We finished and delivered our first Poloidal Field magnet, manufactured in China under F4E contract. The first of the large Poloidal magnets made in France moved close to completion
- We manufactured and delivered all nine Pre-Compression Rings for the magnets using an alternative back-up fabrication route – a example of risk management is action
- The Vacuum Vessel sector production rates of our industrial partners were impacted by Covid-19, but recovered by the end of 2020 thanks to productivity measures
- We completed 100% of the on-site installation of the structure of the Liquid Nitrogen plant at ITER, 90% of the piping and 30% of the pre-commissioning activities
- We managed EU contributions to the Broader Approach fusion projects with Japan to their near completion (~99%) and helped concluded an agreement with Japan for BA-Phase II
- Together with our Japanese partners, we completed assembly of the JT-60SA Satellite Tokamak and cooling the magnets down to 6K at which point they became superconducting

We signed new contracts with industrial partners and laboratories for a total of just under €1bn in 2020 bringing the total investment since 2007 to almost €5bn helping to create jobs and support innovation. I appreciate that this is a tremendous investment of public money and thank you to entrust it to us.

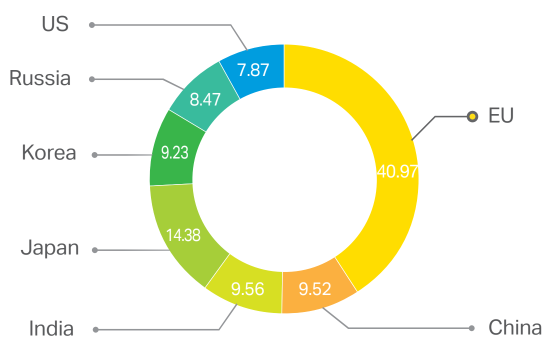
Internal improvement remained in focus at F4E with the completion of many actions from audits and external assessments. We also implemented 100% and 98% of the planned commitment and payments, giving confidence in the improved robustness of project planning.

Overall, it was a very challenging and productive year! I invite you to look through this publication and discover many more of our achievements during 2020 and if you are curious, I encourage you to visit our website and to follow us on social media.

Johannes P. Schwemmer
Director

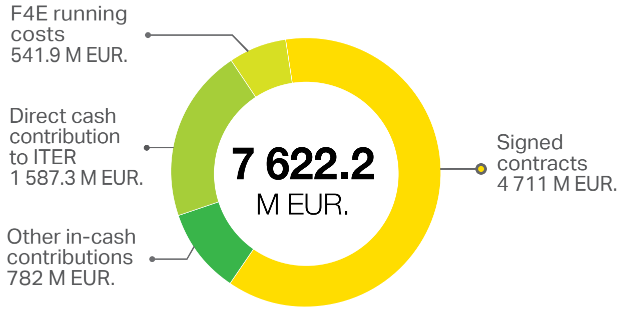
2020 KEY FIGURES

Contributions to ITER



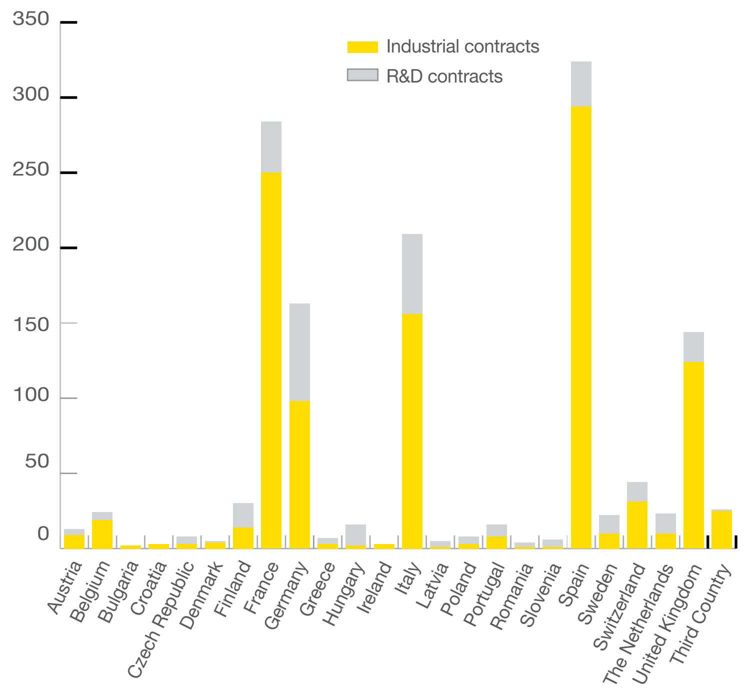
Total contributions in percentages, between the different ITER parties 2008-2020

F4E budget breakdown



Budget breakdown of F4E main activities 2007-2020

Geographical distribution



Contracts and grants awarded by F4E 2008-2020

Contracts with Industry and Laboratories

€243m
Total value of contracts signed in 2020

€4.7bn
Total value of contracts signed 2007-2020

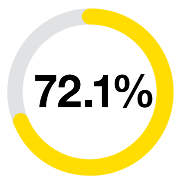
1073
Contracts signed since 2007

500
Companies

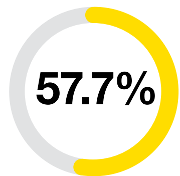
1500
Subcontractors

70
Research Organisations

ITER Project Progress

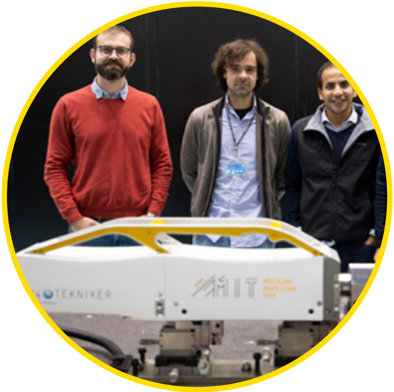


Completion towards ITER First Plasma



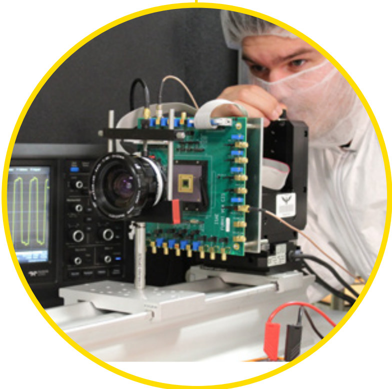
Completion beyond ITER First Plasma

Some of the F4E achievements during 2020



January

F4E and Tekniker develop new tool to inspect quickly and with extreme precision various types of equipment. Meanwhile, production peaks in the factory of CNIM for the ITER Pre-Compression Rings.



February

Testing of image sensors in progress as part of the cameras for ITER Remote Handling system. IFMIF/EVEDA project welcomes delegates from Belgium, Sweden, Germany, Finland, Lithuania, and Italy working in the field of science and technology.

March

ITER Tokamak building ready to receive equipment. Europe completes manufacturing of first Toroidal Field coil. Assembly of JT-60SA completed. Fusion research agreement prolonged between Europe and Japan.

April

Europe delivers first magnet in ITER history. Diagnostics cables in production to monitor plasma performance. Qualification works of Linear IFMIF Prototype Accelerator advance. Impregnation concluded for Fifth Poloidal Field coil.

May

Production of Pre-Compression enters its final stage. F4E and Walter Tosto ready start production of ITER Divertor Cassette bodies. Europe organises Remote Handling workshop in electronics to present latest progress.

June

F4E ready to hand over MITICA vacuum vessel to ITER Organization. Poloidal Field coil six delivered on-site. Another Toroidal Field coil winding pack ready to go through final manufacturing.

July

ITER Assembly begins. Europe hands over ITER Organization nine Pre-Compression Rings. Manufacturing and machining advance for Europe's vacuum vessel sectors.

August

F4E delivers cooling plant of ITER Neutral Beam Test Facility. Scientific breakthrough measuring tritium in tokamak dust particles.

September

Finishing works for Tokamak port cell doors. Successful site acceptance tests for MITICA Ion Source and Extraction Power Supplies (ISEPS). Fusion community attends virtual Symposium on Fusion Technology.

October

Cool down of JT-60SA magnets begins. F4E launches Technologies Marketplace portal. ITER Cask and Plug Remote Handling system concludes preliminary design review. Europe's second Toroidal Field coil arrives in France.

November

Welding works almost completed in Cryoplant. Europe's Inner Vertical Target passes all tests. CNIM-SIMIC start production of Divertor Cassette bodies. Diagnostics equipment in progress for vacuum vessel.

December

Sixth Poloidal Field coil ready. Test Blanket System passes conceptual design review. Europe's third Toroidal Field coil arrives in France. Hydraulic valves installed in Remote Handling facility.

SOME OF THE ITER ACHIEVEMENTS DURING 2020

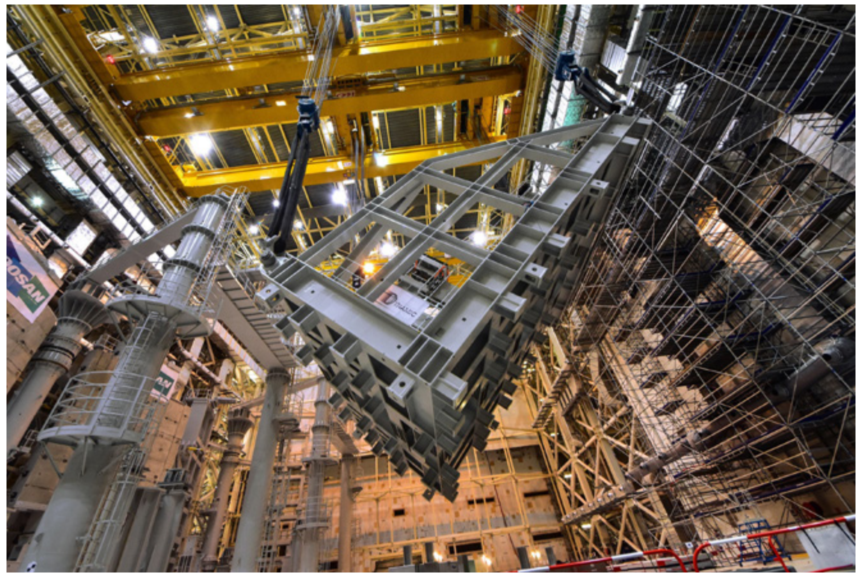
All images provided by ITER Organization

ITER Organization

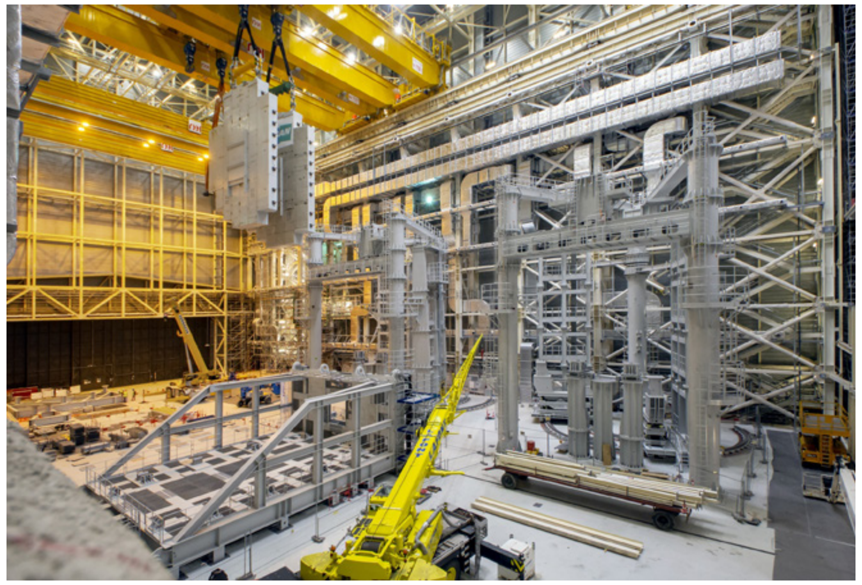
Ten fans installed at the top of the building, one for each cooling tower. Cooling basins passed fill tests.

Fusion for Energy officially handed over the ITER Assembly building to ITER Organization. The building's extensive HVAC system is ready to maintain the specific temperature and humidity levels required during machine assembly.

Five kilometres of actively cooled aluminium busbars, procured by Russia, installed in the Magnets Power Conversion buildings.



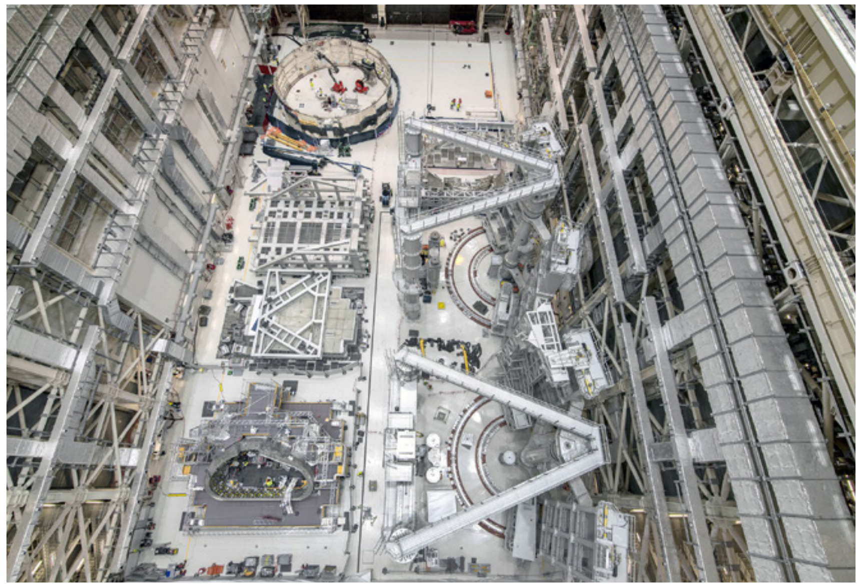
Commissioning of the upending tool and the heavy lift cranes in the Tokamak Building.



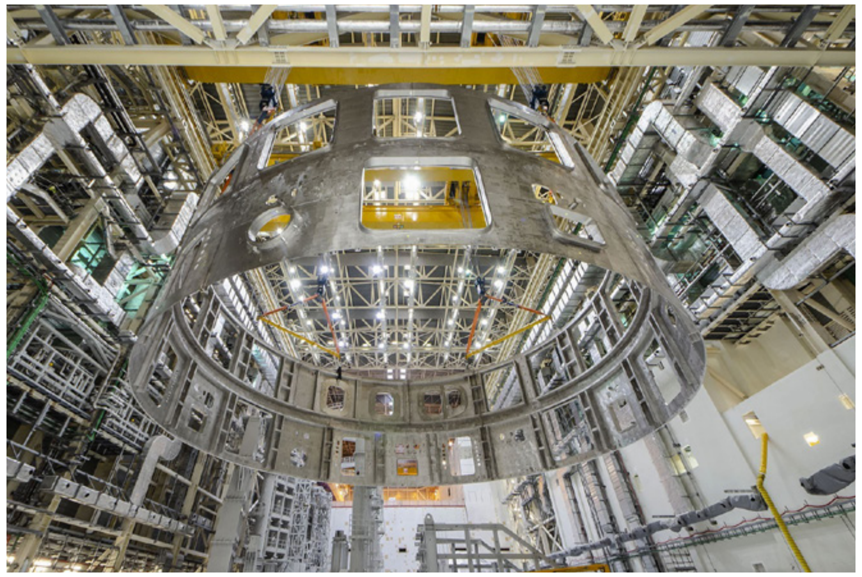
Totaling approximately 1 000 t, the mock loads are ready to undertake their 170-metre-long journey from the entrance of the Assembly Hall all the way to the opposite end of the newly created crane hall.

First major machine component—the cryostat base—lifted by overhead crane and lowered into the Tokamak assembly pit.

ITER Assembly officially starts!

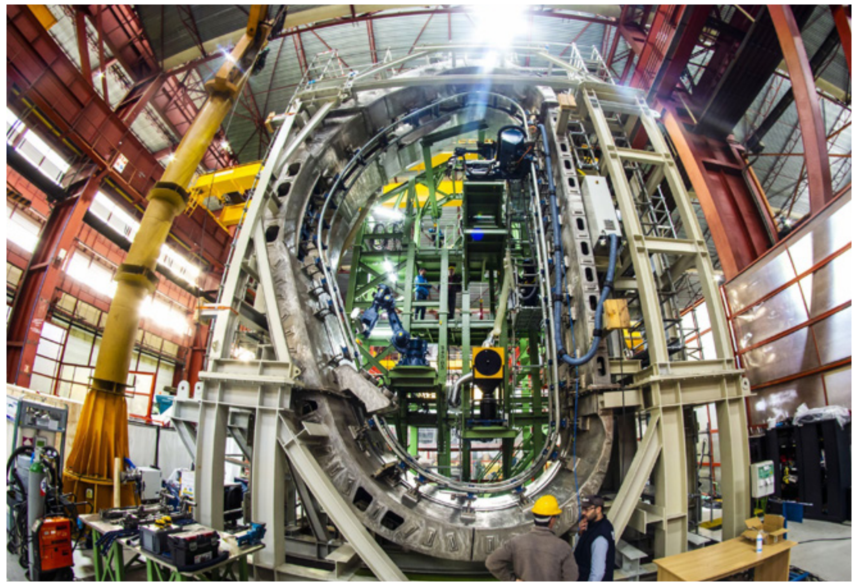


View of the different work zones inside the ITER Assembly Hall. The component the furthest from the Tokamak pit (the lower cylinder thermal shield, top) will be the next one installed.



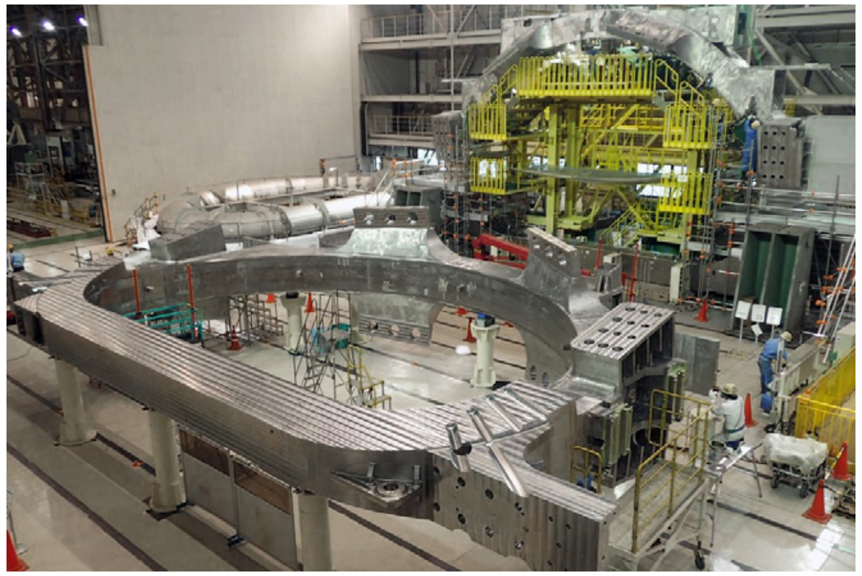
Lower cylinder of Cryostat inserted in the Tokamak pit.

The first vacuum vessel sector passed all site acceptance tests.



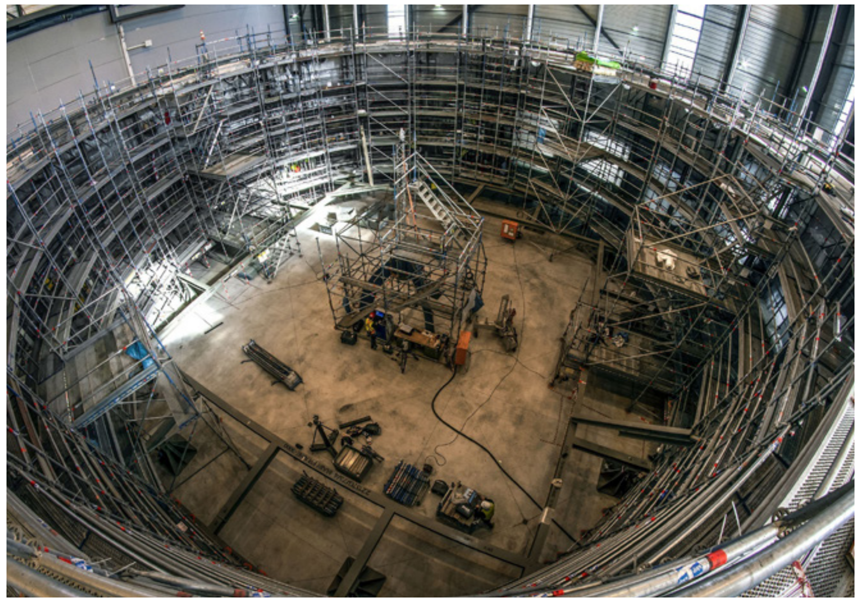
In October 2020, the ITER Organization signed a contract with the Spanish company ENSA (Equipos Nucleares SA) for the welding of the ITER vacuum vessel. The scope of the new contract—called VVW2P, for Vacuum Vessel Welding Production Phase—covers the welding of nine vacuum vessel sector sub-assemblies and 54 ports.

Japan



- Two Toroidal Field coils delivered on the ITER site and seventh TF coil case delivered to Europe.
- Contractors completed the seventh EC gyrotron.
- Contracts placed for divertor outer target prototypes.
- Feasibility study completed for the blanket remote handling system in a humid in-vessel atmosphere.

India



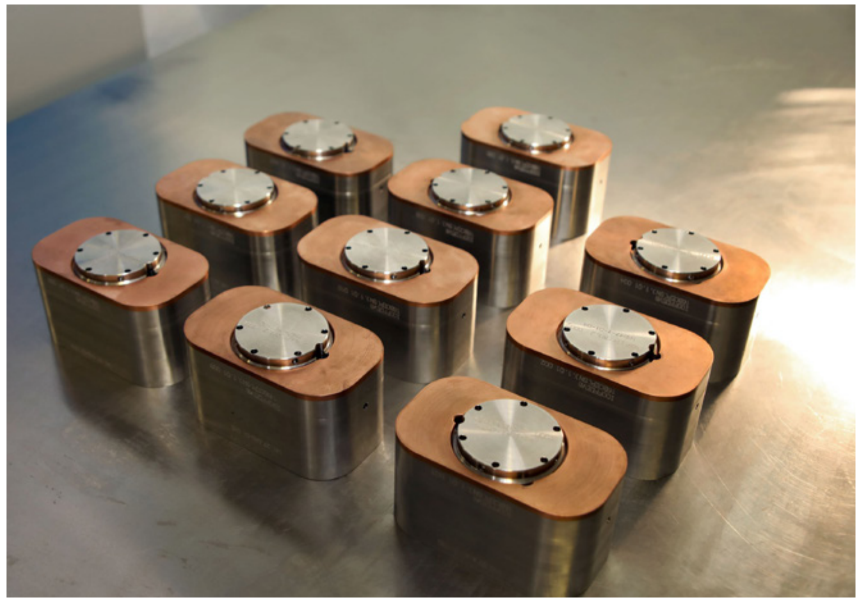
430-tonne upper cylinder of Cryostat completed.

650-top lid of Cryostat completed, it’s the fourth section of the component in order of assembly after the base, the lower cylinder and the upper cylinder.

Russia

- Poloidal Field coil 1 nearly completed.
- Two upper port extensions procured by Russia have been delivered to Korea in order to be welded to the sectors of the Vacuum Vessel.
- Full-scale prototype of Divertor Dome completed.

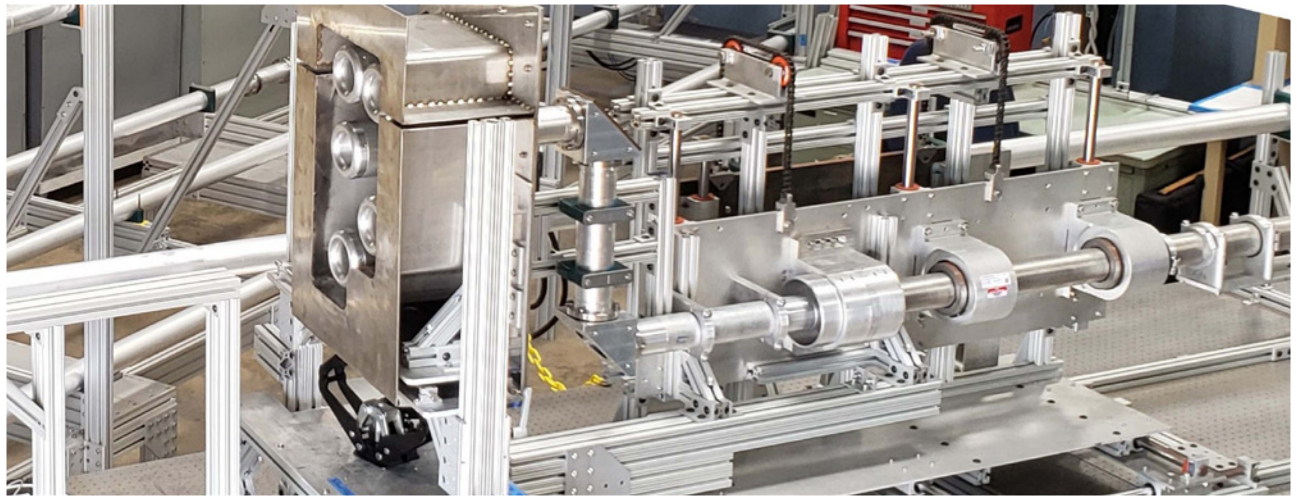
Factory acceptance tests completed for fourth gyrotron set.



Batch of bimetal “pedestals” to delivered to ITER, in order to support blanket electrical connectors and act as low-impedance electrical bridges between blanket modules and the vacuum vessel.

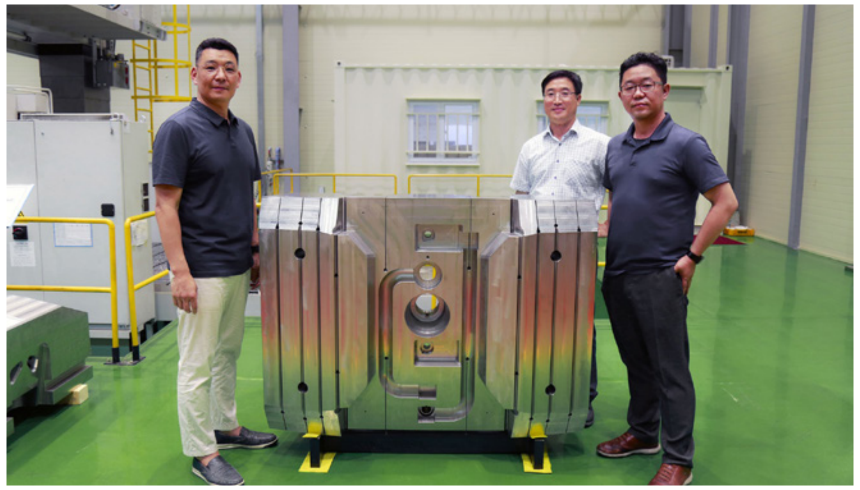
United States

- One of the seven central solenoid modules emerges from the furnace. Other modules are advancing in various stages.
- Final design review for the Electron Cyclotron system’s transmission lines concluded successfully.
- Low-field side reflectometer (LFSR) that will gather data from the outer layers of the ITER plasma—is under development by a team based out of the Princeton Plasma Physics Laboratory.



Korea

First Vacuum Vessel sector completed and final thermal shield.



First Blanket Shield Block completed-440 units of this component will provide nuclear shielding for the vacuum vessel structure and coil systems.

Thermal Shields unwrapped in ITER Assembly Hall

China

First part of the gas injection system –18 crates of spools—delivered. They will be part of a series of pipes that transports all gases into the Tokamak Building from the tritium plant.

Two giant feeders on their way to the ITER site. They will be installed under the machine in order to relay electrical power and cryogens to the correction coils.

01

Building ITER

The ITER platform measures 42 hectares and is located in Cadarache, France. It is considered as one of the largest levelled surfaces in the world.

Europe is responsible for the construction of 39 buildings, the infrastructure and power supplies on-site required to operate the world's biggest fusion device.

More than 2 000 people working for European companies are involved in ITER's civil engineering works. Architects, engineers, technicians, planners, inspectors are some of the professionals contributing to the project. They are building the facilities where the components arriving from all over the world will be stored, assembled and installed.

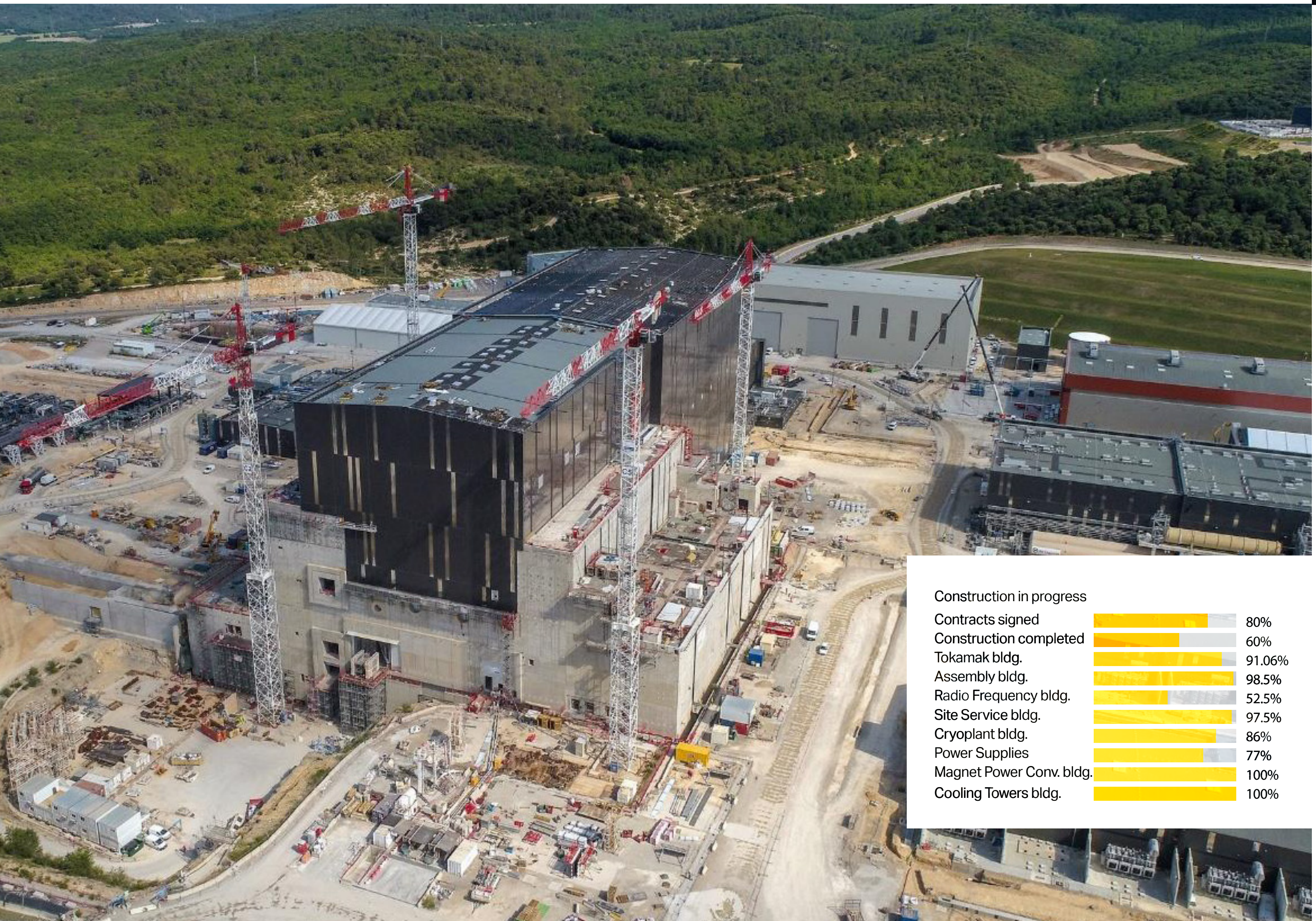
Our teams on the ground are preparing the "home" of one of the most impressive technology projects.

THE ITER SITE

This was the year of important construction milestones, keeping morale high, fostering stronger team spirit and complying with additional health and safety protocols due to the pandemic. Never before had we joined forces to act as one and yet remained physically apart. Our goal was to meet the tight deadlines for the key buildings and infrastructure of the ITER project, while ensuring the safety and well-being of our workforces on the ground. We completed the rooftop of the Tokamak building, the "home" of the ITER device, and allowed the cranes that would carry the heavy components to access it, in order to pave the way for assembly. The evolution of the site during the last ten years is impressive and has been documented with the help of aerial photography.

There was also important progress in the buildings and infrastructure on-site. Our workforces completed the installation of the 46 port cell doors in the Tokamak building. In parallel, painting works progressed in the Tokamak complex with the delivery of all levels up to Level 2 in the Tokamak building, and Level 5 in the Diagnostics building. Works were completed in the Assembly Hall, Site services and Cleaning Facility buildings while more progress was made in the Radio Frequency, and Cryoplant buildings. The electrical load centres needed for the non-nuclear buildings were delivered and two major contracts were signed for the completion of the civil engineering works for the Tritium building and the provision of the emergency electrical power distribution system and its respective infrastructure. 2020 marked the start of ITER assembly!

Aerial view of the Tokamak building, ITER site, Cadarache, France, March 2020 © ITER Organization/EJF Riche



Tokamak pit unveiled ready to receive the Cryostat lower base. The 18 cylindrical support bearings are visible. ITER site, Cadarache, France, May 2020 © ITER Organization

The Tokamak building ready to receive components

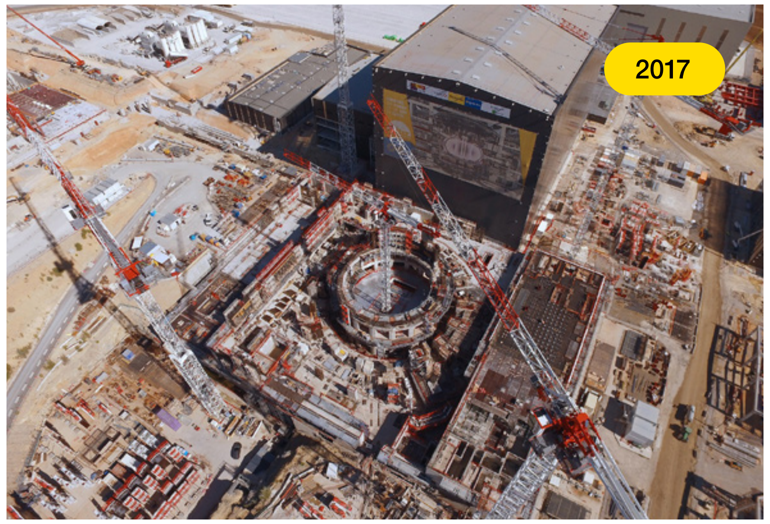
With the rooftop of the Tokamak building in place, the emblematic edifice of the ITER project was officially weathertight. This major achievement laid the foundations for the assembly phase. The two 750-tonne cranes of the Assembly Hall accessed the pit with the possibility to unload components weighing up to 1200 t.

Since 2010, when the first works began, approximately 600 companies (contractors /subcontractors) have been involved under the supervision of F4E. At times more than 1 000 workers rotated in three shifts, and together with a workforce of 700 engineers contributed to the construction of the Tokamak complex. The works performed so far amount to a total of six million hours.

The Tokamak building, complying with the strict standards of the French Nuclear Authority, resulted from 30 000 drawings produced after 1 000 000 hours carried out by the Engage consortium (Egis, Atkins, Assystem, Empresarios Agrupados). The Vinci, Ferrovial,Razel-Bec (VFR) consortium was responsible for the construction of this complex. Up to 275 000 t of various types of concrete were used and approximately 26 500 t of steel and rebars.

> *"What started as a procurement strategy for the civil engineering works of the biggest fusion energy experiment has successfully delivered the buildings and the necessary infrastructure for the next chapter of the ITER project, that of assembly."*
>
> *Laurent Schmieder*
> *F4E Programme Manager for Buildings, Infrastructure and Power Supplies*

The evolution of the Tokamak building and Assembly Hall in pictures



Aerial views © ITER Organization/EJF Riche

Aerial views © ITER Organization/EJF Riche

First heavy component installed

The milestone consisted in demonstrating that the heavy lift cranes could successfully travel between the Assembly Hall and the Tokamak building in order to deliver components to the Tokamak pit. With no less than 1 000 tonnes of steel and concrete, attached to the giant hoists of the bridge crane.

With the ITER Assembly Hall officially handed over by F4E to ITER Organization, the preparatory works for the installation of the first heavy component started. The insertion of the lower base of the cryostat in the Tokamak pit, earmarked the beginning of a new phase for the ITER project. The assembly of the biggest fusion device had officially started. Europe and the companies involved in the construction of the main edifice delivered on time making this possible.

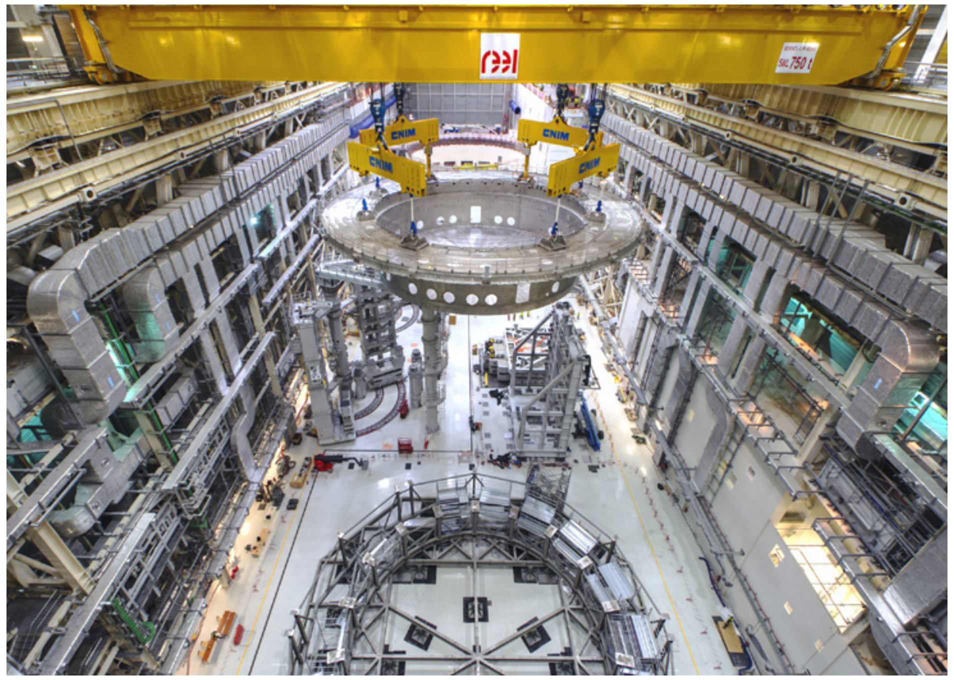
TOKAMAK COMPLEX

Diagnostics, Tokamak and Tritium buildings

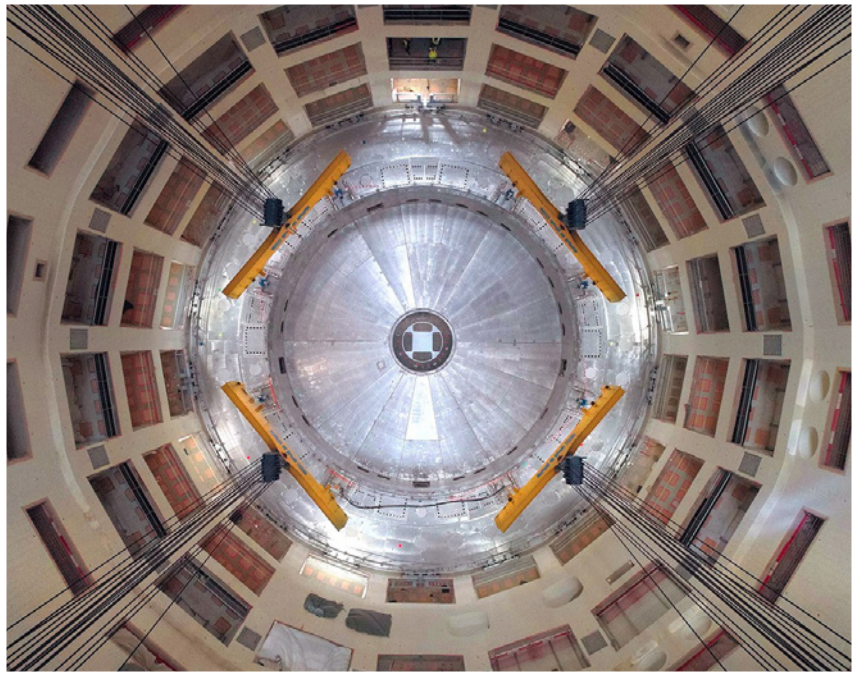
Dimensions:
120 x 80 m,
60 m high, 17 m deep

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

Main load passed the protruding lid that closes the assembly pit, Assembly Hall, ITER site, Cadarache, France, March 2020 © ITER Organization



Operation lift-off! Cryostat lower base, weighing 1 250 tonnes, moving 1 metre per minute at an altitude of 24 metres, travelled 110 metres from the entrance of the Assembly Hall, ITER site, Cadarache, France, May 2020 © ITER Organization



Insertion of the Cryostat lower base in the Tokamak pit. The base sits on the hydraulic jacks, although while attached to the lifting system. ITER site, Cadarache, France, May 2020 © ITER Organization

Inside some of the ITER buildings

Tokamak building

A constellation of embedded plates. One can guess at the number of components that will be installed in this large room by the number of anchor plates on the walls, ceiling and floor. © Les Nouveaux Médias/SNC ENGAGE

Painting works advancing in the Tokamak complex. An estimated 150 tonnes of resin, primer and paint are required. ITER site, Cadarache, France, December 2020 © Les Nouveaux Médias/SNC Engage

Doors of the ITER “castle” installed

F4E in collaboration with the Vinci, Ferrovial, Razel-Bec (VFR) consortium, and their subcontractors Cegelec, Sommer, installed the 46 port cell doors in the Tokamak building.

In order to confine the ITER machine and comply with the strict requirements of radioprotection, special doors were produced. Think of them as “barriers” located on various levels of the “castle” that hosts the ITER device. Basically, they can provide access for the assembly or maintenance works during operation. Level B1 counts 18 doors, L1 and L2 count 14 doors each. The design of the doors proved to be the most complex part of the process because these are no ordinary nuclear doors. They are nearly 80 cm thick and measure 4 x 4 m. Initially, a prototype was developed and tested. Following the successful safety acceptance tests, their manufacturing started in January 2017.

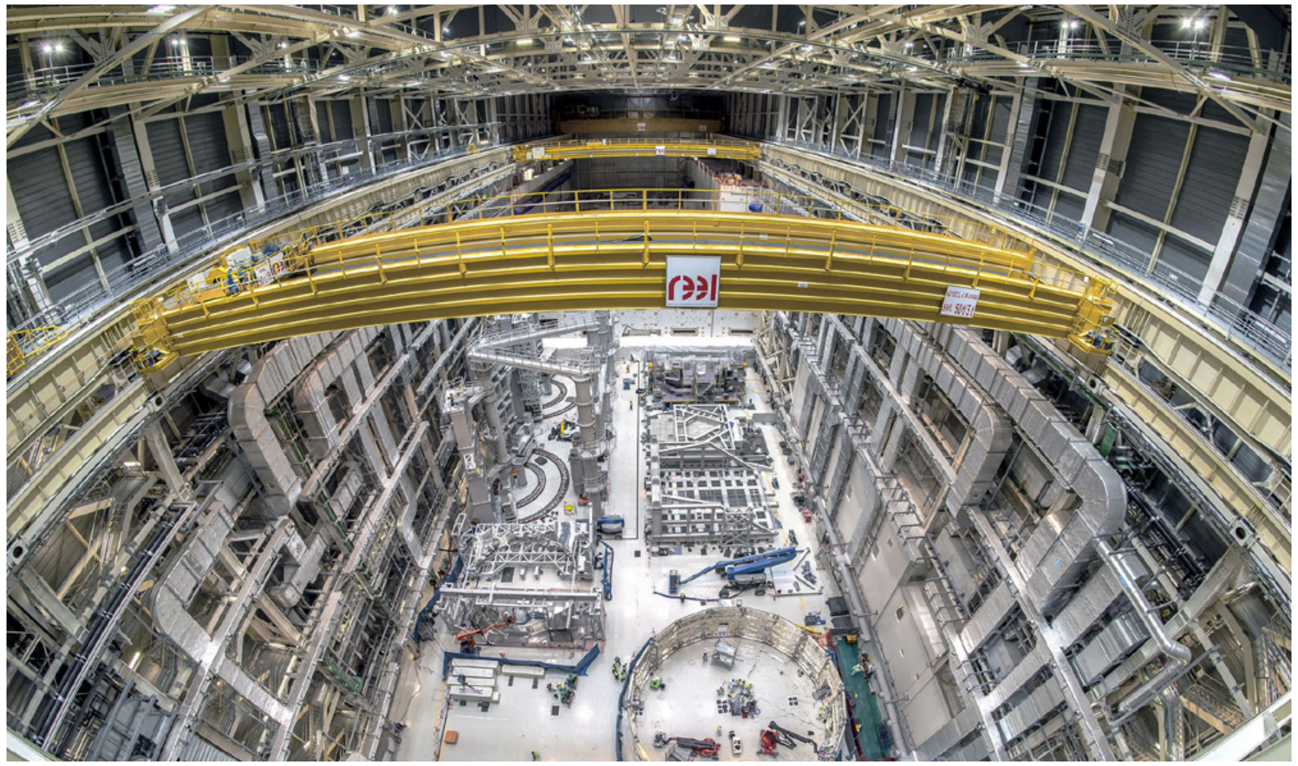
Their production was partly carried out in the factory and partly on the ITER site. Once the thick metallic frames, which weigh 39 t each, were delivered on-site, an additional 28 t of thick density concrete was poured in them raising their load to 67 t. With the help of a temporary lift, they were delivered to the different floors of the Tokamak building.

Port cells connect the bioshield to the outlying galleries. For their installation, it was decided to use reinforcement and concreting of the frames, ITER site, October 2020 © ITER Organization

> *“The completion of the port cell doors installation, is another example of Europe’s commitment to keep up the pace of the civil engineering works in order to facilitate ITER Organization with the assembly and installation of further components.”*

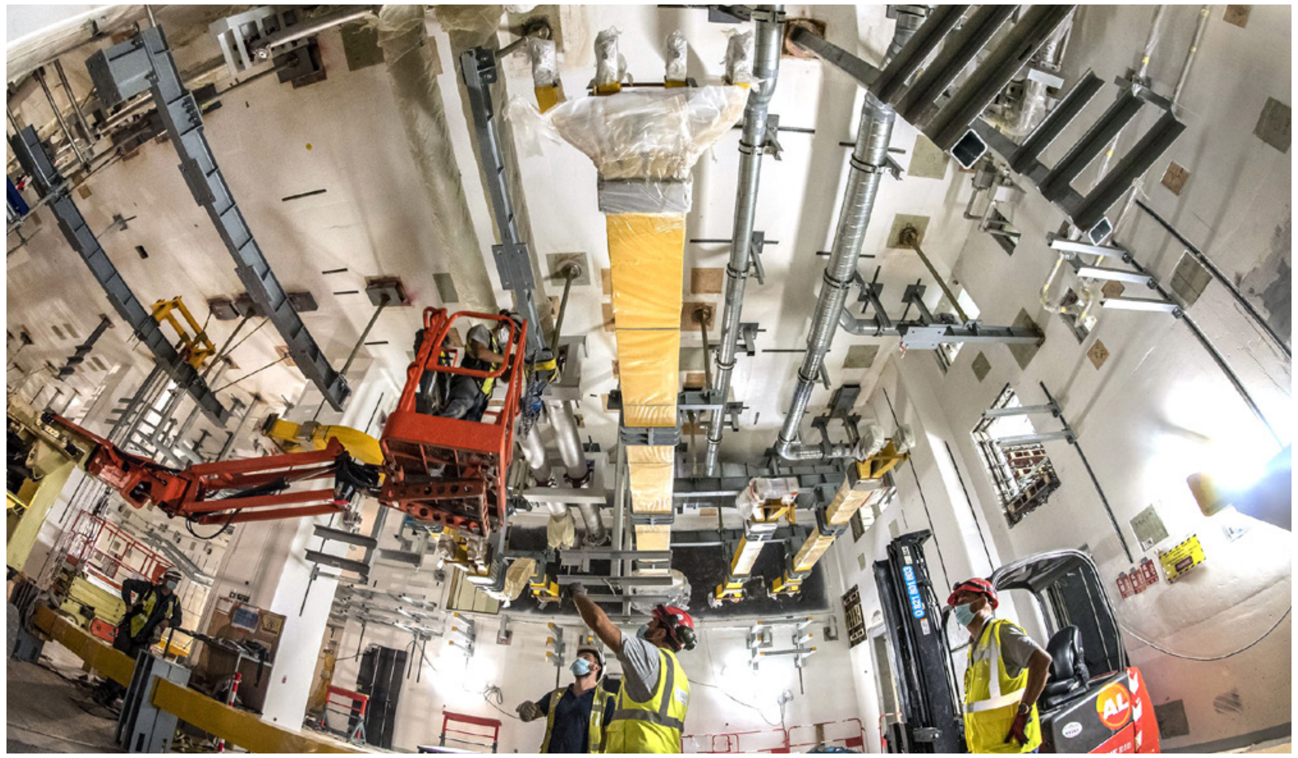
Romaric Darbour
F4E Deputy Programme Manager for “Buildings, Infrastructure and Power Supplies.”

Assembly Hall



View of the Assembly Hall with operations under way, ITER site, Cadarache, France, November 2020, © ITER Organization/EJF Riche

Diagnostics Building



Teams are bolting the busbars to supports anchored in the ceiling. Cable trays and all sorts of piping and HVAC ducts are already in place, ITER site, Cadarache, France, September 2020 © ITER Organization

Magnet Power Conversion buildings

More equipment installed inside and outside of the Magnet Power Conversion buildings to provide DC voltages to the magnets © Les Nouveaux Médias/SNC ENGAGE

Radio Frequency building

The structure of the three-floor Radio Frequency building is in place to welcome the first equipment that started arriving in summer. The ground floor (pictured) will house 12 power supplies for 24 gyrotons (external heating devices). © Les Nouveaux Médias/SNC ENGAGE.

Emergency electrical power distribution system provided by Europe

Ansaldo Nucleare and its partner Monsud, signed a contract with F4E to provide ITER's emergency electrical power distribution system. Essentially, power will be supplied to systems and components whose operation ensures that ITER is kept in a safe mode in the event of a loss of offsite power and/or external grid disruption.

Aerial view of ITER site, ITER site, Cadarache, France, November 2020 ©ITER Organization/EJF Riche

"Our partnership with Ansaldo Nucleare is further strengthened through the signature of this important contract. We rely on their expertise to ensure the successful completion of this essential system for the ITER project."

Johannes Schwemmer
Director of Fusion for Energy

"Ansaldo Nucleare and its partner Monsud are honoured to have been selected by F4E to design, build and commission the infrastructure and buildings required for the safe power of the biggest fusion device…."

Luca Manuelli
Ansaldo Nucleare CEO

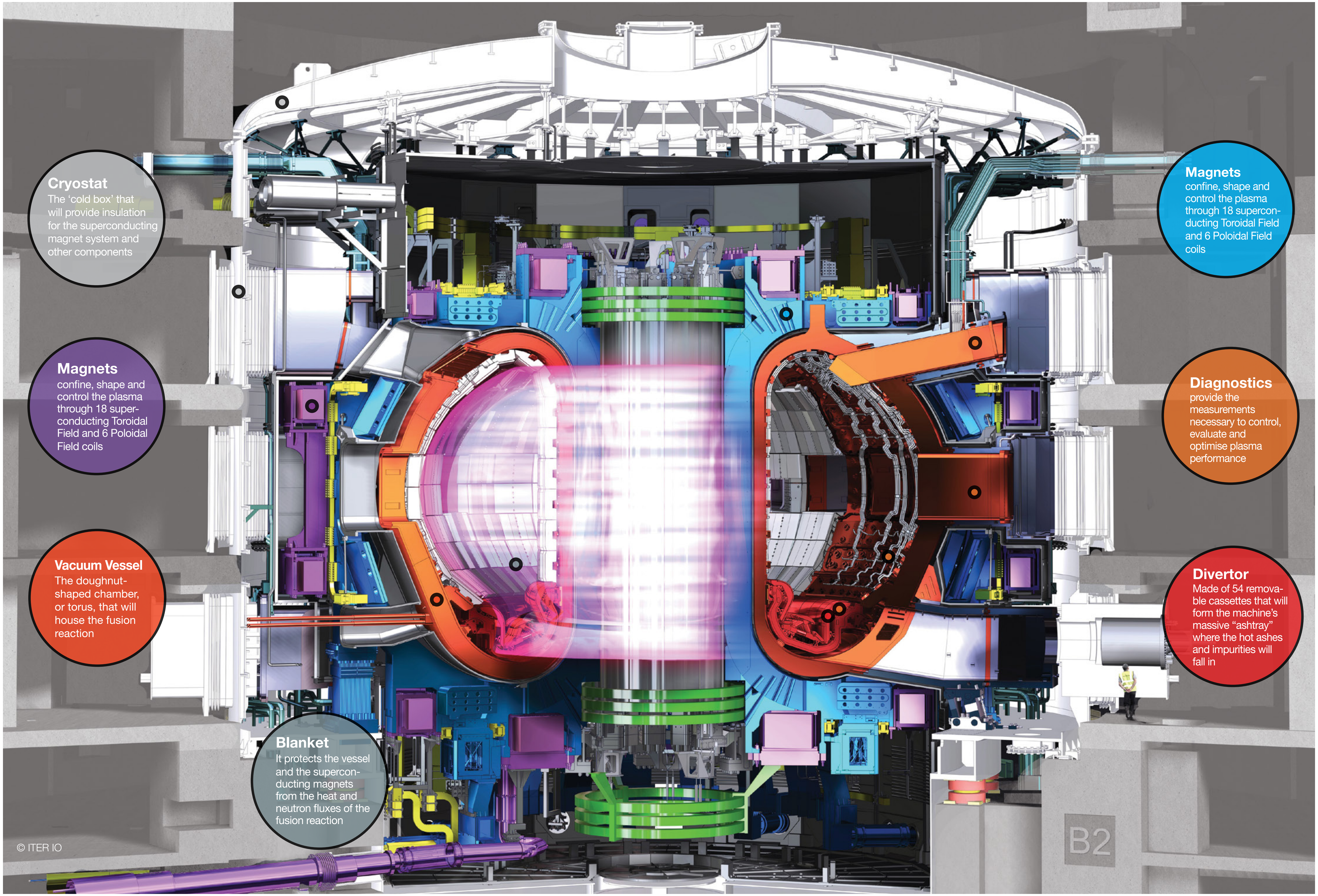
02

Manufacturing the ITER components

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

Europe's contribution to ITER, financed by the EU budget, amounts to roughly 50% making it the biggest of all Parties. It is one-of-a-kind opportunity for industry, SMEs and fusion laboratories to get involved and be part of an emerging energy market. The manufacturing of components spreads all over Europe encompassing an impressive supply chain of at least 500 main contractors and approximately 1500 subcontractors.

Looking back at 2020, the pandemic stood out as the factor that shook our working method to its core. Our business as usual model was severely challenged. New health and safety measures were introduced, supply chains had to be reconfigured, and physical presence in factories needed to be reconsidered. The strong partnership of F4E with its network of companies was a lifeline to keep operations going, in line with regulatory framework, and offered the hope that Europe's industrial workforce would stand again on its feet. This section is dedicated to our suppliers and their employees who carried on working for the ITER project in spite of these exceptional circumstances.


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

© ITER IO

MAGNETS

ITER will operate with the largest and most integrated superconducting magnets system ever built. It will help scientists to confine, shape and control the burning plasma.

The central solenoid will act as the magnets' backbone and the correction coils will reduce any errors resulting from the position and geometry of other coils.

The Toroidal Field (TF) coils will create a massive magnetic cage to confine the plasma, expected to reach 150 million ˚C, by keeping it away from the walls of the vacuum vessel. Europe will manufacture 10 out of the 18 TF coils involving more than 700 people from 40 companies. Japan will manufacture the remaining eight plus one spare.

To cope with the fatigue exercised on the TF coils, and with any deformation resulting from the powerful magnetic fields, three Pre-Compression Rings (PCRs) will be placed on top of them and three below them. An extra set of three will be provided if there is a need to replace the lower set. Europe is responsible for the production all PCRs.

Finally, six Poloidal Field (PF) coils will embrace the TF coils from top to bottom in order to maintain the plasma's shape and stability. Europe is responsible for five of them, of which one manufactured in China, with the agreement to perform cold and final tests in the F4E PF coils factory on-site. Another coil is produced in Russia.

Work in progress Toroidal Field coils

Contracts signed	100%
Tooling	100%
Qualification	100%
Manufacturing	94%*

Work in progress Poloidal Field coils

Contracts signed	100%
Tooling	100%
Qualification	100%
Manufacturing	57%

Work in progress Pre-Compression Rings

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

**All 70 Radial Plates and 10 Winding Packs are completed. The remaining 6% represents the work for seven TF coils that still needs to be performed.*

The heavy exceptional convoy carrying Europe's Toroidal Field coil to the ITER site, Cadarache, April 2020 © ITER Organization

Toroidal Field coils

Three Toroidal Field coils delivered by Europe

In April, Europe made history delivering the first magnet of the project and by the end of the year, two more TF coils reached the ITER site. An achievement of significant importance for F4E and F4E and its main suppliers – ASG Superconductors, Iberdrola Ingeniería y Construcción, CNIM, SIMIC, Elytt, ICAS representing 12 years of work, 40 companies in total and more than 700 people.

"The completion of the first European Toroidal Field coil for ITER has been an important milestone for SIMIC. It has given us the opportunity to demonstrate our skills in complex manufacturing." **Marianna Ginola**, SIMIC Commercial Manager

"This is a significant milestone towards the energy of the future. Thanks to unique international research projects like ITER, our know-how in magnets technology will have cost effective returns in the industrial and medical sectors as well." **Davide Malacalza**, Chairman of ASG Superconductors

"To manufacture our share of ITER components we had to upgrade our industrial facilities, establish new working methods and train new talent. In return, we have become a French reference in high-precision manufacturing for large components." **Philippe Lazare**, CEO of CNIM Industrial Systems

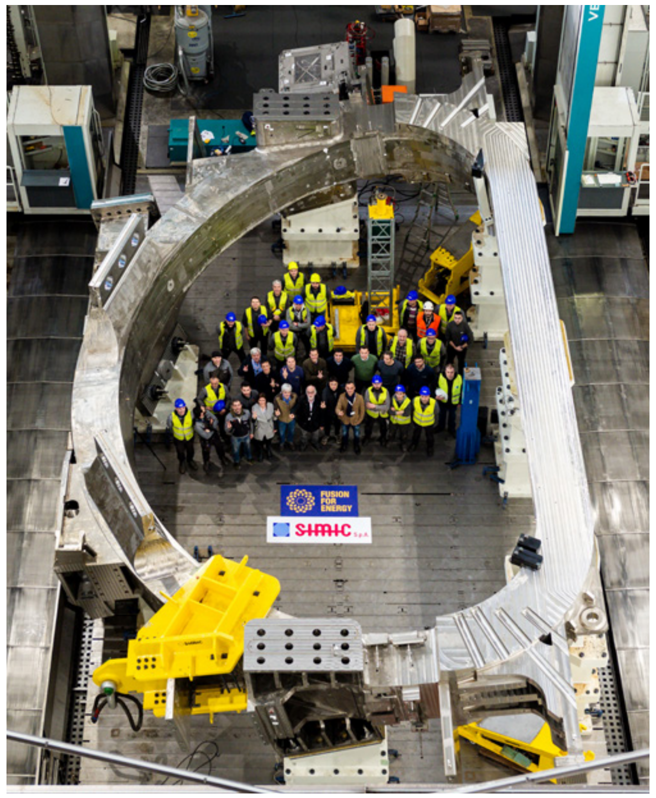
"Our SME has acquired further know-how in superconducting technologies for fusion and particle accelerators." **Aitor Echeandia**, CEO of Elytt

"Our contribution to the superconducting conductor for the ITER magnets allowed us to develop new ideas which helped us improve our production technologies and transfer them in different applications." **Antonio della Corte**, President of the ICAS consortium and Head of ENEA Superconducting Laboratory

"Many factors have made this possible: vision in developing the best procurement strategy; competence in defining the correct technical solutions; cooperation between the different parties to manufacture the most complex magnet to date; and last but not least, passion, perseverance and the full commitment of a highly qualified team. " **Alessandro Bonito-Oliva**, F4E Programme Manager for Magnets

TOROIDAL FIELD COILS

The gigantic "D" shaped coils will be the biggest Niobium-tin (Nb3Sn) magnets ever produced, which once powered with 68 000 A will generate a magnetic field of 11.8 Tesla—about 250 000 times the magnetic field of the Earth! Each coil is approximately 14 m high, 9 m wide and weighs 110 t. When inserted into its metallic case its total load will exceed 300 t, which compares to that of a Airbus 350.



Europe's first TF coil is ready. Members of staff from F4E and SIMIC in the middle of the component, SIMIC factory, Marghera, Italy, March 2020 © SIMIC

Seven out of ten winding packs completed

The fabrication of seven out of the ten winding packs under Europe's responsibility, was another important milestone for F4E and its main suppliers in the production of the TF coils. The massive pieces of equipment departed from the ASG Superconductors factory, La Spezia, and were delivered to Marghera to go through the final steps of manufacturing in SIMIC. Winding packs are the inner-core of the superconducting magnets.

The ITER TF coils are the largest Nb3Sn magnets ever produced in history: 4 570 m of superconducting cable are used for each magnet, and the processing phases involve a mix of heat treatment processes, tests in vacuum chambers, sophisticated welding and manual works.

Members of staff from ASG Superconductors standing in front the seventh winding pack before it departs from the factory, La Spezia, Italy © ASG Superconductors

A completed winding pack for the ITER Toroidal Field coils © ASG Superconductors

Poloidal Field coils

First Poloidal Field coil ready

Poloidal Field coil 6, which will be positioned on the lower part of the machine to embrace the super-hot plasma, was completed. Towards the end of November, the European team announced the successful execution of the final tests. They did it! The story of the magnet, resulting from a collaboration agreement signed in 2013 between Europe's F4E and China's ASIPP laboratory, came to end. Earlier in the year, a delegation headed by Dr. Bernard Bigot, ITER Organization Director-General, welcomed the component on-site to mark the start of the final manufacturing tests. The 10-metre magnet, weighing approximately 350 t, was transported to the PF coils factory. In this facility, financed by Europe, F4E and its industrial partners are manufacturing four additional coils. Russia is also responsible for the production of one PF coil.

"This is a collective achievement of Europe and China working together side by side to manufacture such a magnet. The team in ASIPP carried out the production of the coil, in partnership with F4E, and in close collaboration with the PF coils team of ITER Organization. Special thanks to all colleagues who have spent a good part of the last four years following up the work in China and also the people who have supervised the final steps in Cadarache— a team of extremely dedicated people who made this important achievement possible."

Alessandro Bonito-Oliva
F4E Magnets Programme Manager

Representatives from F4E, ASIPP, ASG Superconductors standing in front of the PF coil six after having successfully completed all final tests, PF coils factory, Cadarache, France © F4E

PF COILS FACTORY

The construction of the PF coils factory was undertaken by F4E together with a number of industrial partners. The factory is about the size of two football pitches: approximately 250 m long, 45 m wide and 17 m high. It includes regular services (heating, ventilation and air conditioning, electrical, piping), two overhead cranes (one standard crane with a capacity of 25 t and another crane especially adapted with a capacity of 40 t), one gantry crane to lift 400 t, offices, technical rooms and workshop space.

Representatives of F4E, ITER Organization welcoming the sixth Poloidal Field coil on-site, ITER site, Cadarache, June 2020 © ITER Organization

Massive coils in full production

There was also impressive manufacturing progress with the rest of the European PF coils. Due to the pandemic, new protocols on shifts, work processes and additional health and safety measures were put in place. In parallel, F4E and contractors used this period to test equipment, while performing heavy lifting activities with the cranes. PF 5 reached the stage of cryotests (nearing the end of manufacturing), PF2 was impregnated (an advanced stage in the production cycle), and for the biggest coil of all, PF4, measuring 24 m in diameter, the winding process was completed for two of its layers (double pancakes).

“What is remarkably different in the production of these magnets is our responsibility as factory owners. We have the supervision of Health & Safety and that of contractual co-ordination between all companies involved.”

Thierry Boutboul
F4E Magnets Programme Manager

PF 5 undergoing dimensional inspection using laser technology. In the back, PF2 assembled inside the impregnation station, Cadarache, November 2020 © EJF Riche/ITER Organization

“We developed and implemented a comprehensive post-confinement Health & Safety framework to ensure the safe acceleration of all activities. A complete set of measures has been designed, such as a system of rotation, one-way circulation in the building, contactless temperature measurement at the entrance, and the reinforcement of the cleaning activities.”

Pierre Gavouyere-Lasserre
F4E Magnets Programme Manager

PF coil 5 lifted with clamps before cold tests start, F4E PF coils factory, ITER site, Cadarache © F4E

Representatives of F4E, ASG Superconductors, Mammoet, Bureau Veritas during the Gantry crane annual regulatory control, F4E Poloidal Field coils factory, ITER site, Cadarache © F4E

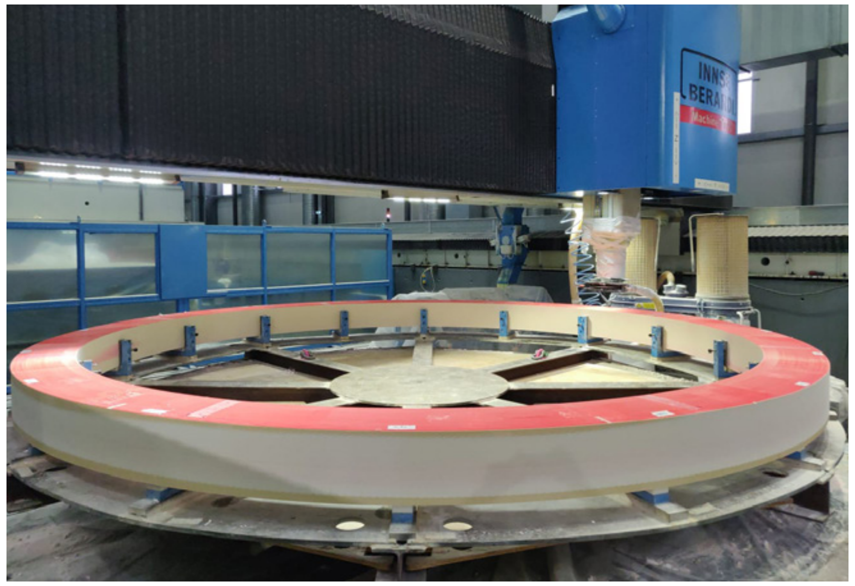
Pre-Compression Rings

All Pre-Compression Rings completed

Pre-Compression Rings (PCRs) are "comfort cushions" that will take the pressure off the TF coils from potential stress and fatigue resulting from the confinement of the burning plasma. Europe is the sole party responsible for the production of the nine PCRs.

Through a contract signed with CNIM their fabrication has been carried out in a special facility, located in the company's factory in La Seyne sur Mer, France. Part of the production of the PCRs was carried out by Exel Composites, Finland. Their production was completed in July.

Pre-Compression Rings packed and stacked, CNIM, May 2020 © CNIM



Manufacturing of ITER Pre-Compression Ring in progress, CNIM, May 2020 © CNIM

"We have come a long way from the production and testing of mock-ups to the completion of all PCRs. In spite of some initial challenges we faced with the production of the component, not only we managed to deliver on time."

Eva Boter
F4E Project Manager

"Although the component is less complex than many others, getting the materials and method of production right from the start was challenging. Once we got them right, and sorted out the logistics, we went full speed."

Angela Hernandez-Sanchez
F4E Technical Support Officer

"Team spirit, commitment and the will to go the extra mile brought us here today. We are pleased with the final result both in terms of quality and in terms of timing."

Alessandro Bonito-Oliva
Magnets Programme Manager

VACUUM VESSEL

The vacuum vessel is a special double-walled container that will house the fusion reactions of the ITER plasma. Within this doughnut-shaped vessel, plasma particles will collide and release energy without touching any of its walls thanks to magnetic confinement.

Europe is providing five of the nine vacuum vessel sectors of thick special grade stainless steel. Manufacturing these first of a kind components is very challenging due to the strict technical requirements compliant with nuclear standards, the application of new techniques, and last but not least, the sheer size of the components as each sector is 12 m high, 6.5 m wide and 6.3 m deep. The sectors weigh approximately 500 t each. More than ten European companies are involved in their fabrication.

Work in progress

Sector 5	
Design	100%
Manufacturing	95.85%
Assembly	12.88%
Overall	89.24%
Sector 4	
Design	98%
Manufacturing	87.12%
Overall	79.9%
Sector 3	
Design	90%
Manufacturing	75.81%
Overall	69.49%
Sector 2	
Design	90%
Manufacturing	71.53%
Overall	65.78%
Sector 9	
Design	90%
Manufacturing	72.24%
Overall	66.75%

Working on the final assembly of segment 2-sector 3 of Europe's contribution to the ITER Vacuum Vessel. Works performed at Belleli, Mantova, Italy © Belleli

F4E industrial partners stood up to COVID-19

F4E is working with the consortium of Ansaldo Nucleare, Mangiarotti, Walter Tosto to deliver Europe's share of the vacuum vessel sectors. Apart from supervising works performed in Italy—Chietti, Mantova, Monfalcone, Ortona—F4E and its industrial partners, follow the co-ordination of an impressive supply chain located in Spain, France and Germany. The pandemic forced all parties to adopt new measures and to reconsider priorities in order to ensure continuity of tasks.

Experts analysed the impact of the pandemic on the production plants, figured out which tasks could continue in line with the instructions issued by the Italian authorities, and proposed new health and safety measures in line with the guidelines. Some of the activities accelerated faster than originally planned, such as the review of manufacturing documentation.

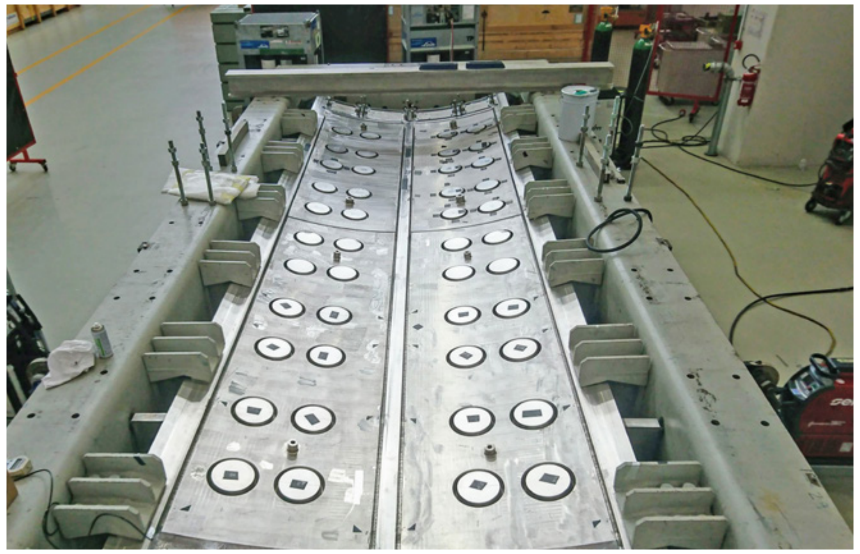
"In spite of the strict rules of social distancing, the lower number of resources in the workshops, and the new measures in place, together with our industrial partners we demonstrated a tremendous amount of resilience."

Max Febvre
F4E Manufacturing Project Manager

Max Febvre, F4E Manufacturing Project Manager for the ITER Vacuum Vessel, Walter Tosto, Chieti, Italy © F4E

"Thanks to the unconditional dedication and the resilience of the entire team, we managed to continue the works responsibly in spite of the many difficulties. Almost in a paradoxical way, the virus that gave birth to social distancing generated a strong team spirit and brought even closer F4E to its industrial partners."

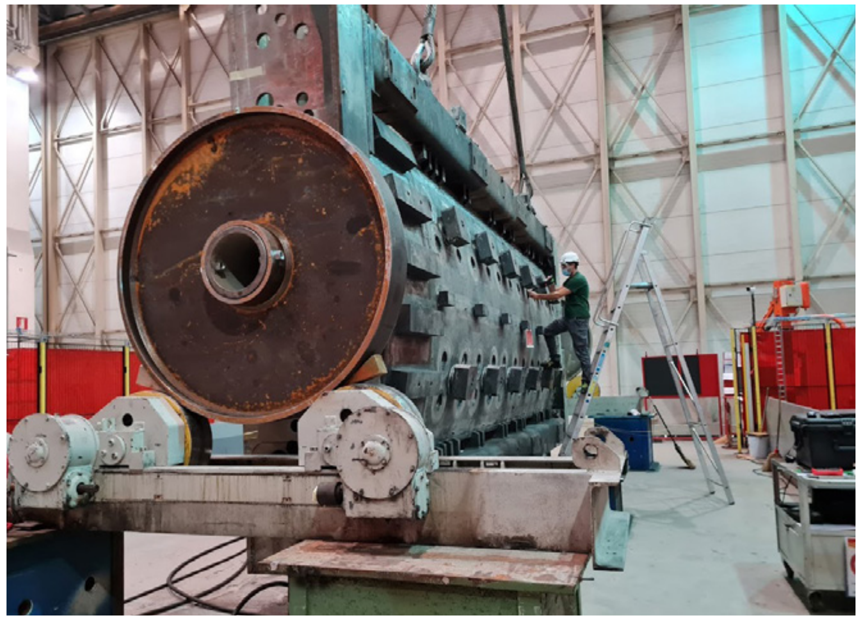
Cristian Casanova
F4E Vacuum Vessel Programme Manager



Welding of the outer shell of poloidal segment 1, sector 5, Mangiarotti, Monfalcone, Italy © Mangiarotti

Manufacturing and machining advancing for Europe's vacuum vessel sectors

Each sector of the vacuum vessel consists of four poloidal segments. The manufacturing of two segments of sector 5, the first to be delivered by Europe, was completed. Their final machining started towards the end of the year. The other two segments entered the final stage of manufacturing. Sector 4, the second to be delivered, reached the final stages of segment manufacturing.



Machining of ITER Vacuum Vessel sector 5, segment 1, Mangiarotti, Monfalcone, Italy © Mangiarotti

"Approaching the completion of the first poloidal segment was an important achievement because it served as a valuable learning curve for the production of the ones to follow."

Andres Dans Alvarez De Sotomayor
F4E Technical Officer

Ansaldo Nucleare, Mangiarotti, Walter Tosto unveil sector 5 -lower segment (PS4) of the ITER Vacuum Vessel close to completion, Mangiarotti, Monfalcone, Italy © Mangiarotti

ITER Vacuum Vessel sector 5 Poloidal segment 2, manufactured in Walter Tosto, Chieti, Italy © Walter Tosto

REMOTE HANDLING

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

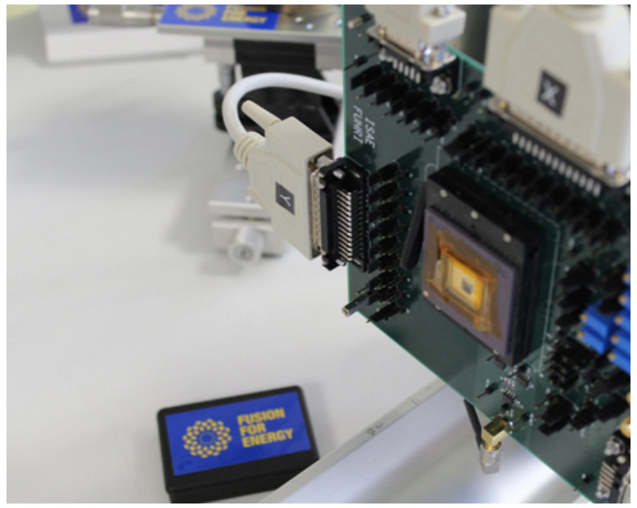
Work in progress Divertor RH	
Contract signed	36%
Design	72%
Cask & Plug RH	
Contract signed	14%
Design	55%
Neutral Beam RH	
Contract signed	22%
Design	60%
In Vessel Viewing System	
Contract signed	18%
Design	67%

Breaking new ground in electronics to cope with radiation

F4E organised a workshop to discuss the state of play in electronics, and the progress required, to operate in the ITER device during its maintenance More than 100 experts from ITER Organization, US, Japan, representatives from research organisations and ten companies joined online to discuss the latest breakthroughs in the field. For Europe, this is a subject of high importance because it will provide three of the ITER Remote Handling systems. Therefore, investing in the right technologies and getting industry involved at an early stage is of essence.

Solutions off the shelf are not an option because the equipment either tends to be too bulky or not precise enough for the ITER requirements. Therefore, there is a clear need to develop new equipment.

The presentations helped experts to capitalise on know-how acquired in the ITER Domestic Agencies. CERN was also invited to share results from projects funded in the field of radiation

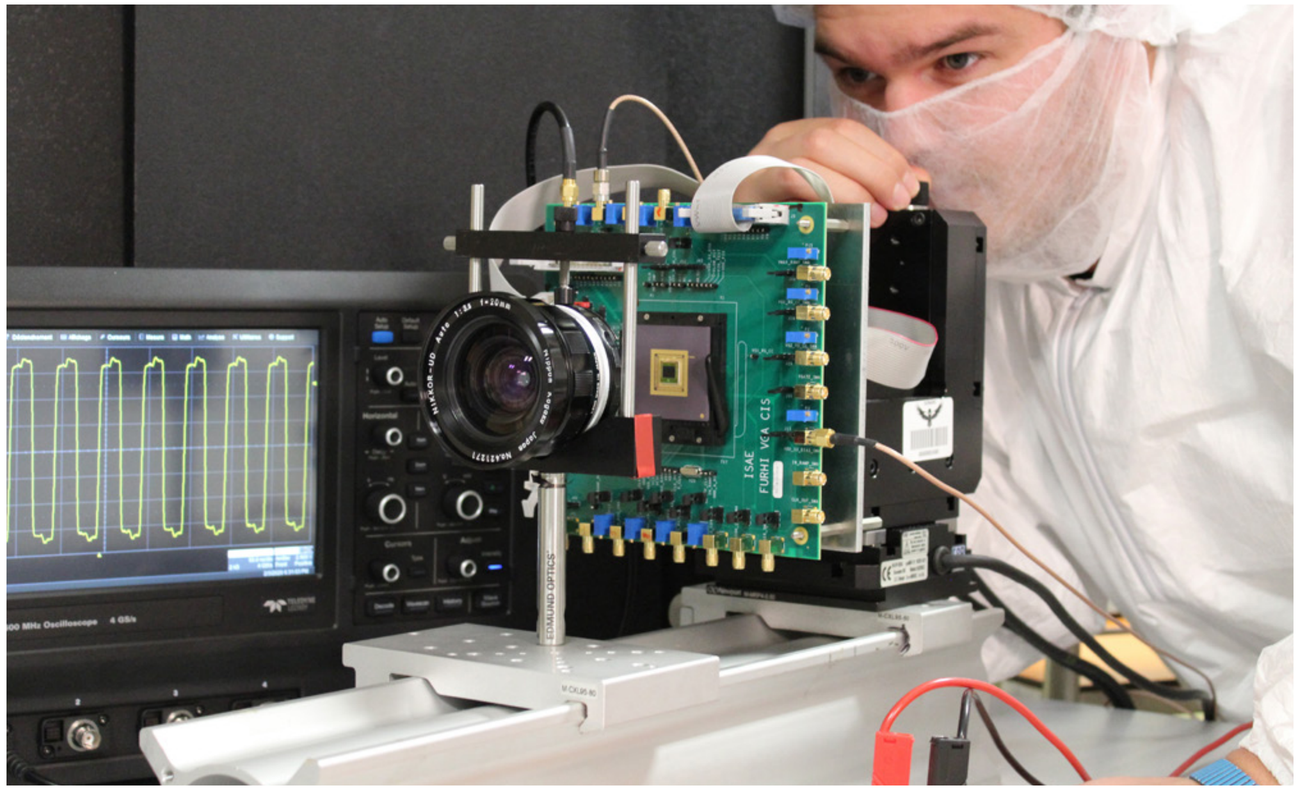


Developing new electronics compatible with the ITER environment © F4E

A prototype financed by F4E presented to companies

Veolia Nuclear Solutions, MAGICS and ISAE-SUPAERO presented their latest progress in rad-hard front-end electronics and rad-hard cameras during a workshop organised by F4E. The need for suitable equipment gave an incentive to companies, collaborating with F4E, to develop electronics with very small cameras to sustain such levels of radiation. In Extenso, F4E's technology broker, pitched the prototype to eight companies working in this field in order to explore the commercial potential. Company representatives were intrigued by the breakthrough achieved. B2B meetings took place to allow various industrial partners to discuss the prospect of further collaboration.

> *"This fourth workshop helped us to make progress on many fronts. It showed technological advancement in the field of electronics and cameras, bringing us closer to industrial exploitation… We have also detected a clear interest by industry and other Big Science Projects."*
>
> **Carlo Damiani**
> F4E Remote Handling Programme Manager



Remote Handeling ITERTest set-up to validate the performance of the demonstrator using a real-size ITER weld. The works have been funded by F4E and result from the collaboration with ISAE-SUPAERO © F4E

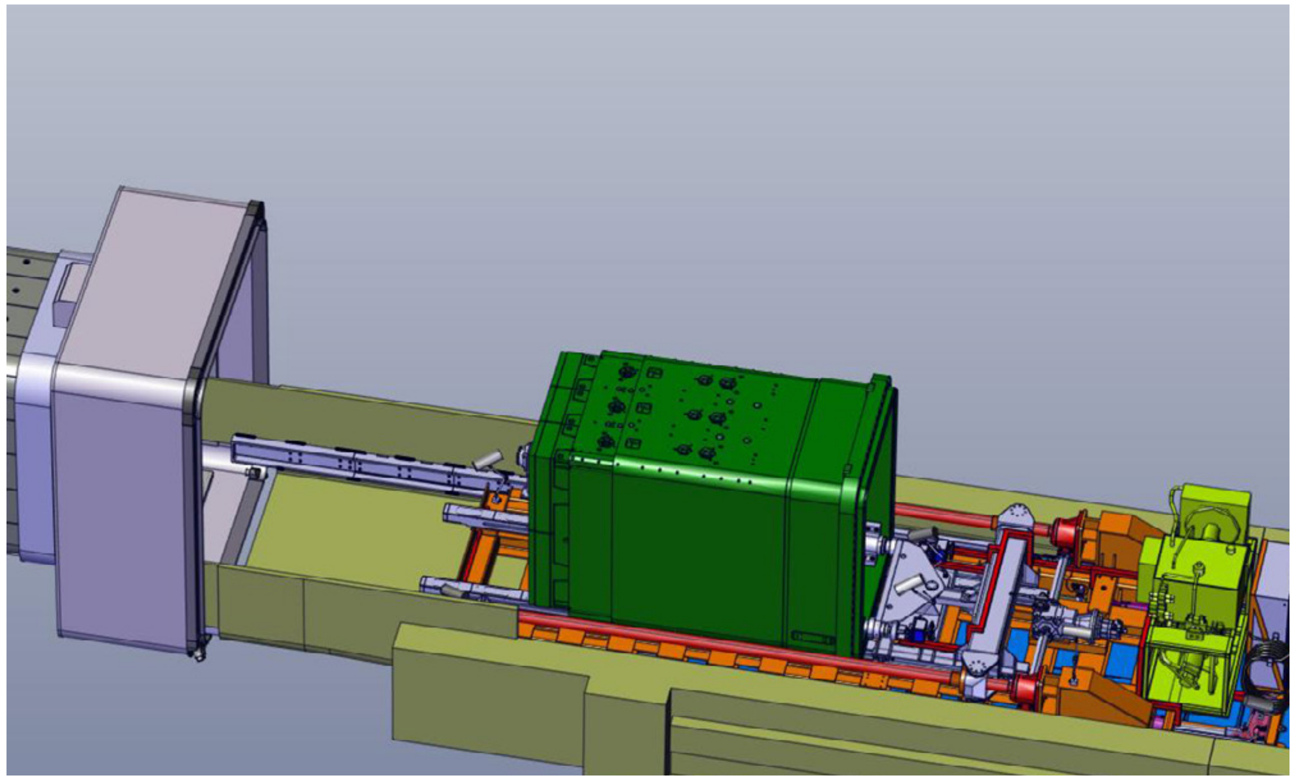
Heading towards the final design of ITER Cask and Plugs Remote Handling system

The Preliminary Design Review of the Cask and Plugs Remote Handling system addressed those cask units that will perform assembly tasks in the ITER machine before first-plasma. The review was organised by F4E and was split in two parts. During the first part, Veolia Nuclear Solutions (VNS), contracted by F4E from February 2019 till September 2020, presented the main features of the design and how it would meet the requirements. During the second part of the review, questions raised by the reviewers were clarified and discussed in detail.

Due to the fact, that the ITER Remote Handling Room will not be available during the initial assembly phases of the machine, Europe's engineers started exploring a simplified version. Lessons will be drawn for the design of future casks, which will also comply with radiation requirements for the second phase of the ITER experiments. Ansaldo Nucleare will develop the final design in collaboration with CNIM, responsible for the corresponding support rails.

“This important milestone was achieved with a very collaborative spirit between ITER Organization, Fusion for Energy, VNS and its sub-contractor. We will continue using this approach as we move to the critical Final Design phase for the manufacturing of this assembly tooling.”

Darren Locke
F4E Project Manager for Cask and Plug Remote Handling System



CAD illustration of the ITER Cask and Plug Remote Handling System to be procured by F4E. The tooling is approaching the port plug insertion into the vacuum vessel. Illustration prepared by Veolia Nuclear Solutions (VNS) for the Preliminary Design Review of the system © F4E

Hydraulic digital valves installed in ITER Remote Handling facility

Maintenance works cannot be performed with the physical presence of engineers in the vacuum vessel. This is why in the Divertor Test Platform facility (DTP2), Tampere, Finland, operators have started becoming familiar with a new system using hydraulic digital valves, which will give them a hand lifting the ITER Divertor Casettes.

For nearly two years, engineers from Tampere University, Fluiconnecto Oy and Tamlink Oy have been designing, manufacturing, and testing the digital hydraulic valves by performing millions of cycles. Subsequently, they introduced several improvements which helped them produce the first prototype of hydraulic digital valves in line with ITER specifications. The team of engineers successfully concluded the installation and commissioning of the equipment of the equipment in DTP2, which led to a series of upgrades in the rest of the facility. New infrastructure and computers running Genrobot, the software that Europe has championed for remote handling operations in ITER, were also put in place.

“The hydraulic digital valves will make our Remote Handling equipment more reliable and robust for the adverse conditions in the ITER device.”

Salvador Esque
F4E Remote Handling Technical Officer

“All novel technologies developed in our Remote Handling programme, will need to fit in order to create a reliable operating system. The hydraulic digital valves and Genrobot, are some of the many pieces that will have to be connected seamlessly to serve the maintenance of the ITER device.”

Carlo Damiani
F4E Remote Handling Programme Manager

(L-R) Hannu Saarinen (VTT), Miika Paloniitty (Tamlink), standing in front of the ITER Cassette Divertor mock-up, which will be used to test the performance of the hydraulic digital valves transferring the heavy component. F4E has financed the mock-up and the hydraulic digital valves prototype © F4E/VTT

DIAGNOSTICS

The Diagnostics systems will help scientists to study and control the plasma behaviour, measure its properties and improve our understanding in physics. This system will act as "the eyes and ears" of engineers giving them insight thanks to a wide range of cutting edge technologies.

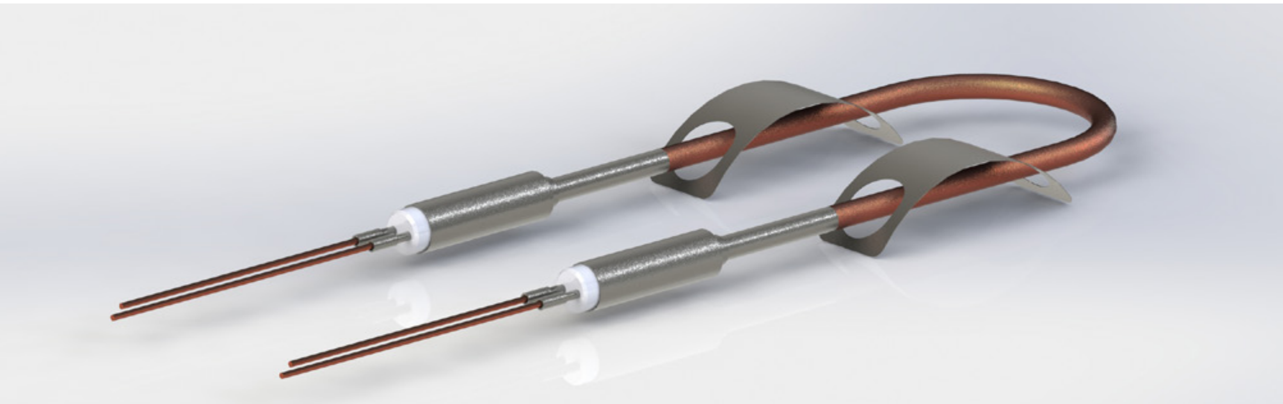
ITER will offer an unparalleled view of the entire plasma, whose pulse duration will be 100 times longer than any fusion device currently in operation. The diagnostic systems will also help to them to ensure the safe operation of the machine, given the extreme environment in the vessel and the large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

Work in progress	
Contracts signed	54%
Design	67%
Manufacturing	5%

How will engineers monitor ITER's plasma performance of ITER?

Special cables will be manufactured to connect 1200 sensors, junction boxes, connectors for the transmission of electrical signals coming from the inner skin of the vacuum vessel. Almost like branches of a tree they will run under the blanket and go through the upper ports of the vacuum vessel reaching in total 60 km of cable length. F4E signed a contract with Thermocoax for the production of 1200 cables for the amount of 1.6 million EUR. The production of cables will be carried out during the next two years with a final delivery scheduled for mid of 2022.

Various parameters had to be taken into consideration prior to moving ahead with production. For example, custom solutions were required for every sector of the vacuum vessel and diagnostic port. There are at least 103 identifiable cable looms, broken down to several similar subtypes. The major thermal loads and plasma radiation to which they will be exposed had to be taken into account.



Sample of a four pin cable to be manufactured by Thermocoax in order to connect 1200 sensors inside the ITER Vacuum Vessel. ©Thermocoax

Carrying the diagnostic signals outside the ITER Vacuum Vessel

Imagine trying to see what is happening in the ITER Vacuum Vessel without being able to go in. Between its walls, various sensors will monitor the performance of the biggest fusion device with the help of 3258 cables of 16 different variants in 27 ports of the machine. They will run from top to bottom in the 1 400 m^3 vessel and the cryostat, neatly packed in 80 feedthroughs procured by F4E. The number of cables inside will vary from 9 to 200. It all depends on their size, the current and the number of diagnostic signals they need to transmit.

F4E has been collaborating with IDOM for the final design of feedthroughs. The tests carried out so far put Europe on the right track. The prototype performed well under normal conditions meeting the requirements of air tight, electrical and pressure tests to name few. Part of the feedthrough will be located in the vacuum vessel. Therefore, it must comply with nuclear safety standards. For this reason, engineers decided to check how it responds to extreme conditions such as seismic events, a possible fire or an explosion. The feedthrough went through thermal tests to assess how it coped. Tecnalia, collaborating with IDOM, repeated the test successfully 500 times.

"The materials for the production of feedthroughs are readily available in the market, but there is always a degree of uncertainty when developing a prototype. The results are extremely encouraging and the good collaboration with IDOM and Tecnalia has helped us to make a lot progress."

Miguel Perez Lasala
F4E Diagnostics Project Officer

Feedthrough prototypes placed in an oven to simulate the thermal stress caused by 500 baking cycles. The thin cables read the temperature inside the prototypes. F4E signed a contract with IDOM for the development of the prototypes. The tests were performed by Tecnalia. ©Tecnalia

Europe delivers equipment for ITER Vacuum Vessel diagnostics

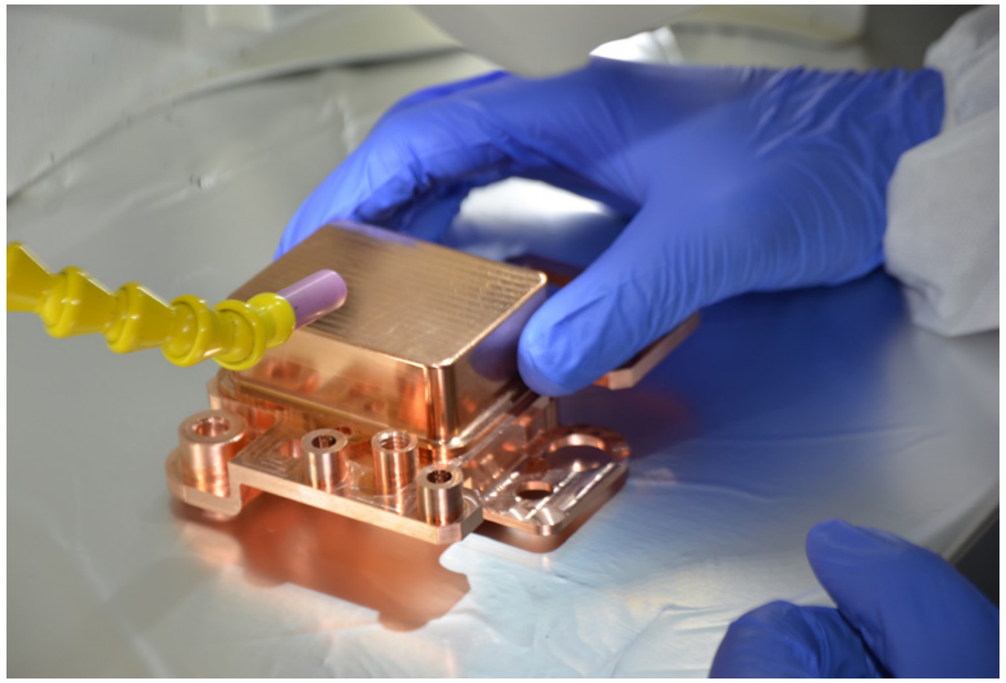
To measure the plasma behaviour of the ITER device, its energy, and instabilities approximately 450 sensors will be installed in the vacuum vessel to help scientists receive this information. F4E is responsible for their production and the platforms in which they will be housed.

Sgenia has been entrusted with the manufacturing of the platforms, whose main role is to offer mechanical support, shielding, conduct heat and ensure electrical connectivity for the coils. Metallic alloys and ceramics will be used for their fabrication. The company will also take care of the assembly integration, welding operations, fixations and the electrical connections for five of the six types of assemblies to be used. In August, the first batch of 2 500 small assemblies was delivered to the ITER site, Cadarache. The remaining three batches, amounting to 450 larger assemblies, will be handed over to ITER Organization to proceed with their installation on-site. All works from this contract are expected to be completed by 2022.

"Our good collaboration and the commitment of all parties to make up for any time lost due to the pandemic have been instrumental in meeting this year's project plan. The first batch was successfully delivered and the second batch will arrive next spring," explained Angela Hernandez-Sanchez following this contract on behalf of F4E.

"The manufacturing of the mechanical platforms for the diagnostics of the magnetic Inner-Vessel coils combines high tech material and advanced manufacturing techniques. The production route has been carefully selected to comply with a medium size production and the strict specifications of the project."

Jesus Lama
Sgenia Project Manager



First of series of a mechanical platform for ITER the diagnostics of Inner-Vessel coils produced by Sgenia
© Sgenia

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 generate a new nuclear system and licensing using advanced materials and top fabrication techniques.

F4E-EUROfusion Joint Project Team created

After having signed the Memorandum of Understanding, formalising the joint organisation of resources and research activities, F4E and EUROfusion put together a joint project team in the area of breeding blanket technologies. The work resulting from this collaboration will be part of the European contribution to the Test Blanket Modules (TBM) for ITER. Two concepts will be studied: a water-cooled lead-lithium (WCLL) and a helium-cooled pebble-bed (HCPB).

Furthermore, the EUROfusion R&D activities needed for the TBM Programme over the next five years (2021-2025) were defined jointly with F4E. More generally, R&D activities will be carried out under F4E specifications by the EUROfusion consortium in the area of tritium technologies, instrumentation, functional materials, modelling tool development.

Conceptual Design Review concluded for Test Blanket System

The Conceptual Design Review meeting took place in the premises of ITER Organization (IO) with 11 people on-site and up to 92 remote attendees. A panel of 19 experts from IO and other entities acknowledged that the level of detail of the technical documentation presented exceeded by far what was expected. The documentation submitted exceeded 3 000 pages. The conclusion was clear: the design should go forward to the next stage. After this important achievement, the team will have to focus on different areas such as design and analyses, safety studies, fabrication, etc. The Preliminary Design Review is planned for November 2022.

"The acknowledgement we have received gives even more motivation to the team to continue with a high level of commitment. It enhances our credibility to our stakeholders and paves the way for the next step."

Italo Ricapito
F4E Project Manager and Chief Engineer of the European TBM Programme

"It is the first time that this type of European TBM Programme organisation, resulting from an F4E-EUROfusion collaboration, has been put in place and it has been successfully implemented and executed. This marked the way forward for the finalisation of the WCLL-TBS design cycle."

Marco Ferrari
European Test Blanket Modules Deputy Programme Manager

Experts during the Conceptual Design Review meeting assessing the quality of the design of the Water-Cooled Lithium-Lead Test Blanket System to be used in the ITER device. Cadarache, September 2020 © F4E

Information Day on the feasibility of Test Blanket Modules fabrication

One of the last meetings with physical presence in F4E premises, before for the pandemic, was the Test Blanket Modules Info Day. Europe was ready to take the next step regarding the feasibility of fabrication and assembly processes. During the meeting, background information and details on the future launch of a framework contract were given. At least twelve entities expressed interest to understand the scope of the work, the range of skills, capabilities and expertise required.

Presentations given by F4E staff explained the manufacturing strategy of TBMs, the main requirements, current achievements in the field of development. In addition, administrative and procurement modalities, quality assurance, and intellectual property rights were discussed. F4E offered the possibility of B2B meetings between participants giving them the opportunity to highlight their expertise and pursue possible partnerships for a future tendering.

F4E representatives explaining the modalities during the Information Day, Barcelona, 4 March 2020 © F4E

IN-VESSEL

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

Work in progress

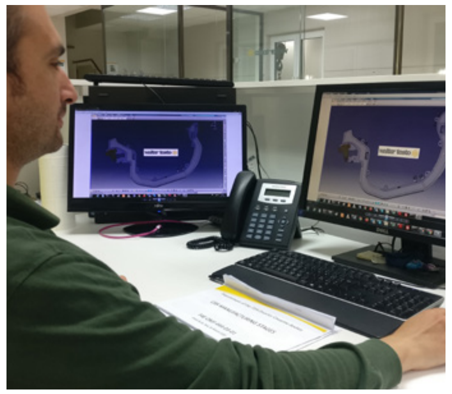
Blanket Cooling Manifold Design & Qualification	95%
Blanket & First Wall Panels Qualification	100%
Divertor Vertical Target Qualification	45%
Divertor Cassette Body Qualification	100%
Divertor Cassette Body Design and Engineering	60%

Europe's first set of ITER Divertor Cassettes ready for manufacturing

One of the components that will experience part of the high-plasma temperature is the ITER Divertor. It covers the lower part of the device and consists of 54 cassettes. The impurities will be diverted to fall inside a massive "ashtray" covering an area of 142m2. Each ITER Divertor Cassette measures 0.8 x 2.3 x 3.5 m and weighs roughly 8 t with all components installed.

Experts in Walter Tosto, Italy, successfully concluded the engineering activities for the ITER Divertor Cassette bodies, part of the series to be manufactured. An important step in the lifecycle of a component, given the fact that it was only produced so far in the form of a prototype.

The complexity of this component led F4E to adopt a procurement strategy in stages and with multiple suppliers in parallel in order to validate different manufacturing designs. Europe will need to deliver in total 58 cassette bodies (54+4 spare). Given the fact that these components are not essential for ITER first-plasma operations, a different delivery date applies in their case. The manufacturing readiness review was concluded ahead of schedule thanks to the fruitful collaboration between Walter Tosto, F4E and ITER Organization.



Engineer at Walter Tosto reviewing the final details of the ITER Divertor Cassette manufacturing stages. F4E has signed a contract with the company for the production of 15 units © Walter Tosto

"It has not been easy reaching this point because Walter Tosto needed to develop a design in line with the specifications of the component. A number of issues needed to be addressed such as the optimal use of resources, materials and time. As we are approaching the phase of production, all parties need to apply superb project management skills to deliver on time, and demonstrate solid know-how to produce the components according to the technical requirements."

Laurent Guerrini
F4E In-Vessel Project Manager

Europe's Inner Vertical Target prototype passes all factory acceptance tests

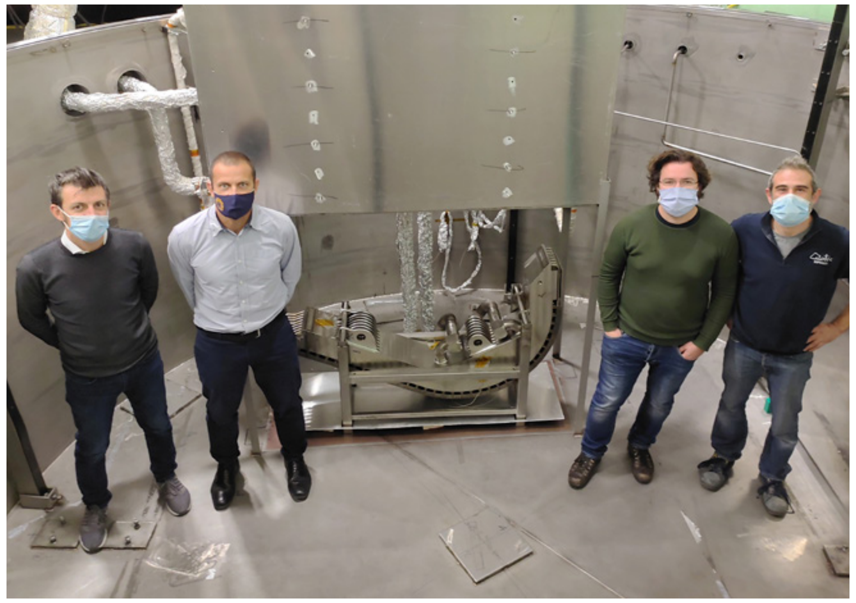
The ITER Divertor, located at the lower part of the vacuum vessel, will experience some of the highest plasma temperatures. It will be equipped with thousands of tungsten blocks cooled down by pressurised water flowing through a circuit of copper alloy pipes. The Inner Vertical Target (IVT) will be there to intercept the heat flux from the particles.

The production of the first-ever IVT prototype pushed Europe's engineers into uncharted waters. Almost two years ago, the first-ever IVT prototype travelled from the factory of Ansaldo Nucleare, Italy, to the Efremov Institute, Russia, to go through a series of heat flux tests. After having successfully concluded them, it went back to Italy to proceed with the final stages.

For almost a year, engineers worked relentlessly on this prototype to complete its manufacturing cycle. First, they used laser and TIG welding techniques to firmly attach it on its structure. Then, a series of non-destructive, pressure and hot helium leak tests at 250 °C were performed to ensure that the component is qualified for the ITER environment. The prototype concluded successfully the factory final acceptance tests.

"The IVT prototype produced by Ansaldo Nucleare, in partnership with ENEA, and with the important involvement of the Ansaldo Energia workshop, and Walter Tosto as subcontractor for the supply of the steel support structure, demonstrates that this is a real pre-production component."

Marco Grattarola
Ansaldo Nucleare Divertor Team Project Manager



(L-R) Marco Roveta, Criotec Impianti, Pierre Gavila, Fusion for Energy, Massimiliano Palermo, Ansaldo Nucleare, Stefano Galignagno, Criotec Impinati, standing next to the first-ever ITER Inner Vertical Target prototype having successfully passed final acceptance tests.
© Ansaldo Nucleare

"We are pleased to see that the first IVT prototype has consistently performed well. Early next year we will be sending it to ITER Organization to go through a series assembly tests."

Pierre Gavila
F4E Technical Officer, In-Vessel

European success for another Inner-Vertical Target prototype

Research Instruments (RI), Germany, successfully completed the ITER Inner-Vertical Target (IVT) prototype's engineering phase. In record time and with tonnes of iron will, the team of experts successfully produced the second European prototype of a component considered as extremely complex even for those counting decades in the fusion community.

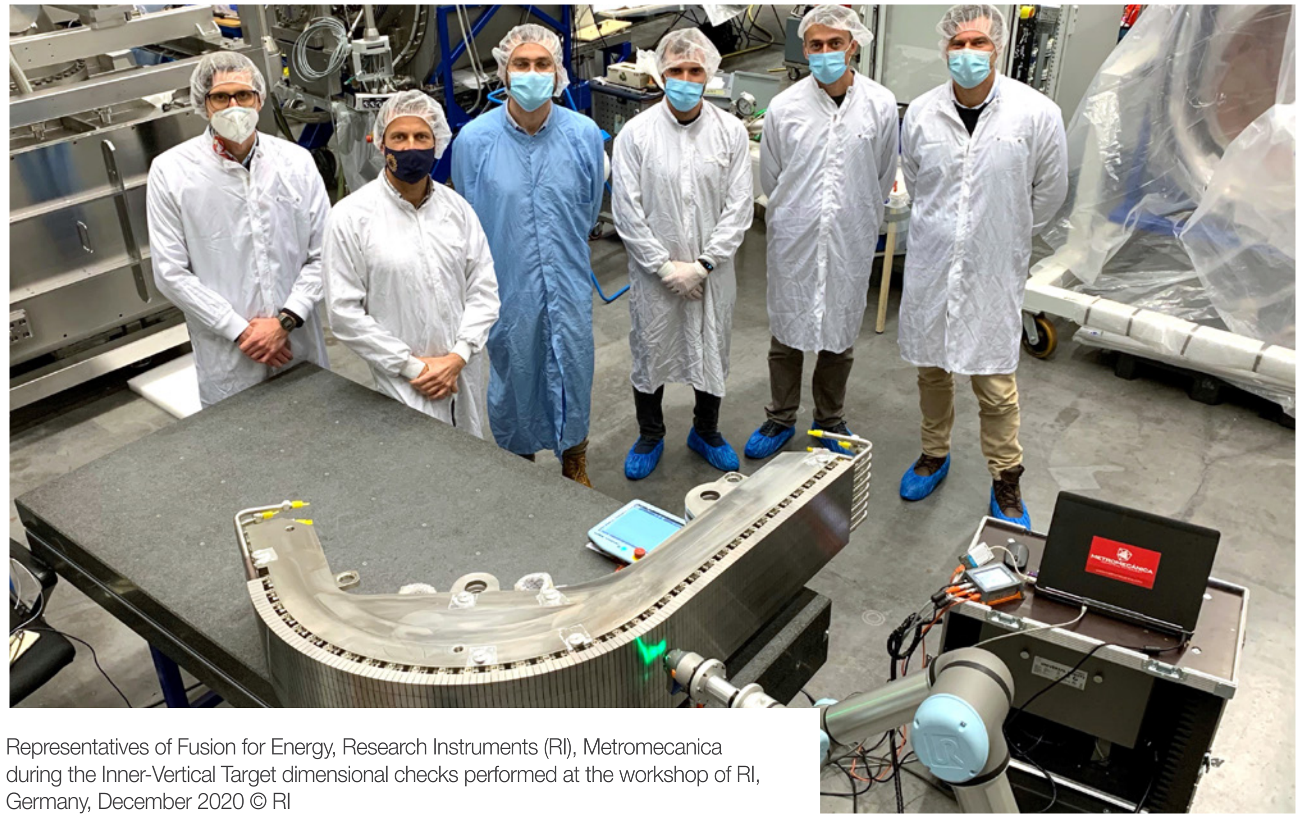
The company with a proven track record in brazing and working with copper alloys, studied the functions of the IVT for roughly two years and took the first R&D steps producing small mock-ups. In 2017, they started working on a bigger prototype, which required procuring larger amounts of materials and scaling up their tools. As soon as the prototype pre-assembly was completed, F4E's Technical Support Services, and their supplier Metromecanica (Spain), provided an automated system to measure quickly and with extreme precision any of the 1200 gaps between the blocks of the component. Towards the end of the year, the prototype was getting ready to leave from RI to the Efremov Institute, Russia, in order to go through high heat flux tests.

"We are very happy to have reached this milestone. This would not have been possible without the excellent cooperation with the F4E team, the passion and dedication of our project team. It is a clear demonstration of the high quality products we design and manufacture at RI."

Michael Pekeler
Director of Superconducting RF, Fusion and Special Manufacturing, Research Instruments

"We are pleased to see the second IVT prototype reaching this important project milestone. It is important to keep in mind that this component has not been produced before and it required from our European suppliers extra effort to meet the strict requirements."

Pierre Gavila
F4E Technical Officer, In-Vessel



Representatives of Fusion for Energy, Research Instruments (RI), Metromecanica during the Inner-Vertical Target dimensional checks performed at the workshop of RI, Germany, December 2020 © RI

European production of ITER first wall panels to start

Europe is responsible for the production of 215 first wall panels—roughly half of the total. China and Russia will provide the rest of them.

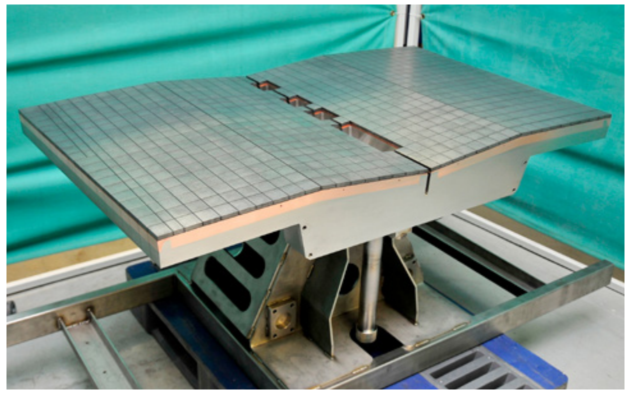
F4E has signed two contracts with two consortia for the production of the first series of panels. One contract with Atmostat–Alsyom, and another with Fusion Business Leadership (FBL), a legal entity made of Leading and Empresarios Agrupados. The value of each contract is in the range of 100 million EUR, running for four years, during which each consortium will have to set up, qualify their production line, and produce 27 panels plus 3 as part of the pre-series. The production of the rest of the panels to be provided by Europe will materialise through additional contracts that will be awarded from 2024 onwards following a reopening of competition between both consortia.

"The signature of the contract marks the end of a long period of R&D, during which we collectively refined the manufacturing processes and developed the necessary skills. We are now ready, and very excited, to start manufacturing the real components that will be part of the ITER device." **Stefano Banetta**, F4E In-Vessel, First Wall Project Manager

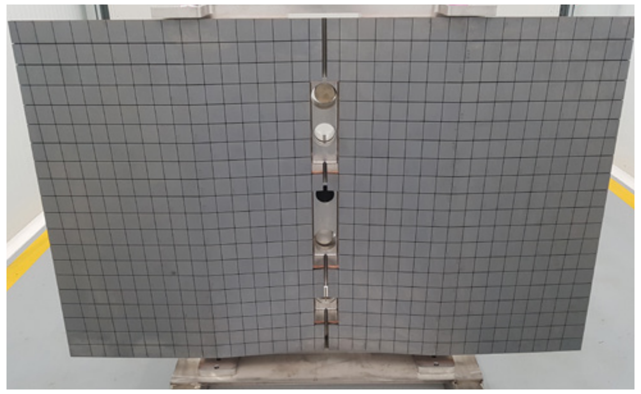
"This success materialises after nearly 20 years of technical, technological and industrial efforts, in particular through our fruitful collaboration with F4E in the frame of the prototype contracts. Through this contract, Atmostat and Alsyom will strengthen their capability to manage long-term complex projects and further develop organisational, technical and industrial skills to deliver highly demanding components," **Eric Giguet**, Alsymex Sales & Business Development Director.

"The industrial production of the first wall panel series will bring out the best values of the companies forming the Leading & Empresarios Agrupados consortium, in order to achieve one of the most complex components of the ITER device." **Marcos Perez-Bedia**, Leading Group Business Development Director

"The award of these two first wall contracts is the outcome of great human endeavour, which started at the time of EFDA (European Fusion Development Agreement) as a maverick project. With time, it managed to grow in scope and size by rallying new skills and competences plus keeping the team spirit alive until this day. We owe the success of this project to each contributor and to F4E for the strong commitment." **Patrick Lorenzetto**, F4E In-Vessel Programme Manager



Real-size prototype of first wall panel produced by Atmostat-Alsyom for F4E. Europe is responsible for 215 out of the 440 first wall panels required for the ITER device © Atmostat



Real-size prototype of first wall panel produced by Leading, Jacobs, Iberdrola for F4E. Europe is responsible for 215 out of the 440 first wall panels required for the ITER device © Fusion Business Leadership (FBL)

New tool developed to measure In-Vessel components

To manufacture the various ITER components, engineers need to think out of the box. Quite often, they may have to develop tooling from scratch because it may not be readily available in the market to test components during fabrication. This is what happened when experts working in the field of In-Vessel components, started searching for tools in the market to take measurements of a specific part of the Divertor Cassette Body. Experts wanted to measure the diameter of the multi-links— the cylindrical hinges connecting the plasma-facing components to the Cassette Body itself.

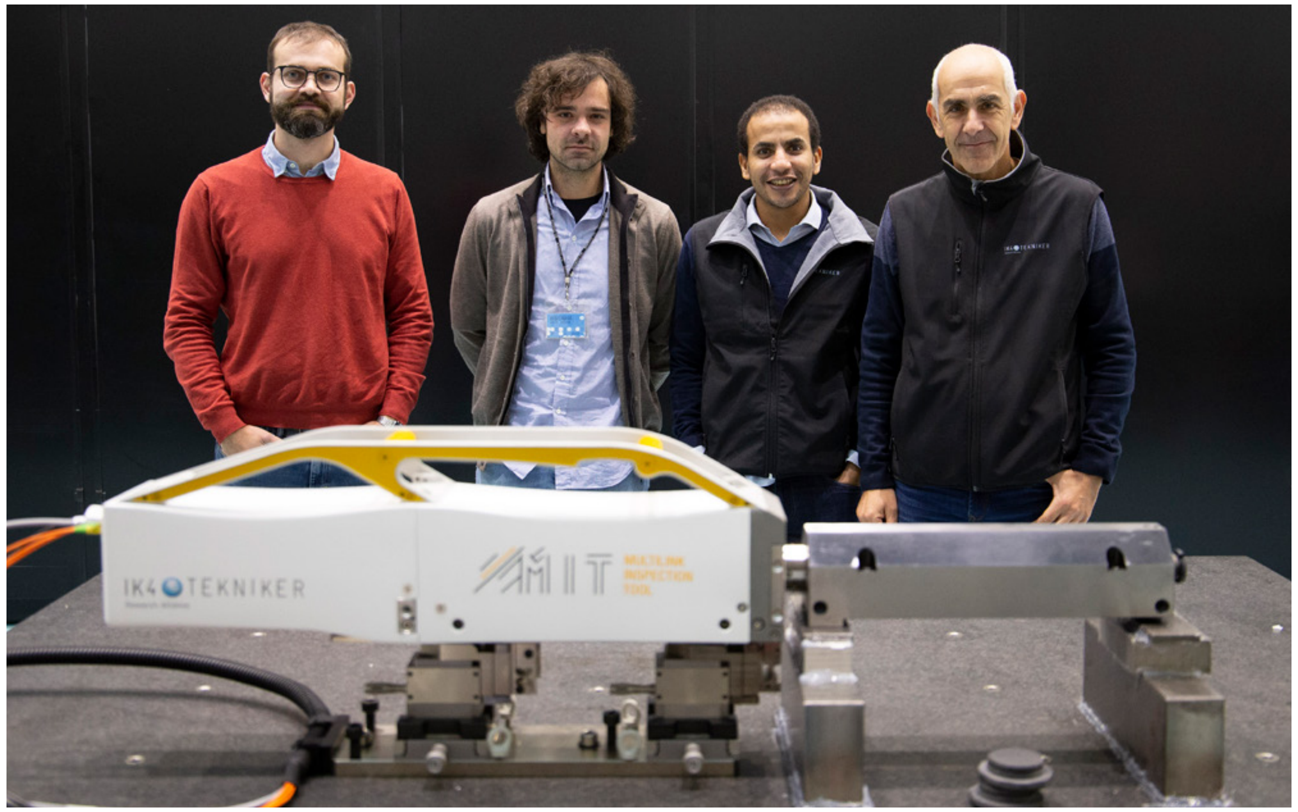
They started by conducting a market survey and concluded that there was no equipment available to perform the task. As a result, F4E launched a call for tender and after 18 months a brand new inspection tool, fully tested, was ready. Tekniker in close collaboration with F4E developed the tooling. The result has been a ground breaking piece of metrology equipment satisfying not only the needs of the In-Vessel components but others as well in the market.

"We developed a tool which allows us to take measurements precisely and quickly. We can perform this task within hours whereas before it took us days. We were faced with this metrology challenge not having any suitable tools in the market. The only way out was to develop our own tool."

Gabriele D' Amico
F4E Technical Officer

"This successful project improved the capabilities and knowledge of Tekniker developing high-precision mechatronic systems for measurements. Through our collaboration with F4E, we have been given the opportunity to contribute to ITER, the world's largest experiment in the field of fusion energy."

Fernando Egaña
Head of Tekniker Mechanical Engineering Department



(L-R) J. Amoros Molinas, G. D' Amico (F4E) with A. Brahim and F. Egaña (Tekniker) behind the Multi-Link inspection tool ©F4E/Tekniker

CRYOPLANT AND FUEL CYCLE

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

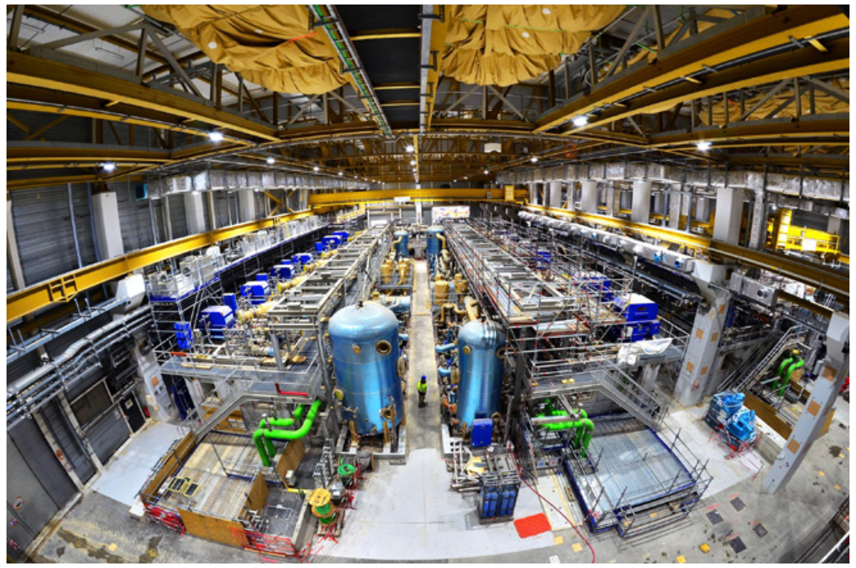
Work in progress

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

Mykhailo Geniuk (Air Liquide Mechanical Supervisor) inspecting a pipe prior to installation, ITER Cryoplant. Works financed by F4E. Cadarache, November 2019. © F4E

ITER Cryoplant entered final phase

Works in the Liquid Nitrogen (LN2) Plant and the installation of auxiliary systems advanced in the ITER Cryoplant. This massive “refrigerator” entered its final phase. More than 50 workers on-site finished all welding operations. The lifting of big tanks, large compressors, and cold boxes, containing either helium or nitrogen, was completed. The installation of pipping, its welding and testing was concluded, with most pressure tests carried out. Approximately 70 % of the electrical and instrumentation installation was performed. The pre-commissioning tests, ensuring that the facility meets all specifications, moved forward.



As big as two football pitches, the cryoplant provides cooling fluids for the superconducting magnets, the cryopumps, and thousands of square metres of thermal shielding. © ITER Organization

“Reaching mechanical completion was a great achievement for the team of professionals who co-ordinated and supervised the work of Air Liquide since 2018. We tackled some issues, which we could not have anticipated, and thanks to our good collaboration with contractors, they have been resolved. With the electrical and instrumentation works well on track, we are on target to deliver this massive cryogenic plant ready to start commissioning in the first half of next year.”

Marc Simon
F4E Deputy Project Leader for Cryogenics

Helium dryer weighing nearly 50 tonnes being rotated into its final position inside the cryoplant buildings. Cadarache, June 2020. © F4E

More progress for torus and cryostat cryopumping system

Most technologies for these components were qualified and the first manufacturing readiness reviews were held. The manufacturing of the eight cryopumps started with the procurement of raw materials, machining and forming operations, setting up specialised workshops.

Contract for leak detection system signed

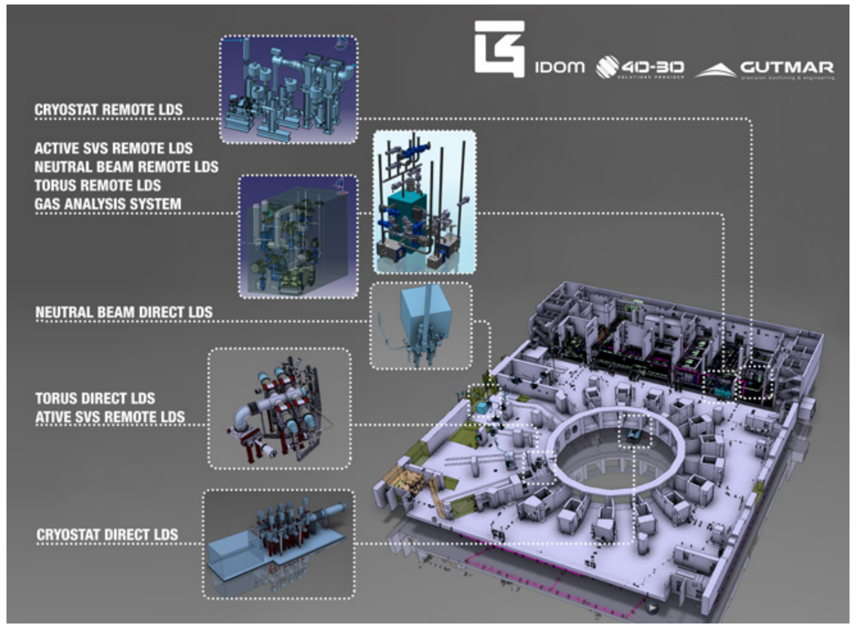
There are roughly 2000 entry points from the cryostat, the vacuum vessel and the neutral beam, which will need to be monitored meticulously to detect any possible leak. F4E signed a contract with the IG4 consortium led by IDOM, counting on the expertise of two SMEs, 40-30 and Gutmar.

“The signature of the contract was one of the many tasks we got done to get there. We spent a whole year to work out the basic functional requirements of the leak detection systems for ITER and to translate them to technical specifications and contract documentation.” **Roger Martín**, F4E Cryoplant & Fuel Cycle Project Manager

“The combination of the technical difficulties posed by a first-of-a-kind project and the challenges posed by the pandemic have been so far excellently tackled by the consortium and the team, paving the road for a successful execution.” **Xabier Ruiz**, Director of IDOM Nuclear Services,

“We are really proud to be involved in this high technical project whose target is to harness clean energy for the mankind. For this mission, 40-30 has assigned its most experienced specialists in vacuum technology and processes, leak detection and gas analysis.” **Charles Agnetti**, 40-30 CEO

“We are convinced that this innovative and technological project places us at the cutting edge of technology. The alliance with IDOM and 40-30 is indeed very positive to achieve optimal results and will be the beginning of a long term partnership open to future collaborations.” **Joan Martorell**, Gutmar CEO



Various leak detection sub-systems (LDS) aimed at verifying the stringent leak tightness requirements which need to be met in the vacuum vessel, the cryostat and other ITER components. © IG4.

NEUTRAL BEAM AND ELECTRON CYCLOTRON POWER SUPPLIES AND SOURCES

To heat up the ITER plasma at 150 million ˚C, roughly ten times the temperature at the core of the Sun, we will need powerful heating systems using high-energy beams. This requires the fabrication and testing of new equipment before manufacturing the ITER components.

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

SPIDER (Source for Production of Ion of Deuterium Extracted from Radio Frequency plasma), will help scientists to develop the ion source, one of the critical elements needed for the operation of the ITER Neutral Beam Injectors.

MITICA (Megavolt ITER Injector and Concept Advancement) will develop and test a full-size prototype of a Neutral Beam Injector.

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

Work in progress

Electron Cyclotron Power Supplies
1st to 8th unit

Contracts signed	100%
Design	100%
Manufacturing	60%
Delivery	25%

Neutral Beam Test Facility
SPIDER

Contracts signed	100%
Design	100%
Manufacturing	100%
Delivery	100%

MITICA

Contracts signed	95%
Design	88%
Manufacturing	70%
Delivery	60%

ITER Neutral Beam Power Supplies

Contracts signed	70%
Design	50%

SPIDER Cooling plant, part of the European contribution to the ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy Copyright: Enrico Sacchetti

Neutral Beam Test Facility Cooling Plant ready

The components of the SPIDER and MITICA experiments will need to be cooled down. The function of the water cooling plant will be to remove the thermal power, up to a total of about 70 MW, for 3600 seconds. The cooling plant consists of a specific system for each of the two experiments, and a common system to release the thermal energy removed from the components. F4E, in close collaboration with Delta Ti Impianti completed the works. F4E handed over the system to ITER Organization after eight years of work. The pipes, which extend to around 5500 m, crosscut the entire Neutral Beam Test Facility. In some areas, the pipes follow a neat pattern almost like tapestry covering the walls. In other parts of the building, the pipes resemble to a labyrinth made of steel full of twists and turns.

We spoke to some of the engineers involved in the project to understand the challenges they faced during the lifecycle of the project. Vincent Pilard, F4E Technical Officer who has been closely following the contract, offered some background. “One of the main difficulties we faced designing the cooling plant was the fact that the building was not constructed. Our design had to adapt to the civil engineering works and eventually fine-tune all inputs so that our supplier could start manufacturing.”
Andrea Garbuglia, F4E on-site supervisor, elaborated on the complexity of the cooling plant. “We counted more than 6000 person days for the plant erection without any accident in six years putting safety first. The valuable contributions of Consorzio RFX, Delta-Ti Impianti and the F4E Neutral Beam cooling team have made this possible.”

Giorgio Biginelli, CEO of Delta-Ti Impianti, shared some thoughts on their involvement in this project. “This has been a great opportunity for us to showcase reliability, competence and innovation. The spirit of collaboration with F4E and Consorzio RFX helped us to complete successfully the work. We have acquired important know-how, to create synergies with other projects such as ITER, laboratories such as CERN, with which we already cooperate, and others we hope to be able to cooperate with such as DTT.”

Tullio Bonicelli, F4E Programme Manager for Neutral Beam & EC Power Supplies and Sources, reflected on the evolution of the works. “After the completion of the SPIDER test bed, in operation since 2018, the acceptance of the NBTF cooling system, and its transfer to ITER Organization, is another important milestone. This massive cooling plant posed substantial technical challenges. Key to its success has been the effective collaborative spirit between all parties and suppliers involved in this project under the ITER umbrella.”

Aerial view of the cooling towers and air coolers, part of the European contribution to the ITER Neutral Beam Test Facility, Padua, Italy © F4E

Top down view of the MITICA cooling plant system in the pit of the experiment, ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy © F4E

MITICA Vacuum Vessel handed over to ITER Organization

The MITCA Vacuum Vessel, procured by F4E, was another component completed and handed over to ITER Organization. De Pretto industrie was entrusted with its fabrication. The vessel consists of two parts weighing in total 127 t (60 t + 67 t). The final welding operations started as soon as the the Italian government lifted COVID-19 restrictions. A total of 12 m of welding was carried out in one week.
More than 300 manufacturing drawings were developed for the fabrication of the component. Its surfaces were chemically cleaned to comply with the needs of the ultra-high vacuum conditions for testing and operation. Many important technical aspects had to be taken into account to connect hydraulic lines, cooling pipes, gas and vacuum system, cryopumps and viewports reaching 119 in a total.

“The vacuum vessel of the most powerful neutral beam injector is ready. It results from years of hard work, lengthy exchanges, and strict factory and site acceptance tests. The good collaboration with De Pretto Industrie, ITER Organization and RFX was instrumental.”
Gonzalo Micó, F4E Project Manager

“We honoured our contribution to SPIDER, and we are continuing by delivering our share of equipment to MITICA. This delivery demonstrates that Europe is and will continue to be a strategic partner in developing key systems for fusion technologies.”
Tullio Bonicelli, F4E Programme Manager for Neutral Beam & Electron Cyclotron Power Supplies and Sources

“In spite of the current restrictions of COVID-19, affecting the last stages of the contract, we were able to manage the on-site installation and testing activities in safe and clean conditions, thanks to the full support of Fusion for Energy, Consorzio RFX and ITER Organization.”
Mauro Giupponi, De Pretto Industrie Project Manager

Technician conducting final checks on MITICA Vacuum Vessel prior to hand over, ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy, May 2020 © F4E

Top down view of the MITICA Vacuum Vessel during the preparatory works before welding operations begin inside the vessel, ITER Neutral Beam Test Facility, Consorzio RFX, Padua, Italy © F4E

MITICA cryopump components manufactured

A key component of MITICA's neutral beam injector is the cryopump. All of its cryopanels and thermal radiation shields were manufactured, tested and were either delivered or stored. The charcoal coating of the cryopanels was launched and the first pumping section was assembled. Ravanat was awarded to produce the main components of the cryopump: the cryopanels and the thermal radiation shields. Experts working from May 2018 to December 2020 delivered 285 cryopanels and 315 thermal radiation shields.

A technician performing a metrological survey on a V-shaped thermal radiation shield, May 2019 © Ravanat

Europe ready to feed MITICA with current

F4E is responsible for the provision of the Ion Source and Extraction Power Supplies (ISEPS) to the ITER Neutral Beam Test Facility. Through a contract signed with OCEM Power Electronics, the company produced and installed the equipment. The site acceptance tests started in January 2020 but were put on hold due to the pandemic. A few months later all teams resumed operations and in September they performed the final tests, transmitted online for those not able to be physically present. The successful execution of the tests marked the end of Europe's contribution to the MITICA power supplies.

ISEPS consists of eight power supplies and auxiliaries producing 5 MVA in total. With the help of cranes, the power supplies were lifted nearly 10 m high and positioned on the two floors of the High Voltage Deck (HVD), a Faraday cage box produced by Siemens.

"The experience and knowledge gained procuring equipment for MITICA will be invaluable as we shift the focus of the project activities to procuring similar equipment for the ITER injector." **Muriel Simon**, F4E Project Manager for Neutral Beam Power Supplies

"No-one could foresee the impact of COVID-19 on our work. We had worked out the dates to perform the tests in Padua and a few weeks later we had to postpone them. During that period we considered different alternatives, and this is how we ended up organising a physical/virtual site acceptance test validating the equipment." **Daniel Gutierrez Garcia**, F4E Technical Officer

"This is a great success for OCEM Power Electronics and it represents a small but important step towards the future of fusion energy. The chapter we started more than six years ago in Padua, with our involvement in both experiments of the Neutral Beam Test Facility, has come to an end. Our team achieved this result with sacrifice and enormous dedication. Not even COVID-19 was able to stop us." **Alessandro Tamburini**, OCEM Project Manager

Final site acceptance tests for the Ion Source and Extraction Power Supplies (ISEPS) in the Neutral Beam Test Facility, Padua, September 2020 © OCEM

Inserting part of MITICA's Ion Source and Extraction Power Supplies (ISEPS) in the High Voltage Deck © F4E

Electron Cyclotron

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

Another High Voltage Unit delivered to ITER

The manufacturing and factory acceptance tests of the second High Voltage Unit were successfully completed. The equipment left from Ampegon, Switzerland and was delivered to the ITER site. In 2020, the manufacturing of MV-AC (Medium Voltage- Alternating Current) cells for the Electron Cyclotron and Ion Cyclotron heating systems (15 in total) were also completed.

More power supplies for the ITER Electron Cyclotron, procured and financed by F4E, leaving from Ampegon, Switzerland, to Cadarache, France © Ampegon

Gyrotrons moving forward

The Procurement Arrangement for the F4E gyrotrons of the Electron Cyclotron system was also signed.

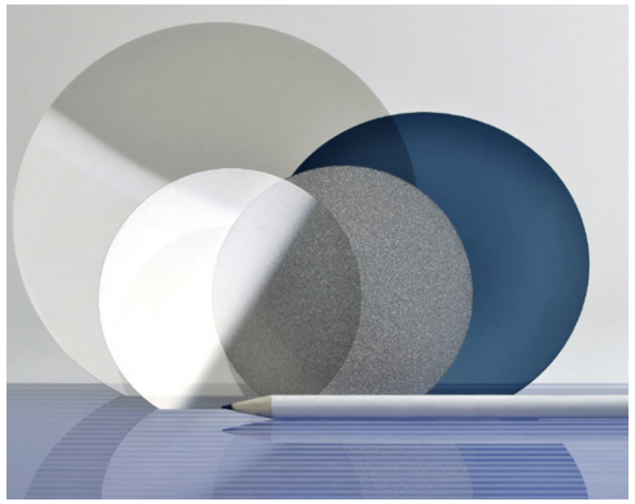
ANTENNAS AND PLASMA ENGINEERING

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

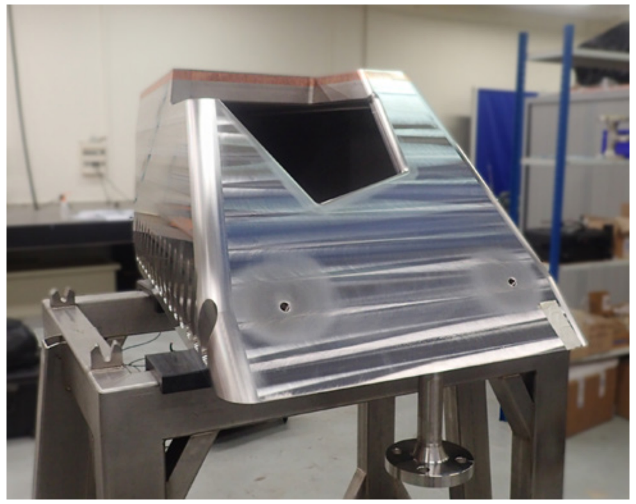
Work in progress

EC Launcher	
In-vessel Design	95%
Ex-vessel Design	70%
Manufacturing	9%
IC Antenna	
Design	48%
EC Control System	
Design	80%
Manufacturing	20%

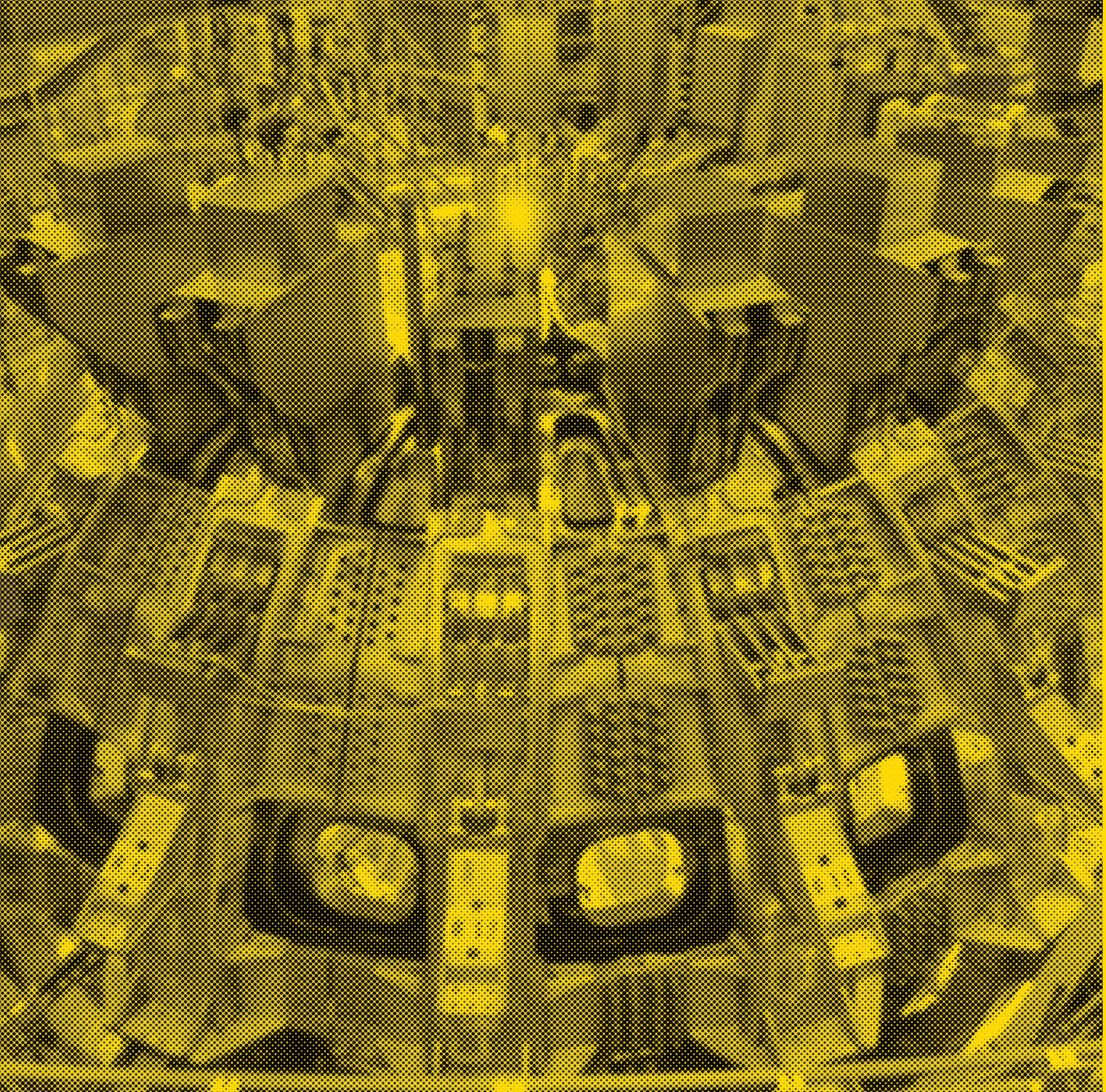
The Antenna Ion Cyclotron design work by ITER Organization passed successfully the Preliminary Design Review. The Electron Cyclotron Upper Launcher and waveguides systems design activities by F4E also progressed and contributed to several achievements. For example, the initial validation of the diamond window unit; the design and initial validation of the ex-vessel waveguides integrated cooling concept; a detailed design of the isolation valve in view of prototyping and qualification, and further validation of the diffusion bonding manufacture process for plasma facing blanket shield module.



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



Works performed by ATMOSTAT on the first prototype of the ITER Blanket Shield Module (BSM) © ATMOSTAT



03

The Broader Approach

Taking a step closer to fusion energy through Research & Development

Bringing together two parties that share the same vision on how to address fusion research, summarises the spirit of collaboration the "Broader Approach". In February 2007, an Agreement was signed between Europe and Japan, complementing the ITER project, to promote R&D in the field of fusion technologies.

The Broader Approach consists of three projects:

- The Satellite Tokamak, known as JT-60SA , a fusion device about half the size of ITER to study plasma operations;
- The International Fusion Materials Irradiation Facility - Engineering Validation and Engineering Design Activities (IFMIF-EVEDA), an installation built to design, test and qualify the materials for future fusion power plants;
- The International Fusion Energy Research Centre (IFERC) comprising three sub-projects for plasma remote experimentation and simulation.

The first phase of the three projects was completed. In 2020, the second phase of the Broader Approach Agreement was signed, offering continuity to this valuable partnership between the European Union and Japan.

JT60-SA

JT-60SA is the largest tokamak in the world until ITER starts operations. Located in Naka, Japan, this device is the upgrade of an existing tokamak. The works entailed the complete dismantling of the old device, the refurbishing of the buildings, the upgrade of power supply and heating systems. This experimental device will support ITER through complementary experiments in order to improve the design of the Demonstration (DEMO) fusion reactor, which will be connected to the grid.

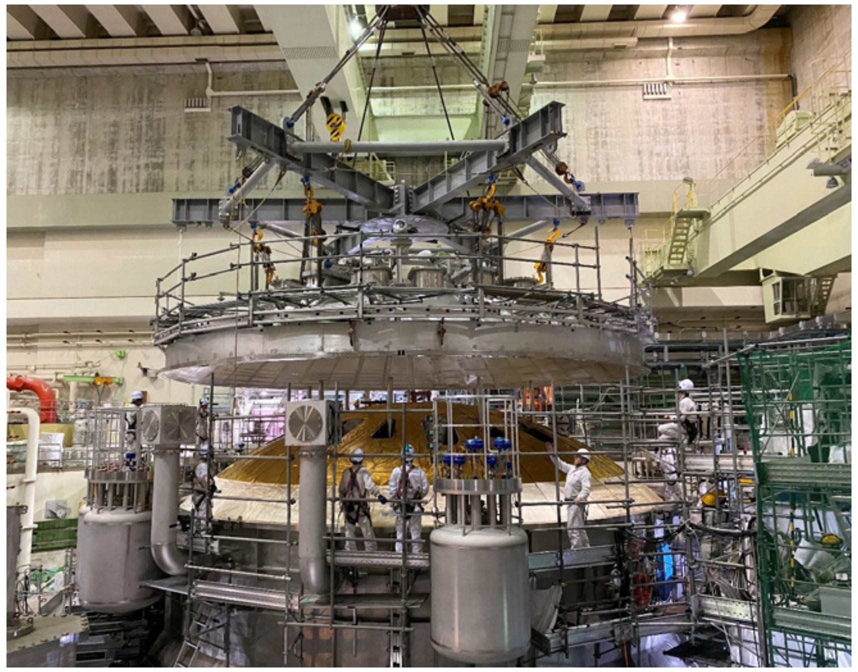
Europe and Japan completed JT-60SA

After nearly twelve years, teams of engineers from Europe and Japan completed JT-60SA. With a diameter of 12 m, the dimensions of JT-60SA are about half the size of ITER. In the future, its powerful heating systems will be able to bring the hydrogen plasma to temperatures over 200 million °C, comparable to those foreseen in ITER. It also has a similar system of superconducting magnets, which will confine and control the plasma, and a liquid helium cooling system that will cool them to -269 °C. In terms of plasma volume, JT-60SA is almost five times smaller than ITER and it will operate with a mix of hydrogen and deuterium gas.

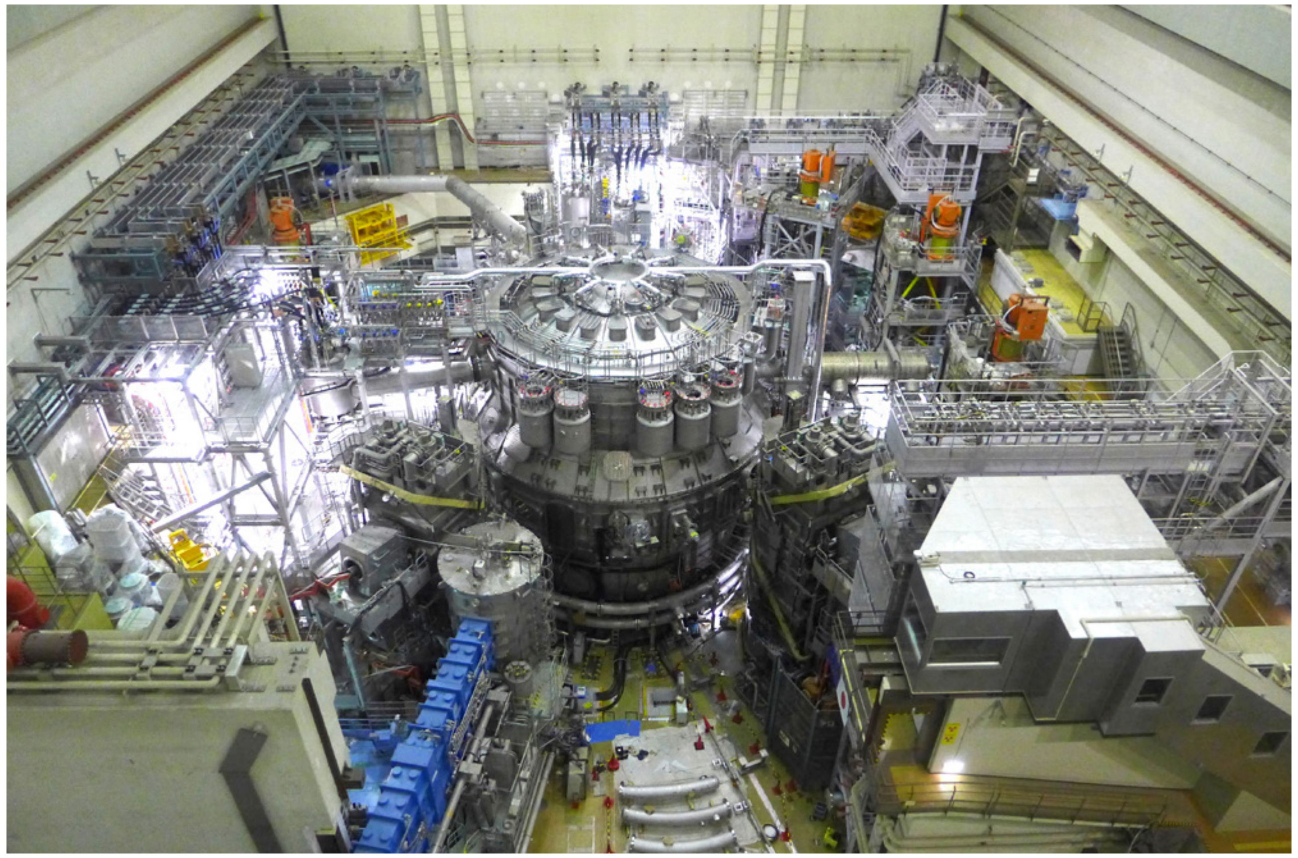
On 30 March 2020, the last component was installed, signaling the completion of its assembly. In October, the cool-down process started, which lasted several weeks and was successfully completed. It kicked off with the evacuation of practically all air from the vacuum vessel and the cryostat, which surrounds the vacuum vessel and superconducting magnets to ensure vacuum and to provide thermal insulation for the ultra-cool environment. From the initial room temperature of 300° Kelvin (27° C) the magnets were cooled down to 4° Kelvin (- 269° C). A complex system of sensors spread inside the cryostat kept an eye on the gradually lowering temperature.

"JT-60SA has been and will be a unique opportunity to raise the 'ITER generation' of engineers and scientists. Maintaining the knowledge and expertise must be guaranteed over long time horizons."

Enrico Di Pietro
F4E4 Programme Manager for JT-60SA



The Cryostat top lid lowered in position marking the end of main assembly operations © F4E/QST



JT-60SA –Completion of assembly, March 2020 © F4E/QST

Engineers from Europe and Japan following from the control room the cool-down of JT-60SA, Naka, Japan © F4E/QST

"This is certainly an exciting time for me to be able to witness first-hand the whole process of bringing the tokamak to life. Although minor issues do pop up from time to time, the extremely thorough Japanese team has been able to resolve them."

Sam Davis
F4E Technical Officer

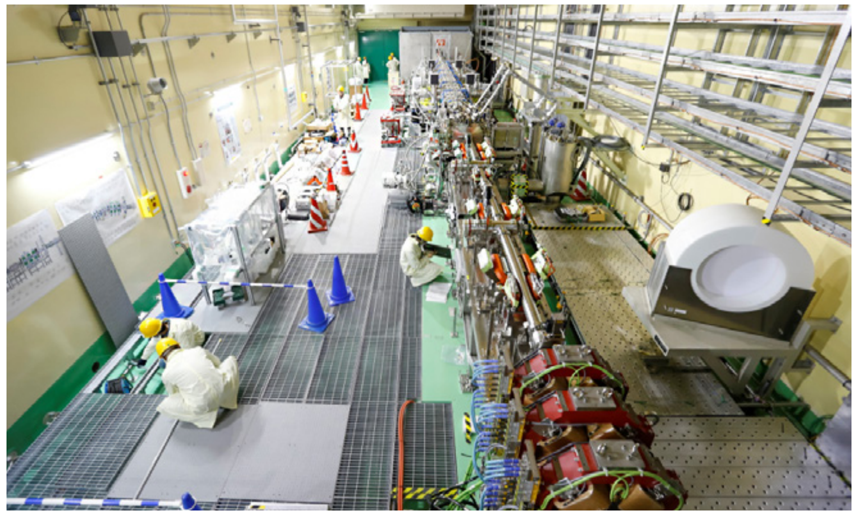
IFMIF/EVEDA

Reproducing the conditions of the future fusion reactors is the objective of the International Fusion Materials Irradiation Facility (IFMIF). This accelerator-based facility will test materials similar to the conditions of the DEMO reactor, which will follow ITER. The know-how acquired will help engineers to improve the durability of materials and minimise their activation. The Engineering Validation and Design Activities (EVEDA) for IFMIF are conducted in Rokkasho, Japan.

Closer to LIPAC qualification

After having managed to accelerate a beam of deuterons (deuterium nuclei) with 125 mA at 5 MeV reaching nearly 90% of transmission from the injector to the beam dump, the team of engineers moved ahead with the installation of most of the remaining components in order to validate the engineering aspects of the accelerator.

Most components were successfully installed and connected according to schedule. For example, the high energy beam transport line, with its high power beam dump, was installed. The intermediate transport line, to allow LIPAc to operate in a continuous wave, was completed. Experts carried out tests in the area of control system together with some maintenance operations.



LIPAc (Linear IFMIF Prototype Accelerator) while teams from Europe and Japan are checking the installation of components, Rokkasho, Japan, March 2020 © F4E/QST

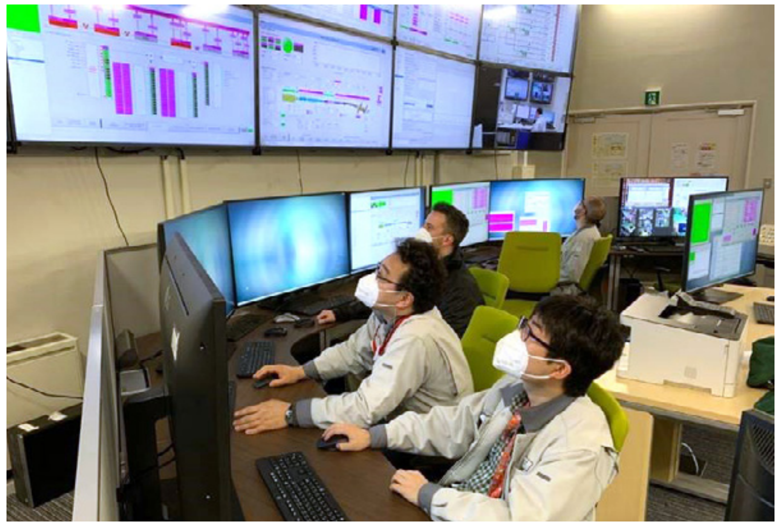
"The intermediate transport line was designed from scratch. We wanted to have it quickly manufactured and at low cost. F4E designed it and QST manufactured it with common project funds. To meet our tight schedule and financial resources, we decided to use old quadrupoles manufactured in early 70s for the KEK Institute which were decommissioned in early 2000."

Hervé Dzitko
F4E Project Manager for IFMIF/EVEDA

Europe and Japan developed remote tools to make progress

Due to the pandemic, some of the activities were reconfigured and staff adapted to a new working style. The use of teleworking tools helped them to coordinate activities. By the end of summer, with the remote support from staff based in Europe, the team developed around 80 additional procedures to run LIPAc safely.

Moreover, the IFMIF team worked closely with colleagues from IFERC to develop a safe ICT environment in order to offer experts remote access to data and interfaces. All this effort in terms of documentation and ICT tools represented significant progress in operational management and facilitated the involvement of various experts when needed. The combination of a minimum amount of personnel on-site and remote support became the new norm at IFMIF.



Data transfer test at Central Control Room in Rokkasho, Japan © F4E/QST

"We have been able to adapt and show an outstanding team spirit on-site, with the unfailing support from Europe. We seized the situation imposed by the COVID-19 to improve our technical and organizational capability. We have already gained in efficiency and in control of the machine, which will be a gain of time when we restart beam operation."

Philippe Cara
IFMIF/EVEDA Project Leader

IFERC

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

- The Computational Simulation Centre (CSC) hosted “Helios”, a supercomputer which offered the fusion community the possibility to run simulations. In 2020 the CSC prepared the framework for an exchange of computer time between Europe and Japan to allow joint projects in their respective supercomputers.
- The Demonstration Reactor (DEMO) activities aim at reinforcing collaboration with EUROfusion in the area of materials, design and planning. This year, the DEMO Activity Integrated Project Team continued working on pre-conceptual DEMO designs.
- ITER Remote Experimentation Centre (REC) started working on offering Europeans remote access to JT-60SA and the LIPAc accelerator, after having successfully demonstrated remote participation in experiments.

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

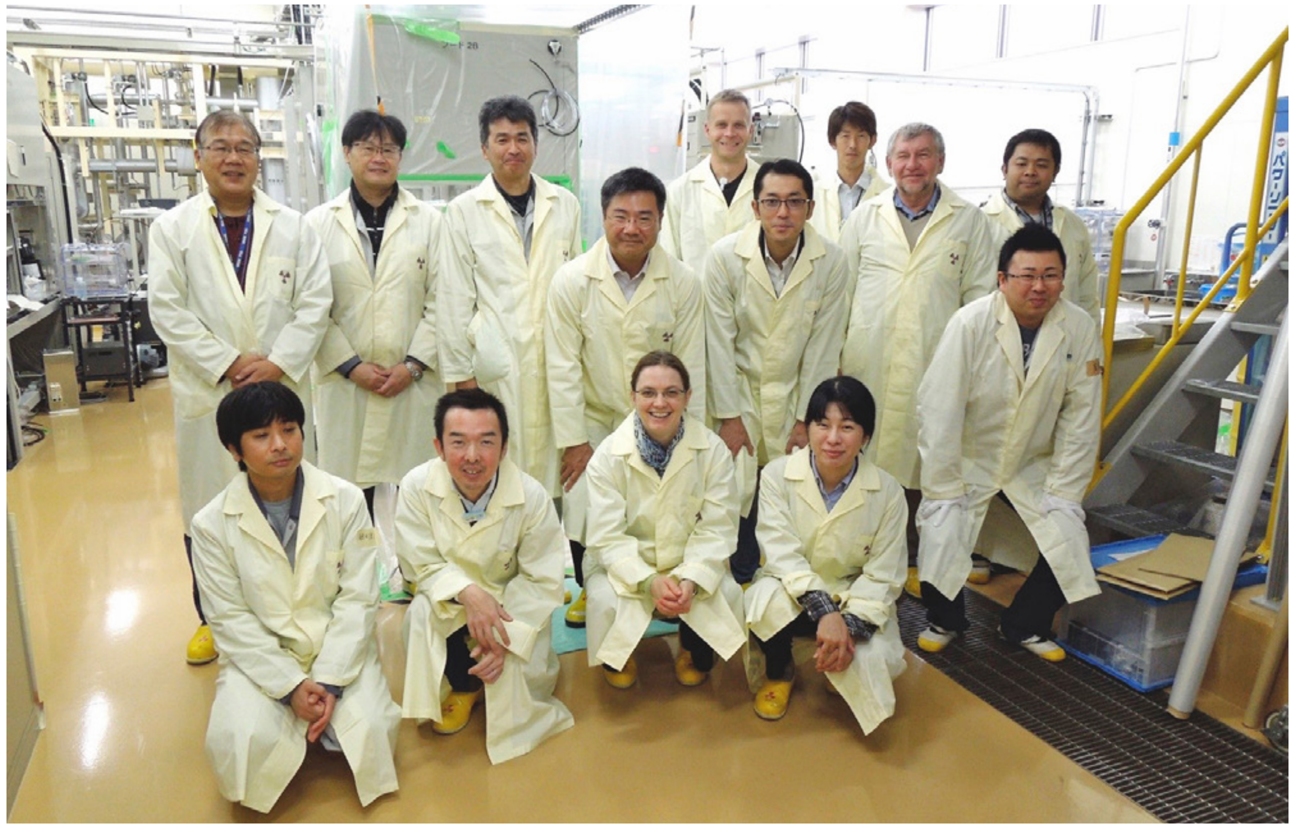
Scientific breakthrough—experts measured the tritium retained in dust particles inside a tokamak

Scientists have always wanted to learn more about the impact of the fusion reaction on the materials that form the wall of the vacuum vessel. For the first time ever, experts successfully measured the amount of tritium in the metal dust on walls similar to those of ITER. This will help scientists to develop models to calculate the quantity of tritium that will be retained in the ITER Vacuum Vessel and improve several aspects of safety.

A joint team of researchers from Europe and Japan carried out the tests in the IFERC materials laboratory in QST Rokkasho Fusion Institute, using wall samples from the Joint European Torus (JET), UK.
F4E and QST conducted the comprehensive analysis in close collaboration with research institutes and universities.

Apart from calculating the tritium inside a small amount of dust particles, the joint team of researchers developed a “new imaging technique” that simultaneously shows the source of many dust particles and the distribution of tritium concentration. The development of the new microanalysis techniques was carried out using small amounts of metal dust samples (one to a few mg).

Members of the Joint Team at the Radioactive Isotope Experimental room, Rokkasho Fusion Institute, Japan. Picture taken before COVID-19 pandemic © F4E/QST



Members of the Joint Team at the Radioactive Isotope Experimental room, Rokkasho Fusion Institute, Japan. Picture taken before COVID-19 pandemic © F4E/QST

04

Working together with stakeholders

F4E engaged with European and national policy-makers using mainly electronic periodic updates respecting the restrictions imposed by the pandemic.

A constant flow of information between F4E, its committees, and the network of ITER Industrial Liaison Officers (ILOs), provided updates on various initiatives putting safety first; new measures were adopted aligning manufacturing procedures with new health and safety standards; tools were put in place to ensure business continuity.

To strengthen the spirit of partnership between ITER Parties, Europe maintained its firm commitment to building stronger ties by reaching out to its international partners in order to share good practice.

Europe and Japan prolonged collaboration in fusion research

Kadri Simson, the EU Energy Commissioner, representing the European Atomic Energy Community (Euratom), and Kazuo Kodama, the Ambassador Extraordinary and Plenipotentiary of Japan to the European Union, signed a joint declaration prolonging the duration of the Broader Approach Agreement covering a number of projects in the field of fusion energy.

The scientific partnership between the two parties has been hailed a success to the extent that policy-makers are considering copying its philosophy in other areas of work. It relies on the development of common projects, the secondment of human resources capitalising on their expertise, voluntary financial contributions, and the open exchange of information and findings. A fine example of science diplomacy underpinned by a one-team spirit.

Under the recently signed prolongation, the projects will run initially for five years, and the possibility of yearly extensions is also envisaged. There are some novelties in this new agreement: objectives and financial contributions will be set annually; Japan as host of these projects is expected to make a higher contribution; voluntary contributions will be agreed according to the availability of resources either by putting personnel or equipment; F4E and EUROfusion will be seconding staff to operate the machines.

(L-R) Kazuo Kodama, the Ambassador Extraordinary and Plenipotentiary of Japan to the European Union, and Kadri Simson, the EU Energy Commissioner, representing the European Atomic Energy Community (Euratom), signing a joint declaration prolonging the duration of the Broader Approach Agreement, March 2020 © European Union

Science & Technology policy-makers at IFMIF/EVEDA

The Delegation of the EU to Japan received at the headquarters of IFMIF/EVEDA, Rokkasho, representatives from Belgium, Sweden, Germany, Finland, Lithuania, and Italy working in the field of innovation, science and technology to visit the IFMIF/EVEDA site. They were all impressed with the spirit of collaboration and developed a true interest in the projects and their potential bringing fusion energy a step closer.

Delegates from Belgium, Sweden, Germany, Finland, Lithuania, Italy, the Delegation of EU to Japan, during a meeting with the teams of IFMIF/EVEDA projects, Rokkasho, Japan, February 2020 © F4E

Positive feedback for F4E business style

Striving for continuous improvement, F4E asked its industrial contractors to evaluate its contractual performance and other relevant administrative practices. F4E passed this test with flying colours, averaging more than 73% positive feedback. 86% of the companies declared that they would be willing to continue doing business with F4E.

F4E Market Analysis Group invited 149 companies, all of which signed a contract in 2017-2019, to participate to the survey. The response rate of 40% was very encouraging and above the average participation for this kind of exercise.

TThe survey asked qualitative questions to assess the level of agreement/satisfaction on several areas and offered the possibility to include recommendations for improvement.

F4E Technologies Marketplace portal launched

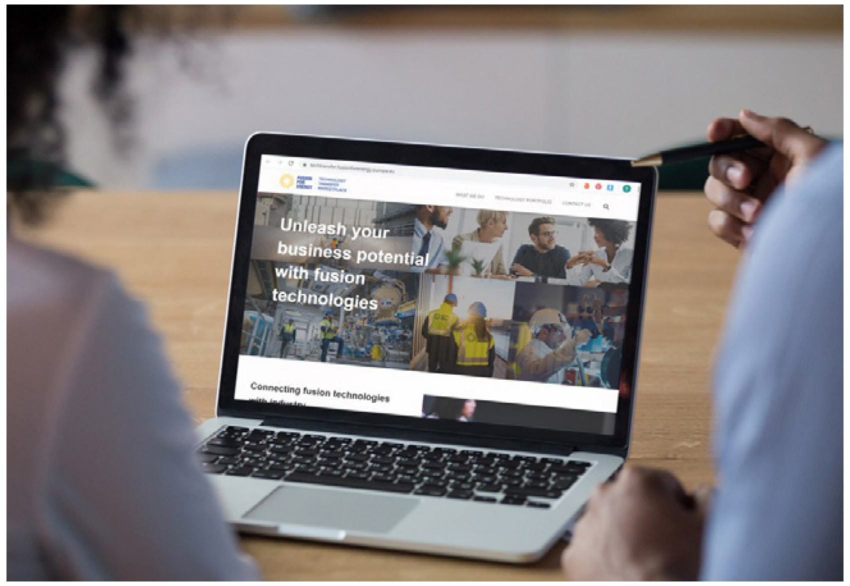
The partnership between F4E, companies and laboratories has not only served as an essential learning curve to manufacture Europe's components for ITER. It has motivated engineers to think out of the box and consider a wide range of technologies, design new tooling, test materials in new conditions, take risks to achieve breakthroughs. Big Science projects invite us to think big because the knowledge we generate can be transferred, customised and applied in ways we have not imagined before.

> *"Since 2015 we have been raising awareness on the value of intellectual property and the transversal application of spin-offs outside the fusion community. In order to deliver on this front, F4E has launched a new portal which lists various technologies developed so far for ITER, financially supported by the EU, which can be directly applied to new markets."*

Gebhard Leidenfrost
Head of Commercial Department/CFO

Short fact sheets are available describing the success stories. The portal will be updated with additional technologies. Meanwhile, brokers based in France, Germany, Italy, Spain, Belgium, and the UK, will be scouting for commercial opportunities, which could lead to successful business deals.

(L-R) Benoit Rivollet, Nicolas Louée (In Extenso Innovation Croissance) with Carmen Casteras, Gebhard Leidenfrost © F4E



F4E Technologies Marketplace portal © F4E

F4E offered updates through BSFB webinars

The Big Science Business Forum (BSBF) brings together all the European big science organisations (CERN, EMBL, ESA, ESS, ESO, ESRF, F4E, ILL, SKA, European XFEL, FAIR) in a business oriented venue aiming to become the meeting point between industry and big science.

BSBF, originally planned for October 2020, was postponed for next year. However, a series of interactive online webinars, covering different topics, were organised to which F4E made a contribution. The impact of COVID-19 and the measures on the Big Science market was one of the themes addressed. Later in the year, procurement and flagship projects were presented.

All information and presentations are available on the BSBF webinars page https://www.bsbf2020.org/Webinars

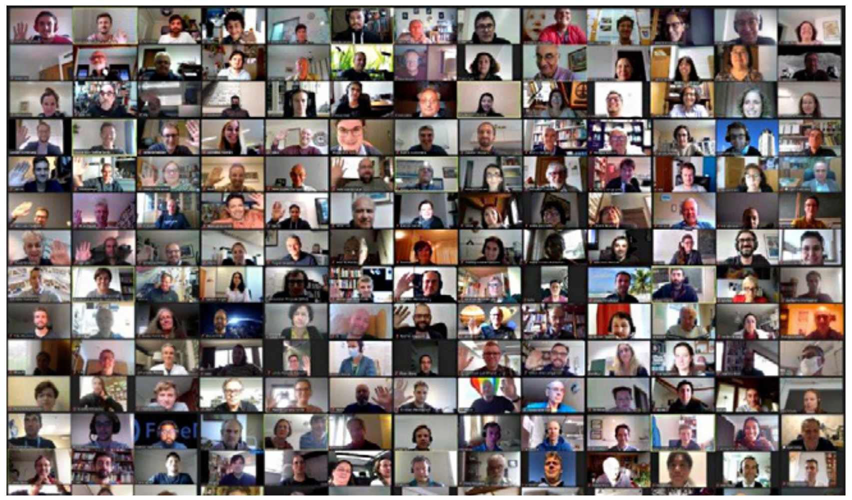
Big Science Business Forum 2021 WEBINAR

F4E participated in European Fusion Teacher Day

A European webinar dedicated to promoting fusion in high schools was organised by FuseNet (the European Fusion Education Network), bringing together more than 300 science and physics teachers from 18 local sessions across 16 European countries.

F4E, in close cooperation with the Barcelona Super Computer Fusion group (BSC), the b_TEC Foundation and the Universitat Politècnica de Catalunya (UPC), organised the Barcelona local session under the umbrella of the FusionCAT project.

The objective of the European-wide webinar was to introduce fusion to high-school teachers and to give them the tools and the knowledge they need in order to introduce fusion in the classrooms.



Screenshot of attendees during the Barcelona local session

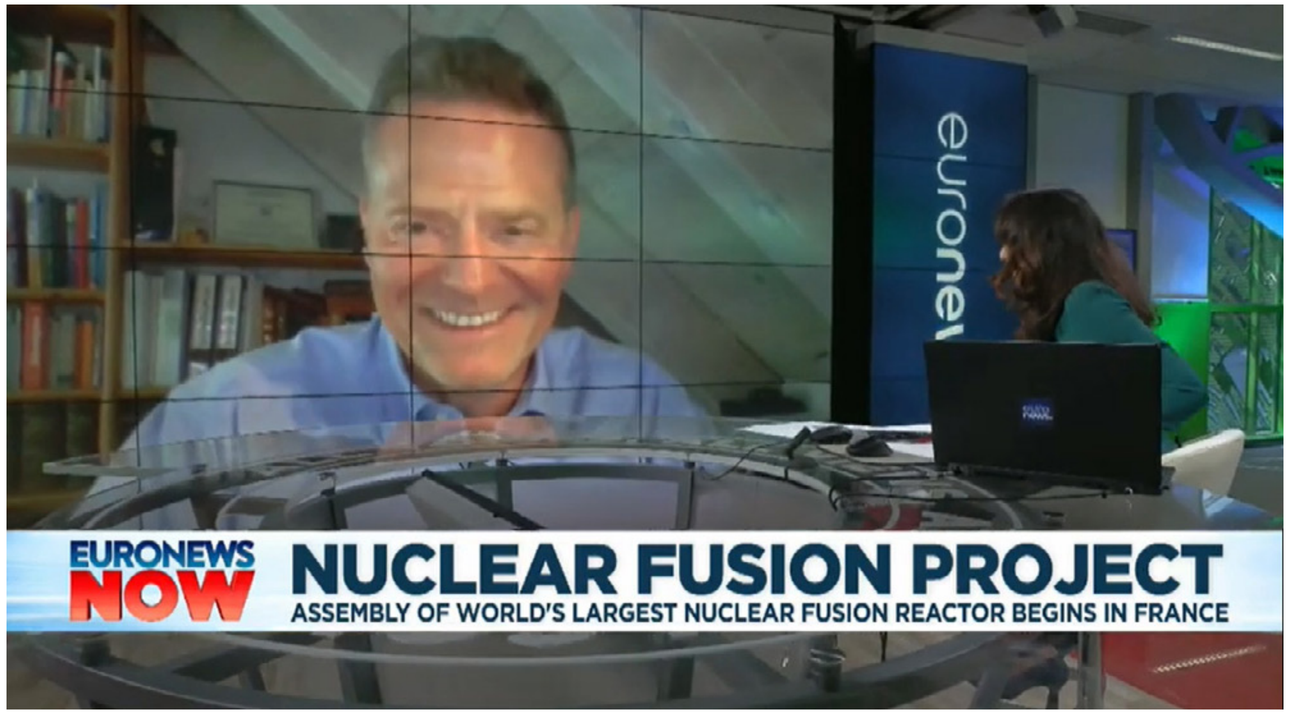
Start of ITER Assembly

During a moving ceremony, which combined physical and virtual attendance, Dr. Bernard Bigot, Director-General of ITER Organization, paid tribute to the contributions of the seven ITER Parties and highlighted the importance of start of assembly. Using live streaming, the event kicked off with a tour on-site giving viewers the opportunity to visit the main buildings and facilities. Europe opened the doors of the factory where the Poloidal Field coils are manufactured, the Cleaning Facility, the Assembly Hall where the ITER components will be put together and last but not least, the Tokamak building– the home of the device.

Leading political figures from the seven ITER parties united their voices to stress the importance of international collaboration. Through their interventions, they praised the role of science and technology, the value of foresight in shaking the status quo and making us take bold steps into the future. The messages delivered by France's President E. Macron, Dr. M. Meister, Parliamentary State Secretary of Germany's Federal Ministry for Education and Research; K. Simson, EU Commissioner for Energy, stressed the one-of-a-kind nature of ITER and its strategic importance as we try to decrease our dependence on fossil fuels and aim towards a greener energy mix. The event concluded with a press conference during which Dr. Bernard Bigot took questions from journalists. Euronews interviewed Johannes Schwemmer, F4E Director, on the potential of fusion energy and the long-term contribution of ITER.

France's President, Emmanuel Macron, joined by leading political figures from the ITER Parties to mark the importance of this achievement, ITER Assembly ceremony, 28 July 2020. © ITER Organization

ITER Assembly Hall turned into an auditorium to celebrate the start of Assembly, 28 July 2020. © ITER Organization



Fusion for Energy Director, speaking on Euronews, July 2020.

Getting in touch with the EU

In person
All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email
Europe Direct is a service that answers your questions about the European Union. You can contact this service:
– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
– at the following standard number: +32 22999696 or
– by email via: https://europa.eu/european-union/contact_en
Finding information about the EU

Online
Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications
You can download or order free and priced EU publications at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

EU law and related documents
For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

Open data from the EU
The EU Open Data Portal (http://data.europa.eu/euodp/en) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

PDF
ISBN 978-92-9214-039-7
ISSN 2363-3212
doi:10.2827/515315

Print
ISBN 978-92-9214-038-0
ISSN 2363-3204
doi: 10.2827/008294

Printed by Imprimerie Bietlot in Belgium

Neither Fusion for Energy (F4E) nor any person acting on behalf of the Fusion for Energy (F4E) is responsible for the use that might be made of the following information.

Luxembourg: Publications Office of the European Union, 2021

© Fusion for Energy Joint Undertaking, 2021
Reproduction is authorised provided the source is acknowledged.
For any use or reproduction of elements that are not owned by Fusion for Energy, permission may need to be sought directly from the respective rightholders.

Fusion for Energy
The European Joint Undertaking for ITER
and the Development of Fusion Energy

c/ Josep Pla, nº 2
Torres Diagonal Litoral
Edificio B3
08019 Barcelona
Spain

Telephone: +34 93 320 1800
Fax: +34 93 489 75 37
E-mail: info@f4e.europa.eu
www.f4e.europa.eu

Fusion for Energy receives funding from the European Union budget

Publications Office