ISSN 2363-3212

FUSION FOR ENERGY

HIGHLIGHTS 2023

THE MAIN ACHIEVEMENTS

2023

Table of contents

FOREWORD

Dear colleagues, partners, stakeholders, dear readers,

It is an honour to introduce the 2023 Highlights, which mark my first year as Director of Fusion for Energy (F4E).

In May 2023, I had the privilege of joining the organisation that serves one of Europe's most strategic objectives: harnessing the power of fusion energy. Naturally, my new duties came with a deep sense of responsibility to our stakeholders, and the promise to lead an incredibly talented and committed team of staff.

Throughout the year, F4E together with its partners (industry, laboratories and SMEs) worked relentlessly to provide Europe's contribution to ITER - the biggest international fusion experiment bringing together seven parties (China, Europe, Japan, India, the Republic of Korea, the Russian Federation and the USA) which represent half of the world's population and 80% of the global GDP.

In parallel, we continued collaborating with Japan through the Broader Approach agreement. Together, we achieved a first plasma in JT-60SA, now the largest operational Tokamak, instilling confidence and motivation for the future.

As stated in this report, F4E successfully demonstrated its capacity to deliver on its projects. To name a few:

- The civil engineering works for the ITER Tokamak Building and the Tritium building were completed.
- Europe's final Toroidal Field coil and the fourth Poloidal Field coil, a magnet unprecedented in size, were handed over.
- More progress was made with Europe's five vacuum vessel sectors, while series manufacturing continued for the ITER First Wall Panels and Divertor Cassette Bodies.
- We advanced in the design of many auxiliary systems for ITER, like the Cask and Plug Remote Handling Systems or the Divertor Tangential Coils for diagnostics.
- Europe signed a new partnership with Korea to jointly develop Test Blanket Modules.
- We kicked off manufacturing of the Electron Cyclotron gyrotrons, while at the Neutral Beam Test Facility we delivered all components for the SPIDER ion source and most for the MITICA prototype.
- We handed over to ITER Organization the Cold Valve Boxes and we made further progress with the commissioning the ITER Cryoplant.
- The LIPAc prototype accelerator was upgraded and we worked with partners to set up the new IFMIF-DONES facility, currently under construction in Granada, Spain.

To accomplish these achievements, F4E capitalised on technical and fusion know-how across Europe, working closely with industry. In 2023 we signed 70 new contracts with industrial partners and laboratories for almost 650 million EUR, bringing F4E's total financial contribution since the start of the project to over 7 billion EUR. Europe's supply chain has directly benefited from these investments, by getting more involved in the acquisition of new skills and expertise, and the prospect of new breakthroughs and technology transfers to other markets. Our capacity to shape the fusion ecosystem is perfectly compatible with the EU's determination to boost competitiveness and innovation.

With fusion gaining momentum, F4E will play a crucial role in the European roadmap towards commercially viable fusion power plants. In line with this, F4E adopted a long-term vision, based on three pillars:

- Our top priority will be the successful construction and operation of ITER, and our contributions to the Broader Approach, DONES and other fusion projects.
- We will foster fusion talent and develop knowledge to deliver commercially viable fusion power plants in Europe.
- We will pave the way for the transition from research to a competitive European industrial fusion sector.

To meet those challenges and make the best use of our expertise and resources, F4E has started working on a more suitable, flexible and modern organisational structure. We have taken steps towards a closer integration with the ITER Organization and strengthened our partnership with EUROfusion.

In addition, we have taken various initiatives to make F4E a better place to work by putting emphasis on staff wellbeing, gender equality and strengthened the foundations of social dialogue. Through a series of participatory workshops, we involved staff to have a say towards F4E's vision.

2023 also marked the end of F4E's year-long mandate as chair of the Network of the 49 EU Agencies (EUAN). Thanks to a collective effort, much was achieved during F4E's tenure including the launch of the EUAN Diversity and Inclusion Awards, reinforced cybersecurity across the EU, implemented a sustainability strategy among the Agencies and united our actions in solidarity with Ukraine.

I would like to underline that none of the above would be possible without the dedication of our staff, our European supply chain, and the support from our stakeholders. The success of our projects relies on a variety of competences which include programme management, technical supervision, legal, commercial and administrative expertise.

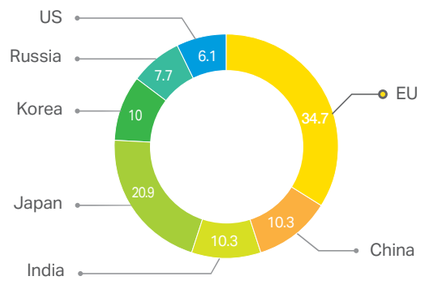
A special acknowledgement goes to Jean-Marc Filhol, Acting Director until the start of my tenure, who retired from F4E this past year.

The report in your hands summarises an important year in our collective journey. A journey towards fusion: a sustainable, safe, and virtually limitless source of power for future generations.

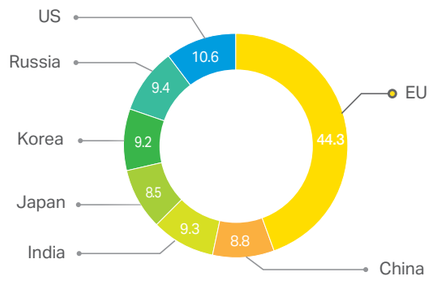
Marc Lachaise
Director

2023 KEY FIGURES

Contributions to ITER

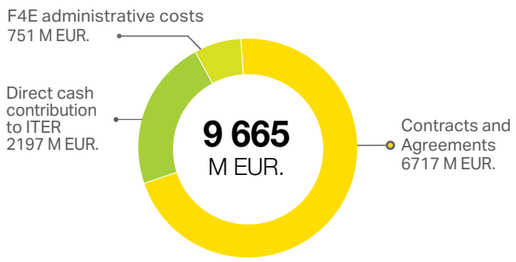


Total In Kind contributions in percentages
ITER Parties 2007-2023

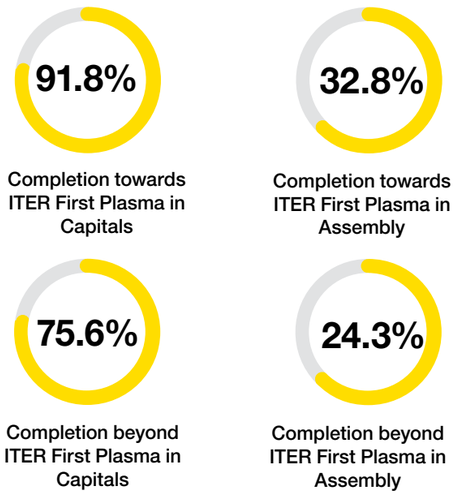


Total In Cash contributions in percentages
ITER parties 2007-2023

F4E budget breakdown of main activities 2007-2023

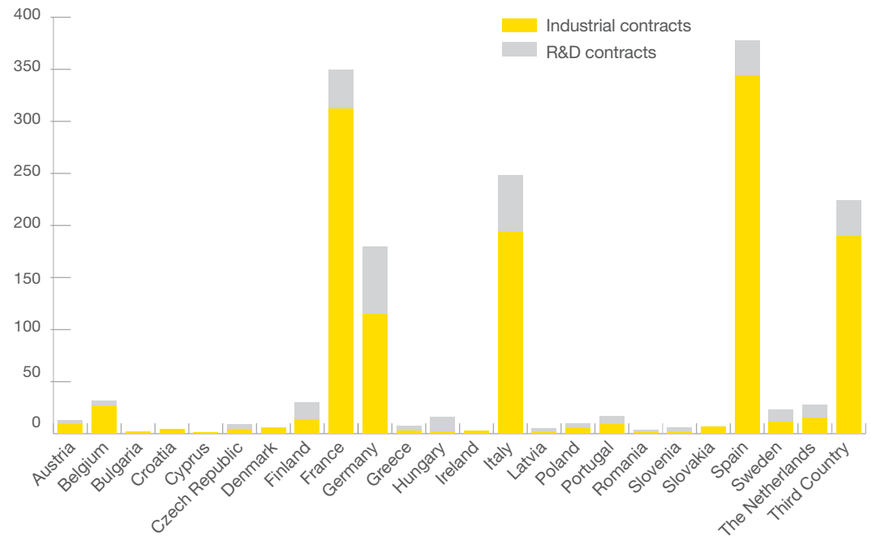


ITER Project Progress 2023



Capitals: encompasses ITER components delivered to ITER Organization, buildings and associated infrastructure.

Geographical distribution



Contracts and grants awarded by F4E 2008-2023
Since 2021 the contribution of Switzerland and United Kingdom is included in “Third Country”

Contracts with Industry and Laboratories

€633m
Total value of contracts signed in 2023

€6.6bn
Total value of contracts signed 2007-2023

1298
Contracts signed since 2007

645
Companies

2100
Subcontractors

75
Research Organisations

SOME OF THE F4E ACHIEVEMENTS DURING 2023

January

Start of manufacturing for the first wall diamond discs. Europe's ninth Toroidal Field coil is delivered to the ITER site.

March

Success for MITICA's Cryopump acceptance tests. The EU and Korea sign an agreement to jointly develop Test Blanket Modules.

May

F4E showcases fusion science diplomacy at a European Parliament workshop. Assembly trials for the ITER feedthrough alignment tool. New F4E Director, Marc Lachaise, takes up duties.

July

All eight Cold Valve Boxes delivered to ITER. JT-60SA magnets cooled down at -268°C. Start of Vacuum Vessel sector 9 assembly. F4E Director presents ITER status to the EP Budgetary Committee.

September

European contractors end civil engineering works in ITER Tokamak building. F4E's contract for blanket cooling manifolds kicks off. JT-60SA International Fusion School hosts students from Europe and Japan.

November

Europe's final ITER Toroidal Field coil travels to ITER. F4E present at the World Nuclear Exhibition.

February

Marc Lachaise is appointed F4E Director. 32 sets of ITER cryojumpers delivered. EU Agencies "Diversity and Inclusion" Award recognises F4E's Women's Network.

April

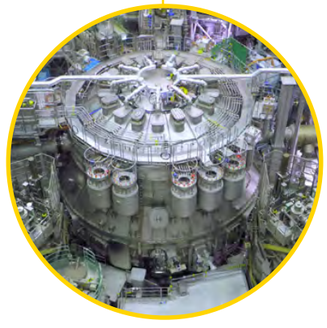
More progress for Europe's five vacuum vessel sectors thanks to robotic welding. F4E Director visits JT-60SA. Procurement Agreement signed for divertor rail

June

Europe's In-Vessel Viewing systems tested on ITER prototype. Second edition of F4E Contracting Professionals Roundtable celebrated.

August

Poloidal Field 4 handed over to ITER Organization. Design ready for ITER Cask and Plug Remote Handling System.



October

Europe and Japan achieve first plasma at JT-60SA. F4E, European Commission and ITER Organization update European Parliament's ITRE Committee. Contract signed for European Gyrotrons.

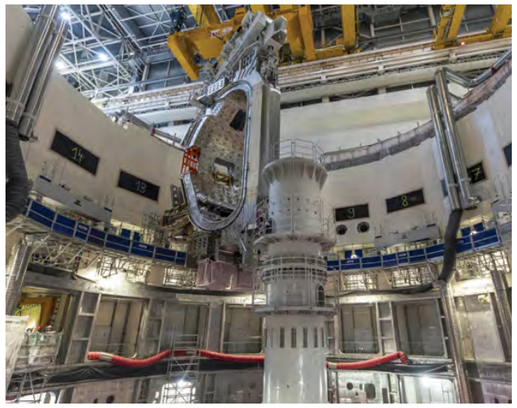
December

Europe and Japan officially inaugurate JT-60SA. ITER Tritium building civil engineering works completed. EUROfusion and F4E continue collaboration in Test Blanket Modules R&D.

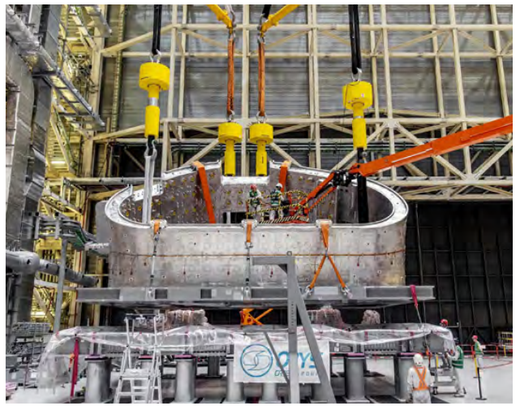
SOME OF THE ITER ACHIEVEMENTS DURING 2023

All images provided by ITER Organization

ITER Organization

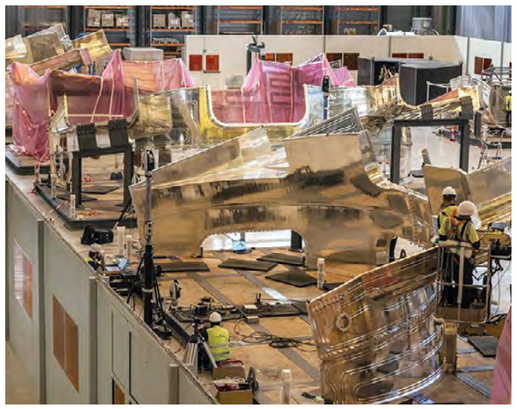


Sector module #6 lifted from the assembly pit and transported to the sub-assembly tool to remove components and perform maintenance. July 2023. ©ITER Organization

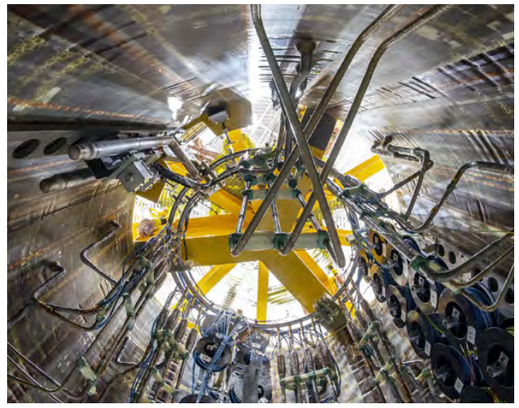


Vacuum vessel sector #8 was returned to a horizontal orientation for removal from the Assembly Hall and repair. September 2023. ©ITER Organization

Two toroidal field coils rest on their sides in storage. They will be called back into the Assembly Hall when works with other components advance. October 2023. ©ITER Organization



Outboard segments of thermal shield await disassembly by contractor teams at the Poloidal Filed coils factory on site. August 2023. ©ITER Organization



Stacking of the central solenoid in the Assembly Hall: two magnet modules are in place and four others will join them. September 2023 ©ITER Organization

The 665-tonne cryostat top lid is stored under protective wrap. April 2023. ©ITER Organization

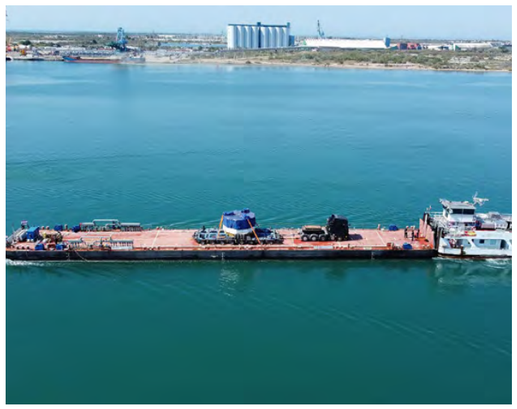
China

Production is more than halfway through for the 440 shield blocks of the blanket split between China and Korea, with the work of suppliers like Dongfang Heavy Machinery. December 2023. ©ITER Organization

The in-cryostat feeder left from China and arrived in France. This semi-circular component will fit inside the cylindrical cryostat to deliver power, cryogens and instrumentation to four of the top correction coils. October 2023. ©ITER Organization

United States

US ITER and its contractor General Atomics delivered the third and fourth out of seven central solenoid modules, each weighing 110 tonnes and standing 2 metres high. December 2023. ©ITER Organization



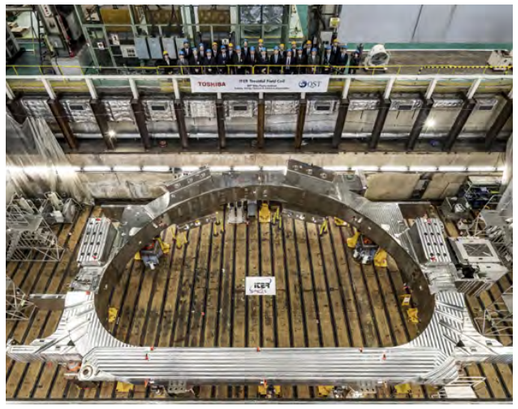
Like the solenoid module in the picture, some of the bigger components arriving at the port of Fos-sur-Mer then cross the inland sea of Barre on a barge on their way to ITER. July 2023. ©ITER Organization

India

The ITER India Gyrotron Test Facility successfully completed the site acceptance of a test gyrotron for ITER power and pulse requirements, including all the associated auxiliaries. March 2023. ©ITER Organization

Procured by India, designed and manufactured by Linde Kryotechnik AG in Switzerland, three of the five auxiliary cold boxes—part of the cryogenic distribution system—have been pre-positioned in the Tokamak Building. December 2023. ©ITER Organization

Japan



Japan's eighth Toroidal Field coil completed manufacturing at Toshiba Energy Systems & Solutions. February 2023. ©ITER Organization

Mitsubishi Heavy Industries shipped a spare Toroidal Field Coil to ITER, the last of nine D-shaped coils to be supplied by Japan. August 2023. ©ITER Organization

Korea

The last of Korea's 18 AC/DC transformer/converter units made it to ITER, where it will be integrated in the power supply system. December 2023. ©ITER Organization

Russia

Poloidal Field coil #1 (PF1), ITER's top ring magnet, was delivered to ITER from Saint Petersburg, Russia. All six PF coils are now at ITER. February 2023 ©ITER Organization

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 have been involved in ITER's civil engineering works. Architects, engineers, technicians, planners, inspectors are some of the professionals contributing to the project. Inside these facilities, 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

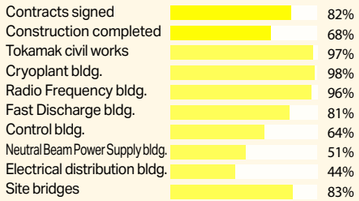
More buildings and infrastructure were completed in 2023 to host people and equipment under their roofs. Works reached a 95% of completion rate for the first phase of the experiment and the F4E Buildings, Infrastructure and Power Supplies (BIPS) team celebrated several milestones during the year.

At the Tokamak Building, the seven-storey home of the device, the installation and testing of the last nuclear doors marked the official end of the civil engineering works. This was the result of F4E's collaboration with the consortium of Vinci, Ferrovial, Razel-Bec (VFR) and ITER Organization (IO), which employed more than 900 people on site in the previous 10 years. Later, the same consortium finished the works for the Tritium building, a 9 000 m^2 facility where the fusion fuel will be stored.

In parallel, the Control Building, constructed by Demathieu Bard Construction for F4E, neared completion. This will be one of the busiest places on site, with up to 80 people monitoring ITER's performance from the main room. The final touches were also made in the Cryoplant building, likened to a refrigerator the size of a football field

The fastest progress was made in some of the electrical infrastructures, like the Fast Discharge Building. The installation of equipment was completed in this facility, where excess energy in the magnets will be extracted and discharged. In addition, the Neutral Beam Power Supply Buildings exceeded 50% of completion as they were coated with the waterproof cladding. Moreover, the steel structures were erected for the two busbar bridges delivering power to the magnets of the tokamak. The Cryoline bridge, carrying cryogenics for 130 m, was also completed.

Construction in progress



Aerial front view of the ITER site, Cadarache, France. September 2023. ©ITER Organization/EJF Riche

ITER TOKAMAK BUILDING

The banner on the façade changed to a message of commitment: "Safely assembling ITER." November 2023. ©ITER Organization

TRITIUM BUILDING

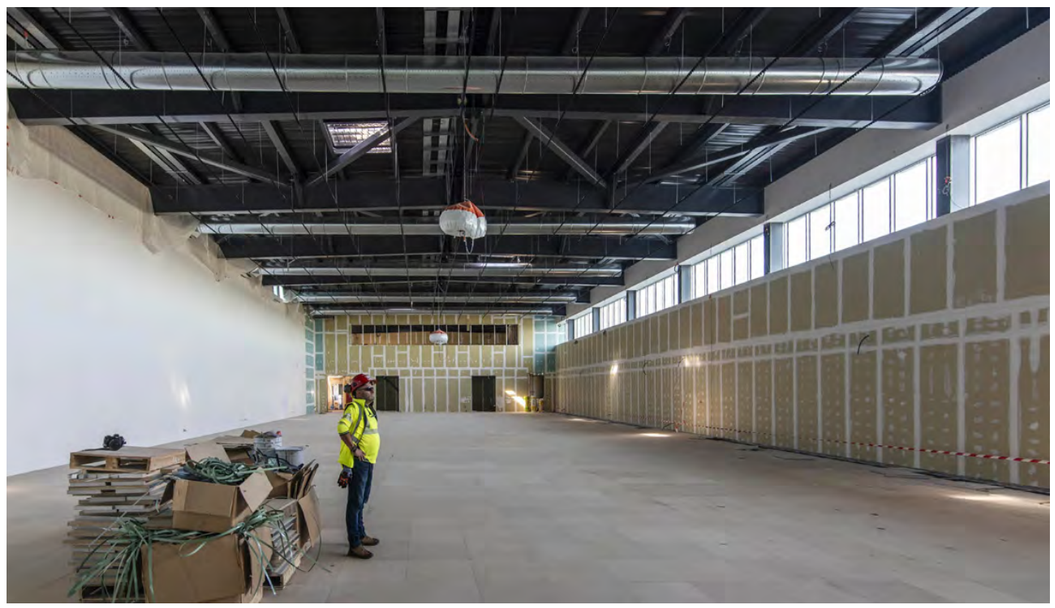
Civil works on the Tritium Building are over and tall cranes will be dismantled, as the building is completely framed out. December 2023. ©ITER Organization

HIGH VOLTAGE SUPPLY BUILDING

The High Voltage Building, newly covered in a layer of silver and black cladding, will house power supplies for the Neutral Beam Injectors. 2023. ©ITER Organization

CONTROL BUILDING

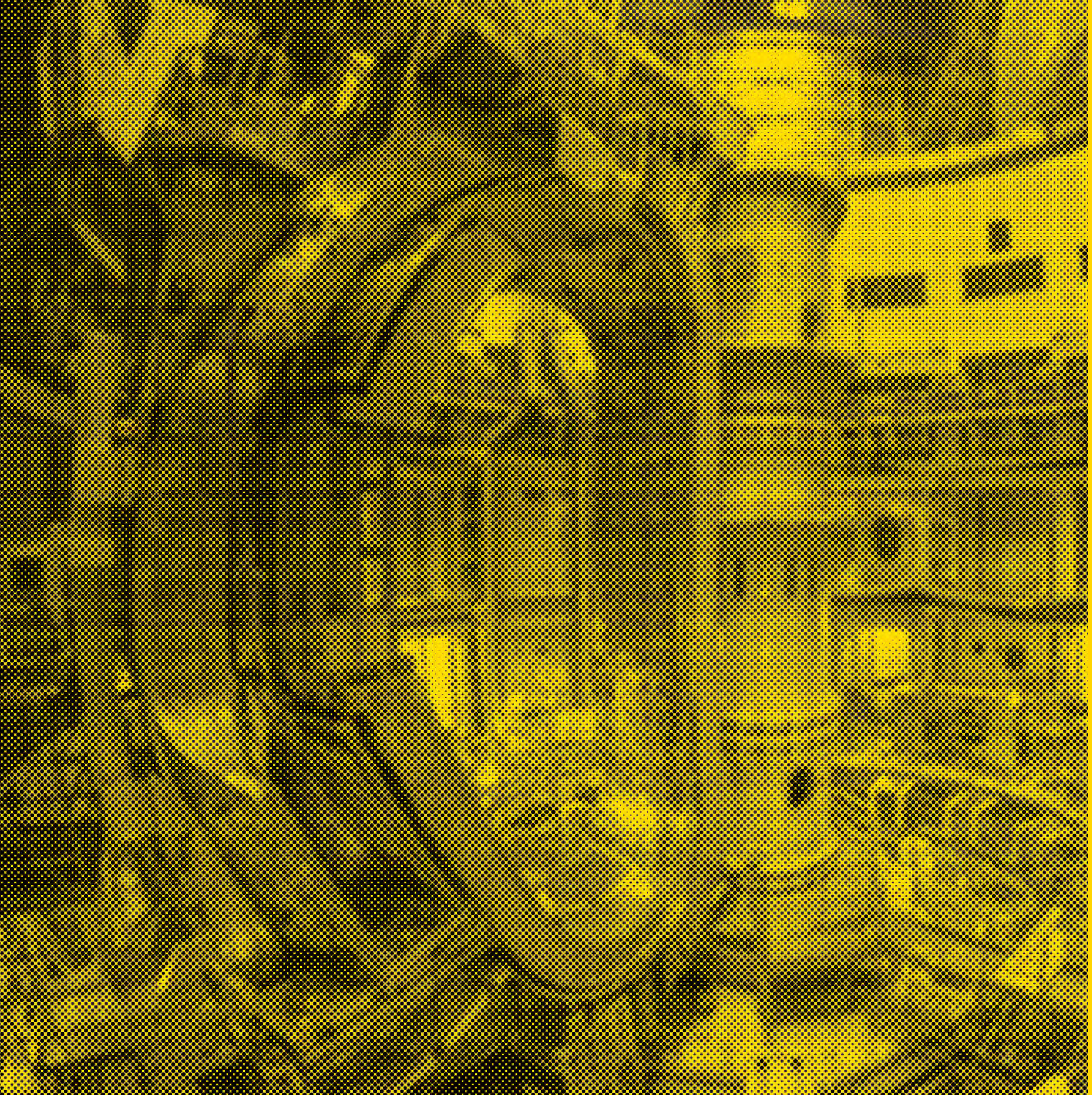
Steady progress in the Control Building, connected underground with the ITER Organization Headquarters. 2023. ©ITER Organisation



The inside of the main Control Room, where experts will survey operations of the ITER machine through large display screens. August 2023. ITER Organization

CRYOPLANT AND BUSBAR BRIDGES

Three new bridges to the Tokamak Complex: the cryoline bridge (foreground) will channel cryogenic fluids, and the two busbar bridges will allow transport of electrical busbars from the Magnet Power Conversion. August 2023. ©ITER Organization



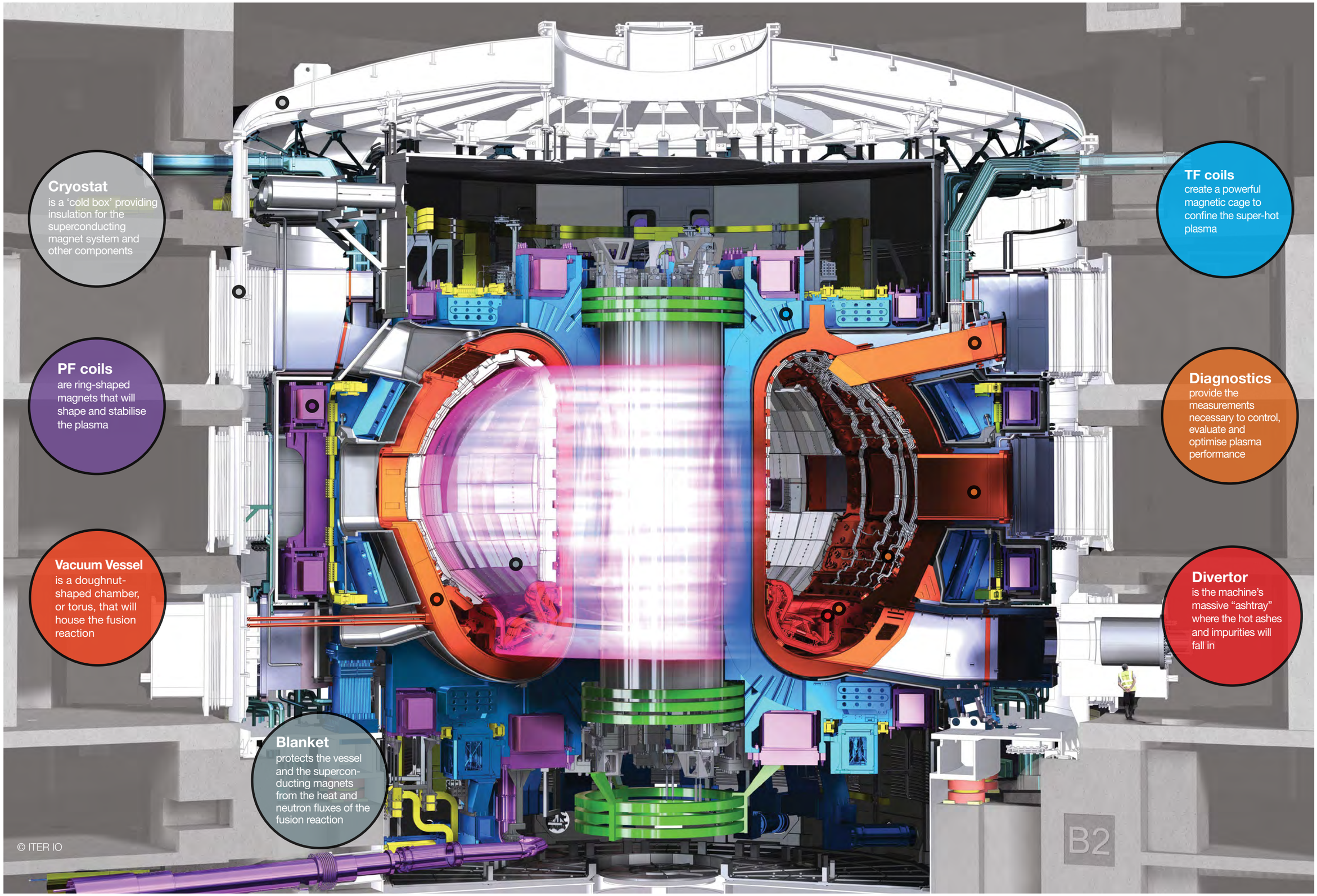
02

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. This brings a one-of-a-kind opportunity for industry, SMEs and fusion laboratories to get involved and be part of an emerging energy market.

During 2023, Europe delivered the last of its ten Toroidal Field coils. Meanwhile on-site, where the Poloidal Field coils are produced, PF4 was completed and works for our biggest coil, PF3, neared completion. The manufacturing of the vacuum vessel sectors made headway in different facilities, while in-vessel components like the First Wall panels and the Inner Vertical Target made more steps towards series production. Europe and Japan signed their collaboration for the Test Blanked Modules. The cryogenics system also saw progress, with all Cold Valve Boxes handed to ITER and liquid nitrogen supplied for commissioning of the Cryoplant. F4E met new milestones as well in the development of its systems for Diagnostics and Remote Handling, like the In-Vessel Viewing System. More power supplies were delivered to the ITER site, while significant progress was made with the components of the MITICA beam source. Europe's six gyrotrons entered production phase after successful testing.


Cryostat
is a 'cold box' providing insulation for the superconducting magnet system and other components
TF coils
create a powerful magnetic cage to confine the super-hot plasma
PF coils
are ring-shaped magnets that will shape and stabilise the plasma
Diagnostics
provide the measurements necessary to control, evaluate and optimise plasma performance
Vacuum Vessel
is a doughnut-shaped chamber, or torus, that will house the fusion reaction
Divertor
is the machine's massive "ashtray" where the hot ashes and impurities will fall in
Blanket
protects the vessel and the supercon-ducting magnets from the heat and neutron fluxes of the fusion reaction
© ITER IO
B2

MAGNETS

ITER will operate with the largest and most integrated superconducting magnet 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 has manufactured 10 out of the 18 TF coils involving more than 700 people from 40 companies, whilst Japan provided the remaining 8, 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. The remaining coil is produced in Russia.

TF Coils manufacturing	99%*
PF Coils manufacturing	97%
Pre-Compression Rings	100%

*All 70 Radial Plates and 10 Winding Packs are completed. The remaining 1% represents the work calculated over the entire production.

TOROIDAL FIELD COILS

All Toroidal Field coils completed: a milestone for celebration

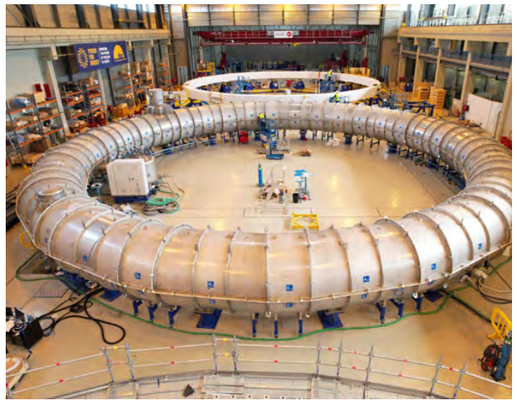
ITER's 18 plus one spare Toroidal Field coils were safely delivered, as Europe's final D-shaped magnet arrived in Cadarache. The delivery of TF #18 closed a 15-year collective endeavour, during which F4E has worked with at least 40 companies from all over Europe. Next, the TF coils will undergo cold tests onsite (at 4 K, or -269° C).

The team celebrates the arrival of TF #18 from Europe. December 2023. ©ITER Organization

POLOIDAL FIELD COILS

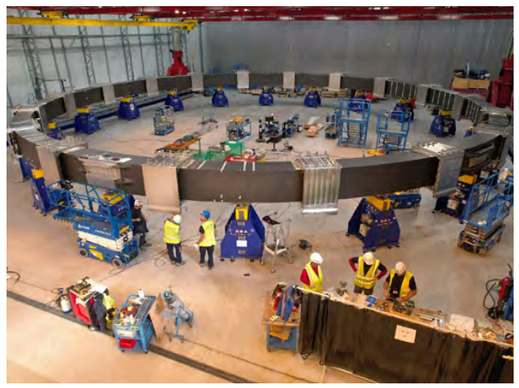
Wrapping up with the two biggest magnets

Europe made good progress with production of the final two Poloidal Field coils, which also happened to be the largest ones. The team celebrated the delivery of PF4, now wrapped and stored. With regards to PF3, the magnet went through final cold testing. Due to their unprecedented size of 24 m in diameter, both magnets were manufactured from start to finish in Europe's factory on-site, involving up to at least ten companies.



Cold tests were successful for PF4 at the European Poloidal Field coils factory, Cadarache. May 2023. ©ITER Organization

Representatives of F4E, ASG, ISQ, Dalkia, Veolia, Onet standing in the middle of PF4, Poloidal Field coils factory, Cadarache. July 2023. ©F4E



PF3 assembled before the cold test. After its delivery, the whole facility will be handed over to ITER Organization for other assembly purposes. September 2023. ©ITER Organization

PF4 and the smaller PF6 in storage on the ITER site. September 2023. ©ITER Organization

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. Each sector is 12 m high, 6.5 m wide and 6.3 m deep and weighs approximately 500 t. At least ten European companies are involved in their fabrication.

Work in progress

Sector 5
Manufacturing 100%
Assembly 87%

Sector 4
Manufacturing 100%
Assembly 44%

Sector 9
Manufacturing 100%
Assembly 2%

Sector 3
Manufacturing 93%
Assembly 0%

Sector 2
Manufacturing 83%
Assembly 0%

Welding and assembly at cruise speed for Europe's vacuum vessel sectors

Work for Europe's five vacuum vessel sectors, produced by the AMW consortium (Ansaldo Nucleare, Mangiarotti, Walter Tosto), advanced by making progress with its segments (the pieces that make a sector). ENSA, one of the subcontractors, developed and applied a new technology in the fabrication of segments: a robot-based automatic welding that enhanced the quality of the process. This enabled the completion of welding of the five segments ENSA is responsible for. The sub-components were shipped to the Westinghouse/ Mangiarotti facility in Monfalcone, Italy.

One of Europe's segments (PS4 of Sector 2) where ENSA performed welding operations with the help of robots, ENSA, Spain, March 2023 © ENSA

Installation of in-wall shield blocks (poloidal segment 2- poloidal segment 3 joints) of Europe's vacuum vessel sector 5 in the factory of Westinghouse Mangiarotti, Italy, 2023. ©F4E

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
Contracts signed 40%
Design 80%

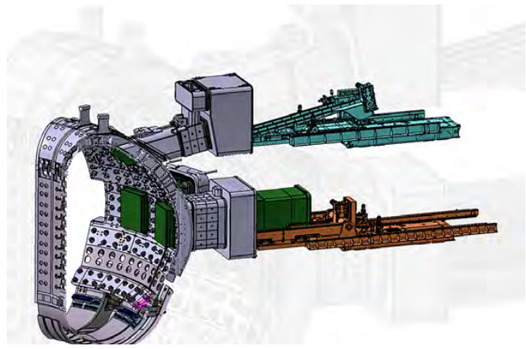
Cask & Plug RH
Contracts signed 24%
Design 69%

Neutral Beam RH
Contracts signed 22%
Design 66%

In Vessel Viewing System
Contracts signed 33%
Design 82%

Cask and Plug Remote Handling System design ready for manufacturing

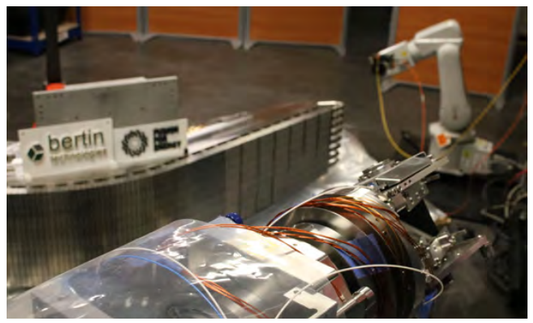
F4E's collaboration with Ansaldo Nucleare, ITER Organization and other partners culminated with the final design review for the Cask and Plug Remote Handling Systems needed for first assembly tasks. Operated through sophisticated man-in-the-loop robotics, the 15 casks will transfer plugs in and out the ports and transport them across the buildings. The design includes a combination of viewing and navigation technologies, sensors, actuators, hydraulics and electronics. Subsequently, the contract was launched for the manufacturing of the different components of the system.



Ilustration of the ITER Cask and Plug Remote Handling System, with the Upper Port Plug and Equatorial Port Plug. April 2022 ©F4E

In-Vessel Viewing Systems successfully tested

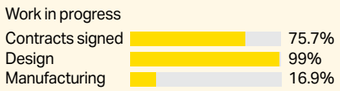
The In-Vessel Viewing System (IVVS) and Target Reflectivity Measurement System (TARMS) showed to be fully operative. Financed by F4E, both technologies were tested on a full-scale prototype of an Inner-Vertical Target. The IVVS, developed by Bertin Technologies within two years of signing the contract, uses an optical probe directing laser beams to scan the in-vessel surfaces for damages or erosion. This is complemented with TARMS, produced by ASE Optics Europe, which calculates the performance of IVVS on a given component based on the reflectivity of the light on its surface.



The IVT prototype, manufactured by Research Instruments, undergoing inspection by the In-Viewing System probe prototype in the workshop of Bertin Technologies, France. May 2023 ©F4E

DIAGNOSTICS

The Diagnostics systems will help scientists to study and control the plasma behaviour, measure its properties and improve our understanding in the respective field of 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.



Final design and assembly trials for the ITER feedthroughs alignment tool

F4E will supply ITER with the 75 feedthroughs that allow diagnostic cables to cross the vessel wall without breaking the vacuum. Transporting and inserting them into place will be a delicate operation, for which F4E and its partner IDOM decided to develop two alignment tools, tailored for the upper and lower ports. The teams in IDOM completed the final design, built a mock-up and successfully ran assembly trials. Meanwhile, series production of the feedthroughs by Alsymex is underway.

Divertor Tangential Coils delivered for Magnetic Diagnostics

F4E handed to ITER Organization a set of Divertor Tangential Coils and associated mechanical platforms, completing Europe’s contribution for these components. These coils form part of the ITER Magnetics Diagnostic suite and comprise 36 compact sensors mounted on electrical platforms that are bolted to the ITER Divertor Cassettes. F4E also delivered the electronics systems required to interface with the signals produced by the suite.

Fitting the feedthrough and the mineral-insulated cable in the port plugs is a precise task that requires specialized tooling. May 2023. ©F4E

Colleagues from F4E, ITER Organization and Elytt present during the site acceptance tests of the equipment. June 2023. ©F4E

TEST BLANKET MODULES

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

Collaboration with Korea for a new TBM concept

Europe and Korea signed an agreement to develop jointly helium-cooled ceramic pebbles, as one of the four TBM breeding concepts under exploration for ITER. In a partnership expected to run until 2042, Korea will lead the in-kind contribution with up to 60%, whilst F4E will provide 40%. An integrated single project team will pilot design, construction and procurement activities to deliver the joint TBM and its ancillary systems.

Representatives of F4E and ITER Korea signed the Partnership Arrangement in Cadarache. March 2023. © ITER Organization

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 98%
- Series qualification 60%

Blanket & First Wall
- Prototype qualification 100%
- Production line 85%
- Production qualification 50%

Inner Vertical Target
- Qualification 90%

Divertor Cassette Body
- Qualification stage I & II 100%
- Design & Engineering 95%
- Manufacturing 28%

Contract signed for blanket cooling manifold

Europe is in charge of the 10-km cooling manifold running beneath the blanket, from top to bottom of the ITER device. In order to remove up to 736 MW of thermal power from the panels, pressurised water will circulate through a network of different types of pipes. F4E signed a framework contract with Dockweiler–Tecnalia–Leading, Altrad Babcock Europe and SIMIC, expected to run for seven years with a budget of up to100 M EUR. The three bidders will compete for different task orders in the qualification and manufacturing of the prototypes.

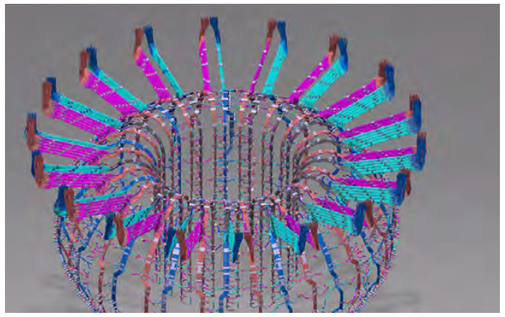


Illustration of the ITER Blanket Cooling Manifold system procured by F4E. ©F4E

First wall and divertor sub-components advance

In the frame of two contracts for the series production of the First Wall panels, manufacturing of pre-series panels by Alsymex (France) and FBL (Spain) made progress. With regards to the Divertor Cassette Bodies, manufacturing, machining, welding, and qualification of ancillary items continued. The engineering and qualification phases for the Inner-Vertical Target series production by Alsymex started.

Pre-Series First Wall panel during manufacturing at Alsymex. December 2023. ©Alsymex

HEATING & CURRENT DRIVE

ITER plans to heat the plasma using several systems. These include the Neutral Beam Heating (NBH), penetrating the magnetic field with high-energy neutral particle beams, and the Electron Cyclotron (EC), injecting powerful electromagnetic waves.

For the NBH, given the ambitious technological leap from similar systems worldwide to those of ITER, a dedicated test facility, known as the Neutral Beam Test Facility (NBTF), has been set up in Padua, Italy. It is the host of two experiments, SPIDER, dedicated to the development of the ion source, which started operations in 2018, and MITICA, which is in progress, dedicated to the development and test of a full-size prototype of an ITER Neutral Beam Injector.

F4E is currently completing its contribution to the NBTF, focusing on the MITICA beam source and beam line components, while in parallel advancing with the fabrication of the first ITER Neutral Beam components.

Europe is also contributing to EC systems with the manufacturing of several sets of dedicated power supplies, six gyrotrons, four upper launchers, and associated ex-vessel waveguide systems.

F4E is actively collaborating with engineering companies and European fusion laboratories for the design, fabrication, and delivery of these components.

Work in progress

Electron Cyclotron Power Supplies
- Manufacturing/Testing 100%
- Delivery/Installation 70%

HNB Power Supplies for Cadarache
- Design 80%
- Manufacturing/Testing 50%

NBTF (MITICA)
- Design 100%
- Manufacturing/Testing 85%
- Delivery/Installation 75%

EC Launcher
- Contract signature 70%
- Design 65%
- Manufacturing 12%

EC Gyrotrons
- Contract signature 70%
- Design 60%

NB Vessels
- Contract signature 100%
- Design 80%

All 60 diamond discs manufactured

German SME Diamond Materials completed the production of the 60 diamond discs (56 needed for ITER plus 4 spare) commissioned by F4E. These round resistant "gates", belonging to the first wall of confinement, are 1,1 mm thick with a 7 cm diameter. They will allow the microwave beams from the Electron Cyclotron Upper and Equatorial Launchers into the hermetically sealed vacuum vessel. After manufacturing, they travelled to the Karlsruhe Institute of Technology (KIT) for optical testing. Once ready, they will be inserted in the so-called Diamond Window Unit (DWU), to be completed by the end of 2026.

Some of the diamond discs, produced by Diamond Materials for Fusion for Energy. 2023. © ITER Organization

Success for MITICA Cryopump site tests

The Cryopump for MITICA experiment successfully completed the on-site acceptance tests in the NBTF in Padua. This marks the success of F4E's five-year multi-million collaboration with SDMS and Ravanat, in partnership with ITER Organization and Consorzio RFX. This piece of equipment, to be inserted inside MITICA's beam vessel, is 8 m long by 2.8 m high and 0.45 m wide and is composed of two pumping assemblies, with 32 sections each. The cryopump's function is creating the necessary vacuum inside the beam source for ions to be accelerated into a beam of 1 MeV of energy.

Inside of the MITICA bunker with the vacuum vessel on the right and the last part of the 1MV transmission line in blue. September 2023. ©ITER Organization

Representatives from ITER Organization, F4E, SDMS, Consorzio RFX on the day of the cryopump site tests in Padua March 2023. ©ITER Organization

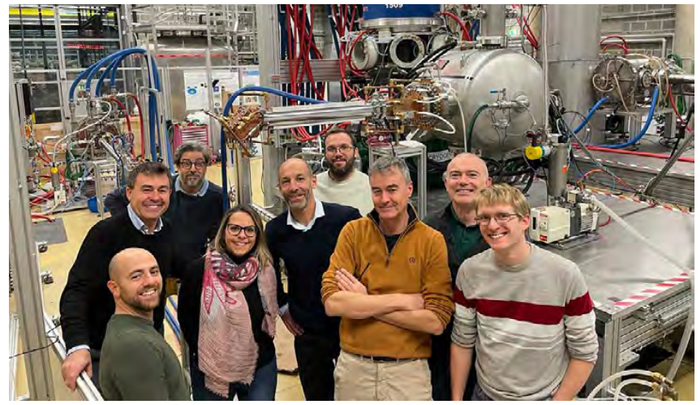
Manufacturing progress of MITICA beam source

The assembly of the MITICA accelerator was finalised, after integrating the five acceleration grids and the extractor. The top connections were also finalised, being assembled in a temporary supporting structure. Meanwhile, the assembly continued for the MITICA beam source, for which more than 20 European companies have been involved.

The five stages accelerator of the MITICA beam source fully assembled together with the extractor. November 2023 ©Alsymex

Kick-off for the manufacturing of gyrotrons

F4E officially tasked Thales with the manufacturing of Europe's six gyrotrons, whose radiofrequency power of 1 MW will heat the plasma electrons in ITER. The green light came after the successful long-pulse tests for a pre-series unit at the test facility FALCON in Switzerland. The contract covers design, production, factory testing, installation and testing and is expected to last six years for a value of approximately 20 million EUR. Russia, Japan and India will provide the rest of the 24 gyrotrons for ITER.



Representatives of F4E, DTT, Swiss Plasma Centre, Thales at the Falcon Facility, testing the gyrotron pre-series unit, December 2023. ©SPC

Installation of Electron Cyclotron Power Supplies

F4E oversees the design, manufacturing, delivery, installation, and commissioning of 8 Electron Cyclotron Power Supply (ECPS) units feeding 16 of the 24 ITER gyrotrons. In 2023, the installation of 4 ECPS units was completed in ITER, leaving them ready for commissioning, whilst the remaining 4 were still under installation in the dedicated building. Besides, the power supplies for the neutral beam heating system moved closer to delivery, with several sub-systems nearing end of fabrication.

The first of Europe's ECPS were installed in ITER, ready for commissioning. June 2023. ©F4E

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.

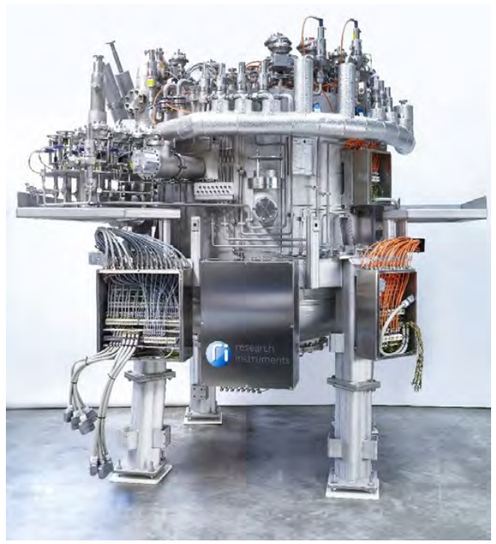
Work in progress

LN2 Plant	
Contracts signed	95%
Design	100%
Manufacturing	100%
Installation & Commissioning	75%
Vacuum Pumping	
Contracts signed	69%
Design	84%
Manufacturing	55%
Tritium Plant	
Contracts signed	32%
Design	35%
Manufacturing	18%
REMS and Rad Waste	
Contracts signed	7%
Design	9%
Manufacturing	0%

All cold valve boxes delivered on time to ITER

The eight Cold Valve Boxes (CVBs) successfully completed their factory acceptance tests. They were manufactured by Research Instruments and with subcontractors Cryoworld and Velan. Located in the lower port cells, six of the boxes are destined for the torus cryopumps and two for the cryostat, connecting them to the refrigeration system. The 4-tonne CVBs are expected to be in place once the installation of the cryolines is completed.

Close up of the valves in the Cold Valve Boxes, that ITER will rely on in order to attain the vacuum conditions in its vessel. 2023. ©RI



The Cold Valve Boxes procured by F4E are designed to operate within an exceptionally large temperature range under the harsh environment of the ITER Tokamak. 2023. ©RI

Cryojumpers ready to distribute cold helium

The five-year contract between F4E and the German company Cryotherm concluded successfully with the delivery of 32 sets of cryojumpers plus spares to ITER. These semi-flexible pipes distribute cold helium to the torus and cryostat cryopumps with minimal heat loss and pressure drop.

ITER Organization and F4E teams celebrated the delivery of cryo-jumpers. March 2023. ©ITER Organisation

Two of the torus and cryostat cryopumps during the factory acceptance tests at Research Instruments. November 2023 ©RI

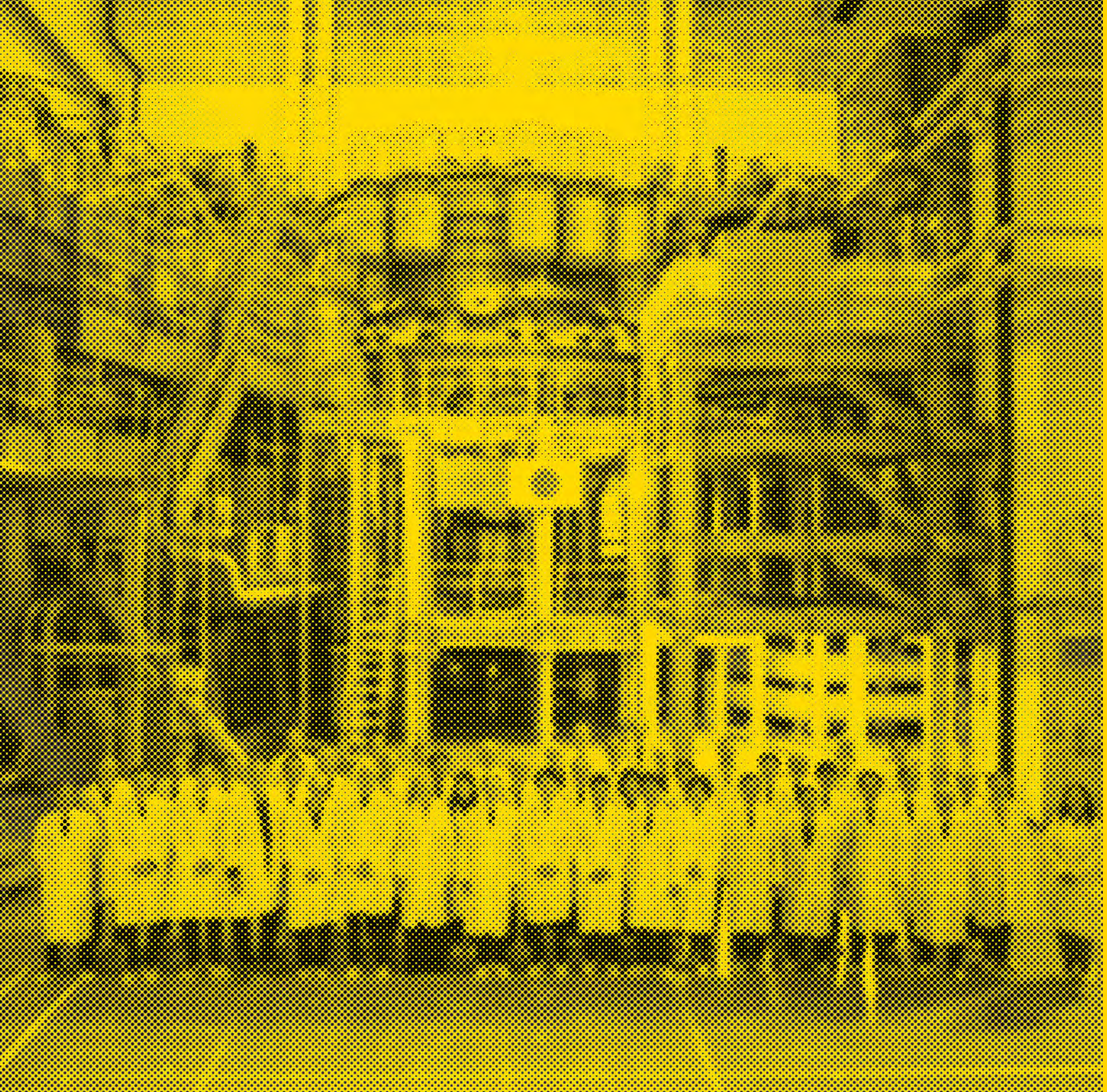
Final stage for cryopumps production

The production of Europe's 8 torus and cryostat cryopumps by the RI-Alsymex consortium advanced through its final stages. These first-of-a-kind components will create and sustain the vacuum conditions inside ITER thanks to cooled absorbing panels. Final assembly started for two of the pumps, with cold and pressure tests successfully passed. All the valves and their associated plugs were manufactured and ready for final assembly.

Quench line header delivered

The commissioning of the Cryoplant continued, with liquid nitrogen being supplied to the liquid helium plant. F4E delivered to ITER the quench line header, the last equipment to be supplied by Europe for the infrastructure that will store, feed and recover cryogenics to and from the network.

The quench line headers stand in the cryoplant storage area. October 2023. ©F4E



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 challenges summarises the spirit of collaboration in 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.

JT-60SA

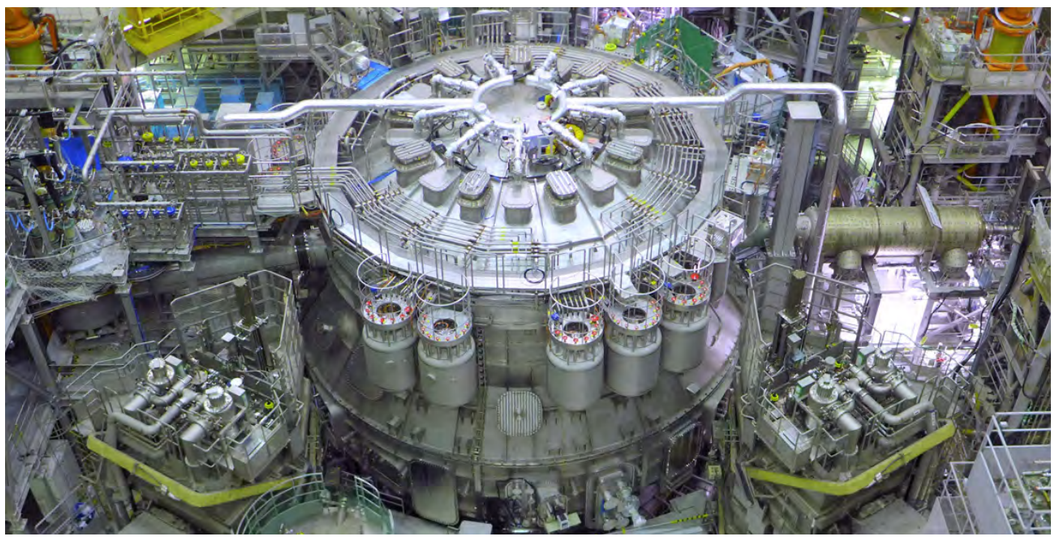
The JT-60SA is the largest tokamak in the world until ITER starts operations. Located in Naka, Japan, and hosted by Japan's National Institutes for Quantum Science and Technology (QST), this device is the upgrade of an existing tokamak to be capable of long pulse operation. This experimental device will support ITER through complementary experiments to improve the design of the Demonstration (DEMO) fusion reactor, which will be connected to the grid.

First plasma for JT-60SA

Europe and Japan successfully achieved plasma for the first time at JT-60SA in October 2023. This breakthrough made it the world's largest operational superconducting tokamak to date.

After the first one, which lasted less than one second, the team pursued tests, producing plasmas with a current greater than 1 MA for a duration greater than 10 seconds. The results are examined in detail, as all the knowledge generated through these activities will feed larger-scale experiments ITER and DEMO.

Members of the JT-60SA team, exchanging on preliminary data in the control room. October 2023. ©QST/F4E



The size of the JT-60SA Tokamak is 135m³. Naka, Japan. 2023. ©QST/F4E

Inauguration ceremony of the device

The official unveiling of JT-60SA took place in December 2023. Senior EU and Japan politicians were joined by representatives from industry and the research community. They witnessed a plasma operation from the control room and celebrated the culmination of a long journey. Works for the device started in 2007 and were completed in 2020 with the end of assembly, after a total investment in the range of 560 million EUR for the construction phase. The contributions from both sides have been coordinated by F4E, EUROfusion and Japan's (QST), in a scientific partnership that has been praised for its dynamic, and efficient modus operandi.

(L-R) Commissioner for Energy, Kadri Simson, Japan's Minister for Education, Culture, Sports, Science and Technology, Masahito Moriyama, and Japan's Minister of State for Science and Technology Policy, Sanae Takaichi. December 2023. ©QST/F4E

A new generation of fusion experts in the JT-60SA International Fusion School

Ten students from Europe and ten from Japan delved into the latest fusion developments at the JT-60SA International Fusion School (JIFS), hosted by QST in Naka (Japan) and with the financial support of QST, EUROfusion and F4E. The young experts attended several lectures carried out practical exercises and visited JT-60SA and other QST facilities.

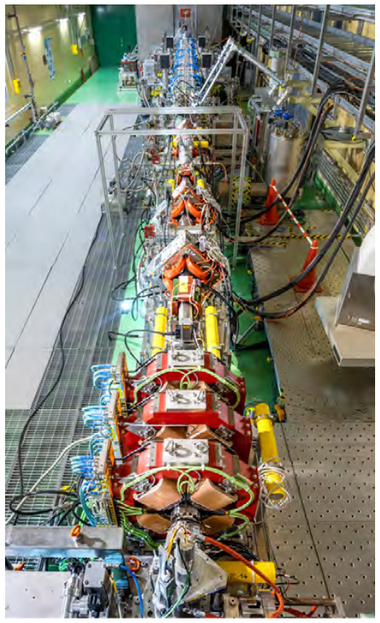
JT-60SA International Fusion School (JIFS) participants in Naka, Japan. September 2023. ©QST

IFMIF/EVEDA

Reproducing the conditions of future fusion reactors is the objective of the International Fusion Materials Irradiation Facility (IFMIF). This accelerator-based facility will test materials for the DEMO reactor, which will follow ITER, simulating the harsh conditions inside the device. 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.

Progress in LIPAc continuous beam campaign

The Linear IFMIF Prototype Accelerator (LIPAc) brings together European and Japanese experts, working to validate the design of a neutron source to test materials for fusion machines after ITER. Operations to secure a continuous beam continued at the LIPAc with a series of “campaigns” analysing equipment and performance. This enabled the Broader Approach Steering Committee (BASC) to propose a new schedule for beam operations in a timely manner.



The accelerator in its configuration for beam operation tests. January 2023. ©IFMIF/EVEDA

IFMIF-DONES

The Demo Oriented Neutron Source (DONES) facility is a research infrastructure under construction in Spain. Its goal will be to help scientists test, validate and qualify the materials to be used in future fusion power plants like DEMO.

Construction underway for the Granada particle accelerator

IFMIF-DONES will soon be a reality in Escúzar, in the province of Granada, Spain. The DONES Steering Committee gave the green light for the construction of the infrastructure. Whilst the first auxiliary buildings have advanced, work on the Main Building is set to begin in 2025. To populate them, the staffing plan foresees the recruitment of 200 professionals in the coming years.

F4E worked with Spain and Croatia, the parties committed to contribute to DONES, to set up the ramp-up phase of the programme, which aims to develop a database of the effects of neutron irradiation on different materials. The facility will host a neutron source with a spectrum similar to that of fusion reactors.

(L-R) Massimo Garribba, Deputy Director-General of the European Commission’s DG Energy; José Carlos Gómez, Andalusia’s Minister of University, Research and Innovation; Diana Morant, Spain’s Minister of Science and Innovation; Radovan Fuchs, Croatia’s Minister of Science and Education; Stasa Skenzic, Head of International Cooperation at the Ministry of Science and Education of Croatia

March 2023 © IFMIF-DONES

04

Working together with stakeholders

F4E actively engaged with European and national stakeholders through periodic updates and the communication of success stories highlighting the direct and indirect benefits of the project. ITER is a motor of economic growth, innovation and competitiveness, ultimately making a contribution to a sustainable energy mix for the future.

With the support of various F4E committees and the network of ITER Industrial Liaison Officers (ILOs), various initiatives were undertaken to reach out to industry, SMEs and research organisations in order to get involved.

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

F4E Director updates the European Parliament

F4E Director Marc Lachaise was invited twice to the European Parliament (EP) to provide updates on the progress of F4E's contribution to ITER. In the context of preparations for the 2024 draft budget, he exchanged with the EP Committee on Budget about the implementation and forecast in the view of the ITER baseline. At the EP Committee on Industry, Research and Energy (ITRE), he also updated MEPs on the progress of ITER.

Marc Lachaise, F4E Director, addressing the ITRE Committee at the EP. October 2023. ©F4E

F4E at the EP's Panel of Science and Technology

F4E was invited by the European Parliament's Panel for the Future of Science and Technology (STOA) to speak in two different events. In February, F4E's Head of Broader Approach, Susana Clement, highlighted the merits of fusion at the discussion "Sustainability and innovative technology for nuclear energy". In May, F4E's Head of JT-60SA, Enrico di Pietro, showcased ITER and JT-60SA as fine models of science diplomacy, in a workshop on international collaboration, coorganised by STOA and the Science and Technology in Society (STS) forum.

F4E's Head of Broader Approach, Susana Clement (second on the right) sitting at STOA's discussion on the place of nuclear fission and fusion within tomorrow's energy mix, February 2023. © EP

F4E Contracting Professionals Roundtable

More than 300 legal professionals from more than 20 countries participated in the second edition of F4E's Energy Contracting Professionals Roundtable in Cadarache. The event, organised in collaboration with the International Nuclear Law Association (INLA) and the ITER Organization, focused on innovative legal thinking for successful fusion megaprojects. Discussions focused on topics like contract strategies, nuclear liabilities, export control, insurance, public procurement law, intellectual property law or regulation of fusion technologies.

Some of the professionals who gathered for the two-day event at the ITER site. June 2023. © F4E/ITER Organization

EC seminar on Green Deal and fusion in Barcelona

F4E, with the support of the Representation of the European Commission (EC) in Barcelona, organised a debate on European green strategy and the role of fusion in the energy mix of the future. Presentations by DG Energy and F4E staff were followed by a session of questions by the attendees, mostly students and members of pro-EU youth associations.

Manuel Szapiro, Head of the European Commission Representation in Barcelona, addresses the audience next to F4E staff members. March 2023. ©F4E

Barcelona Sustainable Energy Days

F4E co-organised once again the Sustainable Energy Days in Barcelona together with the UPC BarcelonaTech University, within the framework of the European Sustainable Energy Week. The 2023 edition invited several experts on stage to discuss the innovation and policy challenges to achieve a low-carbon economy, and also featured a visit to the Center for Research in Multiscale Science and Engineering.

F4E Director Marc Lachaise opened the session with an address on fusion's potential for a decarbonised future. October 2023. ©BTEC

Fusion for Energy at the World Nuclear Exhibition

Fusion for Energy and ITER Organization held a stand at the World Nuclear Exhibition (WNE), an opportunity to meet industry, research centres and other experts in the sector. EU Commissioner for internal Market, Thierry Breton, visited the stand and in his opening speech highlighted the European and international partnerships to develop fusion energy.

The F4E stand featured a miniature model of ITER. November 2023. ©F4E

F4E Women's Network awarded by EU Agencies

The EU Agencies Network (EUAN) recognised F4E's diversity and inclusion (D&I) efforts in an award ceremony celebrating best practices in the field. The first prize winner was F4E Women's Network, a community of over 150 colleagues, aimed at offering a safe space to share experiences and foster personal and professional growth, as well as raising awareness and advocating for women's issues. F4E's campaign for men "Breaking stereotypes: be your own you!" also received a certificate of excellence.

Universidad Internacional Menéndez Pelayo Summer School

F4E Director presented the benefits of fusion and ITER at the Summer school on new technologies in the nuclear sector, at the Universidad Internacional Menéndez Pelayo in Santander, Spain.

Marc Lachaise was among the experts speaking at a roundtable on fusion reactors. July 2023 @UIMP

F4E Director visits CIEMAT

F4E Director, Marc Lachaise, visited the headquarters of CIEMAT, a Spanish public research body focusing on energy and environment, in Madrid. There, he met with CIEMAT managers and had a chance to see the fusion device TJ-II, at Laboratorio Nacional de Fusión.

(L-R) F4E Governing Board Chair, Carlos Alejaldre; F4E Director, Marc Lachaise; CIEMAT Director, Yolanda Benito; CIEMAT Chief Scientist, Joaquín Sánchez. September 2023. @F4E

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 978-92-9214-046-5
ISSN 2363-3212
doi: 10.2827/997724

Print
ISBN 978-92-9214-047-2
ISSN 2363-3204
doi: 10.2827/470374

Printed by Imprimerie Bietlot in Belgium

Luxembourg: Publications Office of the European Union, 2024

FU-AC-24-001-EN-N

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: +34 933 201 800
Fax: +34 933 201 851
E-mail: info@f4e.europa.eu

www.fusionforenergy.europa.eu
www.x.com/fusionforenergy
www.youtube.com/fusionforenergy
www.flickr.com/photos/fusionforenergy
www.linkedin.com/company/fusion-for-energy

ISBN 978-92-9214-046-5

Fusion for Energy receives funding from the European Union budget

Publications Office of the European Union