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FUSION FOR ENERGY

HIGHLIGHTS 2024

THE MAIN ACHIEVEMENTS

2024
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Foreword

Dear stakeholders, colleagues, readers,

Fusion energy is gaining political, technical and industrial momentum.

Technological breakthroughs, increasing private investment and governmental commitment are speeding up the race to harnessing fusion as an environmentally friendly energy source.

Europe could be at the forefront, leveraging its world-class research and industry. The stakes for Europe are high: competitiveness, autonomy, and sustainability are at the centre and Fusion for Energy (F4E), by delivering on key fusion projects with its unique set of competencies, plays a pivotal role in strengthening our continent's leadership.

In this context, 2024 has been a strategic year of progress for F4E. We have continued to deliver on ITER and the Broader Approach (BA) activities, drawing lessons from these key projects while contributing to other experiments as part of the fusion roadmap.

Together with our partners, we have achieved many milestones, such as:

- First European ITER Vacuum Vessel Sector manufactured, a massive industrial achievement.
- Final Poloidal Field Coil delivered to ITER, one of the largest superconducting magnets ever.
- Handover of key ITER buildings, ready for upcoming assembly and integration activities.
- Progress towards continuous wave at the LIPAc accelerator.
- Upgrades in JT-60SA, the world's largest tokamak, built by Europe and Japan.
- Start of construction for the DONES facility to develop fusion materials.

We have also made commendable progress in other areas such as In-Vessel components, Remote Handling, Diagnostics, External Heating and Fuel Cycle Systems. To achieve this, we keep working closely with European industry, SMEs and research organisations. Since 2007, we have signed 1350 contracts with a cumulative value close to 7 billion EUR. These successes were matched by improved project and financial execution, The positive performance is reflected in the 84% completion rate of the F4E planned activities for the ITER project, and 100% on the critical path activities as reported by ITER Organization.

Additionally, the ITER Organization, has presented a new baseline plan of the next stages of the project, reinforcing our commitment to its joint success. We also pursued further integration between F4E and the ITER Organization, especially in civil engineering and buildings, capitalising on resources and delivering efficiencies.

Beyond technical and project achievements, this was also a year of transformation for F4E. We implemented a new organisational structure, which strengthens matrix management, improves collaboration, and capitalises on our expertise—all while ensuring business continuity. At the heart of our success is our people and a new leadership team.

We strengthened our collaboration with the EUROfusion consortium, to better connect research and industry. We also launched the Technology Development Programme to map and advance key technologies for the future of fusion. In parallel, we kept expanding our engagement with the industrial supply chain to ensure Europe's involvement in an ever-evolving fusion landscape. Last but not least, we started exploring partnerships with European private fusion initiatives, paving the transition from experimental to commercial fusion.

I would like to extend my sincere gratitude to the entire F4E team, our partners, and stakeholders for their dedication and expertise. Our achievements this year are a testament to our collaboration and shared vision to delivering this safe, limitless, and sustainable power.

Marc Lachaise
Director, Fusion for Energy

FUSION - AN ENERGY FOR THE FUTURE

Fusion is the process that powers the Sun and other stars. Harnessing it on Earth, as an energy source, is a major scientific and technological challenge whose potential rewards are far-reaching:

- The fuels required are widely available reducing the risk of any geopolitical tensions. There are enough supplies to last millions of years.
- Small amounts of fuel can generate plenty of energy: 60 kg of fusion fuel can provide the same amount of energy as 250 000 tonnes of oil.
- No greenhouse gas emissions or long-lasting radioactive waste are produced. Fusion power plants would be inherently safe posing no risk to populations in the vicinity.
- Fusion plants would be able to complement the power generation with renewables by providing a steady “baseload” electricity supply, when needed.

With these advantages, fusion has the potential to broaden Europe’s energy mix and provide our citizens with safe, sufficient and sustainable power.

FUSION FOR ENERGY

Fusion for Energy (F4E) is a European Union organisation responsible for providing Europe’s contribution to ITER, the biggest scientific experiment on the path to fusion energy, amounting to nearly half of the project. In parallel, F4E is involved in three major fusion R&D projects, as part of the Broader Approach agreement between Europe and Japan, including the JT-60SA fusion device. Ultimately, F4E will use the knowledge and expertise built through these projects to contribute to the construction of industrial fusion power plants.

Our mission relies on three strategic pillars:

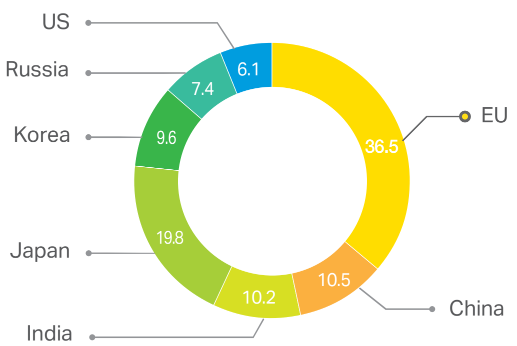
- Ensure the successful construction and operation of ITER and other key fusion projects.
- Build the talent and knowledge base for future fusion power plants in Europe.
- Grow a competitive European fusion supply chain.

INVESTING IN EUROPE’S POTENTIAL

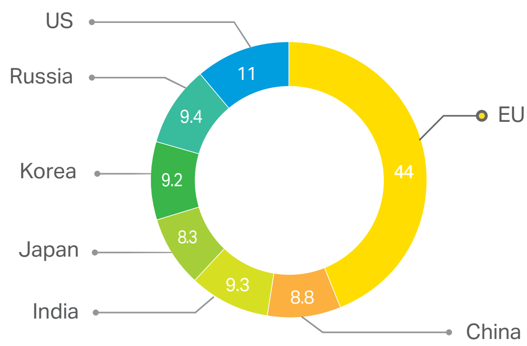
Europe’s investment in fusion brings many business opportunities. F4E works with an impressive supply chain of industry, SMEs and laboratories to manufacture advanced technologies and infrastructure for big projects like ITER. This generates new knowledge, skills and market opportunities, fostering the growth of a competitive fusion industry in Europe.

2024 Key figures

Contributions to ITER

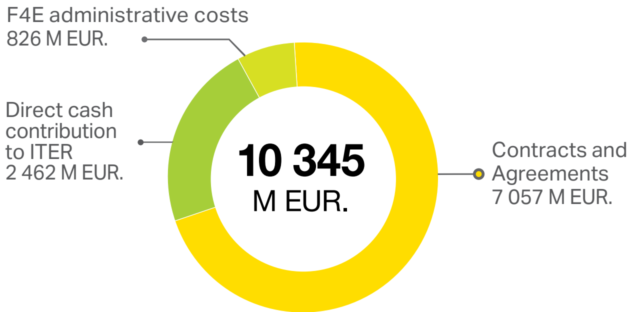


Total In Kind contributions in percentages
ITER Parties 2007-2024

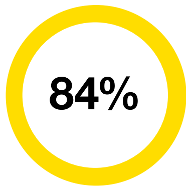


Total In Cash contributions in percentages
ITER parties 2007-2024

F4E budget breakdown of main activities 2007-2024



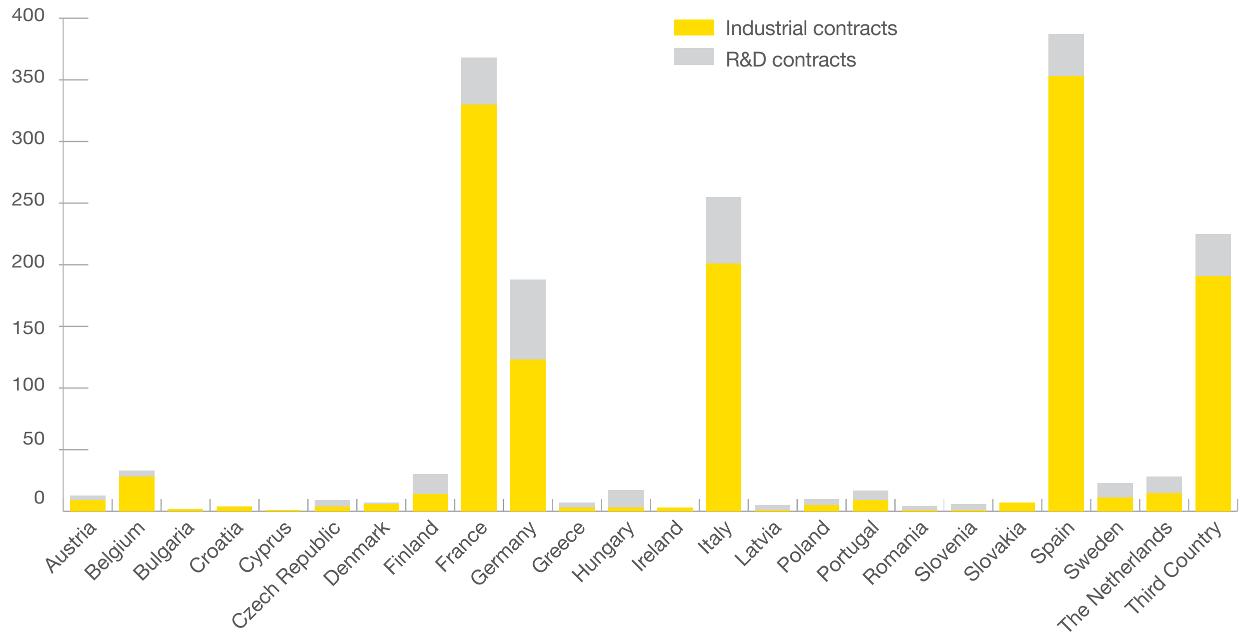
ITER Project Progress 2024



Completion of planned activities in 2024,
as reported by F4E

Completion of planned activities
on critical path in 2024,
as reported by ITER Organization

F4E contracts and grants by country



Number of contracts and grants awarded by F4E 2008-2024
Since 2021 Switzerland and United Kingdom are listed as 'Third Country'

Contracts with Industry and Laboratories

€167M
Total value of contracts signed in 2024

€6.8Bn
Total value of contracts signed 2007-2024

1349
Contracts signed since 2007

655
Companies

2105
Subcontractors

75
Research Organisations

Some of the F4E achievements during 2024

January

Europe's sector 5 of ITER Vacuum Vessel completes first factory acceptance test. Remote Handling Cask and Plugs contract kicks off.

February

F4E, DTT and Thales kick off contract for the manufacturing of Electron Cyclotron gyrotrons. ITER Poloidal Field coil 3 under final cold tests.

March

Successful demonstration for ITER Divertor Remote Handling System. Construction of IFMIF-DONES research facility starts.

April

Stakeholders discuss EU strategy for fusion. Design advances for Neutral Beam Remote Handling crane. Cryodistribution control cabinets delivered.

May

F4E completes Europe's final ITER Poloidal Field coil. First Neutral Beam power supplies arrive in ITER.

June

First cryopump delivered for ITER vacuum and fuel cycle systems. New cycle starts for IFERC supercomputer simulations.

July

Celebration of ITER Toroidal Field coils manufactured by Europe and Japan. Germany hosts EU Fusion Business Forum. Post-irradiation experiments for DEMO materials start.

August

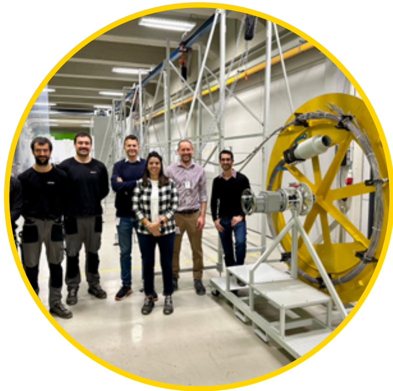
Inner Vertical Targets prototype ready for manufacturing. Successful operation campaign at Linear IFMIF Prototype Accelerator (LIPAc).

September

First European Vacuum Vessel sector completed. European Fusion Technology Marketplace portal launched. Radio Frequency Building handed over to ITER Organization.

October

Tokamak Complex painting works completed. F4E delivers beam line components for MITICA. F4E presents commercial opportunities and promotes the role of women at Big Science Business Forum.



November

Diagnostics feedthrough alignment tool delivered. F4E launches Technology Development Programme. Major ITER civil engineering contract between F4E and b.NEXT consortium.

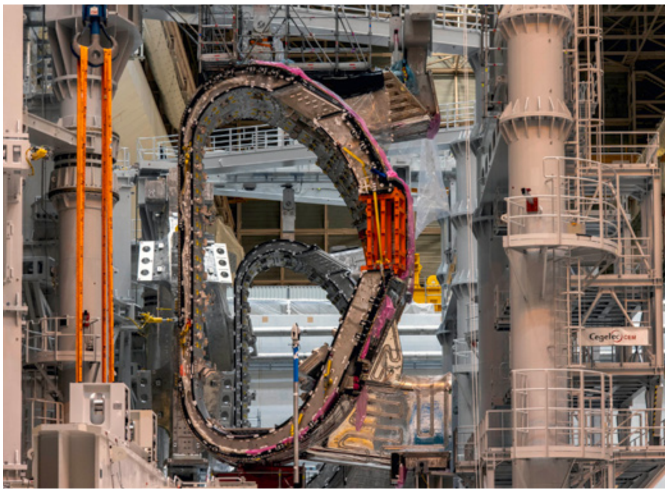
December

EUROfusion and F4E reinforce collaboration. F4E progresses with the design of Leak Detection Systems. First deliveries for Neutral Beam High Voltage Deck. Equipment for ITER Divertor manufactured.

Some of the ITER achievements during 2024

ITER Organization

A revised strategy for the ITER experiment
ITER Organization presented to the ITER Council a proposal for a revised baseline. The new plan foresees a reconfiguration of activities, with the start of research operations in 2034 and deuterium-tritium operations in 2039. November 2024. ©ITER Organization



Progress in vacuum vessel sectors repairs and re-assembly
The assembly of Korea's Vacuum Vessel sectors restarted in the last quarter of the year, after the bulk of the repairs were completed. In the picture, two sectors are suspended vertically in tooling at the Assembly Hall. November 2024. ©ITER Organization

Liquid helium production starts
The commissioning of ITER's cryoplant kept advancing, testing the production of liquid helium at 4 K (-269 °C) through twelve of the compressors and one cold box for storage. December 2024. ©ITER Organization

Installation of special pipes on the cryobridge
Inside the cryobridge, built by Europe, technicians progressed with the precise positioning of the cryolines, that will channel cold from the cryoplant into the Tokamak building. February 2024. ©ITER Organization

China

Workers from the CNPE consortium finalised the joints on the feeders procured by China, which will provide electrical power and cooling fluids to the ITER magnets. April 2024. ©ITER Organization

The first 48 blanket shield blocks were shipped from Guanzhou, China, to ITER. China is procuring 220 (out of 440) of these protective components, with Korea providing the rest. November 2024. ©ITER Organization

United States

The third central solenoid module was successfully lifted and positioned on top of the existing two-module stack, in the ITER Assembly Hall. April 2024. ©ITER Organization

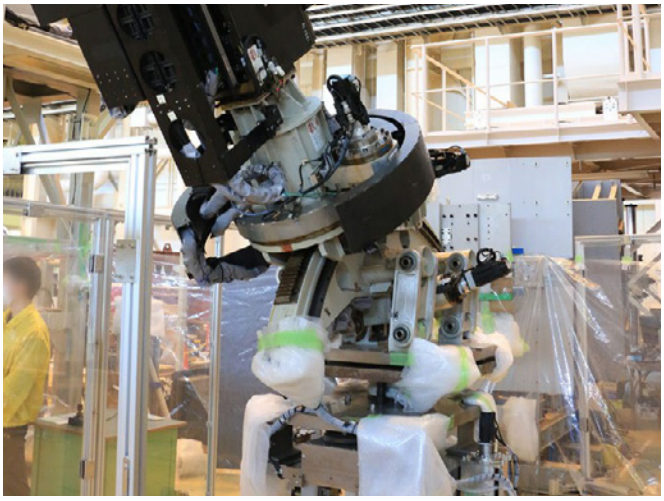
A fourth module was installed on top of the existing central solenoid stack in the ITER Assembly Hall. The US is procuring the six central solenoid modules plus one spare. December 2024. ©ITER Organization

India

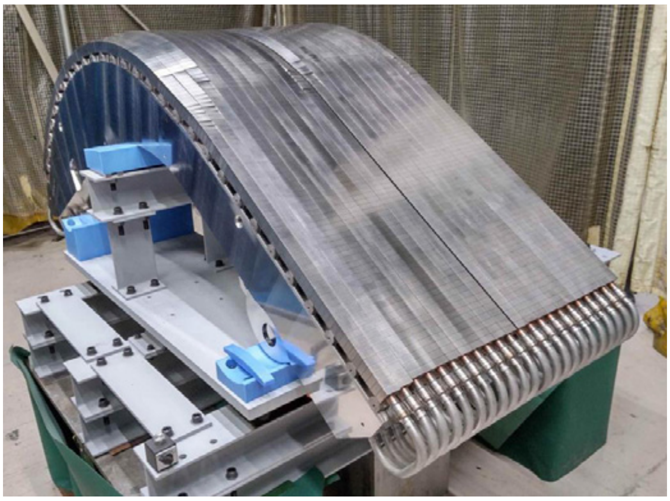
INOX-CVA India started repairing two vacuum vessel thermal shield sets. The first left the factory and travelled to ITER. February 2024. ©ITER Organization

The ITER cooling water and heat rejection systems provided by India entered routine operation and are ready to support the commissioning of other plant systems. April 2024. ©ITER Organization

Japan



A robotic manipulator arm, part of the remote handling system to replace first wall panels, undergoing testing. June 2024. ©ITER Organization



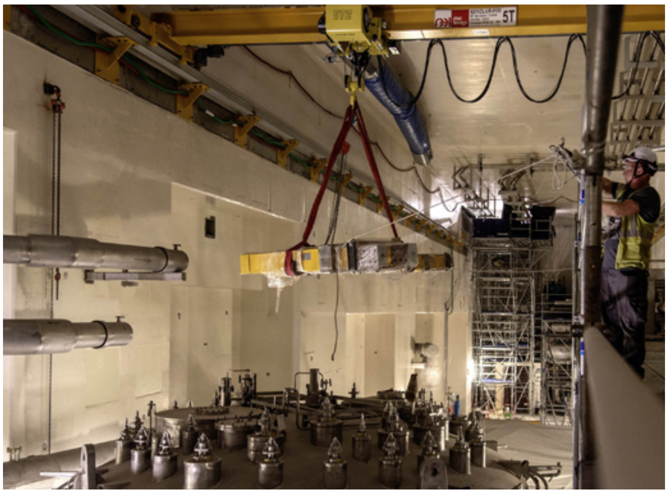
Japan's QST and Mitsubishi Heavy Industries manufactured and qualified a prototype of the divertor outer vertical target, giving green light to series manufacturing. September 2024. ©ITER Organization

Korea

Korea's fourth and last ITER Vacuum Vessel sector completed and ready to leave the factory of Hyundai Heavy Industries. 2024. ©ITER Korea

The last Korean sector took to the sea in late August and, after sailing across the globe, arrived at ITER in France in November. August 2024. ©ITER Korea

Russia



Installation of some of the Russian busbars that will provide current to the superconducting magnets. September 2024. ©ITER Organization.

Russian technicians prepared cubicles and support structures for the future installation of gyrotron sets. 2024. ©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 and inspectors are some of the professionals contributing to the project. Inside these facilities, the components arriving from all over the world are being stored, assembled and installed.

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

The ITER site

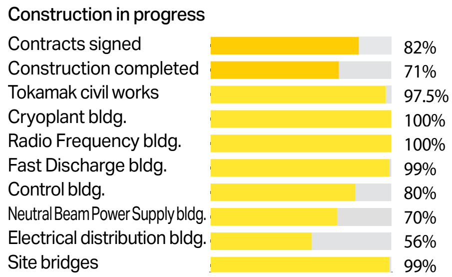
The ITER construction site has gone through an impressive transformation. Many of the buildings and infrastructure that will host and support the world's largest fusion experiment are erected. The progress, captured by the aerial view below, results from the involvement of many European contractors, coordinated by Fusion for Energy (F4E).

In 2024, F4E celebrated the completion of major buildings and infrastructure. It was the case of the Radio Frequency Heating Building, hosting gyrotrons and their power supplies, and the massive Cryoplant buildings. Both facilities, erected by the Vinci, Ferrovial, Razel-Bec (VFR) consortium, were officially handed over to ITER Organization after contractor Demathieu Bard finished installing building services (such as fire protection or ventilation).

In addition, the teams made the last touches to the busbar bridges and the cryobridge, running several metres above ground and into the Tokamak Complex. Specialists finished painting the walls of the seven-story facility, after years of handwork and coordination with other teams.

In parallel, the constructors made visible progress in some of the electrical infrastructures, like the Fast Discharge Building and the Neutral Beam Power Supply Buildings, which is now at over two thirds of completion. The construction of the Control Building, where the operators will monitor the experiment, is also coming to an end. Inside its main room, ITER Organization and F4E celebrated the first digital command to a plant system. Moreover, Ferrovial technicians connected the building to the electricity supply though kilometer-long underground cables.

Finally, F4E prepared for the last stage of civil engineering works with the signature of a multi-million contract with the b.NEXT consortium (Assystem, Egis, Empresarios Agrupados).



Aerial view of the ITER site in Cadarache, France. October 2024 ©ITER Organization/EJF Riche

ITER TOKAMAK COMPLEX

The Tokamak Complex and its surroundings, captured by a drone. October 2024 ©ITER Organization/EJF Riche

The 84-metre-tall crane next to the Tokamak Complex was dismantled after 10 years of service. ©ITER Organization

F4E's contractor GDES completed painting works inside the Tokamak Complex, a laborious 5-year operation in coordination with ITER Organization and the Engage and Energhia consortia. October 2024. ©ITER Organization

RADIO FREQUENCY HEATING BUILDING

F4E officially handed over the Radio Frequency Heating building (adjacent to the Assembly Hall) to ITER Organization. October 2024. ©ITER Organization

CIVIL ENGINEERING

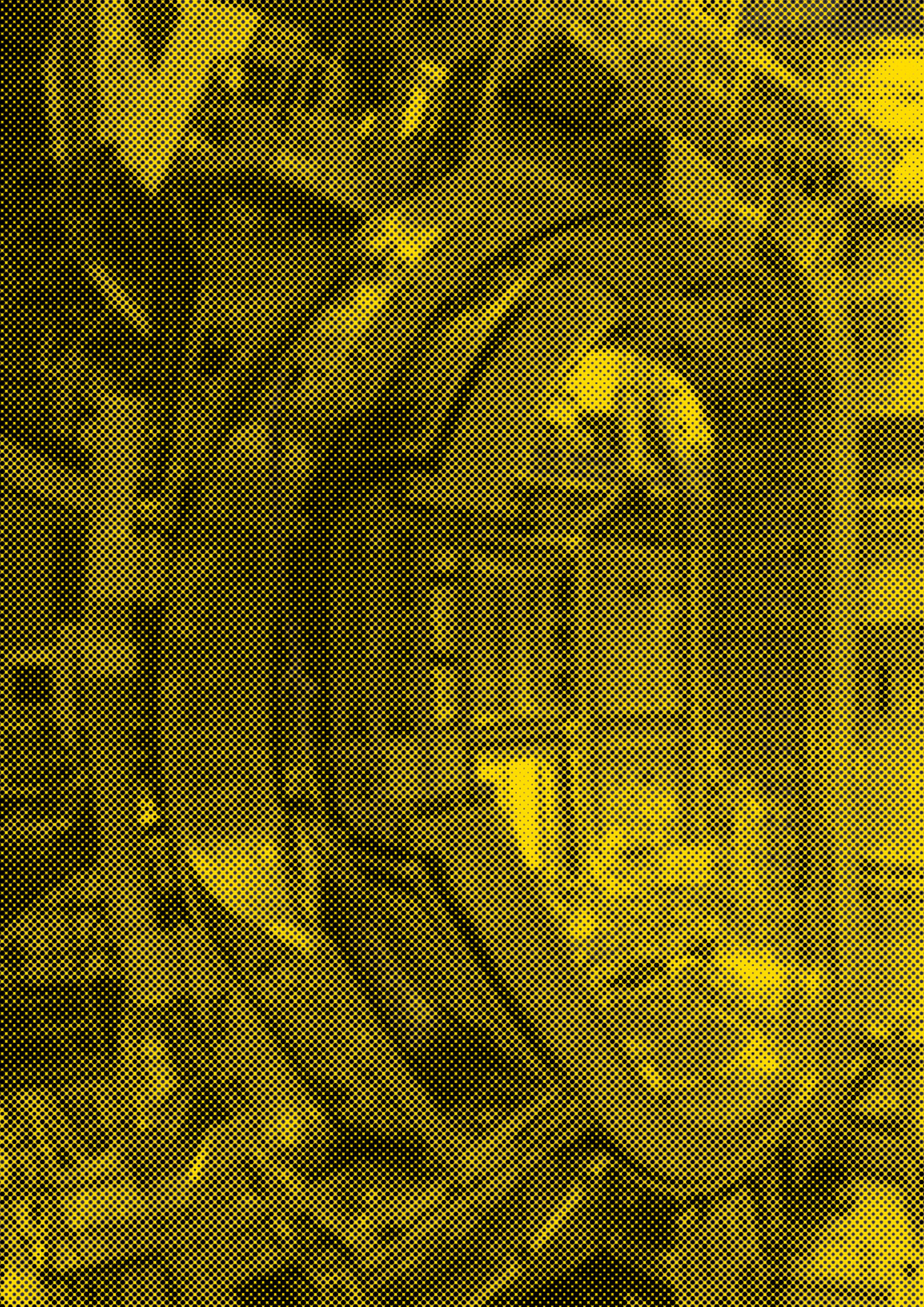
F4E signed a multi-million contract for engineering services on the ITER site until 2030 with the b.NEXT consortium (Assystem, Egis and Empresarios Agrupados). November 2024. ©F4E

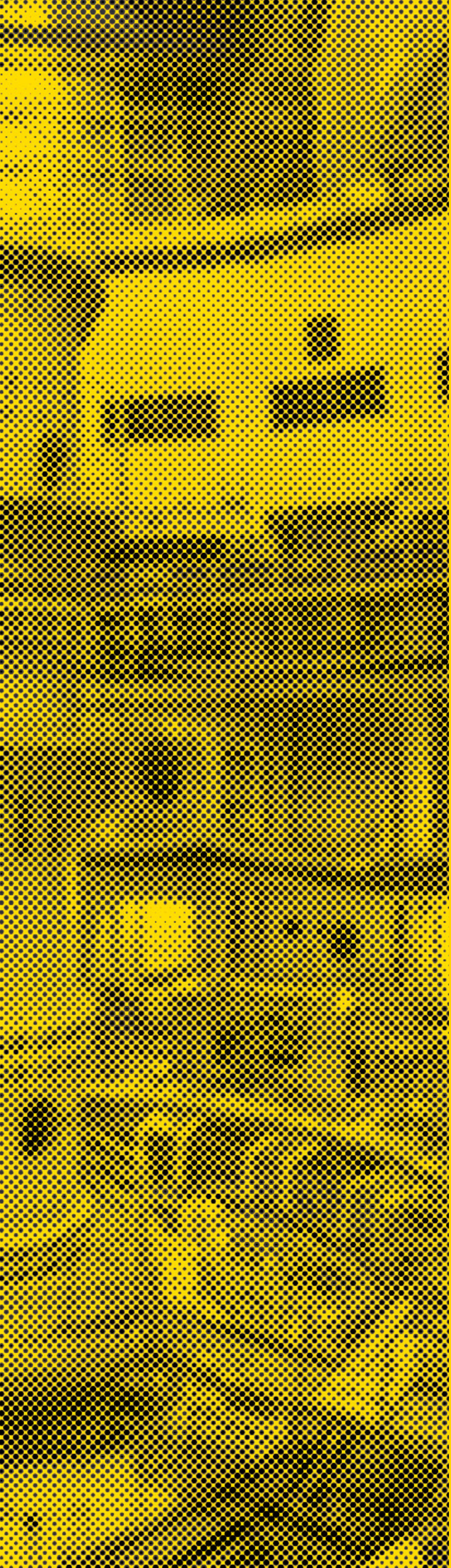
CONTROL BUILDING

Staff from ITER Organization, F4E and contractors gathered in the control room to celebrate the first command to a plant system run from there, as construction works near completion. December 2024. ©ITER Organization

CRYOPLANT BUILDING

The finalisation of building services marked the completion of construction for the buildings hosting ITER's cryoplant. December 2024. ©ITER Organization



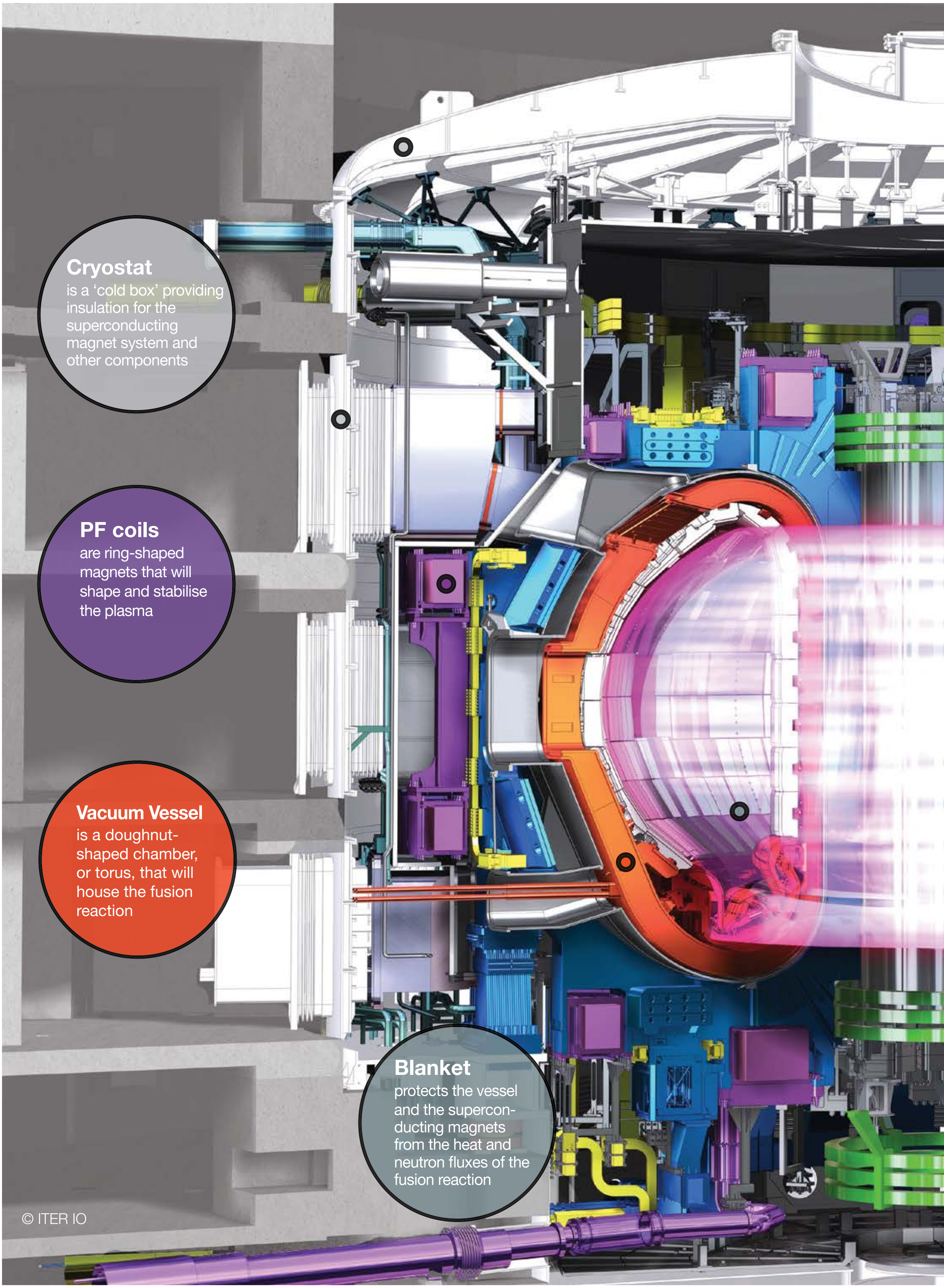


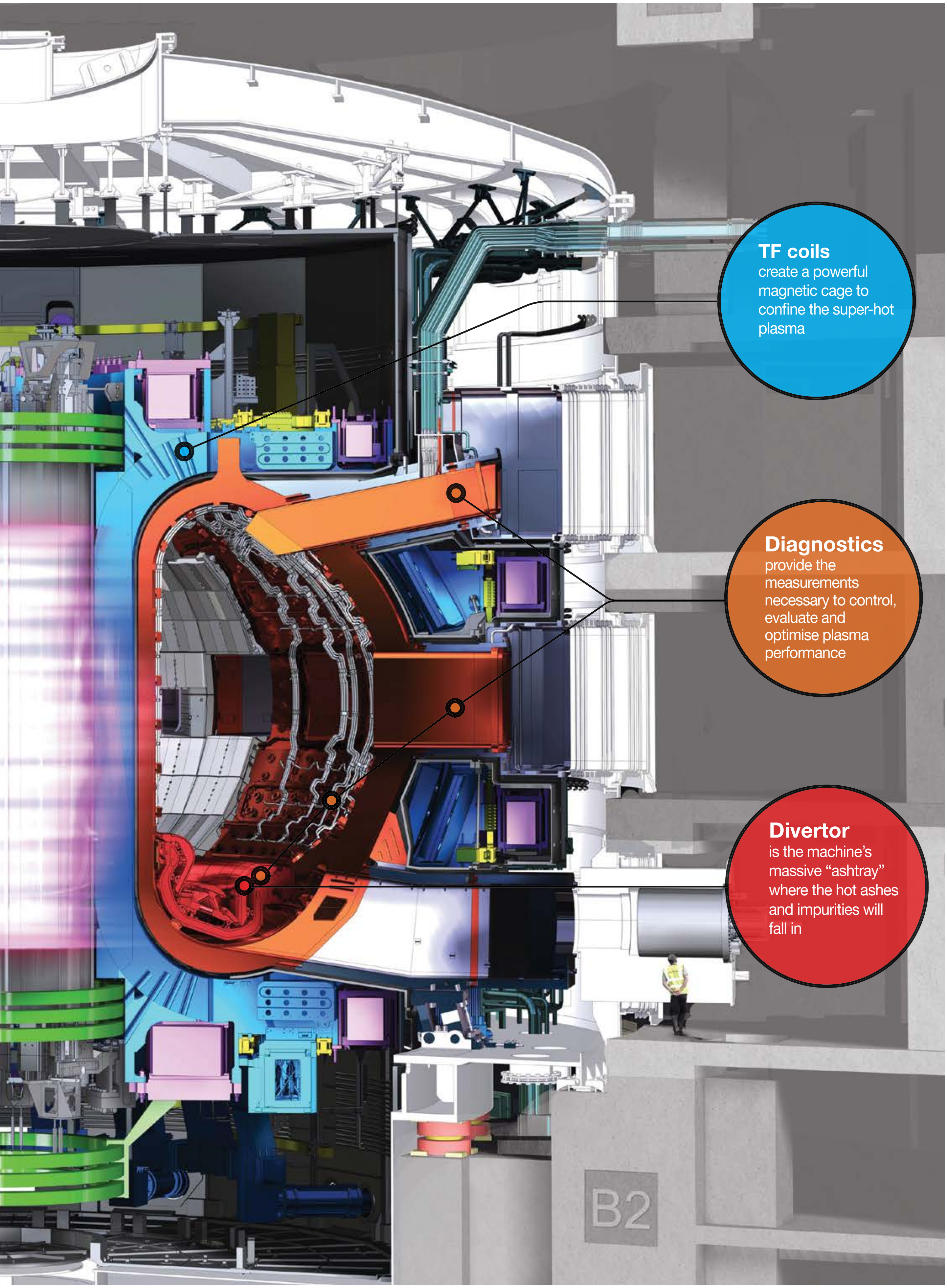
02

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


Cryostat
is a 'cold box' providing insulation for the superconducting magnet system and other components
PF coils
are ring-shaped magnets that will shape and stabilise the plasma
Vacuum Vessel
is a doughnut-shaped chamber, or torus, that will house the fusion reaction
Blanket
protects the vessel and the superconducting magnets from the heat and neutron fluxes of the fusion reaction
© ITER IO


TF coils
create a powerful magnetic cage to confine the super-hot plasma
Diagnostics
provide the measurements necessary to control, evaluate and optimise plasma performance
Divertor
is the machine's massive "ashtray" where the hot ashes and impurities will fall in
B2
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. Japan manufactured 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 provided 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 was produced in Russia.

TF Coils manufacturing	100%
PF Coils manufacturing	100%
Pre-Compression Rings	100%

TOROIDAL FIELD COILS

Japan and Europe celebrate the arrival of all Toroidal Field Coils

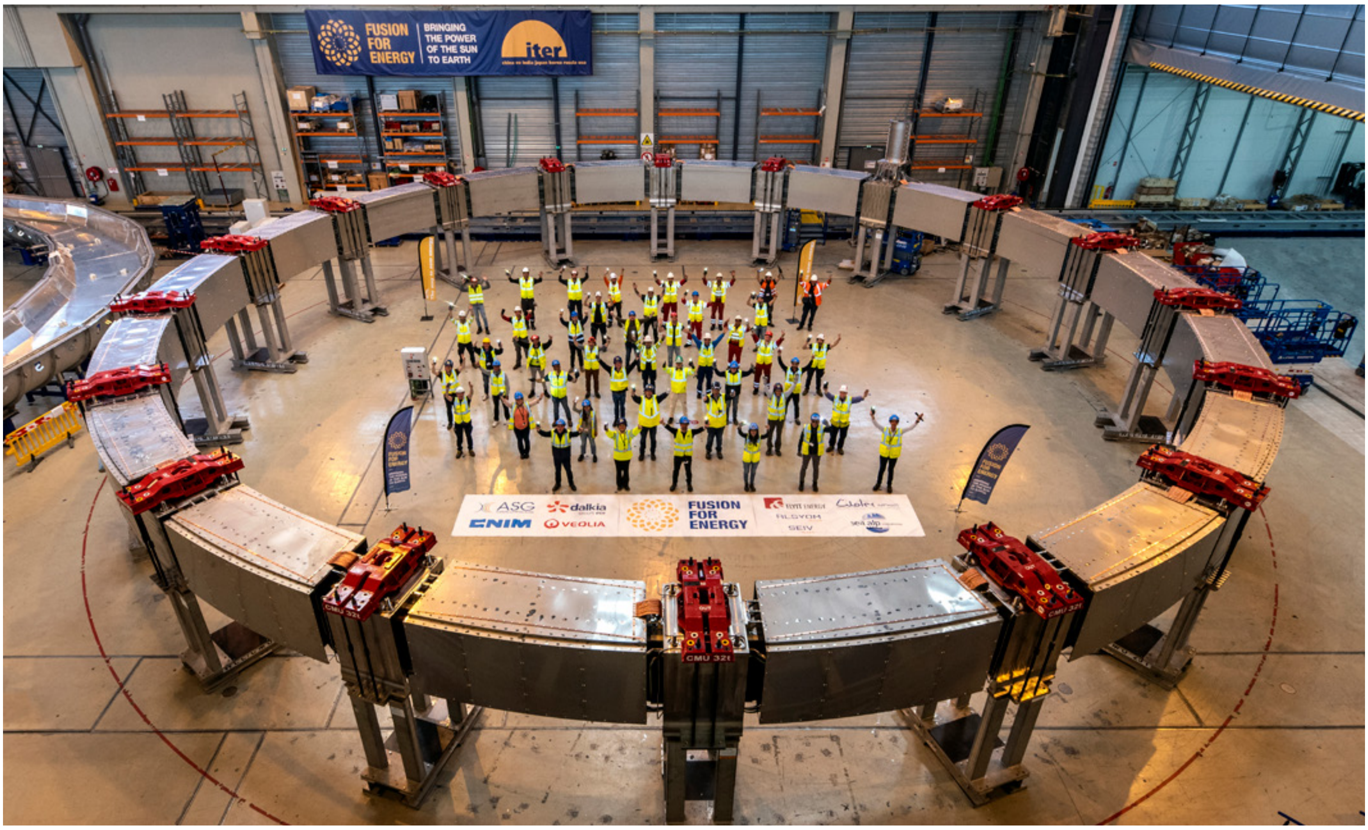
At the ITER Assembly Hall, the European and Japanese teams behind the Toroidal Field coils gathered to mark the successful wrap-up of their 15-year journey. The magnets, stored in ITER, measure 17 x 9 m and weigh roughly 320 tonnes each. F4E was responsible for ten of them, while QST for eight plus one spare. In Europe, more than 40 companies worked in the project, the main contractors being SIMIC, ASG Superconductors, CNIM, Iberdrola, Elytt and the ICAS consortium.

The ITER Director-General, the Director of F4E and the President of QST handed out recognition certificates to the managers of the teams involved in the production of the TF coils. July 2024. ©ITER Organization

POLOIDAL FIELD COILS

Europe delivers ITER's final Poloidal Field coil

After the last cold tests, F4E and its suppliers officially completed PF3, the last and biggest of the six superconducting magnets that will embrace ITER. The ring-shaped coil, measuring 24.7 m and weighing 384 tonnes, was fabricated in a facility onsite, with more than 10 companies working under F4E's coordination. PF3 was completed in under three years thanks to the lessons learned in the production of the rest of Europe's magnets.



The teams celebrated the milestone with a picture inside the magnet, in the European PF factory at the ITER site. April 2024. ©F4E

Group picture after the completion of the final cold tests. March 2024. ©F4E

The massive magnet wrapped and moved to storage on site. May 2024. ©F4E

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 tonnes each. At least ten European companies are involved in their fabrication.

Work in progress

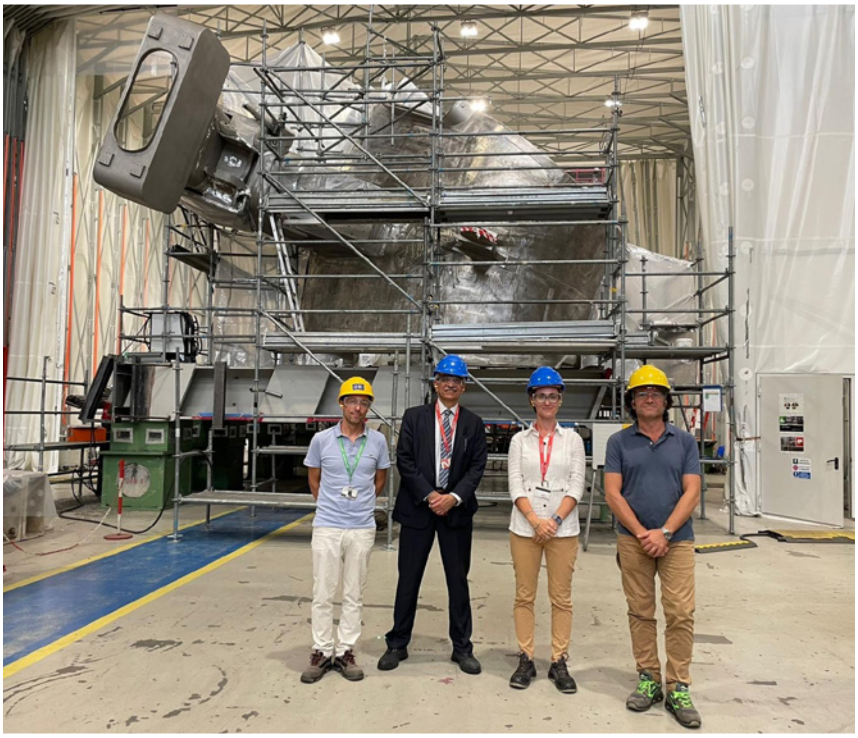
Sector 5	
Manufacturing	100%
Assembly	100%
Sector 4	
Manufacturing	100%
Assembly	98%
Sector 9	
Manufacturing	100%
Assembly	49%
Sector 3	
Manufacturing	100%
Assembly	37%
Sector 2	
Manufacturing	100%
Assembly	4%

Europe's first sector ready

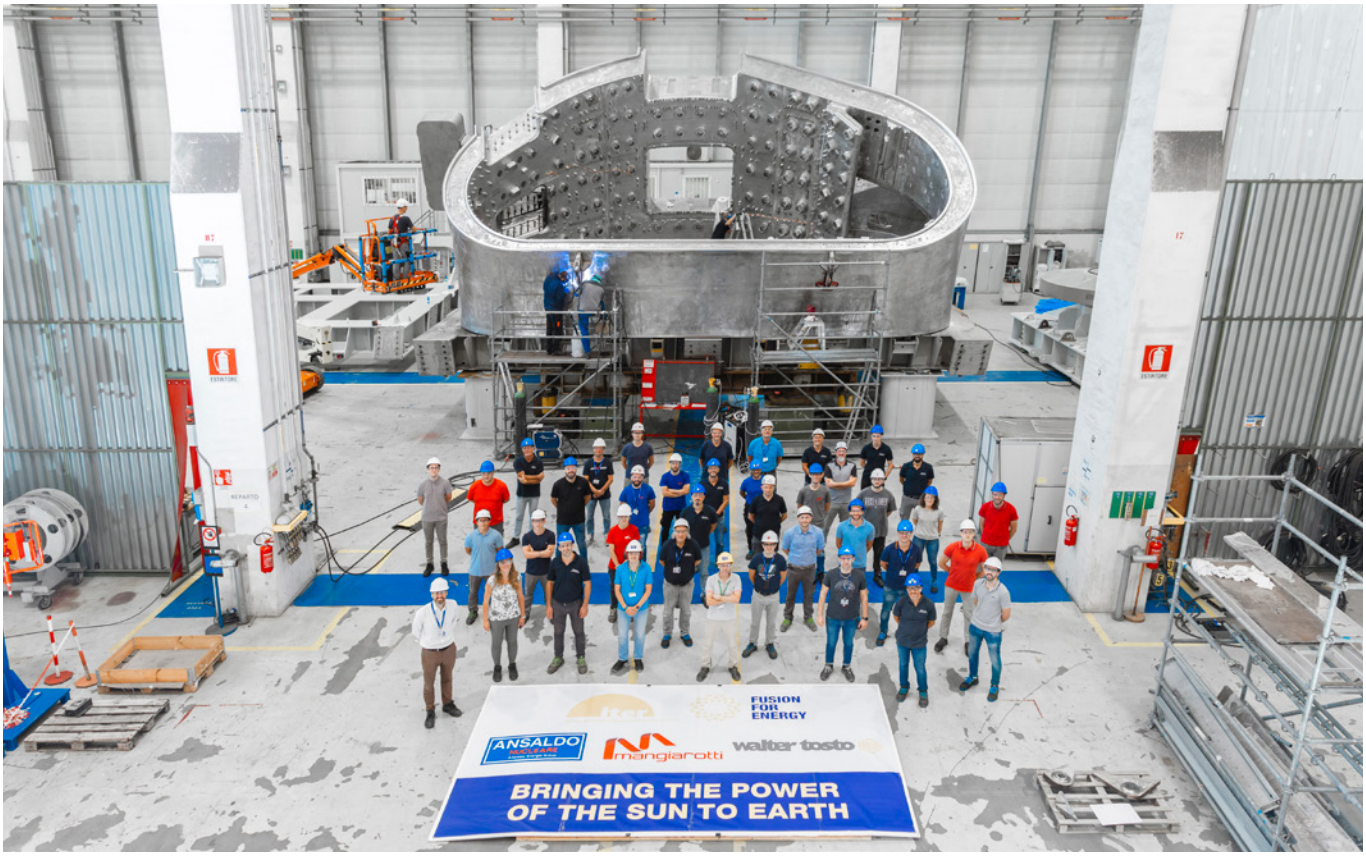
Europe and ITER met a huge technical milestone this year with the completion of the Vacuum Vessel Sector 5, the first of the five produced in Europe. F4E has been collaborating for more than 10 years with the AMW consortium, formed by Ansaldo Nucleare, Westinghouse and Walter Tosto, involving directly 150 professionals, and more than 15 companies across Europe. Together, they went through a challenging journey to finalise the machining, assembly and welding of the sector, shipped from Italy to ITER, in France, in September. In parallel, the other European sectors kept making steady progress at the factories.

Artificial Intelligence at the service of ITER and nuclear engineering

F4E successfully concluded a pilot project to apply AI in the manufacturing of the European Vacuum Vessel sectors. The teams trained an AI model to predict defects during welding. The algorithms proved effective and the results showed gains in time, costs and accuracy, compared to previous methods.



Colleagues involved in the AI application next to Vacuum Vessel sector 5 in the workshop in Mangiarotti. ©F4E



Group picture to celebrate the completion of Europe's ITER Vacuum Vessel sector 5, provided by F4E in collaboration with Ansaldo, Westinghouse, Walter Tosto (AMW) consortium, Monfalcone. August 2024. ©F4E

The teams of Fusion for Energy, ITER Korea and ITER Organization came together to celebrate the completion of Europe's first and Korea's last ITER Vacuum Vessel sectors. November 2024. ©ITER Organization

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	82%
Cask & Plug RH	
Contracts signed	26%
Design	71%
Neutral Beam RH	
Contracts signed	24%
Design	68%
In Vessel Viewing System	
Contracts signed	33%
Design	84%

Success for divertor remote handling systems

At the Divertor Test Platform (DTP2), financed by F4E and hosted at VTT in Tampere (Finland), engineers have developed key robotics technology for ITER. The teams gathered in January to witness a replacement operation of an ITER Divertor Cassette prototype. The drill demonstrated the successful performance of technologies like the digital hydraulic valves, the GENROBOT software and the 3DNode vision system.

Representatives from F4E, VTT, ITER Organization, ITER Korea, ITER Japan gathered in Finland to witness the Divertor Remote Handling system demonstration at DTP2. January 2024. ©VTT

Design of neutral beam remote handling crane advances

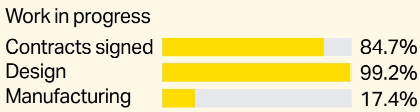
F4E kicked off a contract with Reel for the final design of the crane system that will collect, transport, and dispatch activated components from the Neutral Beam (NB) Cell to the Hot Cell Facility. A full-scale prototype of this trolley, which is operated remotely and runs on special rails, was already tested by Reel in 2022. The new contract will pave the way to manufacturing and installation.

The kick-off meeting brought together experts from F4E, ITER Organization and Reel, at their offices in Lyon, France. March 2024. ©F4E

Diagnostics

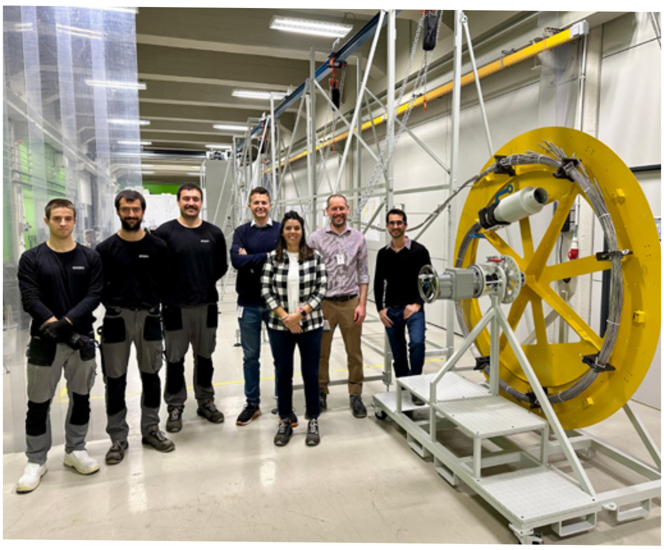
The Diagnostics systems will help scientists to study and control the plasma behaviour, measure its properties and improve our understanding in the respective field of physics. This system will act as "the eyes and ears" of engineers giving them insight thanks to a wide range of cutting-edge technologies.

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.



Tools ready to install cable feedthroughs

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. To do so, F4E and its partner IDOM developed and manufactured two alignment tools, tailored for the upper and lower ports. Thanks to these, experts at ITER can run trials of the procedure, using a prototype of a feedthrough, as their series production is underway at Alsymex.



F4E, ITER Organization and IDOM teams during tests of the feedthrough alignment tools at the premises of IDOM in Spain. October 2024. ©F4E

Electronics to monitor ITER's magnetic field delivered

In collaboration with GTD and subcontractors, F4E completed the electronics that will transmit and process the signals from ITER's magnetics diagnostic. Many of them were custom-made to meet the requirements of the device, such as the 1700 integrators. The teams ran successful simulations with the software and the hardware, which was assembled into 17 cabinets and handed over to ITER.

F4E colleagues revise the electronic cabinets during assembly with the electronics (black boxes) already installed. October 2024. ©F4E

Heating & Current Drive

To heat the ITER plasma and raise its temperature, we plan to use several systems. For example, Neutral Beam Heating (NBH), to release high-energy negative beams, and the Electron Cyclotron (EC), to inject into the gas high-energy 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	95%
Commissioning	5%
HNB Power Supplies for Cadarache	
Design	80%
Manufacturing/Testing	80%
Delivery/Installation	5%
NBTF (MITICA)	
Design	100%
Manufacturing/Testing	90%
Delivery/Installation	85%
NB Vessels	
Contract signature	100%
Design	95%
Manufacturing	10%
EC Launcher	
Contract signature	75%
Design	75%
Manufacturing	12%
EC Gyrotrons	
Contract signature	90%
Design	75%

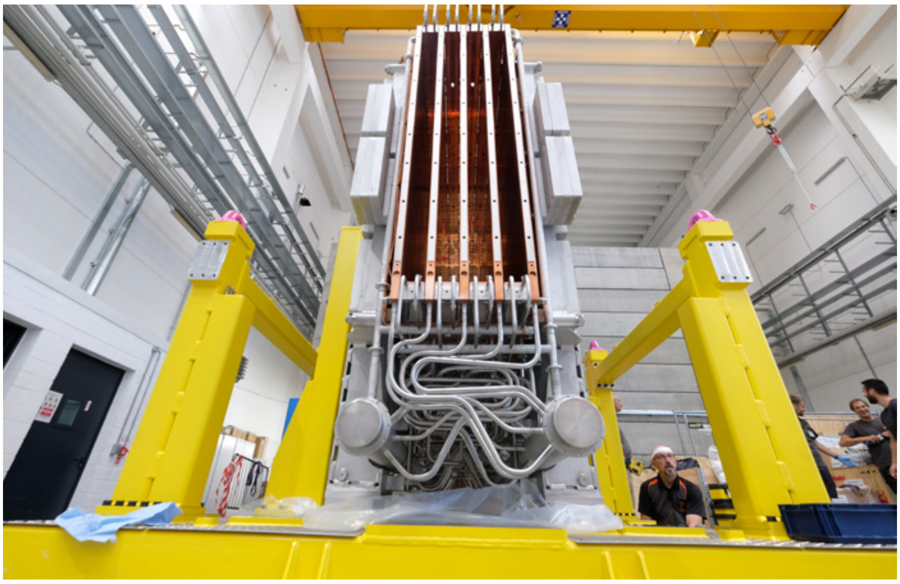
Neutral Beam Power Supplies start arriving in ITER

Europe and Japan are providing the powerful electrical infrastructure to light ITER's Neutral Beam injectors. After producing prototype units for MITICA, F4E is completing the equipment for ITER. The first to be delivered were parts of the Acceleration Grid Power Supplies, manufactured by NIDEC ASI. Later in the year, truckloads started arriving to form the High Voltage Deck and Bushing Assembly, a massive insulation box, produced by Siemens.

Two of the trucks carrying the Acceleration Grid Power Supplies reach the ITER warehouse. May 2024. ©F4E

MITICA beam line components produced

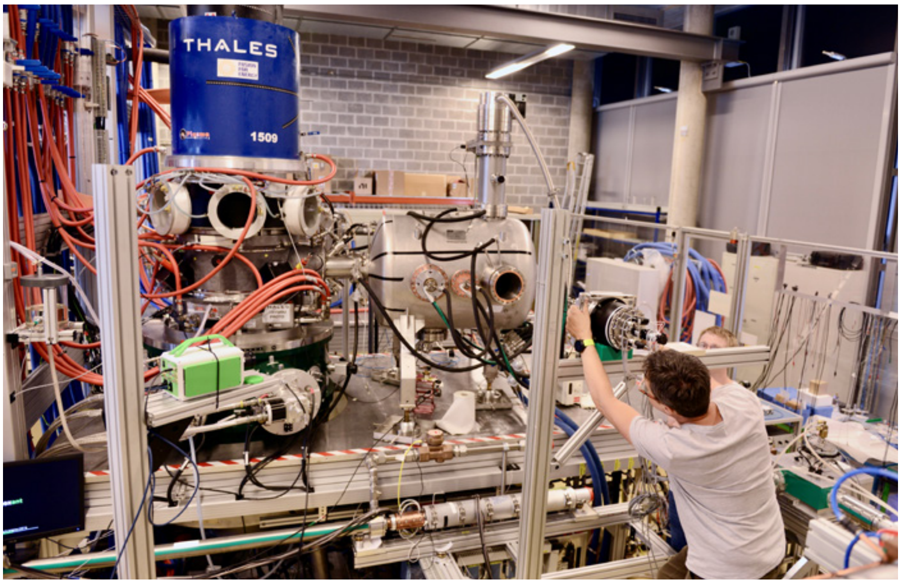
F4E, in collaboration with Spanish contractors AVS and Tecnalia, delivered the neutraliser and the electrostatic residual ion dump, two of the three components forming the beam line of MITICA. Site acceptance tests at the Neutral Beam Test Facility, in Italy, confirmed the success of a highly demanding fabrication process.



The neutraliser will remove the electrical charge of the accelerated ions. September 2024 ©Consorzio RFX

Successful tests for the pre-series gyrotron

Thales, the company tasked with manufacturing Europe's 6 ITER gyrotrons plus 16 units for the Divertor Tokamak Test Facility (DTT), is preparing for series production. The prototype completed tests at the Swiss Plasma Centre, achieving the required power levels for ITER (1MW and long pulses). Subsequently, the unit travelled back to Thales, in France, for the qualification of a new gyrotron test facility.



Technicians preparing qualification tests on the improved European gyrotron prototype in the Swiss Plasma Center, EPFL. 2022. © EPFL

Commissioning of the Electron Cyclotron Power Supplies

The Power Supplies for Electron Cyclotron Heating, provided by F4E, entered commissioning phase. The teams completed the commissioning of the first low voltage parts and prepared the ground for the next steps in 2025: the commissioning of high voltage supplies integrated with the low voltage, control cabinets and dummy loads.

Some of the main high voltage power supplies delivered by Europe occupy the first storey of the Radiofrequency Building. October 2024. ©ITER Organization.

Cryoplant and fuel cycle

The ITER device will have to cope with extreme temperature fluctuations. 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.

The fuel cycle systems will help sustain the fusion reaction by pumping out unburned fuel via the cryopumps, processing it and treating it in a closed loop, so as to re-use it for further operations. Europe is responsible for the production of the cryopumps, water detritiation tanks and auxiliary systems.

Work in progress

LN2 Plant	
Contracts signed	95%
Design	100%
Manufacturing	100%
Installation & Commissioning	77%
Vacuum Pumping	
Contracts signed	71%
Design	92%
Manufacturing	64%
Tritium Plant	
Contracts signed	32%
Design	35%
Manufacturing	18%
REMS and Rad Waste	
Contracts signed	7%
Design	9%
Manufacturing	0%

Cabinets ready to control the cryodistribution cycle

Europe delivered more components for the cryogenic distribution network of ITER. In collaboration with GTD, F4E is providing a series of cabinets that will allow to manage and monitor the cycle feeding the eight torus and cryostat cryopumps.

Three of the first-of-a-kind cabinets delivered by F4E to ITER. April 2024. ©ITER Organization

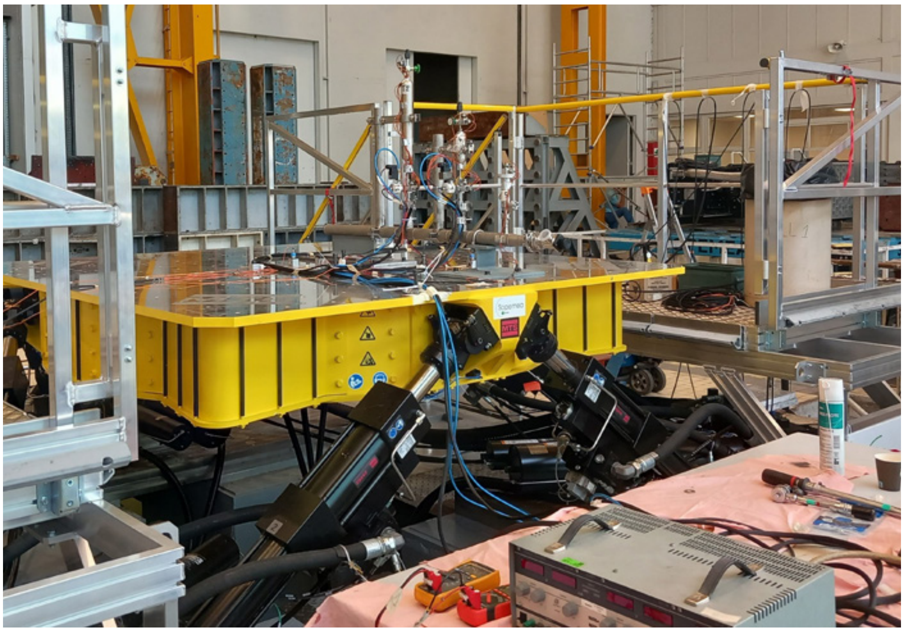
Europe's first cryopumps delivered to ITER

ITER's cryopumps will work like cold traps to suck gas out of the device and achieve the high vacuum needed for operation. F4E is providing two for the cryostat and six for the vacuum vessel. The first units were delivered to the ITER site, after a meticulous fabrication process led by Research Instruments (Germany) and Alsymex (France) and with the involvement of several specialised subcontractors.

Colleagues from several partner organisations travelled to ITER to celebrate the delivery. May 2024. ©ITER Organization

ITER Leak Detection Systems closer to manufacturing

F4E is leading the design and qualification of the Leak Detection Systems to control the vacuum tightness of ITER's vessel, cryostat and neutral beam injectors. The team completed the final design review for three of the eight systems, including a series of strain tests.



A set of valves of the ITER Leak Detection System, mounted on the seismic test table before shaking. 2024 ©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

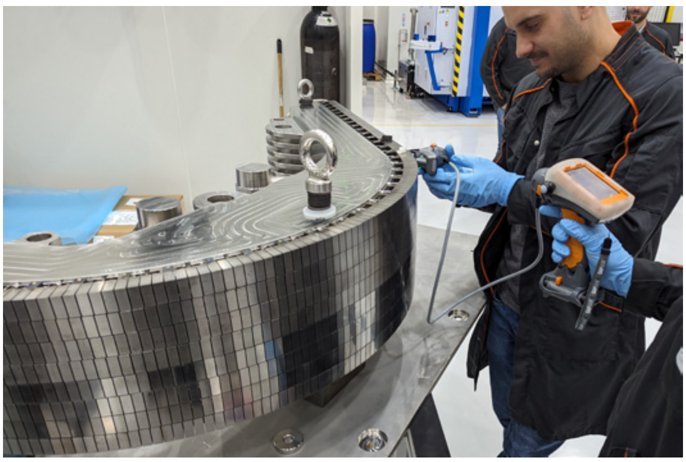
Blanket Cooling Manifold	
Design & Qualification	100%
Series qualification	70%
Blanket & First Wall	
Prototype qualification	100%
Production line	95%
Production qualification	70%
Inner Vertical Target	
Qualification	99%
Manufacturing	0.5%
Divertor Cassette Body	
Qualification stage I & II	100%
Design & Engineering	97%
Manufacturing	35%

Inner Vertical Targets ready for series manufacturing

F4E signed a contract with Alsymex to produce 13 units of the Divertor Inner Vertical Targets (IVTs). This component will face the plasma in ITER thanks to a coat of 1,104 tungsten blocks. The French company qualified a real-size prototype, including with high-flux tests. In total, F4E will provide 54 IVTs, plus 4 spares. In parallel to this contract, the manufacturing of 13 other units by Research Instruments is also underway.

Europe delivers remote handling flanges and transition pieces

Smaller ancillary parts, essential for their remote handling system, will be attached to the bulky components of the ITER Divertor cassettes. F4E and Walter Tosto completed the fabrication of 120 transition pieces and 130 remote handling flanges, plus supplied raw material. These were all delivered to ITER Organization ahead of time. Works lasted four years from the signature of the contract.



F4E Metrology experts inspecting the IVT prototype by Alsymex. April 2024. ©Alsymex

Representatives from F4E, ITER Organization, Walter Tosto opening the last box of remote handling flanges at the ITER site. November 2024. ©F4E

Test Blanket Modules

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

Europe coordinates expertise for the design of ITER Test Blanket Modules

F4E and EUROfusion reinforced their partnership for the design of the TBMs and the development of the DEMO Breeding Blanket system. The coordinated R&D activities cover aspects like functional materials, predictive tools, sensors, welding techniques or the testing of critical technologies.

Representatives from F4E and EUROfusion during the progress meeting at the ITER site. ©EUROfusion

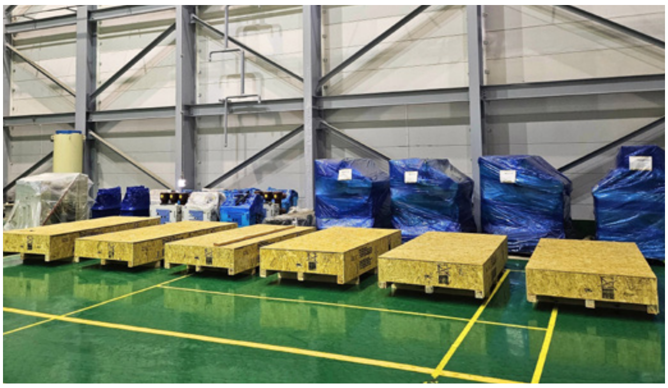
F4E and ITER Organization strengthen cooperation in nuclear safety

The teams working to develop Europe's TBMs progressed with the safety assessment of more than 460 pieces of pressure equipment. For the first time, F4E and ITER Organization set up a joint expert group to efficiently prepare the extensive documentation and address together the challenges of first-of-a-kind technologies.

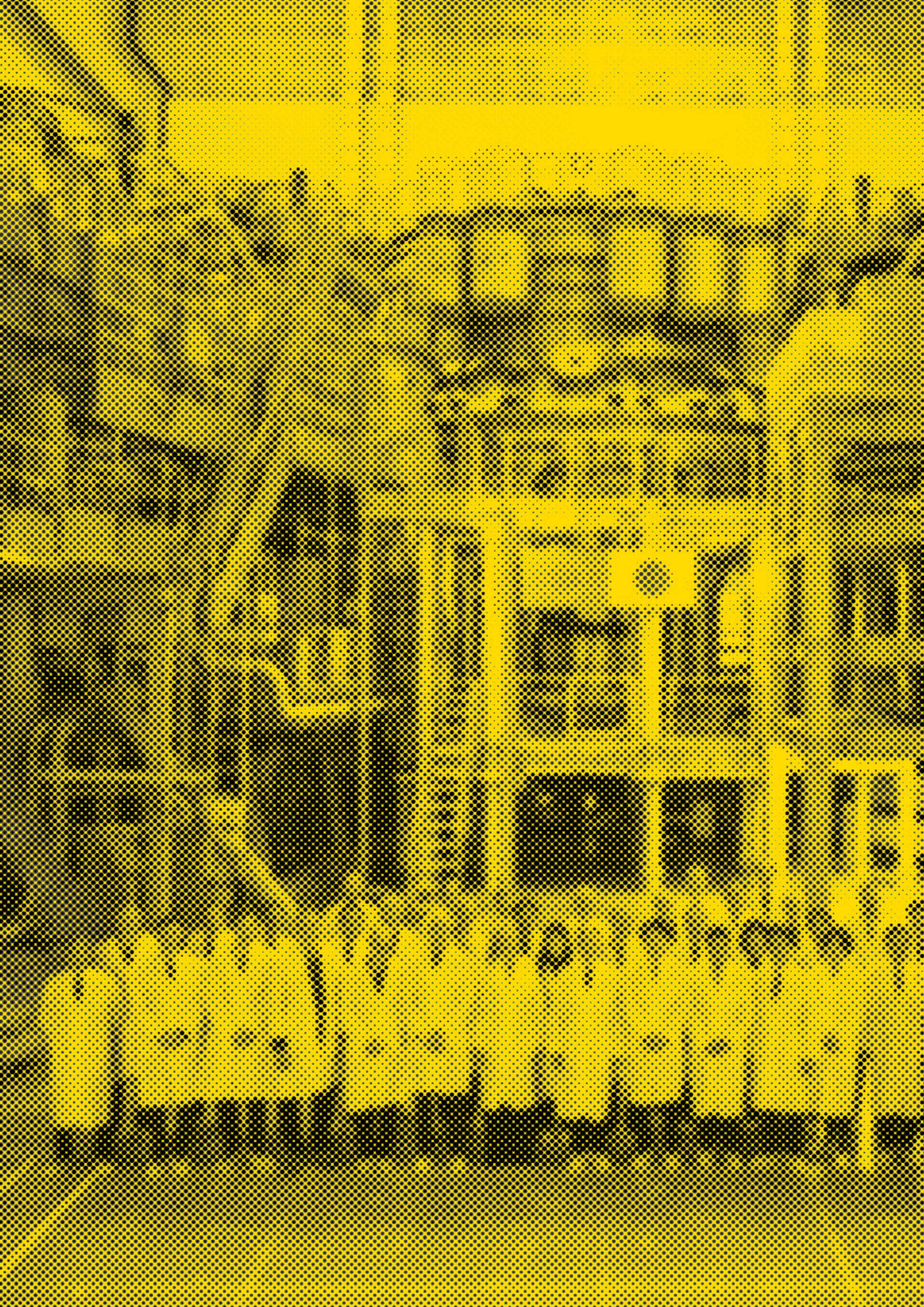
A meeting of the TBM Project team, with members from ITER Organization, F4E and Korean ITER Domestic Agency. ©F4E

European steel for TBMs arrives in Korea

EUROFER97 steel, capable of withstanding extremely high temperatures and radiation, is Europe's choice for the structure of the TBMs and the future breeding blanked of DEMO. A first batch of the material, forged by Saarschmiede for F4E, arrived in Korea for the fabrication development activities of the joint Europe-Korea TBM. This is part of the preliminary design review, a stage expected to run until 2026.



The shipment of EUROFER97 steel stored in Busan, Korea. June 2024. ©ITER Korea



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.

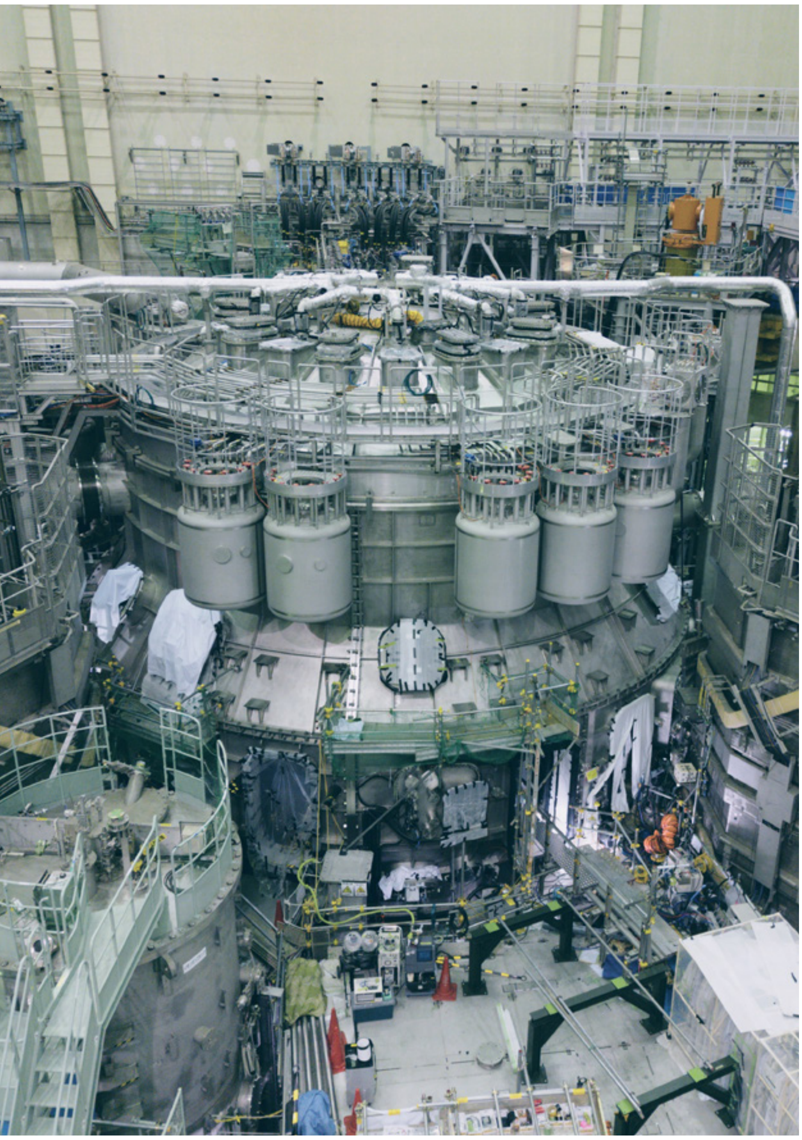
The Broader Approach consists of three projects:

- 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 accelerator-based facility to prepare the neutron source that will test materials for future fusion power plants (in IFMIF-DONES, its next phase);
- 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 achieve long pulse operation. The machine, constructed by Japan and Europe, will support ITER through complementary experiments and help improve the design of the future Demonstration (DEMO) fusion reactor, which will be connected to the grid.



View of the JT-60SA tokamak, surrounded by auxiliary systems. December 2024. ©F4E

Upgrades around and inside the tokamak

The European and Japanese teams were busy all year round adding new components to upgrade the future performance of JT-60SA. They installed the remaining 18 ports and 8 large Neutral Beam tanks onto the vessel, as well as several cryopumps and diagnostics systems. In parallel, they continued equipping the inner wall with auxiliary magnets, like the 18 correction coils.

JT-60SA moves into scientific phase

After the successful construction and commissioning, managed by F4E and QST, the project entered the scientific exploitation phase this year. An Experiment Team was formed, with more than 280 scientists from Europe (mainly from EUROfusion laboratories) and Japan. Their efforts have concentrated on analysing the data from the initial plasma operations and prepare for the next ones in 2026 and 2027, with a more powerful machine.

JT-60SA on the Guiness World Records book

The JT-60SA experiment was officially recognised by Guiness World Records as the world's largest tokamak, as measured in terms of plasma volume. After achieving first plasma in 2023, the experimental device reached a plasma of 160 m^3, far exceeding the previous record of 100 m^3 by other machines. The operation and control of these plasma volumes provides an invaluable expertise source for ITER and DEMO.

Training the next generation of experts at JT-60SA

A group of 20 students from Europe and Japan attended the 2nd edition of the JT-60SA International Fusion School, held at QST Naka, in Japan. Under the title "From JET to JT-60SA", the two-week course offered young experts lectures on topics like plasma physics or nuclear engineering, as well as a visit to the tokamak facility. The school is funded and organised by QST and EUROfusion, with the support of F4E.

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.

LIPAc completes another round of operations

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. The teams made further progress towards securing a high-power continuous beam. This year, they wrapped up a successful round of operations and started preparations for the accelerator's groundbreaking final configuration.

The European and Japanese teams in the control room of LIPAc, in Rokkasho, Japan. 2024 ©IFMIF/EVEDA

A surgical assembly to upgrade LIPAc

In its next phase, LIPAc will incorporate a new high-energy section: the Superconducting Radio Frequency (SRF) linear accelerator. The European teams completed the clean room assembly of this component. F4E's contractor Research Instruments carried out this delicate process, avoiding any contamination.

The Superconducting Radio Frequency linear accelerator ready for the last assembly stages. 2024 ©F4E

IFMIF-DONES

The International Fusion Materials Irradiation Facility – Demo Oriented NEutron Source (IFMIF-DONES) is a future research infrastructure under construction in Spain. As part of the DONES programme, the accelerator-based facility will be used for the testing, validation and qualification of the materials to be used in future fusion power plants like DEMO.

Partnership progresses with talks on governance and contributions

A solid international partnership continued shaping up as the negotiations for DONES progressed. The talks in the Steering Committee focused on defining the governance and contributions, with several parties interested in joining Spain and Croatia. F4E is providing personnel for the ramp-up of the programme and could contribute up to 25% on behalf of the EU, including key accelerator components.

Group picture during the Steering Committee meeting, with representatives of the DONES international parties, including F4E. October 2024. @IFMIF-DONES España

First buildings under construction in Granada

At the IFMIF-DONES construction site in Escúzar, Granada, the first buildings have started to emerge. The civil engineering works are concentrating on the centre for R&D on new materials, the warehouse and the Administration Building, designed to host over 250 employees.

Visit of the Steering Committee to the DONES construction site in Escúzar, Granada. October 2024. @IFMIF-DONES España

IFERC

Through the International Fusion Energy Research Centre (IFERC), Europe and Japan support joint research activities to advance fusion knowledge and contribute to the development of fusion devices after ITER, such as DEMO. IFERC covers the Computational Simulation Centre, the DEMO Design and R&D activities, and the ITER Remote Experimentation centre.

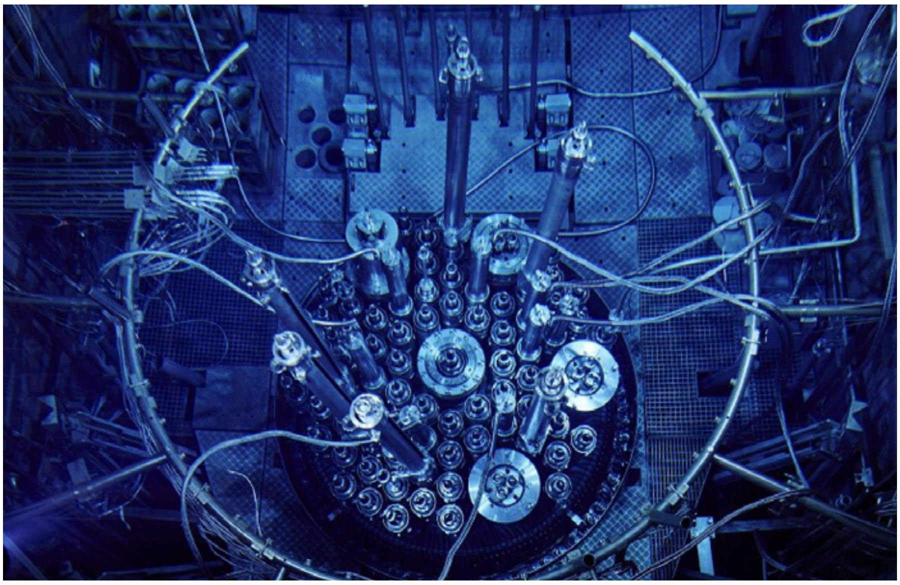
Supercomputers to boost fusion research

As part of IFERC, Europe and Japan set up the Computational Simulation Centre (CSC), which gives fusion researchers the chance to run complex codes through high-performance computing. The CSC currently uses two supercomputers: JFRS-1, in Japan, owned by QST; and MARCONI, in Italy, a contribution by EUROfusion. After the call for proposals, a new cycle of simulations started this year, helping 29 different projects.

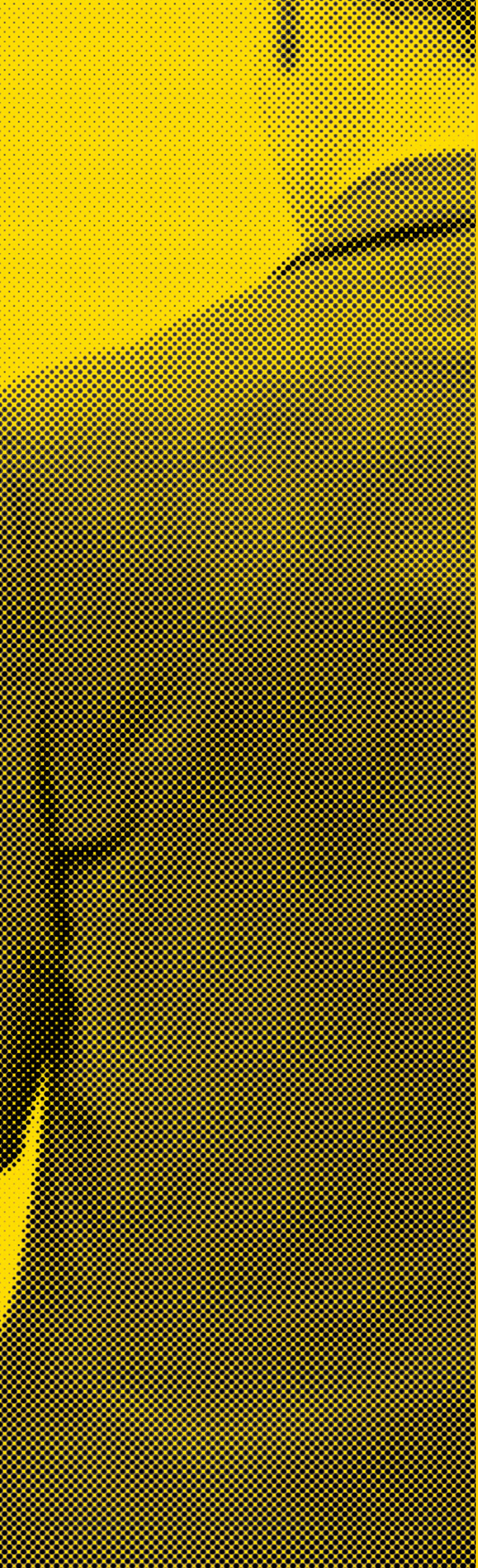
Four racks of equipment form the JFRS-1 supercomputer, in the Computational Simulation Centre room in Rokkasho, Japan. ©QST

New experiments to test breeding materials

Europe and Japan continued their joint R&D activities to advance knowledge on materials for the DEMO breeding blanket. The IFERC teams started a round of experiments to assess the performance of their selected alloys. The samples are undergoing a series of irradiation and post-irradiation tests, thanks to the collaboration with the reactors BR2 (Belgium) and WWR-K (Kazakhstan), and the technical work by several EUROfusion laboratories.



The Belgian Reactor 2 (BR2) at SCK CEN, placed in a water basin, will irradiate tested materials with high neutron flux. ©SCK CEN



04

Working together with stakeholders

F4E actively engaged with European and national stakeholders to highlight the strategic importance of fusion in providing a long-term energy solution. Apart from strengthening Europe's autonomy, it is seen as a motor of economic growth, innovation and competitiveness. Developing an extensive supply chain with the right set of skills, infrastructure, and capabilities is essential to achieving this objective.

During the year, policymakers, industry, SMEs and research organisations met in various events to exchange views on policy and financial incentives to harness the potential of fusion energy. Business opportunities and new models of collaboration between public and private entities were discussed.

F4E maintained its firm commitment to building stronger ties with all parties by participating in conferences and providing the latest updates. Our members of staff reached out to science and business communities, technology clusters, and different publics interested in our mission, vision and contribution to fusion energy.

Strategic & political engagement

F4E and EUROfusion reinforce collaboration

F4E and EUROfusion, the consortium of European fusion laboratories, signed a renewed Memorandum of Understanding, which builds on years of technical collaboration. Both entities committed to keep working together in a wide range of activities to deliver ITER and the European fusion roadmap.

Marc Lachaise, F4E Director, and Ambrogio Fasoli, former EUROfusion Programme Manager, signed the MoU during the EUROfusion General Assembly. ©F4E

F4E contributes to the future EU fusion strategy

As fusion gains momentum globally, EU policymakers held discussions about a European fusion strategy, critical technologies, skills, supply chain and regulation. F4E contributed to the discussions facilitated by the European Commission. The F4E Director, Marc Lachaise, spoke in the Commission's EU Blueprint for Fusion Energy conference, in Strasbourg, together with public and private stakeholders.

F4E speaking at a panel about the industrial ecosystem at the EU Blueprint for Fusion Energy event. April 2024. ©European Commission

Advocating for ITER and fusion at the European Parliament

With the new legislature starting, F4E was present at the European Parliament in Brussels to meet MEPs and showcase the progress towards fusion at an exhibition alongside other EU Agencies. Towards the end of the year, F4E Director Marc Lachaise addressed the EP's Committee on Budgetary Control to update on the status of ITER and complete the financial audit procedure for 2023.

F4E Director, Marc Lachaise, answered the questions from Members of the European Parliament. December 2024. ©F4E

F4E at the Big Science Business Forum

The Big Science Business Forum (BSBF), held in Trieste with the involvement of F4E in the organising committee, brought together roughly 1.000 delegates. Apart from the outreach efforts, F4E's Market Analysis group set up a new tool on the F4E Industry Portal for companies to offer or request partnerships. The Women in Big Science award, championed by F4E and Big Science organisations, celebrated its second anniversary gaining further importance.

F4E Director Marc Lachaise (first on the right) alongside the Directors of Europe's Big Science Organisations at BSBF. ©BSBF

Welcoming political representatives at F4E

Throughout the year, F4E welcomed consuls from Germany, France, Switzerland, Romania, Portugal, and Italy to the headquarters in Barcelona. During their visit, the diplomats learned about F4E's projects from F4E's Director and met F4E colleagues of their same nationality. Moreover, on the week of the European elections, received representatives from the European Parliament's Office in Barcelona to discuss how the elections could affect the energy policy.

F4E Director next to the Consuls of France and Germany. February 2024. ©F4E

Showcasing fusion in local events

F4E, headquartered in Barcelona, actively engages with local authorities and other EU bodies present at regional and national levels. The F4E Director highlighted the importance of fusion at a conference about strategic EU-funded projects in Catalonia, organised by the European Commission office in Barcelona and the Government of Catalonia, and with high-level speakers like former Prime Minister of Italy, Enrico Letta. Additionally, F4E took part in the Sustainable Energy Days in Barcelona, presenting success stories like the application of AI in the production of ITER's Vacuum Vessel.

F4E Director, Marc Lachaise, during his intervention in a panel on strategic EU investments in Catalonia. June 2024 ©European Commission

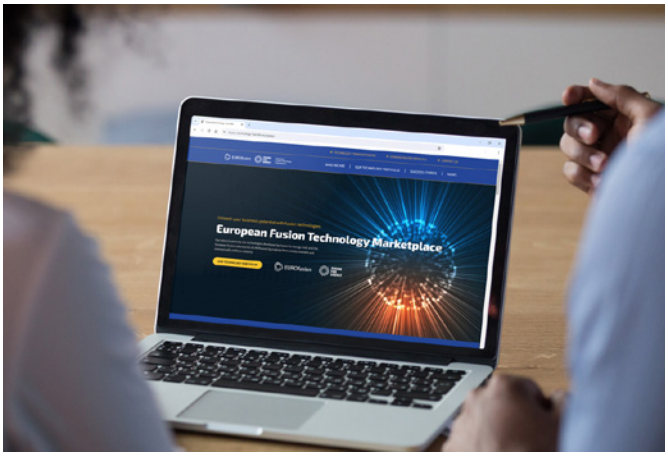
Industrial Policy

Launch of the F4E Technology Development Programme

F4E kicked off its Technology Development Programme (TDP), a funding scheme to help advance critical fusion technologies through R&D. The two first calls were launched as a pilot for those to come. In parallel, F4E started mapping the relevant technologies in different areas in consultation with stakeholders.

A new European Fusion Technology Marketplace

F4E and EUROfusion partnered to promote in one portal their technology transfer programmes. The website offers companies a diverse portfolio of ready-to-market solutions developed by F4E's industrial partners and the EUROfusion laboratories. Calls and financial rewards to assist companies in this area were launched.



F4E and private fusion initiatives collaborate

F4E published a Call for Expression of Interest inviting EU-based private fusion companies to explore mutually beneficial public-private partnerships. The aim is to support the growing fusion private sector and foster the exchange of information and know-how.

Involving SMEs in the fusion supply chain

A total of 50 small and medium-sized enterprises gathered at F4E's SME Day, in Barcelona and online. The event reinforced their participation in the fusion supply chain by presenting opportunities and fostering partnerships.

Building talent

Fostering women's role in fusion and science

F4E showed its commitment to closing the gender gap in science and led various initiatives to offer opportunities for talented women. This year, 18 staff members graduated from F4E's Women's Leadership Programme, focused on empowering them through soft skills. Also, F4E launched the DONES Xcitech Scholarship for young female graduates and promoted the "Women in Big Science" Award to recognise the remarkable role of women in the field.

World experts network and share practices at F4E

F4E organised and hosted several events to facilitate the exchanges between professionals in different fields. For instance, the F4E Roundtable invited experts in nuclear law to discuss regulatory aspects of fusion. Additionally, the Knowledge Management workshop, co-organised with EUROfusion, gathered over 100 people from important European organisations. F4E also hosted the annual event of the Enterprise Risk Management International Network and supported the Nuclear Safety & Quality Assurance Supplier Workshop in ITER.

Supporting young talent in fusion

The future of fusion energy relies on the next generation of experts. This year, F4E welcomed 40 young trainees to gain experience by working in different teams of our organisation. In addition, F4E's experts gave lectures in trainings like the 4th International School on Numerical Modelling for Applied Superconductivity, hosted by F4E, and the 2nd DONES Xcitech school, focused both on the technical and management aspects of Big Science projects.

Getting in touch with the EU

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EU law and related documents
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Open data from the EU
The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

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