

Fusion - A clean future

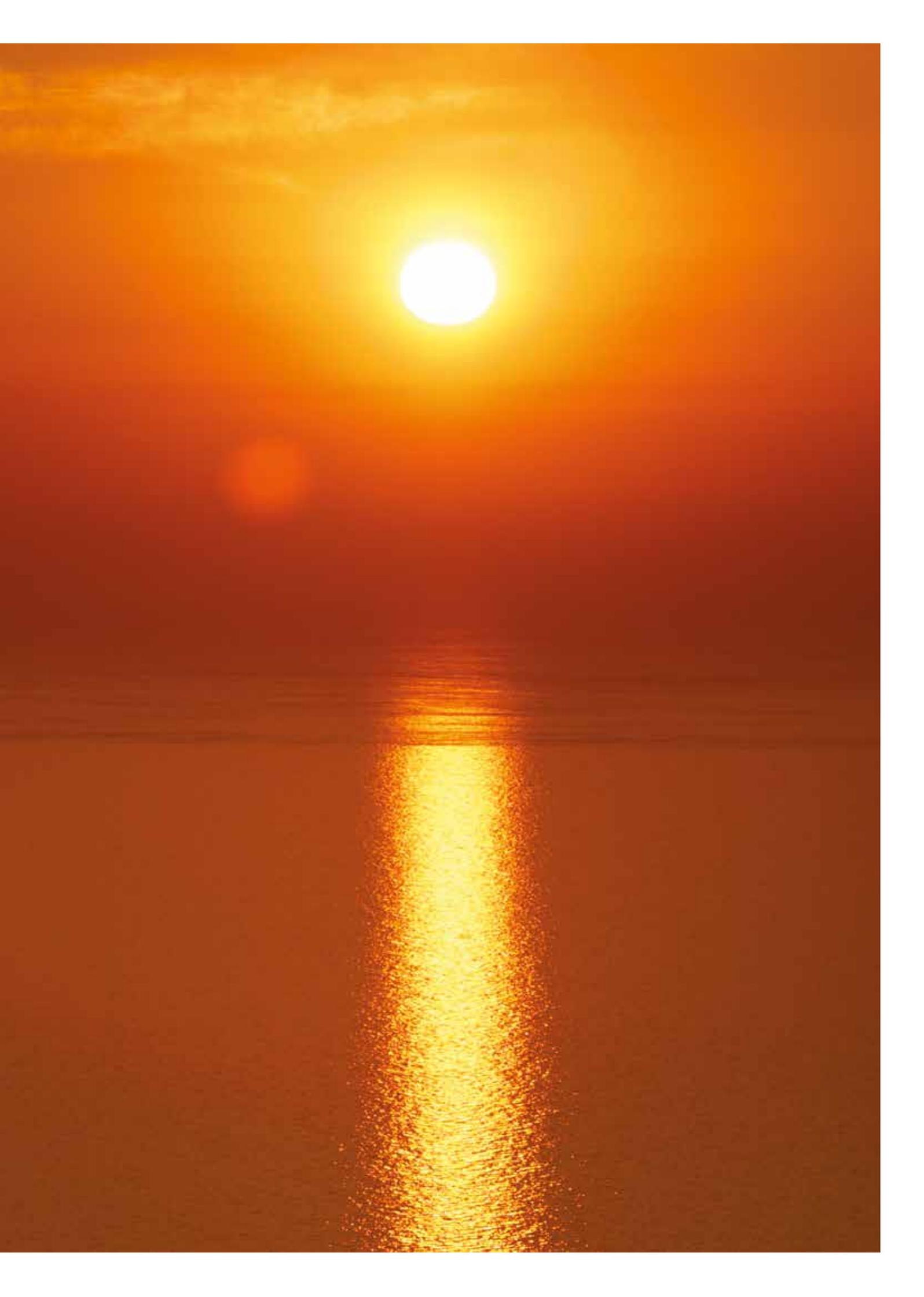
Research at Culham Centre for Fusion Energy



Increasing energy demands, concerns over climate change and limited supplies of fossil fuels mean that we need to find new, cleaner ways of powering the planet. Nuclear fusion – the process that drives the sun – could play a big part in our sustainable energy future.

Around the globe, scientists and engineers are working to make fusion a real option for our electricity supply. At the forefront of this research is **Culham Centre for Fusion Energy, home to the UK's fusion programme and to the world's largest fusion device, JET, which we operate for scientists from over 20 European countries.**







Why we need fusion energy

Energy consumption is expected to grow dramatically over the next fifty years as the world's population expands and developing countries become more industrialised. The population of the developing world is predicted to expand from seven billion to nearly ten billion by 2050. As a consequence, a large increase in energy demand can be expected, even if energy can be used more efficiently.

At the same time, we need to find new ways of producing our energy. Fossil fuels bring atmospheric pollution and the prospect of climate change; Governments are divided over whether to include nuclear fission in their energy portfolios; and renewable sources will not be enough by themselves to meet the demand.

Nuclear fusion can be an important long-term energy source, to complement other low-carbon options such as fission, wind, solar and hydro. Fusion power has the potential to provide more than one-third of the world's electricity by the year 2100, and will have a range of advantages:

- **No atmospheric pollution.**
The fusion reaction produces helium, which is an inert gas – no greenhouse gases or acid rain are emitted;
- **Abundant fuels.**
Deuterium and tritium, the fuels likely to be used for fusion energy, are both forms of hydrogen. Deuterium can be readily extracted from ordinary water, and tritium could be produced in a fusion power plant from a light metal, lithium, which is abundant in the earth's crust;
- **An efficient way of making energy.**
Just one kilogram of fusion fuel produces the same amount of energy as 10,000,000 kilograms of fossil fuel;
- **An inherently safe system.**
Even the most unlikely accident would not require evacuation of the surrounding population;
- **No long-lived radioactive waste.**
All irradiated material from plant components will be safe to dispose of conventionally within 100 years. It will therefore not be a long-term environmental burden for future generations;
- **Economically competitive.**
The cost of fusion-generated electricity is predicted to be comparable to electricity from fossil fuels or nuclear fission.



Fusion fact

The amount of lithium contained in a laptop battery, combined with less than half a bathtub of water, can provide enough fusion fuel to supply the average European person's total energy needs for 30 years.

How fusion works

In a fusion reaction, energy is produced when light atoms are fused together to form heavier atoms. This is the same process that provides the energy in the sun and other stars.

To utilise fusion reactions as an energy source on earth, gaseous hydrogen must be heated to temperatures in excess of 100 million degrees – ten times hotter than the centre of the sun. At these temperatures, the gas becomes a plasma. (Plasma is common on earth – for example in neon signs, flames and lightning – and in the form of stars and interstellar material it makes up 99% of the universe.)

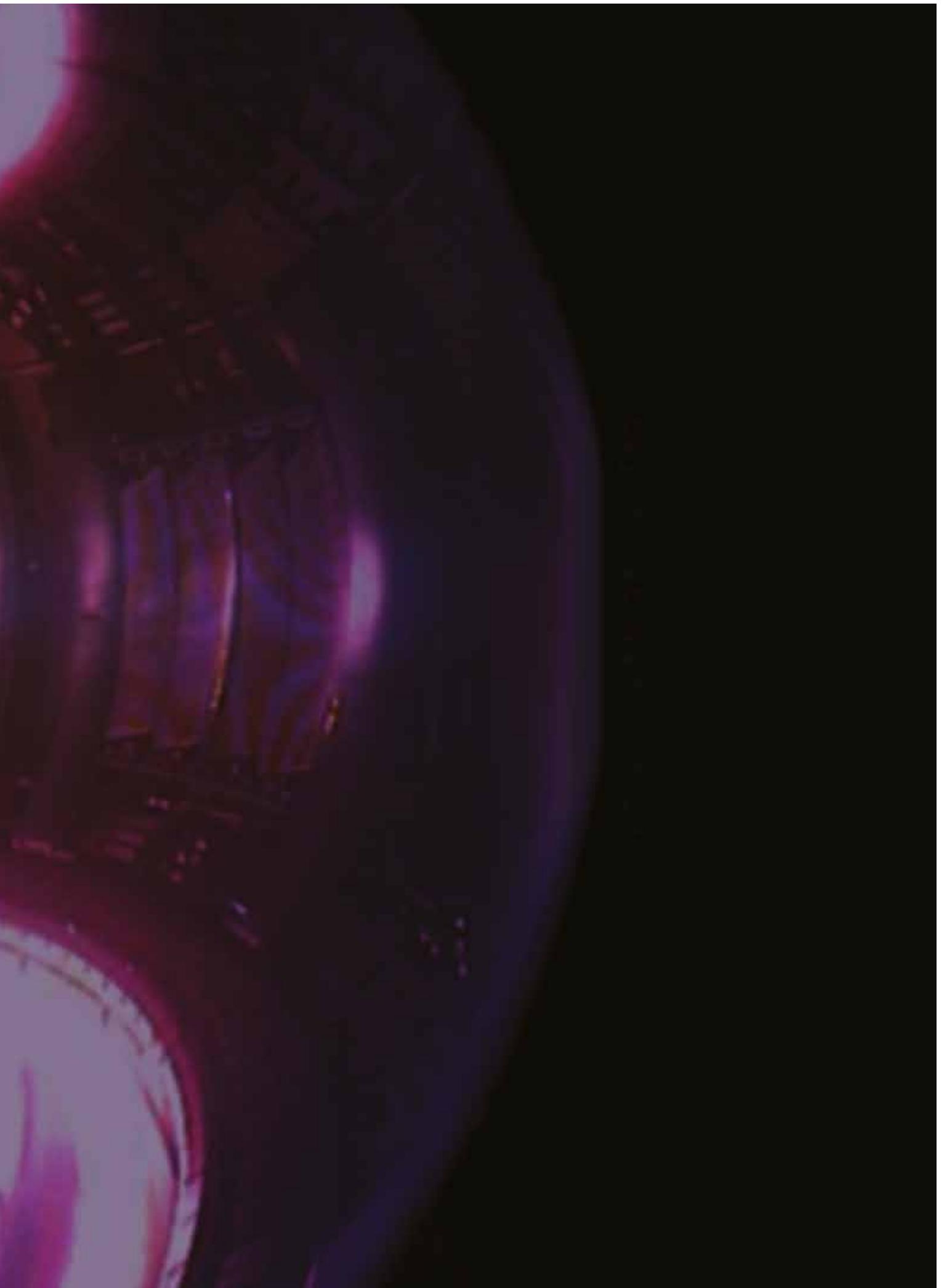
At these temperatures, deuterium and tritium nuclei – both heavy forms of hydrogen – will fuse together to form helium and high-speed neutrons, carrying significant amounts of energy. A commercial power station will use the kinetic energy carried by the neutrons, as they are slowed down by a blanket of denser material (for example lithium), to generate electricity.

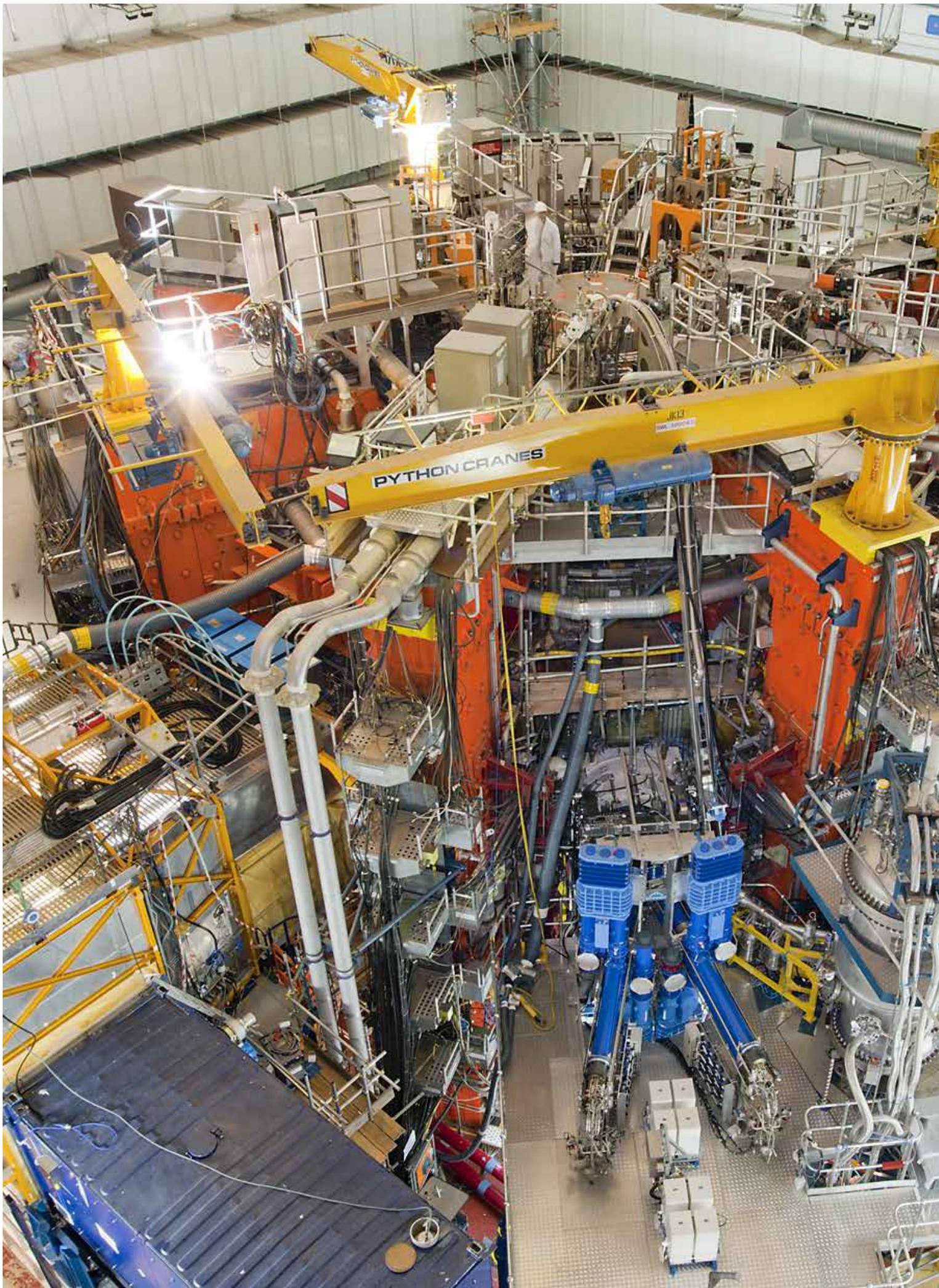
The plasma must be kept away from material surfaces to avoid it being cooled and contaminated; strong magnetic fields are used for this purpose. The most promising magnetic confinement systems are toroidal (ring-shaped) devices called tokamaks. The Joint European Torus (JET), situated at Culham, is the most powerful tokamak in the world.



Fusion fact

The sun is a giant fusion reactor. It fuses 600 billion kg of hydrogen every second to release energy, powering all life on earth.







JET – the world’s largest tokamak

JET, the Joint European Torus, is located at Culham and operated by CCFE on behalf of European fusion researchers. It is the only machine currently capable of operating with the deuterium and tritium fuel mixture that will be used in a commercial fusion power station. JET is the lead project of the EU fusion programme being carried out in all member states (plus Switzerland).

JET was designed to study fusion in conditions approaching those needed for a power plant. Construction began in 1978 and operations started in 1983. In 1991, JET became the first experiment to produce controlled fusion power from deuterium and tritium. In 1997, further JET experiments with deuterium and tritium observed a record 16 megawatts of fusion power (some 67% of the power needed to heat the plasma). More recently, JET has been upgraded with a completely new inner wall to test materials for the next generation of tokamaks. After 30 years, it is still at the cutting edge of fusion science and technology, playing a crucial role as a ‘test bed’ for ITER, its international successor, which is being built in France.

The programme is co-ordinated by the EUROfusion consortium, which manages European fusion research activities on behalf of Euratom. The use of the JET experimental facilities under EUROfusion is an outstanding example of successful European collaboration. JET is a ‘user facility’ similar to those in other fields of physics research, such as CERN – used jointly by decentralised scientific teams. Task Forces of scientists from associated laboratories across Europe come to carry out experiments on JET within the integrated European programme co-ordinated by EUROfusion.

**Fusion
fact**

JET holds the world record for fusion power, at 16MW – achieved in 1997.

MAST – pioneering spherical tokamak research

Most fusion research has concentrated on the so-called ‘conventional’ tokamak with a D-shaped plasma, including JET. From 1991, however, a new design – the ‘spherical tokamak’ – has been pioneered by Culham and is now being explored by laboratories all over the world.

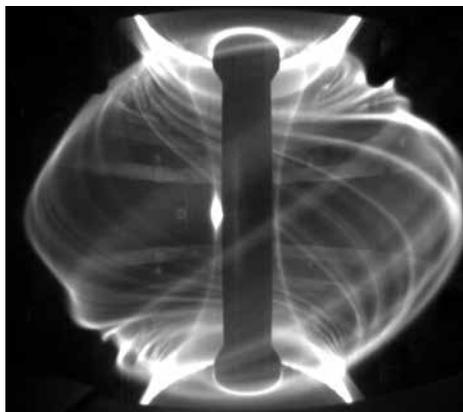
Spherical tokamaks are more compact devices. The plasma is held in a much tighter configuration – more like a cored apple than the ‘car tyre’ shape of conventional tokamaks. One of the chief advantages is that the magnetic field needed to hold the plasma and keep it stable (essential for an efficient fusion power plant) is much less in a spherical tokamak. This means a substantial gain in efficiency and better plasma performance for the engineering cost. Whilst the first fusion power stations will probably be based on the more mature conventional tokamak design, spherical devices could well provide an alternative for the second generation of plants.

The first spherical tokamak, START (Small Tight Aspect Ratio Tokamak), was designed and built at Culham as a low cost experiment to test theoretical predictions. It operated from 1991 to 1998 and produced such impressive results that approval was given for a larger successor experiment, MAST (Mega-Amp Spherical Tokamak).

MAST started operations in 2000. Its objective is to test plasma physics in this tight configuration with strong additional heating. An impressive range of diagnostic equipment has brought new insights into how plasmas behave, which also benefit conventional tokamak research – MAST data is making important contributions to international databases predicting the performance of ITER.

Amongst the most notable results from MAST have been ground-breaking work in understanding and controlling damaging instabilities in the plasma edge (so-called ‘ELMs’) – work that has been key in tackling this issue for ITER.

A £45 million upgrade is now underway to extend the machine’s capability even further. When complete in 2016, MAST will be equipped with new systems to explore the route to spherical tokamak power plants, test reactor design concepts, address physics issues for ITER and keep the UK at the forefront of fusion research.

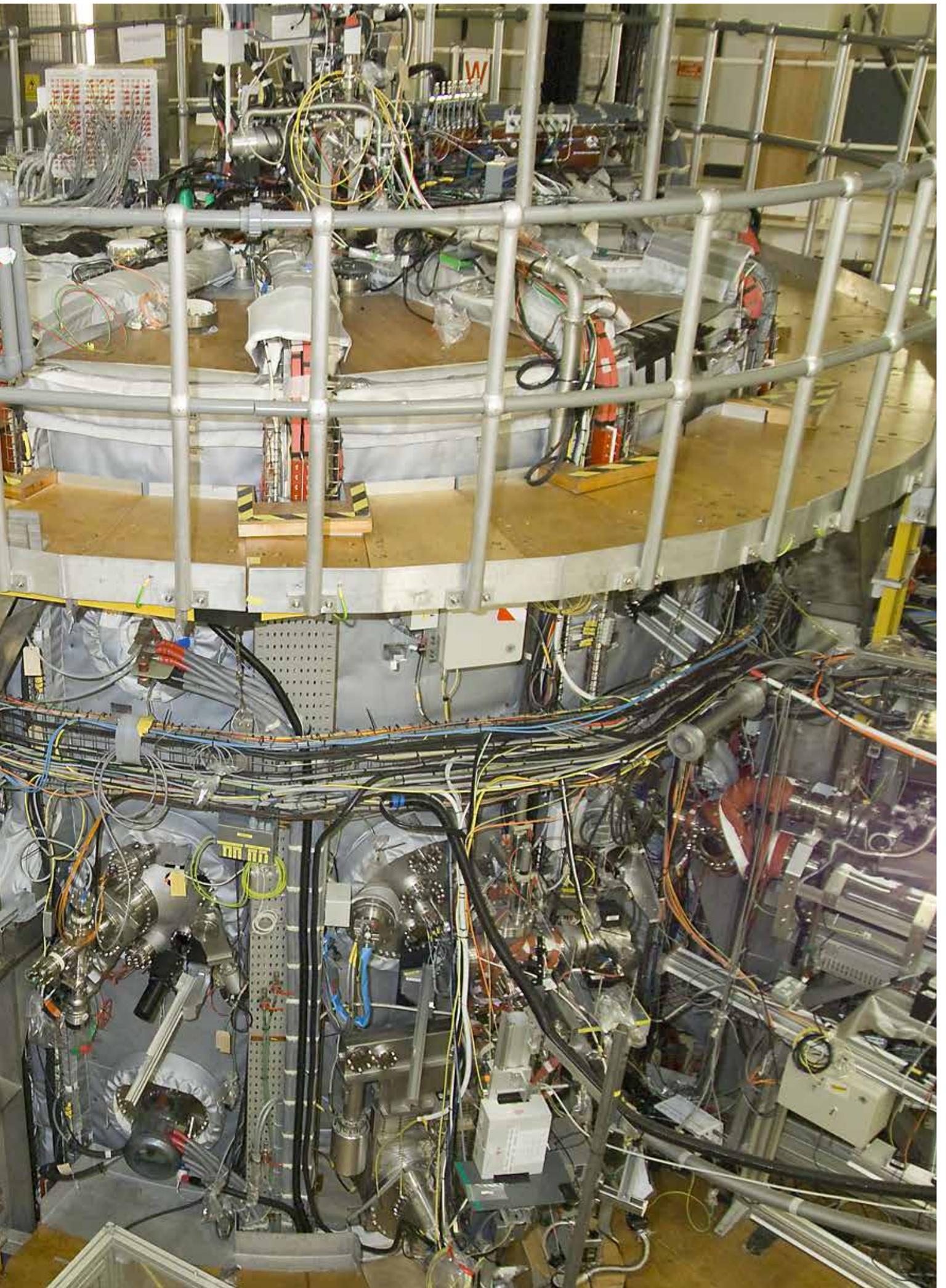


A high-speed camera image of a MAST plasma



**Fusion
fact**

MAST's range of diagnostics includes unique plasma viewing capabilities. It is the only tokamak in the world able to capture images of the whole plasma – made possible by high-speed cameras operating at up to 250,000 frames per second.

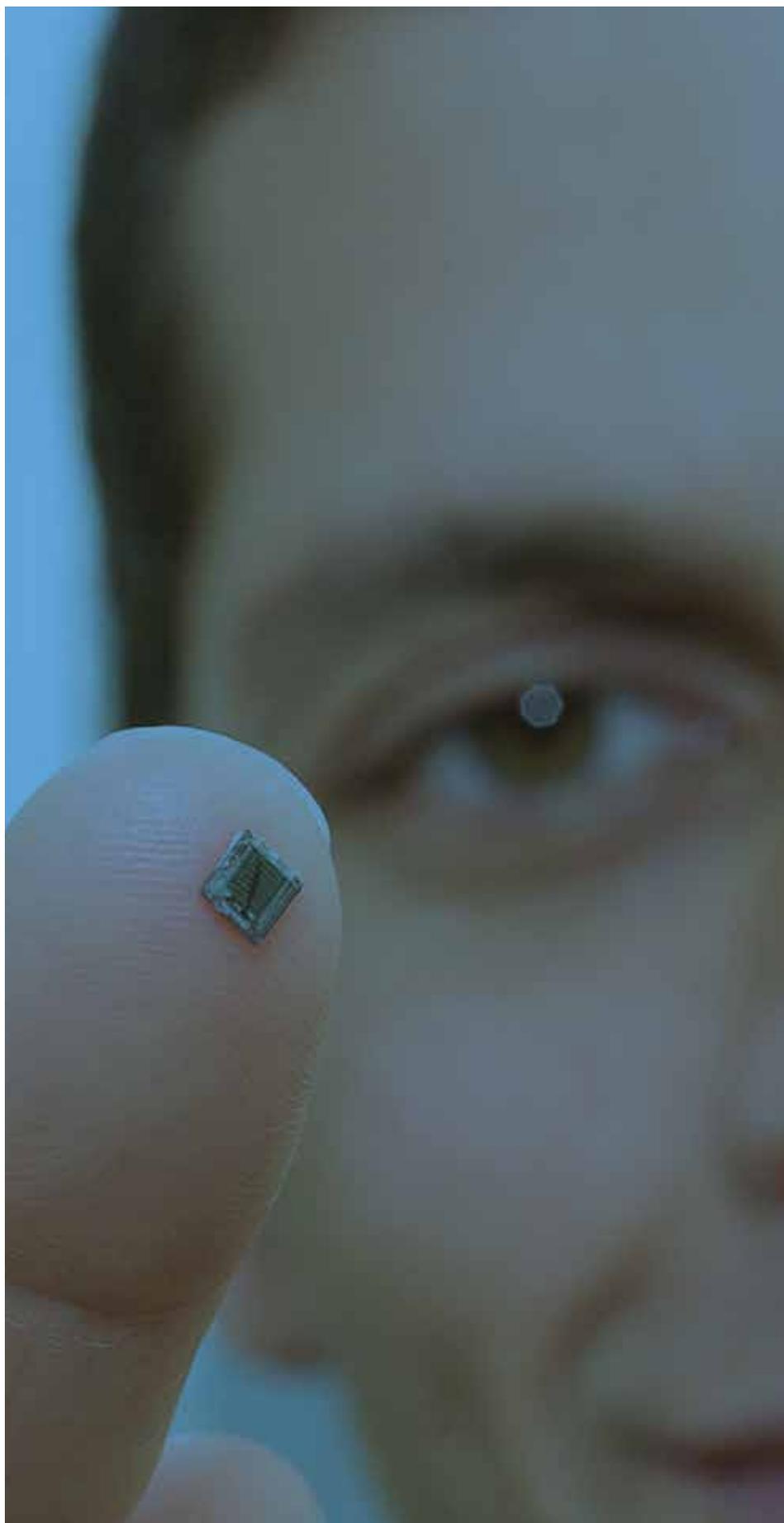


Working with industry

Fusion research offers many 'spin-off' benefits for UK industry. Culham's Fusion and Industry team is helping firms to capitalise on these benefits.

Opportunities to work in the fusion sector are set to expand as the ITER project develops. CCFE is advising companies on these prospects and enabling them to register as suppliers at www.fusion-industry.org.uk.

Technology transfer from fusion to companies occurs in areas as diverse as space research, advanced braking systems and semi-conductor manufacture. The Culham Innovation Centre was set up in 2001 and is managed by Oxford Innovation Ltd. It attracts start-up knowledge-based and service companies, which can use a CCFE technical support package to tap into the skills and technologies from fusion research at Culham. The package has been developed by CCFE to assist companies during the early stages of their business. Depending on their needs, a typical package could include technical advice and access to mechanical, electrical and electronic engineering skills, as well as computer modelling, precision diagnostics, cryogenic systems and microwave systems.



Fusion fact

CCFE is encouraging British hi-tech firms to bid for a share of the estimated €2 billion worth of contracts available in Europe during the construction of ITER.

Spin-off technologies from fusion research are benefiting a range of hi-tech companies at the Culham Innovation Centre



The materials laboratory at CCFE

Materials research at Culham

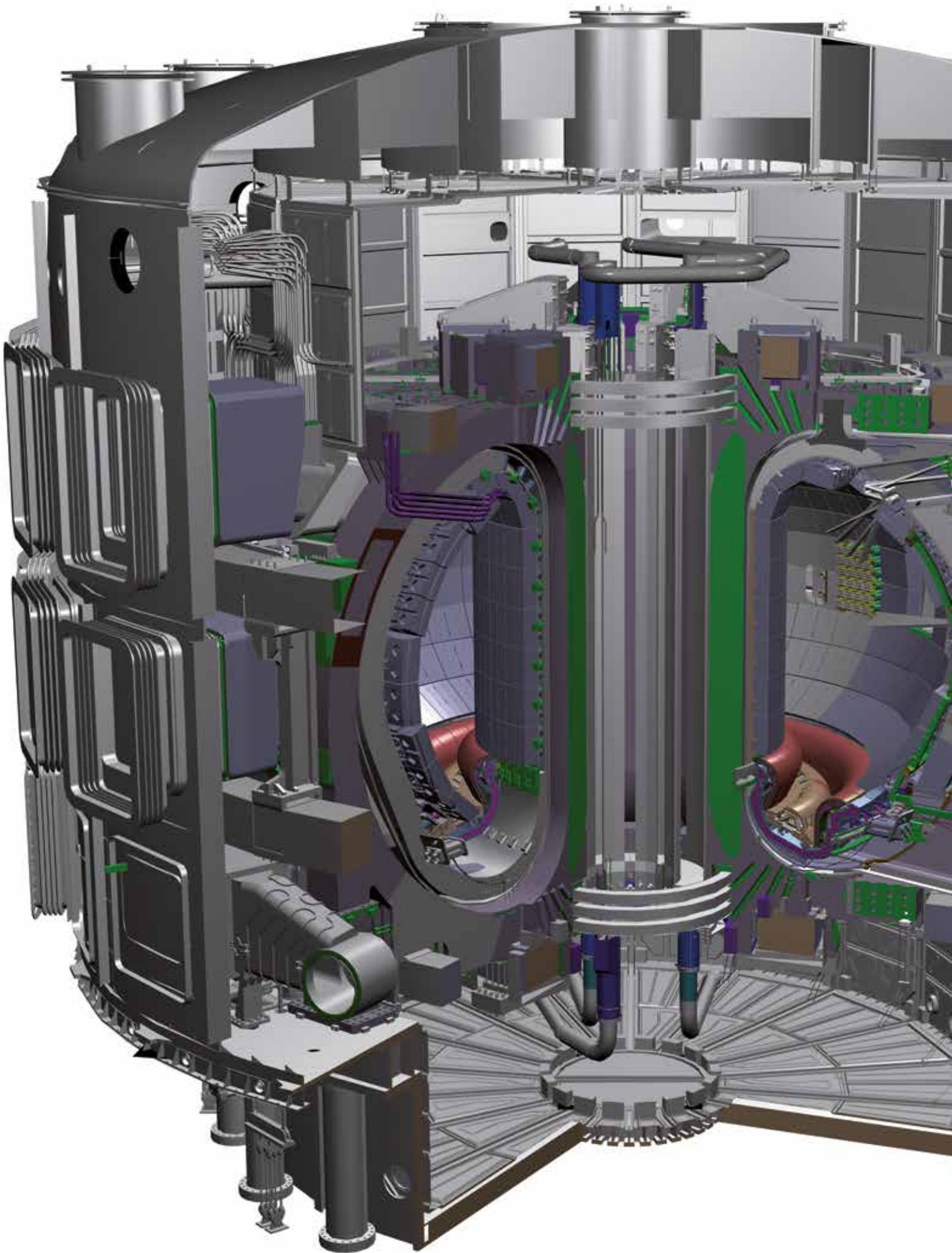
Choosing the right materials will be crucial to the development of fusion power plants. The options include special steels and more advanced materials, such as silicon carbide composites and lithium-based tritium generating materials. All of these materials have to be developed for use in the challenging environment within a power plant, which will impose a unique combination of temperature, neutron bombardment and stress conditions.

In collaboration with university specialists and European colleagues, CCFE has started work on several important aspects of materials research. These include computer simulations of atomic behaviour and experimental work on candidate materials in JET and MAST, which will lead to a better understanding of materials properties and lifetimes.

CCFE has recently opened a materials laboratory to analyse the characteristics of microscopic samples of metals. Part of the National Nuclear User Facility, it can also be used by academic researchers and industrial partners interested in how to develop both fusion and nuclear fission reactors of the future.

Fusion fact

Fusion scientists analyse materials from sub-atomic scale right up to the size that will be used for ITER. This involves spanning a factor ten billion in scale – similar to comparing the size of Culham with that of the entire solar system.



A cutaway model of the ITER tokamak

The next steps...

The European 'road-map' towards fusion energy production, published in 2013, foresees two successive generations of international devices:

- ITER – the next-generation research device now under construction in Cadarache, France;
- DEMO – a prototype power plant which will generate electricity from fusion.

This would lead to the first electricity production from fusion by 2050.

Parallel development of appropriate fusion materials and the demonstration of the environmental and safety case for fusion power will be completed in time for DEMO's construction. CCFE is undertaking significant design work for ITER and DEMO – part of Culham's rapidly growing technology programme.

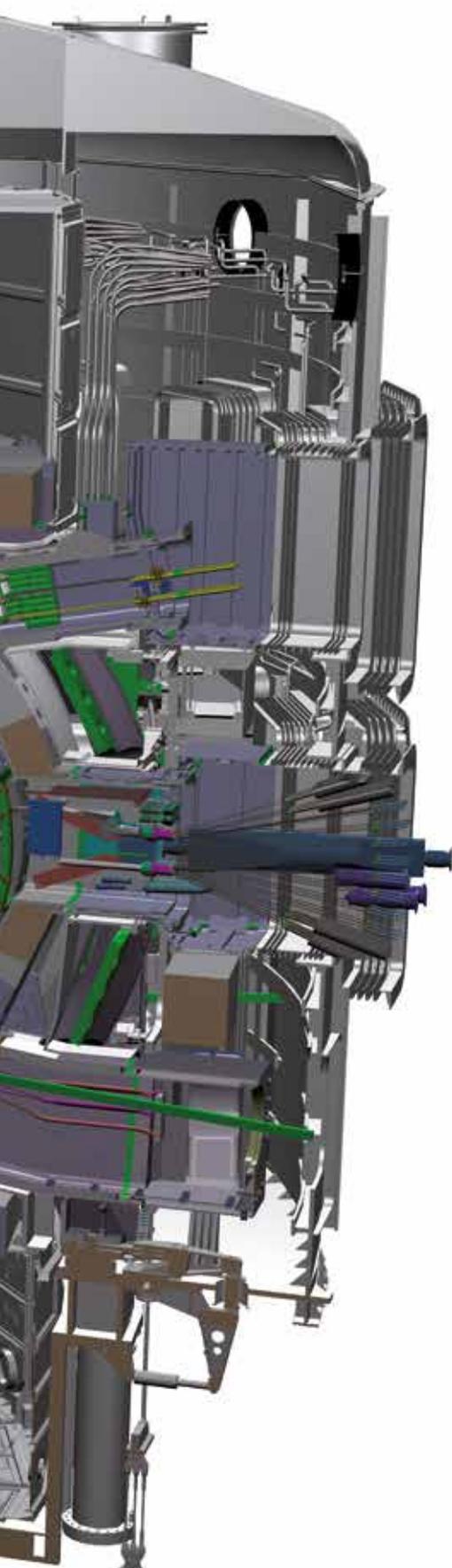
ITER

ITER is the next major international fusion project. As the forerunner to a demonstration power plant, it will be a crucial step towards commercial fusion energy. It is expected to prove the feasibility of electricity from fusion by routinely releasing some 500MW of fusion power.

ITER will be a scaled-up version of JET, with linear dimensions twice the size, but also using more advanced technologies – for example, superconducting magnetic coils.

Participants in ITER represent more than half the world's population: China, the European Union, India, Japan, South Korea, Russia and the USA. ITER will be the world's largest international co-operative research and development project after the International Space Station.

ITER will be located at an existing energy research site at Cadarache in southern France. An international team is now constructing the machine at a cost in the region of €14 billion. Scientists and engineers from Culham are helping to develop tokamak systems and to test ITER plasma experiments on MAST and JET. Completion is expected in the mid 2020's and will be followed by a lengthy period of operation that will trial essential physics and technologies for the fusion power plants of the future.



The ITER tokamak (23 metres in diameter) will be positioned in the centre, surrounded by its cryostat (30 metres in diameter) and concrete bioshield. (ITER Organization)

**Fusion
fact**

ITER will be the first fusion experiment to produce net power gain – releasing ten times the amount of power put in.



World-leading science today...for the energy solutions of tomorrow

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