ITER

The way to a benign and limitless new energy source

Since the 1930s, thousands of scientists have been inspired by the sight of billions and billions of fusion furnaces – stars, like our own sun – that flare across the heavens, releasing vast amounts of light and energy.

ITER is the latest experiment to tap fusion power, and its name means "the way" in Latin. The hope is that fusion could solve our energy needs by generating electricity from water, with no carbon dioxide emissions during operation and with relatively little nuclear waste.

HOW IT WORKS

It's simple – in principle, at least. Take two forms (isotopes) of hydrogen, squash them together, and you get a helium atom and a very energetic subatomic particle called a neutron.

The product of the reaction is a fraction lighter than its atomic ingredients, and by Einstein's famous equation $E=mc^2$ that tiny loss of mass results in a colossal release of energy. Harness that release in an efficient way and the world's energy needs are solved.

The problem is that the atomic ingredients of fusion, like all nuclei, repel each other. In the core of the sun, huge gravitational pressure allows fusion to take place at temperatures of around 15 million °C. In fusion machines, temperatures to achieve fusion need to be much higher – above 150 million °C.

No materials on Earth could withstand direct contact with such temperatures. To achieve fusion, therefore, ITER will use a device called a tokamak, which holds the reacting plasma away from the furnace's walls with intense magnetic fields.

The aim is for ITER to generate 500 megawatts of fusion power. This would pave the way for a demonstration power plant, called DEMO, in which fusion power will produce steam and – by way of turbines – up to 1000 megawatts of net electrical power. That's equivalent to a power plant that could supply about half a million British homes.

FUELLED BY WATER AND INGENUITY

The most efficient fusion reaction is that between two forms (isotopes) of hydrogen: deuterium and tritium.

While deuterium can be extracted from seawater in virtually boundless quantities, the worldwide supply of tritium is limited, estimated at only 20 kilograms.

Future fusion power plants will have to produce their own tritium. They will use "tritium breeding modules" made from lithium, which turns into tritium when bombarded by neutrons from the fusion reaction. Lithium is a light metal, as abundant as lead.

ITER will test experimental tritium breeding modules.

ENVIRONMENTAL IMPACT

The terrific heat generated by fusion will be absorbed using 3 million cubic metres of water per year, about a fifth of the total transported by the local Verdon river.

Tritium releases are predicted to be 100 times lower than the regulatory limit.

Fusion reactions produce no long-lived waste. Low-level radioactive waste will result from the activation of some of the machine's components. All waste materials will be treated, packaged and stored on site.

In all, 39 protected or rare species will benefit from measures on the 180-hectare ITER site. Two areas have been fenced off to protect the Occitan cricket, two species of butterfly, woodlark nesting sites and rare orchids.

Of the 2.5 million cubic metres of earth and rock moved to level the ITER platform, over two-thirds were reused on site.

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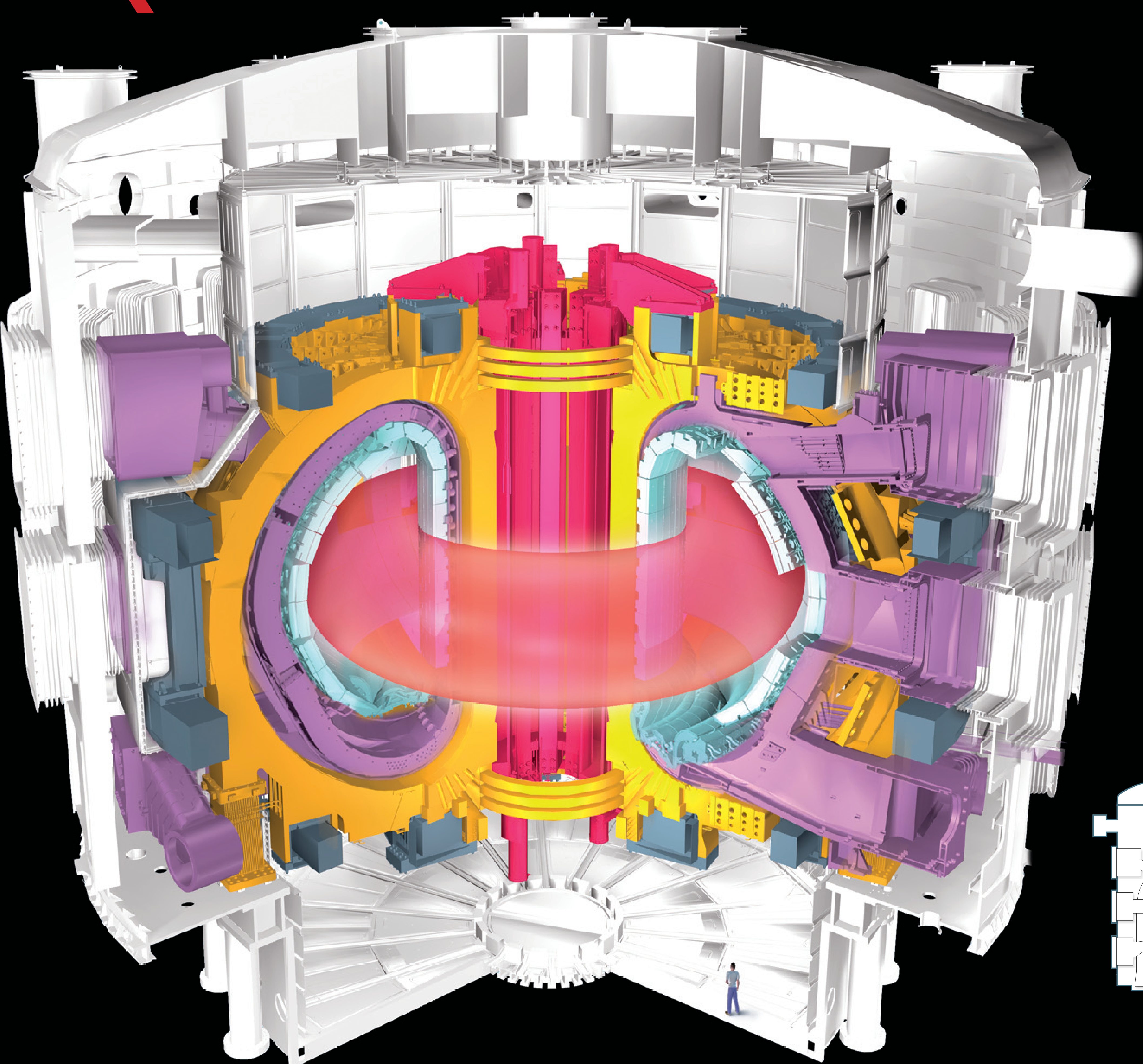
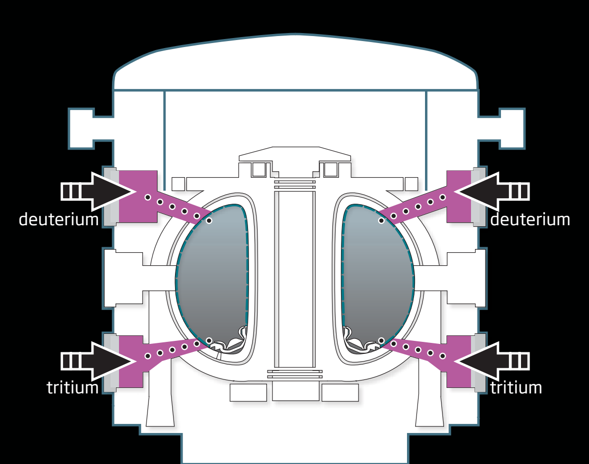
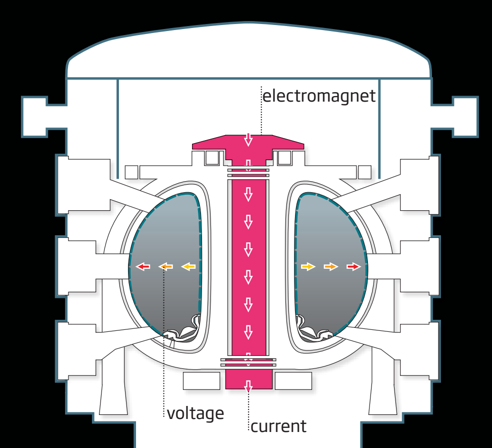
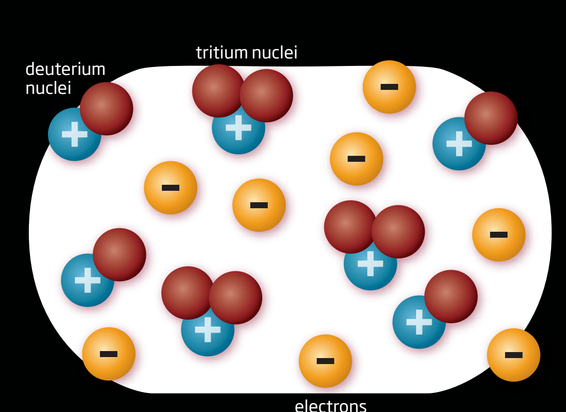




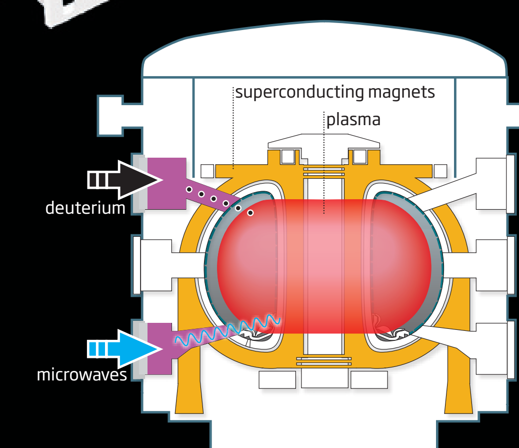
1 Puffs of deuterium and tritium gas are injected into the doughnut-shaped vacuum vessel, called a tokamak. The gas weighs less than a postage stamp and fills a volume one-third that of an Olympic swimming pool.



2 Electricity flowing through this electromagnet produces a voltage across the gas.

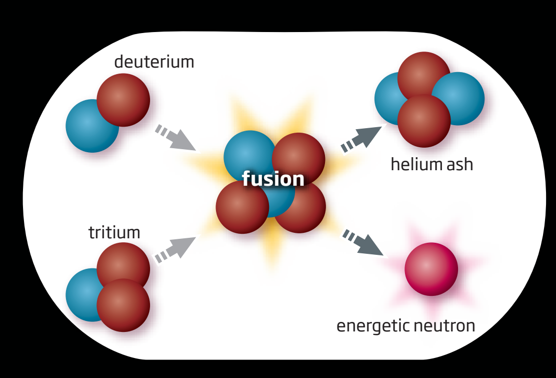


3 Voltage rips electrons from the deuterium and tritium atoms. They turn into charged atoms (ions) within a few microseconds, forming a particle soup called a plasma.

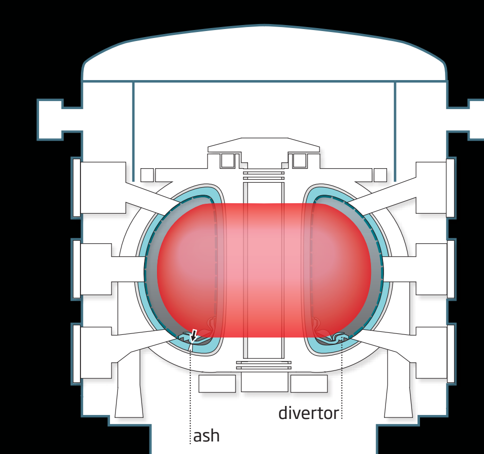


4 Plasma is locked inside the vacuum vessel by magnetic fields that are created by an array of superconducting magnetic coils.

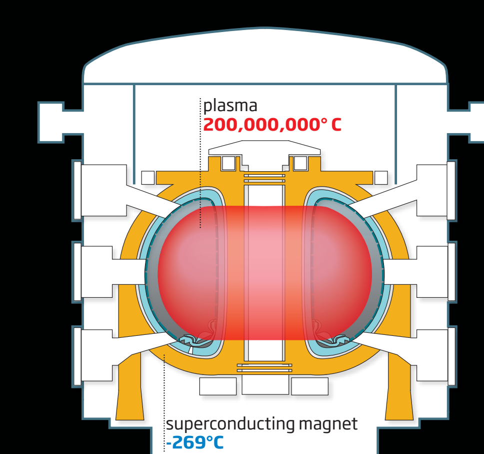
Like the bar in an electric fire, the plasma quickly heats up to 10 million °C, but that's not hot enough for fusion to occur.



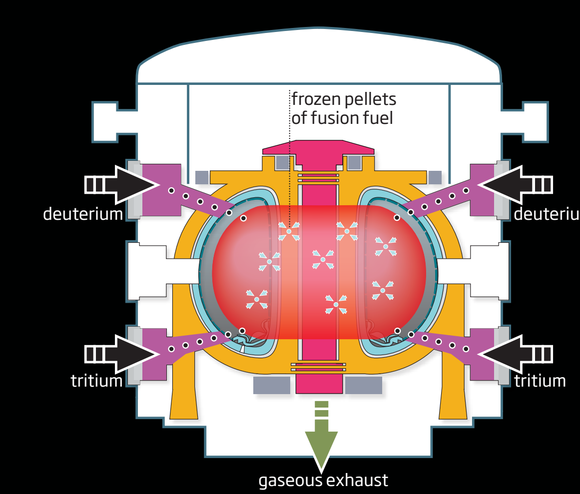
5 To raise the temperature further, scientists fire radio and microwaves into the plasma and high-energy beams of deuterium atoms. The plasma then reaches 100 - 200 million °C, hot enough for the deuterium and tritium nuclei to fuse.



6 Fusion produces high-energy neutrons and helium particles that deposit their energy into the plasma and keep it hot, before becoming "ash". The "ash" is eventually forced out through the divertor.



7 Neutrons and other particles bombard the tiles on the plasma-facing components and heat them. In a future power station this heat will be harnessed to make electricity. Superconducting magnets operate near absolute zero. The distance to the magnets from the heart of the plasma sees the greatest temperature gradient in the universe.



8 The plasma must be continuously refuelled with deuterium and tritium for the process to continue. Unburnt fuel is also recovered from the gaseous exhaust and the reaction is fine-tuned by firing frozen pellets of fusion fuel deep into the plasma.

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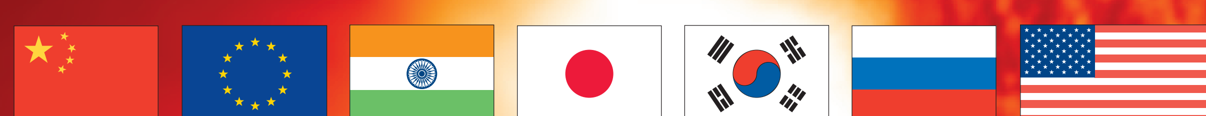
PLANET POWER

Over half of the world's population is represented in the **ITER Organization**.

The ITER Organization was conceived as long ago as 1985 but was only formally established on 24 October 2007, following an agreement between the People's Republic of China, the European Union, the Republic of India, Japan, the Republic of Korea, the Russian Federation and the United States of America.

Conceptual design work began 20 years ago, in 1988. The final design for ITER was approved in 2001. The construction work on ITER is expected to be completed by around 2020. ITER is expected to work for around two decades.

A technician in Forschungszentrum Karlsruhe, Germany, makes final checks of the prototype ITER cryogenic vacuum pumps



BRIEF HISTORY OF FUSION

Some 70 years ago scientists obtained the first insights into the physics of sunshine: when the sun and other stars transmute matter, tirelessly transforming hydrogen into helium by the process of fusion, they release colossal amounts of energy.

By the mid-1950s "fusion machines" were operating in the Soviet Union, the United Kingdom, the United States, France, Germany and Japan. Yet harnessing the energy of the stars was to prove a formidable task.

After pioneering work in the Soviet Union in the late 1950s, a doughnut-shaped device called a tokamak was to become the dominant concept in fusion research. Since then, tokamaks have passed several milestones.

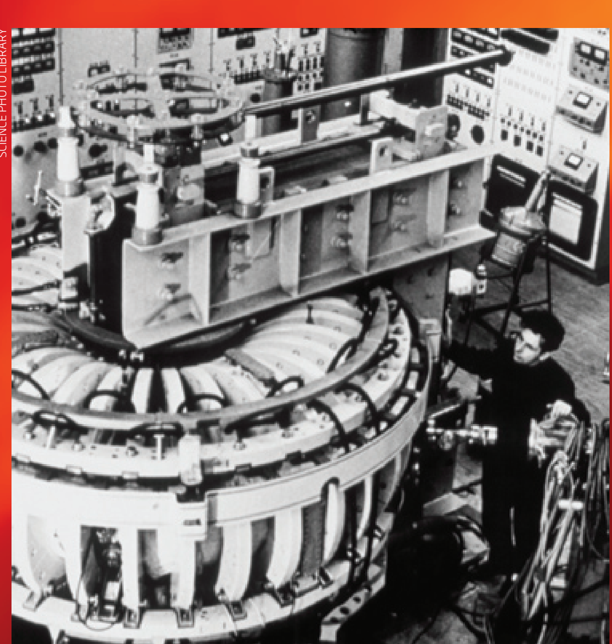
Experiments with actual fusion fuel – a mix of the hydrogen isotopes deuterium and tritium – began in the early 1990s in the Tokamak Fusion Test Reactor (TFTR) in Princeton, US, and the Joint European Torus (JET) in Culham, UK.

JET marked a key step in international collaboration, and in 1991 achieved the world's first controlled release of fusion power. While a significant amount of fusion power was produced by JET, and TFTR, exceptionally long-duration fusion was achieved in the Tore Supra tokamak, a EURATOM-CEA installation located at France's Cadarache nuclear research centre and later in the TRIAM-1M tokamak in Japan and other fusion machines.

In Japan, JT-60 has achieved the highest values of the three key parameters on which fusion depends – density, temperature and confinement time. Meanwhile, US fusion installations have reached temperatures of several hundred million °C.

In JET, TFTR and JT-60 scientists have approached the long-sought "break-even point", where a device releases as much energy as is required to produce fusion. ITER's objective is to go much further and release 10 times as much energy as it will use to initiate the fusion reaction. For 50 MW of input power, ITER will generate 500 MW of output power.

ITER will pave the way for the Demonstration power plant, or DEMO, in the 2030s. As research continues in other fusion installations worldwide, DEMO will put fusion power into the grid by the middle of this century. The last quarter of this century will see the dawn of the Age of Fusion.



The tokamak, a revolutionary magnetic confinement device, was developed in the late 1950s at the Kurchatov Institute in Moscow

HOW TO CATCH A STAR

How can ITER handle matter 10 times as hot as the core of the sun? By trapping it inside a strong magnetic field.

Magnetic fusion machines of various shapes and arrangements were developed in several countries as early as 1950.

But the breakthrough occurred in 1968 in the Soviet Union, when researchers were for the first time able to achieve remarkably high temperature levels and plasma confinement time – two key criteria for fusion. The secret of their success was a revolutionary doughnut-shaped magnetic confinement device called a tokamak, developed at the Kurchatov Institute, Moscow. From this time on, the tokamak became the dominant concept in fusion research.

Doctor Octopus in the film Spiderman 2

FICTIONAL FUSION

Hollywood has paid an indirect tribute to how fusion power has the potential to transform our world by using the technology to spice up movie scripts.

In **Iron Man**, the hero's protective suit is powered by fusion. Before he turns bad, **Spiderman 2**'s Doctor Octopus creates a new power source using fusion.

Chain Reaction, starring Keanu Reeves and Rachel Weisz, hinges on the invention of a rival fusion technology to that used by ITER (so-called bubble fusion).

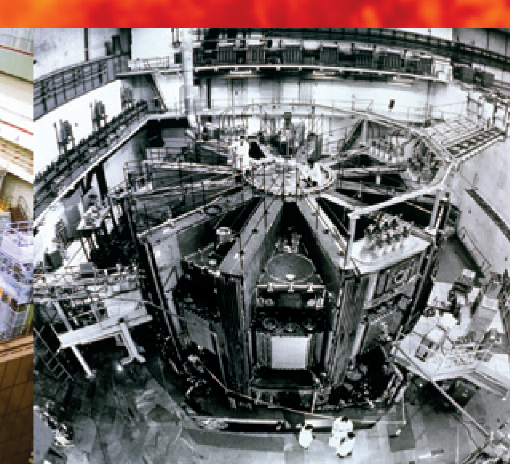
In **The Saint**, Val Kilmer attempts to steal a fusion formula from Elisabeth Shue. Once again, Hollywood scriptwriters have opted for a highly speculative alternative to ITER.

The **Mr. Fusion Home Energy Reactor** was the name of a power source used by the DeLorean time machine that starred in the **Back to the Future** movie trilogy.

Fusion reactors turn up in **Star Trek** too, for instance to power the impulse engines on Federation starships.

Joint European Torus, UK

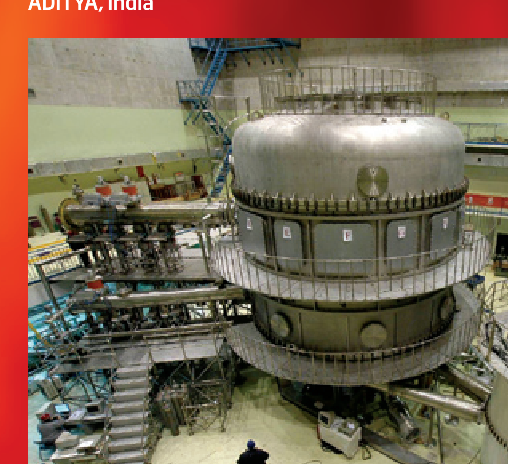
JT-60, Japan



T-15, Russia

ADITYA, India

NSTX, Princeton, US



EAST, China

KSTAR, Korea

TOP TOKAMAKS

ITER is the latest in a long succession of tokamak experiments, and is supported by advanced fusion research programmes around the world.

Joint European Torus (JET) in Culham, United Kingdom (in operation since 1983)
On 9 November 1991, JET achieved between 1.5 and 2 megawatts of fusion power – the first time a significant amount of power was obtained from controlled nuclear fusion. In 1997, JET established the current world record for fusion power of 16 MW for a limited duration and 5 MW for 5 seconds.

JT-60 in Naka, Ibaraki prefecture, Japan (1985)
In 1997, JT-60 set a world record for plasma temperature, density and confinement time.

T-15 in Moscow, Russia (1988)
T-15 is a Russian superconducting tokamak that operated until 1995. It is being upgraded to conduct fusion research to support the ITER and DEMO projects.

ADITYA at the Institute for Plasma Research in Gujarat, India (1989)
Aditya, India's first tokamak, is a medium-sized device operated by the Institute for Plasma Research in Gandhinagar.

NSTX in Princeton, New Jersey (1999)
The National Spherical Torus Experiment (NSTX), at Princeton Plasma Physics Laboratory in the US, is a "spherical tokamak".

EAST (HT-7U) in Hefei, China (2006)
Construction of the Chinese Experimental Advanced Superconducting Tokamak (EAST) took less than five years and was completed in March 2006.

KSTAR in Daejon, South Korea (2008)
The Korean tokamak KSTAR features magnets that are all superconducting, cooled to low temperatures so that they can produce stronger magnetic fields than ordinary electromagnets.