EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET

LEADING DEVICE FOR FUSION STUDIES

HOLDER OF THE WORLD RECORD OF FUSION POWER PRODUCTION

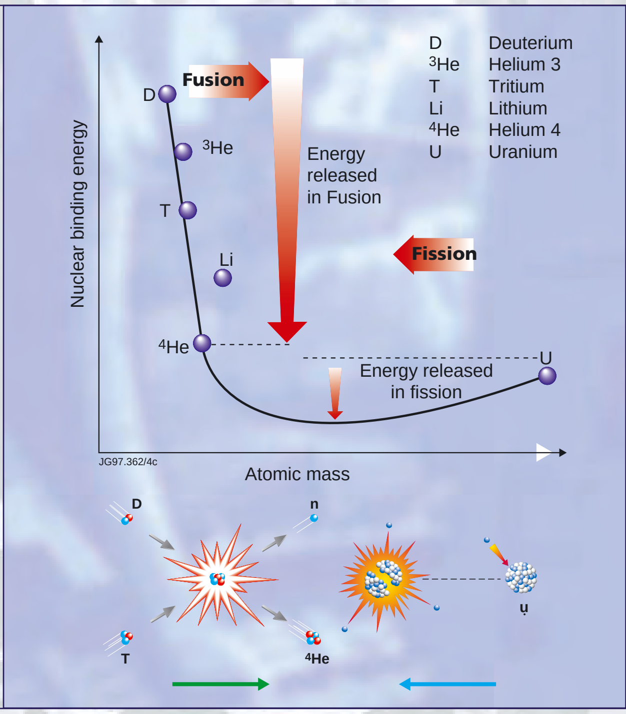
EXPERIMENTS STRONGLY FOCUSSED ON THE PREPARATION FOR ITER

EXPERIMENTAL DEVICE USED UNDER THE EUROPEAN FUSION DEVELOPEMENT AGREEMENT

THE JOINT EUROPEAN TORUS
A EUROPEAN SUCCESS STORY

Fusion: the Energy of the Sun

If the temperature of a gas is raised above 10,000 °C virtually all of the atoms become ionised and electrons separate from their nuclei. The result is a complete mix of electrons and ions with the sum of all charges being very close to zero as only small charge imbalance is allowed. Thus, the ionised gas remains almost neutral throughout. This constitutes a fourth state of matter called plasma, with a wide range of unique features.

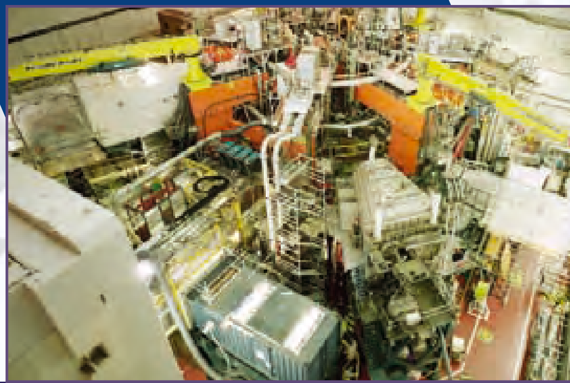


The sun, and similar stars, are spheres of plasma composed mainly of hydrogen. The high temperature, around 15 million °C, is necessary for the pressure of the plasma to balance the inward gravitational forces. Under these conditions it is possible for hydrogen nuclei to fuse together and release energy.
In a terrestrial system the aim is to produce the 'easiest' fusion reaction using deuterium and tritium. Even then the rate of fusion reactions becomes large enough only at high particle energy. Therefore, when the required nuclear reactions result from the thermal motions of the nuclei, so-called thermonuclear fusion, it is necessary to achieve extremely high temperatures, of at least 100 million °C.

Magnetic Confinement and Tokamaks

In the sun the high temperature particles are held together by the gravitational force arising from the sun's mass. In the absence of gravity the particles would escape at their thermal velocities. In a terrestrial system, at the required temperature, particles would escape to the wall in microseconds. It is therefore necessary, without the gravitational field available to the sun, to provide an appropriate confinement system for the plasma. This is possible since the negatively charged electrons and the positively charged nuclei forming the plasma are subject to a magnetic force called the Lorenz force. Because of this force, charged particles gyrate around the magnetic field. Thus the movement of charged particles is strongly restricted, and they 'stick' to the magnetic field lines.
JET is a tokamak in which strong magnetic fields are used to confine the plasma. In this class of devices, the plasma chamber is doughnut shaped, to avoid the end losses which would occur in, for example, a linear cylindrical configuration. The vessel is filled with gas at a very low pressure and this gas is converted to hot plasma by passing an electric current through it. The application of further strong magnetic fields keeps ('confines') the hot particles in the centre of the vessel and avoids melting of the walls.

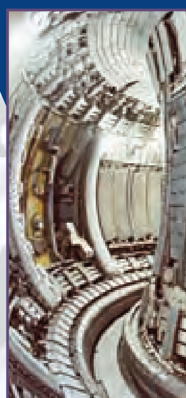
History of Jet and scientific achievements



The design team of JET started their work in September 1973 and by September 1975 they had prepared a design proposal. In 1979 the site work began and in 1983 JET started operation. In the same year 3 MA plasma currents and 2 keV electronic temperatures were produced. In the 1980s the plasma current reached 7 MA, exceeding the design specification, while temperatures as high as 10 keV for electrons and 20 keV for ions were reached and a confinement time greater than 1 second (it was 20 ms when it started) was also recorded.

In the 1990s power handling issues became of crucial importance. In fact, although the magnetic field prevents the hot plasma streaming directly onto the surrounding material surfaces, the heat produced in the plasma will ultimately fall onto such surfaces. In JET this means tens of megawatts of power, and in a reactor hundreds of megawatts. JET has concentrated on solving the problems associated with heat loads and impurity production by modifying the magnetic fields nearest the walls to guide the particles escaping away from the main plasma to localised targets known as divertors.
Finally, JET was the first tokamak in the world to be operated with tritium fuel and today still holds the world record fusion energy. In 1991 a preliminary tritium experiment was carried out. In 1997 a tritium experimental campaign gave 16 MW of fusion power, 22 MJ of fusion energy and a steady fusion power of 4 MW maintained for 4 seconds.

JET under EFDA



Since the 1st January 2000, the overall implementation and co-ordination of the scientific exploitation of JET has been carried out under EFDA, the European Fusion Development Agreement. The ownership of the JET Facilities was transferred at that date into the custody of the UK Atomic Energy Authority (EURATOM-UKAEA Association), which now operates the facilities on behalf of EFDA.
JET, a worldwide recognised centre of excellence, is now a European users' facility attracting many hundreds of scientists, mostly from European laboratories/institutions associated to the EC (EURATOM) but also from the US, Japan and Russian Federation. JET is a prototype of the European Research Area, bringing together European competencies in a joint and focused programme in much the same way as ITER is expected to operate.

EUROPEAN FUSION DEVELOPMENT AGREEMENT

1973

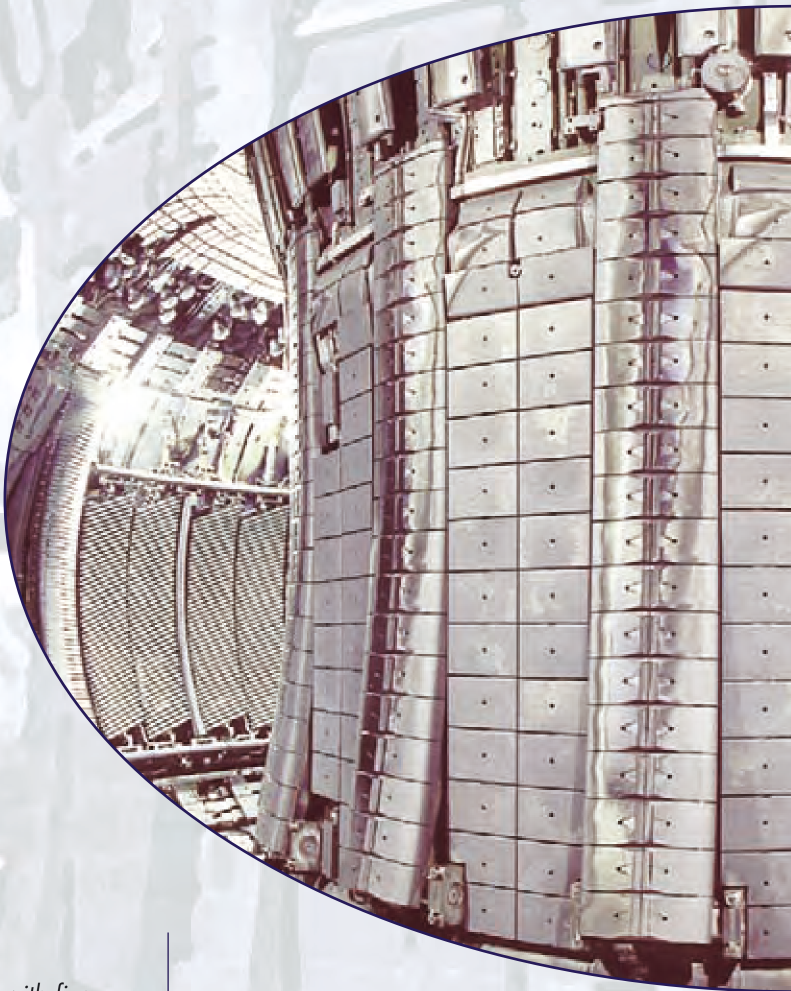
The Design Team starts working on JET

1977

The Culham site (UK) is chosen

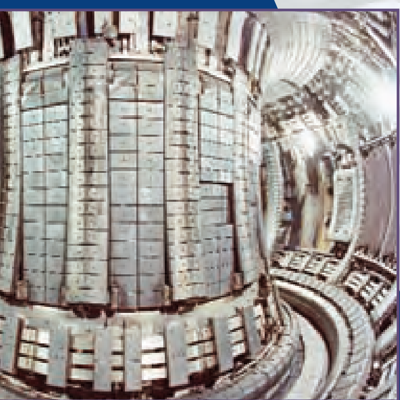
1979

The works at the site start



The JET machine seen from the top of the torus hall. The machine is completely hidden by the many diagnostics used for measuring a wide range of plasma parameters. The orange limbs form the transformer yoke of the machine.

The control room is the nerve centre of the facility. Physicists and engineers operate the machine, monitor its behaviour and run the diagnostics for extracting experimental data.



The JET machine has operated with five different divertor configurations since operations started. The divertor has allowed new operation modes to be achieved and problems of edge physics to be studied.

The JET Desig

Plasma Major Radius
Plasma Minor Radius
Toroidal Magnetic Field (on Plasma axis)
Plasma Volume
Plasma Current

1983

JET operations start

19851985198519851985

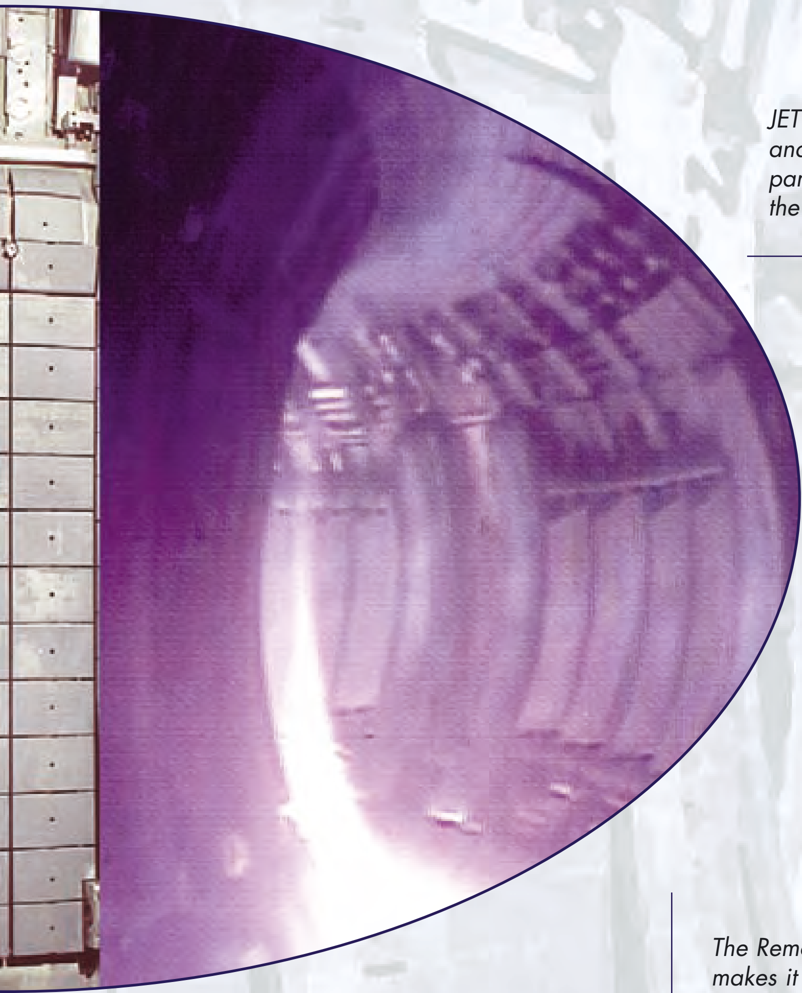
1985

JET achieves a plasma current of 5 MA

19881988198819881988

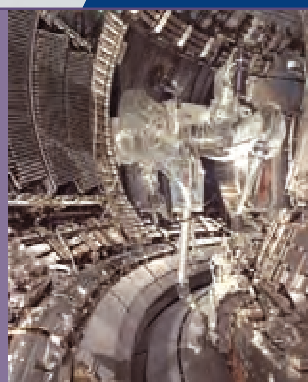
1988

JET achieves a plasma current of 7 MA



JET is located at the UKAEA Culham Science Centre near Oxford (UK) and is operated and maintained by the UKAEA on behalf of the EFDA partners. The EFDA Close Support Unit is responsible for the use of the facilities and for co-ordinating the scientific programme.

Heating is provided in JET through the neutral beam injectors and radio frequency systems. In this picture a neutral beam injector is shown in the forefront.



The Remote Handling equipment makes it possible to work in an activated environment and has been used to replace the divertor after the Tritium phase.

gn Parameters

2.96 m

1.25 m (horizontal) 2.10 m (Vertical)

3.45 T

~ 90 m^3

Circular Plasma 3.2 MA D-Shape Plasma 4.8 MA

1991

JET achieves first controlled release of fusion power

19931993199319931993

1993

Installation of Mark I divertor

19971997199719971997

1997

D-T Experiments World Record of 16 MW fusion power

JET: a bridge to ITER

In ITER, like JET, the activities are conducted under an international collaboration. The aim is to design a tokamak which would produce fusion power of hundreds of megawatts. The successful design of such a reactor calls for answers to many questions which only existing tokamaks such as JET can provide.

The present scientific exploitation of JET is mainly devoted to the preparation of operating scenarios for ITER. Particular attention has been focussed on the validation of the reference scenario for ITER operation and the control of instabilities which can degrade performance and leads to large transient head loads on plasma facing components. Advanced regimes for ITER operation are also being explored where the control of plasma profiles and plasma current can lead to improved performance and long pulse capability. Particular attention has been focussed on the use of real time control techniques.

The unique role of JET

JET is a unique tool and the best asset for the preparation of ITER operations:

- JET is the largest tokamak in the world
- JET has a unique worldwide capability for operating with the ITER fuel, Tritium, and the ITER first wall material, Beryllium
- JET is a facility suited to test heating and diagnostic prototypes for ITER in the most relevant plasma conditions

1999

The Joint Undertaking status ends

2000

JET starts under the EFDA and validates ITER reference operation

2002

The machine restarts after a shutdown in which major enhancements are implemented

The European Strategy is oriented towards a Commercial Fusion Power Plant

In June 2000, a group of independent experts completed the latest in a series of "Five Year Assessments" of the European fusion programme. They recommended the fusion programme should incorporate two major steps before moving to a prototype power plant.

The objectives of these machines will be:

ITER - the "Next Step"

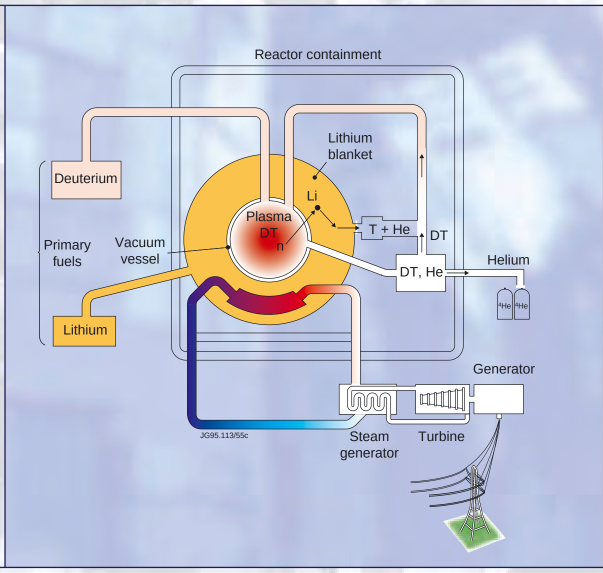
- Fusion Power: 500 MWth
- Long-duration burning plasma
- Test blankets concepts

DEMO - the demonstration power plant

- Fusion Power: 2000 MWth
- Net electricity production
- Tritium self sufficiency
- High reliability of operation

PROTO - the prototype power station

- Electric Power: 1500 MWel
- Improved commercial electricity production



In parallel to ITER, a materials research programme likely to require a large-scale materials test facility was held necessary to develop higher performance, low activation materials for DEMO and PROTO.

A Fast Track towards Fusion Energy

The current timetable of 50 years for large-scale energy production from fusion is mainly due to the priority, and therefore funding levels, for this branch of research.
At the end of 2001, a group of experts, at the request of the Council of the European Union Research Ministers, examined the possibility of having a fast track towards fusion energy production and reached the following main conclusions.
The ITER Project is the essential step towards energy production on a fast track. Its construction should start as soon as reasonably achievable. ITER, with its 500 MW of fusion power, will demonstrate the technical feasibility of fusion power and will represent a major step towards a power plant.

ITER will be built with the well characterised steels currently used in fission reactors. New materials will be needed for a power plant and therefore a high-intensity neutron source, such as the International Fusion Material Irradiation Facility (IFMIF) project, is required to test and verify material performance when subjected to extensive neutron irradiation of the type encountered in a fusion power plant.
In a fast track approach, ITER and IFMIF should proceed in a co-ordinated way with the ITER project starting in parallel with the detailed engineering design of IFMIF. DEMO and PROTO could be combined into a single step designed as a credible prototype for a power-producing fusion power plant, although not fully technically and economically optimised in itself.
The fast track approach could demonstrate the technical feasibility of fusion power on a 20-30 year timescale.

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JET FACTS

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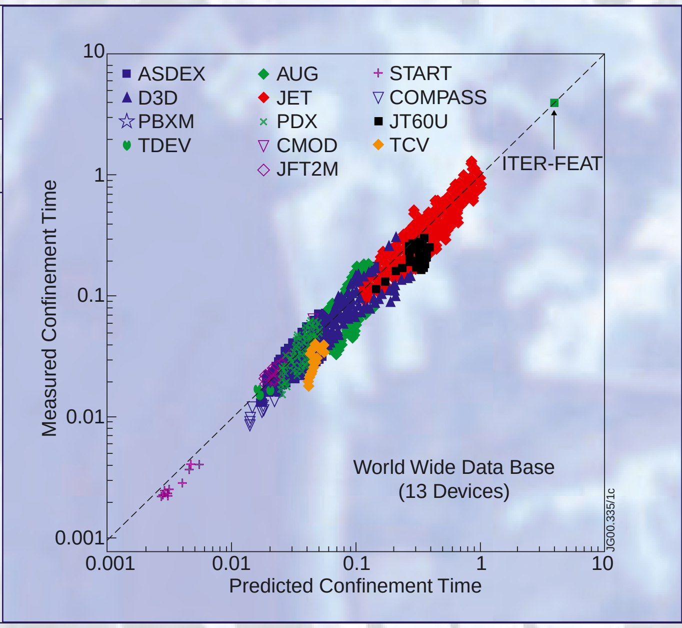
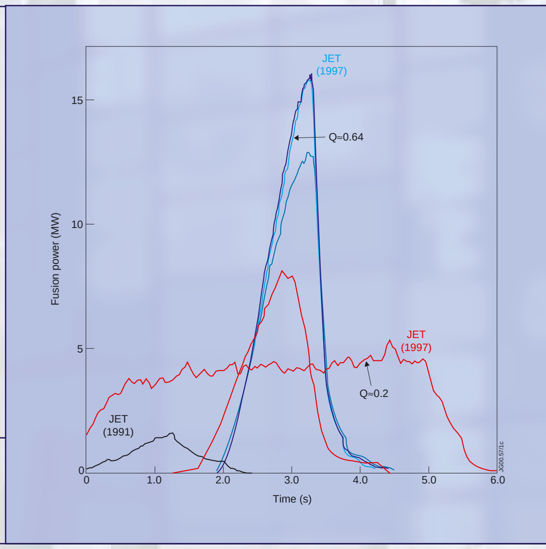


Confinement extrapolation to ITER

(In its reference operating scenario)

Fusion Power experiments at JET



Typical scientist involvement in JET Campaigns

(data from campaigns C1 - C4; by European Country)