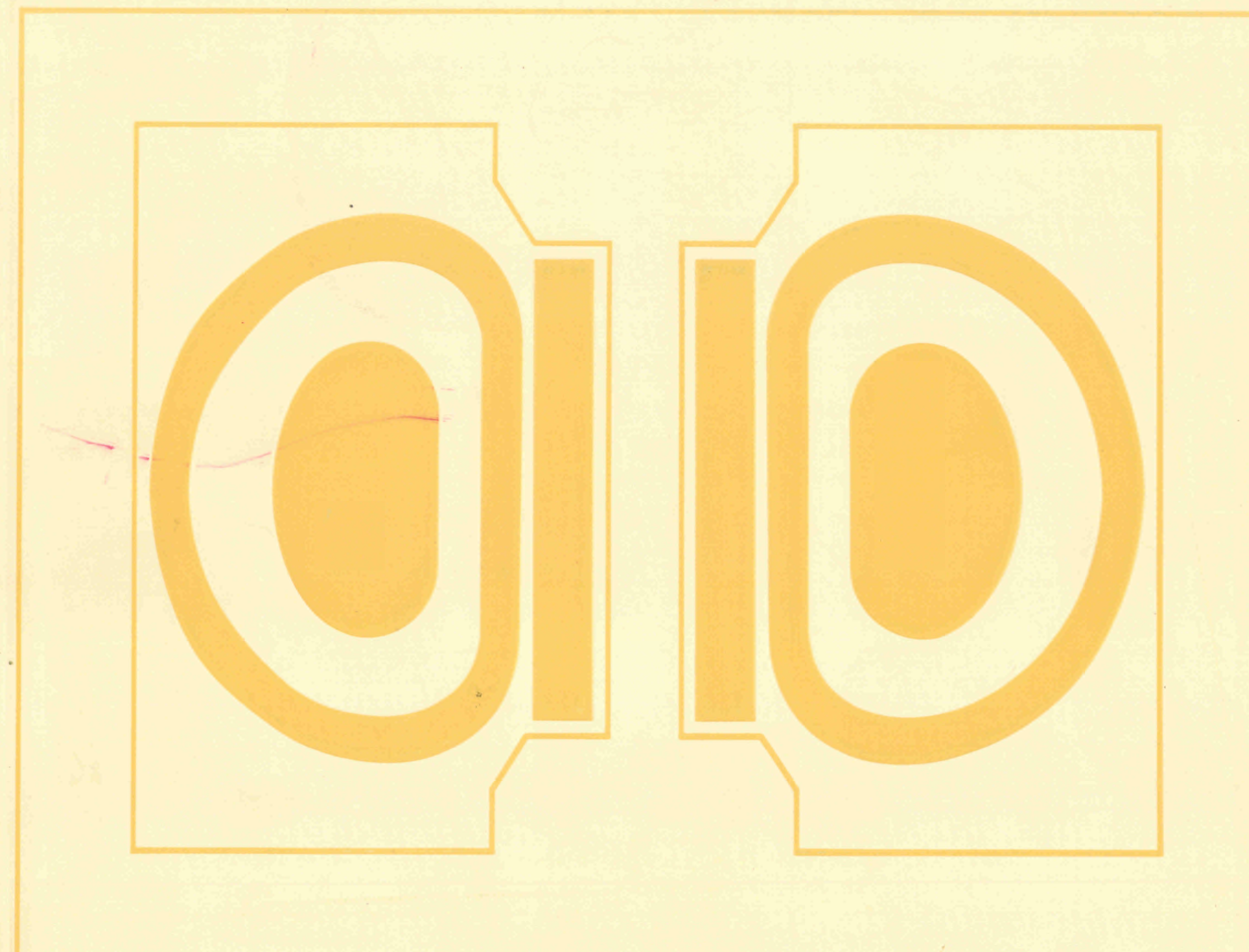
JOINT EUROPEAN TORUS JET

JET

JOINT

UNDERTAKING

ANNUAL REPORT 1995



JET JOINT UNDERTAKING ANNUAL REPORT 1995

EUR 16872-EN-C
EUR-JET-AR18

JET JOINT UNDERTAKING

ANNUAL REPORT 1995

MAY 1996

Catalogue number: **CD-NA-16872-EN-C**

for the report **EUR 16872** (EUR-JET-AR18)

This document is intended for information only and should not be used as a technical reference.

Editorial work on this report was carried out by

B.E. Keen and G.W. O'Hara

Prepared and produced by JET Publications Group.

Printed in England

Preface

Introduction, Summary and Background

JET, Euratom and other Fusion Programmes

Technical Status of JET

Scientific Advances during 1995

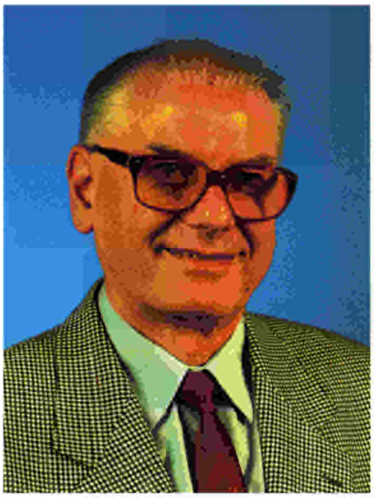
Future Programme

Members and Organisation

Administration

Appendices

Preface



The JET Project had another highly successful year in 1995. The experimental campaign of the Pumped Divertor characterisation phase, which began early in 1994, was completed in June 1995. The shutdown to install the Mark II divertor and undertake essential modifications to the machine then started on schedule during the latter half of the year.

The control of plasma impurities is essential for the development of controlled fusion energy. The JET Project was extended until 1996 with the objective of establishing reliable methods of plasma purity control and plasma exhaust in operational conditions relevant to a Next Step Tokamak. For this purpose, the pumped divertor (Mark I) was installed in 1994 to test various configurations. These tests were completed during the 1995 experimental campaign. A second configuration with improved purity control (Mark IIA) was installed during the subsequent shutdown.

During the 1995 experimental campaign, JET pursued further its investigations of power handling and particle control with the Mark I divertor. This divertor has proven to be effective in handling the power exhaust and in preventing the high impurity influxes which previously terminated high performance discharges. This provided the conditions for JET to conduct a broad based research programme of direct relevance to the Next Step Tokamak, i.e., ITER (the International Thermonuclear Experimental Reactor, on the engineering design of which Euratom, Japan, the Russian Federation and the USA have joined forces). In particular, ITER relevant detached divertor plasmas and radiative power exhaust have eased the power loading on the divertor target tiles.

Carbon fibre composite (CFC) target tiles were used as the power handling material in the divertor until mid-March 1995. These were then replaced by beryllium tiles, a target material favoured for ITER, in order to assess the performance of beryllium as a target tile material compared with CFC. JET is the only machine in the world on which this comparison could be undertaken. The main outcome of wide ranging experiments showed that under normal operating conditions, CFC and beryllium targets result in similar plasma behaviour and have comparable power handling characteristics. The choice between beryllium and carbon as a plasma facing material would depend, therefore, on other factors such as minimising tritium retention.

The results obtained from the experimental campaign were exceptional. A plasma current of 6 MA was achieved, which is a world record in a divertor configuration. The total heating power injected into the plasma was increased to 32 MW. The plasma energy reached 13.5 MJ which was the highest energy recorded in a JET plasma. The rate of production of energetic neutrons attained a new JET record in deuterium of 4.7 x 10^{16} neutrons per second.

JET has achieved near "break-even" conditions (i.e., when the required values for the triple fusion product of plasma density, plasma temperature and confinement time are achieved simultaneously). This matches the best values obtained in JET before the introduction of the pumped divertor, in spite of the 20% smaller plasma volume, and are within a factor of five of those required in a fusion reactor.

The shutdown following the experimental campaign was devoted to stripping out the components of the Mark I divertor and then installing the modules of the support structure for the Mark II divertor. The structure, which is 6 metres in diameter and weighs 7 tonnes was assembled in the JET vacuum vessel to within an accuracy of 0.1mm. This was a notable engineering achievement in view of the restricted working space inside the JET torus. At the end of the year the installation of other components of the Mark II divertor was under way.

A three year extension of the JET Project to the end of 1999 proposed by the JET Council in 1994 has been finally approved by the Council of Ministers of the European Union in May 1996 to enable the Project to provide further data of direct relevance to ITER. The Project can, in particular, contribute significantly to the development and demonstration of a viable divertor concept for ITER. It can undertake experiments using D-T plasmas in an ITER-like configuration, which should provide a sound basis for the D-T operation of ITER. In addition, the extension will permit key ITER relevant technology activities to be carried out, such as the demonstration of remote handling and tritium handling.

On behalf of my colleagues on the JET Council, I congratulate the Director, Professor Dr Martin Keilhacker and the staff for their dedication and perseverance. I thank the members of the JET Council for their unfailing support throughout the year; the members of the JET Scientific Council for their sound advice; and the members of the JET Executive Committee for continuing to monitor the financial, contractual, and personnel aspects of the Project.

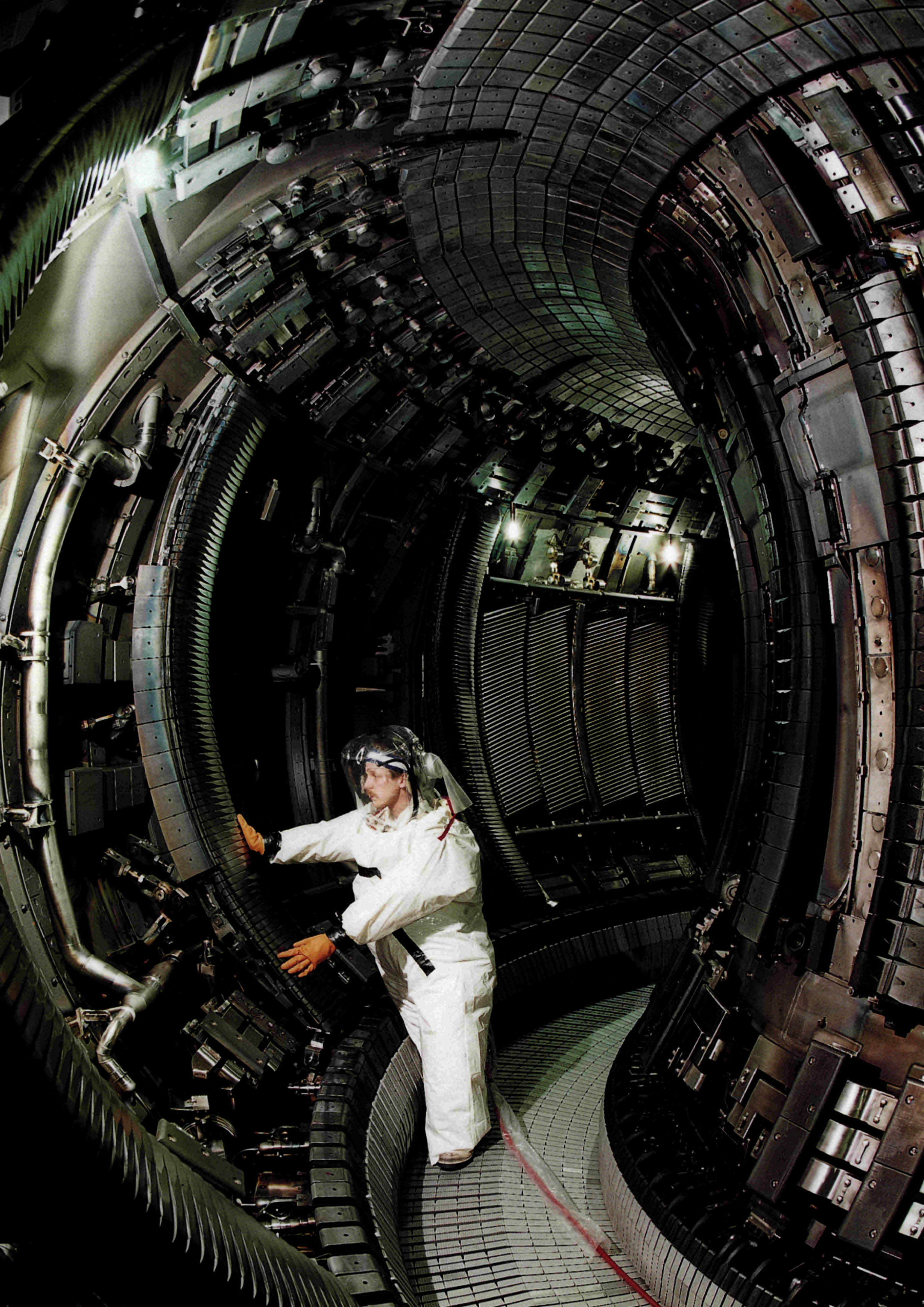
In May 1996, an application from TEKES (Finland) for membership of JET was approved by the Council of Ministers: this is a welcome addition.

We were deeply saddened to learn of the death of Jules Horowitz on 3 August 1995. Professor Horowitz made a substantial contribution to the formation and development of JET. He was Chairman of the JET Council from 1984 to 1987. He will be remembered as an eminent scientist who worked untiringly in the interests of fusion in Europe over a long period.

I would like to record our gratitude to my predecessor as JET Council Chairman, Hans von Bülow. He was a long-standing member of the JET Council and served as Chairman from 1993 to 1995. His guidance and wise counsel throughout the years was widely recognised. We wish him well in his retirement.

The three year extension will allow the JET Project to carry out further investigations, the results of which will be crucial to the design of ITER. I am confident that our work over the period, using what is still the most powerful fusion device in the world and relying on a team of highly experienced scientists and engineers, will help to bring us closer still to the ultimate goal of world fusion research, namely, the development of commercially viable fusion power stations.

F. Troyon
Chairman of the JET Council
May 1996



Introduction, Summary and Background

Introduction

The Joint European Torus (JET) is the largest project in the coordinated fusion programme of the European Atomic Energy Community (EURATOM), whose long term objective is the joint creation of safe environmentally sound prototype fusion reactors.

The Statutes setting up the JET Project include a requirement for an Annual Report to be produced which:

'... shall show the current status of the Project, in particular with regard to timetables, cost, performance of the scientific programme and its position in the Euratom Fusion Programme and in the world-wide development of fusion research.'

This Report is designed to meet this requirement. It provides an overview of the scientific, technical and administrative status of the JET programme, which is intended to be comprehensible to the average member of the public. Where appropriate, descriptive sections (in italics and boxed) are included to aid the reader's understanding of particular technical terms used throughout the Report.

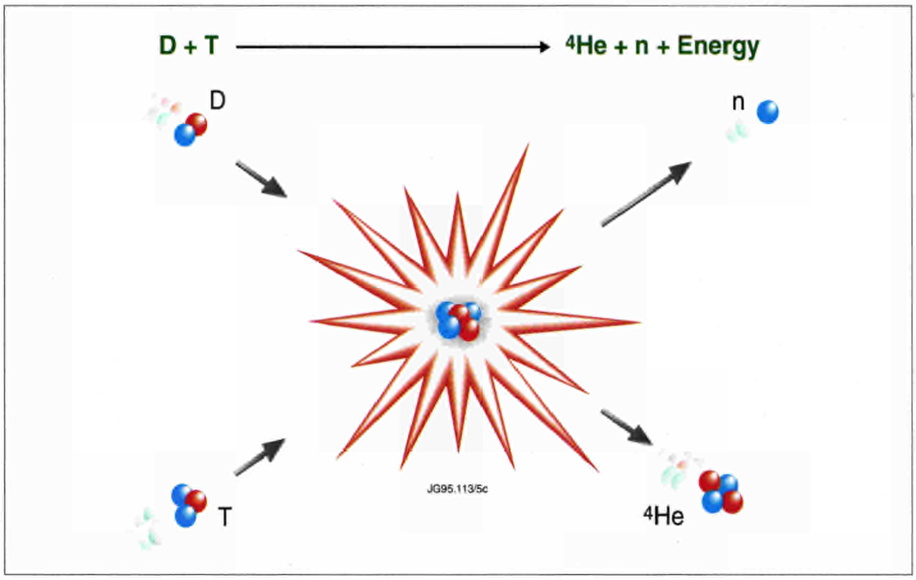
A more detailed and comprehensive description of the technical aspects of the JET Project can be found in the JET Progress Report.

Report Summary

The Report is essentially divided into two main parts:

- the scientific and technical programme of the Project;
- the administration and organization of the Project.

The first part of the Report includes a brief introduction, provides an overview of the planning of the Report and sets the background to the Project. This is followed by a description of JET and its experimental programme and explains its position in the overall Euratom and International Fusion Programmes. In addition,



Nuclear Fusion

Energy is released when the nuclei of light elements fuse or join together to form heavier ones. The easiest reaction to achieve is between the two heavy isotopes of hydrogen (deuterium and tritium).

Most of the energy released in this reaction is carried away by a high speed neutron. The remaining energy goes to the alpha-particle (helium nucleus, ^4He) which is also produced in the reaction. In a fusion reactor, a jacket or blanket around the reactor region would slow down the neutrons, converting their energy into heat. This heat could be extracted to raise steam for conventional electricity generation.

it relates and compares JET to other large fusion devices throughout the world and confirms its pre-eminent position in fusion research.

The following section reports the technical status of JET including: the completion of technical changes during the latest shutdown to install a new divertor configuration; preparations for future tritium experiments (DTE1 and DTE2) and progress on systems for future operation. This is followed by a section on scientific achievements during 1995. It sets out progress towards reactor conditions and compares the performance between JET and other tokamaks. It shows the substantial achievements made by JET since the start of operations in 1983. The scientific part of this Report concludes with a description of the proposed future programme of JET until its planned conclusion.

The second part of the Report explains the organisation and management of the Project. It describes the administration of JET, in which it details the budget situation; contractual arrangements; and sets out staffing arrangements and complement.

Background

In the early 1970's, discussions were taking place within the European fusion research programme on a proposal to build a large tokamak fusion device to extend the plasma parameters closer to those required in a reactor. In 1973, an international design team started work in the UK, and by mid-1975, the team had completed its design for a very large tokamak device.

On 30th May 1978, the Council of Ministers of the European Communities decided to build the Joint European Torus (JET) as a Joint Undertaking of the European Fusion Programme. To implement the Project, the Joint Undertaking was originally established

Fuels

As deuterium is a common and readily separated component of water, there is a virtually inexhaustible supply in the oceans of the world. In contrast, tritium does not occur naturally in any significant quantities and must be manufactured. This can be achieved by using reactions that occur between neutrons formed in the fusion reactions and the light metal lithium.

Therefore, although the fusion reactions occurring in a reactor will be between deuterium and tritium, the consumables will be deuterium and lithium.

Fusion Reaction $D + T \rightarrow {}^4He + n$

Tritium Breeding

Reactions ${}^6Li + n \rightarrow T + {}^4He$

${}^7Li + n \rightarrow T + {}^4He + n$

There are sufficient reserves of lithium available to enable world electricity generation using fusion reactors, to be maintained at present levels, for several hundreds of years.

Conditions for Fusion

Fusion reactions can only take place if the nuclei are brought close to one another. However, all nuclei carry a positive charge and therefore repel each other. By heating the gaseous fuels to very high temperatures, sufficient energy can be given to the nuclei that the repulsive force can be overcome and they to fuse together. In the deuterium-tritium reaction, temperatures in excess of 100 million degrees Kelvin are required - several times hotter than the centre of the sun. Below 100 million degrees, the deuterium-tritium reaction rate falls off very rapidly: to one-tenth at 50 million degrees, and 20,000 times lower at 10 million degrees.

A reactor must obtain more energy from the fusion reactions than is put in to heat the fuels and run the system. Reactor power output depends on the square of the number (n) of nuclei per unit volume (density) and the volume of gas.

Power losses must also be kept to a minimum acceptable level by holding the hot gases in thermal isolation from their surroundings. The effectiveness of this isolation can be measured by the energy confinement time (τ_E) - the time taken for the system to cool down once all external forms of heating are switched off.

In a fusion reactor the values of temperature, density and energy confinement time must be such that their product ($n_i\tau_E T_i$), exceeds the figure of $5x10^{21}m^{-3}$skeV. Typical values for the parameters that must be attained simultaneously for a reactor are:

Central ion temperature, T_i
10-20keV
Central ion density, n_i
$2.5x10^{20}m^{-3}$
Energy confinement time, τ_E
1-2s

The temperature is expressed as the average energy of the nuclei (1keV is approximately equal to 10 million degrees K).

for a period of 12 years, beginning on 1st June 1978. The device would be built on a site adjacent to Culham Laboratory, the nuclear fusion research laboratory of the United Kingdom Atomic Energy Authority (UKAEA), and that the UKAEA would act as Host Organisation to the Project. Figure 1 shows an aerial view of the site of the JET Joint Undertaking at Culham in the United Kingdom.

The Members of the Joint Undertaking are Euratom, its Associated Partners in the framework of the Fusion Programme, including Sweden and Switzerland, together with Greece, Ireland and Luxembourg, who have no Contracts of Association with Euratom.

Eighty per cent of the expenditure of the Joint Undertaking is borne by Euratom. As the host organisation, UKAEA pays ten per cent, with the remainder shared between Members having Contracts of Association with Euratom in proportion to the Euratom financial participation in the total costs of the Associations.

The Project Team is formed mainly by personnel from the Associated Institutions, although some staff are assigned on a secondment basis from the Institutions and the Directorate General of the Commission responsible for Science Research and Development (DGXII).

In July 1988, the Council of Ministers agreed the prolongation of the JET Joint Undertaking to 31st December 1992. A further proposal to prolong JET to 31st December 1996 was approved by the Council of Ministers in December 1991. The extension is to allow JET to implement the new Pumped Divertor Phase of operation, the objective of which is to establish effective control of plasma impurities in operating conditions close to those of the Next Step. An extension of the JET programme to 1999 in support of the ITER divertor while satisfying the requirements of JET D-T operations, is supported by the JET Council, and is currently being considered by the Council of Ministers.

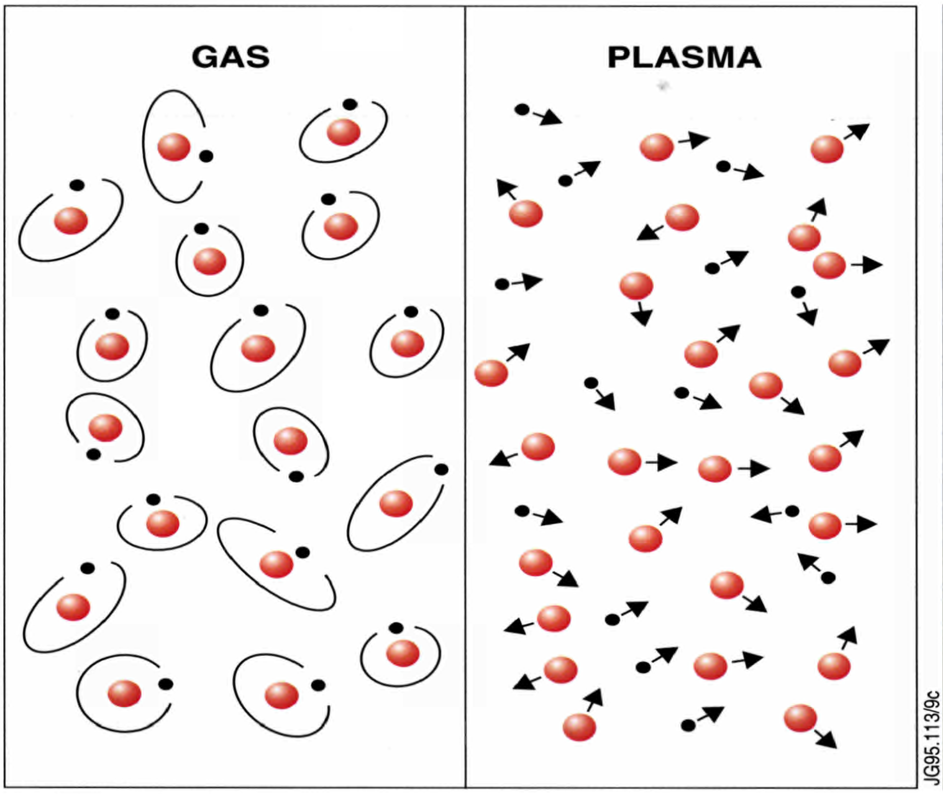
Objectives of JET

The original decision of the Council of Ministers in 1978 states that the JET Joint Undertaking's mandate is to:

'... construct, operate and exploit as part of the Euratom fusion programme and for the benefit of its participants in this programme, a large torus facility of tokamak-type and its auxiliary facilities in order to extend the parameter range applicable to controlled thermonuclear fusion experiments up to conditions close to those needed in a thermonuclear reactor.'

The principal objective of JET is to enable the essential requirements of a tokamak reactor to be defined. To implement this, it was necessary to create and study plasma in near-reactor conditions.

Fig.1: Aerial view of the JET Joint Undertaking, situated near Oxford in the United Kingdom



Plasma

As the temperature of the fuel is increased, the atoms in the gas become ionised, losing their electrons, which normally orbit around the nuclei. The mixture of positively charged ions and negatively charged electrons is very different from a normal gas and is given a special name - PLASMA.

The fact that a plasma is a mixture of charged particles means it can be controlled and influenced by magnetic fields. With a suitably shaped field it should be possible to confine the plasma with a high enough density and a sufficiently long energy confinement time to obtain net energy gain.

The configuration that has so far advanced furthest towards achieving reactor conditions and on which most data is available is the TOKAMAK, originally developed in the USSR.

Fusion Reactor

In a fusion reactor a lithium compound would be incorporated within a blanket surrounding the reactor core so that some neutrons can be utilised for manufacturing tritium. The tritium produced would then be extracted for use in the reactor.

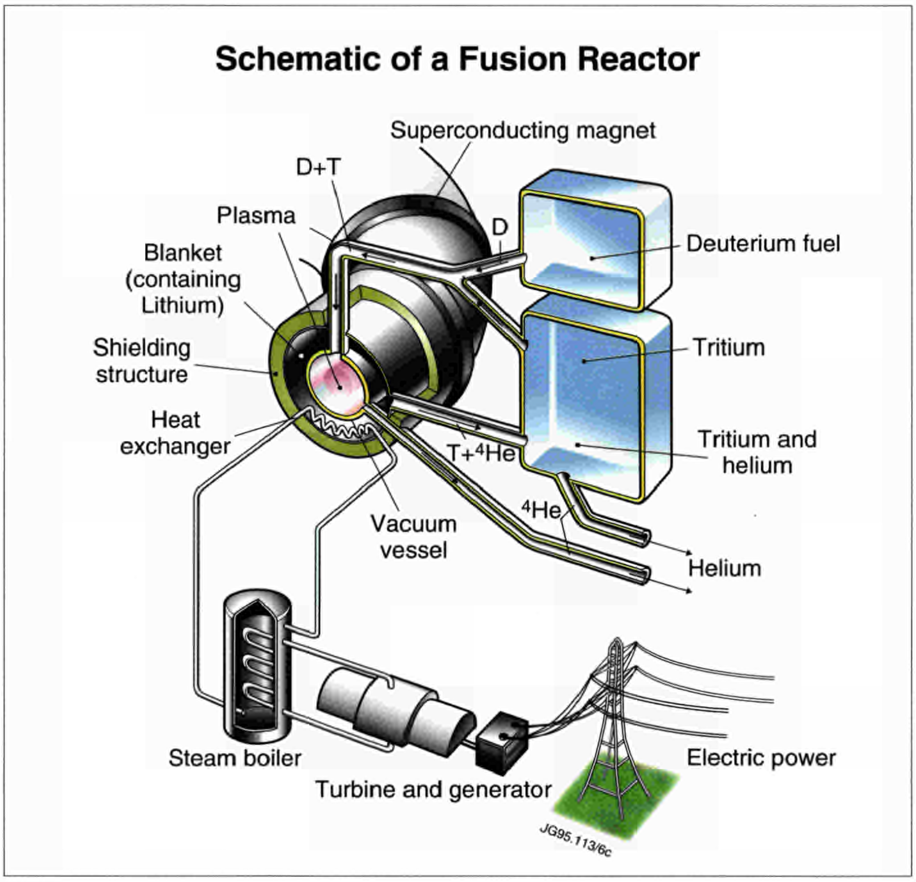
The blanket would also provide the means of utilising the energy carried away from the reactions by the neutrons. As the neutrons are slowed down within the blanket, its temperature would rise thus enabling steam to be raised so that electricity could be generated in the conventional manner.

Ultimately, it is hoped that the conditions would be reached to enable a reactor to be built utilising the deuterium-deuterium reactions below:

$$D + D \rightarrow {}^{3}He + n$$

$$D + D \rightarrow T + p$$

In this case there would be no need to manufacture tritium and a virtually inexhaustible reserve of energy would become available.



There are four main areas of work:

1. the study of scaling of plasma behaviour as parameters approach the reactor range;
2. the study of plasma-wall interaction in these conditions;
3. the study of plasma heating;
4. the study of alpha-particle production, confinement and consequent plasma heating.

In addition, JET is pioneering two key technologies required in fusion reactors: the use of tritium and remote handling techniques.

JET, Euratom and other Fusion Programmes

The Joint European Torus

JET uses the tokamak magnetic field configuration to maintain isolation between the hot plasma and the walls of the surrounding vacuum vessel. A diagram of the JET apparatus is shown in Fig.2 and the original main design parameters are presented in Table I.

The toroidal component of the magnetic field on JET is generated by 32 large D-shaped coils with copper windings, which are equally spaced around the machine. The

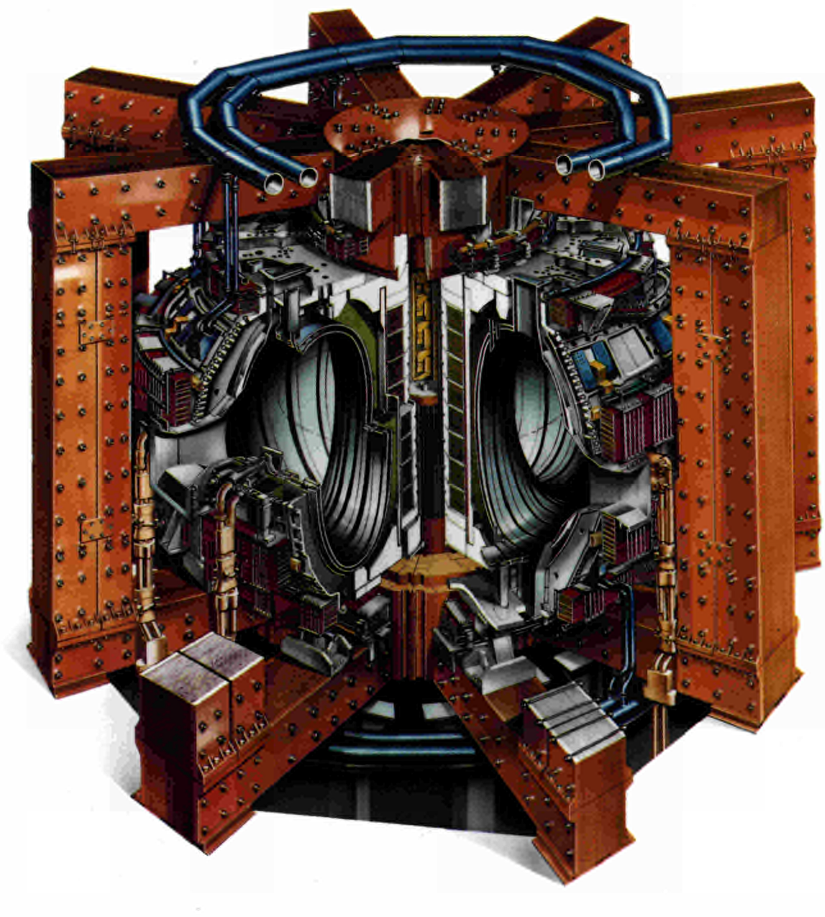


Fig.2: Technical illustration of the JET Apparatus

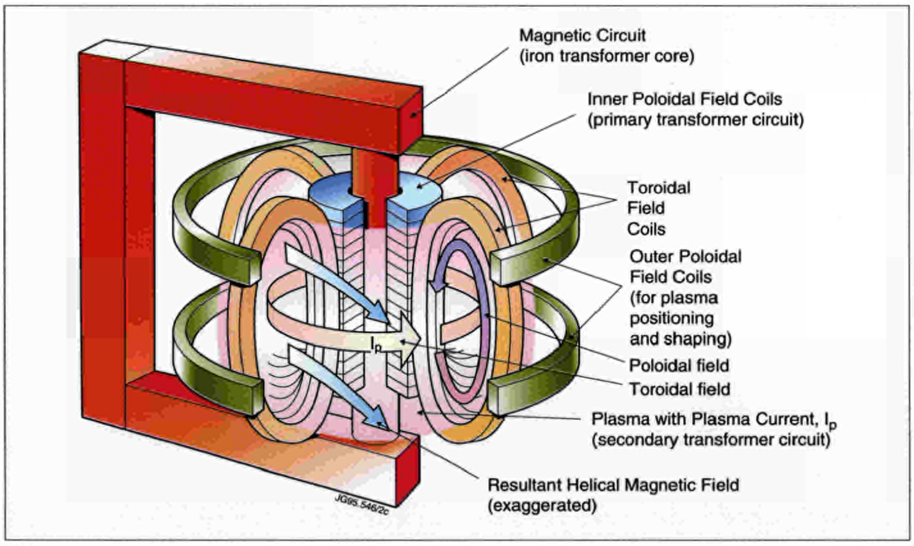
PARAMETER	SIZE
PLASMA MINOR RADIUS:	
HORIZONTAL	1.25m
VERTICAL	2.10m
PLASMA MAJOR RADIUS	2.96m
FLAT-TOP PULSE LENGTH	20s
WEIGHT OF THE IRON CORE	2800t
TOROIDAL FIELD COIL POWER (PEAK ON 13s RISE)	380MW
TOROIDAL MAGNETIC FIELD AT PLASMA CENTRE	3.45T
PLASMA CURRENT:	
CIRCULAR PLASMA	3.2MA
D-SHAPE PLASMA	4.8MA
VOLT-SECONDS TO DRIVE PLASMA CURRENT	34Vs
ADDITIONAL HEATING POWER	25MW

Table 2: JET parameters

primary winding (inner poloidal field coils) of the transformer, used to induce the plasma current which generates the poloidal component of the field, is situated at the centre of the machine. Coupling between the primary winding and the toroidal plasma, acting as the single turn secondary, is provided by the massive eight limbed transformer core. Around the outside of the machine, but within the confines of the transformer limbs, is the set of six field coils (outer poloidal field coils) used for positioning, shaping and stabilising the position of the plasma inside the vessel.

During operation large forces are produced due to interactions between the currents and magnetic fields. These forces are constrained by the mechanical structure which encloses the central components of the machine.

The use of transformer action for producing the large plasma current means that the JET machine operates in a pulsed mode. Pulses can be produced at a maximum rate of about one every ten to twenty minutes, and each one can last for up to 60



Magnetic Field Configuration

The tokamak magnetic field configuration is built up from three components. The first of these is produced by a set of coils around the minor circumference. These coils produce the toroidal magnetic field around the major axis of the machine. The second component (poloidal field) is produced by a large current caused to flow through the plasma by transformer action. The combination of these produces a helical magnetic field which keeps the plasma away from the vessel walls. The final component is generated by a set of hoop coils, which is used to shape and stabilise the position of the plasma.

seconds in duration. The plasma is enclosed within the doughnut shaped vacuum vessel which has a major radius of 2.96m and a D-shaped cross-section of 4.2m by 2.5m. The amount of gas introduced into the vessel for an experimental pulse amounts to less than one tenth of a gramme.

The construction phase of the Project, from 1978 to 1983, was completed successfully within the scheduled period and within 8% of projected cost of 184.6 MioECU at January 1977 values. The first plasma pulse was achieved on 25 June 1983 with a plasma current of 17000A lasting for about one tenth of a second. This first phase of operation was carried out using only the large plasma current to heat the gas. In 1985, the first additional heating system, employing radio-frequency heating, came into operation and during 1991 reached 22MW of power into the plasma. The neutral beam heating system was brought into operation in 1986, and exceeded its design capability in 1988, with 21.6MW of power injected into the torus.

Experiments have been carried out mainly using hydrogen or deuterium plasmas, although during 1991, experiments were performed in helium-3 and helium-4 and a preliminary experiment was performed using 10% tritium in deuterium. In the final stages of the programme, it is planned to operate with deuterium-tritium plasmas so that abundant fusion reactions occur. The alpha-particles liberated from the reactions should produce significant heating of the plasma. During this phase, the machine structure will become radioactive to the extent that any repairs and maintenance would have to be carried out using remote handling systems.

Impurities

Impurities released from interactions between the plasma and material surfaces can have major effects on plasma behaviour by causing:

(a) increased radiation losses;

(b) dilution of the number of ions available in the plasma between which fusion reactions can occur.

A measure of the overall impurity level is given by Z_{eff} which is defined as the ***average*** *charge carried by the nuclei in the plasma. A pure hydrogen plasma would have $Z_{eff}=1$ and any impurities in the plasma would cause this value to be increased. In JET, Z_{eff} is generally in the range from 1.2-3.*

Major energy losses can result from two radiation processes:

- *Bremsstrahlung Radiation - radiation is emitted when electrons are decelerated in the electric field of an ion. The amount of radiation emitted increases with Z_{eff}. Bremsstrahlung radiation imposes a fundamental limit to the minimum plasma temperature that must be attained in a fusion reactor;*
- *Line Radiation - heavy impurities will not be fully ionised even in the centre of the plasma and energy can therefore be lost through line radiation.*

Considerable effort is made to keep the level of impurities in the JET plasma to a minimum. The vacuum vessel is baked at 300°C to remove gas particles trapped on the vessel walls which might be released by plasma bombardment.

Interactions between the plasma and vacuum vessel walls would result in the release of heavy metal impurities. To reduce this possibility, the edge of the plasma is defined by upper and lower belt limiters. These are cooled structures circling the outboard torus wall with carbon or beryllium tiles attached. Carbon and beryllium have a relatively low electric charge on the nucleus.

The Community Fusion Programme

Objective, Strategy and Near-term Programme

The long-term objective of the programme, embracing all activities undertaken in Member States (plus Switzerland) in the field of controlled thermonuclear fusion by magnetic confinement, is "the joint creation of safe, environmentally sound prototype reactors, which should result in the construction of economically viable power stations, which will meet the needs of potential users. In this context, particular attention will be given to the constraints imposed by the requirements of power utilities" (Council Decision 94/799/Euratom of 8 December 1994 adopting thermonuclear fusion, OJ No L 331, 21.12.94). The long time span and the large human and financial efforts needed to attain this objective call for a concentration of Community action on the objective, complete cohesion of the network of organizations associated in the Community action and full exploitation of cooperation with the major fusion programmes outside the Community.

Safety and environmental issues will play a central role in the realisation of the large devices, which, after JET, are included in the strategy leading towards a

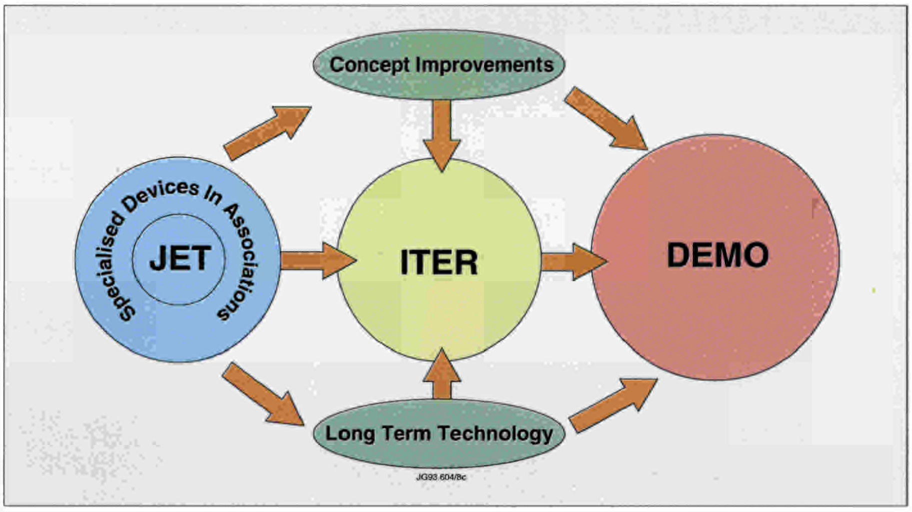


Fig.3: Interactions of European and International Activities

prototype reactor. This strategy includes, in particular:

- an experimental reactor, Next Step, the overall objective of which is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes;
- a demonstration reactor, DEMO, capable of producing significant quantities of electricity.

For the period 1994-98, the priority objective is to establish the engineering design of the Next Step within the framework of the qaudripartite cooperation between Euratom, Japan, Russia and the USA on the Engineering Design Activities for the International Thermonuclear Experimental Reactor (ITER-EDA). Specialized studies are also needed to look at possible improvements to concepts in plasma physics and plasma engineering, as well as to carry out the long term technology developments required for progressing towards the exploitation of fusion as an energy source. The results of such studies will be of benefit both in the operation of ITER and, in the longer term, in the conceptual definition of DEMO.

The proposed strategy calls for the simultaneous development of three areas of activity (see Fig.3), on which efforts will be concentrated mainly by means of shared-cost actions:

- Next Step Activities: design proper and R&D supporting design, construction and operation of the Next Step;
- Concept Improvements: R&D on plasma physics and engineering for the definition of DEMO and to help to finalize the Next Step design;
- Long Term Technology: DEMO- and reactor- oriented R&D on technology.

1995 Achievements

In the frame of the 1994-1998 Fusion Programme, a large fraction of the activities in 1995, including those on JET and within the Associated Laboratories, was in support of the Next Step. Following an extensive experimental campaign, JET was modified during the second half of the year to install a new type of divertor. At its meeting on 22/23 March 1995, the JET Council decided to propose an extension of the JET programme by 3 years to the end of 1999, to provide further data of direct relevance to ITER (especially on the divertor) before entering into a final phase of D-T operation.

Next Step Activities

The Next Step engineering design has progressed in the framework of Protocol 2 of the Quadripartite Agreement (Euratom, Japan, Russia and the USA) on cooperation in the ITER-EDA. The overall programme objective of ITER is "to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes". ITER would accomplish this objective by "demonstrating controlled ignition and extended burn of deuterium-tritium plasmas, with steady-state as an ultimate goal, by demonstrating technologies essential to a reactor in an integrated system, and by performing integrated testing of high heat-flux and nuclear components required to utilize fusion energy for practical purposes". The ITER-EDA is conducted by the four ITER Parties under the auspices of the IAEA (International Atomic Energy Agency) and carried out by a Joint Central Team (JCT) located in three internationally staffed joint work sites in San Diego (USA), Naka (Japan) and Garching (EU) and by four Home Teams.

Following the transmission in July from the ITER Council to the ITER Parties of the ITER Interim Design Report (IDR) Package, a European domestic assessment has been completed. The Research Council expressed a positive view about the IDR Package: in particular, the management, the design and the supporting R&D of ITER were considered to be on the right track. The Council further considered it appropriate for the Community to participate in interrelated issues of siting, licensing and host support for ITER. For this purpose, the Commission was invited to develop, by the end of March 1996, framework assumptions for consideration by the Member States, to facilitate the presentation of possible candidatures with a view to identifying a European candidate site for ITER. The ITER Council approved the ITER IDR in December, together with its Cost Review and Safety Analysis, as the basis on which to continue the technical work of the EDA until completion in 1998. The Commission launched in December a new procedure (OJ No C 337, 15.12.95) to qualify European firms and/or groupings of firms in the "15 Technologies" (over a new period of 3 years) both specific to fusion and essential for the Next Step (in particular the ITER-EDA). The NET (Next European Torus) Team pursued its Next Step related activities, in particular in assisting the Euratom Home Team (HT) Leader in the performance of his duties and responsibilities in the ITER frame.

Heating

Initial production and heating of the plasma is produced by the large electric current flowing in the plasma itself (ohmic heating) used to generate the poloidal magnetic field.

The heating effect of this current is reduced as the plasma gets hotter as the electrical resistance of the plasma decreases with increasing temperature. Therefore, it is necessary to provide additional means of heating if the temperatures needed for a reactor are to be reached.

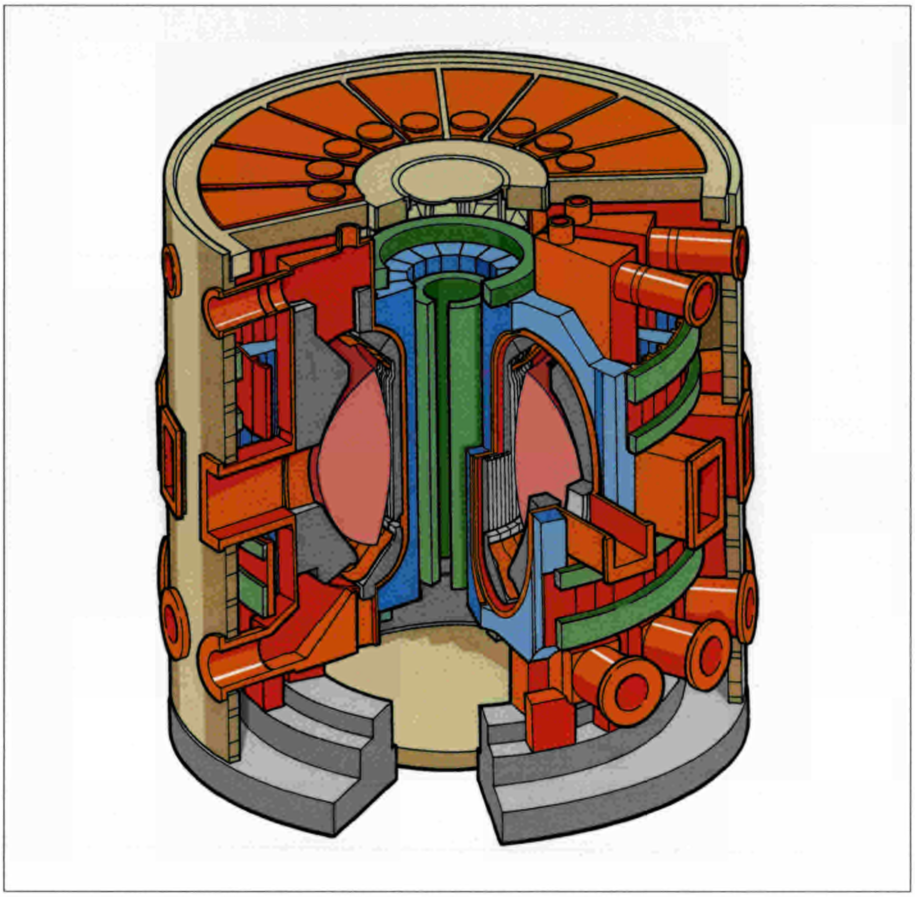
Two main additional heating methods are in general use:

(1) Neutral Beam Heating: In this method, a beam of charged hydrogen or deuterium ions is accelerated to high energies and directed towards the plasma. As charged particles cannot cross the magnetic field confining the plasma, the beam must be neutralised. The resulting neutral atoms cross the magnetic field and give up their energy through collisions to the plasma, thereby raising its temperature.

(2) Radio Frequency Heating: Energy can be absorbed by the plasma from high power radio-frequency waves. The frequency of operation is chosen to be close to that at which the ions or electrons orbit or gyrate in the magnetic field.

Concept Improvements

Research on concept improvements is essential for finalising the design of the Next Step and, in the longer term, for the definition of DEMO. Concept improvements studies were carried out, in the Associated Laboratories, on the existing specialised devices (TORE SUPRA, ASDEX-Upgrade, TEXTOR, FTU, TCV, COMPASS, START, RTP, ISTTOK, W 7-AS, RFX, EXTRAP-T2, etc ...) - which explore the accessible parameter range and the possible modes of operation for different confinement concepts and configurations - and in the accompanying programmes of Member States where there is no Association. These devices also serve for fundamental fusion physics



Principal Parameters of ITER

Major Radius	*8.0m*
Minor Radius	*3.0m*
Elongation	*1.6*
Plasma Current	*24MA*
Toroidal Field	*5.7T*
Fusion Power	*1.5GW*
Burn Time	*1000s*

studies, for the development of diagnostics, for the preparation of collaboration on larger devices, for innovative studies and for the training of young professionals. These are the links which allow the incorporation of university research into theoretical, numerical or diagnostic activities.

Two existing tokamaks were given an extended programme (introduction of a new divertor in ASDEX-Upgrade at IPP-Garching, Germany, and upgrading of the TORE-SUPRA ergodic divertor at CEA-Cadarache, France) and a new one was launched (MAST at UKAEA-Culham, UK, to explore the low aspect ratio takamak concept with performant plasmas). A new large advanced stellarator proposed by IPP-Garching, Germany aimed at the exploration of the physics and engineering relevant to stellarator reactor-grade fusion plasmas along the HELIAS line, was decided (Wendelstein 7-X, to be built at Greifswald). A contract of Association with the Technology Department Centre of Finland (TEKES) was signed in March 1996 and the negotiations for such a contract with Ireland and Austria are in hand.

Long-term Technology

Long-term technology effort, in the Associated Laboratories and Industry, was increased and streamlined towards a restrained number of options for the various reactor components. On advanced materials, martensitic steels were chosen and will be assessed in view of their use as DEMO-relevant structural materials, in particular, for the construction of tritium breeding blanket modules to be tested in ITER. On blanket options envisaged, their choice was reduced from four to two. Also, Euratom participated - in the frame of an Implementing Agreement of the International Energy Agency (IEA) - in the conceptual design study of an intense neutron source based on the acceleration of deuterons, on which a report will be produced in 1996. A study on the Safety and Environmental Assessment of Fusion Power (SEAFP), made at the request of the Council and the Parliament (OJ No L 115, 6.5.94), was completed and reported. Some further considerations on safety, environment and economicity aspects of fusion reactors will be undertaken.

Involvement of Industry

European industry has been involved in the Fusion Programme for some time, through specific contracts for the supply of components, scientific equipment, materials and service for the construction and successive exploitation and upgrading of JET and the current generation of fusion facilities in the Associations and the Joint Research Centre.

Measures have been implemented to strengthen the role of industry, with the double aim of introducing industrial expertise into the realisation of the Next Step/ ITER (in particular at plant and systems engineering levels during its engineering design) and of ensuring that European industry will master all key technologies needed to build future fusion power plants (in particular by encouraging more continuity in the industrial efforts in fusion specific R&D). Such measures lay the foundations for the involvement of industry in the possible construction of the Next Step/ITER. To meet the related organisational and technical challenges, further steps will need to be taken to maximise the synergy between the Programme and relevant European industries.

The scientific and technological achievements of the Community Fusion Programme place Europe in the forefront of world fusion research. Concentration on the most successful toroidal magnetic confinement line, the Tokamak, and on a few promising lines akin to it - while keeping a watch brief on inertial confinement fusion and on other approaches - continues to be fully justified by the results.

Density Control

Increasing the density can be achieved by introducing additional gas into the vacuum vessel, by the injection of energetic neutral atoms (neutral beam heating) and by solid pellet injection.

Increasing the input power to the plasma through additional heating raises the electron density limit. However, problems can occur when this heating power is switched off, if the electron density is too high. To overcome this problem, the outer layer of the plasma is moved, prior to the switch-off point, so that it bears on the carbon tiles covering the inner wall. The tiles have been found, to provide a pumping mechanism for removing particles so that the density can be reduced below the critical limit.

Management of the Programme

All magnetic fusion research is integrated into **one** Community Fusion Programme which presents itself as a single body in its relations with other fusion programmes in the world. The European Commission, assisted by a Consultative Committee for the Fusion Programme (CCFP) composed of national representatives, is responsible for the implementation of the Fusion Programme. The Programme operates principally through: contracts of Association with Member States (plus Switzerland) or organisations within Member States, the JET Joint Undertaking, the NET Agreement which takes account of the Euratom participation in the ITER-EDA, the JRC, contracts of limited duration (in particular with organisations in Member States without Association) and industrial contracts. Through the multipartite Agreement for "Promotion of Staff Mobility", the mobility of scientists and engineers was developed. In coordination with the "Human Capital and Mobility" programme, Fellowships were awarded. The dissemination of knowledge and exploitation of results was performed through laboratory reports, publications in scientific journals, workshops and conferences. The travelling fusion exhibition, run by the "Fusion EXPO" consortium, was further developed and upgraded to a "Fusion-Industry" exhibition on the occasion of the Fusion-Industry seminar at Strasbourg in November.

Community financial participation continued to be about 25% of the running expenditure of the Associations, 45% of capital cost of projects having been awarded priority status, and 80% of JET expenditure. Currently, Community funding of fusion research is about 200MioECU: when funding by national administrations and/or bodies is taken into account, the expenditure on fusion from all sources in Europe amounts to about 450MioECU per annum. About 1,750 professional scientists and engineers are currently engaged in fusion research in Europe.

Breakeven

This condition is reached when the power produced from fusion reactions is equal to that necessary for maintaining the required temperature and density in the plasma volume.

International Collaboration

The Community approach has led to an extensive collaboration between the fusion laboratories. For example, most Associations undertake work for other Associations. The Associations are partners in JET, NET and ITER and carry out work for them through various Contracts and Agreements. The Programme has built a genuine scientific and technical community of large and small laboratories across Europe, readily able to welcome newcomers and directed towards a common goal. The leading position of the community Fusion Programme has also made Europe an attractive partner for international collaboration. Apart from the most far-reaching collaboration, illustrated by the ITER project, bilateral Framework Agreements have been concluded (with USA and Japan), or are to be concluded (with the Russian Federation). Also, the Commission and Canada signed in July a Memorandum of Understanding concerning cooperation in the field of Controlled Thermonuclear Fusion, as well as the Agreement for the involvement of Canada in the Euratom contribution to the ITER-EDA. In addition, collaboration has progressed under the nine implementing Agreements in the frame of the IEA.

Ignition

Ignition of a mixture of deuterium and tritium would be reached if the power produced by the alpha-particles (20% of the total thermo-nuclear power) released from the fusion reactions is sufficient to maintain the temperature of the plasma.

Large International Tokamaks

Now that the ITER Engineering Design Activity (EDA) is making good progress, achievements in tokamak research and, particularly, for the largest tokamaks (Fig.4), have become even more relevant. Table 2 sets out an overview of the larger tokamaks worldwide, together with their main parameters and starting dates. Considerable progress has been made by these tokamaks, and these are highlighted below.

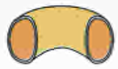
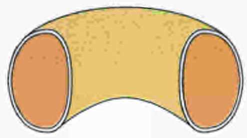
		TFTR	JET	ITER
				
MINOR RADIUS	a	0.85m	1.25m	3.0m
MAJOR RADIUS	R	2.5m	2.96m	8.0m
ELONGATION	κ	1.0	1.8	1.6
TOROIDAL FIELD	B	5.5T	3.45T	5.7T
INPUT POWER	P	32MW	36MW	30-200MW
FUSION FACTOR	Q_{DT}	0.3	1.1	30 - IGNITION
PLASMA CURRENT	I	3MA	7MA	24MA

Fig.4: Operating parameters of three large tokamak designs

Fusion Performance

During 1995, the US tokamak, TFTR, increased its fusion performance by introducing lithium pellets into the supershot discharges before the main heating pulse for vessel conditioning purposes. Its performance was further boosted by increasing the toroidal magnetic field from 5.1 to 5.5T, and its plasma current from 2.5 to 2.7MA. This yielded a fusion power in a 50:50 deuterium-tritium plasma rising to 10.7MW over a period of one second, with a fusion efficiency Q_{DT} of 0.27. The highest triple product, $n_i\tau_E T_i$, which is related to the Q_{DT} reached a value of $8.7\times10^{20}m^{-3}$skeV in a discharge with only 17MW of neutral beam injection of tritium. In the coming year, further enhancements in machine parameters are foreseen and other operating regimes will be explored. In particular,

MACHINE	COUNTRY	MINOR RADIUS a(m)	ELONGATION κ	MAJOR RADIUS R(m)	PLASMA CURRENT I(MA)	TOROIDAL FIELD B(T)	INPUT POWER P(MW)	START DATE
JET	EC	1.00	1.8	2.96	7.0	3.5	42	1983
JT-60U	JAPAN	0.85	1.6	3.2	4.5	4.4	40	1991
TFTR	USA	0.85	1.0	2.50	2.7	5.6	40	1982
TORE-SUPRA	FRANCE	0.80	1.0	2.4	2.0	4.2	22	1988
T-15	CIS	0.70	1.0	2.4	2.0	4.0	-	1989
DIII-D	USA	0.67	2.5	1.67	3.0	2.1	22	1986
ASDEX-U	GERMANY	0.5	1.7	1.67	1.4	3.5	16	1991
FT-U	ITALY	0.31	1.0	0.92	1.2	7.5	-	1988

Table 2: Large Tokamaks operating around the World

the so-called high beta poloidal and the negative central magnetic shear regimes promise to increase the fusion performance even further.

The large Japanese tokamak device JT60-U has also achieved remarkable results during 1995. The highest fusion performance measured by the triple product, $n_i\tau_E T_i$, now stands at $1.1 \times 10^{21} m^{-3}$skeV, with electron and ion temperatures of 11 and 37 keV, respectively. At these ion temperatures, this results in a calculated Q_{DT} of about 0.6. These plasmas were obtained in the so-called high beta poloidal and hot-ion H-mode regime, which has peaked density profiles (similar to the TFTR supershot discharges), in contrast to the normal hot-ion H-mode. Also, negative central shear regimes are being developed and show promising results.

The potential of this latter regime has already been demonstrated by the other large US tokamak, DIII-D. During 1995, this machine has tripled its neutron rate in the negative central shear H-mode compared with its best VH-mode in 1994. A calculated fusion efficiency, Q_{DT}, of 0.3 has been reached in discharges with very high beta, even at its moderate toroidal fields of 2.1 T.

JET, still the largest tokamak in the world, curtailed operation in mid-1995 to rebuild the divertor configuration to make it even more robust and capable of handling larger energy fluxes and to prepare for the forthcoming tritium operation in 1996/97. Even so, the fusion performance in JET with the pumped divertor configuration was further improved during 1995. By the end of the campaign, a neutron yield of 4.7×10^{16} neutrons per second had been achieved with an input power of 19MW in plasma with a toroidal field of 3.4T and a current of 3.8MA. If this discharge had contained a 50:50 D-T mixture, then a peak Q_{DT} of 1.07 would have been achieved. The triple fusion product, $n_i\tau_E T_i$, was $8.5 \times 10^{20} m^{-3}$skeV which was close to the previous best value.

A summary of the fusion triple products obtained in the largest tokamaks is shown in Table 3.

Disruptions

There is a maximum value of density which can be contained with a given plasma current. If this value is exceeded a disruption occurs when the plasma confinement is suddenly destroyed and the plasma current falls to zero in a short period of time. Under these conditions high mechanical and thermal stresses are produced on the machine structure. Disruptions are thought to be caused by certain instabilities developing on specific magnetic surfaces.

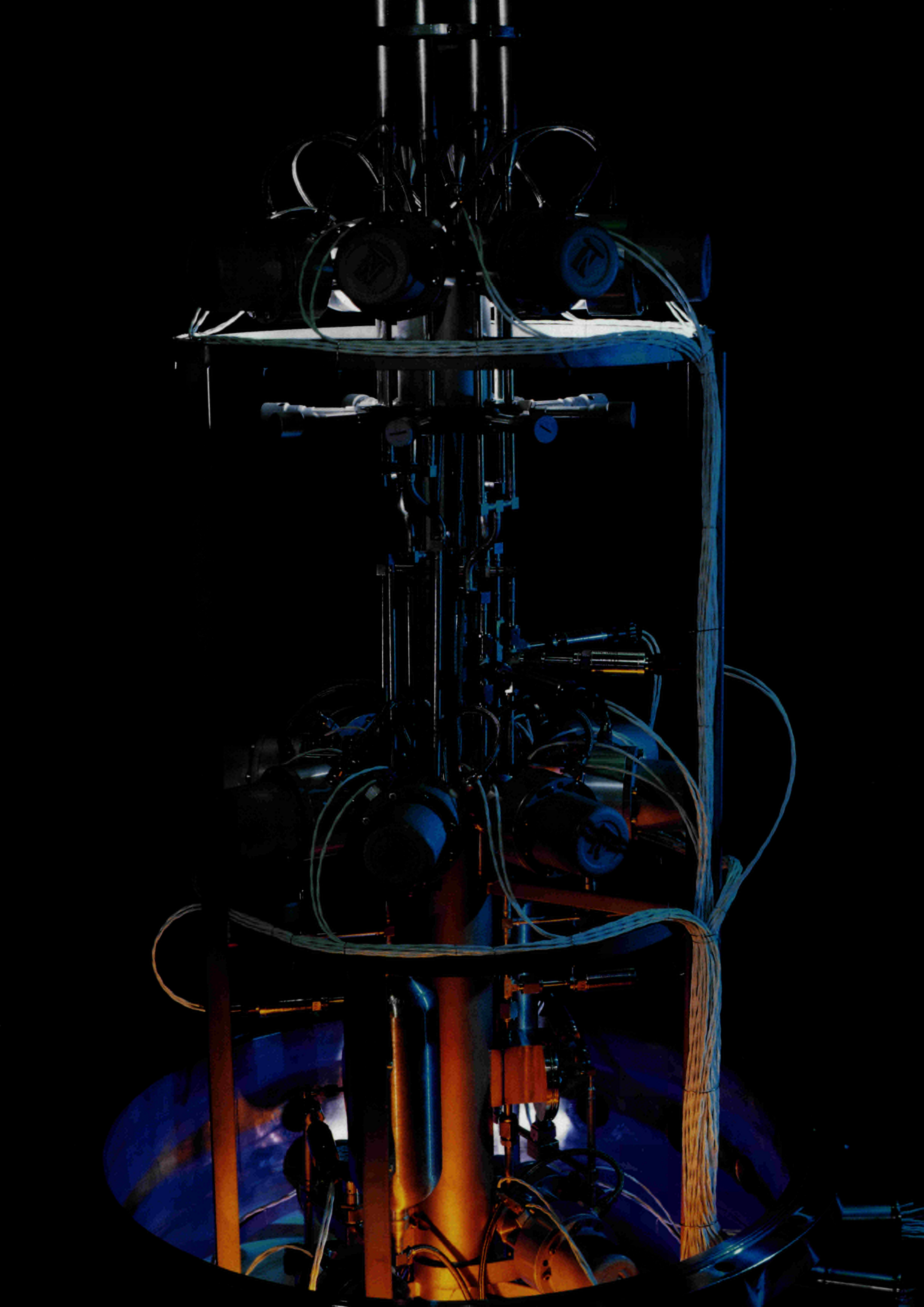
Performance Limitations

As yet, no major effect on the transport processes in the large tokamaks has been observed of instabilities related to fast particles, and, in particular, to the energetic alpha-particles, even at the high fusion power levels produced in TFTR. However, the highest performance discharges in the present machines occurs over a limited period of time. Only when frequent MHD activity occurs, such as regular ELM activity, can a quasi-steady state be obtained. So, except for the high beta poloidal H-mode in JT60-U, all other hot-ion H-mode discharges make a transition to a lower performance regime after a timescale

MACHINE	JET	JT-60U	TFTR	DIII-D
ELECTRON TEMPERATURE				
T_e(keV)	11	10	11.5	6
ION TEMPERATURE				
T_i (keV)	18	41	45	20
DURATION (s)	1.5	0.6	0.33	0.35
FUSION PRODUCT				
$n_i T_i \tau_E$ ($X10^{20}m^{-3}keVs$)	10	12.3	8.7	5

Table 3: Fusion Products in Large Tokamaks

of about one second. Even major current disruptions may occur especially if the instabilities are related to steep core pressure profiles. In cases where the instabilities are related to steep edge pressure gradients, large Edge Localised Modes (so-called ELMs) occur, which usually lead to a permanent change in confinement. It seems therefore that a careful control of the pressure profile is required to maintain the high performance phase.



Technical Status of JET

Introduction

JET entered 1995 in the middle of the Pumped Divertor Characterisation Phase. This phase had begun in February 1994 and ended in June 1995. During this period, the Mark I pumped divertor was very effective and allowed a broad-based and highly ITER-relevant research programme to be pursued. The 1995 experimental campaign addressed the central problems of the ITER divertor: efficient dissipation of the exhausted power, control of particle fluxes and effective impurity screening. The year started with carbon fibre composite (CFC) tiles in the vessel as the power handling material. The inside of the vessel during this period is shown in Fig.5.

The campaign with CFC tiles was successfully completed in mid-March. The CFC tiles were then replaced by beryllium. The efficiency of the in-vessel training work was improved with the effective use of the in-vessel training facility and the use of an observation platform, adjacent to the torus access cabin, to allow the control of in-vessel work via closed circuit video cameras.

Experiments were then performed to assess the performance of beryllium as a divertor target tile material and to compare it with the CFC tiles. Following a request from the ITER Joint Central Team, beryllium melting was induced at ITER-relevant heat fluxes to investigate whether a protective radiative shield was established.

In June, the major shutdown started for the installation of the Mark IIA divertor and the modification of the ICRF antennae. The shutdown is scheduled for completion in March 1996.

Preparations were also continuing for the next period of D-T operation (DTE-1), scheduled for the end of 1996. Work was also continuing on the procurement of the ITER specific Mark II Gas-box divertor target assembly, due to be installed by remote handling in 1997.

The following sections detail notable technical achievements during 1995.

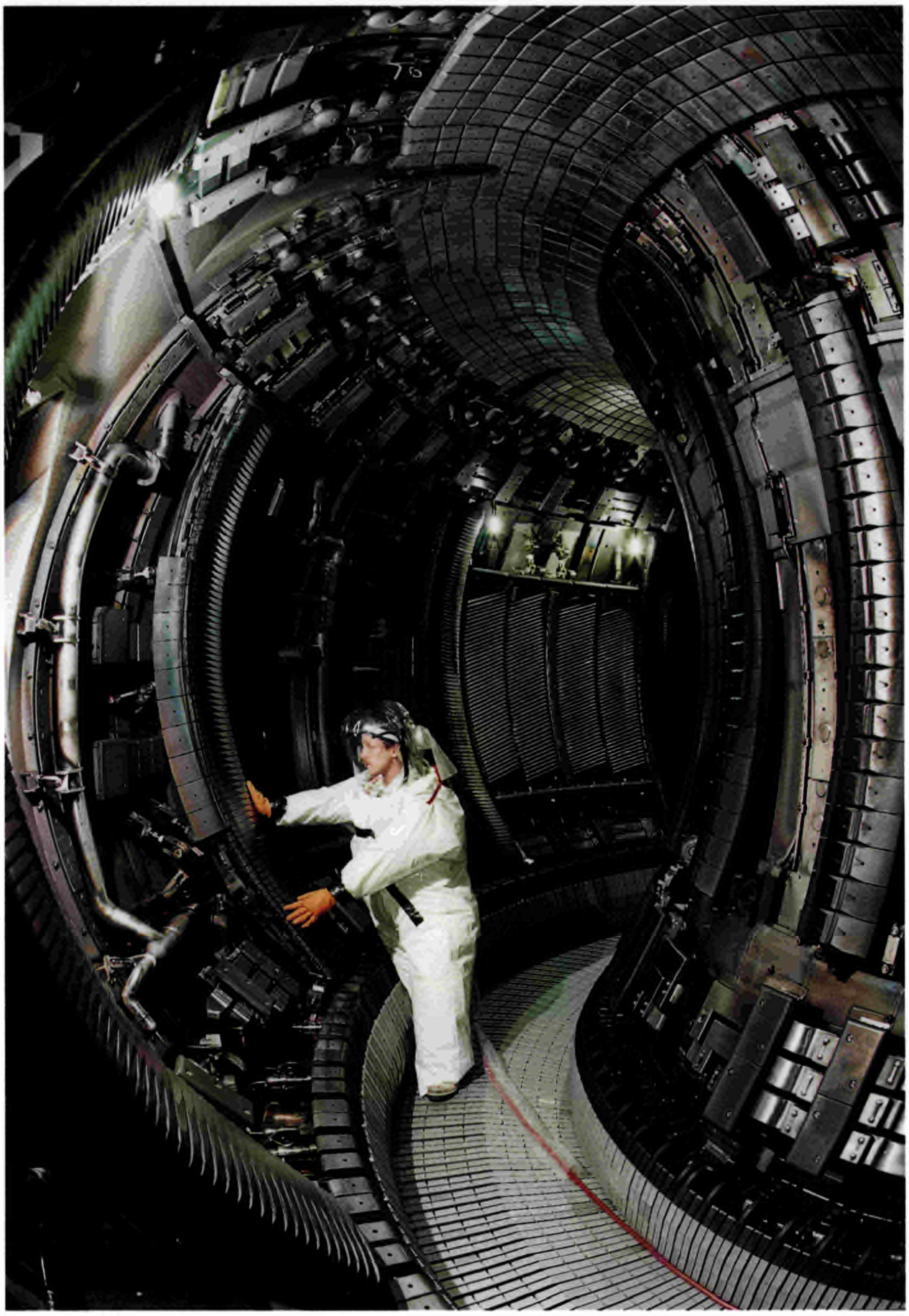


Fig.5: The inside of the vessel during the 1994/95 campaign

First Wall Activities

Installation of Mark II Divertor Support Structures

The shutdown for the Mark IIA divertor installation started in June 1995. The installation of the Mark II support structure constituted a major development in JET (Fig.6). This support structure is designed to allow JET to investigate a wide variety of divertor geometries by the installation of different tile carriers. These carriers can include the necessary diagnostics and can be attached to the support structure easily, quickly and with high precision. The whole procedure is designed to be possible by remote handling.

This phase of in-vessel work involved installation of the modules of the Mark II divertor support structure (Fig.7), which is about 6 metres in diameter and has a weight of 7 tonnes. This was assembled on time and to an accuracy of within 0.1mm. This was a remarkable engineering achievement considering the confined space available inside the vacuum vessel.

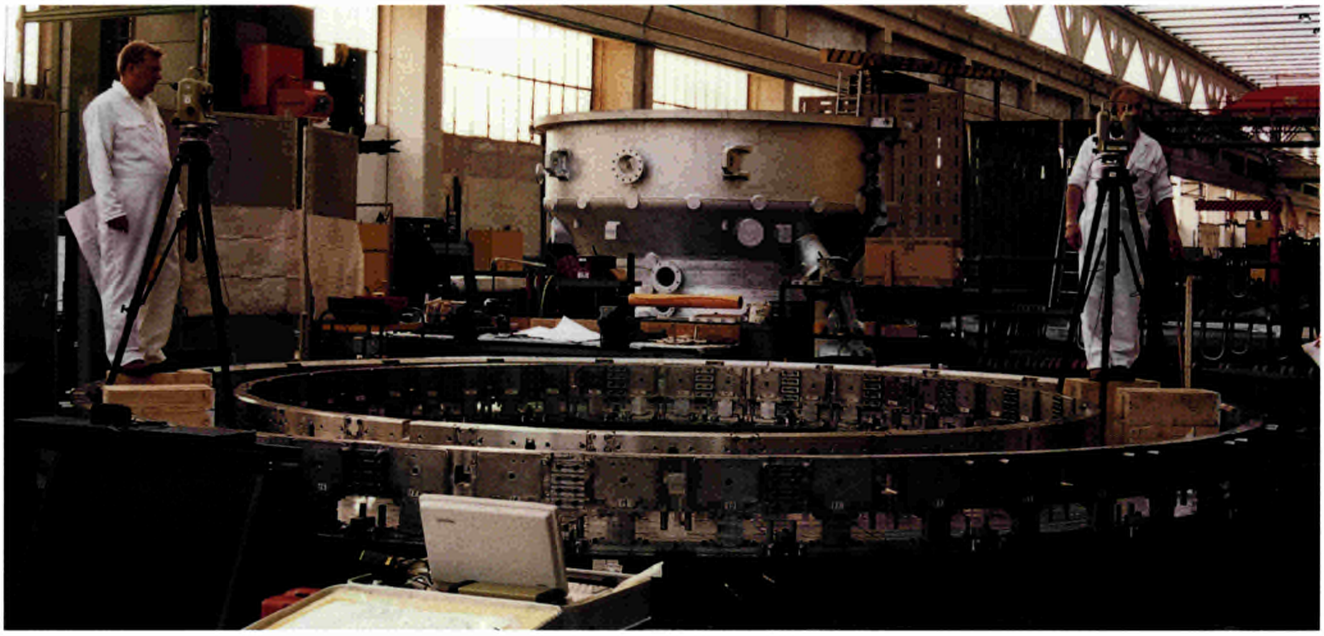


Fig.6: The Mark II divertor support structure being surveyed using the Computer Aided Theodolite (CAT) system at the manufacturers

Mark IIA Tile Carriers and Tiles

During the year, the Mark IIA Tile Carriers (Fig.8) were completed to the high tolerance requirements of JET. In addition, the 480 target tiles, later to be attached to the carriers, and which are made of carbon/carbon fibre composite material were machined to very high precision (50μm) with very few scrapped tiles. These tiles are carefully designed to withstand a high power load conducted by the plasma along magnetic field lines, whist shielding all corners and edges from direct heat loading.

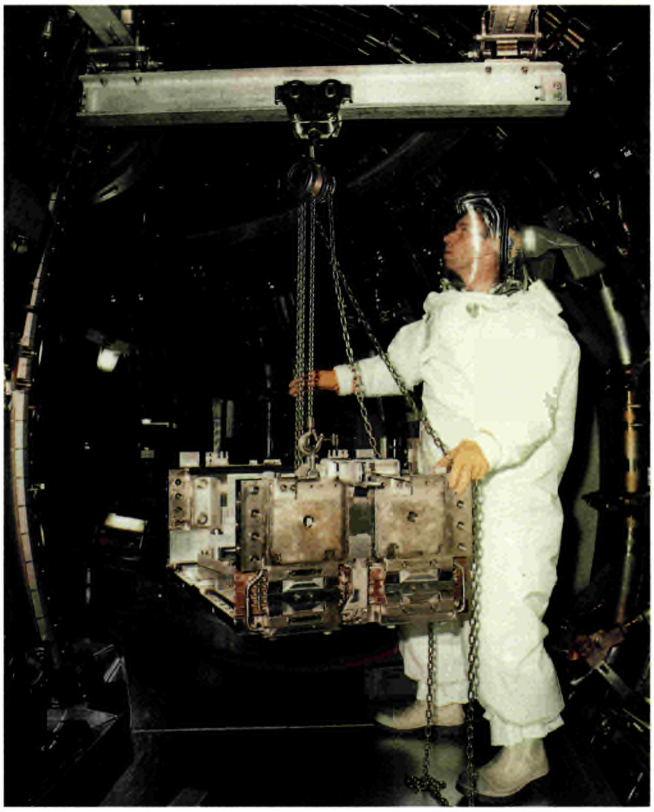


Fig.7: Divertor support structure being installed in the vessel

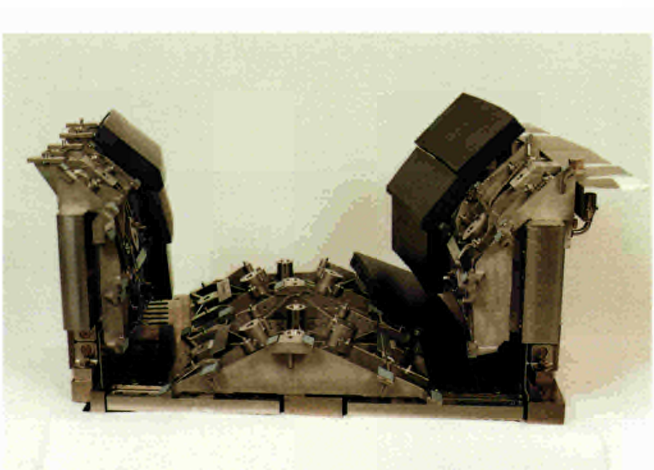


Fig.8: The Mark IIA Tile Carrier Assembly

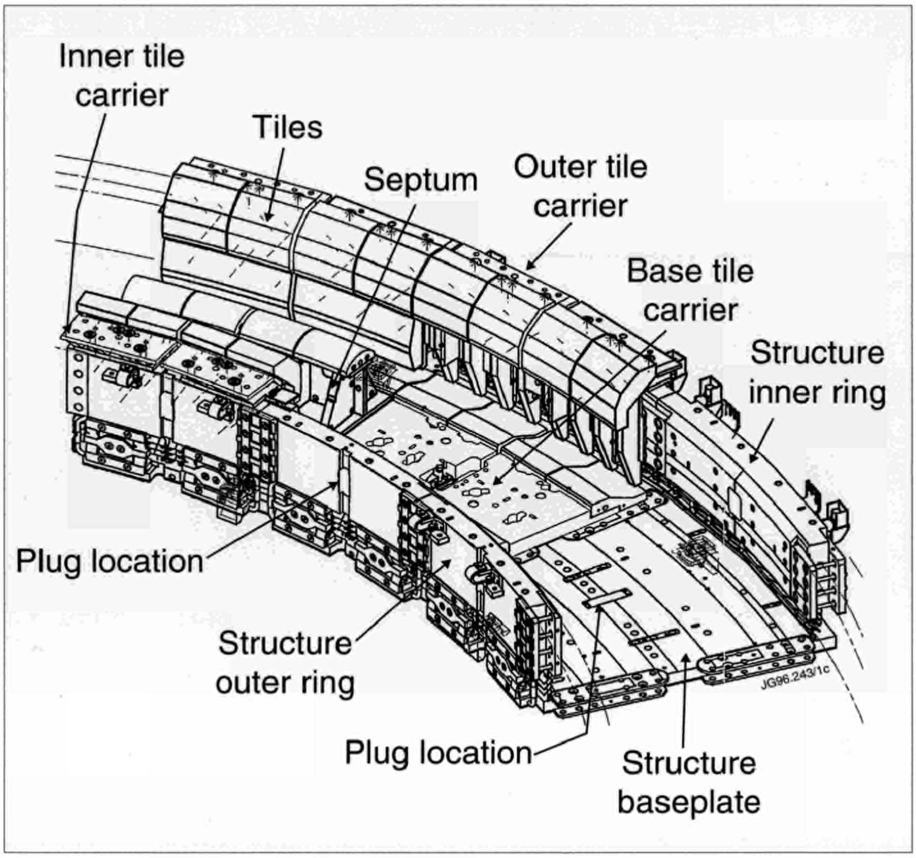


Fig.9: Model of the Mark II Gas-Box Divertor

The Mark II Gas-Box Divertor

The Mark II Gas-Box Divertor is the structure, which will be installed in the support structure during the 1997 Remote Tile Exchange shutdown. 1995 saw the finalisation of the design of the Gas-box Divertor and the CFC material for the tile carriers and tiles was ordered.

The novel feature of the Gas-box Divertor is the first use of CFC material for structural purposes in JET. The primary reason for this choice of material is the relatively high heat flux (<2MW/m^2) falling onto some structural components (Fig.9). A series of experiments were undertaken to test the predictions and to determine some of the uncertainties in the calculations.

High heat fluxes are expected to the various tiles of the Gas-box configuration that are not structural parts. Computations show that, for a wide range of plasma parameters fluxes of up to 18MW/m^2 are expected for non-radiating divertor plasmas in the Gas-box. It is expected that the Gas-box Divertor will allow 3-6 seconds of operation before the surface temperature reaches intolerable levels.

Remote Handling

Since the Mark II divertor will become active during its use with tritium plasmas, it has incorporated an important and novel feature in its design - it has been engineered to allow replacement of the divertor target structure by full remote handling techniques. To validate the capability of the remote handling approach, part of the Mark II divertor target plates will be installed by remote handling in early 1996. A full scale mock-up testing programme was started to prepare the equipment and operators for the fully remote exchange of Mark II tile carriers. The programme included the testing and proving of the task feasibility, both under normal operating conditions and under failure case conditions. This mock-

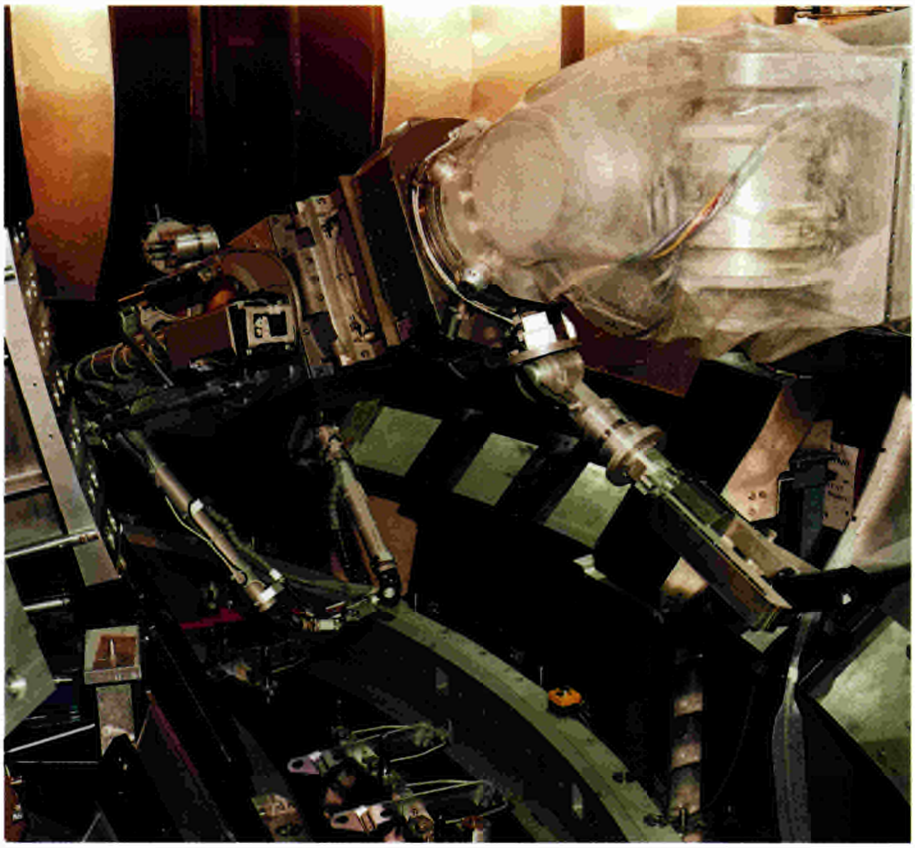


Fig.10: Boom and Mascot operating in the In-Vessel Training Facility

up programme, executed in the In-Vessel Training Facility, has been a major part of the Remote Handling work during 1995 in preparation for the planned fully remote installation in February 1996 of 36 of the 144 Mark IIA tile carriers in the vessel during the Mark IIA Divertor Installation Shutdown (Fig.10).

The trials have been successfully carried out on the mock-up arrangement and results have provided a high degree of confidence that target plate exchange with an active machine can be achieved in a reasonable time-scale. It will be the first time that such a complex remote handling operation has been performed on an active machine, providing most valuable engineering experience for the finalisation of ITER design.

The remote tile exchange concept requires the transfer of tile carriers and tools into and from the torus through the Octant No.1 main horizontal port. This transfer task and the placing of tile carriers in a transport container will be carried out fully remotely by means of a new Tile Carrier Transfer Facility which will be installed and operated at Octant No. 1 (see Fig.11). The facility comprises a so called short boom with an end effector suitable for carrying the various tile carriers and tools housed within a sealed enclosure for contamination control but with interface doors for a man-access module and tile carrier transfer containers.

The short boom was manufactured and delivered during 1995. The contamination control enclosure and the end effector have been designed in detail and are being assembled to be ready for commissioning and testing in the Torus Hall during 1996. The control system has been designed and is now being manufactured.

To obtain a general view of remote handling during in-vessel operations, it had been intended to deploy the In-Vessel Inspection System (IVIS) viewing probes. These probes are designed and are very effective for inspecting the torus under vacuum and high temperature conditions. However, mock-up tests found the system not to be suitable for operational purposes during remote handling procedures. Accordingly, a new system comprising four colour cameras mounted on

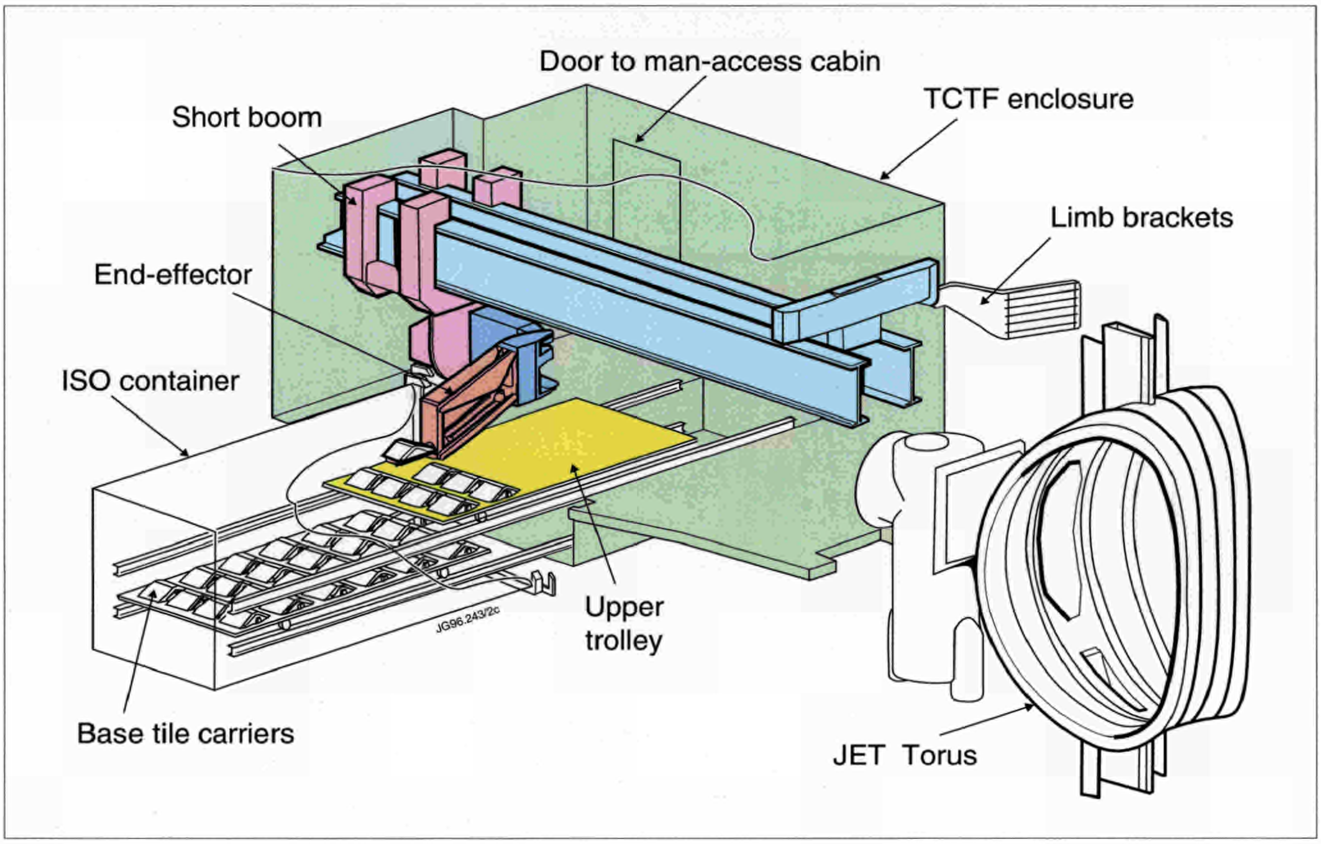


Fig.11: Octant No:1 Facility designed to transport title carriers and tools fully remotely into and from the torus

pan/tilt heads with zoom and other optic control was devised and found acceptable. Each unit is housed within a contamination protective dome and will be deployed by the Mascot servo-manipulator at the start of the intended operations. Miniature cameras attached to the servo-manipulator wrist by flexible mounts have proven invaluable during In-Vessel Training Facility trials and these cameras have now been fully integrated into the remote handling viewing system.

Plasma Control

Due to enhanced asymmetry of the plasma in the divertor configuration and to the strong coupling with the divertor coils, reconsideration of essential plasma and machine control and protection was necessary. Disruptive instabilities frequently lead to loss of vertical position and, consequently, to larger vertical plasma displacements (up to 1m). The associated vertical force acting on the vessel is large at high plasma current and when larger shaping currents are applied, such as in divertor configurations. The vertical instability can produce potentially dangerous forces on in-vessel elements, such as protection tiles.

Since Divertor (elongated) plasmas are more vertically unstable and require plasma-wall gap control, a new Plasma Position and Current Control (PPCC) was introduced. The system was designed with 'intelligent' software to control plasma-wall gaps and poloidal coil currents. The flexibility of the new PPCC has greatly simplified JET operations, since it allowed accurate control of the plasma boundary. PPCC has proven to have the capability of controlling the plasma distance from the outer, inner and top vessel wall, the X-point position and the plasma current simultaneously, and to change control behaviour to satisfy different requirements during a pulse. Switching from coil current to gap control does not affect plasma equilibrium. Although the vertical stabilisation performance is presently limited by noise introduced in the feedback signals by thyristor switching of the divertor power supplies, the system has demonstrated the ability to cope with plasma with growth rates of $800s^{-1}$. This has allowed the Mark I campaign to be conducted effectively without vertical instabilities not generated by plasma internal events. Improvements are now underway for the Mark II campaign. The most significant modifications are being made to the vertical stabilisation system, as new, faster ADCs have been developed to provide data to the central processors more quickly than in the past.

Since the processing capability of the vertical stabilisation controller was limited essentially by the delay in providing the data to the processors, this will allow much greater flexibility in the control algorithm. For example, data from other diagnostics such as soft X-rays can be incorporated into the vertical stabilisation and more advanced approaches to feedback control can be investigated. The increased processing power in the shape controller is required to provide the control capability required for more closed Mark II configuration as well as to permit additional facilities requested by operational teams. In particular, additional control gaps are being provided to allow for better control of the plasma boundary for specific experimental scenarios.

Power Supplies

The electric power to the JET device during an experimental pulse is counted in hundreds of megawatts.

An agreement with the Generating Boards allows up to 575MW of pulse power to be taken directly from the 400kV grid, which after transformation down to 33kV is fed to the JET loads through a system of circuit breakers.

Two flywheel generators are used to provide the peak power for the toroidal magnetic field coils and ohmic heating circuit. Each of the generators has a rotor 9m in diameter weighing 775 tonnes. Between pulses, 8.8MW pony motors are used to increase the speed of rotation. When power is required for a JET pulse, the rotor windings are energised and the rotational energy of the flywheel is converted into electrical energy. On slowing down from the maximum speed of 225rpm to half speed, the generators can reach deliver 2.6GJ of energy with a peak power output of 400MW.

Plasma-Machine Interactions

Plasma instabilities, leading to fast plasma vertical displacement events (VDE's) usually followed by plasma disruptions, can generate large forces on the vacuum vessel and on in-vessel components. It had always been assumed that these forces were toroidally symmetric, and so the main concern were the total forces on the vessel. In early operation with the Mark I divertor, toroidal asymmetries of the force distribution were observed. During 1995, a new topology of such forces was seen, leading to sideways movements of the vessel of several millimetres.

These events, raised additional concern on the integrity of the machine and on the design of a tokamak fusion reactor, such as ITER. Measurements were performed on other machines, around the world in similar configurations and the asymmetric behaviour of forces and vessel movements were confirmed. It is believed that the main contribution to these asymmetries is linked with non-uniform distribution of halo currents. While the plasma behaviour leading to these phenomena is not clearly understood, ITER designers are now taking these new events into consideration to substantially modify the design of the vacuum vessel. JET has dedicated a substantial amount of work during 1995 to perform engineering analysis on the vacuum vessel (see Fig.12) and electromechanical system, to the upgrading of the machine instrumentation and of the machine protection system.

In addition, a review has been undertaken of the supports of the vacuum vessel and a new set of vessel restraints have been designed to specifically limit sideways motions (see Fig.13). Implementation should reduce the extent of sideways motions, as well as

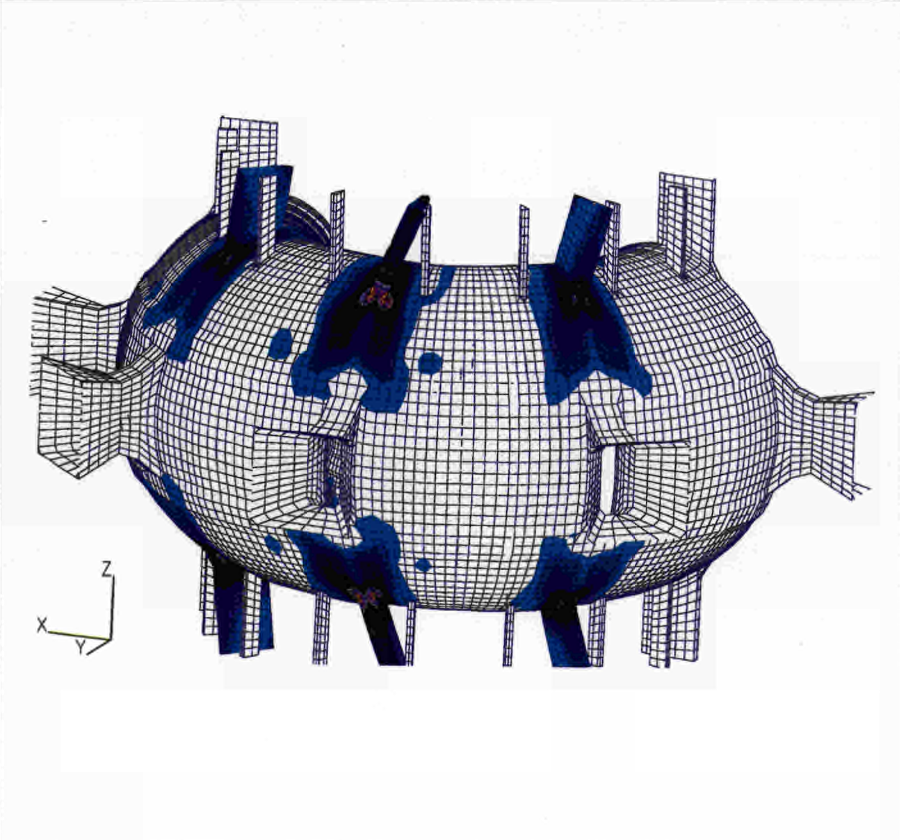


Fig.12: Stress distribution in the vessel for a vertical displacement event (VDE) at a plasma current of 3.8MA

the magnitude of the peak stresses at the main vessel ports by a factor of 3. The vessel is restrained in toroidal direction by the struts connected to the ports and by the neutral beam injectors, through the rotary valve cases. To avoid damage to this structure, new hydraulic supports on the main vessel ports have been designed. These should absorb most of the horizontal load, causing the stresses to be distributed more uniformly across each Octant.

Cryopumps and Cryoplant

An integral part of the divertor is a large cryocondensation pump which extends over the full toroidal length of the outermost divertor coil. It has been used routinely to provide high speed active pumping during plasma pulses with a pumping speed of $2x10^5 \ell s^{-1}$, operation of the divertor cryopump proved to be of significant importance during the experimental campaign, as it allowed achievement of extremely low levels of impurity in the torus vacuum, with the consequence that the cryopumps were routinely used for vacuum conditioning. In addition, it was used in a demonstration of density control of the plasma. The divertor cryopumps were also important in recycling control during the development of high fusion performance plasmas and were used with Argon frosting to study the helium transport in the plasma.

Good availability of the lower hybrid current drive (LHCD) cryopump proved to be important for conditioning and also for high performance operation of the LHCD launcher. The cryopump was operational permanently during 1995 operations. Figure 14 shows the cryopump installed at the torus LHCD launcher. Pumping speed measurements with the cryopump confirmed the design values of $\sim 10^5 \ell s^{-1}$. Introduction of a regeneration flap proved to be a very important component. When closed it has allowed the cryopump to be kept operational and filled with liquid helium, both under helium glow discharge cleaning conditions in the torus, and during regeneration of the divertor cryopump without affecting torus operation. The performance of the LHCD cryopump has been satisfactory and no modifications have been planned for the shutdown period.

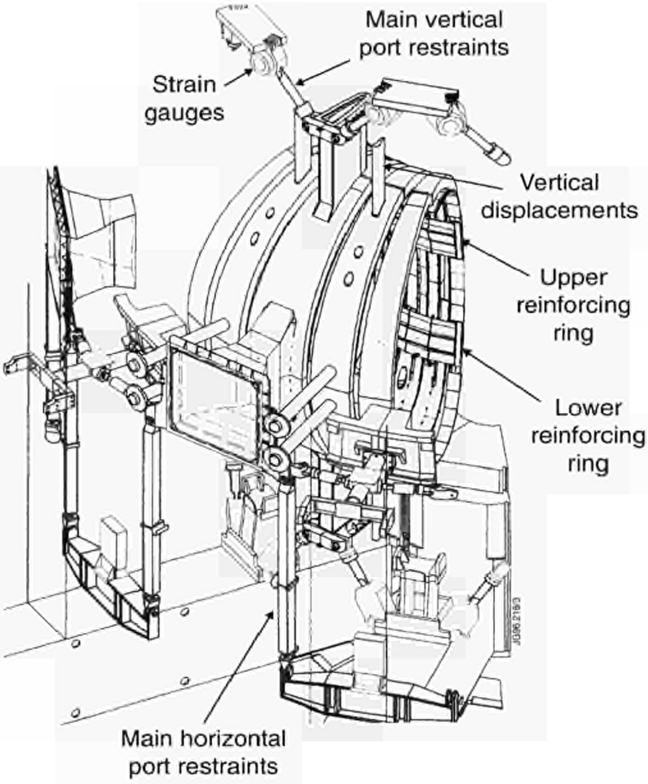


Fig.13: Schematic of a section of the vacuum vessel showing new vessel restraints

Heating and Current Drive Systems

Neutral Beam Heating

For the 1994/95 campaign, the neutral beam systems had been modified and upgraded. Some injectors had been converted to the new high current 85kV configuration originally developed for the Preliminary Tritium Experiment. Eight of these were installed on the beam system at Octant No. 4. The Octant No. 8 beam system operates at 140kV. The high voltage injector routinely delivered up to 8MW to the plasma, whereas the injected power level of the high current injector was progressively increased up to 13MW.

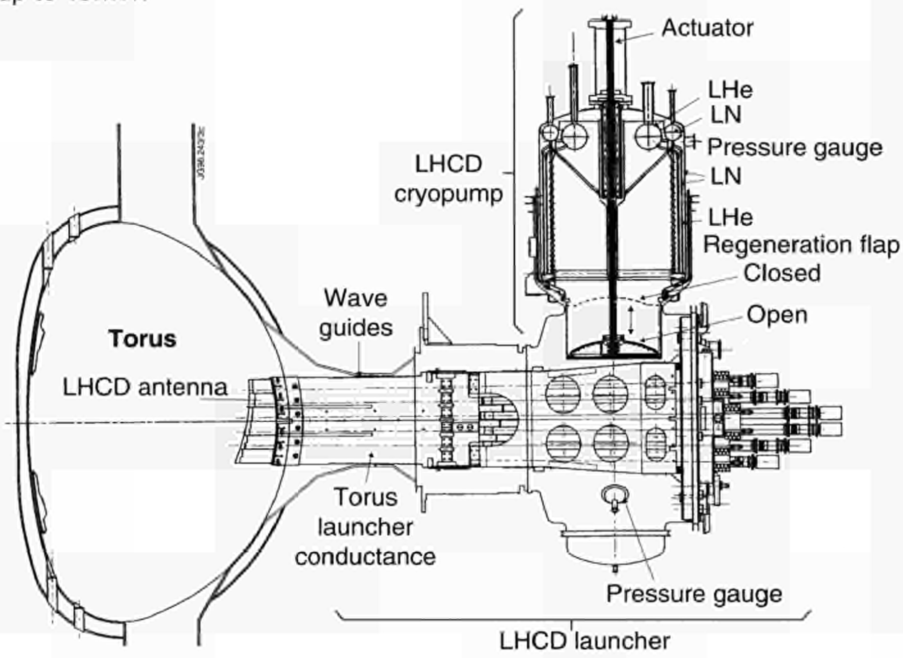


Fig.14: Cryopump installed at the LHCD launcher

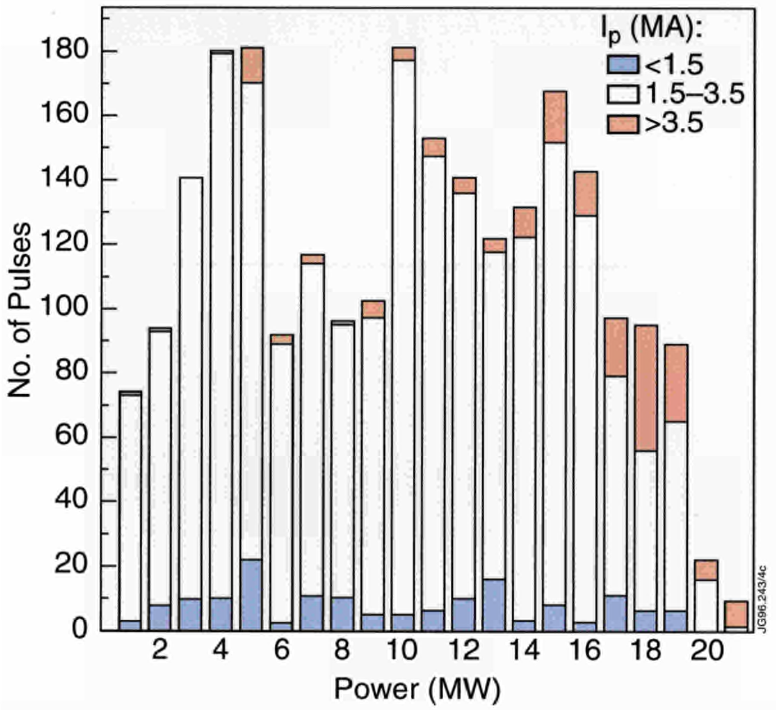


Fig.15: Histogram of frequency distribution of neutral beam power injected into JET in the 1994/95 experimental campaign. The frequency at low plasma currents (I_p<1.5MA) and high plasma currents (I_p>3.5MA) is indicated

Neutral beam injection was used on nearly every operational day of the 1995 experimental campaign, and was used in 63% of all pulses, which was the highest of any operating period. Figure 15 shows the distribution of neutral beam pulses as a function of injected power level for the 1994/95 campaigns combined. The level of reliability achieved during 1995 was typically in the range 80-90%. Power levels of up to 21.2MW were reached. At these levels, the Octant No. 4 injector contributed a world record 13.1MW from a single injection port.

Preparations for the Deuterium-Tritium experiment (DTE1); scheduled for the end of 1996, have involved considerable effort during 1995. During DTE1, the Octant No. 8 Position Ion Neutral Injectors (PINIs) will be used for injecting tritium into the plasma and will operate at up to 160kV/30A, compared with 140kV/30A in deuterium. Several PINIs were successfully commissioned to >158kV during 1995.

Neutral Beam Heating

The two JET neutral beam systems have been designed for long (~10s) beam pulses. They have the unique feature that each injector consists of eight beam sources in a single integrated beamline system connected to the torus. The first beam sources were designed to operate at accelerating voltages up to 80kV and in 1990 one system was substituted with units capable of operating up to 140kV. In addition, this box was also converted to operate with helium (^{3}He and ^{4}He) beams during 1990. In the D-T phase, one unit will be converted for operation with tritium at 160kV.

Each system is connected to the torus by a long narrow duct through which up to 12MW of power can be directed.

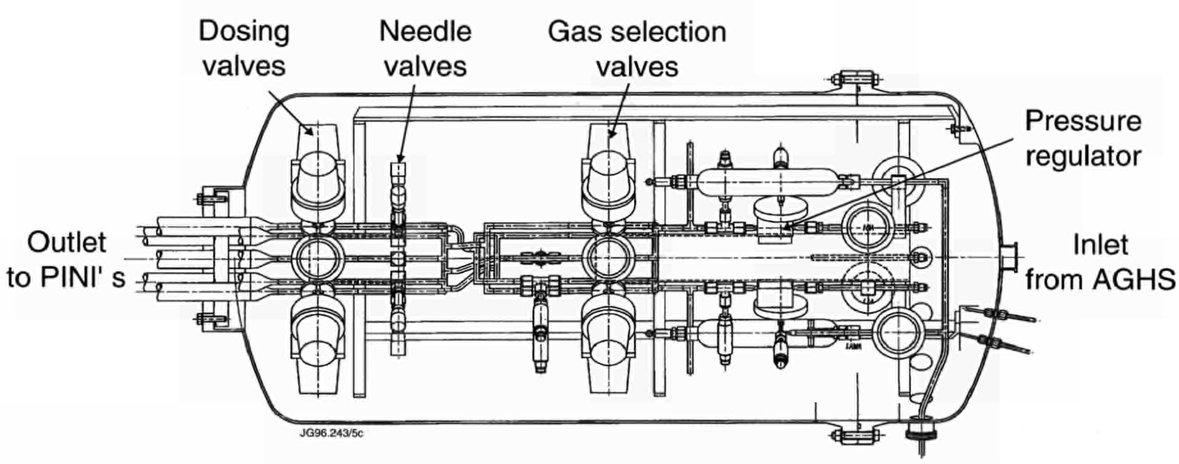


Fig.16: Schematic layout of tritium/deuterium gas introduction module

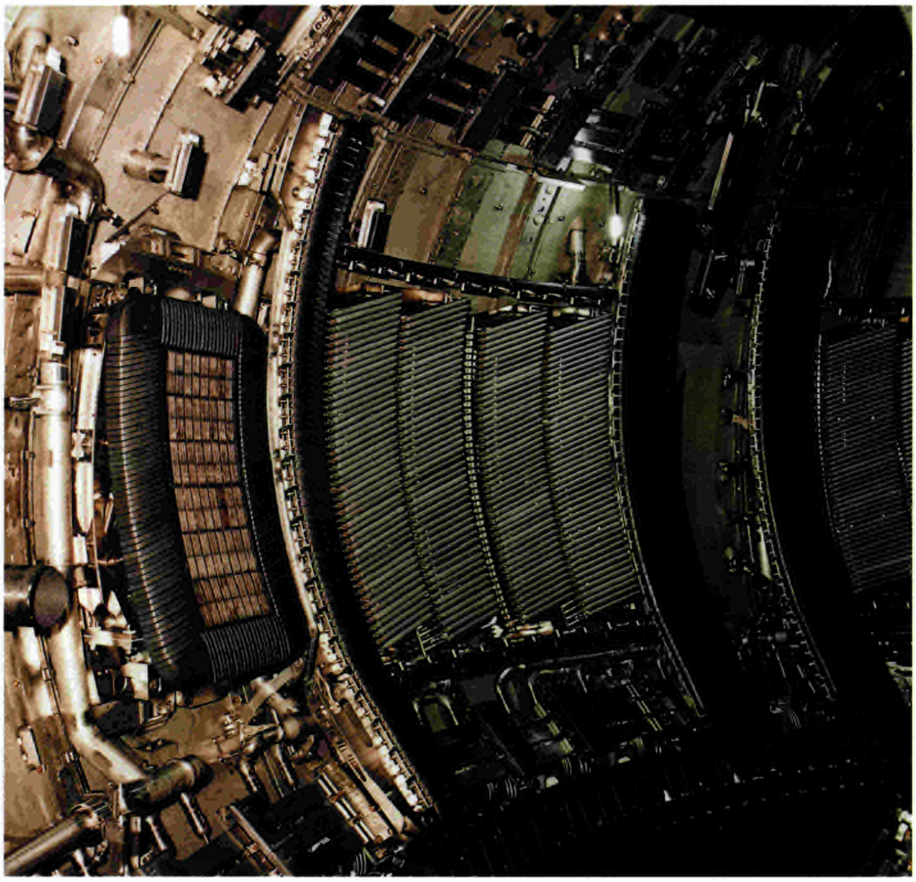


Fig.17: View of one of the four ICRF modules (on the right) with the LHCD launcher (on the left)

Significant effort has involved the design and construction of an active phase PINI gas introduction system, and will be installed during 1995/96 shutdown. Deuterium or tritium gas is supplied at subatmospheric pressure from the Active Gas Handling System (AGHS) via a local control and handling system and onward to the two gas neutral beam handling and distribution system. At this stage,tritium will only be used in the 140kV injector, to avoid contamination of injector components in the Octant No.4 system. The layout of one of these gas introduction modules is show in Fig.16.

Radio Frequency Heating

The ion cyclotron resonance frequency (ICRF) heating system is used for high power centralised heating of the plasma, with increased emphasis on Fast Wave Current Drive studies with the new antennae. The localisation depends mainly on the magnetic field and is insensitive to parameters such as density and temperature. Wide-band operation (23-57MHz) allows variation in both the choice of minority ion species heated (H or He^3 at present, D in the future D-T phase) and the localised position of the heating.

New ICRF antennae (Fig.17) have been optimised to the geometry of the divertor plasmas. Their location in the torus has been revised to give four arrays of two adjacent antenna. Each array has four RF radiating conductors or straps, which provide an enhanced radiated spectrum. Variation in the relative phase of the RF currents in the straps allows this spectrum to be varied for both heating and current

Radio Frequency Heating

Ion Cyclotron Resonance Frequency (ICRF) heating has been chosen for JET and the wide operating frequency band (23-57MHz) allows the system to be operated with the various mixes of ion species required in the different phases of the scientific programme and to choose the location where the heating in the plasma occurs.

The ICRF heating system has been designed in eight identical modular units. Each unit is composed of a tandem amplifier chain, a network of coaxial transmission lines and matching elements and finally on antenna located in the vacuum vessel on the outer wall. The eight RF generators produce a maximum output power of 32MW. The net power coupled to the plasma has reached 22.7MW, compared with theoretical limit of 24MW.

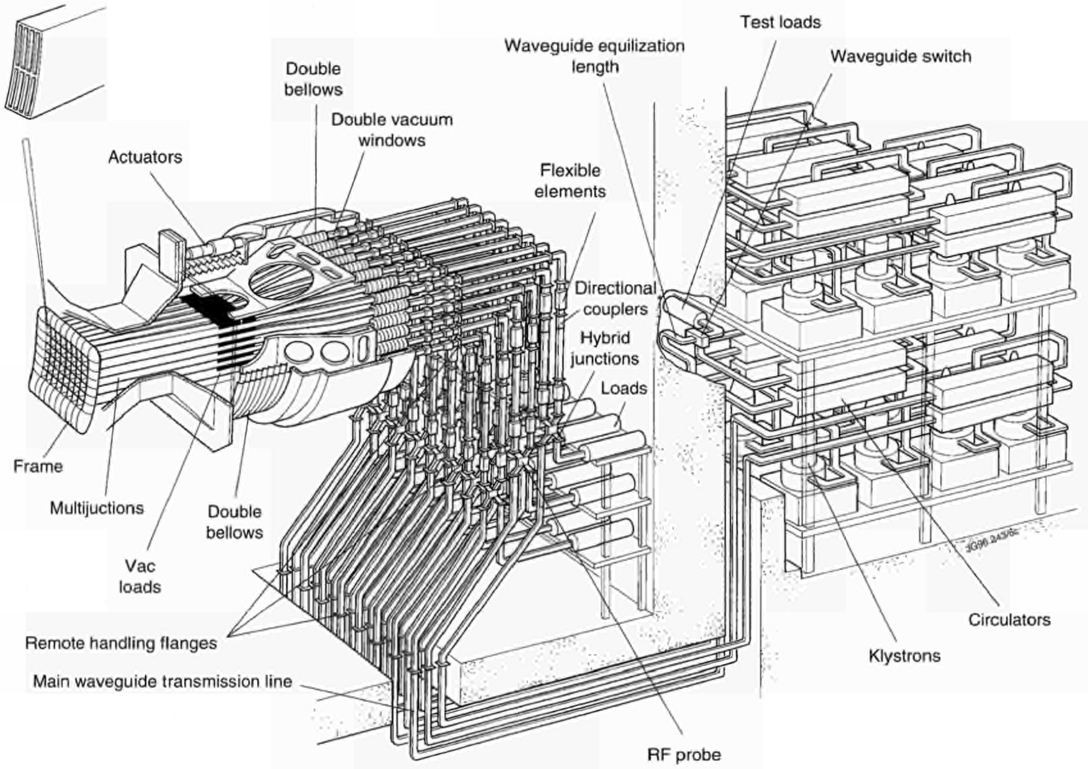


Fig.18: The Lower Hybrid Curent Drive (LHCD) System

drive experiments. In addition, the control electronics have been completely rebuilt to allow operation with four straps closely coupled and to improve the reliability of the ICRF plant by reducing the cross-talk between modules. Operations were made difficult by the fact that both the control electronics and the antennae were new systems and have required considerable commissioning time. Several problems have been identified and remedial action has been taken.

In spite of early difficulties, a record power of 16.5MW were launched in a divertor (H-mode) plasma, compared to 12MW in X-point plasmas in the 1991/92 campaign. Combined heating power of 32MW (15MW of ICRF and 17MW of neutral beam power) was launched for several seconds into radiative divertor plasmas.

Lower Hybrid Current Drive

The Lower Hybrid Current Drive (LHCD) system, operates at 3.7GHz and is capable of driving a significant fraction of the toroidal current in the plasma (Fig.18). This is achieved by launching an RF wave predominantly in one toroidal direction. This wave accelerates the high energy electrons in the plasma and so drives a current. It may be used to stabilise sawtooth oscillations, thereby increasing central electron temperatures. It is this system for controlling the plasma current profile, which is considered to be the main tool to stabilise high beta poloidal plasmas with a large bootstrap current (the so-called advanced tokamak scenarios).

Lower Hybrid power up to 7.3MW has been coupled to plasmas, using 8.2MW of generator power and has been used to fully drive a plasma current of 3MA. Powers at a level of 6MW have been applied to long pulses up to 13 seconds duration and a maximum energy of 67MJ was transferred to the plasma. Experiments focussed on profile control experiments with LHCD off-axis current drive. The LH power deposition profile was studied for a wide plasma parameter range. The performance of hot-ion H-modes was improved with LHCD profile control. In discharges with negative vcentral magnetic shear, improved confinement was obtained during strong central electron heating with LHCD.

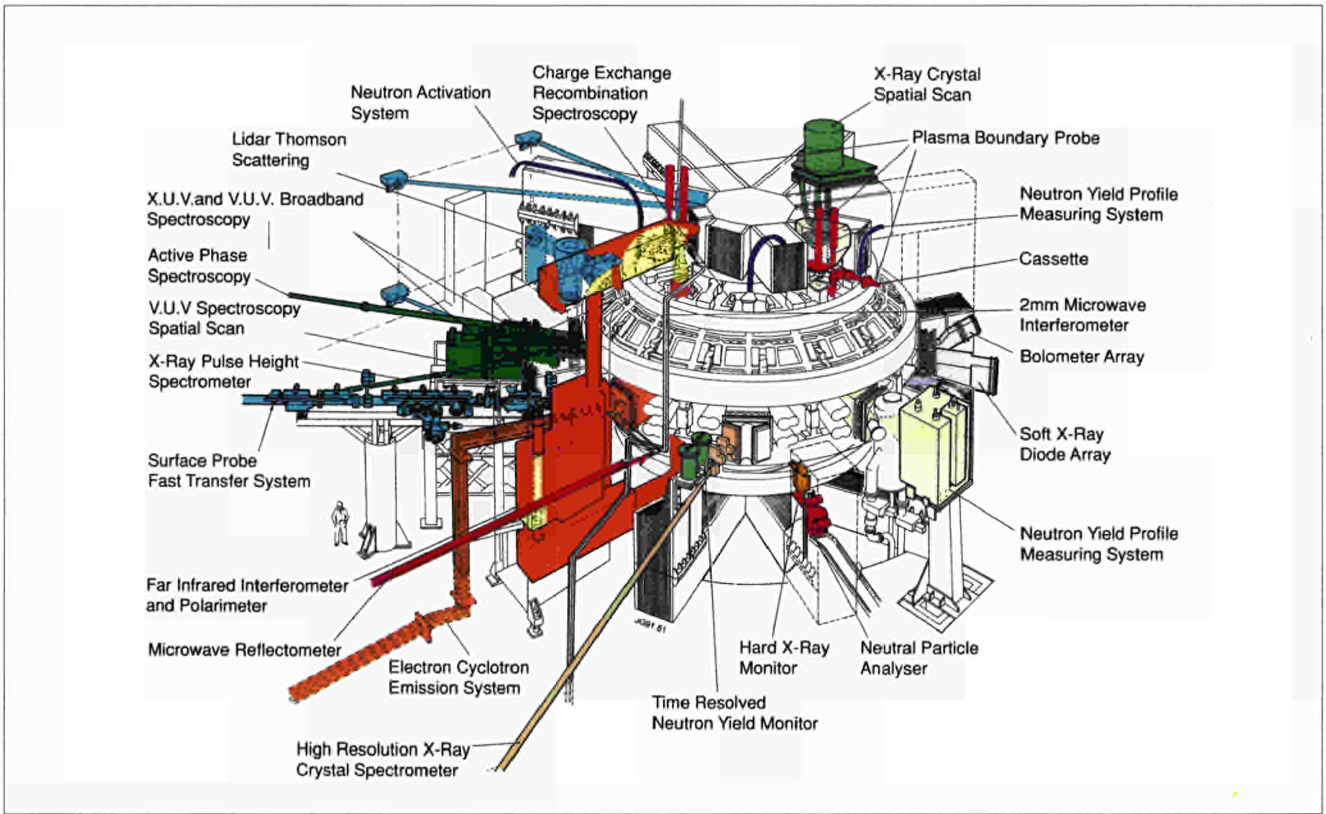


Fig.T19: General layout of diagnostics in the machine

Diagnostics Systems

The status of JET's diagnostic systems at the end of 1994 is summarised in Table 4, and their general layout in the machine is shown in Fig.19. The staged introduction of the diagnostic systems onto JET has proceeded from the start of operation in June 1983. The present status is that 58 systems are in operation of which 20 new systems were brought into operation in 1995. Nine other systems are new diagnostics which are not yet operational. Operational experience on the existing diagnostics has been good and most of the systems have operated automatically with minimal manual supervision. The resulting measurements have been of high quality in terms of accuracy and reliability, and have provided essential information on plasma behaviour in JET.

Control and Data Management

The JET Control and Data Acquisition System (CODAS) is a fully integrated computer-based system. A network of UNIX-based computers is used for controlling, monitoring, data acquisition and storage of data. This network is also used to analyse the data from the tokamak, its power supplies, auxiliary equipment and diagnostic devices. CODAS also provides the following common services: Network Information Services (NIS), Mail, file servers, printing, network monitoring and off-line programme development. These services have grown further and over 100 systems are now in use.

JET components and diagnostic devices are grouped into a number of sub-systems. Sub-systems that include parts of the tokamak and its auxiliary systems are referred to as control sub-systems; diagnostic devices are grouped into diagnostic sub-systems. Each sub-system is controlled and monitored by one dedicated computer interfaced to the machine and its diagnostics through CAMAC and/or VME instrumentation. Embedded front-end intelligence is implemented through CAMAC and VME-based microprocessors for real-time applications.

SYSTEM	DIAGNOSTIC	PURPOSE	ASSOCIATION
KB1	Bolometer cameras	Time and space resolved total radiated power	IPP, Garching
KB3D*	In-vessel main plasma bolometers	Time and space resolved radiated power	JET
KB4*	In-vessel divertor bolometer	Time and space resolved radiated power	JET
KC1	Magnetic diagnostics	Plasma current, loop volts, plasma position, shape of flux surfaces, diamagnetic loop, fast MHD	JET
KC1D*	Magnetic pickup coils	Plasma geometry in divertor region	JET
KD1D*	Calorimetry of Mark I divertor target	Power balance of divertor plasma	JET
KE1E+	Edge Thomson scattering	T_e and n_e in scrape-off layer	JET
KE3	LIDAR Thomson scattering	T_e and n_e profiles in core plasma	JET and Stuttgart University
KE4*	Fast Ion and alpha-particle diagnostic	Space and time resolved velocity distribution of alpha particles and fast ions	JET
KE9D+	Divertor LIDAR Thomson scattering	T_e and n_e profiles in divertor plasma	JET
KF1	High energy neutral particle analyser	Ion energy distribution up to 3.5MeV (ICRF minority and fusion products)	Purchased from Ioffe, St Petersburg
KG1	Multichannel far infrared interferometer	$\int n_e d\ell$ on four vertical chords and four horizontal chords – electron density	CEA, Fontenay-aux-Roses
KG3	O-mode microwave reflectometer	n_e profiles and fluctuations	JET and FOM, Rijnhuizen
KG4	Polarimeter	$\int n_e B_p d\ell$ on four vertical and four horizontal chords – poloidal magnetic field	JET and CEA, Fontenay-aux-Roses
KG6D*	Divertor microwave interferometer	$\int n_e d\ell$ on sightline across the divertor plasma	JET
KG7D*	Divertor microwave comb reflectometer	Peak n_e on sightline across divertor plasma	JET
KG8A+	E-mode reflectometer	Measurement of n_e fluctuations and profiles in edge and SOL	JET and CFN IST, Lisbon
KG8B*	Correlation reflectometer	Density fluctuations	JET
KH1	Hard X-ray monitors	Runaway electrons and disruptions	JET
KH2	X-ray pulse height spectrometer	Monitor of T_e, impurities and LH fast electrons	JET
KJ3*	Compact, re-entrant soft X-ray camera	MHD instabilities, mode identification, plasma shapes and impurity transport	JET
KJ4*	Compact, in-vessel soft X-ray camera	MHD instabilities, mode identification, plasma shapes and impurity transport	JET
KJ5+	Active phase, soft X-ray cameras	MHD instabilities and vertical position sensing, DT compatible	JET
KJ6+	Compact VUV camera	Divertor view in VUV	JET
KK1	Electron cyclotron emission spatial scan	$T_e(r,t)$ with scan time of a few milliseconds	NPL, UKAEA Culham and JET
KK2	Electron cyclotron emission fast system	$T_e(r,t)$ on microsecond time scale	FOM, Rijnhuizen
KK3	Electron cyclotron emission heterodyne	$T_e(r,t)$ with high spatial resolution	JET
KK4D*	Electron cyclotron absorption	n_eT_e profile on sightline across divertor plasma	JET
KL1	CCD viewing and recording	Plasma viewing	JET
KL1E+	Endoscopes	To allow an unrestricted view of the divertor in the visible and IR	JET
KL2*	Impurity flux camera	Impurity influx from the divertor targets with high spatial resolution	JET
KL3A*	Infra-red camera (1 dim)	Divertor tile temperature profiles	JET
KL3B+	Infra-red camera (2 dim)	Divertor tile temperature profiles with high dynamic range	JET
KL4*	Infra-red protection diodes	Machine protection – divertor tile temperature	JET
KL5*	Fast spectroscopic cameras	Fast D_α measurements at two toroidal locations for ELM studies	JET
KL6*	Colour view of divertor tiles	Colourimetry – used for erosion/redeposition measurements	JET
KM2	14MeV neutron spectrometer	Neutron spectra in D-T discharges, ion temperatures and energy distribution	UKAEA Harwell
KM3U+	2.4MeV time-of-flight neutron spectrometer	Neutron spectra in D-D discharges, ion temperatures and energy distributions	JET and NFR, Studsvik

* Brought into operation in 1995
\+ New Diagnostic – not yet operational

JG96.94/1

SYSTEM	DIAGNOSTIC	PURPOSE	ASSOCIATION
KM5	14MeV time-of-flight neutron spectrometer	Neutron spectra in D-T discharges, ion temperatures and energy distribution	NFR, Gothenburg
KM7	Time-resolved neutron yield monitor	Triton burnup studies	JET and UKAEA, Harwell
KN1	Time-resolved neutron yield monitor	Time resolved neutron flux	UKAEA, Harwell
KN2	Neutron activation	Absolute fluxes of neutrons	UKAEA, Harwell
KN3U*	Neutron yield profile monitor and FEB	Spatial and time resolved profiles of neutron flux and fast electron Bremsstrahlung	JET and UKAEA, Harwell
KN4	Delayed neutron activation	Absolute fluxes of neutrons	Mol
KR2	Active phase, neutral particle analyser	Ion distribution function, T(r) and H/D/T flux ratios	ENEA, Frascati
KS1	Active phase spectroscopy	Impurity behaviour in active conditions	IPP, Garching
KS3	H-alpha and visible light monitors	Ionisation rate, Z_{eff}, impurity fluxes from wall and divertor	JET
KS4	Charge exchange recombination spectroscopy (using heating beam)	Fully ionized light impurity concentration, T_i(r) and rotation velocities	JET
KS5	Active Balmer alpha spectroscopy	Neutral beam deposition, plasma effective charge and motional Stark measurement (for internal magnetic field)	JET
KS6	Bragg rotor X-ray spectroscopy	Monitor of low and medium Z impurity radiation	UKAEA, Culham
KS7	Edge charge exchange	Multichannel measurement of edge poloidal rotation, ion temperature and impirity density	UKAEA, Culham
KT1D	VUV spatial scan of divertor	Time and space resolved impurity densities	JET
KT2	VUV broadband spectroscopy	Impurity survey	UKAEA, Culham
KT3	Active phase CX spectroscopy	Fully ionized light impurity concentration, T_i(r), rotation velocities and divertor sources	JET
KT4	Grazing incidence XUV broadband spectroscopy	Impurity survey	UKAEA, Culham
KT5P*	Divertor gas analysis	Analysis of divertor exhaust gasses	
KT6D*	Poloidal view, visible spectroscopy of divertor plasma using periscopes	Impurity influx, 2D emissivity profile of spectral lines	JET
KT7D*	VUV and XUV spectroscopy of divertor plasma	Impurity influx, ionization dynamics, electron temperature and density	JET
KX1	High resolution X-ray crystal spectroscopy	Central ion temperature, rotation and Ni concentration	ENEA, Frascati
KY3	Plasma boundary probes	Vertical drives for reciprocating Langmuir and surface collector probes	JET and UKAEA, Culham
KY4D	Langmuir probes in divertor target tiles and limiters	n_e and T_e at the divertor and limiters	JET
KY5D	Fast pressure gauges	Neutral flux in divertor region	JET
KY6*	50kV lithium atom beam	Electron density in scrape-off layer and plasma edge	JET
KY7D	Thermal helium beams	n_e and T_e in the divertor plasma (together with KT6D)	JET
KZ3	Laser injected trace elements	Particle transport, τ_p, impurity behaviour	JET
Kα1⁺	Thin foil charge collectors	Lost alpha-particle detection	JET
Kγ5 & 8	Gamma rays	Fast ion distribution	JET

* Brought into operation in 1995

⁺ New Diagnostic – not yet operational

JG96.94/1

Table 4: Status of JET Diagnostics Systems, December 1995 - Existing Diagnostics

During the last campaign, experience was gained of the new Control Room layout and its flexible, compact X-terminals. It offers much more usable space that the former purpose-built consoles and has been generally well liked (Fig.20). The Session Leaders suite has been modified to improve communications with the Physicist-in-Charge and to reduce crowding around the Engineer-in-Charge. A special area has been set aside for next-pulse preparation, being within sight of the Session Leader, but far enough away not to disturb operations of the current pulse. A new overhead display system was brought into use in the Control Rooms. This provides staff with information relevant to JET operation.

Fig.20: Overview of JET Control Room

The mainframe computing service is based on an IBM 3090/300J three-way processor mainframe with two vector facilities. There are 160 Gigabytes (GB) of disc storage and a further 2000GB of automated cartridge tape storage. During the 1994/95 campaign, there was a considerable increase in the amount of JET data with pulse file size up to 130MB per pulse (compared with 35MB during the operations period to March 1992), yielding up to 3.5GB of data each day of operation.

The data are transmitted from the CODAS UNIX systems to the IBM at speeds of about 600 kilobytes per second ensuring that the JET data are available for analysis on the mainframe promptly after collection on the CODAS systems. The development of a very sophisticated data archiving and retrieval system based on a cache of 32GB of on-line disc backed by tape storage accommodates the storage of about 650GB (before compression) of raw JET data (JPF). The mechanism gives almost instant access to any JPF data that is available on disc (currently the preceding five weeks of data), and access typically within two minutes to restore the complete pulse file for a given shot from the automated tape library, for any pulses back to original start-up (in 1983).

Summary of Machine Operations

The Mark I divertor Operations Phase covered the period February 1994 to June 1995. Out of the total of available 473 days, the high figure of 312 operations days (66%) was achieved. During this time, a total of 7005 pulses were run, of which 4288 had plasmas above 1MA. The total number of pulses carried out in 1995 was 2520.

During 1995, JET operations continued until mid-June, representing a total of 150 operational days. An analysis of the days on which operation took place has shown that ~20% of operation time was lost through machine failure of some kind. JET is an

Control and Data Acquisition

Due to the high number of components and their distribution throughout a large site, the operation and commissioning of JET is supported by a centralised Control and Data Acquisition System (CODAS). This system is based on a network of minicomputers interfaced to the experiment through distributed front-end instrumentation (including front end micro-processors) and signal conditioning modules. The various components have been logically grouped into subsystems with each one controlled and monitored by a computer. After a pulse, all the information from the subsystem is merged together into a single file on the storage and analysis computer. This file is then transmitted to the IBM mainframe computer for detailed analysis. A summary of information from the JET pulses is held in the JET Survey Data Bank.

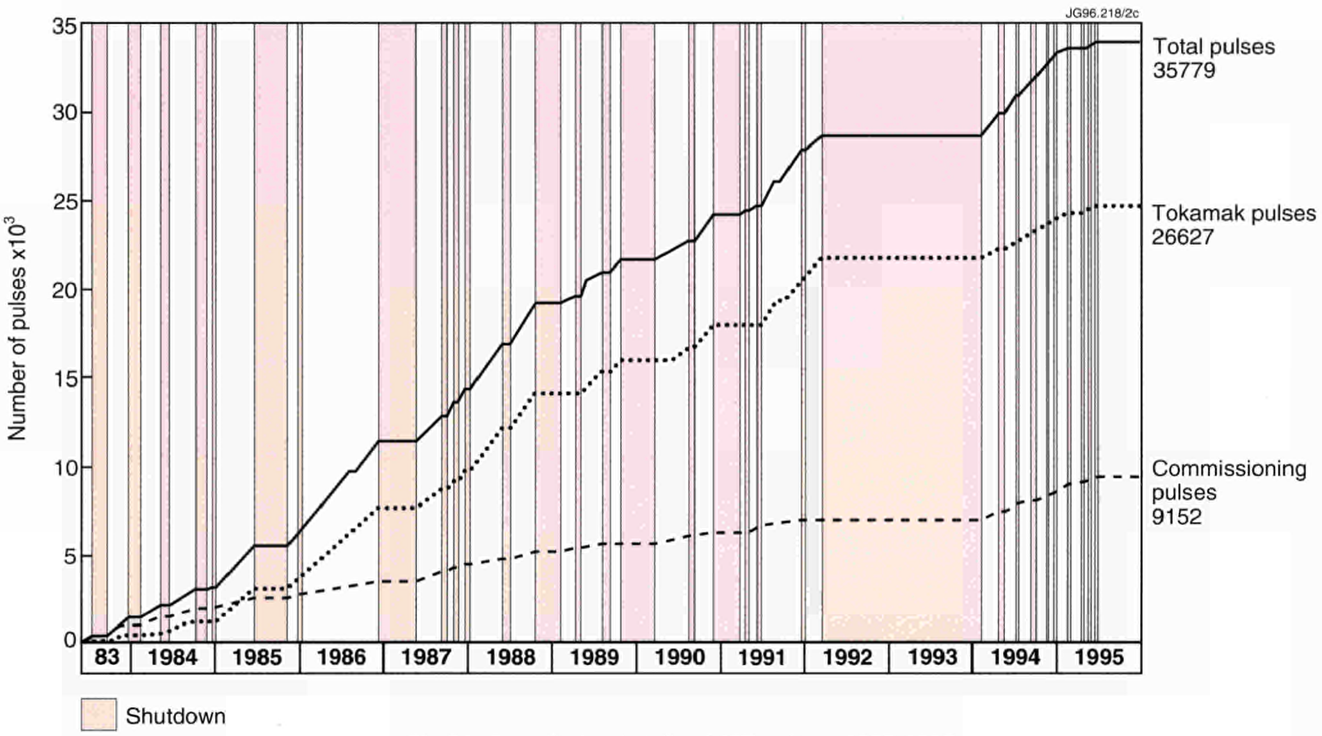
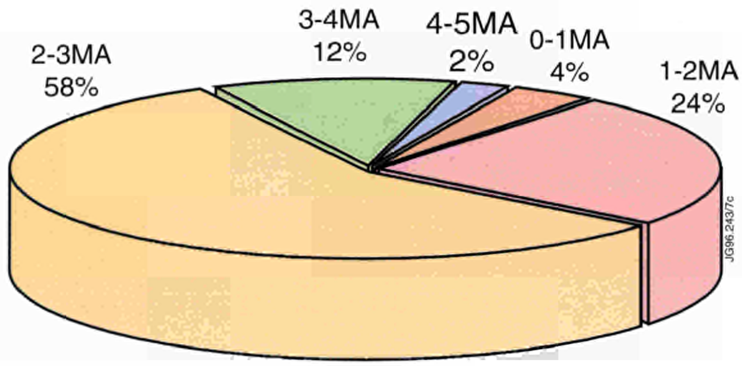


Fig.21: Cumulative totals of JET pulses: 1983-1995

experimental machine and changes and developments are required by the experimental programme. Therefore, the figure of only 20% daily down-time is remarkably good. A typical pulse rate of one every 30 minutes was achieved. This is slower than previous operations, but the complexity of operation has increased substantially. Also, the quality and returns per pulse have improved steadily over JET's lifetime, especially in view of the increasing sophistication and data capabilities of the diagnostics.

Overall, the number of pulses carried out in 1995 was 2520, with a total overall distribution over 1983-95, as shown in Fig.21. The overall ratio of successful pulses either for commissioning or plasma reached the high level of 84% compared with the 77% achieved in the 1994 experimental campaign. An analysis of the distribution of the plasma current shows that operations up to 2MA and 3MA continued to be routinely established as they represented 58% of the plasma pulses (Fig.22).

Fig.22: Plasma Current Distribution for 1995



Technical Developments for Future Operations

Considerable effort was devoted during the year to the design and procurement of equipment for installation on the machine during future shutdown periods. Reference should be made to the section on the Future Programme of JET to relate these technical developments to the overall JET Programme.

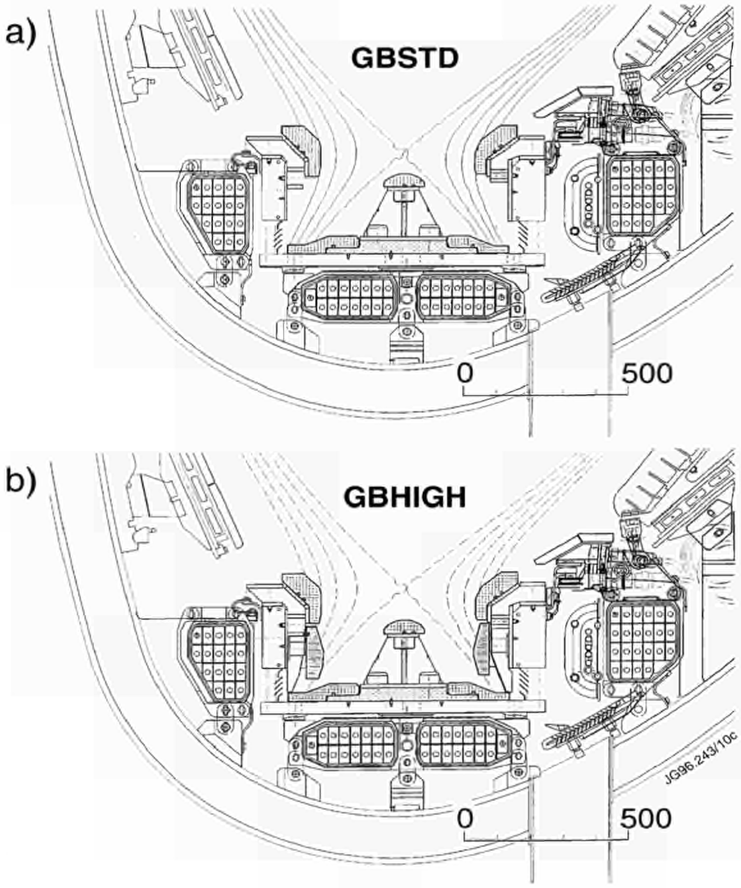


Fig.23: Poloidal cross-section of the Mark II Gas-box divertor configurations: (a) "horizontal target" configuration' (b) "vertical target" configuration

Advanced Divertor Studies

The Mark I divertor has been successful from several points of view. In particular, its power exhaust capability in the sweeping mode has been very good, and the cryopump operates effectively. The fact that Mark I is relatively open has made it possible to investigate a large variety of magnetic equilibria with strike points on both the horizontal and vertical sections of the target tiles.

However, the openness of the divertor also has drawbacks. Such an open divertor is not as effective in restraining neutrals in the divertor region as a more closed design, particularly at high powers and low to moderate main chamber densities. Under these conditions, the divertor plasma itself is not opaque enough to re-ionise the recycling neutrals. Thus, a series of more closed divertors were investigated, beginning with Mark IIA, to be installed in 1995, and followed by Mark IIGB (Gas-box) in 1997. The purpose of these close divertors is to permit a high neutral density in the divertor volume while maintaining a low neutral density in the main chamber. The first condition is required to exhaust power to a large fraction of the total divertor wall area by the volumetric processes of radiation and charge exchange (i.e. to operate in the highly radiating, partially or fully detached regime). The second requirement, that of low neutral density in the main chamber, is necessary for the highest main plasma performance.

During 1995, Advanced Divertor studies concentrated on finalising the design of the Mark IIGB (Gas-box) divertor and modelling the various options, which will be tested in the year of Gas-box operation following the DTE1 experiments in Mark IIA. The Gas-box divertor represents the second step in an integrated divertor programme based on the Mark II support structure, which allows for changes of divertor shape via remote tile/tile carrier replacement. It is more ITER-

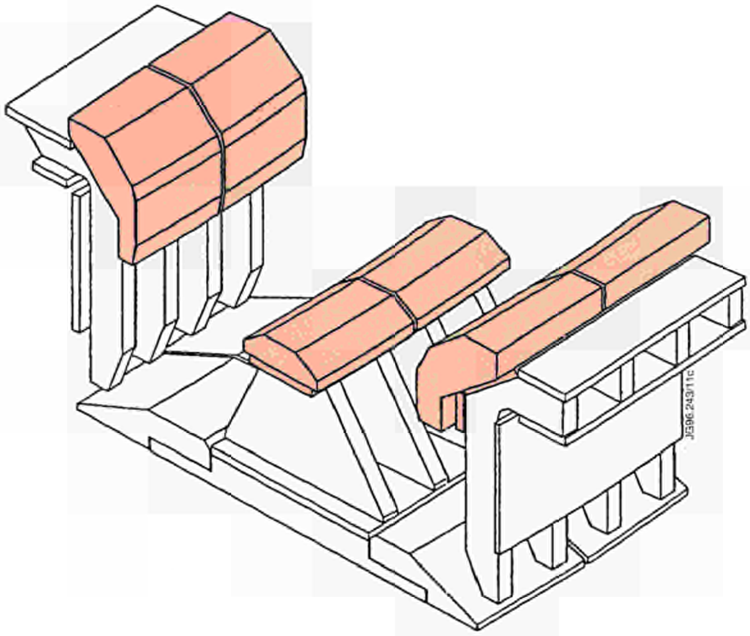


Fig.24: Mark II Gas-box divertor showing its make-up with toroidally discrete radially-oriented plates with a toroidally continuous top-tile

specific than Mark IIA in that it is a deep divertor, with a relatively close fitting "entrance baffle" which begins below the X-point and continues above it to reduce the probability of neutrals escaping from the divertor chamber to the main plasma chamber. As a consequence, only a relatively small range of X-point heights can be accommodated.

The Mark II GB experimental programme is scheduled to last twelve months, with a short break to permit a configurational change. Two of the possible configurations are shown in poloidal cross-section view in Fig.23. The make up of the Gas-box divertor is shown in Fig.24. The poloidal flux contours adjacent to the baffle surface are 3cm from the separatrix at the midplane, which corresponds to several scrape-off layer lengths. This clearance may be necessary to prevent ELMs from depositing a large amount of energy and particles on the top of the baffle rather than deep in the divertor.

Tritium Handling

The purpose of the Active Gas Handling System is to pump the torus, to collect gases from various systems (torus, neutral beam injection, pellet ingestion and various diagnostics), to purify and isotopically separate these gas mixtures (consisting of the six hydrogen molecules, helium and impurities such as hydrocarbons, oxygen, nitrogen, etc.) and to re-inject pure tritium and deuterium gas into the torus. The system is situated in a separate building and can be separated into sub-systems, as shown in Fig.25. During the year, the inactive commissioning phase of the sub-systems continued in accordance with the JET programme for D-T operations in 1996, and this was completed on: the Cryogenic Forevacuum; Impurity Processing System; Gas Chromotography System; Impurity Processing System; Product Storage System; Analytical Laboratory; Exhaust Detritration System; and other systems. Trace tritium commissioning was then started on these sub-systems as the next stage in the commissioning process.

JET is required to satisfy the United Kingdom Atomic Energy Authority (UKAEA - the host organisation) that adequate safety standards exist prior to tritium operation. The UKAEA endorsed the issue of an Authority to Operate (ATO) for tritium commissioning of the AGHS, following submission of a Pre-Commissioning Safety Report (PCMSR), an audit, and clearance of considerable number of follow-up actions arising from AGHS safety submissions.

The safety submission for DTE1 are now being submitted for review by the Safety Directorate Group of AEA Technology

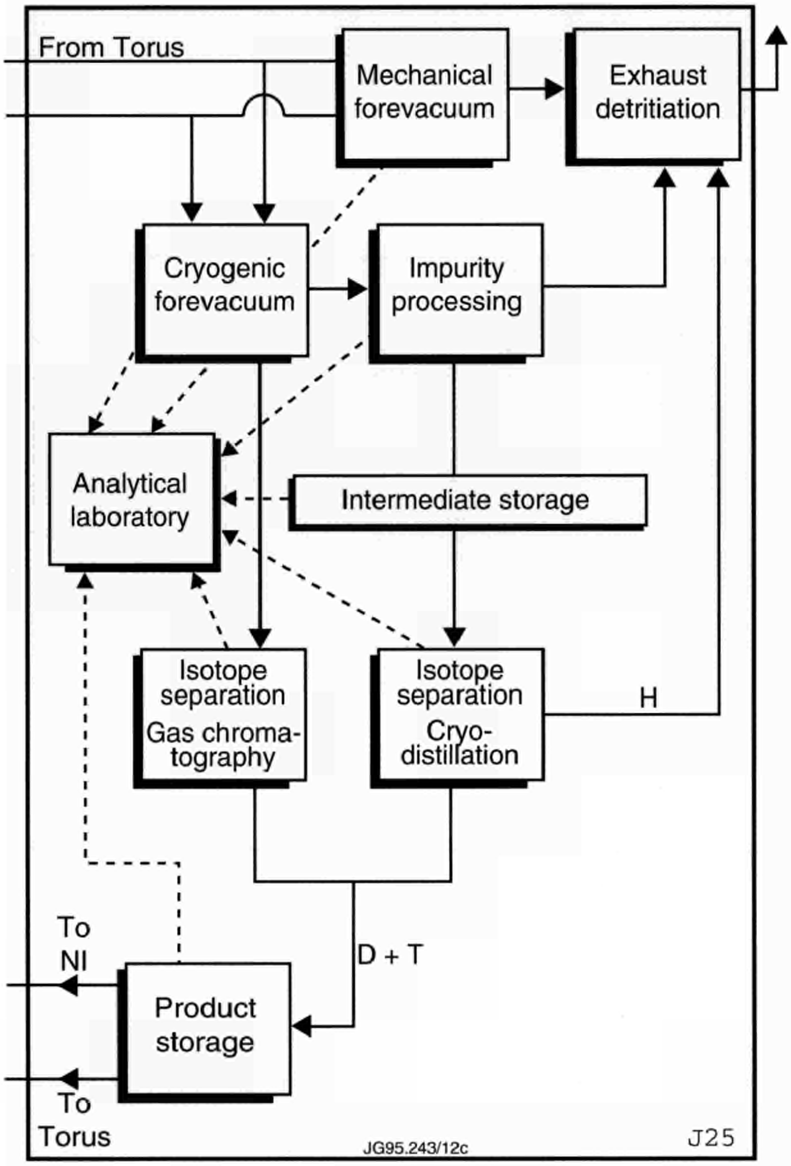


Fig.25: Block Diagram of Active Gas Handling System (AGHS)

on behalf of the UKAEA. The so-called Pre-Construction Safety Report contains an overview of the engineered safety of JET, a deterministic analysis (showing that the dose on-site and off-site for conceivable accidents is small) and a probabilistic risk assessment (showing that the UK's Health and Safety Executive (HSE) limits are complied with).

Plans for D-T Operation

A Working Group was constituted to propose plans for D-T operations in 1996 (DTE1). The programme was prepared within the constraints of a limit of $2x10^{20}$ D-T neutrons and a programme duration of 3-4 months. The Group included the Programme Leaders and Task Force Leaders from the 1994/95 Experimental Campaign, and as well, there were a number of additional Proposal Co-ordinators.

A set of initial proposals were considered by the Group and this was narrowed down to twelve main experiments, and two necessary calibration and clean-up experiments. In addition, seven subordinate and six parasitic experiments were also selected. This gave a total of $2x10^{20}$ neutrons and 350 D-T neutron shots. Preparations are underway for experiments with D-T plasmas (DTE1) scheduled to start at the end of 1996. The aim is to ensure that technical provisions are made, and the 1996 deuterium campaign performs the necessary preparatory experiments.

The four main objectives set for the experiment are summarised, as follows:

(a) High fusion power demonstration in a reactor-like configuration, with Q approaching unity ($Q \approx 1$) for over one energy confinement time. This should allow the observation and study of alpha-particle effects, at least in the plasma centre;

(b) D-T physics of a reacting divertor tokamak, in an ITER like geometry, including H-mode threshold behaviour;

(c) Demonstration of a reactor-relevant fully remote handling operation (ie replacement of the divertor target assembly);

(d) Operation of the Tritium Processing System integrated with a reacting tokamak (the JET Tritium Processing Facility is reactor scale and uses reactor relevant technology).

Studies for Machine Performance Enhancement

In the light of the proposed JET extension to the end of 1999, studies have been undertaken on possible enhancement options of the some sub-systems. In particular, it has been considered that, the toroidal magnetic field could be increased from the present 3.45T to a value of ~4 Tesla and that the output power of the neutral beam injectors could be improved by increasing the power supplies from 80kV at 60A to 120-140kV at 60A.

Toroidal Field to 4T

The strategy for operating the coils is based on high reliability, long life and minimal risk. However, a reliability analysis performed in 1992/93, showed that only a small percentage of the coil's life has been used since JET started operation in 1983. Therefore, with a moderately increased risk and an acceptable reduction of life, it was thought that operation of the TF coils at up to 4T should be possible. The stresses in the tokamak coil system have been re-assessed for the TF magnetic field at 4T and the new requirements for the power supplies have been studied. Engineering analysis and tests on the existing power supply system, indicate that this goal can be achieved, basically, by replacing the four static unit transformers and the thyristor and cable protecting fuses, while the thyristor themselves have a built-in capability suitable for the new scenarios.

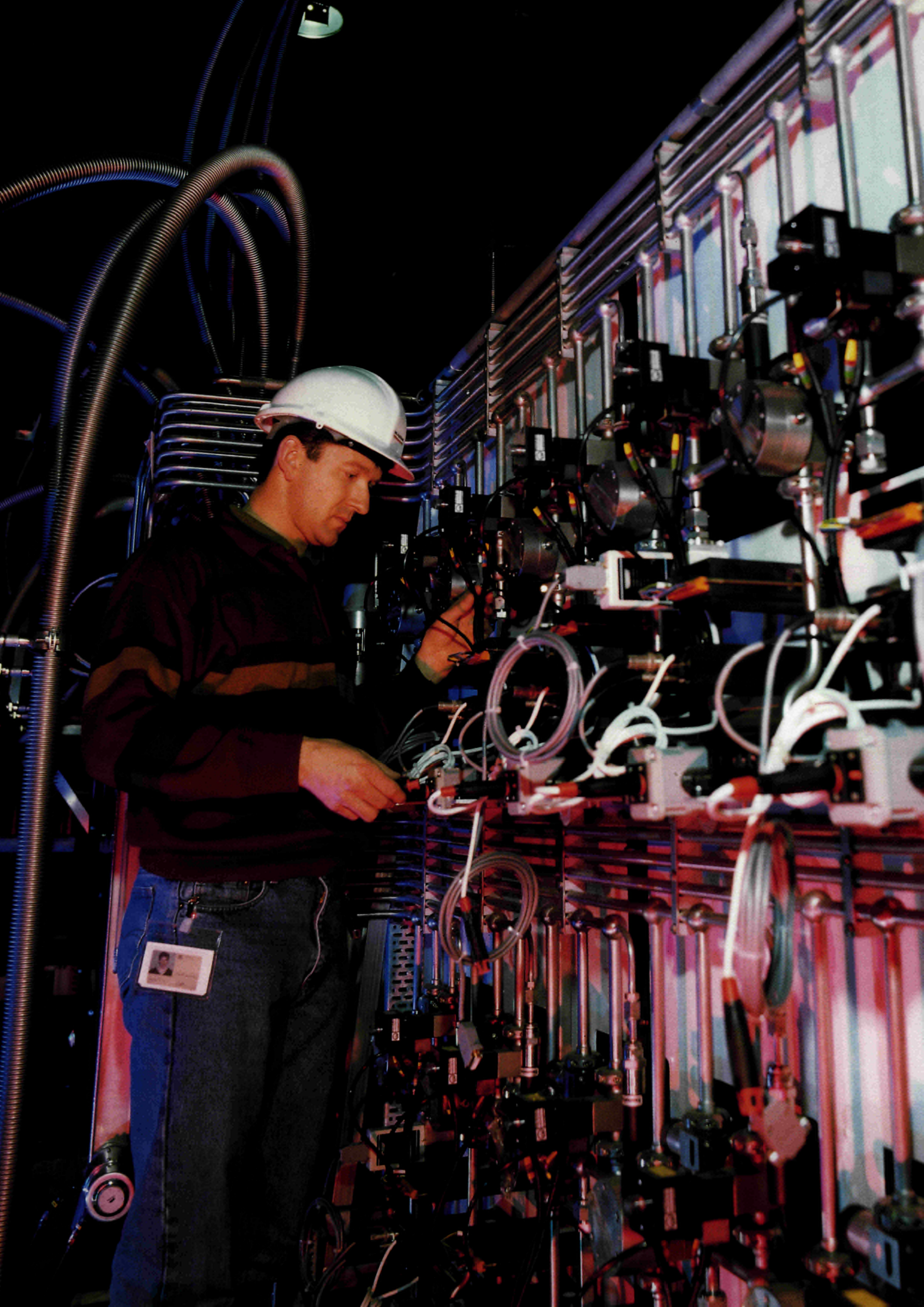
In addition, operation at 4T is practicable without changing the present levels of allowable stress and force. However, further studies are underway. A high-resolution model is being prepared in order to analyse in more detail the stress distribution in the most critical areas of the toroidal field coils.

Enhancement of Neutral Beam Heating System

An investigation into possible enhancements to the neutral beam system has been started, which would raise the available heating power from that presently available (21MW with deuterium beams in both Injectors or 25MW with deuterium beams in the Octant No.4 Injector and tritium beams in the Octant No.8 Injector). For reasons of economy and to avoid major modifications to the Injectors, the most viable option was to upgrade the high voltage (140kV) PINIs at Octant No.8 from 30A to 60A operation by upgrading the power supplies and regapping the PINI accelerating structures.

Some tests have been undertaken on the feasibility of this approach. A system in which the Octant No.8 Injector was upgraded to 140kV/60A deuterium operation, when combined with the present Octant No.4 system would inject into the plasma: ~28.5MW when both injectors were in deuterium); ~32MW when Octant No.8 was in tritium and Octant No.4 in deuterium; and ~38MW when both injectors were in tritium.

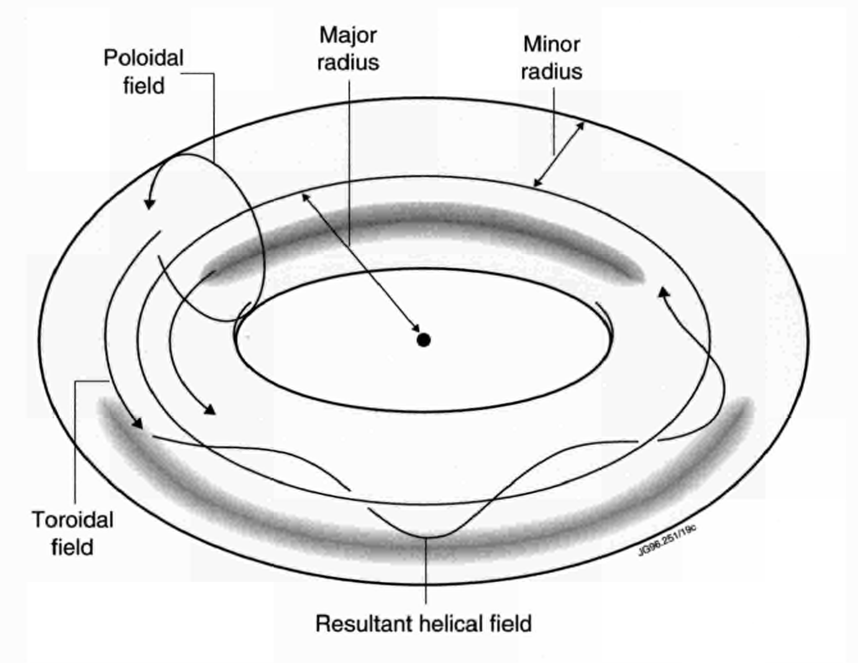
Studies have been performed on the general input parameters from this system (eg: power deposition profiles; particle fuelling and momentum). In addition, predictions of plasma performance have also been made in the hot-ion H-mode using code calculations. This shows that the upgraded injectors would assist in retaining the central parameters of JET plasmas.



Scientific Advances during 1995

Introduction

The overall objective of the Project is to study plasma in conditions and with dimensions close to those needed in a fusion reactor. The central values of temperature, density and energy confinement time required for a reactor operating with deuterium and tritium are such that the fusion triple product, ($n_i\tau_E T_i$), must exceed the value of $5x10^{21}m^{-3}$skeV. Typical individual values for these parameters, in a reactor, are central ion density (n_i) of $2.5x10^{20}m^{-3}$, central ion temperature (T_i) of 10-20keV and a global energy confinement time (τ_E) of 1-2 seconds. With ohmic heating alone in JET, temperatures of 3keV and 4keV for the ions and electrons, respectively, densities of $4x10^{19}m^{-3}$ and energy confinement times of 1s are the limits that have been achieved. These parameters were obtained simultaneously during one discharge and resulted in a fusion product of $1.2x10^{20}m^{-3}$keVs. However, higher peak values of electron and ion temperature have



Magnetic Field Configuration

The toroidal and poloidal magnetic fields combine to form helical magnetic field lines, which define a set of magnetic surfaces. As the strengths of the magnetic fields vary across the minor cross-section of the machine, the pitch of the field lines vary and usually decrease with increasing minor radius. The number of turns a field line must traverse around the major direction of the torus, before closing on itself, is denoted by the safety factor, q. Of special importance are the positions where q is numerically equal to the ratio of small integers, as these regions are specially sensitive to perturbations. Instabilities arising from these perturbations can result in enhanced energy losses.

In addition, the maximum plasma pressure, which can be maintained by a given magnetic field is dependent on the plasma current value. The effectiveness with which the magnetic field confines the plasma is given by β, which is defined as the ratio of plasma pressure to the magnetic field pressure.

JET can be operated with elongated plasma cross-section rather than circular. This enables larger plasma currents to be carried for given values of magnetic field, major radius and minor radius, as well as producing larger values of β.

been reached using additional radio frequency heating and neutral beam heating and combinations of these methods. Even so, these substantial increases in temperature were associated with a reduction in energy confinement time as the heating power was increased. Thus, gains in plasma temperature have been partly offset by degradation in energy confinement time. The fusion product values obtained have not shown the full gains anticipated over conditions with ohmic heating only. However, a substantial increase in the values of the fusion product has been achieved, by operating in the so-called magnetic limiter (X-point) configuration. During the 1991/92 campaign, values of 9-10x$10^{20}m^{-3}$skeV were obtained using up to 16MW of additional heating.

Higher values of temperature, density and energy confinement have been obtained individually in separate experiments, but not simultaneously during one discharge. These include peak ion temperature up to 30keV, energy confinement times up to 1.8s and central densities up to 4x$10^{20}m^{-3}$.

Breakeven

This condition is reached when the power produced from fusion reactions is equal to that necessary for maintaining the required temperature and density in the plasma volume.

Experimental Programme

The strategy of JET is to optimise the fusion product by building up a high density and high temperature plasma in the centre of the discharge, while still maintaining an acceptable high confinement time. These conditions should ensure that sufficient alpha-particles are produced with deuterium-tritium operation so that their confinement and subsequent heating of the plasma can be studied.

The original scientific programme of JET was divided into four phases. The Ohmic Heating, Phase 1, was completed in September 1984 and Phase II - Additional Heating Studies - started early in 1985. By December 1986, the first part, Phase IIA, had been completed. The machine then entered a planned shutdown for extensive modifications and enhancements before the second part of the Additional Heating Studies, Phase IIB, which started in June 1987. The objective of this phase, from mid-1987 until late-1988, was to explore the most promising regimes for energy confinement and high fusion yield and to optimise conditions with full additional heating in the plasma. Experiments were carried out with plasma currents up to 7MA in the material limiter mode and up to 5MA in the magnetic limiter (X-point) mode and with increased radio frequency heating power up to 18MW and neutral beam heating power exceeding 20MW at 80kV. The ultimate objective was to achieve full performance with all systems operating simultaneously. Phase III of the programme on Full Power Optimisation Studies started in 1989 and was completed in early 1992. In 1991, JET's lifetime was prolonged by four years until the end of 1996. The extension was to allow JET to implement the new Pumped Divertor Phase of operation, the objective of which is to establish effective control of plasma impurities in operating conditions close to those of the Next Step. This programme will be pursued before the final phase of full D-T operations in JET.

Ignition

Ignition of a mixture of deuterium and tritium would be reached if the power produced by the alpha-particles (20% of the total thermonuclear power) released from the fusion reactions is sufficient to maintain the temperature of the plasma.

Operating Modes

Under normal operating conditions the magnetic surfaces are nested inside each other. The edge of the plasma is defined by the magnetic surface which intersects the limiter. The only magnetic field lines intersecting the walls of the chamber are those beyond the region bounded by the limiters as shown in the diagram on the left. This is termed material limiter operation.

The magnetic field configuration on JET can be modified so that one of the closed surfaces near the limiter is opened up so that it intersects with the vacuum vessel wall. In this configuration, the magnetic separatrix is moved to within the vacuum chamber.

This so-called X-point configuration (or magnetic limiter) can be operated with the two nulls of the separatrix within the vacuum chamber (double null) or with only one inside (single null) as shown in the diagram on the right.

During X-point operation with additional heating, the plasma can behave, with respect to confinement, as though its edge were bounded by limiters. This is called the Low (L)-mode. Under certain circumstances, the plasma can be induced to behave in a different manner which produces better plasma confinement. This is termed the High (H)-mode of operation.

The 1991/92 experimental period concentrated on: optimisation of plasma performance; advancing understanding in certain key areas of tokamak physics, (such as: physics of the H-mode; energy transport and confinement; and transport of particles and impurities); and establishing the basis for pumped divertor and Next Step physics (including a Preliminary Tritium Experiment).

The machine entered a major shutdown in early 1992, which lasted throughout 1992 and 1993, to prepare the machine for the divertor phase of operation. During this long shutdown, the interior of the vacuum vessel was essentially replaced. In the 1994/95 experimental campaign, JET began its planned programme of operations to demonstrate effective methods of power exhaust and impurity control in conditions close to those envisaged for ITER.

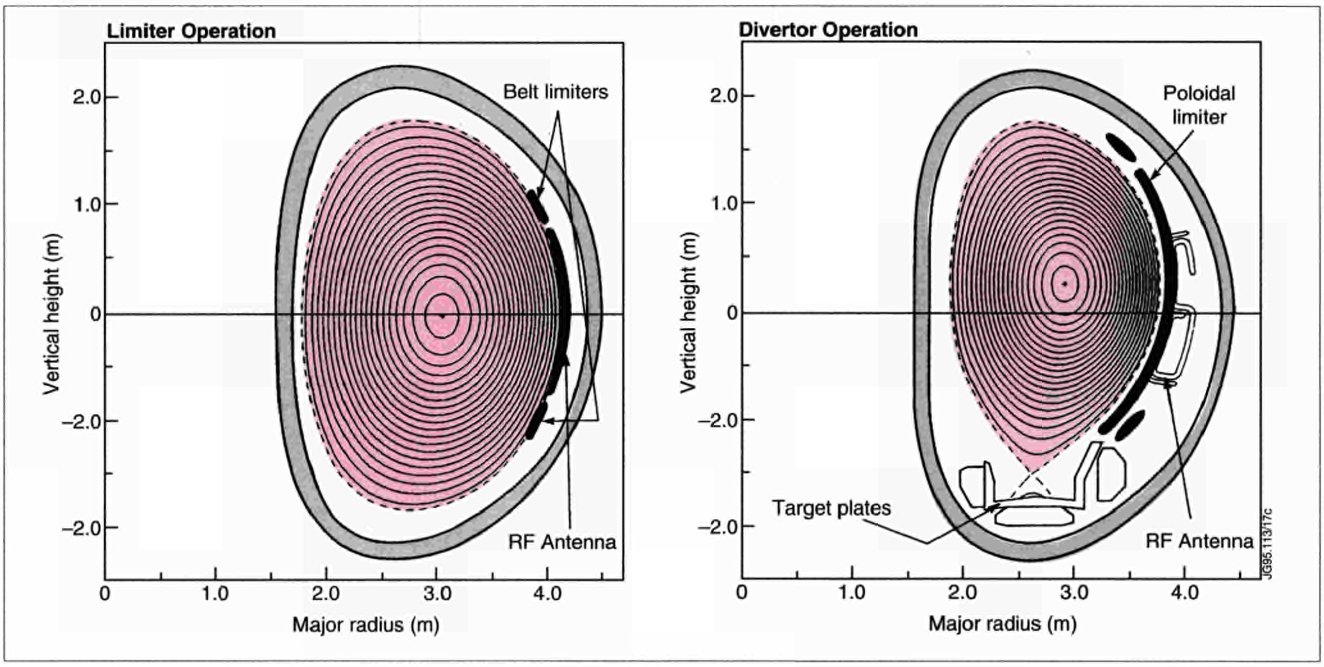
Main Scientific Results

The main objectives of the 1994/95 campaign period were: to assess divertor performance on the vertical and horizontal targets of the Mark I divertor; to demonstrate the high performance capability of the JET pumped divertor; and to study those physics areas in which JET could make important contributions to ITER and DEMO. The main scientific results obtained during the 1995 are set out below.

Steady State ELMy H-modes

Power Handling

The study of divertor performance under steady-state conditions at high power has been a central goal of the programme. Particular care was taken in the design and installation of the power handling surfaces of the Mark I divertor target to optimise



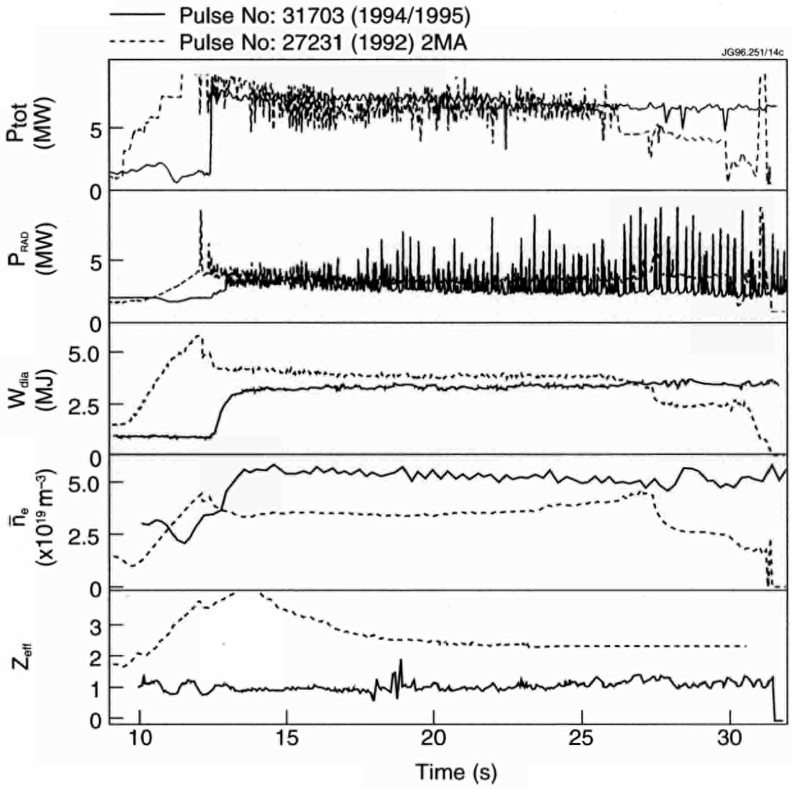


Fig.26: Comparison of steady-state ELMy H-modes in the old JET configuration (Pulse No. 27231) and in the pumped divertor configuration (Pulse No. 31703).

power handling, in particular, by avoiding exposure of tile edges. The strike points could be swept over the target plates at 4Hz with an amplitude of ~10cm to increase the area of the target effectively "wetted" by the plasma. Sweeping of the strike points over the target plates spreads the power load and improved the power handling capability of tiles. The Mark I divertor showed excellent power handling capability, with no "carbon blooms" limiting the performance, as seen in the past. The performance of the target was investigated over a wide range of plasma conditions.

A particular feature of the plasma behaviour with the Mark I divertor has been the appearance of edge limiter modes (ELM) instabilities. From the power handling point of view, the appearance of these edge instabilities had two effects. Firstly, they deposit power on the surfaces other than the strike zones, and secondly, since they create a spike in the radiated power, the power conducted to the strike zones decreased immediately after the ELM event. In this sense, ELMs are extremely effective in alleviating the heat load on the strike zones, but the penalty is the uncontrolled deposition of power in zones which may have a poor power handling capability.

Since frequent ELMs broaden the power profile and reduce the peak temperature on the divertor target tiles, ELMy H-mode plasmas with steady-state conditions for many energy confinement times are considered a credible mode of operation for ITER. After a period free of ELM instabilities, plasmas with the pumped divertor develop regular ELMing behaviour, with a high energy confinement time (H-modes) which is typically a factor H≈1.8 higher than in the normal low confinement (L-mode) plasmas.

Divertor

JET was originally configured as a "limiter Tokamak" where the edge of the plasma (the "last closed flux surface" - LCFS) was defined by contact with a material boundary called a limiter, which absorbs the exhaust power of the plasma. Since the edge of the plasma is quite hot, material is eroded by sputtering and the sputtered impurities enter the plasma relatively easily. This enhances radiative losses and dilutes the plasma, which lowers the fusion reaction rate.

The JET vacuum vessel and magnetic field system have been modified to operate in a "divertor" mode. The field configuration includes an "X-point" so that the LCFS (in this case designated the separatrix) bounding the main plasma does not intersect the wall. The power crossing the separatrix is transmitted in a thin layer called the scrape-off layer (SOL) to the divertor at the bottom of the vessel and is absorbed by the divertor "target plates". Divertor operation reduces the impurity content of the main plasma through a combination of effects. The divertor plasma is generally much cooler than the main plasma edge, so that sputtering and erosion are reduced. Moreover, impurities which are produced at the target plate tend to be retained in the divertor area by friction with the plasma streaming towards the divertor plates. In addition to controlling impurity content, divertor operation tends to allow higher SOL temperatures, thus facilitating access to high confinement regimes.

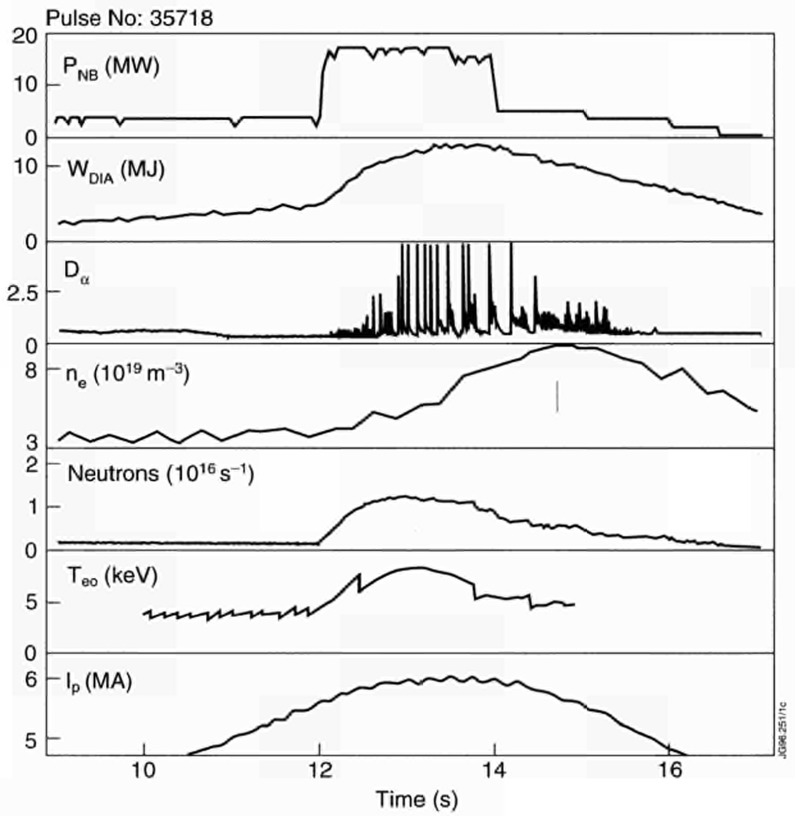


Fig.27: ELMy H-mode discharge at 6MA plasma current and with 18MW of neutral beam heating.

Long Pulse ELMy H-modes

The excellent power handling capabilities of the divertor target, together with the in-vessel cryopump (which allowed good density control) and the facility for sweeping the strike zone position, have been exploited to produce long pulse steady-state H-modes. The H-modes produced are characterised by frequent regular giant ELM behaviour, and have electron density, effective ion charge, radiated power loss and stored plasma energy remaining constant up to 20s (≈50 energy confinement times). Figure 26 shows a comparison of a steady state ELMy H-mode in the new divertor configuration compared with a similar status in the old configuration.

The latest 1994/95 results show higher confinement enhancement, reduced impurity content, smaller radiation emission and no evidence of saturation in pumping. Steady-state H-modes were established with durations of up of 20 seconds at 2MA plasma current and 10 seconds at 3MA, and these pulse lengths were limited only by technical constraints on the tokamak systems.

ELM

An ELM (Edge Localized Mode) is an edge instability which occurs in the high confinement (H-mode) regime. It affects a narrow region in the plasma edge and leads to a loss of particles and energy from the edge on a timescale ≤1 millisecond and therefore is a rapid, but transient, instability. However, ELM's can occur as repetitive instabilities which cause a reduction in the time-averaged energy and particle confinement time.

High Current 6MA ELMy H-modes

The full 6MA current capability of JET was demonstrated and H-modes were obtained with up to 18MW of neutral beam heating (Fig.27). The beneficial current dependence of scalings for energy confinement in H-modes was also demonstrated for currents up to 6MA. At 4.7MA plasma current, 28MW of neutral beam and ICRF heating power was coupled to ELMy H-modes, which exceeded 10MJ of energy in the plasma.

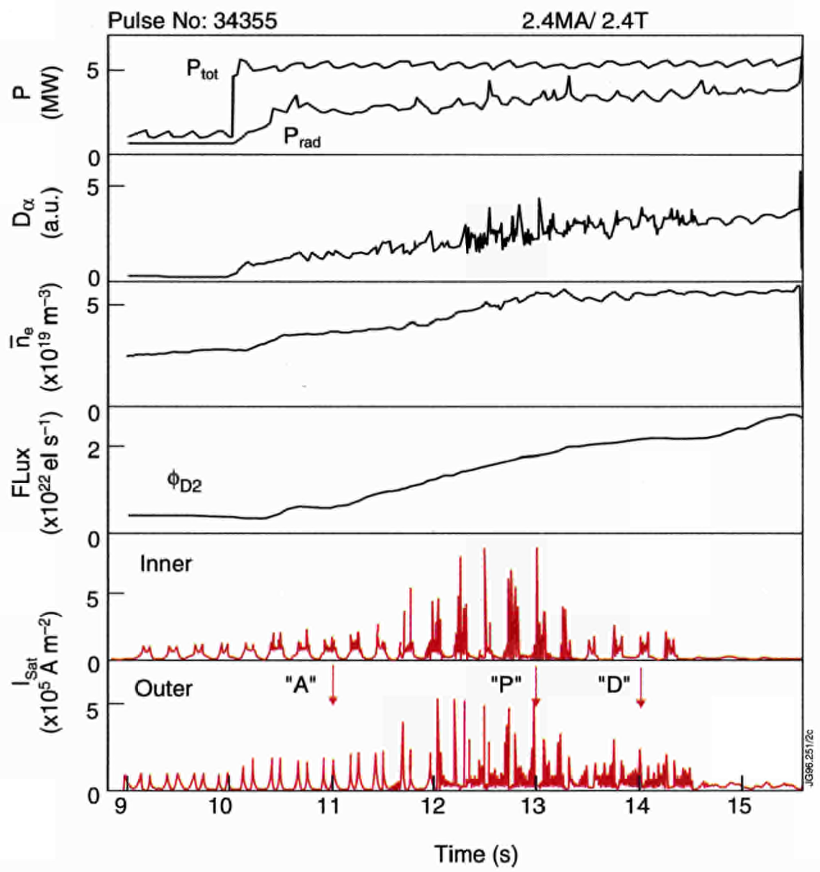


Fig.28: L-mode discharge where detachment of plasma from divertor target is obtained by deuterium puffing with intrinsic impurities only

Detached Divertor Plasmas with Radiative Power Exhaust

While poloidal divertors have been employed successfully in many tokamaks to reduce impurity contamination of the plasma core, an operating scenario which scales to reactor plasmas has not yet been demonstrated. The exhaust of particles, momentum, and power from a burning plasma is such that, the divertor target plates would not survive unless a significant fraction of the exhaust is redirected across magnetic field lines by volume loss processes. In addition, it has been shown that radiation alone cannot be used to solve the power loading problem in a so-called high recycling divertor where there is no loss of momentum along the scrape-off layer (SOL) field lines. A pressure drop of a factor of ten is consistent with a radiation fraction sufficient to satisfy constraints on ITER target loads (~5MWm^{-2}).

Detached divertor plasmas with radiative power exhaust can reduce the particle, momentum and energy fluxes to the divertor target plates, thereby easing power handling and erosion. The investigation of such divertor plasmas has been pursued in depth with the relatively open (Mark I) divertor during the 1994/95 campaign.

Sawteeth

Perturbations on the q=1 magnetic surface can result in the formation of large fluctuations in the central temperature and density. These fluctuations have been termed 'sawteeth'. They are also associated with the expulsion of energetic ions from the central region of the plasma. Understanding this process is important as the alpha-particles produced from deuterium-tritium fusion reactions might be lost before they can produce any effective heating of the plasma.

Detachment with Intrinsic Impurities in L-mode Plasmas

Figure 28 shows data from a detached L-mode discharge in which deuterium fuelling increased the plasma density to about 5 x $10^{19}$$m^{-3}$ and the radiated power to about 70% of the input power. As the density increased, the particle flow to the

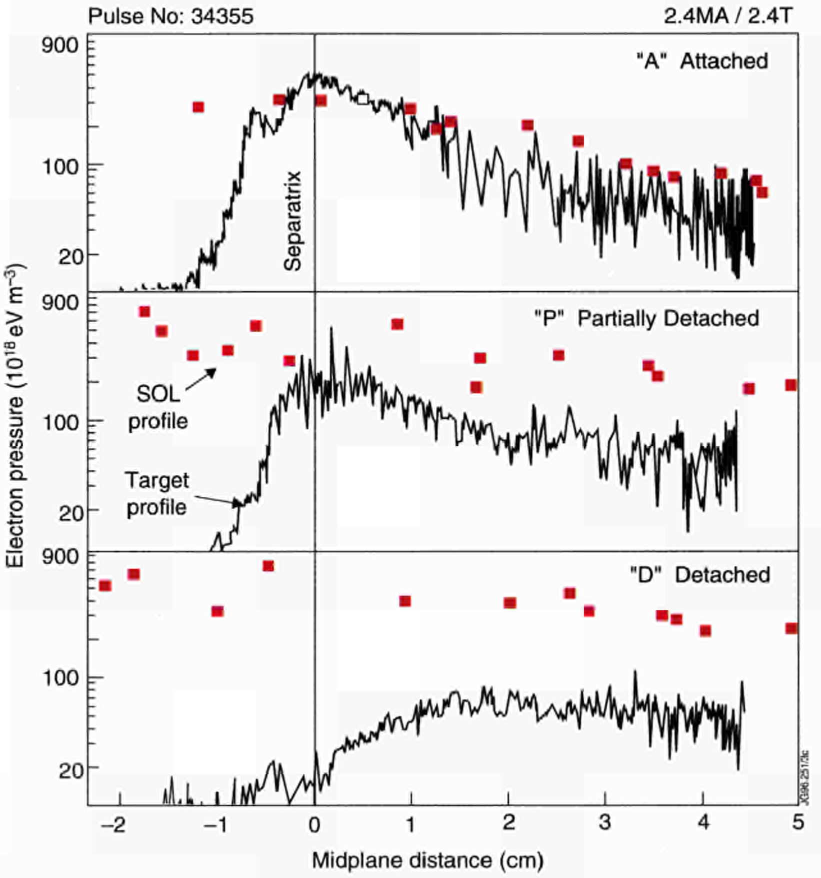


Fig.29: Evolution of parallel electron pressure gradient between the midplane and divertor target at the three times marked in previous figure.

inner and outer targets, (as measured by Langmuir probes), first increased (high recycling), then levelled off ("rollover"), and finally decreased (detachment). The temperature also decreased, so that both the heat flux and pressure at the target decreased. This is illustrated in Fig.29, which shows that the profile of electron pressure at the midplane of the scrape-off layer plasma and along the target mapped to the midplane distances, for the three times (A, P and D) indicated in Fig.28. A significant pressure drop (more than a factor of 10 near the separatrix) developed between midplane and target when detachment occurred.

> **Disruptions**
>
> *There is a maximum value of density which can be contained with a given plasma current. If this value is exceeded a disruption occurs when the plasma confinement is suddenly destroyed and the plasma current falls to zero in a short period of time. Under these conditions high mechanical and thermal stresses are produced on the machine structure. Disruptions are thought to be caused by instabilities mostly developing on the magnetic surface where q=2.*

Detachment with Extrinsic Seed Impurities in H-mode Plasmas

It was not possible to produce detached divertor plasmas with H-mode confinement in JET using deuterium fuelling alone. This had been predicted theoretically for both JET and ITER. At the powers required to maintain the H-mode, the density required to reduce the divertor temperature to the point where detachment could occur (below 5eV) exceeded the H-mode density limit, and a transition back to the L-mode occurred. H-mode detached plasmas could, however, be produced by introducing an extrinsic seed impurity into the divertor enhance radiation. Neon, nitrogen, and argon seeds were injected into JET, either pre-programmed or feedback-controlled on the divertor radiation or the ion saturation current at the targets.

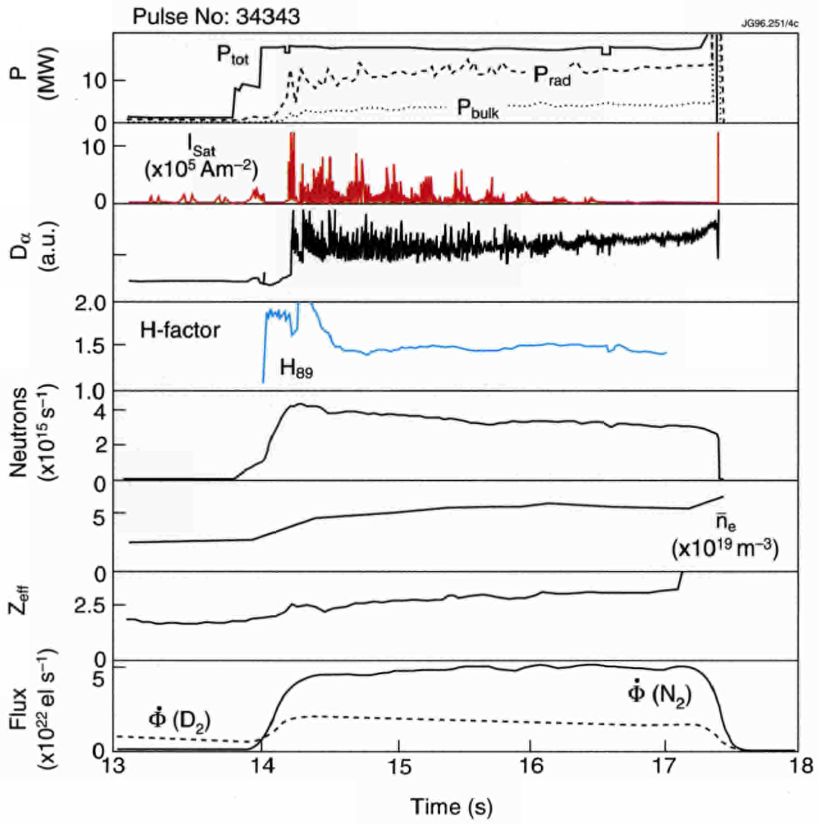


Fig.30: H-mode discharge in which a radiative detached divertor plasma is established by nitrogen seeding.

With nitrogen seeding, (Fig.30), the radiated power fraction rose to more than 85%, with two-thirds of this being in the divertor. The H-factor levelled at H≈1.5 typical of detached H-mode discharges in JET. The effective ion charge, Z_{eff}, rose to more than 2.5. Figure 31 shows tomographic reconstructions of the radiation pattern in the lower half of the vacuum vessel measured by a bolometer array. This shows that the radiated power fraction is low (≈20%), when the plasma was attached to the target plates and that the radiation is well distributed throughout most of the divertor volume below the X-point when the plasma was partially detached. In the latter case, 50% of the input power was radiated and some power still flowed to the targets. Z_{eff} was also somewhat lower than at later times. At later times, ≈80% of the input power was radiated and the radiating volume, which moved away from the targets, was located at the X-point. Some fraction of the radiation emanated from inside the separatrix. The motion of the radiating volume was smooth, but occurred over a fairly small range of total radiated power.

Significance for ITER

The results obtained are promising for ITER, since the achieved radiated power fractions of 80% to 85% were sufficient to prevent target damage, overheating and erosion. Detachment was accompanied by a transition from large ELMs to more benign "continuous" ELMs, which should not cause target damage. However, these results were achieved at the expense of the main plasma confinement and

Density Control

Increasing the density can be achieved by introducing additional gas into the vacuum vessel, by the injection of energetic neutral atoms (neutral beam heating) and by solid pellet injection.

Increasing the input power to the plasma through additional heating raises the electron density limit. However, problems can occur when this heating power is switched off, if the electron density is too high. To overcome this problem, the plasma is moved, prior to the switch-off point, so that it bears on the carbon tiles covering the inner wall. The tiles have been found, to provide a pumping mechanism for removing particles so that the density can be reduced below the critical limit.

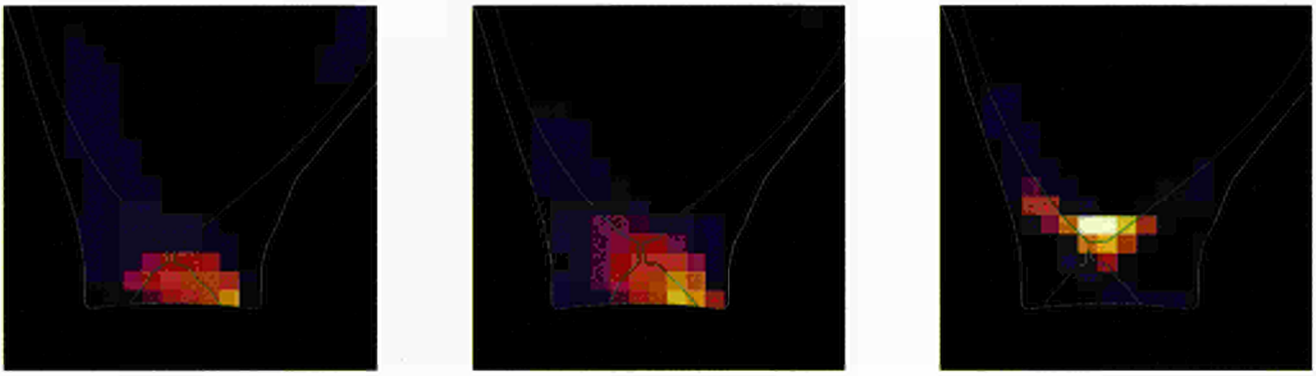


Fig.31: Topographic reconstruction of radiation pattern in lower half of the vessel when the divertor plasma is attached (at 14.2s), partially detached (at 14.8s) and fully detached (at 19.0s) at the target plates.

purity. The H-factor decreased as the radiated power fraction increased and, at the highest power levels, it was just sufficient for ignition in ITER (Fig.32).

With regard to main plasma purity, nitrogen radiated more in the divertor, but radiating 80% of the input power required $Z_{eff} \approx 3$ (Fig.33). With argon, radiating 80% of the input power required $Z_{eff} \approx 2$, but significant radiation then emanated from the main plasma. The observed seed impurity concentrations with nitrogen, neon or argon would not be acceptable in ITER, which requires $Z_{eff} < 1.6$ for ignition.

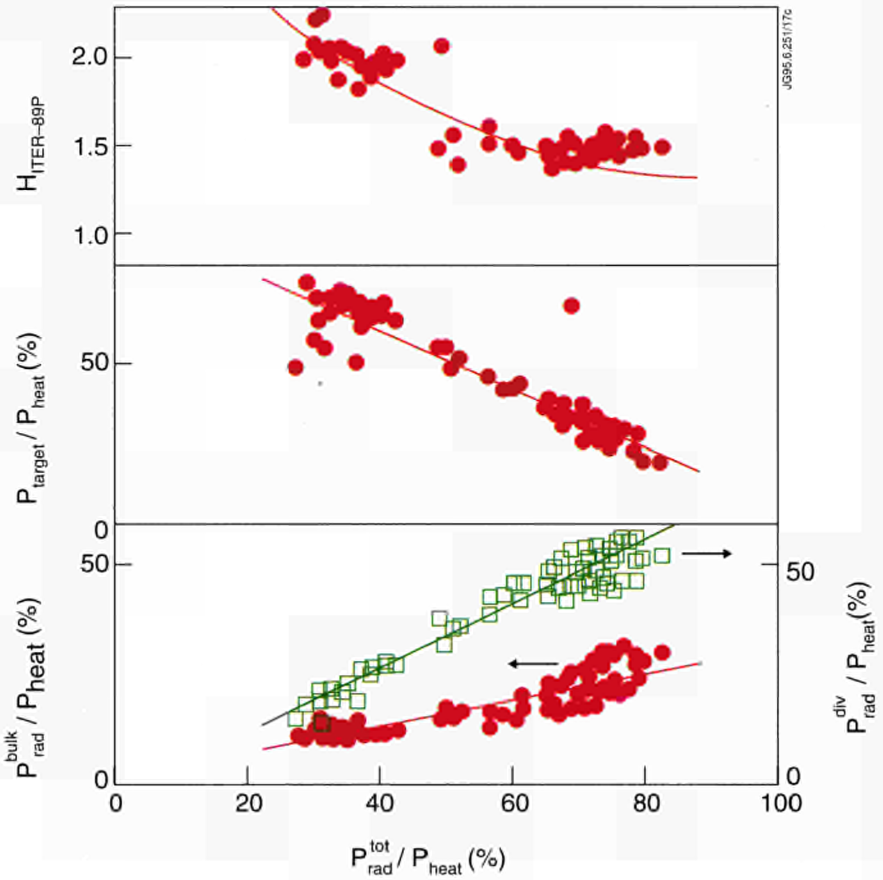


Fig.32: The power flux to the targets and the confinement enhancement decrease as the radiated power fraction increases.

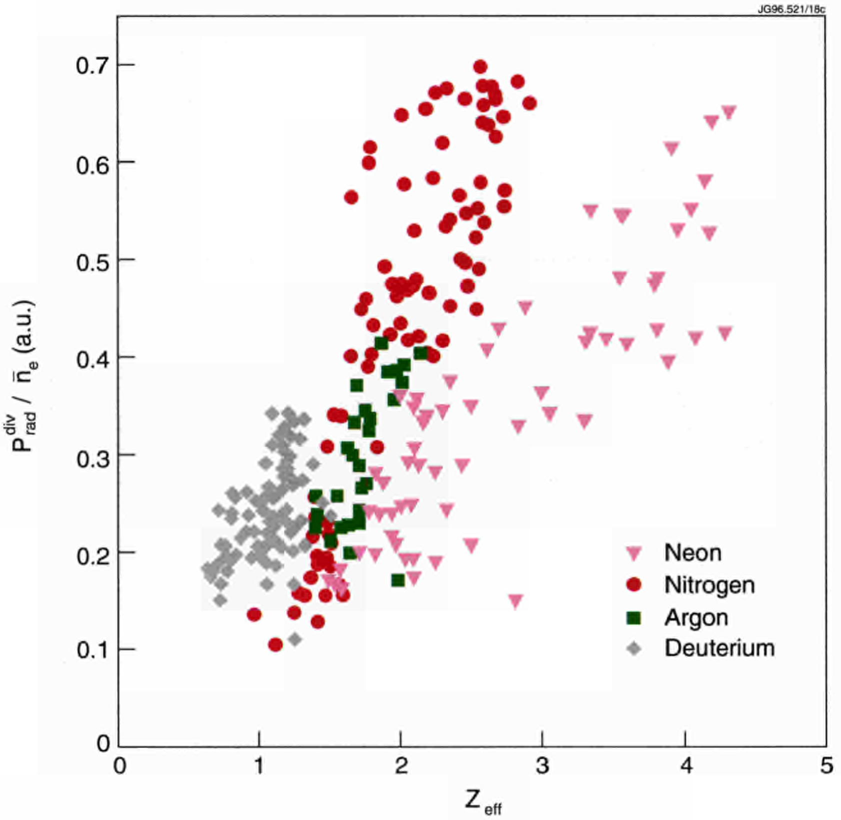


Fig.33: The radiated power loss per electron for increasing levels of contamination by various seed impurities.

High Performance in ELM-Free H-modes

Highest Fusion Performance in 1994/95

The major objective was to develop plasmas with high core plasma performance in the new configuration. This included the optimisation of parameters such as temperature, density, stored energy, and fusion yield, with a view to defining regimes of relevance to future D-T operation of diverted configurations with plasma currents up to 6MA with safety factors of, typically q~3 (and down to 2.2), in line with the mainstream ITER design. The improved current capability in diverted configurations opened up the domain of H-mode operation and raised the question of scaling of confinement with plasma current at such low safety factor.

ELM-free hot-ion H-mode plasmas achieved the highest fusion performance in JET. Performance improved as the duration of the ELM-free period was lengthened by reducing recycling (wall conditioning and/or use of the cryopump), expanding the magnetic configuration to fill the divertor, and increasing magnetic shear at the plasma edge. The highest fusion performance achieved in 1995 was comparable to the best achieved prior to installation of the pumped divertor, even though the plasma volume was 20% smaller. Figure 34 shows an ELM-free hot-ion H-mode at 3.8MA, plasma current which resulted in a neutron yield of 4.7 x $10^{16}s^{-1}$ (the best rate achieved in deuterium with JET). The fusion triple product of plasma density, temperature and energy confinement time, $nT\tau_E$ was >8 x $10^{20}m^{-3}$keVs, within 10% of the previous best. The equivalent fusion amplification factor in D-T plasmas, Q_{DT} was ≈1, transiently.

MARFE

A MARFE (Multifaceted Asymmetric Radiation From the Edge) is a toroidally symmetric band of cold, highly radiating plasma which normally forms at the plasma inner wall. It can occur when the plasma edge density is high and results from of an imbalance between the power flowing along magnetic field lines in the edge and the power lost locally due to radiation. A MARFE grows rapidly, on a timescale of ≈10-100 milliseconds, but it can persist for several seconds. In some cases, the MARFE leads to a disruption, but in others the main consequence is a reduction in the edge density.

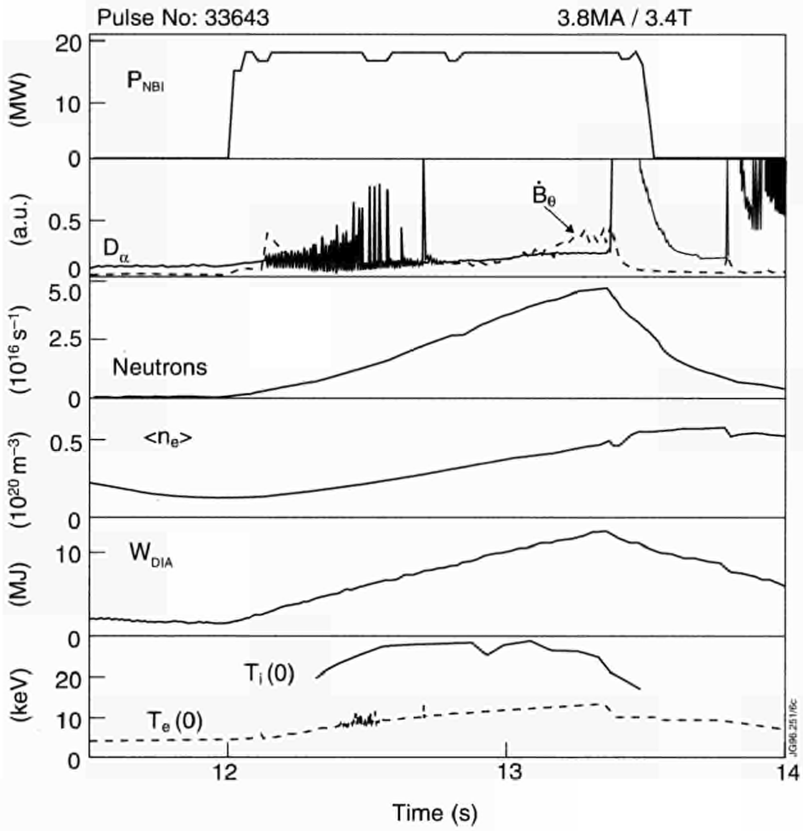


Fig.34: Pulse characteristics of the H-mode discharge that gave rise to the highest JET neutron rate in deuterium.

Plasma Beta

The economic efficiency of a tokamak reactor is determined, partly, by the maximum plasma pressure which can be contained by the magnetic fields in the device. In particular, the important parameter is the plasma beta β_T, defined as the ratio of plasma pressure to the pressure of the confining magnetic field (β_T is proportional to nT/B_T^2, where n is the plasma density, T the plasma temperature and B_T the toroidal magnetic field). This limit expected theoretically, is the so-called Troyon limit $\beta_T(\%)=2.8I_p(MA)/B_T(T)a(m)$, where I_p is the plasma current and a is the minor radius.

Limits to High Performance

In general, three classes of magnetohydrodynamic (MHD) phenomena were involved in setting the limit to the high performance: sawteeth and other internal MHD instabilities occurred in the plasma centre; low frequency modes occurred in the outer 20% of the plasma radius; and "giant" ELMs occurred in the very edge of the plasma. In the discharge with the highest performance (Fig.34), the high performance phase was terminated by a "giant" ELM, simultaneous with a sawtooth, and preceded for ≈200ms by high frequency MHD activity from the plasma within the radius at which the safety factor, q, was unity. This MHD activity was observed on the magnetic pick-up coils and was seen to affect the central ion temperature and the neutron rate. Other discharges were limited by modes in the outer 20% of the plasma radius (as shown in Fig.35). Stability analyses suggested that the edge current density could be sufficient to destabilise these modes. Furthermore, MHD measurement suggested that the terminating events included a low frequency character. Concomitant with the increase in low frequency edge activity, the loss power, the temperatures of the inner and outer divertor targets and the level of recycling as indicated by deuterium excitation measurements (D_α signal) all increased, the edge temperature fell and the total plasma stored plasma energy and neutron rate exhibited "rollover". First experiments with lower hybrid current drive showed that sawteeth could be controlled and the effect of the "outer" modes could be softened, so that the duration of the high performance phase was extended to the end of the heating pulse.

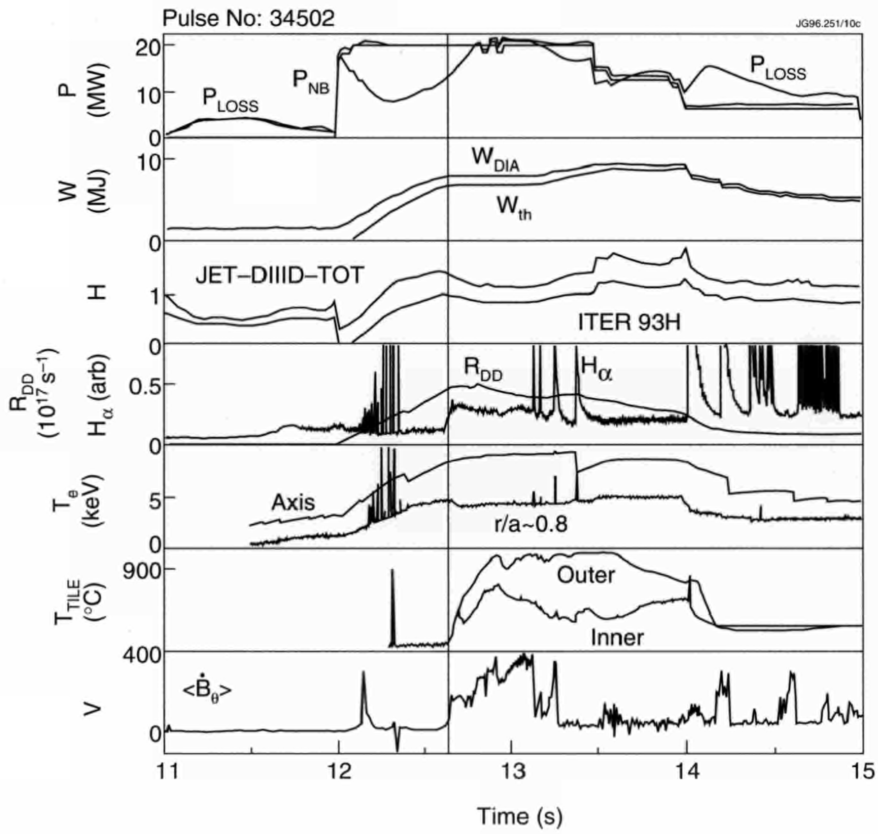


Fig.35: Pulse characteristics showing the limitation in performance in hot-ion H-modes by an MHD mode in the outer 20% of the plasma radius.

High Performance Quasi-Steady State Operation

It was possible to delay the termination of the high performance phase by reducing the neutral beam heating power to maintain MHD stability. In this way, the neutron rate and the stored plasma energy remained high and steady for up to 1s. Such a power step-down experiment is shown in Fig.36, where the equivalent Q_{DT} remained above 0.7 for almost 1s. The density continued to rise after the power step-down, albeit at a reduced rate, due to the retention of the low current 140kV neutral beams. The density increase facilitated the convergence of the electron and ion temperatures, but led to lower average rates.

ITER Specific Experiment

Multi-Machine Database Collaboration

JET is making a significant contribution to the ITER multi-machine databases. The ITER Confinement Database and Modelling Expert Group is now responsible for the ITER L-mode Database, the ITER H-mode Database, the ITER H-mode Threshold Database and the ITER Profile Database. The official Expert Group (three members from each of the three ITER Parties) acts as a Steering Committee for the activities, whereas the actual Working Group is much larger. All participating tokamak groups, (i.e. ASDEX, ASDEX Upgrade, C-MOD, COMPASS-D, DIII, DIII-D, FTU, JET,

Impurities

Impurities released from interactions between the plasma and material surfaces can have major effects on plasma behaviour by causing:

(a) increased radiation losses;

(b) dilution of the number of ions available in the plasma between which fusion reactions can occur.

*A measure of the overall impurity level is given by Z_{eff} which is defined as the **average** charge carried by the nuclei in the plasma. A pure hydrogen plasma would have Z_{eff} =1 and any impurities in the plasma would cause this value to be increased. In JET, Z_{eff} is generally in the range from 1.2-3.*

Major energy losses can result from two radiation processes:

- *Bremsstrahlung Radiation - radiation is emitted when electrons are decelerated in the electric field of an ion. The amount of radiation emitted increases with Z_{eff}. Bremsstrahlung radiation imposes a fundamental limit to the minimum plasma temperature that must be attained in a fusion reactor;*
- *Line Radiation - heavy impurities will not be fully ionised even in the centre of the plasma and energy can therefore be lost through line radiation.*

Considerable effort is made to keep the level of impurities in the JET plasma to a minimum. The vacuum vessel is baked at 300°C to remove gas particles trapped on the vessel walls which might be released by plasma bombardment.

Interactions between the plasma and vacuum vessel walls would result in the release of heavy metal impurities. To reduce this possibility, the edge of the plasma is defined by upper and lower belt limiters. These are cooled structures circling the outboard torus wall with carbon or beryllium tiles attached. Carbon and beryllium have a relatively low electric charge on the nucleus.

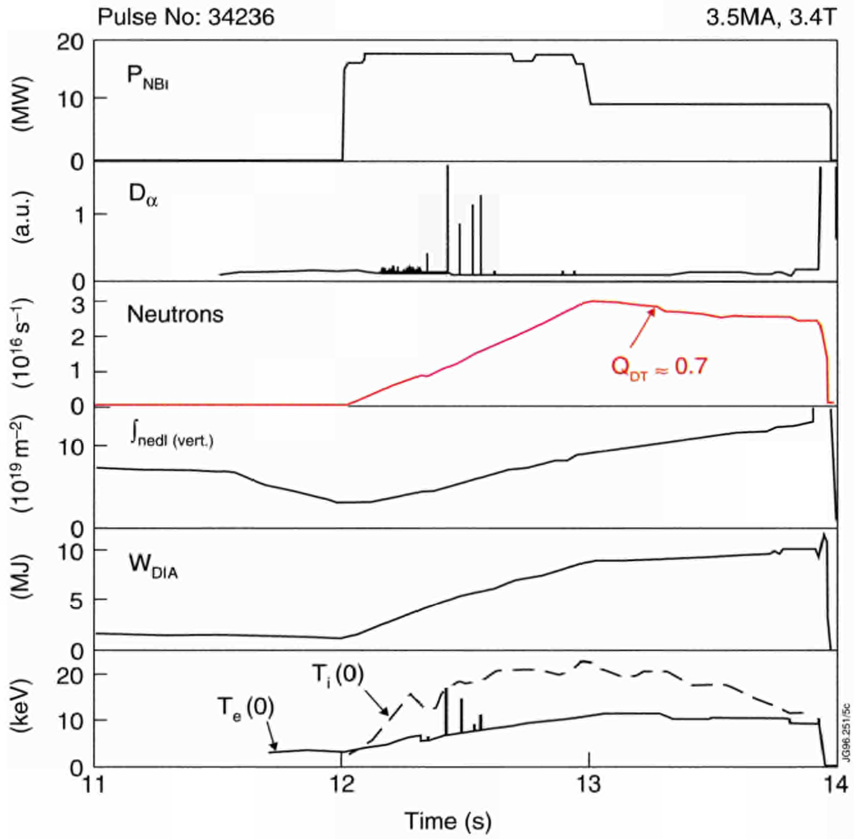


Fig.36: Pulse characteristics of quasi-steady state power "step-down" discharge

Energy Confinement

Energy confinement in tokamaks when the plasma is bounded by a material limiter generally degrades as the input power to the plasma increases. The result is that the energy confinement time, τ_E falls approximately as the square root of the input power. This regime is said to exhibit L(low)-mode confinement. In plasmas with a magnetic limiter (that is with an internal magnetic separatrix or X-point), a transition can occur above a certain threshold input power to a regime in which the energy confinement time is increased by a factor of two or more greater than in the L-mode situation. This has been called H(high)-mode confinement. However, a similar degradation with input power is observed.

In addition to the improved energy confinement time, enhanced particle confinement is observed and the temperature and density close to the separatrix can increase substantially, resulting in the formation of plasma profiles with an edge 'pedestal'. The precise conditions for the transition into the H-mode vary with plasma parameters. For example, the threshold power for the transition increases at least linearly with the toroidal magnetic field. In recent years, the H-mode transition has also been observed in plasmas with a material limiter, although the power threshold is usually significantly higher than in magnetic limiter (X-point) plasmas.

JFT-2M, JT-60, PBX-M, PDX, RTP, START, TORE SUPRA, TEXTOR, TFTR and T-10) are represented in the Working Group.

The H-mode threshold database has been extended and improved by the addition of new data. The database now consists of data from ALCATOR C-MOD, ASDEX, ASDEX Upgrade, COMPASS-D, DIII-D, JET, JFT-2M and PBX-M. It has been suggested that the threshold power increases linearly with the product of density (n) and toroidal field (B) for each device and that the plasma surface area, S, could be used to unify the multi-machine database. A standard dataset has been identified which represents the lowest achieved threshold in each tokamak. In one approach, the lower boundary of the data in the standard dataset has been regarded as the threshold power scaling. The following candidates fit this boundary reasonably well:

i) $P_{thr} = 0.3 n_{20} B R^{2.5}$

ii) $P_{thr} = 0.03 n_{20} B R^{0.6} S$

iii) $P_{thr} = 0.016 n_{20}^{0.75} B S$

iv) $P_{thr} = 0.025 n_{20} B S$

Figure 37(a-d) show the comparison between the data and the above expressions. The first three expression are dimensionally correct. The predicted H-mode power threshold for ITER ranges from 60MW (third expression) to 150MW (first expression) at a density of 0.5 x 10^{20}m^{-3}.

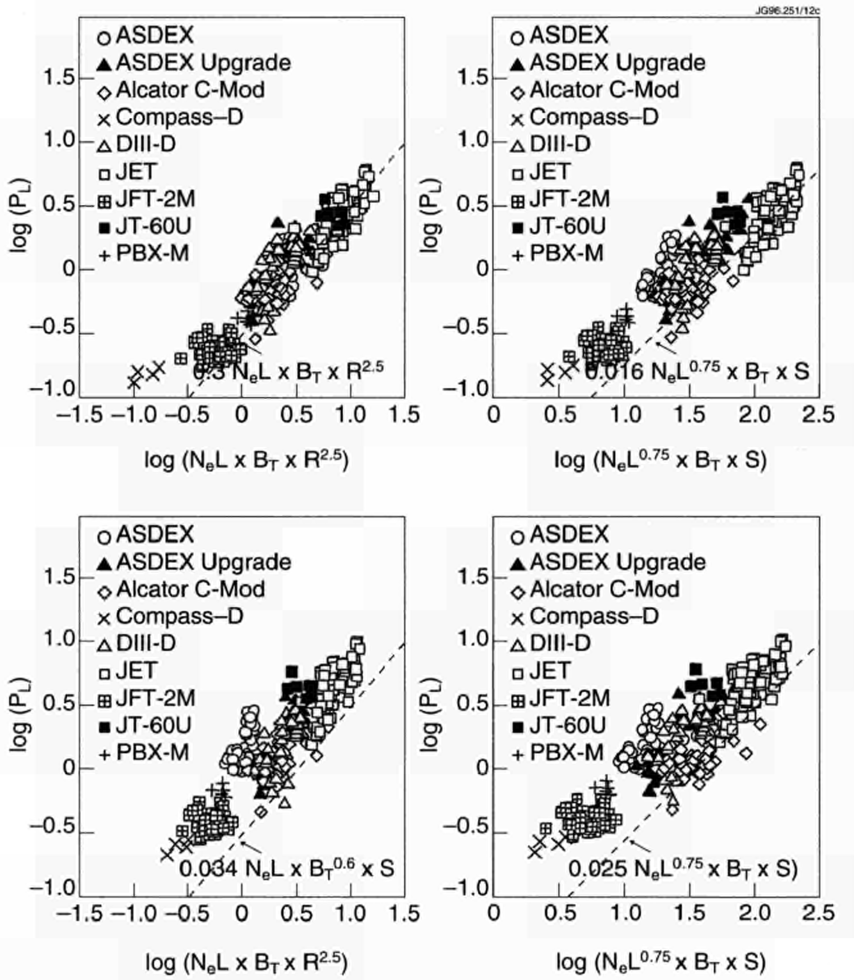


Fig.37: Results from the threshold combined database in which the existence diagrams have been derived with expressions from considerations made with dimensionless variables: $P_{th} \sim n^a B^b S^c$.

Scaling Experiments in ELMy H-modes

The plasma cross-section envisaged for ITER shows a strong resemblance to the geometries that can be produced in JET and DIII-D (General Atomics, USA). Therefore, it is possible to carry out experiments on both JET and DIII-D in which dimensionless parameters describing the plasma have the same values as intended for ITER. There may be 15-20 dimensionless parameters, but only a few are found to have an impact on confinement. The variables are:

a) Normalised collisionality, υ^*;

b) Plasma beta, β;

c) Shape parameters like elongation, and triangularity;

d) Safety factor, q, and aspect ratio;

e) Normalised Larmor radius ρ^*.

The only difference between ITER, JET and DIII-D lies in ρ^*. (Here $\rho^* = \rho_i/L$, where L is the machine scale-length and ρ_i is the Larmor radius, which is the radius of the plasma ions motion gyrating in the magnetic field, B.) Therefore, the variation of confinement scaling with ρ^* is crucially important to predictions of ITER's performance. Such predictions must include (i) L-mode confinement; (ii) the threshold power and density values needed to obtain an H-mode; and, (iii) H-mode confinement scaling.

Two particular scaling models used to predict confinement and H-modes and power threshold behaviour are the so-called Bohm and gyro-Bohm models. For confinement time τ_E variations, the models would predict $\tau_E \propto B^{1/3}$ for Bohm and $\tau_E \propto B$ for gyro-Bohm behaviour. For experiments in JET and DIII-D, not close to the H-mode threshold, the confinement time was found

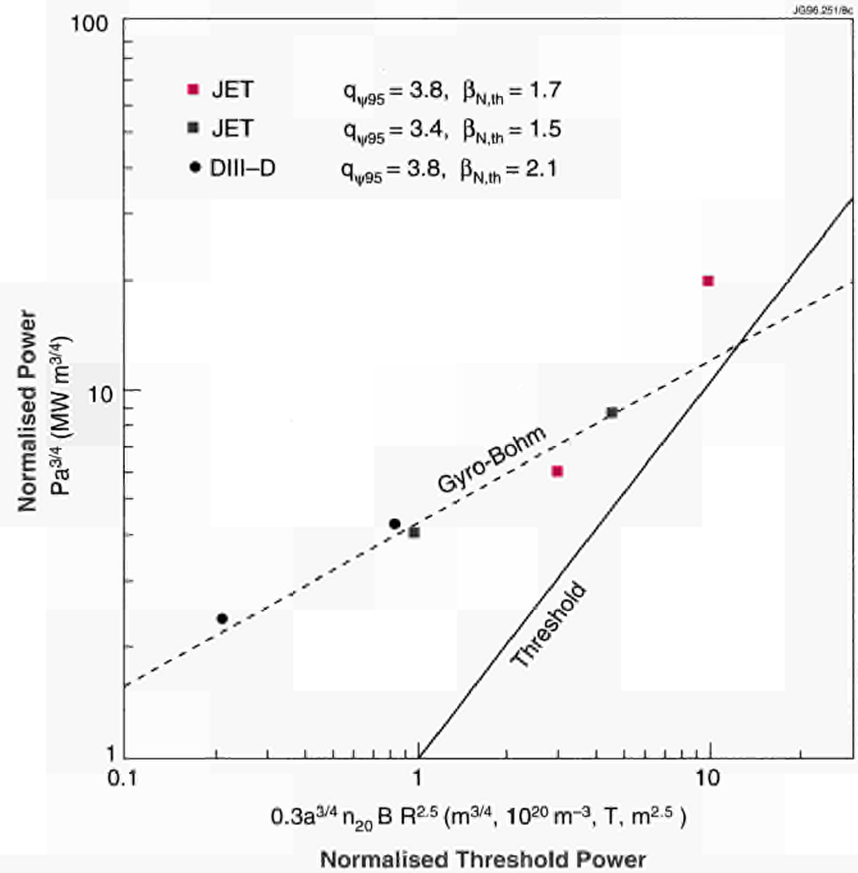


Fig.38: ρ* scaling data of energy confinement in relation to H-mode threshold power. This can be interpreted in terms of gyro-Bohm scaling which is lost near the H-mode threshold.

to be directly proportional to the tokamak field B, suggesting a gyro-Bohm model was relevant. However, for experiments in which the power levels were closer to the H-mode threshold, a variation nearer to Bohm behaviour was indicated.

The powers needed to achieve the correct dimensionless pararameters in the ρ* scaling experiments are plotted in Fig.38 versus a fit to the H-mode threshold power data from several tokamaks operated with the same geometry. Figure 38 shows clearly that discharges well above the H-mode threshold exhibited a clear gyro-Bohm dependence but, close to the threshold, this scaling was lost and became Bohm-like, and followed the threshold.

When Fig.38 is expanded to include the operating point foreseen for ITER, it was clear that, with 100MW of heating power, ITER would operate close to both the β limit and the H-mode threshold (Fig.39). It would then be necessary to enter the H-mode at low density ($\approx 3 \times 10^{19} m^{-3}$) and to rely on the H-to-L transition in a deuterium-tritium mixture being lower than the L-to-H transition in deuterium in order to sustain ignition at higher density. The multi-machine scaling studies for ITER need, therefore, to provide more accurate data on the H-mode threshold and on transport scaling close to the threshold and at high β. Confidence in the accuracy of the scalings would increase if JET operated at lower ρ* and higher β.

Toroidicity-Induced Alfven Eigenmodes

Toroidicity-induced Alfven Eigenmodes (TAEs) can be driven unstable by fast particles originating from neutral beam injection, ICRF heating or fusion reactions. Destabilisation of such modes in reactors is a subject of concern as they may lead to anomalouly rapid losses of energetic alpha-particles, reducing alpha-particle heating efficiency and potentially damaging the first wall. These modes are characterised by high frequency (typically 100-200kHz in JET), which depends on the Alfven speed.

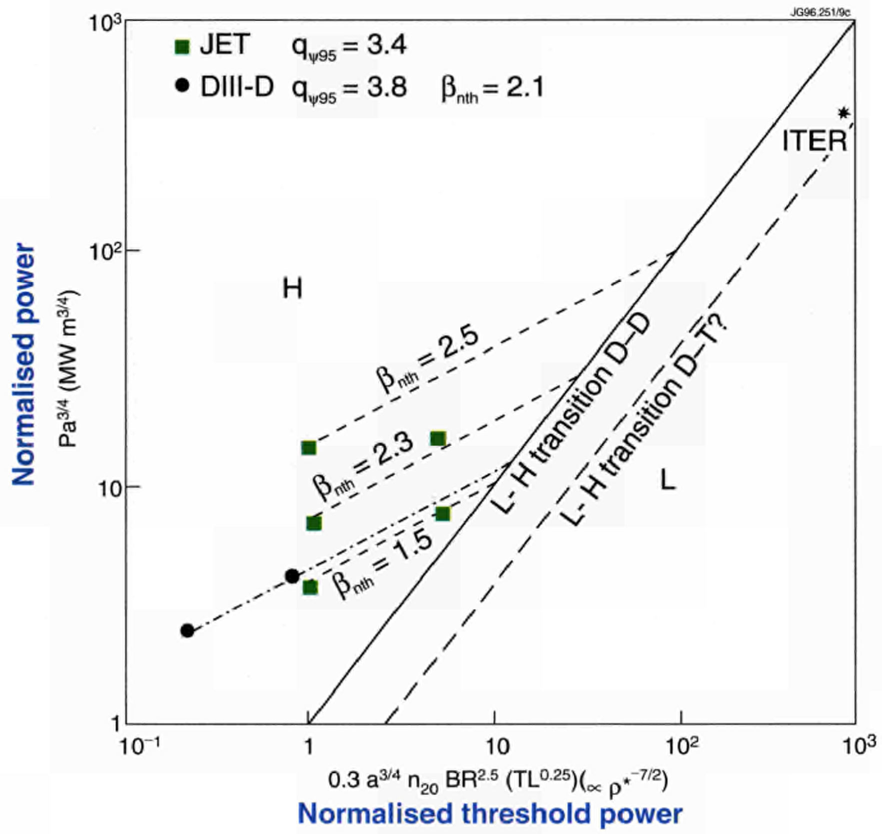


Fig.39: ρ^* **scaling data of energy confinement at various** β_N **show that ITER would operate close to the H-mode threshold power and at high** β_N**.**

Experiments have been carried out, in which Alfven eigenmodes have been externally excited using the saddle coils driven by a high frequency amplifier. The Alfven nature of the observed resonances has been verified by scanning the toroidal magnetic field and comparing the measured resonance frequency with that calculated. A strong multi-peak structure was seen with very weak damping. These are the first reported observations of kinetic Alfven eigenmodes. The TAE resonance was also excited when radio frequency waves launched into the plasma from two ICRF antennae differed in frequency (Δf) by the TAE frequency, (f_{TAE}), which generated a "beat" wave. The TAE frequency was matched to Δf by scanning the toroidal field.

Toroidal Field Ripple Experiments

In 1991, JET carried out an experiment in which only one of two sets of toroidal field coils was energised. This increased the toroidal field (TF) ripple at the plasma edge from about 1% to 10%. The effects of high toroidal ripple on plasma behaviour in general, and on fast particle losses, in particular, were studied. Results from these experiments were sufficiently encouraging to prepare for a second ripple experiment. In this case, the two sets of coils were operated at different currents. This modification made possible the exploration of the intermediate ripple regimes.

The toroidal magnetic field ripple was varied in JET in the ITER-relevant range of 0.1% to 2% ripple at the plasma edge. Low levels of ripple ($\approx$1% at edge) were found to improve H-mode confinement, probably due to the effect on ELM frequency, while high levels of ripple (>1.5% at edge) degraded H-mode confinement. Ripple losses induced losses of thermal and high energy particles (125keV neutral beam ions and 1MEV tritons) were very small (a few per cent, or less) and were consistent with calculations. However, the observed losses of intermediate energy particles (thermal to 10s of keV) were higher than predicted. In general, these experiments indicated that the toroidal field ripple in ITER should have no significant effect on energetic particle confinement.

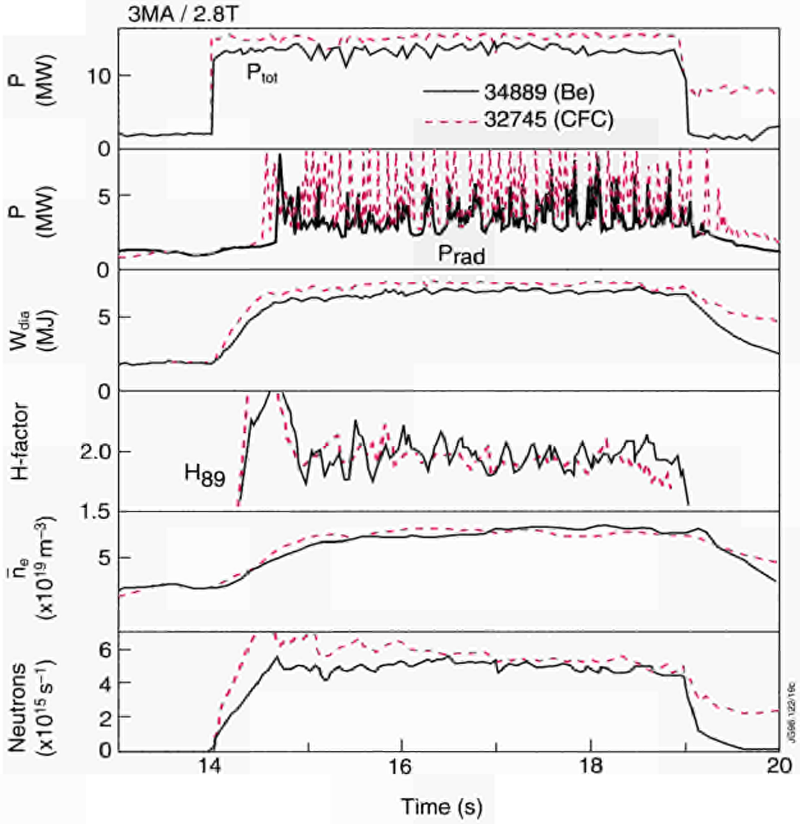


Fig.40: Comparison of the global characteristics of equivalent steady-state H-modes using the CFC and Be targets.

Beryllium Target Tile Assessment

For the last three months of the 1994/95 campaign, the CFC divertor target tiles were replaced by beryllium tiles of similar geometry and a full experimental programme was carried out to assess beryllium as a divertor target tile material for ITER.

Under normal operating conditions, beryllium was proven to be an acceptable divertor target material. The power handling characteristics of the CFC and beryllium target were comparable. Steady-state H-modes were explored from 1 to 6MA at total powers up to 30MW, and the general plasma behaviour (H-mode power threshold, the behaviour at the density limit and the density range for detachment) was similar to that with CFC (Fig.40). In particular, for both cases, H-mode confinement was lost when the radiated power fraction reached ≈50% with intrinsic impurities and detached H-modes (radiated power fraction ≈80%) could only be achieved with impurity seeding. Gross melting of the target tiles was generally avoided by limiting the input energy and by "sweeping" the magnetic configuration over the target tiles, but superficial melt damage occurred due to some giant ELMs in hot-ion H-mode discharges which deposited ≈1MJ of plasma energy onto the target in about 20ms.

Controlled Beryllium Melt Experiment

Most of the experiments on the beryllium target were conducted to avoid melting. However, at the end of the campaign, an experiment was carried out specifically to address the question of operation on beryllium in molten and/or damaged conditions. An important motivation for these experiments was to test the speculation that, in ITER, a beryllium target would self-protect against excessive heat-fluxes in off-normal operating conditions. In this scenario, evaporating beryllium would lead to high radiative power losses and thus reduce the heat flux to the target. This scenario is usually referred to as a 'vapour shield', although beryllium vapour as such plays no role.

With ITER reference off-normal heat loads of 25MW/m^{-2}, which resulted in significant surface melting, only a moderate degree of self-protection of the beryllium target was found. At best, the radiated power increased to ≈50%

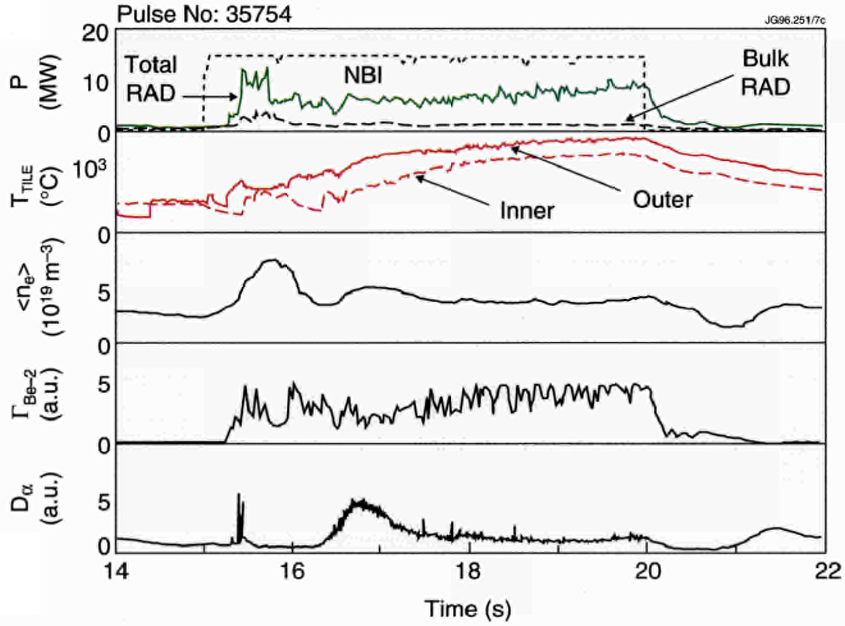


Fig.41: Pulse characteristics of a discharge in which 75MJ was deposited on a beryllium target and resulted in melting. The radiated power increased to ≈70% of the input power, but only after several seconds.

of the input power, but only after several seconds (Fig.41). Following these experiments, ELMy H-mode discharges and nitrogen seeded radiative divertor discharges were established on the molten beryllium surface and found to be essentially unchanged. Furthermore, high power swept operation resulted in 180MJ of input energy being deposited on the target, causing additional melting.

Figure 42 shows a sector of the target near the outer strike zone, after the experiment, in which three annuli of damage are visible. The inner ring already existed before these experiments. The middle ring is due to the unswept melting discharges, while the outer ring is due to the swept high power discharges. All damage exhibits full toroidal symmetry around the machine, highlighting the installation accuracy of the Mark I divertor.

Following melting, the effect of a damaged beryllium target on the operating regimes relevant to ITER was found to be small. Overall, beryllium remains one of the candidate materials for the divertor target in ITER. The final choice will depend largely on other considerations such as tritium retention and erosion lifetime.

Summary of Scientific Achievement in 1995

The 1994/95 Experimental campaign on the Divertor Characterization Phase had begun in February 1995 and lasted until June 1995. During this period, the Mark I pumped divertor was most effective and allowed a broad-based and highly ITER-relevant research programme to be pursued. It had addressed the central problems of the ITER divertor-efficient dissipation of the exhausted power, control of particle fluxes and effective impurity screening, using both carbon fibre composite (CFC) and beryllium as the power handling material. Significant advances were made as follows:

- The plasma current was increased to 6MA (a world record in an X-point configuration), the total heating power to 32MW, plasma stored energy to 13.5MJ (the highest energy ever recorded in a JET plasma) and the neutron rate to a new JET record in deuterium of 4.7 x 10^{16} neutron per seconds which is comparable to the best achieved prior to the installation of the pumped divertor and was achieved even though the plasma volume was 20% smaller;
- The high power handling capability of the Mark I divertor target was demonstrated and the severe impurity influxes (carbon "blooms"), which previously terminated high performance plasmas, were eliminated. About 180MJ of combined neutral beam and ICRF energy was injected during ELMy H-mode plasmas;
- The use of the divertor cryopump has proved to have several advantages related to both vessel conditioning and plasma performance. It has allowed good density control and facilitated the production of long, clean, stationary ELMy H-mode plasmas with electron density, effective ion charge, radiated power loss and stored plasma energy remaining constant for up to 20s;
- ELMy H-mode plasmas with steady-state conditions for many energy confinement times are considered the most credible operation mode for ITER and these have been studied at high power up to the 6MA current capability of JET. ELMy H-modes with heating powers up to 32MW and detached divertor plasmas and radiative power exhaust (the regime foreseen for ITER) have been found to reduce the power loading to the targets, but at the expense of main plasma confinement and purity;

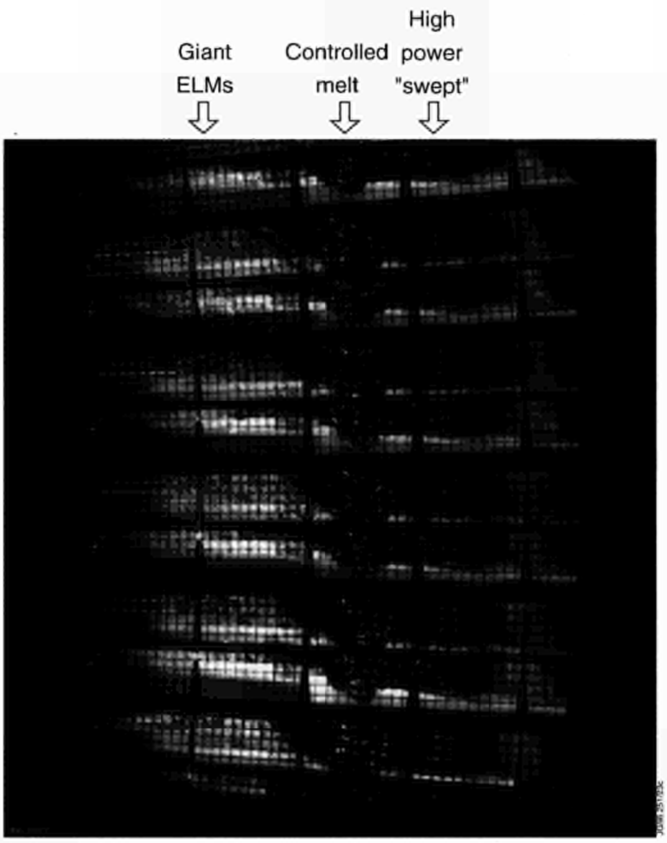


Fig.42: The beryllium divertor target after the melting experiments.

- Improved plasma shaping has allowed long ELM-free H-modes (up to 1.2s) to be produced with plasma currents up to 4.5MA. A neutron yield of 4.7×10^{16} neutrons per second, the best JET rate in deuterium, and the fusion triple product of $nT\tau_E > 8 \times 10^{20} m^{-3} keVs^{-1}$ (within 10% of the previous best), were achieved at 3.8MA with 18MW of neutral beam heating;
- The neutral beam injectors operated reliably and routinely and reached power levels of up to 20.4MW. At these levels, the Octant No. 4 injector contributed a world record 12.6MW for a single injection port. ICRF power up to 15MW has been coupled to the plasma, and high density, high power plasmas (>10MW) show a soft transition to the H-mode, small ELMs and high confinement. Lower hybrid power up to a record 7.3MW has been used to fully drive a plasma current of 3MA, to produce reversed magnetic shear configurations, to control sawteeth and to soften the termination of hot-ion ELM-free H-modes;
- A wide range of experiments, in various plasma configurations, were performed to assess the performance of beryllium as a divertor target material for ITER. When tested under normal operating conditions, beryllium was found to be acceptable and the power handling characteristics of CFC and beryllium were comparable and the general plasma behaviour was very similar. The best fusion performance obtained in beryllium target plasmas was approximately two-thirds of that obtained in equivalent plasmas with CFC. The general characteristics of steady state H-modes were similar in CFC target plates and beryllium;
- In further experiments, the beryllium tiles were subjected to significantly higher heat fluxes than normal to test the hypothesis put forward by ITER that a beryllium target would 'self protect' by evaporated beryllium leading to high radiation from the plasma and reduced heat fluxes. Significant surface melting and only moderate self protection was observed with ITER relevant heat fluxes.

Progress towards a Reactor

The fusion performance in JET with the pumped divertor configuration was further improved during 1995. By the end of the campaign a neutron yield of 4.7×10^{16} neutrons per second had been achieved with an input power of 19MW in plasma with a toroidal field of 3.4T and a current of 3.8MA. If this discharge had contained a 50:50 D-T mixture then a peak Q_{DT} of 1.07 would have been achieved. The triple fusion product, $nT_i\tau_E$, was $8.5 \times 10^{20} m^{-3}$s keV which was close to the previous best value.

The carbon bloom, which was a restriction on JET performance in the old divertor configuration, has been eliminated by the new divertor. However, at high values of the stored energy (W~12MJ), the fusion performance is limited now by a variety of MHD phenomena (slow rollover, giant ELMs, etc). A comprehensive experimental and theoretical study of these events is being undertaken in an effort to alleviate the problems.

To avoid this problem a series of power stepdown experiments were carried out, so that the occurrence of the MHD events could be delayed. Using this technique discharges have been obtained with an equiavalent Q_{DT} of 0.7, maintained for periods greater than 1 second. These discharges should be ideal for the demonstration of alpha-particle heating in the future D-T phase.

During 1995, progress has been made on other experiments TFTR, DIII-D and JT-60U. The main effort has gone into trying to exploit the improved central confinement in plasmas with reversed or flat central shear. In this type of regime an approximate doubling of the D-D yield has been obtained in DIII-D compared to that achieved with the normal shear. In the other two devices TFTR, JT-60U the reverse shear regime has been achieved but the performance has not yet

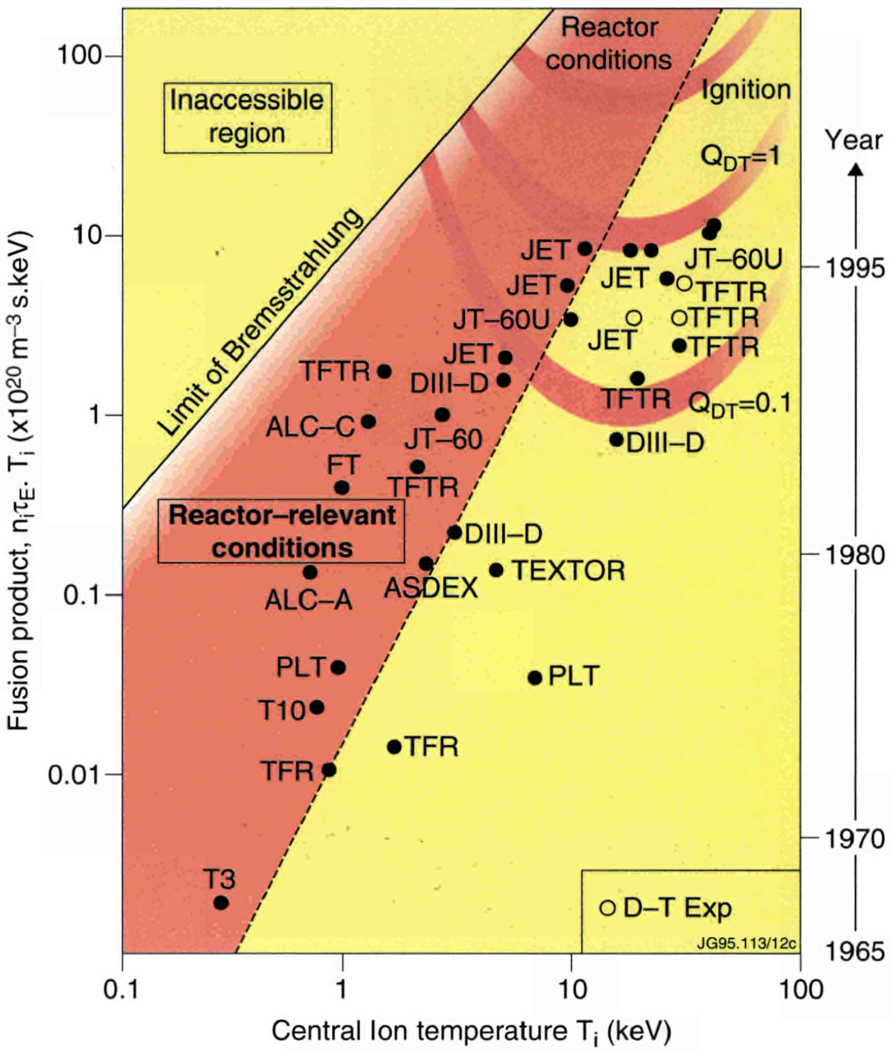
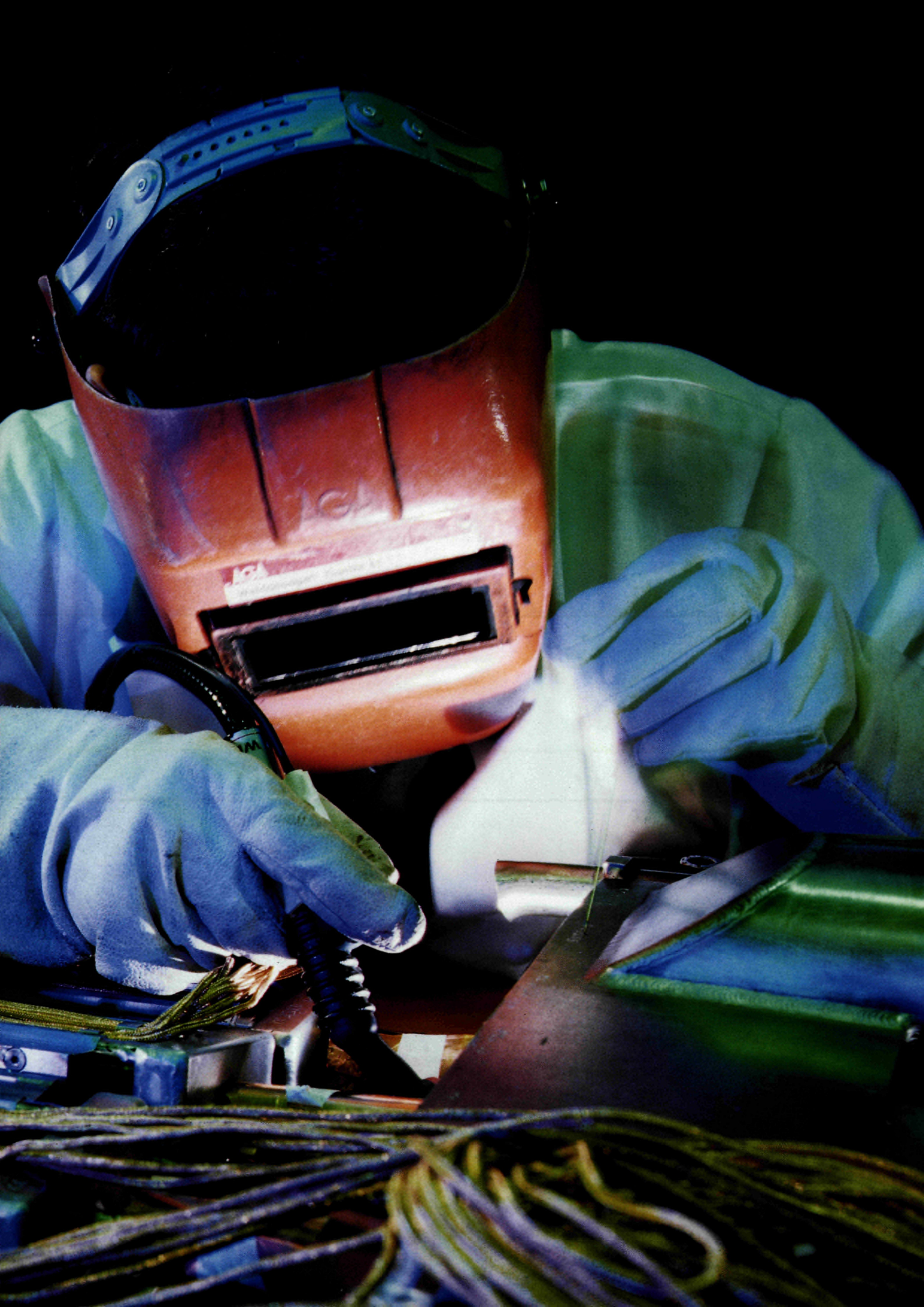


Fig.43: Triple fusion product as a function of ion temperature, T_i, for a number of tokamaks world-wide.

surpassed that previously achieved. These regimes will also be studied in JET in the 1996 campaign.

The fusion triple product values of the high performance pulses in both impure deuterium and in the D-T pulses for JET and TFTR are compared in Fig.43 with the latest results from other machines world-wide to illustrate the progress that has been made over the last 30 years.



Future Programme

Introduction

In 1978, the original objectives of JET were set out in the JET Design Proposal, EUR-JET-R5, as follows:

'The essential objective of JET is to obtain and study a plasma in conditions and dimensions approaching those needed in a thermonuclear reactor. These studies will be aimed at defining the parameters, the size and the working conditions of a Tokamak reactor. The realisation of this objective involves four main areas of work:

i) the scaling of plasma behaviour as parameters approach the reactor range;

ii) the plasma-wall interaction in these conditions;

iii) the study of plasma heating; and

iv) the study of alpha-particle production, confinement and consequent plasma heating.

The problems of plasma-wall interaction and of heating the plasma must, in any case, be solved in order to approach the conditions of interest.

An important part of the experimental programme will be to use JET to extend to a reactor-like plasma, results obtained and innovations made in smaller apparatus as a part of the general tokamak programme. These would include: various additional heating methods, first wall materials, the control of the plasma profiles and plasma formation.

Objectives of JET

The essential objective of JET is to obtain and study plasma in conditions and with dimensions approaching those needed in a thermonuclear reactor. These studies will be aimed at:

1. Scaling of plasma behaviour as parameters approach the reactor range;
2. Plasma-wall interactions in these conditions;
3. Plasma heating; and
4. Alpha-particle production, confinement and consequent plasma heating.

At the start of 1995, JET was in an operating phase, continuing the Pumped Divertor Characterization Phase, which had begun in February 1994 and which ended in June 1995. During this period, the Mark I divertor was most effective and allowed a broad-based and highly ITER-relevant research programme to be pursued.

Since the beginning of its experimental campaign, extensive studies had been made in the first and third areas of work of JET's objectives: reactor relevant temperatures (up to 30 keV), densities (up to 4 x $10^{20}m^{-3}$) and energy confinement times (up to 1.7s) had been achieved in separate discharges. The second area of work had been well covered in the limiter configuration for which JET was originally designed. However, the highest performance JET discharges had been obtained with a 'magnetic limiter', (or X-point configuration). The duration of the high performance phase of these discharges exceeded 1.5s; this was achieved by careful design of the targets and specific operation techniques, but is limited, ultimately, by an unacceptably high influx of impurities, characterized by a rapid increase in electron density, effective ionic discharge and radiated power (referred to as the 'bloom').

The fourth area of work had been started by earlier studies of energetic particles produced as fusion products or by ion cyclotron resonance heating (ICRH). It was addressed further during 1991 by the first tokamak plasma experiments in deuterium-tritium mixtures. The high performance achieved in deuterium discharges, together with the experience gained in making substantial modifications to JET in a beryllium environment and with significant vessel activation, gave confidence that an experiment with about 10% tritium in the plasma could be performed and would provide data that could be used to plan an effective campaign of deuterium-tritium experiments in 1996.

During 1991, the JET Council had approved the policy of a step-wise approach to the introduction of tritium in advance of the full D-T phase of JET operations. As a first such step, after having obtained all necessary regulatory approvals, JET successfully carried out the preliminary tritium experiment (PTE-1) in November 1991. A release of fusion energy in the megawatt range in a controlled fusion device was achieved for the first time in the world.

In the 1991/92 campaign, JET achieved parameters approaching breakeven values for about a second, resulting in large bursts of neutrons. However, in spite of the pulse continuing for many seconds after reaching peak plasma values, the neutron count fell away rapidly as impurities entered the plasma and lowered its performance. This limitation on the time for which near-breakeven conditions could be maintained was due to the poisoning of the plasma by impurities (the 'bloom'). This further emphasised the need to provide a scheme of impurity control suitable for a Next Step device.

In late 1991, the Council of Ministers approved a modification to the JET Statutes, which prolonged its statutory lifetime by four years until 31st December 1996. The extension will allow JET to implement the new Pumped Divertor Phase of operation, the objective of which is to establish the effective control of plasma impurities in operating conditions close to those of the Next Step. This programme of studies will be pursued before the final phase of full D-T operations in JET.

During 1993, a large proportion of JETs effort was devoted to shutdown work for the pumped divertor phase of operations. The first stage of the shutdown in

1992 had involved removal of components and replacement of faulty toroidal magnetic field coils. The second stage in 1992/93 involved assembly of the four divertor coils and casings inside the vacuum vessel. The third stage of the shutdown began in mid-1993, with the final positioning of the coils. The shutdown was successfully completed with pumpdown of the torus in January 1994. The first plasma in the Pumped Divertor Characterisation Phase was produced in mid-February. During 1994, the plasma current was increased to 5MA, the total heating power to 26MW, the stored energy to 11.3MJ and the neutron rate to 4×10^{16} neutrons per second.

1994 saw significant progress in optimising peak fusion performance and extending operation to the reactor relevant steady-state ELMy H-mode, which was obtained under a variety of conditions. The high β_p regime was also extended to steady-state and to the reactor relevant domain.

The high power handling capability of the Mark I divertor target was demonstrated and the severe impurity influxes (carbon "blooms"), which previously terminated high performance plasmas, were eliminated. The cryopump reduces recycling, eliminates the effects of wall saturation (observed in previous long pulse operation), allows effective particle control, and generally allows higher performance.

The 1995 experimental programme addressed the central problems of the ITER divertor: efficient dissipation of the exhausted power, control of particle fluxes and effective impurity screening, using both carbon fibre composite and beryllium as the power handling material. The plasma current was increased to 6MA (a world record in an X-point configuration), the total heating power to 32MW, plasma stored energy to 13.5MJ (the highest energy recorded in a JET plasma) and the neutron rate to a new JET record in deuterium of 4.7×10^{16} neutrons per second (comparable to the best achieved prior to the installation of the pumped divertor and was achieved even though the plasma volume was 20% smaller). ITER-relevant quasi-steady state ELMy H-modes were also studied at high power, high current, high β and in combination with detached divertor plasmas and radiative power exhaust.

The campaign with CFC tiles on the first-wall was successfully completed in early-1995. This was followed by experiments to assess the performance of beryllium as a divertor target tile material and to compare it with CFC. In response to a request from the ITER Joint Central Team, beryllium melting was induced at ITER-relevant heat fluxes to see whether a protective radiative shield was established.

Overall, these achievements show that the main objectives of JET are being actively addressed and substantial progress is being made.The overall aim for JET can be summarised as a strategy "to optimise the fusion product ($n_i T_i \tau_E$)". For the energy confinement time, τ_E, this involves maintaining, with full additional heating, the values that have already been reached. For the density and ion temperature, it means increasing their central values $n_i(0)$ and $T_i(0)$ to such an extent that D-T operation would produce alpha-particles in sufficient quantities to be able to analyse their effects on the plasma.

In parallel, preparations continued for the next phase of D-T operations (DTE-1), which is scheduled for the end of 1996. JET has also continued the commissioning phase of the sub-systems of the active gas handling system in accordance with the JET programme for D-T operations.

Future Plans

The JET Programme was divided into phases fitting within the accepted life time of the Project. Phase I (Ohmic Heating Studies) was completed in September 1984, and Phase II (Additional Heating Studies) in October 1988. Phase III (Full Power Optimization Studies) ended in February 1992. The scientific aims of Phase III were to obtain maximum performance in limiter configuration (currents up to 7MA) and to optimize X-point Operation (currents up to 6MA).

JET future plans are dominated by the insertion of a new phase of the Project (Phase IV: Pumped Divertor Configuration and Next-Step Oriented Studies). This phase is subdivided into a Divertor Characterization Plasma and an ITER Support Phase. This new phase extended the lifetime of the Project up to the end of 1996.

The Pumped Divertor Characterisation Phase began in February 1994 and ended in June 1995. During this period, the Mark I pumped divertor was most effective and allowed a broad-based and highly ITER-relevant research programme to be pursued.

In June 1995, a shutdown started for the installation of the Mark IIA divertor and the modification of the ICRF antennae. The shutdown is due to finish in March 1996. The next phase of in-vessel work involved installation of the modules of the Mark II divertor support structure. The modified ICRF antennae were then reinstalled.

Preparations were also continuing for the next period of D-T operation (DTE-1), scheduled for the end of 1996 and work was continuing on the procurement of the ITER specific Mark II Gas-box divertor target assembly, due for installation by remote handling in 1997.

Extension of Programme to end of 1999

A proposal for the extension of the JET Programme to the end of 1999, which is supported by the JET Council, is currently being sent to the Council of Ministers for approval. The purpose of the extension of JET to the end of 1999 is to provide further data of direct relevance to ITER, especially for the ITER-EDA, before entering into a final phase of D-T operation. In particular, the extension:

i) should make essential contributions to the development and demonstration of a viable divertor concept for ITER; and

ii) carry out experiments using D-T plasmas in an ITER-like configuration, which will provide a firm basis for the D-T operation of ITER;

while allowing key ITER-relevant technology activities, such as the demonstration of remote handling and tritium handling, to be carried out.

Divertor Studies

The divertor must fulfil three main functions: (i) exhaust plasma power at acceptable erosion rates; (ii) control plasma purity; and (iii) exhaust helium "ash" and provide density control. For ITER, successful divertor operation must also be compatible with high confinement (H-mode) operation with Edge Localised Modes (ELMs).

Erosion can be reduced by decreasing the plasma temperature at the target plates which can be achieved with high density and high recycling near the target plates. However, the exhausted plasma power conducted to the targets in this high recycling regime is not reduced and has to be distributed over a large surface area. To some extent, this can be achieved by inclining the targets so as to project a larger surface area to the conducted heat flux which flows along the magnetic field. In JET, the plasma "footprint" can also be swept across the targets, but this would not be possible in ITER or a reactor.

An alternative approach is to reduce the conducted power to the targets by atomic physics processes (charge exchange and hydrogen and impurity radiation) in the divertor channel. These power losses can be enhanced by generating plasma and impurity flows in the divertor. This requires sufficient pumping and recirculation of the plasma in the divertor. Of course, the divertor conditions must not affect adversely the main plasma performance and this requires the divertor plasma to be as decoupled as possible from the main plasma. In particular, the leakage of neutrals from the divertor to the main plasma must be reduced as far as possible. Such "closure" of the divertor can be achieved by introducing baffle structures at the entrance to the divertor or maintaining a sufficiently dense plasma to attenuate neutrals within the divertor (plasma "plugging"). The geometry of the divertor is thus important in providing the necessary degree of closure, and this requires the testing of several different divertor configurations.

In the ITER-CDA, the solution adopted for the divertor was to use the high recycling approach with steeply angled target plates, which offers good purity control. However, with the adoption of a single null configuration and higher power in the ITER-EDA, the high recycling approach does not suffice, and a gas target (detached plasma) divertor was adopted to exhaust power over the sidewalls of a deep divertor via charge exchange and radiation. This approach requires the relatively free recirculation of the hydrogenic and impurity neutrals within the divertor, and plasma density and purity control must therefore be demonstrated.

The JET divertor programme is based on three divertor configurations (Mark I, Mark IIA and an ITER-specific Mark IIGB) which will be introduced and tested sequentially in the period up to the middle of 1998 (end of the ITER-EDA).

During the present shutdown, the relatively open Mark I divertor used for the 1994/95 Experimental Campaign is being replaced by the Mark II divertor which comprises a common base structure capable of accepting various target assemblies. This allows the divertor geometry (degree of closure and target configuration) to be varied and its effect on divertor and main plasma performance to be studied.

Due to the need to test various divertor geometries for ITER, the Mark II divertor has been designed so that its target assembly can be exchanged by remote handling, but does not lend itself to the use of active cooling. No financial provision is made in the proposed Programme to study target materials other than CFC.

The first target assembly (Mark IIA) is a moderate "slot" divertor which is significantly more closed than Mark I, thus improving purity control and increasing atomic losses. Mark IIA allows operation under a wide range of plasma configurations and conditions and makes high power, high current operation possible on both the horizontal and vertical target plates.

The second target assembly (Mark IIGB) is a deep divertor with a well baffled entrance. The aim of the Mark IIGB configuration is to distribute the exhaust power over the length of the divertor and this is assisted by the free recirculation of neutrals below the baffle on one or both sides of the divertor plasma legs. Recirculation also allows greater flows, better pumping and better impurity retention in the divertor.

The investigation of these three generically different configurations will allow a coordinated and timely investigation of the various options for an ITER divertor and is designed to lead to a solution giving compatibility between power exhaust, purity control and high performance (H-mode). A major part of the strategy is development and validation of numerical codes for the edge and divertor plasma so that they may be used for extrapolation to ITER geometry, dimensions and operating conditions . The experimental results from all three divertor configurations, together with those from smaller tokamaks and model calculations, will allow the ITER divertor design to be validated. This should be possible by mid-1998, in line with the ITER-EDA schedule.

D-T Plasma Studies

The first magnetic confinement experiments using a mixture of 10% tritium in deuterium took place in JET in 1991 and produced significant fusion power (peaking at 1.7MW and averaging 1MW over 2 seconds). Since then the US tokamak TFTR, using 50% tritium in deuterium, has produced about 10MW of fusion power and shown that, with their particular operating conditions and geometry, D-T plasmas have more favourable confinement properties than deuterium plasmas (isotopic effect). Subject to the necessary approvals, two further periods of D-T operation (DTE-1 and DTE-2) are foreseen for the JET programme to the end of 1999.

The physics mission of DTE-1 would have the crucial objective of studying the isotopic effect on confinement scaling and H-mode threshold power in D-T plasmas. These would be the first experiments of this kind in the geometry appropriate to ITER and including a divertor. These experiments would be essential to determine whether the D-T performance improvements observed in the circular cross-section TFTR tokamak are also realised in the D-shaped cross section of JET, and ITER. Furthermore, the H-mode threshold power in D-T plasmas would be determined for the first time in these JET experiments. This would allow more accurate assessments of the ignition margin and the heating requirements for ITER.

In addition, JET's capability for long pulse operation and impurity control should permit about 10MW of fusion power for several seconds (typically with 50% tritium). The α-particle heating would then make a significant contribution to the plasma power balance and this would allow the effects of α-particle heating (confinement and thermalisation of α-particles and stability of toroidal Alfven eigenmodes in the presence of α-particles) to be studied and experience gained for ITER. The operating conditions foreseen for ITER, namely long pulse ELMy H-mode detached radiative divertor plasmas, could also be studied in D-T, albeit at reduced levels of fusion power. These results could provide important information for the design of the ITER divertor.

As well as a physics mission, DTE-1 would also have a technology mission to carry out and demonstrate key ITER and reactor-relevant technologies, such as tritium handling and processing, remote handling and control, and heating systems operating in D-T. Specifically, DTE-1 would provide a first test of large scale technology for processing tritium through an operating tokamak.

Operation in TFTR and detailed preparations for DTE-1 on JET have shown that a longer phase of D-T operation than DTE-1 is needed for a thorough study of the physics and technology of D-T plasmas. This is provided for by DTE-2, with substantial α-particle heating, capitalising on the performance improvements achieved in the preceding experimental campaigns with deuterium.

This period of D-T operation will also provide full evaluation of the technology of processing tritium in support of an operating tokamak.

Programme Plan

The programme to the end of 1999 is illustrated in Fig.44. It covers all the agreed objectives for the JET extension. Its main aspects are summarised below.

ITER-EDA Support Phase (mid-1995 to mid-1998)

The present shutdown which commenced in June 1995 is scheduled to be completed in March 1996. During this shutdown the Mark II divertor, its first target structure (Mark IIA) and modified ICRF antennae are being installed. Work is also being undertaken to prepare for the D-T operations planned for the end of 1996.

During 1996 the experimental campaign will concentrate on divertor and other ITER-specific studies (including development toward long pulse high performance operation) and optimisation for D-T. The programme will therefore extend many of the issues addressed initially with the Mark I Divertor and give, in particular, further emphasis to studies of the effect of geometry on radiative detached divertor plasmas, which form the physics basis for the divertor concept favoured by ITER.

A period of D-T operation (DTE-1) is scheduled for late 1996, following an intervention to make necessary final adjustments for D-T operations. The precise content and duration of DTE-1 is being defined at present and takes account of developing needs of ITER and experience gained in JET and TFTR. It will require prior approval of the JET Council. The extent of DTE-1 will be a compromise between studying essential D-T physics for the ITER-EDA and minimising delays in the experimental programme that could result from certain component failures during DTE-1.

The physics mission of DTE-1 could last about four months and produce up to 2×10^{20} neutrons. In this case, the activation of the vessel would prevent manned in-vessel intervention for up to one year after D-T operation. However, in-vessel components which are accessible can be repaired using the remote handling equipment developed for the Mark IIGB target assembly change. This equipment has demonstrated a very high level of reliability and is now fully proven for the planned remote handling tasks. Its versatility and ability to perform a wide variety of other tasks has also been demonstrated, provided access can be obtained. Manned access for ex-vessel repairs will be possible after DTE-1.

In a six-month shutdown in the first half of 1997, the Mark IIA target structure will be exchanged for a second target structure, an ITER-specific divertor of the "Gas-box" class (Mark IIGB). The exchange will be made by remote handling without manned intervention. This remote handling operation will demonstrate for the first time one of the central technologies required both for ITER and for a fusion reactor.

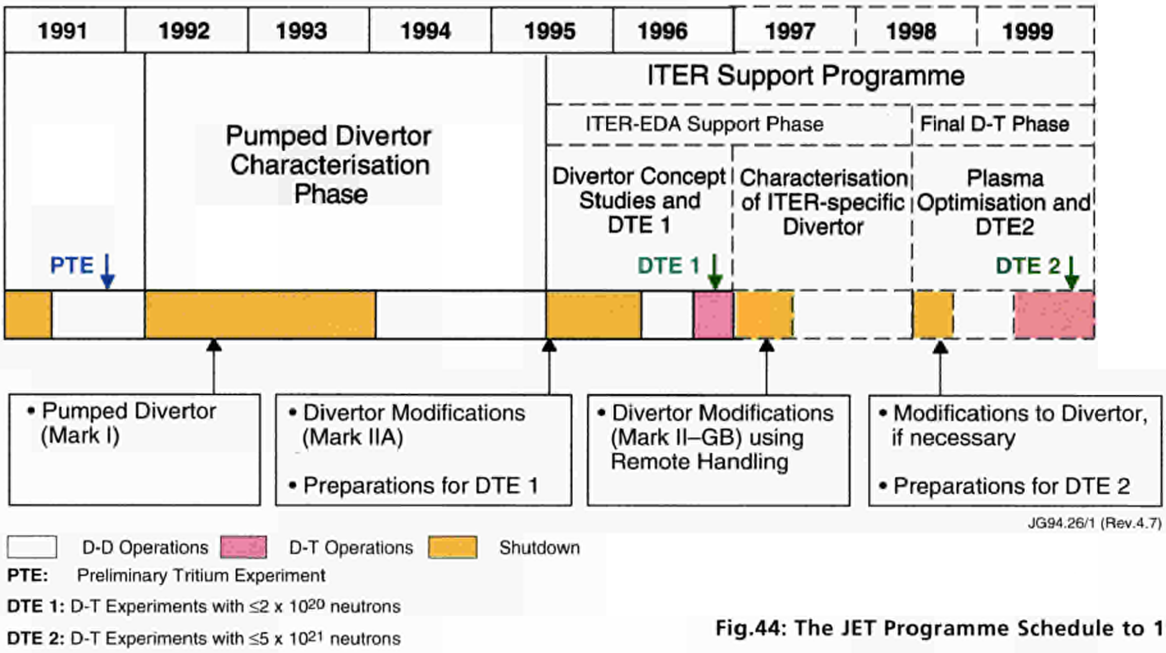


Fig.44: The JET Programme Schedule to 1999

During the remainder of 1997 and the first half of 1998, the Mark IIGB divertor will be tested experimentally with deuterium plasmas at high power. The design of the Mark IIGB provides flexibility to modify the target geometry with relative ease. The Programme Plan provides for two target geometries for Mark IIGB, together with a septum which may, or may not, be included to limit the communication between the inner and outer divertor legs and to absorb energy from energetic neutrals and photons.

Possible ways of improving JET's performance which are under consideration include improving the wall condition, increasing the toroidal magnetic field (to 4T) and plasma current, increasing the heating power (by ≈30%) and overcoming the performance limitations due to MHD instabilities.

Final Phase of D-T Operation (mid-1998 to end-1999)

A four month shutdown in 1998 will permit any necessary modifications to the divertor and final preparations for DTE-2. Normal manned in-vessel interventions will again be possible in this shutdown. The Mark IIGB divertor target structure is less flexible than Mark IIA with respect to the variety of equilibria which can be accommodated. Furthermore, its power handling capability in attached divertor operation is somewhat lower. It may therefore not be compatible with the highest plasma performance obtained in JET, such as the low density, high magnetic shear, hot-ion H-mode of operation. This has to be tested experimentally and if it proves to be the case, it will be possible to re-install Mark IIA (for DTE-2) following the completion of the Mark IIGB studies.

During late 1998 and early 1999, the experimental programme will continue by optimising plasma performance in deuterium in preparation for a further period of D-T operation (DTE-2). DTE-2 is scheduled to take place during the remainder of 1999. DTE-2 experiments could last up to eight months and could produce up to 5 x 10^{21} neutrons. Actual neutron production, within this upper limit, will be reassessed in the light of the experience with D-T operations on JET and TFTR. Every effort will be made to reduce this upper limit, while still satisfying JET's role in supporting ITER and the world fusion programme. In this way, the activation of the JET structure would be kept as low as possible compatible with fulfilling the required objectives.

Members and Organisation

Members

The JET Joint Undertaking has the following Members:

The European Atomic Energy Community (EURATOM);

The Belgian State, acting for its own part ('Laboratoire de Physique des Plasmas de l'École Royale Militaire - Laboratorium voor plasma-physica van de Koninklijke Militaire School') and on behalf of the Université Libre de Bruxelles' ('Service de physique statistique, plasmas et optique non-linéaire de l'ULB'); and of the 'Centre d'Études de l'Energie Nucléaire (CEN)/ 'Studiecentrum voor Kernenergie' (SCK);

The Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain;

The Commissariat à l'Énergie Atomique (CEA), France;

The 'Ente per le Nuova Tecnologie, l'Energia e l'Ambiente' ('ENEA') representing all Italian activities falling within the Euratom Fusion Programme including that of the 'Consiglio Nazionale delle Ricerche', (CNR);

The Hellenic Republic, Greece;

The Forskningscenter Risø (Risø), Denmark;

The Grand Duchy of Luxembourg, Luxembourg;

The Junta Nacional de Investigaçao Científica e Tecnológica (JNICT), Portugal;

Ireland;

The Forschungszentrum Jülich GmbH (KFA), Germany;

The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. Institut für Plasmaphysik (IPP), Germany;

The Swedish Natural Science Research Council (NFR), Sweden;

The Swiss Confederation, Switzerland;

The Stichting voor Fundamenteel Onderzoek der Materie (FOM), The Netherlands;

The United Kingdom Atomic Energy Authority (UKAEA), Host Organisation.

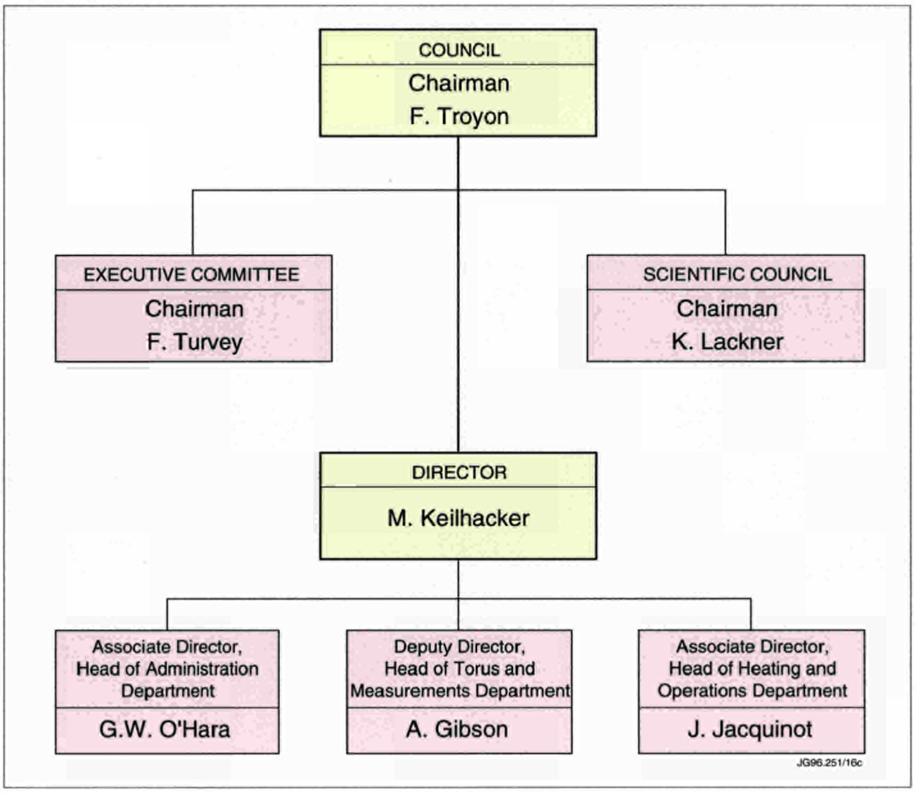


Fig.45: Overall Project Structure

Management

The JET Joint Undertaking is governed by Statutes which were adopted by the Council of the European Communities on 30 May 1978. The organs of the Joint Undertaking are the JET Council and the Director of the Project. The JET Council is assisted by the JET Executive Committee and is advised by the JET Scientific Council (see Fig.45).

JET Council

Each member of the Joint Undertaking is represented on the JET Council, which is required to meet at least twice yearly. The Council is responsible for the management of the Joint Undertaking and for:

- Nomination of the Director and Senior Staff of the Project with a view to their appointment by the Commission or the Host Organisation as appropriate;
- Approval of the annual budget, including staffing, the Project Development Plan and the Project Cost Estimates;
- Ensuring collaboration between the Associated Laboratories and the Joint Undertaking in the execution of the Project, including the establishment of rules on the operation and exploitation of JET.

Three meetings of the JET Council were held during the year: on 22nd-23rd March, 14th-15th June and 7th-8th November 1995. The membership of the JET Council is shown in Appendix I.

JET Executive Committee

The JET Executive Committee is required to meet at least six times a year. Its functions include:

- Advising the JET Council and the Director of the Project on the status of the Project on the basis of regular reports;
- Commenting and making recommendations to the JET Council on the Project Cost Estimates and the Draft Budget, including the establishment of staff, drawn up by the Director of the Project;

- Approving, in accordance with the rules on the award of contracts established by the JET Council, the tendering procedure and the award of contracts;
- Promoting and developing collaboration between the Associated Laboratories and the Joint Undertaking in the execution of the Project.

The membership of the JET Executive Committee is shown in Appendix II. The Committee met six times during the year: on 9th-10th February, 27th-28th April, 12th-13th July, 15th September, 2nd-3rd November and 7th-8th December 1995.

JET Scientific Council

The Statutes confer the following functions on the JET Scientific Council:

- Upon the request of the JET Council, to advise on scientific and technical matters, including proposals involving a significant change in the design of JET, its exploitation, and its long-term scientific implications;
- To perform such other tasks as the JET Council may request it to undertake.

The Scientific Council met three times during the year: on 28th February - 1st March, 23rd - 24th May and 26th - 27th September.

The JET SC Chairman reported to the JET Council on three occasions, on:

- the results of the 1994/95 Experimental Campaign, including implications for JET and ITER, and operation with beryllium divertor target tiles;
- engineering analysis of JET operations, including an assessment of in-vessel components and proposed modifications to the saddle coils;
- the JET Programme to the end of 1996, including progress with the 1995/96 shutdown, physics and strategy of D-T experiments and the Mark IIGB divertor;
- proposed enhancements to the toroidal magnetic field and neutral beam heating power.

During 1995, several technical assessment groups were established and/or reported on:

- modifications to the ICRF and related systems (Joint ICRF Assessment Group);
- the technical design of the Mark IIGB divertor;
- the technical risks of the proposed enahncement of the toroidal field to 4T (Joint JET and JET-SC Assessment Group).

The full Scientific Council membership is detailed in Appendix III.

Host Organisation

The United Kingdom Atomic Energy Authority, as the Host Organisation for the JET Joint Undertaking, has made available to the Joint Undertaking, the land, buildings, goods and services required for the implementation of the Project. The details of such support, as well as the procedures for co-operation between the Joint Undertaking and the Host Organisation, are covered by a 'Support Agreement'

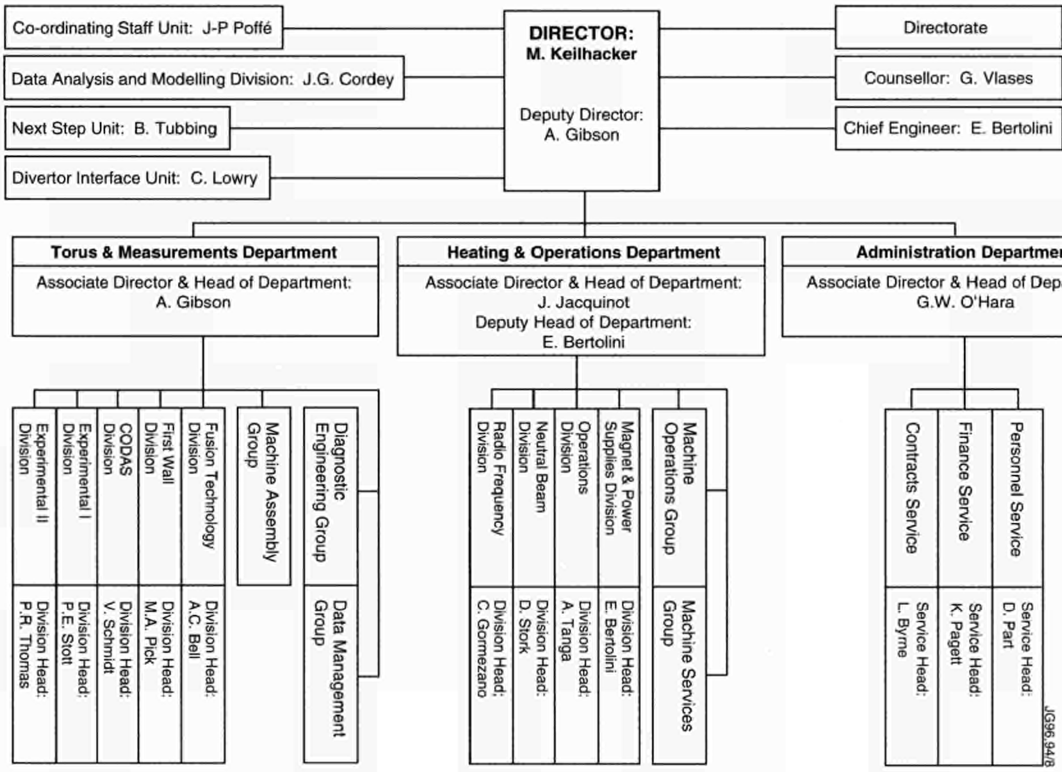


Fig.46: JET Departmental and Divisional Structure

between both parties. In addition to providing staff to the JET team, the Host Organisation provides support staff and services, at proven cost, to meet the requirements of the JET Project.

Project Team Structure

The Director of the Project

The Director of the Project, Dr. M. Keilhacker, is the chief executive of the Joint Undertaking and its legal representative. He is responsible to the JET Council for the execution of the Project Development Plan, which specifies the programme, and for the execution of all elements of the Project. The Project Development Plan covers the whole term of the Joint Undertaking and is regularly updated. The Director is also required to provide the JET Council and other subsidiary bodies with all information necessary for the performance of their functions.

Internal Organisation

The internal organisation of the Project consists of three Departments and the Directorate. The three Departments are:

- Torus and Measurements Department;
- Heating and Operations Department;
- Administration Department.

The Project Departmental and Divisional structure is shown in Fig.46.

Directorate

The Heads of the Departments report to the Director of the Project and together with the Director form the JET Directorate. Various special functions are carried out by the Director's Office. The Internal Audit Office monitors the financial activities and provides advice on accounting and control procedures as well as maintaining links with the Court of Auditors. The Project Control Office is responsible for financial planning and for the preparation of the Project Development Plan and Project Cost Estimates. The JET Council Secretariat provides Secretarial Services to the JET Council and to the Executive Committee and also to the JET Project Board.

Within the Directorate, are four technical units and a Chief Engineer, reporting directly to the Director. The main responsibilities are as follows:

(a) *The Co-ordinating Staff Unit* is responsible for the availability of a comprehensive health physics and safety project organisation; and for the provision of centralised engineering support services. It comprises four Groups: Health Physics and Safety Group; Quality Group; Technical Services Group; and Drawing Office.

(b) *The Data Analysis and Modelling Division* is responsible for the provision of software for the acquisition and processing of data from JET diagnostics; for confirming the internal consistency of the processed data and assembling it into public databases; and the development and testing of theoretical models against JET data. In addition, the Unit is responsible for prediction by computer simulation of JET performance, interpretation of JET data and the application of analytic plasma theory to gain an understanding of JET physics. It comprises three groups: Analytic Theory Group; Simulation Group; and Data Processing and Analysis Group

(c) *The Next Step Unit* is responsible for co-ordinating contributions from JET to the European effort in support of the ITER-EDA. This responsibility includes drawing up proposals, initiating relevant work programmes on JET and taking part in their execution and evaluation.

(d) *The Divertor Interface Unit* is responsible for assessing the impact of developments in the experimental programme and operation on the design requirements for JET divertors. This includes a high level of participation in the experimental programme on divertor physics, thermomechanical analysis of plasma induced loads on the divertor, and the definition of advanced divertor concepts.

In addition, there is a *Chief Engineer*, who reports to the Director, and is responsible for ensuring the overall coherence of technical aspects of JET operations.

Torus and Measurements Department

The Torus and Measurements Department has overall responsibility for the performance capacity of the machine: this includes enhancements directly related to this (excluding heating) and the long term planning associated with integration of these elements to achieve ultimate performance. The Department is also responsible: for fusion technology requirements for the active phase including tritium handling and processing; for construction and operation of necessary measurement diagnostic systems and the interpretation of experiment data; and for data systems comprising data control, acquisition and management. The main functions of the Department are:

- to design, procure and implement enhancements to the JET device;
- to provide and maintain clean conditions inside the vessel which lead to high quality plasma discharges;
- to conceive and define a set of coherent measurements;
- to be responsible for construction of necessary diagnostics;
- to be responsible for diagnostics operation, quality of measurements and definition of plasma parameters;
- to organise and implement data acquisition and computing;

- to design and develop remote handling methods and tools to cope with JET requirements;
- to design and construct facilities for handling tritium and for waste management.

The Department consists of five Divisions and three Groups (Machine Assembly, Diagnostic Engineering and Data Management):

(a) *First Wall Division*, which is responsible for the vital area of plasma wall interactions. Its main tasks include the provision and maintenance inside the vacuum vessel of conditions leading to high quality plasma discharges. The Division develops, designs, procures and installs the first wall systems and its components such as limiters, wall protections and internal pumping devices. The area of responsibility encompasses the mechanical integrity of the vacuum vessel as a whole and the development and implementation of mechanical and remote handling techniques;

(b) *Fusion Technology Division*, is responsible for all nuclear engineering aspects of the Project including tritium and gas handling, vacuum systems, waste management and regulatory approvals;

(c) *Control and Data Acquisition System Division (CODAS)*, which is responsible for the implementation, upgrading and operation of computer-based control and data acquisition systems for JET;

(d) *Experimental Division 1 (ED1)*, which is responsible for specification, procurement and operation of about half the JET diagnostic systems. ED1 undertakes electrical measurements, electron temperature measurements, surface and limiter physics and neutron diagnostics;

(e) *Experimental Division 2 (ED2)*, which is responsible for specification, procurement and operation of thc other half of the JET diagnostic systems. ED2 undertakes all spectroscopic diagnostics, bolometry, interferometry, the soft X-ray and neutral particle analysis.

Heating and Operations Department

The overall responsibility of the Heating and Operations Department is for the efficient and effective day-to-day operation of the machine. In addition, the Department has responsibility for plasma heating and auxiliary equipment and related physics; the design and operation of power supplies as well as contributing to the execution and evaluation of JET's experimental programme. The main functions of the Department are:

- preparing and co-ordinating operation of the machine across Departments and Divisions;
- heating and current drive and analysis of its effects in the plasma;

- plasma fuelling, including pellet injection;
- designing and employing power supplies for ensuring efficient operation and control of the machine.

The Department consist of two Groups (Machine Operations and Machine Services) and four Divisions:

(a) *Operations Division* plays a major role in the efficient planning and execution of JET's experimental programme and in the integration of existing or imminent systems into an effective experimental programme. In addition, it is responsible for effective methods of fuelling the plasma including the development of methods based on solid high speed hydrogen pellets; development of new plasma wall conditioning techniques; plasma control systems; development of disruption control methods; training of operations staff; and monitoring of machine operations;

(b) *Neutral Beam Heating Division*, which is responsible for construction, installation, commissioning and operation of the neutral injection system, including development towards full power operation. The Division is also responsible for all cryo-systems and also participates in studies of physics of neutral beam heating;

(c) *Radio Frequency Heating Division*, which is responsible for the design, construction, commissioning and operating RF heating and current drive systems during the different stages of its development to full power. The Division is also responsible for the TAE excitation system and also participates in studies of the physics of RF heating;

(d) *Magnet and Power Supplies Division* is responsible for the design, construction, installation, operation and maintenance of the electromagnetic system and plasma control. The area of responsibility encompasses the toroidal, poloidal and divertor magnets, mechanical structure; and all power supply equipment needed for magnets, plasma control, additional heating and auxiliaries.

Administration Department

The Administration Department is responsible for providing Contracts, Finance and Personnel services to the Project. In addition, the Department is responsible for the administration of Publications and Public Relations Groups.


V 14
WARNING: ELECTRIC TRACE HEATERS
ISOLATE SUPPLY BEFORE REMOVING LAGGING
isopad

Administration

Introduction

The three main aspects of JET's administration - Finance, Contracts and Personnel - are reported in this section. There are also contributions on Safety and Health Physics, Public Relations and Publications Groups.

Finance

The initial budgets for 1995 were approved at 85.59MioECU for Commitments and 88.17MioECU for both Income and Payments, subject to a blockage of 6.00MioECU in the Commitments Budget and 4.00MioECU in the Income and Payments Budget. These funds in the Operations Reserve would only have been required if the JET Council advised that a programme ending in 1996 should again become the Project's central planning assumption. This was not the case and the Director did not request release of the blocked amounts. Therefore, the final 1995 budgets were 79.59MioECU for Commitments and 84.17MioECU for both Income and Payments.

The Commitments and Payments Budgets each are divided into two phases of the Project - Extension to Full Performance and the Operational Phase; subdivisions distinguish between investment, operating, and personnel costs, each with further detailed cost codes.

Commitments

Of the total final appropriations in 1995 of 89.71MioECU (including 10.12MioECU brought forward from previous years), 81.09MioECU was committed and the balance of 8.62MioECU was available for carrying forward to 1996. The details of the commitment appropriations available (Table 5) and of the amounts committed in each Phase during the year (Table 6) are summarised as follows:

COMMITMENT APPROPRIATIONS	MioECU
INITIAL COMMITMENTS BUDGET FOR 1995	75.59
AMOUNTS BROUGHT FORWARD FROM PREVIOUS YEARS.	10.12
	89.71
COMMITMENTS MADE DURING THE YEAR	81.09
BALANCE OF APPROPRIATIONS AT 31 DECEMBER 1995 AVAILABLE FOR USE IN 1996	**8.62**

Table 5: Commitment Appropriations for 1995

- In the extension to Full Performance Phase 0.52MioECU was committed leaving 2.46MioECU commitment appropriations not utilised at 31 December 1995, to be carried forward to 1996.
- In the Operational Phase, 80.57MioECU was committed leaving a balance of 6.16MioECU to be carried forward to 1996.

Income and Payments

The actual income for 1995 was 83.37MioECU to which was added 1.22MioECU available appropriations brought forward from previous years giving a total of 84.59MioECU. The 0.42MioECU excess income over budget is carried forward to be offset against Members' future contributions. Total payment appropriations for 1995 were 89.31MioECU; payments in the year amounted to 82.50MioECU, and 0.07MioECU was transferred from the Special Account to income. The balance of 6.74MioECU was transferred to the Special Reserve Account to meet commitments outstanding at 31 December 1995. (Payments are summarised in Tables 6 and 7).

Contributions from Members

The budget for Members' contributions was 82.15MioECU funded as follows:

		COMMITMENTS		PAYMENTS	
BUDGET HEADING		BUDGET APPRO-PRIATIONS MioECU	OUTTURN MioECU	BUDGET APPRO-PRIATIONS MioECU	OUTTURN MioECU
PHASE 2	**EXTENSION TO FULL PERFORMANCE**				
TITLE 1	PROJECT INVESTMENTS	2.98	0.52	0.98	0.82
PHASE 3	**OPERATIONAL**				
TITLE 1	PROJECT INVESTMENTS	3.36	2.99	6.82	5.85
TITLE 2	OPERATING COSTS	36.24	32.44	33.89	30.83
TITLE 3	PERSONNEL COSTS	47.13	45.14	47.62	45.00
TOTAL PHASE 3		86.73	80.57	88.33	81.68
PROJECT TOTAL - ALL PHASES		**89.71**	**81.09**	**89.31**	**82.50**

Table 6: Commitments and Payments for 1995

Table 7: Income and Payments for 1995

INCOME AND PAYMENTS	MioECU	
INCOME		
BUDGET FOR 1995		84.17
INCOME RECEIVED DURING 1995		
(I) MEMBERS' CONTRIBUTIONS	82.15	
(II) BANK INTEREST	1.20	
(III) MISCELLANEOUS	0.02	
(IV) UNUSED APPROPRIATIONS BROUGHT FORWARD FROM PREVIOUS YEARS	1.22	
TOTAL INCOME		84.59
VARIATION FROM BUDGET		0.42
REPRESENTING:		
INCOME IN EXCESS OF BUDGET CARRIED FORWARD FOR OFFSET AGAINST MEMBERS' FUTURE CONTRIBUTIONS		0.42
PAYMENTS		
BUDGET FOR 1995	84.17	
AMOUNTS AVAILABLE IN THE SPECIAL ACCOUNT TO MEET OUTSTANDING COMMITMENTS AT 31 DECEMBER 1994.	5.14	
TOTAL AVAILABLE APPROPRIATIONS FOR 1995		89.31
ACTUAL PAYMENTS DURING 1995	82.50	
FROM SPECIAL ACCOUNT TRANSFERRED TO INCOME.	0.07	
		82.57
UNUTILISED APPROPRIATIONS AT 31 DECEMBER 1995 CARRIED FORWARD IN THE SPECIAL ACCOUNT TO MEET OUTSTANDING COMMITMENTS AT THAT DATE.		6.74

- 80% from the general budget of the European Atomic Energy Community (Euratom);
- 10% from the UK Atomic Energy Authority as Host Organisation;
- 10% from members who have Contracts of Association with Euratom in proportion to the previous year's contribution from Euratom towards the cost of their Association Contracts.

Table 8 gives contributions from Members for 1995.

Table 8: Percentage Contributions to JET for 1995

MEMBER	%	Mio ECU
EURATOM	80.0000	65.72
BELGIUM	0.2258	0.19
CIEMAT, SPAIN	0.3489	0.29
CEA, FRANCE	1.8388	1.51
ENEA, ITALY	1.6903	1.39
RISO, DENMARK	0.0741	0.06
LUXEMBOURG	0.0012	0.00
JNICT	0.0730	0.06
KFA, GERMANY	0.7221	0.59
IPP, GERMANY	2.4244	1.99
KFK, GERMANY	0.9921	0.81
NFR, SWEDEN	0.2168	0.18
SWITZERLAND	0.5257	0.43
FOM, NETHERLANDS	0.3663	0.30
UKAEA	10.5005	8.63
	100.0000	**82.15**

FINANCIAL TRANSACTIONS	MioECU
CUMULATIVE COMMITMENTS	1,566.6
CUMULATIVE PAYMENTS	1,544.8
UNPAID COMMITMENTS	21.8
AMOUNT CARRIED FORWARD IN THE SPECIAL ACCOUNT	6.7
AMOUNT AVAILABLE FROM 1993 AND 1994 TO SET OFF AGAINST FUTURE CONTRIBUTIONS FROM MEMBERS	0.8

Table 9: Summary of Financial Transactions at 31 December 1995

Bank Interest

During the year funds are normally received on a quarterly basis in respect of Members' contributions and intermittently for other items. Therefore, the Project has funds not immediately required for the discharge of its commitments; these funds are placed on deposit accounts at market interest rates. During 1995, earned interest amounted to 1.20 MioECU.

Appropriations from Earlier Years

Unused payment appropriations and excess income over budget of 1.22MioECU arising in 1993 were transferred to income in 1995.

Summary

Table 9 summarises the financial transactions of the JET Joint Undertaking as at 31 December 1995, which have yet to be audited. The final audited accounts will be published in due course.

Contracts Service

Contracts Activity

In 1995, contract activity took place as set out in Table 10.

Many of the larger contracts involved advance and retention payments for which bank guarantees were required by JET. The total value of guarantees held as at 31 December 1995 was 1.9MioECU.

Imports and Exports Services

Contracts Service is also responsible for the import and export of JET goods. 609 imports and 311 exports were handled in 1995. There were also 1304 issues of goods to UK firms. The total value of issues to all countries for the year was 5.953MioECU.

FORMAL TENDER	SUPPLY	SERVICE	PERSONNEL	TOTAL
ACTIONS: NUMBER	58	2	32	92

CONTRACTS PLACED	MAJOR (>75KECU)	MINOR (<75KECU)	DIRECT ORDERS	AMENDMENTS AND WARRANTS	TOTAL
QUANTITY	64	4,236	12,633	839	17,772
VALUE MIOECU	7.450	17.809	2.654	22.964	50.877

Table 10: Formal Tender Actions and Contracts placed during 1995

Table 11: Allocation of JET Contracts

COUNTRY	TOTAL OF KECU	% OF TOTAL
UK	605,334	57.38
GERMANY	165,398	15.67
FRANCE	90,582	8.58
ITALY	59,877	5.67
SWITZERLAND	42,872	4.06
DENMARK	13,354	1.27
NETHERLANDS	17,863	1.69
BELGIUM	12,190	1.16
SWEDEN	7,006	0.66
IRELAND	1,003	0.10
OTHERS	39,713	3.76

Stores Organisation

The bulk of JET material is procured on a "just in time" basis and the stores organisation provides a receipts and delivery service for this material to the Project. The total number of such receipts in 1995 was19,287.

Administration of Contracts

The distribution of contracts between countries is shown in Tables 11 and 12. Table 11 includes all contracts with a value of 10,000 ECU and above placed prior to 1984, together with all contracts placed during the period 1984-95. Table 12 is an allocation of "high-tech" contracts, which is based on the figures shown in Table 11 but excludes all contracts below 5,000 ECU and contracts covering civil works, installation, pipework, consumables (including gases), maintenance operations and office equipment (including PCs).

Table 12: Allocation of JET "High-Tech" Contracts

COUNTRY	TOTAL OF KECU	% OF TOTAL
UK	144,788	27.89
GERMANY	144,310	27.81
FRANCE	79,374	15.29
ITALY	52,110	10.04
SWITZERLAND	35,057	6.76
DENMARK	7,448	1.44
NETHERLANDS	16,522	3.18
BELGIUM	5,080	0.98
SWEDEN	4,566	0.88
IRELAND	402	0.08
OTHERS	29,313	5.65
TOTALS	**518,970**	**100.00**

	DEC 1993	DEC 1994	DEC 1995
UKAEA	228.5	218.5	227.5
EURATOM	143.0	127.0	117.0
DGXII	7.0	6.0	6.0
TOTAL	**371.5**	**351.5**	**350.5**

Table 13: JET Staffing Position over 1993.95

Personnel Service

Staffing Position

JET's staffing position has been stabilised this year after several years of declining team strength (Table 13) and is in line with approved staffing projections. A slight increase in staff numbers will be required to meet work programme needs in 1996.

Twenty-six team posts were vacated in 1995 by staff departures (7.4% of strength). Eleven Euratom staff left (17 in 1994), including two retirements, two moving to ITER and six gaining positions in the Commission. UKAEA staff vacated 15 posts; of which there were six retirements and two departures to ITER.

New UKAEA staff assignments to the Project filled 24 vacant posts, including two at JET Group Leader level. One new Euratom Division Head was recruited. Euratom recruitment at JET is now limited mainly to the management levels. There were 255 individual contract personnel at JET at the year end, charged to Title 3 of the JET budget.

The JET team now comprises 64% British staff (2% more than in 1994) as a result of UKAEA recruitment and departures of Euratom staff, especially French and Italian (Fig 47).

Promotions

During the year, three existing team staff were selected to fill posts at Group Leader level and one was promoted to Division Head. Following the annual promotion exercise, 35 team staff were promoted to a higher grade.

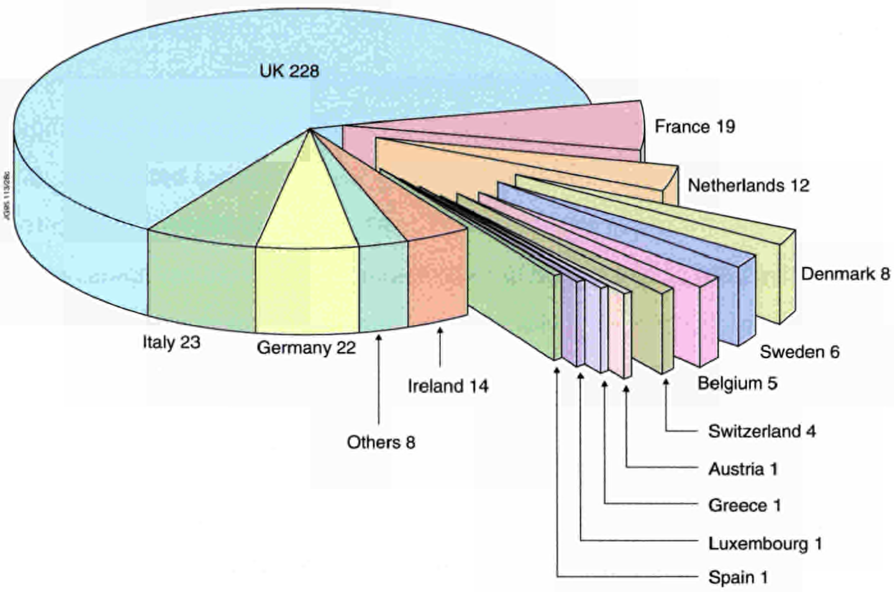


Fig.47: Composition of JET Team by nationality

Conditions of Service

Team staff received the usual inflation-related pay rises, and UKAEA or Euratom pay increments and bonuses were awarded, following reviews of staff performance where necessary.

The staff appraisal system at JET was reviewed and managers given new guidance on the completion of annual staff reports.

The UKAEA Retention of Experience Allowance was paid to the 209 eligible UKAEA team staff in post on 31 December 1995, at a cost of 1.05 MioECU.

Staff Relations

JET Management had four formal meetings with the Staff Representatives Committee during 1995. Working arrangements at JET have been discussed with staff representatives, in view of the continuation of rosters for a 6-day week, occasional Sunday and Public Holiday working and the prospect of night-shifts for tritium operations. A guidance note was prepared setting out Management's aims in organising the work programme and the demands which may be placed on team staff on a regular or exceptional basis.

Consultants

Ten consultants were appointed by contribute to specific scientific/technical work. The man-day total in 1995 was 322, considerably more than in previous years reflecting the contribution of a Finnish consultant who could not at the time be taken under the Assigned Associate Staff Scheme, pending Finland becoming a member of JET.

Assigned Associate Staff

The Associations provided a total of 27.7 man-years of effort to JET during 1995, slightly lower than in 1994.

Tables 14 and 15 show the contributions made by the Associations in 1995 and the distribution of the Assigned Associated Staff within the Project.

Visiting Scientists

JET selects Visiting Scientists to be appointed through the UKAEA as Temporary Research Associates. During 1995, four new appointments were made, including two non-EU nationals. There were six Visiting Scientists on site at the year-end.

JET Fellows

During the first half of 1995, the last three JET Fellows (2 scientists and 1 engineer) selected under the Commission's Human Capital and Mobility scheme began their

LABORATORY		MAN-YEARS 1995	MAN-YEARS 1994
UKAEA	(UK)	12.5	12.0
IPP	(GERMANY)	4.0	4.6
NFR	(SWEDEN)	3.0	2.8
ENEA	(ITALY)	2.5	2.7
CEA	(FRANCE)	1.6	2.9
JNICT	(PORTUGAL)	1.4	1.1
CRPP	(SWITZERLAND)	1.4	2.1
KFA	(GERMANY)	0.7	0.0
CIEMAT	(SPAIN)	0.5	0.9
FOM	(NETHERLANDS)	0.1	0.0
TOTAL		**27.7**	**29.1**

Table 14: Staff assignments from Associated Laboratories during 1994-95

fellowships. In October, the Training and Mobility of Researchers scheme was approved by the Commission. Seven applicants were selected for JET Fellowships (5 scientists and 2 engineers).

In total 26, Fellows (16 scientists and 10 engineers) were on site at the end of the year. Four of the research projects were at post-doctoral level, with the remainder at post-graduate level.

Students

In 1995, fewer students were recruited, for budgetary reasons. There were 29 students during the year, 21 of whom stayed for long-term placements of 13 weeks or more. Eight of the students were British and the majority of the other students were either French or German.

Training

During 1995, individual staff needs for skills training were met where possible through attendance on external short courses (about 60 courses). Safety training is described below.

170 team staff, composed of about 50% UKAEA and 50% Euratom continued to receive tuition in French, German or Italian. 26 candidates passed the London Chamber of Commerce and Industry examinations in the relevant language held in 1995, an 81% success rate.

Seven staff are supported by JET on long term courses for professional development.

Up to 140 JET personnel (from all personnel categories) attended major Conferences or Workshops during the year, notably the 22nd EPS Conference in the UK and the SOFE Conference in USA.

DEPARTMENT	MAN-YEARS 1995	MAN-YEARS 1994
TORUS AND MEASUREMENT	13.6	17.5
HEATING AND OPERATIONS	7.5	5.9
DIRECTORATE AND DATA ANALYSIS AND MODELLING	6.6	5.7
TOTAL	**27.7**	**29.1**

Table 15: Assigned Staff within the Project during 1994-95

Health Physics and Safety

The Director is responsible for safety and is required by the JET Statutes to undertake all organisational measures to satisfy relevant safety requirements. JET continues to meet all the requirements of relevant UK and EC legislation and, in accordance with the Host Support Agreement, JET complies with the Safety Regulations of the Host Organisation. Responsibilities for Safety and Health Physics matters are discharged by the Health Physics and Safety Group within the Co-ordinating Staff Unit.

Safety

The Safety Group provides a general safety service that incorporates safety related training, monitoring, co-ordination and planning of statutory inspections. It ensures there is an awareness of any new legal requirements or changes to existing legislation.

Following a request from the Safety Directorate Group of UKAEA, new management of safety arrangements were introduced at JET during the year. The arrangements introduced a new Permit to Work and Safety Assessment Procedure to ensure that: (1) all safety related aspects of planned work were adequately assessed and analysed; and (2) work is authorised by a competent Area Responsible Officers, formally appointed through the management line. Training for the new system was undertaken prior to its introduction, with 359 persons attending. The opportunity was taken to revise the Control of Substances Hazardous to Health (COSHH) and hot working procedures at this time.

The safety related training provided during the year was dominated by the two in-vessel interventions, the tile exchange shutdown in March/April and the Mark II divertor shutdown that commenced in June and continued for the remainder of the year. These shutdowns resulted in the safety training to be in support of the progress of the programme and as such the numbers of courses and those attending are not comparable with the previous year which was mainly an operations year. The figures given in brackets are those for 1994. Safety Induction continued to be the requirement for new staff with 530 (320) persons attending. Basic Radiological Protection courses were attended by 232 (67) while 229 (46) attended Beryllium Introduction courses. There were 139 (30) operators trained as pressurised suited workers with their training being assessed by an independent body. Cardio- pulmonary resuscitation courses continue to be well supported with 199 (220) attending. In total, safety related training addressed 39 topics with 3095 (1474) attendees.

Throughout 1995, there were 122 (78) accidents reported to the Safety Section and all but two were categorised as minor. Two accidents were reported to the Health and Safety Executive, since these resulted in more than three days absence from work (a condition of RIDROR). There were 3 (1) Incident Review Panels and 1(0) Working Group to review electrical isolation of the machine, established during 1995. The implementation of the recommendations made by the Review Panels is monitored by the Safety Section of the Group.

Health Physics

The Group provides a comprehensive radiological protection and occupational hygiene service, dosimetry service, beryllium analysis and environmental monitoring both on and off-site.

From the beginning of the year, arrangements were in hand to construct a new Health Physics Laboratory at JET. There is now considerable experience at JET of beryllium analysis to ensure the new laboratory was designed to a high standard and with a capability of providing a rapid service of a large number of analyses. The laboratory was commissioned in time for the start of the Mark II Divertor shutdown in June and was able by shift arrangements to provide a service 20 hours per day. The total number of analyses of personal air samples was 12392 (4715), and all exposures were below the maximum exposure limit for beryllium of 2μg/m^3 specified in the UK's Control of Substances Hazardous to Health.

Throughought the year, there were three interventions into the torus vessel with the tile exchange shutdown lasting three weeks in March/April and the Mark II Divertor shutdown commencing in June and continuing for the remainder of the year. At any torus intervention, the radiation levels are made to aid in determining work schedules to control personal exposure. The maximum dose rate measured in-vessel in March was 162 μSv/h while the maximum dose rate measured in June was 125 μSv/h.

The collective dose accrued as a result of torus intervention was 0.241 manSv with the total dose for all radiation work on the Project was 0.251 manSv. These figures are approximately ten times the values for 1994 (0.021 manSv and 0.026 manSv, respectively), which was predominantly an operations year with only short term interventions. The maximum individual dose arising from in-vessel work was 4.53 mSv (1.37 mSv) which was within the JET dose limitation policy and well below UK statutory limits.

Emergency Exercises

As part of the preparations for the extensive in-vessel working planned for the year, a casualty evacuation exercise was organised to take place in the In-Vessel Training Facility. The objectives of the exercise were to test the Incident Response Team and personnel involved in rescuing a collapsed casualty dressed in a pressurised air suit.

The exercise successfully demonstrated that the procedures ensured the rapid rescue of a casualty from in vessel.

As part of the preparations for the D-T operations (DTE-1), JET has produced an Emergency Plan that was endorsed during the year by the JET Fusion Safety Committee. Subsequently, personnel were appointed to key positions in the Site Emergency Organisation and throughout the year training was provided. Before the trace tritium commissioning phase of the AGHS, evacuation and mustering exercises were held. Table top exercises were held before a full exercise was held testing aspects of the Emergency Plan for an on-site incident. The exercise was witnessed by personnel from the Health & Safety Executive and representatives of the Director of Safety, UKAEA. The exercise was judged to be a successful demonstration of the emergency procedures in place at JET.

Press and Public Relations

1995 was a busy year for Public Relations at JET. There was a very considerable workload and a background of important events for JET in the public arena. Also there were personnel changes following the retirement of the previous Head of the Group, after many years serving fusion research and the Project. The Public relations approach of the Project was re-assessed and a plan was set out against a clear set of agreed objectives.

Initial work for a new film about JET was a major task. Filming was scheduled for 1996 to include, early in the year, significant archive footage of in-vessel work on the installation of the MkII divertor and later on the tritium experimental campaign. During 1995 funds were raised to supplement JET internal funds allocated to the film. A number of the Contract of Association Laboratories have given generous contributions as have JET supplier companies.

During the year the JET World Wide Web server was made available to the general public (http://www.jet.uk). It has resulted in a considerable number of requests for further information from interested visitors to the web site. Development of the web site will continue so as to ensure it remains a dynamic, interesting and recognised source of information; for instance it is planned to incorporate up to date reports on the status of JET.

A systematic programme for the up date and renewal of our printed publicity material was also started. This will lead to the publication of a set of brochures and fact sheets designed to be accessible to a broad public and to constitute also a full information pack (with the film) which will have educational value (fusion is now part of the National curriculum for UK schools).

JET was pleased to receive 153 visiting groups during the year. One of the most important was by a delegation from the European Parliament Committee on

Research technological Development and Energy (responsible for Parliamentary scrutiny of the EU Fusion Programme). Other distinguished visitors included His Excellency M. Jean Gueginou, the French Ambassador to the UK, Mr Richard Page MP the British Minister responsible for fusion research and Admiral Sir Kenneth Eaton the new Chairman of the UK Atomic Energy Authority. In October JET was host to a meeting of the Science and Technology Committee of EURATOM chaired by Dr. Derek Pooley the Chief Executive of the UKAEA. There were several media visits including filming by Dutch and German TV crews.

Particular importance is attached to informing JET's local community about developments at JET and the maintenance thereby of positive relations. One of the methods employed for achieving this was to set up a series of visits by delegations from all the relevant Local Authorities. In addition care is taken to inform the local media using both written material and visits to the site.

Publications Group

The Publications Group provides a Graphics, Phototypesetting, Photographic and Reprographics service for the Project. The Group is led by the Publications Officer, who is also responsible for the clearance, production and distribution of all JET documents. In addition, the Group arranges attendance at major international Conferences, and prepares papers and posters for these Conferences and Meetings.

During 1995, JET hosted the 22nd European Physical Society Conference on Plasma Physics and Controlled Fusion which was held at the Bournemouth International Centre during the period 3rd-7th July. The Publications Group provided the Scientific Secretariat and was responsible for other technical services at the meeting.

Conferences

JET provided contributions to a number of major meetings, as follows:

- 15th Topical Meeting on Tritium Technology, Lake Maggiore, Italy (June 1995). (1 Invited Paper, 8 Posters).
- 22nd European Physical Society Conference on Plasma Physics and Controlled Fusion, Bournemouth, UK. (July 1995) (4 Invited Papers and 62 Posters).
- 16th Symposium on Fusion Engineering (SOFE-16), Champaign, USA (October, 1995). (3 Invited Papers and 13 Posters).
- 37th Annual Meeting of the American Physical Society - Division of Plasma Physics, Louisville, USA (November 1995) (1 Invited Paper and 8 Posters).

In total, the Group prepared 156 Papers and 140 Posters for presentations to about twenty different Conferences throughout the world. Arrangements were also made by the Group for 120 participants to attend these major meetings during the year.

Publications

The Publications Office is responsible for the clearance and production of all JET presentations (including Journal Papers, Reports, Conference Papers, Poster Contributions, Lectures, etc). Throughout 1995, over 430 publications were cleared for external presentation.

The Group also produced one volume of the Book of Abstracts and four volumes of the Proceedings of the 22nd European Physical Society Conference on Plasma Physics and Controlled Fusion. In addition, the Group edited and prepared the Invited Papers of this Conference, which were published in the journal Plasma Physics and Controlled Fusion (Volume 37, Supplement 11A, November 1995).

During the year, 276 documents were published from the Project and the full list is included as an Appendix to the 1995 JET Progress Report. This total included 10 JET Reports, 82 JET Preprints, 7 JET Internal Reports, 3 JET Technical Notes and 6 JET Notes. All these documents are produced and disseminated by the Group on a wider international distribution. In addition, 122 papers were published in scientific Journals.

In total, the Group produced 3659 new illustrations and figures and took 4617 new photographs for publications and other disseminated material during 1995.

APPENDIX I
The JET Council

Member	Representative
The European Atomic Energy Community (EURATOM)	P. Fasella C. Maisonnier (Vice-Chairman, from March)
The Belgian State, acting for its own part ('Laboratoire de Physique des Plasmas de l'École Royale Militaire - Laboratorium voor plasma-physica van de Koninklijke Militaire School') and on behalf of the Université Libre de Bruxelles' ('Service de physique statistique, plasmas et optique non-linéaire de l'ULB'); and of the 'Centre d'Études de l'Energie Nucléaire (CEN)/'Studiecentrum voor Kernenergie' (SCK)	P.E.M. Vandenplas G. Michaux
The Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain	A. Grau Malonda
Commissariat à L'Énergie Atomique (CEA), France	D. Escande J-P. Schwartz (to February) Mrs. C. Cesarsky (from February)
The 'Ente per le Nuova Tecnologie, l'Energia e l'Ambiente' ('ENEA') representing all Italian activities falling within the Euratom Fusion Programme including that of the 'Consiglio Nazionale delle Ricerche', (CNR); dell'Energia Nucleare e delle Energie Alternative (ENEA), Italy	R. Andreani C. Mancini
The Hellenic Republic (Greece)	A. Katsanos A. Grecos (from January)
The Forskningscenter Risø (Risø), Denmark	H. von Bülow (Chairman, retired March) J. Kjems
The Grand Duchy of Luxembourg (Luxembourg)	Mrs. S. Lucas R. Becker
The Junta Nacional de Investigação Cientîfica e Tecnológica (JNICT), Portugal	C. Varandas Mrs. M.E. Manso
Ireland	F. Turvey P. O'Neill
The Forschungszentrum Jülich GmbH (KFA), Federal Republic of Germany	G. von Klitzing
The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. Institut für Plasmaphysik (IPP), Federal Republic of Germany	K. Pinkau
The Swedish Natural Science Research Council (NFR), Sweden	G. Leman H. Wilhelmsson (until March) T. Hellsten (from May)
The Swiss Confederation	F. Troyon (Vice-Chairman until March, then Chairman) P. Zinsli
The Stichting voor Fundamenteel Onderzoek der Materie (FOM), The Netherlands	M.J. van der Wiel K.H. Chang
The United Kingdom Atomic Energy Authority (UKAEA)	J.R. Bretherton D.R. Sweetman

Secretary: J. McMahon, JET Joint Undertaking

APPENDIX II
The JET Executive Committee

Member	Representative
The European Atomic Energy Community (EURATOM)	J.P. Rager P.J. Kind
The Belgian State, acting for its own part ('Laboratoire de Physique des Plasmas de l'École Royale Militaire - Laboratorium voor plasma-physica van de Koninklijke Militaire School') and on behalf of the Université Libre de Bruxelles' ('Service de physique statistique, plasmas et optique non-linéaire de l'ULB'); and of the 'Centre d'Études de l'Energie Nucléaire (CEN)/'Studiecentrum voor Kernenergie' (SCK)	R. Vanhaelewyn P.E.M. Vandenplas (from November)
The Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain	F. Manero A. Grau Malonda (from June)
Commissariat à L'Énergie Atomique (CEA), France	R. Gravier Mrs. P. Livanos
The 'Ente per le Nuova Tecnologie, l'Energia e l'Ambiente' ('ENEA') representing all Italian activities falling within the Euratom Fusion Programme including that of the 'Consiglio Nazionale delle Ricerche', (CNR); dell'Energia Nucleare e delle Energie Alternative (ENEA), Italy	A. Coletti F. Pecorella
The Hellenic Republic (Greece)	N. Chrysochoides
The Forskningscenter Risø (Risø), Denmark	Mrs. L. Grønberg V.O. Jensen
The Grand Duchy of Luxembourg (Luxembourg)	C. Bartocci
The Junta Nacional de Investigação Cientîfica e Tecnológica (JNICT), Portugal	J. da Costa Cabral F. Serra
Ireland	F. Turvey (Chairman) D. Taylor
The Forschungszentrum Jülich GmbH (KFA), Federal Republic of Germany	V. Hertling
The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. Institut für Plasmaphysik (IPP), Federal Republic of Germany	Mrs. I. Zilker-Kramer
The Swedish Natural Science Research Council (NFR), Sweden	G. Leman (Vice-Chairman) L. Gidefeldt
The Swiss Confederation	M. Tran S. Berthet
The Stichting voor Fundamenteel Onderzoek der Materie (FOM), The Netherlands	A. Verhoeven
The United Kingdom Atomic Energy Authority (UKAEA)	D.C. Robinson T. Conlon

Secretary: J. McMahon, JET Joint Undertaking

APPENDIX III
The JET Scientific Council

Members appointed by the JET Council

K. Lackner (Chairman)
EURATOM-IPP Association
Max-Planck-Institut für Plasmaphysik
Boltzmannstraβe 2
D-85748 Garching bei München
Federal Republic of Germany

C. Alejaldre
Centro de Investigaciones Energéticas
Medioambientales y Tecnológicas (CIEMAT)
Avenida Complutense 22
E-28040 Madrid 3, Spain

R. Bartiromo
EURATOM-ENEA Association
ENEA Centro di Frascati
Casella Postale 65
I-00044 Frascati/Roma, Italy

F. Engelmann
NET Team
Max-Planck-Institut für Plasmaphysik
Boltzmannstraβe 2
D-85748 Garching bei München
Federal Republic of Germany

M. Gasparotto
EURATOM-ENEA Association
ENEA Centro di Frascati
Casella Postale 65
I-00044 Frascati/Roma, Italy

A. Grosman
EURATOM-CEA Association
Département de Recherches sur la Fusion Contrôlée
Centre d'Études Nucléaires Cadarache
Boîte Postale No.1
F-13108 St. Paul lez Durance, France

T. Hellsten (Honorary Secretary)
EURATOM-NFR Association
Royal Institute of Technology
Alfven Laboratory
Department of Fusion Plasma Physics
S-10044 Stockholm, Sweden

F. Hofmann
EURATOM-SUISSE Association
Centre de Recherches en Physique des Plasmas
Ecole Polytechnique Fédérale
21 Avenue des Bains
CH-1007 Lausanne, Switzerland

P. Lallia
DG-XII, European Commission
200, Rue de la Loi
B-1049 Brussels, Belguim

D. Moreau
EURATOM-CEA Association
Département de Recherches sur la Fusion Contrôlée
Centre d'Études Nucléaires Cadarache
Boîte Postale No.1
F-13108 St. Paul lez Durance, France

D.C. Robinson
EURATOM-UKAEA Association
UKAEA Government Division
Culham Science and Technology Centre
Abingdon, Oxfordshire, OX14 3DB
United Kingdom

F.C. Schueller
EURATOM-FOM Association
FOM Instituut voor Plasmafysica 'Rijnhuizen'
Postbus 1207 - Edisonbaan 14
NL-3430 BE Nieuwegein, The Netherlands

D.R. Sweetman
EURATOM-UKAEA Association
UKAEA Government Division
Culham Science and Technology Centre
Abingdon, Oxfordshire, OX14 3DB
United Kingdom

F. Wagner
EURATOM-IPP Association
Max-Planck Institut für Plasmaphysik
Boltzmannstraβe 2
D-85748 Garching bei München
Federal Republic of Germany

R. Weynants
EURATOM-EB:BS Association
Laboratoire de Physique des Plasmas/
Laboratorium voor Plasmafysica
Ecole Royale Militaire/Koninklijke Militaire School
Avenue de la Renaissancelaan, 30
B-1040 Brussels, Belgium

G. Wolf
EURATOM-KFA Association
Forschungszentrum Jülich GmbH
Institut für Plasmaphysik, Postfach 1913
D-52425 Jülich 1, Federal Republic of Germany

Staff Secretary: M.L. Watkins, JET Joint Undertaking