JOINT EUROPEAN TORUS JET

JET JOINT UNDERTAKING

ANNUAL REPORT 1984

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EUR-JET-AR7

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AUGUST 1985

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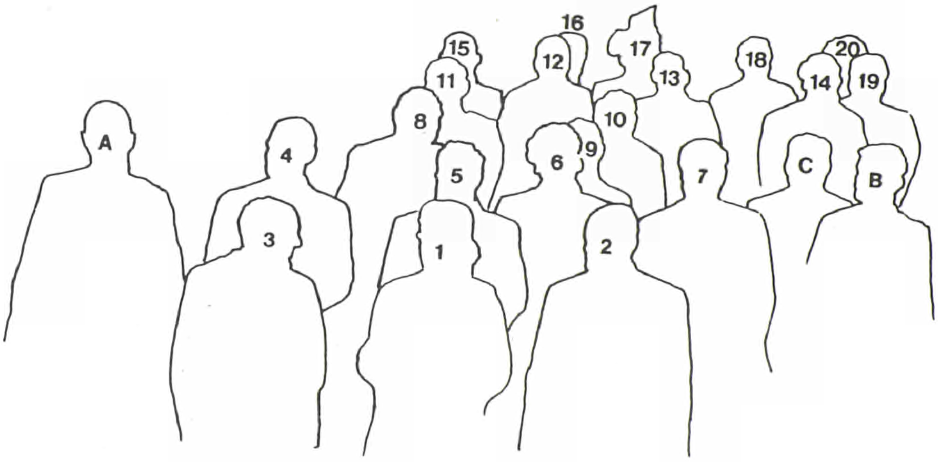


The JET Opening Ceremony, 9 April 1984

1. Her Majesty Queen Elizabeth II
2. President François Mitterrand, President of the French Republic
3. Prof. J. Teillac, Chairman of the JET Council
4. H.R.H. The Duke of Edinburgh
5. M. Gaston Thorn, President of the Commission of the European Communities
6. Mme Liliane Thorn-Petit
7. M. J. Auroux, French Minister of State for Industry and Research
8. Dr Hans-Otto Wüster, Director of the JET Joint Undertaking
9. Sir William Heseltine, Deputy Private Secretary to Her Majesty
10. Baroness Elles, Vice President of the European Parliament
11. Sir Ashley Ponsonby, Lord-Lieutenant for Oxfordshire
12. Dr P.H. Rebut, Deputy Director of the JET Joint Undertaking
13. Commandant Bourgoin, Aide to President Mitterand
14. Vicomte Davignon, Vice President of the Commission of the European Communities
15. G.W. O'Hara, Associate Director of the JET Joint Undertaking
16. Dr R.J. Bickerton, Associate Director of the JET Joint Undertaking
17. Lady Martha Ponsonby
18. Lieutenant-Col. Blair-Stewart-Wilson
19. C. Thiery, Interpreter to President Mitterrand
20. Lady Susan Hussey

A Detective
B Detective } names unknown
C Aide

Preface

A major objective of the JET Project for 1984, the first full year of operation, was to reach and then consolidate the design performance of the machine in its basic configuration with ohmic heating only. I am pleased to report that this was fulfilled. Plasma currents of up to 3.7 MA were obtained for several seconds within overall pulse lengths of 15 seconds. Plasma temperatures of 3 keV (35 million degrees), densities of $3.5\times10^{19}\,m^{-3}$ and a record energy confinement time of 0.8 seconds were recorded. These results established JET as the leading tokamak in the world.

The performance of the machine is now being extended, principally by the addition of neutral beam and radio frequency heating systems. During a scheduled shut-down period towards the year-end the first two radio frequency antenna/generator units were installed and since then they have been operated successfully. Further diagnostic systems were also installed during this shut-down.

The year inevitably brought some problems. The level of impurities in the plasma has been higher than anticipated; steps have since been taken to reduce this level by coating the whole of the inside of the vacuum vessel with carbon. Also, unexpected vertical disruptions of the plasma occurred, one of which was of particular concern as it resulted in substantial forces being transmitted to the vacuum vessel which, if repeated, could have caused serious damage to the vessel. Modifications to the vessel supports and to the feedback control system have since been introduced. Furthermore, the neutral beam heating programme suffered delays primarily due to welding problems with some highly stressed components. Following design changes to certain high heat load dissipating elements, the assembly of the first beamline system was brought close to completion.

Turning to the funding of the Project, I record that the budgets for 1984 were approved at 75.5 MioECU for commitments and 107.1 MioECU for both income and payments.

As was reported last year a special working party on the manpower requirements for the Operational Phase of JET was convened at the request of the JET Council early in 1984. Following its report the JET Council decided that, for the time being, the total number of personnel in post should not exceed 650 of which 484 should be team staff. It decided to review again JET's personnel needs at the beginning of 1986 at the latest, or earlier if operational conditions clearly indicate that 625 people in post would not allow a successful and vigorous programme to be pursued.

Successive annual reports have drawn attention to the difficulties which JET has experienced in recruiting suitable staff. In co-operation with several of the Associated Laboratories a major effort was made last year to attract candidates. The results were satisfactory in terms of the numbers who applied, although only 15% came from within the Associations. It is disappointing to note, however, that almost a third of candidates to whom offers of employment were made, declined. In spite of this pattern, I am happy to report that with the help of contract staff JET was for the first time almost up to complement at the end of 1984.

The scheme for the assignment of Associate staff to JET, which was introduced at the end of 1981, is operating satisfactorily. During 1984, 65 staff from 9 Associated Laboratories were assigned to work on the Project. This represents 15 man-years compared with 8 man-years in 1983.

During the year also, shift working was introduced in the Project for the first time.

The JET Council met three times, the JET Executive Committee seven times and the JET Scientific Council three times during the year under review. I record with gratitude the support that I have received from my colleagues on the JET Council. On their behalf I express my appreciation also to the members of the two other committees for their constant commitment and important contribution to the Project.

It is with sadness that I refer to the deaths in December 1984 of Professor G Holte, a Swedish delegate to the JET Council and JET Executive Committee since their inception in 1978, prior to which he served on the JET Management Committee and the Interim JET Council, and in July 1985 of Mr M F van Donselaar, a representative to the JET Executive Committee from the Netherlands since 1979. Their wise councels will be greatly missed.

In June of the year under review, Mr J Teillac retired from the Chairmanship of the JET Council. It is well to recall that he had also been Chairman of the Interim JET Council when the framework for the Joint Undertaking was being drawn up. He was thus at the helm, so to speak, for over six years. It is appropriate, and my pleasant duty therefore to express on behalf of the JET Council my appreciation for his vision and diplomacy over all this period.

The United Kingdom Atomic Energy Authority maintained its high level of support to the Project in terms of staffing, services and advice. The demands on Culham Laboratory are particularly heavy, but in meeting them unfailingly it has contributed substantially to JET's success.

I also thank the Commission of the European Communities and their various services at Brussels and Luxembourg for their continuing assistance. I record my appreciation also of the very active role played by the Associated Laboratories in many aspects of the Project.

Finally, I pay tribute to all those who work on JET for their substantial achievements during the year under review. The team's success was fittingly marked by the nomination in 1984 by President Mitterrand of Dr P H Rebut, Deputy Director of the Project, as Chevalier de la Legion d'Honneur.

JET is at the forefront of fusion research. Maintaining this position will call for scientific skill, imagination and ingenuity coupled with engineering competence on the part of the JET team. It will also require faith and perseverance on the part of the Members and funding authorities. Thus only can the continued success of the Project be assured.

Just as we go to final printing of this report, we have learned with great sadness and with regret of the sudden death of Dr Hans-Otto Wüster, the Director of the JET Joint Undertaking. His contribution to the formation and success of the Project to date was immense. His energy, leadership and infectious enthusiasm were qualities recognised by all of the members of the JET Council and the tributes to his memory which have come from all over the world bear testimony to this. Fusion in Europe and the world has lost a great man.

July 1985

J. Horowitz
Chairman of the JET Council

Organs of the JET Joint Undertaking

1. The JET Council

Member	Representatives
The European Atomic Energy Community (EURATOM)	P. Fasella (Vice-Chairman) D. Palumbo
The Belgian State, acting for its own part (Laboratoire de Physique des Plasmas of the Ecole Royale Militaire) and on behalf of the Université Libre de Bruxelles (Service de Chimie-Physique II of the ULB)	P.E.M. Vandenplas, Mlle. L. Buyse
The Commissariat à l'Energie Atomique, France (CEA)	J. Teillac (Chairman to June) J. Horowitz (Chairman from June)
The Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia, Nucleare e delle Energie Alternative, Italy (ENEA) (Previously known as Comitato Nazionale per l'Energia Nucleare, Italy (CNEN).)	B. Brunelli, P. Longo
The Consiglio Nazionale delle Ricerche, Italy (CNR)	
The Hellenic Republic (Greece)	A. Katsanos
The Forsøgsanlaeg Risø, Denmark (Risø)	H. von Bülow, N.E. Busch
The Grandy Duchy of Luxembourg (Luxembourg)	J. Hoffman, M. Thill (Jan.—Sept.) P. Gramegna (from Oct.)
Ireland	C. Cunningham (Jan.—March) N.V. Nowlan (from April) D. Byrne
The Kernforschungsanlage Jülich GmbH, Federal Republic of Germany (KFA)	A.W. Plattenteich
The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.—Institut für Plasmaphysik, Federal Republic of Germany (IPP)	K. Pinkau
The Swedish Energy Research Commission (SERC). (Previously known as The National Swedish Board for Energy Source Development)	Mrs. B. Bodlund, G. Holte
The Swiss Confederation	F. Troyon, P. Zinsli
The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)	C.M. Braams, C. le Pair
The United Kingdom Atomic Energy Authority (UKAEA)	A.M. Allen (Jan.—Sept.) F. Chadwick (from Oct.) R.S. Pease

2. The Director of the Project

H-O. Wüster

JET in the Euratom and International Fusion Programme

Research and Training Programme for Euratom in the field of Controlled Thermonuclear Fusion

(Euratom Fusion Programme)

Under the Euratom Treaty, the Community research programme in the field of controlled thermonuclear fusion is adopted by the Council of Ministers for periods not exceeding five years. In accordance with the decision of the Council, the programme is part of a long-term co-operative project embracing all the work carried out in nuclear fusion. It is designed to lead in due course to the joint construction of fusion power-producing prototype reactors, with a view to their industrial production and marketing. After three years of implementation, a new five-year programme is adopted which overlaps with the last two years of the previous one. The current programme, for the period 1982-86, was adopted by the Council on 25 May 1983.

The programme is implemented by means of Contracts of Association between Euratom and organisations within the member states that are active in the field, and by the JET Joint Undertaking. Part of the programme of the Joint Research Centre at Ispra is devoted to fusion technology.

In 1976, Sweden, and in 1978 Switzerland, at their request, joined the Community fusion programme, and since 1980 Spain has participated in the exchange of scientific staff. The location of fusion research laboratories involved in the Euratom fusion programme is shown in Fig. 1.

The strategic assumptions underlying the Euratom fusion programme which were recommended in 1981 by the "European Fusion Review Panel" and endorsed by the Council of Ministers when adopting the 1982-86 programme are:-

- The need to pursue a substantial programme following the tokamak route towards a demonstration fusion reactor (DEMO);
- The completion of the first stage of the programme, which is the JET project with its extensions, and carrying out programmes in support of the tokamak confinement systems;
- A reasonable effort within available resources on alternative confinement systems with reactor potential;
- The concept of a single step, NET (Next European Torus), between JET and DEMO and an increased activity towards the development of the technology required in this context, guided by conceptual studies.

The JET Project

The Council of Ministers of the European Communities on 30 May 1978 decided to build the Joint European Torus (JET) as the principal experiment of the Euratom fusion programme. To implement the Project the JET Joint Undertaking was formally established for a duration of twelve years beginning on 1 June 1978.

The decision 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".

It was also decided that the device would be built on a site adjacent to the 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.

The members of the JET Joint Undertaking are: Euratom, all its associated partners in the frame of the fusion programme including Sweden and Switzerland, and Greece, Ireland and Luxembourg, which have no Contract of Association with Euratom.

The expenditure of the Joint Undertaking is borne by Euratom 80 per cent, and the United Kingdom Atomic Energy Authority (UKAEA) 10 per cent. The remaining 10 per cent is shared between all 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 in part by personnel put at the disposal of the Undertaking by the associated institutions other than the UKAEA, and in part by staff made available by the UKAEA (Host Organisation). The former are recruited by Euratom as temporary agents: 165 such positions were foreseen in the Community budget 1984. The others remain employees of the UKAEA. Each Member having a Contract of Association with Euratom undertakes to re-employ the staff whom it placed at the disposal of the Project and who were recruited by the Commission for temporary posts, as soon as the work of such staff on the Project has been completed.

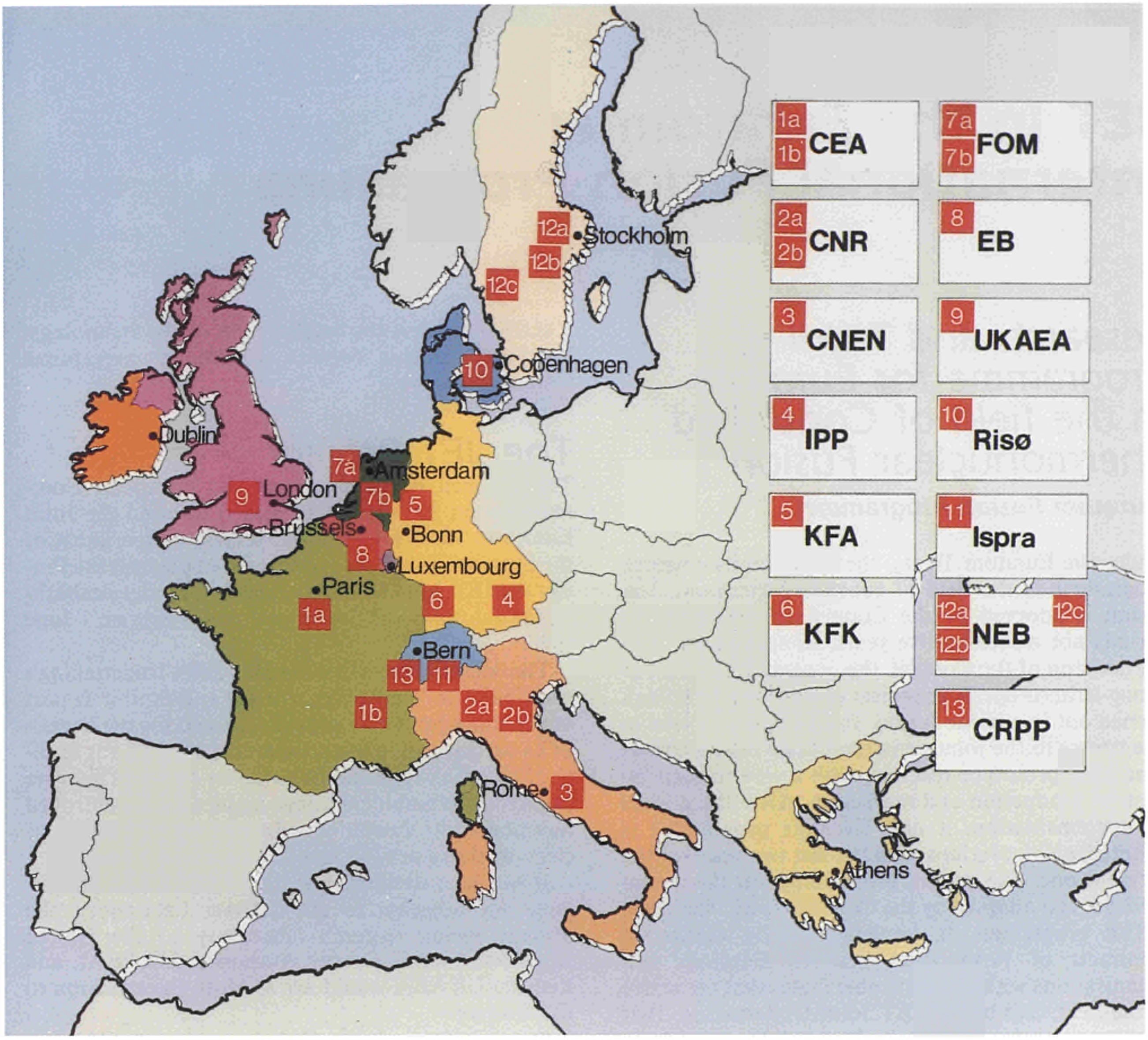


Fig. 1 Location of the organisations associated with the Euratom fusion programme.

1. *Commissariat à l'Energie Atomique, France Centre d'Etudes Nucleaires de*
   - 1a *Fontenay-aux-Roses*
   - 1b *Grenoble*
2. *Consiglio Nazionale delle Ricerche, Italy*
   - 2a *Milan*
   - 2b *Padua*
3. *Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative, Italy (formerly CNEN)*
4. *Max-Planck Institut für Plasmaphysik, Garching, Federal Republic of Germany*
5. *Kernforschungsanlage Jülich GmbH, Federal Republic of Germany*
6. *Kernforschungszentrum Karlsruhe GmbH, Federal Republic of Germany*
7. *Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands*
   - 7a *Nieuwegein*
   - 7b *Amsterdam*
8. *Etat Belge, Ecole Royale Militaire et Université Libre de Bruxelles, Belgium*
9. *United Kingdom Atomic Energy Authority, Culham Laboratory, United Kingdom*
10. *Risø National Laboratory, Risø, Denmark*
11. *Centro Commune Ricerche, Ispra, Italy*
12. *National Swedish Board for Energy Source Production, Sweden*
    - 12a *Stockholm*
    - 12b *Studsvik*
    - 12c *Gothenburg*
13. *Confédération Suisse, Centre de Recherches en Physique des Plasmas, Lausanne, Switzerland*

Objectives of JET

Detailed studies in a series of different sized tokamaks throughout the world have produced a consistent pattern of encouraging results. Plasmas with increasingly higher temperatures have been confined and controlled for progressively longer times. The knowledge gained from these smaller scale experiments indicates that a reactor will need to have large dimensions and a large plasma current.

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

- The study of plasma processes and scaling laws in regions close to those needed for a fusion reactor;
- The study of interaction of the plasma with the walls of the torus chamber. This interaction is important because it controls the purity of the plasma, which in turn determines the energy lost by radiation;
- The study of methods of heating the plasma to temperatures approaching those required for a reactor;
- The study of the behaviour of the energetic alpha-particles (the nuclei of helium) produced as a result of the fusion between deuterium and tritium.

Two of the key technological issues in the subsequent development of a fusion reactor will be faced for the first time in JET. These are the use of tritium and the application of remote maintenance and repair techniques. The physics basis of the post-JET programme will be greatly strengthened if other fusion experiments currently in progress are successful. The way will then be clear to concentrate on the engineering and technical problems involved in going from an advanced experimental device like JET to a prototype power reactor.

Large Scale Tokamaks

Of the world's three largest tokamaks, TFTR (USA) was the first to start operating in December 1982. JET (Europe) followed in June 1983. JT-60 (Japan) will begin operations in 1985. The three projects have complementary aspects. For example, JET and TFTR are designed to operate with deuterium and tritium plasmas. JT-60 has a form of divertor and will use a wide range of heating techniques.

The Construction and Development of JET

Introduction

The JET experimental device is a large tokamak in which the hot plasma is confined away from the walls by a strong suitably shaped magnetic field jointly formed by the toroidal field coils, the poloidal field coils (these include the primary coils of the transformer as well as the shaping and positioning coils surrounding its central core), and the plasma current itself (the plasma represents the secondary coil). Figure 2 illustrates the principle. The plasma current is also used to heat the plasma. However, since the plasma resistance decreases with increasing temperature, additional heating will be necessary to approach thermonuclear temperatures. On JET, this additional heating is provided by two means:first, by injecting beams of hydrogen atoms with energies far in excess of the average energy of the plasma particles (neutral beam injection); and second, by coupling high-power radiofrequency waves to the plasma ions at frequencies close to their cyclotron frequency (ICRH).

A diagram of the JET apparatus is shown in Fig. 3. Its principal design parameters are given in Table 1. The frame of the transformer with its massive eight-limbed magnetic circuit (15 m in diameter and 12 m high) dominates the machine. Within it, the plasma is

Table 1
JET's Main Design Parameters

Plasma minor radius (horizontal)	1.25m
Plasma minor radius (vertical)	2.10m
Plasma major radius	2.96m
Flat top pulse length	20s
Weight of the vacuum vessel	108t
Weight of the toroidal field coils	384t
Weight of the iron core	2800t
Toroidal field coil power (peak on 13s rise)	380MW
Total magnetic field at plasma centre	3.5T
Plasma current: circular plasma	3.2MA
D-shape plasma	4.8MA
Volt-seconds available to drive plasma current	34 Vs
Additional heating power	25MW

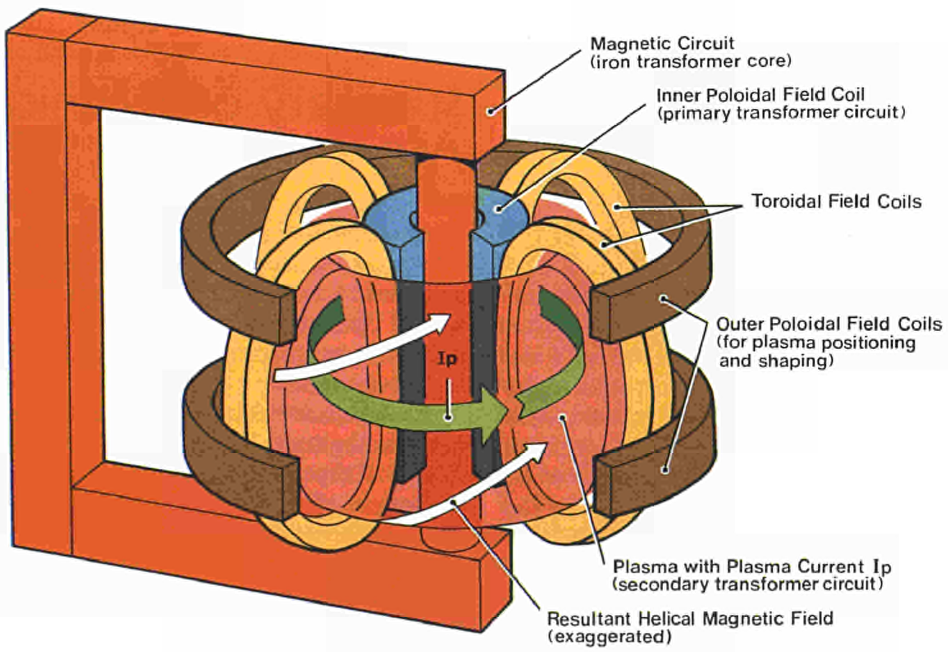


Fig. 2 Tokamak magnetic field configuration.

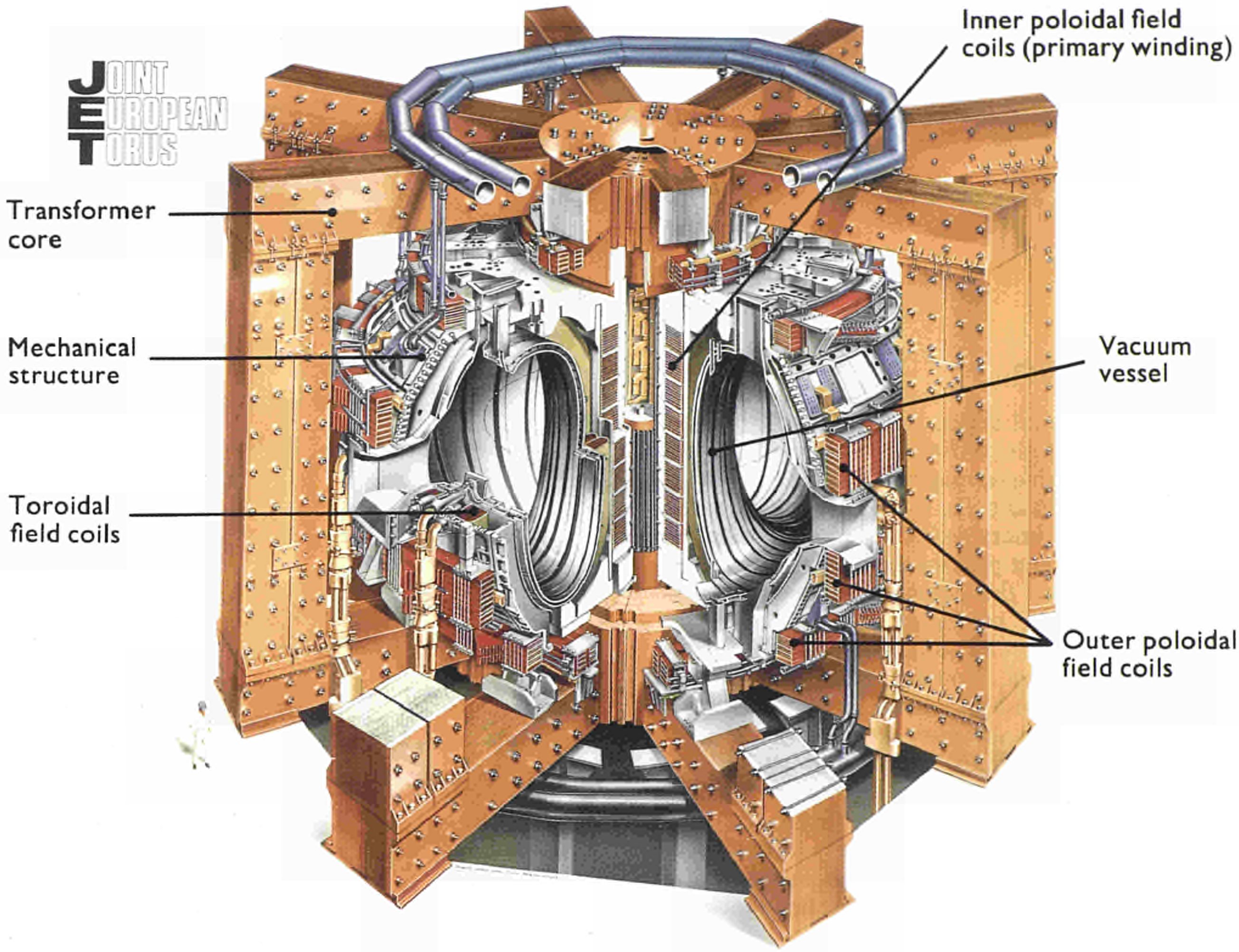


Fig. 3 Diagram of the JET Tokamak.

enclosed in a toroidal vacuum vessel of about 3 m major radius and a D-shaped minor cross section of 2.5 m in width and 4.2 m in height. The vacuum vessel is equipped with a large number of ports to connect services such as vacuum pumping, diagnostics, neutral beam injectors and ICRH power to the tokamak. For plasma start-up, a small quantity of hydrogen gas is introduced into the vacuum vessel and a large current of several million amps is induced in the gas by the transformer. So-called limiters define the outer rim of the plasma several centimeters away from the walls and absorb a large fraction of the energy and power given to the plasma. Thirty-two D-shaped coils around the minor cross section of the vacuum vessel produce the toroidal magnetic field whereas the set of poloidal field coils parallels the vacuum vessel around the central transformer column. The mutual magnetic forces of the plasma (via limiters and vacuum vessel) and of the toroidal and poloidal field coils are taken up by a massive shell-like mechanical structure. A total view of the machine is given in Fig. 4.

Initial experiments are being carried out in either hydrogen or deuterium plasmas. In the final stages of operation of JET it is planned to operate with deuterium-tritium plasmas so that fusion reactions may occur and alpha-particle heating investigated.

Summary of Technical Achievements in 1984

In the first full year of JET operation, a major aim was to reach and then consolidate the full performance of the operational equipment. This was generally achieved. A second aim was to improve the equipment where operational experience had shown it to be necessary or advantageous. A few highlights are given in this summary.

The toroidal field coils and their power supplies have been brought up to their full performance level of 67 kA. They have routinely generated a toroidal magnetic field of 3.4 T for a flat-top time of 10 seconds. The ohmic heating circuit and its poloidal field coils (P1) have been commissioned up to 60 kA premagnetisation current (design value 80 kA) and up to 100 kA of slow rise and flat top currents (design value 100 kA). They have been routinely operated at 40 kA and 80 kA respectively. Plasma currents of up

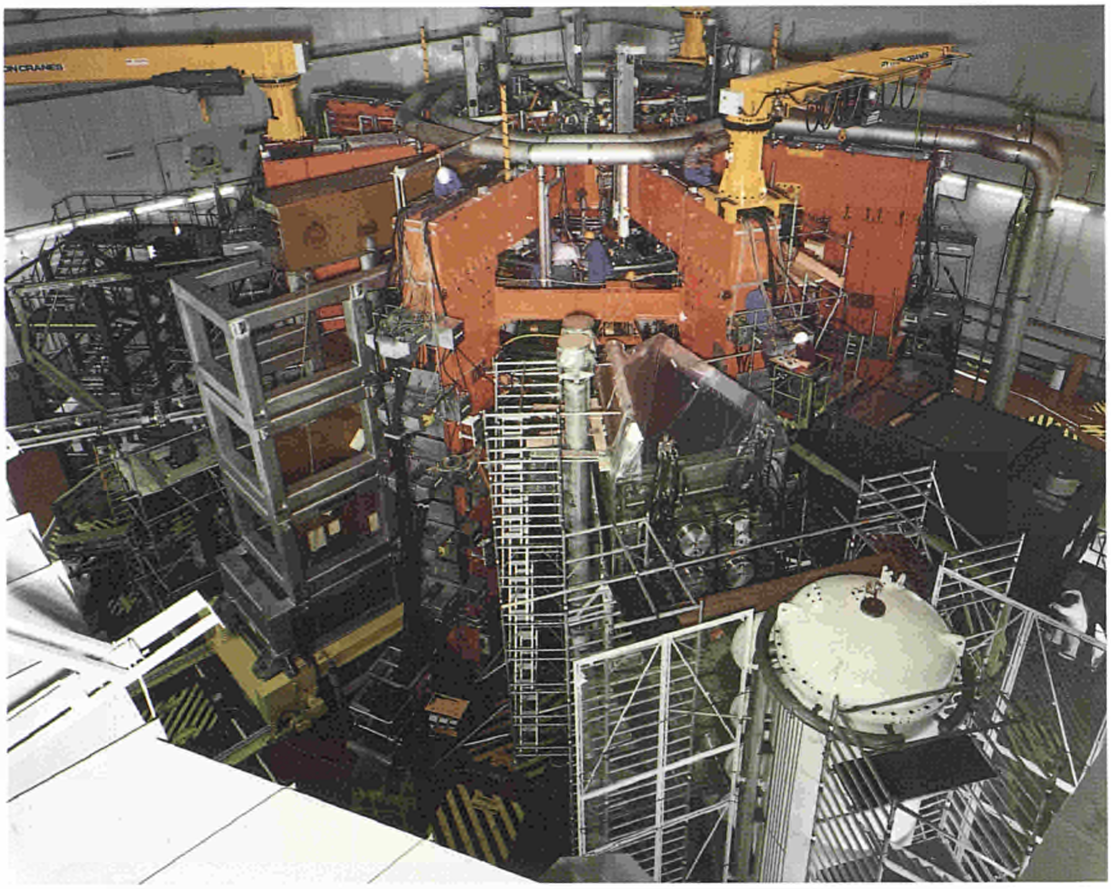


Fig. 4 View of the completed JET device showing the eight transformer limbs (in orange)

to 3.7MA with a flat top duration of several seconds were induced. Since the full flux swing of the transformer could not be applied due to limitations in the current rise time acceptable to the plasma, arrangements have been made for the reconnection of P1 coils from parallel to series operation. Modifications to the ohmic heating circuit will permit operation using the full flux swing and studies are under way to extend the plasma current range to 5MA and more. The capability of the poloidal vertical and radial field amplifiers have been doubled by adding two additional units to the two initially installed on each.

In response to the vertical instability encountered during pulse #1947, which potentially threatened to jeopardise the mechanical integrity of the vacuum vessel, several measures have been introduced. The vacuum vessel suspension has been strengthened by vertical tie bars from the horizontal ports to the lower magnetic circuit limbs and by horizontal hydraulic shock absorbers from the vertical ports to the mechanical structure. Further enhancement is being considered. Ellipticity and current range of the plasma will remain somewhat restricted until a full assessment of the situation is completed. The small signal bandwidth of the poloidal radial field amplifier has been increased from about 60 to 150Hz. Plasma shaping control during the pulse is being prepared for feeding the outer poloidal coils P2 and P3 independently of P4 (the largest one). The busbar connections have been modified accordingly and the design of the corresponding power supplies is progressing.

On the control side, successful density feed-back has been accomplished by linking the gas introduction controls to the interferometric line density signal. An extensive alarm handling package was incorporated into the controls to increase the general level of reliability and safety of operation.

In line with the policy of employing first-wall materials of low atomic number, an important fraction of the inboard wall area (about 2m in height) has been covered with graphite tiles. As for the limiters, the results from the next phase of operation together with the full evaluation of the beryllium limiter experiment in ISX-B, jointly carried out in 1984 by the Oak Ridge National Laboratory and JET, are expected to allow a decision between the further use of either carbon or beryllium. The cooling structure of the belt limiters to be installed in 1986 is now under manufacture.

Concerning additional heating, the neutral beam heating programme suffered delays with welding problems. However, after design changes to the high heat load dissipating elements, the assembly of the first beamline system was brought close to completion. The large cryopump system and the liquid helium refrigerator plant were successfully commissioned. The proton fraction of the ion sources and the focussing of beamlets were brought up to the specifications and pulses of 80kV/62A were achieved on the testbed for pulse lengths of more than 15 seconds. The PINI beam sources in the first neutral injector box are now being precommissioned at octant 8 with the high-voltage power supplies. Most of the auxiliary power units and the SF_6 tower with the high-voltage lines and snubbers are ready for operation. Assembly of the second neutral injector box is advancing.

Radio frequency heating has two antennae of different coupling properties already installed in the vacuum vessel and the first power supply and RF generator is ready to operate at the 3MW level. The second unit will be completed in early 1985. All essential components of the transmission line system were conditioned and tested at the RF testbed at Fontenay-aux-Roses prior to their installation on JET.

During the year further diagnostic systems were installed. At the end of the year, the following systems were operational:

- Bolometer Scan
- Magnetic Diagnostics
- Single Point Thomson Scattering
- Multichannel Far Infrared Interferometer (partly)
- Single Channel 2mm Interferometer
- Microwave Reflectometer (prototype)
- Hard X-ray Monitors
- Limiter Surface Temperature
- Electron Cyclotron Emission (Spatial Scan) (partly)
- Time Resolved Neutron Yield Monitor
- 2.4MeV Neutron Spectrometer (prototype)
- Neutral Particle Analyser Array (partly)
- H-alpha Monitors (partly)
- Visible Spectroscopy
- VUV Broadband Spectroscopy
- Provisional Soft X-ray Detectors
- Provisional Pulse Height Analysers
- Plasma Boundary Probe (partly)

For the active phase of JET, preparations are being made to cope with later requirements. The articulated boom to handle a one tonne load inside the vacuum vessel has been delivered and is under test. Also a number of important remote handling units—a turret truck, a radio-controlled support vehicle, and two force-feedback servo-manipulators—have been ordered or are under design. The design of the tritium recycling system is well advancing and prototype key components are being manufactured and prepared for testing.

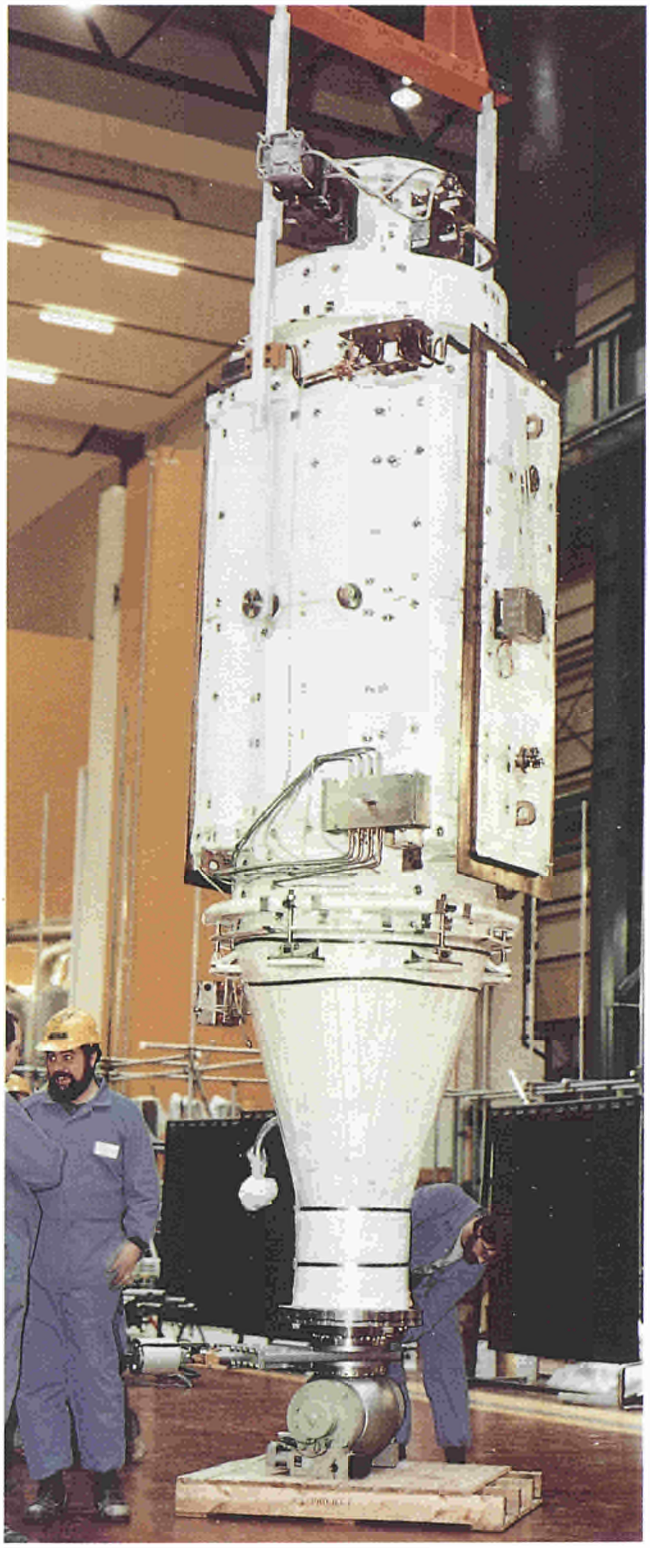


Fig.5 The high vacuum rotary valve.

Vacuum systems

The Vacuum Vessel and Pumping System

The number of new systems directly connected to the main torus vacuum increased considerably during the year. In January, the high vacuum rotary valve was welded to the port at octant 8 (see Fig.5). This is an absolute valve to isolate the box containing the neutral injector systems from the main Torus. The valve is of a novel design and provides a large aperture by means of a cylindrical rotor.

A large number of new diagnostics was also installed. Whenever possible these were connected to the Torus through conventional gate valves. In October, the first two RF antennae and their pumping systems were also installed. By the end of the year, there were about 200 sealed and 150 welded flanges for attaching equipment to the vessel. These numbers illustrate the complexity of the vacuum system and the difficulties associated with leak testing. Even so, leak testing and repairing has to date never delayed the operating programme.

The procedure used to restore clean vacuum conditions after a shutdown involving assembly work inside the vessel has become a well established and effective routine. The vessel is first carefully vacuum-cleaned and then washed by means of high pressure water jets. This latter operation requires special protection for systems that may be damaged by water. The vessel is drained through drain pipes at low points, then dried by mild baking under vacuum before leak detection can begin. The final wall conditioning for plasma operation relies on full baking and glow discharge cleaning.

Bake-out System

The vessel can be baked by circulating a hot gas through the interspace of the double-walled structure. This process out-gasses the walls and enables high vacuum conditions to be obtained. During operations in 1984, the baking plant was used routinely to keep the vessel at a temperature between 200° and 300°C. The plant has been using a temporary blower and nitrogen as the heat carrying gas.

During the October shutdown, a new blower with a single stage radial turbo compressor was installed (see Fig. 6). By the end of December, it was available to bake the vessel. This new unit, now operating with helium, can provide a gas flow rate of $25\,m^3/s$. It will be able to heat the vessel up to a temperature of 500°C. Helium is preferred to nitrogen since, as a low Z gas, a much larger leak rate can be tolerated between the interspace and the main vacuum. In addition, helium is not activated by neutrons and can be easily cleaned of contaminants, such as tritium, which may permeate through the first wall.

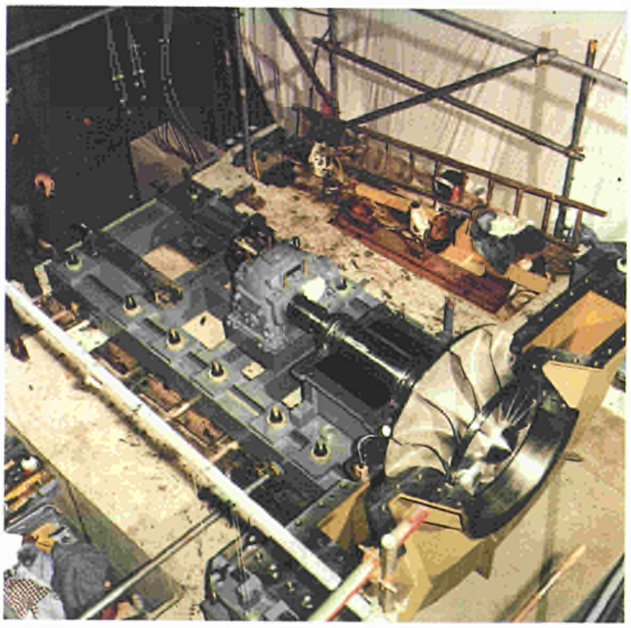


Fig. 6 Installation of the new blower for the baking plant.

Since the ports of the vessel and the vessel attachments are not double-walled, they are baked by means of electrical heaters attached to their outer surfaces. It is indeed essential to bake all elements of the vacuum system to avoid thermal stresses due to temperature gradients and recondensation of impurities on the cooler parts. The electrical baking system includes a total of 84 heating loops with feedback controlled thyristor supplies.

Glow Discharge Cleaning

Glow discharge cleaning has proved to be a simple and yet powerful means to restore satisfactory wall conditions for plasma operation.

Glow discharge is carried out with the walls of the vessel at a temperature of 300°C to optimise the removal of oxygen. The discharge is assisted with radio frequency power to decrease the pressure and enhance the impurity removal. The discharge is normally carried out at a pressure of 5×10^{-3} mbar with a DC current of 4A for each of two electrodes. After a run of 72 hours, the impurities are reduced to a barely detectable level. The hydrogen pressure is typically 2×10^{-7} mbar at a wall temperature of 250°C and 3×10^{-9} mbar at room temperature.

By the end of 1984, the effectiveness of glow discharge was somewhat reduced since one of the two electrodes had an internal short circuit. This fault was rectified in October when two more electrodes were converted bringing the total number of RF assisted electrodes to four.

Inner Protection Tiles

Initially, it was decided that the tiles protecting the bellows of the vacuum vessel should be made of Inconel since there was insufficient data available to support the use of another material. There are now indications that better plasma performances could be achieved if only low-Z materials were facing the plasma. For this reason, it has been decided to replace the Inconel tiles by graphite tiles on the inboard side of the vessel (see Fig. 7). The inboard side has been selected for this modification since the most severe plasma-wall interactions take place there. This was confirmed in October when the vessel was opened and it was found that practically all heat damage was localised inside a relatively narrow band on the inboard side along the equatorial plane. During the October shutdown, nearly one thousand tiles were fitted to cover the inboard wall over a height of 2 metres.

New Vessel Supports

Studies originating from the vertical instability that occurred during pulse #1947 have revealed that the vacuum vessel could be subjected to large vertical forces during a disruption. With the vessel supports that then existed, these forces could have reached a dangerous level with plasma currents of 4MA or more.

As a result, additional mechanical supports were designed to restrain the vessel and damp the rocking motion set up by vertical forces. These new supports include rigid vertical struts to link all main horizontal

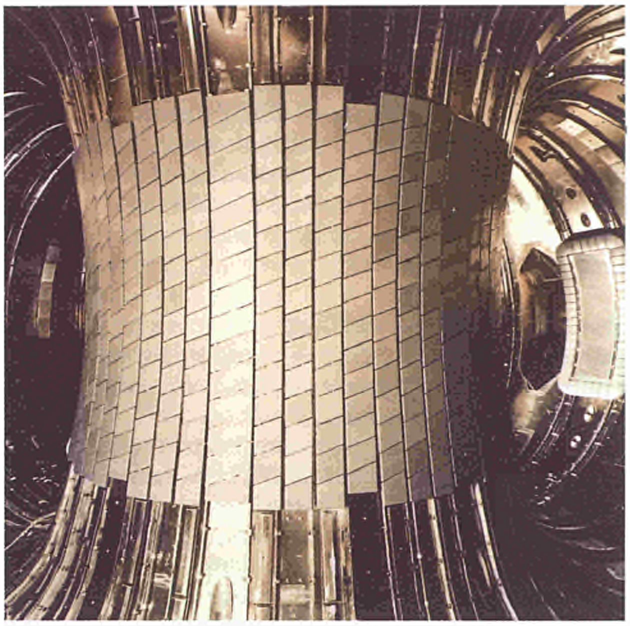


Fig. 7 Graphite tiles in the vessel.

ports to the lower limbs of the magnetic circuit, and hydraulic dampers to connect all 16 main vertical ports to the mechanical structure. These supports were installed in the October shutdown.

Gas Introduction System

The gas introduction system establishes the gas (hydrogen or deuterium) pressure for the initiation of the discharge, and then provides the additional gas required to achieve the specified plasma density. The system includes fast valves, which empty prefilled calibrated reservoirs into the vessel, and dosing valves, which bleed gas according to pre-programmed waveforms or feedback control signals.

Three gas introduction modules were operational in 1984. A non-linear response of the dosing valves, which affected the functioning of the system initially, was found to be due to control problems and rectified. Feedback control of the dosing valves was introduced in September, whereby the gas feed is automatically controlled to achieve a specified plasma density.

Belt Limiters

The design of belt limiters for JET is for two toroidal rings above and below the equatorial plane of the vessel. They will be used in conjunction with the RF antennae, which will be placed between the two rings. Each ring includes a structure with water cooling pipes and cooling fins welded to the pipes. This structure is made up of sixteen sections to allow remote replacement. The limiter plates are inserted between the fins and are thus radiation cooled. This design is attractive because of the absence of critical thermal stresses and the possibility of exchanging easily the limiter plates.

The contract to manufacture the cooling structure was placed in August 1984. By the end of 1984, the detailed manufacturing drawings and all manufacturing processes had been settled and qualified. All materials were in procurement and the manufacturing tools were essentially ready to start the prototype structure.

A contract has also been placed for the blackening of the fins of the cooling structure. The fins are made of nickel and blackening is essential to achieve the required emissivity. Plasma spraying of metal oxides under vacuum has been developed for this purpose. At the end of the year, the first samples were ready for qualification and acceptance tests.

Magnet Systems

The Toroidal Field System

The toroidal field busbars and coil system has been used routinely during 1984 at the full design value of 3.45 Tesla. For this, the power supplies have delivered their full design value current of 67 kA with a flat top time of 10 seconds. The energy of 5000 MJ delivered per pulse has been close to the maximum design value of 5500 MJ. Instrumentation channels which monitor temperatures and displacements indicated that all systems were behaving in accordance with calculations.

The short circuit detection system (DMSS) protects the toroidal field coils by removing the input voltage when a voltage imbalance is detected between adjacent coils. Spurious trips have been generated by the system when fast variations in the radial flux of the poloidal field took place, for example, in the case of a vertical instability. The trips are believed to be due to the non-axisymmetric distribution of the flux channelled by the gaps of the mechanical structure. This will be remedied by rewiring the system so that only coils in similar positions with respect to the mechanical structure are compared.

The Poloidal Field System

The poloidal field coil system includes the primary circuit and the position and shape control circuits.

The primary circuit has been commissioned and used for plasma operation up to the maximum design value of the current of 80 kA. This value has in fact been exceeded and once reached 100 kA in a faulty pulse. All displacements measured during this pulse indicated a sound behaviour of the coil. An inspection after the event revealed no damage, demonstrating that the design and construction are robust and have adequate safety margins. Provisions have been taken, however, to ensure that such an event cannot be repeated.

The experience gained during the first twelve months of operation has shown that the initial rate of rise of the plasma current must be limited in order to obtain good quality discharges. As a result, new busbars have been prepared to change the primary coil system from a parallel to a series connection. The change will be implemented early in 1985. It will increase the time constant of the circuit thus reducing the current derivative.

Full use was made during the year of the operational flexibility offered by the position and shape control system. A large number of coil configurations has been explored in order to obtain nearly circular, elliptical and D-shaped plasma cross sections.

The problem of vertical instabilities has prompted a modification of the circuit whereby the outer coils P2 and P3 are no longer connected in series with coil P4, but form a separate circuit devoted to plasma shape control. New busbars had to be manufactured to implement this modification. They were assembled in October.

The DMSS also protects the poloidal field coils by detecting ampere turn imbalance between symmetrical coils above and below the equatorial plane. The system has in general been working well and, for the outer poloidal field coils, produced no spurious trips. For the inner poloidal field coils, however, spurious trips have been generated by plasma disruptions. This is because the system detects radial fields rather than ampere turns. Methods of eliminating the problem are being investigated.

Power Supplies

The peak electrical power required for JET during operational pulses could exceed 900MW. There are five principal loads, although their peaks are not simultaneous: the toroidal magnetic field which needs up to 600MW of DC power, the ohmic heating circuit up to 300MW, the plasma position control up to 150MW, neutral injection up to 80MW, and radio frequency heating up to 60MW.

The JET power supply system uses two incoming high voltage lines: one from the Central Electricity Generating Board (CEGB) at 400kV and the other from the Southern Electricity Board (SEB) at 132kV. Pulse power is drawn from the 400kV line, transformed down to 33kV, and fed to the JET loads through a system of circuit breakers. A schematic of the power distribution to the main pulsed loads is shown in Figure 8. Additional power, for example for motors,

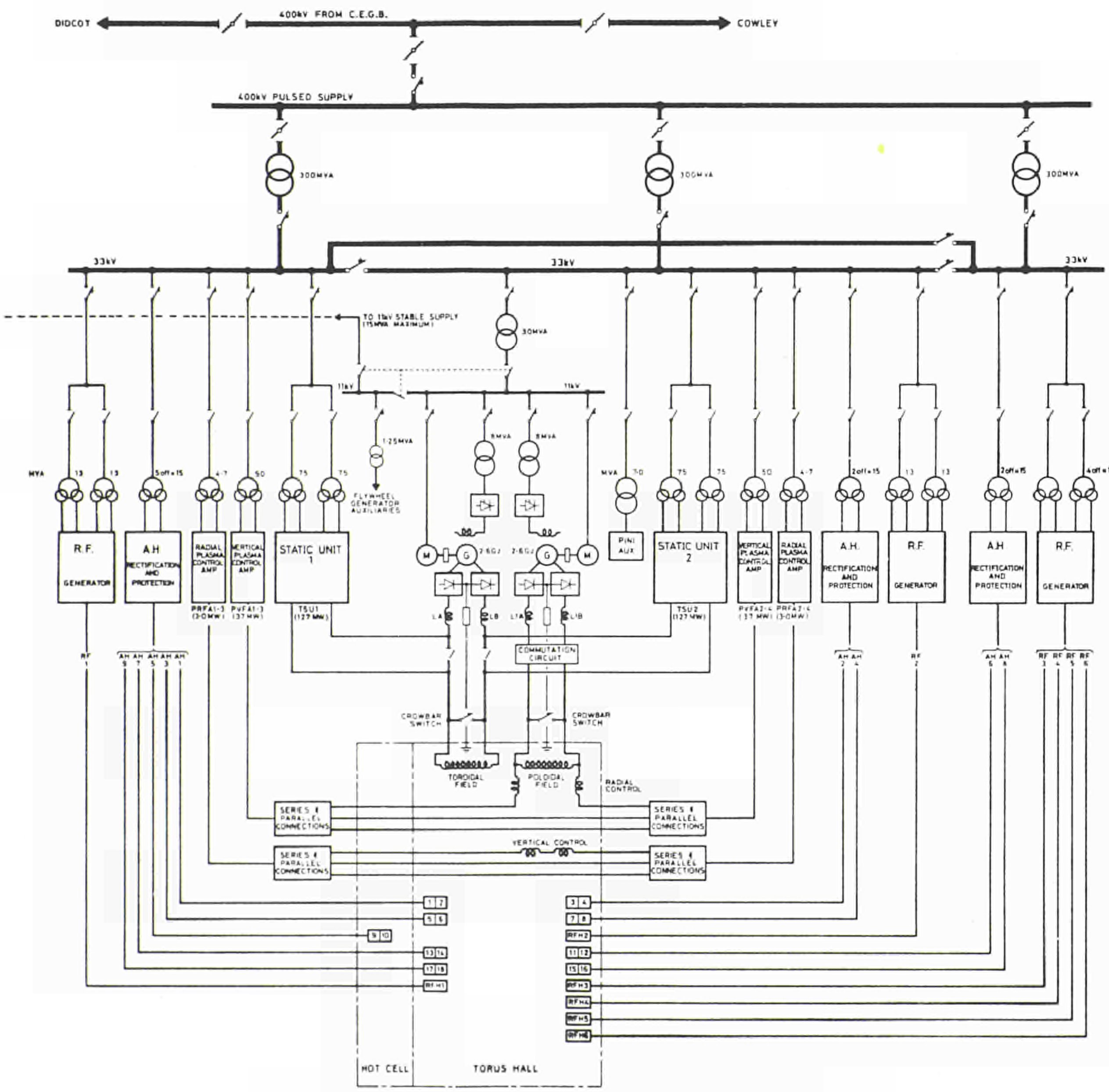


Fig. 8 Schematic of the power distribution to the main pulsed loads.

pumps, and air compressors, is taken from the 132 kV line and distributed around the site at voltages of 11 kV, 3.3 kV and 415 V.

As the CEGB limits the power that may be drawn directly from the grid, the peak power for the toroidal magnetic field coils and for the ohmic heating circuit has to be provided by two large flywheel generators. Each of these identical vertical shaft generators is capable of delivering 400 MW of peak power and 2600 MJ of energy. They were commissioned in 1983. Each rotor, weighing 775 tonnes, is accelerated between pulses by an 8.8 MW pony motor to a speed of 225 revolutions per minute. When power is needed for the operation of JET, the rotor windings are energised, the rotational energy of the flywheel is converted into electrical energy and the rotor slows down to half speed. The AC power from each generator is converted to DC power by diode rectifiers before it is delivered to the loads.

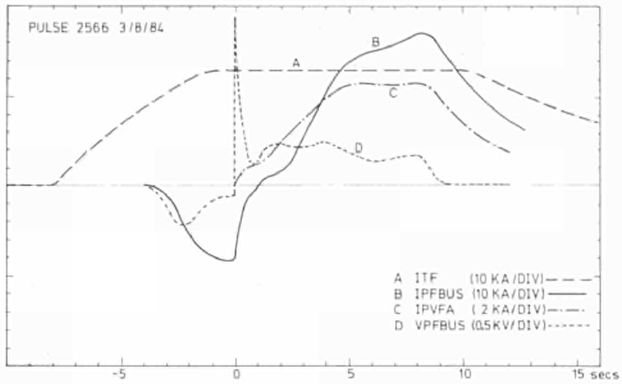


Fig. 10 Typical current profiles for the magnet power supplies during a JET pulse, where the plasma current has reached a value of 3.7MA.

The Toroidal Field System

During the summer operating session, the maximum design value of the toroidal magnetic field of 3.45 T was reached with a flat top of several seconds. In order to achieve this performance, the full energy output of the toroidal flywheel generator was required together with the two toroidal field static units (see Fig. 9) operating at full power. The output limitations on the toroidal generator, mentioned in the 1983 Annual Report, were removed in the first part of the year, after the introduction of forced oil cooling at the leading edge of the thrust bearing pads. The oil cooling has reduced the full speed temperature on the pads below 80°C.

The Poloidal Field System

The ohmic heating circuit has been commissioned up to 60 kA of premagnetisation current and 100 kA of slow rise and flat top currents. Plasma currents up to 3.7 MA for several seconds have been produced with toroidal magnetic fields of 3.45 T (see Fig. 10). Only some three-quarters of the total available flux swing has been used, because larger plasma breakdown voltages would at present lead to early plasma disruptions. The study of modifications to allow the use of the full flux swing and to allow plasma currents of 5 MA or more has started.

The poloidal flywheel generator underwent the same thrust bearing modification as the toroidal generator. The second pair of vertical field amplifiers (see Fig. 11) was commissioned and has subsequently been operated in series with the first pair. During December, the second pair of radial field amplifiers was commissioned and connected in series with the first pair.

Neutral Injection Power Supplies

Each neutral injection beamline requires 40 MW of power from the 33 kV system, the major part to drive the acceleration grids. The power to these grids is regulated and switched by large tetrode valves. The system requires the voltage to be controlled to within one per cent. The voltage must also be switched off in times of less than 10 microseconds for the protection of the PINIs, in the event of a grid breakdown,

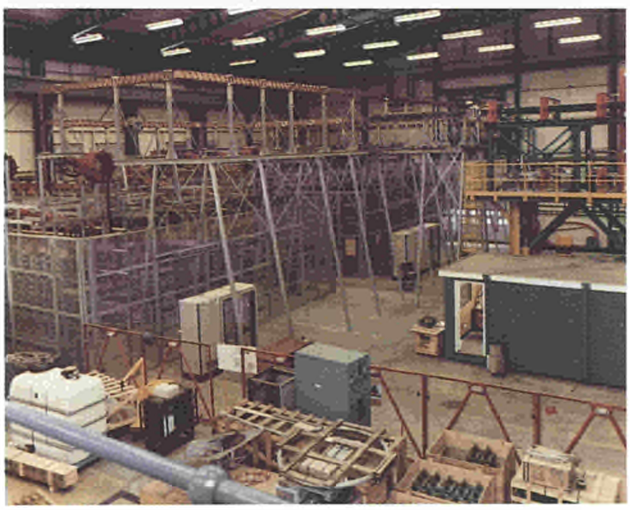


Fig. 9 One of the toroidal field static units.

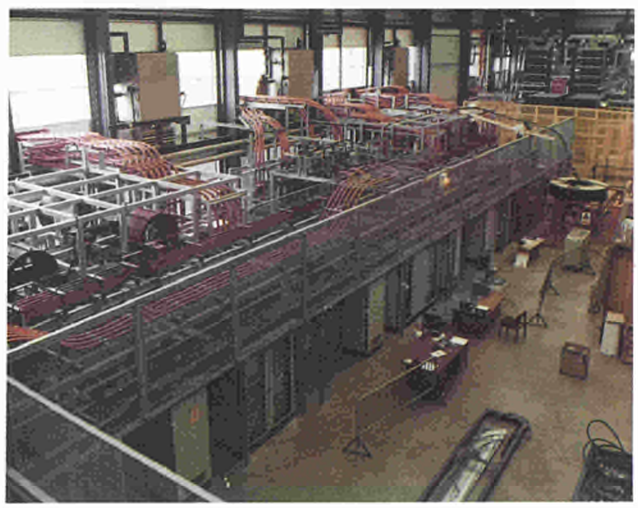


Fig. 11 The second set of vertical field amplifers PVFA 3 & 4.

and must subsequently be re-applied within 50ms.

The main components of the PINI power supplies are: the outdoor power supplies transforming and rectifying the 33kV AC into 95kV DC; the protection and regulation units giving fast turn-on and providing fast turn-off in case of a breakdown in the PINIs themselves; the auxiliary power supplies used mainly to generate the plasma of the PINI and to bias the snubbers; the transmission lines for transporting the high voltage and auxiliary power to the PINIs; and the snubbers to dump the capacitive energy of the transmission lines and power supplies in case of a PINI breakdown.

Major progress in this area during the year allowed testing of neutral injectors up to their design values of 60A and 80kV in hydrogen for pulse lengths up to 17s.

All nine outdoor high voltage grid power supply modules, four for each beamline and one for the testbed, have been successfully tested on a dummy load (see Fig. 12). The four modules for the first beamline with their protection systems have been commissioned on a dummy load. Two of the protection systems for the second beamline have been delivered (see Fig. 13) and two more are under manufacture.

All eight PINI auxiliary power supply units for the first beamline and two for the testbed have been delivered on site and installed. Six of the ten units have been fully commissioned on a dummy load. The units for the second beamline are still under manufacture.

The eight SF_6 insulated transmission lines, which will carry the power to the first beamline from the J1 North Wing to the Torus Hall, have been installed and tested up to 260kV DC, well above the maximum operating voltage of 80kV in hydrogen and 160kV in deuterium. Three of them are connected to the receiving side and one has already been used for preliminary testing of a PINI installed in the Torus Hall (see Fig. 14). The location of the PINI power supplies in the North Wing and hence the need for transmission lines, 90 to 110 metres long, is because high fluences of thermonuclear neutrons could eventually damage the power supplies and their electronics, if they had been situated in the Torus Hall basement, where also maintenance activities would be restricted.

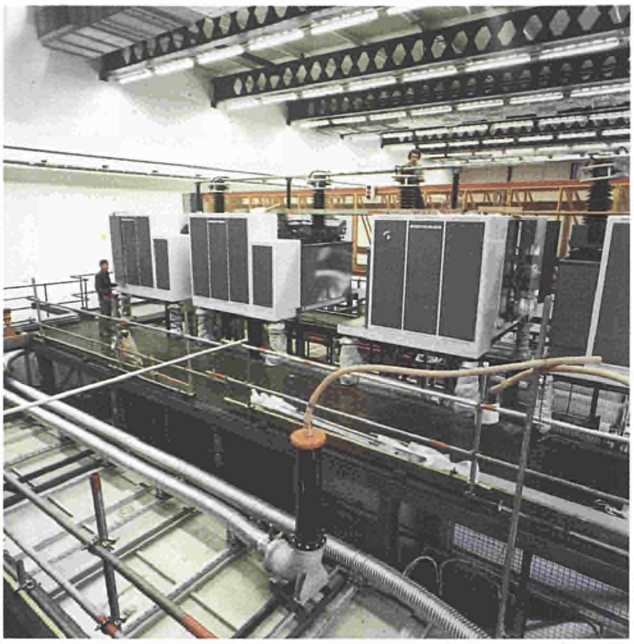


Fig. 13 The protection system modules and auxiliary power supplies for the first neutral injection system.

Fig. 12 The outdoor high voltage grid power supply modules for JET's neutral injection system.

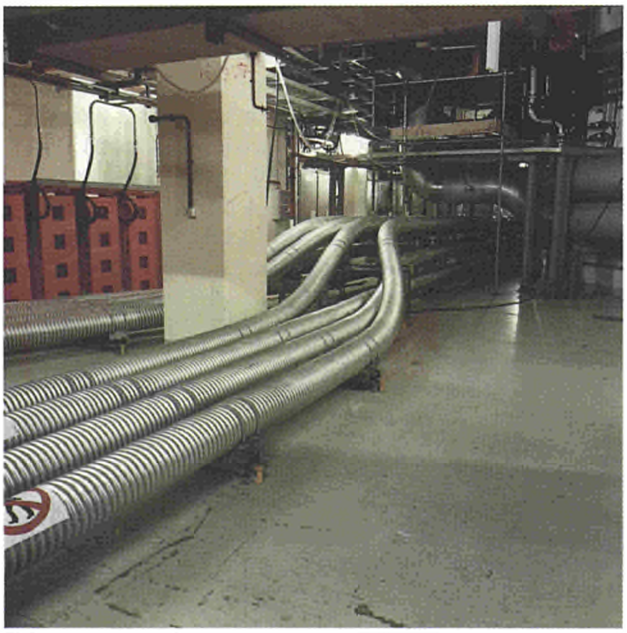


Fig. 14 The SF_6 transmission lines in the Torus Hall Basement.

The first SF_6 tower, which creates the high voltage break for the supplies to the PINIs of water, compressed nitrogen and fuelling gas, contains eight snubbers. It has been installed and tested in the Torus Hall (see Fig. 15). The main components of the second tower have been delivered and its snubbers have been assembled and fully tested.

Fig. 15 The first SF_6 Tower, which serves as a high voltage break for the power supplies to the PINIs in the first neutral injection box.

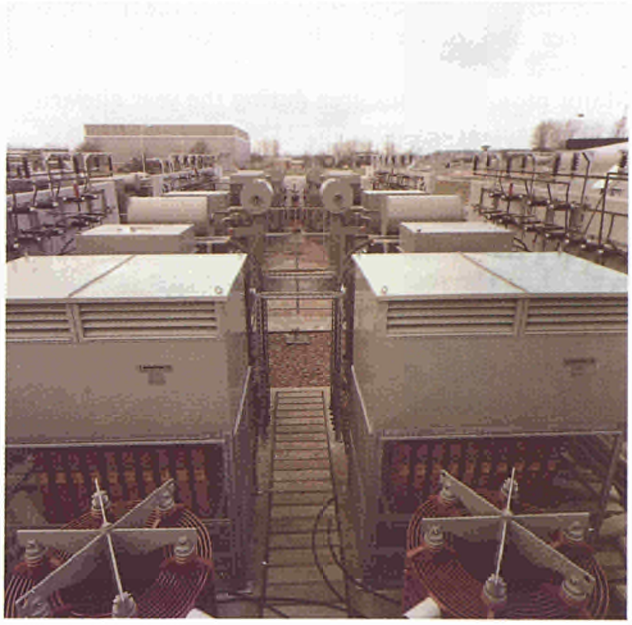


Fig. 16 The four outdoor units of the power supplies for the RF generators, each one consisting of two step-down transformers, two sets of control thyristor bridges, two rectifier transformers and two stacks of HV diodes and RC filters.

RF Heating Power Supplies

The DC power supplies to the radio frequency generators include the main power supplies at nominal 22 kV DC and the auxiliary power supplies at 415 V AC. Each unit of the main power supplies consists of two identical circuits each comprising a matching transformer and two sub-units of a rectifier transformer with an active fast regulation capability, a diode rectifier array and a resistor-capacitor filter. Each sub-unit provides a nominal voltage of 11 kV DC. The two sub-units are connected in series to provide a range of voltages between 14 and 26.4 kV with currents up to 300 A. The units, installed outdoors, are each equipped with one 33 kV breaker with two disconnectors.

All four outdoor units ordered so far have been delivered on site (see Fig. 16). Two of them have been fully tested, and one has already supplied power to an RF generator. The RF auxiliary power supplies are under manufacture. Until they are available, a temporary supply will be connected. The power supply for the prototype RF driver has been delivered and fully commissioned. It has been used to supply the driver for delivering the first 200 kW to one of the two antennae installed in the vacuum chamber.

Power Distribution

The 400 kV/33 kV sub-station was extended during the year by the addition of a further 400 kV busbar-isolator and 400 kV/33 kV arrestor-transformer (see Fig. 17). Commissioning will take place in mid-1985. The 33 kV distribution system has been extended with the addition of eleven new 33 kV breakers and isolators to connect the new AC/DC power supplies (see Fig. 18). The three 33 kV busbars have been arranged so that each

Fig. 17 The 400 kV/33 kV substation showing the third arrestor-transformer system installed.

Fig. 18 The extension of the 33kV switching system, showing the new 33kV, SF_6 Breakers.

of the 400kV/33kV transformers can supply any one of the loads. The 415V distribution system underwent further extension for the auxiliaries of the above supplies, in particular for RF heating and new diagnostics.

Power Supply Development

The operational experience on JET has suggested the need for certain modifications and improvements to the toroidal and poloidal field power supplies. On the flywheel generators, an AC reverse current braking system now reduces the braking time to about 20 minutes. There has also been installed a lubricating oil purification system, oil cooling on the thrust bearing pads as previously mentioned, a new tachometer driving system and a fire fighting system for each generator pit. In addition, the earthing switches on the ohmic heating circuit have been modified to allow breaking of the higher than expected remanence current of the generators. As far as the AC/DC conversion systems are concerned, a number of modifications have been introduced in the control systems. For example, the bandwidth of the radial field amplifiers has been increased from 60 to 150Hz, to improve the control system for plasma vertical instabilities.

A number of new projects was also implemented in 1984. These included smoothing filters to reduce voltage ripples of the toroidal field coils. They are now almost fully installed. Tender actions have been undertaken on tuned filters for the vertical field amplifiers. Plasma shaping power supplies are being designed to modify the plasma elongation during a pulse; data for their detailed design will be obtained in the first part of 1985 by the temporary use of a pair of vertical field amplifiers for that purpose.

Studies for further new projects have been organised, such as filters for the radial field amplifiers, a modification of the ohmic heating circuit for plasma currents of 5MA and above, the modification of one high voltage neutral injection module for 160kV operation, reactive power compensation and harmonic filters at 33kV, and a busbar arrangement for using the toroidal generator as the source of power and energy for the poloidal system in case of a major fault on the poloidal generator.

Neutral Beam Heating

In the neutral beam heating technique, powerful beams of energetic hydrogen or deuterium atoms are injected into the plasma. After ionisation, the beam particles are confined by the same magnetic fields as the plasma and dissipate their kinetic energy by collisions to the plasma particles, thereby heating the plasma.

The beams are generated by the electrostatic acceleration of positive ions, which subsequently have to be neutralised in a gas cell, since charged particles would not be able to penetrate the magnetic fields of the Torus. The neutralisation efficiency is quite low. The remaining ion beams are deflected and dumped in a controlled way.

During the early phases of the JET programme, hydrogen beams will be injected at 80keV with a beam pulse length of 10s. The total beam power into the Torus will be around 15MW with 10MW in the full energy beam component. The power will be provided from 16 beam sources with an extracted ion beam current of 60A each, arranged in two systems of eight sources. For the latter phases of the programme, the system will be modified to inject 160keV deuterium beams with an extracted beam current of 30A per source. Figure 19 shows an elevation of one of the neutral injector systems and Fig. 20 gives a plan view.

The choice of parameters has determined the engineering layout of the system. Long pulse operation requires active cooling of high power density dumps and scrapers as well as the beam source extraction grids. At 80keV per nucleon, the limited neutralisation efficiency leads to a 70% loss of the extracted power. The high number of beam sources and neutralisers per system result in a gas flow requiring a very high pumping speed. Also, due to the Torus ports being narrow, good beam optics are required in order to achieve high beam transmission.

The Ion Beam Sources

The development of the beam sources was a joint venture between JET, the CEA-Euratom Association at Fontenay-aux-Roses and the UKAEA-Euratom Association at Culham. During 1984, the ten sources so far manufactured were tested and each completed around a hundred pulses of 5s duration at 75kV and 57A. Two sources were operated in the JET testbed for pulse lengths beyond 15s at the nominal 80kV and 62A.

Two problems requiring further development in 1984 were finally solved. First, the mixture of atomic and molecular ions measured in the beams from prototype sources gave unacceptably low full-energy and unacceptably high fractional-energy beam components. Joint development by Culham Laboratory and JET of an internal magnetic filter resulted in a proton fraction of 84% and a plasma uniformity of $\pm 8\%$ over the $800\,cm^2$ extraction area. These parameters fully

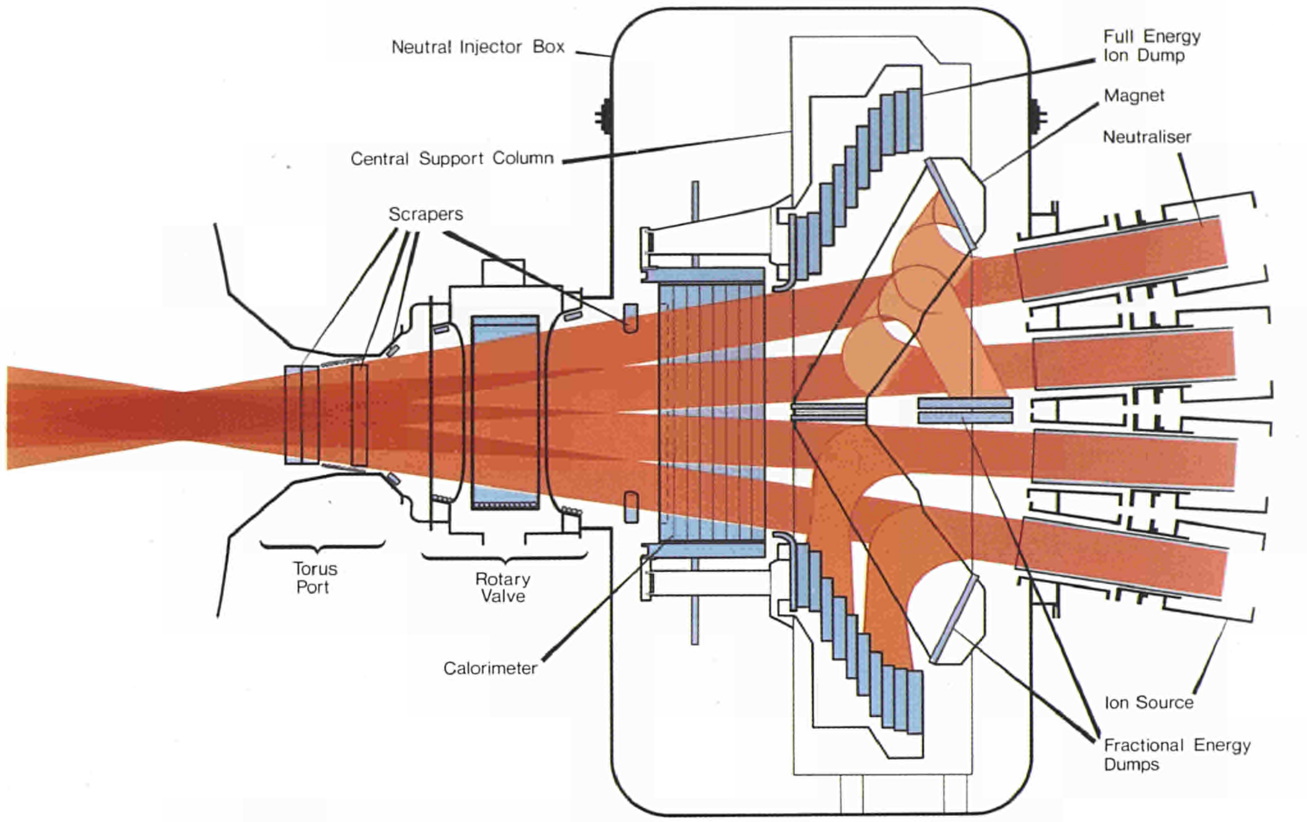


Fig.19 Elevation of the neutral injector, as assembled to the 7m high vacuum box.

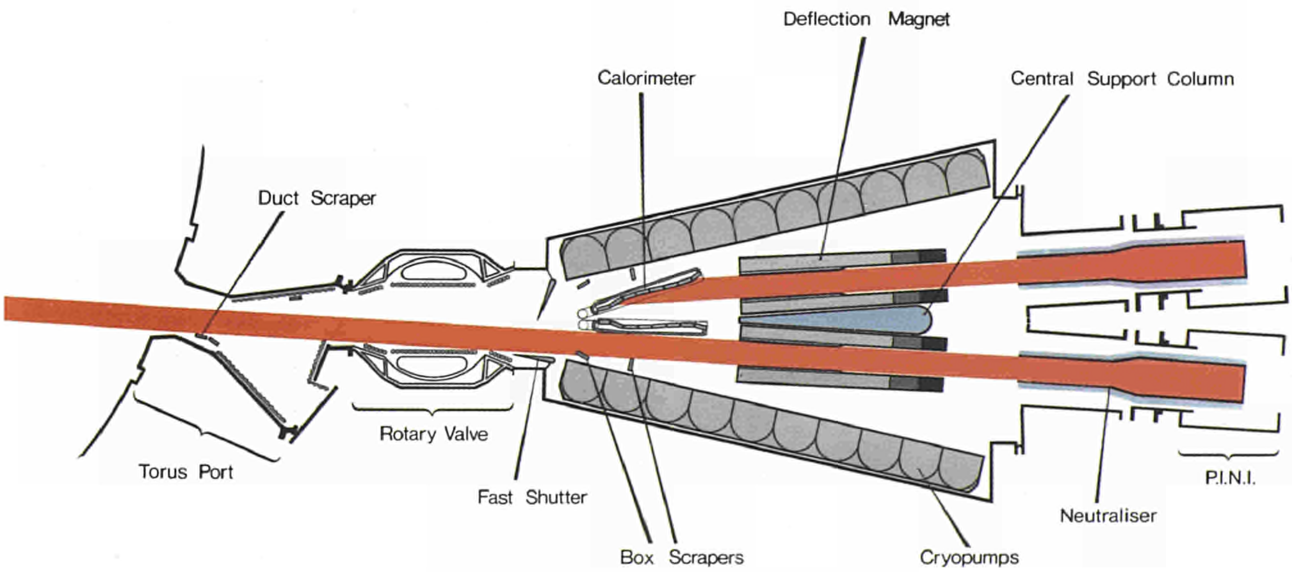


Fig.20 Plan view of the neutral injector.

meet the requirements.

Second, each beam is produced by the extraction of some 260 beamlets through an electrode system with circular apertures. By an offset of the apertures in one electrode, these beamlets are steered towards a common focus to enable the passage through the torus port. The focus measured during tests was different from the design value and would have led to destructive beam power loadings on certain beamline components. This was corrected by re-drilling the apertures in one electrode of every source. In the meantime, the method of computation has been improved and now matches the test results.

In preparation for the later phase of deuterium beam injection, one of the prototype beam sources has been successfully modified at the Fontenay-aux-Roses Laboratory and subsequently operated with deuterium beams at 160 keV beam energy and 37 A ion current for 5 s pulses.

The Beamline System

After passing through the neutraliser, the remaining ion beam fractions are magnetically deflected and dumped in various types of beam dumps. The neutralised beams are tailored by beam scrapers for entrance through the torus port. All these components are designed for quasi-stationary thermal power loadings of 10 MW/m^2 After manufacture, these components were therefore thermally cycled to 300°C and pressure and vacuum tested to stringent specifications.

During these tests, certain beam dumps produced from a chromium-zirconium copper alloy, developed cracks adjacent to electron-beam welds. The necessary design changes and repairs of these components have delayed the assembly of the beamline system.

The deflection magnets (see Fig. 21) with their electro-formed cooled liners, the various beam dumps and a calorimeter to measure the beam power-density profiles have all been assembled onto a central support and cooling water supply column. At the end of 1984, the system was close to completion.

For the gas handling in the beamline system a vacuum pumping speed of 8×10^6 l/s for hydrogen is required. This is provided by a cryopump (see Fig. 22) operated at liquid helium temperature with a nominal thermal load of 80 W continuous into the helium system. The cryopump has been delivered and successfully tested on the JET site. For the cryoliquid supply, flexible transfer lines of up to 80 m length have been manufactured and tested. The helium refrigerator has been installed (see Fig. 23) and the commissioning started.

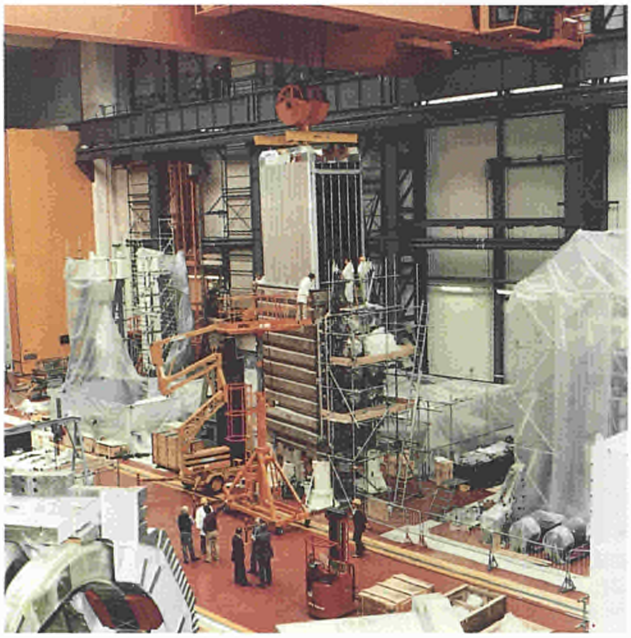


Fig. 22 Installation of the cryopump into the injector vacuum box.

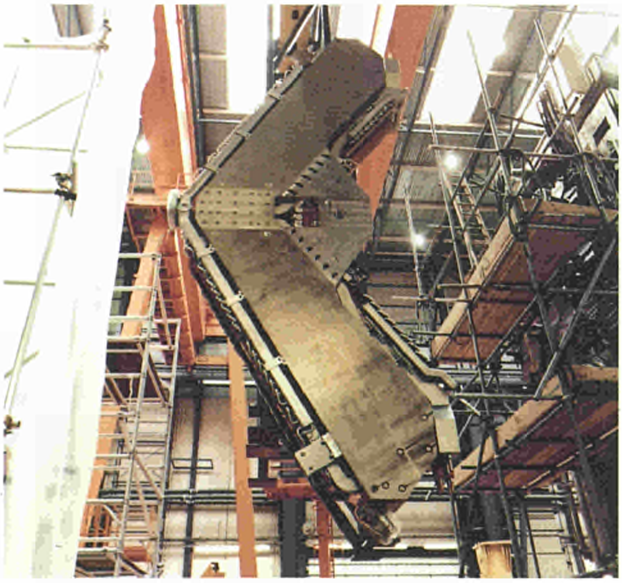


Fig. 21 Deflection magnet after installation of the internal liners and the dumps for fractional energy beams.

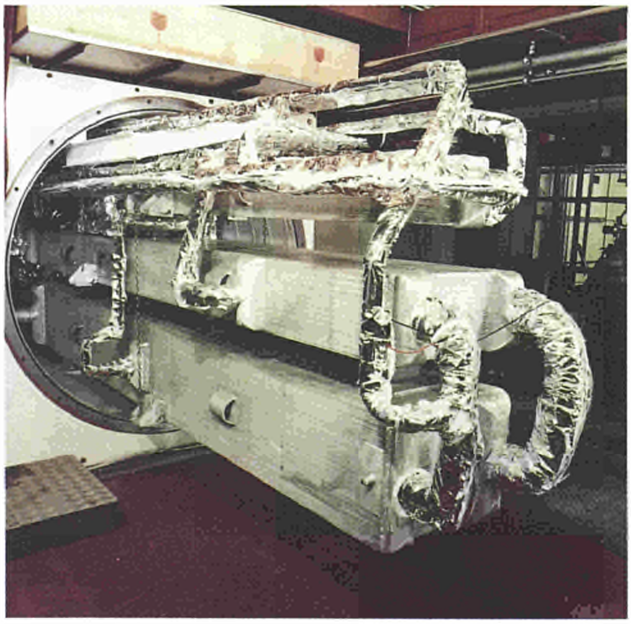


Fig. 23 The cold box of the helium refrigerator during assembly.

At the Torus, the installation of the first injector system has been progressing (see Fig. 24). So far installed are the high power beam scrapers in the Torus duct, the absolute valve to isolate the Torus and injector vacuum system (see Fig. 5), and the fast shutter on the neutral injection box itself. The valve was baked to 400°C in an oven on the JET site prior to installation, and the leak tightness was unchanged afterwards. The duct scrapers were submitted to ten baking cycles to 300°C prior to installation and leak tested. The cryopump has also been installed as well as the neutralisers and most of the beam sources, including all supply systems.

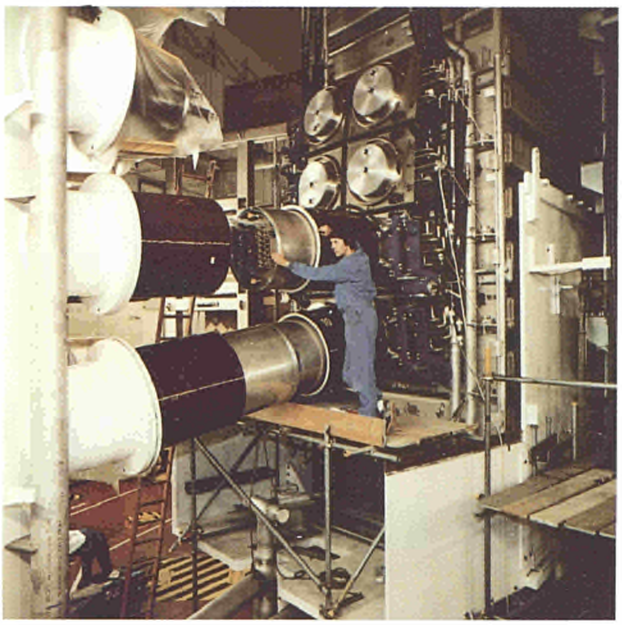


Fig. 24 Two beam sources during installation to the injector vacuum box at the Torus.

Commissioning

A neutral injector testbed (see Fig. 25 and 26) including power supplies for two beam sources has been set up in the JET Hot Cell. Beam operation started at the beginning of 1984. Where possible, the testbed is identical to the injector systems on the Torus. So far, it has been used to commission the system of power supplies and beam sources with their controls as well as the diagnostics, data acquisition and data analysis system. Long pulse operation of a beam source at full parameters has been achieved.

Prior to installation on the Torus, the beamline system will be commissioned in the testbed. This will, however, be limited to the operation of the beam sources for one quadrant, which in its beamline components has been specially instrumented for this purpose.

In parallel to this, the tokamak injector system of power supplies and beam sources with their controls will be commissioned in their final configuration. Short-pulse beams will be extracted from pre-tested sources and absorbed in an inertially cooled dump, which has been temporarily installed in the injector box on the Torus. The aim is to operate eight sources simultaneously during plasma discharges. After this, the beamline system will be transferred from the testbed to the Tokamak for final system commissioning.

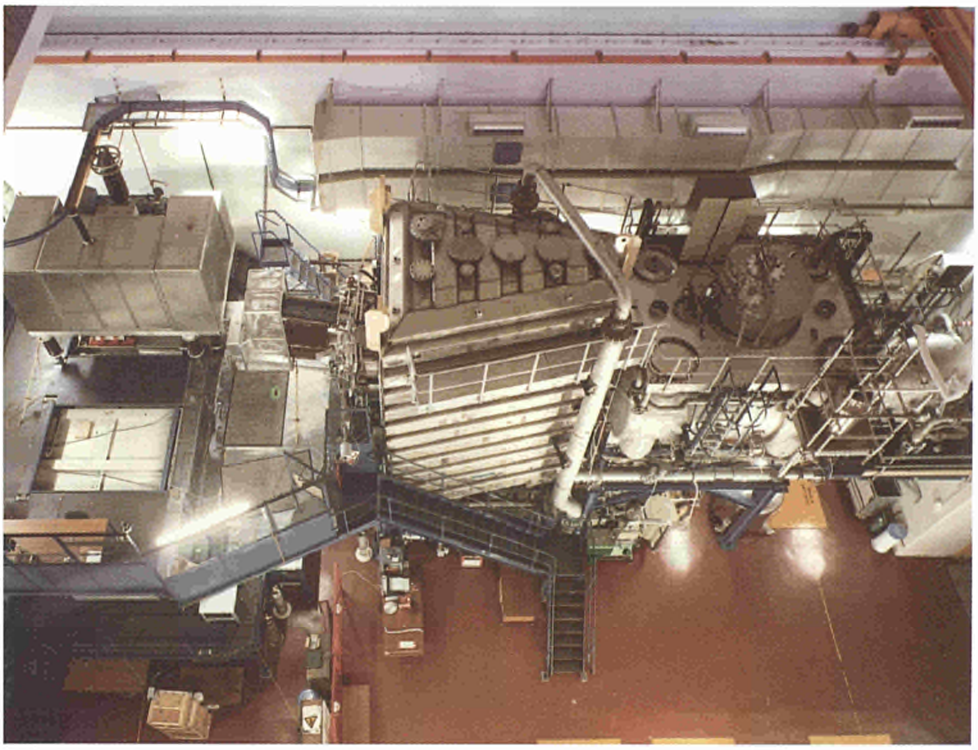


Fig. 25 The JET neutral injection testbed with (from left to right) the filament and arc power supplies mounted on top of the high voltage protection unit, a beam source, the injector vacuum box, and the target tank.

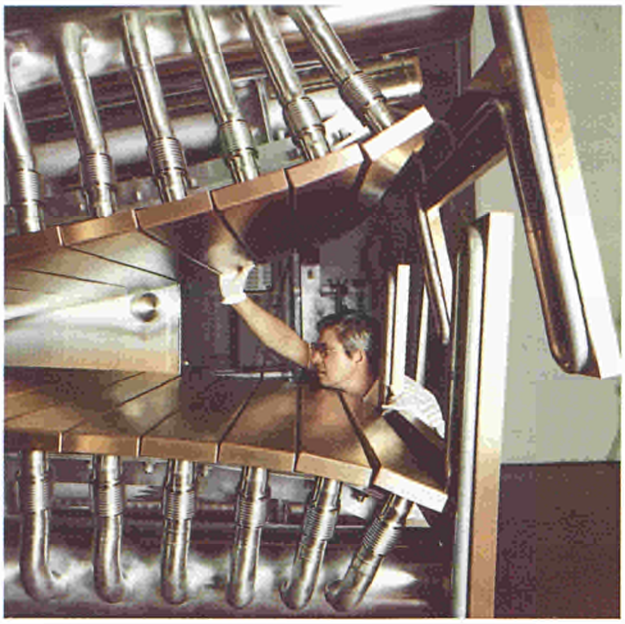


Fig. 26 The testbed beam dump for 10MW stationary beam power.

Radio Frequency Heating

For radio frequency heating, high power electromagnetic waves are radiated from antennae located on the walls of the vacuum vessel. Power is coupled into the plasma by selecting a frequency of radiation (25—55MHz on JET) equal to that of an ion species gyrating around the magnetic field lines near the centre of the plasma. The accelerated ions then transfer their energy to the bulk of the plasma through collisions between charged particles. This heating is known as ion cyclotron resonance heating (ICRH). The wide frequency band chosen for JET allows the RF system to be operated with the various mixes of ion species required in the different phases of the scientific programme.

Ultimately, ten RF generators will be installed, producing the 30MW of power required. The power from each generator will be coupled into the upper and lower halves of an antenna by two 230mm co-axial transmission lines. About one-half of the 30MW of generated RF power will be coupled into the plasma. The generators situated in the North Wing of the main building will use large tetrode electronic tubes, each one capable of generating 1.5MW of radio-frequency power. The major components of a generator-antenna unit (3MW of generator output power) are described in Fig. 27.

The RF programme has three stages:

(1) In the first stage covering 1985 and 1986, up to 3 complete units will be operated. Several types of antenna configuration will be tested on the plasma during this period;

(2) Then, for the second stage, 6 units will become operational at the beginning of 1987 for use with deuterium plasma;

(3) Finally, up to 10 units will become operational

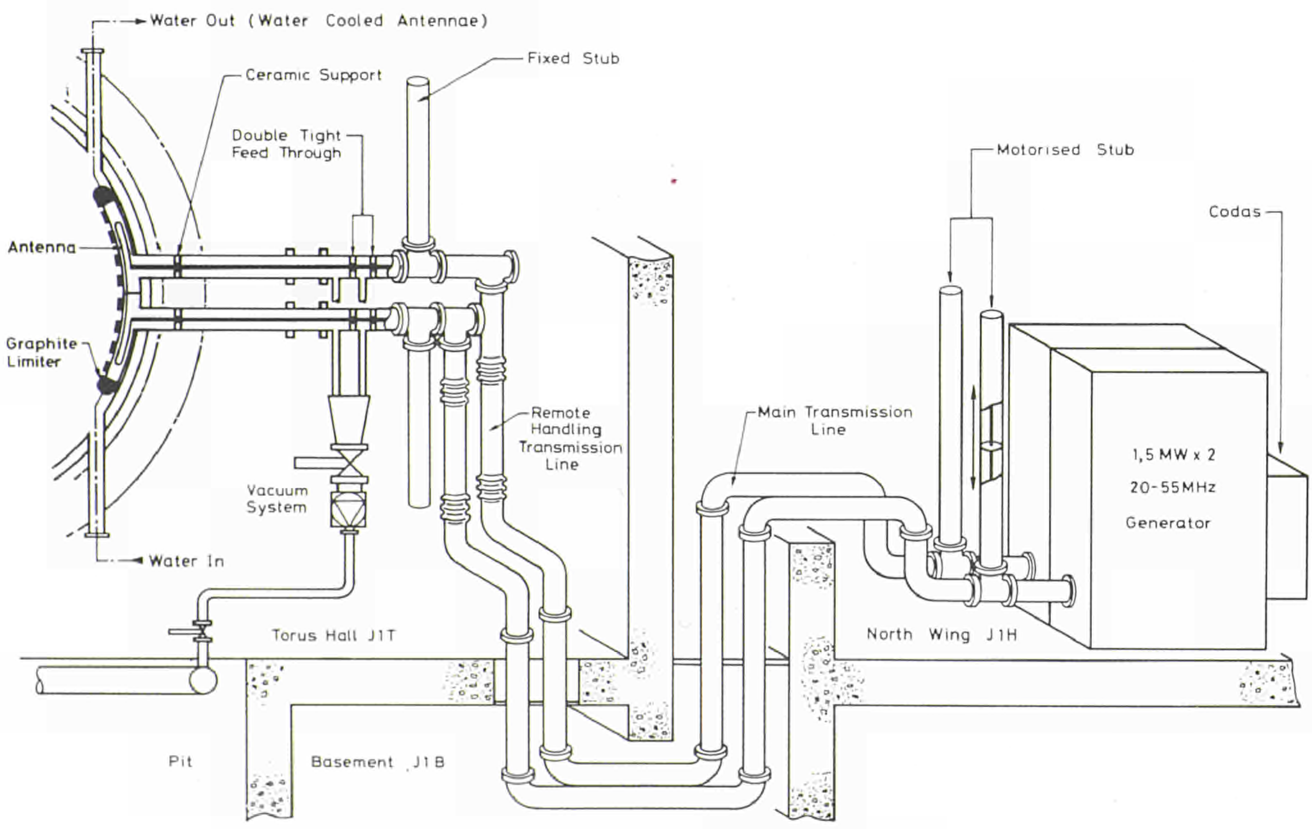


Fig. 27 Layout of one 3MW unit of the JET ICRF system.

at the beginning of 1989. They will be compatible with D-T operation.

During 1984, the main emphasis of the RF programme was on the construction and testing of the first two antenna-generator units. These were installed during the shutdown at the end of 1984. Experiments on a complete unit aimed at measuring the antenna losses started before the end of the year. At the same time, the design of equipment required for the second stage of the RF programme was completed and the major contracts placed.

The ICRH Power Plant

The first stages of the contracts for the manufacture of the DC power supplies, the RF generators and the main transmission lines were placed during the first half of 1983. These covered a prototype driver, a complete prototype unit, and six series units. The first generators have been received and installed on site. The prototype driver, which delivers a total of 200kW, has been connected to an antenna and fully commissioned in remote operation. Early plasma experiments on coupling and matching have started. The prototype unit has demonstrated full power operation over the entire bandwidth during long pulses (20 seconds) and will be operated on the second antenna early in 1985 as soon as remote controls and instrumentation are commissioned.

The contracts are running close to schedule and no fundamental difficulty has been encountered despite the fact that the performances specified are at the limit of the current state of the art. All eight generators necessary for the first two stages of the RF programme are expected to be on site at the beginning of 1986.

Figure 28 shows the first two generators installed in the North Wing. The generators rest on a false floor leaving below a space of 4m to accommodate the output trimming circuit and services. The coaxial transmission lines can be seen in the background of the photograph.

Antennae

The two antennae recently installed in JET are each equipped with a different central conductor. In one, the two current elements are phased in order to create the usual single current loop running in the poloidal direction. In the second, there is the new quadrupole geometry. This was proposed by JET in mid 1984 as an attempt, based on theoretical studies, to reduce edge fields and the associated impurity release. This concept has recently been substantiated by experiments in both TFR (CEA Fontenay) and JFT2M (JAERI Japan). Made of four alternate current elements, the quadrupole conductor emits a radiation pattern that excludes the long wavelengths that can cause deleterious edge fields. This arrangement is however more difficult to operate as it requires a higher driving voltage and produces a large coupling between the two feeding generators.

Figure 29 shows one of the two prototype antennae as installed in JET. The graphite limiter frame is designed to protect the screen. A third antenna of the same design is presently under construction and will be installed in mid 1985. The central conductors of the third antenna will be of the type that gives the better results during the first half of 1985.

Status of Testing and Commissioning

The RF testbed has been operated since August 1983 at CEA Fontenay by a joint CEA-JET team. All critical items have been systematically and separately tested. Finally, the complete antenna and vacuum transmission line assembly was tested with the nominal RF

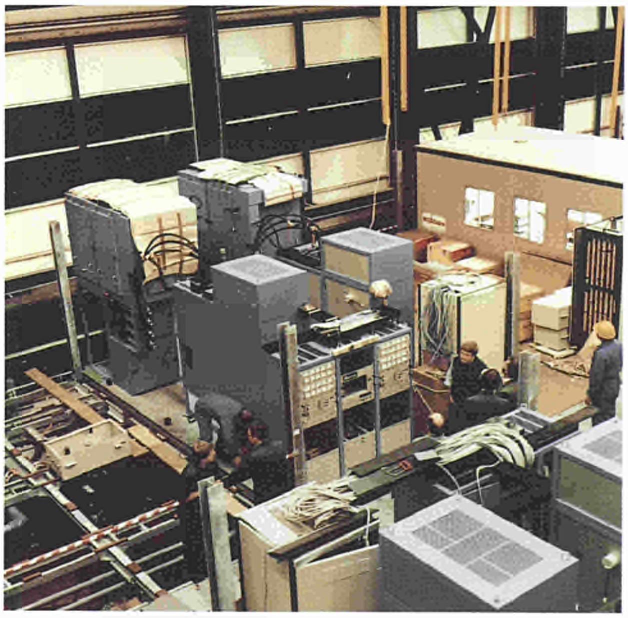


Fig. 28 Photograph of two ICRF generators installed on the false floor of the North Wing.

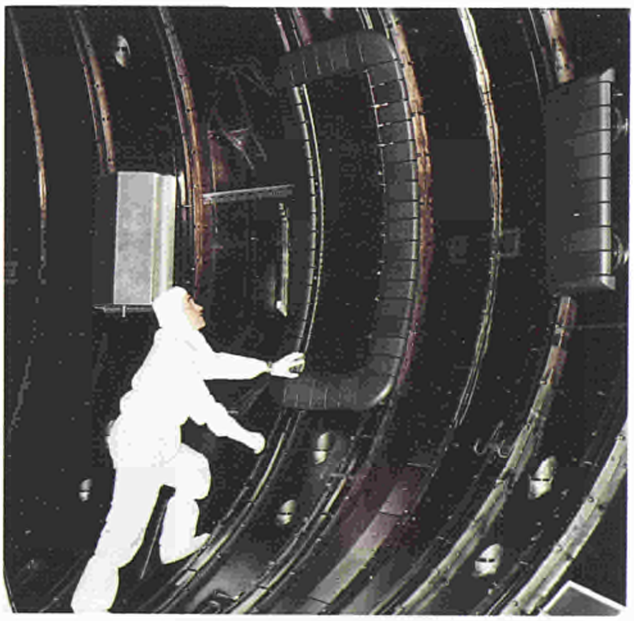


Fig. 29 One of the two prototype antennae installed in the JET device at the end of 1984. To the left is a carbon limiter.

pulse length at full reactive power (45 kW, 1500 A). The antenna behaved as expected. It should however be stressed that it is impossible to simulate in a test the Tokamak plasma effects, which could reduce high voltage stand-off values. These tests have been partly repeated in JET in the commissioning period that started at the end of the year. The various losses on the system have been measured and were in agreement with expectation. The losses of the screen were directly verified from its heating rate under long pulse operation (see Fig. 30). These losses will be carefully monitored during operations as they influence directly the power transfer efficiency. Their level could change through plasma surface effects.

On the experimental side, the RF laboratory has been completed and connected to the Torus. This will allow the radiating and receiving characteristics of the antennae to be measured during plasma operation.

RF Physics Studies

The physics of RF coupling and power deposition has been pursued in collaboration with the Associations. Computer codes have been developed with IPP Garching and ERM/KMS in order to make detailed predictions relevant to the present plasma conditions. They have been extensively used to select the operating scenarios in JET. A deuterium plasma with the addition of a small quantity of Helium-3 (around 5%) appears to offer the best combination of properties and has been chosen for initial plasma experiments.

Remote Handling

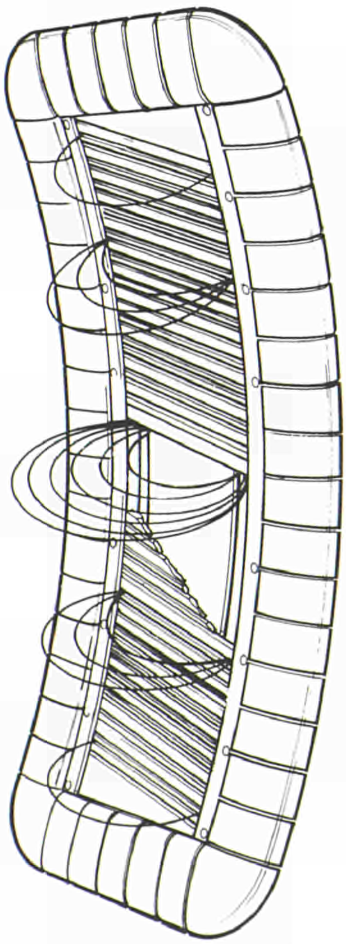
Some remote handling is expected to be needed inside the vessel from the middle of 1986 and full remote handling both inside and outside the vessel from the end of 1989. The philosophy remains that all remote handling of JET components will be performed by end effectors (specially designed handling devices) carried into position by transporters, and themselves carrying special or general purpose tools. The most sophisticated of the end effectors will be the force-feedback servomanipulators. Support vehicles will carry and interconnect or decouple the various elements.

Operations will be controlled with the aid of television from a central control room linked to a host (CODAS) computer so that higher level (computer generated) command systems can be added later.

End Effectors

The gripper to handle the present poloidal limiters was delivered with the boom in October 1984 (see Fig. 31). Design is continuing on a gripper for the belt limiters, first in hands-on form, to be followed by a remote handling version. Grippers for the first and second generation antennae are also being designed.

A detailed survey of presently and imminently available force-feedback servomanipulators, combined with an international competitive call for tender resulted in a contract for the supply of two master-slave



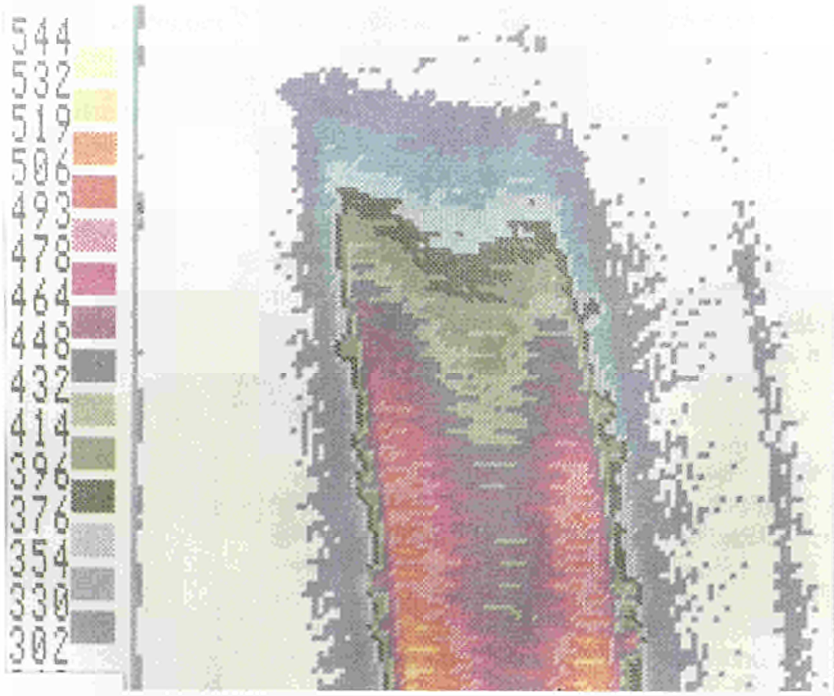


Fig. 30

Temperature distribution on an antennae in the Torus under very long RF puls (30 min., 8 kV peak RF voltage). Heating is due to the eddy currents generated by the pinching of the flux between the screen bars.

Schematic diagram of the electromagnetic flux radiated from an ICRH antenna

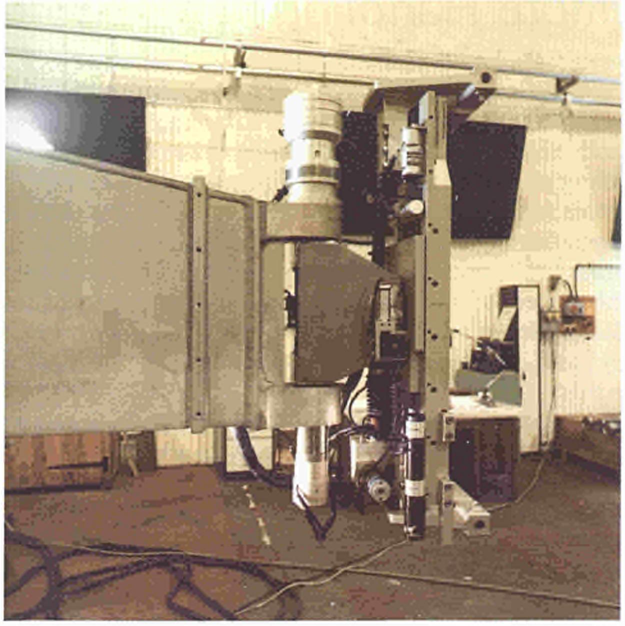


Fig. 31 The gripper for remote handling limiters.

sets of the Mascot type. Development work at JET has continued to produce a reduction in size of the Mascot manipulator so that it can pass through the vessel port. Controls have been developed so that the signals can be multiplexed without sacrificing sensitivity.

Tasks on JET Components

A system has been established whereby remote handling procedures, describing the planned operations, are required before the design of a component is released for manufacture. This system is being applied retrospectively to most components already fitted. Each remote handling procedure will eventually certify that a physical check has been made to ensure that the component is fitted as drawn and that the procedure is feasible. The procedures will be used to establish remote handling operating schedules used in the control room, verified by mock-up simulations.

Transporters

The articulated boom (see Fig. 32) capable of carrying a one tonne load inside the vacuum vessel was delivered to JET in October 1984. It is almost fully commissioned. It will be used for mock-up tests and will assist in the hands-on in-vessel operations during the shutdown in June 1985.

A study contract has been placed to produce layout designs and specifications for the major transporters for the outside of the JET machine. So far, a design has been completed for a transporter with a telescopic mast and telescopic boom to reach up the sides of the machine and across the top, with inclination of the boom so that it can reach the overhead crane and also the floor. A design is also well advanced for a transporter to reach underneath the overhanging portions of the JET machine, for example to reach the turbomolecular pumps. These designs are being assessed with a view to ordering early in 1985.

Orders were placed at the end of 1984, after international competitive tendering, for two vehicles: a turret truck to carry components and end effectors so that they can be attached to transporters by remote control; and a small radio-controlled support vehicle, with a track drive, carrying a simple manipulator and television. This support vehicle will be used to plug in umbilical cables and carry light equipment, such as tools and television cameras.

Orders have been placed for long-lead items, and tenders have been requested for the manufacture of a boom extension, which will provide additional three-axis motion at the end of each of the transporters. The vertical motion can be locked, if the device is required to carry a load in excess of the capacity of the joint.

Tools

Experimental development during 1984 has produced an effective working version of the self-propelling cutter which can now cut the welded Inconel lip joints. In a trial, a length of 20m was cut without adjustment or replacement.

Welding parameters and special weld preparations have been devised and proven so that pipes with alignment spigots can be welded remotely by orbital welders with full penetration and no cavities.

Television

Design is in progress on a set of motorised arms, mounted on the boom extension, for positioning a pair of cameras behind the end effectors, in particular behind the manipulators. Provision has been made to add a short arm on the front of each manipulator shoulder box to carry a camera for general viewing of its work area.

Control and Control Room

The closed loop controller for the articulated boom has

Fig. 32 The articulated boom, capable of carrying a one-tonne load inside the vacuum vessel. Seen at the manufacturer's works.

been designed and is under construction. This takes into account the measured dynamic response of the boom.

Input to this controller will initially be from a simple one-fifth scale model with a resolver at each joint. This model master is under construction. It will be commissioned in the early part of 1985. Depending on the experience gained, this principle may be extended to the boom extension. Alternatively, resolved motion control can be introduced using a microprocessor. Master-slave control may also be used for the camera arms, where it would be valuable for avoiding collisions between the manipulator arms and the camera arms.

Studies have been made of an integrated control room layout, from which to control all of the transporters and support vehicles, end effectors, tools and television.

Tritium Handling

During 1984, the detailed duties of the tritium handling system were decided and the interfacing conditions to other JET systems defined. Concepts and flow diagrams were developed for the integration of the gas supply and vacuum systems of the neutral injection and Torus into a closed gas recycling loop with the tritium handling plant. The tritium recycling system will reprocess and separate the gases into hydrogen isotope fractions ready for re-use in plasma pulses or for reconditioning the Torus in a closed loop glow discharge cleaning mode. It will also provide for the removal of impurities.

An air clean up system will remove tritium in the gaseous waste streams from the recycling plant, with a high detritiation factor. This clean up system will also be used to process tritiated gases produced during maintenance of the plant. The removed tritium will be fixed as tritium oxide on desiccant beds allowing safe disposal. A dedicated clean up system will also treat the helium gas of the Torus baking system which will become gradually tritiated as tritium permeates through the primary Torus wall. The plant duty has not yet been determined. Experimental work during 1985 and 1986 to measure the permeation rate of hydrogen and deuterium through the Torus wall and the build-up of the respective concentrations will provide much of the data required to define the necessary processing and disposal parameters.

Plant Duty

The nominal design of the tritium recycling system is based on the daily reprocessing of 48 pulses each of 10s duration. The amount of gases introduced into the Torus for a typical pulse will be approximately 1.86 normal litre (Nlt) of gas consisting of around 0.9Nlt of tritium (equivalent to 250mg or 2450 curie), 0.9Nlt of deuterium, and up to 0.1Nlt of Helium-3 or protium.

The gases will be transferred from the Torus to the recycling system after each pulse by turbomolecular pumps compressing the gases to between 0.1 and 1mbar at the system inlet. The gases will be frozen out onto the liquid-helium cooled cold surface of an accumulating panel contained in one of the three parallel identical cold boxes and accumulated for twelve pulses. Any Helium-3 will be continuously removed from the panel with a minimum of tritium carry-over. After twelve pulses, the gases will be directed to the panel in standby and the first panel warmed to 80K, its contents analysed, assessed and transferred to the liquid-helium cooled cryotransfer pump, which when warmed to ambient temperature will compress the gases to around 5 to 6 bar as required for further treatment and for separation into isotopic fractions. It is planned to separate the isotopes in two gas chromatographic units working alternately in order to minimise the process inventory.

The amount of gases that have to be processed from the neutral injection system totals about 4.3Nlt per pulse consisting mainly of deuterium with up to 2% of tritium. These gases will be accumulated on the cryopanels of the neutral injection boxes and released to the tritium recycling system at the end of the operating day. They will be transferred to the accumulating panel of the third cold box, then assessed and compressed by the cryotransfer pump into an intermediate pressurised holding tank from which the gas will be passed into the gas processing-separation process.

The processed fractions will be stored in product tanks at pressures between 0.2 and 0.8bar at the purity levels required for re-use in the Torus or neutral injection, while interfractions containing mostly HT, HD and DT will be recycled.

For the closed loop glow discharge cleaning of the Torus, about 140Nlt/h of deuterium needs to be recirculated continuously through the Torus. Turbomolecular pumps will compress the deuterium from the Torus pressure to between 0.1 and 1mbar upstream of the inlet of the tritium recycling system. The gas stream will be passed through one of the accumulating panels kept at 20°K for removal of impurities before return to the Torus.

The clean up system is being designed to allow processing of up to 10 normal m^3/h of tritiated air or inert gases. This will allow the pumping of the Torus from ambient to operating pressure within two days. The detritiation factor of the system will exceed 1000.

The total tritium inventory of the recycling system will be about 100,000 curie (10g). Studies have been carried out to determine the consequences of total or partial releases of this inventory.

The plant design is being developed giving consideration to the reliability of components or systems and to the consequences of potential failure modes, maintenance and of routine operation. To minimise tritium emissions most of the equipment will be designed to allow baking under vacuum prior to maintenance or repair.

Detailed Design of Plant Equipment

The detailed design of long lead-time equipment, particularly for the cryogenic processing of the gases, was well under way at the end of 1984. Design options for certain key components such as the accumulating panels and the cryotransfer pumps were under construction and will be performance tested in a special test rig early in 1985. The tests will allow optimisation of the equipment for its performance, control, reliability and consumption of cryogenics.

Suitable engineering codes for the design of plant equipment and interconnecting piping under various thermal cycling conditions have been identified. Stress analysis on thermally cycled components and piping will be applied to guarantee a high degree of reliability.

Control and Data Acquisition

The purpose of the control and data acquisition system (CODAS) is to allow a centralised control and monitoring of all actions to be performed during normal operation. It is based on a network of Norsk Data minicomputers (see Fig. 33) interfaced to the experiment through CAMAC instrumentation and signal conditioning modules. At each pulse, all reference values specified by the operation team are set and all relevant information is acquired and gathered in a single JET pulse file. Some information is analysed immediately and displayed in the control rooms (see Fig. 34 and Fig. 35). Each JET pulse file is also sent through a data link to Harwell where more elaborate data analysis is performed on the IBM-Cray computers.

During 1984, the main control subsystems to be installed and commissioned were for neutral injection and radio frequency heating and their respective testbed facilities.

The allocation and configuration of all computers at the end of 1984 is given in Table 2. The computer configurations have been expanded to cope with higher demands. Most on-line NORD-100s now have 1M byte of memory and the NORD-500s 2M byte. In order to provide better hard copy facilities, one laser printer has been installed and remote spooling facilities have been developed.

With the new subsystems and certain extensions to those existing, 37 new CODAS cubicles were installed, bringing the total of such cubicles to 94. The total inventory of electronic modules is now:

2,500 CAMAC modules;

5,100 Eurocards for signal conditioning;

270 Console devices (TV screens, touchpanels, etc.).

The Central Interlock and Safety System (CISS), which provides a high reliability protection system, has been considerably expanded to cover additional units and subsystems and its logic revised in line with the experience gained during operations. Several auxiliary services such as public address, intercom and closed circuit TV systems have been completed and commissioned. Eight new diagnostic systems have been connected and their control and data acquisition commissioned.

The construction and commissioning programme will continue in 1985. The main efforts will be on the

Fig. 33 Overview of the computer room.

Fig. 34 Overview of the control rooms in J2. Foreground, machine control room. Background right, computer room. Background left, experimental control room.

Fig. 35 Overview of the console used for control and monitoring during operation.

Table 2
CODAS Computer Configuration at the end of 1984

Subsystem	Usage	Model	Memory (MByte)	Disks (MByte)
AH	NI Additional Heating	ND100	1.0	1×75
CA	Message Switcher A	ND100	0.375	1×10
CB	Message Switcher B	ND100	0.375	1×10
DA	On-line diagnostic	ND520	2.25	2×75
DB	On-line diagnostic	ND520	2.25	1×75
DC	On-line diagnostic	ND520	2.25	2×75
DD	On-line diagnostic	ND520	2.25	2×75
DE	Off-line diagnostic	ND520	2.25	2×75
DF	On-line diagnostic	ND520	2.25	2×75
DG	Diagnostic Commissioning	ND520	2.25	2×75
EC	Experiment Console	ND570	3.0	2×75 1×288
EL	Electronic	ND100	0.5	1×75
GS	General Services	ND100	1.0	1×75
HL	Harwell Link	ND100	0.5	1×10
MC	Machine Console	ND100	1.0	1×75
PF	Poloidal Field	ND100	1.0	1×75
RB	Radio Frequency Test Bed	ND520	2.25	2×75
RF	Radio Frequency	ND100	1.0	1×75
RH	Remote Handling	ND100	1.0	1×75
SA	Storage & Analysis	ND560	2.25	1×75 1×288
SB	Standby-System/Backup	ND100	1.0	2×75 2×10 1×288
SS	Safety & Access	ND100	1.0	1×75
TB	NI Test Bed	ND100	1.0	1×75
TF	Toroidal Field	ND100	1.0	1×75
TR	Tritium	ND100	0.75	2×75 1×288
TS	Test	ND100	1.0	1×75
VC	Vacuum	ND100	1.5	1×75
YB	Integration	ND530	2.25	2×75 1×288
YC	CODAS Commissioning/NIB-C	ND530	2.25	2×75 1×288
YD	Sc.Dpt. Development	ND570	2.5	2×75
YE	CODAS Development	ND100	1.0	1×75
AS	Assembly Database	Compact	0.75	1×45
MD	Cable Database	ND530	1.25	2×75
SD	Built-in, Pool, Computer dB	Compact	0.75	1×45

extension of the radio frequency subsystems (see Fig. 36), the inclusion of neutral beam heating into plasma operation, the commissioning of the second neutral injection system, the design of the CODAS systems for tritium and remote handling, and the addition of more diagnostics. These extensions will require services support from the central timing and the central interlock and safety systems.

The supporting software has been expanded and improved during 1984. For example:

- The handling of the ohmic heating and earthing switches is now fully automated and covers all modes of operation;
- The countdown program sequence covers all on-line computers and handles all required pre- and post-pulse sequence checks;
- The alarm handling package is now able to handle conditional alarms depending on the state of the plant and time;
- More user-friendly interfaces have been developed for setting the timing and for the selection of waveforms to be used in the next pulse;
- The hardware and software for the plasma density feedback control has been successfully commissioned; and
- The plasma fault protection system has been enhanced and recommissioned, and the handling of the so-called soft termination of a pulse has been improved.

During 1985, there will be further improvements and extensions of the software facilities. These will have as a general goal the provision of more resilient and more user-friendly means of operating JET and its subsystems from the machine control room.

Diagnostic Systems

The status of JET's diagnostic systems at the end of 1984 is summarised in Table 3. The location of these systems on the machine is shown in Fig. 37. Further details of the principal systems are given below.

Thomson Scattering Diagnostics

The Thomson Scattering system that has been constructed for JET by the Risø National Laboratory, Denmark, has the conventional 90° scattering configuration. Light from a powerful ruby laser illuminates

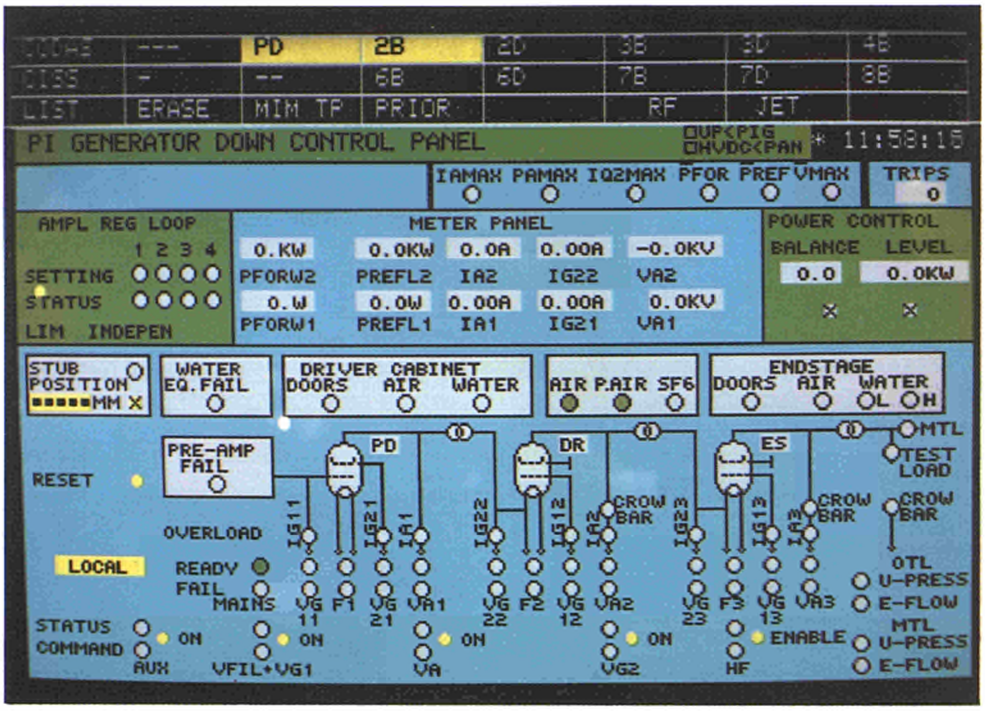


Fig. 36 Mimic diagram used for the operation of the pre-ionisation radio frequency generator.

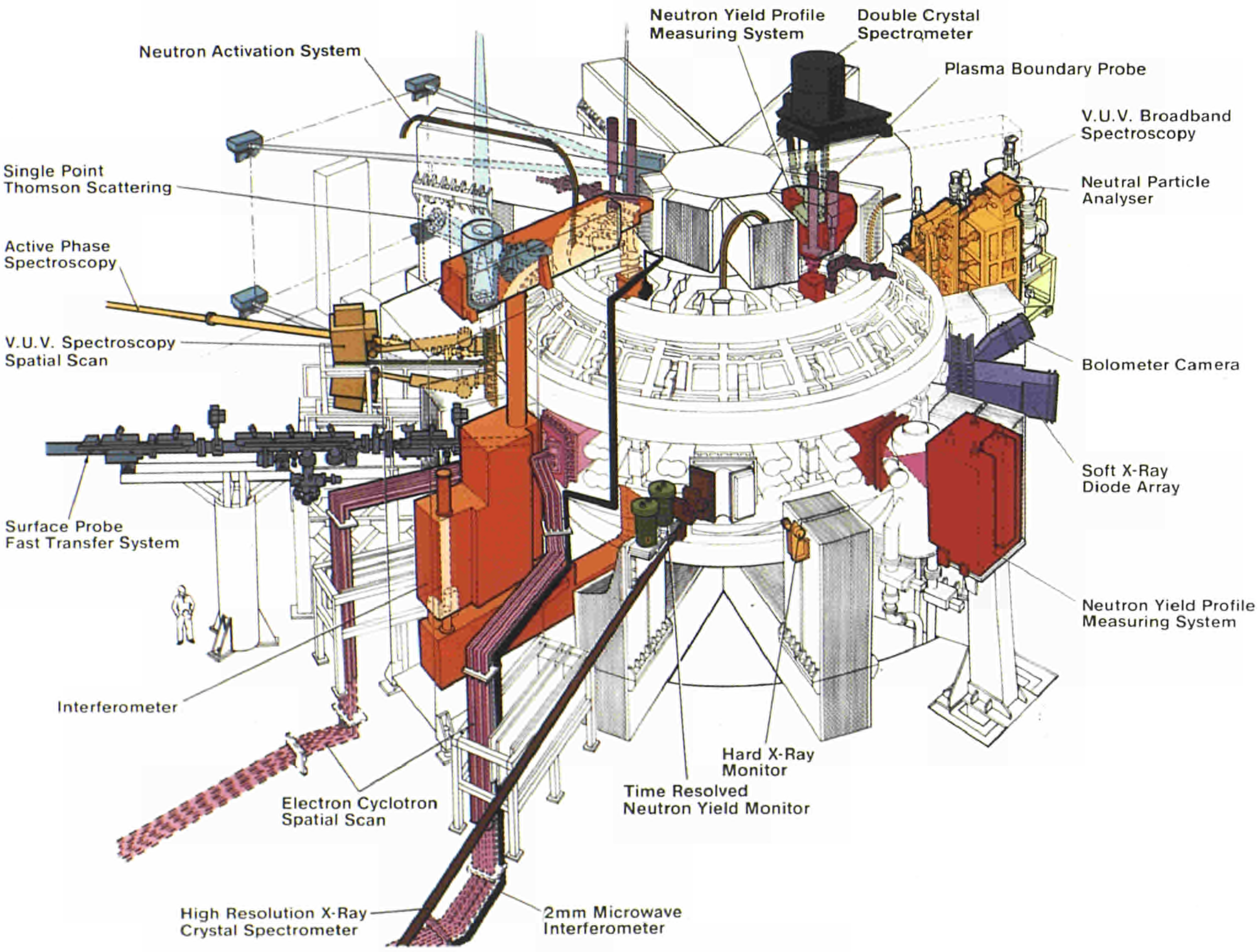


Fig. 37 Location of JET diagnostic systems.

Table 3
Status of the JET Diagnostics Systems

Diagnostic System No.	Diagnostic	Purpose	Association	Status Dec. 1984	Date for operation in JET
KB1	Bolometer Scan	Time and space resolved total radiated power	IPP Garching	Operational	Mid 1983 partly Early 1984 fully
KC1	Magnetic Diagnostics	Plasma current, loop volts, plasma position, shape of flux surfaces	JET	Operational	Mid 1983
KE1	Single Point Thomson Scattering	T_e and n_e at one point several times	Risø	Operational	Mid 1984
KE3	Lidar Thomson Scattering	T_e and n_e profiles	JET and Stuttgart University	Design	Early 1987
KG1	Multichannel Far Infrared Interferometer	$\int n_e(r)ds$ on 7 vertical and 3 horizontal chords	CEA Fontenay-aux-Roses	Operational	Mid 1984 partly Early 1985 fully
KG2	Single Channel 2mm Interferometer	$\int n_e(r)ds$ on 1 vertical chord in low density plasmas ($>10^{14}cm^{-3}$)	JET and FOM Rijnhuizen JET	Operational Extension to 1mm	Mid 1983 Early 1985
KG3	Microwave Reflectometer	n_e profiles and fluctuations	JET	Prototype system operating	Mid 1983
KH1	Hard X-ray Monitors	Runaway electrons and disruptions	JET	Operational	Mid 1983
KH2	X-ray Pulse Height Spectrometer	Plasma purity monitor and T_e on axis	JET	Under construction Provisional systems	Mid 1985 Mid 1984
KJ1	Soft X-ray Diode Arrays	MHD instabilities and location of rational surfaces	IPP Garching	Provisional system operational. Full system under construction	Mid 1985
KK1	Electron Cyclotron Emission Spatial Scan	$T_e(r,t)$ with scan time of a few milliseconds	NPL, Culham and JET	Partly operational	Late 1983 partly Early 1985 fully
KK2	Electron Cyclotron Emission Fast System	$T_e(r,t)$ on microsecond time scale	FOM, Rijnhuizen	Commissioning	Early 1985
KL1	Limiter Surface Temperature	(i) Temperature of wall and limiter surfaces (ii) Monitor of hot spots on limiter	JET and KFA Jülich	Operational	Mid 1984
KM1	2.4MeV Neutron Spectrometer	Neutron spectra in D-D discharges, ion temperatures and energy distributions	UKAEA, Harwell	Construction proceeding	Mid 1985
KM3	2.4MeV Time-of-Flight Neutron Spectrometer		NEBESD,Studsvik	Calibration	Mid 1985
KN1	Time Resolved Neutron Yield Monitor	Time resolved neutron flux	UKAEA, Harwell	Operational	Mid 1983
KN2	Neutron Activation	Absolute fluxes of neutrons	UKAEA, Harwell	Construction proceeding	Mid 1985
KN3	Neutron Yield Profile Measuring System	Space and time resolved profile of neutron flux	UKAEA, Harwell	Construction proceeding	Mid 1985
KR1	Neutral Particle Analyser Array	Profiles of ion temperature	ENEA Frascati	Operational	Mid 1984 partly Mid 1985 fully
KS1	Active Phase Spectroscopy	Impurity behaviour in active conditions	IPP Garching	Under construction	Early 1986
KS2	Spatial Scan X-ray Crystal Spectroscopy	Space and time resolved impurity density profiles	IPP Garching	Under construction	Early 1986
KS3	H-alpha and Visible Light Monitors	Ionisation rate, Z_{eff}, Impurity fluxes	JET	Operational	Early 1983 Mid 1985 Full System
KT1	VUV Spectroscopy Spatial Span	Time and space resolved impurity densities	CEA Fontenay-aux-Roses	Partly installed	Early 1985
KT2	VUV Broadband Spectroscopy	Impurity survey	UKAEA, Culham	Operational	Early 1984
KT3	Visible Spectroscopy	Impurity fluxes from wall and limiters	JET	Operational	Mid 1983
KT4	Grazing Incidence Spectroscopy	Impurity survey	UKAEA, Culham	Under construction	Early 1986
KX1	High Resolution X-ray Crystal Spectroscopy	Ion temperature by line broadening	ENEA Frascati	Under construction	Mid 1985
KY1	Surface Analysis Station	Plasma-wall and limiter interactions including release and hydrogen isotope recycling	IPP Garching	Construction proceeding	Mid 1985
KY2	Surface Probe Fast Transfer System		UKAEA, Culham	Construction proceeding	Mid 1985
KY3	Plasma Boundary Probe	Simplified probe system for monitoring progress of discharge cleaning and preliminary plasma-wall interaction experiments	JET UKAEA, Culham and IPP Garching	One unit operating Second unit being installed	Mid 1984 Early 1985
KZ1	Pellet Injector Diagnostic	Particle transport, fuelling	IPP Garching	Under construction	Late 1985

the plasma along a vertical chord. The scattered light is collected and spectrally resolved. The electron temperture and electron density are determined from the spectral width and intensity of the scattered light respectively. Items sensitive to nuclear radiation such as the laser and the detection systems are housed behind the radiation shielding in the roof laboratory (see Fig. 38). The system is thus compatible with the active phase of operation of JET.

This system was brought into operation in mid 1984 and has since worked successfully. Figure 39 shows the electron temperature of the plasma measured both by Thomson scattering and by electron cyclotron emission (see below). There is good agreement between the two measurements.

During the past year, considerable progress has been made in assessing the feasibility of the LIDAR Thomson scattering system, proposed by a group at the University of Stuttgart. In this novel technique, an ultrashort laser pulse is used to illuminate the plasma, and the back-scattered (around 180° scattering) radiation is collected. The spatial resolution is determined by the time delay between the transmission of the laser beam and the arrival of the scattered light back at the detector. Although the technique is new to fusion research, it is well established in other areas such as atmospheric physics. It is particularly well suited to diagnosing large plasmas such as JET. The feasibility study has established that this technique could be applied to JET and could share much of the optics already installed for the existing single point Thomson scattering system, thus reducing the cost and engineering complexity. Work is continuing on the design of this system with a view to its being operational on JET early in 1987.

Fig. 38 The diagnostic roof laboratory showing the laser input and light collection system of the Thomson scattering diagnostic.

Electron Cyclotron Emission Diagnostics

Two electron cyclotron emission (ECE) diagnostic systems have been constructed for JET. One is a spatial scan system for measuring the spatial dependence of the electron temperature in the poloidal cross-section, while the other is a fast scan system for measuring the time-dependence of the temperature at fixed positions in the plasma on a fast time-scale. This year has seen substantial progress in both systems.

Both systems share an array of ten antennae (see Fig. 40) mounted inside the vacuum vessel to view the plasma poloidal cross-section along different chords. The ECE radiation passes through crystal quartz windows and then through aluminium waveguides to the Diagnostics Hall. The design of this system has presented considerable problems both in terms of the

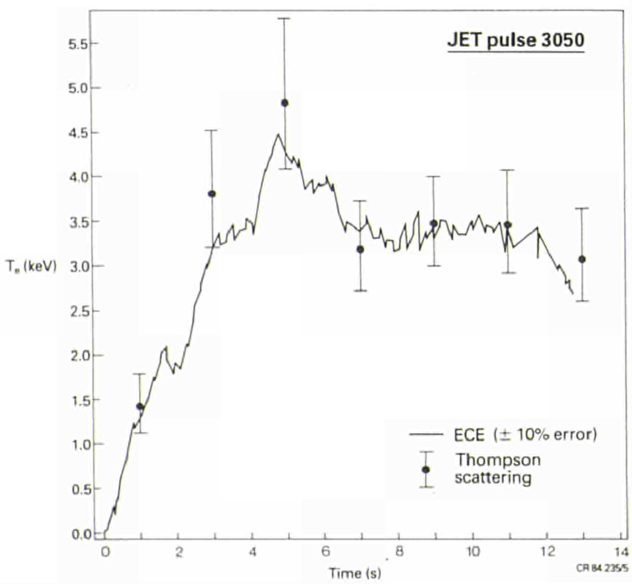


Fig. 39 The electron temperature of a pulse measured by two techniques.

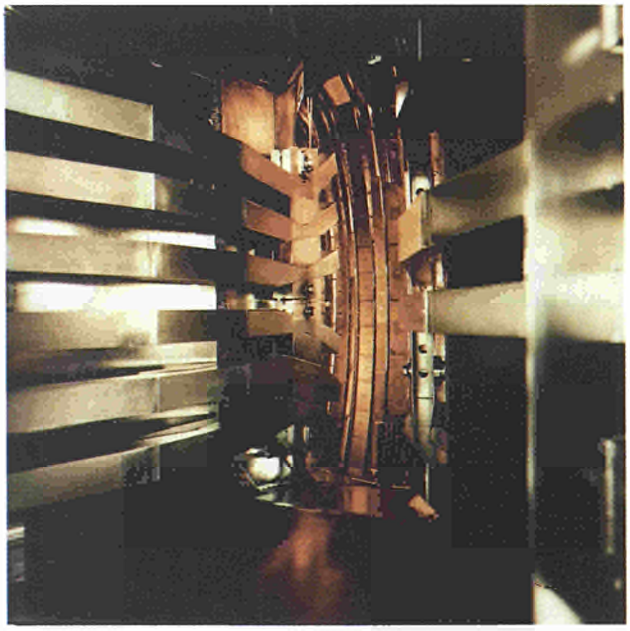


Fig. 40 The antennae of the electron cyclotron emission diagnostic passing through a horizontal part of the Torus.

physics of the propagation of single waveguide modes through long oversized waveguides and antennae and in terms of engineering to meet JET's requirements. Four antennae were installed in the Torus during August 1983, and the remainder in early 1984. The system was commissioned during 1984 using two temporary waveguide runs. The full set of ten waveguides was installed at the end of 1984.

The spatial scan system was developed and constructed by the National Physical Laboratory, London. The full system will measure the profile of electron temperature along each of ten chords, which intersect a (vertical) poloidal plane of the torus, thus giving a two dimensional map of electron temperature in the poloidal cross-section. During 1984, considerable care was given to calibrating the system so that it could yield absolute electron temperatures without the need for cross-calibration against other diagnostics. An example of the excellent agreement with the Thomson scattering measurements is shown in Fig. 39. When operated in the fixed frequency mode (i.e. not spatially scanned) the system can be used to monitor fluctuations in the electron temperature at a selected position in the plasma. An example of the "sawteeth" oscillation in the centre of the plasma is shown in Fig. 41, together with the correlation of similar signals from other diagnostic systems.

The fast scan system has been designed and constructed by the FOM Institute at Rijnhuizen (Netherlands). This consists of a multi-channel polychromator, which will be used to measure the local electron temperatures at twelve points along a single chord with a time resolution on the microsecond timescale. The system was installed at JET during the latter part of 1984 and will be commissioned early in 1985.

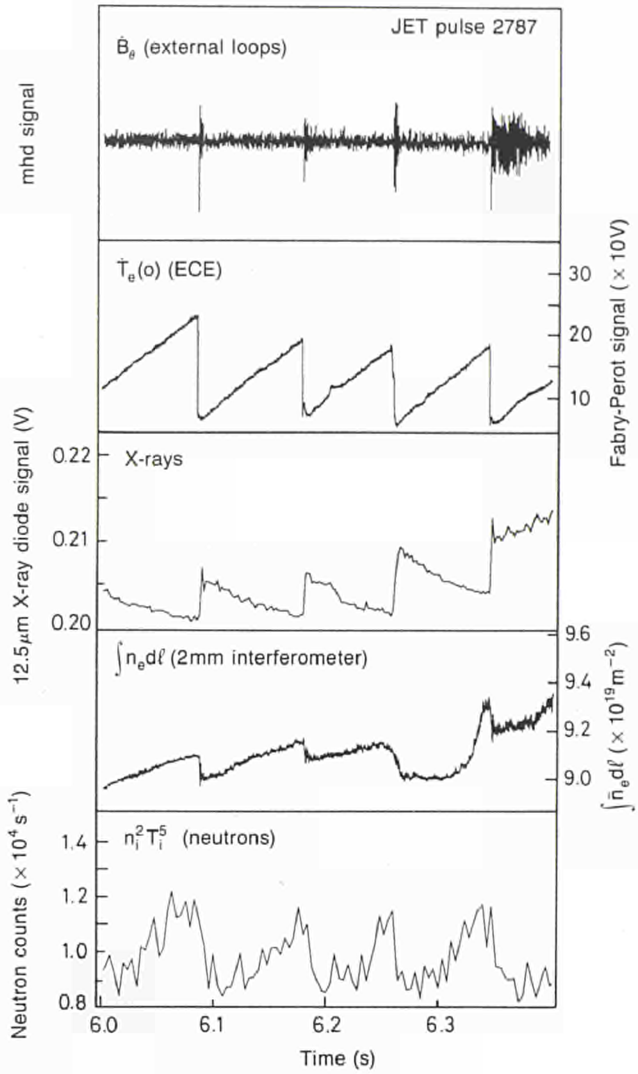


Fig. 41 Correlation between a variety of diagnostics showing saw tooth behaviour.

Magnetic Diagnostics

The main magnetic diagnostic consists of sets of eighteen poloidal field pick-up coils mounted inside each octant of the vacuum vessel, fourteen saddle flux loops on the outside of each octant, and eight full flux loops completely encircling the torus. In addition, there are sets of six large flux loops for plasma position control on two octants. There are also four Rogowski and two pairs of diamagnetic loops mounted on the toroidal field coils.

With the exception of the diamagnetic loops, these systems are fully commissioned and operational. Their measurements allow plasma loop voltage, plasma current and the position of the plasma in the vessel to be derived.

The diamagnetic loops will be commissioned early in 1985 with plasma shots, a procedure which requires careful balancing to remove spurious signals from the toroidal and other fields.

Limiter Surface Temperature Diagnostic

The limiter surface temperature diagnostic provides real-time information on the plasma-limiter interaction by imaging the limiters through sapphire windows on the machine. There will be two types of camera system on JET, one of which is already operational. The first system uses charge-coupled-device video cameras to image the limiters in a narrow wavelength band in the visible and near infrared. Depending on which optical filters are used, this system provides a thermal image of the limiters in a narrow temperature range at temperatures above 500°C or an image of the spectral light emission from the limiter and its surroundings. Windows have been installed to view some of the limiters with three cameras operating simultaneously. The second camera system, which is still at the conceptual design stage, will operate at longer wavelengths to provide surface temperature data over a wider temperature range.

Surface Measurements

Two probe systems are being constructed to expose probes at the edge of the JET plasma. The more comprehensive system is the fast transfer system, which consists essentially of a train running in a long vacuum tube connecting the Torus to the Diagnostic Hall (see Fig. 42). Four probes can be mounted on the front of

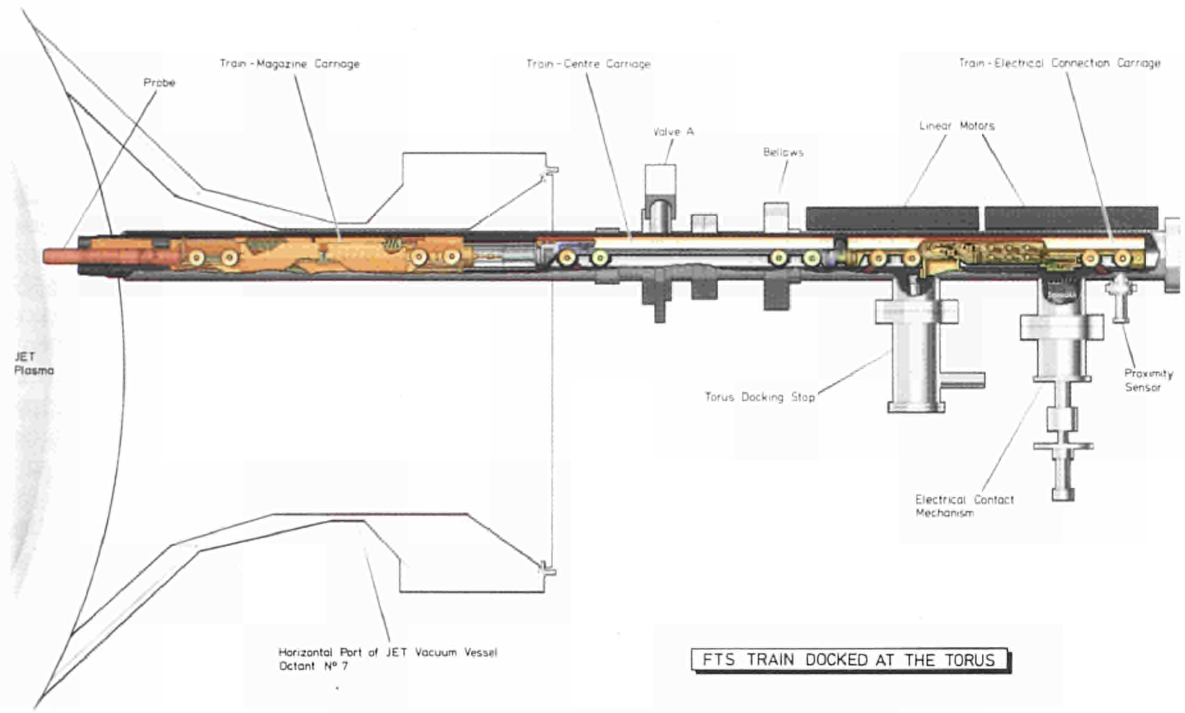


Fig. 42 The train of the fast transfer system docked at the Torus.

the train and exposed in the edge of the JET plasma, and then transferred under vacuum to an analysis chamber in the Diagnostic Hall. This system, which has been designed by Culham Laboratory and by IPP Garching, will be installed during 1985.

The simpler system is the plasma boundary probe system, consisting of two vertically mounted probe drives, which allow probes to be inserted into the top of the JET vacuum vessel. These probes cannot, however, be retrieved without intervention in the Torus Hall. The first of these probe drives is now operational, and the second will be installed early in 1985.

Two types of probe can be used with either system. The first provides direct electrical readings of the plasma parameters, for example, temperature and density in the boundary layer. The second has passive collecting surfaces, which after exposure can be examined by surface analytical techniques to determine the erosion and surface deposition of impurities and other materials.

Neutron Diagnostics

A comprehensive range of neutron diagnostics is needed to study deuterium and tritium plasmas in conditions close to those required for a fusion reactor. The main quantities to be measured will be neutron yields, their spatial and time dependencies and their energy spectra. From these, the plasma temperatures and fast ion distributions can be deduced.

The time-resolved neutron yield is measured with three pairs of uranium 235 and 238 fission counters mounted on the vertical limbs of the transformer. In hydrogen discharges, the detected neutrons are due to emission by the photoneutron process when energetic electrons (runaways) strike the walls and limiters. In stable deuterium discharges above a temperature of about 5 keV, the main source of neutrons is from fusion reactions. The ion temperature derived from these measurements is in good agreement with other diagnostics (see Fig. 43). Measurements have also been made using several prototype neutron spectrometers which give the ion temperature and deuterium atom density directly whereas the total neutron yield is very sensitive to non-thermal ions in the plasma. These results are very encouraging for the properly engineered

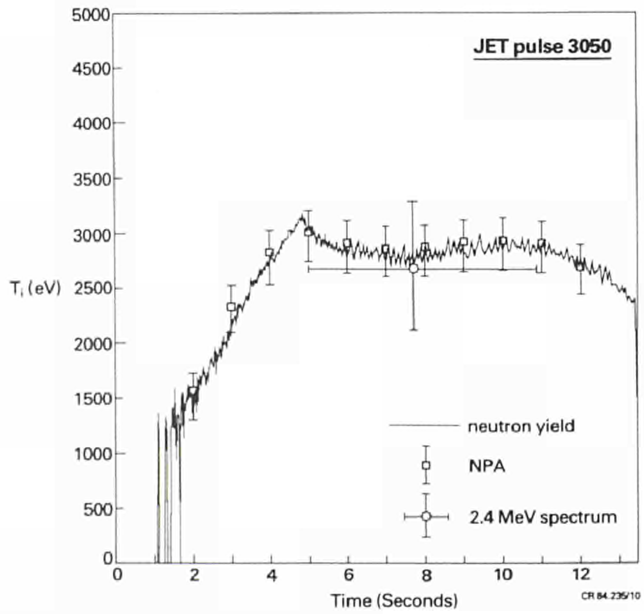


Fig. 43 Ion temperatures for a pulse measured by three techniques.

neutron spectrometers, which are under construction at Studsvik, Sweden, and at Harwell, UK, for installation at JET during 1985.

Hard X-Ray Monitors

Operating JET over a wide parameter range will inevitably result in some plasmas with large runaway electron currents. It is important to be able to observe the occurrence of such plasmas so as to learn how to avoid them and the consequent risk of damage to the limiters. On impact with the limiters, runaway electrons produce Bremsstrahlung radiation, which is monitored with a set of simple detectors mounted on the vertical limbs of the transformer and the walls of the Torus Hall. They provide a measure of the Bremsstrahlung intensity (total power).

H-Alpha Monitors

In order to establish the particle balance in the plasma it is necessary to measure the ionisation rate. This is done by an absolute measurement of the H-alpha light emitted from the plasma at nine points around the Torus. The collected light is transmitted via optical fibres to the diagnostic wing where it can be analysed by means of filters or spectrometers and detected by photomultipliers.

The system was operational in June 1983. It provides measurements of the particle confinement time and gives information on the effective ion charge (Z_{eff}) of the plasma. The system will be supplemented by a poloidal scan of the light emission to yield spatial profiles of the ionisation rate and of Z_{eff}.

Visible Spectroscopy

Some of the optical fibres for the H-alpha monitors are equipped with visible spectrometers lent to JET under the Task Agreement with Culham Laboratory. In addition, a spectrometer closely coupled to the Torus is installed for limiter observation. In this way, a consistent picture is obtained concerning the influx, nature and long term evolution of impurities. Doppler measurements on H-alpha lines and on forbidden impurity lines allow the determination of the ion temperature.

Vacuum Ultraviolet Spectroscopy

One of the most important problems in tokamaks is the role of impurities, which contribute through radiation to the power losses and also shape the plasma current distribution through the electrical resistivity. In order to understand the role of impurities in JET and to assess the effectiveness of various methods of improving the purity of the JET plasma, it will be necessary to measure spectroscopically space and time-resolved profiles of the different impurity ion densities.

The main spectroscopic diagnostic system to be used will cover the wavelength range of 100 to 2000 Å and is based on a system successfully operated on the TFR tokamak at Fontenay-aux-Roses which provides high quality spectroscopic information. The spatial scan is obtained by viewing the plasma through a rotating mirror which has a gold-plated face and is used in near grazing incidence. The spatial scan will take 3 milliseconds to complete and will be repeatable every 20 milliseconds. The three mirrors are synchronised to rotate together and can also be stopped at any predetermined position in order to obtain continuous time resolution along fixed chords. This system is partly installed and will be commissioned early in 1985.

There is also a broadband spectrometer covering the wavelength range 125 to 1700 Å. It has a microchannel plate detector and is being used for time-resolved line identification and impurity monitoring studies. This spectrometer has been operational since May 1984. Most of the information on impurity concentrations in JET are based on the results of this instrument. It has been calibrated on ASDEX during the Autumn 1984 shutdown. It will be complemented by a grazing-incidence spectrometer covering the wavelength range between 10 and 300 Å, which in addition has survey capability using the same detector. It is aiming particularly at the resonance lines of light impurities.

X-ray Spectroscopy

The wavelength range in vacuum ultraviolet spectroscopy is most suited to the relatively low temperature plasmas to be found in the early operation of JET before the full additional heating power is available. When higher temperature plasmas are obtained, the region observed by these spectrometers will shift towards the outer regions of the plasma. Shorter wavelength instruments will be needed to view the highly stripped impurities in the centre of the discharge. Work is in progress at IPP Garching on a spatial scanning X-ray crystal spectrometer which will operate at shorter wavelengths (1—20 Å). It is scheduled to be installed in 1985. This instrument will use two crystals which must be rotated and translated synchronously to carry out a wavelength scan. In order to obtain a spatial scan with these spectrometer systems, it will be necessary to locate them close to the Torus. This means that they will not be usable for deuterium-tritium plasmas with high radiation fluxes.

An active phase spectroscopy system is being designed, which will allow impurity spectroscopy measurements to be continued under active conditions. This will also be based upon a two crystal spectrometer, though the crystals will now be located outside the Torus Hall and will view the plasma through a vacuum pipe passing through a small hole in the shielding wall. The two crystals and the detector will be separated by a neutron shielding labyrinth allowing the detector to be located in a region of low neutron flux. This system is scheduled to be operational in 1986.

High Resolution Spectroscopy

Spectroscopy also provides a valuable method of determining plasma ion temperatures by measuring the spectral width of selected impurity lines. A group at Frascati (Italy) is building a high resolution crystal spectrometer for JET which will have both the crystal and the detector placed outside the Torus Hall behind the neutron shielding wall. The system is scheduled to be operational in 1985.

Soft X-ray Pulse Height Analysis

The measurement of the soft X-ray spectrum using a cooled Si(Li) detector is a standard diagnostic method in most tokamaks and is usually used to obtain estimates of Z_{eff}, the electron temperature T_e, and to measure deviations from a Maxwellian distribution of the electrons. The construction of a comprehensive system is in progress. A first provisional system was operational in August 1984. It confirmed the electron temperature measured so far by ECE, and gave results on the enhancement factor in the soft X-ray regime.

Soft X-ray Diode Arrays

The main task of this diagnostic system is to provide a means of investigating magnetohydrodynamic and other fluctuations and to locate the magnetic surfaces with rational values of the safety factor q. It can also be used to measure the radial radiation profile with a coarse spectral resolution by applying a filter technique. The system being built by IPP-Garching consists of two X-ray imaging cameras, which view the same toroidal cross-section of JET in orthogonal directions (one mounted on a vertical port and one on a horizontal port).

A provisional system with four diodes behind different filters was installed in August 1983. It indicates the onset of magnetohydrodynamic activities in the plasma centre. This information is useful in determining the central current density and hence the ohmic power density. The full system will be installed in June 1985.

The most serious restriction of this diagnostic arises from the sensitivy of the detectors to neutron and gamma radiation. Massive shielding will be required to allow the system to operate in deuterium plasmas with high power heating. However, this system will not be able to operate in deuterium-tritium plasmas, because of radiation induced signals and detector damage. The search will continue for detectors which are less sensitive to radiation and which therefore might be used in the future to extend the range of operation of this system.

Bolometry

The aim of the bolometer diagnostic is to make time and space resolved measurements of the total plasma radiation losses. It uses multichannel arrays of bolometers to view the JET plasma in orthogonal directions through vertical and horizontal ports. The full system, which was built by IPP Garching, is now installed.

Total radiation losses and spatially resolved radiation profiles have been obtained and used as input for the evaluation of the energy balance. The radiation losses vary between 40 and 100% of the ohmic input, depending on vessel conditions and density. At higher densities, the profiles are always hollow.

Interferometry

Density is one of the funadamental parameters of the plasma and its measurement has to be made reliably for every pulse. The main system used at JET is a multichannel far-infrared interferometer directly extrapolated from the apparatus which has successfully operated for many years on the TFR tokamak at Fontenay-aux-Roses. The system built by CEA Fontenay-aux-Roses for JET uses a deuterium cyanide laser transmitted through crystal quartz windows in the vacuum vessel wall. Figure 44 shows a natural stone before cutting and polishing. The optical components for the interferometer are mounted on a single large C-frame which is mechanically decoupled from the JET machine in order to minimise vibrations (Fig. 45).

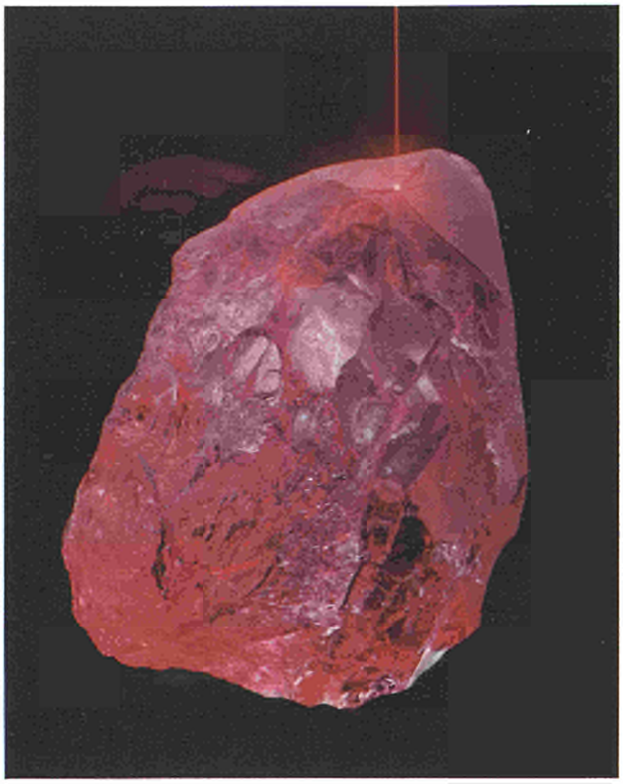


Fig. 44 A 20kg stone of natural crystalline quartz illuminated by a laser. The core of this stone is pure perfectly crystalline material which will be cut into discs to manufacture high temperature optical windows for installation on the Torus.

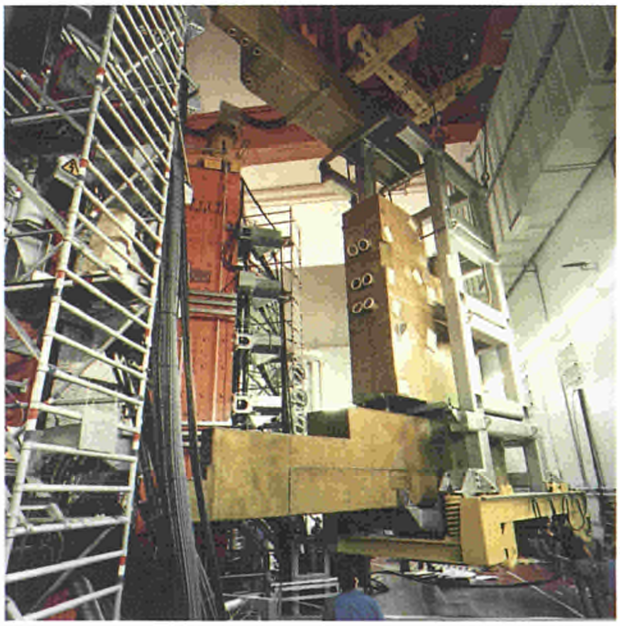


Fig. 45 The FIR interferometer during installation on the machine showing the arms which contain optical components and the support tower.

The interferometer has been fully operational except for the compensating interferometer. First measurements showed a moderate peakedness of the JET electron density profiles.

In addition, a single channel 2mm microwave interferometer has been operating throughout 1984 when it was the principal means of density measurement. This system is being upgraded to 1 mm to work at higher densities.

Reflectometry

The microwave reflectometer, like the interferometer, is a diagnostic for measuring plasma density, but whereas in the interferometer the microwave beam passes through the plasma, in the reflectometer the beam is reflected from a critical density layer within the plasma. A prototype system has been tested and developed on JET using one of the ECE waveguides. It has given some useful data on density profiles. A more comprehensive system is now being designed.

Charge Exchange Neutral Particles

The standard method of measuring ion temperatures in tokamaks is based upon the analysis of the energy distribution of escaping fast neutral atoms produced by resonant charge exchange between plasma ions and neutral atoms.

The system, constructed for JET at the ENEA Frascati Laboratory (Italy), consists of an array of five separate analysers arranged to view different chords in a vertical section of JET. One analyser has been operational since May 1984. It routinely provides measurements of the ion temperature and of the ratio of hydrogen to deuterium in the plasma. Three more analysers have been installed in the Autumn 1984 shutdown and will be commissioned early 1985.

Diagnostic Pellet Launcher

The hydrogen/deuterium pellet injector system for JET was given a high priority in 1984. A detailed specification of performance, of the interfaces to JET, and the preparation of a detailed design was completed in October 1984. Approval for manufacturing to start was given in December 1984. Piece-wise installation of the system will begin in July 1985, and full operation of the pellet injector is planned before the end of 1985.

The pellet injector is of the pneumatic type. The pellet is accelerated over a path of up to 80cm by application of room temperature pressurised hydrogen or helium gas behind the solid hydrogen or deuterium pellet. Cylindrical pellets with diameters of 2.6mm, 3.6mm and 4.6mm will be obtained at velocities between 1200m/s and 1500m/s. The pellets contain sufficient atoms to effect a 10 to 100% increase in the particle content of JET at the plasma densities and volumes expected during 1986.

The pellet injector has been designed by IPP, Garching and Leybold-Heraeus Gmbh. JET staff were heavily involved in the design of interfaces to the JET machine. The pellet injector system is being manufactured by Leybold-Heraeus Gmbh. The system will be tritium compatible, making it suitable for operation in the active phase. A liquid helium supply suitable for active phase operation remains to be designed.

The pellet injector will expand the scope of studies of particle transport, confinement and recycling of the host species and also of impurities (using neon doped hydrogen/deuterium pellets), and will facilitate the tailoring of the plasma density profile to optimise heating. It will also provide empirical data to arrive at a specification of a pellet refuelling device for JET.

The Operation of JET

Summary of JET Operations in 1984

JET was in operation as a tokamak for 17 weeks in 1984, the remaining time being devoted to modifying the machine and to commissioning. In all, about 500 plasma pulses were fired, the majority of them above 1 MA as shown in Fig. 46.

The time dependences of the plasma current, loop voltage and average density for a representative pulse are shown in Fig. 47. The plasma current (I_p) rises to 3.7 MA in about 5 seconds, remains at around this level for 5 seconds, and then decays away in a similar time. The driving loop voltage falls to less than 1 volt during the constant current phase, highlighting the high electrical conductivity of these plasmas. Figure 48 shows the plasma cross-section, 7 seconds into the pulse, as deduced from magnetic measurements. The limiter is shown schematically on the equatorial plane mounted inside the vacuum vessel. The contours correspond to magnetic surfaces of constant flux

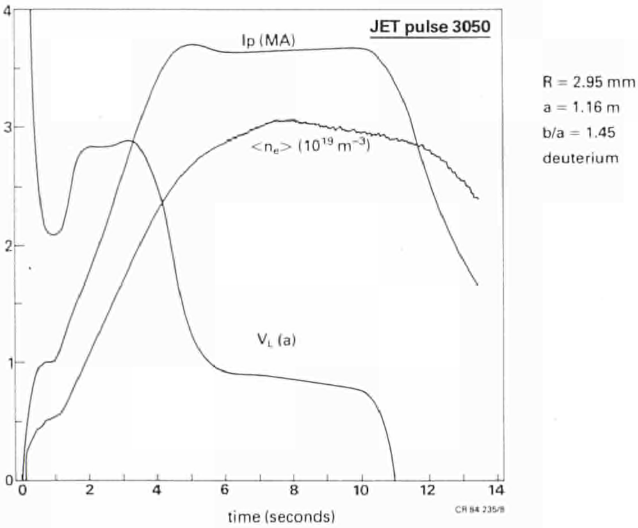


Fig. 47 Time dependences of the plasma current (I_p), loop voltage (V_l) and average density (n_e).

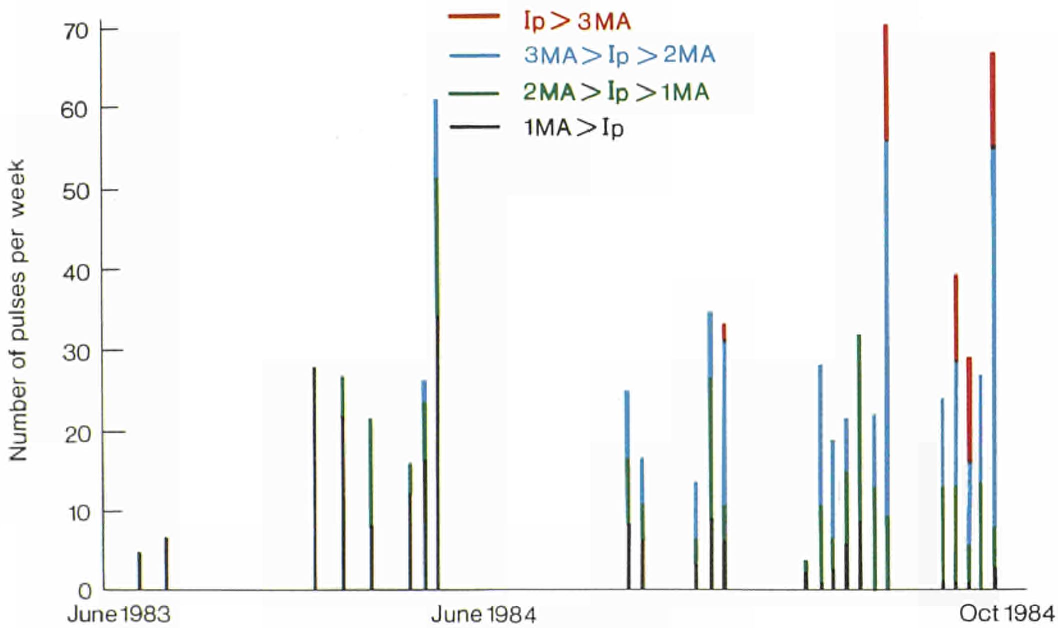


Fig. 46 Frequency of JET plasma shots.

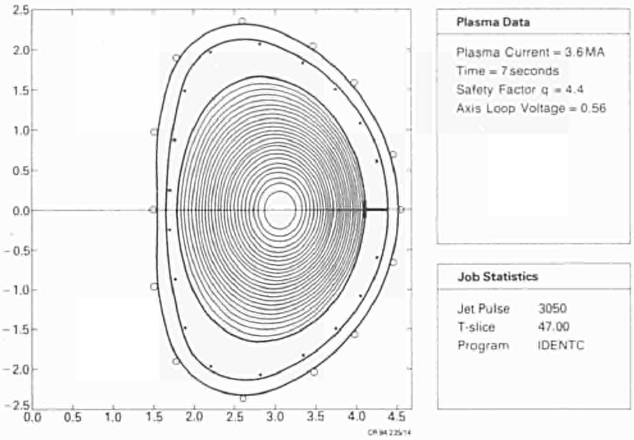


Fig. 48 Poloidal flux contours in the plasma.

calculated by using the plasma equilibrium equation to interpret measurements of time-varying magnetic fields both inside and outside the torus wall. In this particular case, the ratio of vertical to horizontal plasma dimensions, known as the elongation ratio, is 1.4. It should be noted that the vacuum vessel is fairly well-filled by the plasma, although there still remains some scope for modifying the shape and increasing the elongation.

Figure 39 shows the time-dependence of the central electron temperature. The continuous line is derived by analysis of the millimetre wave emission from the hot electrons gyrating about the magnetic lines of force (electron cyclotron emission). The points at discrete times are from an entirely different technique in which the light from a brief laser pulse is scattered by the electrons and their temperature deduced from the observed Doppler frequency broadening of the scattered light. The two methods of electron temperature measurement agree well within the errors of the two techniques.

Figure 43 shows for the same pulse the corresponding central ion temperatures, measured again by two techniques. A third independent method measures the energy spectrum of the neutrons emitted from this deuterium plasma during the current flat-top. This gives one time-averaged value for the ion temperature in good agreement with other methods.

In summary, the 1984 experiments extended the current level up to 3.7 MA, operated in deuterium as well as hydrogen, increased the plasma elongation to 1.6, operated at the full toroidal field (B_ϕ) level of 3.45 T, and tested different vacuum vessel cleaning and conditioning techniques. All the operations were done with four carbon limiters and the vacuum vessel maintained at a temperature of about 270°C.

An informative way of showing the range of operations in a tokamak is to show the flat-top performance figures in a graph of $1/q_{CYL}$ vs $\bar{n}R/B_\phi$, where q_{CYL} is the cylindrical safety factor. This plot is shown for JET in Fig. 49. The parameter $1/q_{CYL}$ is a normalised measure of the plasma current, while $\bar{n}R/B_\phi$ measures the plasma density. Results from tokamaks of all physical sizes and field strengths can be compared on this type of diagram. Figure 49 shows that JET behaviour in this normalised sense is similar to that of other tokamaks. At a fixed $\bar{n}R/B_\phi$, the maximum current is bounded by the low q disruptive instabilities corresponding to a q_{CYL} of around 2.3, while for a given value of q_{CYL} there is another type of disruptive instability at the density limit given by:

$$\frac{\bar{n}R}{B_\phi} = \text{constant}\left(\frac{1}{q_{CYL}}\right) \tag{1}$$

The value of the constant is found to be higher the cleaner the plasma. In JET in 1984, the constant was about 50% lower than that found in the best ohmically heated tokamaks elsewhere. The limiting density equation can be rearranged to give the relation:

$$\bar{n}_c = \text{constant}\ \bar{j} \tag{2}$$

where $\bar{n}_c$ is the maximum average density before disruption, and $\bar{j}$ is the average current density in the plasma.

The global energy confinement time (τ_E) is defined in steady state as the ratio of the plasma energy content to the input power. The energy content is calculated from the measured densities, temperatures and plasma volume. The power input is derived from the magnetic measurements. The results are discussed later in this report and for JET where the major radius and minor horizontal radius have been kept more or less constant they show that the data as a whole is roughly fitted by the relation:

$$\tau_E = \text{constant}\ \bar{n}\, q_{CYL} \tag{3}$$

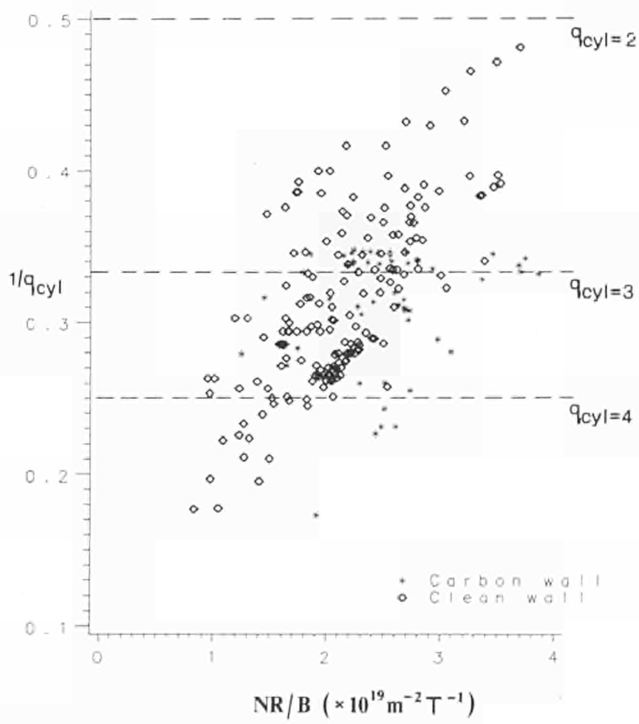


Fig. 49 Flat-top performance figures for JET.

The constant is systematically 20% higher for deuterium plasmas than for hydrogen. These scaling laws, equations (2) and (3), show that in JET the maximum achievable confinement time is:

$$(\tau_E)\text{max} = \text{constant } B_\phi \tag{4}$$

while the maximum value for the more significant parameter $(\bar{n}\tau_E)$ is:

$$(\bar{n}\tau_E)\text{ max} = \text{constant } \frac{B^2_\phi}{q_{CYL}} \tag{5}$$

where only the parameters varied in JET have been retained outside the constant. Although the relation (5) follows from the above experimental scaling relations, it should be emphasised that the relation has still to be explored within the full range of B_ϕ and q_{CYL}.

From the long-term viewpoint of alpha-particle heating and fusion power, the progress of JET is properly measured in the Lawson diagram in which the parameter $(\hat{n}_i\ \hat{\tau}_E)$ is plotted against the central ion temperature $\hat{T}_i$. The central value of the hydrogen (or deuterium) ion density is obtained from a knowledge of the measured electron density profile, the measured effective ion charge, Z_{eff}, in the plasma centre and the estimated charge state of the impurity species in the centre. In general, $\hat{n}_i$ is significantly less than $\hat{n}_e$, illustrating the important effect of impurities in "diluting" the central plasma, i.e. in reducing the density of the potentially reactive hydrogen isotopes. The central confinement time is calculated from the central energy balance, using the current density and driving voltage deduced from magnetic measurements. Typically $\hat{\tau}_E \sim 1.3\tau_E$, where τ_E is the global confinement time discussed earlier. Figure 50 shows the 1984 JET data plotted in this way. As expected the best performance is obtained with the highest plasma currents. Figure 51 shows the logarithmic plot of $(\hat{n}\hat{\tau}_E)$ vs $\hat{T}_i$ with the predictions for the various phases of JET as shown in the 1983 Annual Report. Superimposed are the experimental results with ohmic heating in 1984. The results are evidently in fair agreement with expectation. In detail, the main differences are a higher impurity content giving Z_{eff} of 3 to 6 compared with an expectation of close to 1, a confinement time of about double the assumed value, and temperatures about twice as high as the expectation due to the increased power input and longer confinement. The product $(\hat{n}_i\ \hat{\tau}_E)$ has about the expected value, the longer confinement time being compensated by the dilution due to the impurities.

The 'vertical' disruption that occurred in pulse #1947 gave rise to an unanticipated phenomenon. After the feedback system for plasma position control had used up its full voltage swing and had therefore been switched off by a protection system for the amplifier, the plasma moved rapidly downwards a distance of nearly one metre without significant reduction in current. This was followed by a rapid current quench and movement of the plasma towards the inner (small major radius) section of the wall. The unexpected feature was that large forces of the order 200 tonnes were transferred to the vacuum vessel causing rapid displacements of about 1 cm and a permanent reduction in the mean major radius of the vessel by 1 mm. A tentative explanation is that poloidal currents flow through the plasma and the rigid sectors transferring the full destabilising force on the plasma to the vessel. This explanation has not yet been proven by direct measurement of the associated magnetic

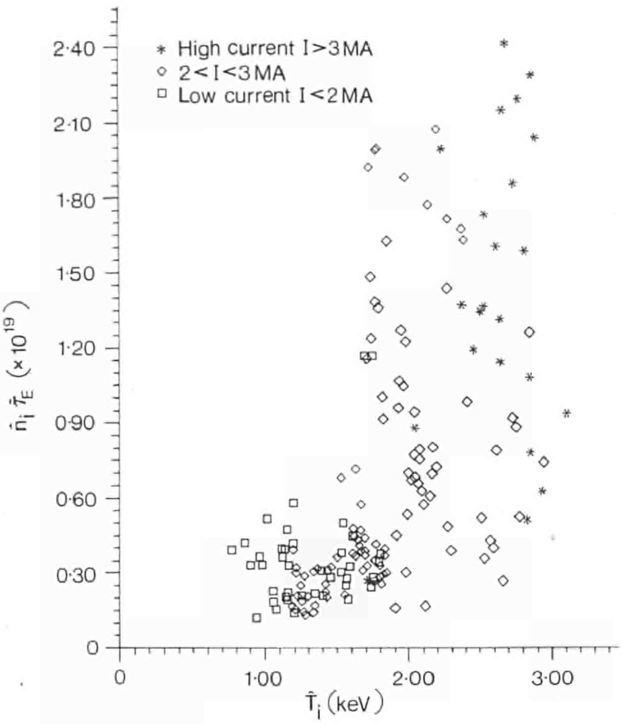


Fig. 50 Lawson plot.

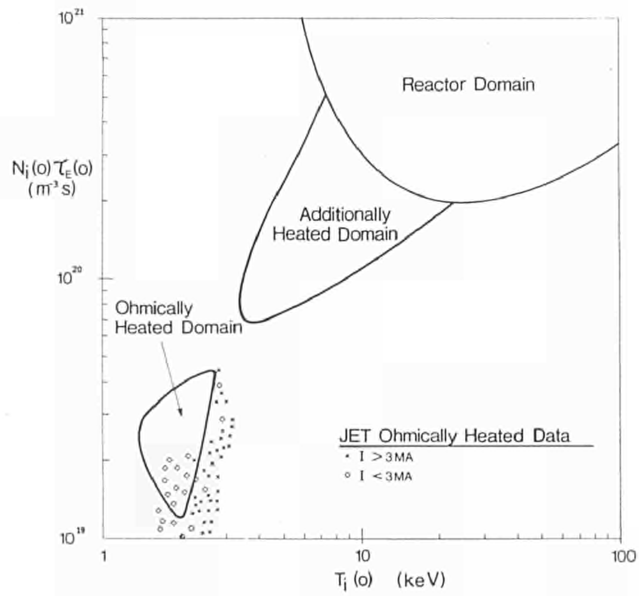


Fig. 51 1984 data compared with predictions for the various phases of the JET programme.

fields. In view of the potential dangers to the vessel, the campaign to increase the plasma current above 4MA was suspended until the vessel's mechanical support system was improved and the full implications understood.

In 1985, it is hoped to increase the performance level in cautious steps towards 5MA, while the major emphasis will be on additional heating experiments with both ion cyclotron resonance and neutral injection techniques. The ohmic plasmas obtained in 1984 form an adequate starting point for these experiments.

Plasma Optimisation

An important activity in any tokamak programme is the establishment of the control settings required to give reliable operation over the full range of performance. These settings are influenced by the recent history of the machine. For example, a disruption will decondition the machine by changing limiter and wall surfaces by coating them with metals. Recovery calls for special operating procedures, otherwise subsequent plasmas will disrupt and so make matters worse. The process of establishing these operational procedures for JET has been called plasma optimisation. It can best be illustrated by describing the main phases of a plasma pulse and the key factors that determine its behaviour.

Figure 47 shows the behaviour of the plasma current, applied voltage and electron density with time in a typical JET pulse. The pulse can be divided into four phases: start-up, current-rise, flat-top and termination. A pulse starts with the energisation of the main toroidal field coils. Shortly afterwards the primary coil P1 is premagnetised by the poloidal flywheel generator convertor (PFGC) and the prefill of hydrogen or deuterium admitted to the chamber. The plasma is initiated by opening a pair of circuit breakers which divert the premagnetisation current through a set of resistors. A toroidal electric field appears around the vessel by transformer action. This voltage ionises the prefill gas and starts the plasma current. As the primary coil current decays, the voltage falls until it equals that across the PFGC. At this point a pair of switches close to reconnect the PFGC (now in the reverse sense) across the poloidal field coils. The excitation of the PFGC is then controlled to give the desired rate of current rise, the flat-top value of plasma current and finally the time at which the termination starts. During the plasma current rise and flat-top, further hydrogen or deuterium is bled into the chamber to increase the plasma density. In recent operation, the plasma current and density have been controlled by feedback loops.

Start-up is the most sensitive phase of the pulse. The seed for the ionisation process is the electron population arising from natural radioactivity, cosmic rays or internal sources such as the ion gauges used to measure the Torus pressure. The applied voltage accelerates the electrons until they collide with molecules or atoms. If the electrons have sufficient energy, the molecules and atoms will be ionised so that an electron avalanche occurs. The rate at which the avalanche proceeds depends on three factors. Firstly, the applied voltage determines the energy of the electrons. Secondly, the pressure of hydrogen or deuterium in the chamber determines how far an electron travels before it collides. Thirdly, the strength of stray magnetic fields is important, because the electrons travel principally along the field lines. Stray fields direct the field lines out of the toroidal direction and cause the electrons to run into the walls of the chamber. If they do so without having caused any ionisation, the avalanche will fail. For typical JET conditions, the avalanche is inhibited at stray field levels which are a fraction of one per cent of those required to maintain equilibrium later in the pulse. Consequently, a major source of stray fields has been small currents flowing in the radial and vertical field windings and considerable care must be taken with their control at start-up. The distance that the field lines travel to arrive at the wall increases with toroidal field for fixed stray fields. The stray field is, therefore, mainly a problem at low values of toroidal field.

Once ionisation is complete, the plasma temperature begins to rise with the current. Fully ionised, high temperature plasmas have the property that the electrical conductivity increases strongly with electron temperature. A consequence of the increase in conductivity is that magnetic fields penetrate the plasma more slowly and so a current skin begins to form on the outside. Current skins are highly unstable and the current is redistributed in a series of internal rearrangements of the plasma. Unfortunately, these rearrangements increase the interaction of the plasma with the limiters and chamber wall. The interaction brings impurities such as carbon, oxygen, nickel and chromium into the plasma. These cool the plasma through ultra-violet and soft x-ray radiation. The cooling due to carbon and oxygen may clamp the electron temperature at such a low value that the plasma current is prevented from increasing at all. The metallic impurities cool the centre of the plasma, thereby making it locally more resistive and so exacerbating the formation of the current skin. The rearrangements may become more and more violent until there is a major disruption. It is important, therefore, to avoid these effects by operating the machine in such a way as to prevent current skin formation. If the rate at which the plasma current is increased is small enough, the plasma current can penetrate resistively and current skin formation can be avoided. However, the characteristic time for current penetration is typically as long as the toroidal field pulse so something must be done to make it faster. Two techniques are used with some success in JET to enhance current penetration. These are to increase the aperture of the plasma and to ramp the toroidal field as the plasma current increases. In both cases, the current is effectively carried into the centre of the plasma even when formed at the edge.

As mentioned earlier, special recovery procedures are required following a major disruption. Whilst disruptions are rare during operation with routine settings, some are inevitably caused by exploration of new operating regimes. A major disruption can erode limiter surfaces, so exposing to the plasma fresh and more easily removed carbon, or it can coat them with metals from the walls. The net effect is to increase the impurity content of subsequent discharges. This can have the consequences for start-up that are described in the previous paragraph. Recovery is often accomplished with a low prefill pressure, to avoid excessive cooling of the discharge by impurities, and low plasma currents to minimise the effects of a further disruption.

Generally speaking, it is found to be convenient to increase the plasma density with the plasma current. A certain proportion of the density arises from the desorption of gas from the limiters. After glow discharge cleaning, the operating range can be quite restricted because of the density increase due to desorption. However, it is found that the effect rapidly becomes less important during a session as the stored hydrogen is removed by plasma pulses. The maximum density is set by the disruption limit. This limit is proportional to the plasma current except near resonant values where the magnetic field lines close on themselves after two or three toroidal transits (q of 2 or 3). The limit also depends on the impurity content of the plasma and on other tokamaks is increased by additional heating. In contrast with smaller devices, changing the control settings, i.e. the way in which the density is programmed, has little effect on the limit in JET.

The arrangement of the connections to the poloidal field flywheel generator is such that it is not possible to drive the plasma current down. The driving voltage is removed at the end of the flat-top and the plasma current is allowed to decay resistively. The decay usually takes ten seconds or so. The plasma density usually decays with the current. However, in pulses that have the highest density in the flat-top, the density often pauses in the decay so that the high density limit is exceeded with the result that a disruption occurs at a current which while less than the peak value may still be uncomfortably large. As yet, no means has been found of combating this effect. A development programme has been initiated to produce a device that will pump the particles from the discharge. It is hoped that this will prevent the density pause in the current decay.

Energy and Particle Confinement

The energy and particle confinement properties of JET plasmas were examined throughout the various phases of JET operation during 1984. At each new phase of operation, limited scans of the density, current and toroidal field were made in an effort to obtain the scaling of the confinement with these parameters. The plasma major and horizontal minor radius were kept approximately constant at 3 m and 1.1 m respectively and the elongation was varied from near circular values of around 1.15 to elliptical ones of 1.5.

For the energy confinement, both a global and local analysis has been completed. To calculate the global energy confinement time, values of the density were obtained from the single channel microwave interferometer, values of the electron temperature profile from the electron cyclotron emission at the second harmonic, and values of the ion temperature from the neutral particle analyser. The data from these diagnostics was cross-checked with that from other diagnostics. For example, the ECE measurements of electron temperature were cross-checked against a single point Thomson scattering measurement and the ion temperature measurement of the neutral particle analyser against neutron flux measurements in the deuterium plasmas. The differences between the respective measurements were all well within their experimental errors.

The global energy confinement time was found to increase initially with density (see Fig. 52) as in many other ohmically-heated tokamaks. At higher densities, there was some evidence of saturation in the energy confinement time. This was identified as being due to an increase in the radiated power with density. In Fig. 52, the data has been split into four groups: hydrogen and deuterium, before and after carbonisation. Grouping the data in this fashion shows that the energy confinement time in deuterium is some 20% better than in hydrogen and that confinement was marginally better after the wall carbonisation.

In an attempt to determine the scaling of the energy confinement with the plasma parameters, regression analysis has been completed using several combinations of the basic parameters. Due to the rather limited range of variation of the parameters and the usual problem of the interdependence of the parameters, it is not possible to give a precise conclusion. The best fit is that the energy confinement time is proportional to the product of density and q, the elliptic cylinder safety factor. This connects with data from the smaller tokamaks, if we assume an R^2a dependence on the plasma dimensions as shown in Fig. 53.

A detailed local power balance has been completed for selected shots. It was found that, for the central region of the plasma out to r/a = 0.75, the radial transport is dominated by thermal conduction and in the outer region by radiation. The accuracy of

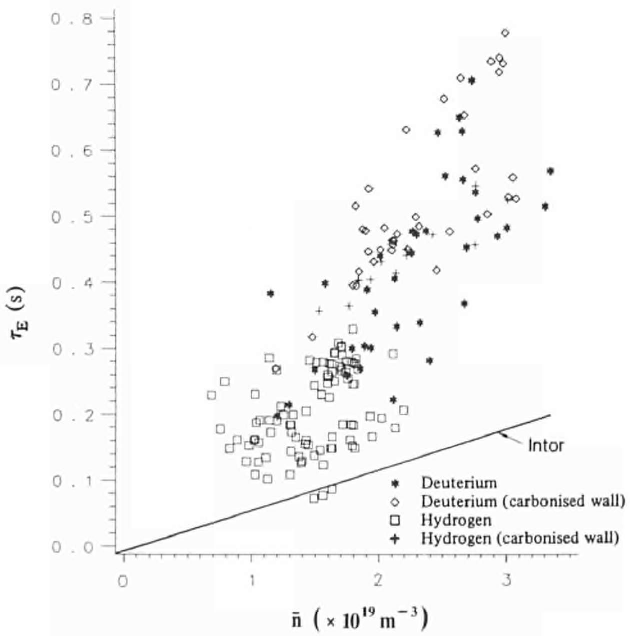


Fig. 52 Global energy confinement time with density.

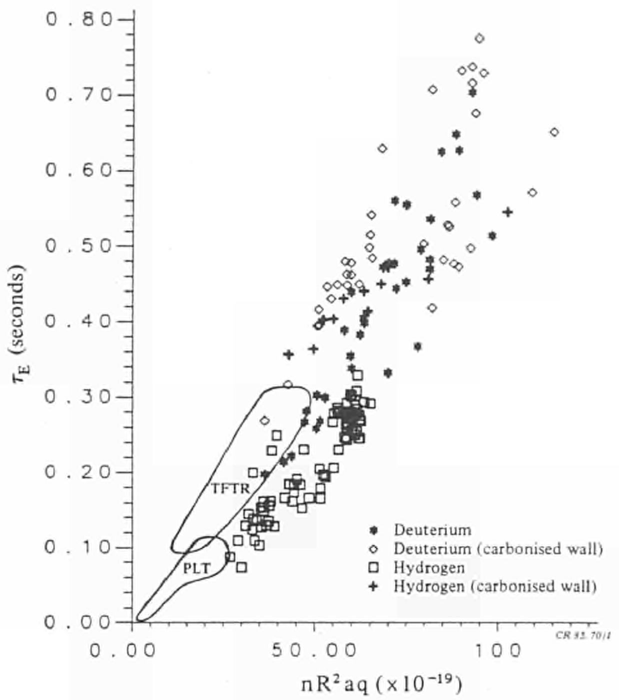


Fig. 53 Comparison using TFTR/PLT scaling law.

measurements does not permit a conclusive determination of whether the main loss channel in the central region is via electrons or ions. If the assumption is made that the ion thermal conduction is neoclassical, then the electron thermal conduction is found to scale inversely with density and the toroidal magnetic field, as in other tokamaks.

The global particle confinement time is determined from the particle balance equation, in which the source of new plasma particles is obtained from H-alpha measurements along various chords viewing the walls and limiters. The main source of gas in the present series of experiments is the limiter, however the ratio of the gas flux from the walls to the limiter does increase as plasma elongation is increased, and as the plasma comes closer to the walls.

The scaling of the global particle confinement time has shown a general pattern in which at low densities the particle confinement time increases with density, whereas at higher densities, the particle confinement time decreases with density, showing that at high densities the plasma is impervious to neutrals. The carbonisation of the wall further reduces the particle confinement time.

Instabilities and Disruptions

Observed as well as predicted instabilities pose an immediate threat to the target of increasing the product of plasma energy content and heat isolation to a level sufficient to reach partial or full ignition. Microinstabilities and turbulence enhance the heat transfer from inner to outer plasma layers, in other words they reduce the energy confinement time. Macroinstabilities may abruptly end the plasma pulse when either the density becomes too large (high density disruption limit) or the plasma pressure becomes too large (beta-limit).

The driving force behind these instabilities is the inhomogeneity in the distribution of the current, the magnetic field, and the plasma energy. This is, of course, unavoidable since the plasma needs to be hot in the centre and cold where it is in contact with the limiters and vessel wall. The challenge is to establish such distributions of the inhomogeneities that the growth rates of the instabilities become sufficiently low or that instability amplitudes are sufficiently dampened to have no great effect on heat transfer.

Instabilities Driven by the Current Distribution: "Tearing Modes and Disruptions"

The electrical conductivity of plasma rises with temperature. In a stationary state, therefore, the current density is highest in the hot centre at the axis and lowest at the cool edge. In the plasma, the magnetic field is helical consisting of a poloidal contribution caused by the plasma current and an externally applied toroidal field. On certain surfaces, the helical magnetic field will show resonances: after m revolutions around the Torus, a field line will have made n revolutions in poloidal direction and will therefore "bite in its own tail" if the ratio of m to n is a ratio of integer numbers. On such resonant surfaces, the current density will have the tendency to condense into so-called magnetic islands (see Fig. 54) which follow the resonant magnetic field line, i.e. there will be m islands on a cross-section of the surface in the poloidal plane. These islands or tearing-modes grow in radial dimension with increasing difference in current density inside and outside the resonant surface.

In many tokamaks, these islands are observed mainly with small m/n numbers (1/1, 2/1, 3/2) except during the start-up phase when the values of m/n are high. With small radial dimensions, these islands do not pose problems. They enhance the heat-transfer locally, but the thermal isolation between resonant surfaces is still good. However, if the islands grow radially to such dimensions that they overlap, a large heat transfer will take place from the central core to the edge. These so-called disruptions are also observed in JET: in a period as short as a millisecond half the confined plasma energy can be drained and deposited on the limiter (energy-quench phase). Normally the applied driving voltage for maintaining the current cannot rise sufficiently fast to compensate for the increased resistivity of the cooled plasma and therefore the current dies quickly (current quench phase). If position equilibrium can still be upheld (soft disruptions), the current quench takes 0.3 s, whilst it can become as short as 0.02 s if the position control amplifier reaches saturation voltage and so loses control of the position (hard disruption). See also Fig. 55.

The question to be answered is what causes the current distribution to change such that magnetic islands grow from a modest size to become overlapping. It is experimentally observed in JET as in all other tokamaks that an increase in particle content beyond a certain limit induces such unwanted disruptions (the

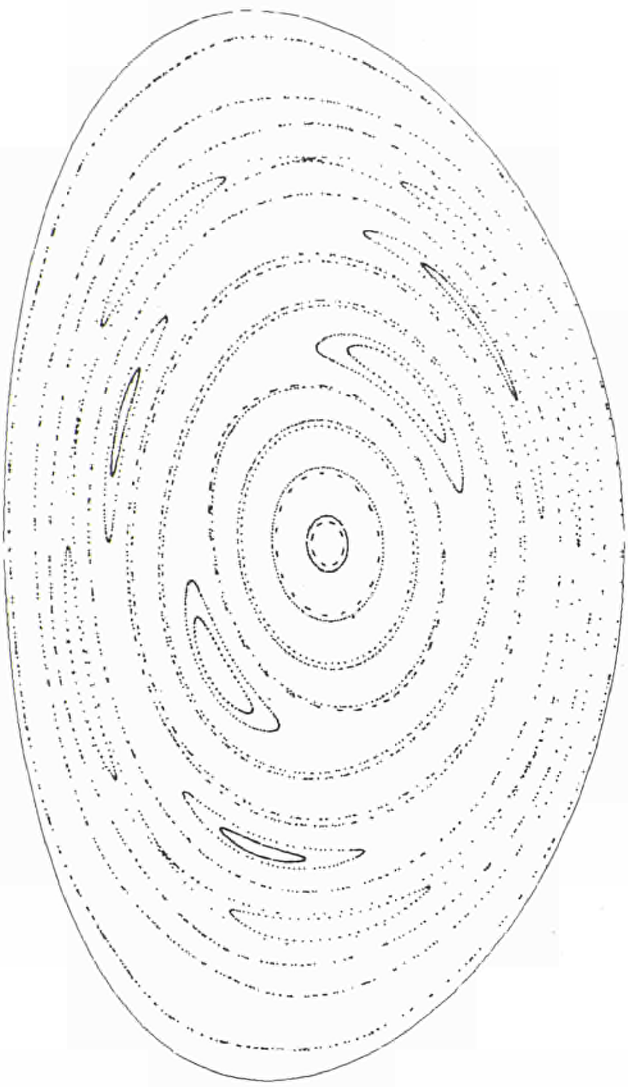


Fig.54 Magnetic islands distorting the magnetic surfaces of a JET plasma as calculated by the 3-dimensional MASCOT-code. Noticeable are the m = 2, 3 and 4 islands.

high density limit). The density at which these limiting processes begin increases with current and to a certain degree with magnetic field, but decreases with increasing impurity content. A plausible explanation under investigation is that impurities cause radiation losses that are larger in the cold edge than in the hot centre. Increasing the particle content by conventional gas injection from the outside will raise the radiation losses relatively more at the outside than in the core. Therefore, the resistivity will increase more outside than inside and so the difference in the current density across a resonant surface will increase, leading to growing island sizes and eventually to a disruption.

If this explanation is accepted, the course of action is clear. A reduction in impurities will lead to a density limit that is marginally sufficient. If, in addition, JET adopts fuelling methods which deposit particles in the centre (pellet-injection), island growth will be prevented since density increases will not lead to differential radiation increases. Indeed results with pellet-injection, for instance in ALCATOR-C, are promising.

Instabilities Driven by the Pressure Distribution: "Ballooning Modes and Beta-Limits"

Instabilities driven by the pressure distribution have not yet been found in JET. They are expected to play a role only at the high levels of plasma energy content that will be reached with large amounts of additional heating. In medium-sized tokamaks elsewhere, beta-limits are already found in cases of intense additional heating. These limits follow roughly the theoretically predicted scaling.

A crude description of the ballooning instability leading to energy-content limits or beta-limits is that at high values of the energy content the plasma can be kept in equilibrium only by allowing strong gradients in the plasma pressure distribution at the outboard side of the Torus, i.e. at a large major radius. However, at

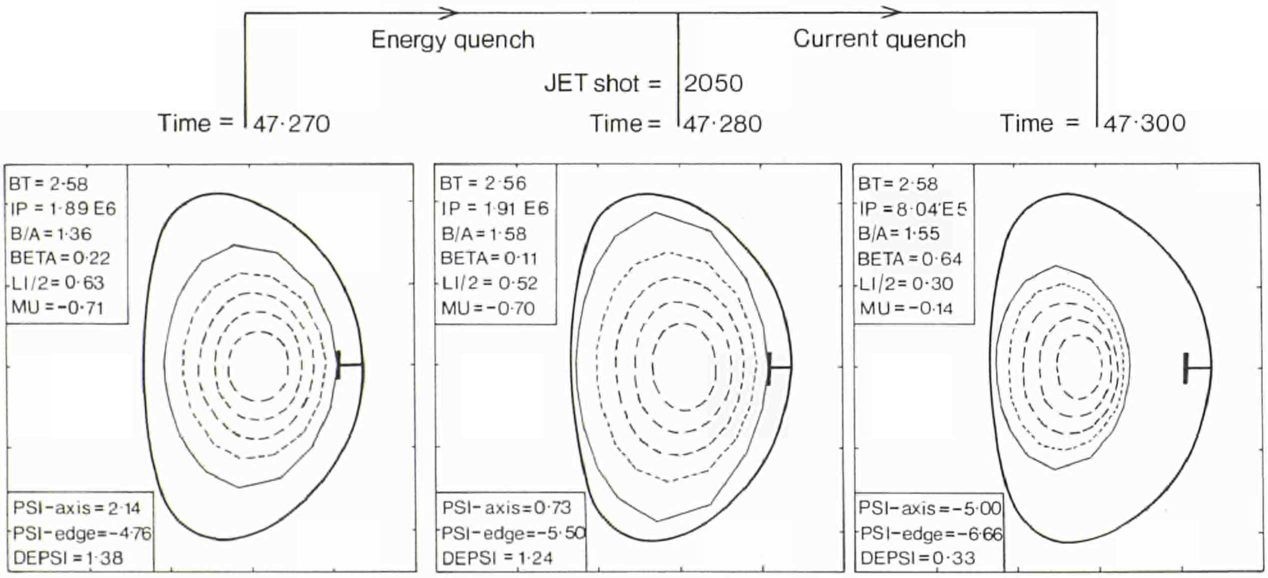


Fig.55. The plasma cross section as measured by magnetic diagnostics during a hard disruption terminating pulse 2050. Note the flow-up during the energy quench in which half the plasma energy is lost (Beta poloidal = 0.22 → 0.11). Subsequently the current decays so quickly that position control is lost and the plasma quenched at the inside wall.

this location the configuration of the magnetic field is at its weakest with the result that isobaric surfaces start to bulge in ripples, say 5 to 20 (ballooning), at the outboard side, whilst being smooth at the inboard side. By means of sophisticated scattering diagnostics, a much enhanced turbulence has indeed been observed at the outboard side in certain tokamaks in the USA, but scaling with the theoretical beta-limit is not yet fully established.

Impurities and Radiation Losses

Impurities in the JET plasma have been studied by visible and VUV spectroscopy, and from bolometer and soft X-ray signals. Visible spectroscopy is essentially restricted to lines of neutral atoms and low ionisation stages, providing information on sources and local influxes of impurities. Measurements in the VUV spectrum are more suitable for deriving impurity concentrations in the plasma, though, in the case of light impurities, the analysis is limited to the plasma edge, since these elements are fully stripped in the interior. Figure 56 shows a JET VUV spectrum in the range from about 10nm to 100nm containing lines from carbon, oxygen, chlorine and metals.

Oxygen, carbon, metals from the wall material (nickel, chromium, iron), chlorine and molybdenum have been identified as the main impurities in the plasma. Chlorine is believed to have been introduced when washing the Torus with detergent. The carbon limiters are the obvious source of carbon, though there is also a substantial carbon influx from the vessel walls. The walls also seem to play a dominant role for the oxygen and chlorine impurities. Metals are deposited on the limiter surfaces in the course of operation (from wall material) or during manufacturing (in the case of molybdenum). Subsequently, limiter sputtering is the main source of metals in the plasma.

The metal densities increased with plasma current and decreased with electron density, while the light impurities were relatively insensitive to these plasma parameters and depended more on the state of the vacuum vessel and size and elongation of the plasma. These facts led to the usually falling tendency of Z_{eff} with electron density during an experimental campaign, as illustrated in Fig. 57 for JET pulses in the late 1984 period. The lowest values at the end of this period were in the range two to three. An inverse correlation of light impurities and metals was observed throughout.

Apart from glow discharge cleaning, there were two main campaigns in 1984 to clean the plasma; a period of 12,000 pulse-discharge-cleaning pulses; and

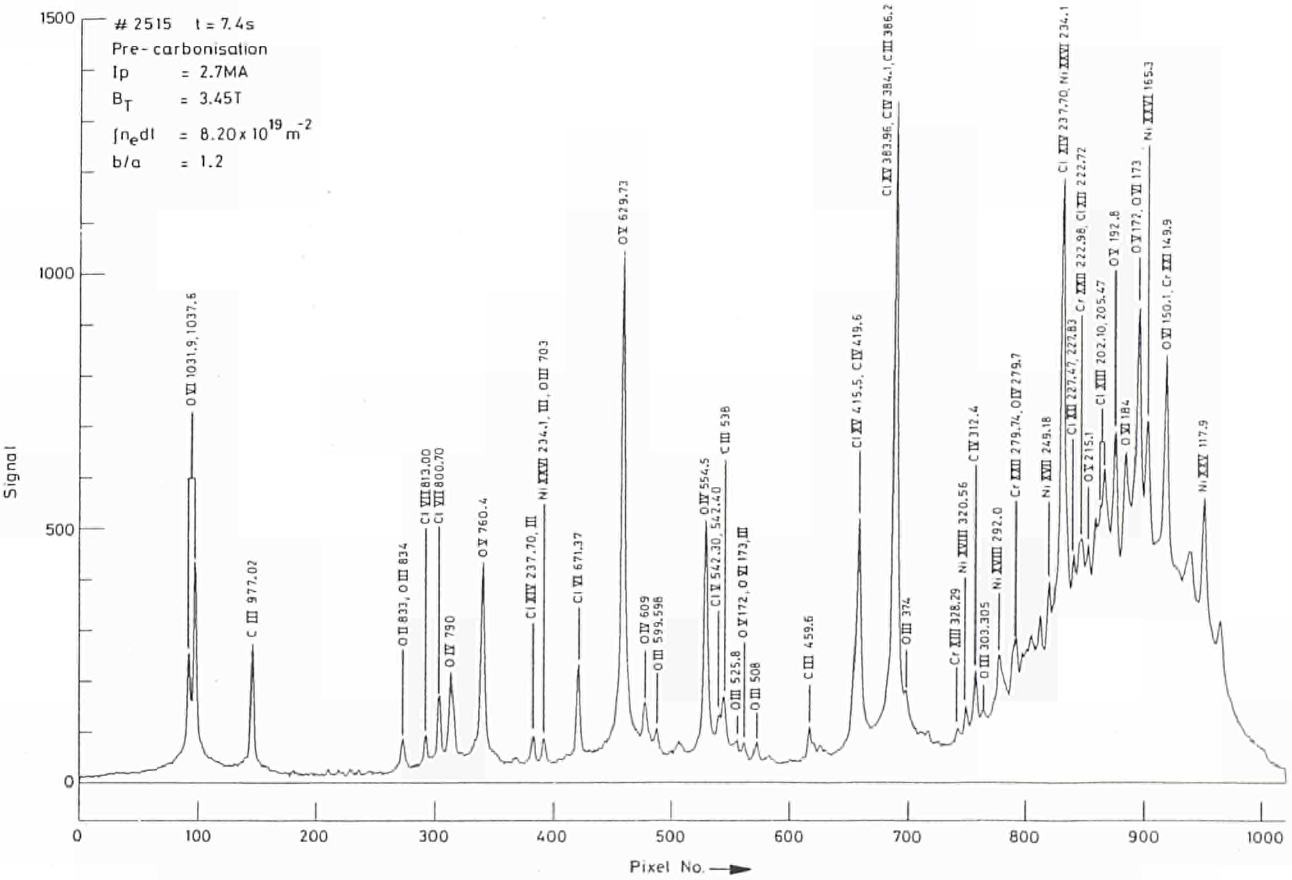


Fig.56 Example of JET VUV spectrum: annotations are in Angstrom units, signals in arbitrary units.

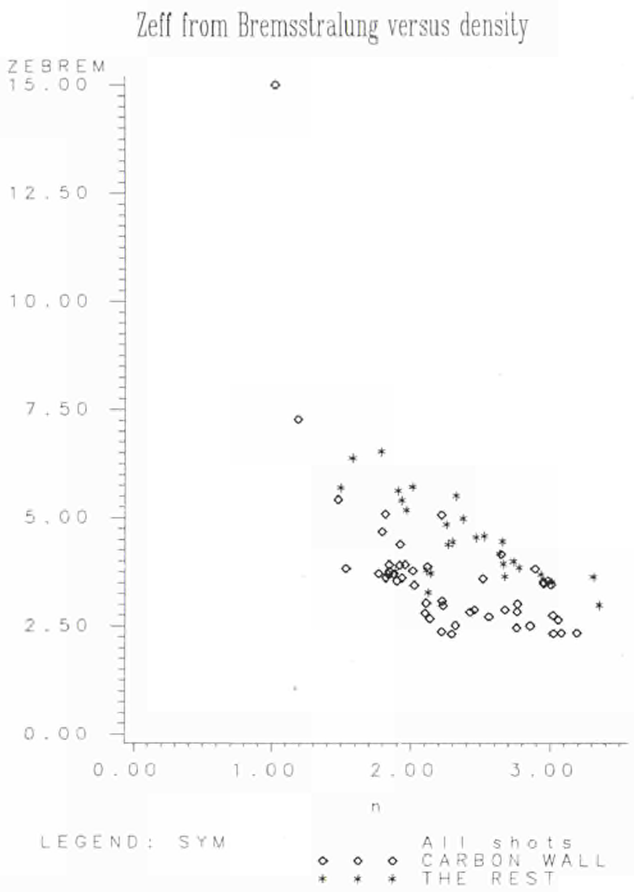


Fig. 57 Values of Z_{eff} before and after carbonisation.

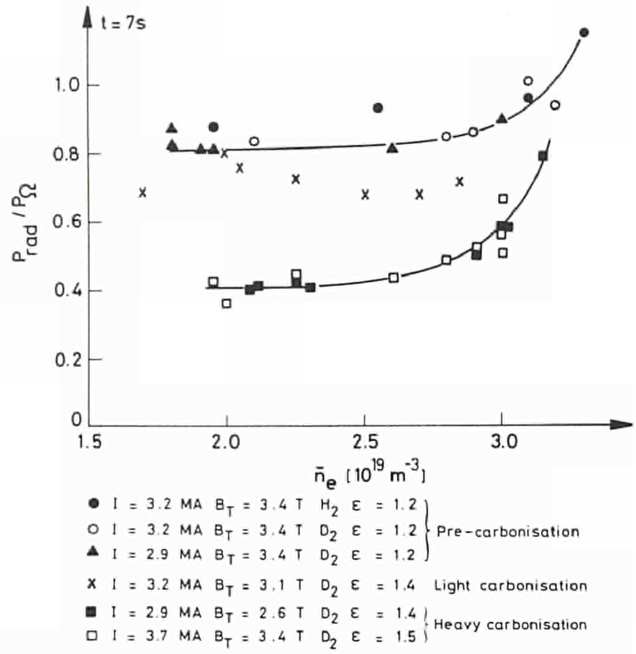


Fig. 58 Fraction of radiated power as a function of electron density.

repetitive carbonisation of the vessel walls. In the first case, some reduction of oxygen and chlorine was noted and the molybdenum fraction in the plasma decreased. However, at electron densities of $2\times10^{19}m^{-3}$ the radiated power was still about 90% of the ohmic input power and Z_{eff} was in the range 4 to 5. Carbonisation reduced the metal content of the immediately following pulses by about a factor of five, but the metals recovered after removing the carbon layer or after a day's ageing of the carbon. Oxygen and chlorine decreased gradually during the carbonisation campaign, while the carbon fraction in the plasma increased. Thus, the radiated power was as low as 40% for electron densities of $2\times10^{19}m^{-3}$ and a considerable heat load on the limiters could be observed.

Operation at higher electron densities (above $3\times10^{19}m^{-3}$) led to higher radiated power before and after carbonisation, 100% and 80% respectively, as shown in Fig. 58. High density pulses were always dominated by light impurities and their radiation profiles were hollow, i.e. radiation from the plasma edge dominated that from the centre. Quite frequently, poloidal asymmetries were observed in the radiation, starting in the horizontal midplane near the inner wall and growing in poloidal direction. Eventually, a radiation mantle formed around the plasma leading to a shrinking of the minor radius and a disruption at low current. Due to the reduction of oxygen and chlorine during the carbonisation period, the total radiation was lower and the values of Z_{eff} came down to 2.5, consisting of about 2.5% C, 1% 0, 0.05% Cl, and 0.015% metals. The density limit was somewhat higher for the cleaner plasmas and there is hope to increase it further by removing the remaining oxygen fraction.

Plasma Boundary Phenomena

The plasma in JET is surrounded by material surfaces, notably the Inconel walls of the vacuum vessel and the carbon limiters. The interaction of the plasma with these surfaces is the source of impurities, which contaminate the plasma and which exert a considerable influence on the behaviour of the plasma as discussed in other sections of this report. Whilst the basic physics processes that are involved such as sputtering are reasonably well understood and have been extensively studied under carefully controlled laboratory conditions, for example, for monoenergetic particle beams impinging on carefully prepared pure surfaces, the complex mixture of these processes, which occurs in a device such as JET, is less well understood.

To build up a picture of these interactions in JET, we have combined data from spectroscopic measurements of light emitted at the edge of the plasma, from probes inserted into the edge of the plasma, and from examining surfaces that have been exposed to plasmas in JET. During the period when the vacuum vessel was open at the start of 1984, small samples of carbon, nickel and Inconel, were attached to the inside of the vacuum vessel. These samples, having been exposed to all the discharges and cleaning procedures of the 1984 operations, were removed when the vacuum vessel was opened in October 1984 and were subsequently analysed by a variety of techniques. Samples were also taken and analysed from the carbon tiles on the limiters, the Inconel protection plates lining the wall of the vacuum vessel, and from the body of a diagnostic probe which was exposed to the edge of the plasma during a sequence of tokamak discharges.

The picture that has been built up from this data is that there is a variety of processes by which metallic impurities enter the plasma. There is also a variety of processes which redistribute the impurities on the surfaces surrounding the plasma. The metals nickel, chromium and iron are eroded from the Inconel walls and deposited on the carbon limiter. Analysis of the limiter tiles (see Fig. 59) shows nickel concentrations

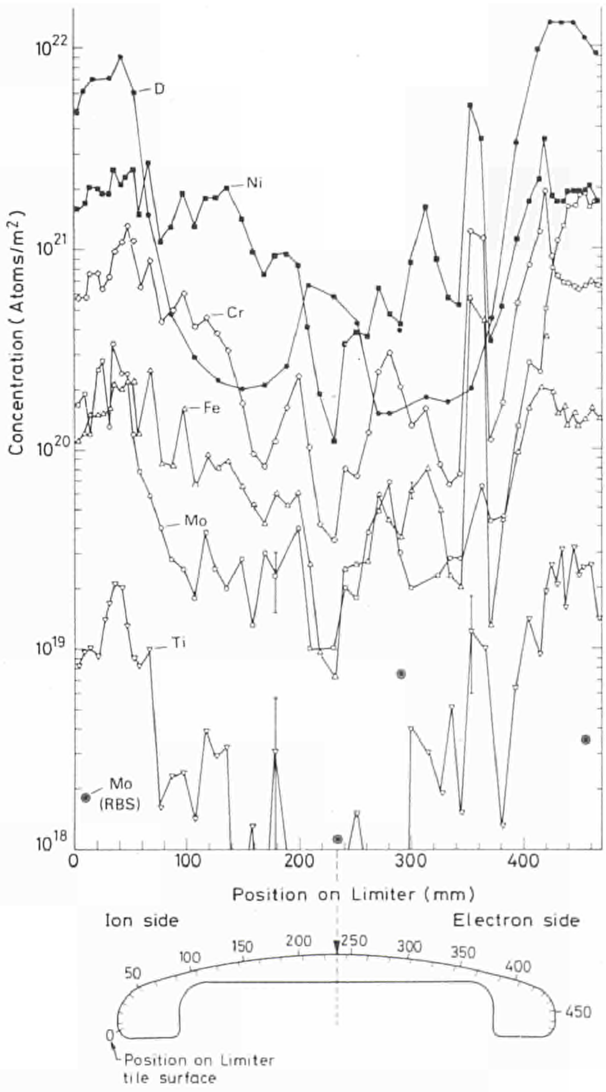


Fig. 59 Concentration of impurities on limiter tiles.

in the range 1×10^{20} to 5×10^{21} atoms m^{-2}, and smaller concentrations of chromium and iron consistent with the composition of Inconel. The analysis also shows that there is molybdenum (1×10^{19} to 3×10^{20} atoms m^{-2}) on the limiter surface. The molybdenum was deposited on the carbon limiter tiles inadvertently when they were vacuum baked before being installed in JET. There is a large variation in the distribution of metals across the surface of the tile, with maxima at the edges and a substantial minimum at the centre. These profiles are of similar shape to the power flux to the limiter which raises the temperature in the centre of the tile to over 1000°C. It appears that the metal concentrations represent an equilibrium between erosion and deposition. Erosion is stronger in the centre of the tile where the plasma flux is stronger; deposition is stronger at the edges where the plasma flux is weaker. If uniformly distributed over the surfaces of the limiter, the metals would form a layer 10 to 100 monolayers thick, but scanning electron microscopy shows that the limiter surface is very rough on a microscopic scale, with the result that there is still a significant amount of carbon exposed.

The metals on the limiters appear to be the main source of metal influx into the plasma, except in very elongated discharges where the plasma is in closer contact with the top and bottom of the vacuum vessel wall. Further work is necessary to identify the main release mechanism.

The nickel, chromium and iron can reach the limiters by various methods: sputtering of the wall by charge-exchange neutral atoms during tokamak discharges; melting and vaporisation of localised areas of the wall by energetic electrons following plasma disruptions; and sputtering by ions during glow and pulsed discharge cleaning. All of these processes appear to have contributed to the metal deposits which we have seen on the limiter.

In order to understand these processes more quantitatively, a better model of the plasma at the edge of the discharge is needed. Measurements have been made of the plasma density, temperature and power flux using a special type of probe that can be inserted into the plasma edge at a radius outside that of the limiters. The temperature rise of the limiter surface has also been measured and other power flux on to the limiter deduced. These two sets of data are generally consistent.

During this period of operation, three methods have been used to condition the vacuum vessel: glow discharge cleaning in hydrogen; pulsed discharge cleaning; and carbonisation by glow discharge cleaning in hydrogen with a 3% mixture of methane. The first two methods are effective at removing lightly bound contaminants such as water vapour, but less effective at removing oxide layers. As already mentioned both of these methods also result in the deposition of metals onto the limiter. Carbonisation, on the other hand, appears to work by covering the walls and limiter with a fresh layer of carbon, and in effect physically burying the metal contaminants. However, during the 1984 experiments, it was not possible to measure the depth of the carbon layer or its chemical form (for example, graphite or carbide). Experiments were also carried out on the change-over from tokamak discharges in hydrogen to deuterium. In contrast to experience on some other tokamaks, the change-over in JET was achieved in as few as 5 to 10 discharges. This is consistent with a simple model of isotope exchange between the plasma and gas absorbed in the wall and limiters.

Results of JET Operations with Graphite Limiters

Up to the end of 1984, JET was operated with four graphite limiters (see Fig. 29). In shape, each is straight in the poloidal direction with a length of 80cm, and curved in the toroidal direction with a projected width of 40cm. The curvature is a compromise between an evenly distributed power load for the assumed thickness of the scrape-off layer, the width of the main ports through which the limiters are introduced into the machine, and restrictions due to manufacturing procedures. The limiters are fixed to the midplane of the vacuum vessel at its outer circumference on the left hand side of octants two, four, six and eight.

Under the assumption that one-half of the ohmic input power for up to 5s is deposited on the limiters, the chosen shape can accommodate a scrape-off thickness between 7 and 30mm without being overloaded. Due to the curvature, the power load is peaked on both sides of the limiter, the distance between the peaks being a measure of the thickness of the scrape-off layer.

The limiters are observed by charge-coupled-device infra-red video cameras, which image the limiter surface in a narrow wavelength band in the visible to near infra-red. Depending on which filters are used this system provides a thermal image at any temperature above 500°C. The following results were observed.

- The limiters withstood, without damage, power loads of up to 1.9MW (shot 2995) for a flat top time of 5s and a discharge duration of over 12s. The limiter temperature under these conditions reached values above 1500°C.
- The scrape-off thickness as measured from the spacing of the maximum heat deposition zone was found to be 15mm. This value was not strongly dependent on the plasma parameters. It increased during the current rise and fall to a thickness of nearly 30mm.
- The thermal load on the limiters was not symmetrical with respect to the ion and electron side. The ion side was usually 10% hotter. This may be associated with the observation that hydrogen recycling occurred mainly on the ion side.
- Arcing was observed on the limiters during the early operation of JET then almost disappeared during the later stages in normal operation. Arcing still occurs as a result of disruptions.
- Hot spots were normally not observed on the limiter surface, though intermittent bright areas were seen at the limiter edges.

A post-mortem analysis of the limiter material showed that the surface was covered with metals: iron, chromium and nickel, from the walls of the vacuum vessel, and molybdenum, which originated in the manufacturing process of the graphite itself. Hydrogen and deuterium retention was surprisingly high—$2\times10^{17}\,cm^{-2}$ on the limiter edges and $6\times10^{16}\,cm^{-2}$ in the regions of maximum power load.

Conclusions

The limiters performed well during the first year of JET operation. Observed damage was only superficial. The load on the limiters is now close to the design value. The increase in the power load in 1985 with the introduction of additional heating will necessitate the installation of additional limiters. It is planned that a further four graphite limiters will be installed in mid-1985. Loads of 4—5MW can then be accommodated. The new limiters will be manufactured in such a way that molybdenum contamination is avoided.

Plasma Position and Current Control

Three feedback control systems have been used for plasma current and radial position control and for the stabilisation of the vertical position. A fourth system has been prepared for the control of the elongation ratio of the plasma cross section.

During most of the operating periods in 1984, the plasma current was controlled by pre-programming the excitation voltage of the poloidal flywheel generator according to a simplified simulation model of JET. In a subsequent phase of commissioning, the current feedback system was successfully tested and used in September. It provided a more convenient way of achieving current pulses with constant flat top. The control error was less than 5%. It can be reduced by auxiliary pre-programming.

The radial position control uses the measured difference in the poloidal flux between the limiter and the desired inboard position of the limiter magnetic surface (which is roughly equivalent to the plasma boundary) as feedback control signal for the thyristor power source of the vertical field coil. The inboard position may be varied during the pulse by pre-programming, for example to build up the plasma starting from a small initial radial diameter. This system has been working satisfactorily. The radial position control has been extended, doubling the voltage range of the vertical field power source with the intention of coping more easily with large amplitude perturbations, such as disruptions.

The feedback stabilising system of the vertical plasma position is similar to the radial position control, but it requires much less current. A fast response time of the amplifier output voltage upon a vertical position change is essential. The feedback controller includes therefore a derivative stage for the measured radial poloidal flux, equivalent to velocity feedback of the vertical position.

During one pulse, #1947, with an elongation ratio exceeding 1.6, the stabilisation limit of this system was exceeded and the plasma became vertically unstable. This caused strong forces and stresses on the vessel. The stabilisation circuit has since therefore been studied in greater detail. Temporary improvements of the feedback circuitry were implemented. Preparations were made to increase the voltage range of the power source by a factor of two and its response speed by a factor of two to three. As a precaution the Tokamak operation was restricted to plasmas with elongation ratios of less than 1.5 for the rest of the year.

A system for the independent control of the plasma elongation ratio has been prepared. It was partially commissioned in December. In its first stage, it uses one of the two amplifers which had been employed for radial position control. The connections of the poloidal field coils have been modified to include this new system.

Organisation of JET Operations

The JET operating programme during the Ohmic Heating Phase involved three types of activity (see Fig. 60), broadly classified as shutdown, commissioning and tokamak operation. During shutdown periods, there was no machine operation and the installation of new systems, for example, protective tiles for the vessel interior, a blower for the gas baking system, additional heating systems, machine instrumentation and diagnostic systems, took place. Commissioning periods provided for the integration of newly installed equipment and for the testing of more advanced control programmes on systems such as power supplies, gas introduction and plasma density feedback, magnet coil short circuit protection, plasma position and current control, and plasma fault protection.

In periods of tokamak operation, the main activities broadly speaking were (a) to define the operating regimes of JET, and (b) to study in detail the machine and plasma performances within the relevant operation regimes and to attempt to improve them. During operating periods, a certain amount of commissioning was necessary to reintegrate subsystems where remedial work had been required for tokamak operation to continue.

The way that the JET operating programme is defined is represented schematically in Fig. 61. After the Experiments Committee has discussed both the long and short term programmes, the detailed machine settings and control waveforms are specified in a day's pulse schedule prepared by those in charge of operations for that day, namely the Session Leader, the Engineer-in-Charge and the Physicist-in-Charge.

The Session Leader is responsible for seeing that the programme goals are achieved. The Engineer-in-Charge is responsible for the overall operation of the machine, for its protection, and for the safety of operating staff. He supervises activities in the Machine Control Room. The Physicist-in-Charge is responsible for co-ordinating the measurements of plasma diagnostics and for the acquisition of results. He supervises activities in the Experimental Control Room.

Operational duties were shared among different divisions so that although Torus Division was directly responsible for machine operation, the high-voltage pulsed power supplies were operated by nominated staff from the Power Supplies Division, and the computers, control room hardware and control software

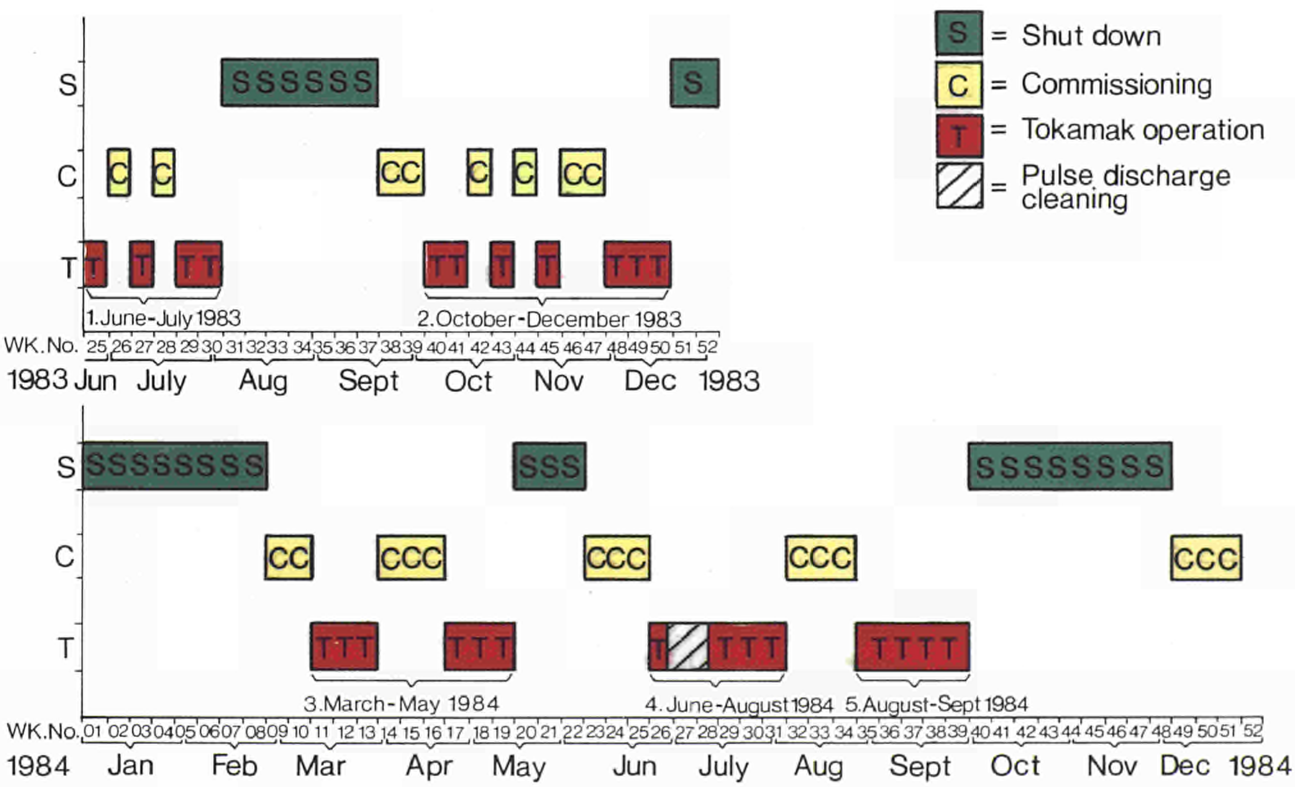


Fig. 60 JET operation programme.

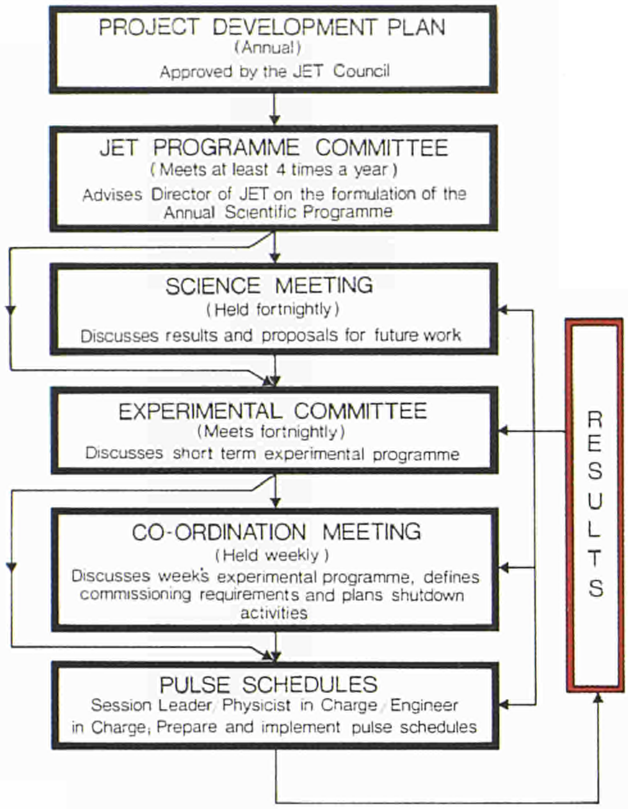


Fig. 61 Establishment of the JET operations programme.

were maintained by staff from CODAS Division. The number of staff members actually involved in operation in 1984 is shown in Table 4. It should be noted that on-call staff were required to back up operations staff in the Control Room and that additional staff were required for specific duties such as the search and closure of operational areas.

In 1984, staff were rostered for duty based on a normal working day. Preparations began at 0745 to allow tokamak operations to begin at 1000. Operations were normally completed by 1700, after which the closing-down procedures were carried out. On some occasions, operation was extended to 1900. Nights and weekends were reserved for maintenance, installation and remedial work and for wall conditioning. General operating procedures were developed and were used not only to streamline operations and make them reliable, but also to train further staff members required for operating duties.

During 1984, eleven members of a twelve-man team of shift technicians were recruited to the Torus Division. These members of staff are rostered in shifts to provide continuous surveillance of JET subsystems and building services. They also played an important role in operating sessions both inside and outside the machine control room. Inside the control room they acted as operators: establishing operation settings for some systems, (e.g. gas introduction), controlling certain systems (e.g. the demineralised water cooling for the coils), establishing and maintaining control waveforms for power supplies, operating the countdown and data-acquisition programme, as well as monitoring the operation of JET subsystems, (e.g. vacuum). Outside the control room, they kept a regular check on building services (e.g. ventilation for the computer and control room), they monitored the status of some equipment and controlled it locally and, in certain cases, they carried out remedial work where they had been authorised to do so.

To carry out these duties, the shift technicians have received training from specialist groups within the project team and this is an on-going activity. Because of the experimental nature of the project, some systems have been significantly modified or have been regularly changed in less obvious ways, therefore an important part of the time spent with the specialist groups was used to inform the shift technicians of system changes to ensure that their knowledge was up to date.

To assist operating staff in their duties, description and operating manuals for important JET systems have been prepared and have been kept up to date. In addition, emergency procedures have been established so that any risk to staff or to JET buildings and equipment can be minimised. To ensure that planned alterations to the machine and its services were properly and safely implemented, a strict control of access to the Torus Hall and Basement was maintained both by the Personnel Safety and Access Control System (PSACS) and by nominated staff of the Torus Division.

The provisional plans for 1985 are to operate two programmes (additional heating and ohmic heating) on a shift basis. This will result in an overall increase in operating time. Above all, it will be essential to increase the actual time spent in tokamak operation within operating sessions. This means that time must be devoted to improvements to obtain an increased reliability of machine systems.

Table 4
Number of staff directly involved in operations

	On Duty			
	In J2	In P.S.Areas	On Call	Other Tasks
Senior Duties				
Engineer in Charge	1	—	—	—
Physicist in Charge	1	—	—	—
Session Leader	1	—	—	—
Rostered Duties				
Torus operation group	3	—	1	1
First wall group	—	—	2	—
Vacuum system group	—	—	3	— ↑3↓
Magnet and instrumentation group	—	—	1	—
Power distribution group	—	—	1	1
Poloidal and toroidal group	— ↑2↓	2 ↑1↓	—	1
Advanced power supplies and systems operation group	—	—	—	—
Computer operation group	3	—	—	—
Computer and control group	2	—	—	—
Diagnostic data acquisition group	1	—	—	—
Electrical and instrumentation group	—	—	2	—
Experimental division 1 average	8*	—	*	—
Experimental division 2	4	—	5	—
Theory division	1	—	—	—
Physics operation group	1	—	—	—
Technical services	—	—	1	—
Machine services	—	—	1	—
Totals	28	3	17	6

JET Theory

The central task of JET's Theory Division is to provide a quantitative theoretical model of tokamak plasmas in JET. The long term objective is to include in this model all essential quantitative plasma physics knowledge gained from JET and other tokamaks, at least as an empirical description. It is, however, preferable first to understand the mechanisms theoretically in terms of basic physics. The Theory Division is also responsible for JET's data banks and data interpretation codes.

Data Banks

From the raw data collected in the JET pulse files (JPF), a bank of physics data files, the Processed Pulse Files, (PPF) is created, whereby the raw data is sorted, correlated, and transformed into physically meaningful data (such as radiated power and light intensities). At the end of 1984, this bank contained data for some 700 pulses in a volume of about 600 MBytes. This compared with the 2.5 GBytes of raw data in the JPF for all 1600 discharges.

Largely based on this first level physics data, a Survey Data Bank has been compiled. It contains up to 20 characteristic time functions for each discharge with plasma and a collection of global scalar parameters and comments. This bank is intended for survey purposes and is proposed to be regularly released to Associated Laboratories. In addition, several high-level topic data banks have been produced for special studies, for example for the scaling of plasma confinement or for disruptions. In order to unify the input for data interpretation codes, a Technical Data Bank is being installed containing JET specific constants such as probe positions, vessel size and injection angles.

Data Management Software

Considerable effort has been spent in developing and adapting software for the efficient storage, retrieval, display and monitoring of the large JET data banks.

The PPF storage-retrieval system developed by JET has dealt well with most requirements, as have the display facilities and various specifically written directories. In addition, the Statistical Analysis System package has been adapted to meet JET's needs and has been used widely for data evaluation.

In order to cope with future large data volumes and with further requests such as data security and data processing speed, a number of commercially available data base management systems have been screened and tested. In December 1984, the NOMAD2 DBMS was purchased. It is intended to merge into this system all the existing smaller ones.

Code Libraries

The programs for a first level evaluation of data from most diagnostic systems were originally developed for the local NORD computers. With increasing refinement and consequently increasing demand for computing power, and also with decreasing availability of the NORD computers for data evaluation, the codes have been transcribed and in certain cases rewritten for the IBM and CRAY computers at Harwell.

A systematically maintained collection of interpretation codes, the JET Interpretation Code Library, has been started and will be made available to JET personnel during 1985. A similar collection for predictive codes, the JET Prediction Code Library, is being built up in parallel.

Data Interpretation

Programs for the intershot analysis of data have been speeded up considerably. New features for the analysis of RF heating, such as plasma shape/antenna matching and computation of resonance positions have been added.

A sizeable effort has been put into consistency checks of the data from various diagnostics with both interpretative and predictive codes. Most effectively, this has been accomplished with the complete plasma models (transport codes) based on the conservation laws. Besides the continuing evaluation of global confinement (see Fig. 52) and disruption data (Fig. 62) studies of localised transport have started. For one of these, data near the ($q = 2$) surface is collected and heat fluxes derived by means of the energy balance. Several other contributions interpret the so-called sawtooth oscillations in the central plasma and derive localised transport and other properties, such as equilibration times and effective ionic charge.

Modelling JET Plasma Geometry

In contrast to many other tokamaks, plasma modelling for JET must take into account the two-dimensional non-circular plasma cross sections. This problem has been attacked along four lines. First, the existing stepwise adjustment of the flux coordinates for the transport equations with evolving equilibrium has been prepared for routine use. Second, the equilibrium solver has been rewritten for a free plasma boundary using the profile of the safety factor (q) as input function. In connection with this, the transport equations, including an impurity package, are being recorded for two-dimensional applications. Third, extensive computations for neutral beam injection and RF heating codes have been made to determine energy and particle

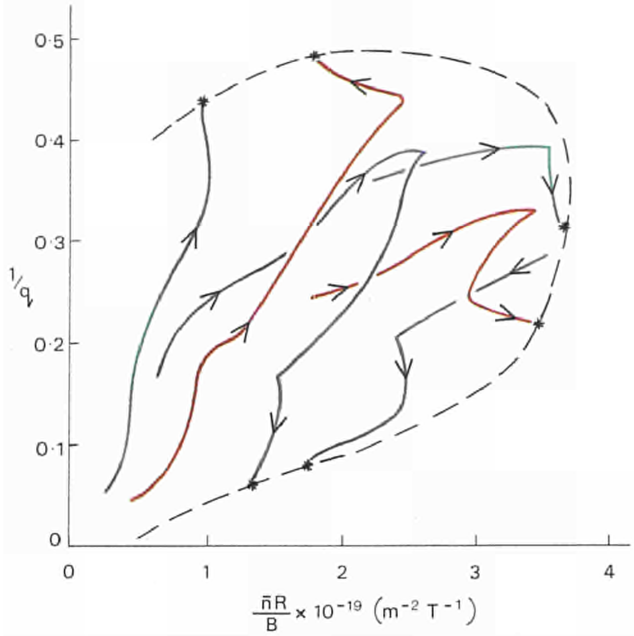


Fig. 62 The diagram shows the present limitation of the operating regime resulting from disruptions. The vertical axis is $1/q$, where q is the safety factor at the edge of the plasma and the horizontal axis is $\bar{n}R/B$ where $\bar{n}$ is the mean electron density, R the major radius and B the toroidal magnetic field. The lines show the movement in time during the discharge and the stars indicate the points at which disruption occurs. Within this region it is possible to operate without disruption.

deposition in JET plasma geometry. Finally, a Monte-Carlo code for neutral atoms in the plasma boundary has been adjusted and tested for the actual JET limiters.

Modelling of Plasma Phenomena

Because of limited manpower, the problem areas of the plasma boundary, impurities, ICRF heating and pellet injection were selected for preferential treatment. In addition to the Monte-Carlo program for neutral atoms, a fully two-dimensional plasma flow code has been constructed for the boundary layer, including the open magnetic field lines area in the limiter shadow. It is based on classical theory along the magnetic field and can also accommodate anomalous transport in the perpendicular direction.

An extensive atomic physics package (ionisation, recombination, charge exchange and radiation) has been compiled for JET-relevant impurities. Several impurity transport programs, developed through contracts, have been installed, compared and debugged. In order to calculate the energy deposition through ICRF, both Fokker-Planck and ray tracing codes have been implemented and tested; these large programs are intended for bench-marking simplified models for routine use. In order to control the plasma density, pellets might be injected into the JET plasma. A code package for such computations has been acquired, adapted to JET geometry, and tested.

Predictive Computation

This work concentrated on JET plasmas with various degrees of additional heating from both neutral injection and RF, separately and combined, as well as on heating by alpha-particles. Fig.63 shows, for example, the neutron economy for JET as evaluated and assessed from these computations.

The predicted plasma performance depends not only on the assumptions for additional heating but also—crucially—on the models for confinement. Several such models (both of the empirical and theoretical types) have been compared with JET data and their applicability assessed. Depending on the degree of confinement degradation during additional heating and the focussing of energy absorption, the full range of plasma performance up to ignition seems still possible. Major difficulties could arise from density or plasma beta limits, which are taken into account within these calculations only by crude extrapolation of an empirical formula.

Analytic Theory, Mechanisms and Methods

A most urgent problem is to understand disruptions which produce an abrupt loss of confinement and are found on all tokamaks. As a possible mechanism the contraction of the current profile due to edge cooling, for example by radiation, has been studied. The non-linear development of resistive tearing modes is being studied in order to understand anomalous current penetration and growth of magnetic islands.

With regard to ICRF heating, the limits on the ray tracing approximation have been investigated. A more exact global code has been developed, which solves the wave propagation equation in exact geometry and includes the coupling between antenna and plasma.

The classical effect of induced electric fields has been invoked to explain some of the observed degradation of confinement with ion heating. A systematic theory on the statistical derivation of scaling laws has been developed. With its help, the uncertainties of such laws will be assessed.

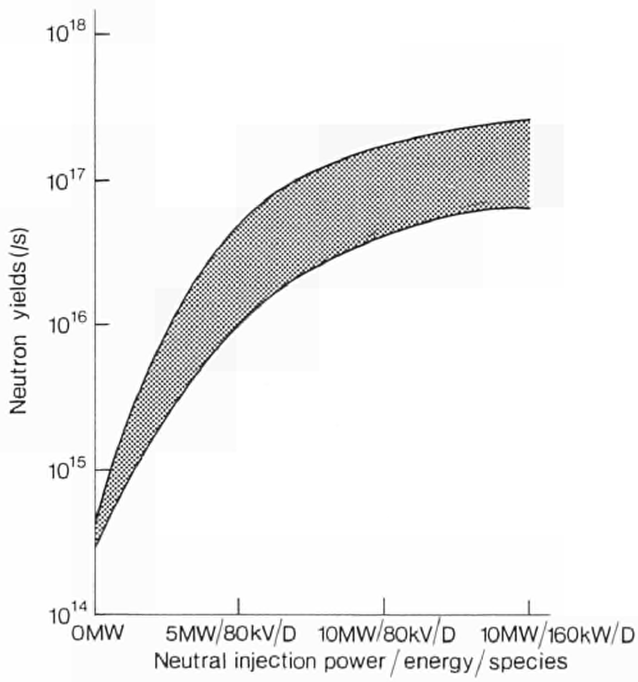


Fig. 63 The range in total neutron yields in deuterium plasmas with neutral deuterium injection is shown for various power levels, injection energy and transport models.

The Members and Organisation of JET

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 of the Ecole Royal Militaire) and on behalf of the Université Libre de Bruxelles (Service de Chimie-Physique II of the ULB)
- The Commissariat à l'Energie Atomique, France (CEA)
- The Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative, Italy (ENEA)
- The Consiglio Nazionale delle Ricerche, Italy (CNR)
- The Hellenic Republic (Greece)
- The Forsøgsanlaeg Risø, Denmark (Risø)
- The Grand Duchy of Luxembourg (Luxembourg)
- Ireland
- The Kernforschungsanlage Jülich GmbH, Federal Republic of Germany (KFA)
- The Max-Planck-Gesellschaft zur Förderung der Wissenschaften eV. — Institut für Plasmaphysik, Federal Republic of Germany (IPP)
- The Swedish Energy Research Commission (SERC)
- The Swiss Confederation
- The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)
- The United Kingdom Atomic Energy Authority (Host Organisation)

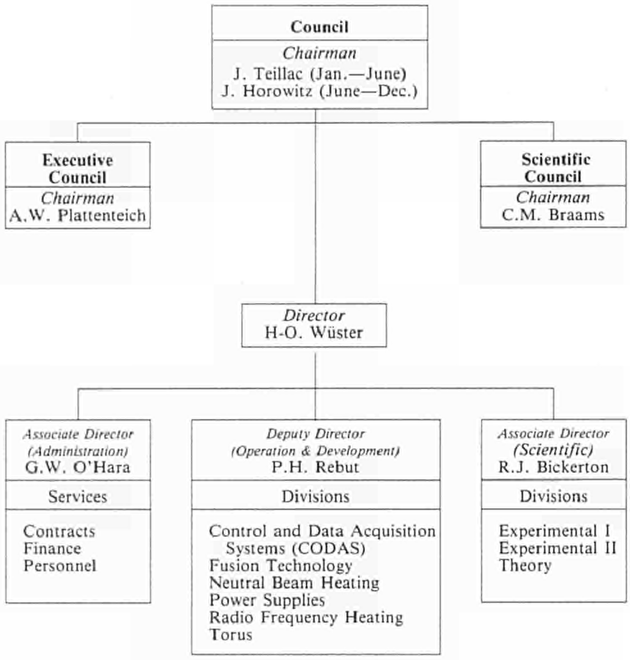


Fig. 64 Organisation of JET Joint Undertaking (December 1984).

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 (page iii). The JET Council is assisted by the JET Executive Committee and is advised by the JET Scientific Council (see Fig. 64).

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 is also responsible inter alia for:

- The 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;
- The approval of the annual budget, including staffing, as well as the Project Development Plan and the Project Cost Estimates;
- Ensuring the 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 1984: on 29/30 March, 7 June, and 26 October. Mr J. Teillac's second three-year term as Chairman came to an end in June. Mr J. Horowitz was unanimously elected Chairman to succeed him.

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 representation of the members in the JET Executive Committee is shown in Appendix I. The Committee met seven times during the year on 9 February, 8/9 March, 10/11 May, 12/13 July, 27 September, 15 November, and on 14 December.

JET Scientific Council

The JET 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.

There were three meetings of the Scientific Council during 1984: on 7/8 February, 9 May, and 10/11 October. Extensive discussions were based on regular reports on the progress of the JET ohmic heating programme, on the status of diagnostic systems, neutral beam injection and the beryllium limiter experiments on ISX-B, and on considerations regarding magnetic limiter configurations and pumping panels for JET. The dissemination of information from JET was also discussed.

The Director of the Project

The Director of the Project 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 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, the JET Executive Committee, the JET Scientific Council and other subsidiary bodies with all information necessary for the performance of their functions.

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

Project Team Structure

At the start of the Operational Phase in mid-1983, a new structure of the Project was introduced. The three Departments are now: the Operation and Development Department; the Scientific Department; and the Administration Department.

The Jet Directorate

The three Heads of Department report to the Director of the Project and together with the Director they form the JET Directorate. Various special functions are carried out by the Director's office, as shown in Fig. 65. The Internal Audit Office monitors the Project's 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 Secretariat provides secretarial services to the JET Council and to the Executive Committee and also to the JET Project Board, JET's internal management committee.

Administration Department

The Administration Department is responsible for providing administrative support and services to the Project. The structure of the Department with its three administrative services—Contracts, Finance and Personnel—is shown in Fig. 66.

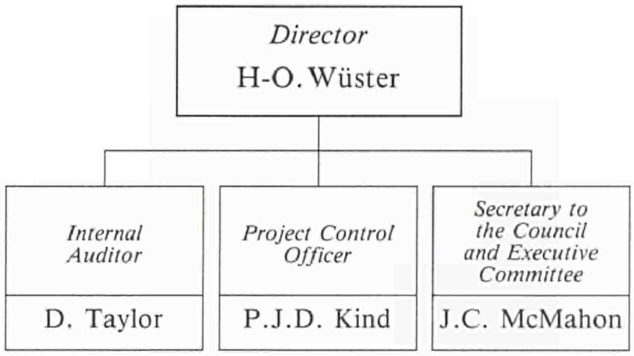


Fig. 65 Structure of the Director's Office (December 1984).

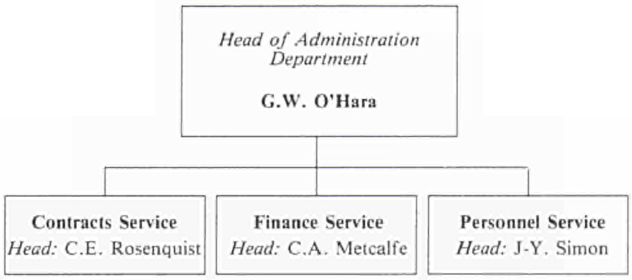


Fig. 66 Structure of the Administration Department (December 1984).

Operation and Development Department

The Operation and Development Department is responsible for the operation and maintenance of the Torus and its systems and for developing the necessary engineering equipment to enhance the machine to its full performance. The Department contains six Divisions:

1. Torus Division, which is responsible for the operation of the Torus, including the creation and training of the operating team and the organisation and execution of maintenance work in the Torus Hall and Basement. The Division also organises major shutdowns for the installation and commissioning of the new equipment and for development work necessary for the improvement of the sub-systems integrated into the JET device (vacuum system, baking and cooling plant, limiters, first wall, etc.).
2. Power Supply Division, which is responsible for the design, installation, operation, maintenance and modification of all the power supply equipment needed by the Project.
3. Neutral Beam Heating Division, which is responsible for the construction, installation, commissioning and operation of the neutral injection system, including the development towards full power operation of the device. The Division will participate in the studies of the physics of neutral beam heating.
4. Radio Frequency Heating Division, which is responsible for the design, construction, commissioning and operation of the RF heating system during the different stages of its development to full power. The Division will participate in the studies of the physics of RF heating.
5. Fusion Technology Division, which is responsible for the design and development of remote handling methods and tools to cope with the requirements of the JET device, for maintenance, inspection and repairs. The Division's tasks also include design and construction of facilities for the handling of tritium.
6. Control and Data Acquisition Systems Division (CODAS), which is responsible for the implementation, upgrading and operation of the computer-based control and data acquisition system for JET.

The divisional and group structure of the Department is shown in Fig. 67.

Scientific Department

The Scientific Department is responsible for the definition and execution of the experimental programme, the specification, procurement and operation of the diagnostic equipment and the interpretation of experimental results. The Department contains three Divisions:

1. Experimental Division 1, which is responsible for the specification, procurement and operation of approximately half the JET diagnostic systems. ED1 will, in particular, look after electrical measurements, electron temperature measurements, surface, and limiter physics and neutron diagnostics. The Division is also responsible for:
   - The execution, in collaboration with ED2, of the experimental programme.
   - The interpretation of results in collaboration with ED2, Theory Division and the appropriate Divisions in the Operation and Development Department.
   - Making proposals for future experiments.
2. Experimental Division 2, which is responsible for the specification, procurement and operation of the other half of the JET diagnostic systems. ED2 will in particular look after all spectroscopic diagnostics, bolometers, interferometry, the soft X-ray array and neutral particle analysis.
3. Theory Division, which is responsible for the prediction by computer simulation of JET performance, the interpretation of JET data and the application of analytic plasma theory to gain an understanding of JET physics.

The divisional and group structure of the Department is shown in Fig. 68.

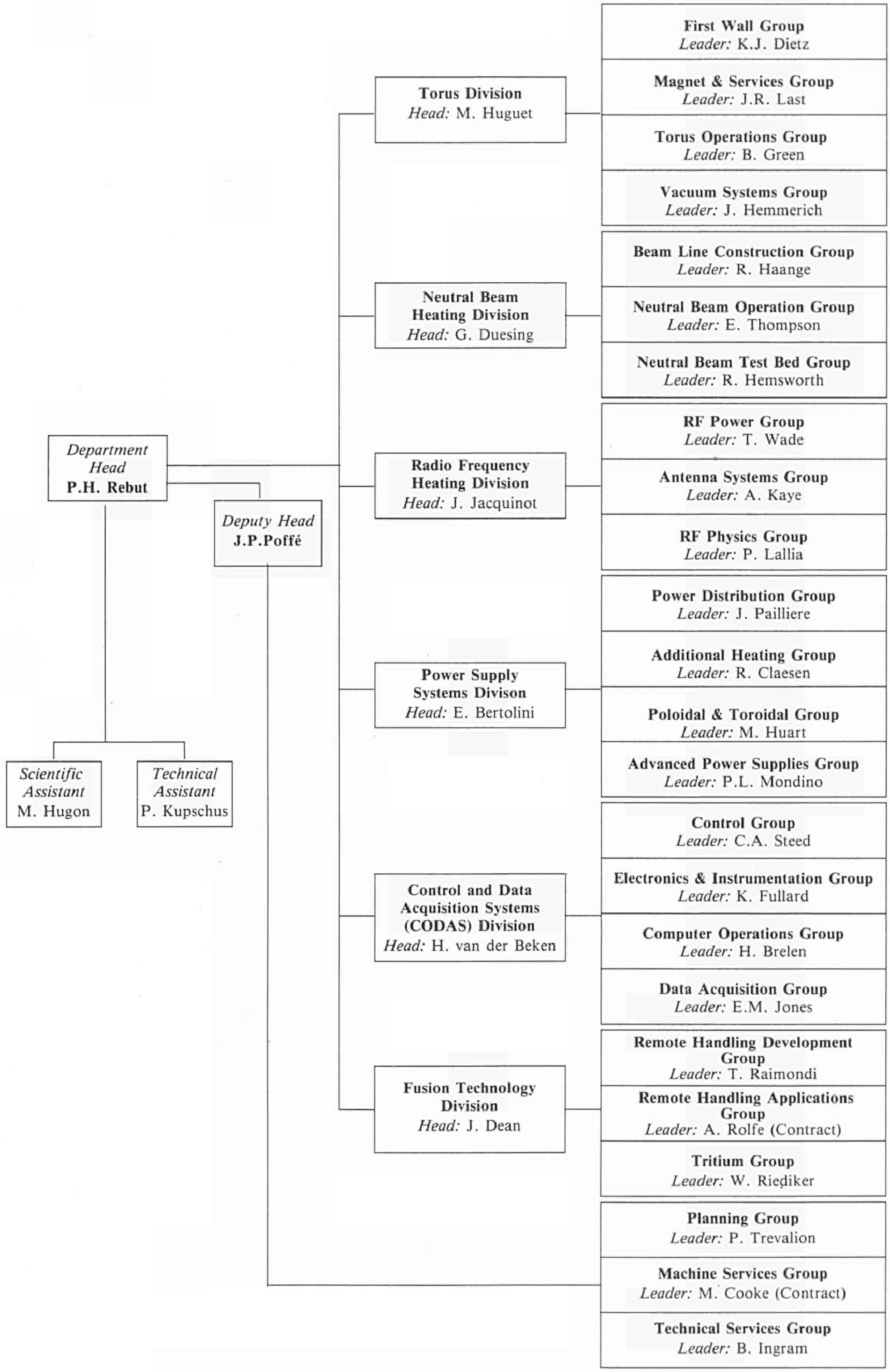


Fig. 67 Structure of the Operation and Development Department (December 1984).

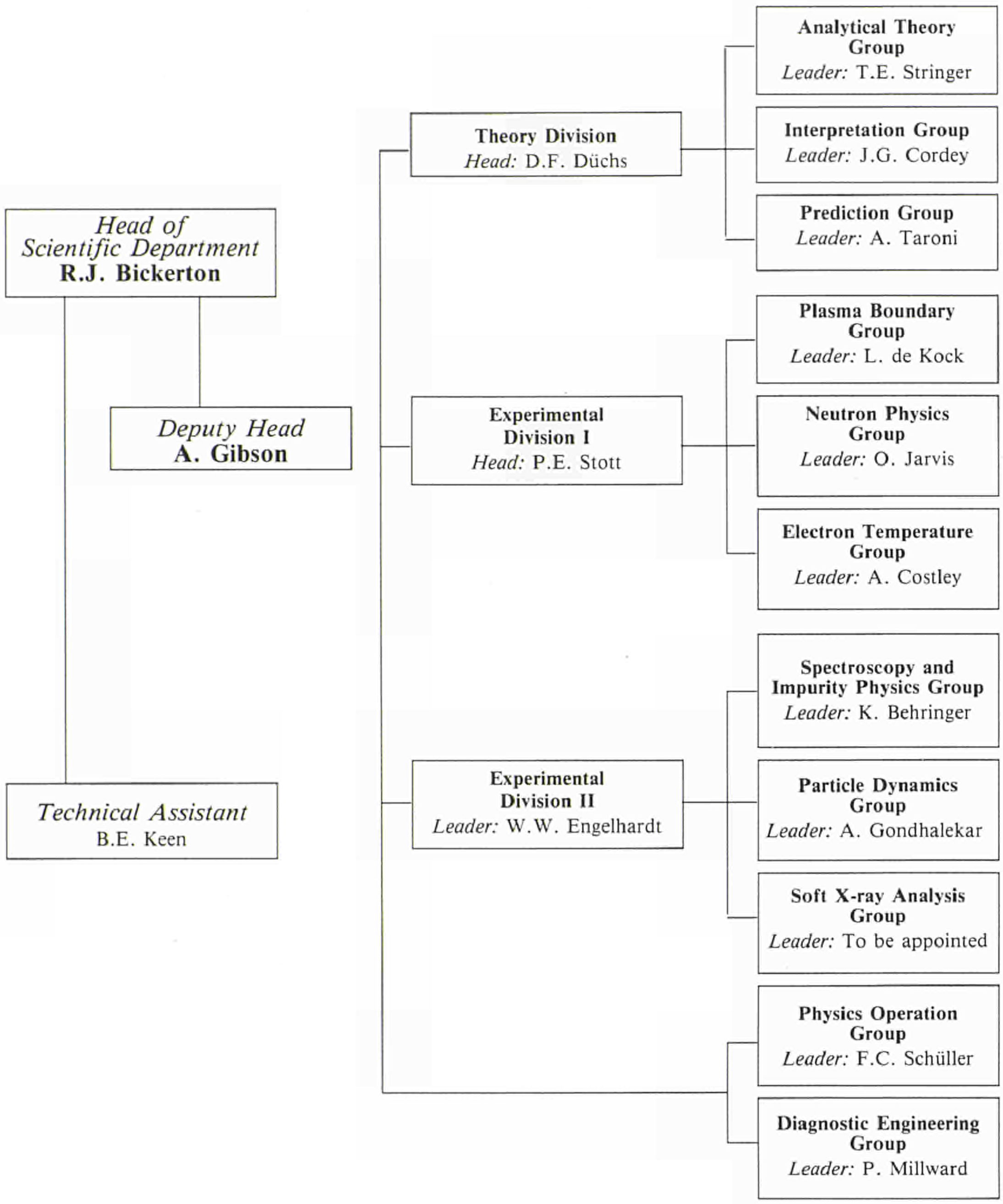


Fig. 68 Structure of the Scientific Department (December 1984).

The Administration of JET

The five main aspects of JET's administration—Finance, Contracts, Personnel, Safety and External Relations—are discussed in this section. There is also a contribution from the Headmaster of the European School at Culham, which is associated with the JET Project.

Finance

JET's financial resources are governed by revisions each third year to the Euratom Pluriannual Fusion Programme. A programme for the period 1982—1986 was approved by the Council of Ministers on 25 May 1982. The financial resources made available to JET for that period are shown in Table 5.

Annual Budgets

Budgets are adopted annually by the JET Council after notification by the Commission of its contribution to JET as shown in the finally adopted budget of the European Communities. There are three annual budgets:

1. Income—arising mainly from contributions of Members augmented by miscellaneous income, principally bank interest;
2. Commitment appropriations—representing the upper limit of the legal obligations that can be met from the budget;
3. Payment appropriations—representing the upper limit of the payments that may be incurred to cover commitments entered into in the budget year or in previous years.

The budgets for 1984 were approved at 75.5 MioECU for commitments, and 107.1 MioECU for both income and payments. The Commitments and Payments Budgets each subdivide into the three phases of the Project—Basic Performance, Extension to Full Performance, and the Operational Phase. Further subdivisions distinguish between investment costs, operating costs and personnel costs.

Commitments (Table 6)

Of the total appropriations in 1984 of 114.3 MioECU (including 38.7 MioECU brought forward from previous years), 83.5 MioECU was committed and the balance of 30.8 MioECU was available for carry forward to 1985. Commitments against the investment programme were 25.2 MioECU, almost entirely in the Extension to Full Performance Phase of the Project. The balance of 58.3 MioECU was committed on operating and personnel costs in the Operational Phase.

Details of the amounts committed for each Phase during the year are shown in Table 7. 0.2 MioECU was committed in the Basic Performance Phase representing the final requirements for completion of the construction of the JET device in its Basic Performance configuration. The small balance of 0.4 MioECU remaining on this Phase is not likely to be required.

Table 5
Financial resources made available to the JET Project up to the end of 1986 within the Euratom Pluriannual Fusion Programme 1982—86

Euratom Pluriannual Fusion Programme for 1982–86					
JET Project costs with future expenditure after 1981 at January 1982 values					
		1977–81	**1982–86**	**Later Years**	**Total**
Basic Performance Phase	Commitments	226.75	85.35	–	312.1
	Payments	163.90	148.20	–	312.1
Extension to Full Performance	Commitments	–	156.45	1.05	157.5
	Payments	–	140.20	17.30	157.5
Operational Phase (to end of 1986)	Commitments	–	158.20	–	158.2
	Payments	–	153.30	4.90	158.2
TOTAL	Commitments	226.75	400.00	1.05	627.8
	Payments	163.90	441.70	22.20	627.8

Table 6
Commitment Appropriations for 1984

	Mio ECU
1984 Commitments Budget	75.55
Uncommitted amounts available from 1983	38.72
	114.27
Commitments made during the year (including escalation on major contracts amounting in total to 1.29 Mio ECU)	83.52
Balance uncommitted in 1984 now available for use in 1985	30.75

24.9 MioECU was committed in the Extension to Full Performance Phase and 30.0 MioECU was carried forward to 1985, in respect of commitment appropriations not utilised on this phase at 31 December 1984. In the first full year of the Operational Phase, 58.4 MioECU was committed. The small balance of 0.3 MioECU remaining on this phase at 31 December 1984 was available for carry forward into 1985.

Income and Payments (Table 8)

Out of the total of 142.2 MioECU payment appropriations available during the year, 46.2 MioECU remained unused at the end of the Financial Year. A further amount of 2.4 MioECU, representing income received in excess of budget, was also available to give an overall total of unused appropriations of 48.6 MioECU. Of this total 30.5 MioECU has been retained to meet commitments outstanding at 31 December 1984 leaving a balance of 18.1 MioECU to be carried forward to be offset against the future contributions of Members.

More detailed comments are given in the following paragraphs. A summary of commitments and payments under each phase is shown in Table 7:

1. **Contributions from Members.** The Budget for Members contributions was 105.63 MioECU. It was funded as follows:
   - 80% from the general budget of the European Atomic Energy Community (Euratom);
   - 10% from the United Kingdom Atomic Energy Authority as Host Organisation;
   - 10% from Members having Contracts of Association with Euratom in proportion to the previous year's contribution from Euratom towards the cost of their Association Contracts. (Delay in confirming the final proportions for any year results in provisional figures being included in the Annual Accounts with final adjustments in the following year. Table 9 gives the final percentage contributions from Members relating to 1983).
2. **Bank Interest.** Contributions from Members are normally requested on a quarterly basis so that throughout the financial year, depending on the

Table 7
Commitments and Payments for 1984

Budget Heading	Commitments		Payments	
	Budget Appropriations Mio ECU	Out-Turn Mio ECU	Budget Appropriations Mio ECU	Out-Turn Mio ECU
Phase 1—Basic Performance				
Title 1—Project Investments	0.63	0.30	19.42	14.20
Title 2—Operating Costs	0.01	− 0.07	0.08	0.01
Title 3—Personnel Costs	0.03	—	0.11	0.10
TOTAL Phase 1	0.67	0.23	19.61	14.31
Phase 2—Extension to Full Performance				
Title 1—Project Investments	54.90	24.90	61.51	30.36
TOTAL Phase 2	54.90	24.90	61.51	30.36
Phase 3—Operational				
Title 2—Operating Costs	40.27	40.13	42.30	33.07
Title3—Personnel Costs	18.43	18.25	18.76	17.47
TOTAL Phase 3	58.70	58.38	61.06	50.54
Project Total—All Phases	114.27	83.51	142.18	95.21

Table 8
Income and Payments for 1984

	ECU		
Income			
Budget for 1983		107.13	
Income received during 1984:			
(i) Members' Contributions	105.63		
(ii) Bank Interest	3.15		
(iii) Income transferred from Reserve	0.72		
(iv) Unused payment appropriations brought forward from 1982	0.01		
Total Income		109.51	
Excess income to be carried forward against Members' future contributions			2.38
Payments			
Budget for 1984		107.13	
Amounts available in the Reserve Account to meet outstanding commitments at 31 December 1983		35.05	
		142.18	
Payments during 1984	95.21		
Transfer of excess Reserve Provisions to Income Account	0.72	95.93	
Balance of unutilised appropriations			46.25
Total unutilised payment appropriations			48.63
to be allocated as:-			
(i) Reserve at 31 December 1984 to meet outstanding commitments at that date			30.52
(ii) Reduction of Members' future Contributions			18.11
			48.63

Table 9
Final percentage contributions to JET based on the Euratom participation in Associations' contracts for 1983

Member	%
Euratom	80.0000
Belgium	0.2254
CEA France	2.2774
ENEA, Italy	0.8276
CNR, Italy	0.1186
Risø, Denmark	0.0974
Luxembourg	0.0070
KFA, FRG	0.9470
IPP, FRG	2.5797
KFK, FRG	0.2727
SERC, Sweden	0.1365
Switzerland	0.4302
FOM, Netherlands	0.5601
UKAEA	11.5204
	100.0000

receipt of contributions and the incidence of payments, the Project has funds that are not immediately required for the discharge of its commitments. Such funds are placed on deposit at market rate. During 1984, they earned interest amounting to 3.15 MioECU.

3. **Transfer from Reserve.** During the year, 0.72 MioECU of the amount reserved at 31 December 1983 to meet outstanding commitments was transferred to income as the relevant commitments had either been cancelled or were discharged at a lower figure than anticipated.
4. **Unused Payment Appropriations from Earlier Years.** A small balance of 0.01 MioECU from 1982, held for future set-off against Members contributions, was credited to income in 1984.
5. **Payments (Table 8).** Out of the total available payments appropriations of 142.18 MioECU, actual payments were 95.21 MioECU and transfers to income of reserve in excess of requirements were 0.72 MioECU, leaving a balance of 46.25 MioECU. This sum together with the excess of income over budget, 2.38 MioECU, giving a total of 48.63 MioECU, has been carried forward as described above.

Summary

Table 10 summarises the financial transactions of the JET Joint Undertaking as at 31 December 1984. The final audited accounts are published as a separate document.

Table 10
Summary of Financial Transactions at 31 December 1984

	Mio ECU
Cumulative commitments	509.5
Cumulative expenditure	448.3
Unpaid commitments	61.2
Of which carried forward on reserve account	30.5
Amount available from 1984 due to be set off against future contributions from Members	18.1

Contracts

The changing status of the JET Project, from the Construction Phase to the Operational Phase, has as one would expect brought about changes in the various facets of the work of JET's Contracts Service. Such changes include not only a change in the volume of work, but also in the content of contracts being placed.

Minor Contracts

Minor contracts are those which have a value below 50,000ECU. The volume handled by the Contracts Service increased from 3562 in 1983 to 4791 in 1984. Such an increase represents the higher demand for consumables, which was to be expected as JET entered the Operational Phase.

To cope with this increase in volume, a computerised system was introduced at the start of this year to handle requisitions. This system allocates the contract number and stores the data in such a way as to allow easy reference. A further innovation, which will be introduced from the beginning of 1985, is a small value order system to allow the more rapid processing of orders with a value below 500ECU. These represent about 50% by number of all contracts placed by JET, though less than 1% by value.

Major Contracts

The larger major contracts placed during 1984 covered various items of diagnostic equipment and components for radio frequency heating. Contracts were also placed for radiation cooled limiters and for modification of the prototype octant to allow for its use as a spare should one of the machine octants need to be replaced.

A major concern in the placing of large contracts is the need to involve suppliers from all Member states (whenever practical) in the tender action. As a means of establishing records of potential tenderers, a computerised register of suppliers has been established. This system, containing details of 1600 suppliers, is capable of producing tender lists for any one of 450 different categories of supply. The data contained in the system is of use not only to JET, but also to other organisations working in a similar field. To date, JET has already supplied information from the system to several research establishments and is now looking at ways in which such information can be exchanged between JET and other European laboratories.

As well as placing orders, the Contracts Service is also responsible for the import and export of JET goods. JET is entitled to claim exemption from customs duties and VAT on its goods under privileges granted by the host country. This entails close control of each consignment while in transit. Goods dealt with include new supplies arriving on site for the first time, items being returned for repair, and items being sent out of the country for analysis. The busiest time for such movements is during the machine shutdowns when goods are required urgently for fitting to the machine.

The total number of imports and exports handled during 1984 were 771 and 351 respectively. The average size (in terms of weight) of consignments has reduced since the end of the Construction Phase. This was to be expected given that the larger items were on the whole basic components for the machine. The larger items imported to JET in 1984 included transformers from Italy and SF_6 towers from France, as well as several large items for the RF heating system.

Historical records of goods movements have been loaded into a computerised system, to which is added new data. Details of all movements can therefore be readily recalled for use by Contracts Service and the technical divisions. The data is also used to assess the value of insurance cover required by JET for its import and export operations.

As an illustration of JET's endeavours to involve industry throughout Europe in its operations, Table 11 shows how contracts placed to date have been allocated between countries. Included in the figures are all contracts with a value of 10,000ECU and above, placed prior to 1984, together with all contracts placed in 1984, regardless of value.

Table 11
Allocation of JET Contracts
(position as at 31 December 1984)

Country	Total of ECU Values	% of Total
UK	149 233 903	43.66
Germany	83 061 908	24.30
France	34 324 973	10.04
Italy	27 717 015	8.11
Switzerland	20 149 525	5.90
Netherlands	7 626 315	2.23
Denmark	6 337 961	1.85
Belgium	4 845 371	1.42
Sweden	2 709 735	0.79
Ireland	276 786	0.08
Others	5 506 425	1.62
Totals	341 789 917	100.00

Personnel

At the request of the JET Council, a special working party on the manpower requirements for the Operational Phase of JET was convened at the beginning of 1984. The proposals from this working party were considered by the Council in June, together with the Director's revised proposals on manpower requirements. The Council approved the following:

(i) That the total number of personnel in post should not exceed 650, of which 484 would be Team staff;

(ii) That the JET Director should have the flexibility to fill vacant DG XII Euratom and Associated Staff posts with either contract staff or visiting scientists;

(iii) That JET's personnel needs should be reviewed again at the beginning of 1986 at the latest, or whenever operational conditions clearly indicate that 625 people in post would not allow a successful and vigorous programme.

The main task of the JET Personnel Service for 1984 was to endeavour to fill all 484 Team posts. These posts include the JET Team members themselves (UKAEA 260, JET Euratom 165 posts), Assigned Associate Staff (40 posts) and DG XII Euratom Staff (19 posts). Figures 69 and 70 respectively show the development of numbers for Euratom and UKAEA staff over the period from mid 1981 to the end of 1984. Figure 71 shows the composition of staff by nationality. A full list of staff is given in Appendix III.

JET Team Members

JET has from the beginning experienced recruitment difficulties due to the inability of the Associated Laboratories to supply sufficient staff to meet the needs of the Project. In an effort to fill vacant posts, the Personnel Service held meetings with the heads of personnel of several of the Associated Laboratories to explore ways of attracting candidates to apply for specific vacancies. Advertisements were placed in the local press in a number of countries. Whilst the results in terms of the number of applications received were satisfactory, only 15% of all applications were from within the Associations and the number of suitable candidates fell short of expectations.

A total of 116 candidates were selected by interview boards during the year. It was somewhat disappointing that 38 of these subsequently declined offers of employment.

Euratom Staff

During 1984, a total of 30 newly appointed Euratom staff took up duty at JET. In the same period, twelve Euratom staff resigned from the Project—six to return to their parent organisations, four to take up positions with the NET Project, and two to take up other employment. There was therefore a net increase of 18 Euratom staff during the year, of which eight were professional and ten non-professional. The Swiss, Dutch and Danish Associations were particularly helpful in advertising vacant JET posts in their press.

At the end of 1984, for the first time since the beginning of the Project, all A category (professional) posts were filled. At the same time, five B category (non-professional) posts remained unfilled. There are good prospects of filling these remaining B posts during 1985.

UKAEA Staff

Applications for JET posts were actively sought through the United Kingdom Atomic Energy Authority. The extensive newspaper advertising was, however, not as successful as expected. Although a very large number of applications was received, it appears that qualified personnel suitable for the JET Project are in short supply on the UK market. The number of candidates selected from outside the UKAEA, was indeed very low.

During the year, 48 UKAEA staff were recruited while 21 staff resigned. There was therefore a net increase of 27 staff, of which only one was a professional. Almost half the resignations were from the administrative staff where the turnover was unusually high in 1984.

JET has from the beginning adopted the practice of engaging contract staff (against unfilled budgeted posts) where suitable team staff could not be recruited, where the numbers needed were such that the UKAEA could not provide them from their own resources. At the end of 1984, 24 such contract staff occupied UKAEA posts at JET (twelve A category and twelve B category).

At the end of the year 18 UKAEA posts were still unfilled. Bearing in mind that many of the UKAEA resignations took place towards the end of 1984, and that a six-month period is generally required to secure replacements, the number of unfilled posts was not excessive.

Assigned Associate Staff

Assigned associate staff are staff from the Associated Laboratories who are assigned to JET by their laboratories for periods of between one month and two years. Costs are shared by the associated laboratory concerned and JET.

The assigned associate staff scheme came into operation at the end of 1981. The growth of the scheme has been slow and up to 1983 most of the assignments were for periods of three months or less. During 1984, however, most of the assignments were of longer duration and many were for the maximum period of two years. Longer term assignments are considered to be much more satisfactory for all concerned.

During 1984, 65 staff from nine Associated Laboratories (other than the UKAEA) were assigned to JET. This represented a total of 15 man-years, against eight man-years in 1983. The following was the contribution of the individual Associated Laboratories in 1984 in man-months:

IPP	(Fed. Rep. of Germany)	69.50	man-months
ENEA	(Italy)	41.75	
CRPP	(Switzerland)	25.25	
RISØ	(Denmark)	11.00	
SERC	(Sweden)	9.50	
FOM	(Netherlands)	8.00	
CEA	(France)	6.00	
CNR	(Italy)	5.50	
ERM	(Belgium)	2.00	
KFA	(Fed. Rep. of Germany)	0.50	
	Total	179.00	

The utilisation of these assigned associate staff within JET was as follows:

Experimental Division II	70.50	man-months
Experimental Division I	55.75	
Theory Division	17.00	
Scientific Department Directorate	13.75	
Neutral Beam Heating Division	8.00	
Radio Frequency Heating Division	7.00	
Torus Division	7.00	
Total	179.00	

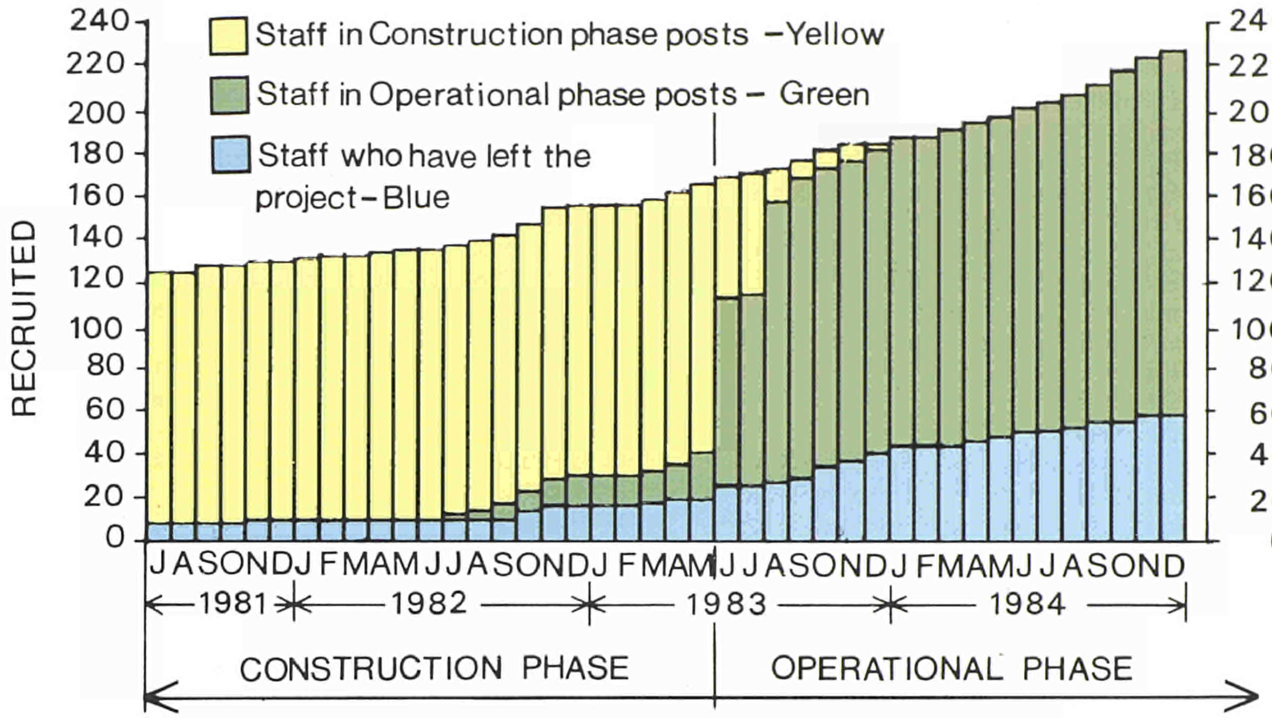


Fig. 69 Recruitment of EUR team staff (position as at the first of each month). July 1981—December 1984.

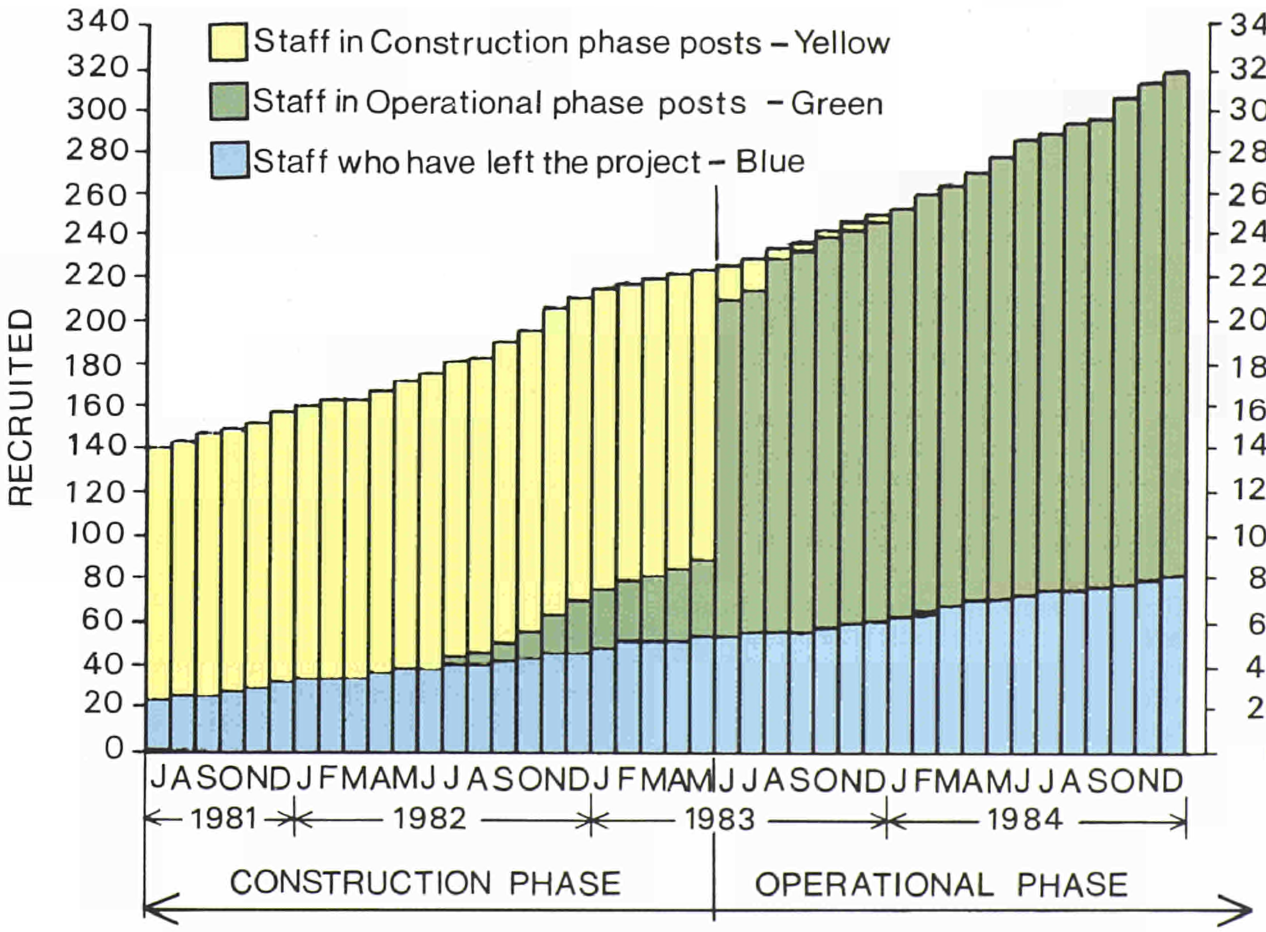


Fig. 70 Recruitment of UKAEA team staff (position at the first of each month). July 1981—December 1984.

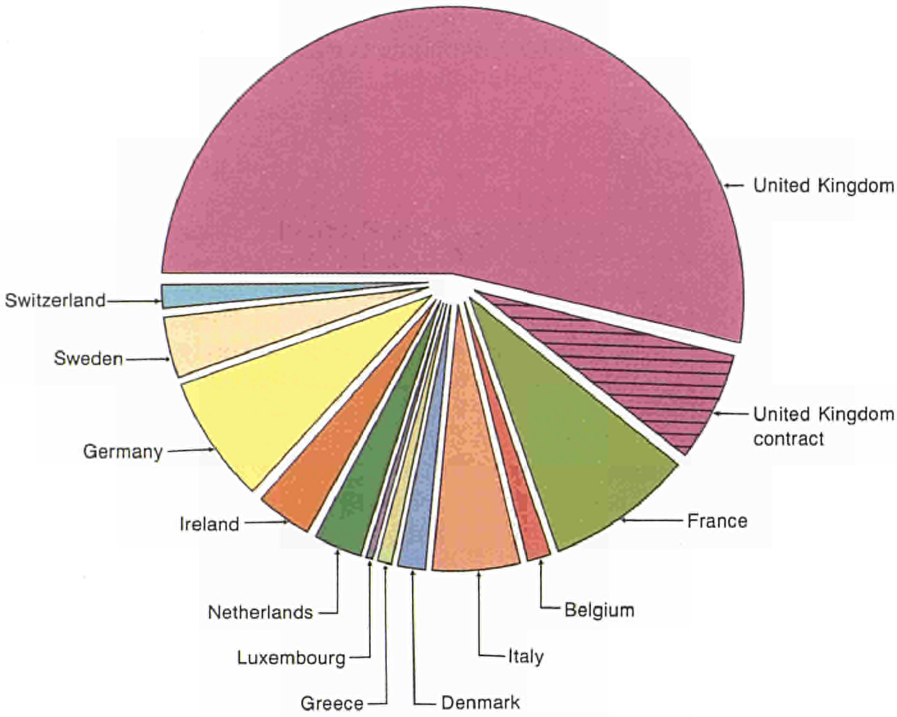


Fig. 71 Project team staff by nationality.

It is difficult to quantify accurately the contribution of the UKAEA Culham staff who carry out their assignments in Culham Laboratory often on a part-time basis over a long period. Culham Laboratory and JET between them estimate that the contribution for 1984 was about eight man-years.

DG XII Euratom Staff

At the commencement of JET, DG XII, the Directorate General of the Commission that has responsibility for the EEC Fusion Programme, agreed to allocate four of its staff to the JET Project. It later agreed to increase this figure to 19 to complement the limited number of Euratom posts at JET. These posts were already assigned to Euratom Associated Laboratories. There were eight DG XII staff at JET at the end of 1984 of whom one was assigned during 1984.

During 1984, the Commission agreed to recruit three DG XII staff against vacant Commission posts and to assign them to JET immediately on recruitment. This recruitment process has been slow, but is expected to be completed early in 1985.

Other Categories of Staff

Visiting Scientists

For 1984, the full visiting scientist complement of five man-years was almost reached. Ten appointments were made during the year—four from the United States, two from the United Kingdom and one each from Spain, Italy, China and Poland. As most of these appointments extend into 1985, the complement for 1985 is already filled.

Fellowships

At the end of 1983, the JET Council approved the creation of five JET Fellowships for post-doctorate students. This scheme, which was operated through the existing Euratom Fellowship Scheme, was promulgated amongst the partners. The response was not encouraging, but nevertheless two suitable candidates were selected and took up duty. In addition, the Commission assigned three candidates under the Euratom Fellowship Scheme to JET during 1984.

Students

A JET Studentship Scheme was introduced for the first time in 1984, under which appointments were made under the four categories of sandwich, pre-university, vacation and junior students. In all, 29 students were employed for a total of 100.5 man-months with pre-university and sandwich students accounting for three-quarters of this figure. All the students were EEC nationals, and were employed on scientific, engineering, computing and administrative work. The demand for student places has now risen substantially. The complement for 1985 has accordingly been increased to 15 man-years, three of which will be allocated to vacation and junior students.

Support Staff

The policy of providing specialist services to all divisions in JET through the grouping of support staff into common pools has continued successfully throughout 1984. The number of support staff has increased by 17 to 152. All but seven of this total are contract staff.

The Administration of Personnel

The machine was operational for 17 weeks during the year, the remainder of the time being used for the commissioning and installation of new systems. Although many staff were involved with tasks directly related to the machine operation, the large majority of them continued to work normal hours, supplemented by standby duty and overtime working on a regular basis.

Shift Work

Shift working was formally introduced only into Torus and CODAS Divisions. In Torus Division, shift working was necessary to monitor and inspect certain of the machine's subsystems on a round-the-clock basis. The selection of suitable candidates to man these shifts regularly had started in 1983. By the end of 1984 all twelve had been appointed. To enable shifts to operate while recruitment was proceeding and the technicians were being trained, casual shift work was undertaken by other staff in Torus Division. Within CODAS Division, the shift system provided a team of computer operators. From the middle of the year, this shift was manned entirely by contract staff.

During shutdown periods, a small number of staff from various divisions was asked to undertake casual shift working in order to supervise contractors who were working round the clock on the installation and commissioning of new devices.

Towards the end of 1984, it was decided that a two-shift system involving a much larger number of staff would be required in 1985. This two-shift system will be introduced during the first machine operating period of 1985.

Overtime

As it was impossible to introduce more extensive shift working in 1984, the machine when operational was run on an extended day. The schedule involved regular overtime. Although normal hours were re-established during shutdown periods, the level of overtime was not significantly changed as a number of nights and weekends, for safety reasons, was used to supervise the testing and installation of new equipment.

On-Call

Staff on-call rotas were introduced during the year for a number of subsystems. A large number of staff was rostered for these duties. Throughout the year, many were frequently called to site outside normal hours.

The shift technicians, when they become fully trained, will take over these duties, reducing the on-call requirements to emergency call-out only. The decision to introduce two-shift operation in 1985 will mean that more staff will be available on site over a much longer period, thus reducing the requirement for standby duty. This should leave only a few areas that will continue to require specialist cover round the clock.

Staff Training

In order to assist new personnel to settle into JET, the special one-day induction programmes continued throughout the year for new staff. In all, five such programmes were held during the year and 66 staff attended.

Language training continued throughout 1984. During the year 50 staff from non-English speaking countries took English lessons while over 100 staff took lessons in other European languages.

Safety refresher courses and lectures organised by Joint Safety Services were held throughout the year, as well as other specialised courses to meet specific staff needs. As the Operational Phase progresses, training will become increasingly important for staff needing to acquire new skills and to update their professional knowledge.

Staff Representation

During the year, four meetings were held between JET Management and the Staff Representatives Committee, where many matters relating to conditions of service were discussed.

Liaison with the Partners

Contact with the Associated Laboratories continued throughout the year in relation to the guarantees of re-employment and, as mentioned earlier, regarding the recruitment of staff for JET. Annual staff reports were completed on all staff from the partners and sent to these partners. There reports are intended to be used when re-absorbing staff into the partner organisations.

Safety

Organisation and Procedures

The JET Director is responsible for safety and is required by the JET Statutes to undertake all organisational measures to meet relevant safety requirements. JET staff, assisted by safety advisers appointed for each division and for defined experimental areas, have a specific line management responsibility for the safety of activities under their control. Further support is provided by the Joint Safety Service, which supports both JET and Culham Laboratory in a range of areas, including health physics, safety training, and safety documentation. Safety tours, led by the appropriate safety adviser, monitor safety in the working areas and the JET Safety Working Group reviews the reports of these tours and all other matters of everyday safety. Contractors working on the JET site have, of course, a legal obligation to work safely, but JET Responsible Officers also ensure that contractors comply with JET safety rules. The Director regularly reviews safety matters with his senior managers and safety advisers in the JET Safety Committee, and JET representatives participate in the Joint JET/Culham Laboratory Health and Safety Committee.

Comprehensive and flexible procedures have been set up to control potential hazards as part of the JET Technical Control System for the design of new equipment and in the JET Safety at Work System for all working activities in assembly, testing, operation and maintenance. There are additional arrangements to review the safety of diagnostic equipment supplied by Associated Laboratories. Safety assessments must be prepared for all work to be undertaken by JET Staff and contractors, and the safety precautions must then be approved at senior management level before the work is started. Precautions include the use of permits to work for tasks in hazardous areas or on any equipment which needs to be made safe for the work proposed.

Safety Standards

JET meets as a minimum all the requirements of the relevant UK legislation. Further to this, under the Host Support Agreement, JET has agreed to comply with the safety regulations of the Host Organisation with special reference to radiological safety standards. These obligations have been implemented by the adoption in JET of the standards and procedures of Culham Laboratory as the basis for safe working. There is a continuing close consultation between JET and Culham Laboratory on all safety matters, through the Joint Safety Services and the JET-UKAEA Liaison Committee set up under the Support Agreement. As one result, new safety rules applying to staff in both laboratories are issued as Joint Safety Notices by both Directors, in addition to the Safety Notices issued by the Director of JET in relation to rules applicable only to JET activities. The safety rules thus established for everyday working hazards incorporate UKAEA Codes of Practice. The principal safeguard for people is to exclude them from areas of potential hazard during operation, with appropriate enclosures to contain the hazard.

Safety in 1984

The major hazards continue to be primarily electrical due to the high-voltage high-current pulses used to produce strong magnetic fields. Operation of the JET machine was carried out under the personal supervision of senior engineers within strict administrative procedures before the Personnel Safety and Access Control System of interlocks for controlling access to the Torus Hall and Basement was available. This system was extensively tested during the year and is now in operation, apart from the turnstile access, which should become fully operational early in 1985. The whole access control system is being subjected to a safety and reliability assessment.

The radiation produced by energetic electrons striking the walls during certain plasma discharges described earlier was monitored by the radiological protection instrumentation already installed and by personal dosimeters worn by selected staff. This confirmed the efficacy of the instrumentation and shielding. The very low level of activation of the vacuum vessel detected at the start of the autumn shutdown was shown to be due to electrons striking the walls rather than to neutrons from deuterium plasmas. The neutron yield from the plasmas was in line with that forecast for this stage of the operation. This enhances confidence in the calculation of future radiation levels and in the adequacy of the protection measures envisaged. No radiological hazard existed outside the shielded Torus Hall and Basement. No precaution was required to control radiation exposure of personnel during shutdown periods, even when working inside the Torus.

Occupational hygiene hazards, for example, excessive noise, toxic fumes and the use of asphyxiating gases such as sulphur hexafluoride, were successfully controlled by appropriate precautions adopted after assessment of each problem as it arose. A preliminary assessment of the problems associated with beryllium limiters in JET was made following an experiment commissioned by JET on the ISX-B tokamak of the Oak Ridge National Laboratory in Tennessee.

Summary and Prospects

The JET safety record is most satisfactory and there will be the continued vigilance needed to maintain this record. In 1985, safety documentation and operating procedures will continue to be developed in step with progress in the operation of the JET machine. Particular attention will, of course, be paid to the increasing radiological hazards as the operating parameters are raised.

External Relations

The official opening of JET by HM Queen Elizabeth II on 9 April was the highlight of the year (see Fig. 72). The ceremony was attended by President François Mitterrand, HRH The Duke of Edinburgh, M Gaston Thorn and senior representatives—government Ministers and Ambassadors—of the twelve member countries of the JET Joint Undertaking. During the Ceremony, Her Majesty The Queen applauded "this magnificent technical achievement" and went on to say "The talents and expertise of the European Community and two other European countries have combined to show that international scientific co-operation can be resoundingly successful". Both President Mitterrand

Fig. 72 Her Majesty The Queen and President Mitterrand signing the visitors' book during the JET Opening Ceremony in April.

and M Gaston Thorn emphasised that JET was an outstanding example of European collaboration and expressed the wish that what had worked for JET could bring success for other sectors of Community activity.

After the Opening Ceremony the principal guests toured the JET laboratories before being entertained to luncheon. There was considerable press interest in this event and there was good coverage in newspapers, journals and on television in Member countries.

Throughout the year there was much interest worldwide in the JET Project from a broad cross section, including members of the scientific community, press and media, as well as the general public. Over 4500 people were conducted around JET during the year, of which about 40% were from schools, colleges and universities. There has also been considerable interest shown in JET by local groups in the neighbourhood. Amongst the notable visitors to JET during the year were Dr David Owen MP, leader of the British Social Democratic Party (see Fig. 73), M Saadi, Moroccan Minister of Energy (see Fig. 74), M Isurugi, Japanese Minister of State for Science and Technology (see Fig. 75), and a party of United States Congressmen.

A party of eleven journalists from the British Association of Science Writers visited JET for a tour and a detailed briefing on the results and future programme. In addition, journalists from France, Germany, Belgium, Sweden, UK, USA and Japan visited JET during the year, resulting in good media coverage. A German film crew have made a film on JET for German television.

Many of the overseas journalists were introduced to JET by members of the JET Information Network. These are public relations representatives in Member countries who transmit JET press information to journalists in their own country. Meetings of the JET Information Network were held during the year to brief members on the performance of JET and to discuss the forward programme.

Delegates from scientific conferences organised locally have visited the Project during the year, including the IAEA Seminar on Remote Handling Equipment, 5th International Symposium on Gas Flow and Chemical Lasers and the 21st Culham Laboratory Plasma Physics Summer School.

JET was joint host with Culham Laboratory for the 10th International Conference on Plasma Physics and Controlled Nuclear Fusion Research held in London on 12—19 September. This IAEA conference attracted over 600 delegates from 39 countries. Five papers by JET authors were presented at this conference, including one by the Deputy Director entitled "First Experiments in JET" which gave a detailed description of experiments carried out in the first year of operation (see Fig. 76). Four hundred delegates visited the Project as guests of JET on Saturday 15 September.

Among the many meetings held at the Project were the Joint JET/TFTR Discussion Group, the European Fusion Review Panel, Scientific and Technical Committee, the Study Group on the Fusion Research

Fig. 74 Monsieur Saadi, the Moroccan Minister of Energy, (2nd from left), being shown around JET by the Project's Deputy Director, Dr Rebut.

Fig. 75 A delegation from Japan led by the Minister of State for Science & Technology, Mr. Isurugi, on a tour of JET.

Fig. 73 The Right Honourable Dr David Owen, Leader of the Social Democratic Party, being shown the JET Project by the Director.

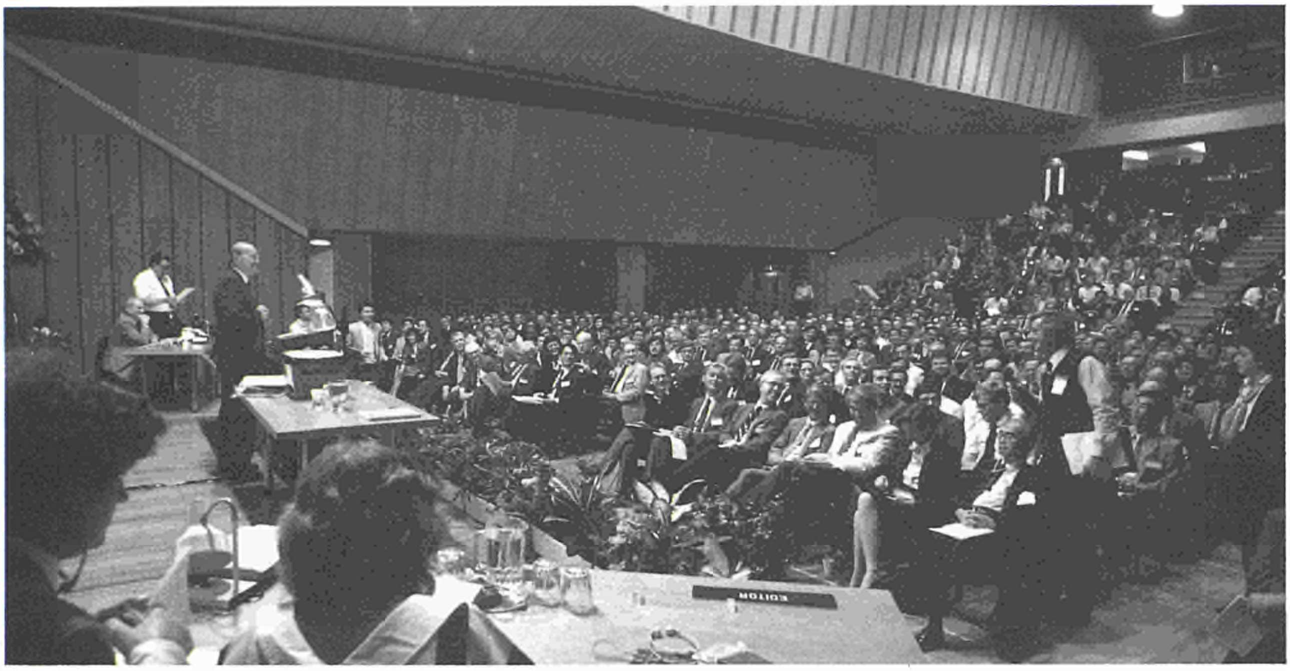


Fig. 76 Dr Rebut, the Project's Deputy Director, giving his paper entitled "First Experiments in JET".

Programme of the Economic and Social Committee, and the Institution of Electrical Engineers.

The Project buildings were given a commendation by the Royal Institute of British Architects. Certificates will be presented to the architects, contractors, consulting engineers and the JET Joint Undertaking in January 1985.

The European School at Culham

(A Contribution by the Headmaster)

1984 brought further growth and development to the European School. For the third time, the School presented candidates for the European Baccalaureate examination. All thirty candidates, from seven different countries, were successful and moved on to higher education or training in Finland, France, Germany, Italy and the United Kingdom. They were the last to take the European Baccalaureate in its old style, for in 1985 the reformed examination will be introduced.

At the other end of the pupil age-range, an exciting event for the School was the completion of a new building especially designed and built by the United Kingdom Government for primary pupils aged six to nine. This provides the first accommodation in the former College purpose-built for young children.

The beginning of the School year 1984-1985 brought preparations for the introduction of remedial teaching in the primary school, principally for children suffering a handicap in language and which may have occurred where a pupil is bi-lingual or tri-lingual but needs to strengthen mastery of the first language. The European Schools are also engaged in the development of computer education at both primary and secondary levels.

The school was visited during 1984 by the Danish Minister for Nordic Relations and by the British Under-Secretary of State of the Department of the Environment. Since it is the only European School in the United Kingdom, the School continues to attract many visitors and others engaged in research on international aspects of education. Like all the other European Schools, the School at Culham has engaged in an exchange of a pupil with an American high school, a scheme prompted by the President of the United States.

The Parents' Association was again very active throughout the year, participating in various school committees, organising meetings and social events, and what is very important for the School, raising money for activities and equipment. The School is grateful for gifts of books and of equipment for the playground, sports, computing, music, film making and drama.

During the year, younger pupils visited various adventure centres and the Isle of Wight; older boys and girls went to Snowdonia, the Brecon Hills, the Netherlands, Luxembourg, Germany, Belgium and Denmark. In November, the School took part in a new event, a Model European Council held in Munich. By lot, the European School at Culham was given the task of representing the Grand Duchy of Luxembourg.

A final note of interest: the Pupils' Committee, elected by the whole of the secondary school, chose as its chairman a pupil from Greece.

Appendix 1

JET Executive Committee

Member	Representatives
The European Atomic Energy Community (EURATOM)	C. Maisonnier (Vice Chairman) K. Melchinger
The Belgian State, acting for its own part (Laboratoire de Physique des Plasmas of the Ecole Royale Militaire) and on behalf of the Université Libre de Bruxelles (Service de Chimie-Physique II of the ULB)	R. Vanhaelewyn
The Commissariat à l'Energie Atomique, France (CEA)	B. Garric, F. Prevot
Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative, Italy (ENEA)	R. Andreani M. Samuelli
The Consiglio Nazionale delle Ricerche, Italy (CNR)	
The Hellenic Republic (Greece)	A. Theofilou
The Forsøgsanlaeg Risø, Denmark (Risø)	I. Rasmussen, V.O. Jensen
The Grand Duchy of Luxembourg (Luxembourg)	R. Becker
Ireland	C. Cunningham (Jan.—March) N.V. Nowlan (from April) F.G. Burrows
The Kernforschungsanlage Jülich GmbH, Federal Republic of Germany (KFA)	V. Hertling A.W. Plattenteich (Chairman)
The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.—Institut für Plasmaphysik, Federal Republic of Germany (IPP)	G. Von Gierke
The Swedish Energy Research Commission (SERC)	G. Holte E. Hellstrand (from September)
The Swiss Confederation	A. Heym, P. Zinsli
The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)	C. Westland M.F. van Donselaar
The United Kingdom Atomic Energy Authority (UKAEA)	D.M. Levey, W.M. Lomer

Appendix II

JET Scientific Council

Members nominated by the JET Council:

C.M. Braams (Chairman)
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H. Wilhelmsson
EURATOM-NE Association
(CTH) Institute for Electromagnetic
Field Theory and Plasmaphysics
Chalmers University of Technology
Fack
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G. Wolf
EURATOM-KFA Association
Kernforschungsanlage Jülich GmbH
Institut für Plasmaphysik
Postfach 1913
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Federal Republic of Germany

Appendix III

JET EURATOM and UKAEA Staff

(as at December 1984)

DIRECTORATE

Director: H-O. Wüster

DIRECTORATE:

Mrs A. Auckland
Mrs D. Geldhof
P.J.D. Kind
J.C. McMahon
Miss A.M. Renati
Mrs J. Talbot
D. Taylor
Mrs H.S. Tyndel
Mrs A. Wauters

SCIENTIFIC DEPARTMENT

Head of Department: R.J. Bickerton
Deputy Head of Department: A. Gibson

DIRECTORATE:

Head: A. Gibson

A. Ainsworth
N. Barnes
C. Caldwell-Nichols
S. Cooper
Mrs S. Costar
N. Foden
J. Gowman
A. Hancock
C.J. Hancock
Miss T. Haynes
B. Keen
R.C. Lobel
P. Lomas
M. Malacarne
P. Millward
B. Oliver
Mrs W. Prill
J. Reid
P.J. Roberts
Mrs M. Rowe
P. Rutter
Miss S.J. Scard
F.C. Schüller
Mrs C. Simmons
A. Tanga
P. Thomas
Miss J.L. Thompson
A. Tiscornia
C.H. Wilson

THEORY DIVISION:

Head: D.F. Düchs

M. Brusati
J. Christiansen
J.G. Cordey
W. Core
J. Davis
A. Galway
A. Gottardi
T. Hellsten
B. Keegan
E. Lazzaro
Miss M. Nave
Mrs M-G. Pacco
Mrs J. Roberts
R.T. Ross
R. Simonini
E. Springmann
T.E. Stringer
Mrs P. Stubberfield
A. Taroni
M. Watkins
J. Wesson

EXPERIMENTAL DIVISION I:

Head: P.E. Stott

D. Bartlett
C. Best
B.W. Brown
D. Campbell
J. Coad
A. Costley
L. de Kock
J. Fessey
C. Gowers
M. Hone
I. Hurdle
O. Jarvis
J. Kallne
C. Nicholson
P. Nielsen
R. Prentice
P. Roach
G. Sadler
Miss K. Slavin
A. Stevens
Miss D. Strange
D. Summers
P. van Belle
J. Vince
D. Wilson

EXPERIMENTAL DIVISION II:

Head: W.W. Engelhardt

K. Behringer
J.L. Bonnerue
G. Braithwaite
A. Bulliard
S. Corti
Miss G. Denne
A. Edwards
Mrs A. Flowers
R. Gill
A. Göndhalekar
J. Holm
Mrs. E. Kallne
L. Lamb
G. Magyar
J-L. Martin
P. Morgan
E. Oord
J. O'Rourke
A. Ravestein
J. Ryan
F. Sieweke
M. Stamp

ADMINISTRATION DEPARTMENT

Head of Department: G.W. O'Hara

DIRECTORATE:

G. Janes
Mrs. A. Morrison

CONTRACTS SERVICE:
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