JOINT EUROPEAN TORUS JET

JET JOINT UNDERTAKING

ANNUAL REPORT 1985

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EUR-JET-AR8

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JUNE 1986

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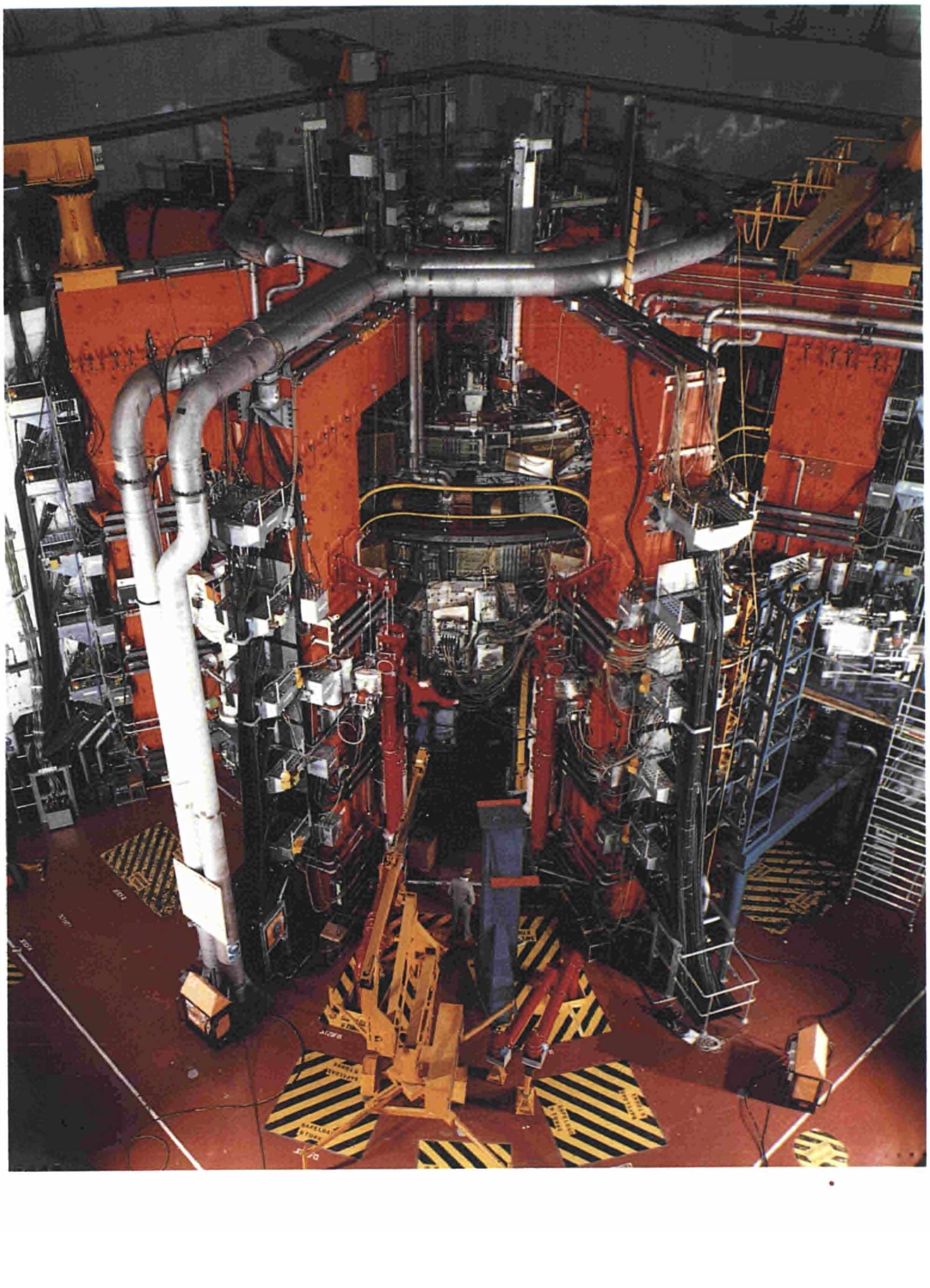


Preface

A successful year for the JET Joint Undertaking was marred by the sudden death of Dr Hans-Otto Wüster in June 1985 which was a great shock to all of us associated with him. His contributions to the formation and smooth running of the Project during the first years are immeasurable. We all owe him a great debt.

The JET Council is fortunate to have been able to call upon the exceptional talents of Dr Paul-Henri Rebut to take over the leadership of the Project. Dr Rebut has been involved with JET from its earliest days, first as leader of the JET Design Team and then as Deputy Director of the JET Joint Undertaking from its formation in 1978. Dr R J Bickerton, formerly an Associate Director and Head of the Scientific Department, has been appointed as Deputy Director and Head of the Heating and Theory Department. Also, Dr M Keilhacker has come from IPP Garching to be an Associate Director and Head of the Experimental Department.

I am pleased to report the excellent technical performance of JET in 1985. The first half of the year was devoted to machine operations with, for the first time, additional heating from the two RF antennae installed during the shutdown at the end of 1984. In July, operations were halted, as scheduled, for a four month shutdown to allow the installation of additional components including the third RF antenna. The final preparations were also completed for the first neutral injection system. Operations then continued until the end of the year. In 1985, the total number of tokamak pulses with a plasma current in excess of 1MA was 1446. This represents a consistent increase over the 69 in 1983 and 472 in 1984. Throughout 1985, many plasma pulses were produced with the maximum rated value of 3.45T for the toroidal magnetic field. A plasma current of 5MA has been reached and held at this level for one second. At present, machine operations at high currents are restricted to plasma elongation ratios of 1.4 to avoid the possibility of damaging the machine if control of the vertical stability is lost. The design of new vessel supports is nearly complete and these, when installed, should enable this restriction to be removed. Other modifications are planned to enable the current to be maintained at the 5MA level for longer times with the possibility of cautiously raising the current to higher levels.

The additional heating used during 1985 employed the technique of ion cyclotron resonance heating and by the end of the year a record input power of 6MW had been achieved with 15MJ of energy coupled to the plasma. A degradation of the confinement time with increasing power was observed similar to that seen on smaller tokamaks, but experience on other machines has shown that this degradation may be reduced or avoided by operating in a mode with a magnetic separatrix. This so called X-point operation has been demonstrated on JET with plasma currents up to 1.5MA, but so far without additional heating. The beneficial effects of this mode of operation, however, have still to be demonstrated on JET.

Plasma impurities remained high in 1985 as in previous years and although they do not lead to a significant radiated power loss from the plasma core, they do dilute it somewhat. A combination of multiple pellet refuelling and powerful additional heating, which will be tested in 1987, are considered the most promising approach to improving this situation.

The scientific results that have been achieved so far on JET are encouraging. In terms of plasma density, temperature and confinement, JET has already reached a point where each of these parameters is within a factor of three of those needed for a reactor.

At the beginning of 1986, the first neutral injection system for additional heating was successfully operated and I look forward to the details of this important stage of JET's programme being reported next year.

It is encouraging to note that JET's position in the forefront of fusion research has been maintained. Early in 1986, a collaborative agreement was signed between the Japan Atomic Energy Research Institute (JAERI), the US Department of Energy and the European Atomic Energy Community (on behalf of both EURATOM and the JET Joint Undertaking). The agreement sets out a basis for the exchange of staff and information between the three large tokamaks, JT-60 in Japan, TFTR in the USA, and JET. This emphasises the strong international nature of the research which I believe to be essential for the eventual success of fusion as a new source of energy.

It is clear that there are many important aspects yet to be investigated on JET, some of which were not envisaged when the design was completed ten years ago. The JET Council has therefore supported the extension of the research programme of the Project until 1992 so as to incorporate these new initiatives. This still requires the approval of the Council of Ministers of the European Communities.

The difficulties in recruiting staff, experienced in previous years, has persisted. The main aim during the past year has been to fill the 484 team posts approved by the JET Council in 1984 for the Operational Phase of the Project. As a result, at the year-end, the number of team posts filled increased from 384 to 410, with an additional 43 posts filled by contract staff.

Last year, I referred to the decision of the JET Council to reconvene the special Working Party on the manpower requirements for the Operational Phase of JET at the beginning of 1986 at the latest. The Working Party met in early April in the current year and discussed the future personnel requirements of the Project with the JET Director and senior management. The Working Party will report their findings to the JET Executive Committee in May, who will in turn report to the JET Council in June.

During the year, the JET Council met four times, the JET Executive Committee seven times and the JET Scientific Council four times. I thank my colleagues on the JET Council for their continuing support over the past year and on their behalf offer our thanks to the members of the Executive Committee and Scientific Council for their advice and dedication to the Project.

As in previous years, the UKAEA and especially Culham Laboratory have continued to provide a high level of support to the Project in terms of advice, staffing and services. I would like to thank the members of the Commission of the European Communities and the Associated Laboratories for the active involvement with the Project and their enthusiasm for ensuring its continuing success.

Finally, I would like to express my personal thanks to all the members of the JET Team who have continued to work with such dedication, enthusiasm and skill. Much of the responsibility for maintaining JET at the forefront of world fusion research remains with them. I hope they will continue to meet the tremendous challenges offered by this demanding Project.

May 1986

J. Horowitz
Chairman of the JET Council

DR HANS-OTTO WÜSTER
1927-1985

Professor J Horowitz paid the following tribute to Dr H-O Wüster at the extraordinary meeting of the JET Council held on 20 September 1985.

"In scientific research, it is often necessary to design, construct and then operate complex and costly experiments. The success of these projects relies heavily on the qualities of the people chosen to lead them. It is their ability to overcome the scientific and technical problems, to deal with questions of administration and, above all, their capacitiy to inspire staff and promote team spirit that is essential for ensuring the success of such projects.

Hans-Otto Wüster possessed all of these qualities. In 1978, he was appointed as Director of the JET Joint Undertaking from outside the world of fusion, which indicated the high esteem in which he was already held. It was, however, as Director of JET that his great qualities were truly demonstrated.

Upon taking office, he had the difficult task of setting up the organisation of the Project and of ensuring that there was no delay in the start of the Construction Phase. Hans-Otto Wüster left his personal imprint on the Project by the way he overcame, with such authority and diplomacy, the difficulties that arose. It was a great achievement for the machine to be brought into operation on schedule and within the original cost estimates. Under his leadership, the results achieved with ohmic heating established JET as the world's leading Tokamak experiment.

JET has demonstrated that a large Community based scientific project can be successfully managed with staff brought together from various countries within a framework of a temporary organisation. Dr Wüster played an essential role in bringing together the needs of the Commission, the participating countries and member organisations, as well as those of the host country.

Hans-Otto Wüster's success extended beyond the confines of JET. He became one of the outstanding personalities in the world of fusion, guiding us through the uncertainties facing the field of fusion research in the challenges that have to be confronted. Firstly, there is the need to supply the scientific data that will be required as a basis for the next step in the development of fusion. Secondly, there is the challenge faced by the whole Community Fusion Programme, with JET as the principal element, in complying with tight, financial constraints. Hans-Otto Wüster played a crucial role in the lengthy and difficult negotiations on these matters. With his pragmatic approach, he defined and maintained a sound course of action for JET and it was with the same resolution that he worked for the entire Community Programme.

The legacy left by Hans-Otto Wüster, will help to guide us through any difficulties which lie ahead, although nothing can compensate us personally for the loss."

Organs of the JET Joint Undertaking

1. The JET Council

Member	Representative
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 Horowitz (Chairman) F Prevot
The Comitato Nazionale per la Ricerca e per lo Svilluppo dell'Energia, Nucleare e delle Energie Alternative, Italy (ENEA) (Previously known as Comitato Nazionale per l'Energie Nucleare, Italy (CNEN)).	B Brunelli (Jan-Sept) A Bracci (from Oct) 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 Hoffmann P Gramegna
Ireland	N V Nowlan D Byrne
The Kernforschungs-anlage Jülich GmbH, Federal Republic of Germany (KFA)	A W Plattenteich
The Max-Plank-Gesellschaft zur Förderung der Wissen-schaften e.V.—Institute 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 Develop-ment)	Mrs B Bodlund (Jan-March) G Leman (from April) S Bergström (from March)
The Swiss Confederation	F Troyon P Zinsli
The Stichting voor Fundamenteel Onder-zoek der Materie, the Netherlands (FOM)	C M Braams, C le Pair (Jan-March) K H Chang (from April)
The United Kingdom Atomic Energy Authority (UKAEA)	F Chadwick R S Pease

2. The Director of the Project

H-O Wüster until his death on 30 June 1985.
P H Rebut was nominted as Director on 20 September 1985.

Nuclear Fusion

Introduction

The Joint European Torus is the largest project in the co-ordinated programme of the European Atomic Energy Community (EURATOM) which is aimed at proving the feasibility of using nuclear fusion as a source of energy for generating electricity.

Present research is concentrated towards proving scientific feasibility and reaching the conditions that will be needed in a reactor. After the successful completion of this stage there will still remain the need for large programmes to develop suitable technology and prove the economic viability of a reactor system. The long-term nature of these research programmes makes it unlikely that the development of nuclear fusion as an energy source on a commercial scale will be completed successfully until well into the next century.

Nuclear Fusion

Energy is released when the nuclei of light elements fuse or join together to form heavier ones. The fusion reaction of most interest, because it presents the least difficult path towards achieving reactor conditions, is that occurring between the two heavy isotopes of hydrogen—deuterium and tritium, see Fig. 1. Most of the energy released in this reaction is carried by a high speed neutron formed in the reaction. The remaining energy is given to the other particle produced from the reaction, the nucleus of the inert gas helium.

In a fusion reactor, the neutrons produced would be captured and slowed down in a jacket surrounding the reactor core. The energy of the neutrons would be deposited in the jacket, thus increasing its temperature and enabling steam to be raised for generating electricity in the conventional manner.

Fuels

As deuterium is a readily separated component of water, there is a virtually inexhaustible supply in the oceans of the world. In contrast, tritium does not occur naturally in any significant quantities on the earth and must be manufactured. This can be achieved by using reactions occurring between the neutrons and the light metal lithium, see Table 1. This process will take place in the surrounding jacket which will contain a compound of lithium. The tritium formed would then be extracted for use in the reactor. Thus, although a fusion reactor would depend upon fusion reactions between deuterium and tritium, the actual fuels consumed would be deuterium and lithium. There are sufficient reserves of lithium available to enable fusion reactors to be run for several hundred years.

Ultimately, it is hoped that the conditions might be reached to enable a reactor to be built utilising the deuterium-deuterium reaction. In which case, the only fuel needed would be deuterium.

Table 1

Fusion Reaction	$D+T \rightarrow {}^4He+n$	$+28.1\times10^{-3}$ joules
Tritium Breeding Reactions	${}^6Li+n \rightarrow T+{}^4He$ ${}^7Li+n \rightarrow T+{}^4He+n$	$+7.7\times10^{-13}$ joules -4.0×10^{-13} joules
Overall Reaction	$D+Li \rightarrow 2{}^4He$	

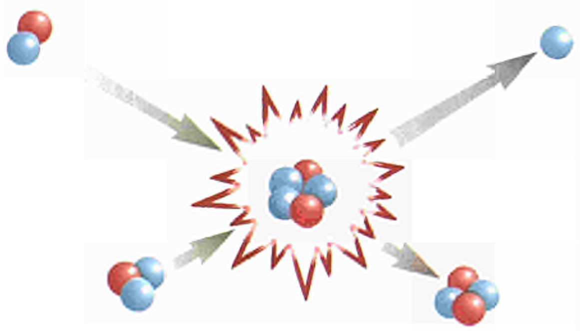


Fig. 1 The deuterium-tritium reaction which yields an energetic neutron and a helium nucleus.

CR86.101

Conditions for Fusion

Fusion reactions can only take place if the nuclei are brought into close proximity to one another. Difficulties arise because all nuclei carry a positive charge and therefore repel one another. By heating the gaseous fuels to very high temperatures, enough energy can be given to the nuclei for the repulsive force to be overcome sufficiently for them to fuse together. In the case of the deuterium-tritium reaction, temperatures in excess of 100 million degrees Celsius are required—several times hotter than the centre of the sun.

To ensure a net energy gain it is essential in a reactor that more energy is released from the fusion reactions than is required to heat the fuels and run the system. The power output from a reactor will be dependent upon the square of the number density (n) of nuclei and the volume of gas.

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

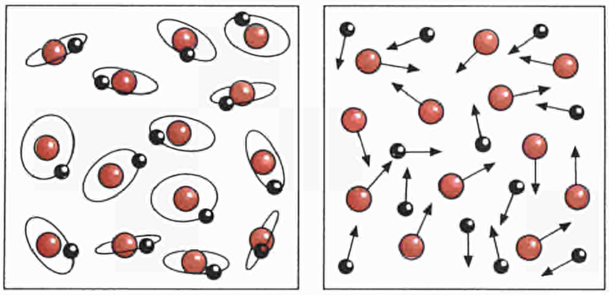
The requirement for a net power gain can be expressed by a combination of these two terms and is given by

$$n \times \tau_E > 2 \times 10^{20}\ \mathrm{m^{-3}\,s}$$

together with a temperature above 100 million degrees Celsius.

Plasma

As the temperature of the fuel is increased, the atoms in the gas become ionised. The electrons, which normally orbit around the nuclei, are stripped away and a mixture of positively charged ions and negatively charged electrons is formed. In this state the physical properties of a gas are very different from those under normal circumstances and a special name is given to this fourth state of matter—PLASMA, see Fig. 2.



Hydrogen gas *Hydrogen plasma.*

Fig. 2 Plasma is a mixture of positively and negatively charged particles. CR86.102

The fact that a plasma is a mixture of charged particles means it can be controlled and influenced by magnetic fields. With a suitably shaped field it should be possible to confine a gas with a high enough density and a sufficiently long energy confinement time to provide the conditions for a reactor. One of the major problems associated with the development of nuclear fusion as an energy source has been to find a magnetic field configuration capable of meeting these requirements.

The configuration that has proved to be most successful in approaching reactor conditions is the so called TOKAMAK, originally developed in the USSR.

Detailed studies with 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 the small scale experiments indicated that large machines are needed if reactor conditions are to be achieved. As early as 1971, discussions within the European fusion research programme were taking place on a proposal to build a much larger tokamak to extend the plasma parameters closer to those required in a reactor. In 1973, agreement was reached to set up an international design team which started work in the UK later that year. By the later half of 1975 the design for a large device had been completed and accepted by the partners. Following lengthy discussions on the siting of the Project, the Council of Ministers agreed in October 1977 that JET should be built at Culham, near Oxford in the UK. The JET Joint Undertaking was established on 1 June 1978 to construct and operate the Joint European Torus.

The Joint European Torus

The JET Project team was set up with scientists, engineers and administrators from the member countries of the JET Joint Undertaking.

Assembly of the JET tokamak started early in 1982 as soon as the torus hall for housing it had been completed. This building has 2.8m thick concrete walls to provide adequate protection from the high energy neutrons expected from JET during the final stages of the operation.

The magnetic field used to hold the hot plasma away from the containing vessel walls on JET is formed from three components. The first of these, the toroidal field around the major axis of the machine, is generated by 32 large D-shaped copper coils equally spaced around the major circumference of the machine, see Fig. 3. The second component, or poloidal field, is the magnetic field produced by the plasma current, which is induced to flow through the hot gas by transformer action. The primary winding of the transformer is situated at the centre of the machine and is coupled to the plasma which acts as the single turn secondary. Around the outside of the machine, but within the confines of the transformer limbs, are the six outer poloidal field coils for producing the third component, used for stabilizing and shaping the plasma. A diagram of the JET apparatus is shown in Fig. 4 and the principal design parameters are given in Table 2.

The plasma is enclosed within the toroidal vacuum vessel which has a major radius of 2.96m and D-shaped cross-section of 4.2m by 2.5m. The vacuum chamber was constructed from eight identical octant sections, each built of a double-walled structure made from five

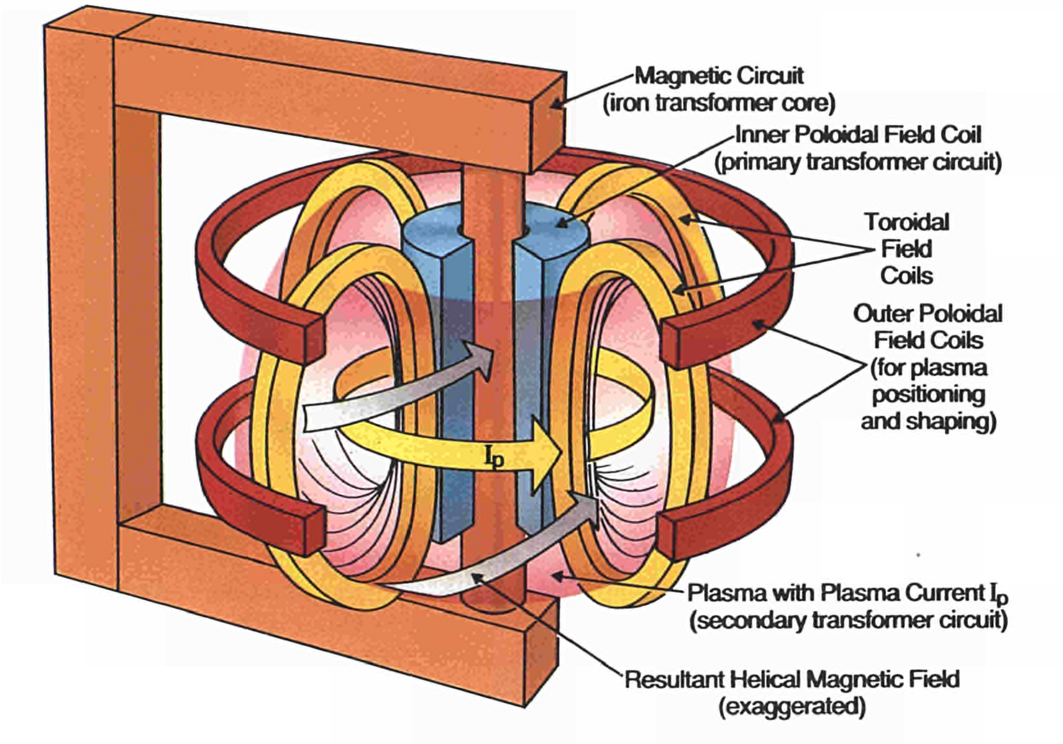


Fig. 3 Tokamak magnetic field configuration.
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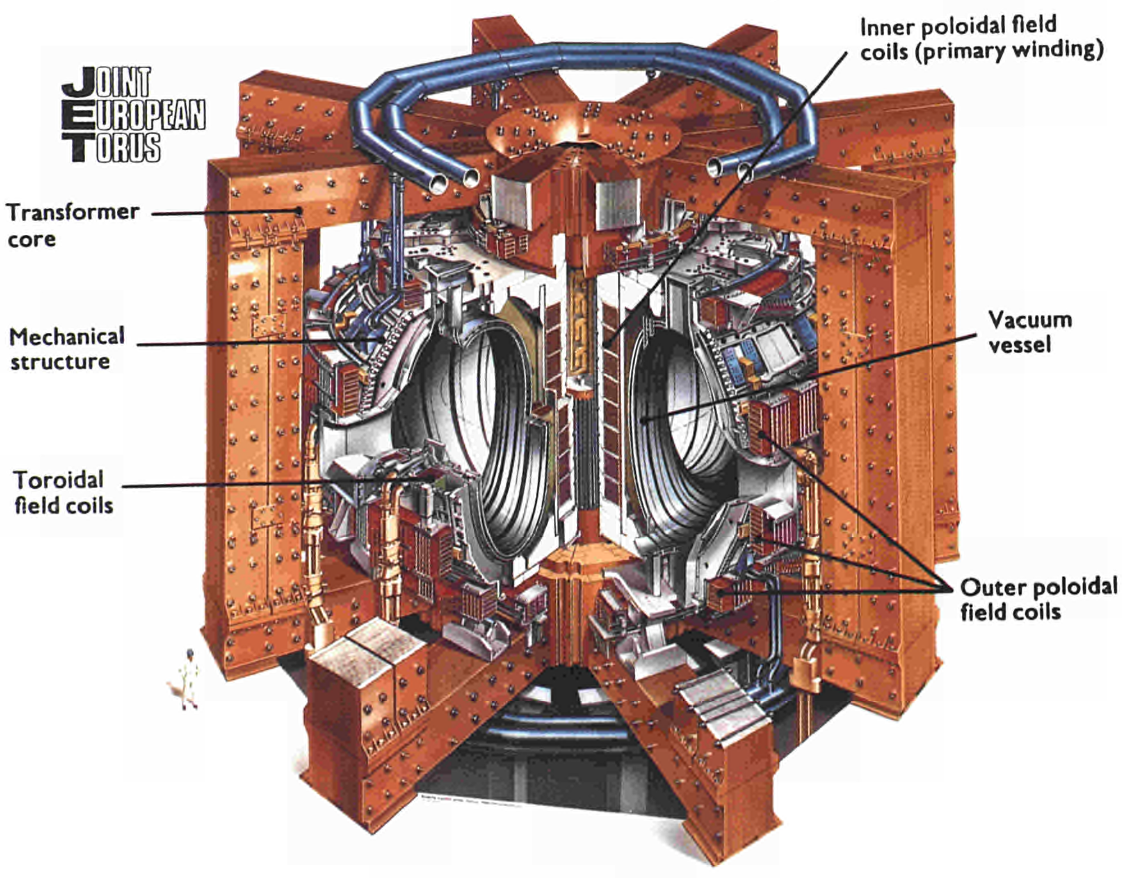


Fig. 4 Diagram of the JET Tokamak.
82.348C/A

Table 2
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	34Vs
Additional heating power	25MW

rigid sections joined together with thin-walled bellows. The bellows give the complete vessel a relatively high electrical resistance so that only a very small fraction of the plasma current flows through the vessel itself. The double-walled construction allows the vacuum chamber to be baked to 500 °C to remove impurities from the walls as these would rapidly cool the plasma.

The construction phase of the Project from 1978 to 1983 was completed successfully within one month of the prescribed five year period and within 8% of the projected cost of 184.6 Mio ECU, at January 1977 values, corresponding to a current cost of 316.8 Mio ECU.

The first plasma pulse was achieved on 25 June 1983 with a plasma current of 17,000 A lasting for about one tenth of a second. Within a year this plasma current had been increased to 3.7 MA with total pulse lengths of 15 s. In 1985, the plasma current was increased to 5 MA which was above the original design value for the machine. The first phase of operation, till the end of 1984, was carried out using the large plasma current to heat the gas. During the plateau of the current this produced plasma temperatures of 30 million degrees Celsius, densities of $3 \times 10^{19}\,m^{-3}$ with energy confinement times of 0.6 s. The JET tokamak is shown in Fig. 5 just prior to the start of operations in June 1983.

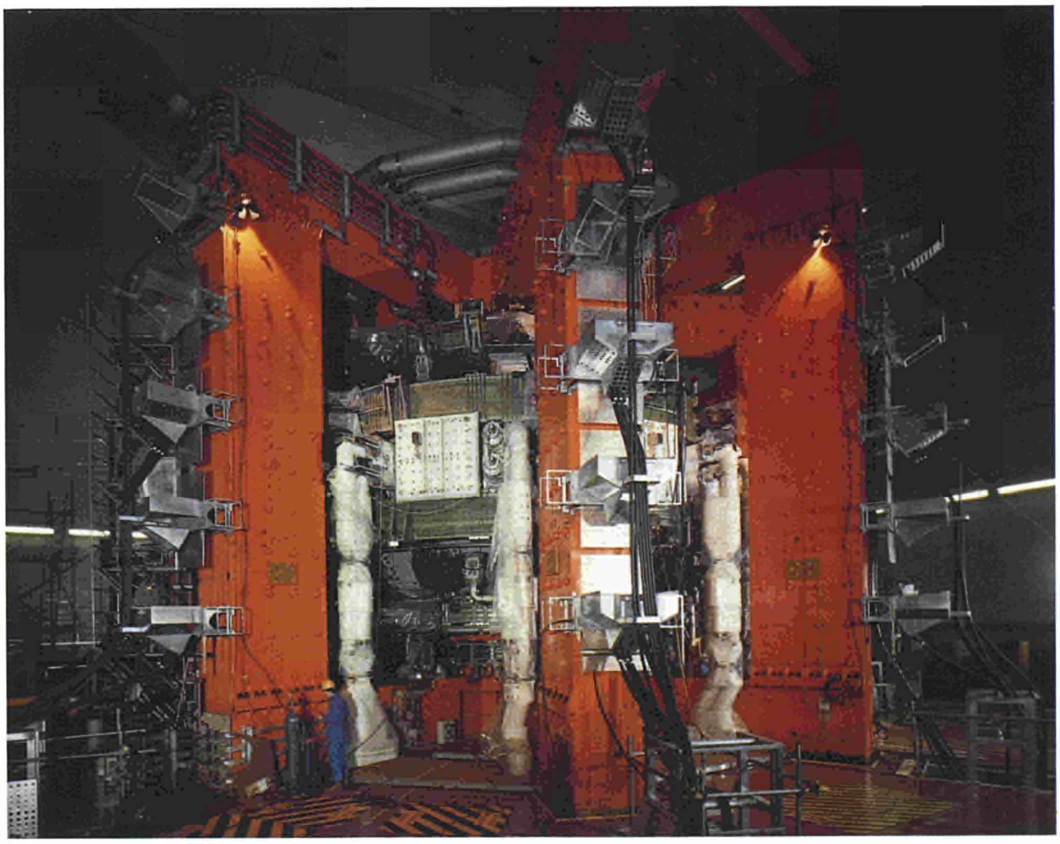


Fig. 5 The JET Tokamak prior to the start of operations in June 1983.
83.772c

Additional Heating

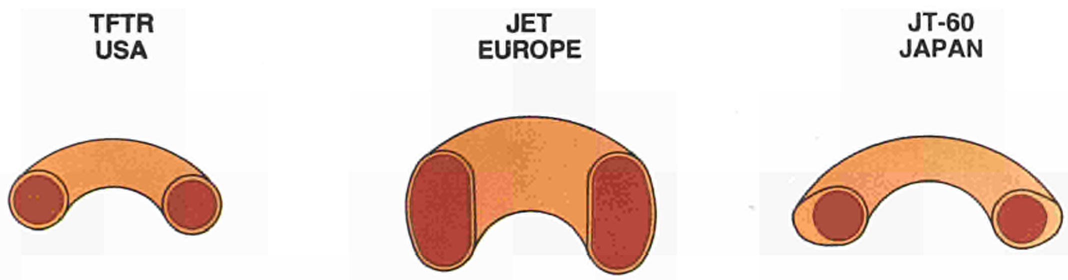
The heating effect of the current is reduced as the plasma gets hotter because its resistance decreases with increasing temperature. It is therefore necessary to provide additional heating if the temperatures needed for a reactor are to be approached. On JET two additional methods of heating are being used.

1. Neutral Beam Heating. In this method, a beam of charged hydrogen or deuterium ions is accelerated to high energies and directed towards the plasma. As charged particles cannot cross the magnetic field confining the plasma, the beam must be neutralised. The resulting neutral atoms cross the magnetic field and on entering the plasma give up their energy through collisions thereby raising the temperature. The neutral beam heating system on JET will consist of two 5MW units.

2. Radio Frequency Heating. Energy can be absorbed by the plasma from high power radio frequency waves. The frequency is chosen to be close to the gyration frequency of the ions in the magnetic field so that there is efficient coupling between the RF waves and the plasma. It is planned to couple 16MW of radio-frequency power into the JET plasma from a set of eight antennae fixed on the inside wall of the vacuum vessel.

Large Scale Tokamaks

There are now three large tokamaks operating in the world. TFTR, at Princeton in the USA, started operating in December 1982, JET followed in June 1983 and the Japanese machine, JT-60, became operational in April 1985. The three projects have complementary aspects. For example, JET and TFTR are designed to operate with deuterium-tritium plasmas. JT-60 has a form of divertor and will use a wide range of heating techniques. Fig. 6 illustrates the relative sizes of these three tokamaks and their major operating parameters.



TFTR USA	
Minor Radius	0.85m
Major Radius	2.48m
Toroidal Magnetic Field	5.0 T
Plasma Current	3.0 MA
Pulse Length	2 s.
Additional Heating Power	27 MW (total)
D-T Operation Capability	
1st Plasma	Dec 1982

JET EUROPE	
Minor Radius	1.25m (Horz) 2.1m (Vert)
Major Radius	2.96m
Toroidal Magnetic Field	3.5 T
Plasma Current	5.0 MA
Pulse Length	20 s
Additional Heating Power	44 MW (total) [25 MW high grade]
D-T Operation Capability	
1st Plasma	June 1983

JT-60 JAPAN	
Minor Radius	0.95m
Major Radius	3.0m
Toroidal Magnetic Field	4.5 T
Plasma Current	2.7 MA
Pulse Length	5-10 s
Additional Heating Power	54 MW (total) [30 MW high grade]
Magnetic Limiter Configuration	
1st Plasma	April 1985

Fig. 6 The three large tokamaks in the world.
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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. Periodically, a new five-year programme is adopted which overlaps with the last two years of the previous one. The current programme, for the period 1985-89, was adopted by the Council on 12 March 1985.

The programme is implemented by means of Contracts of Association between Euratom and organisations within the member states that are active in the field, by the JET Joint Undertaking and by the NET (Next European Torus) Team at IPP, Garching. 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. Since 1980, Spain has participated in the exchange of scientific staff. Greece became a member of the Community fusion programme on joining the European Economic Community in 1981 and formerly joined the JET Joint Undertaking in 1983. The location of fusion research laboratories involved in the Euratom fusion programme is shown in Fig. 7.

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 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, 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 12 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, together with 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.

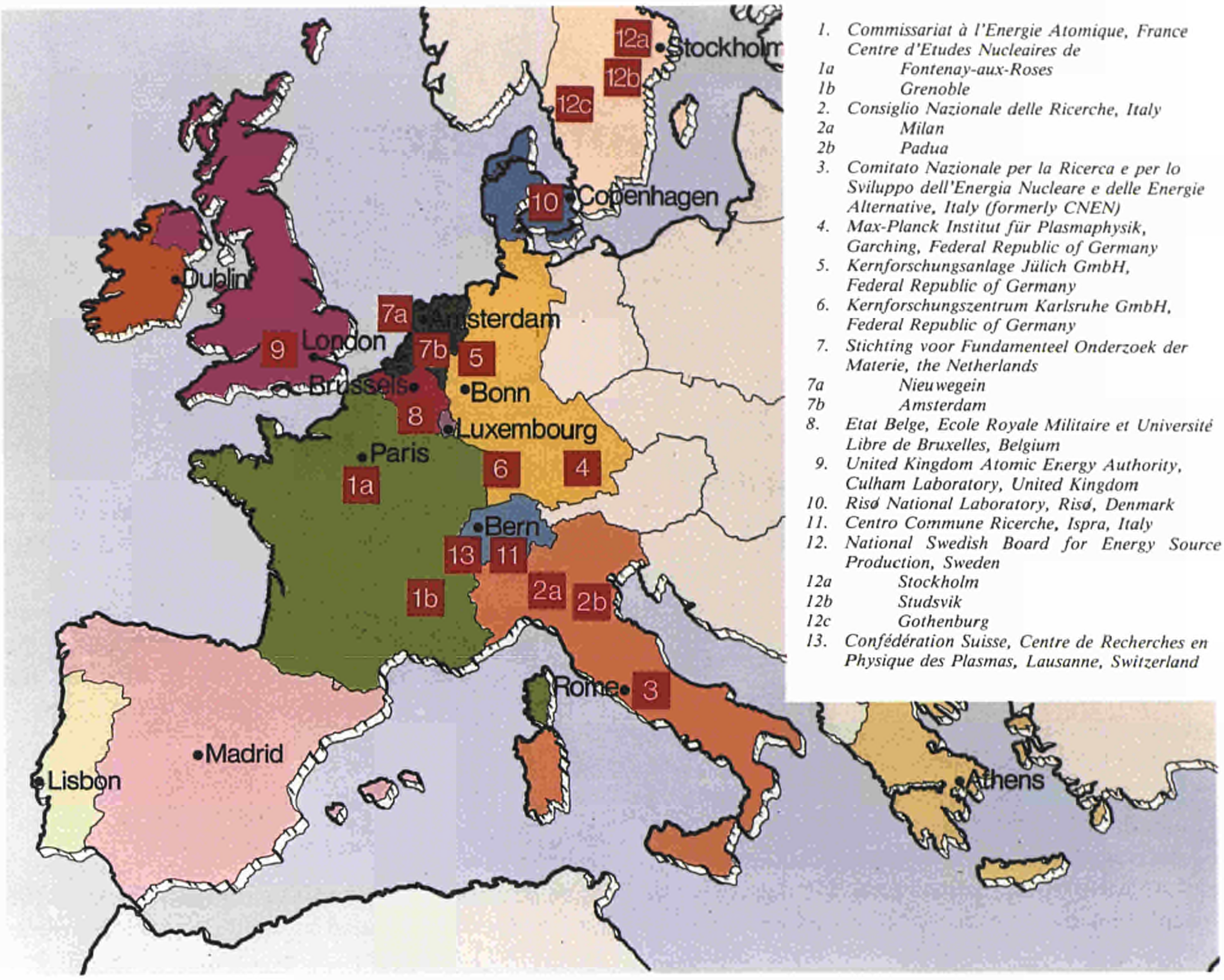

Fig. 7 Location of the organisations associated with the Euratom fusion programme.

86.613c

The Project Team is formed by personnel put at the disposal of the Undertaking by

- The Associated Institutions other than the UKAEA. These members of the team are recruited by Euratom as temporary agents.
- The Associated Laboratories. These team members are assigned to the Project for periods of up to two years.
- The UKAEA (Host Organisation). These team members remain employees of the UKAEA.
- Directorate General of the Commission responsible for Science, Research and Development (DGXII).

Each Member having a Contract of Association with Euratom undertakes to re-employ the staff whom it placed at the disposal of the Project as soon as the work of such staff has been completed.

Objectives of JET

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

- The study of scaling of plasma behaviour as parameters approach the reactor range.
- The study of plasma-wall interaction in these conditions.
- The study of plasma heating.
- The study of α-particle production, confinement and consequent plasma heating.

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 Results of JET Operations in 1985

Introduction

JET operated for about seven months in 1985. During the year the first experiments were carried out with additional heating applied to the plasma. This was done using the ion cyclotron resonance technique at the ~4.5MW level with two antennae in the machine. The technical performance of JET and its power supplies proved to be excellent with many discharges using the toroidal field strength at the full rated level of 3.45T.

The following summarises the most important results obtained during the year.

1. The plasma current was increased to 5MA and held at this level for one second. This is to be compared with the rated value of 4.8MA. At this level of current the plasma elongation must at present be limited to 1.4 in order not to damage the machine in the event of loss of control of the vertical position of the plasma. Strengthening of the torus mounting planned for the 1987 shut-down should remove this limitation. At the same time changes to the poloidal field system will enable the full volt-second capability of the machine to be used. This will give much longer flat-top times at the 5MA level and the possibility of cautiously raising the current to perhaps as high as 7MA.

2. For discharges with ohmic heating only, the maximum value of energy confinement time τ_E at about 0.8s in the 1985 experiments, is not significantly higher than that obtained in 1984. However many careful scans of density at different currents have now been carried out and have revealed that the linear scaling of τ_E with density ($\bar{n}$) is limited to the low range of density. At higher values a saturation is seen so that a regression fit over the whole range gives $\tau_E \propto n^{0.4}$.

3. The first experiments with RF heating showed immediately the phenomenon of confinement degradation. In a typical case when the input power is doubled the energy content of the plasma increases only by 50%. In fact the confinement time scales with power in a similar way to that seen initially with neutral injection heating on smaller tokamaks — the so-called Goldston L-mode scaling. This is a most serious problem since to reach significant α-particle heating in JET we need to maintain an energy confinement time comparable to the maximum ohmic value of 0.8s.

The measurements fully demonstrated the expected ability of the RF system to deposit power in a very localised region of the plasma. With the power deposited in the centre this leads to very dramatic large amplitude fluctuations of the central electron temperature and to a lesser extent of the ion temperature (giant sawteeth). These results have intensified interest in methods which might stabilise these oscillations, holding the temperatures at their peak values. Although small in volume this central region is where the α-particle production will first occur.

4. JET has been operated in a new mode in which the plasma is bounded not by a material-limiter but by a magnetic separatrix. Outside this separatrix the field lines do not form closed toroidal surfaces but intersect the wall of the vacuum vessel at the top and bottom of the machine. The ability to operate in this way is a natural consequence of the JET design aimed at D-shaped rather than circular cross-section plasmas. This so-called X-point mode of operation has been demonstrated at the 1.5MA level with only ohmic heating so far. The importance of this result is that experience on other machines has shown that such discharges may avoid or at least reduce the confinement degradation with additional heating. The first ohmic results are encouraging in that there is evidence for the formation of high density, cold and radiating plasma clouds near the regions where the field lines intersect the wall. These discharges are operating at elongation factors of 1.8 to 1.9 and pose severe problems for the feedback control of the vertical position of the plasma. However, the system designed for the less demanding elongation of 1.6 has so far proved adequate for the task.

The critical test of this operational mode will be when it is used with a substantial level of additional heating power. Subject to some limitations this test will be performed in 1986.

5. The impurity level remained high in the 1985 experiments as in 1984. Over the operating range the effective ion charge (Z_{eff}) ranged from ~3 to 6. Putting a carbon layer on the walls (carbonisation) by running glow discharges in hydrogen/methane mixtures for several hours reduces the metal content dramatically but has only a marginal influence on Z_{eff}. The effect of carbonisation wears off after 20 to 200 high power pulses depending on the amount of carbon deposited.

The impurities in JET do not lead to significant radiated power loss from the plasma core but they do dilute the core plasma so that the deuteron density there is typically 0.5 to 0.7 times the electron density. With a D-T plasma this would reduce the α-particle power by a factor between 4 and 2. The main hope for improvement is through the combination of multiple pellet fuelling and powerful additional heating. This combination will be first tested in 1987.

6. The single figure representing achievement is the so called fusion product ($\hat{n}_D\ \hat{T}_i\ \bar{\tau}_E$) where $\hat{n}_D$ and $\hat{T}_i$ are the central deuteron density and ion temperature while $\bar{\tau}_E$ is the global confinement time. For D-T plasma this combination measures the ratio of thermonuclear power to the power input. In 1985 operation this parameter reached the maximum value of 6×10^{19}m^{-3}keVs for ohmic and RF heated discharges. In the RF case the drop in confinement time is compensated by the increase in ion temperature.

Energy Confinement

An extensive series of experiments was carried out during 1985 to characterise the energy confinement properties with ohmic heating. Experiments with ion cyclotron heating were started during 1985 and towards the end of the year the power coupled to the plasma by the ICRH exceeded the ohmic input by a factor of two. A preliminary assessment of the effect of this additional heating on the confinement has been obtained.

In the ohmic heating studies, the toroidal field B_T, the toroidal current I_p and the density were all varied over the range of parameters given in Table 3. The size and shape of the plasma were also varied extensively.

The energy confinement time τ_E is found to increase almost linearly with low values of density and then saturate at higher densities ($\bar{n}\sim2.5\times10^{19}$m^{-3}). This can be clearly seen in Fig. 8 where a few representative density scans are shown in the plot of τ_E versus nqR^2a (neo-Alcator scaling). The saturation in the confinement time at high densities is typical tokamak behaviour and has been seen in many smaller experiments but the reason for this behaviour is not clear. Power lost by radiation certainly increases as the critical density is approached, but this is probably due to changes in the plasma edge conditions, associated with the poor penetration of neutrals at high densities, rather than an increase in the accumulation of impurities.

Fig. 8 shows that the nqR^2a neo-Alcator scaling reasonably describes the JET data set and the best fit line is very close to that obtained on the TFTR and PLT

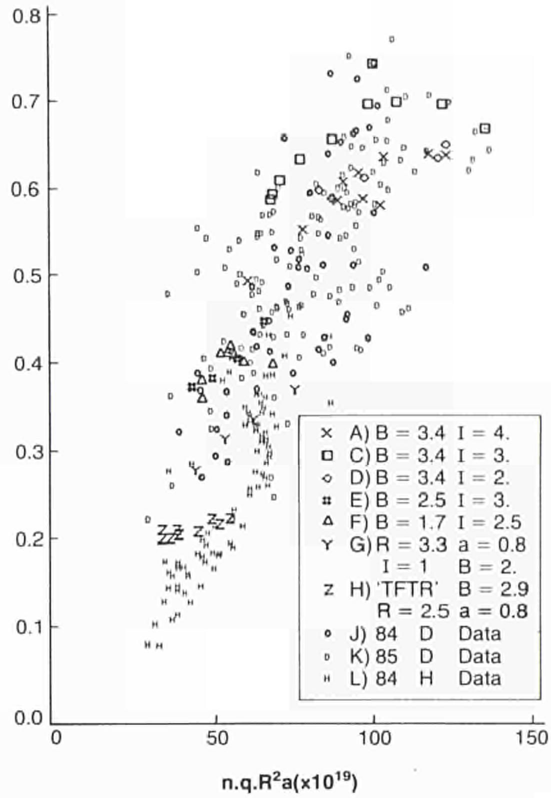

Fig. 8 Plot of energy confinement time with neo-Alcator scaling.
CR86.104

data set. A slightly better fit can be obtained by using regression analysis and is given by

$$\tau_E(\mathrm{s}) = 0.013\,B^{0.5}(\mathrm{T})\ q^{0.3}\ \bar{n}_{19}^{0.4}\ K^{0.2}\ R^{3.2}(\mathrm{m})\ \epsilon^{1.7}A^{0.5}$$

where q is the cylindrical safety factor, K the elongation, R the major radius, ϵ the inverse aspect ratio and A the atomic mass (the JET data set includes both hydrogen and deuterium plasmas).

The local transport properties of these discharges have been analysed by both interpretative (JICS) and predictive codes. The dominant energy loss processes change

Table 3

Parameter Ranges in JET During Ohmic Heating Studies

Parameter	Range
Plasma Current (I_p)	up to 5MA
Toroidal Field (B_T)	1.7 to 3.4T
Minor Radius (a)	0.8 to 1.23m
Major Radius (R)	2.5 to 3.4m
Elongation Ratio (K)	1 to 1.7
Electron Density ($\bar{n}_e$)	0.5 to 3.6×10^{19}m^{-3}
Cylindrical Safety Factor (q_{cyl})	1.7 to 12

with minor radius and three distinct regions have been clearly identified:

(i) an inner region where the main energy transport is by field line mixing following the sawtooth collapse.

(ii) an intermediate region in which electron and ion thermal transport are dominant.

(iii) an edge region where impurity radiation and other atomic processes dominate.

In the intermediate region the main loss channel is via the electrons. The ion thermal conductivity is between one and five times neo-classical values with the higher levels occurring at lower densities. The electron thermal conductivity in this region decreases with increasing density with a coefficient $\chi_e \simeq C/n$ (m^2s^{-1}). The constant C is between 1 and 2×10^{19} and no clear dependence on toroidal magnetic field or plasma current has been observed.

An independent measurement of the electron thermal conductivity, using the 12-channel electron cyclotron emission grating polychrometer has been obtained by following the relaxation of the electron temperature profile after the sawtooth collapse. Preliminary analysis of the date gives a $\chi_{eHP} \propto \sqrt{I_p/n}$ in ohmic discharges with no change in χ_{eHP} observed during ion cyclotron resonance heating. The parametric dependence of χ_{eHP} is similar to that obtained from transport studies, however, numerically χ_{eHP} is a factor 2-5 greater. This discrepancy may be a consequence of the simple diffusion model used in the analysis of the propagation of the heat pulse. Simulating the evolution of the heat pulse with a full transport code, which includes sources and sinks, does appear to reduce the discrepancy between the measured and simulated pulse propagation speeds.

A preliminary investigation of 'profile consistency' has shown that the current and electron temperature profiles are only a function of the safety factor when the plasma is in steady-state, with the current fully diffused. Several different explanations for the invariance of these profiles have been proposed.

The addition of ion cyclotron resonance heating shows the classic L-mode behaviour observed in smaller tokamaks with the confinement time reducing with increasing input power.

In Fig. 9 both the total kinetic energy and energy confinement time are shown versus power for several different conditions of current and toroidal magnetic field. For all conditions the total kinetic energy increases approximately linearly with the additional heating power and hence the data in Fig. 9 has been fitted to the forms

$$w = P_\Omega \tau_\Omega + (P - P_\Omega)\, \tau_{aux}$$

and

$$\tau_E = \frac{P_\Omega}{P} \cdot \tau_\Omega + \left(1 - \frac{P_\Omega}{P}\right) \tau_{aux}$$

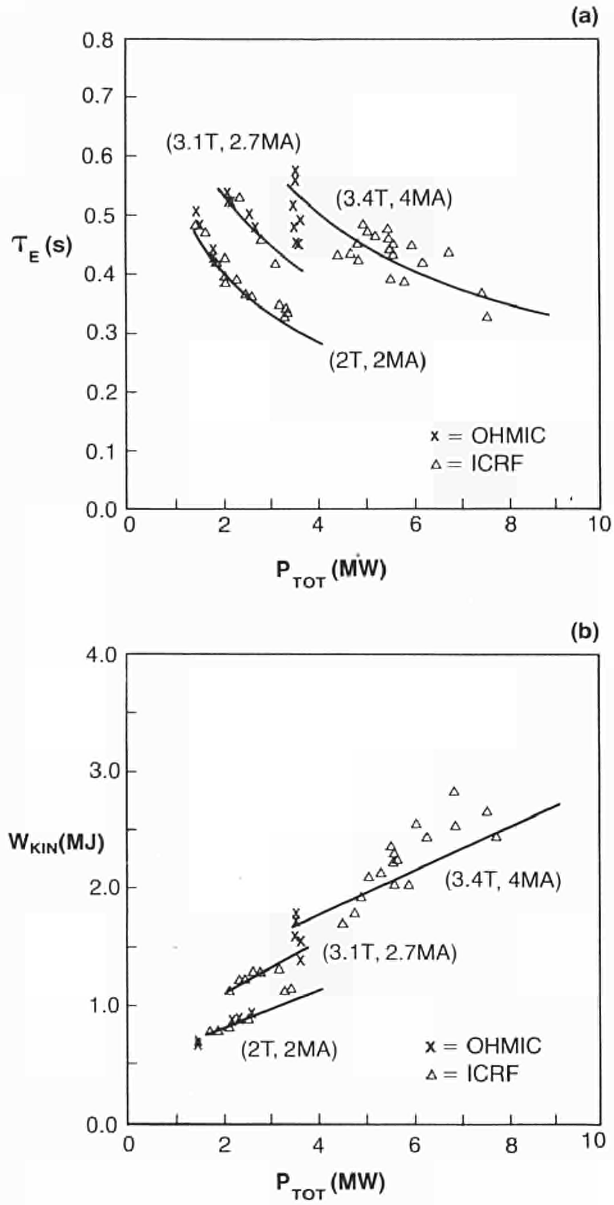

Fig. 9 Power dependences of plasma energy (W) and gross energy confinement time (τ_E) for three different conditions.

CR86.105

where P is the total power, P_Ω the ohmic input power, τ_Ω is the ohmic confinement time, and τ_{aux} is the auxiliary heating confinement time. In smaller experiments, τ_{aux} is found to be quite a strong function of toroidal current I_p. This strong current dependence has not been seen on JET, as shown in Fig. 9, which may be due to the very limited range of power used at low currents.

MHD Activity and Disruptive Instabilities

MHD instabilities in tokamaks constrain the operational space and might also be a determining factor in the transport behaviour. Many aspects of the MHD instabilities observed in JET are being actively studied but recently emphasis has been placed on two particular subjects. The first is that of plasma disruptions which suddenly destroy the confinement if too high a density or too high a plasma current is attempted. The second subject is sawtooth oscillations in which confinement of the central core is periodically lost as the plasma undergoes a relaxation oscillation.

Disruptions

Most effort has been applied to understanding disruptions which occur when a critical density is reached. Increased density implies increased impurity radiation and associated energy losses. This can lead to strong instabilities in two ways. It is possible for a magnetic island to form and to be unstable to a thermal instability in which radiation losses from the island drive a growth of the island. The possible occurrence of this phenomenon is receiving detailed experimental study.

The other process follows a sequence of stages. The radiation energy losses at the plasma surface increase as the density is increased. A critical point is reached where almost all of the energy input is lost in this way. The plasma is then unstable to a slow contraction of the plasma column. This contraction also narrows the current channel and at some point the configuration becomes strongly unstable to a tearing instability. Finally, the instability pervades the plasma and destroys confinement.

Figs. 10 and 11 show the contraction of the radiating layer and the electron temperature profile. These features together with the unstable onset of the contraction and the final disruption have been simulated using a transport-stability code.

Sawtooth Oscillations

Sawtooth oscillations are an almost universal feature of tokamaks. It had generally been accepted that their basic behaviour was understood. However, the experimental results from JET are not consistent with previous models and this has led to a substantial revival in interest in this subject.

The sawtooth behaviour is observed on many diagnostics, for instance on temperature and density measurements. In the standard form of the sawtooth the collapse phase is preceeded by precursor oscillations and the collapse occurs on a timescale which would allow a resistive reconnection of the magnetic field to take place. Generally, on JET the precursor oscillations are absent and the collapse time is believed to be too short ($\sim 100\,\mu s$) for the magnetic reconnection to take place. Typical sawtooth behaviour is shown in Fig. 12.

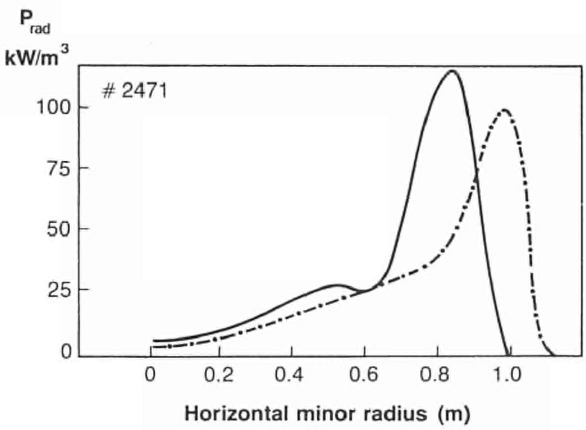

Fig. 10 Radiated power before a disruption. Two radiation profiles are shown, separated by one second, during the contraction phase.
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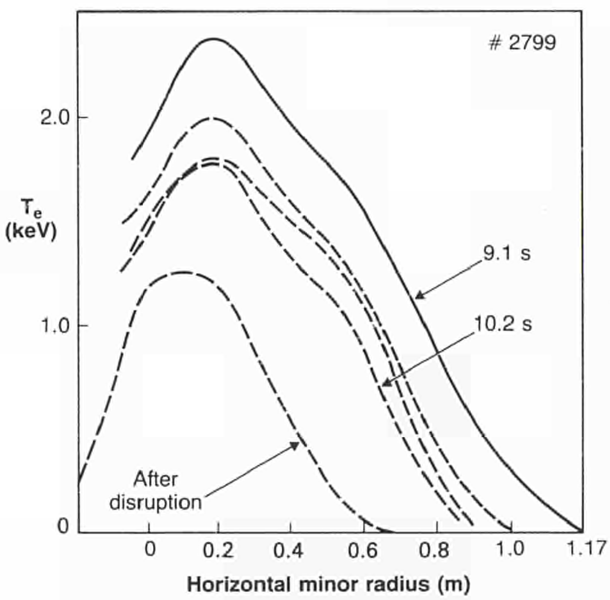

Fig. 11 Temperature profiles determined from the electron cyclotron emission during the contraction phase.
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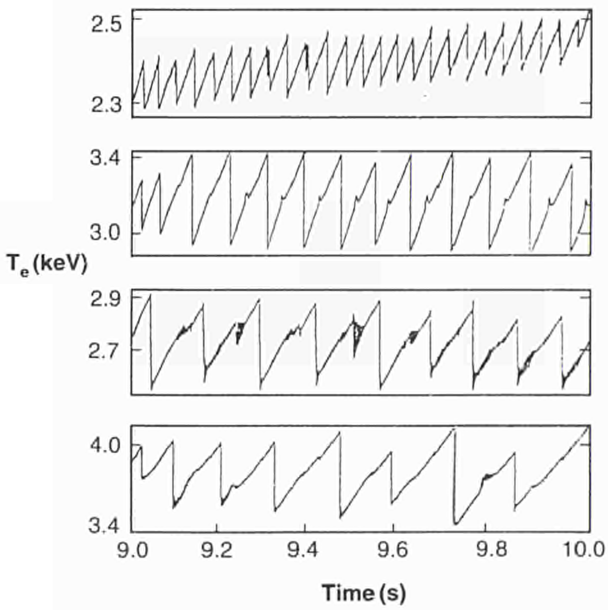

Fig. 12 Typical sawteeth on the electron temperature for plasma currents of 1, 2, 3, and 4MA (from top to bottom).
CR86.108

Further evidence comes from tomographic reconstruction of the soft X-ray signals measured along 100 lines of sight. Fig. 55, Page 52 shows a sequence of profiles of the X-ray emission. The central emission is seen to be rapidly displaced to one side, this displacement giving the observed rapid sawtooth collapse. The emission profile is then hollow at the axis and this hollow fills on a longer timescale.

These results are consistent with a new theoretical model in which the sawtooth is caused by an instability in which the plasma flows in such a way as to interchange but not bend magnetic field lines. The motion is then limited only by inertia and this allows the rapid behaviour observed.

Impurities and Radiation Losses

For the operation of JET in 1985, the carbon limiters were fitted with new carbon tiles without any metal coating or molybdenum contamination on their surfaces. To avoid damage and metal splashes during disruptions, the inner wall was protected by carbon plates to within ± 1 m of the horizontal midplane. The vessel was washed with pure water and a very light carbonisation (2% CH_4, 6 hours) carried out prior to the first plasma operation. Further carbonisations were carried out during 1985 with the aim of suppressing metal impurities during RF heating.

The overall impurity behaviour during ohmic heating discharges in 1985 was very similar to that of previous operating periods. In particlar, metal impurities decreased at higher average electron density ($\bar{n}_e$) with oxygen and carbon being weakly dependent on $\bar{n}_e$. The ratio of nickel to chromium increased, indicating that the nickel originated from the nickel antennae screens rather than the Inconel vessel walls. Molybdenum disappeared and chlorine only played a minor role in the level of radiation and value of effective ionic charge (Z_{eff}), although there was no tendency for it to decrease further.

During the first weeks of operation, with the new carbon tiles, metal concentrations in the plasma were very low and the radiated power was only 40% of the ohmic heating power (P_Ω). Later on, the graphite became coated with metals, which led to higher metal concentrations in the plasma, particularly at low electron densities. This behaviour is illustrated in Figs. 13a and 13b which show the recorded brightness of the Ni XXV line as a function of pulse number for selected pulses ($\bar{n}_e = 2\times10^{19}m^{-3}$) from these two periods. OV and C IV intensities are also shown in Fig. 13 for comparison.

When the limiters were coated with metal, a light carbonisation (12% CH_4, 6 hours) led to an immediate reduction of metal impurities by a factor of five and a reduction of radiated power from about 70% P_Ω to 50% P_Ω. Recovery to the former levels occurred after

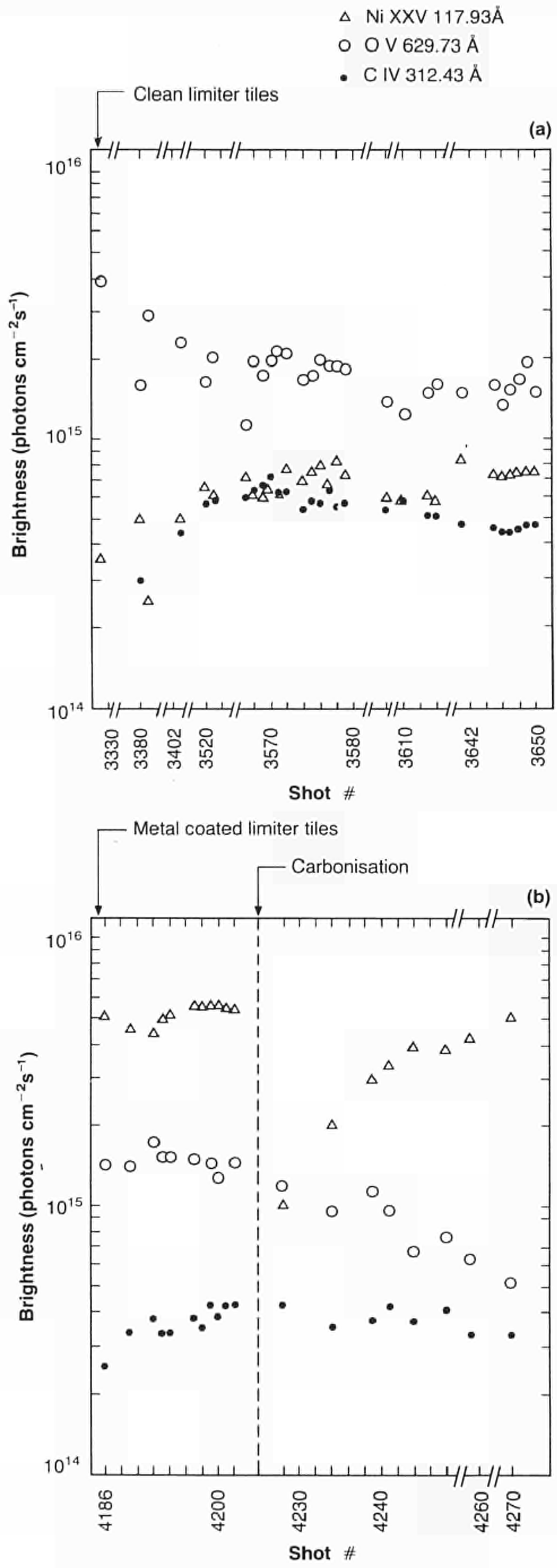

Fig. 13 Intensities of some VUV impurity lines for selected plasma pulses ($\bar{n}_e = 2\times10^{19}m^{-3}$) with:
a) clean limiter tiles
b) metal coated limiter tiles, including light carbonisation.
CR86.109

about 20 plasma pulses, as is demonstrated again in Fig. 13b by the intensity behaviour of Ni XXV. Oxygen tended to decrease in the long term, while carbon remained unchanged or increased slightly. These observations are in good agreement with the results of the 1984 carbonisations. After a very heavy carbonisation (17% CH_4, 48 hours) there was a reduction by a factor of 100 in metal impurities and the recovery period was extended to some 200 plasma pulses. Typical impurity concentrations for a carbonised vessel were 3% n_e of C, 1% n_e of O, 0.05% n_e of Cl and 0.01% n_e of metals, resulting in a $Z_{eff} \approx 3$.

During RF heating, increased influxes of hydrogen and impurities were observed, leading to an increase in $\bar{n}_e$. Impurity concentrations of light elements did not change significantly during RF heating. Systematic studies of metal behaviour (after carbonisation) showed that the metal concentration was essentially constant during ^{3}He minority heating (B_T=3.4T), while it increased to some extent during H minority heating (B_T=2.0T). The respective results are summarised in Fig. 14 showing Ni XXV line intensities divided by $\bar{n}_e^2$ as a function of radio frequency power for three records of operation with RF heating. Dividing the line intensities by $\bar{n}_e^2$ provides a good measure of the nickel concentration in the plasma. The basic metal levels during these pulses were very low due to carbonisation (0.01% n_e). If no carbonisation was carried out for a long time, then the absolute increase in metal concentration appeared to be similar but starting from a higher base level.

Due to the higher $\bar{n}_e$ values and flatter n_e profiles, the radiated power increased during RF heating so that about 50% of the total input power was radiated. Z_{eff} remained virtually constant during RF heating. No significant differences were detected, within the experimental error bars, due to antennae configurations.

During preliminary X-point studies in JET, the total radiated power approached 100% P_Ω with about 30% of this radiation localised in the vicinity of the X-points.

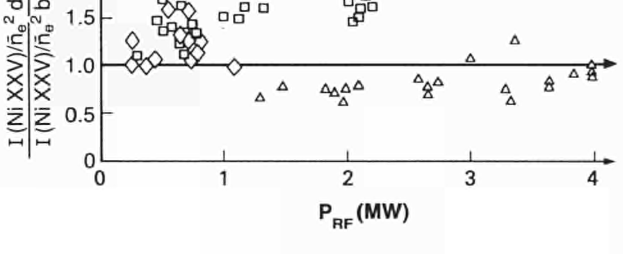

Fig. 14 Variations of $\frac{Ni\ XXV}{\bar{n}_e^2}$ (nickel concentration) with RF power for three periods of operation after carbonisation.
CR86.J10

The general impurity situation in 1985 was very similar to that at the end of 1984. It did not deteriorate significantly during RF heating, but the usual decrease in the level of impurities and Z_{eff} with higher electron densities (at constant plasma current) was not observed, either. The main problem at present is still the appreciable dilution of the deuterons (n_D=70%n_e) due to the high fraction of carbon and oxygen in the plasma.

Plasma Evolution

An understanding of the dynamic processes associated with transitions from one phase of a plasma pulse to the next is essential if these transitions are to be successful.

The specific problems related to the various transitions are outlined in Table 4.

Table 4

Transition		Determining Process and Problems
From	To	
Premagnetisation	Fast Rise	Breakdown and ionisation in the presence of stray fields.
Fast Rise	Slow Rise	Too rapid current rise leading to skin currents and instabilities.
Slow Rise	Flat Top	Skin effects to be counteracted by simultaneous ramping of fields and plasma shape; build up of density; enhanced chance of disruption.
Flat Top	Decay	Density decay not always sufficiently fast; 'marfes'; disruptions; negative skin current effects.

Breakdown and Ionisation

A small fraction of the gas particles, introduced into the torus for an experimental pulse, is ionised due to natural radioactivity, cosmic rays, etc. Application of a toroidal electric field (E_T) causes the free electrons to be accelerated along the toroidal magnetic field, B_T and if the ratio of E_T and the torus pressure P_{fill} is above a certain threshold, then the electrons gain sufficient kinetic energy to ionise gas molecules through collisions. Under the right conditions, this leads to an avalanche process resulting in the formation of a fully ionised gas. However, the formation of an avalanche can be prevented by loss mechanisms. If stray magnetic fields are present, the particles will follow the resultant total field, with helical topology, and be lost at the torus wall. Additional losses occur because the electrons travel faster than the ions and space charges are built up producing poloidal electric fields that cause E×B drifts.

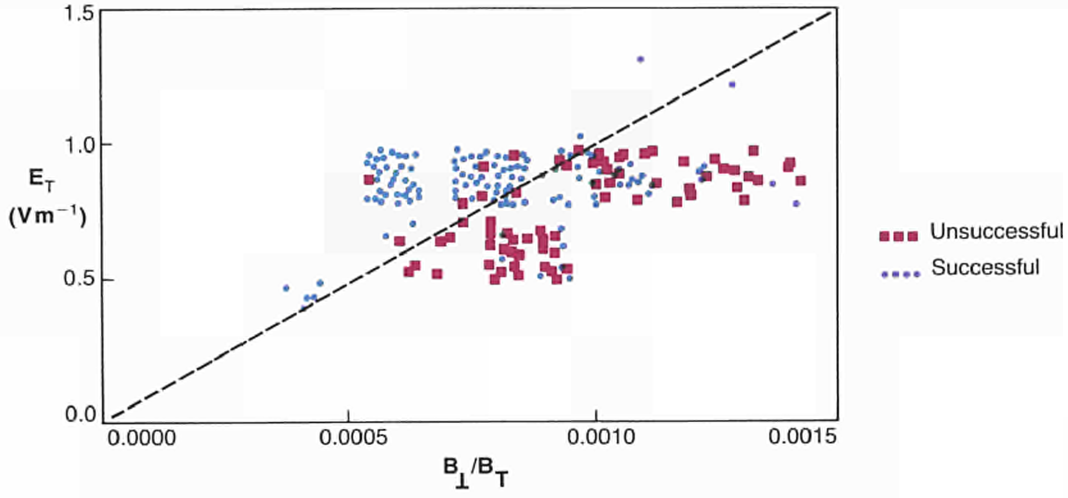

Fig. 15 Success and failure to sustain breakdown as indicated in the E_T versus $B_\perp/B_T$ plane.
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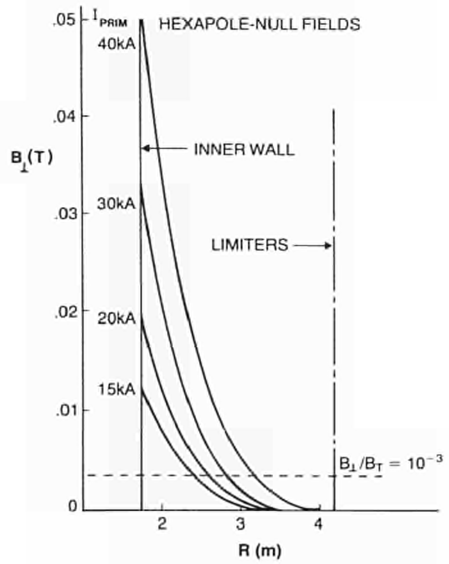

Fig. 16 Stray field distribution in the midplane for various values of premagnetisation current as predicted by the Blum-code.
CR86.112

In JET, as in other tokamaks, the chance of a successful breakdown is increased with decreasing B_{stray}/B_T and increasing E_T/P_{fill}. This is illustrated in Fig. 15

Stray fields increase non-linearly with the premagnetisation current as the iron transformer becomes progressively more 'leaky' as shown in Fig. 16. An example of the total field in shown in Fig. 17. This means that increasingly greater electric fields must be applied if the levels of premagnetisation, needed to produce higher flat-top plasma currents of longer duration, are to be obtained. At the full design value of 20MA turns for the premagnetisation current in the primary winding, the electric field required is so high, that when an avalanche occurs and develops into a plasma, the toroidal current I_p increases too rapidly. This results in extreme skin currents being produced and positional control problems. So far, reliable breakdown has only been possible up to 12MA turns. Hardware changes are necessary if the full 20MA turns are to be made available. Agreement has been reached for the provision of voltage reduction switches, which will lower the electric field immediately after breakdown has occurred (eg ~ 50ms) from the start. Without these switches it is impossible to obtain voltage reduction prior to 400ms after breakdown. Installation of the switches is planned to take placed in 1987.

The stray fields can be reduced at high premagnetisation by manipulating the current distribution along the length of the primary winding. Until now, the distribution has been homogeneous and discussions are underway for the provision of the extra busbars that would be needed to provide this facility.

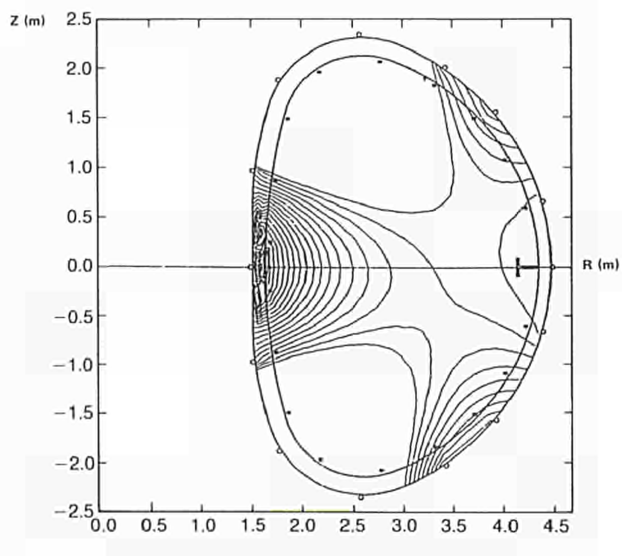

Fig. 17 The measured field distribution at 50ms indicating the primarily hextapolar field geometry.
CR86.113

Skin Currents and their Effects

The behaviour of current flowing in a plasma can be very different from that in a normal conductor. During a current ramp a *skin current* is formed but the redistribution to a homogeneous profile, occurring in a normal conductor, is made more complex and is highly nonlinear due to plasma transport and instabilities.

The formation of a skin current leads to off-axis heating and a rise in temperature in the outer regions of the plasma. As the conductivity of the plasma increases with temperature this produces a larger skin current and longer relaxation time.

Further complications arise because plasmas with hollow current distribution, resulting from the skin effect, are prone to tearing mode instabilities. These instabilities result in the redistribution of the current inwards, producing an anomalously fast skin relaxation time. Observations show an increase in the skin effect and relaxation time, due to off-axis heating, with increasing ramp rate. However, above a certain threshold anomalously short relaxation times are produced with a strong increase in magnetic activity. The threshold between classical and anomalous current penetration in JET lies at about $1\,MA\,s^{-1}$ with constant aperture and B_T.

This means that, with the full design value of 5MA plasma current, at least five seconds of pulse time are needed to avoid instabilities during current ramp-up. At faster ramp rates the instabilities resulting from the anomalous penetration cause an increase in the level of impurities. This effect, however, can be kept to acceptable levels if metal impurities can be avoided.

A second effect produced by the faster ramp rate is that the plasma locks itself in a state of continuous instability, even during the subsequent flat-top period. This leads to an increased chance of a disruption occurring at very low density levels, both in the early part of the flat-top and at the start of additional heating.

Two ways of increasing the critical ramp rate of $1\,MA.s^{-1}$ have been studied with some success:

1. Ramping the toroidal field together with the current enhances the classical penetration
2. Expanding the aperture of the plasma in conjunction with the current so that the average current density remains constant.

Using these methods, the critical ramp-rate has been increased to $2\,MA\,s^{-1}$ and further studies of skin current relaxation will be carried out.

Plasma Boundary Phenomena

Plasma boundary phenomena are studied to gain an understanding of the mechanisms causing the release of impurities from the wall and limiters and their subsequent penetration into the plasma. The recycling of hydrogen and deuterium and wall pumping are also of interest because of the need to control the plasma density and for estimating the inventory of hydrogen isotopes for deuterium-tritium operation.

Three Charged Coupled Detector (CCD) cameras with 900mm filters have been used to observe two RF antennae and one limiter. The recorded images are built up from two components; one part is the intensity due to thermal radiation and the other from line radiation from hydrocarbons and molecular hydrogen. The images can be quantitatively analysed and the two components separated. The footprint produced by the plasma on the limiter can be fully explained and is used to measure the thickness of the scrape-off layer. Measurement of the heat flux on the limiters has been impossible because a substantial amount of power is taken by the RF antennae and the lower camera threshold of 650^0C was not generally exceeded. Consequently, it has not been possible to make a detailed power balance. A second camera, working in the 3 to $5\,\mu m$ range and with a lower temperature threshold and greater dynamic range, is in an advanced state of preparation but full commissioning has not been completed.

Measurement of plasma parameters, from the probes and surface analysis of impurity coverage, have been successfully used in computer models to describe the sputtering processes on the limiter. The calculated impurity influxes are similar to those obtained from spectroscopic observations. An analytical transport model has been used with the same data to calculate the average impurity concentrations from the influxes and these seem to be in broad agreement with vacuum ultraviolet measurements.

Two vertical probe systems have been used to give direct access to the plasma boundary. One system has been used throughout the year to take measurements of plasma parameters and to expose samples of clean material to the impurities and heat fluxes at the boundary. The second system has been installed but not commissioned and will be used for exposing a rotating collector probe to the impurity fluxes.

Surface analysis of samples from the limiters and carbon tiles removed from the torus during shutdown have revealed that the limiters responsible for the influx of impurities are covered by wall material. The spatial distribution of the material on the limiter corresponds to the plasma footprint during the flat top of the discharge. The limiter surfaces are gradually cleaned as material from the centre is eroded by sputtering and redeposited at the edges. Analysis of small samples of carbon and wall material attached to the inside of the vessel has shown that material is eroded from the inner half of the vessel and not from the vicinity of the limiters and RF antennae. A 2m band of graphite tiles on the inner wall of the vessel prevents direct wall erosion in this area. However, about $0.5\,\mu m$ seems to have been eroded from the region immediately above and below these tiles. Surface analysis of different materials and samples has shown a very high deuterium content in the vessel walls, typically of 10^{23} atoms$\,m^{-3}$ and about 10^{24} atoms$\,m^{-3}$ in the graphite tiles. This inventory is nearly all trapped in the carbon layers deposited during tokamak discharges and carbonisation.

The carbonisation programme during 1985 was developed with the aid of qualitative samples introduced into the torus through the air lock of the vertical probe system. Some of the results obtained are shown in Fig. 18. Early attempts at carbonisation did not give significant layers of carbon, but by increasing the methane content to 17%, coatings of good quality were obtained.

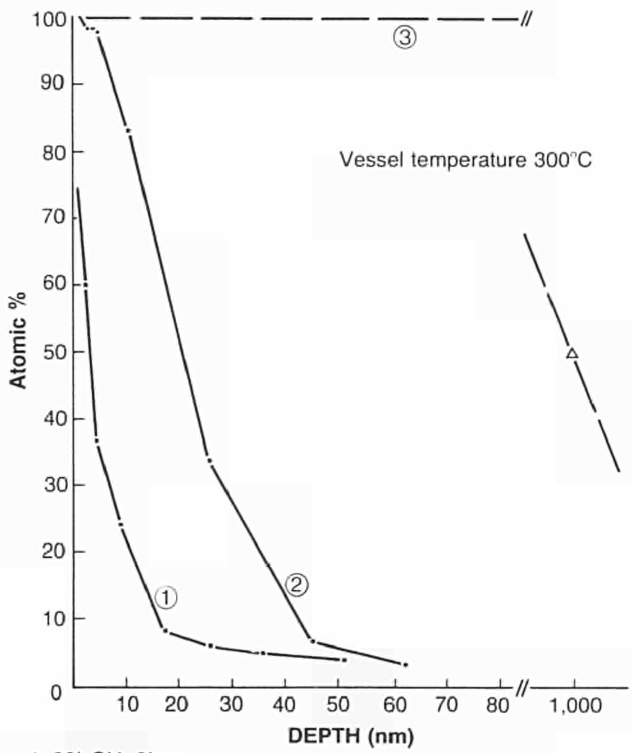

Fig. 18 Thickness of carbon layers deposited during carbonisation.
CR86.114

Control of Plasma Current, Position and Shape

The two previously-planned enhancements of the plasma control system, those for feedback control of the plasma current and vertical diameter (shape), were brought into operation in 1985.

The feedback control for the plasma current, which has a relatively long response time of about 0.5s with a control error usually below 5%, is backed up by a pre-programmed contribution to the excitation voltage of the poloidal flywheel generator. To avoid excessive currents in the central poloidal field coil, in the event of disruptive plasma behaviour, the feedback and pre-programmed voltages are set to zero whenever the plasma current error exceeds preset limits or if a fault is detected by the plasma fault protection system.

Although the plasma current feedback controller has not been optimised for the change in poloidal field configuration, which took place early in 1985, satisfactory control has been achieved by making slight modifications to the pre-programmed reference current waveforms.

The feedback control system for shaping the plasma operates on the same principle as the radial position feedback system. The current in a pair of shaping coils is determined by feedback from the measured poloidal magnetic flux difference between the limiter and two symmetric and continuously adjustable reference positions in the upper and lower halves of the vessel. With zero control error the limiter magnetic surface (plasma boundary) passes through these positions. Using this method, the vertical plasma diameter can be controlled and, in conjunction with the feedback control of the radial position (or radial diameter), the elongation ratio of the plasma cross-section can also be controlled. This system has been working satisfactorily but the range over which the elongation ratio can be controlled is limited by the choice of turns on the poloidal field coil and the connections that have been used. If the turns ratio in the shaping coil is chosen incorrectly, mutual interaction with the radial position feedback can cause oscillations in both systems which also restricts the operating range.

By using the shape control, it is possible to produce elongated plasmas with a ratio $b/a \sim 1.8$ and also an internal separatrix with X-points close to the top and bottom of the vessel walls.

Simplified models have been used to study the current, radial position and shape feedback control systems together with interactions occurring between them. Agreement with experimental tests is reasonable and an improvement seems possible when more detailed information becomes available on certain system parameters.

Detailed investigations have been made on the performance of the system for stabilising the vertical plasma position as well as the effects of simulated failures. The voltage range and the response speed of the poloidal radial field power amplifier have been increased and the vertical position of the plasma can now be stabilised with elongation ratios exceeding $b/a = 1.8$.

When the stabilisation is disabled during a pulse the vertical position of the plasma becomes unstable with a growth rate in the range $\gamma = 50$ to $150 s^{-1}$, depending on plasma elongation. Tests have been carried out to establish safe operating limits to safeguard against excessive vertical forces and stresses on the vessel. Despite the installation of additional radial supports on the large vertical ports of the vessel, it was decided that operations must be limited to a maximum elongation ratio of 1.4 as the current is raised to 5MA. Additional vertical vessel supports are being designed to allow safe operation with larger elongation ratios at higher currents.

RF Heating Topic

RF heating operations in JET started in February 1985 using two prototype antennae installed in the torus. Each antenna was connected to a generator with a peak power of 3MW. The two antennae, located in diametrically opposed octants, had different inner conductor configurations to enable an assessment to be made of the effect of exciting shorter wavelengths in the toroidal direction. Initial operations until June were devoted to testing the RF system, checking its power capability with plasma present, measuring the coupling resistance of the antennae, comparing the relative merits of the two types of excitation, monopole or quádrupole, and starting the characterisation of energy confinement with additional heating. Operations resumed in November after the installation, during the summer shutdown, of a third antenna close to the existing one in octant two.

Most experiments were performed with the operating frequency adjusted to that of the resonance of the minority ions close to the centre of the plasma. An increase in sawtooth activity of the plasma was observed with a modulation of the peak electron temperature of up to 2keV, reflecting peaking of the power deposition profile. However, an increase in the volume averaged electron temperature is observed only when the RF power exceeds twice the ohmic power.

Modulation of the central ion temperature was also observed, but in contrast to the electron temperature the minimum value at the sawtooth relaxation was significantly above the value without RF heating. On average the central ion temperature increased by between 1.5 and 2keV, bringing the ion and electron temperatures close together at peak values. This is illustrated in Fig. 19 which shows the effect of a 5MW radio frequency square pulse lasting for 2 seconds on a 3.5MA discharge.

Because of the small increase in the volume average electron temperature, the global energy confinement time decreases, despite a significant increase in the electron density of up to 30%. This degradation seems to follow a very similar trend to that observed on other Ion Cyclotron Range of Frequency (ICRF) heated tokamaks, with a saturation occurring at the highest RF power yet achieved.

The impurity influx resulting from the RF heating has not proved to be a problem on JET. The relative importance in the power balance of the power radiated by impurities and the value of Z_{eff} were not significantly increased above the ohmic heating levels. However, Z_{eff} was higher than in an ohmically heated plasma with the same electron and current densities.

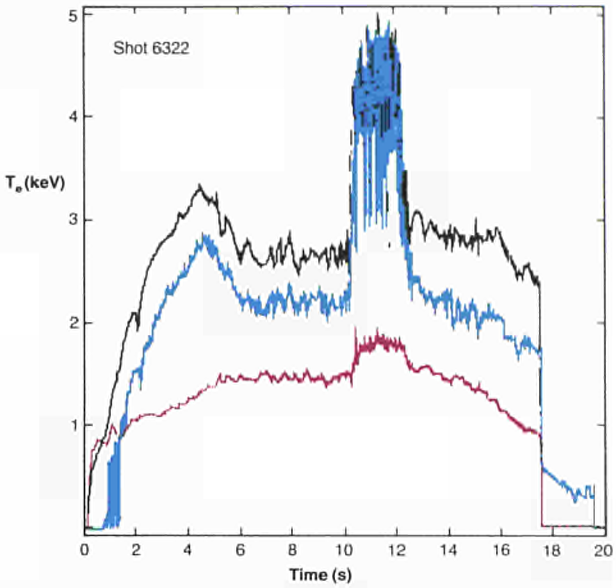

Fig. 19 Time evaluation of the peak (black curve) and volume averaged (red curve) electron temperature and of the peak ion temperature (blue curve). The 6MW ICRF pulse was applied between t=10.2s and 12.2s.

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The expected differences in coupling resistance between the various types of antennae excitation was observed. But their heating efficiency, in terms of the increase in plasma energy for each megawatt of RF power, is very similar at around $0.2-0.3\,MJ\ MW^{-1}$. It was shown, however, that the quadrupole configuration did not induce such large sawteeth as that of the monopole/dipole.

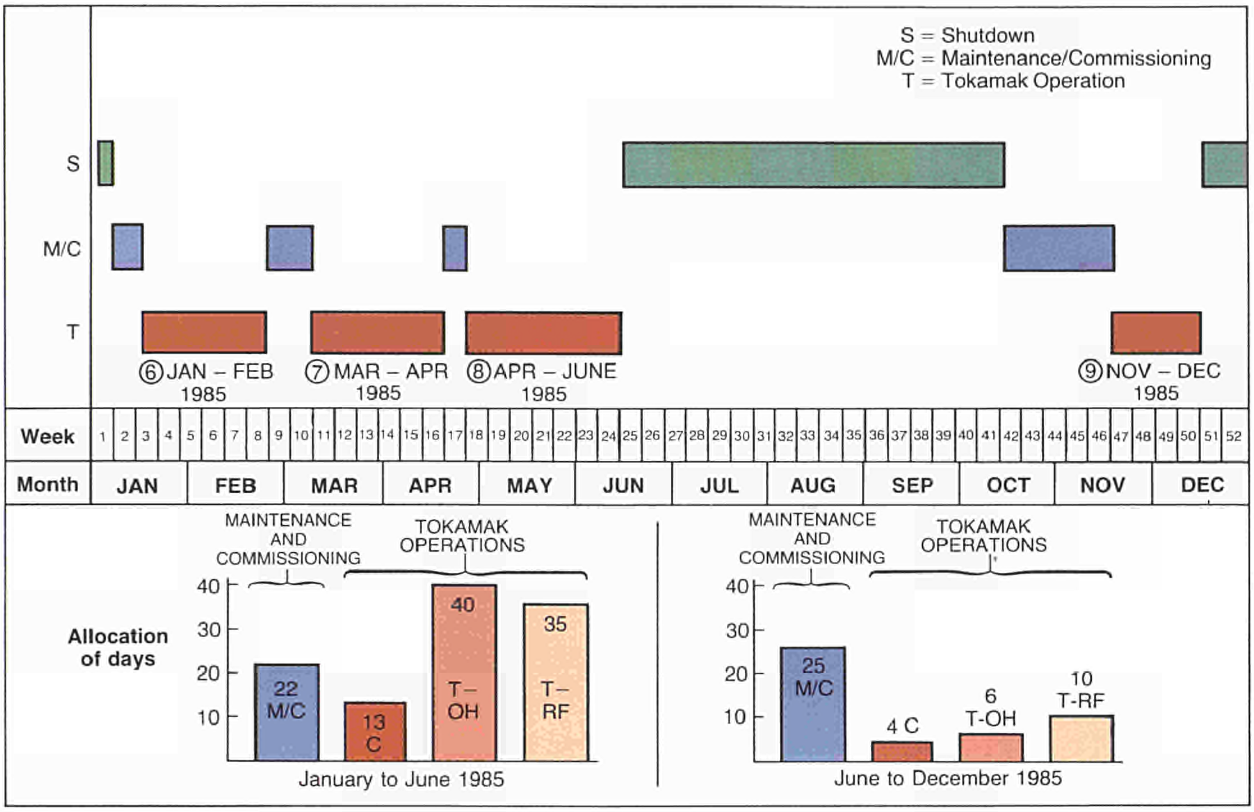
A preliminary comparison between the heating efficiency of ^3He and H minority species has not shown any significant difference.

Organisation of JET Operations

In 1985, the JET operations programme consisted of 22.5 weeks of tokamak operations and 9.5 weeks devoted to maintenance and commissioning. The remaining period, classified as shutdown, was used for the repair and maintenance of existing equipment and installation of new equipment, see Fig.20. For comparison in 1984 there were 17 weeks of tokamak operation.

Shutdown

A considerable amount of equipment was installed onto the machine during the summer shutdown period from weeks 25 to 41. The number of carbon limiters was increased from four to eight and the four nickel limiters were removed. Extra graphite tiles were added to cover completely the eight octant joints. A third RF antenna



was installed and the separation between all of the antennae and their screen protections was increased. The other major activities completed during the shutdown were the final preparations for the neutral injection system on octant eight and the large scale installation of cable trays and cable re-routing in the basement.

At the end of the year, operations were stopped one week earlier than planned to allow remedial work to be carried out on the rotary valve and neutral injection box at octant eight.

Commissioning

Commissioning periods were used for the integration of newly installed equipment and for testing more advanced control programs for systems such as plasma current feedback, plasma shape, plasma position and stabilisation, plasma fault protection and plasma density feedback.

Full design performance of the toroidal field system was achieved with a coil current of 67kA lasting for 11.5s corresponding to an energy dissipation in the coils of 5.4GJ. The poloidal field circuit was operated with premagnetisation currents of 30kA and 40kA but satisfactory control of the plasma at these levels has not been accomplished.

By the end of the year, three RF heating antennae had been operated together. The neutral beam injector box at octant eight was commissioned and 45keV beams of hydrogen fired into the blocking calorimeter in preparation for full-scale heating experiments in 1986. The Central Interlock and Safety System (CISS) was modified and recommissioned as a result of a review of the protection for machine systems.

Operations Programme

Tokamak operations were subdivided into ohmic heating (OH) and RF heating programmes. About the same number of days were devoted to each of these programmes. (46 for OH and 45 for RF). Operations with a 4MA plasma current with a flat top lasting for 4s became routine during the year and a maximum plasma current of 5MA was achieved in June.

Operations Organisation

The internal reorganisation of the project team in October 1985 led to modifications in the operating procedures, Fig. 21. Operational duties were decentralised, with the disbanding of the Torus Division, and redistributed across the new departments.

Shift working was introduced in 1985 for operating periods with the shutdown and commissioning periods based on a normal working day, although these frequently involved extended working hours. The number of staff involved in shift operations in 1985 is shown in Table 5.

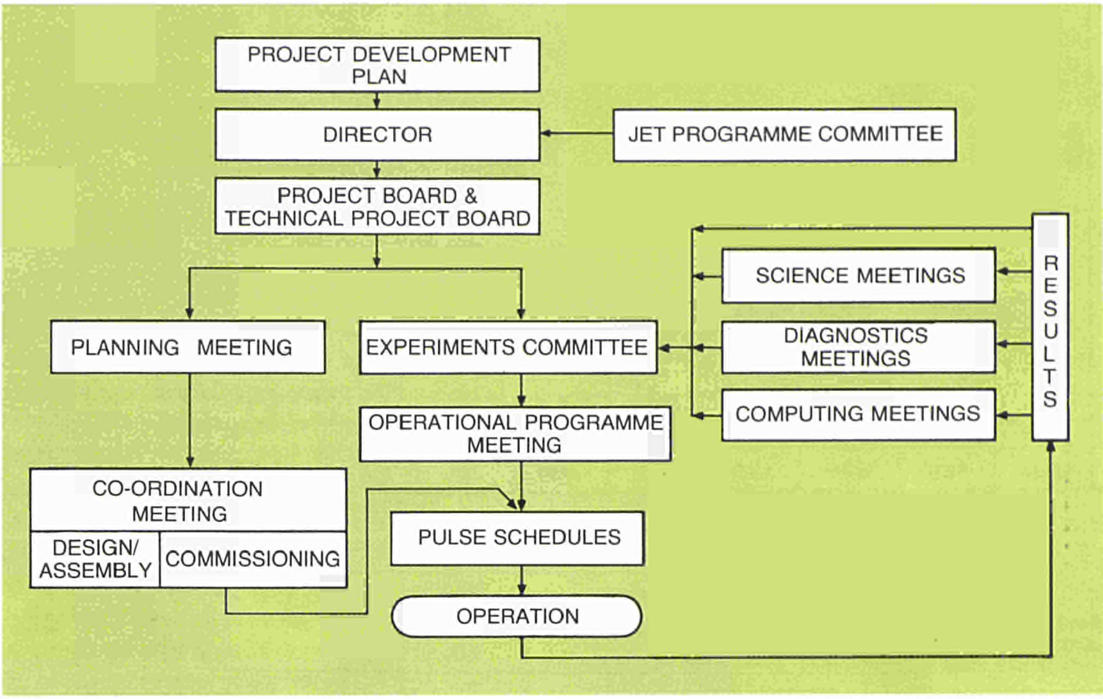


Fig. 21 Establishment of the JET operations programme (October 1985 onwards).
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Tokamak operating weeks were scheduled as follows:

- **Monday** — machine commissioning, culminating in full tokamak operation in preparation for the week's experimental programme.
- **Tuesday to Friday** — tokamak operation with:
  early shift - 06.30 to 14.30
  late shift - 14.30 to 22.30

Tuesday and Wednesday were allocated to one experimental programme with Thursday and Friday allocated to another. Nights were primarily used for emergency remedial work to avoid interference with existing operational systems. However, a significant amount of installation, maintenance and commissioning work was carried out overnight as well as at the allocated weekends.

Table 5
Number of Staff Involved in Two Shift Operations

	On Duty		On Call
	In J2 Contol Rooms	In Other Areas	
Senior Duties			
Engineer in Charge	2	—	—
Physicist in Charge	2	—	—
Session Leader	2	—	—
Rostered Duties			
Torus Operation Group	6	2	—
Vacuum System Group	—	—	2
Power Distribution Group		2	
Poloidal and Toroidal Group			
Advanced Power Supplies Systems and Operation Group	4	—	1
Additional Heating Group		—	
Computer Group		6	—
Control Group	4	—	—
Diagnostics Data Acquisition Group		—	—
Electronics and Instrumentation Group		4	—
RF Heating (note 1)	4	1	—
Experimental Division 1 (note 2)	7	—	—
Experimental Division 2 (note 2)	5	1	—
Theory Division	2	—	—
Physics Operation Group	2	—	—
Radiological Protection and Occupational Hygiene	—	—	1

Note 1: RF Programme days only
Note 2: The numbers depend on the experimental programme

Throughout the year, operating procedures improved with over 12 hours of the 16 hour double shift becoming available for the experimental programme. The remaining time was taken up by energisation and isolation of the power supplies and a half-hour meal break per shift. During the year, the total number of tokamak discharges exceeded the total number of commissioning pulses since the start of operations in June 1983, this is shown in Fig. 22. In 1985, there were 2343 tokamak pulses compared with 1142 from mid 1983 to the end of 1984. The number of commissioning pulses dropped from 2048 to 789 for the same periods.

Operations Support

The team of shift technicians was bought up to the full complement of twelve. This team participates in machine operation and monitors the state of JET systems in non-operational periods. More shift technicians received training in all operational areas during 1985 to ensure the effective operation of the shift system. On-duty training was supplemented by a course held during the summer at Harwell. As in 1984, each of the technicians spent time with specialist groups within the Project to become more fully informed about the operating systems.

New operating documentation was prepared and existing information updated for the description and operation manuals and emergency procedures. The personnel safety and access control system was extended and the door entry system to the torus hall became operational towards the end of the year. Modifications were made during the year to the fire detection, alarm and suppression system so that the operational areas (torus hall and basement) became fully protected, with a gas flood system for fire suppression installed in the basement.

Future Programme

Three different programmes, ohmic heating, RF heating and neutral beam injection heating have been included in the initial plans for 1986. There is a continuing requirement for modifications to be made to operating procedures so that further increases in operating time can be realised. As in previous years, it will be essential to improve the reliability of all operation systems.

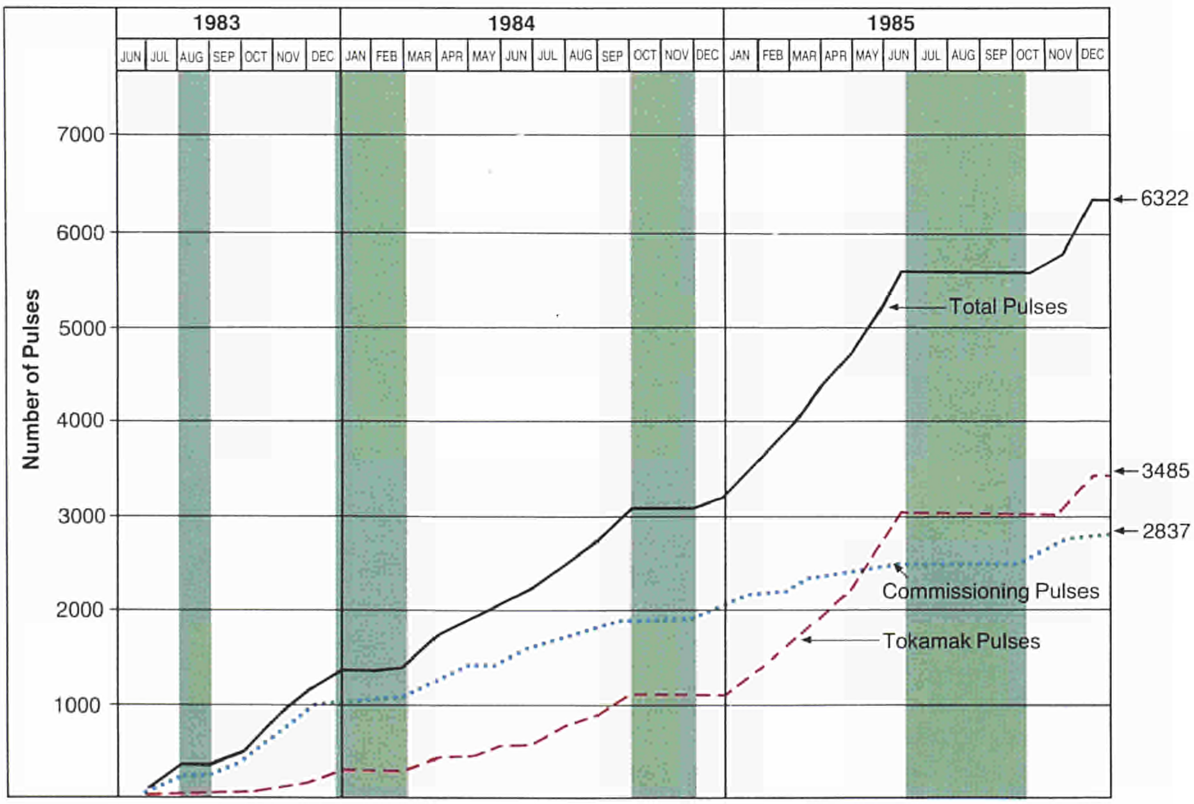

Fig. 22 Cumulative total of JET pulses.
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Summary of Technical Achievements in 1985

During 1985, machine operation with ohmic heating was further consolidated and the first operations were carried out with additional heating. Two more of the main design parameters for the machine were reached. A plasma current of 5MA was achieved compared with the design value of 4.8MA and 5.5MJ of energy was applied to the toroidal field coils at a magnetic field of 3.45T.

Some of the technical changes and achievements that occurred during 1985 are highlighted below.

Several measures were taken to improve the control of the plasma shape and position and to prevent the occurrence of damaging disruptions. These were:

1. Supports were fitted to the vacuum vessel to restrict its movement.
2. A new shaping circuit was formed which included part of the number two and three outer poloidal field coils.
3. The speed of response of the poloidal vertical field amplifier was increased.

A detailed mechanical analysis of the vacuum vessel was carried out to enable a second generation of vessel supports to be designed to link the vertical ports of the vessel to the limbs of the magnetic circuit. Preparations are continuing for the procurement of these supports.

The supply to the primary winding was changed from a parallel to series connection so that the rate of current rise during plasma start-up could be limited. Although some improvement was obtained, successful operation at full premagnetisation was still not possible. On investigation, it was concluded that stray fields from the saturated ion core are responsible and a number of remedies are being prepared, including:

1. Modification and re-configuration of the primary winding.
2. Redistribution of the outer poloidal field coils with windings operated by separate amplifiers.
3. Switching of resistors in the primary winding circuit during ramp-up.

These modifications all fall in line with the enhancement of the shaping capability as well as enabling X-point pulses to be carried out with plasma currents in excess of the 1.5MA already achieved. An order for new poloidal vertical field amplifiers (numbers 5 and 6) has been placed for this purpose.

The switching station for power drawn from the 400kV grid has been increased to its final size and a third 400/33kV step-down transformer of 300MVA has been installed to expand JET's basic power capability.

The door entry system of the Personnel Safety Access System at the entrance to the torus hall and basement has been brought into operation as well as the fire protection system using halon gas flooding.

Early in 1985, the Inconel plates damaged by the plasma were replaced by a 2m high inboard wall protection collar of graphite tiles. This, together with the removal of metal deposits from the four carbon limiters, initially resulted in metal-free discharges. However, the metal contamination gradually returned with continuing machine operation. After six months of operation, the machine was opened and no damage was found on the carbon tiles even though they had been used with discharges similar to those that had damaged the Inconel plates.

The inboard protection has been increased by installing eight rings of carbon tiles over the joints between the vessel octants and additional tiles to cover the Inconel bellow protection plates have been ordered for installation in 1987. Graphite tiles have also been installed on octant five where the neutral beam is expected to penetrate through the plasma.

Four more graphite limiters have been installed and all limiters have been fitted with a frame of carbon tiles to prevent the plasma flowing behind them onto the metal supports, Procurement of the belt limiter, which has been designed to cope with 40MW of power, has continued satisfactorily, especially the manufacture of the cooling structure and fins for the radiative heat transfer from the limiter tiles. The design of evaporators to coat the vessel walls with beryllium was almost complete by the end of 1985.

Additional heating was started with ion cyclotron resonance heating and by the end of the year, three uncooled antennae (Ao) were operational. The antennae had different configurations and were each coupled to a transmitter with an output power of 3MW. By operating the three antennae simultaneously, a maximum of 6MW of RF power has been coupled

to the plasma and 15 MJ of energy deposited into it. The coupling properties were roughly as expected and no particular impurity problems have been encountered.
The cause of frequent high-voltage breakdown in the RF transmission lines has been identified and remedial action has been taken. Because of the excellent performance of the prototype RF system, plans have been modified to procure eight transmitters upgraded to 4 MW rather than the ten originally envisaged. Each unit will be coupled to a water-cooled antennae (A1) installed between the two toroidal belt limiters and fitted with a frame of either graphite or beryllium tiles as protection. These systems will be installed during the shutdown in 1987. The RF power supplies commissioned during 1985 at 300 A will be upgraded to 400 A.

The eight sources for the first neutral beam injection system have been modified to produce an improved species mix, well in excess of 80% of atomic ions with both hydrogen and deuterium, and to correct the ion optics. These beam sources have been commissioned on the neutral injector box, without the central support column, and delivered simultaneously 80 kV, 37 A hydrogen beams for 0.5 s, this was limited only by the capability of the provisional beam dump. Meanwhile, the central support column was tested in the neutral injector testbed by injecting a mixed beam of ions and neutral particles from one beam source through one quadrant of the deflecting magnet with around 2000 hydrogen and deuterium pulses in the range from 40 to 80 kV for up to 10 seconds. Calorimetric measurements revealed that, despite very sound operational properties, two unexpected phenomena limit the performance of the integrated system: the line density of the neutraliser gas is lower by a factor of two compared to the value measured in the absence of a beam and at 80 kV the beam profile of the full energy ion fraction is considerably wider and peaked in the apex of the dump. During the summer shutdown, the central support column was installed in the neutral beam injector box at octant eight and the beam sources were recommissioned to operate simultaneously in hydrogen at 60 kV for up to 10 seconds. Damage to a seal on the rotary valve between the injector box and the torus prevented injection into the plasma before the end of the year. The liquid helium refrigerator came into operation during the year and is now operated routinely in conjunction with the cryopump system in the neutral injection box. In the testbed, the high-voltage and auxiliary power supply were modified and successfully tested on a dummy load in preparation for the 160 kV beam source tests with deuterium.

Design and testing of prototype components for the tritium plant continued in preparation for the active phase of JET. The acquisition of transporters and end effectors with their respective controls for the various remote handling tasks have made good progress. Successful demonstrations, such as the use of the articulated boom in the removal of the nickel limiters and the installation of the Ao antennae, provided confidence that difficult remote handling operations can be handled. The design of a telescopic arm to be attached to the 150 tonne crane for work around the outside of the torus is still continuing.

Vacuum Systems

Vacuum Vessel and Pumping Systems

At the beginning of 1985, the vacuum system had to be re-commissioned following the shutdown period at the end of 1984. When vacuum was first re-established some difficulties were experienced with leak detection because of the high background pressure of helium gas desorbing from the newly installed graphite tiles. The graphite tiles are in fact saturated with helium before installation in the machine, to avoid the contamination of the plasma by atmospheric gases. Baking the vessel for a week at temperatures at about 300°C reduced the helium pressure down to a level where leak detection became possible again.

This kind of difficulty and also the increasing use in JET of deuterium as a working gas (helium and deuterium both have a molecular mass of 4 and cannot be separated by conventional mass spectrometers) prompted the design and installation of a new global leak detection system based on the detection of the atmospheric argon. The new system was operated successfully and gave indications of a global leak rate of the vacuum system in the range of 2×10^{-5} mbar ls^{-1}.

In spite of its ever increasing complexity, the operation of the vacuum system was remarkably trouble free during the operational period from January to June 1985.

From July 1985 the machine was shutdown and new systems were connected to the torus. The second neutral beam injector box was connected to the port at octant four through its dedicated high vacuum rotary valve. A third RF antenna was connected at octant two.

During the recommissioning which followed, the high vacuum rotary valve at octant eight was damaged and could no longer be brought into the fully open position, thus making it impossible to start neutral beam heating experiments. The valve was replaced by the spare unit shortly before Christmas. The inspection of the faulty valve revealed that the seal was distorted and had jammed the movement of the rotor. The damage was thought to be caused by differential expansion of the seal with respect to the rotor. Minor design changes were being envisaged to avoid the repetition of this fault.

Bake-out System

The baking plant circulates a hot gas through the interspace of the double wall structure of the vacuum vessel. This process outgases the walls and enables high vacuum conditions to be achieved. The plant was operated continuously and reliably with the new single stage radial turbo compressor. Improvements made to the heat exchanger considerably reduced thermal leaks and increased the working efficiency of the heat exchanger. The process gas used for 1985 was still nitrogen, but operation with helium gas is planned in 1986.

First Wall

Gas Introduction and Glow Discharge

The gas introduction system provides the gas (hydrogen or deuterium) required to initiate the discharge and achieve the desired plasma density. The gas system is now well established and requires only minor improvements. A notable modification, which eased operation considerably, was the introduction of an automatic setting of the gas pressure in the reservoirs which feed the gas to the torus valves. Pressure sensors together with buffer volumes were also installed close to the torus to provide a precise gas flow measurement during the discharge. This measurement is important to assess the behaviour of the vessel walls with regard to transient particle pumping.

The glow discharge system reached its final configuration with four RF assisted electrodes. The electrodes were water cooled for the first time. Glow discharges, in hydrogen, deuterium or with methane mixtures for the carbonisation of the walls, became routine procedure in 1985.

Inner Wall Protection

The contamination of the plasma by wall material enhances radiative power losses from the plasma. To minimize this effect the walls facing the plasma need to be covered with material of low atomic number. In JET, it was decided to cover the inboard side of the vessel with graphite tiles because it was here that the greatest plasma wall interaction and extensive wall damage had been observed. The tiles were installed in November 1984.

In January 1985, the machine was operated for the first time with the graphite protection tiles. This was the first step in a long term programme aimed at having only materials of low atomic number facing the plasma. When the vessel was reopened in July 1985, after six months of plasma operation, virtually no damage could be seen on the graphite tiles. Only minor signs of erosion were observed in areas where, for geometrical reasons, the edges of the tiles were projecting slightly towards the plasma. This was in contrast to the serious damage observed on the Inconel protection plates at the end of the 1984 operational period even though in 1985 the number of disruptions and the dose of photo-neutrons, which is a measure of the energy deposited onto the inboard wall by run-away electrons, was comparable to that observed in 1984.

In August 1985, additional graphite protections were installed to reduce further the contamination of the plasma by metals. The inboard protection was extended by eight discrete poloidal rings covering the octant joints, Fig. 23. Each graphite limiter was fitted with a

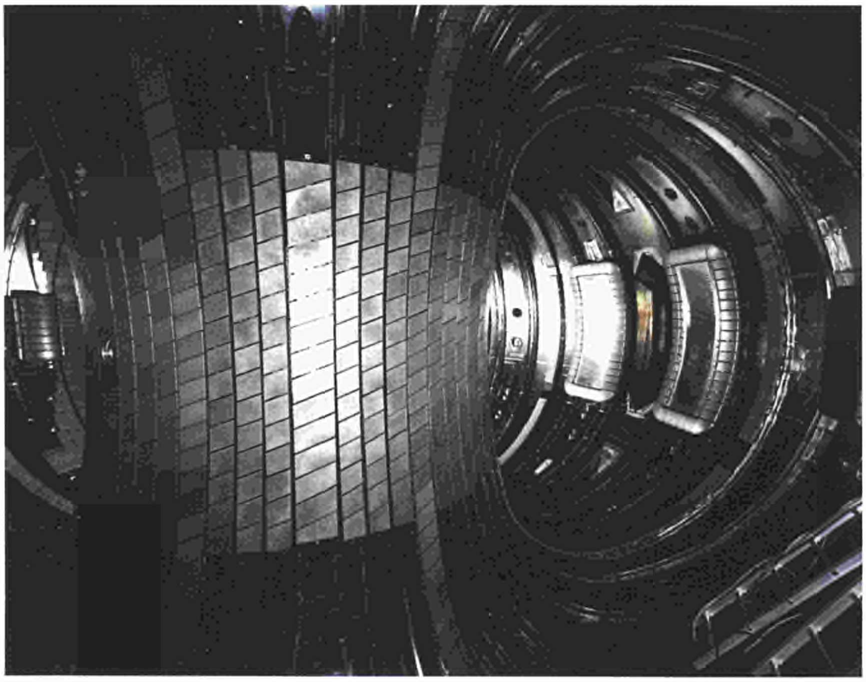

Fig. 23 Interior of the JET vacuum vessel showing the graphite tiles at the inboard wall and at the octant joints.
85.1650c

frame of graphite tiles to prevent the plasma from flowing behind the limiter towards the Inconel support structure.

The design of the tiles for protecting the graphite bellows was completed and procurement contracts placed with installation planned for early 1987. Protection is also required where the neutral beams impinge on the wall of the vessel. In July 1985, graphite tiles were installed on the outer wall of the vessel interior, in the vicinity of the port at octant five, to protect the Inconel walls against tangential beams, Fig. 24. Under normal operating procedures the most severe conditions occur at the inboard wall where the power deposition due to neutral beams shining through the plasma could reach $500\,W\,cm^{-2}$. In an abnormal situation i.e. if the safety systems were unable to switch off the beams in the absence of plasma, then the power deposition could reach $2\,kW\,cm^{-2}$. A series of tests carried out in 1985 showed that graphite tiles crack when the power deposition exceeds 1 to $1.5\,kW\,cm^{-2}$ for more than a few seconds. The testing of alternative materials, i.e. graphite-fibre reinforced graphite, is planned for 1986. This new material, if found satisfactory, could be used in areas where the incident neutral beam power exceeds $1\,kW\,cm^{-2}$.

Discrete Limiters

For the operation from January to June, four discrete graphite limiters were used on JET. The surface of the limiter tiles had been cleaned from metallic contamination prior to the restart of operation in January. This condition, together with the presence of newly- installed tiles at the inner wall resulted in metal free plasma discharges early in 1985. However, after a few weeks of operation, the metallic contamination already observed in 1984, gradually came back. The cause of this contamination, whether due to sputtering during glow discharge cleaning, plasma discharges or metals evaporated from the walls during vertical plasma instabilities, was not clear. Nevertheless the good results obtained initially were an encouragement to pursue further the policy of covering the walls with materials of low atomic number.

In July 1985, four additional limiters were installed bringing the total number of graphite limiters to eight and increasing the limiter area facing the plasma to $2.56\,m^2$. It is clear from the experience acquired with this sort of limiter that eight of them would cope with the power levels expected in 1986. The total power injected into the plasma may reach 20MW but a substantial fraction ($\simeq 50\%$) of this power is expected to be radiated to the walls.

The nickel-clad limiters were removed from the machine in July 1985. These were water-cooled and designed to withstand long pulses at high power loads but it was decided to remove them as they represented a potential source of metallic contamination.

Fig. 24 Neutral beam protection at octant five.
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Belt Limiter

The belt limiter is designed to withstand 10s long discharges with a total power input to the plasma of 40MW. The belt limiter consists of two toroidal rings, above and below the main horizontal ports of the vessel, with the RF antennae placed between the two rings and protected by them. Each ring includes a structure of water cooling pipes with cooling fins welded to them. The limiter tiles made of graphite or beryllium are inserted between the fins and thus cooled by radiation.

Discussions on the material to be used for the tiles of the belt limiter resulted in the selection of graphite and beryllium. Beryllium was considered superior to graphite from the point of view of plasma operation because of its low atomic number and oxygen gettering properties. However, the toxicity of the beryllium dust would somewhat complicate future in-vessel maintenance. It was decided to proceed with the procurement of both beryllium and graphite tiles and contracts were placed for these in 1985. In the case of beryllium tiles, full scale prototype pieces were manufactured to assess the production problems, characterize the final product and select the least expensive manufacturing processes. It was found that the cost of beryllium tiles could be reduced by using half the number of tiles and doubling the thickness of each tile. This modification has been adopted and the design of the cooling structure changed accordingly.

The contract for the manufacture of the cooling structure progressed satisfactorily in 1985 with the production and testing of the prototype sector, Fig. 25, At the end of 1985, the start of the series production was held up by minor changes in the method of attachment of the belt limiter to the walls of the vessel.

Good progress has also been achieved for blackening the fins of the cooling structure, which is required to increase the radiative heat transfer. All parameters of the plasma spraying process were selected and by the end of 1985, most production fins had been blackened and were ready for final welding to the cooling structure.

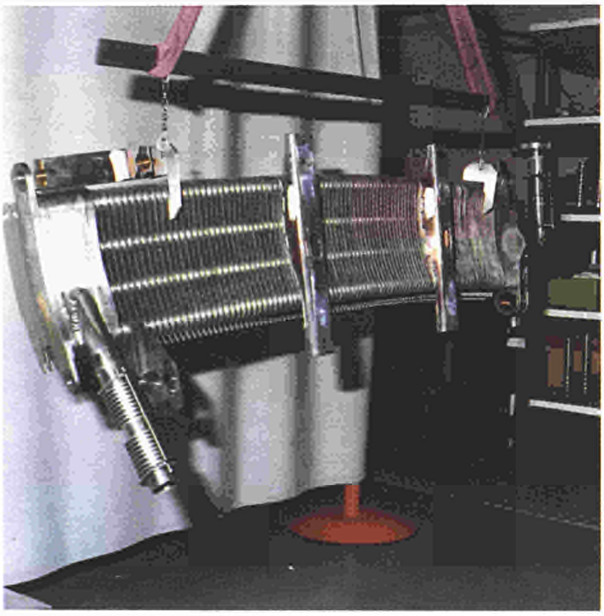

Fig. 25 Prototype sector of the cooling structure of the belt limiters.
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First Wall Developments

It is planned to install four beryllium evaporators in the machine for coating the Inconel walls and graphite tiles with a thin layer of beryllium. This evaporator scheme, if used in conjunction with the beryllium tiles of the belt limiter, will provide JET with material of low atomic number for both walls and limiters. The design of the evaporators was nearly complete in 1985 and procurement is planned for 1986. Some work was also initiated during 1985 in the area of density control.

Four small probes were introduced into the machine in July 1985. One probe will function as a small scoop limiter while the others were fitted with palladium membranes to assess transient particle pumping.

Multi–Pellet Injection for Fuelling and Refuelling

The potential advantages of fuelling by injecting frozen hydrogen or deuterium pellets deep into the plasma has become apparent from a number of experiments in other laboratories. JET has decided to explore the fuelling and refuelling of the plasma core in a systematic way. A collaboration has been agreed with the US Department of Energy for the temporary use (1987 to 1989) of a three–barrel repetitive launcher. This launcher will produce multiple pellets of equal length with a range of diameters from 2.7 to 6mm. The pellet velocities will be about $1500 ms^{-1}$ with repetition rates up to several per second. JET will supply the various interfaces needed to interface the launcher to the torus. The largest of these will be the vacuum interface consisting of an additional neutral injector box with its cryopump and conventional pumping system. The main components for this were ordered at the end of the year.

JET has placed contracts with Risø NL, CEA–CEN Grenoble, and Ernst Mach Institut, Freiburg, for the development of components for a JET launcher with pellet speeds of over $5 km s^{-1}$. This new launcher will replace the temporary one and the auxilliary equipment that has been procured has been designed to cope with this.

Containment of the Forces Occurring During Vertical Instabilities

The fast movement of the plasma during a vertical instability gives rise to a large vertical force acting on the vacuum vessel.

This force which was observed for the first time in May 1984, it has been found to scale with the square of the plasma current. As the forces could reach a dangerous level with plasma currents in excess of 4MA, additional supports were installed in October 1984 to restrain the vacuum vessel and damp its rocking motion.

In February 1985 a systematic study of the vertical instability was conducted to make a better assessment of the behaviour of the plasma and the performance of the vertical position of the feedback stabilisation system. The effect of the new mechanical supports on the vacuum vessel was also investigated and it was found that the amplitude of the displacements was effectively reduced by the supports. However, these supports are only a temporary measure since they could not safely restrain the vessel with plasma currents in excess of 5MA at highly elongated cross sections.

A detailed mechanical analysis of the vacuum vessel was carrried out using finite element models and this led to the design of a new generation of vessel supports. These supports link the upper and lower vertical ports of the vessel to the upper and lower horizontal limbs of the magnetic circuit, Fig. 26. They will be able to resist a maximum load of 1600 tonnes acting on the vessel. By the end of 1985, the design of the supports, including the mechanism which allows for the thermal expansion of the vessel, was nearly complete. Procurement was planned for 1986 with installation early in 1987.

The attachment of the new mechanical supports on the vacuum vessel will require a considerable strengthening of the flanges at the ends of the vertical ports. Many diagnostics are affected by this modification and design work is underway to adapt them to the new design.

The outer poloidal field coils are also subjected to large vertical loads during vertical instabilities. An analysis of the forces and of the strength of the supports indicated that the existing design was adequate, provided that certain parts of the coil supports were remade with stronger material. These changes are planned to take place early in 1987.

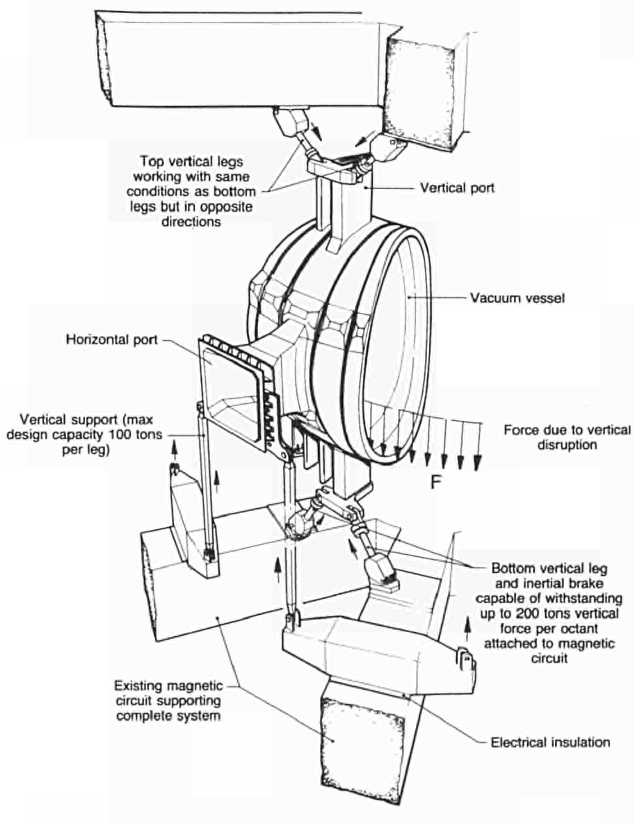

Fig. 26 Final design of the vacuum vessel supports.
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Magnet Systems

Toroidal Field Systems

The toroidal field system was used routinely at the full design value of the current of 67 kA, corresponding to a field of 3.45 T. The energy delivered to the magnets per pulse also reached its full design value of 5.5 GJ.

The safety system (DMSS) protects the coils by removing the input voltage when a voltage imbalance is detected between adjacent coils. This system, which used to give some spurious trips during vertical instabilities, was rewired in 1985 so that only coils in similar positions with respect to the mechanical structure are compared. This should eliminate the spurious trips.

Poloidal Field Systems

The central poloidal field coil system was changed from a parallel to a series connection by the end of 1984 to limit the rate of rise of the current during the initial phase of the plasma discharge. Experiments in 1985 showed that, although the expected effect had been obtained, operation at full premagnetisation, i.e. using the full flux swing capability of the magnetic circuit, was still unsuccessful. The cause of the problem was identified as stray fields from the saturated iron core. Experimental studies and computer field mapping suggested three possible remedies.

1) Compensation of the stray field by means of small differential currents flowing in some of the coils of the primary system.
2) Reduction of the stray field by the addition of the two spare coils to the existing central poloidal field coil system (thus bringing the total number of coils from 8 to 10).
3) Compensation of the stray field by a careful selection of the vertical field, shaping field and premagnetisation compensation field. This solution does not require any hardware change and was planned to be tested in January 1986.

In the assessment of these proposals, the total flux swing capability was a key parameter as it affects the long-term high current capability of the machine. Selection of the final solution, which could also be a combination of the three methods outlined above, was expected to take place in January 1986.

Design work was initiated with a view to increasing the current capability of the machine in the magnetic limiter (X-point) mode of operation. In this mode, the current flowing in the number two poloidal field coils must be as large as possible to obtain the X-points well inside the vacuum vessel. New busbars were being designed to include more turns of the number two poloidal field coils in the shaping circuit.

The new shaping circuit, which includes part of number two and three outer poloidal field coils and provides independent control of the plasma elongation, was used very successfully and became a permanent feature of the plasma control system.

During the shut down period in July and August 1985, a large amount of work, such as installation of new walkways, platforms and ladders, was done to improve the accessibility and safety for maintenance work on the machine and in the pit beneath it. The mechanical protection of electrical equipment was also considerably improved by installing rubber sheaths and wooden boxes around critical busbars.

Safety Systems

The Personnel Safety and Access Control System controls personnel access into restricted areas e.g. the torus hall and basement, and provides essential safety interlocks together with warning signals. The system was operational in 1983 and has been modified progressively to take into account new hazards and requirements.

For example, door entry systems, consisting of turnstiles and identity card/dosimeter readers, one at an entrance to the torus hall and one at an entrance to the basement were fully commissioned and operating by the end of 1985. New door entry systems for the roof laboratory and the hot cell have been installed but not yet commissioned.

The fire alarm system in the main experimental building was modified to cope with the increased number and new types of fire alarm and detection zones. The basement, which was regarded as one of the most vulnerable and critical areas with regard to the risk of fire, was fully equipped with fire alarm and detection systems in 1985. Point smoke and heat detectors and air sampling fire detection systems (VESDA) were installed there. A halon gas flood (fire extinguishing) system for the whole basement was installed in August 1985 and was almost fully commissioned by the end of 1985.

A review and complete maintenance of the fire detection equipment in the other areas of the experimental building took place in 1985 and two VESDAs were installed in the power supply areas of the north wing. Further VESDA installations will be made in there and in the torus hall, west wing and hot cell.

The fire alarm and detection systems of the other operational buildings were also reviewed and new maintenance agreements concluded. The JET fire/fault alarm connection and remote bell ringing interface connection with the Culham Laboratory Engineering Services Division Watch Room was checked and essential modifications arranged. The fire alarms from all JET operational buildings were routed to the machine control room and duplicated on CODAS.

Power Supplies

Electrical power for a JET pulse is supplied from the 400kV national grid network. Part of the energy is stored between pulses in two flywheel generators situated on site. The predicted maximum future power requirements of the five principal loads, although not simultaneously, are:

- toroidal magnetic circuit —600MW
- ohmic heating circuit —300MW
- position control —150MW
- neutral injection heating — 80MW
- radio frequency heating — 60MW

An agreement with the Central Electricity Generating Board (CEGB) allows up to 575MW of pulse power to be taken directly from the 400kV grid which after transformation down to 33kV is fed to the JET loads through a system of circuit breakers. It is not envisaged that this power limit will be exceeded.

The two flywheel generators are used to provide the peak power for the toroidal magnetic field coils and ohmic heating circuit. Each of the generators has a rotor 10m in diameter weighing 775 tonnes. Between pulses, 8.8MW pony motors are used to increase the speed of rotation. When power is required for a JET pulse, the rotor windings are energised and the rotational energy of the flywheels is converted into electrical energy. On slowing down from the maximum speed of 225rpm to half speed, the generators can each deliver 2.6GJ of energy with a peak power output of 400MW.

The non-pulsed auxiliary power is supplied by the Southern Electricity Board (SEB) from the 132kV grid. The amount of electrical energy drawn from the two grid systems is similar in terms of size and cost.

Power Distribution within the JET Site

The CEGB 400kV Switching Station has been increased to its final size allowing power to be fed through a common breaker to three separate 400/33kV step-down transformers. The third 300MVA transformer was successfuly commissioned in July. All three transformers are equipped with tap changers so that the busbar voltage can be boosted to counteract the voltage drop during a pulse. All 33kV busbars and circuits breakers are housed in an in-door substation.

Installation of the third transformer and busbar is part of the programme to increase the capability of JET and will be used to supply some of the power for neutral particle beam and radio frequency heating systems. It also increases the reliability of the 33kV power supply as the third transformer bus is only lightly loaded and can be combined with either of the other two.

In August, during the 1985 shutdown, there was a malfunction in one of the pony motor disconnectors causing considerable damage to the intermediate 33/11kV, 30MVA transformer. A temporary replacement was acquired from the SEB, and is supplied from the third transformer. A new transformer of increased electro-mechanical strength will be installed in 1986.

In April, the 33kV connection to the Culham

Laboratory substation was inaugurated by supplying power to the AC/DC high voltage equipment for new additional heating systems on DITE, COMPASS and other experiments.

In September a new tariff, which reduces the cost of electricity, was negotiated for the CEGB supply as the number of JET pulses is now less than originally planned. A computer model of the 400kV load has been developed mainly for studying the interphase conditions with CEGB. The JET load has unusual characteristics with its low power factor, large power swing (noticeable by the frequency drop on the CEGB interconnected system) and rapid change of load power during a pulse. The siting of JET near Didcot Power Station is an advantage as it increases the voltage stability of the supply, however, it does expose the windings and shafts of the generators in the power station to torsional shocks. The CEGB supply agreement, therefore, includes safe-guards to limit the shocks and drop in transmission line voltage resulting from a JET pulse.

It 1985 the peak power supplied by CEGB to JET was 242MW with a maximum voltage drop at the 400kV supply point of 1.4%. Most of this power supplies the toroidal field coils with the remaining going to the plasma position and shaping coils and the RF additional heating. The model will continue to be used to study future power load requirements and to enable an assessment to be made of possible future problems, especially those related to fast changes of active (MW) power and large excursions of reactive (MVAR) power.

Power from the SEB 132kV distribution line is stepped down to 11kV in a 20MVA transformer and distributed to a number of 11kV/3.3kV and 11kV/415V transformers. The intermediate voltage is used for heavy loads such as cooling water pumps, compressors and ventilation.

Work was carried out on detailed designs for the new cable tray routes and on the modifications needed to improve the distribution of both 415 and 240V in some congested areas of the torus hall basement. More than 50km of cables were ordered for the summer shutdown. After installation, on existing or new cable trays, they were connected and tested ready for the start of operations in October.

Magnet Power Supplies

The magnet power supplies feed the poloidal and toroidal field coils that are used to induce and sustain the current in the plasma and to control the vertical and horizontal position of the plasma within the vacuum vessel.

The power supply for the toroidal field consists of two transformer-thyristor rectifiers, each rated at 135MW pulse power, and one of the flywheel-generator-convertors to provide the regulating power.

The supply for the poloidal field consists of the second flywheel- generator-convertor and a switching network to achieve the necessary flux swing in the magnetising coil. In addition, there are two transformer thyristor rectifiers, each rated at 70MW pulse power, for the radial position and plasma shape control.

During a pulse, the rotor winding of the generator is energised from a 9.6MVA thyristor rectifier exciter to convert the rotational energy of the rotor to electrical energy. The AC power of each generator is converted to DC power by diode rectifiers.

The switching network is used to induce a high voltage in the central poloidal field coil for plasma breakdown and for reversing the current flow in this coil. The high breakdown voltage for ionising the gas is produced by diverting the DC current (up to 80kA) into commutating resistors (200MJ capacity each) using two powerful air-blast circuit breakers. The DC switching capability of the breakers is limited and a capacitor bank and saturable inductor are used to produce an artificial zero current of short duration while the circuit breaker is being opened.

Reconnection of Magnet Coils and Power Supplies

In January, the central poloidal field coil was reconnected from a series-parallel to a series configuration so that the current demand could be comfortably accommodated within the voltage-current capability of the generator-convertor, the associated busbars and the switching network. Another reconnection was made to Poloidal Vertical Field Amplifiers (PVFA) 3 and 4. These had been connected in series with PVFA 1 and 2 and with windings in the number three and four outer poloidal field coils. In February, PVFA 3 and 4 were dedicated to the number four outer poloidal field coils for radial position control and another air-cooled busbar added to enable PVFA 1 and 2 to control the shape of the plasma cross-section. The busbar 'B' of the central poloidal field coil is used as a return for the amplifier currents, Fig.27. In 1986, further studies will be made to assess

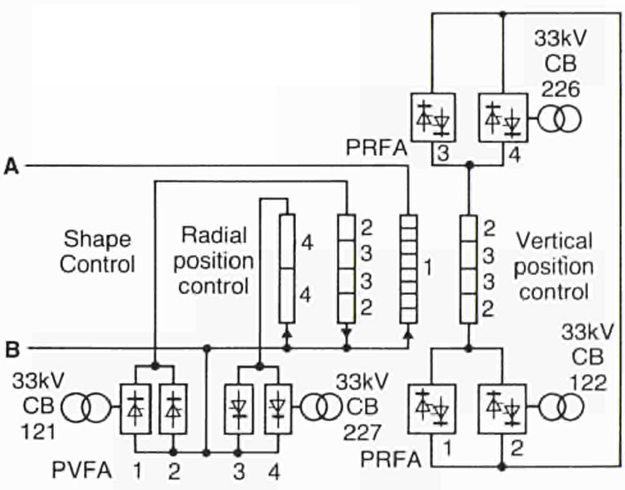

Fig.27 Power supply interconnections with the poloidal magnetic field coils P1, P2, P3 and P4.

CR86.119

the possibility of adding more busbars to provide separate circuits.

Operation and Shutdown

During 1985, the magnet power supplies were operated in eight week cycles: six weeks of operation, one week of maintenance and one week of commissioning. In an operational week, some maintenance was usually carried out during the weekend followed by re-commissioning on Monday. Operation of the magnet power supplies from Tuesday to Friday was carried out in two eight hour shifts. The annual shutdown was used to overhaul and make various improvements and repairs to the system, as well as to install new equipment.

Experience gained from the operation of the magnet power supplies has led to the following changes and improvements being implemented.

- Development of Computer Software

  This has generally reduced the number of actions that need to be taken by the operators between pulses and during start-up and shutdown as these are now partly executed under computer control.

- Mimics and Touch Panels

  The poloidal field, toroidal field and general services subsystem touch panels are now organised in a tree form giving varying degrees of detail and allowing remote control of the plant.

- Alarm Handling

  Approximately 1800 alarms can be generated by the poloidal field, toroidal field and general services subsystems. These are divided into four levels of urgency, each requiring a pre-defined intervention before operations can proceed. Further redefinition and updating has been performed to save memory space and about 50% of the alarms are now conditioned upon some identifiable event to reduce the number of alarms requiring intervention.

- Central Interlock and Safety System (CISS)

  A new logic for CISS was progressively evolved over the year and implemented during the shutdown periods. With the new logic system voltage is removed from the loads in the emergency shutdown state with all load circuit breakers opened and the DC earthing switches closed during the full shutdown state.

- Power Supply Data Analysis

  At the end of each pulse the most significant signals are extracted from the JET pulse file and displayed on a dedicated screen on the main console. In addition, calculations are performed so that comparisons can be made with the limit values for I^2t, power, energy, etc.

- Transient Records

  Several recorders, which were initially installed to record important electrical parameters of the power supplies, have now been made operational. This has led to an increased understanding of recurrent faults, as the records are triggered by specific fault signals.

Maintenance and Trouble Shooting

Contracts were placed for the regular maintenance of the two flywheel generators and for the six transformer thyristor rectifiers. Discussions are being held to define a maintenance contract for the air blast circuit breakers and fast make switches.

A system of regular preventative maintenance has been established. This includes weekly maintenance on Saturdays, monthly maintenance during the maintenance week and an annual overhaul during the shutdown period. To cover these duties there is a basic team of six people increasing to seventeen for the annual overhaul.

With the introduction of a two-shift system, the time available for intervention on the power supplies is reduced. Consequently, a centralised system of recording and repairing faults has been introduced. Operation fault sheets and reports are filled in by the operating team and handed weekly to the maintenance team. These are analysed regularly for monitoring the reliability of the power supplies, for modifying and improving the maintenance schedule and to initiate modifications to the equipment. A large effort has been concentrated on documentation aimed at defining schematics to ease the task of trouble shooting. Over two hundred schematics have already been produced for the generators.

A start has been made on a computer system for recording the level of spares held in stock. This is particularly important for the magnet power supplies as there is no standby capacity at the full level of performance.

Installation and Procurement

Equipment required for the full performance of JET has already been installed. New equipment is therefore only being installed to improve operations or as a result of newly defined objectives. A high power resistive-capacitive (untuned) filter, to smooth the output voltage of the toroidal field power supplies and reduce the associated induced currents in the tokamak structure, was installed and commissioned during the summer shutdown. A noticeable reduction in the noise originating from the tokamak during a pulse has been achieved.

The procurement of the filter for the vertical field amplifier, originally planned to be tuned to the 24th harmonic, has been postponed and is awaiting a decision on the possible series/parallel connection of PVFA subunits during the plasma breakdown phase.

The contract for the supply of new amplifiers PVFA 5 and 6 has been placed. This new power supply is for the modification that is being considered for the magnetic circuit poloidal field coils. They are basically identical to PVFA 3 and 4 and have the following rating: no load voltage: 2.8kV DC, load voltage: +2.3kV to −1.8kV at 25kA DC, current capability: 25kA for 25s and 35kA for 12s every 10 minutes.

The specification of a booster power supply for the vertical field has been defined. This equipment is aimed at achieving a higher voltage capability (up to 12kV DC total) in the magnetic field circuit of the number four poloidal field coils during plasma breakdown to provide better control of the initial plasma formation. This power supply is short-time-rated (6kA for 0.5s) and would be bypassed by a diode stack during the remainder of the JET pulse.

The letter of intent for the upgrading of the commutating resistors R3 and R4 has been issued. This upgrade increases the energy capability of R3 from 200MJ to 400MJ and the capability of R4 from 120MJ to 240MJ.

In December, a letter of intent was issued for an addition to the poloidal switching circuit. The busbars A-B feed into the central poloidal field coil as shown in Fig. 28. The loop voltage needed to produce a definite breakdown can result in the plasma current increasing too rapidly. By using the additional thyristor switches, T_1 to T_6 the resistors R_{81} to R_{86} can be switched in parallel to R4. This enables the net resistance and voltage across the coil to be varied and controlled with time. An example of how closing thyristor switches T_1 to T_6 influences the voltage on the coil one and the increase in plasma current is shown in Fig. 29, with the main breakers S1 opening at t=0. This, in combination with the increased energy rating of resistors R3 and R4, will provide more freedom in the choice of premagnetisation current, including operation at the nominal value of 40kA.

Consideration has been given to additional power supplies for alleviating the problems of stray field in the vessel from the central poloidal field coil and for creating a magnetic separatrix. The detailed planning of the associated busbars, earth switches, thyristor switches, etc will continue in 1986.

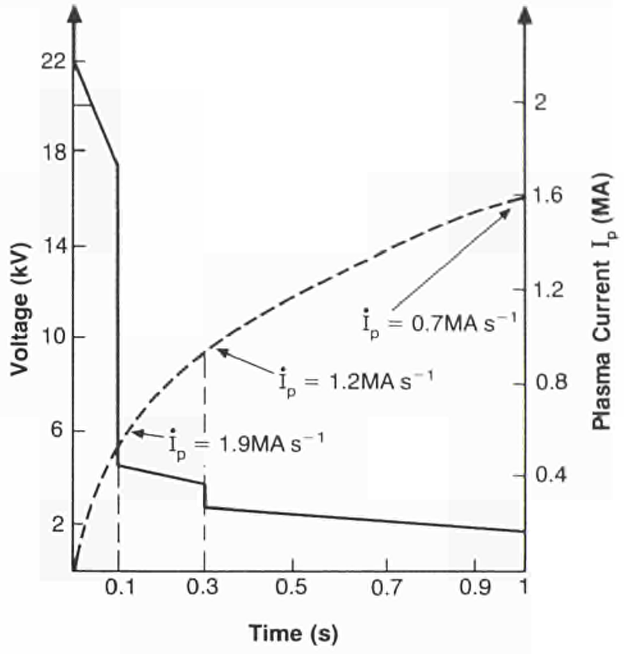

Fig. 29 Voltage across P1 after opening switch S1 at t=0 if T_{1-4} are closed at t=0.1s and t_{5-6} at t=0.3s.

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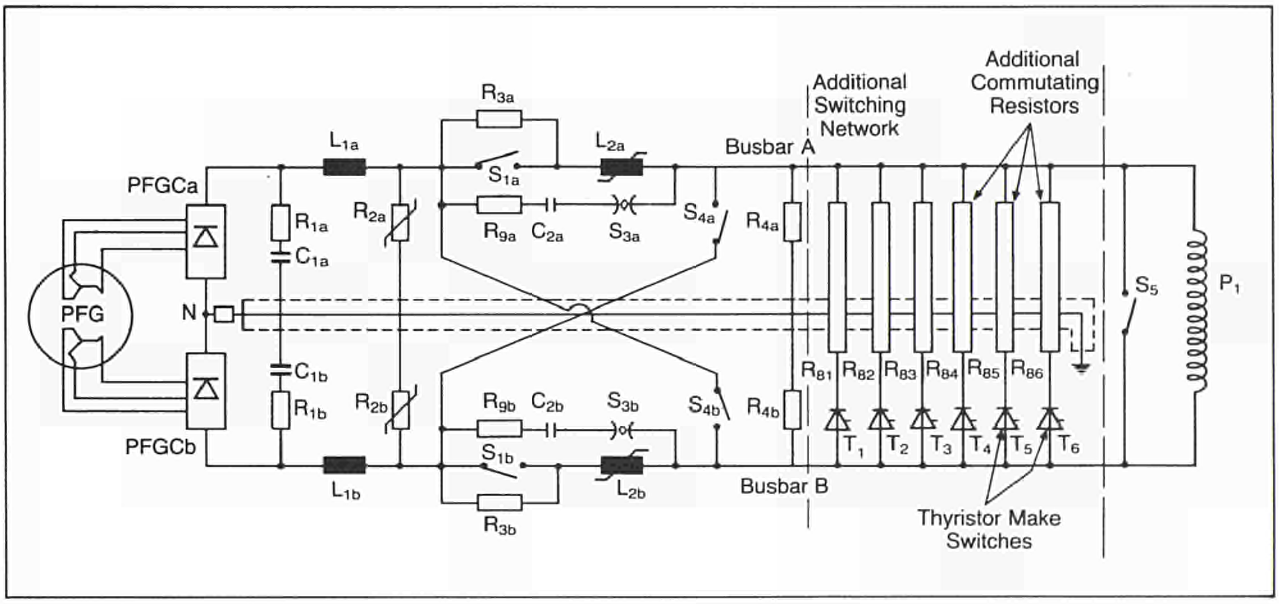

Fig. 28 Poloidal switching circuit with additional network.

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Additional Heating Power Supplies

The power supply and protection modules for the first neutral beam injection system are ready for operation. The grid power supply and protection modules for the second system have been commissioned and the auxilliary power supplies, transmission lines and snubbers are being installed and tested.

The RF power supplies for eight antennae have been commissioned. Four are in full operation: for the three antennae and the RF test bed. The RF auxiliary power transformer has been commissioned and the changes to the power supplies necessary for running the RF system at a rated current of 400A instead of the present 300A, have been studied and will be evaluated further.

Tests of Neutral Beam Source Power Supply and Protection Module at 160kV

Each of the eight power supplies for each neutral beam system can supply up to 80kV and 60A. Following a development programme these can be connected in pairs to produce 160kV and 60A so that a source can be supplied with 30A at 160kV. The combination of two 80kV units requires that both tetrodes are controlled simultaneously to achieve the same fast protection as if run individually. Fig. 30 shows the principal interconnection of a pair (module) of neutral beam source protection units.

Following adjustments to the control and protection electronics, two power supply and protection modules have been successfully tested on a dummy load up to the rated voltage and current. Following a neutral beam source breakdown, the stray capacitance associated with this series connection results in a fault current, which has now been measured. The development program will continue in 1986 to include tests with 160kV rated beam sources. Fig. 31 illustrates some of the electrical equipment for the transmission line tests at 240kV and for the development work towards a 160kV beam source power supply.

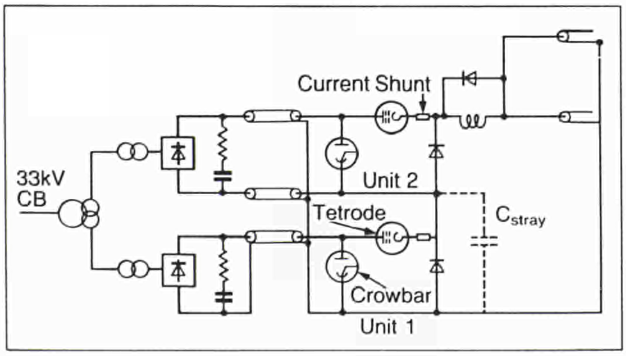

Fig. 30 One module of neutral beam source power supply and protection circuit with two units connected in series for 160kV operation.
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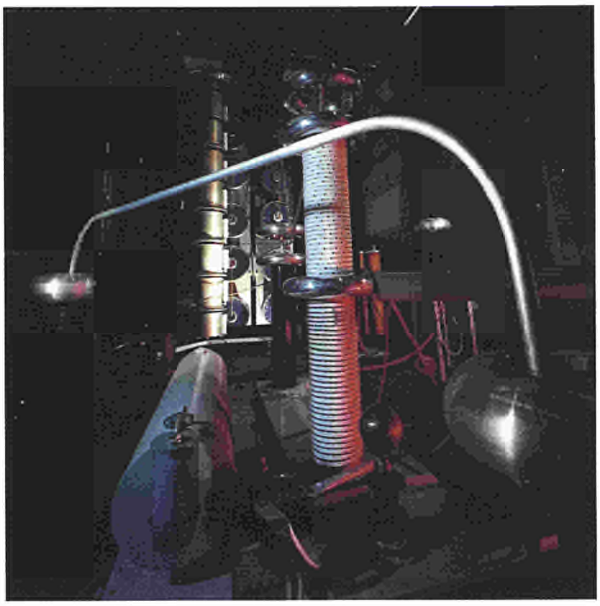

Fig. 31 High voltage test area with 130kV and 280kV (0.15A) test voltages. A water cooled dummy load, rated at 200kV at 60A for 20s, with eight-stage ignitron crowbar, is used for simulating breakdown in a neutral beam source.
84.209c

Neutral Beam Heating

The neutral beam heating technique relies on injecting powerful beams of energetic hydrogen or deuterium atoms into the plasma. After ionisation, the beam particles are confined by the same magnetic field as the plasma and dissipate their kinetic energy by collisions with the plasma particles, thereby heating the plasma.

The beams are generated by the electrostatic acceleration of positive ions, and subsequently neutralising them in a gas cell, as charged particles would not be able to penetrate the magnetic field confining the plasma. The neutralisation efficiency is quite low. The remaining ion beams are deflected magnetically and dumped in a controlled way.

The stages of the JET neutral beam heating programme are as follows.

Late in 1985 the first injector was ready for heating experiments to commence. Operation in 1986 will be with a 10s beam pulse length and with up to 5MW total power into the torus from 60keV hydrogen beams or up to 10MW from 80keV deuterium beams. The first injector will be modified for 160keV deuterium operation in mid 1988, and the second injector about one year later.

The main emphasis in 1985 has been on the completion of the first injector, Fig. 32, consisting of eight beam sources, an integrated beamline system for the eight beams, and ancillary systems of which the most important is the cryocondensation vacuum pump.

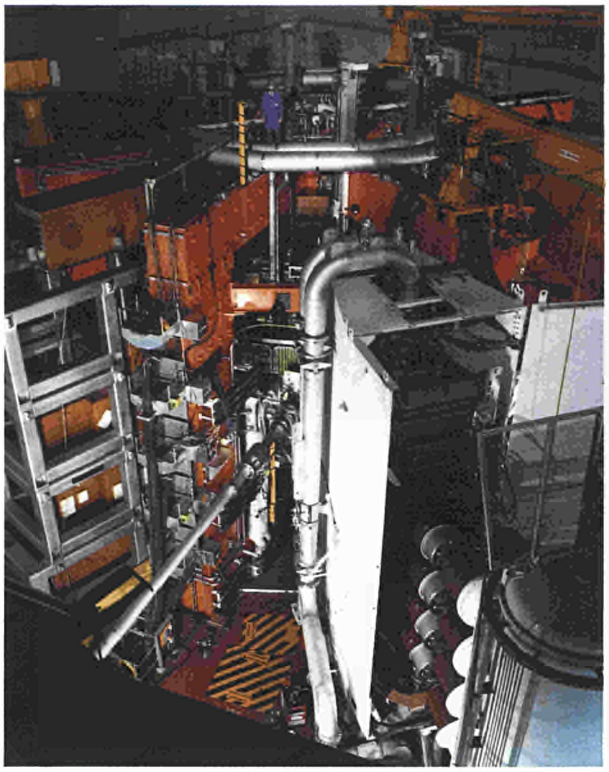

Fig. 32 First neutral injector installed at the torus showing the eight beam sources, the magnetic shielding around the injector box, the beamline water cooling pipes and, in the foreground, the high voltage transmission tower for the beam source supplies. 85.1780c

Major progress has also been made in component procurement, assembly and installation of equipment for the second injector. This system is ready for the commissioning of the beam source power supplies and controls, with sources, which were pre-tested at Culham Laboratory under contract to JET, installed at the torus, as soon as the power supplies become available.

Beam Sources

The beam sources for the first injector have been modified in two major aspects:

- The plasma source species mix was improved (in a joint development by UKAEA Culham Laboratory and JET). By superimposing a long range filter field on the original multipole magnetic field, the H^+ : H_2^+ : H_3^+ ratio in the extracted beams was increased from 64% : 28% : 8% to 84% : 12% : 4%.

- The 262 beamlets from a beam source are steered towards a focus to counteract the beamlet divergence. The steering is produced by an offset of the apertures in the decel grid of the extraction system. The design values had to be corrected by re-drilling the apertures of the existing decel grids to about 50% of the original offset.

Beam sources were operated in the neutral injection testbed with hydrogen beams at 80kV, 60A for 15s. The species mix of deuterium at 80kV and 41A was determined as D^+ : D_2^+ : D_3^+ = 82% : 11% : 7% by optical measurments.

Eight pre-tested beam sources were mounted onto the injector vacuum box at the torus, and the final system of beam sources, power supplies, control and data acquisition commissioned. The beam sources were operated simultaneously at 60kV, 37A each, for 0.5s. The pulse length at this stage was limited by the capability of a provisional beam dump.

Beamline System

The central part, Fig. 33, of the beamline system for the eight beams consists of a support and water supply ($1800 m^3h^{-1}$) column onto which are mounted the deflection magnets, full-energy ion dumps, fractional-energy ion dumps and a calorimeter. This 'central column' consists of four identical quadrants (Fig. 34), which each handle the beams from two sources. The deflection magnets have water-cooled inner liners; several fractional-energy ion dumps are mounted inside the magnets. The calorimeter, which is capable of catching the eight non-neutralised long-pulse beams, is a two-gate system hinged in the midplane. When it

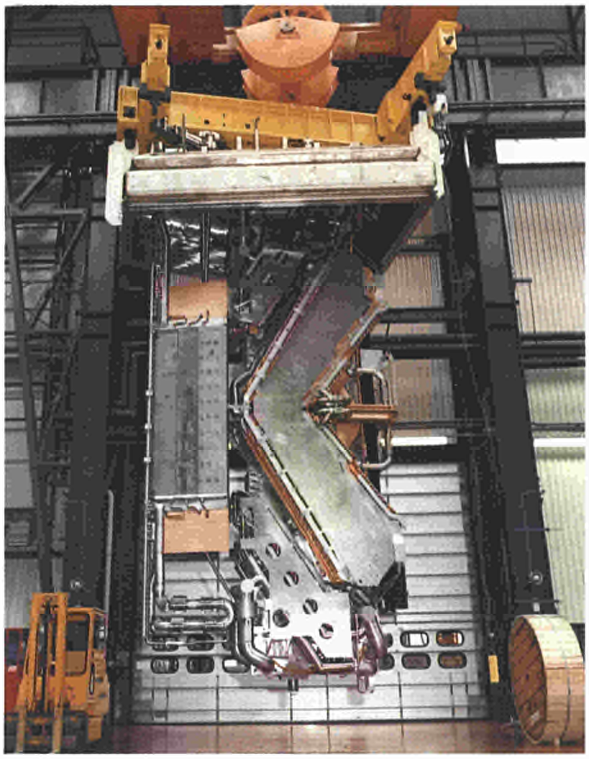

Fig. 33 Central column of the beamline system attached to the lid of the injector box, with the deflection magnet at the right, the full energy ion beam dumps in the middle, at the top and bottom, and the rear side of a calorimeter gate on the left. 86.215c

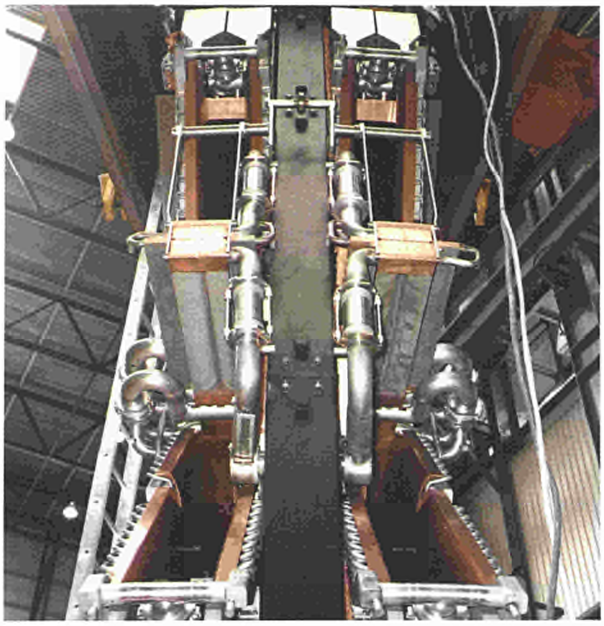

Fig. 34 Beam entrance side of the central column, showing the deflection magnet apertures for the four pairs of beams and, at mid-height, dumps for fractional ions after their 270 degree deflection.
85.T.383c/2

is closed, its back panels act as beam scrapers. During 1985, the assembly of the central column was completed on site, and it was transferred into the neutral injection testbed, Fig. 35.

In the testbed, one quadrant was tested using about 2000 hydrogen and deuterium beam pulses of various energies (40–80keV) and lengths (≦10s). Temperatures were measured and power density levels determined from the initial temperature rise and the equilibrium temperatures of thermocouples mounted 3mm below the surface of the high heat transfer components. Cooling water calorimetry was carried out using thermocouples in the water outlets and turbine or ultrasonic flowmeters.

Beam properties were determined from horizontal beam profiles on the testbed beam dump, 12m from the source, and it was found that:

a) during beam-on time the beam moves by 0.1°;

b) the full beam (ions plus neutrals) shows a constant deflection with respect to the neutral beam of 10–20mm, which is less than that expected due to the Earth's magnetic field;

c) the beamlet divergence deduced from either type of beam is 0.7°.

A difference was found between the power densities derived from the initial temperature rise of the thermocouples during the first few 100ms (peak power density $5.2\,kW\,cm^{-2}$) and that from their maximum temperatures (peak power density $7.2\,kW\,cm^{-2}$), indicating that the beams contract during the pulse, a phenomena which is not yet understood.

The power distribution of the extracted ion beam power was determined with the beamline system in operation, and results are shown in Table 6 for neutraliser line densities of 2.0 (or 1.2)$\times 10^{16}\,cm^{-2}$.

The neutraliser has dimensions of approximately 430mm × 180mm cross-section and 1.8m length. Gas is introduced into the source and at a point half way along the neutraliser. The neutraliser efficiency was determined as a relative measurement of the power

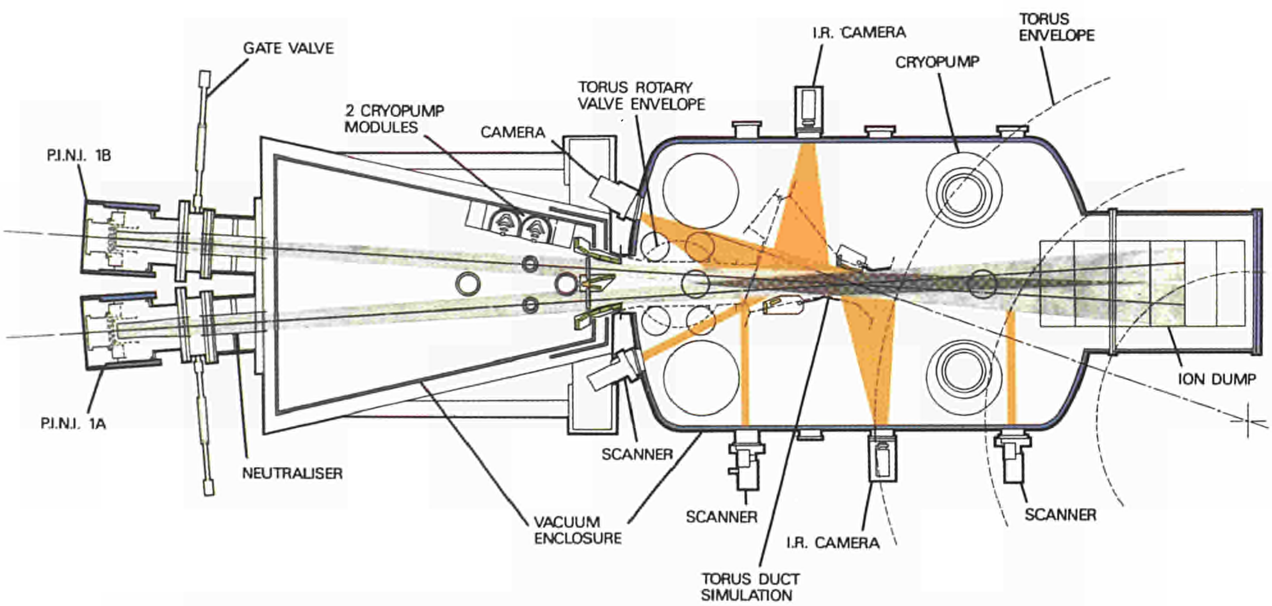

Fig. 35 Schematic of the neutral injection testbed, part of which (on the left) is a standard injector vacuum box.
85.868c

Table 6

Hydrogen Beam 80 kV, 4.8 MW	Deuterium Beam 80 kV, 3.2 MW	Comment
12 (10) %	11 (9) %	lost in source and neutraliser
65 (70) %	37 (45) %	to beam dumps and scrapers
20 (17) %	47 (45) %	would go to the plasma (minus re-ionisation losses in the torus duct)

onto the testbed beam dump with and without beam deflection, and was counterchecked by other measurements. The results were found to be independent of the pulse length between 1 s and 10 s. The efficiency was calculated from the known species mix, published neutralisation cross-sections and the line density determined from neutraliser pressure profile measurements (without beam). Re-ionisation losses were taken into account as determined from the power accountability.

The unexpected result, Fig. 36, was that agreement between the calculated and measured neutralisation efficiencies was only achieved by taking half of the measured line density for the efficiency calculation. Hence it must be concluded that the neutraliser line density during beam-on time is only half the value measured in the absence of the beam. The observation has been explained at CEA Fontenay-aux-Roses as heating of the neutraliser gas by the beam.

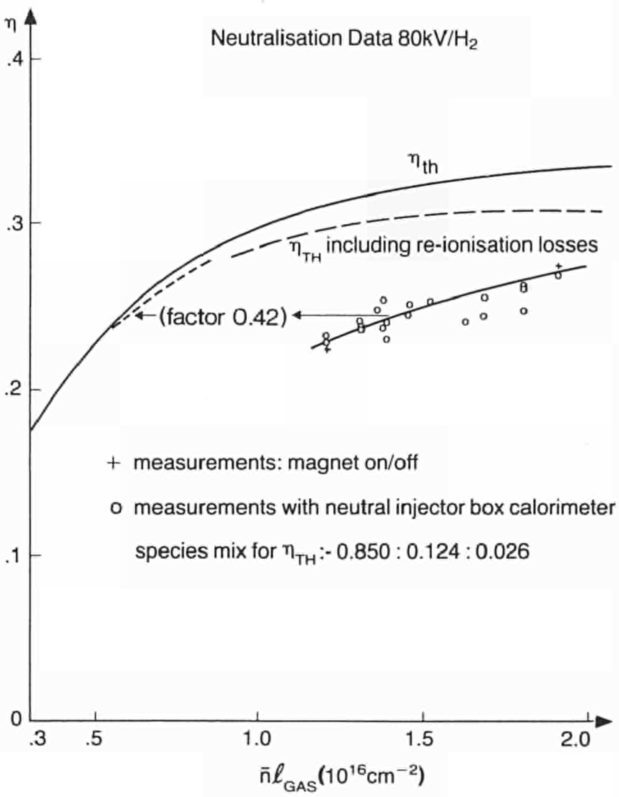

Fig. 36 Calculated and measured neutralisation efficiencies plotted against the line density measured in the absence of the beam. The discrepancy has been explained by beam heating of the neutraliser gas.

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Beam profiles on the full-energy ion dump have been determined, Fig. 37, using about 70 thermocouples. In the non-bend plane a double-hump profile along the dump surface is expected for the V-shaped dump and from a diverging beam. This has been confirmed by the measurements for 40 kV H^+ and 80 kV D^+ beams. At higher energies and current densities, however, discrepancies develop, and at 80 kV H^+ the profile is

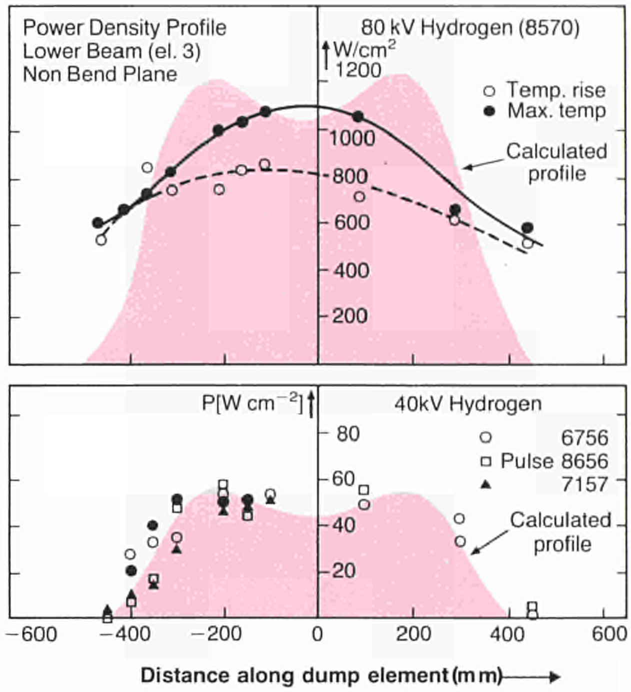

Fig. 37 Power density profile on the full-energy ion dump in the non-bend plane for 80 keV and 40 keV hydrogen beams. The shading shows the calculated profiles.

CR86.124

considerably wider than calculated and peaked in the apex of the dump. No quantitative explanation is yet available for what may be due to space charge effects in the deflection magnet.

In summary, beams from individual sources in different positions have been run through the central column of the beamline system at

80 kV, 60 A for 6 s in hydrogen and
80 kV, 42 A for 10 s in deuterium.

The unexpected beam profiles on the main ion dump have limited the pulse length of hydrogen beams to the value given above.

Cryopump System

The liquid helium refrigerator and distribution system, Fig. 38, was successfully commissioned, producing 300W at 3.8K in its internal calorimeter and has now completed approximately 6000 hours running time. Other cryosystem plant, eg. purifiers, helium recovery, liquid helium storage, liquid nitrogen storage and supply all now operate routinely. The control of the complete plant is initialised and monitored by its programmable controller, which also updates CODAS and the central control mimic displays with relevant status data.

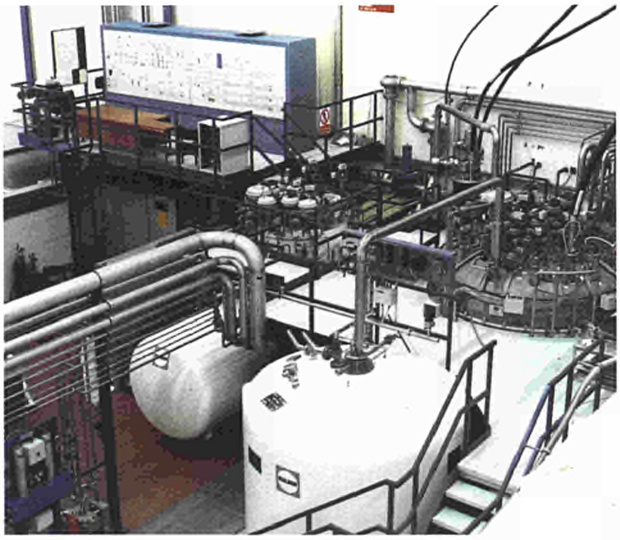

Fig. 38 Cryosupply plant showing the refrigerator cold box in the middle, the liquid helium distribution box at the right and the back-up subcooler system in the background.

85.T.137c/9

Up to now the most important function of the cryoplant has been to supply routinely the cryopump, Fig. 39, of the octant eight neutral injector through the 80m long cryoliquid transfer lines, in which state the system runs mostly unattended. It is controlled by liquid helium and liquid nitrogen level sensors in the cryopump. When external faults occur, such as insufficient vacuum or cooling water flow in the injector, it switches off and restarts automatically when the (intermittent) faults have disappeared. If CODAS (through which the cryoliquid level signals are temporarily transferred to the cryoplant) fails, the system switches over to a back-up control.

The main operational procedures are as follows. The pump is cooled down and filled with liquid nitrogen in approximately two hours. Normally it is then left at a radiative pre-cooling stage for 15hours by which time the liquid helium panels have reached 130K. Further cool-down and filling from the liquid helium supply takes about another six hours. This cool-down procedure requires less than 1000 litres of liquid helium.

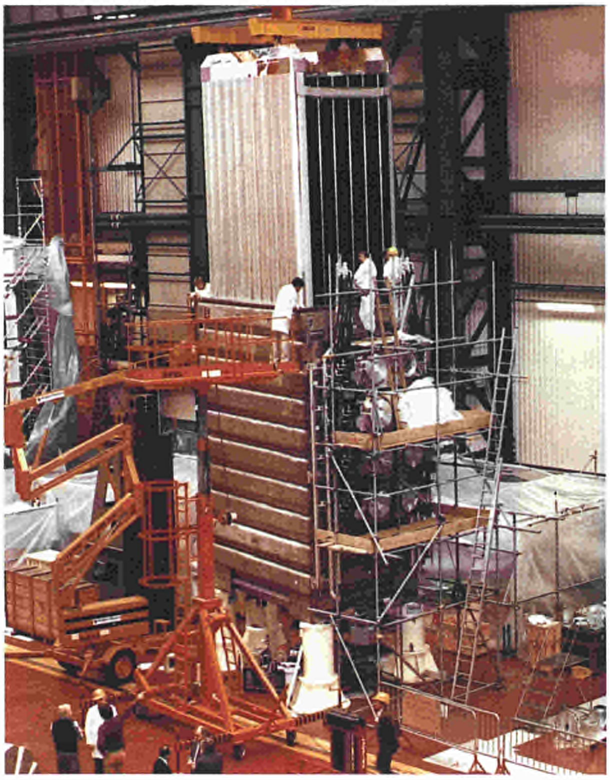

Fig. 39 Installation of the cryopump into the injector vacuum box.

84.T.1990c/12

Warming the pump up with its four tonnes of aluminium alloy structure, from operational conditions to above the freezing temperature of injector cooling water takes around 15hours in the case of a forced regeneration and warm-up enhanced by the presence of about 10mbar of contact gas in the injector box.

Regeneration of the pump is required when the quantity of condensed hydrogen approaches the limit of an explosive mixture in case of a major air leak and sudden evaporation of the condensate. The pump has been regenerated several times without problems.

Injector System Tests

During the 1985 summer shutdown the injector at octant eight was completed with the installation of the central column (improved inter alia by extension tiles to the full-energy ion dumps) and the re-installation of the neutralisers (now with Inconel hoses) and the beam sources (with additional electrostatic shields and filament stem protection caps).

The injector was then commissioned, including all associated subsystems, in a mode where the neutral beams were intercepted by the calorimeter. The beam sources were simultaneously operated in hydrogen at 60kV for pulse lengths up to 10s. No significant disturbance of the injector by the stray fields from the tokamak was observed. The system was ready for injecting beams into the torus but this was not possible because of a malfunction of the rotary vacuum valve between the injector and the torus.

Radio Frequency Heating

For radio frequency heating, high power electromagnetic waves are radiated from antennae located on the wall of the vacuum vessel. Power is coupled into the plasma by selecting a frequency of radiation (25-55 MHz 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 and to choose the location where the heating in the plasma occurs.

First Operations on JET

The first stage of the RF programme, involving the operation of three complete Ion Cyclotron Range of Frequency (ICRF) units simultaneously, started at the beginning of 1985 and will continue into 1986. The 3 MW of power from each unit is generated by a tandem amplifier system using two large tetrodes in the final stage of amplication. Two 230 mm diameter pressurised co-axial transmission lines are used to couple what was expected to be about half of the generated power to each antenna.

The first operations on JET were a crucial step as it was impossible to simulate the power coupling and the system had to be designed using theoretical estimates. The RF systems became available for operations ahead of schedule during the first half of 1985. By the end of the year three units were operating simultaneously with a record value of 6 MW of power and 15 MJ of energy coupled to the plasma. The power was maintained at its maximum level for one second. A variety of experiments have been performed with different frequencies, antenna configurations (monopole, dipole and quadrupole) and plasma conditions (minority species and plasma configurations).

The following conclusions can be drawn from these experiments:

1. The coupling between the antennae and plasma is close to the expected value. The original matching system, based on fine frequency tuning, is convenient and effective and allows changes over a wide band of operating frequencies to be made without any mechanical changes.

2. The design specification for the antennae was exceeded, as 2 MW of power instead of 1.5 MW was launched from each one and, though uncooled, easily coped with the specified one second pulse length. The concept of combining limiter and antenna together worked well without the occurrence of voltage breakdown or the need for conditioning. No particular impurity problems have been encountered during operation of the antennae.

3. The main operating problem has been voltage breakdowns in the main transmission lines. This has limited operations at full power to the condition of optimum coupling between the antennae and the plasma. The cause of the problem has been identified and the necessary modifications will be implemented in 1986.

4. The availability and reliability of the system was satisfactory and enabled the experimental physics programme to be carried out.

The Upgraded ICRF System

The RF heating programme originally envisaged that six units would be operational in 1987 and ten units at the beginning of 1989. In the light of the excellent performance of the prototype systems, the programme has been revised to give the full power earlier at a reduced cost. It is now planned to procure eight units with each one upgraded to 4 MW. This will be achieved by replacing the 1½ MW final tetrodes and output circuit with 2 MW modules that have recently been developed by European industry. As seven generators of the 3 MW type have already been constructed, only the last unit will be delivered in the upgraded form. Upgrading of the other units will take place on site throughout 1987, see Fig. 40.

Upgrading of the generators will be accompanied by the installation of phase shifters (two per unit) needed to operate the eight units at the same frequency and phase locked to a pattern suitable for ICRF current drive experiments. New matching elements consisting of stubs, using variable vacuum capacitors, have been designed and are being constructed. When these are installed close to the antennae, the coupling efficiency increases to about 95% but with a reduced operating

Fig. 40 The second floor of the ICRF power plant showing, in the foreground, three of the 3 MW units presently operated on the tokamak and, in the background, another unit being lowered into position. Eight units will be in operation by the end of 1987.

85.T.1817c/3

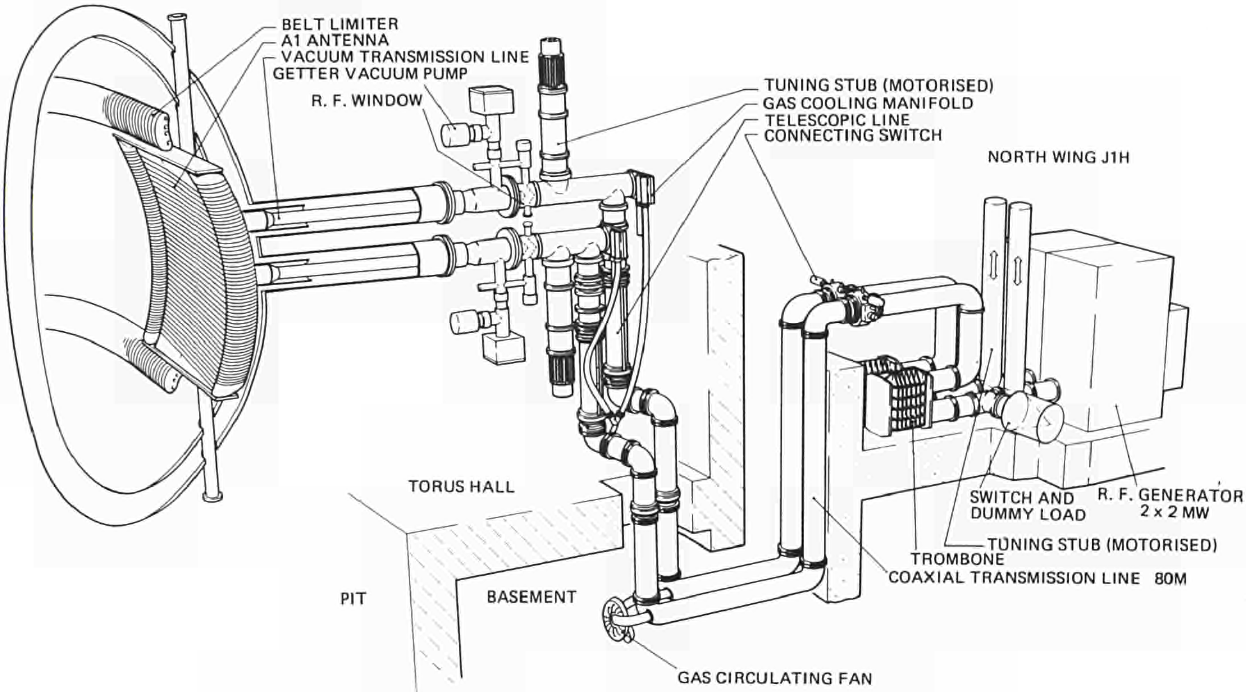

Fig. 41 Layout of an ICRF unit in its upgraded version. The additions to the present system include phase shifter, capacitive stubs, forced air cooling, water cooling and new antenna design.
CR86.98

frequency range. As they are easily installed or removed, they offer the choice of operating at high coupling efficiency with a reduced frequency range or full frequency band operation but with lower efficiency, see Fig. 41.

The Antenna System

The three prototype antennae (A_0) presently being used have been designed to test the performance of various antenna configurations. Fig. 42 shows two of these antennae installed side by side inside the vacuum vessel. A compromise must be found between the coupling efficiency and the capability of adjusting the radiated spectrum for either current drive experiments or for the investigation of the mechanisms of heating and impurity release.

Experimental results obtained in 1985 shows that the interesting configurations are the monopole for its high power coupling capability and the quadrupole for its potential for ion heating and spectrum shaping. A new configuration has been designed to allow both of these operating modes to be achieved with the same antenna.

The eight second generation antennae (A_1) will be installed between the two toroidal limiters and will be actively cooled by water flowing inside each of the screen elements. The vacuum transmission lines will be cooled by a closed airflow circuit, Fig. 43. The vacuum system has been considerably simplified and the turbomolecular pump system of the prototype antennae will be replaced by renewable getter pumps (zirconium, iron,

Fig. 42 Two of the three prototype A_0 antennae installed in the vacuum vessel. These antennae were coupling 6MW of power to the plasma by the end of 1985 and are expected to be used throughout 1986.
85.T.1232c/2

vanadium). These normally operate at room temperature and only require re-generating every ten weeks at about 500°C. New co-axial vacuum feedthroughs for the RF power have been developed with an enhanced high voltage capability (> 60kV). The interfaces between the

Fig. 43 A vacuum transmission line and interface for the A_1 antenna. A net forward power of 1.5 MW is transmitted through this reduced section. 85.T.1298c/4

vacuum transmission lines and the antennae have been modified to improve the remote handling capability of the system. The antennae sides are protected by either graphite or beryllium tiles, alternated with water cooled fins to remove the heat between plasma pulses.

Status of the Upgraded System

All major contracts have been placed and delivery of the new antenna systems has started. The RF testbed has been moved from the CEA site at Fontenay-aux-Roses to JET, upgraded to allow baking at higher temperatures then reassembled and connected to a 3MW unit. The testing programme is conducted with the participation of the EUR-CEA Association. Tests with the new ceramic feedthroughs have already been performed and those on the new antenna components will start early in 1986 and will continue, by mid 1986, with testing of a complete water-cooled antenna. Commissioning of the 4MW prototype generator should be complete at about the same time.

RF Physics Studies

Collaboration with the Associations on the physics of ICRF heating has been actively pursued. Sophisticated codes have been developed by ERM/KMS, IPP Garching and CEA to predict and analyse the antenna plasma coupling, detailed heating mechanisms and power deposition profiles. General agreement with the observed well localised deposition profiles is found but interpretation of the large amount of electron heating still requires detailed analysis.

Remote Handling

During 1985, the specification, acquisition and commissioning of major items of remote handling equipment continued. Considerable effort has been devoted to analysing tasks, inside and outside the vacuum vessel, to provide a basis for the specification of equipment and to supply the material for the data bases that will be used during remote handling operations.

The introduction of tritium into the plasma will mean that all work on the torus will have to be performed remotely. Until then increasing background radiation, the generation of slightly activated dust and the use of beryllium will require special equipment and methods for gaining access and working inside the torus.

Transporters

The articulated boom, which is the main transporter used for in-vessel operation, was commissioned early in 1985 and used successfully on the machine during the summer shutdown to remove some of the original limiters, Fig. 44, and install the Ao antennae, Fig. 45. A three axis extension to the boom for pan, tilt and roll motion has been procured and commissioned. Successful demonstrations were carried out with a complete set of remote handling equipment, ie boom, extension, servomanipulator and some special power tools, Fig. 46. An additional joint, which can be fitted to the boom to extend its reach, has been designed and ordered. This will enable the boom to reach anywhere within the torus from a single port but with the load capacity reduced from 1 tonne to 350 kg.

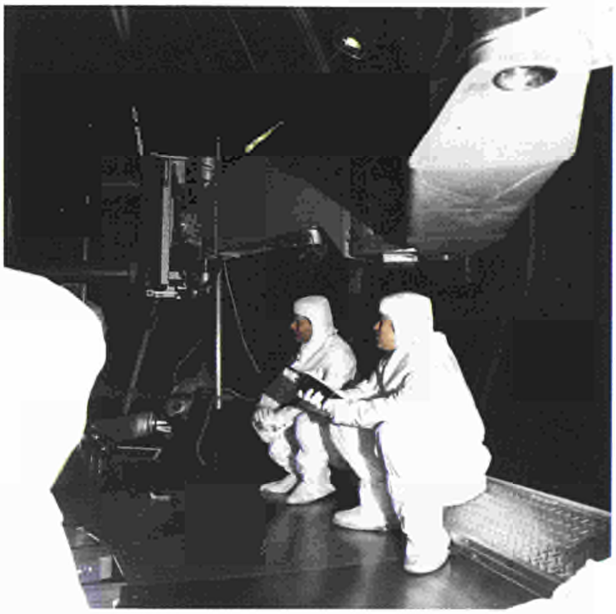

Fig. 44 The articulated boom being used to remove one of the original limiters from the interior of the vacuum vessel. 85.T.1075c/2

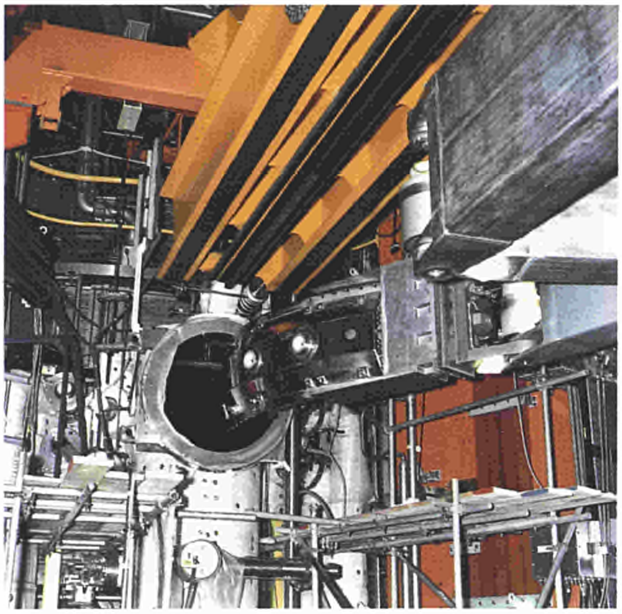

Fig. 45 An A_0 antenna being manoevered through one of the access ports using the articulated boom.
85.T.1652c/8

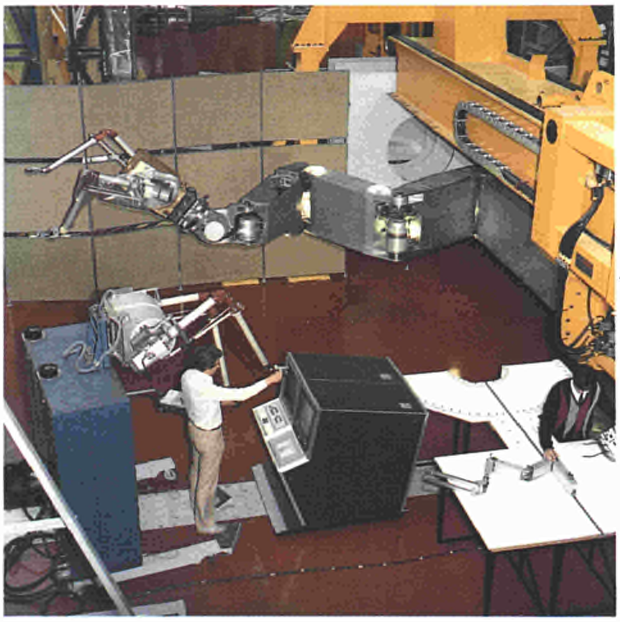

Fig. 46 Tests being carried out on a complete set of remote handling equipment including the articulated boom, servomanipulator and special power tools.
85.T.1850c/3

A feasibility study has been made for a vertical telescopic arm and horizontal boom that would be attached to the crab of the main crane and used to carry manipulators, end-effectors and tools to locations on the outside of the torus. Work on this transporter is continuing.

In June the turret truck for lifting items onto the boom was used for the first time and a radio-controlled battery-operated roving vehicle for carrying a simple manipulator and TV cameras was delivered at the end of 1985, Fig. 47.

Fig. 47 The battery operated roving vehicle for carrying a simple manipulator and TV cameras.
86.T.118c/4

Servomanipulators and end Effectors

The relationship of articulated boom, end effectors, manipulators and tools is shown in Fig. 48. The Mascot servomanipulator used for feasibility tests has been reduced in size and refurbished to a high standard. During the summer shutdown it was mounted on the end of the articulated boom and inserted into the torus, Fig. 49. Two new models are under construction and will be delivered in September 1986. These will have microprocessor control with serial links to provide computer aided operation modes such as teach-and-repeat.

A specially designed gripper was used to install the Ao antennae during the summer shutdown as well as a special tool that has been manufactured for attaching the antennae to the transmission lines. The grippers for the belt limiters and for the shields and housings of the A1 antennae have been designed and tenders called for.

Tools

Special tools have been defined and designed for special tasks: they will be used hands-on initially but

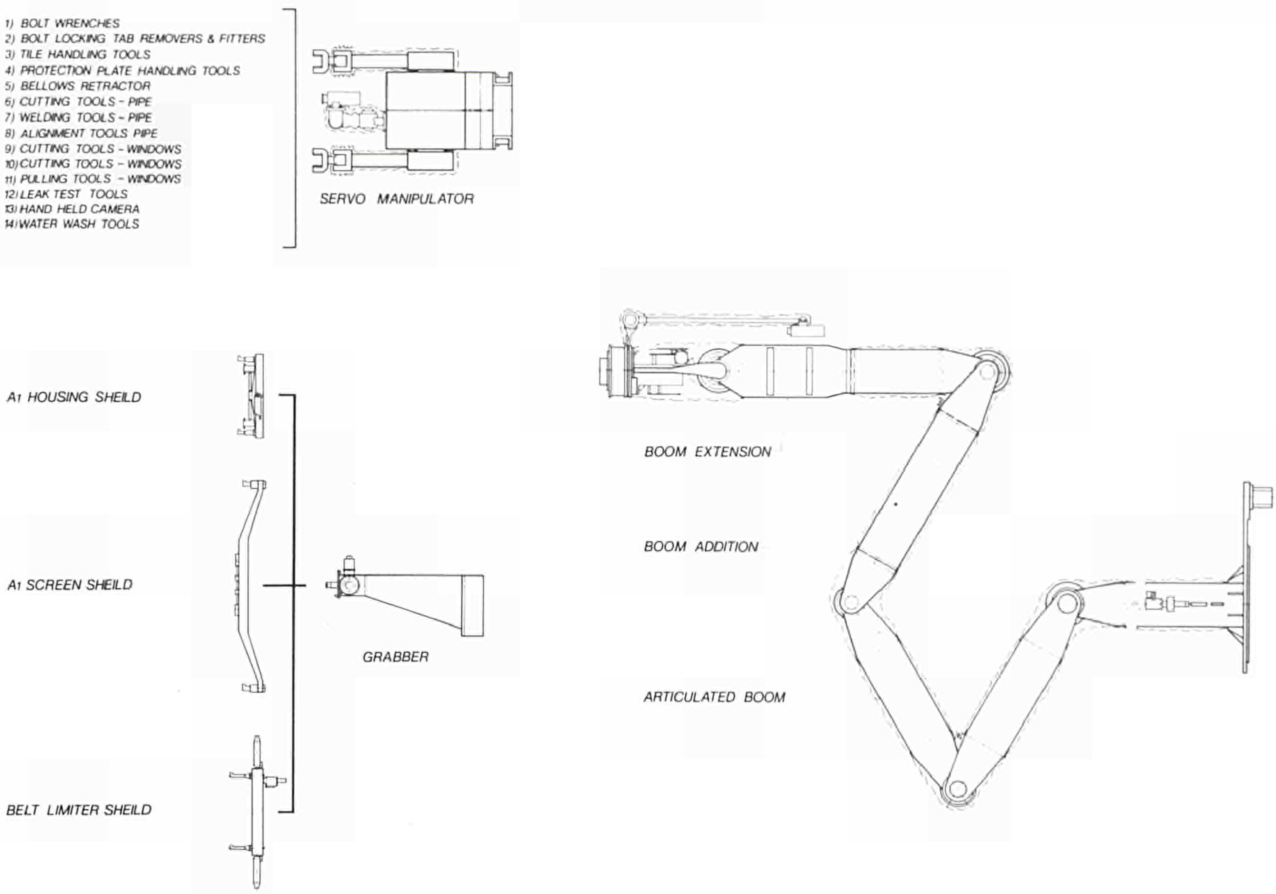

Fig. 48 Diagram of the articulated boom and extension together with a servomanipulator and specially designed grippers.
CR86.125

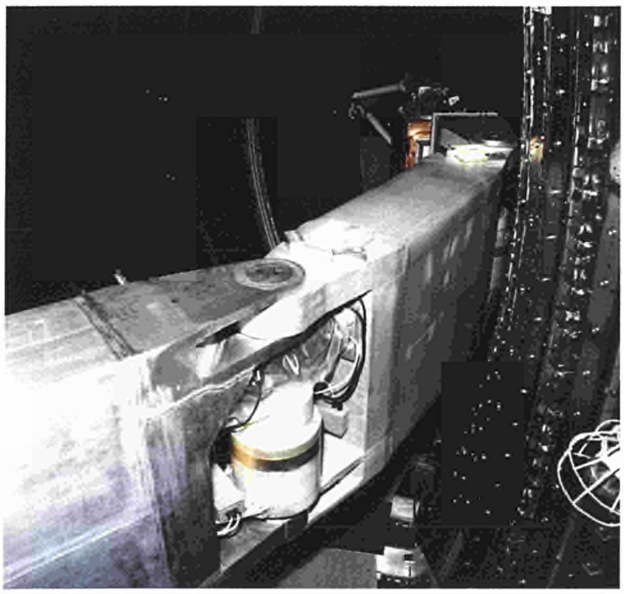

Fig.49 A servomanipulator, attached to the articulated boom, being used on the interior of the vacuum vessel.
85.T.1273c/4

will be used fully remotely later. Examples of such tasks are the installation of the belt limiters and RF antennae and replacement of all the vacuum vessel windows at the end of 1986. A specification has been written, as part of this programme, for a power pack capable of operating a welding head and striking the arc at the end of a 100m cable.

Experimental versions of the self-propelled lip welding and cutting machines were used during the shutdowns on the flanges of the horizontal ports connecting the neutral injector boxes to the vacuum vessel. The welding machine has been developed so that it can follow 60mm radius corners. Parts for three prototypes have been ordered. The cutting machine is being developed along similar lines.

Television

TV cameras and the motorised arms for positioning them in the working area of the manipulators, carried on the last segment of the boom extension, have been ordered. In February, the in-vessel inspection system was used to scan the inside of the vessel. The quality of the pictures was acceptable and shows detail down to two millimetres across. However, because of the darkness inside the vessel, due to the graphite tiles and carbonisation, a device has been installed to integrate the illumination from a number of successive flashes.

Remote Handling Controls

The control system will integrate real-time Local Control Units (LCUs) with general purpose workstations for all of the equipment except the servomanipulators, which will have their own special ones.

The conceptual design for a general purpose workstation has been finalised and is shown in Fig. 50. Construction has started on a prototype for use at the end of 1986. The LCU to operate the boom and its end-effectors has been ordered and will be delivered in July 1986. Work station display of the boom and associated equipment will be a combination of direct camera views and a computer-generated perspective graphical display. The development of the graphical display is being carried out by personnel assigned to JET from KFK, Karlsruhe.

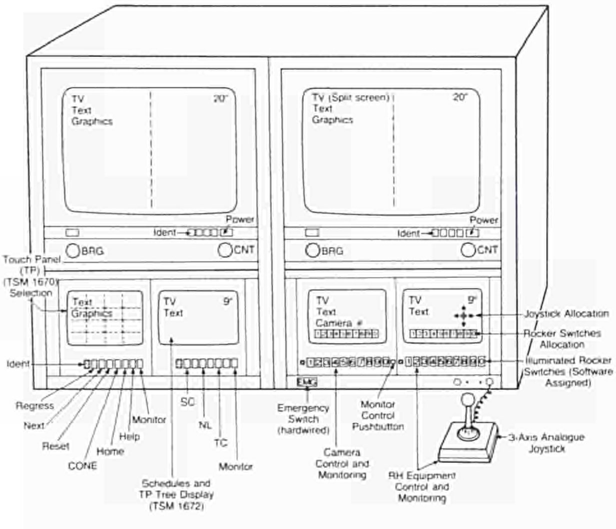

Fig. 50 Conceptual design of a general purpose workstation.
CR86.126

The two special servomanipulator workstations will each control the manipulator arms, the boom extension, four independent cameras on articulated arms carried by the boom extension, the end-effectors and all of the remote handling tools. A conceptual design for this workstation, taking into account technical and ergonomic requirements is being developed by CEA Saclay.

One programmable controller will be used to control the welding heads and their remote power sources with another controlling the remote cutters.

So far, the articulated boom has been controlled with a manual push button controller but a 1/5 scale model, with the corresponding joints linked by closed servo loops, has also been developed. These controls are shown in Fig. 46.

Active and Toxic Component Handling

During 1985 a design was completed and an order placed for delivery in July 1986 of a torus access cabin through which workers can enter the torus in air-line suits while it is contaminated with beryllium dust or lightly activated dust. The cabin, shown in Fig. 51, will seal on to a vacuum vessel port and will contain showers, changing facilities and all the necessary services and monitoring systems. It will have a workroom through which components can pass and be de-contaminated.

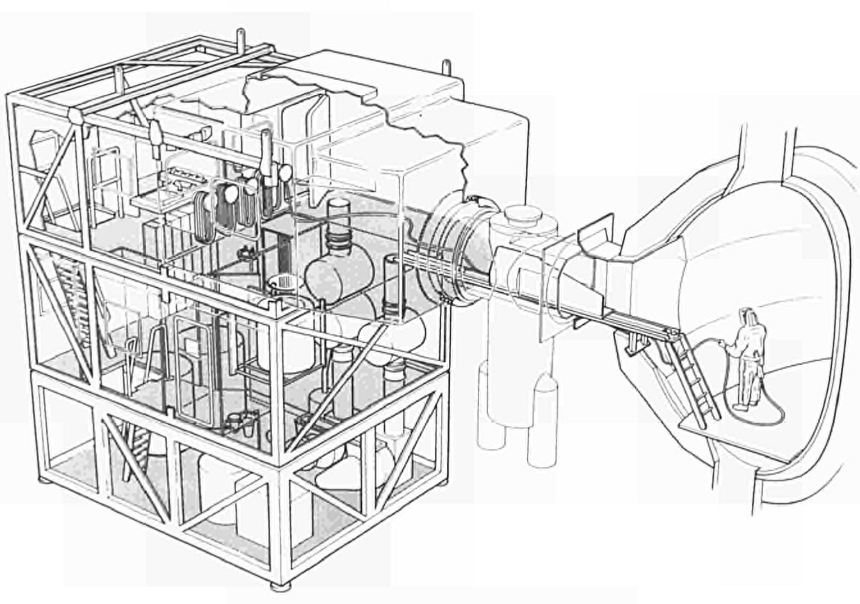

Fig. 51 Diagram of the torus access cabin.
CR85.283

Tritium Handling

System Design

The conceptual designs for various subsystems of the tritium handling plant have been developed to the stage where mechanical design can commence. The principal consideration in the engineering design of this plant is its safety. The design philosophy therefore adopted is to contain any equipment with significant amounts of tritium within leak-tight secondary containment vessels. These would normally be operated under vacuum but have been designed to cope with pressures resulting from any failure of primary equipment within them. The primary equipment will be stringently leak tested at 200^{0}C with helium and all flanges and welded joints placed so they are easily accessible for testing and repair when in service. The equipment will be bakeable at 200^{0}C under vacuum for in-service operation so that contamination resulting from repair work can be removed and processed in a small clean-up system.

Cost Evaluation

A cost evaluation carried out during the year shows that the proposed expenditure of 15-20MioECU on the tritium handling system will be made up as follows:-

Vessel and box structures 27%, process instrumentation 24%, vacuum system and torus link 12%, process valves 12%, civil engineering 6% and radiological protection and transport equipment 4%.

Component Design and Testing

A number of prototype process components have been designed and are now under test. First results confirm the feasability of the engineering approach, especially in the use of cryogenic techniques for hold-up, transfer and purification of gas from the torus and neutral injectors. Further tests will provide the data for optimisation of the control and operating parameters.

Material Technology Studies And Tests

Handling hydrogen isotopes, including tritium, at temperatures from 4K to 752K and at pressures from vacuum to 6bar limits the choice of materials to 304 and 316 series stainless steels and nickel alloys such as Inconel. Particular attention is being paid to welding since the ductility of welded materials may be reduced drastically at cryogenic temperatures if procedures are not chosen with care. A study contract has been placed to develop welding and testing procedures for use during the manufacture of the tritium plant. Initial tests have identified materials and procedures which will allow components to be manufactured to specifications well above the minimum requirements of the relevant engineering codes.

Tritium Supply And Management

In the tritium make-up and disposal system, container vessels of up to 15 litres volume will be taken on and off the plant through a double-lidded lock system which will maintain leak tightness and only expose non-contaminated surfaces to the exterior. The transportor for the containers will be docked into one of three vacuum boxes and the containers moved and clamped onto the process line using external control levers. For ease of handling, all transportors for disposable waste pumps, absorbers, dryer beds, etc will have the same external dimensions.

Control and Data Acquisition

The operation and commissioning of JET is supported by a centralised Control and Data Acquisition System (CODAS) due to the high number of components and their distribution on a large site. This system is based on a network of Norsk Data minicomputers interfaced to the experiment through CAMAC instrumentation (including front end microprocessors) and signal conditioning modules. The various components have been logically grouped in subsystems such as the toroidal field (consisting of one flywheel-generator-converter, two static units, 32 coils and instrumentation), or the poloidal field (with one flywheel-generator-coverter, vertical radial amplifiers, ohmic heating switching network, plasma position current and shape control and instrumentation). Each subsystem is controlled and monitored by one computer. During operation, the actions of each subsystem are co-ordinated and checked by the machine console computer which provides operation staff with global supervision and control facilities.

Before each pulse the operation team selects, through the interactive consoles, the parameters specificed in the pulse schedule. From this point all operations are co-ordinated through the countdown sequence which is divided into three main phases; pre-pulse, pulse and post-pulse, each one triggered by a touch-panel button.

The pre-pulse phase checks the readiness of all subsystems and presets all selected parameters (timing, voltages, etc) and data acquisition sequences. After completion of this phase the operators can verify the selected parameters and then trigger the plasma discharge.

In the pulse phase the various power supplies are armed and, after a last status check, the central timing system is triggered. During the pulse the operators follow, through mimic diagrams and analog displays updated in real time, the evolution of the plasma discharge.

At the completion of the pulse the operator triggers the post-pulse phase which collects all measurements from the front end instrumentation. All information from all subsystems is merged together into a single file, the JET pulse file, in the storage and analysis computer. This file is sent to an IBM 3084Q at Harwell for detailed analysis and long term storage. Local processing, at JET, is done in two ways. Firstly, before merging all subsystem information, a subset of the data is sent to the experiment console computer where a first analysis provides the physicists with a survey of the last pulse. Secondly, various data processing, displays and hardcopies are done on certain subsystem computers to allow closer monitoring of some parameters.

Although all attempts are made to detect abnormal conditions in the control software, the protection of the machine relies on other layers. Firstly, the machine design includes as much resilience as reasonably possible. Secondly, local units include protection circuits. Thirdly, when fast interlocks are necessary direct connections are established, for example between the coils (Direct Magnet Safety System, DMSS) and power supplies. Finally, a network of Programmable Logic Controllers (PLC) implements a Central Interlock and Safety System (CISS) between local units and between subsystems.

The allocation and configuration of all CODAS computers at the end of 1985 is given in Table 7, while Table 8 provides other quantitative data on the CODAS installation.

The main achievements during 1985 are summarised below:

- Introduction of the RF subsystem in the operation of JET.
- Procurement, installation and commissioning of the neutral beam injector subsystem for octant eight and preparatory work for the octant four subsystem.
- Preliminary work on the remote handling subsystem for the master-slave tests of the articulated boom.
- Upgrade and commissioning of the Plasma Fault Protection System (PFPS) to include interlocks with neutral beam injectors, in case of low plasma current and density, and improved user interface.
- Extension of the soft termination network facilities.
- Provision of new supervisory software to standardise count down sequence and provide easier subsystem operation in stand alone mode for commissioning periods.
- Upgrade of operating system to Release J of Sintran to benefit from its improved efficiency.
- Substantial improvements were made on the following packages:

    Alarm handling;
    Wave form generation and selection;
    Flywheel generator convertor, static units, circuit breakers support software;
    Gas introduction;
    Cryosystem and helium plant monitoring and control;
    Access control;

- Continuous development of automated procedures to relieve the operation team from tedious tasks and to implement sequences which have been tried and tested by the operation team.
- Study of improvements in data throughput and, as a first phase, installation and commissioning of a hyper-channel link between Harwell and JET.
- Complete revision and recommissioning of all existing CISS PLCs and addition of PLCs for neutral beam and neutral beam test bed.
- Design, commissioning and installation of a serial link between the CISS PLCs and CODAS computers to improve fault condition diagnostics.
- Design, manufacture, installation and commissioning of 15 CODAS interface cubicles.
- Installation of 800 additional transient recorder channels to investigate transient and fault conditions.
- Re-configuration of the physics terminal room to match operational requirements.
- Release to users of the cable management data base which contained 800,000 records by the end of 1985.
- Work started on the IBM computer to investigate response time problems and to install a JET version of PLOT-10 to improve software compatibility and to allow connection of the Westward terminals through a 7171 interface unit.

The main targets for 1986 are:

- Full commissioning of the second neutral injector subsystem.
- Design and installation of a remote handling work-station and supporting software. First commissioning with the articulated boom.
- Implementation of density signals validation for improvement of PFPS reliability.
- Continuous improvement of the data throughput.
- Upgrade of software performance and reliability
- Development and commissioning of software for translating required plasma parameters (current, elongation, position, density etc) into machine parameter settings.
- Re-engineering of the plasma position current and shape control to make use of the flexibility of digital control techniques.

- Design, manufacture, installation and commissioning of 18 additional CODAS interface cubicles mainly for extensions of the diagnostics.
- Extension of the close circuit television system to cover remote handling and tritium plant requirements.

Table 7
CODAS Computer Configuration at the end of 1985

Sub-	Usage	Model	Memory (MByte)	Disks (MByte)
AH*	NI Additional Heating	ND100	2.0	1×75
AS	Assembly Database	Compact	0.75	1×45
CA*	Message Switcher A	ND100	0.5	1×75
CB	Message Switcher B	ND100	0.5	1×75
CP	Cable Database	ND530	5.0	1×75 1×288
DA*	On-line diagnostic	ND530	3.0	2×75
DB*	On-line diagnostic	ND540	3.0	1×75 1×288
DC*	On-line diagnostic	ND520	3.0	2×75
DD*	On-line diagnostic	ND520	3.0	2×75
DE*	Off-line diagnostic	ND520	3.0	2×75
DF*	On-line diagnostic	ND520	3.0	2×75
DG	Diagnostic Commissioning	ND520	5.0	2×75
EC*	Experiment Console	ND570	5.0	1×75 1×288
EL	Electronic	ND100	1.0	1×75
GS*	General Services	ND100	1.5	1×75
HL*	Harwell Link	ND100	1.5	1×75 1×10
MC*	Machine Console	ND100	1.5	1×75
PF*	Poloidal Field	ND100	2.0	1×75
RB*	Radio Frequency Test Bed	ND100	1.5	1×75
RF*	Radio Frequency	ND100	1.5	1×75
RH	Remote Handling	ND100	1.5	1×75
SA*	Storage and Analysis	ND560	3.0	1×75 1×288
SB	Standby-System/Backup	ND100	1.5	2×75 2×10 1×288
SD	Built-in, Pool, Computer dB	Compact	0.75	1×45
SS*	Safety and Access	ND100	1.5	1×75
TB*	NI Test Bed	ND530	3.0	2×75
TF*	Toroidal Field	ND100	1.5	1×75
TR	Tritium	ND100	1.5	1×75 1×288
TS	Test	ND100	1.5	1×75
VC*	Vacuum	ND100	2.0	1×75
YB	Integration	ND530	3.0	2×75
YC	CODAS Commissioning/NIB-C	ND100	1.5	1×75
YD	Sc Dpt Development	ND570	5.0	1×75 1×288
YE	CODAS Development	ND520	5.0	2×75

* indicates on-line computers

Table 8
Quantitative Information on CODAS Installation at end of 1985

Item	Number
CODAS Interface Cubicles	113
CAMAC Crates	187
CAMAC Modules	2,953
Eurocard Modules (Signal Conditioning)	5,739
Computer Terminals	151
CAMAC Serial loops (Fibre Optic)	22
On-line Computers	20
Off line and Commissioning Computers	14
Size of JPF (MB)	6.6
Number of diagnostics on-line with CODAS	15
Number of diagnostics under commissioning with CODAS	8

Diagnostic Systems

The status of JET's diagnostic systems at the end of 1985 is summarised in Table 9. Almost all of the diagnostic systems started during the construction phase are now operating. Further details of the principal systems are given below:

Magnetic Measurements

The magnetic diagnostics have been described in previous reports and have continued to work routinely and reliably during the year. Software has now been implemented to carry out an automatic self consistency check on the data after each discharge to check for errors and to validate the data. This is working well. The data acquisition system was extended during the shutdown to give additional channels and longer time windows for fluctuation studies.

The diamagnetic loops have been commissioned and now give measurements of the plasma energy content consistent with other measurements. It is envisaged that this will become a routine measurement during 1986.

Electron Cyclotron Emission Measurements

Radiation emitted from the JET plasma at low harmonics of the electron cyclotron frequency is received by an array of 10 antennae which view the plasma along different chords in the poloidal plane. The radiation is transmitted via the basement to the diagnostic hall where it is analysed by three types of instrument. A mixture of Michelson and Fabry-Perot interferometers is used to measure the spatial profile of electron temperature. Each instrument is connected to one of the antennae and can be scanned on a time scale in the order of 10ms to measure the temperature profile along that particular chord of the plasma. By combining the results from several chords a two dimensional map of the temperature can be constructed. During 1985 this system has been carefully re-calibrated to within an absolute accuracy of about 10%.

The Fabry-Perot interferometers can also be operated in a fixed frequency mode to measure fluctuations in temperature on a much faster time scale at a selected point in the plasma. Temperature fluctuations are also measured using the multichannel ECE polychromator which can measure the temperature at 12 pre-selected points along a single chord, with a similar time resolution to that of the Fabry-Perot, Fig. 52. These instruments have been used to study the development and collapse of the internal disruption at the plasma centre—the so-called 'sawtooth' oscillations. The character of JET discharges during the current rise phase and for discharges with a relatively high value of the safety factor q is similar to those seen in smaller tokamaks. The main feature of these is that the sawtooth collapse seems to be triggered by a growing precursor oscillation. However, at lower values of q and during the current plateau, the precursor disappears and the sawtooth collapse occurs spontaneously without any warning.

The ECE polychromator has also been used extensively to observe the outwards propagation of the heat pulse following the sawtooth collapse to determine the local value of thermal diffusivity.

Thomson Scattering

The Thomson scattering diagnostic, which measures the plasma temperature from the Doppler shift of a scattered laser beam, has worked routinely throughout the year. There is generally good agreement between the Thomson scattering and ECE diagnostics, but careful analysis of the data has shown that the agreement is not as good as would be expected statistically. This disagreement has

Table 9
STATUS OF THE JET DIAGNOSTICS SYSTEMS

Diagnostic System	Diagnostic	Purpose	Association	Status Dec. 1985	Date of 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	(1) Operational (2) Enhanacement	Mid 1983 Late 1985
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	Construction	Early 1987
KG1	Multichannel Far Infrared Interferometer and Polarimeter	(1) $\int n_e ds$ on 7 vertical chord and 3 horizontal chords (2) $\int n_e B_p ds$ on 6 vertical channels	CEA Fontenay-aux-Roses	(1) Operational (2) Under construction	Mid 1984 partly Early 1985 fully Early 1987
KG2	Single Channel Microwave	$\int n_e(r) ds$ on 1 vertical and 3 horizontal chords in low density plasmas ($<10^{20} m^{-3}$)	JET and FOM Rijnhuizen JET	2mm Operational Extension to 1mm	Mid 1983 Not proceeding
KG3	Microwave Reflectometer	n_e profiles and flucutations	JET	(1) Prototype system operating (2) Multichannel system being designed	Mid 1983 Mid 1987
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	Installed	Early 1986
KJ1	Soft X-ray Diode Arrays	MHD instabilities and location of rational surfaces	IPP Garching	Operational	End 1985
KK1	Electron Cyclotron Emission Spatial Scan	T_e (r,t) with scan time of a few milliseconds	NPL, Culham Lab. and JET	Operational	Late 1985
KK2	Electron Cyclotron Emission Fast System	T_e (r,t) on microsecond time scale	FOM, Rijnhuizen	Operational	Early 1985
KL1	Limiter Surface Temperature	(i) Monitor of hot spots on limiter and RF antennae (ii) Temperature of wall and limiter surface	JET and KFA Jülich	Operational Development	Mid 1984 1986
KM1	2.4MeV Neutron Spectrometer		UKAEA Harwell	Construction proceeding	1986
KM3	2.4MeV Time-of-Flight Neutron Spectrometer	Neutron spectra in D-D discharges, ion temperatures and energy distributions	NEBESD, Studsvik	Commissioning	1986
KM4	2.4MeV Spherical Ionisation Chamber		KFA Jülich	Commissioning	1986
KM2	14MeV Neutron Spectrometer	Neutron spectra in D-T discharges, ion temperatures and energy distributions	UKAEA Harwell	Design completed	
KM5	14MeV Neutron Spectrometer		NEBESD, Gothenberg	Decision on construction under review	
KN1	Time Resolved Neutron Yield Monitor	Time resolved neutron flux	UKAEA Harwell	Operational	Mid 1983
KN2	Neutron Activation	Absolute fluxes of neutrons	UKAEA Harwell	Installation	1986
KN3	Neutron Yield Profile Measuring System	Space and time resolved profile of neutron flux	UKAEA Harwell	Construction proceeding	1986
KN4	Delayed Neutron Activation	Absolute fluxes of neutrons	Mol	Awaiting delivery	1986
KP1	Fusion Product Detectors	Charged particle produced by fusion reactions	JET	Prototype operational Upgrade	1985 1986
KR1	Neutral Particle Analyser Array	Profiles of ion temperature	ENEA Frascati	Operational	Mid 1984 partly End 1985 fully
KS1	Active Phase Spectroscopy	Impurity behaviour in active conditions	IPP Garching	Under construction	Mid 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 Poloidal Scan	Early 1983 Early 1986
KS4	Active Beam Diagnostics (using heating beam)	Fully ionized light impurity concentration $T_i(r)$ rotation velocities	JET	Provisional system Under construction	Early 1986 Early 1987
KT1	VUV Spectroscopy Spatial Scan	Time and space resolved impuritiy densities	CEA Fontenay-aux-Roses	Operational	Mid 1985
KT2	VUV Broadband Spectroscopy	Impurity survey	UKAEA Culham Lab.	Operational	Early 1984
KT3	Visible Spectroscopy	Impurity fluxes from wall and limiters	JET	Operational	Mid 1983
KT4	Grazing Incidence Spectroscopy	Impurity survey	UKAEA Culham Lab.	Under construction	Early 1986
KX1	High Resolution X-ray Crystal Spectroscopy	Ion temperature by line broadening	ENEA Frascati	Installed	Early 1986
KY1	Surface Analysis Station	Plasma wall and limiter interations including release of hydrogen isotope recycling	IPP Garching	Commissioning	Mid 1986
KY2	Surface Probe Fast Transfer System		UKAEA Culham Lab.	Commissioning	Mid 1986
KY3	Plasma Boundary Probe	Vertical probe drives for electrical and surface collecting probes	JET UKAEA Culham Lab. IPP Garching	Both units installed	Mid 1984-86
KZ1	Pellet Injector Diagnostic	Particle transport, fueling	IPP Garching	Partly installed	Early 1986

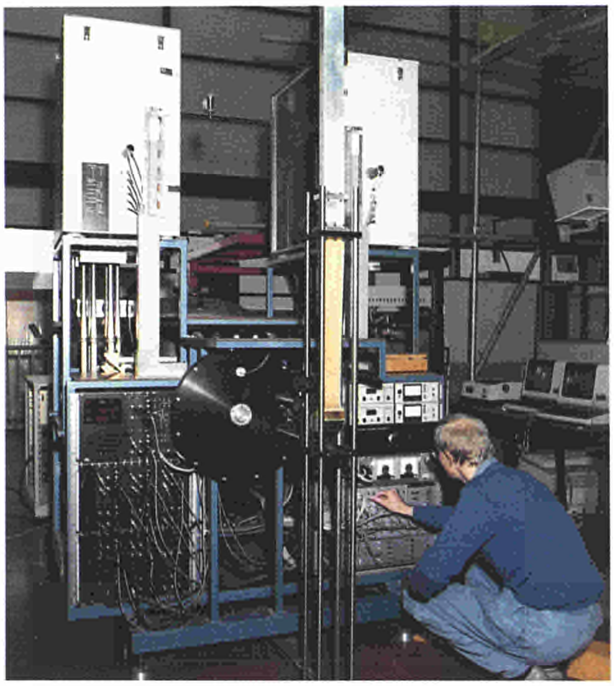

Fig. 52 The 12 channel electron emission polycrometer used for measuring temperature at selected points along a single chord.
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only become apparent because of the extremely high accuracy of the absolute calibration of the ECE systems in JET. It has now been established that there is a systematic problem of chromatic aberration in the Thomson scattering optics and this is being rectified. Construction has started on the new LIDAR Thomson scattering system which will use an extremely short pulsed laser to measure the spatial profile of electron temperature by time-of-flight technique. Contracts have now been placed for most of the items of equipment and it is planned to install this new system during the shutdown at the end of 1986.

Microwave Measurements

The microwave interferometer has continued to be used in routine operation for measurements of the line of sight density and plasma control purposes. A new microwave reflectometer system has been designed and construction started. The system will have 12 discrete wavelength channels and will be optimised to provide density profile data near the edge of the plasma where data from the far infra-red interferometer are sparse. The reflectometer can also be used to monitor localised density fluctuations.

Neutron Flux Measurements

Measurements of the total neutron yield using ^{235}U and ^{238}U fission chambers have continued to be made routinely. For discharges in deuterium this now gives a direct measurement of the fusion yield from which the ion temperature can be deduced. The detectors have been absolutely calibrated using a neutron source inside the JET vacuum vessel during a shutdown.
Construction has continued on the neutron yield profile diagnostic and the neutron activation system and both systems are now scheduled for installation during 1986.

Neutron Spectrometry

First measurements of neutron spectra in JET have been obtained using a ^3He ionisation chamber in the roof laboratory. The penetration through the roof acts as a collimator. Results are in good agreement with other measurements of the ion temperature and, when taken simultaneously with the total neutron yield, permit a determination of the deuteron density in the core of the JET plasma. Typical values are $n_d / n_e \sim 0.5$.

The time-of-flight neutron spectrometer, also located in the roof laboratory, has been installed and partly commissioned. Full operation is planned for 1986. Construction on the 2.4MeV spectrometer collimator and shield for inside the torus hall has continued. Installation is planned for mid 1986, Fig. 53.

Fig. 53 The neutron time of flight spectrometer in the roof laboratory during commissioning.
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Fusion Products

First measurements of charged fusion products in JET have been obtained with a prototype detector mounted inside the vacuum vessel. These data have given interesting results on the confinement of energetic particles and have helped to further the design of more sophisticated diagnostics.

Plasma Boundary Probes

Measurements of the plasma temperature, density and heat flux in the region outside the limiter have been made with electrical direct reading probes introduced into the edge of the plasma by a vertical probe drive. These data are important in developing models of the plasma boundary layer.

Limiter Diagnostics

Measurements of the plasma limiter interactions using infra-red cameras have continued, and similar measurements have been extended to the RF antennae. The threshold temperature of these cameras is $\sim 700°C$ and when the limiter surface temperature exceeds this value it is possible to estimate the power flux to the limiter surface. A new more sensitive type of camera is being developed to extend the range to lower temperatures.

Plasma Wall Interactions

Construction and installation of the system to expose surface collecting probes to the plasma and retrieve the samples for surface analysis has continued. The system is scheduled to become operational in mid 1986.

Samples have also been exposed on the walls of the vacuum vessel for longer periods and removed for analysis at scheduled maintenance periods. These, together with samples taken from the limiters, provide valuable data for understanding the migration of impurities from the walls onto the limiter and the processes by which these impurities enter the plasma.

Hard X-Ray Monitors

Operating JET over a wide parameter range inevitably results in some plasmas with large runaway electron currents. It is important to be able to observe the occurrence of these plasmas in order 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. A measure of the Bremsstrahlung intensity (total power) is monitored with a set of simple detectors mounted on the vertical limbs of the transformer and the walls of the torus hall.

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 has been in operation since 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 of the H-alpha monitors are equipped with visible spectrometers lent to JET under a 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 of impurities from various sources such as walls, limiters and antennae.

Active Beam Diagnostics

In a plasma, fully stripped ions cannot normally be detected as they do not emit line radiation. However, the particles in the neutral beams, injected into the plasma for heating, can undergo charge exchange reactions with these ions, resulting in the emission of radiation due to recombination. Analysis of the radiation, which is emitted over the complete visible spectrum, allows measurements to be made of the impurity concentrations of helium, carbon and oxygen as well as ion temperatures, flow velocities during neutral injection and helium minority temperatures during R.F heating. The source of radiation is defined by the intersection of the viewing lines and the trajectory of the neutral beam, thus enabling local measurements to be made. One or more of the neutral beams will be modulated to improve the signal to noise ratio.

A provisional system has been installed which utilises some of the H-alpha monitors. Light is transmitted from two optical viewing heads along optical fibres to the diagnostic hall for analysis. The final system, capable of carrying out a complete radial scan, is under construction and will become operational after the shutdown at the end of 1986. Consideration is being given to the deployment of a low power diagnostic neutral beam for these measurements.

Vacuum Ultraviolet Spectrometry

Due to the high temperature of the JET plasma impurities are highly ionised and emit light at short wavelengths. Vacuum ultraviolet spectrometry covers the spectral range between 10 and 2000 Å allowing the study of light emission from impurities exposed to temperatures below 1 keV.

There is a single channel 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 is based on the results of this instrument. It will be complemented by a grazing-incidence spectrometer covering the wavelength range between 10 and 300 Å, which also has survey capability using the same detector. It is aiming particularly at the resonance lines of light impurities. Both instruments have been procured through Culham Laboratory.

A spectrometer system, supplied by CEA, Fontenay-aux-Roses and successfully operated on the tokamak TFR, is being used to obtain spatial impurity ion profiles. The spectral scan is obtained by viewing the plasma through a rotating mirror with a gold-plated face and used in near grazing incidence. A spatial scan takes 3ms to complete and is repeatable every 20ms. The three mirrors, scanning different portions of the plasma cross-section, are synchronised to rotate together and can be stopped to obtain continuous time resolution at fixed chords. The two horizontal channels of the system are operational and delivered the first results in 1985.

X-Ray Spectroscopy

During additional heating the temperature of the plasma increases. This means that the portion of the plasma, whose temperature can be measured by vacuum ultraviolet spectroscopy, is shifted to the outer regions.

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 (1–24 Å). It is scheduled to be installed early in 1986. This instrument will use two crystals which must be rotated and translated synchronously to carry out a wavelength scan. To obtain a spatial scan with this spectrometer system, it will be necessary to locate it close to the torus. This means that it 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 a 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 ENEA, Frascati (Italy) has built 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 has been installed and will be operational early in 1986

Soft X-Ray Pulse Height Analysis

The measurements 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. A first provisional system was operational in August 1984. The full system has now been installed and will become operational early in 1986.

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 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), Fig. 54.

The provisional system intalled in 1983 has now been replaced by the full system. It has already delivered

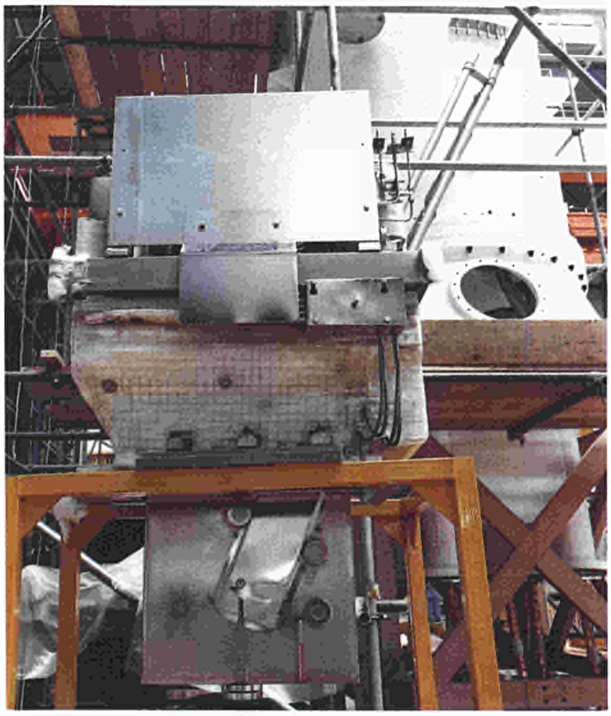

Fig. 54 One of two X-ray imaging cameras used to view a cross-section of JET.
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extremely important results on the stability of the plasma core during RF heating. The high time resolution of the detectors enabled the development of the periodic sawtooth instability to be followed in detail. The plasma seems to become unstable on a very short timescale ($\sim 50-200\,\mu$sec) resulting in a large helical deformation of the central configuration, Fig. 55. Subsequently the temperature in the helix drops and a slightly hollow, but again axial symmetric, profile results. It is expected that these experimental findings will have a tremendous impact on the understanding of this instability which has been known to exist for more than a decade, but has never been fully explained.

The most serious restriction on this diagnostic arises from the sensitivity 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 therefore which 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 system was built by IPP Garching.

Total radiation losses and spatially resolved radiation profiles have been obtained and used as input for the evaluation of the energy balance.

The total radiation losses vary typically between 40 and 80% of the input power depending on vessel conditions and density. This holds for both ohmic and radio frequency heating. At higher densities the profiles are generally hollow. They are, however, difficult to assess as the proximity of the antennae leads to a local enhancement of radiation which perturbs the symmetry of the profiles.

Interferometry

Density is one of the fundamental parameters of the plasma and its measurement has to be made reliably for every pulse. The main system used 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 with the beams transmitted through crystal quartz windows in the vacuum vessel wall. The optical components for the interferometer are mounted on a single large C-frame which is mechanically decoupled from the JET machine to minimise vibrations.

The interferometer is fully operational including the compensating interferometer for correcting movements of the mirrors mounted inside the torus vessel. Due to carbonisation these mirrors lose reflectivity and a change of wavelength for the compensating intereferometer must be considered.

The density profiles are always more or less peaked indicating an inward drift of the plasma particles.

In addition, a single channel 2mm microwave interferometer has been operating throughout 1985, but its role as the principal means of density measurement is being taken over by the infra-red system.

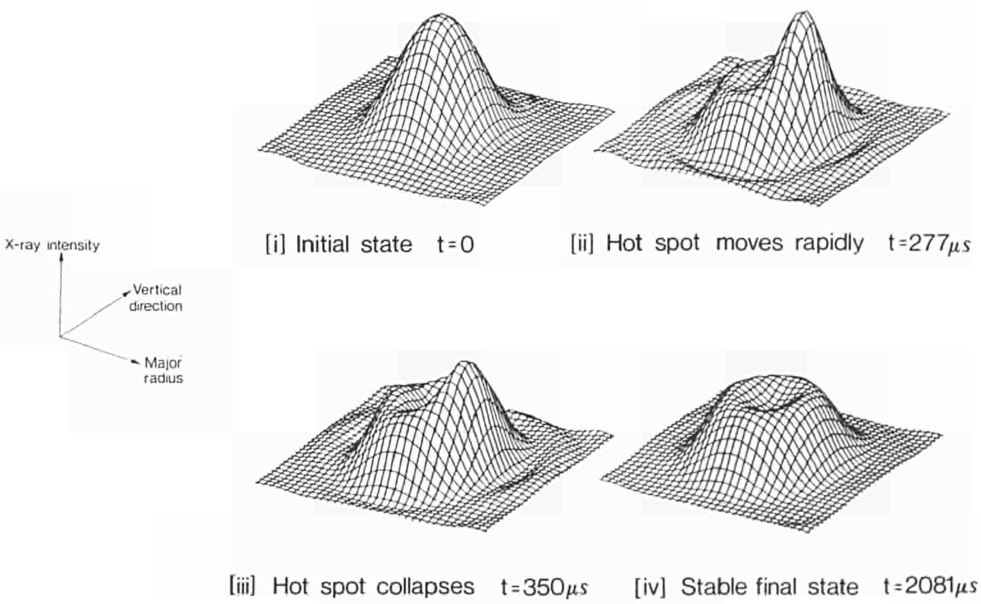

Fig. 55 X-ray emission during a sawtooth crash.
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Polarimetry

The interferometer can also be used to measure Faraday rotation caused by the poloidal field, if the rotation of the polarisation direction is recorded. In this way it is possible to obtain information on a crucial quantity—the current density profile. These measurements, together with others, should make it possible to determine the central current density within 10% accuracy. A contract, with CEA, Fontenay-aux-Roses, has been agreed to carry out the necessary modifications on the existing interferometer.

Reflectometry

The microwave reflectomer, like the interferometer , is a diagnostic for measuring plasma density. 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 been given some useful data on density profiles and 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 exchanges between plasma ions and neutral atoms.

The system, constructed for JET at the ENEA Frascati Laboratory, consists of an array of five separate analysers arranged to view different chords in a vertical section of the plasma. The full system is now operational. It routinely provides measurements of the ion temperature and of the ratio of hydrogen to deuterium in the plasma as well as ion temperature profiles of the central plasma. Due to its toroidal scanning capability, it will be possible to study the slowing down of the injected neutral beam particles.

Diagnostic Pellet Launcher

The hydrogen/deuterium pellet injector, developed by IPP Garching, Germany, is nearly complete including the work on the JET interface. Preparations are underway for installation of the equipment early in 1986.

The planned pellet injector from Oak Ridge would intrude on the space presently used by the diagnostic pellet launcher. It is therefore intended to install both injectors on the same neutral injector box which will be used as a common cryopump.

The diagnostic pellet injector is of the pneumatic type. The pellet is accelerated over a path of up to 800mm 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 produce a 10 to 100% increase in the particle content at the plasma densities and volumes expected during 1986.

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

JET THEORY

Introduction

Theory Division is responsible for the application of plasma theory and theoretical tools to describe the JET plasma, to gain an understanding of the plasma behaviour and to participate in the interpretation of measurements. The central task is, therefore, to provide a quantitative (computational) model of tokamak plasmas with the ultimate objective of including in this model all important effects observed in JET and other tokamaks. This model, then, provides a basis for predicting and planning future plasma experiments.

Although it is preferable to understand each effect theoretically (starting and ending up with analytical theory), in some cases it is necessary to rely on an empirical description. The effort allocated within JET to analytic theory is limited and the Project relies, through extended visits and Article 14 contracts, on assistance provided by theorists within the Associations. The principal contracts are listed in Appendix VI.

Theory Division interacts much more strongly with experiment than in most other plasma physics institutions as complex theoretical and computational procedures are needed to evaluate and interpret many measurements. Producing data banks for comparison with theory, checking the consistency of data, and assessing their margin of error are major practical tasks.

The Division is divided into three groups: 'Prediction Group', 'Analytic Theory Group' and 'Interpretation Group'. There is considerable overlap between their roles, requiring extensive collaboration between the groups and others within the Project. The close interaction between theory and experiment, which has resulted from both data interpretation and analysis being done in the same division, has proved to be very beneficial.

Data Banks (and Computing Hardware)

The number of people from JET using the Harwell IBM/CRAY computers has increased further to about 200. The computer hardware available at JET has been expanded and now consists of 32 colour graphics, 46 non-graphics terminals, and four Versatec printer-plotters. In addition, an IBM 5285 micro-computer with a floppy disc unit is available to facilitate transfer of programs between the local NORD system and the Harwell mainframe computers. A powerful 'personal computer' (IBM 3270-PC/GX) has been connected to the mainframe and tested with respect to local data evaluation.

During 1985, the JET bank of raw data (JPF) increased from 2552 MB to 13 388 MB of data for 2413 new pulse files. The corresponding first level of extracted physics data (PPF) grew from 630 MB to 3260 MB with 7938 new processed pulse files (in general, several PPFs are generated per pulse).

It has been agreed by the JET Council that the JET Survey Bank, among the higher level data banks, shall be used to fulfill the statutory requirement for JET data to be regularly released to the associations. This bank contains characteristic parameters for each plasma discharge. At the end of 1985, it contained 240 MB of data from 2177 pulses with a total of 23 333 time traces. The first four volumes, with the data to the end of 1984, have been distributed. Improvements in calibration of several diagnostics necessitated fairly extensive reprocessing of the 1985 PPF and derived data, causing a delay in their release.

Data Management Software

The most important new development has been the implementation of the data base management system NOMAD2. The Survey Bank and several others are managed by this system which proved both powerful and flexible. Interfaces to local software have been developed.

The data banks stored under the Statistical Analysis System, SAS, have been restructured completely. New maintenance programs based on 'menus' allow a wider application. Easier access to these banks and improved data loading have extended the use of SAS considerably.

To make JET data easier to access, the general access package GETDAT and the IBM graphical display programs have been upgraded in collaboration with the Experimental Divisions.

Code Libraries (Interpretation and Prediction)

The JET (Interpretation and Prediction) Code Libraries are collections of systematically written and maintained codes which as far as possible are made available for general use through documentation and advice.

A distinction must be made, for data interpretation, between codes for off-line analysis and those for intershot analysis. In the latter group, the FAST program has been fully integrated as a 'real-time' program on the local NORD computer system. Both FAST and CONKIN (packages for intershot analysis) have been expanded to include the new diagnostic systems of diamagnetic loops, multi-channel FIR interferometer, and the new gas introduction system. In addition, the computation of plasma boundary flux surface geometry, including the treatment of X-points, has been refined and an estimation of impurity influx has been introduced.

Among the stand-alone off-line interpretation codes the magnetic flux surface identification code IDENTB has been extended by annexes to calculate magnetic field line lengths in the plasma scrape-off layer and to identify rapidly the geometry of the magnetic surfaces where the safety factor q assumes rational values.

The program RFCALC produces for each RF antenna, data on generator power, coupling resistances, coupling efficiencies, voltage standing wave ratios and coupled RF power from transmission line measurements.

A code, which retrieves raw data from the neutral particle analyser diagnostic and produces the first level evaluation, has been installed and is now routinely used. A similar program has also been set up for the electron cyclotron emission diagnostic.

Two packages are now fully operational for inverting line- integrated data, from bolometry and far infra-red interferometry, into spatial radiation and electron density profiles, respectively, for a prescribed flux surface geometry. A program for producing the Hugill parameters, which indicate the stability of the plasma as a function of time, has been made available.

- The program MESHJET delivers a finite element grid for plasma equilibrium calculations starting from given engineering structures such as coils, vessel, iron core, etc.
- An extensive package to provide the cross-sections for atomic physics processes such as ionisation, recombination, excitation of impurities has been compiled. In addition, a stand-alone code to compute spatial impurity distributions, by solving a set of continuity equations for given electron density and temperature profiles, has been completed.
- In preparation for the heating of JET plasma by neutral particle beams a multiple pencil beam code has been modified to include JET flux surface geometry, and, together with an updated program to compute the slowing-down of the fast ions, delivers energy and particle deposition profiles for injected neutrals.

Also in expectation of future developments a stand-alone package for pellet ablation (W A Houlberg, Oak Ridge, USA) has been obtained and adapted to JET needs.

Data Interpretation

A great deal of the interpretation work has been done under the topics of 'Confinement of Energy and Particles' and 'MHD Activity and Disruptive Instabilities' and is described in the section reporting on the results of JET operations in 1985. Several additional studies are summarised below.

The analysis of bolometer data has revealed that in many cases the surfaces of isoemissivity and of magnetic flux do not coincide, a result which questions the widely applied generalised Abel inversion. A similar analysis showed, on the other hand, good agreement between isoelectron density and magnetic flux surfaces.

An operating regime for the present JET configuration in which the plasma is bounded by a magnetic separatrix, see Fig. 57, has been identified by analysing the multipolar field produced by poloidal field coils and iron core.

In another study, a correlation has been established between various types of MHD instabilities and the formation of electron temperature and current density profiles.

The dependence of the limiting temperature gradient on machine parameters has been investigated in connection with the observation of 'profile consistency' for the electron temperature.

An estimate of anomalous electron energy transport has been obtained from the propagation of heat pulses launched by sawtooth oscillations in the plasma interior. This gives a thermal diffusivity higher than derived from equilibrium profiles by transport analysis. This discrepancy could be resolved by including a convective term in the heat flux. A similar analysis of the density pulse originating from a sawtooth yields a particle diffusivity which is consistent with that deduced by other methods.

The fraction of the ICRH power coupled into the torus which is absorbed by the plasma has been estimated at about 75 % by examining the evolution of the plasma energy during switch-on and switch-off periods of the ICRH waves.

Modelling of JET Plasmas

Progress towards a comprehensive and consistent quantitative plasma model has been achieved along three lines: firstly the model has been refined by including more effects; secondly new extensive and accurate codes for special effects have been acquired or developed as stand-alone programs; finally, simplified and routinely applicable codes have been constructed, benchmarked with the above mentioned more accurate codes, and connected to the overall model.

For practical reasons, there are still two basic equilibrium transport codes, GETTO and ICARUS. Refinements in these codes now allow calculations for a free boundary plasma, including plasma shift and compression. The computation of the magnetic field has been extended to cover also the region outside the plasma for comparison with magnetic signals measured on the exterior of the vessel. New links have been completed with the pellet injection code, non-coronal impurity transport package, and with the updated multiple pencil beam code, all mentioned above.

Much effort has been spent on accurate stand-alone codes to describe the propagation and absorption of ion cyclotron waves.

A multi-dimensional wave propagation code (S-I Itoh et al, Hiroshima University, Japan) has been installed and compared with others. Ray tracing codes have been found to be inadequate in some parameter ranges.

As in neutral particle beam heating, ICRH produces fast non-Maxwellian ions. The interaction of these ions with the background plasma must therefore be described by a code based on kinetic equations. The code BAFIC has been run for fundamental minority, second harmonic, and RF/neutral particle beam hybrid heating schemes in JET.

In the plasma boundary layer, magnetic flux surfaces are not closed so that genuine two-dimensional flows and transport must be considered. A corresponding fluid code has been completed and linked to a Monte-Carlo code (NIMBUS) for consistent treatment of recycling neutral particles.

MHD-stability and kinetic equations are typical examples of codes that are much too bulky for routine connection to the main model.

As a step towards overcoming this difficulty, a package which checks a series of stability criteria (D Lortz, IPP Garching) for any given equilibrium has been installed and tested.

In collaboration with Chalmers University of Technology, Göteborg, the code BAFIC is approximated by a simple semi-analytic model; results of both are in good agreement for typical cases.

Comparison of Model Results and Measurements

The results of the plasma model have been extensively compared with measurements from both ohmic and RF heated JET pulses.

Fig. 56 and Table 10 provide an impression of the typical degree of agreement. Fig. 56 compares electron temperature spatial profiles and Table 10 other characteristic parameters.

Table 10
Comparison of Results for Shot 3852 (3.4T, 3.0MA)

Parameter	Measured	Computed
$\bar{n}_e(10^{19}m^{-3})$	2.61	2.55
$n_{e0}(10^{19}m^{-3})$	3.55	3.60
T_{e0}(keV)	2.95	2.95
T_{i0}(keV)	2.46	2.45
Z_{eff}	3.8	2.8
P_{RAD}(MW)	1.12	1.09
P_{Ω}(MW)	2.14	2.37
τ_E(ms)	680	710

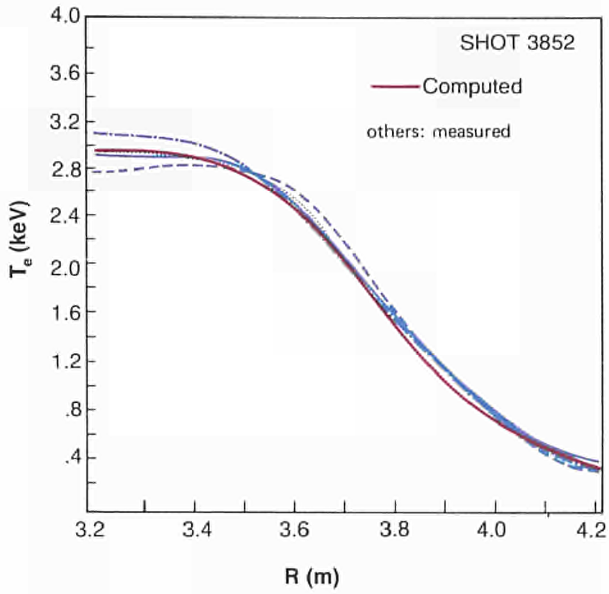

Fig. 56 Comparison of measured and computed values of electron temperature spatial profiles.
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In spite of its partial empirical basis, the model can be used for relative comparisons, from discharge to discharge, to examine whether the measurements are consistent. As a result of such procedures, it was concluded that the 1985 measured electron temperatures were too high. This conclusion was confirmed by a recalibration of the ECE diagnostics. Many other comparisons, especially for ICRH discharges have been affected by this and must be repeated. An independent result is that the (empirical) sawtooth description in the model reproduces both the ohmic and the giant ICRH sawteeth with the same assumptions. A detailed computation of the background neutrals in JET shows a strong poloidal asymmetry. A comparison with neutral particle analysis data is still pending.

Predictive Computations

Plasma equilibrium codes have shown that separatrix (X-point) configurations with plasma currents up to about 4MA should be possible in JET with minor alterations to the polidal field coils. Fig. 57 shows an example. Extensive studies on X-point location and plasma shape have been carried out.

The full plasma model has been applied to assess the performance of JET for a variety of possible limiter materials in the tritium phase with the full planned additional heating power.

A study on the effects of pellet injection found that speeds of about 10kmså[1] are necessary for a 6mm diameter pellet to penetrate into the interior ($q \leq 1$) region of a plasma close to ignition conditions.

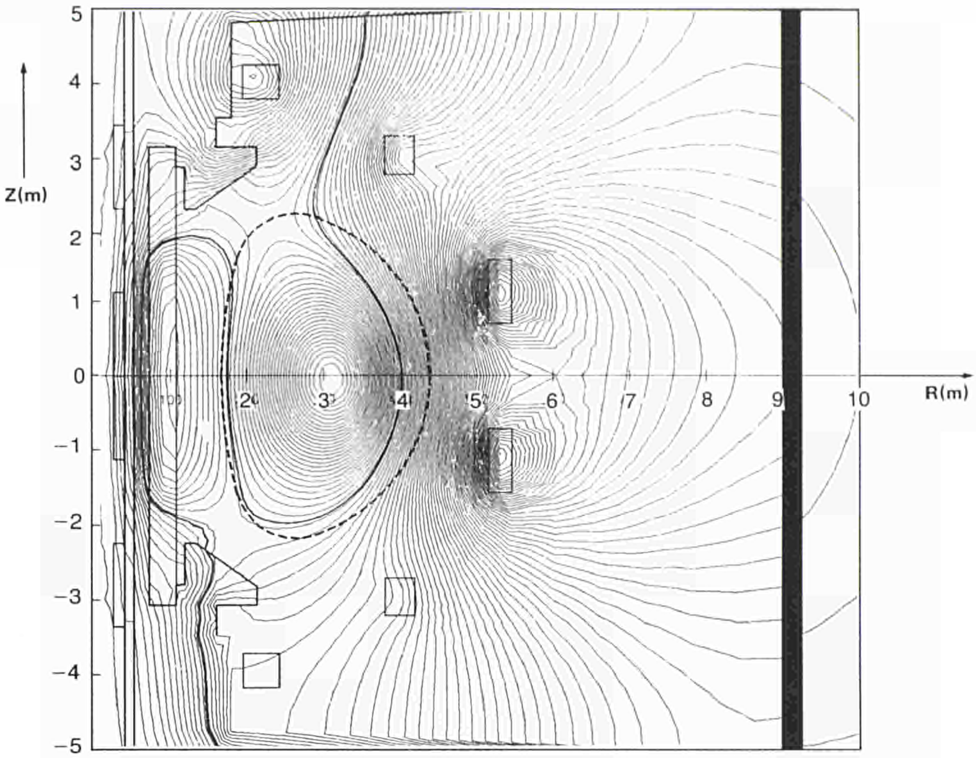

Fig. 57 Separatrix (X-point) configuration. Plasma equilibrium codes have shown that this configuration should be possible in JET, up to 4MA plasma current, with only minor alterations to the poloidal field.
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Finally, the feasibility of stabilising the sawtooth oscillations by feedback with ICRH and neutral beam current drive has been investigated.

Analytic Plasma Theory

Theories have been derived from first principles for a number of plasma effects.

Plasma flows which must be expected in JET, at least in the case of neutral injection, can modify the plasma equilibrium. The new equilibrium equation can change its mathematical character from elliptic to hyperbolic depending on the strength of the flow, and these transitions are being studied.

A plasma flow, ie, toroidal and poloidal rotation, can also have a strong effect on the transport of impurities. This has been shown by solving steady−state fluid equations in the large−aspect ratio approximation.

The MHD theory of sawtooth oscillations for JET had to be modified considerably to take into account the absence of precursor signals and the rapidity of the collapse.

A frequent type of plasma current disruption appears when the particle density is increased. This type of disruption in JET has been explained in terms of an unstable contraction of a strongly radiating plasma boundary layer.

In a systematic analysis of the method of 'scaling laws' the effect of experimental errors are taken into account. Procedures to identify truly independent variables have been investigated.

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)

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 ix). The JET Council is assisted by the JET Executive Committee and is advised by the JET Scientific Council, see Fig. 58.

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.

Four meetings of the JET Council were held during 1985: on 28/29 March, 13/14 June, 20 September and 24/25 October. (The meeting held on 20 September was an extraordinary meeting convened to nominate a new Director following the death of Dr H-O Wüster in June 1985).

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 1. The Committee met seven times during the year on 8 February 14/15 March, 9/10 May, 12 July, 26/27 September, 6 November and 12/13 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;

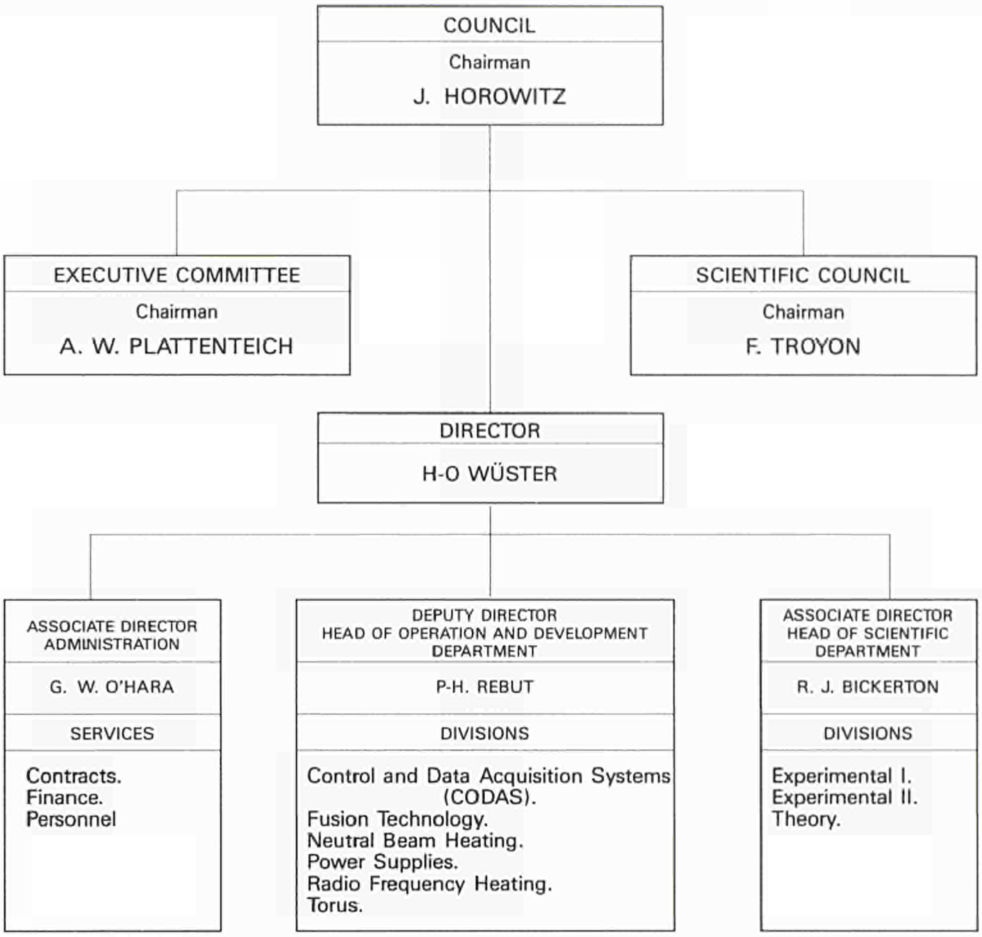

Fig. 58 Organisation of the JET Joint Undertaking (January 1985).

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● To perform such other tasks as the JET Council may request it to undertake.

The membership of the JET Scientific Council is shown in Appendix II. The Scientific Council met four times during the year on 29/30 January, 19/20 March, 4/5 June and 10/11 October.

Discussions were based on regular reports on the progress of the JET ohmic and RF heating programmes, the release of JET data, the status of diagnostic systems and neutral beam injection and extensive analysis of limiter and impurity controls strategies, pellet injection and the consequences of different funding levels for the JET Programme 1985-1989.

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 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 and services at proven cost, to meet the requirements of the JET Project.

Project Team Structure

From the start of the Operational Phase in mid-1983 until towards the end of 1985 the structure of the Project consisted of three Departments: the Operation and Development Department; the Scientific Department; and the Administration Department. This structure is shown in Fig. 58

The JET Directorate

The three Heads of Department reported to the Director of the Project and together with the Director they formed the JET Directorate. Various special functions were carried out by the Director's office as shown in Appendix III. The Internal Audit Office monitored the Project's financial activities and provided advice on accounting and control procedures as well as maintaining links with the Court of Auditors. The Project Control Office was responsible for financial planning and for the preparation of the Project Development plan and Project Cost Estimates. The Secretariat provided secretarial services to the JET Council and to the Executive Committee and also to the JET Project Board, JET's internal management committee.

Administation Department

The Administration Department was 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 Appendix III.

Operation and Development Department

The Operation and Development Department was 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 contained six divisions:

1. Torus Division, which was 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 organised major shut-downs 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 was 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 was 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 participated in the studies of the physics of neutral beam heating.

4. Radio Frequency Heating Division, which was responsible for the design, construction, commissioning and operation of the RF heating system during the different stages of development to full power. The Division participated in the studies of the physics of RF heating.

5. Fusion Technology Division, which was 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 included design and construction of facilities for the handling of tritium.

6. Control and Data Acquisition Systems Division (CODAS), which was 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 Appendix III.

Scientific Department

The Scientific Department was 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 contained three divisions:

1. Experimental Division 1, which was responsible for the specification, procurement and operation of approximately half the JET diagnostic systems. ED1 in particular, looked after electrical measurements, electron temperature measurements, surface, and limiter physics and neutron diagnostics. The Division was 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 was responsible for the specification, procurement and operation of the other half of the JET diagnostic systems. ED2 in particular, looked after all spectroscopic diagnostics, bolometers, interferometry, the soft X-ray array and neutral particle analysis.

3. Theory Division, which was 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 Appendix III.

New Project Team Structure

In September 1985, the JET Council nominated Dr P-H Rebut as Director of the Project and Dr R J Bickerton as Deputy Director. Subsequently, at its October meeting, the Council approved a revised organisational structure put forward by Dr Rebut.

The new organisation required a number of new senior nominations:

- Dr R J Bickerton to be Head of Heating and Theory Department
- Dr M Keilhacker to be an Associate Director and Head of Experimental Department
- Dr M Huguet to be Head of Machine and Development Department

Mr G W O'Hara remains as Associate Director and Head of the Administration Department.

This new organisational structure, which is shown in Fig. 59 will be described fully in the 1986 JET Annual Report.

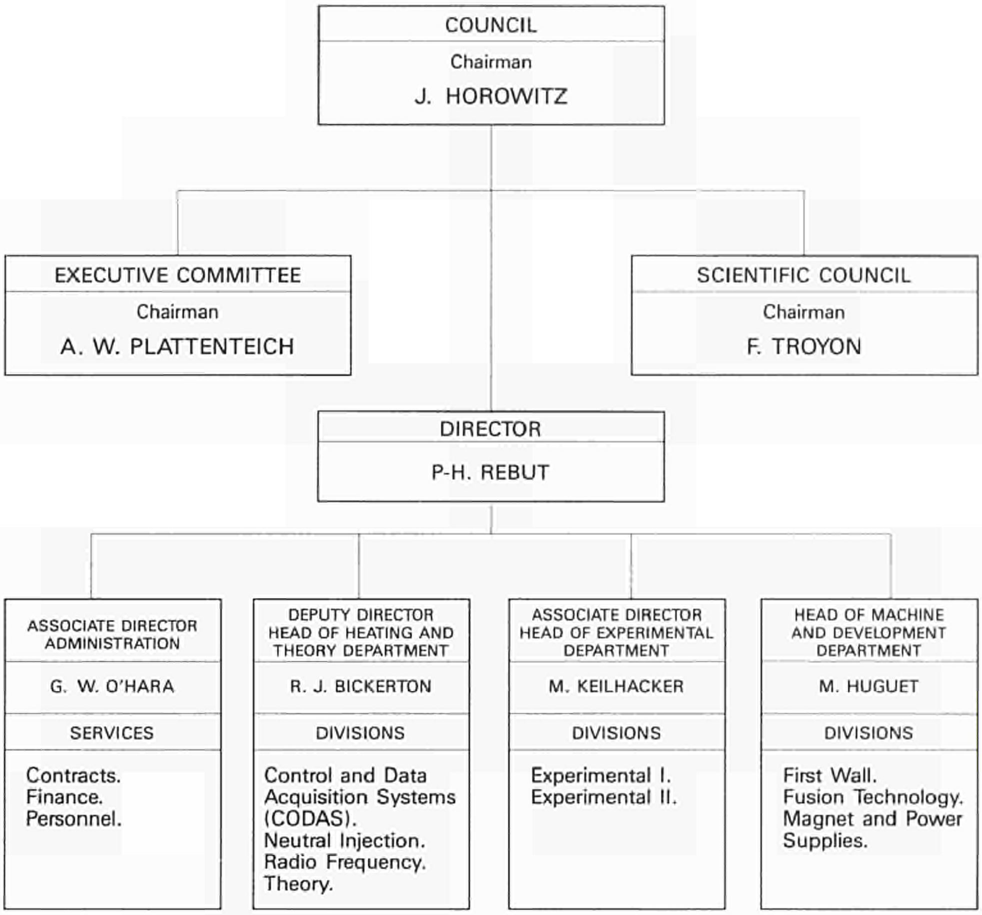

Fig. 59 The new organisational structure of the JET Joint Undertaking (January 1986).
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The Administration of JET

Finance

JET's financial resources are governed by periodic revisions to the Euratom Pluriannual Fusion Programme. A programme for the period 1985 to 1989 was adopted in outline by the Council of Ministers on the 19 December 1984. Details of the allocation available to JET are not yet available.

The budgets for 1985 were approved at 96.676 Mio ECU for commitments and 94.667 Mio ECU for both income and payments. Towards the end of the financial year the JET Council, having regard to the available cash resources of the Project, elected to forego the 4th Quarter contribution from Members thus, in effect, reducing the Income Budget to 72.792 Mio ECU; the Payments Budget was also reduced to the same total.

The Commitments and Payments Budgets each subdivide into three phases of the Project – Basic Performance, Extension to Full Performance, and the Operational Phase; further subdivisions distinguish between investment, operating and personnel costs. The Basic Performance Phase is complete with the exception of minor items of a residual nature.

Commitments (Tables 11 and 12)

Of the total appropriations in 1985 of 127.43 Mio ECU (including 30.75 Mio ECU brought forward from

Table 11
Commitment Appropriations for 1985

	Mio ECU
1985 Commitments Budget	96.68
Uncommitted amounts available from 1984	30.75
	127.43
Commitments made during the year	90.96
Balance uncommitted in 1985 available for use in 1986	36.47

Table 12
Commitments and Payments for 1985

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	0.15	−0.31	4.85	3.83
Title 2 — Operating Costs	0.08	—	—	—
Title 3 — Personnel Costs	0.03	—	—	
TOTAL Phase 1	0.26	−0.31	4.85	3.83
Phase 2 — Extension to Full Performance				
Title 1 — Project Investments	60.95	25.85	35.29	30.64
TOTAL Phase 2	60.95	25.85	35.29	30.64
Phase 3 — Operational				
Title 2 — Operating Costs	44.33	44.16	42.54	39.59
Title 3 — Personnel Costs	21.89	21.26	20.64	19.94
TOTAL Phase 3	66.22	65.42	63.18	59.53
Project Total—All Phases	127.43	90.96	103.32	94.00

previous years) 90.96 Mio ECU was committed and the balance of 36.47 Mio ECU was available for carry forward to 1986.

The details of the commitment appropriations available and of the amounts committed in each Phase during the year given at Table 12 are summarised as follows:

The appropriations available in the Basic Performance Phase of the Project during 1985, 0.26 Mio ECU, have been supplemented by a further 0.31 Mio ECU, representing commitments which are no longer required in this Phase; the total of 0.57 Mio ECU will be transferred in 1986 to meet commitment requirements in the Extension to Full Performance Phase of the Project.

In the Extension to Full Performance Phase of the Project 25.85 Mio ECU was committed, leaving commitment appropriations not utilised at 31 December 1985 of 35.10 Mio ECU to be carried forward to 1986.

In the Operational Phase 65.42 Mio ECU was committed leaving a small balance of unused appropriations, 0.80 Mio ECU, to be carried forward to 1986.

Income and Payments (Table 13)

The original budgets in 1985 of 94.67 Mio ECU for both Income and Payments were reduced to 72.79 Mio

Table 13
Income and Payments for 1985

	Mio ECU		
Income			
Revised Budget for 1985		72.79	
Income received during 1985			
(i) Members Contribution	65.62		
(ii) Bank Interest	3.81		
(iii) Income transferred from Reserve	0.71		
(iv) Unused payment appropriations brought forward from 1984	5.67		
(v) Miscellaneous	0.02		
Total Income		75.83	
Excess income to be carried forward against Members' future contributions			3.04
Payments			
Revised Budget for 1985		72.79	
Amounts available in the Reserve Account to meet outstanding commitments at 31 December 1984		30.53	
Total Payment Appropriations		103.32	
Payments during 1985	94.00		
Transfer of excess Reserve Provisions to Income Account	0.71		
		94.71	
Balance of unutilised appropriations			8.61
Total unutilised appropriations			11.65
to be allocated:-			
(i) Reserve at 31 December 1985 to meet outstanding commitments at that date			8.61
(ii) Reduction of Members' future Contributions			3.04
			11.65

ECU as a result of the JET Council's decision not to make the final quarterly call for contributions from Members; The actual income in 1985 was 75.83 Mio ECU – an excess over budget of 3.04 Mio ECU which is being carried forward to be offset against the future contributions of Members, together with 12.44 Mio ECU carried forward from 1984.

Of the total available payment appropriations of 103.32 Mio ECU, payments amounted to 94.00 Mio ECU and 0.71 Mio ECU were transferred to income leaving a balance of 8.61 Mio ECU which has been retained in the Special Reserve Account to meet commitments outstanding at 31 December 1985. More detailed comments are given in the following paragraphs (Payments by Phase are summarised in Table 12).

Contributions from Members

The Budget for Members' contributions (revised) was 65.62 Mio ECU 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 14 gives the final percentage contributions from Members relating to 1984).

Bank Interest

Income is normally received on a quarterly basis in respect of Members Contributions and intermittently in respect of VAT refunds and interest credits. Throughout the financial year, depending on the timing of the receipt of income 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 1985, interest earned amounted to 3.81 Mio ECU.

Transfers from Reserve

During the year 0.71 Mio ECU of the amount reserved at 31 December 1984, 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.

Unused Payment Appropriations and Excess Income From Earlier Years

5.67 Mio ECU of unused payment appropriations and excess income arising in 1984 and held for reduction of Members' future contributions was transferred to income in 1985.

Summary

Table 15 summarises the financial transactions of the JET Joint Undertaking as at 31 December 1985. The final audited accounts are published as a separate document.

Table 14
Final pecentage contributions to JET 1985 based on the Euratom participation in Associations' contracts for 1984.

Member	%
Euratom	80.0000
Belgium	0.1401
CEA, France	2.3010
ENEA, Italy	0.9058
CNR, Italy	0.1240
Risø, Denmark	0.0835
Luxembourg	0.0039
KFA, FRG	0.8068
IPP, FRG	2.6358
KFK, FRG	0.5276
SERC, Sweden	0.1578
Switzerland	0.4236
FOM, Netherlands	0.4390
UKAEA	11.4511
	100.0000

Table 15
Summary of Financial Transactions at 31 December 1985

	Mio ECU
Cumulative commitments	600.5
Cumulative payments	542.3
Unpaid commitments	58.2
Of which carried forward on reserve account	8.6
Amount available from 1984 and 1985 due to be set off against future contributions from Members	15.5

Contracts

The nature and volume of the work of JET's Contract Service has continued to change during 1985, reflecting the requirements of the operational phase.

Minor Contracts

Minor contracts are those which have a value below 50,000 ECU. The volume handled by the Contracts Service increased from 4791 in 1984 to 6578 in 1985, an increase of 37% over 1984. This increase is a result of the continuing higher demand for consumables which was expected with the commencement of the JET operational phase.

This is illustrated by the fact that minor contracts placed in 1985 are three times greater in volume than those placed in 1982, the last full year of the Construction Phase.

To cope with increase in volume, a computerised system was introduced at the beginning of 1984 to handle requisitions. This system allocates contract numbers and stores the data in such a way that allows easy reference. A small value order system introduced from the beginning of 1985 allows the speedier processing of orders with a value below 500 ECU. These orders are now processed within 24 hours of receipt of the demand requisition. The number of orders processed in this way in 1985 amounted to 3,788, representing 55% of all minor contracts placed while their aggregate value of 739,074 ECU amounted to 5% of the total value of all minor contracts placed, including amendments.

Major Contracts

Major contracts are those that have a value greater than 50,000 ECU. The number of these contracts placed increased from 81 in 1984 to 91 in 1985.

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 1899 suppliers, is capable of producing tender lists for any of 458 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. 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.

In addition to placing orders, the Contracts Service is also responsible for the import and export of JET goods. JET is entitled to claim for 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 United Kingdom 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 handled during 1985 was 860, an increase of 11.5% over the 1984 figure. The number of exports in 1985 was 332, a number similar to that for 1984. There were also 523 issues of goods to UK firms during 1985.

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 are 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 16 shows how contracts placed to date have been allocated between countries. Included in the figures are all contracts with a value of 10000 ECU and above, placed prior to 1984, together with all contracts placed in 1984 and 1985 regardless of value.

Table 16
Allocation of JET Contracts
(position as at 31 December 1985)

Country	Total of ECU Values	% of Total
UK	179182713	44.57
Germany	95889190	23.85
France	40339456	10.03
Italy	29197602	7.26
Switzerland	22524534	5.60
Netherlands	8036436	2.00
Denmark	7506970	1.87
Belgium	5978371	1.49
Sweden	3133013	0.78
Ireland	311051	0.08
Others	9950240	2.47
Totals	402049576	100.00

Personnel

The main task of JET's Personnel Service in the past year has been to try to fill the full allocation of 484 team posts approved by the JET Council in 1984 for the Operational Phase of the Project. The difficulties in recruitment, experienced in previous years, has however, persisted.

The allocation of team posts includes 260 seconded from the UKAEA, 165 Euratom posts, 40 Assigned Associated Staff and 19 DG XII Euratom posts. During 1985, the number of team posts filled increased from 384 to 410 with an additional 43 posts temporarily filled by contract staff. Fig. 60 shows the composition of staff by nationality. Figures 61 and 62 respectively show the

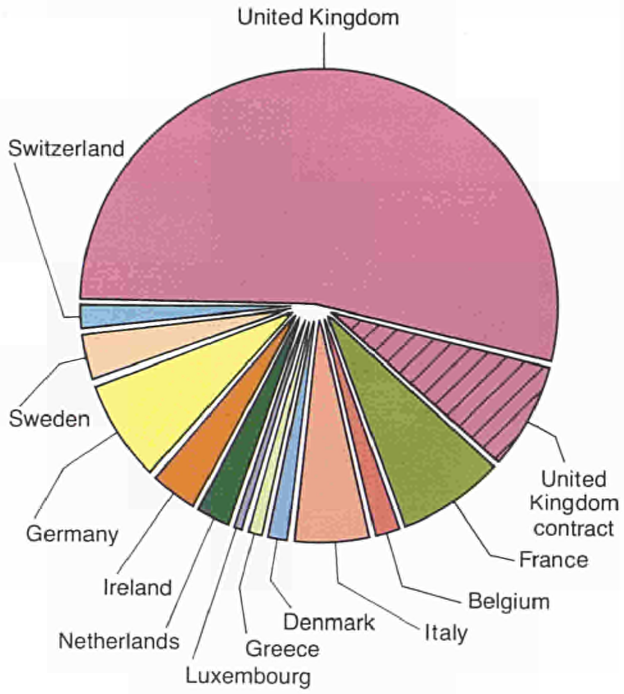

Fig. 60 Project team staff by nationality.
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development of numbers for Euratom and UKAEA staff over the period from mid 1981 to the end of 1985. A list of staff is given in Appendix IV.

Euratom Staff

The number of applications received from the Associated Laboratories was low during 1985. During the year, 11 newly appointed Euratom staff took up duty, but this was offset by the 10 staff in this category who left, mainly to return to their parent organisations. At the end of 1985, there were 150 Euratom staff in team posts, one more than at the end of 1984.

UKAEA Staff

Joint recruitment of scientific and technical staff by JET and the UKAEA has also continued to be disappointing. This is despite the use of extensive advertising, specialist recruitment agencies and contacts with university appointment boards. There is no reluctance on behalf of the UKAEA to guarantee employment to candidates at the end of their contracts with JET and this difficulty in recruitement reflects, to some extent, the lack of competitiveness of the UKAEA salaries in the United Kingdom employment market.

Of the 26 additional staff seconded to JET during the year, only six were already in the employment of the UKAEA. Allowing for resignations, this represents a net increase of 15 staff over the previous year, two of these being professionals. More than half of those who resigned were administrative staff.

Assigned Associate Staff

The Assigned Associate Staff Scheme came into operation in 1981 to enable staff from the Associated Laboratories to be seconded to JET for periods of up to two years. The costs of each member of staff assigned in this way are shared between the Laboratory concerned and JET.

Most of the assignments, since the introduction of the scheme, have been for relatively short periods. In 1985 the average period for an assignment was about four months. Ways are being considered of making more use of this scheme to help cope with the shortfall in the recruitment of permanent staff. Table 17 shows the contribution made by the Associated Laboratories during 1985 and Table 18 the deployment of Assigned Associate Staff within the Project.

Table 17

Contribution made by Associated Laboratories During 1985

Associated Laboratory	Man-Months
IPP (The Federal Republic of Germany)	61.00
ENEA (Italy)	45.50
FOM (The Netherlands)	30.50
CEA (France)	30.25
CRPP (Switzerland)	25.50
Risø (Denmark)	24.00
ERM (Belgium)	18.00
JEN (Spain)	10.00
CNR (Itlay)	7.25
SERC (Sweden)	6.50
KFA (The Federal Republic of Germany)	4.00
Total	262.50

Table 18

Assigned Associate Staff within the Project

Division	Man-Months
Experimental I	81.50
Experimental II	98.75
Radio Frequency Heating Division	46.25
Theory Division	23.00
Neutral Beam Heating Division	12.00
Fusion Technology Division	1.00
Total	262.50

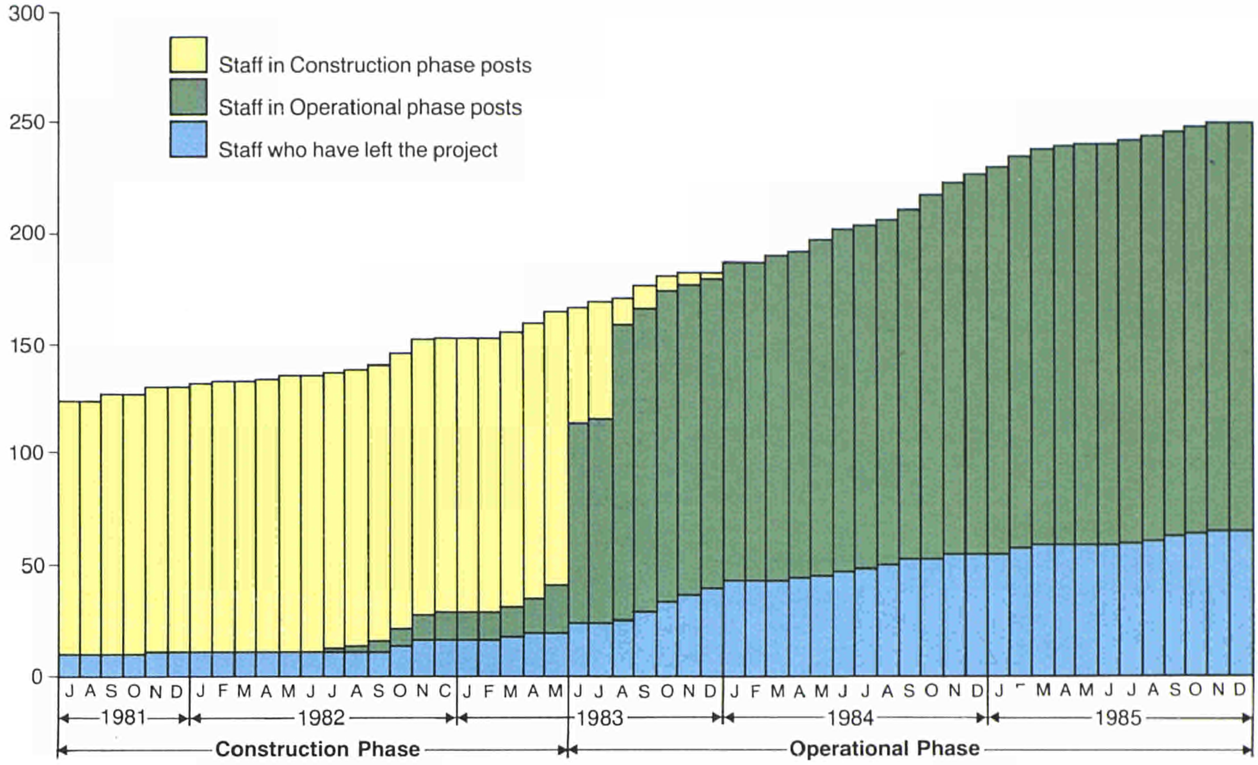

Fig. 61 Recruitment of EUR team staff (position at the first of each month). July 1981—December 1985.
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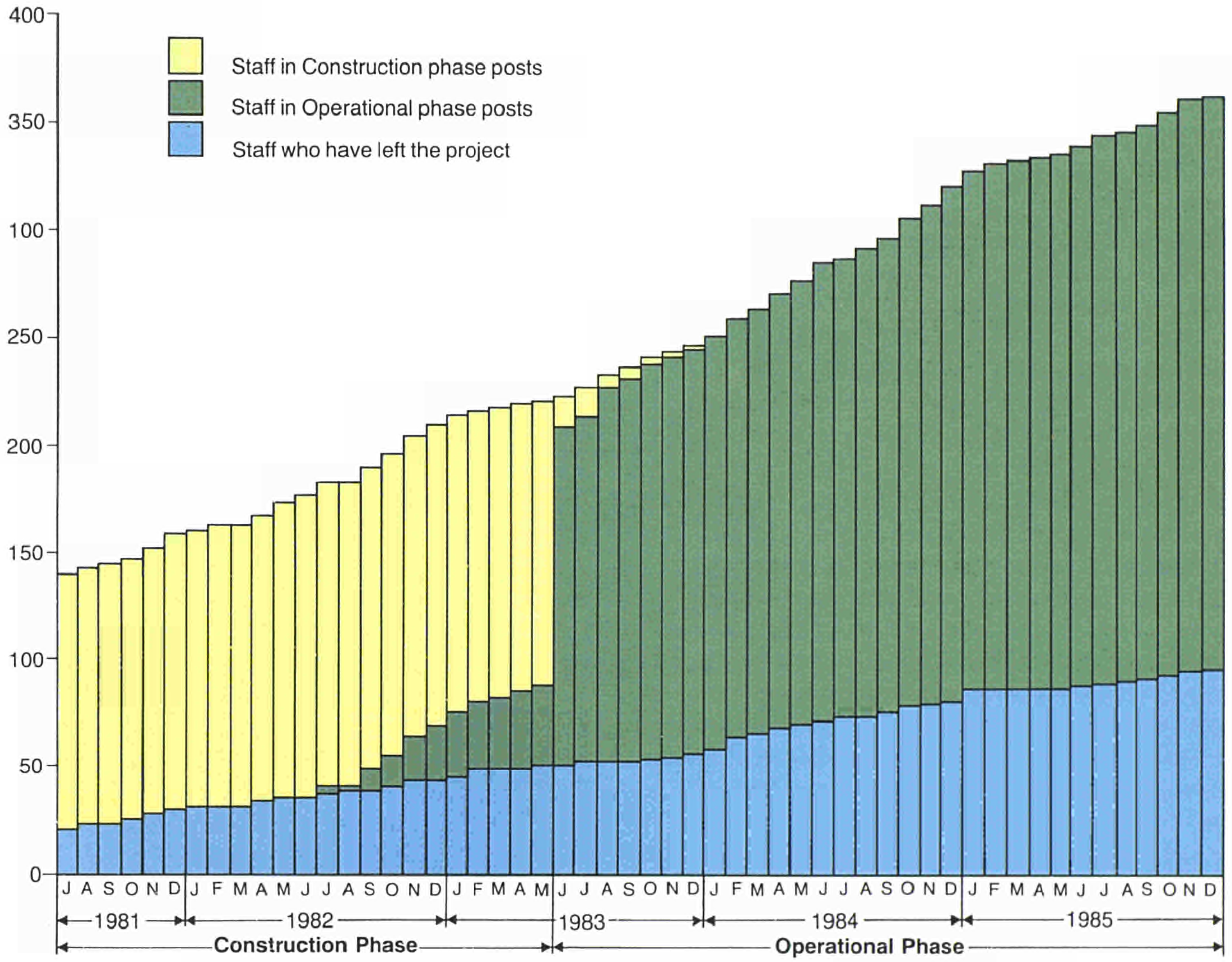

Fig. 62 Recruitment of UKAEA team staff (position at the first of each month). July 1981—December 1985.
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DG XII Euratom Staff

These are staff who have been assigned to the Project from the Directorate General of the Commission responsible for Science, Research and Development (DGXII). Initially, four staff were allocated to JET from posts already allocated to the Euratom Associated Laboratories. This number was later increased to 19 to complement the limited number of Euratom posts at JET.

In 1984 the Commission agreed to utilise three DGXII vacancies for the recruitment of staff specifically for JET. Two of these candidates have been appointed. The total number of staff from DGXII assigned to JET at the end of the year was twelve.

Other Categories of Staff

Visiting Scientists

At the beginning of 1985, the JET Council approved an increase in the number of visiting scientists from five to ten. During 1985, there were nine visiting scientists working at JET — two from the United Kingdom and one each from Australia, Canada, China, Italy, Poland, Spain and the United States of America. By the end of the year arrangements were well advanced for five new appointments in 1986, including two from the USSR.

Students

The JET Student Scheme enables four categories of students — sandwich, pre-university, vacational and junior — to be appointed through the UKAEA.

The demand for student places increased substantially during 1985, as expected, and 67 students were employed for a total of 180 man-months. In 1985, the students, who were all EEC nationals, were employed in scientific, engineering, computing and administrative areas of work with over three quarters of the students in the sandwich and pre-university categories. Because of the high demand, the total complement for student places has been increased to 220 man-months for 1986.

Fellowships

The JET Fellowship Scheme, for scientists at post-doctoral level, has been under review during the year and a new scheme is expected to be introduced during 1986. The two fellows who joined JET in 1984 completed their appointments in 1985, both having made valuable contributions to the Project. One of these fellows has been recruited by a partner and joined JET under the Assigned Associate Staff scheme.

In addition, one candidate from the Euratom Fellowship Scheme, which is open to students up to doctorate level, was assigned to JET during 1985. This brings the number of these fellowships at JET to a total of four, the other three having been assigned in 1984.

Support Staff

This category is made up from staff from industry who provide services, under JET direction, on a long term basis. Experience has shown that this is an effective way of providing specialist services for all divisions. Except for supervisors, they are all at a non-professional level, being grouped into teams of electricians, draughtsmen, computer operators, vacuum technicians and staff employed for the Main Assembly Contract (MAC) and Main Electrical Contract (MEC).

The number of support staff working on JET in 1985 was 152, the same number as in the previous year.

Consultants and Attached Staff

The seven consultants, who were appointed in 1985, provided specialist advice on a variety of topics including additional heating and diagnostic techniques.

Eleven attached staff from the USA, Canada and Japan, worked on JET during 1985, mostly for short periods. These staff were supported financially by their parent Laboratories.

The Administration of Personnel

The introduction of two-shift operation on the machine, which was introduced at the beginning of 1985, influenced the working conditions of many staff. A consequential effect of this change was to concentrate maintenance work and the commissioning of new equipment at the weekends, when the machine was not operational. Generally, staff who have been affected by these changes have readily adapted to the new patterns of work.

Shift Work

During operational periods the machine was operated from Tuesday to Friday between 0630 and 2230. This required 113 staff from the Operational and Development Department (including 12 shift technicians and 26 contract staff) to man 16 posts, each person working on average five shifts per month. The number of shifts worked by staff from the Scientific Department varied according to the scientific programme. On average, four shifts per month were worked by the 45 staff involved in this part of the programme.

Overtime

On average, 500 hours per week of overtime were worked during the first half of the year. This represents an increase of 35% over the average weekly figure for 1984. Most of this overtime (79%) was worked by staff from the Operation and Development Department with 65% occurring at weekends because of restricted access to the machine on weekdays.

The pattern of overtime working remained substantially the same for the second half of the year with a peak occurring towards the end of the summer shutdown period.

On-Call

On-call rotas were reduced during the year, chiefly due to the introduction of the two-shift system, which meant that staff were available for longer periods on site to monitor the operating systems. This resulted in a reduction by about a quarter in the number of staff on-call.

A further reduction is expected in 1986 as the programme of job training for the twelve shift technicians is completed. The shift technicians, whose duties include a round-the-clock safety monitoring service, will be able to cover more of the on-call duties outside the hours of machine operation.

Staff Training

Training courses were organised for the shift technicians during the summer shutdown period by the Harwell Education and Training Centre. The courses covered seven different aspects of the shift technicians work and were aimed at increasing their capability to make them more effective.

The one-day induction courses for new staff continued throughout the year and a total of 75 staff attended the six sessions held during 1985.

Under the language tuition scheme run by the Project, 35 staff from non-English speaking countries received English tuition and over 90 staff took lessons in other European languages.

The Joint Safety Section organised cardio-pulmonary resuscitation courses as well as those on safety and manual lifting. A lecture was also organised on the safe use of radio-frequency equipment.

Various other specialised courses were arranged for staff with specific training needs.

Staff Representation

Three meetings were held during the year between the JET management and the Staff Representatives Committee (SRC) to discuss a wide range of topics concerning working conditions.

Liaison with the Partners

Contact between JET and the Associated Laboratories was maintained on a regular basis to discuss such matters as recruitment of staff and their re-employment at the end of their secondment to JET. The UKAEA and in particular, Culham Laboratory, continued to give valuable assistance to the Project in this regard.

Annual staff reports required by partners in respect of their staff in the JET team were completed during the year. These reports provide the partners with information for career development and assistance in re-absorbing staff into their parent organisations.

EEC Pension Scheme

Negotiations to include JET Euratom staff in the EEC Pension Scheme were concluded towards the end of the year. The EEC Council of Ministers agreed to a change in the Staff Regulations which resulted in JET Euratom staff qualifying for benefits under the EEC Pension Scheme. Two meetings were organised between staff and senior officials of the Commission's staff office to explain the general provisions of the scheme and to deal with individual cases.

Transfer of Staff Following Re-organisation

The re-organisation of JET, which was approved by the JET Council in October, involved the regrouping of many staff into new departmental and divisional structures. A number of new posts have been created as a result of the re-organisation and these have been advertised. By the end of the year, the first stage of these internal transfers had been completed.

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 areas, have a specific line management responsibility for the safety of activities under their control. Further support is provided by the Joint Safety Services, 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 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 some categories of work undertaken by JET staff and contractors. The proposed safety precautions must then be approved at senior management level before the work is started. Precautions include the use of permits to work for activity 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 Service and the JET-UKAEA Liaison Committee set up under the Support Agreement. As a 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 1985

The major potential hazards continued to be primarily electrical due to the high-voltage and high-current pulses used to produce strong magnetic fields. During the year the Personnel Safety and Access Control System of interlocks controlled access to the torus hall and basement. The turnstile access to these areas was commissioned in 1985 and is expected to become fully operational early in 1986. The whole access control system was subjected to a safety and reliability assessment.

The electro-magnetic radiation produced by energetic electrons striking the walls during plasma discharges was monitored by the radiological protection instrumentation already installed. This confirmed the efficacy of the instrumentation and shielding. Low level activation of the vacuum vessel due to electrons striking the walls resulted in some minor restrictions on access into the torus for the first four days of the summer shut down. The neutron yield from the plasmas was in line with that forecast for this stage of the operation and some small amounts of short-lived radioactivity (half life approximately 2½ hours) were detected at the end of each day of deuterium plasma operations. At no time during the year was radiation in excess of the natural background level detected outside the shielded areas.

The fire detection and alarm system in the torus hall within the biological shield has been improved. Inert gas (halon) flood fire extinguishing systems have been installed in the basement of the torus hall and in the flywheel generator pits.

Assessments were made of potential occupational hygiene hazards (for example, excessive noise, toxic fumes and the use of asphyxiating gases such as sulphur hexafluoride) and appropriate precautions were adopted. Further assessments of the problems associated with beryllium limiters in JET were made during the year.

A Tritium Safety Assessment Panel was set up during the year under the chairmanship of the Head of Joint Safety Services. The panel keeps under review the safety of the design of the tritium plant and the proposed operating system. It also ensures that all statutory requirements for holding and discharging radioactive materials are met as the need for them arises.

Summary and Prospects

The JET safety record is most satisfactory and there will be the continued vigilance needed to maintain this record. In 1986 safety documentation and operating procedures will continue to be developed in step with progress in the operation of the JET machine. Particular attention will be paid to the increasing radiological hazards as the operating parameters are raised.

External Relations

Throughout 1985, the JET Project continued to attract widespread interest from the general public, the media and the scientific community. During the year, over 4000 people visited JET, mainly in groups organised by universities, colleges and local organisations. Although most of the groups from universities and colleges come from the UK, a substantial number now come from educational establishments in the other European countries, who include a visit to JET in their study tours.

Delegates from several scientific conferences held locally also visited the Project. Among these were delegates from the 8th International Conference on Gas Discharges and their Applications, 2nd International Symposium on Laser-Aided Diagnostics and the 22nd Culham Laboratory Plasma Physics Summer School.

In addition to the people coming in organised groups over 4500 members of the general public visited JET during the successful Open Days held on the 18 and 19 May, Fig. 63. On this occasion, visitors were free to follow a designated route, at their own pace, to the various exhibits where members of the JET team were available to answer questions.

Among the more notable visitors to JET during 1985 were HIH Prince Naruhito of Japan, Fig. 64, Mr K H Narjes, Vice President of the Commission of the European Communities, Fig. 65, Mr Jacques Viot, the French Ambassador to the UK, Sir Keith Joseph, PC, MP, Secretary of State for Education and Science and Mr Alastair Goodlad, MP, Parliamentary Under Secretary of State, Department of Energy. The Energy Policy Committee of the Danish Parliament, accompanied by the Danish Minister of Energy, Mr Knud Enggard visited JET on 11 October.

Fig. 63 Members of the general public watching a demonstration of remote handling equipment in the assembly hall during the JET Open Days.
85.T.764c/8

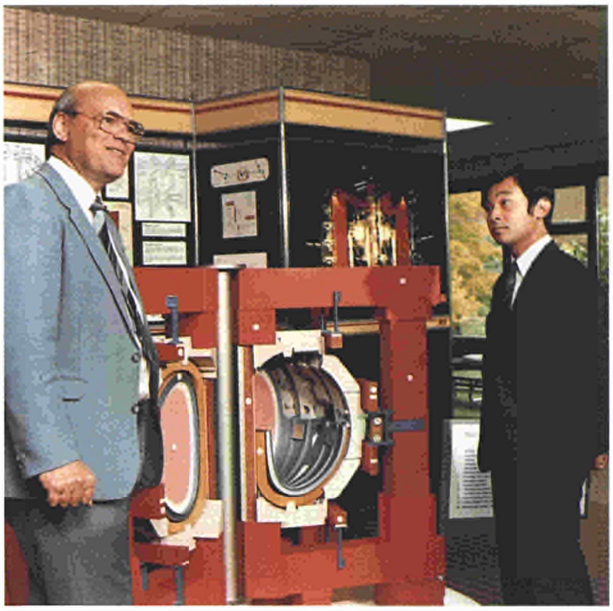

Fig. 64 HIH Crown Prince Naruhito of Japan being shown the JET Project by Dr P-H Rebut.
85.T.1459c/8

A debate on nuclear fusion in the House of Lords promoted considerable interest among the members and Lord Bessborough, the Earl of Halsbury and Lord Stoddart came to Culham and visited JET to see the progress being made in fusion research for themselves.

The progress of the Project has continued to attract the attention of the media. Visits were arranged for journalists from Belgium, Japan, Netherlands, Sweden, UK and USA. In October, a group of 25 members of the European Union of Science Journalists visited JET which resulted in the publication of several articles in the European Press. Facilities were provided for television crews from Italy and Norway for the filming of two educational films.

The JET Information Network was established in 1983 to improve the dissemination of information within the countries participating in the Project. The Network has proved to be especially useful in providing information to journalists and in making arrangements for them to visit JET.

A large display of the JET Project was included in the DG XII exhibit at the Europe 2000 Exhibition which was organised by the European Parliament, and held in Strasbourg at the beginning of October.

Fig. 65 Mr Karl-Heinz Narjes, Vice President of the European Commission (centre right) during his visit to the JET Joint Undertaking. With him, from left to right are Dr H-O Wüster, Mr H J Allgeier, who accompanied Mr Narjes and Dr P-H Rebut.
85.T.731c/8

APPENDIX I

JET Executive Committee

Member	Representative
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 Universitè Libre de Bruxelles (Service de Chimie-Physique II of the ULB)	R Valhaelewyn
The Commissariat à l'Energie Atomique, France (CEA)	B Garric (Jan-Aug) C Gourdon (from Sept) F Prevot (Jan) J C Saey (From Feb)
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 (Jan-Sept) O Gunneskov (from Oct) V O Jensen
The Grand Duchy of Luxembourg (Luxembourg)	R Becker
Ireland	N V Nowlan F G Burrows
The Kernforschunsanlage Jülich GmbH, Federal Republic of Germany (KFA)	V Hertling A W Plattenteich (Chairman)
The Max-Plank-Gesellschaft zur Förderung der Wissenschafter e.V.—Institut für Plasmaphysik, Federal Republic of Germany (IPP)	G Von Gierke (Jan-June) M Kaufmann (from July)
The Swedish Energy Research Commission (SERC)	E Hellstrand
The Swiss Confederation	A Heym, P Zinsli
The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)	C Westland M F van Donselaar (Jan-July)
The United Kingdom Atomic Energy Authority (UKAEA)	D M Levey, W M Lomer

APPENDIX II
JET Scientific Council

Members appointed by the JET Council:

F Troyon (Chairman)
EURATOM-SUISSE Association
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École Polytechnique Fédérale
21 Avenue des Bains
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Département de Recherches sur la Fusion Contrôlée
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D C Robinson (Secretary from 10/10/85)
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Great Britain

A Samain (Secretary until 10/10/85)
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S Segre
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H Wilhelmsson
EURATOM-SERC Association
(CTH)Institute for Electromagnetic
Field Theory and Plasmaphysics
Chalmers University of Technology
Fack
S-412.96 Göteborg 5
Sweden

G Wolf
EURATOM-KFA Association
Kernforschungsanlage Jülich GmbH
Institut für Plasmaphysik
Postfach 1913
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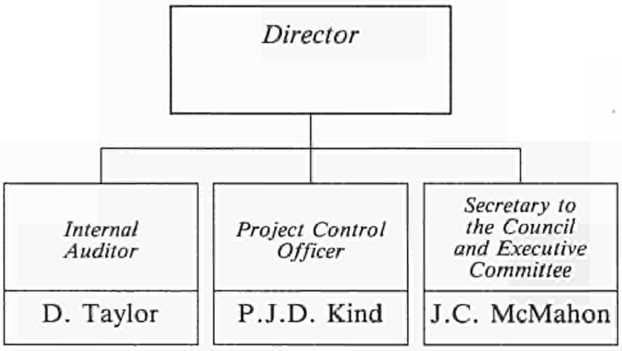
Federal Republic of Germany

Appendix III

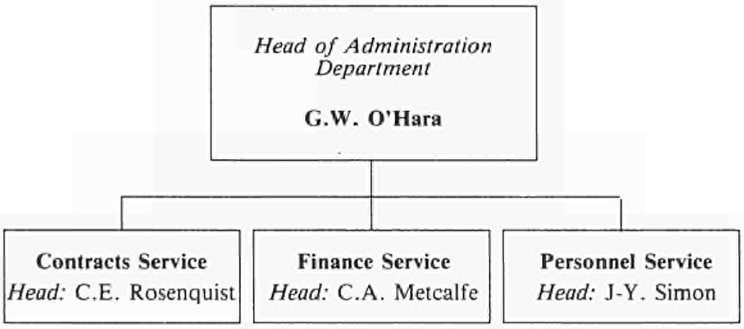
Project Team Structure

The diagrams depict the internal structure of the JET Joint Undertaking prior to the organisational changes which took place towards the end of 1985.

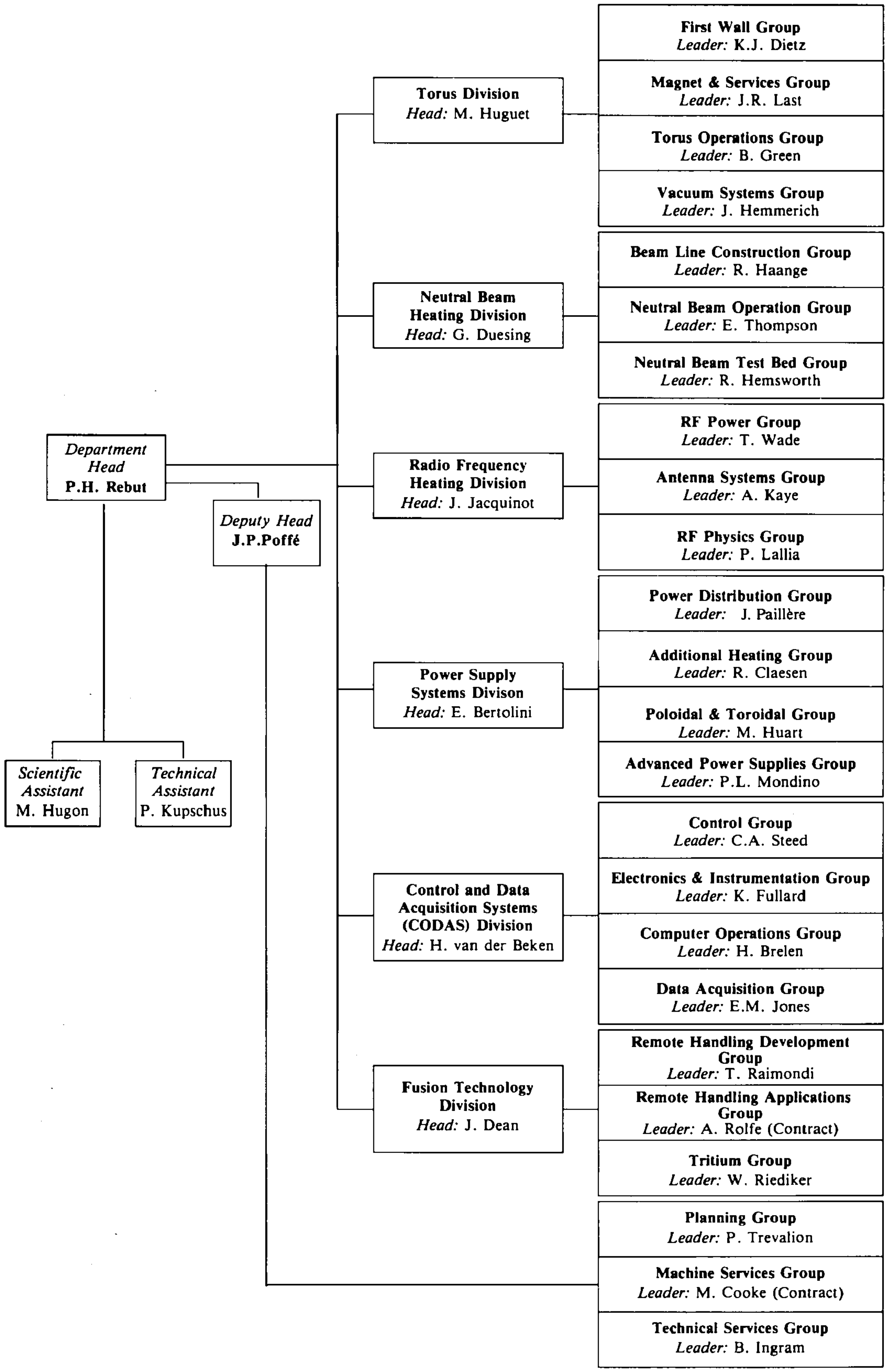
1. Structure of the Director's Office



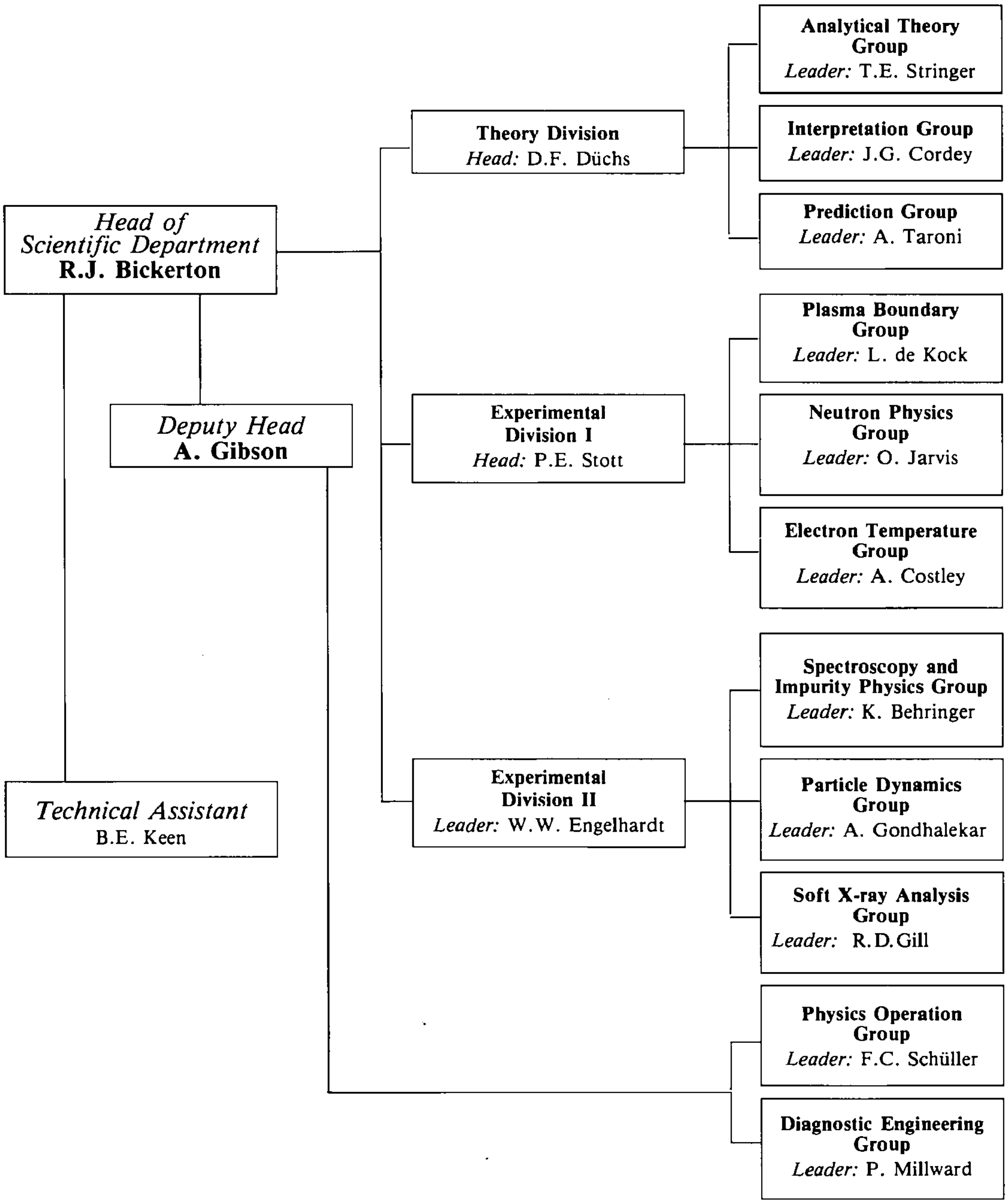
2. Structure of the Administration Department



3. Structure of the Operation and Development Department



4. Structure of the Scientific Department



Appendix IV

JET EURATOM and UKAEA Staff

(as at September 1985)

DIRECTORATE

Director: P. H. Rebut

Directorate

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

SCIENTIFIC DEPARTMENT

Head of Department: R. J. Bickerton

Deputy Head of Department: A. Gibson

DIRECTORATE

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

THEORY DIVISION

Head: D.F. Düchs	J. Davis	E. Lazzaro	E. Springmann
M. Brusati	A. Galway	Miss M. Nave	T. E. Stringer
J. Christiansen	N. A. Gottardi	Mrs M-G. Pacco	Mrs P. Stubberfield
J. G. Cordey	T. Hellsten	Mrs J. Roberts	A. Taroni
W. Core	Mrs S. Hutchinson	R. T. Ross	M. Watkins
Mrs S. Costar	B. Keegan	R. Simonini	J. Wesson

EXPERIMENTAL DIVISION I

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

EXPERIMENTAL DIVISION II

Head: W. W. Engelhardt	Mrs A. Flowers		
K. Behringer	R. Gill	J-L. Martin	B. K. Scheidt
J. L. Bonnerue	A. Gondhalekar	P. Morgan	F. Sieweke
G. Braithwaite	J. Holm	E. Oord	M. Stamp
S. Corti	Mrs E. Kallne	J. O'Rourke	E. van der Goot
Miss G. Denne	L. Lamb	A. Ravestein	B. Viaccoz
A. Edwards	G. Magyar	J. Ryan	M. von Hellerman

ADMINISTRATION DEPARTMENT

Head of Department: G. W. O'Hara

Directorate

G. Janes

CONTRACTS SERVICE

Head: C. E. Rosenquist

J. Brett	M. O'Casey	G. Manning	B. Treacher
L. Byrne	Miss K. Rout	Mrs D. Newton	Miss G. Way

FINANCE SERVICE

Head: C. A. Metcalfe	Mrs J. Hay	Mrs C. Norris	J. P. Spoor
Miss T. Bradley	J. Heyes	Mrs P. Press	Mrs J. Stevens
N. Coules	Mrs O. Hobart	Mrs I. Robins	Mrs I. Walker
J. A. Donovan	Mrs B. Jones	Mrs V. Rolstone	Mrs J. Webber

PERSONNEL SERVICE

Head: J-Y. Simon	Miss F. Haslam	G. Garraway	Mrs M. Russell
Mrs S. Austin	Mrs P. Howe	Mrs J. Hammond	Mrs F. Silk
Miss S. Fuller	L. Rasmussen	Mrs M. Harper	Mrs J. Smyth
Miss M. Gallacher	J. A. Russell	Miss C. Harris	Mrs P. Wiseman

OPERATION AND DEVELOPMENT DEPARTMENT

Head of Department: P. H. Rebut

Deputy Head of Department J. P. Poffé

DIRECTORATE

Head: J. P. Poffé	Miss M. Fraser		
P. Barker	L. French	B. Ingram	L. Nickesson
D. Carré	M. Guillet	P. Kupschus	H. Panissie
G. Dalle-Carbonare	Mrs E. D. Harris	D. Lecornet	T. Potter
Mrs D. Dalziel	Mrs M. Hicks	Mrs H. Marriott	Miss A. Strange
N. Davies	R. Howes	J. McGivern	P. Trevalion
H. Duquenoy	M. Hugon	S. McLaughlin	M. Walravens
G. Edgar	A. H. Humphreys	P. Meriguet	C. Woodward

TORUS DIVISION

Head: M. Huguet	T. Dale	D. Holland	
K. Adams	E. Daly	M. Hughes	Mrs M. Rydalm
W. P. Bailey	W. Daser	Mrs I. Hyde	R. L. Shaw
B. Bignaux	K. Dietz	G. Israel	W. Smith
A. Boschi	K. Fenton	H. Jensen	K. Sonnenberg
H. Buttgereit	C. Froger	H. Key	R. Thomas
D. Cacaut	B. Glossop	J. Last	S. Turley
G. Celentano	K. Grabenstatter	P. McCarthy	E. Usselmann
P. Chuilon	B. Green	P. Noll	J. van Veen
A. Conway	N. Green	J. Orchard	T. Winkel
D. Cook	L. Grobusch	D. Pratt	M. Young
Mrs A. Cranstone	J. Hemmerich	R. Rigley	J. Zwart

NEUTRAL BEAM HEATING DIVISION

Head: G. Duesing	D. Ewers		
H. Altmann	H. Falter	A. Jones	M. Mead
C. Brookes	J. Gallacher	T. T. C. Jones	W. Obert
A. Browne	Mrs S. Gerring	D. Kausch	S. Papastergiou
A. Burt	A. Geode	E. Kussel	D. Raisbeck
D. Cooper	R. Haange	F. Long	R. Roberts
Mrs D. Cranmer	R. Hemsworth	J. Lundqvist	D. Stork
J. F. Davies	H., Hupfloher	D. Martin	E. Thompson
G. Deschamps	F. Hurd	P. Massman	Miss D. Vernall
A. Dines	J. Jensen	C. Mayaux	W. Watson

RADIO FREQUENCY HEATING DIVISION

Head: J. Jacquinot	Mrs L. Brookes		
R. J. Anderson	M. Bures	G. Jessop	Mrs L. Rowe
J. Arbez	G. Cottrell	A. Kaye	F. Sand
S. C. Booth	D. T. Edwards	P. Lallia	M. Schmid
G. Bosia	A. Franklin	C. Maradan	A. G. Sibley
M. Brandon	E. Hanley	P. Murray	T. Wade
H. Brinkschulte	E. Horn	J. Plancoulaine	C. Walker

POWER SUPPLY SYSTEMS DIVISION

Head: E. Bertolini	P. Doidge	L. Mears	
Mrs C. Allen	B. Eriksson	A. Moissonnier	K. Selin
U. Baur	H. Fielding	P. Mondino	S. Shaw
T. Bonicelli	J. Goff	G. Murphy	A. Skinstad
O. Buc	D. Halliwell	Mrs J. Nolan	N. Walker
J. Carwardine	M. Huart	J. Paillère	Mrs L. T. Wall
C. Christodoulopoulos	A. Keymer	I. Piacentini	C. Wilson
R. Claesen	V. Marchese	C. Raymond	G. Wilson
J. Dobbing	G. Marcon	A. Santaguistina	L. Zannelli

CONTROL AND DATA ACQUISITION SYSTEMS DIVISION

Head: H. van der Beken	P. Card		
Mrs A. M. Bellido	Mrs L. M. Dines	J. G. Krom	J. Saffert
M. Botman	S. E. Dorling	Miss K. Mathiä	C. A. Steed
H. Brelen	K. Fullard	D. Nassi	J. van Montfoort
W. Brewerton	R. F. Herzog	J. P. Nijman	A. Wallander
M. L. Browne	E. M. Jones	C. G. Pollard	J. R. Watkins
T. Budd	Miss J. Kedward	G. Rhoden	I. D. Young

FUSION TECHNOLOGY DIVISION

Head: J. Dean			
S. J. Booth	E. Gebler	M. Pescatore	J. Schreibmaier
R. Cusack	Mrs M. E. Jones	P. Presle	L. Sonnerup
Mrs M. Daish	P. D. Jones	T. Raimondi	A. Tesini
L. Galbiati	A. Konstantellos	J. Removille	M. Tschudin
A. Galetsas	A. Nowak	W. Riediker	M. Wykes

APPENDIX V

Articles, Reports and Conference Papers Published, 1985

1. Manufacture of beam sources and neutralisers for JET neutral injection.
Altmann H, Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984.
Vol. 1, pp. 579–585.

2. Textbook finite element methods applied to linear wave propagation problems involving conversion and absorption.
Appert K, Hellsten T, Vaclavik J, Villard L.
Ecole Polytechnique Federale de Lausanne, September 1985.
Report LRP 268/85.
Presented at the 3rd European Workshop on Problems in the Numerical Modeling of Plasmas, Varenna, September 1985.

3. Overmoded millimetre waveguide transmission system for the JET ECE diagnostic.
Baker E A M, Daly D J, Dellis A, Bartlett D V, Campbell D J, Costley A E, de Kock L C J M, Fessey J.
Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, 4th Int. Workshop, Rome, 28–30 March 1984.
Rome, Editor dall'ENEA, 1984.
pp. 11–14.

4. Absolute calibration of the JET ECE system.
Baker E A M, Bartlett D V, Campbell D J, Costley A E, Hubbard A E, Moss D G.
Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, 4th Int. Workshop, Rome, 28–30 March 1984.
Rome, Editor dall'ENEA, 1984.
pp. 23–26.

5. An interpretation code for ECE measurements on JET.
Bartlett D V, Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, 4th Int. Workshop, Rome, 28–30 March 1984.
Rome, Editor dall'ENEA, 1984.
pp. 27–33.

6. Measurement and interpretation of electron cyclotron emission on JET.
Bartlett D V, Baker E A M, Campbell D J, Costley A E.
Review of Scientific Instruments.
Vol. 56, No. 5, pt. 2, May 1985.
(Procs, 5th Topical Conference on High Temperature Plasma Diagnostics, Tahoe City, California, 16–20 September 1984).
p. 940.

7. The neutral injector auxiliary power supply system in JET: design, manufacture and tests.
Basile G L, Ciscato D, Dobbing J A, Mondino P L.
Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984.
Vol. 2, pp. 835–842.

8. RF tests on JET first stage antenna system.
Arbez J, Beaumont B, Brugnetti R, Franklin A, Hanley E, Jacquinot J, Kaye A, Plancoulaine J, Speziale A, Walker C.
Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984.
Vol. 1, pp. 599–604.

9. Impurity studies and transport code modelling of JET plasmas.
Behringer K H, Bonnerue J, Bulliard A, Carolan P G, Decker G, Denne B, Duchs D F, Ehrenberg J, Engelhardt W W, Forrest M J, Gill R, Gondhalekar A, Hawkes N C, Kallne G E, Krause H, Magyar G, Martin J L, Mast F, McCracken G M, Morgan P, Muir D, O'Rourke J, Peacock N J, Ravestein A, Stamp M F, Stubberfield P M, Taroni A, van Maanen–Abels A, Watkins M L.
Plasma Physics and controlled nuclear Fusion Research, 10th Int. Conference, London, 12–19 September 1984, Vienna, IAEA, 1985.
Vol. 1, pp. 291–300.

10. Measurement of impurity influxes in JET by visible and VUV spectropscopy.
Behringer K H, Denne B, Forrest M J, Stamp M F, Summers H P. American Physical Society, Bulletin, October 1985, (27th Annual Meeting of the Division of Plasma Physics, San Deigo, 4–8 November 1985).
Vol. 30, No. 9, pp. 1414.

11. Impurity and radiation studies during the JET ohmic heating phase.
Behringer K H, Denne B, Engelhardt W W, Gill R, Gottardi N, Kallne E, Magyar Mansfield M, Morgan P, Stamp M F, Summers H P, Carolan P G, Forrest M J, Hawkes N C, Peacock N J, Decker G, Krause H, Mast F.
Joint European Torus, JET, 1984, report JET–P(85)08.

12. Tokamak Experiments.
Bickerton R J, and Keen B E.
JET Report, JET-P(85)24.

13. Physics performance of the Joint European Torus.
Bickerton R J, Plasma Physics and Controlled Fusion, December 1984.
Vol. 26, No. 12a, pp. 1355–1365 and JET Report JET–P(84)02.

14. Latest Results from JET.
Bickerton R J, Alladio F, Bartlett D V, Behringer K, Behrisch R, Bertolini E,
Best C, Bonicelli T, Bracco G, Brusati M, Campbell D J, Carolan P G, Christiansen J, Chuilon P, Coad J P, Cordey J G, Corti S, Costley A E, Q ' RCrisanti, de Michelis C, Denne B, Dietz K J, Duchs D F, Dupperrex P A, Edwards A, Ejima S, Engelhardt W W, Ehrenberg J, Erents S K, Ericksson B T, Forrest M J, Gadeberg M, Gibson A, Gill R, Gondhaleka A, Goodhall D, Gottardi N, Gowers C, Green B J, Grosso G, Hawkes N C, Hemmerich J, Hendricks F, Huart M, Huguet M, Jacquinot J, Jarvis O N, Jones E M, Kallne E, Kallne J C, Kellman A, Kissel S, de Kock L, Krause H, Kukral H, Lallia P, Last J, Lazzaro
E, Lomas P, McCracken G, Magyar G, Malacarne M, Mansfield M, Marchese V, Martinelli P, Mast F K, Mondino P L, Morgan P D, Morris A W, Murphy G, Nave M, F F, Nielsen P, Niestadt R M, Noll P, O'Rourke J, Pasini D, Peacock N J, Piekaar M W, Pochelon A, Prentice R, Rebut P H, Robinson D C, Ross R, Sadler R G, Santaguistina A, Schuller F C, Segre S, Stamp M F, Stangeby P, Steed C A, Stott P E, Stringer T E, Summers D, Summers H P, Tagle J A, Tanga A, Taroni A, Thomas P R, Thomsen K, Tonetti G, Tubbing B J D, Turner M, Valisa M, van Belle P, van der Beken H, Watkins M L, Wesson J A, Zanza V.
JET Report, JET-P(85)15.

15. Integrated control and data acquisition of experimental facilities.
Bombi F. Computing in Accelerator Design and Operation Europhysics Conference held in Berlin, 20-23 September 1983. Edited by Busse W, and Zelazny R, Springer-Verlag, 1984.
pp. 311-315.

16. The central interlock and safety system of JET.
Bombi F, Nijman J, Van Montfoort J.
Fusion Technology 13th Symposium, Varese, 24-28 September 1984, Oxford, Pergamon, 1984.
Vol. 2, pp. 1133-1139.

17. The gas introduction system of JET.
Boschi A, Dietz K J, Rebut P H.
Fusion Technology 13th Symposium, Varese, 24-18 September 1984, Oxford, Pergamon, 1984.
Vol.1, pp. 247-254.

18. Transport analysis of JET discharges.
Brusati M, Cordey J G.
Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6
September 1985. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 1, pp. 247-254.

19. Plasma-antenna coupling and the related scrape-off layer studies on JET.
Bures M, Evrard M P, Jacquinot J, Lallia P, Sand F. Controlled Fusion and Plasma Physics 12th European Conference, Budapest, 21-6
September 1985. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 2, pp. 148-151.

20. Analysis of sawtooth instabilities in JET.
Bartlett D V, Best C, Brusati M, Campbell D J, Christiansen J P, Coda S, Cordey J G, Costley A E, Cottrell G A, de Kock L, Dupperex P A, Edwards A, Fessey J A, Gambier D J, Gill R D, Gondhalekar A, Gowers C W, Hugill J, Hubbard A, Jacquinot j, Jarvis O H, Kissel S E, Lallia P P, Lazzaro E, Morgan
P D, Niestadt R M, O'Rourke J, Oyevaar Th, Piekaar H W, Pochelon A, Prentice R, Ross R T, Sadler G, Stamp M F, Stinger T E, Summers D, Tonetti G, Tubbing B J D, Valisa M, van Belle P, Wesson J A.
Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6
September 1985. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 1, pp. 130-133.

21. Observation of Zeeman splitting of spectral lines from the JET plasmas.
Carolan P G, Peacock N J, Forrest M J, Trotman D L. Joint European Torus, JET, 1985, report JET-P(85)05.

22. Charge exchange recombination spectroscopy of ASDEX.
Carolan P G, Duval B P, Field A R, Fielding S J, Hawkes N C, Peacock N J, Behringer K H, Fussman G, Janeschitz G, Soldner F.
Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6
September 1985l. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 1, pp. 267-270.

23. Resistivity and field diffusion in JET.
Christiansen J P, Campbell D J, Cordey J G, Ejima S, Lazzaro E.
Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6 September 1985. Contributed papers, 2 volumes. European Physical Society, 1985.
Vol. 1, pp. 327-330.

24. Commissioning and early operation of the power supply and protection system for the extraction grid of the JET neutral injectors.
Claesen R, Dobbing J A, Hartline R, Egerszegi L, Hrabal D, Mondino P L, Tournesac B.
Fusion Technology 13th Symposium, Varese, 24-28 September 1984, Oxford, Pergamon, 1984.
Vol. 2, pp. 571-834.

25. Impurity fluxes in the boundary layer of JET.
Coad J P, de Kock L, Tagle T, McCracken G M, Erents S K. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6 September 1985. Contributed papers, 3 volumes. European Physical Society, 1985. Vol. 2, pp. 571-574.

26. Erosion and redeposition of wall and limiter material in JET.
Coad J P, de Kock L, McCracken G M. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 2, pp. 575–578.

27. Impurity sources in JET.
Coad P, de Kock L, Stott P E, Erents S K, McCracken G, Ehrenberg E, Behrisch R. American Physical Society, Bulletin, October 1985 (27th annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985).
Vol. 30, No. 9, p. 1525.

28. Particle and energy confinement in ohmically heated JET plasmas.
Cordey J G, D V Bartlett, Bickerton R J, Bracco G, Brusati M, Campbell D J Christiansen J P, Corti S, Costley A E, de Kock L, Fessey J, Gadeberg M, Gibson A, Gill R D, Gottardi N, Gondhalekar A, Gower C W, Hubbard A, Hugenholtz C A, Jarvis O N, Krause H, Lazzaro E, Lomas P J, Mast F K, Morgan P D, Nielsen P, Noll P, Pick M, Prentice R, Ross R T, Sadler G, Schuller F, Stamp M F, Summers D, Tanga A, Thomas P R, Tonetti G, van Belle P, Zanza V. Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12–19 September 1984, Vienna, IAEA, 1985
Vol. 1, pp.167–177.

29. Present status of JET.
Cordey J G. Journal of Nuclear Materials, August 1985, (Procs. 1sr Int. Conference on Fusion Reactor Materials, Tokyo, Japan, 3–6 December 1984). Vol. 133/134, pp. 14–17 and Joint European Torus, JET, 1985 report JET–P(85)06

30. Unification of Ohmic and Additionally Heated Energy Confinement Scaling Laws.
Cordey J G. JET Report, JET–P(85)28.

31. Global energy confinement studies in ohmically heated JET plasmas.
Cordey J G, Bartlett D V, Bickerton R J, Brusati M, Campbell D J, Christiansen J P, Corti S, Costley A E, Edwards A, Ejima S, Fessey J, Gadeberg M, Gibson A, Gill R D, Gottardi N, Gondhalekar A, Gowers C W, Hendriks F, Jarvies O N, Kallne E, Kallne J, Kissel S, de Kock L, Krause H, Lazzaro E, Lomas P J, Mast F K, Morgan P D, Nielsen P, Prentice R, Ross R T, O'Rourke J, Sadler G, Schuller F, Stamp M F, Stott P E, Summers D R, Tanga A, Thomas P R, Tonetti G, Watkins M L. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society, 1985.
Vol. 1, pp. 26–29

32. A Solution of the ICRF Fokker–Planck Equation.
Core W G. JET Report, JET–P(85)30

33. Analysis of neutral particles in JET.
Corti S, Bracco G, Brusati M, Gondhalekar A, Cordey J G, Grosso G, Hendriks F, Segre S, Zanza V. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed Papers, 3 volumes. European Physical Society 1985.
Vol. 1, pp. 219–222.

34. First measurements of ECE from JET.
Costley A E, Baker E A M, Bartlett D V, Campbell D J, Kiff M G, Neill G F. Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, 4th Int. Workshop Rome, 28–30 March 1984, Rome Editor dall'ENEA, 1984. pp. 1–10

35. Measurements of electron cyclotron emission on JET.
Costley A E, Baker E A M, Bartlett D V, Campbell D J, Kissel S E, Piekaar H W, Niestadt R M, Tubbing B J D. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985. pp. 1414.

36. Electron temperature measurements on JET.
Costley A E, Baker E A M, Brusati M, Bartlett D V, Campbell D J, Decker G, Gadeberg M, Gill R D, Kallne E, Kissel S, Nielsen P, Pasini D, Prentice R. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985.
Vol. 1, pp. 227–230.

37. Measurements of Ion Cyclotron Emission from Ohmic and ICRF Disharges in JET.
Cottrell G A. JET Report JET–P(85)13.

38. Determination of experimental tokamak plasma profiles using maximum–entropy analysis.
Cottrell G A, Fairbanks E S, Stockdale R E. Review of Scientific Instruments, vol. 56, no. 5, pt. 2, May 1985, (Procs. 5th Topical Conference on High Temperature Plasma Diagnostics, Tahoe City, California, 16–20 September 1984) pp. 984–986.

39. Impurity behaviour during RF heating in JET.
Denne B, Behringer K, Mansfield M, Morgan P D, Stamp M F, Summers H P, Hawkes N C, Peacock N J. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985. p. 1585.

40. Spectroscopic measurements of the impurity content of JET plasmas with ohmic and RF heating.
Denne B, Behringer K H, Engelhardt W, Gill R D, Kallne E, Magyar G, Mansfield M, Morgan P D, Summers H P, Hawkes N C, Peacock N J, Krause H,

Mast K F, De Michelis C, Pasini D, Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 379–383.

41. Fabrication and characterization of graphite 5890 PT limiters used in TFR and JET tokamaks.
Deschamps P, Dietz K, Yvars M. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. Vol. 2, pp. 1243–1246.

42. Start-up and initial operation of JET.
Dietz K J, Bartlett D, Baumel G, Behringer K, Bertolini E, Best C, Bickerton R J, Bombi F, Boschi A, Browne M L, Brusati M, Bulliard A, Campbell D, Carolan P G, Clausing R, Christiansen J, Chuilon P, Cordey J G, Costley A, de Kock L, Duchs D F, Duesing G, Emery R K F, Engelhardt W W, Eriksson T, Forrest M J, Froger C, Fullard K, Gibson A, Gill R, Gondhalekar A, Gowers C, Green B J, Hemmerich J, Huart M, Hugenholtz C A, Huguet M, Jarvis O N, Jensen B E, Krause H, Kupschus P, Last J, Lazzaro E, McCracken G M, Magyar G, Mast F K, Mead M, Mondino P L, Morgan P, Morris A W, Nickesson L, Niedermeyer H, Noll P, Paillere J, Peacock N J, Pick M, Raymond C, Rebut P H, Ross R, Sadler G, Schmidt V, Schuller F C, Sonnenberg K, Stamp M F, Steed C A, Stella A, Stott P E, Summers D, Tanga A, Thomas P R, Usselmann E, van Belle P, van der Beken H, van Montfoort J E, Waelbroeck F, Wesson J A, Winkel T, Winter J, Zwart. Journal of Nuclear Materials, vol. 128 and 129 December 1984, (Proc. 6th Int. Conference on Plasma Surface Interactions in Controlled Fusion Devices, Nagoya, Japan, 14–18 May 1984). pp. 10–18.

43. Impurity control in JET.
Dietz K J, Sonnenberg K. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985). p. 1585.

44. Wall Protection in JET. K J Dietz et al. JET Report, JET-P(85)16.

45. JET neutral beam injection system, construction and component tests.
Duesing G. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. Vol.1, pp. 59–75.

46. Construction, operation and enhancement of JET.
Dietz K J, Duesing G. Journal of Vacuum Science and Technology A: Vacuum, Surface and films, vol. 3, no. 3, pt. 2 May/June 1985, (Proc. 31st National Symposium American Vacuum Society, Reno, 4–7 December 1984). pp. 1151–1156.

47. Relation of magnetic activity with confinement in JET and TCA tokamaks.
Duperrex P A, Keller R, Pochelon A, Sawley M L. Laser Aided Plasma Diagnotics 2nd Int. Symposium, Culham Laboratory, 10–12 September 1985, Culham, Culham Laboratory 1985. pp. 53–58.

48. Magnetic activity during internal disruptions in JET discharges.
Duperrex P A, Keller R, Malacarne M, Pochelon A. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp 126–129.

49. Technical aspects of the joint JET–ISX–B beryllium limiter experiment.
Edmonds P H, Dietz K J, Goodall D H J. Oak Ridge National Laboratory 1984, 19p, Report CONF 841219–19.

50. Technical aspects of the joint JET–TSX–B beryllium limiter experiment.
Edwards P H, Dietz K J, Goodhall D H J. Journal of Vacuum Science and Technology A: Vacuum, Surfaces and Films, vol. 3, no. 3, pt. 2 May/June 1985 (Proc. 31st National Symposium American Vacuum Society, Reno, 4–7 December 1984). pp. 1100–1104.

51. Energy confinement scaling of ohmic and ICRF heated JET plasmas.
Ejima S, Bures M, Christiansen J P, Cordey J G, Jacquinot J, Lallia P P, Thomsen K. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985). pp. 1525.

52. Parameters of the JET edge plasma during OH, RF and open boundary experiments from Langmiur/heat flux probes.
Erents S K, McCracken G, Stangeby P, Tagle J A, de Kock L. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985). p. 1525.

53. Operation and control of the JET poloidal field power supply system.
Eriksson T, Corbyn D B, Huart M, Marchese V, Mondino P L, Raymond C. Fusion Technology 13th Symposium, Varese, 14–18 September 1984, Oxford, Pergamon, 1984. Vol. 2, pp. 843–850.

54. The JET neutral beam test bed facility and first results.
Falter H D, Cowern N E B, Deschamps G H, Hemsworth R S, Jones T T C, Massmann P, Mead M J, Stork D. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. pp. 571–578.

55.JET plasma electron density measurements from 2mm wave interferometry.
Fessey J A, Gowers C W, Hugenholtz C A J, Slavin K. Joint European Torus, JET, July 1985, report JET–P(85)04.

56. Studies of the edge plasma in JET by visible spectroscopy during ICRF heating.
Forrest M J, Carolan P G, Hawkes N C, Peacock N J, Cottrell G, Lallia P. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985). p. 1415.

57. Recycling, isotopic exchange and density behaviour in JET discharges.
Forrest M J, Morgan P D, Corti S, Gondhalekar A, Gowers C W, Magyar G, O'Rourke J J, Stamp M F, Summers D D R, Tanga A, Watkins M L, Ehrenberg J. Controlled Fusion ad Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 535–538.

58. Impurity sources and impurity influxes in the JET tokamak.
Forrest M J, Stamp M F, Behringer K H, Morgan P D, Summers H P. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 539–542.

59. Minimum required beta in a tokamak reactor.
Freidberg J P, Wesson J A. Nuclear Fusion, vol. 25, no. 7, July 1985. pp. 759–769.

60. Electron power deposition profile during ICRF heating on JET.
Gambier D J, Bartlett D V, Bures M, Campbell D J, Cottrell G A, Jacquinot J, Kissel S, Lallia P, Niestadt R, Sand F, Thomsen K, Tubbing B J D. Controlled Fusion and Plasma Physics 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 152–155.

61. Resistively heated plasmas in JET: characteristics and implications.
Gibson A. Int. Conference on Plasma Physics, Lausanne, 27 June – 3 July 1984. Invited papers, 2 volumes, 1984, Brussels, EEC. pp. 13–38.

62. Obituary – Dr H O Wüster.
Gibson A. Plasma Physics and Controlled Fusion, vol. 27, no. 8, August 1985. pp. I–II.

63. Sawtooth oscillations in JET.
Gill R D, Campbell D J, Bartlett D V, Best C, Coda S, Costley A E, Edwards A, Gowers C W, Hubbard A, Kissel S E, Morgan P, Ross R, Stringer T E, Wesson J A. Institute of Physics Plasma Physics Group 12th Annual Conference on Plasma Physics, Glasgow, 26–28 June 1985.

64. Real–time plasma fault protection system for JET.
Gondhalekar A, Lomas P, Noll P, Reed K, Schuller F. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. Vol. 2, pp. 1661–1665.

65. Density build–up in JET.
Gondhalekar A, Cheetham A, Corti S, Morgan P, O'Rourke J, Schuller F C, Watkins M. American Physical Society, Bulletin, vol. 30, no. 9, October 1985, (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985. p. 1525.l

66. Limits in evaluating energy loss profiles from bolometric measurements at JET.
Gottardi N, Krause H, Mast F. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 30–33.

67. The scientific programme of the Joint European Torus, JET.
Green B J. Physikalische Blatter, vol. 40, no. 3,. 1984. pp. 70–72 (In German).

68. Controlled nuclear fusion. Inexhaustible energy from plasma.
Green B J. Umschau, vol.84, no. 25/26, 1984. pp. 770–773 (In German).

69. Developments in neutral injection heating.
Green T S, Coupland J R, Hammond D P, Holmes A J T, Martin A R, Hemsworth R S, Thompson E. Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12–19 September 1984, Vienna, IAEA, 1985. Vol. 3, pp. 319–327.

70. Components for the neutral injection beam lines.
Haange R. Preprints of papers presented to The Institution of Mechanical Engineers seminar on The Mechanical Engineering aspects of JET, London, November 1984. Joint European Torus, JET, 1984, report JET–P(84)12.

71. Effect of particle trapping in ICRF–beam heated tokamak plasmas.
Hellsten T, Core W, Hamnen H, Appert K, Succi S. Controlled Fusion and Plasma Physics 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 124–127.

72. Commissioning of the JET flywheel–generator–convertor systems.
Huart M. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon 1984. Vol. 2, pp. 851–858.

73. JET flywheel generators.
Huart M. Preprint of papers presented to The Institution of Mechanical Engineers seminar on The Mechanical Engineering aspects of JET, London, November 1984, Joint European Torus, JET 1984, report JET–P(84)12.

74. A Simple Fixed Frequency Reflectometer for Plasma Density Profile Measurements on JET.
Hubbard A E, Costley A E, Gowers C W. JET Report, JET–P(85)32.

75. Assembly, commissioning and first operation of JET.
Huguet M. Joint European Torus, JET, 1984, report JET–P(84)03.

76. Present status of commissioning and operation of JET.
Huguet M and others. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. Vol. 1, pp. 91–103.

77. JET Contributions to the 11th Symposium on Fusion Engineering (Austin, Texas, USA, November 1875).
Huguet M, Bertolini E, Noll E et al. JET Report, JET–P(85)26.

78. Fusion power and the JET project: A general presentation.
Huguet M. Preprint of papers presented to The Institution of Mechanical Engineers seminar on The Mechanical Engineering aspects of JET, London, November 1984, Joint European Torus, JET, 1984, report JET–P(84)12.

79. JET Contributions to the 13th Symposium on Fusion Technology (SOFT).
Part 1 – Invited papers. Huguet M, Duesing G, Hemmerich H, van der Beken H, and Mondino P L.

80. Impurity accumulation in ISX–B during counter–injection – are alternative hypotheses valid?
Isler R C, Morgan P D, Peacock N J. Nuclear Fusion, vol. 25, no. 3, March 1985. pp. 386–392.

81. Heating and Current Drive Scenarios with ICRF Jacquinot J. JET Report JET–P(85)112.

82. Preliminary RF heating results from JET.
Jacquinot J. Institute of Physics Plasma Physics Group 12th Annual Conference on Plasma Physics, Glasgow, 26–28 June 1985.

83. ICRF studes on JET.
Jacquinot J, Anderson R J, Arbez J, Bartlett D, Beaumont B, K Behringer, Bertolini E, Bhatnagar V P, Bonicelli T, Bosia G F, Brinkschulte H W, Browne M L, Brusati M, Bures M, Campbell D, Christiansen J P, Christodoulopoulos C O A, Chuilon P, Claesen R, Coad J P, Cordey J G, Corti S, Costley A, Cottrell G, Denne B, Dietz K, Ejima S, Erents S K, Eriksson B T, Evrard M, Fullard K, Gambier D, Gill R D, Gottardi N, Breen B, Grosso G, Hawkes N C, Hellsten T, Hemmerich J L, Huguet M, Jarvis O N, Jones E, Kaye A S, Kimura H, de Kock J, de Kock L, Krause H, Lallia P P, Last J, Lazzaro E, Lomas P J, Magyar G, Mansfield M, Marchese B, Mast F K, McCracken G M, Mondino P, Morgan P, Niedstadt R M, O'Rourke J, Piekaar H, Plancoulaine J, Rebut P H, Rhoden G, Sadler G, Sand F, Santaquistina A, Schmic M S, Schüller F, Segre, Sibley A, Stamp M F, Steed C A, Summers D, Tanga A, Tagle J A, Thomas, P R, Thomsen K, Tubbing B J D, Valisa M, van Der Beken H, Watkins M, Wade T J, Walker C I. JET Report, JET-P(85)20

84. Preliminary ICRF results from JET.
Jacquinot J, Anderson R, Arbez J Bartlett D, Beaumont B, Behringer K, Bertolini E, Abosia G, Brinkschulte H, Bures M, Campbell D, Christiansen K, Christodoulopoulos C, Claesen R, Cordey J, Corti S, Costley A, Cottrell G, Denne B, Evrard M, Gambier D, Green B, Grosso G, Huguet M, Jarvis O N, Kaye A, Kimura H, Krause H, Lallia P P, Lomas P, Magyar G Mansfield M, Mast K, Mondino P L, Morgan P Plancoulaine J, O'Rourke J, Rebut P H, Sadler G, Sand F, Schmid M, Segre S, Sibley A, Stamp M, Summers D, Thomsen K, Tanga A, Valise M, Wade T, Walker C. Plasma Physics and Controlled Fusion, vol. 27, no. 12A, December 1985 (12th Annual Conference, Plasma Physics Group of the Institute of Physics, 26–28 June 1985, University of Glasgow: Invited papers. Edited by R J Bickerton). pp. 1379–1390 and JET Report JET–P(85)09.

85. Nuclear Data Involved in Present–Day Fusion Reactors.
Jarvis O N. JET Report, JET–P(85)22.

86. Ion temperature and density measurements in JET using neutron diagnostics.
Jarvis O N, Gordi G, Hone M, Kallen J, Merlo V, Sadler G, van Belle P. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2–6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 223–226.

87. Status of the JET Control and Data Acquisition System (CODAS).
Jones E M. JET Report, JET–P(85)21.

88. Control, data acquisition and analysis for the JET neutral injection testbed.
Jones T T C, Brenan P R, Rodgers M E, Stork D, Young I D. Fusion Technology 13th Symposium, Varese, 24–28 September 1984, Oxford, Pergamon, 1984. Vol. 2, pp. 1125–1132.

89. High resolution X–ray spectroscopy diagnostics of high temperature plasmas.
Kallne E, Kallne J, Marmar E S, Rice J E. Massachusetts Institute of Technology, Plasma Fusion Centre, February 1985. Report PFC/JA–85–10.

90. Study of diagram lines and satellites in plasma atomic X–ray spectroscopy.
Kallne E, Kallne J, Marmar E S, Rice J E. American Physical Society, Bulletin, vol. 30, no. 6, June 1985 (Minutes of 5th APS Topical Conference on Atomic Processes in High Temperature Plasmas, Pacific Grove, California, 25–28 February 1985). p. 1115.

91. Plasma atomic X–ray spectroscopy of tokamaks.
Kallne E, Kallne J, Marmar E S, Rice J E. Nuclear Instruments and Methods in Physics Research, section B: Beam Interactions with Material and Atoms, vol. B9, no. 4, July 1985 (Procs. Int. Conf. on the Physics of Highly Ionised Atoms, Oxford, England, 2–5 July 1984). pp. 698–703.

92. Neutron time-of-flight spectrometer for diagnostics for D-T fusion plasma.
Kallne J, Elevant T. Joint European Torus, JET, 1985, report JET-P(85)03.

93. The JET ICRF antennae systems: description and testbed results.
Kaye A, Arbez J, Beaumont B, Franklin A, Hanley E, Jacquinot J, Panissie H, Plancoulaine J, Walker C. Fusion Technology 13th Symposium, Varese, 24-28 September 1984, Oxford, Pergamon, 1984. Vol. 1, pp. 669-674.

94. Breakdown conditions in JET.
Kellman A, Lazzaro E, Noll P, Schüller F C, Thomas P. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4-8 November 1985). p. 1524.

95. Status and Prospects of RF Waves in Tokamaks.
Lallia P. JET Report, JET-P(85)29.

96. The toroidal and poloidal coil systems of JET.
Last J R. Preprints of papers presented to The Institution of Mechanical Engineers seminar on the Mechanical Engineering aspects of JET, London, November 1984. Joint European Torus, JET, 1984, report JET-P(84)12.

97. Magnetic separatrix formation in JET.
Lazzaro E, Campbell D, Cordey J G, Denne B, Gibson A, Gottardi N, Kellman A, Last J, Noll P, Schuller F, Summers D, Tanga A, Tagle T, Taroni A, Thomas P. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4-8 November 1985. p. 1585.

98. Identification of magnetic helical perturbation in a tokamak.
Lazzaro E, Alladio F, Crisanti F, Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6 September 1985. Contributed papers, 3 volumes. European Physical Society, 1985. Vol. 1, pp. 319-322.

99. Neutral Injection heating in fusion devices: Beam production and heating mechanism.
Lomas P. Europhysics News. European Physical Society, Bulletin, vol. 16, no. 4, April 1985. pp. 5-8.

100. Current ramp rate variations in JET.
Lomas P, Malacarne M, Piekaar H W, Schuller R C, Tanga A, Thomas P. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4-8 November 1985. p. 1524.

101. Precision measurement of the 1s lamb shift in hydrogen-like argon on the Alcator C tokamak.
Marmar E S, Rice J E, Kallne E, Kallne J, LaVilla R, American Physical Society, Bulletin, vol. 30, no. 6, June 1985 (Minutes of 5th APS Topical Conference on Atomic Processes in High Temperature Plasmas, Pacific Grove, California, 25-28 February 1985). p. 1117.

102. Precision measurement of the 1s lamb shift in hydrogen-like argon.
Marmar E S, Rice J E, Kallne E, Kallne J and others. Massachusetts Institute of Technology, Plasma Fusion Centre, October 1985, 12p, report PFC/JA-85-33.

103. Bolometric diagnostics in JET.
Mast K F, Krause H, Behringer K, Bulliard A, Magyar G, Review of Scientific Instruments, vol. 56, no. 5, pt. 2, May 1985 (Procs. 5th Topical Conference on Plasma Physics, Glasgow, 26-28 June 1985. Glasgow Institute of Physics, 1985, paper 1.

104. The Interpretation of Plasma Edge Conditions in Tokamaks.
McCracken G M, Stangeby P. JET Report, JET-P(85)27.

105. The JET power supplies: a review after one year of operation.
Mondino P L. Fusion Technology 13th Symposium, Varese, Oxford, Pergamon, 1984. Vol. 1, pp. 119-131 and Joint European Torus, JET, 1984.

106. Spectroscopic measurements of the Joint European Torus using optical fibres to relay visible radiation.
Morgan P D, Behringer K H, Stamp M F, Carolan P G, Forrest M J, Peacock N J. Review of Scientific Instruments, vol. 56, no. 5, pt. 2, May 1985 (Procs. 5th Topical Conference on High Temperature Plasma Diagnostics, Tahoe City, California, 16-20 September 1984). pp. 862-864.

107. The JET plasma position and current control system.
Noll P, Browne M, Huart M, Piacentini I, Santaguistina A, Watkins J R. Fusion Technology 13th Symposium, Varese, 24-28 September 1984, Oxford, Pergamon, 1984. Vol. 1, pp. 503-509 and Joint European Torus, JET, 1984, report JET-P(84)08.

108. The JET cryopump system -and its cryolines for neutral injection.
Obert W, Duesing G, Kussel E, Kupschus P, Mayaux C, Rebut P H, Santos H. Fusion Technology 13th Symposium, Varese, 24-28 September 1984, Oxford, Pergamon, 1984. Vol. 1, pp. 311-318.

109.Poloidally asymmetric edge phenomena in JET.
O'Rourke J, Campbell D, Denne B, Gondhalekar A, Gottardi N, Krause H, Magyar G, Malacarne M, Mast F, Morgan P, Nave M F, Schüller F C, Stamp M F, Summers D. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2-6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 155-158.

110. Impurity fluxes and concentrations in the ISX–B beryllium limiter experiment.
Peacock N J, Kallne E, Morgan P D, Lomas P J, Isler R C and others. Nuclear Fusion, vol. 25, no. 11, November 1985. pp. 1635–1655.

111. Scaling law systematics.
R Firsch D, Duchs D F, Joint European Torus, JET, 1985, report JET–R(85)01.

112. Limiter viewing on JET.
Pick M A, Summers D. Journal of Nuclear Materials, vol. 128 and 129 December 1984 (Proc. 6th Int. Conference on Plasma Surface Interactions in Controlled Fusion Devices, Nagoya, 14–18 May 1984). pp. 440–444.

113. The role of metal–hydrogen systems in fusion research.
Pick M A. Journal of the Less–Common Metals, 103, 1984, papers presented at the Int. Symposium on the Properties and Applications of Metal Hydrides IV, Eilat, 9–13 April 1984. pp. 5–17.

114. A model for atomic hydrogen – metal interactions application to recycling, recombination and permeation.
Pick M A, Sonnenberg K. Journal of Nuclear Materials, vol. 131, no. 2+3, April 1985. pp. 208–220.

115. Electron thermal conductivity coefficients derived from the electron temperature relaxation after an internal disruption.
Piekaar H W, Goedheer W, Niestadt R M, Stringer T, Tubbing B J D. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4–8 November 1985. p. 1525.

116. First results from Thomson scattering on JET.
Prentice R, Nielsen P, Gadeberg M. Review of Scientific Instruments, vol. 56, no. 5, pt. 2, May 1985 (Procs. 5th Topical Conference on Hight Temperature Plasma Diagnostics, Tahoe City, California, 16–20 September 1984). p. 1070.

117. Report on the 3rd European Tokamak Programme Workshop.
Rager J P, Gibson A, Engelmann F, Wegrowe J G. Plasma Physics and Controlled Fusion, vol. 27, no. 7, July 1985. pp. 801–825.

118. First experiments in JET.
Rebut P H, Bartlett D V, Baumel G, Behringer K, Behrisch R, Bertolini E, Best C, Bickerton R J, Bombi F, Bonnerue J L, Boschi A, Bracco G, Browne M L, Brusati M, Bulliard A, Campbell D J, Carolan P G, Christiansen J, Chuilon P, Cordey J G, Corti S, Costley A E, Decker G, de Kock L, Dietz K J, Duchs D F, Duesing G, Emery R K Fk, Engelhardt W W, Eriksson T, Fessey J, Forrest M J, Froger C, Fullard K, Gadeberg M, Gibson A, Gill R, Gondhalekar A, Gowers C, Green B J, Grosso G, Hawkes N C, Hemmerich J, Huart M, Hubbard A, Hugenholtz C A, Huguet M, Jarvis O H, Jensen B E, Jones E M, Kallne G E, Kallne J C, Krause H, Kupschus P, Last J R, Lazzaro E, Lomas P, McCracken G M, Magyar G, Mast F K, Mead M, Mondino P L, Morgan P, Morris A W, Nickesson L, Niedermeyer H, Nielsen P, Noll P, Paillere J, Peacock N J, Pick M, Poffe J P, Prentice R, Raymond C, Robinson D C, Ross R, Sadler G, Saffert J, Schmidt V, Schuller F C, Sonnenberg K, Stamp M F, Steed C A, Stella A, Stott P E, Summers D, Tanga A, Thomas P R, Tonetti G, Usselmann E, von Belle P, van der Beken H, von Mondtfoort J E, Watkins M L, Wesson J A, Winkel T, Zanza V, Zwart J. Culham Laboratory Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12–19 September 1984, Vienna, IAEA, 1985. Vol. 1, pp. 11–27.

119. Thermal instability and disruptions in a tokamak.
Rebut P H, Hugon M. Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12–19 September 1984, Vienna, IAEA, 1985. Vol. 2, pp. 197–211.

120. First JET results and it prospects.
Rebut P H. Twenty Years of Plasma Physics Workshop, International Centre for Theorectical Physics, Trieste, September 1984. Edited by B McNamara Philadelphia, World Scientific, 1985. pp . 3–14 and Euratom Joint European Torus, JET, 1984, report JET–P(84)11.

121. The Joint European Torus: installation, first results and prospects.
Rebut P H, Bickerton R J, Keen B E. Nuclear Fusion, vol. 25, no. 9, September 1985. pp. 1011–1022.

122. Low–Z material for limiters and wall surfaces in JET: Beryllium and carbon.
Rebut P H, Hugon M, Booth S J, Dean J R, Dietz K J, Sonnenberg K, Watkins M L, Joint European Torus, JET, 1985, report JET–R(85)03.

123. Magnetic topology, disruptions and electron heat transport.
Rebut P H, Brusati M, Joint European Torus, JET, 1985, Report JET–P(85)18, (Invited paper at the 12th European Conference on Controlled Fusion and Plasma Physics, Budapest, 2–6 September 1985).

124. Observations of recombination dominated population of upper levels in helium – like argon in the Alcator C tokamak.
Rice J E, Marmar E S, Kallne E, Kallne J. American Physical Society, Bulletin, vol 30, no. 6, June 1985 (Minutes of 5th APS Topical Conference on Atomic Processes in High Temperature Plasmas, Pacific Grove, California, 25–28 February 1985). p. 1116.

125. High resolution X – ray observation of argon, molybdenum and sulphur from the Alcator C tokamak.
Rice J E, Marmar E S, Petrasso R, Kallne E, Kallne J, Cowan R. IEEE Int. Conference on Plasma Science, St. Louis, 14 – 16 May 1984. Abstracts, New York, IEEE, 1984. p. 43.

126. Observation of charge transfer between intrinsic neutral hydrogen and Ar (sup 17 +) in the Alcator C tokamak.
Rice J E, Marmar E S, Fiore C L, Kallne E, Kallne J. American Physical Society, bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4 – 8 November 1985. p. 1413.

127. Observation of charge – transfer between intrinsic neutral hydrogen and Ar(sup + 16) from neutral hydrogen in the ground and excited states in a tokamak plasma.
Rice J E, Marmar E S, Terry J L, Kallne E, Kallne J. Physical Review Letters, vol. 56, no. 1, 6 January 1986.
pp. 50 – 53.

128. The JET Cryogenic Supply System.
Roberts R L et al. JET Report, JET – P(85)14.

129. Modulation of the turbulence level and of the energy flux by sawtooth relaxations in tokamaks.
Rogister A, Hasselberg G, Kaleck A, Boileau A, van Andel H W H, von Hellermann M. Laser Aided Plasma Diagnostics 2nd Int. Symposium, Culham Laboratory, 10 – 12 September 1985, Culham, Culham Laboratory, 1985. pp. 7 – 12.

130. MHD Activitiy on JET.
Robinson D C, Haynes P, Morris A W. JET Report JET – P(85)11.

131. Charged particle fusion product measurements in JET.
Sadler G, Jarvis O N, van Belle P, Gowman J, Hone M, Kallne J, Merlo V. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4 – 8 November 1985. p. 1585.

132. Fokker – Planck calculations for JET ICRF heating scenarios.
Scharer J, Jacquinot J, Lallia P, Sand F. Nuclear Fusion, vol. 25, no. 4, April 1985. pp. 435 – 444.

133. Fokker – Planck calculations for JET ICRF heating scenarios.
Scharer J, Jacquinot J, Lallia P, Sand F. Controlled Fusion and Plasma Physics 12th European Conference, Budapest, 2 – 6 September 1985k. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 144 – 147.

134. Fokker – Planck calculations for JET ICRF heating scenarios.
Scharer J E, Jacquinot J, Lallia P. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4 – 8 November 1985. p. 1589.

135. Experimental observation of disruptions in JET.
Schüller F C, Alladio F, Campbell D, Crisanti F, Kast F K, de Kock L, Krause H, Lomas P, Malacarne M, Nave M F F, Niestadt R, Tonneti G, Tubbing B, Wesson J. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 151 – 154.

136. Plasma evolution and skin – effects in JET.
Schüller F C, Thomas P R, Kellman A, Lazzaro E, Lomas P, Piekaar H W, Tanga A. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 287 – 290.

137. Mechanical design assessments of structural components and auxiliaries of JET.
Sonnerup L. JET Report, JET – P(85)19.

138. Tables of excited quantum shell populations of hydrogen – like and lithium – like impurity ions in fusion plasmas, I. The bundled n picture.
Spence J, Summers H P. Joint European Torus, JET, 1985, report JET – R(85)02.

139. MESHJET. A mesh generation package for finite element MHD equilibrium codes at JET.
Springmann E, Taroni A. Joint European Torus, JET, 1984, report JET – R(84)01.

140. Recent results from the JET tokamak.
Stott P E. American Physical Society, Bulletin, vol. 30, no. 9, October 1985 (27th Annual Meeting of the Division of Plasma Physics, San Diego, 4 – 8 November 1985. Vol. 1, pp. 86 – 89.

141. A theory of marfes.
Stringer T E. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 86 – 89.

142. Anomolous transport in tokamak confinement.
Stringer T. JET Report, JET – P(85)17.

143. Computational models for wave – particle interactions.
Succi S, Appert K, Core W, Hamnen H, Hellsten T, Vaclavik J. Ecole Polytechnique Federale de Lausanne, September 1985, 45p, report LRP 269/85. Presented at the 3rd European Workshop on Problems in the Numerical Modeling of Plasmas, Varenna, September 1985.

144. Infrared measurements on carbon limiters in JET.
Summers D, Lowry C, Mast F, Morgan P, Stangeby P C. Institute of Physics Plasma Physics Group 12th Annual Conference on Plasma Physics, Glasgow, 26 – 28 June 1985.

145. Density, temperature and power measurements in the JET edge plasma using heat flux/Langmuir probes.
Tagle J A, de Kock L, Erents S K, McCracken G M. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 2, pp. 579 – 582.

146. Global particle balance and recycling in first JET discharges.
Tanga A, Gowers C W, Hugenholtz C A, Morgan P, Schüller F C. Joint European Torus, JET, 1984, report JET – P(84)09.

147. Start – up of the Ohmic Phase.
Tanga A and Thomas P R. JET Report, JET – P(85)23.

148. The formation of a magnetic separatrix in JET.
Tanga A, Campbell D J, Denne B, Gibson A, Gottardi N, Kellman A, Lazzaro E, Mast K F, Noll P, Schuller F C, Summers D, Tagle A J, Thomas P R, Valisa M, McCracken G, Stangeby P. Controlled Fusion and Plasma Physics, 12th European Conference, held in Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 22 – 25.

149. Transport calculations for JET discharges with ICRH.
Taroni A, Abels van – Maanen A E P M, Core W, Duchs D F, Hellsten T, Muir D G, Stubberfield P M, Tibone F, Watkins M L. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 22 – 25.

150. ICRF heating experiments in TFR using a low – field – side antenna.
TFR Group, Sand F. Nuclear Fusion, vol. 25, no. 12, December 1985. pp. 1719 – 1732.

151. MHD behaviour and discharge optimization in JET.
Thomas P R, Wesson J A, Alladio F, Bartlett D, Behringer K, Bickerton R J, Brusati M, Campbell D J, Christiansen J P, Cordey J G, Costley A E, Crisanti F, de Kock L, Dietz K J, Dupperrex P A, Engelhardt W W, Gibson A, Gill R D, Gottardi N, Gowers C W, Green B J, Hemmerich J L, Hugenholtz C A, Huguet M, Keller R, Krause H, Last J, Lazzaro E, Mast F K, Morgan P, Morris A W, Niedermeyer H, Noll P, Pick M, Pochelon A, Rebut P H, Robinson D C, Ross R T, Sadler G, Schuller F C, Stringer T E, Summers D, Tanga A, Tonetti G, van Belle P. Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12 – 19 September 1984, Vienna, IAEA, 1985. Vol. 1, pp. 353 – 361.

152. Volt – seconds consumption of JET discharges.
Thomas P R, Christiansen J P, Ejima S, Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 283 – 286.

153. A twelve – channel grating polychromator for measurement of electron temperature in JET.
Tubbing B J D, Barbian E, Campbell D J, Hugenholtz C A J, Niestadt R M, Oyevaar Th, Piekaar H W. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, p. 215 – 218.

154. Vacuum system and wall conditioning in JET.
selmann E, Dietz K J, Hemmerich H, Schüller F C, Tanga A. Fusion Technology 13th Symposium, Varese, 24 – 28 September 1984, Oxford, Pergamon, 1984. Vol. 1, pp. 105 – 117.

155. Fluctuation measurements on Textor using $C0_2$ laser scattering.
N Andel H W H, Boileau A, von Hellermann M. Laser Aided Plasma Diagnostics 2nd Int. Symposium, Culham Laboratory, 10 – 12 September 1985, Culham, Culham Laboratory 1985. pp. 1 – 6.

157. JET ICRF power plant.
Wade T, Anderson R, Bosia G, Schmid M. Fusion Technology 13th Symposium, Varese, 24 – 28 September 1984, Oxford Pergamon, 1984. Vol. 1, pp. 727 – 732.

158. The vacuum vessel.
Walravens M J. Preprint of papers presented to The Institution of Mechanical Engineers seminar on The Mechanical Engineering aspects of JET, London, November 1984. Joint European Torus, JET, 1984, report JET – P(84)12.

159. Welding and brazing of JET machine components.
Walravens M (Ed.). JET Report, JET – R(85)04.

160. Sawtooth Oscillations.
Wesson J. JET Report, JET – P(85)25.

161. Density limit disruptions in JET.
Wesson J, Gowers C, Mast F, Nave F, Watkins M, Turner M F, Hahn W. Controlled Fusion and Plasma Physics, 12th European Conference, Budapest, 2 – 6 September 1985. Contributed papers, 3 volumes. European Physical Society 1985. Vol. 1, pp. 147 – 150.

162. Tokamak disruptions.
Wesson J A, Sykes A, Turner M F. Plasma Physics and Controlled Nuclear Fusion Research, 10th Int. Conference, London, 12 – 19 September 1984, Volume 2, Vienna, IAEA, 1985. pp. 28 – 31.

163. JET magnet coil instrumentation.
Zwart J W, Keane D V, Thomsen F. Fusion Technology 13th Symposium, Varese, 24 – 28 September 1984, Oxford, Pergamon 1984. Vol. 2, pp. 1119 – 1124.

164. JET Joint Undertaking Progress Report 1984.
Edited and compiled by Keen B E, Kupschus P. Euratom, JET Joint Undertaking, September 1985. 161p. EUR 10223EN, EUR – JET – PR2.

165. Annual Report 1984.
Edited by Kind P J D, O'Hara G W. Euratom, JET Joint Undertaking, Abingdon, August 1985 82p EUR 10222EN, EUR – JET – AR7. M.

166. JET contributions to 12th European Conference on Controlled Fusion and Plasma Physics, Budapest, 2 – 6 September 1985.
Many JET Authors. Joint European Torus, JET, 1985, Report JET – P(85)10.

167. JET Poster Contributions at 27th American Physical Society (APS) Meeting (San Diego, USA, November 1985).
Many JET authors. JET Report, JET – P(85)31.

Appendix VI

Article 14 Contracts with Associated Laboratories

Article 14 contracts are for work carried out in support of the Project by the Associations, where such work is specified and controlled by arrangements concluded between the Joint Undertaking and the Association concerned. The cost of such work is borne in accordance with the relevant provisions of the contract of association.

Year	*Association*	*Subject*
1979	CRPP	Installation of ERATO MHD Stability Code on Harwell Computer
	CEA	Study of Interferometric System for JET Geometry and Plasma Parameters
	CNEN	Design Study of Neutral Particle Diagnostic System
	UKAEA	Study of Heat Deposition by Neutral Injection in D-Shaped Plasma
	UKAEA	Design Study of a Spatial Scan Thomson Scattering Diagnostic System
	UKAEA	Design Study of Spectrometers for JET
	UKAEA	Design Study of Collective Scattering of Infrared Radiation on JET
	UKAEA	Design Study of a Diagnostic System for JET to Investigate Internal MHD Oscillations by Measuring Fluctuations in the Soft X-ray Emission
	UKAEA	Design Study for Plasma Wall Interaction Experiments in JET
	UKAEA	Design Study for Neutral Diagnostics for JET
	NPL	Design Study of an Electron Cyclotron Emission Diagnostic System for JET
	CEA	Design Study VUV Spectroscopy
	CNEN	Design Study of X-ray Crystal Spectrometer
	IPP	Design Study of a Quasi-Continuous Thomson Scattering Diagnostic System for JET
	IPP	Design Study of Plasma Wall Interaction Experiments in JET
	KFA	Design Study of a Diagnostic System using Excited Atomic Fluorescent Spectroscopy to Measure Impurty Densities
	KFA	Design Study of a Diagnostic System to Measure Neutral Hydrogen Densities by H-Alpha Fluorescence
	KFA	Study of Methods of Measuring Surface Temperature of the Limiters or Other Surfaces at JET
	FOM	Design Study of an ECE Diagnostic System for JET
	FOM	Design Study of a Method of Measuring Plasma Temperatures by Neutral Particle Scattering
	CRPP	Design Study of the Application to JET of Scattering Diagnostics using Optically Pumped Far Infra-red Lasers
	Risø	Design Study of a Basic Thomson Scattering Diagnostic System
	NSBESD	Design Study of Neutron Diagnostics
	CEA	Conceptual Design of an ICRH System
	UKAEA	Design Study of the Applicability of Computerised Tomography to the Optimisation and Obtainment of Plasma Parameter Profiles for Multichannel Line of Sight Diagnostics on JET
	CEA	Diagnostic Code to Calculate the Plasma Boundary in JET from Magnetic Coil Measurements made at Selected Locations Close to the Surface of the Vacuum Vessel
	IPP	Design Study of a Diagnostic System to measure Densities by Lyman Alpha and Fluoresence
	CNEN	Development of a Package of Advanced Diagnostic Codes for JET
1980	CNEN	Collaboration of Mr Malavasi in JET
	KFA	Experimental Investigation on Optimisation Glow Discharge in Collaboration with FOM
	FOM	Application of Glow Discharge Cleaning, etc., in Collaboration with KFA
	CEA	R & D for JET Neutral Injection
	UKAEA	Diagnostic Design Study on CO_2 Thomson Scattering
	UKAEA	Design of a Neutron Yield Monitor Diagnostic System

Year	*Association*	*Subject*
1980	Risø	Design of a Single Point Thomson Scattering Diagnostic System
	CNEN	Design of a Neutral Particle Analyser Diagnostic System
	UKAEA	R & D of Antennae and Wavelengths for ECE Diagnostics
	UKAEA	Study to measure Deuterium Trapping in low Z coating for JET limiters
	NSBESD	Scientific and Engineering Design of a Time of Flight 2.4 MeV Neutron Spectrometer Diagnostic System
	FOM	Engineering Design of a Fast Time Response ECE Diagnostic System
1981	IPP	Design of a Bolomter Scan Diagnostic System
	IPP	Scientific and Engineering Design of Soft X-ray Diode Array Diagnostic System
	CNEN	Scientific and Engineering Design of X-ray Crystal Spectrometer Diagnostic System
	UKAEA	Scientific and Engineering Design of Advanced Neutron Diagnostics
	IPP	Technical Specification for Vacuum Cassette Probe System
	IPP	Scientific and Engineering Design of a Surface Analysis Station
	IPP	Development and Implementation of a Numerical Simulation Code on Recycling and Inventory Problems
	IPP	Design Study of Cryogenic Hydrogen Pellet Refuelling for JET
	ETAT BELGE	Theoretical Study of JET Antenna Loading at the Ion Cyclotron Frequency
	UKAEA	Design Construction and Operation of ¼ Scale Model of Optical System of CO_2 Scattering Diagnostic
	UKAEA	Scientific and Engineering Design of a Surface Analysis Fast Transfer System for JET
	UKAEA	Scientific and Engineering Design for Extreme Ultra-Violet Spectroscopy Diagnostic System
	IPP	Computer Simulation of Reflection of Hydrogen and Deuterium from Cu
	CEA	Plasma Tests in TFR of Antenna Limiter
	UKAEA	Scientific and Engineering Design of a Diagnostic System for JET, based on Thomson Scattering of light from a CO_2 Laser
	ETAT BELGE	Design Study of Neutron Diagnostic Systems for JET
	KFA	Manpower to Assemble and Test Two Complete RF Systems and Matching Networks for Glow Discharge Electrodes
	UKAEA	Design Study of Broadband Crystal Spectroscopy
	ETAT BELGE	Theoretical Ion Cyclotron Resonance Heating Studies for JET
	IPP	Theoretical Ion Cyclotron Resonance Heating Studies for JET
1982	CEA	Self-consistent Equilibrium and Diffusion Code for JET
	UKAEA	R & D of Antenna and Wave-guides for ECE Diagnostics
	UKAEA	Numerical Simulation of the Plasma in JET using ½-d Transport Code
	FOM	Design Study of a Broadband Crystal Spectrometer for the Active and Non-Active Phase of JET
	FOM	Preparatory Work for the Scientific and Engineering Design of a Single Channel 2mm Interferometer
	CEA	Code for Interpretation of ECE Measurements in JET
	CNR	ECE Simulation Code for JET
	IPP	Angular Distribution of Reflected Energy by Hydrogen Bombardment of Cu
	IPP	Sputtering of Cu and Cu/Cr Targets of High Energy Ions at Different Angles of Incidence
	NSBESD	Design Study of Neutron Diagnostic Systems for JET
	IPP	Fast Plasma Boundary Identification Code for JET
	IPP	Impurity Transport Package for Analysis of JET Data and use in Predictive Code
	UKAEA	Scientific and Engineering Design of 14 MeV Neutron Spectrometer for JET
	CEA	Theoretical Study of an Antenna Limiter at the Ion Cyclotron Resonance Frequency

Year	Association	Subject
1982	IPP	Scientific and Engineering Design of Pellet Injectors for JET
1983	IPP	Detailed Design of the Broadband X-ray Crystal Spectrometer Diagnostic System for JET
	IPP	Scientific and Engineering Design of Time Resolving Collector Probes for the JET Plasma Boundary Probe System
	UKAEA	Computational Physics
	UKAEA	Neutral Injection Simulation Code for JET
	FOM	Optimisation of the Transmission of the Polychromator and its Associated Filters and Waveguides
	UKAEA	Development of a ½-d Transport Code for a Multispecies Free-Boundary Plasma
	IPP	Codes for JET Plasma Heating
	IPP	Hydrogen Retention and Sputtering Measurements in Beryllium
	CEA	Supplementary Plasma Tests in TFR of an Antenna Limiter for JET
	IPP	Design Study of a Diagnostic System for JET to measure Electron Temperature by Thomson Scattering of Laser Light using a LIDAR Based Technique
	IPP	Numerical Calculations for Temperature Build-up
	FOM	Neutron Transport Calculations
	IPP	Nuclear Emulsion Plates in Support of Neutron Diagnostics at JET, Design Study
	UKAEA	Additional Development Tasks on the Design of a Surface Analysis Fast Transfer System for JET
1984	IPP	Testing of Centrifuge Pellet Injector
	ENEA	Study of the Modifications of the Mascot Servomanipulator required for its use on JET
	CEA	Extension of the Plasma Boundary Code
	CNR	Extension of ECE Simulation Code
	SERC	Scientific and Engineering Design of a 14keV Neutron Spectrometer Diagnostic System for JET
	FOM	Code for Simulation of Non-Thermal Aspects of the ECE Spectra
	SERC	Scientific and Engineering Design of a 14keV Neutron Spectrometer Diagnostic System for JET
	KFA	Measurement of Material release from Beryllium Limiters in the JET Tokamak
	Risø	Investigation of Pellet Acceleration by an Arc Treated Gas Gun
	CRPP	A Toroidal Global-Wave Numerical Model of ICRF Heating
1985	KFA	Comparison of High Purity Graphite from Different Suppliers with regard to Physical Mechanical and Thermal Properties
	CEA	Prototype Development of Pellet production and Charging Unit for a Pellet Injector
	ETAT BELGE	Theoretical Ion Cyclotron Resonance Heating Studies for JET
	CEA	Development of an ICRF Global Wave Code
	UKAEA	Initial Design Study for an Active Beam Diagnostic for JET
	UKAEA	A Functional and Ergonomic Design Study of a Servomanipulator Master Station.
	CEA	Numerical Simulation of 'Sawtooth' behaviour in Tokamaks
	FOM	Study of Profile Control and Suprathermal Electron Production in ECRH
	IPP	Study of Profile Control and Suprathermal Electron Production in LHRH
	ENEA	Upgrading of an Equilibrium Transport Code for a Multi-species Free Boundary Plasma

The full titles and abbreviations for the Associations are given under Organs of the JET Joint Undertaking on Page ix of this report. The following abbreviations are also used in the above list of contracts:

CRPP — Centre de Recherches en Physique des Plasmas, École Polytechnique Fédérale de Lausanne, Switzerland.
NPL — National Physical Laboratory, Teddington, London, United Kingdom.