JOINT EUROPEAN TORUS JET

JET JOINT UNDERTAKING

ANNUAL REPORT 1983

Her Majesty Queen Elizabeth II and M. François Mitterrand at the JET Opening Ceremony on 9th April 1984

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EUR-JET-AR6

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Preface

JET began operations on 25 June 1983. Its performance by the year-end was among the best yet accomplished in the fusion world. At the first attempt to introduce plasma, a plasma current of 19,000 amps was obtained. By the end of the year currents of up to 3 million amps were achieved. This was a most satisfactory start to the experimental programme of the Project.

The importance of the Project both as a scientific experiment and as an exercise in European co-operation was fittingly underscored by the official opening ceremony performed by Her Majesty Queen Elizabeth II on 9 April 1984, at which theEuropean Communities were represented by M. François Mitterrand, President of the French Republic and M. Gaston Thorn, President of the Commission. Each of the member countries was also represented. It was an elegant occasion.

At the outset, I should mention that, with the start of operations a detailed account of JET's scientific and technical progress will be produced in a separate report prepared by the JET Director. The report which follows, contains administrative information and only a general review of scientific and technical developments.

In last year's report I stated that the construction programme of the Project was completed on schedule. The JET machine was commissioned in its Basic Performance configuration by June 1983. The plasma position control system was also commissioned during 1983. In its final form the system allows the radial position and size of the plasma to be accurately programmed. This played a major role in the success of the operations during the latter part of the year:

- A peak plasma current of 3MA with a loop voltage as low as 1.4V was achieved in a pulse lasting over 10 seconds. In this pulse, the current was over 1MA for 6.5 seconds. Non-disruptive termination of the current pulse was achieved. In another pulse the current was held constant at 2.3MA for 4 seconds.
- Electron temperatures in the range 1.5 → 2.0keV were obtained with peak mean densities in excess of $2 \times 10^{19} m^{-3}$.

On the funding of the Project, I wish to report that the budgets for 1983 were approved at 93.0 MioECU for commitments, 123.8 MioECU for payments and 123.8 MioECU for income.

As regards staffing, I mentioned last time that all recruitment specifically related to the Construction Phase had ceased in 1982, when a peak staffing level of 272 was reached.

During the past year the recruitment effort was directed at filling vacancies in the newly introduced staffing structure for the Operational Phase. It is worth noting that of all applications received, only 12% came from the partners other than the UKAEA, reflecting the continuing difficulty in having to recruit through the Associations. The Project is currently discussing with the individual laboratories how best to obtain suitable staff.

In last year's report I referred to the decision of the JET Executive Committee, on the recommendation of a working party, to monitor carefully the recruitment programme of the Project and to review the manpower needs again in 1984, or earlier if personnel numbers reached 600. It has since been decided that the working party should meet again in Spring 1984.

The Project owes a debt of gratitude to the United Kingdom Atomic Energy Authority for its continuing support covering many facets. In particular, the persistent requests for staff at all levels by the Project, both for team posts and for support work, made great demands on the Host Organisation. It is perhaps indicative of the good working relationship between the UKAEA and the Project that the Support Agreement, which details the support to be provided by the Host Organisation and the procedures for co-operation between both parties, was fully reviewed after 5 years of operation and did not require revision.

I also thank the Commission of the European Communities and the Associations for their continued support.

In March 1983, the JET Council appointed a new Scientific Council, retaining the 14 members of the previous Scientific Council and adding three new members. The Scientific Council met 4 times in 1983 and prepared reports for the JET Council on the Remote Handling of JET, the revised Project Development Plan for JET, and "chances and risks" in the operation of JET. On behalf of the JET Council I thank them for their deliberations and advice.

In July 1983, Mr. A. Plattenteich was elected Chairman and Mr. C. Maisonnier, Vice-Chairman of the JET Executive Committee. The Committee met 7 times during the year under review and their continued work is greatly appreciated by the JET Council and the management of the Project.

Greece formally became a member of the JET Joint Undertaking in 1983 and was represented for the first time at the 20th meeting of the JET Council in October 1983.

It is with great regret that I refer to the death on 30 March 1984 of Mr. C. Cunningham, one of Ireland's nominees on the JET Council and JET Executive Committee. He was diligent in his attendance at both committees and was a committed supporter of the Project. Before the JET Joint Undertaking was formally established in June 1978, he served on the Management Committee and on the interim JET Council. He will be sadly missed.

As I will be relinquishing my role as Chairman of the JET Council this year, I take this occasion to pay tribute to my colleagues on the Council for their unfailing understanding and guidance. I have found it a great privilege and joy to serve the Project and, along with everyone involved, I take pride in its achievements so far.

On behalf of my colleagues on the JET Council, I congratulate whole-heartedly the Director of the Project and his fellow team members on their outstanding achievement in making the Project so successful. In looking to the future I would like to echo the words of Queen Elizabeth II when, on the occasion of the official opening of JET, she said:
"No-one can guarantee that research will be successful, more particularly in a territory still uncharted, such as nuclear fusion. Fortune favours the bold, however, and the building here, in the heart of Oxfordshire, of the Joint European Torus puts the Community in the very forefront of the attempt to develop the fusion reactor. There is a long way to go before we will know for sure whether fusion can be used to generate electricity reliably and economically, and without harm to the environment. It is a challenge which will be a great stimulus to human ingenuity, and one which has already evoked from the Project team a response of the highest quality."

J. Teillac
Chairman of the JET Council

June 1984

Organs of the JET Joint Undertaking

1. The JET Council

Member	*Representatives*
The European Atomic Energy Community (EURATOM)	P. Fasella (Vice-Chairman) D. Palumbo
The Belgian State, acting for its own part (Laboratoire de Physique des Plasmas of the École 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'Énergie Atomique, France (CEA)	J. Teillac (Chairman) J. Horowitz
The Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia, Nucleare e delle Energie Alternative, Italy (ENEA) (Previously known as Comitato Nazionale per l'Energia Nucleare, Italy (CNEN).)	B. Brunelli, P. Longo
The Consiglio Nazionale delle Ricerche, Italy (CNR)	
The Hellenic Republic (Greece) from June	A. Katsanos
The Forsøgsanlaeg Risø, Denmark (Risø)	H. von Bülow, N.E. Busch
The Grand Duchy of Luxembourg (Luxembourg)	J. Hoffmann, P. Schüller (Jan – April) N. Didier (May – Oct) M. Thill (from Nov)

Member	*Representatives*
Ireland	C. Cunningham, J. O'Callaghan (Jan–Dec) D. Byrne (from Dec)
The Kernforschungsanlage Jülich GmbH, Federal Republic of Germany (KFA)	A.W. Plattenteich
The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.– Institut für Plasmaphysik, Federal Republic of Germany (IPP)	K. Pinkau
The Swedish Energy Research Commission (SERC). (Previously known as The National Swedish Board for Energy Source Development)	Mrs. B. Bodlund, G. Holte
The Swiss Confederation	F. Troyon, P. Zinsli
The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)	C.M. Braams, C. le Pair
The United Kingdom Atomic Energy Authority (UKAEA)	A.M. Allen, R.S. Pease

2. The Director of the Project

H-O. Wüster

Contents

JET in the Euratom and International Fusion Programme

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

(Euratom Fusion Programme)

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

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

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

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

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

The overall financial effort devoted to fusion in Europe by the national institutions and by the Community is of the order of 10 per cent of the overall energy R & D effort in the Community countries; the corresponding US and Japanese figures are both around 17 per cent. In absolute values, Europe spends at present for fusion as much as Japan and about half as much as the USA. These relatively large budgets are justified by the enormous long-term potential of fusion.

The JET Project

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

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

It was also decided that the device would be built on a site adjacent to the Culham Laboratory, the nuclear fusion research laboratory of the United Kingdom Atomic Energy Authority (UKAEA), and that the UKAEA would act as Host Organisation to the Project.

The members of the JET Joint Undertaking are: Euratom, all its associated partners in the frame of the fusion programme including Sweden and Switzerland, and Greece, Ireland and Luxembourg, which have no Contract of Association with Euratom. Greece joined the JET Joint Undertaking on 14 June 1983.

The expenditure of the Joint Undertaking is borne by Euratom 80 per cent, and the United Kingdom

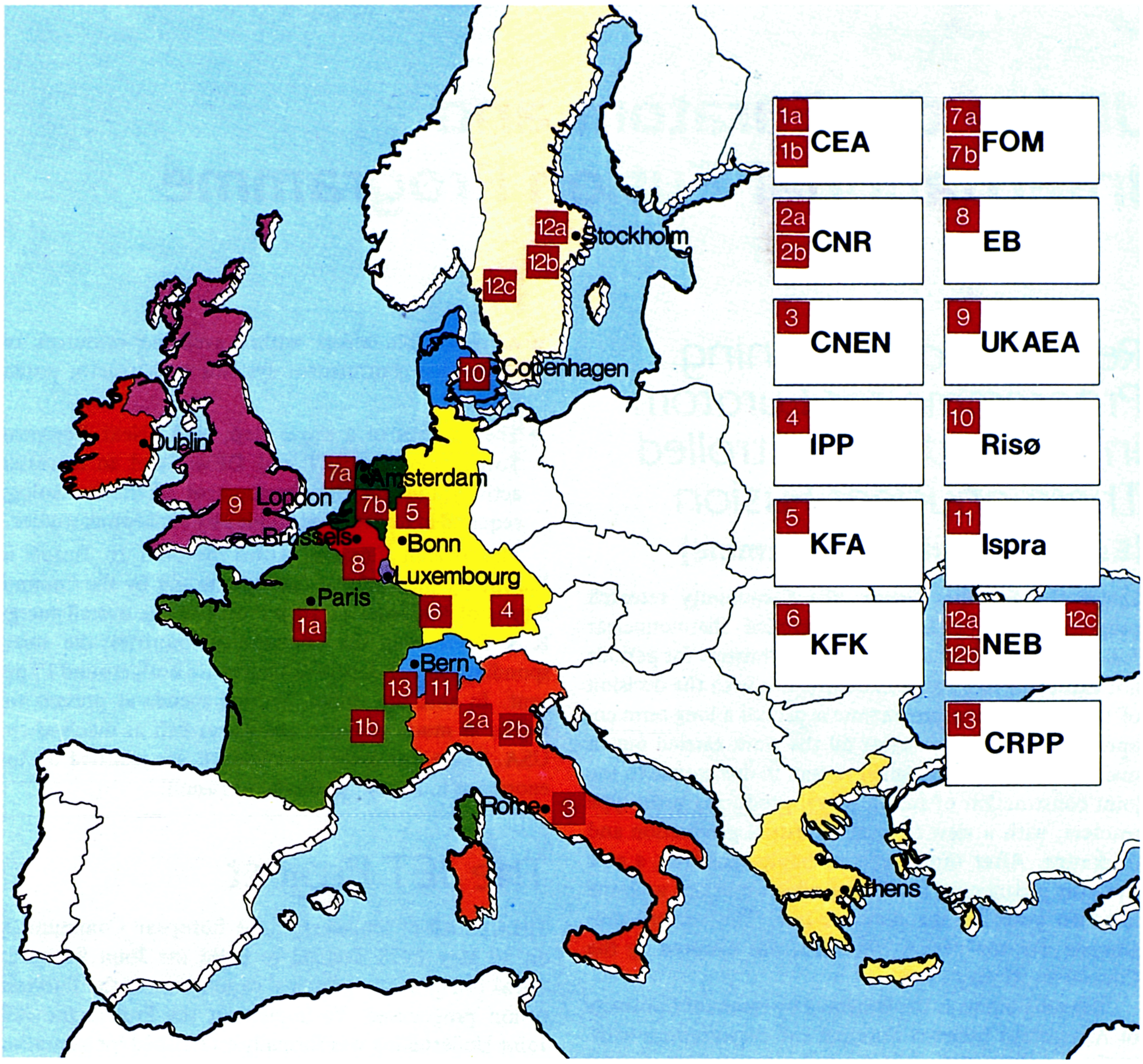


Fig. 1 Location of the organisations associated with the Euratom fusion programme.

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

Atomic Energy Authority (UKAEA) 10 per cent. The remaining 10 per cent is shared between all Members having Contracts of Association with Euratom in proportion to the Euratom financial participation in the total costs of the Associations.

The Project Team is formed in part by personnel put at the disposal of the Undertaking by the associated institutions other than the UKAEA, and in part by staff made available by the UKAEA (Host Organisation). The former are recruited by Euratom as temporary agents: 165 such positions were foreseen in the Community budget 1983. The others remain employees of the UKAEA. Each Member having a Contract of Association with Euratom undertakes to re-employ the staff whom it placed at the disposal of the Project and who were recruited by the Commission for temporary posts, as soon as the work of such staff on the Project has been completed.

Objectives of JET

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

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

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

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

Large Scale Tokamaks

Throughout the world there are four large tokamaks at present under construction. These are TFTR (USA), JT-60 (Japan), T-15 (USSR) and JET (Europe). TFTR was the first of these four to start operating (December 1982), followed by JET (June 1983). JT-60 is expected to be operating by the end of 1984 and T-15 in 1985. Although each of the experiments has a different scientific objective they all represent a major and logical step towards the development of a fusion reactor. JET and TFTR are designed to operate with deuterium and tritium plasmas. T-15 will have super-conducting toroidal field coils and powerful heating at the electron cyclotron frequency. JT-60 has a form of divertor and will use a wide range of heating techniques.

The Construction of JET

Introduction

JET is a large tokamak device with overall dimensions of about 15 metres in diameter and 12 metres in height. A diagram of the apparatus is shown in Figure 2 and its principal parameters are given in Table 1. At the heart of the machine, there is a toroidal vacuum vessel of major radius 2.96 metres having a D-shaped cross-section 2.5 metres wide by 4.2 metres high. During operation of the machine, a small quantity of hydrogen gas is introduced into the vacuum chamber and is heated by passing a large current (2.6 million amperes to begin with and 4.8 million amperes at a later stage of the Project) through the gas. This current is produced by transformer action using the massive eight-limbed magnetic circuit, which dominates the apparatus (Fig. 3). A set of coils around the centre limb of the magnetic circuit forms the primary winding of the transformer with the hot gas or "plasma" acting as a single turn secondary. Additional heating of the plasma is provided by injecting beams of energetic hydrogen atoms into the system and by the use of high power radio frequency waves.

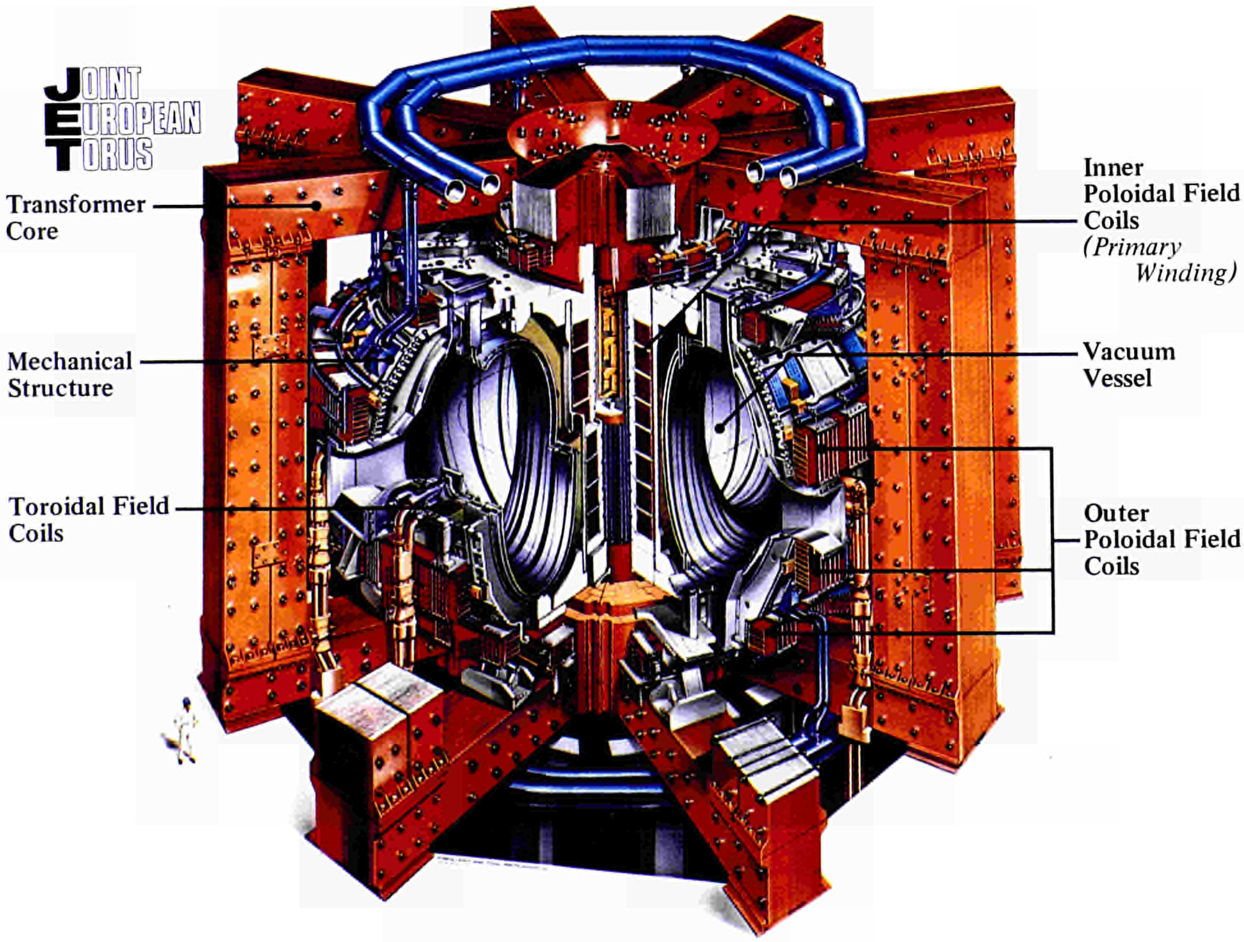


Fig. 2 Diagram of the JET Tokamak.

Table 1
Main JET Parameters

Plasma minor radius (horizontal)	a	1·25 m	
Plasma minor radius (vertical)	b	2·10 m	
Plasma major radius	R_0	2·96 m	
Flat top pulse length		20 s	
Weight of the vacuum vessel		108 t	
Weight of the toroidal field coils		384 t	
Weight of the iron core		2800 t	
		Basic*	**Full Design***
Toroidal field coil power (peak on 13 s rise)		250 MW	380 MW
Total magnetic field at plasma centre		2·8 T	3·5 T
Plasma current:			
circular plasma		2·6 MA	3·2 MA
D-shape plasma		3·8 MA	4·8 MA
Volt-seconds available to drive plasma current		25 Vs	34 Vs
Additional heating power		5 MW	25 MW

**Basic performance refers to that mode of operation characterised by the parameters given. A staged increase of the power supplies will make possible the mode of operation referred to as full design performance. This refers to that mode of operation which seeks to exploit the full design capability of the machine.*

The plasma is confined away from the walls of the vacuum vessel by a complex system of magnetic fields (Fig.4). The main component of the magnetic field, the so-called toroidal field, is provided by 32 D-shaped coils surrounding the vacuum vessel. This field, coupled with that produced by the current flowing through the plasma, form the basic magnetic fields for the tokamak confinement system. Additional coils positioned around the outside of the vacuum vessel are used to shape and position the plasma. These coils, together with the coils making up the primary winding of the transformer, are called poloidal field coils.

Initial experiments are being carried out using ordinary hydrogen plasmas. In the later stages of the operation of JET it is planned to operate with deuterium-tritium plasmas so that fusion reactions can occur.

Vacuum Systems

The assembly of the main components of the JET device was essentially complete by the end of 1982. By that time, all eight machine octants, having been pre-assembled in the Assembly Hall, had been transferred to the Torus Hall and installed there. The only major items left to be installed in 1983 were the upper poloidal field coils, and the horizontal limbs (Fig. 5) and core elements of the magnetic circuit.

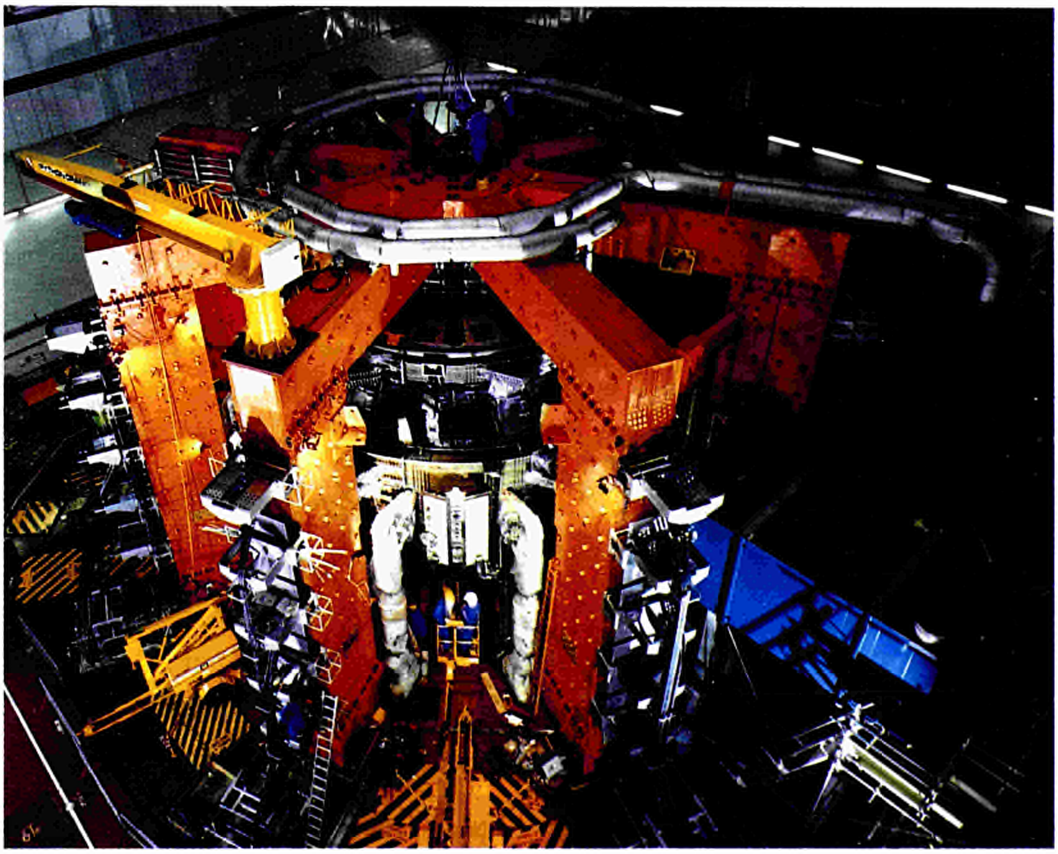


Fig.3 View of the JET device nearing completion showing the eight transformer limbs (in orange).

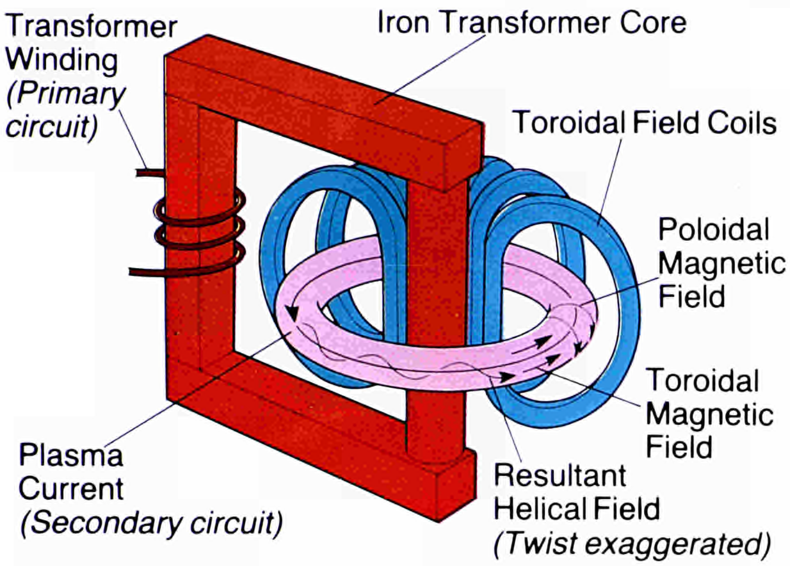


Fig.4 Tokamak magnetic field configuration.

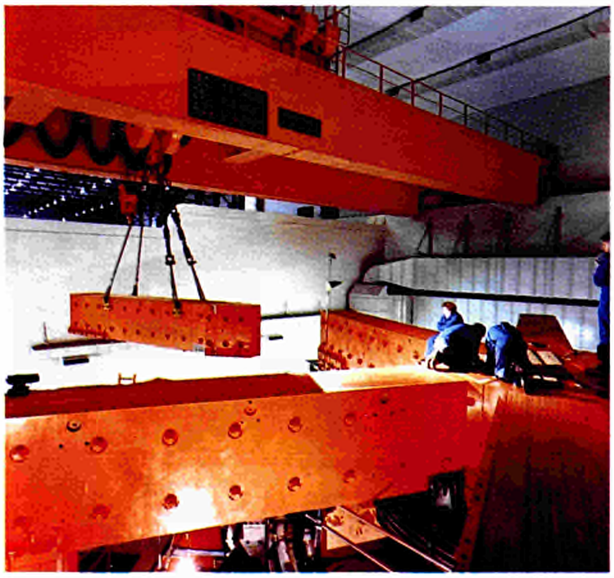


Fig.5 The final upper horizontal limb being installed in January 1983 to complete the magnetic circuit.

Fig.6 Welding of the torus U-joints, the vacuum seals, between octants.

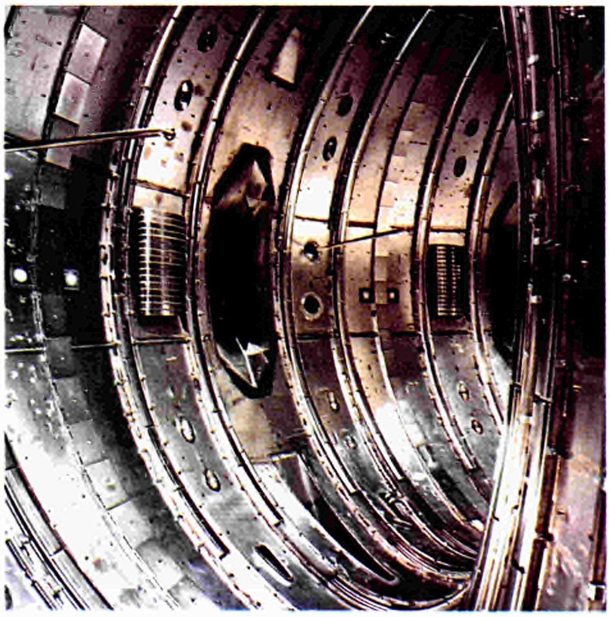


Fig. 7 A view inside the Torus showing two nickel-clad limiters and two high-pressure water spray heads.

Vacuum Vessel Completion and Commissioning

For easy installation into the tokamak assembly, the vacuum vessel octants, being double-walled, were slightly reduced in width by evacuating the interspace. The excellent dimensional accuracy of the vessel became apparent when, after installation, gaps of an even width were found between adjacent octants.

The vacuum sealing lips between octants were welded (Fig. 6) using a remotely controlled welding tool that was developed for use in the active phase of JET operation. These joints were leak tested using local pumping fixtures with special pipes used to introduce helium gas close to the welds. In all cases, leak rates better than 10^{-9} mbar.ℓ.s^{-1} were measured.

The final mechanical cleaning of the Torus was an automatic high pressure scouring with hot water and detergent (Fig. 7). After this cleaning, the Torus was

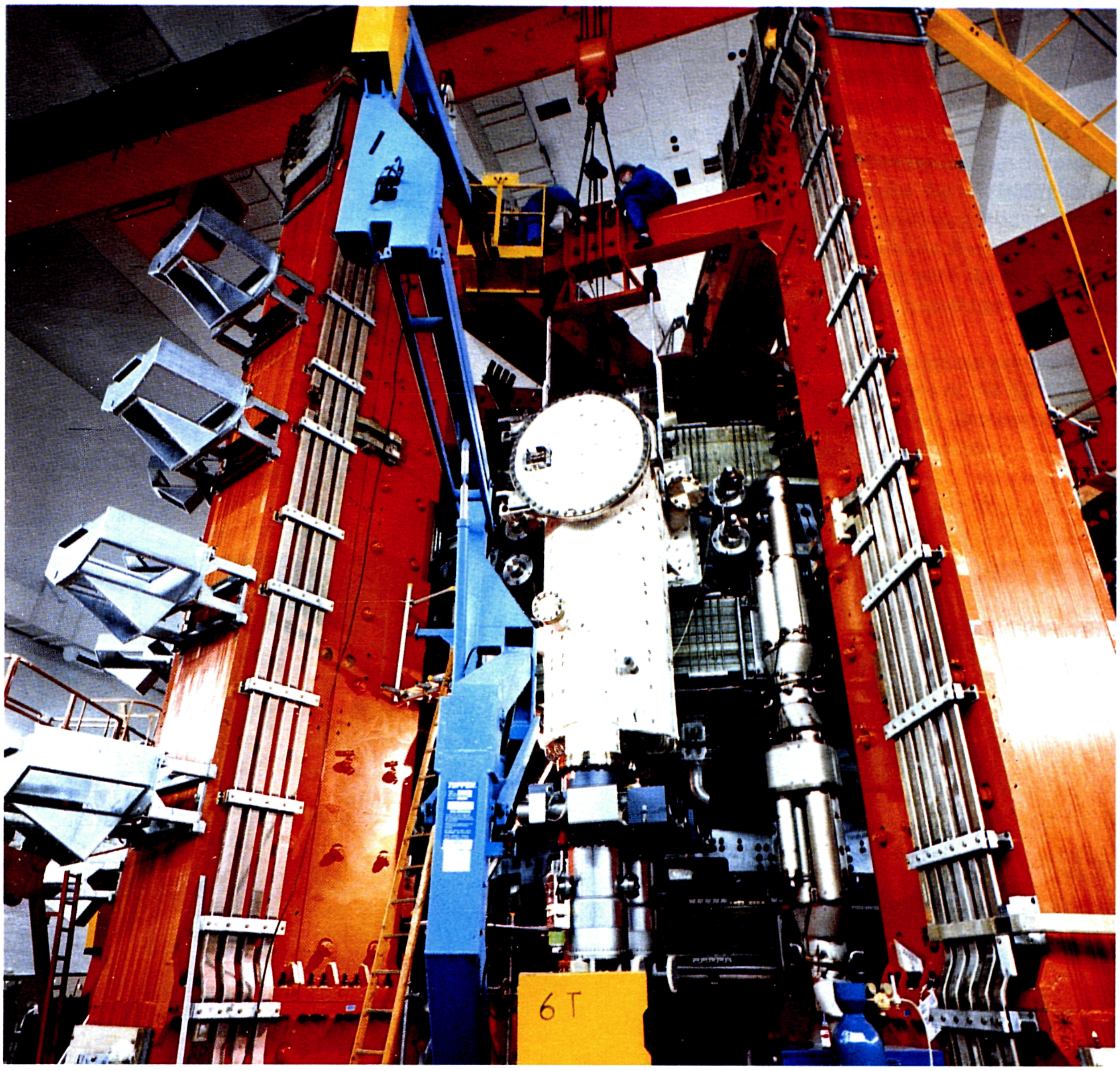


Fig.8 Installation of a pumping chamber to a Torus main port. The circular door at the front of the pumping chamber gives access to the Torus. At the bottom of the chamber, two gate valves and turbomolecular pumps are installed.

ready for the first pump down (Fig. 8). Only two leaks on external welds had to be repaired, after which the Torus was leak free. A pressure down to several times 10^{-6} mbar was achieved immediately, limited by outgassing only. Baking of the Torus and the Torus ports and external attachments at approximately 250°C and subsequent glow discharge cleaning at 200°C soon led to a total impurity base pressure of 3×10^{-9} mbar, measured at a Torus temperature of 100°C. The total outgassing rate for impurities was 1×10^{-12} mbar.ℓ.s^{-1} cm^{-2}, again measured at a wall temperature of 100°C.

Systems contributing to the above achievements are described below.

Bake-Out

To achieve the plasma conditions required for studies on the JET experiment, it is necessary to establish a high vacuum in the plasma container. Under normal conditions the attainable vacuum is limited by the continuous evolution of gas from the vacuum chamber walls. To reduce this outgassing, it is necessary to bake the whole vacuum vessel at a high temperature for several hours by passing a hot gas through the double-walled interspace of the vacuum vessel. This process drives the gas from the walls and subsequently enables high vacuum conditions to be obtained.

The gas blower plant for heating (and cooling) the toroidal part of the vacuum vessel is designed to heat the vessel to 500°C. A single stage radial turbo compressor with a particularly high compression ratio has now been chosen for this duty. Such a compressor makes it possible to use gases other than the originally foreseen carbon dioxide. Helium, though it requires a higher volume flow rate than carbon dioxide, is particularly attractive since, with its lower atomic mass, leaks an order of magnitude larger between the Torus main volume and interspace can be tolerated in tokamak operation. Furthermore, helium can be continuously cleaned from contaminants, such as tritium, by a cryogenic trap in a by-pass loop. In addition, helium will not be activated as would carbon dioxide in active operation.

The bake-out plant has been run routinely since plasma operations began, though with a temporary blower using air. With this temporary system, the vessel has been maintained for long periods at 300°C. The temperature was restricted to this level because the nickel limiters were not yet water cooled.

Effective cleaning during baking is achieved only if no surface on the vacuum side of the Torus remains cold. Since ports, port adaptors, pumping chambers, valves and attached diagnostic equipment (altogether 150 units) cannot be heated by the gas flowing through the interspace of the Torus, an additional electrical heating system is required. This system with its thermocouples and power supplies has been installed and commissioned. Electrical baking has been used on a routine basis to heat the ports up to 200°C and has substantially improved the quality of plasma discharges. Computer control of the system was introduced in November.

Wall Conditioning

From October to December, the wall conditioning was performed regularly with a bake-out assisted by glow discharge. Five days before plasma operation, the bake-out cycle was started by raising the temperature of the ports and the vessel walls to 200°C and 300°C respectively in approximately 30 hours. At this temperature the pressure took typically 24 hours to settle before the glow discharge was produced. Glow discharge was assisted by RF power to allow for a lower pressure during cleaning so that a higher removal rate of impurities could be achieved. The typical pressure during glow discharge was 3.10^{-3} mbar. Glow discharge cleaning was kept running for three full days before plasma operations. This resulted in barely detectable (less than 10^{-9} mbar partial pressure) impurity levels measured with the residual gas analyser; the only impurities observed were CH_4, H_2O and C_2H_4/CO. The temperature of the vessel and the ports were then reduced to 100°C or 200°C and maintained at this level during plasma operations. Further glow discharges were carried out each night between operating sessions to remove impurities generated during operations or by leaks.

These procedures have been successful and have resulted in low loop voltages and reasonably reproducible plasma discharges. It has also been demonstrated that these procedures were effective in re-establishing conditions leading to good quality plasma discharges very shortly after a vacuum vessel opening. Notably, in November, when the vessel was vented by a window breakage, plasma operations were successfully resumed after only three days of glow discharge cleaning at an elevated temperature.

During the whole period, the residual gas analyser was operational and proved to be a powerful tool for leak testing, for assessing the effectiveness of wall conditioning procedures, and for evaluating the release of impurities after each disruptive shot.

Gas Introduction System

The gas introduction system worked reliably from October to December with two introduction modules at octants 2 and 6. The fast valve, which provides a pulsed filling by opening a calibrated reservoir, had been operating since June, though the dosing valves for pre-programmed filling were commissioned and became computer controlled only by the end of November. This represented an important step in the JET operation as the gas feed, and as a consequence the plasma density, could be better controlled. In particular, this helped to achieve a smooth termination of pulses.

Limiters

For the beginning of operations, eight actively cooled nickel-clad limiters and four uncooled graphite limiters had been installed. The graphite limiters (Fig. 7) are of identical geometry to the cooled limiters. During operations in 1983, only the graphite limiters were used. The nickel-clad limiters were retracted ten centimetres behind the line of the graphite limiters. During discharges, one of the four graphite limiters was viewed by an infra-red camera. There were some indications of arcing especially during the early phases of operation. Later, arcing became less frequent and some limiter surface heating was observed. The surface temperature, however, never rose above 500°C.

No attempt was made to try the nickel-clad limiters because of the satisfactory behaviour of the graphite limiters and also because of the lack of time to investigate comparisons with different types of limiters. In addition, some leaks opened up between the main vacuum and the water cooling circuits in three of the nickel limiters. These circuits have now been blanked and pumped down. The leaks are probably due to a metallurgical problem, which will be investigated when the affected limiters are removed in the shutdown at the end of 1983 (Fig. 9).

During 1983, several developments were initiated with the aim of an upgraded machine performance. One of the principal developments concerned the design of a next generation of limiters.

Belt Limiters

A new concept of belt limiters has been developed. It consists of two toroidal rings above and below the equatorial plane, with the RF antennae placed between them (Fig.10). Each ring is composed of sixteen sections to allow remote replacement. The ring is made up of water cooling pipes with cooling fins welded to the pipes. The limiter plates are inserted between the fins and are thus radiation cooled. This design is attractive because of the simplicity of the water circuit and the absence of critical thermal stresses. The limiter plates can also be easily exchanged and different materials can be envisaged. At the

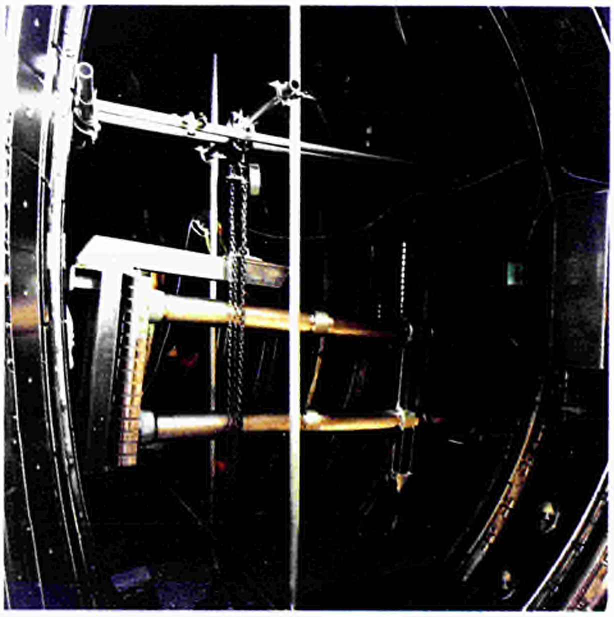


Fig.9 A nickel-clad limiter being removed from its mountings.

end of the year, the detailed design of the water cooling structure was complete and technical specifications were ready for a call for tender to be sent out early in 1984.

Beryllium as a Limiter Material

Beryllium promises a number of advantages compared with graphite. Its use in JET is now seriously contemplated following encouraging results from preliminary investigations and tests. In particular, a contract placed to run a small tokamak at Dusseldorf with beryllium limiters showed that radiation due to metallic impurities of high atomic number reduced substantially after the beryllium limiters were introduced. At the end of the year, JET placed a contract with Oak Ridge National Laboratory (USA) to operate their ISX-B tokamak for a period of at least a month with a beryllium limiter assembly. Also, a study contract with IPP Garching was placed to find more systematic and reliable data for sputtering and the retention of hydrogen implanted in beryllium.

The health hazard presented by beryllium has been discussed with the only beryllium manufacturer in the

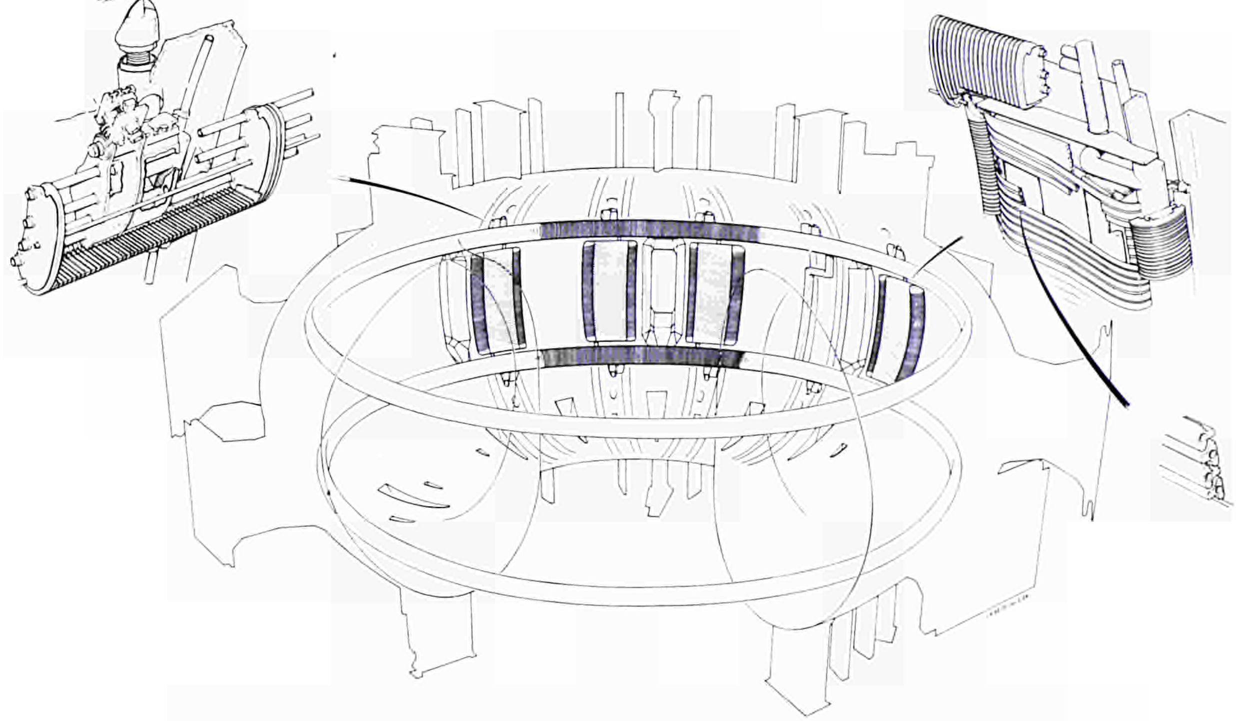


Fig.10 A sketch showing the two belt limiters, one above and one below the equatorial plane.

West and with establishments which have experience in processing and machining the material. Safety rules are well established and their application to JET should not present a major difficulty.

Actively Cooled Belt Limiters

Actively cooled belt limiters using hypervapotron cooling need to be developed in parallel with the radiation cooled belt limiters described above in case radiation cooling proves to be insufficient for the full heating power of JET. The development of a hypervapotron structure made of a copper-chromium-zirconium alloy plated with beryllium tiles has started. Investment casting has been studied for the production of the hypervapotron structure. Initial test samples exhibit mechanical properties close to the optimum values for such alloys. For plating with beryllium, the following techniques are to be investigated: vacuum brazing, solid state bonding with an intermediate silver layer, plasma spraying of beryllium and electroplating of the cooling structure onto the beryllium tiles, and explosive welding. First results of brazing tests show that this technique can be used, though the properties of the copper-chromium-zirconium alloy are somewhat degraded. Solid state bonding and explosive welding do not present this disadvantage, but are far less developed. It is expected that JET will place study contracts to study these techniques. Preliminary tests were also performed to investigate plasma spraying and electroplating.

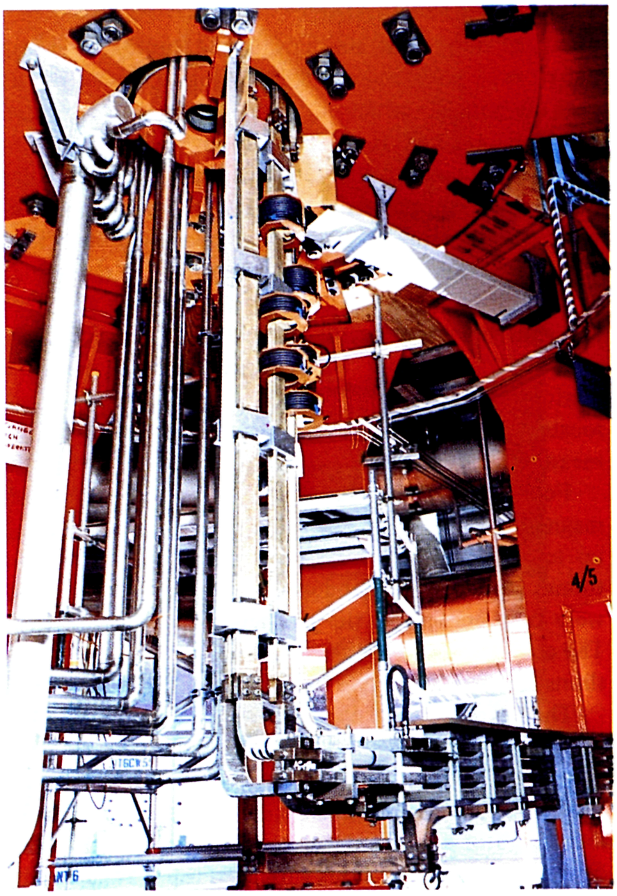


Fig.11 Busbars and cooling water pipes to poloidal field coil No.1.

Toroidal and Poloidal Field Systems

The mechanical assembly of the JET machine was completed in January 1983 with the positioning of the upper poloidal field coils and the upper limbs of the magnetic circuit. The busbar systems for both the poloidal and toroidal fields were also erected during the first months of 1983. The poloidal and toroidal field coil systems were then commissioned in stages during the year.

The plasma position control system was also commissioned in stages during 1983. In its final form, the system allowed the radial position and size of the plasma to be accurately programmed. The performance of this system played a major role in the success of the operations from October to December.

The Poloidal Field System

In January 1983, the two upper poloidal field coils and the upper limbs of the magnetic circuit were installed on the machine. By the end of January, most busbars and accessories had been delivered and the assembly of the poloidal field busbar system (Fig. 11) made rapid progress. The assembly was completed at the end of April with the erection of a protective cage along the busbar runs in the basement.

In May 1983, prior to power tests, field and flux measurements were carried out to check the poloidal field configuration. The leakage flux during pre-magnetisation was measured in the area occupied by the plasma and found to be small as expected. Field maps for the vertical and radial equilibrium field showed excellent agreement with predicted values. In general, the symmetry of the system and in particular that of the iron circuit was good.

The coil system was used for plasma operation from June to December 1983. The performance achieved is compared with the system's design values in the table below.

Table 2
Status of the Poloidal Field System

Circuit	Mode of Operation	Maximum Current Reached kA	Maximum Design Value kA
Ohmic Heating	Premagnetisation	40	80
Ohmic Heating	Slow rise	64	80
Vertical Field	Slow rise	20	45
Radial Field	–	2	3

The Toroidal Field System

The final step in the assembly of the toroidal field magnet was the positioning and shimming of the coils inside the mechanical structure. The straight part of each toroidal field coil is designed to fit into a cylindrical groove machined on the inner cylinder so that the coil is located and supported against lateral forces. The coils were pressed radially against the inner cylinder with a force of 10 tonnes per coil by means of the mechanical jacks provided on the mechanical structure. At this stage, the gaps between the mechanical shell and the lateral surfaces of the coils were measured along the outer contour of each coil. The shims (608 in total), which locate and support the coils, were machined to the measured dimensions and inserted.

Following this initial shimming, the coils were pressed magnetically against the inner cylinder, using coil currents up to 15kA. In this way, centripetal forces up to 100 tonnes per coil were produced and ensured that all coils were fully engaged in the grooves of the inner cylinder. The collar and ring teeth were then tightened and the ring shims inserted to provide full lateral support to the coils.

The toroidal field coils were commissioned initially up to 25kA using the static unit alone as a power supply. In June, with the flywheel generator, a current of 40kA was passed in the coils. Finally, towards the end of 1983, the generator and the static unit in combined operation delivered a current of 53kA with a flat top of ten seconds. The maximum energy delivered per pulse at this current level was 3100MJ, compared with the maximum design value of 5100MJ.

The expansion of the coils in the radial and vertical directions was measured and found to be in agreement with calculated values. This confirmed that bending stresses have been eliminated completely by the D-shape of the coils.

Plasma Position Control

The radial position control of the plasma is based upon the measurement of the poloidal flux difference between the limiter and the desired inboard position of the limiter magnetic surface. The flux error signal is combined with a pre-programmed voltage to control the output voltage of the poloidal vertical field amplifier. At the correct position the flux difference becomes zero.

The stabilisation of the vertical position is achieved in an analogous manner using the measured flux difference between symmetric top and bottom reference positions for feedback control of the poloidal radial field amplifier. Derivative feedback is essential as the JET plasma is unstable in vertical direction if the plasma elongation ratio exceeds 1.2.

In the course of the JET operation, the position control system was enhanced in several steps. From June to August, external flux loops were used for radial position control and only a passive and partial stabilisation of the vertical position was applied by shorting the radial field coil. The plasma pulse duration did not exceed a quarter of a second, largely as a result of vertical instability. In October, feedback stabilisation of the vertical position allowed the pulse duration to extend to about two seconds.

During November and December, the full position control system was available as designed, except for plasma height limitation. It was found that the plasma radial diameter followed closely the programmed diameter and that the vertical position was centred within a few centimetres.

Power Supplies

The peak electrical power required for JET during operational pulses could exceed 900MW. As the Central Electricity Generating Board limits the power which may be drawn directly from the grid, much of this power has to be provided by two flywheel generators.

The JET power supply system uses two incoming high voltage lines: one at 400kV and the other at 132kV. Pulse power is drawn from the 400kV line, transformed down to 33kV, and fed to the JET loads through a system of circuit breakers. Additional power, for example for motors, pumps, and air compressors, is taken from the 132kV line and distributed around the site at voltages between 415V and 11kV. The incoming supplies are shown in Figure 12.

Magnet Circuit Power Supplies (Fig. 13)

The two large flywheel generators provide the base power to the principal JET loads – the toroidal and poloidal field coils. Each of these vertical shaft generators can provide 2600MJ of energy. They are identical and are capable of delivering 400MW of peak power. Each rotor, weighing 775 tonnes, is accelerated between pulses by a 8.8MW pony motor to a speed of 225 revolutions per minute. Normally when power is needed for the operation of JET, the rotor windings are energised, the rotational energy of the flywheel is converted into electrical energy and the rotor slows down to half speed. The AC power from each generator is converted to DC power by diode rectifiers before it is delivered to the loads.

The two flywheel generator systems were commissioned in time for plasma operation in June. Commissioning was performed in successive steps to ensure the smooth integration of all auxiliaries and of each flywheel generator system into the JET power supply system. By the end of May 1983, the following performance had been achieved on load:

- Interruption of current up to 40kA in the ohmic heating circuit (dummy load);
- Toroidal field current pulse up to 40kA and energy up to 1200MJ.

The period from June to December was dedicated to plasma operation and to further commissioning the poloidal and toroidal field power supplies. By the end of

Fig.12 A view north, showing the incoming spur from the 400kV supergrid entering the 400kV substation.

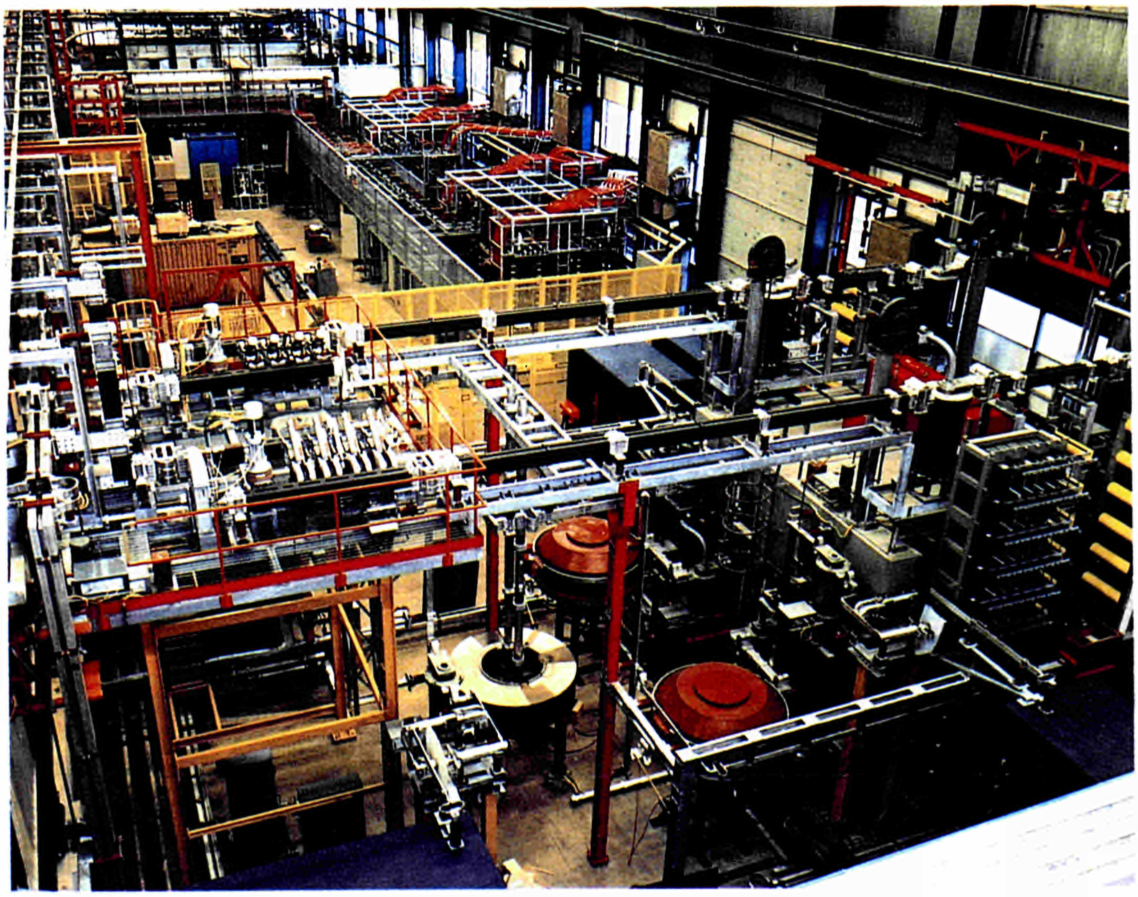


Fig.13 J1 North Wing, showing ohmic heating equipment, poloidal field busbars and vertical & radial field amplifiers.

1983, the following performance had been achieved:

- A peak poloidal field generator current at the end of a JET pulse of 79kA;
- A toroidal field current pulse of up to 53kA for 10 seconds flat top with the series operation of the flywheel generator and one toroidal field static unit;
- A maximum output energy from the toroidal field generator of 2000MJ.

Concern over elevated thrust bearing temperatures led to a decision to limit the available output energy of the toroidal field flywheel generator system (design 2600MJ). A modification to the thrust bearing is planned for the shutdown at the beginning of 1984 to resolve the problem.

Neutral Injection Power Supplies

Each neutral injection box requires 60MW of power from the 33kV system, the major part to drive the accelerator grids. The power to these grids is regulated and switched by large tetrode valves. The system requires the voltage to be controlled to within one per cent and to be switched off in times of less than 10 microseconds for the protection of the PINIs in the event of a grid breakdown.

The main components of the PINI power supplies are: the outdoor power supplies rectifying the 33kV AC into 95kV DC; the protection and regulation units giving fast turn-on and providing fast turn-off in case of a breakdown in the PINIs themselves; the auxiliary power supplies used mainly to generate the extraction plasma of the PINI; the transmission lines for transporting the 80kV to the PINIs; and, the snubbers to dump the capacitive energy of the transmission line in case of a PINI breakdown.

Stage 1 of the neutral injection power supplies foresees the installation of five complete high voltage power supply modules each serving two PINIs: four modules for the eight PINI beam sources in the first neutral injection box, and one for two PINI beam sources in the PINI test bed. Site acceptance tests of the first three modules have been completed. Testing of the next two has started. The installation of the first protection system in the hot cell was completed and acceptance tests are in progress. Integrated tests between the outdoor power supply, the protection system in the hot cell, and the first auxiliary power supply have started and are due to be completed during January 1984. During 1983, modules 2 and 3 of the protection system were successfully tested in the factory. Installation on site of module 2 is finished and site testing has started.

Stage 2 of the neutral injection power supplies covers the remaining four power supply modules for the second neutral injection box. Three of the outdoor units were delivered during 1983; the fourth will arrive in 1984.

Transmission lines insulated in SF_6 (Fig. 14) will guide the power from the J1 North Wing where the indoor power supplies are installed (the high voltage modulators and the auxiliary power supplies) to the Torus Hall where the neutral injection box is installed. Manufacture of the

Fig.14 A section of a SF_6-insulated high voltage transmission line for the supply of power to the neutral injectors.

eight transmission lines for the first neutral injection box is almost complete and factory acceptance tests are in progress. The first three lines have been delivered on site. Transmission lines for the second box were also ordered in 1983.

The interface between the injectors and the transmission line is made by an SF_6 tower, which will house the snubbers, provide the isolation for the cooling of the PINIs and will contain different high voltage components to activate the PINIs. The snubbers for the first and second boxes were ordered during 1983. Assembly of snubbers for the first box will start in January 1984 in time for the acceptance tests and installation on the SF_6 tower, which is now in the late stage of manufacture.

Radio Frequency Heating Power Supplies

The power supplies for the RF heating can be divided into three parts: the power supply for the preionisation generator; the auxiliary power supplies for the RF generators; and the main power supplies for the RF transmitters.

The call for tender for the preionisation generator power supply was issued in May and the contract placed in August 1983. This power supply provides a fixed DC voltage of approximately 10kV and a current capability of 60A. The manufacture of the main components is finished and some have been factory tested. Final acceptance test, delivery and installation is planned for early 1984.

The reference design for the auxiliary power supplies for the RF generators is in progress. The call for tender will be issued and the contract placed in 1984. Installation and commissioning is intended for early 1985.

The call for tender for the main power supplies for the RF generators was issued at the end of 1982 and the contract awarded in March 1983. The contract is split into stages in line with the RF generators themselves. Four power supply modules providing the DC power for eight RF generator units have so far been released.

Neutral Beam Heating

Neutral beam heating is achieved by injecting intense beams of energetic neutral atoms across the confining magnetic field into the plasma. There the neutral particles are ionised and captured within the magnetic field. The resulting energetic (supra-thermal) ions give up their energy to the bulk plasma through collisions and thus increase the plasma temperature.

Although the basic physics of both the production of energetic neutral beams and the subsequent interaction with the plasma are well understood, injection requirements for JET make necessary a substantial extension of technology in terms of total power and pulse duration.

In order to meet these requirements, a joint design team was formed drawing mainly upon expertise in the Associated Laboratories of Fontenay-aux-Roses (France) and Culham (UK). The team has been responsible for the development of the physics and technology of the PINI beam sources. The Culham Laboratory contribution is orientated towards the development of high power 80keV hydrogen beams with long pulse duration, while Fontenay concentrates on problems associated with the deuterium beams and higher voltage operation required in later phases of the JET programme.

The neutral injection for JET will be provided by two systems, each capable of delivering 5 MW of power in the full energy component of the beam. The first system, part of the Basic Performance Phase, is scheduled to operate before the end of 1984, and the second, part of the Extension to Full Performance Phase, one year later. Each neutral beam injection system uses eight PINI beam sources, each capable of providing an equivalent hydrogen beam current of 60 amps at an energy of 80 keV..At a later stage in the experimental programme, the voltage will be increased to 160 kV using deuterium beams. The systems are designed for a beam pulse length of 10 seconds. A schematic of the neutral injection system is shown in Figure 15.

Progress in 1983

On the first injection system, (Fig. 16), good progress has been made on component manufacture and assembly preparation. A pre-assembly of duct scraper, injector vacuum box, turbomolecular pump, cooling water piping and magnet shielding was completed at the tokamak.

Eight PINI beam sources (Fig. 17) have been delivered, of which three have been tested. In the testing, beams have been extracted at the nominal 80 kV and 60 amps with beam durations of 5 seconds. The PINI has proved to be a robust structure and easy to condition. However, the focussing of the beams appears to be stronger than

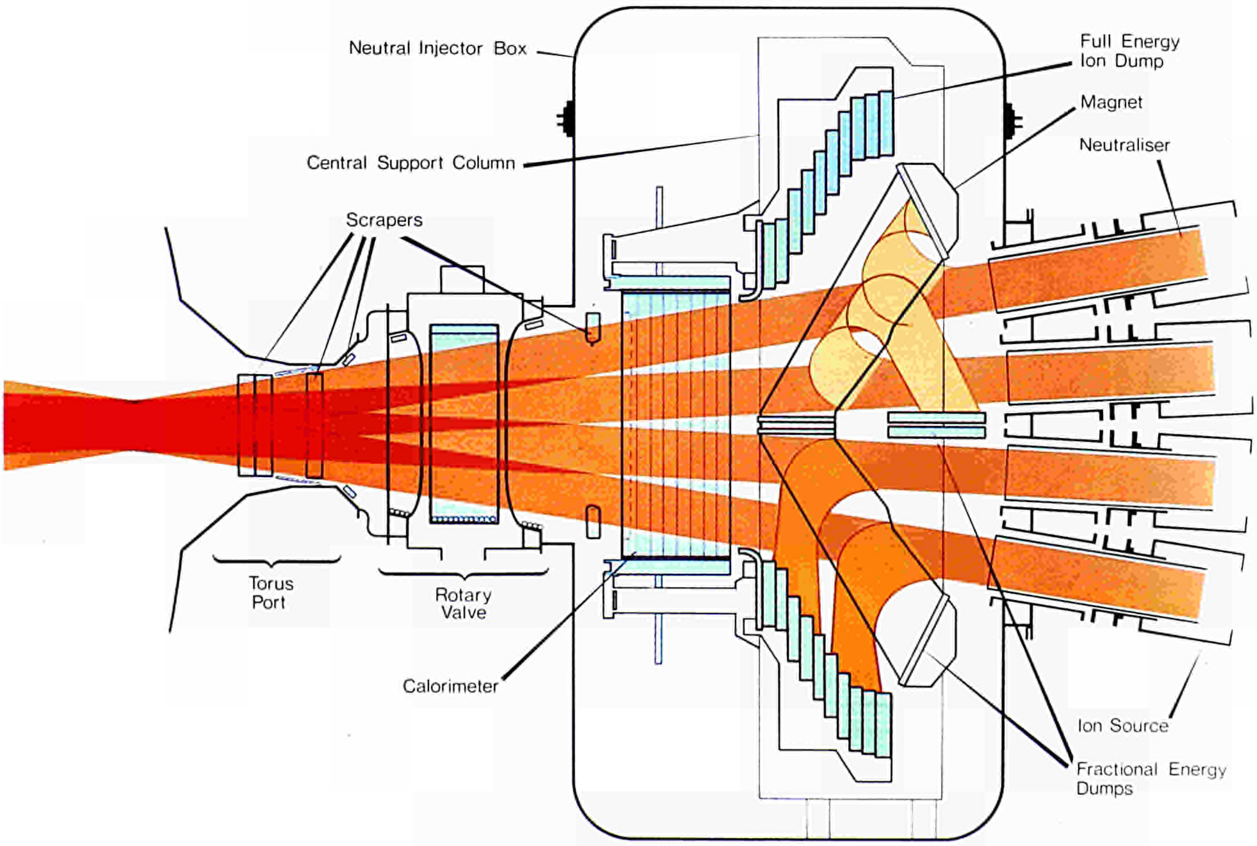


Fig.15 An elevation of a JET neutral injector.

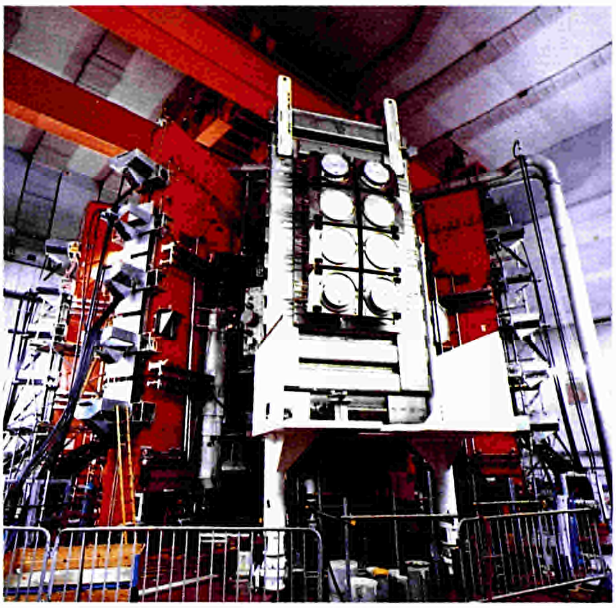


Fig.16 The neutral injection box at Octant 8 awaiting installation of the PINI beam sources.

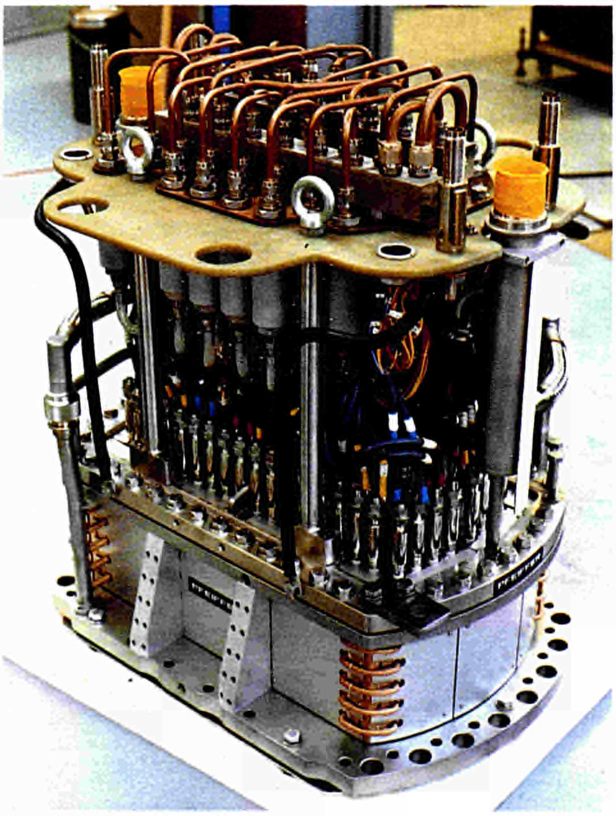


Fig.17 A PINI plasma source.

expected. This factor is important with respect to power loadings on beam wing scrapers and ion beam dumps, and is being further investigated. It may lead to a slight change in the aperture positions in one of the four grids of the PINI, which can be done on the existing grids.

The species yield of the bucket ion sources is being improved in co-operation with Culham Laboratory by superimposing a super-cusp field to the normal magnetic field configuration of these sources. Preliminary tests lead to the expectation that the proton yield can be increased into the 80 per cent range without deteriorating the specified plasma uniformity of ±5 per cent.

The JET neutral injection test bed (Fig. 18) was installed and commissioned during the year. The test bed is designed to operate two PINI beam sources simultaneously at full hydrogen injection parameters. All internal components of the beamline system can be tested there before being transferred to the JET machine. The first PINI was operated on the test bed in November. Arc currents of up to 900 A were obtained, compared with the maximum value of 1200 A that will be used ultimately.

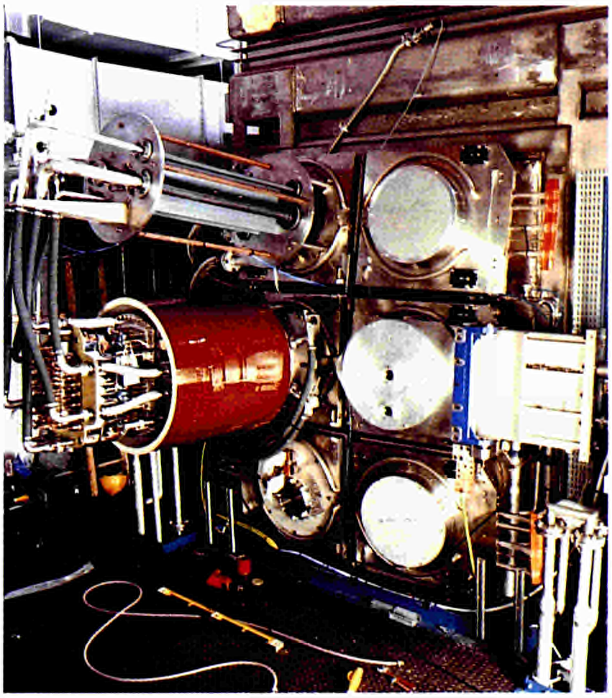


Fig.18 A PINI source installed for testing on the Neutral Injection Test Bed.

The rotary valves (the gate valve between the injector system and the Torus), fast shutter, central support column and deflection magnets have been delivered to site and are being prepared for installation. The cryopump (Fig. 19) is complete and ready for delivery. A one-tenth section of the pump has been operated on the test bed and has confirmed fully the design parameters. The cryoliquid transfer lines have been successfully tested and installed. The manufacture of the liquid helium plant

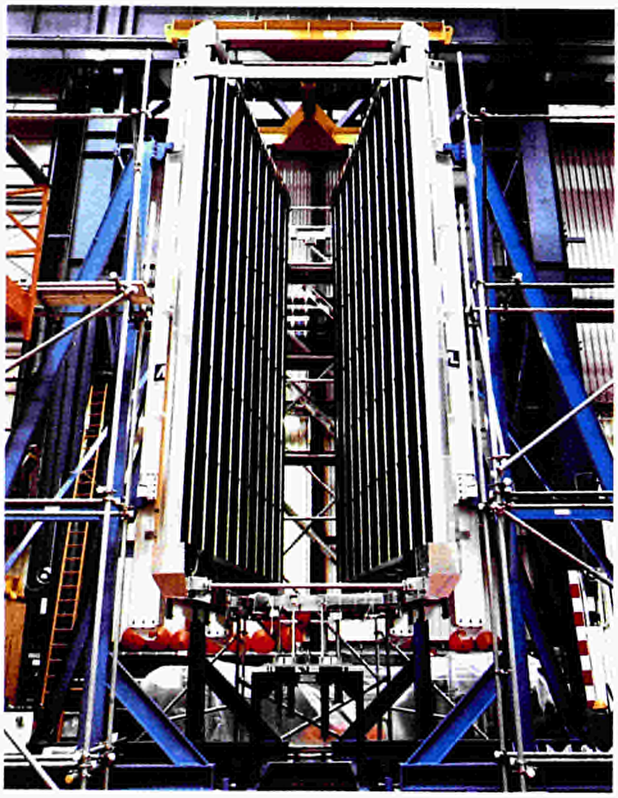


Fig.19 A neutral injection cryopump consisting of two six-metre high assemblies to cover the side walls of the neutral injection box.

serving both neutral injection systems and the test bed is well under way and major components have been delivered. During 1983, it was decided to undertake pre-operational thermal cycling tests on all beam stopping or scraping components. The first full energy ion dumps, duct scrapers and box scrapers have passed these tests and are now ready for delivery.

The first injection system will be assembled in the first part of 1984. In early summer, the system will be installed in the test bed and commissioned there with the simultaneous operation of two PINIs with long beam duration. Before the end of the summer shutdown, the beam line system should be ready to be transferred to the tokamak for final commissioning.

On the second system, all but a few of the major components are ordered and are in an advanced state of manufacture. Their delivery is expected in 1984. Assembly of the second system will carry on in parallel with the commissioning and operation of the first system.

At the Fontenay-aux-Roses Laboratory, the extraction system of a PINI was modified to a three-electrode system for 160kV operation. The PINI was operated reproducibly at this voltage with pulses of 35amps extracted current for 100 milliseconds. These experiments were in hydrogen with the perveance unmatched at the higher voltages.

Radio Frequency Heating

For radio frequency heating, high power electromagnetic waves are radiated from antennae located on the walls of the vacuum vessel. Power is coupled into the plasma by selecting a frequency of radiation (25–55MHz on JET) equal to that of an ion species gyrating around the magnetic field lines at the centre of the plasma. The accelerated ions then transfer their energy to the bulk of the plasma through collisions between charged particles.

Ultimately, ten RF generators will be installed, producing the 30MW of power required. The power from each generator will be coupled into the upper and lower halves of an antenna by two 230mm co-axial transmission lines. About one-half of the 30MW of generated RF power will be coupled into the plasma. The generators situated in the north wing of the main building will use large tetrode electronic tubes, each one capable of generating 1.5MW of radio-frequency power.

The ten antennae will be distributed almost equally around the torus where they will be built into the shadow of the belt limiters attached to the walls of the vacuum vessel. During 1983, the main emphasis of the work on RF heating was on the detailed design of the antennae. Major systems components were also procured and some critical items tested.

The ICRH Power Plant

The major contracts for the manufacture of the DC power supplies, the RF generator and the main transmission lines were placed between the end of 1982 and the first half of 1983. Only the first stage of each contract, which involves a prototype and six units, has been released. A generator unit consists of two identical chains of four amplifiers driven by a low power oscillator. JET has also ordered a smaller pre-ionisation generator unit (PIG) which does not have the final amplifier stage. The PIG, which delivers a total of 200kW, will first be connected to the antennae for early plasma experiments on coupling and matching; it will then be used to drive the RF test bed equipment.

Table 3 summarises the status of the construction of the power plant. The contracts are progressing on schedule. Figure 20 illustrates the organisation of the RF power plant in the north wing of the Torus. The steel structure is complete and will be ready to receive the PIG in February 1984. Figure 21 shows the prototype 3MW unit under construction at the manufacturers.

Antennae

The design of antennae is based on the most efficient use of the penetration space in the torus chamber, which both limits the size of antennae that can be introduced into the chamber and severely restricts the diameter of the coaxial feeds. With the available dimensions, thermal effects due to resistive losses in long pulse operation set an upper limit of 1.5MW to the heating power effectively coupled to the plasma by a complete antenna. The screen

Table 3
Status of the construction of
RF Power Plant and Transmission Lines

Scope	Status
DC power supplies	Order placed in the beginning of 1983 (see the section on JET power supplies).
200 kW PIG generator	High power tests under way at the manufacturers. (To be commissioned at JET in March 1984).
RF generators	A prototype and 6 units of 3 MW are under construction. (First unit to be commissioned at JET in November 1984, then subsequent units each month in 1985).
Main transmission lines	Contract for 6 units placed in July 1983. (Installation in JET of 2 units between May and September 1984).

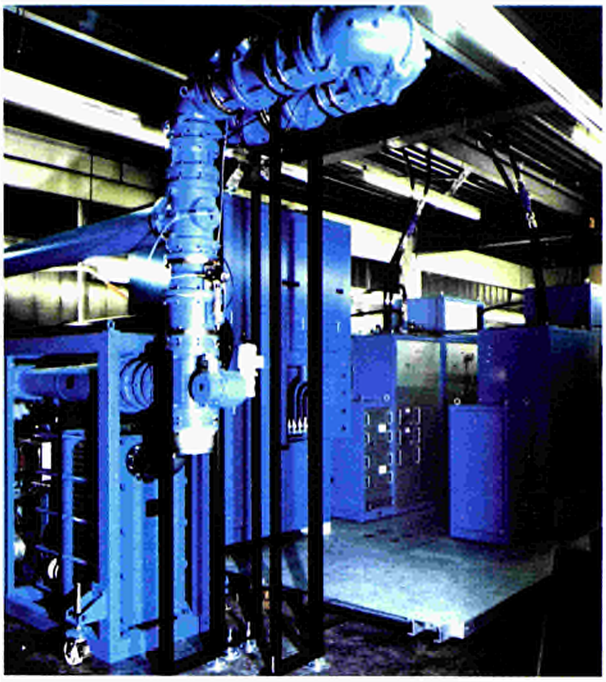
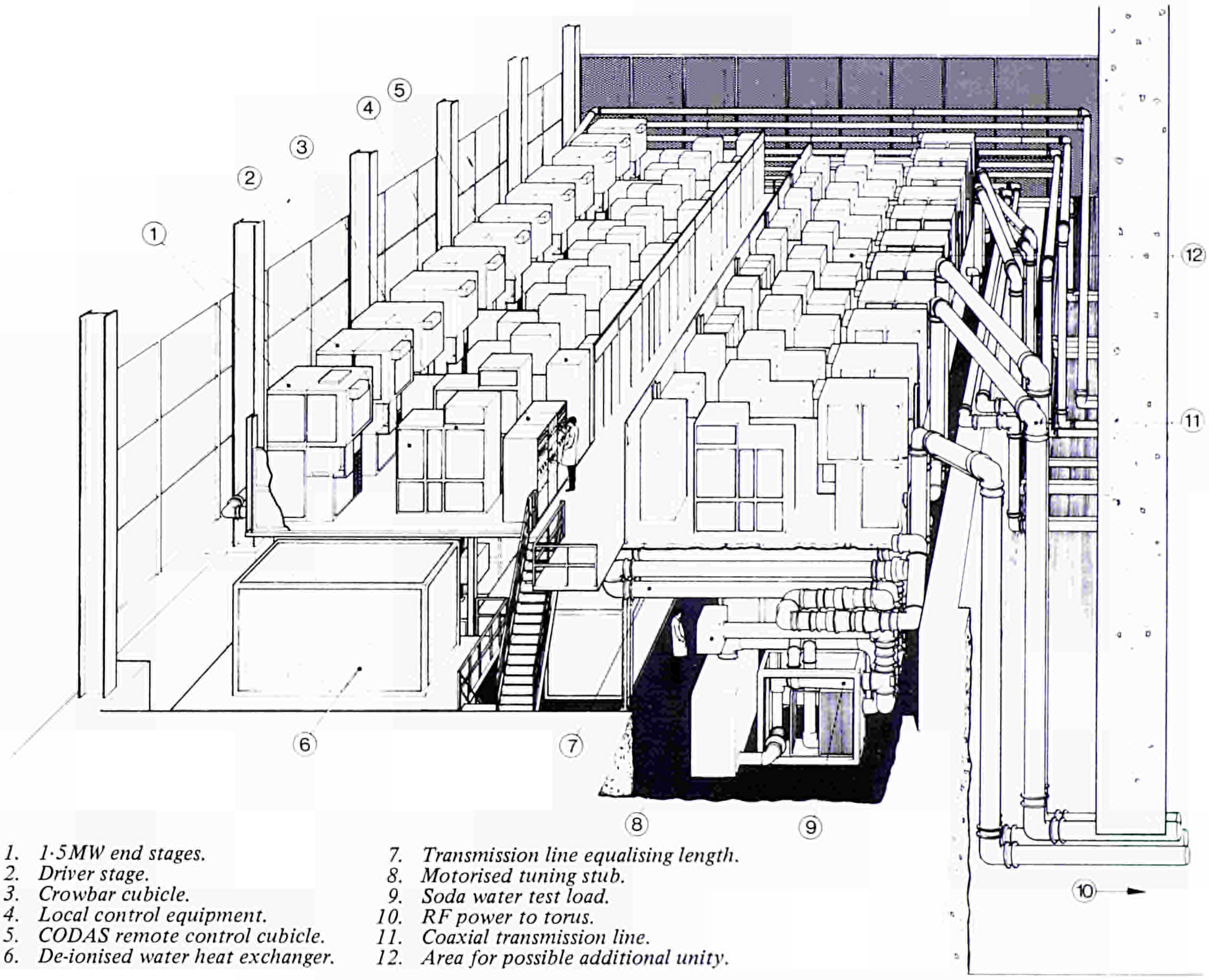


Fig.21 View of the prototype 3MW ICRF generator under test at the manufacturer's works.



1. *1·5MW end stages.*
2. *Driver stage.*
3. *Crowbar cubicle.*
4. *Local control equipment.*
5. *CODAS remote control cubicle.*
6. *De-ionised water heat exchanger.*
7. *Transmission line equalising length.*
8. *Motorised tuning stub.*
9. *Soda water test load.*
10. *RF power to torus.*
11. *Coaxial transmission line.*
12. *Area for possible additional unity.*

Fig. 20 Layout of the radio frequency plant in the J1 North Wing.

(Fig. 22), responsible for the main RF losses, has to be made of a good electrical conductor preferably with low atomic number to avoid impurity contamination.Nickel was chosen for the two prototype antennae and beryllium is contemplated for a future generation. The screen will be water-cooled for long pulse operation. Its elements will be oriented along the lines of force in order to minimise coupling to surface modes.

For the prototype antennae, the active parts will be completely surrounded by a limiter frame made of the same material as a normal JET limiter. The limiter frame allows the coupling element to be placed close to the plasma, thus enhancing the radiation resistance and reducing wave surface effects. The antennae will now be equipped with two different central conductors. In the original version, the two current elements were phased in order to create the usual single current loop geometry. However, plasma tests in TFR with an antenna model suggested that as an option, a new quadrupole central conductor might be considered. Made of four alternate current elements, the quadrupole conductor emits a radiation pattern which excludes the long wavelength radiation that is a possible candidate for the impurity generation observed in TFR.

The design of the second generation of water-cooled antennae, capable of twenty second pulse operation, started towards the end of 1983. In this design, the antennae will be located between the two belt limiters, which receive the major part of the thermal load transported by plasma particles. The residual load is taken by the antennae side protection, which will probably be made of beryllium tiles. The cooling water will flow from the bottom belt limiter, passing through the antenna and entering the top belt limiter. Each element of the antenna screen will be actively cooled. The beryllium tiles placed on the antenna manifold will be radiation cooled between pulses.

Status of Construction and Commissioning

The RF test bed (Fig. 23) has been operating successfully since August 1983 at CEA Fontenay. Intensive tests at nominal RF current and voltage have been performed on the most critical items of the antenna, for example the large ceramic vacuum barrier, ceramic supports, vacuum and pressurised transmission line elements. No arcing or overheating has been observed up to a peak voltage of 45kV and a current of 1500 amps. The overall results already obtained with the test bed constitute an important step in the qualification of the JET antenna design.

The A_0 antenna and vacuum transmission line components had reached the last phase of manufacture at the year end. Integrated tests of a complete antenna at Fontenay were scheduled for April 1984.

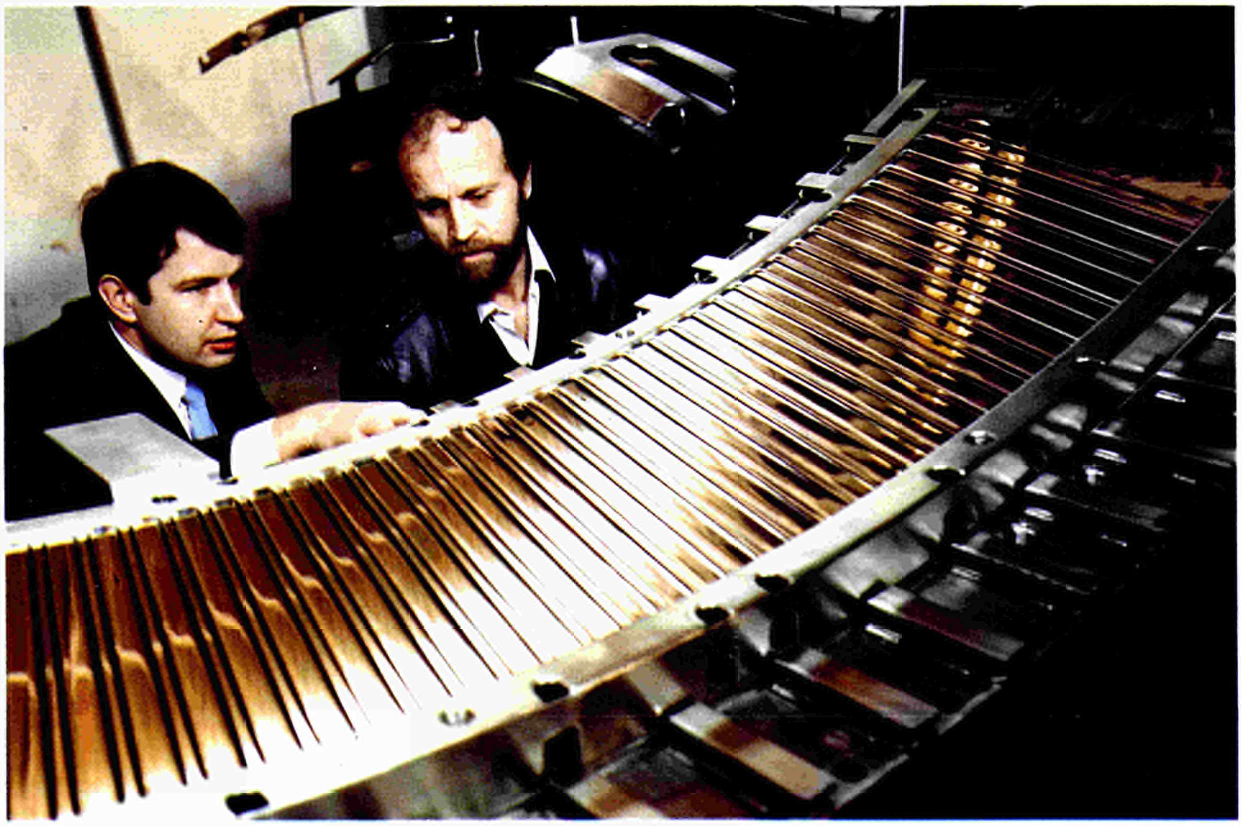


Fig.22 View of an A_0 antenna showing the electrostatic screen.

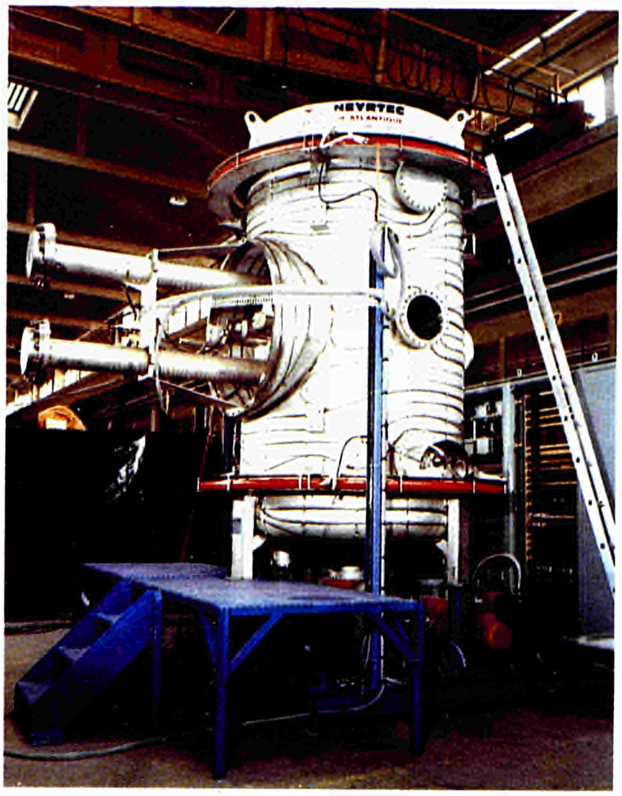


Fig.23 The RF test bed.

Remote Handling

During later stages of the JET Project, high energy neutrons produced by fusion reactions will activate the machine structure. This will severely restrict or even prevent access of personnel to the machine area. Any operations that need to be performed on the machine, such as inspection, maintenance or enhancement, either inside or outside the torus, will therefore necessarily involve remote handling techniques.

JET policy is to perform each operation with a specially designed or adapted tool which can be placed in position by one or more of the general purpose remote-handling machines. At the heart of this system is an accurate and sensitive 150 tonne crane, an articulated boom to reach inside the torus, and several two-armed force-feedback manipulators. Transporters will be able to carry the manipulators and tools to every part of the plant. The operation of the tools will be facilitated by special design features of the plant, in so far as these have been incorporated. Unplanned and unexpected requirements should be met by the flexibility of the overall system, aided by ad hoc expedients.

Progress on JET Remote Handling Systems

The in-vessel inspection system (Fig.24) was manufactured by August 1983. The system uses remotely

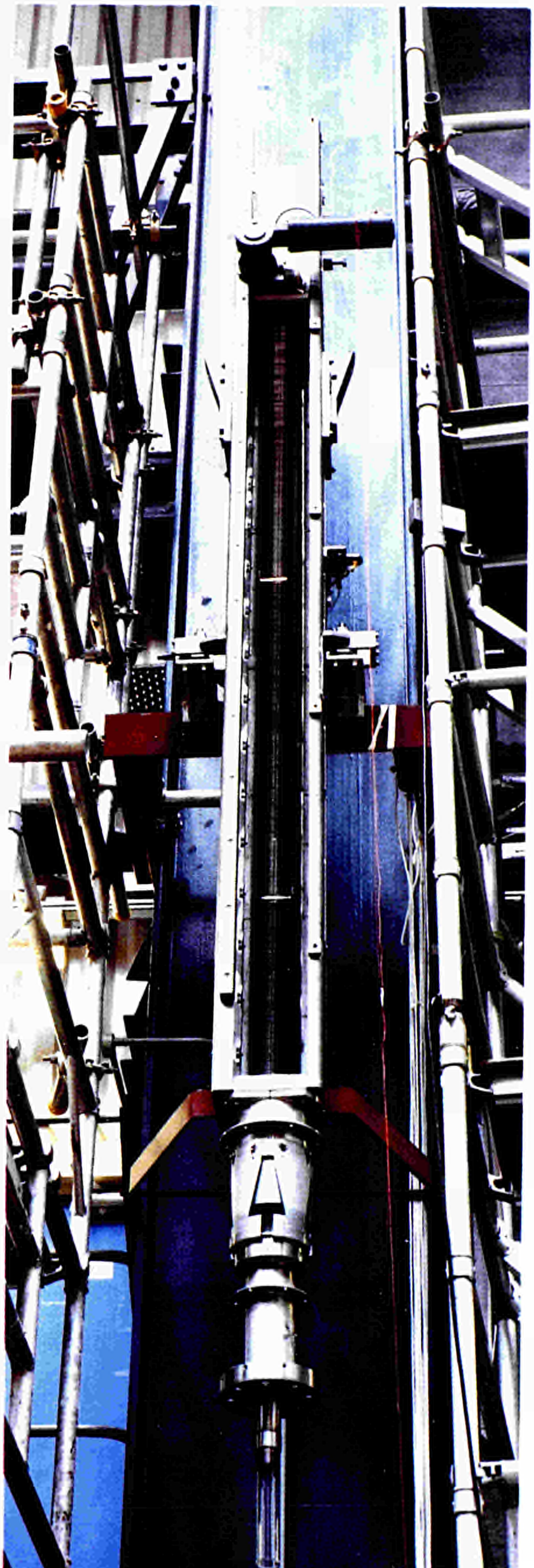


Fig.24 The retractable camera guide assembly for the in-vessel inspection system.

controlled television cameras to inspect the vessel with 0.5 mm resolution without breaking vacuum. Installation and commissioning of the system was to be completed during the shutdown in January 1984.

In July 1983, the in-vessel articulated boom was ordered for delivery in mid-1984. The boom will be able to reach 180° of the vessel from either of two opposite ports. The design of adaptors to carry and manoeuvre tools on the boom has been completed to meet the requirements of the water-cooled limiters, the prototype RF antennae, and the projected belt limiters. The adaptor to hold and orientate (pan and tilt) the manipulator on the boom has also been designed. Tender action is underway for shrouding to protect the boom from contamination by active dust and the vessel from the lubricant vapour.

A two-arm servo controlled manipulator has been in use at JET for some years for development work. The manipulator is being progressively modified for in-vessel operations mounted on the in-vessel boom. It is to be operational by August 1985. A cantilever beam for the remote removal of vacuum pumps is designed and is also to be operational in 1985.

Automatic cutting and welding equipment (Fig. 6) was used for the installation of the octant joints. The same equipment will be used for the neutral injection joints. A range of special cutting and welding equipment is being designed to service the future toroidal limiter and ICRF antenna systems. These tools will be capable of both manual and servomanipulator placement and operation and will be used for initial installation and both "hands-on" and remote maintenance.

Tritium Handling

In JET's scientific programme, the performance of the machine will be built up with plasmas of hydrogen and deuterium, with increasing additional heating power, until conditions justify the introduction of tritium. Currently, it is expected that this stage will be reached by the middle of 1989.

A preliminary design of the tritium plant (Fig. 25) was presented to the JET Scientific Council in October 1983. The plant is designed to process all of the gases, including tritium, exhausted from the torus and from the neutral beam injector boxes of JET. It will chemically purify the hydrogen and then separate the isotopes – protium, deuterium and tritium – and store them for re-use. Even allowing for the cost of the plant, reprocessing will be much less expensive than buying fresh tritium and disposing of the tritiated exhaust gases.

It is intended to accumulate the torus exhaust from about 12 machine pulses at a time, say three hours operation, alternately on one of two cryopanels (accumulators) while the other is discharged through the reprocessing

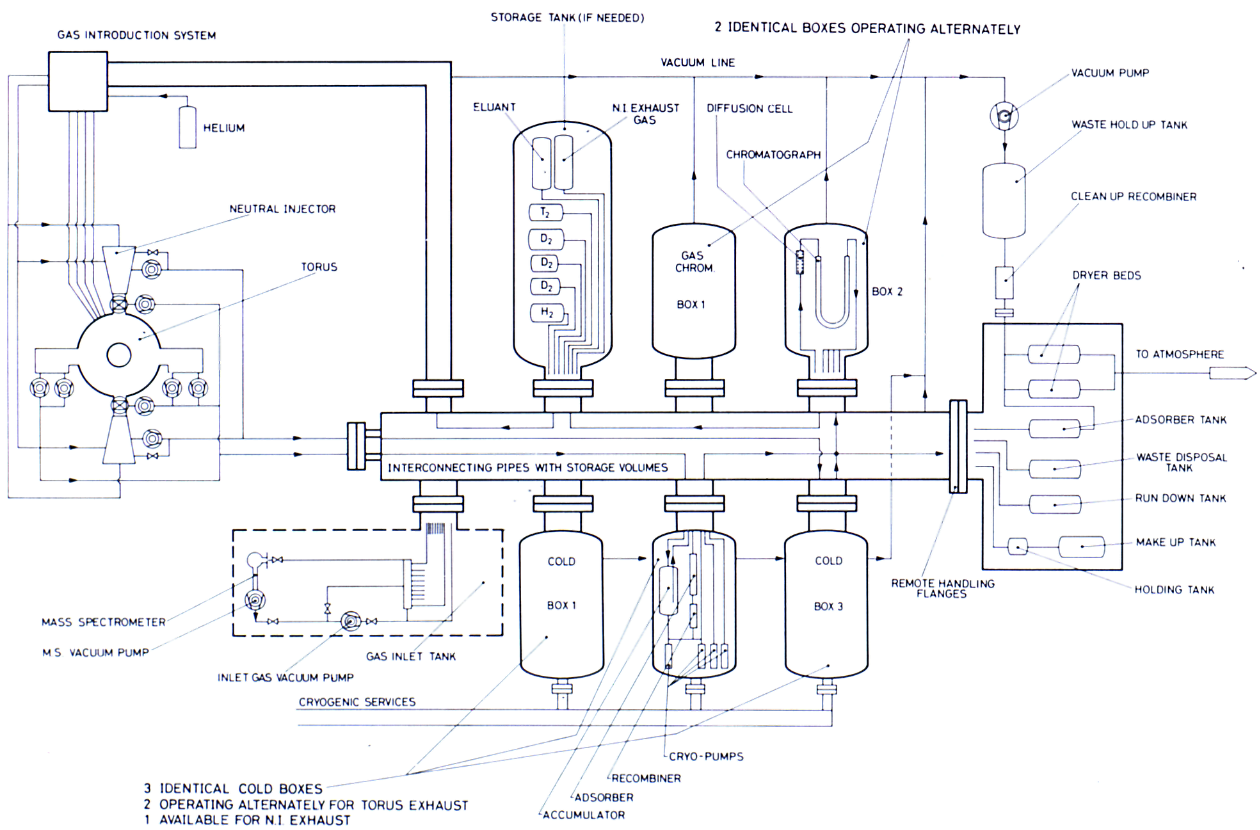


Fig.25 An engineering layout concept for the JET tritium plant.

plant by a system of cryopumps. The gases first pass through a recombiner to remove oxygen (if any) and a cold loop (absorber) to remove impurities, housed together with the accumulator in one of three identical cold boxes. From there they pass into one of two boxes at ambient temperature, each containing a palladium diffusion cell (if necessary) and a gas chromatography column to separate the isotopes. Gas chromatography was adopted, on the recommendation of the CEA, because it is claimed to provide a high separation purity with a small tritium inventory. The third cold box handles the exhaust gases from the neutral injection boxes.

The whole plant will be contained in a series of steel vacuum vessels. If tritium leaks from the primary circuit into a vessel, the vessel will be sealed off, pumped to a hard vacuum and baked to remove all contamination before it is opened. By using components with very high reliability, for example cryopumps rather than mechanical pumps, the number of maintenance interventions during the two years' life of the plant will be minimised.

Control and Data Acquisition Systems

JET uses a computerised Control and Data Acquisition System (CODAS) to provide a flexible, easy and safe method of operating the experiment. This requires the interfacing and processing of more than 10,000 digital and 1,500 analogue signals.

Control and monitoring of the experiment is carried out using a network of Norsk Data ND-100 and ND-500 mini-computers. The hierarchical structure of the control system reflects the way JET is made up from sub-systems. Each computer is responsible for monitoring and controlling a part of the JET experiment with the overall supervision being performed by the two console computers. Any transfer of information between computers is carried out via the two communication computers. A real time data base holds a description of the JET experiment in the CODAS computers and forms the basis of all control and monitoring operations.

Acquisition of experimental data from the diagnostic equipment on the experiment requires in excess of one million items of data to be gathered during each pulse. This data acquisition is handled by the same kinds of computers and interface electronics that are used for the control and monitoring of the experiment. Filing of experimental data is performed by the largest computer in the Computer Room, an ND-560, so that experimentalists can gain easy access to the information. The experimental data is then transferred to the large computers at Harwell for permanent archiving and more detailed evaluation.

Computer operators and experimentalists can communicate with the control system either via the two main consoles in the Control Room (Figs. 26 and 27) or through a number of mobile consoles. The following

Fig.26 JET machine control room console with synoptic viewer above.

Fig.27 Machine subsystems consoles in machine control room.

facilities can be used with these units:

- Touch sensitive panels replacing conventional push buttons;
- Colour television screens for displaying mimic diagrams of the JET systems, processed data in a graphical form or closed circuit television pictures;
- Trackerballs, to allow identification of points on the screen, thus providing additional facilities to the touch sensitive panels;
- Keyboards and display screens;
- Black and white screens for closed circuit television pictures and high resolution graphic displays.

The control and interlock functions for JET are normally performed by the CODAS system. To ensure the safety of both personnel and the machine, basic back-up interlock functions are provided by the Central Interlock and Safety System, which can automatically revert equipment into a safe state or inhibit JET pulses in the event of abnormal conditions or computer failures.

The first half of 1983 was devoted to the completion of the commissioning of the subsystems required for the machine start-up and to the integration of the major software and hardware components required for the centralised operation of the JET device and its diagnostics. Although the integration was compressed into an extremely short period of time, CODAS was ready to provide a comprehensive data acquisition service and essential control functions from the very first experimental pulse.

Once JET had become operational, the emphasis shifted towards keeping the commissioned systems working and towards making adjustments to the control and monitoring services to keep them in line with our increasing knowledge of the performance of JET and its auxiliaries. The number of hardware failures was small, considering the large amount of untried equipment at risk. Most trouble occurred at the interface with the controlled equipment, reflecting the difficulty of communicating detailed information between different design organisations.

The CODAS Computer System

The CODAS computer system (Fig. 28) has now been extended to 25 Norsk Data computers, which have been commissioned and integrated into the system network. Eight of these computers are 32-bit ND-500 series computers equipped with 1.25 megabytes of main memory to support data acquisition and analysis of the diagnostic subsystems and to give fast presentation of results after each pulse. With the advent of JET operation in the summer, 14 computers have been put "on line" to their subsystems. They have formed the basis for the control and data acquisition of the JET operations so far. Thirteen computers are on-line to the JET device, and one on-line to the neutral injection test-bed.

The on-line network of machines has been operating consistently and reliably, providing availability in excess of 99 per cent. This figure has been achieved by use of a standby computer system providing redundancy in case of faults on operational machines. The overall availability of the total computer system has been better than 98 per cent with the average availability of each individual computer system being better than the target 95 per cent. A continuing programme of work is proceeding, in conjunction with Norsk Data, to improve this availability still further.

Fig.28 The computer room.

Computer Peripherals

The number of terminals attached to the computer system has been increased by the purchase of 66 Westward graphics terminals, including 13 colour graphics terminals and 13 high-resolution graphics terminals. To give better utilisation of terminals, a Gandalf terminal multiplexer has been installed to replace the former manual patching system. A line concentrator has also been installed to merge the messages produced by the error device of each computer and to route them to a single terminal. This arrangement will allow the monitoring from a single point of the complete network performance and the permanent logging of systems errors and alarm messages. The pressure on terminal resources, in particular graphics terminals, has continued to increase and further graphics terminals will be purchased in 1984. To support the need for the hardcopy of graphical results, five Versatec hardcopy units have been purchased. Operational experience has shown that these facilities will soon need to be supplemented and therefore a laser printer/plotter was ordered at the end of 1983.

Interface Electronics

At the end of 1983, some 65 CODAS interface cubicles were installed, compared with the 25 installed at the start of the year, of which 8 had been commissioned. Most of this increase was due to an intense period of cubicle specification, manufacture, installation and commissioning in the first half of the year. This achievement ensured the availability of control and monitoring services from the control computers as soon as such services were required by the JET equipment they served.

The Software System

The operation of JET is steered entirely from the control rooms in J2 and is based on two classes of software: the pulse related package, mainly the general acquisition program (GAP); and specific applications software in charge of local units like the ohmic heating circuit or the gas introduction. GAP is used to preset all parameters of the machine, including the central timing system and the reference waveform generators. Then the pulse itself is driven only by the timers. After the pulse, GAP proceeds to the collection and archiving of the engineering and diagnostic data. The specific application software is in charge of all operations requiring sequencing and testing. Examples of this are the positioning of the ohmic heating switches, their presetting for opening or closure and the sequence of operations on the valves of the gas introduction system to prepare the gas to be introduced in the Torus ready for the plasma breakdown.

The integration of major software components at the end of 1983 could be summarised as follows:

(a) The Plasma Fault Protection System had been integrated. This is based on a program which checks the plasma quality and issues a soft termination request if a disruption is predicted or detected.

(b) The Direct Magnet Safety System had been fully integrated on the toroidal field and commissioned on the poloidal field.

(c) The software to drive pulse discharge cleaning had been commissioned and allowed to define the operating parameters.

(d) The alarm handling and reporting was available and would be integrated in the early months of 1984.

(e) Most of the CODAS "drivers" had been written. The drivers consist of a set of re-entrant shared subroutines which mask from the user the idiosyncrasies of the CAMAC modules thus allowing him to concentrate on accessing process variables (input or output) by name.

(f) The electrical-baking software had been integrated. It controls currently some seventy electrical heaters to regulate the temperature of the vessel and its various attachments during the baking phase.

(g) Various applications of the CAMAC auxiliary crate controller had been integrated. They cover the control of three types of low-level multiplexor, control of the data link to the flywheel generator convertors, control of the data link to the high voltage power supplies for the neutral injector and its test bed, control of real-time waveform generators, and control of the cameras for the in-vessel inspection system.

Diagnostic Systems

The status of JET's diagnostic systems at the end of 1983 is summarised in Table 4. The location of these systems on the machine is shown in Figure 29.

As can be seen from the table, the bulk of those systems not already installed will be brought into operation before mid-1985. The following systems were operational for the first plasma discharge in June:

- Single channel interferometer;
- Flux loops;
- Internal poloidal field pick-up coils;
- One bolometer;
- Limiter surface temperature diagnostic;
- Hard X-ray monitors;
- Neutron yield counters;
- Health physics monitors;
- Visible spectrometers using fibre optics;
- H-alpha monitors.

Further diagnostic systems became operational before the end of 1983. These included a fourteen channel bolometer array, four X-ray diodes, a quartz UV spectrometer, an optical multichannel analyser, and part of the electron cyclotron emission system.

Thomson Scattering Diagnostics

The Thomson scattering system that has been constructed for JET by the Risø National Laboratory, Denmark, has the conventional 90° scattering configuration. Light from a powerful ruby laser illuminates the plasma along a vertical chord, and the scattered light is collected and spectrally resolved. The electron temperature and electron density are determined from the spectral width and intensity of the scattered light respectively. Items sensitive to nuclear radiation such as the laser and the detection systems are housed behind the radiation shielding in the roof laboratory. The system is thus compatible with the active phase of operation of JET.

Substantial progress has been made on the system during 1983. The laser has been installed and commissioned in the roof laboratory at JET. Construction of the input optics, collection optics, dispersion systems, detectors, electronics and alignment systems was completed at Risø, and a series of system performance tests carried out. Many of these items have been installed in their final position at JET. A significant stage was the successful installation alongside the torus of the large concrete tower (Fig. 30) which supports the collection optics. Commissioning of the system was planned for February–March 1984 with the first plasma measurements possible in late March.

Because the Thomson scattering system described above can explore only a limited part of the plasma cross-section, an additional spatial scan system has been considered. The design of one particular spatial scan system based on a carbon dioxide laser, was completed in early 1983. Following an extensive review of its feasibility, it was decided not to proceed with it, but to look at the LIDAR type system, recently proposed by researchers at the University of Stuttgart and IPP Garching, as an alternative. In this technique, an ultra-short laser pulse illuminates the plasma along a vertical chord and the back-scattered radiation (~ 180° scattering) is detected. The spatial resolution is determined by the time delay between the transmission of the laser beam and the arrival of the scattered light back at the detector. This is a novel technique, as yet untried on tokamaks, although the principles have been well established in other areas such as the monitoring of atmospheric pollution. It appears to be particularly well suited to the investigation of the large plasmas in JET.

During 1983, a contract was placed with IPP Garching to carry out a study of the feasibility of applying the technique to JET. The study is being carried out in collaboration with the University of Stuttgart. The target performance is to measure the temperature and density profiles to an accuracy of 10% with a spatial resolution of 15 cm at a repetition rate above one a second. It is expected that the feasibility study will be completed by the end of May 1984.

Table 4
Status of the JET Diagnostics Systems

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

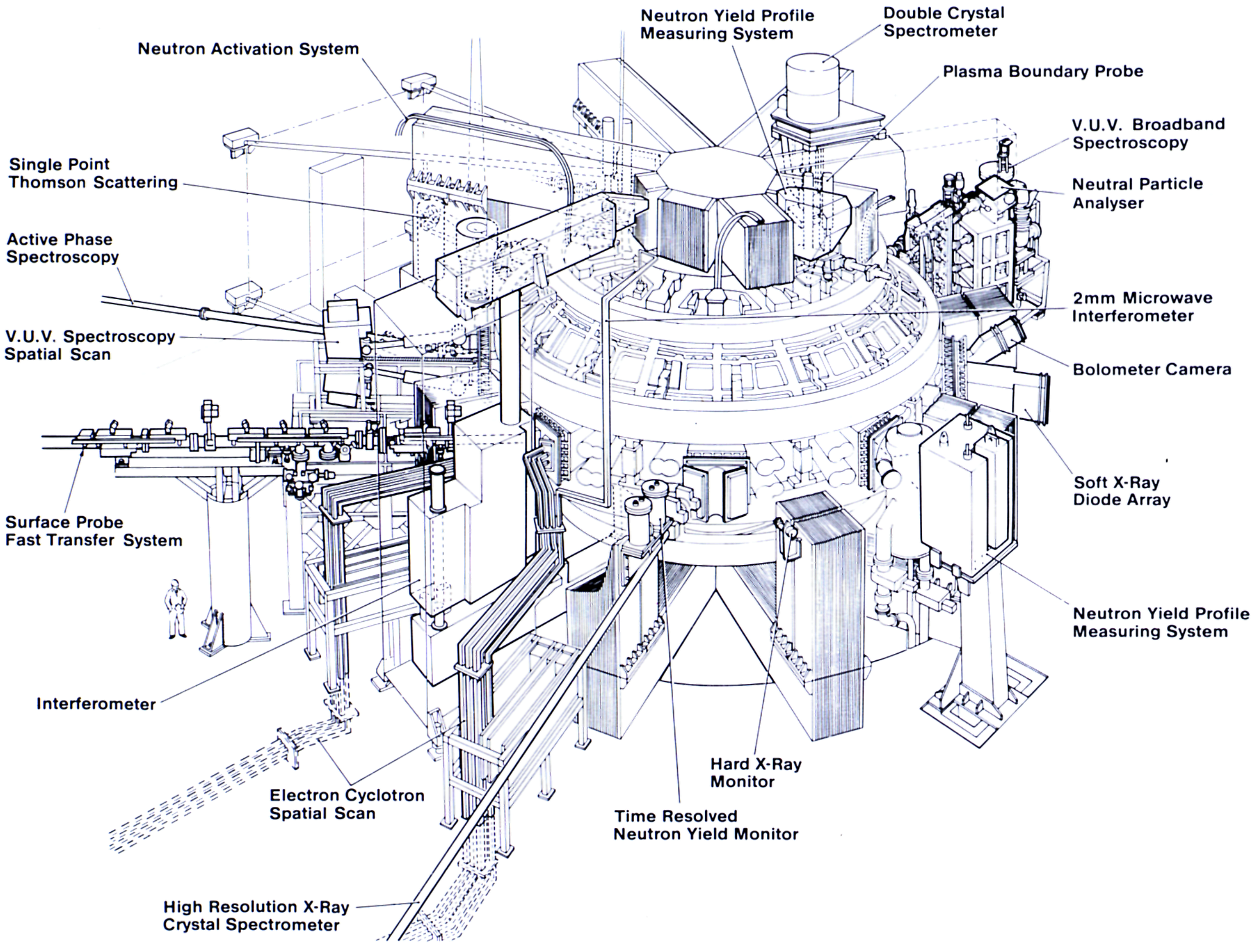


Fig.29 Location of the JET Diagnostic systems.

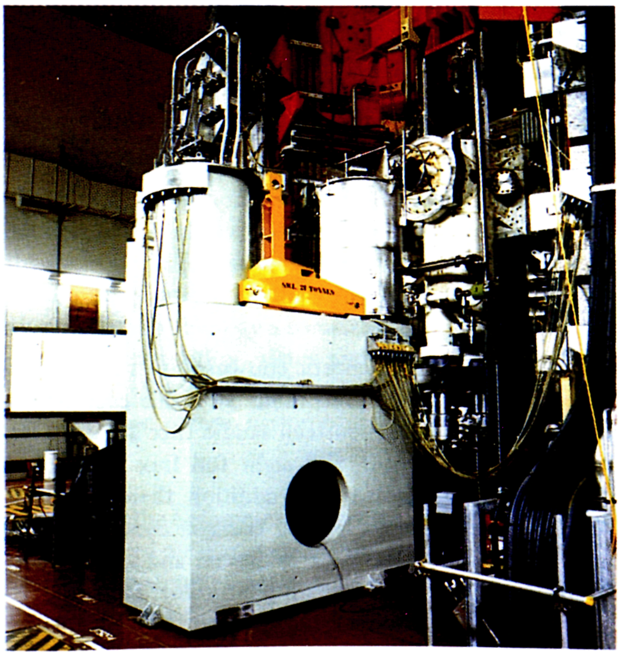


Fig.30 The tower supporting collecting optics for the Thomson scattering system.

Electron Cyclotron Emission Diagnostics

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

Both systems will share an array of ten antennae mounted inside the Torus vacuum vessel to view the plasma poloidal cross-section along different chords. The ECE radiation passes through crystal quartz vacuum windows and then through aluminium waveguides to the Diagnostics Hall. The design of this system has presented considerable problems both in terms of the physics of the propagation of single waveguide modes through long oversized waveguides and antennae and in terms of engineering to meet JET's requirements. Four antennae (Fig. 31) were installed in the Torus during August 1983. The remainder have been manufactured and will be installed in early 1984. The system was commissioned using two temporary waveguide runs (Fig. 32), and the

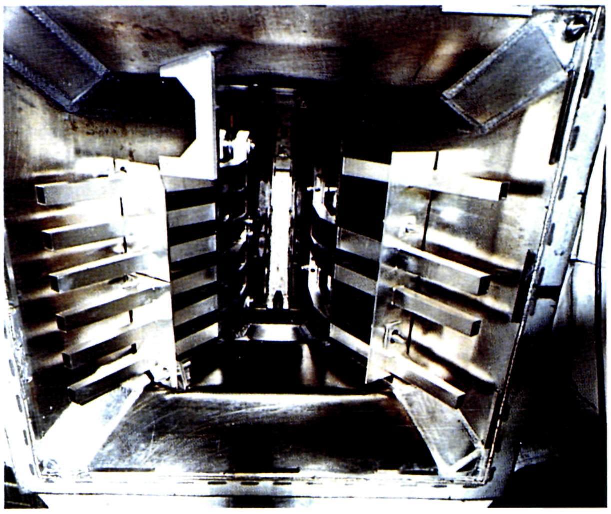


Fig.31 View into octant 7 showing the inconel antennae for the electron cyclotron diagnostic system.

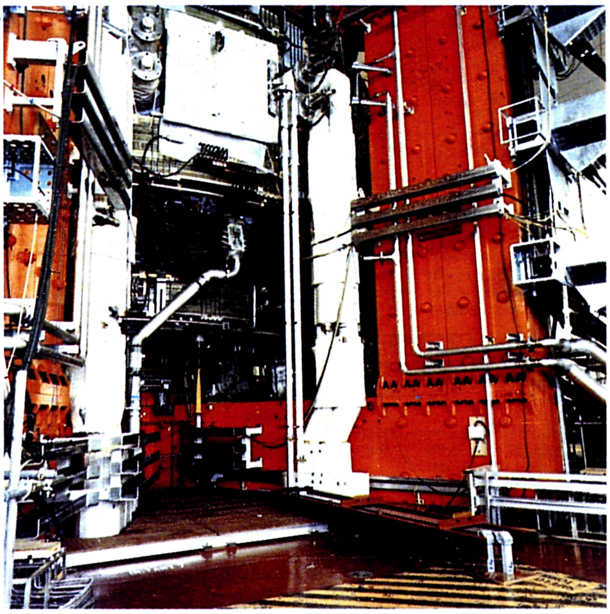


Fig.32 View of octant 7 showing waveguides for the electron cyclotron emission system and the microwave interferometer.

full permanent system of ten waveguides will be installed in May 1984.

The spatial scan system is being developed and constructed by the National Physical Laboratory, London. Completion of the installation of the system is planned for May 1984. It is expected that the system will be fully operational by the summer of 1984.

The fast scan system is being constructed by the FOM Institute at Rijnhuizen (Netherlands). The construction contract was started early in 1983. Much of the necessary hardware has been constructed and initial assembly has been carried out. Completion of the construction phase is expected by June 1984 with installation on JET expected to commence in September.

Limiter Surface Temperature Diagnostic

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

During the current reporting period, two of the carbon limiters were observed thermally and one was observed simultaneously at the H-alpha wavelength in order to determine the hydrogen recycling behaviour in the vicinity of a limiter. The following observations were made:

- The early discharges in JET were accompanied by numerous arcs on the surface of the limiters. Arcing had virtually disappeared in more stable discharges later in the year though it tended to reappear during disruptive discharges.
- At plasma currents of above 1 MA, thermal loading of the limiters was observed with temperatures reaching 800°C in the hottest regions. The temperature distribution showed two peaks, the distance between them being a direct measurement of the thickness of the energy scrape-off layer. The thickness was found to be of the order of 13 mm.
- Viewing the limiter at the H-alpha wavelength showed that hydrogen recycling occurred primarily on the ion side of the limiter. The thermal load on the limiters was also not completely symmetrical. The ion side of the two limiters viewed was usually slightly hotter than the electron side. The explanation for these observations is not understood.

Magnetic Diagnostics

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

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

Plasma Edge and Surface Diagnostics

These two complementary diagnostic systems will allow direct reading probes and collector probes to be introduced into the area between the vacuum wall and plasma boundary. Collector probes will be analysed in an analysis laboratory, which is being constructed adjacent to the JET Torus Hall.

The main system, the fast transfer system, will allow probes to be exposed through a horizontal port for one or more plasma pulses and removed under ultra high vacuum directly to the analysis station. The main feature of this system is a carriage which is driven through the tube by means of linear motors. A variety of direct reading and collector probes can be mounted on the carriage. Collector probes will provide time resolution during a single shot by rotating a cylinder behind a slit. The system, which has been designed by the UKAEA Culham Laboratory, is now being manufactured. Installation on JET is scheduled for September 1984.

The complementary system, the plasma boundary probe system, will use vertical ports in the torus. The basic system is of a modular design and can be used in three configurations: (a) with direct reading probes only; (b) with an exchangeable magazine of five probes; (c) with collector probes that can be analysed in-situ. The first two versions will be installed in early 1984.

H-Alpha Monitors

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

The system was operational in June 1983. It provided measurements of the particle confinement time and gave information on the effective ion charge (Zeff) of the plasma. The system will eventually be supplemented by a poloidal scan of the light emission.

Visible Spectroscopy

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

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.

A single bolometer was available for radiation monitoring on day one. In August, a vertical camera equipped with a bolometer array was installed together with seven further radiation monitors. Total radiation losses and spatially resolved radiation profiles could then be obtained. The results were used as input for the evaluation of the energy balance. Typically 70 per cent of the ohmic power was found to be radiated. Losses from the plasma centre, however, were only 20 to 30 per cent of the input. The radiation was emitted mainly from metallic impurities.

Interferometry

Density is one of the most fundamental parameters of the plasma and its measurement has to be made reliably for every pulse. The main system proposed for JET is a multichannel far-infra-red interferometer directly extrapolated from the apparatus which has successfully operated for many years on the TFR tokamak at Fontenay-aux-Roses. The JET system will use a deuterium cyanide laser. The optical components for the interferometer will be mounted on a single large C-frame which will be mechanically decoupled from the JET machine in order to minimise vibrations (Fig. 33). The interferometer is partly delivered and will be installed on the machine in May 1984.

Since the multichannel interferometer described above was not due to be ready for the first operation of JET, a simpler single channel interferometer was built. The system was operational in June and, since then, the system has operated routinely with the high availability of over 95 per cent.

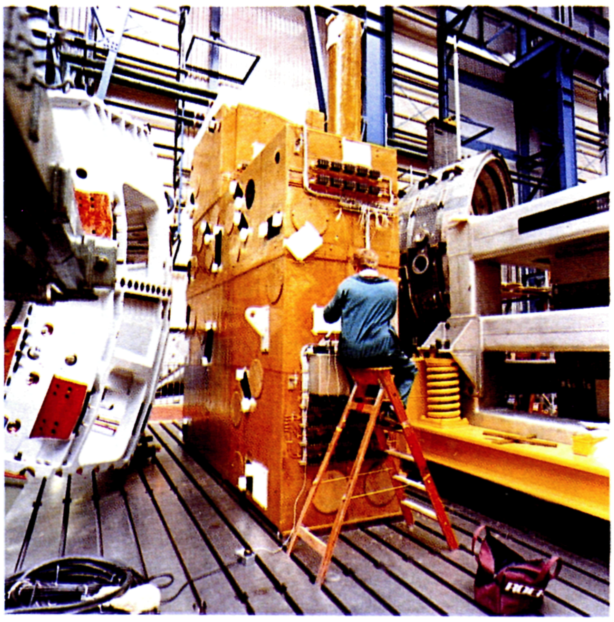


Fig.33 One of the fibreglass boxes for the interferometer tower.

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 consists of two X-ray imaging cameras, which view the same toroidal cross-section of JET in orthogonal directions (one mounted on a vertical port and one on a horizontal port).

A provisional system with four diodes behind different filters was installed in August (Fig. 34). It provided first estimates of the electron temperature and indicated the onset of magnetohydrodynamic activities in the plasma centre. This information was useful in determining the central current density and hence the ohmic power density.

The most serious restriction of 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 which therefore might be used in the future to extend the range of operation of this system.

Soft X-ray Pulse Height Analysis

The measurement of the soft X-ray spectrum using a cooled Si(Li) detector is a standard diagnostic method in most tokamaks and is usually used to obtain estimates of

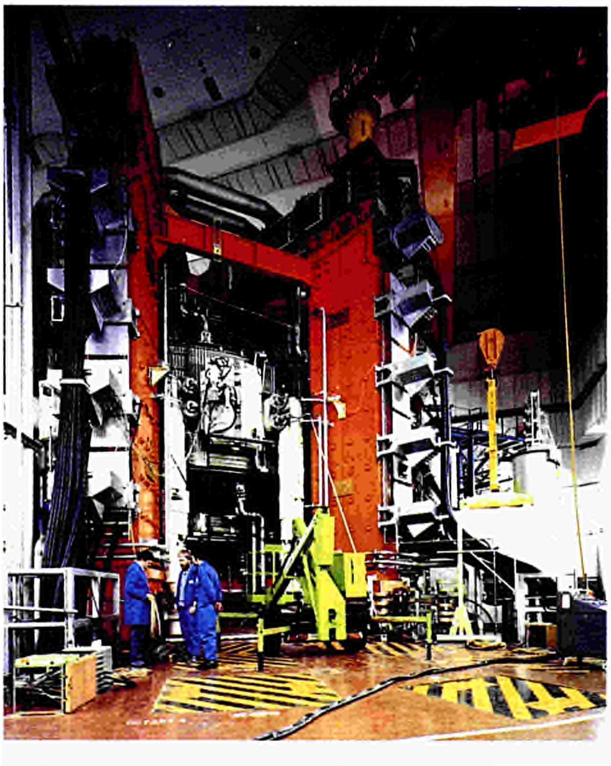


Fig.34 The provisional soft X-ray diode array at octant 4. To the right, at octant 5, the concrete tower of the Thomson scattering system.

Zeff, the electron temperature Te, and to measure deviations from a Maxwellian distribution of the electrons. Engineering design studies of a comprehensive system are in progress. A first provisional system should be operational in May 1984.

Hard X-ray Monitors

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

With favourable plasma discharges, the Bremsstrahlung emission is continuous in time and of low intensity, but when the occasional disruption occurs, the signals are of short duration and of sufficient intensity to saturate the linear amplifiers in the existing monitors. In order to obtain a measure of the emission during a disruption, it will therefore be necessary to install logarithmic response amplifiers. In addition, a group of three monitors is planned to be installed on the North Wall of the Torus Hall to measure the energy spectrum of the Bremsstrahlung emission.

Impurity Spectroscopy

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

The main spectroscopic diagnostic system to be used will cover the wavelength range of 100 to 2000 Å and is based on a system successfully operated on the TFR tokamak at Fontenay-aux-Roses which provides high quality spectroscopic information. The spatial scan is obtained by viewing the plasma through a rotating mirror which has a gold-plated face and is used in near grazing incidence. The spatial scan will take 3 milliseconds to complete and will be repeatable every 20 milliseconds. The three mirrors are synchronised to rotate together and can also be stopped at any predetermined position in order to obtain continuous time resolution along fixed chords. This system was expected to be installed in September 1984.

There will also be a broadband spectrometer covering the wavelength range 125 to 1700 Å. This will have a microchannel plate detector and will be used for time-resolved line identification and impurity monitoring studies. This spectrometer will be installed during the shutdown in January/February 1984. The beam line of the spectrometer has been designed to allow a replacement by other instruments at a later stage. A high resolution normal incidence spectrometer and a grazing incidence spectrometer covering the range between 20 and 100 Å are envisaged as possible future developments.

The wavelength range covered by these instruments is most suited for the relatively low temperature plasmas expected in the early operation of JET before the full additional heating power is available.

When higher temperature plasmas are obtained, the region observed by these spectrometers will shift towards the outer regions of the plasma. Shorter wavelength instruments will be needed to view the highly stripped impurities in the centre of the discharge. Work has started at IPP Garching on a spatial scanning X-ray crystal spectrometer which will operate at shorter wavelengths (1–20 Å). It is scheduled to be installed in 1985. This instrument will use two crystals which must be rotated and translated synchronously in order to carry out a wavelength scan.

In order to obtain a spatial scan with these spectrometer systems, it will be necessary to locate them close to JET. This means that they will not be usable for deuterium-tritium plasmas with high radiation fluxes. An active phase spectroscopy system is therefore being designed, which will allow impurity spectroscopy measurements to be continued under these 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 and this will allow the detector to be located in a region of low neutron flux. This system was scheduled to be operational in 1986.

High Resolution Spectroscopy

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

Charge Exchange Neutral Particles

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

The system, constructed for JET at Frascati (Italy), consists of an array of five separate analysers arranged to view different chords in a vertical section of JET. The system was delivered before the year end and a first detector was to be installed during the shutdown in January/February 1984.

Neutron Diagnostics

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

The time-resolved neutron yield is measured with three pairs of uranium 235 and 238 fission counters mounted on the vertical limbs of the transformer (Fig. 35). These counters were already operational at the end of 1983, although not fully commissioned. All discharges so far have been in a hydrogen plasma so that any neutron emission was due to Bremsstrahlung radiation.

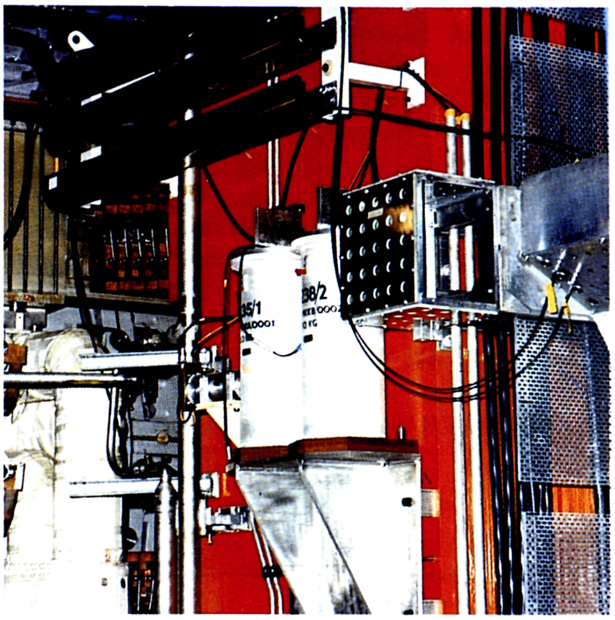


Fig.35 A set of U-235 and U-238 neutron yield monitors mounted on a limb of the transformer core.

The observed neutron count rates were used to provide estimates of the runaway electron current and the total energy deposited during disruptions. In the most serious disruption to date (shot 1349), the instantaneous neutron emission reached 10^{15} n/s, though the total emission integrated over 0.1 second, was only 5×10^{13} neutrons. This corresponds to a total energy deposited on the inner protection plates of over 100 kJ, or an initial runaway current of around 300 kA. During well-behaved discharges the total neutron yield was typically $10^{10} - 10^{11}$ neutrons, the production being spread uniformly over the 5–10 second discharge. Assuming an electron confinement time of 0.5 second, the corresponding runaway electron currents were only 1.10 amps.

At the end of 1983, the neutron activation system was well into its construction phase. The neutron emission profile system had entered the detailed design stage. Work on the 2.5 MeV neutron spectrometer, to be located in the Torus Hall, suffered a delay whilst the design of the support tower was being determined. A second spectrometer, to be located in the roof laboratory, was nearly ready for testing at the Associated Laboratory. It was expected that all these systems would be commissioned on JET within the next eighteen months.

Some extensions of these neutron systems are already planned. For example, the radiation counters for the neutron activation system can be supplemented by delayed neutron counters. This entails using small quantities of fissile material as the target material to be activated. The method offers high efficiency and a capability for recycling the targets between plasma discharges, which cannot normally be done with activation foils. The basic neutron spectrometer detectors associated with the 2.5 MeV neutron diagnostic can also be supplemented with a spherical hydrogen filled ion chamber, which should provide high efficiency and good energy resolution.

Pellet Injection

A new system, the pellet injector, has been introduced. It was expected to be delivered in 1985 and will be used as a diagnostic device to study the transport of particles. It will also serve to explore the requirements for a full refuelling system.

The Operation of JET and International Tokamak Research

The JET machine was completed and commissioned in its basic performance configuration in June 1983. The experimental programme began on 25 June, with a plasma current of 19,000 amps at the first attempt to obtain plasma. Within the remaining six months of the year, currents of up to 3 million amps within overall pulse lengths exceeding 10 seconds were achieved and this performance remains a world record. The plasma parameters achieved in 1983 did not compare favourably with the more established smaller tokamaks – and would not have been expected to. JET's plasma temperature was around 5 million degrees.

JET Scientific Programme

The phases of JET's scientific programme are set out in Table 5. In the first year of the programme, JET will concentrate on producing hydrogen plasmas with modest heating (2–3 megawatts) provided by the plasma currents, on learning how to use the apparatus, and on adding diagnostic equipment to measure the plasma behaviour. A mean plasma temperature of between 5 and 10 million degrees at modest densities is expected. Between 1984 and 1987, the additional heating systems will be progressively added to the machine, starting with 8 megawatts of additional heating towards the end of 1984 and finishing with a total capacity of 25 megawatts by 1988 as shown in Figure 36.

At full power an average plasma temperature of 50 million degrees at the required densities is expected. If this can be achieved the machine will be operated with a deuterium-tritium plasma. The extra power deposited in the plasma by thermonuclear reactions would then cause the temperature to rise towards the required 100 million degrees. In the extremely optimistic case of ignition (Fig. 37), the external heating systems could be

Table 5
Phases in the operation of JET

Phase	*Date*	*Heating Power (above ohmic)*	*Description*	*Objective*
I	mid 83	0	Commissioning initial operation ohmic only	Establish target plasma for heating
IIA	end 84	5 MW	5 MW 80 keV(H) heating (~ 9 MW total)	• Impurity control • n limits • compare with theory
IIB	end 85	16 MW	Progressively increase to 10 MW 80 keV(H) + 6 MW ICRH	
IIIA	1987	19 MW	Increase heating to full level including 10 MW (17 MW total) 160 keV D for D–T plasma	• Establish limits to performance • Compare with theory • Decide if D–T is justified • Commission D–T systems
IIIB	1988	25 MW	+ 15 MW ICRH	
IV	1989	25 MW	D–T operation with α-heating dominant at least near axis.	• study approach to ignition • study plasmas with profile • set by α-heating • find β limit in this system

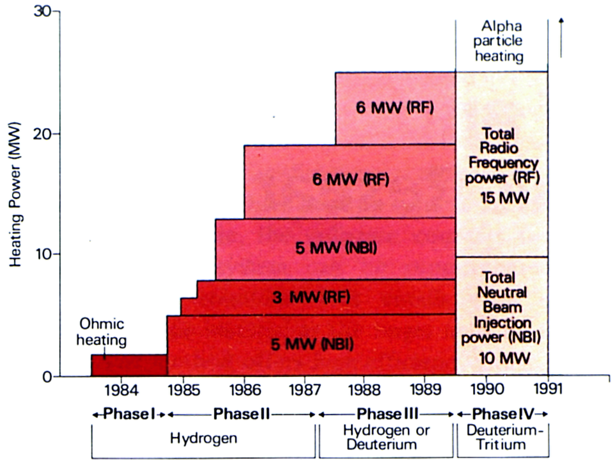


Fig.36 The JET scientific programme.

turned off and the plasma temperature would continue to rise until the end of the pulse. At the other extreme, the pessimistic result would be that the plasma will not reach high enough temperatures to justify the use of tritium. Whatever the outcome, JET will provide valuable and definitive information on the possibilities of fusion power development.

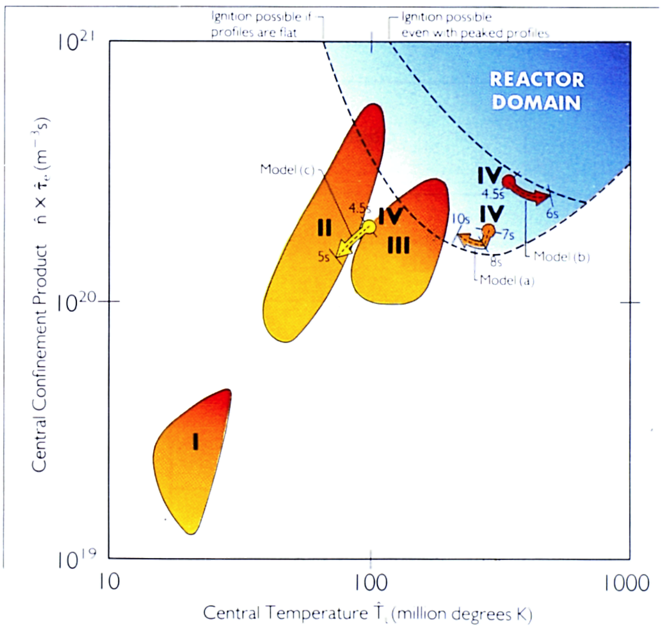


Fig.37 Predicted performance of various phases of JET operation.
Model (a) Reference: INTOR transport loss.
Model (b) Optimistic: as (a) but with transport loss divisible by 2.
Model (c) Pessimistic: as (a) but with an addition of anomalous inward transport for hydrogen and impurities.

Operations in June-December 1983

As mentioned earlier, the first experimental campaign began on 25 June 1983, with a plasma current of 19,000 amps at the first attempt (Fig. 38). Later in the campaign, which ended with the August shutdown, a current of 600kA was obtained with a loop voltage of 14 volts. From the high loop voltage, it was clear that the plasma resistivity was high and the temperature correspondingly low, at around 50 electron volts. Spectroscopic measurements showed that the discharge was dominated by radiation from the light impurities, carbon and oxygen. In this first campaign, the vertical position control had not been commissioned. As a result, the plasma was vertically unstable and moved to the bottom of the vacuum vessel, terminating the pulse when contact was established.

At the start of the second campaign in October, the bakeout temperature for the torus and ports was raised to 270°C. It was immediately apparent that the discharge was much cleaner. Spectroscopic measurements showed that metallic impurities, nickel and chromium, were playing a role, since there was now a significant amount of radiation coming from the centre of a much hotter plasma (around 1keV). By the end of October, 1.4MA was obtained with 4 volts around the torus.

In November, a more sophisticated feedback system was implemented to give tight control of the horizontal and vertical positions of the plasma. With this, the plasma size could be controlled to increase slowly during the current rise, thus allowing the current to penetrate to the centre of the plasma. The initial rate of current rise was also lowered, and these two changes resulted in much quieter and hotter plasmas. By the end of November, 1.9MA was reached with 1.3 volts around the torus. The discharge showed all the attributes of a true tokamak discharge, i.e. low loop voltage and sawtooth oscillations at the plasma centre.

In December, plasma currents in the range 2 to 3MA were obtained. The pulse length was typically 10 seconds with a flat top of some 4 seconds. Central electron temperatures measured by the newly commissioned electron cyclotron emission diagnostic were in the region of 1.5 to 2keV. The loop voltage was down to around 1 volt, and the safety factor q at peak current was in the range 2.4 to 5.0. Towards the end of the second campaign, control was established over the density behaviour by adjusting the gas feed rate and density flat tops of 4 seconds were obtained. Average plasma density was approximately 2.5 x 10^{19} per cubic metre, plasma radius 1.1 metres, and elongation 1.2. The highest global energy confinement time was estimated at three-tenths of a second.

These results were much in line with expectation. To achieve them a substantial amount of commissioning work was necessary, both on the engineering elements of the machine, as well as on diagnostics and interpretation codes. Up to the end of 1983, only about half the full

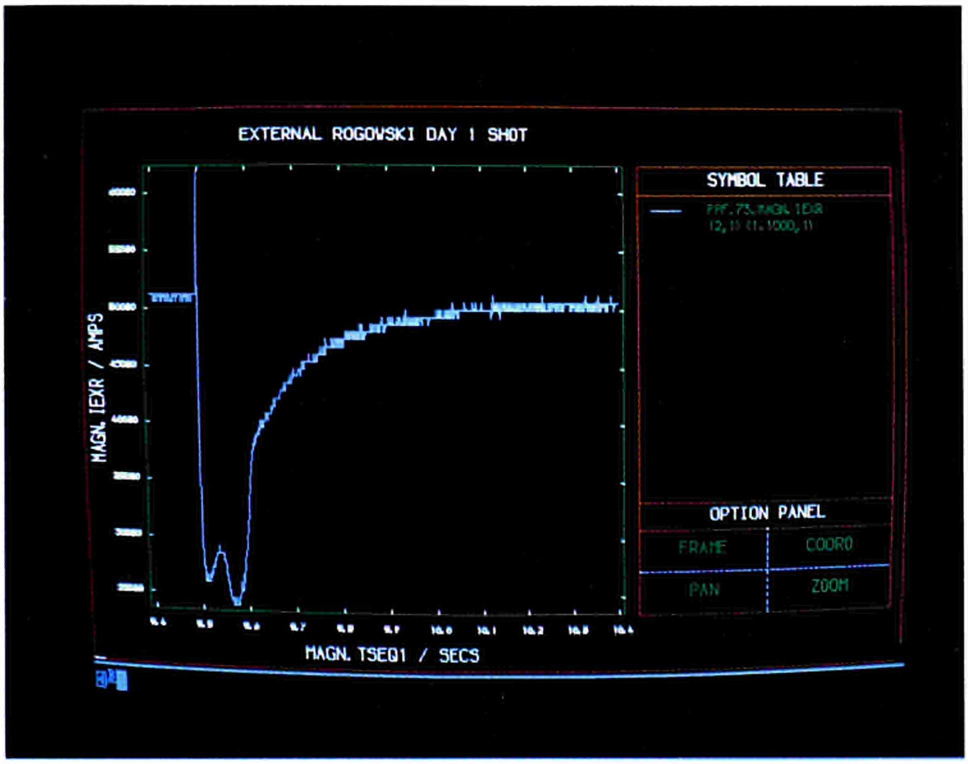


Fig. 38 A plot of the total current flowing through the torus (vessel current plus plasma current) during the first plasma pulse. The second depression shows the influence of the plasma current itself.

volume of the torus had been used for the discharge. The first campaign of 1984 will therefore concentrate on increasing the plasma size, reducing still further the impurity content and increasing the plasma density.

JET Theory

There is worldwide activity in efforts to describe plasma behaviour in realistic conditions as plasma parameters approach those necessary for a fusion reactor. New mechanisms of plasma behaviour are constantly being identified and new mathematical methods invented to assist in interpretation of results. A major goal of the JET experiment is to contribute to a better understanding in both the practical and theoretical senses, under conditions appropriate to a fusion reactor.

Theoretical models are being developed so that the dominant plasma phenomena in JET can be explained. The long-term goals are consistent quantitative descriptions of such important physical phenomena as:

- The equilibrium and stability of the plasma in the confining magnetic field;
- The transport of plasma particles, momentum and energy across the magnetic field lines (diffusion, heat conduction, turbulence etc.);
- The effect of neutral beam injection, application of RF fields and fusion-produced alpha particles for plasma heating;
- Energy losses, especially those by radiation due to impurities released by interactions of the plasma with the chamber walls.

During 1983, a number of codes were installed and tested, partially through contracts with the Associations. These included: two transport codes; a free boundary equilibrium code; a three dimensional Monte-Carlo code for neutrals; two non-coronal impurity transport and radiation loss codes; and a Fokker-Planck code for RF heating. Most of the codes are still being used independently of each other, but efforts to connect them systematically are continuing.

As only a few diagnostic systems were installed in the first periods of JET operation, plasma modelling was used extensively to interpret the data that became available. The dominance of metal impurities was identified by this technique in July.

Predictive codes have been used for assessing the choice of first wall materials for JET. Beryllium, nickel and carbon have been investigated, as has the use of controlled neon puffing. On the question of a magnetic limiter in JET, some plasma equilibria with stagnation points inside the vacuum vessel were calculated, although this option has been set aside for the present time due to the large stresses imposed on the magnetic coil support system at the fields needed to meet necessary configurations.

International Tokamak Research in 1983

Results reported from the ohmic heating operation of the TFTR tokamak at Princeton (USA) during 1983 have been of considerable interest to JET. Shortly after the end of the year, a maximum current of 1.5 MA with a flat-top duration time of one second was reached. Normalised tokamak parameters show JET and TFTR to be working in essentially similar ranges. As in JET, the central electron temperature reached values in the range 1.5 to 2 keV. The maximum global energy confinement time was about 270 milliseconds, which within the measurement accuracies, was essentially the same as that found on JET. Experiments on TFTR have shown only a very weak dependence of confinement time on the minor radius of the discharge. Comparison with data from other tokamaks shows that the principal advantage of increased size results from the increase in the major radius.

During the year, experiments continued worldwide on a number of medium-sized tokamaks with powerful additional heating. An important result for JET has been the observation on the ISX-B limiter tokamak at Oak Ridge National Laboratory (USA) of good confinement with additional heating when the discharge was ungettered or when neon gas was puffed into the plasma. Although not completely understood these results show that confinement degradation is not the inevitable result of applying additional heating in a tokamak such as JET where the plasma is bounded by a limiter.

Since the major additional heating method on JET will be ion cyclotron resonance heating (ICRH), the experiments worldwide in that field were especially significant. Work on the TFR tokamak in France, partly in response to JET requests, has shown that the generation of impurities at the plasma boundary by this heating method remains a critical problem. For the same power input, the production of metallic impurities was about three times higher for ICRH than for ohmic or neutral beam injection heating. The RF input increased the plasma density at the boundary by a factor ten and the electron temperature by a factor two to about 10 eV. This effect was independent of whether the slots in the Faraday shield were aligned with the toroidal field or with that of the local magnetic field. Investigating these effects and possible solutions will be an important part of the first experiments on JET with the prototype antennae, early in 1985. By contrast, heating of tokamaks and stellarators at the electron cylotron resonance (ECR) frequency has shown further notable success with no problems of coupling the energy into the plasma, localising the power absorption or of impurity generation. The major difficulty and the main reason why it is not yet planned to apply this technique to JET is the lack of suitable high power sources (gyrotrons) at the required frequencies of 100 GHz.

On the theoretical front, the Lausanne group have derived a 'universal' relationship between the maximum stable β (plasma pressure/confining magnetic field pressure) of the discharge. This gives β max $\sim 3\%$ for the extended JET performance current of 5 MA at full field and aperture. To obtain plasma ignition at this β would require the unlikely confinement time of about 4 seconds. However, by increasing the current above 5 MA both β and the energy confinement time will increase linearly according to present ideas and significant alpha-particle production should be obtainable at the $\sim$ 7 MA level, at least.

Theoretical efforts worldwide have so far been unsuccessful in providing a convincing and definitive explanation for the high energy transport observed in ohmic-heated discharges. Some work at UKAEA Culham Laboratory has attempted to explain the further increase in energy transport observed when additional heating is applied. This work has developed the notion that the critical plasma pressure gradient for ideal ballooning modes is reached for a progressively larger proportion of the minor radius as the additional input power is increased. This model applied to JET would severely limit its performance. However, it should be emphasised that there are many potential reasons why such speculation may prove to be incorrect. Plasma stability might be improved by the presence of high energy particles produced by neutral injection and thermonuclear reactions. In addition, the non-linear consequences of violating stability criteria might be less than anticipated. Definitive answers will come only from the on-going programme of worldwide tokamak research.

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 École Royal Militaire) and on behalf of the Université Libre de Bruxelles (Service de Chimie-Physique II of the ULB).
- The Commissariat a l'Énergie 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 e.V. – 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).

*Greece became a member on 14 June 1983.

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 vii). The JET Council is assisted by the JET Executive Committee and is advised by the JET Scientific Council (Fig. 39).

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 in due time of rules on the operation and exploitation of JET.

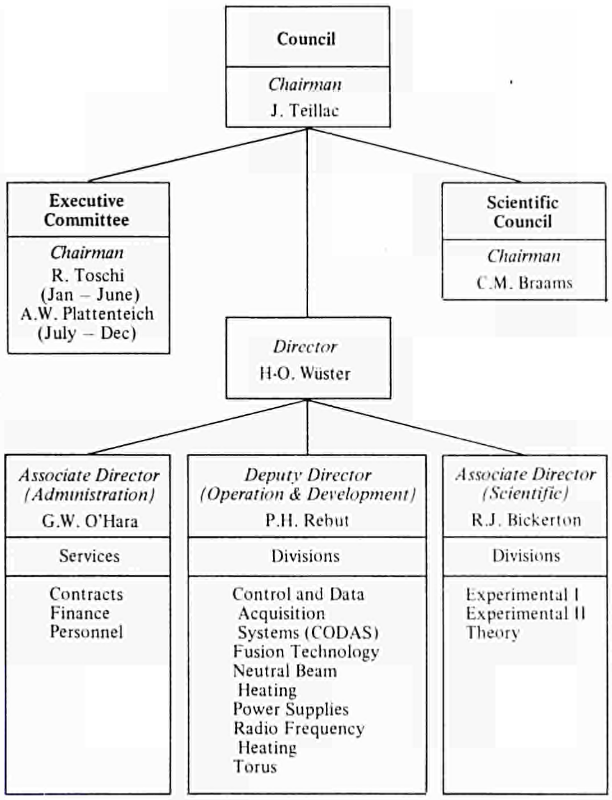


Fig.39 Organisation of the JET Joint Undertaking.

Three meetings of the JET Council were held during 1983, on 24/25 March, 30 June/1 July, and on 20/21 October. The Council's main item of business during the period was the discussion of the Project Development Plan and Project Cost Estimates for JET for the next Euratom Pluriannual Programme, 1985–89. The JET Council appointed Mr. A.W. Plattenteich to be Chairman of the JET Executive Committee in succession to Professor R. Toschi who resigned following his appointment as Chairman of the NET Team. Professor Toschi was warmly thanked by the JET Council for the very important contribution that he made to the Project from the beginning.

JET Executive Committee

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

- Advising the JET Council and the Director of the Project on the status of the Project on the basis of regular reports;
- Commenting and making recommendations to the JET Council on the Project Cost Estimates and the Draft Budget, including the establishment of staff, drawn up by the Director of the Project;
- Approving, in accordance with the rules on the award of contracts established by the JET Council, the tendering procedure and the award of contracts;
- Promoting and developing collaboration between the Associated Laboratories and the Joint Undertaking in the execution of the Project.

The representation of the members in the JET Executive Committee is shown in Appendix I. The Committee met seven times during the year on 3/4 February, 10/11 March, 19/20 May, 12/13 July, 29/30 September, 18 November, and on 16 December.

JET Scientific Council

In 1979, in accordance with the JET Statutes, the JET Council established a JET Scientific Council and appointed the members, including Professor C.M. Braams as its Chairman, for a four-year term. In October 1982, the JET Council reappointed Professor Braams as Chairman of the JET Scientific Council for a further three years from 1 January 1983. Then in March 1983, the JET Council established a new JET Scientific Council comprising the fourteen existing members together with three new members (see Appendix II) for a term of two years from 1 January 1983.

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

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

The Scientific Council met four times during 1983 on the following dates: 20 April, 31 May/1 June, 5/6 July and 6/7 October. They prepared reports for the JET Council on the Remote Handling of JET , the Revised Project Development Plan for JET, and Chances and Risks in the operation of JET. These reports were based on extensive discussions on the diagnostic requirements, impurity control, the experimental programme, remote handling and tritium handling. Working parties comprising members of the Scientific Council, the JET team and experts nominated by the Directors of the Associated Laboratories were established by the Scientific Council to provide specialist assessments of the JET team proposals relating to remote handling and tritium handling.

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 plan for the execution of all elements of the Project, in particular, work to be performed by the Project Team, by third parties and by members of the Joint Undertaking. The Project Development Plan covers the whole term of the Joint Undertaking and is regularly updated. The Director is also required to provide the JET Council, the JET Executive Committee, the JET Scientific Council and other subsidiary bodies with all information necessary for the performance of their functions.

Host Organisation

The United Kingdom Atomic Energy Authority, as the Host Organisation for the JET Joint Undertaking, has made available to the Joint Undertaking 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. The Host Organisation is required to bear the costs of putting the JET site into "standard condition". All standard site conditions as defined in the Annex to the JET Statutes have now been completed by the UKAEA. The Host Organisation also provides such technical, administrative and general services as are required by the Joint Undertaking. In addition to providing staff to the JET team, the Host Organisation provides support staff, at proven cost, to meet the requirements of the JET Project.

Project Team Structure

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

The JET Directorate

The three heads of department report to the Director of the Project and together with the Director they form the JET Directorate. Various special functions are carried out by the Director's office, as shown in Figure 40. The Internal Audit section monitors the Project's financial activities and provides advice on accounting and control procedures, as well as maintaining links with the Court of Auditors. The Project Control Office is responsible for financial planning and for the preparation of the Project Development Plan and Project Cost Estimates. The Secretariat provides secretarial services to the JET Council and to the Executive Committee and also to the JET Project Board, JET's internal management committee.

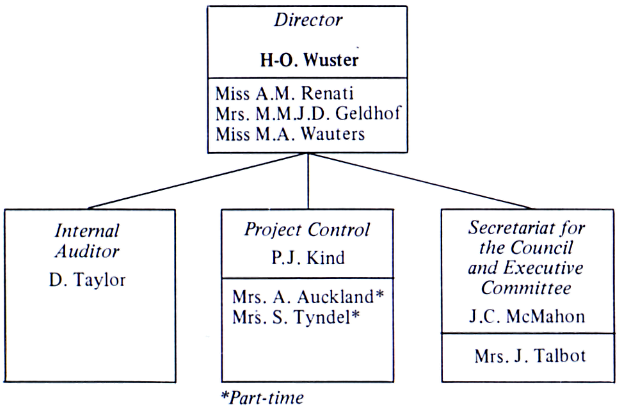


Fig. 40 Project team staff in the Director's office (December 1983).

Administration Department

The Administration Department is responsible for providing administrative support and services to the project. The Project team staff in the three administrative services – Contracts, Finance and Personnel, are listed in Figure 41.

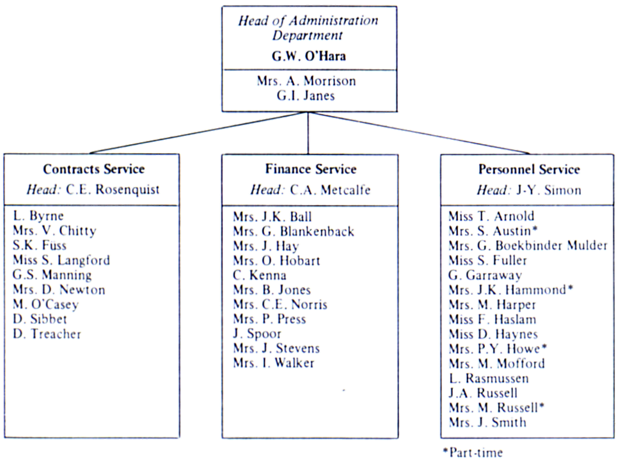


Fig. 41 Project team staff in the Administration Department (December 1983).

Operation and Development Department

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

(1) Torus Division, which is responsible for the operation of the Torus, including the creation and training of the operating team and the organisation and execution of maintenance work in the Torus Hall and Basement. The Division also organises major shutdowns for the installation and commissioning of the new equipment and for development work necessary for the improvement of the sub-systems integrated into the JET device (vacuum system, baking and cooling plants, limiters, first wall, etc.).

(2) Power Supply Division, which is responsible for the design, installation, operation, maintenance and modification of all the power supply equipment needed by the Project.

(3) Neutral Beam Heating Division, which is responsible for the construction, installation, commissioning and operation of the neutral injection system, including the development towards full power operation of the device. The Division will participate in the studies of the physics of neutral beam heating.

(4) Radio Frequency Heating Division, which is responsible for the design, construction, commissioning and operation of the RF heating system during the different stages of its development to full power. The Division will participate in the studies of the physics of RF heating.

(5) Fusion Technology Division, which is responsible for the design and development of remote handling methods and tools to cope with the requirements of the JET device, for maintenance, inspection and repairs. Tasks also include design and construction of facilities for the handling of tritium.

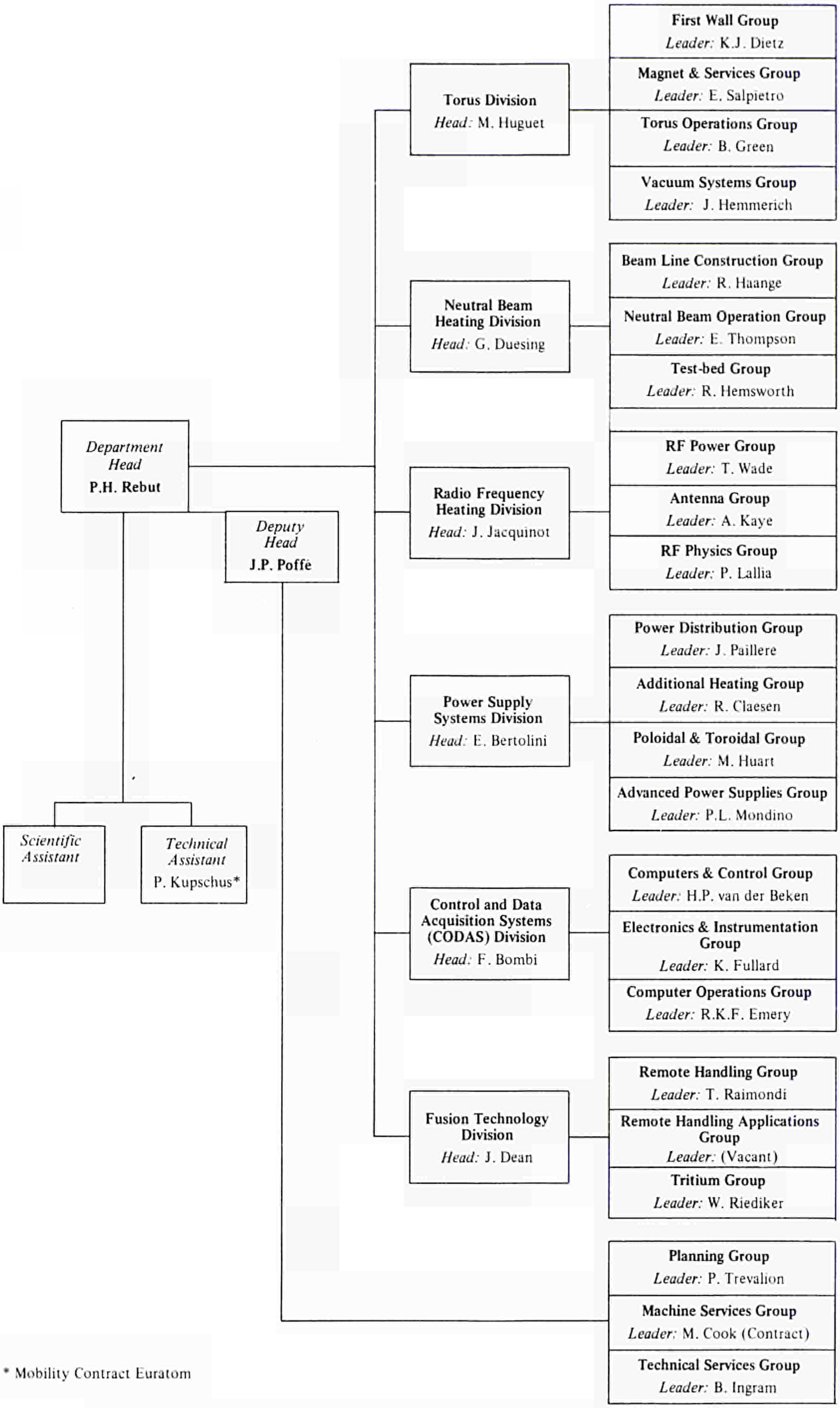
(6) Control and Data Acquisition Systems Division (CODAS), which is responsible for the implementation, upgrading and operation of the computer-based control and data acquisition system for JET.

The divisional and group structure of the Department is shown in Figure 42. The Project team staff in the Department at the end of 1983 are listed in Figure 43.

Scientific Department

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

(1) Experimental Division 1, which is responsible for the specification, procurement and operation of approximately half the JET diagnostic systems. ED1 will, in particular, look after electrical measurements, electron temperature measurements, surface, and



* Mobility Contract Euratom

Fig. 42 Operation and Development Department: Group structure (December 1983).

Head of Department
P.H. Rebut

T. Arthur
Mrs. D. Dalziel
N. Davies
H. Duquenoy
G. Edgar
Miss M. Fraser
L. French
M. Guillet
Mrs. E.D. Harries
Mrs. M. Hicks
R. Howes
A.H. Humphreys
B. Ingram
P. Kupschus*
Mrs. H. Marriott
J. McDonald
J. McGivern
P. Meriguet
P. Mouturat
L. Nickesson
H. Panissie
B. Pavan
T. Potter
W. Scott
P. Trevalion
M. Walravens
C. Woodward
Mrs. A. Young

Torus Division
Head: M. Huguet

W. Baker	K. Grabenstätter	Mrs. M. Rydalm
G. Bäumel	B. Green	E. Salpietro
B. Bignaux	J. Hemmerich	R.L. Shaw
J. Booth	D. Holland	K. Sonnenberg
A. Boschi	G. Israel	R. Thomas
D. Cacaut	H. Jensen	S. Turley
G. Celentano	J. Last	E. Usselmann
P. Chuilon	G. Malavasi	J. van Veen
W. Daser	P. McCarthy	T. Winkel
K. Dietz	P. Noll	M. Young
C. Froger	J. Orchard	J. Zwart

Neutral Beam Heating Division
Head: G. Duesing

Mrs. C. Allen	Mrs. S. Gerring	F. Long
H. Altmann	J. Gallacher	J. Lundquist
C. Brookes	A. Goede	D. Martin
A. Burt	R. Haange	C. Mayaux
N. Cowern	R. Hemsworth	M.J. Mead
Mrs. D. Cranmer	H. Hupfloher	W. Obert
J.F. Davies	F. Hurd	R. Roberts
G. Deschamps	A. Jones	D. Stork
A. Dines	T.T.C. Jones	E. Thompson
D. Ewers	D. Kausch	M. Watson
H. Falter	E. Küssel	

Radio Frequency Heating Division
Head: J. Jacquinot

R.J. Anderson	E. Hanley	F. Sand
J. Arbez	G. Jessop	M. Schmid
G. Bosia	A. Kaye	T. Wade
Mrs. L. Brookes	P. Lallia	C. Walker
W.H. Clark	J. Plancoulaine	B. Willis
J. Firrell	Mrs. L. Rowe	

Power Supply Systems Division
Head: E. Bertolini

U. Baur	A. Eyrard	J. Paillère
O. Buc	H. Fielding	A. Paynter
C. Christodou-lopoulos	J. Goff	R. Perez-Taussac
	D. Halliwell	C. Raymond
R. Claesen	M. Huart	K. Selin
D. Corbyn	V. Marchese	A. Skinstad
E. Daly	G. Marcon	A. Stella
Miss D. Davies	L. Mears	N. Walker
J. Dobbing	P. Mondino	G. Wilson
P. Doidge	G. Murphy	L. Zannelli
B. Eriksson	Mrs. J. Nolan	

Control and Data Acquisition Systems Division
Head: F. Bombi

M.L. Browne	E.M. Jones	J. Saffert
A.J. Cleeves	Miss J. Kedward	V. Schmidt
Mrs. L.M. Dines	Miss K. Mathia	C.A. Steed
S.E. Dorling	D. Nassi	C. Torelli
R.K. Emery	Miss N. Nicholas	H. van der Beken
K. Fullard	J.P. Nijman	J. van Montfoort
R.F. Herzog	C.G. Pollard	J.R. Watkins
B.E. Jensen	G. Rhoden	I.D. Young

Fusion Technology Division
Head: J. Dean

S.J. Booth	P.D. Jones	W. Riediker
R. Cusack	A. Nowak	J. Schreibmaier
Mrs. M. Daish	P. Presle	L. Sonnerup
L. Galbiati	T. Raimondi	M. Wykes

*Mobility Contract Euratom

Fig. 43 Project team staff in the Operation and Development Department (December 1983).

limiter physics and neutron diagnostics. The Division is also responsible for:

- The execution, in collaboration with ED2, of the experimental programme.
- The interpretation of results in collaboration with ED2, Theory Division and the appropriate Divisions in the Operation and Development Department.
- Making proposals for future experiments.

(2) Experimental Division 2, which is responsible for the specification, procurement and operation of the other half of the JET diagnostic systems. ED2 will in particular look after all spectroscopic diagnostics, bolometers, interferometry, the soft X-ray array and neutral particle analysis.

(3) Theory Division, which is responsible for the prediction by computer simulation of JET performance, the interpretation of JET data and the application of analytic plasma theory to gain an understanding of JET physics.

The divisional and group structure of the Department is shown in Figure 44. The Project team staff in the Department at the end of 1983 are listed in Figure 45.

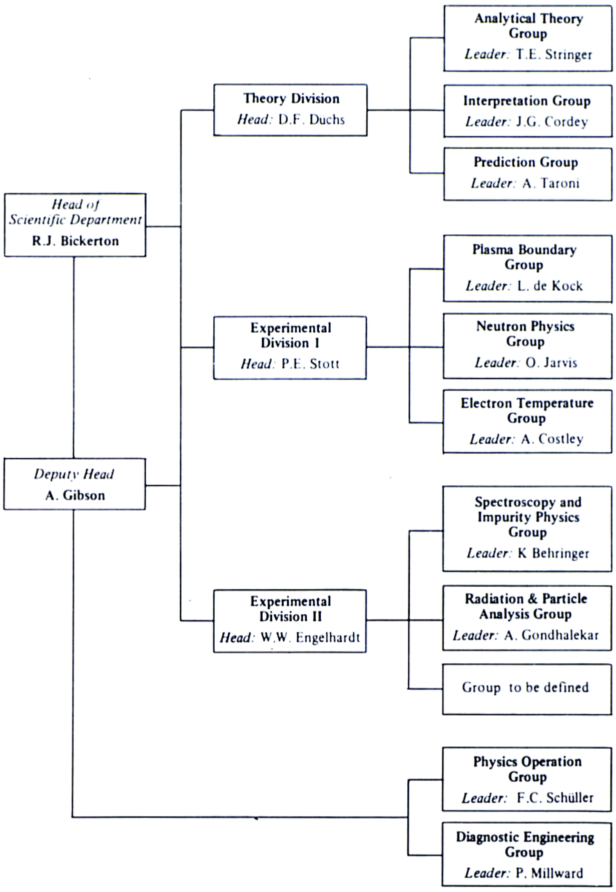


Fig. 44 Scientific Department: Group structure (December 1983).

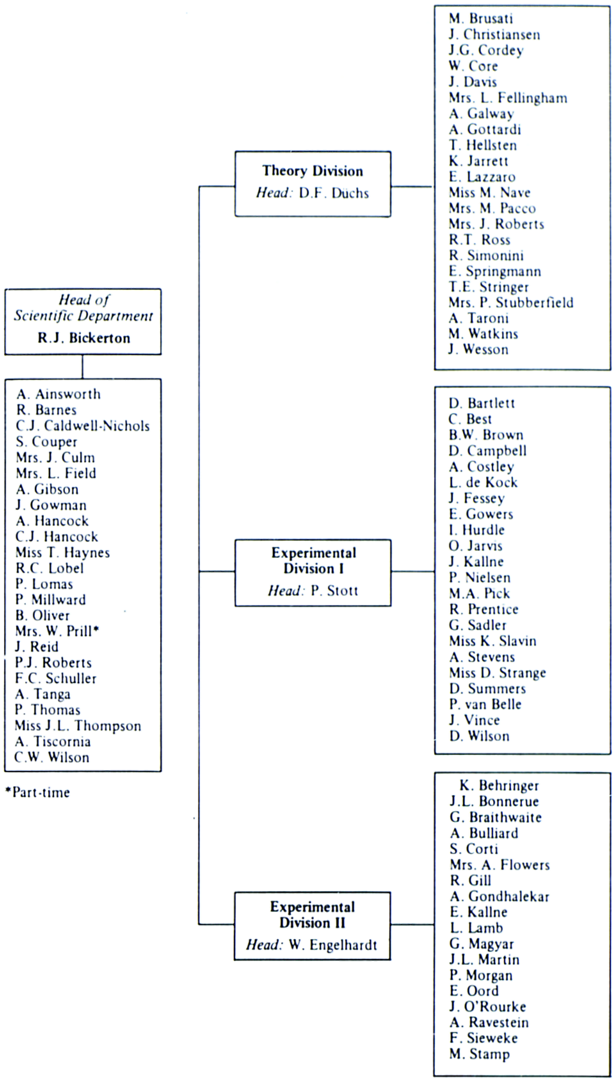


Fig. 45 Project team staff in the Scientific Department (December 1983).

The Administration of JET

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

Finances

JET's financial resources are governed by revisions each third year to the Euratom Pluriannual Fusion Programme. A programme for the period 1982–86 was approved by the Council of Ministers on 25 May 1982. The financial resources made available to JET for that period are shown in Table 6.

Annual Budgets

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

(1) Income – consisting of contributions of Members, augmented by miscellaneous income, principally bank interest;

(2) Commitment appropriations – representing the upper limit of the legal obligations that can be met from the budget;

(3) Payment appropriations – representing the upper limit of payments that may be incurred to cover commitments entered into in the budget year or previous years.

The budgets for 1983 were approved at 93.0 MioECU for commitments, 123.8 MioECU for payments and 123.8 MioECU for income. Each of these budgets is subdivided into the three phases of the Project – Basic Performance, Extension to Full Performance and Operational Phase. Further subdivisions distinguish between investment costs, operating costs and personnel costs.

Commitments (Table 7)

Of the total appropriations in 1983 of 129.0 MioECU (including 36.0 MioECU brought forward from the previous years) 90.3 MioECU was committed and the balance of 38.7 MioECU was available for carry forward to 1984. Commitments against the investment programme were 46.8 MioECU and the balance, 43.5 MioECU, was committed in respect of operating and personnel costs in the Basic Performance and Operational Phases.

Table 6
Financial resources made available to the JET Project up to the end of 1986 within the Euratom Pluriannual Fusion Programme 1982–86

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

Table 7
Commitment Appropriations for 1983

	ECU
1983 Commitments Budget	93 000 000
Amounts available as uncommitted	36 011 995
	129 011 995
Commitments made during the year (including escalation on major contracts amounting in total to 4 223 944 ECU)	90 287 050
Balance uncommitted in 1983 now available for use in 1984	38 724 945

Details of the commitments entered into for each Phase during the year are shown in Table 8. 27.1 MioECU was committed in respect of the Basic Performance Phase and represented the bulk of outstanding requirements before completion of the construction of the JET device in its basic performance configuration. A small balance of 0.7 MioECU was available to be carried forward to 1984 to meet the possibility of further unexpected terminal commitments attributable to the Phase. 32.6 MioECU was committed in respect of the Extension to Full Performance Phase and approximately 37.5 MioECU was carried forward to 1984 in respect of commitments not utilised on this Phase at 31 December 1983. The figures demonstrate the continuing scale of investment to enhance the JET Device. 30.6 MioECU was committed in respect of the Operational Phase which officially commenced in June 1983, and a small balance of around 0.5 MioECU unutilised at 31 December 1983 was carried forward to 1984.

Income & Payments (Table 9)
Compared with the total available payment appropriations of 149.1 MioECU, unused payment appropriations at the end of the financial year, after retaining 35.0 MioECU to meet commitments outstanding at 31 December 1983, amounted to 1.2 MioECU. Actual income received fell short of the Income Budget of 123.8 MioECU by the same amount, 1.2 MioECU. There was, therefore, no balance to be carried forward to be offset against Members' future contributions. More detailed comments are given in the following paragraphs and a summary of commitments and payments under each phase is shown in Table 8.

(1) **Contributions from Members.** The Budget for Members contributions was 118.7 MioECU which is funded as follows:

- 80 per cent from the general budget of the European Atomic Energy Community (Euratom)
- 10 per cent from the United Kingdom Atomic Energy Authority as Host Organisation;
- 10 per cent from Members having Contracts of

Table 8
Commitments and Payments for 1983

Budget Heading	Commitments		Payments	
	Budget Appropriations	Out-Turn	Budget Appropriations	Out-Turn
	ECU	ECU	ECU	ECU
Phase 1 – Basic Performance				
Title 1 – Project Investments	14 847 029	14 216 196	69 093 000	49 777 450
Title 2 – Operating Costs	5 732 414	5 717 188	7 017 000	6 925 448
Title 3 – Personnel Costs	7 202 927	7 176 987	7 696 000	7 563 688
TOTAL Phase 1	27 782 370	27 110 371	83 806 000	64 266 586
Phase 2 – Extension to Full Performance				
Title 1 – Project Investments	70 162 529	32 580 959	37 045 000	25 703 380
TOTAL Phase 2	70 162 529	32 580 959	37 045 000	25 703 380
Phase 3 – Operational				
Title 2 – Operating Costs	21 437 096	21 086 876	18 771 000	13 787 856
Title 3 – Personnel Costs	9 630 000	9 508 844	9 437 000	8 767 856
TOTAL Phase 3	31 067 096	30 595 720	28 208 000	22 555 712
Project Total – All Phases	129 011 995	90 287 050	149 059 000	112 525 678

Table 9
Income and Payments for 1983

	ECU		
Income			
Budget for 1983:		123 773 000	
Income received during 1983:			
(i) Members' Contributions	118 750 000		
(ii) Bank Interest	2 638 999		
(iii) Gains on exchange transactions	796 086		
(iv) Income transferred from Reserve	288 033		
(v) Unused payment appropriations brought forward from 1981	22 958		
(vi) Miscellaneous Income	80 634		
Total Income		122 576 710	
Shortfall of Income to be set off against unused payment appropriations			1 196 290
Payments			
Budget for 1983		123 773 000	
Add amounts available in the Reserve Account to meet commitments at 31 December 1982		25 286 000	
Total available appropriations		149 059 000	
Payments during 1983		112 525 678	
Balance outstanding which has been utilised		36 533 322	
Transfer of excess Reserve provisions to Income Account	288 033		
Carry forward to Reserve Account at 31 December 1983 to meet outstanding commitments as at that date	35 048 999	35 337 032	
Leaving unused payment appropriations to be offset against shortfall of income			1 196 290
Carry forward for offset against Members' future Contributions			NIL

Table 10
Final percentage contributions from Members based on the Euratom participation in Associations' contracts for 1982

Member	%
Euratom	80.0000
Belgium	.2268
CEA, France	2.0685
ENEA, Italy	0.8111
CNR, Italy	0.1189
Risø, Denmark	0.0672
Luxembourg	0.0045
KFA, FRG	1.0041
IPP, FRG	2.4539
KFK, FRG	0.4255
SERC, Sweden	0.1531
Switzerland	0.3611
FOM, Netherlands	0.5172
UKAEA, U.K.	11.7881
	100.0000

Association with Euratom in proportion to the previous year's contribution from Euratom towards the cost of their Association contracts.

The 10 per cent contribution from Members other than Euratom is finally allocated on the basis of the previous year's contribution from Euratom towards the cost of their Association contracts. However, because of the delay in establishing the final figures, provisional percentages are used in the preparation of the Annual Accounts leaving the final adjustment to be made in the succeeding financial year. Table 10 gives the final percentage contributions from Members relating to 1982.

(2) **Bank Interest.** Contributions from Members are normally requested on a quarterly basis so that throughout the financial year, depending on the receipt of contributions and the incidence of payments, the Project has funds that are not immediately required for the discharge of its commitments; such funds are placed by the Project's bankers on deposit at market rate and during 1983 earned interest amounting to 2.6 MioECU.

(3) **Gains on Exchange Transactions.** The net variations on exchange transactions resulted in income of 0.8 MioECU during 1983.

(4) **Transfers from Reserve.** During the year 0.3 MioECU, which had been reserved at 31 December 1982 to meet outstanding commitments, was transferred to income as the relevant commitments had been either cancelled or discharged at a lower figure than anticipated.

(5) **Unused Payments Appropriations from Earlier Years.** A balance of 0.023 MioECU from 1982, held for future set off against Members' contributions, was credited to income in 1983.

(6) **Miscellaneous Income.** The miscellaneous income of 0.08 MioECU shown in Table 9 arose from sales of scrap, assets disposal and other miscellaneous items.

Payments (Table 9)

Payments of 112.5 MioECU were made out of the total available appropriations of 149.0 MioECU, leaving a balance of 36.5 MioECU not utilised as payments in the year. Of this balance, 0.3 MioECU, a reserve no longer required, was transferred to income. 35.0 MioECU has been carried forward to Reserve Account to meet outstanding commitments as at 31 December 1983 and the balance of 1.2 MioECU was set off against the shortfall of income.

Summary

Table 11 summarises the financial transactions of the JET Joint Undertaking as at 31 December 1983. The

Table 11
Summary of Financial Transactions
at 31 December 1983

	ECU
Cumulative commitments	426 025 055
Cumulative expenditure (payments)	353 112 757
Unpaid commitments	72 912 298
Of which carried forward on reserve account	35 048 999
Amount due to be set off against future contributions from Members	
from 1982	6 585
from 1983	NIL

final audited accounts are published as a separate document.

Contracts

In the construction of JET, there has been a strong involvement by European industry as most of the JET components were manufactured in industry. It was also necessary to employ consulting engineering firms, especially in the areas of power supply construction, very heavy engineering component manufacture and large scale project control. With this involvement, it is hoped to ensure that European industries will have a long-term competitive position in the field of fusion.

An analysis of the allocation of major countries is given in Table 12. This demonstrates the European-wide nature of the Project.

Table 12
Analysis of the Allocation of Contracts
valued at over 10000 ECU's
(position as at 5 December 1983)

Country	Total of ECU Values	% of Total
UK	122 508 500	42.27
Germany	73 561 545	25.38
France	30 961 428	10.68
Italy	24 116 366	8.32
Switzerland	16 051 860	5.54
Netherlands	7 031 691	2.43
Denmark	5 951 917	2.05
Belgium	4 061 877	1.40
Sweden	896 348	0.32
Others	4 650 633	1.61
Totals	289 792 165	100.00

Personnel

All recruitment specifically related to the Basic Performance Phase had ceased in 1982, at which time a peak staffing level of 272 had been reached. Most of the staff were reselected for the Operational Phase and formally reappointed to divisions during the summer of 1983. Those not selected left the Project by the end of the year. The system of return tickets worked smoothly and the co-operation of the Associations was greatly appreciated.

Figures 46 and 47 show the development of team numbers for both Euratom and UKAEA staff and the decline in staff numbers during the year 1983.

Recruitment during the Construction Phase

Several features relating to the recruitment of staff during the construction phase are worth noting. In particular, recruitment during these years was characterised by protracted delays in filling posts, persistent shortfalls in the numbers recruited against the numbers of budgeted posts, and a high usage of contract manpower.

Several factors produced this pattern. The statutory necessity to recruit through the Associations meant that the total pool from which staff could be recruited was quite restricted. Also, the early belief that the Associations could supply ample staff to the Project in all disciplines proved to be ill-founded. In certain categories, for example, engineers and technicians, some Associations were already short of staff for their own needs. Added to this was the growing difficulty that the Project experienced in attracting staff from the Associations, particularly at the lower grades.

Furthermore, it became evident in the late 1970's that the staff requirements in certain areas had been understated in the original cost and manpower estimates for the JET Project (EUR-JET-R5 Annex, November 1975). This led to the introduction of special arrangements to cover the staffing needs of, for example, the neutral injection programme. In spite of these difficulties, the Associations, with the exception of the UKAEA, were unwilling to advertise for staff in the market place for assignment to JET, mainly, it is presumed, because they did not wish to take on long-term staff commitments in order to meet the shorter-term needs of the Project.

Another important feature of recruitment during the construction phase, which still persists, has been the long lead time between the preparation of a job specification and the arrival of a successful candidate. In most cases, there is a minimum interval of six months, of which three are accounted for by the publication and selection procedures and the remainder by the period of notice normally expected by the previous employer.

UKAEA Staff

The burden on the UKAEA in respect of the staffing of JET has been especially onerous. As the second employing organisation, it had to make staff available for those team posts over and above the limited number of Euratom posts approved for the Project. However, the competing demands of its own work programmes have in many instances delayed the release of staff for assignment to

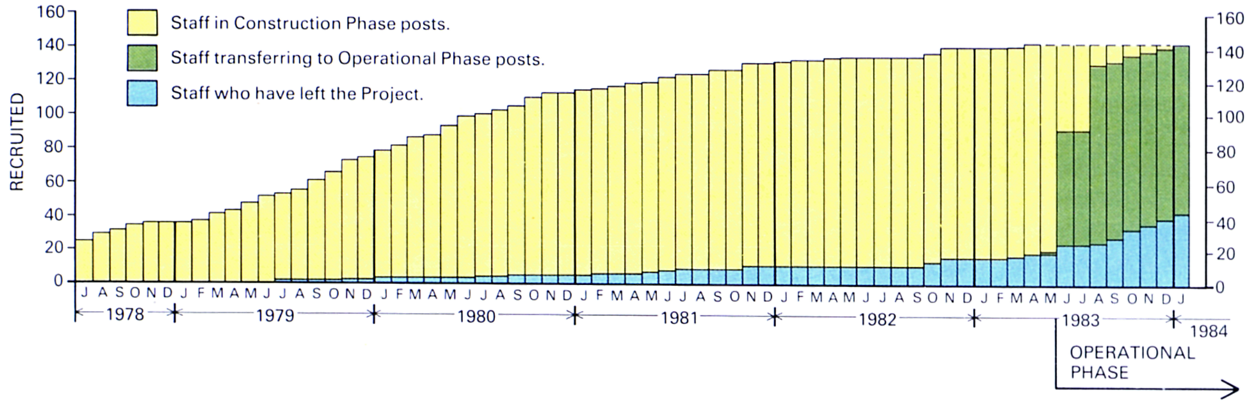


Fig. 46 Recruitment of EUR Team Staff (position at the first of each month).

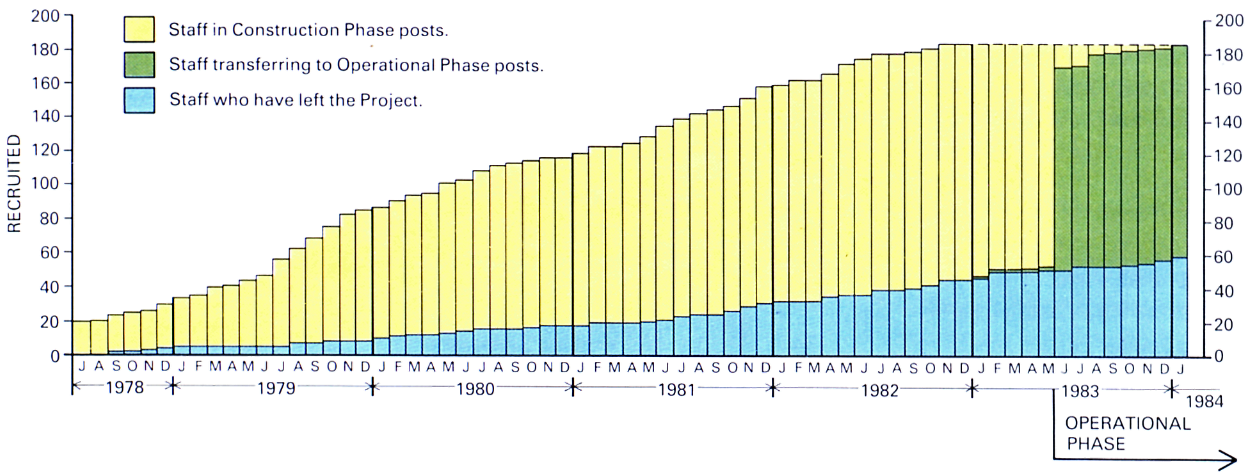


Fig. 47 Recruitment of UKAEA Staff (position at the first of each month).

JET.

The release of certain staff has presented particular difficulties for Culham Laboratory, because it has needed such staff to execute the broad range of work that the Laboratory has undertaken in support of JET. Therefore, the Director of Culham Laboratory has identified for the Director of the Project those members of his staff whom he regards as key staff and who should not be assigned to JET until replacements are available.

There was a further complication in that the Authority itself was short of staff in certain categories (for example, engineers, programmers, accountants) and were finding difficulty in recruiting them.

Contract Staff

To resolve the problems created by the shortfall of staff, the Project has had to engage contract labour. In this way, it managed to take on (against vacant budgeted posts) engineers, programmers and planners in addition to other skilled personnel. It also engaged draughtsmen under contract, because the numbers needed were such that the UKAEA could not provide them from their own resources and their recruitment by the Authority would have presented re-employment difficulties at the end of the JET Project. In addition, JET has used contract staff to undertake specific short-term tasks, particularly for the assembly of the machine. While the use of contract staff has been costly, without it the timetable for the construction phase would have gone seriously awry.

Recruitment of Team Members for the Operational Phase

Recruitment for the operational phase was confined to identifying suitable candidates to fill the remaining vacant positions allocated to the Divisions. On average, two selection boards per week were arranged and, out of the 61 successful candidates, 21 professionals and 34 non-professionals finally took up their duties during the year.

Although 579 applications were received, as many as 88 per cent came from the U.K. and only 12 per cent from the other partners, underlining the observations already made about recruitment during the construction phase. The large number of applicants from the UK was the result of several advertising campaigns undertaken by the UK Atomic Energy Authority on behalf of JET for professional as well as non-professional posts. The competition created by the more optimistic outlook for the British economy did not, however, favour the recruitment for JET of experienced technicians in specialised areas (electronic, vacuum, electrical). For less skilled staff, the response on the whole was satisfactory.

During the second part of the year, the experience gained in operating the machine indicated the type of shift technician team needed. Twelve posts were allocated to Torus Division in order to create the backbone of this team. The Authority initially advertised these posts internally, but when the results proved disappointing, they advertised externally.

In addition to the 23 staff employed during the construction phase who left the Project during the year, 16 others, who had been selected for the operational phase, resigned. This represents a staff turnover of about five per cent which does not seem inordinate taking into account the temporary nature of the Project.

Towards the year-end, a number of posts blocked by contract staff during the construction phase were freed and reallocated within the departments. At the end of the year, the pattern of allocated posts filled was as follows:

	Allocated	Filled
Management Posts (not including Administration)	14	14
Group Leader Posts	34	32
Other Professional Posts	114	99
Non-professional Technician Posts	166	138
Non-professional Administrative Support Posts	25	23
Administration Posts	53	49
TOTAL	406	355

Twenty-one longer-term contract staff on team posts with the approval of the JET Executive Committee are also included in the above figures. The table shows that nearly ninety per cent of the professional posts allocated have been filled. Figure 48 shows the number of selected team staff by nationality.

At the end of the year, nine posts remained unallocated. Of these, five were Euratom posts of too low a grade to be of use to the Project. The Director of the Project has sought to upgrade these posts to meet the needs of JET, but up to now his request has only partially been met.

Associated Attached Staff

The Associations agreed in 1981 to introduce a scheme whereby they would contribute to the scientific programme of JET, by assigning appropriate scientific and technical members of their staff to work on the Project for limited periods. The agreement which was drawn up in consultation with all the Associations came into operation towards the end of 1981. It is envisaged that this contribution from the Associations will eventually reach about forty man-years per year.

From a modest start, the scheme began to gather momentum in the latter part of 1983. The total effort supplied by the Associations under this agreement in 1983 amounted to around 8 man-years.

Visiting Scientists

In 1983 the first three Visiting Scientists came to JET on one year temporary research associate appointments from the UK Atomic Energy Authority. Two came from the People's Republic of China, the third from Spain.

The adoption of the scheme by JET was originally intended to attract personnel from countries that are not members of the Joint Undertaking. However, as requests for appointment were received from organisations within

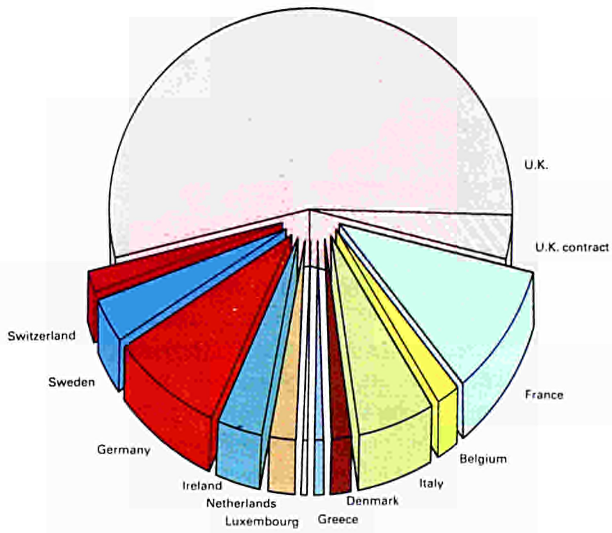


Fig. 48 Composition of team staff by nationality.

the member countries, the JET Council decided to include these in the scheme. By the end of the year, three further appointments were being considered and the complement of five man-years for 1984 is therefore expected to be filled.

Student Assistants
Applications for student assistant appointments under the Culham Laboratory scheme increased steadily throughout the year. Appointments have ranged from three months to one year. In addition, under the Vacation Student Scheme of Culham Laboratory, five students received training at JET. Two Euratom fellows and three professionals under mobility contracts were also assigned to JET during the year.

Support Staff
The level of support staff was redefined in order to cope on the one hand with the operation of the machine and on the other with the work associated with the extension to full performance. A large number of support staff was regrouped into common pools to provide specialist services to all divisions in JET. The following pools had been formed at the year-end:

	Allocated	Filled through		
		UKAEA	Contract	Total
Support Staff in Pools				
Mechanical Maintenance	38		38	38
Draughtsmen	44		44	44
Electricians	12		10	10
Electronic Maintenance	9		9	9
Scientific Computer Programmers	8		7	7
Vacuum Maintenance	6	4		4
Support Staff not in Pools				
Computer Staff	9		9	9
Technical Clerks	8	1	7	8
Others	6	2	4	6
Total Support Staff	140	7	128	135

Because of the number needed to support its own programmes in addition to that of JET, it was not feasible for the authority to supply the bulk of JET's requirements for support staff from its own resources. As the table shows, JET's needs were satisfied largely by contract manpower.

Administration of Staff

Shift Work
As the Project moved into the operational phase, the difficulties in the recruitment of staff began to have an impact on the staffing arrangements for the operation of the machine. It was originally envisaged that operations would be organised on three shifts but the lack of sufficient professional staff to form the operation teams prevented this. During the period following the start-up until the end of the year, the machine when operational was operated only on an extended day basis from 0800 to 1900 hours. Furthermore, the problem in recruiting technicians made it difficult to ensure that staff were available to work on the associated tasks of machine preparation (e.g. gas and electrical baking and glow discharge cleaning) and on monitoring and inspecting the machine's electrical supply, vacuum and cryogenic sub-systems on a round-the-clock basis.

It had to be considered, therefore, how best these difficulties in the staffing arrangements could be met within the existing conditions of service for UKAEA and Euratom staff, bearing in mind that apart from an insufficiency in the number of trained and experienced staff available, some work would be carried out during normal hours, while other work could only be done outside these hours. It was decided that the staff who were qualified and experienced in these tasks should work a combination of normal hours, overtime, shift work and on-call duty during this period and that additional JET staff would be provided in a supporting role from other divisions as control room assistants to ensure that the safety regulation for two-man working during silent hours was fully observed.

Overtime
Because of the shortfall in staff and the introduction of a shift system with the start of operations, overtime working reached a relatively high level. However, the recruitment of further staff in 1984 to maintain the shift working pattern together with improvements in the organisation of the experiment should help reduce overtime working.

Staff Representation
Four meetings were formally held during the year between the Management and the Staff Representatives Committee, where matters relating to the conditions of service of staff were discussed.

Staff Training
To assist the large number of newly appointed permanent and temporary staff to settle into the Project, the JET Personnel Service introduced an induction scheme. The scheme started in October and thanks to the JET and Culham Laboratory staff who contributed, it has proved to be beneficial. Also, information briefings, designed to

inform administration staff of the Project's progress, were held at regular intervals with the help of the Joint Public Relations Service. It was decided to extend these briefings in the future to technical staff not directly involved in machine operation.

Language training continued throughout the year. Since relatively fewer staff now come from the Continent there has been a decline in the level of English language tuition accompanied by an increase in tuition in other European languages. Other specialised training courses were organised to meet specific technical needs of the Project. During July, the majority of JET staff attended safety refresher courses organised by the Joint Safety Service.

During the Operational Phase, training will become increasingly important as staff need to acquire new skills for the operation of the machine and to update their professional knowledge to facilitate their re-integration into parent organisations at the end of their work with JET.

Liaison with the Partners

Formal extensions of contract were prepared and issued to Euratom staff reselected for the start of the Operational Phase and the partners were asked to reissue a guarantee of re-employment in respect of their staff.

As in previous years, JET continued with its system of 'open' internal annual and probation reports; reports were also completed for parent organisations. These latter reports are intended to be used as the basis for the reabsorption of staff on their return to their home employers.

Summary

A recurring problem since 1978 has been JET's difficulty in recruiting staff through the Associations. Because of the restrictive recruitment procedure within which JET must operate, stronger action must be undertaken in conjunction with the Project's partners in 1984 if Team posts are to be adequately filled.

Safety

Organisations and Procedures

The JET Director has made specific arrangements to ensure the safety of the activities for which he is responsible. JET staff, assisted by safety advisers appointed for each division and for defined experimental areas, take 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. Contractors working on the JET site, of course, already 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 advisors 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 stage and in the JET Safety at Work System for all working activities in assembly, testing, operation and maintenance. There are additional arrangements to review the safety of diagnostic equipment supplied by Associated Laboratories. Safety assessments must be prepared for all work to be undertaken by JET staff and contractors, and the safety precautions must then be approved at senior management level before the work is started. Precautions include the use of permits to work for tasks in hazardous areas or on any equipment which needs to be made safe for the work proposed.

Safety Standards

JET must meet all the requirements of the relevant UK law as the minimum acceptable standard. 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 continuing close consultation between JET and Culham Laboratory on all safety matters, through the Joint Safety Services and the JET-UKAEA Liaison Committee set up under the Support Agreement. As one result, new safety rules applying to staff in both laboratories are issued as Joint Safety Notices by both Directors, in addition to the Safety Notices issued by the Director of JET in relation to rules applicable only to JET activities. The safety rules thus established for everyday working hazards incorporate UKAEA Codes of Practice. For the special rules needed for JET operations, the principal safeguard for people is to exclude them from areas of potential hazard when these are in operation, with appropriate enclosures to contain the hazard.

Safety in 1983

The start of machine operations introduced new hazards additional to those associated with the continuing installation, connection and commissioning of additional power supplies. The major new hazards are primarily electrical with high voltage, high current pulses producing strong magnetic fields. The radiation produced during certain plasma discharges described earlier was monitored by the radiological protection instrumentation already installed and by personal dosimeters worn by selected staff. This confirmed the efficacy of the instrumentation and shielding. All operation of the JET machine has been carried out under the personal supervision of senior engineers within strict administrative procedures, which will continue until the Personnel Safety and Access Control System of interlocks for controlling access to the hazardous areas of the Torus Hall and basement, now being installed, is complete. Preliminary safety documentation has been prepared to cover these initial operations.

As would be expected in a period of intensive testing of new equipment in a complex high power system, there were a few potentially dangerous failures of plant in operation during the year. However, the precautions applied were effective in preventing harm to anyone in these incidents. Occupational hygiene hazards, for example, excessive noise and toxic fumes, were successfully controlled by appropriate precautions adopted after individual assessment of each problem as it arose.

Summary and Prospects

The JET safety record so far is good, particularly when compared with the national averages in construction projects. However, continued vigilance will be needed to maintain this record during 1984 and beyond as operations and new installation work continue in parallel. During 1984, the Personnel Safety and Access Control System and other interlock systems to control entry to high-voltage enclosures will be completed, while the safety documentation and operating procedures will be developed in step with progress in the operation of the JET machine. Particular attention will, of course, be paid to the increasing radiological hazards as the operating parameters are raised.

External Relations

Interest in the Project has continued to grow over the past year and nearly 450 visits were organised for individuals of the scientific community, press and media, politicians and for over 3,000 members of the general public in more than 150 groups. A significant number of group visits were organised for a wide range of local organisations, reflecting the interest that has been generated within the local community.

To help disseminate information about the Joint European Torus in Europe, a network has been established consisting of representatives in the Member countries, mainly within the national fusion laboratories. This arrangement has led to an increase in the number of articles written about the Project in the European press. In the UK, the Financial Times published a special three-page feature devoted to the Project. Besides information given through the information network, briefings were arranged for more than twenty journalists at JET, including members of the press from France, Denmark, Germany, Ireland and Sweden. Facilities were also made available for fifteen film and television crews to visit the site.

In the UK, a 90 minute documentary, entitled "A Cage for the Sun" was made for Channel 4 television and the United Kingdom Atomic Energy Authority produced a 22 minute film called "Nuclear Fusion – Power for the 21st Century". Both films featured the Joint European Torus. Also during the year, several exhibitions were mounted, including one at the summer meeting of the British Association for the Advancement of Science.

The European School at Culham

(A Contribution by the Headmaster)

Six years after its foundation, the European School at Culham will be, in September 1984, thirteen times larger than it was when it opened its doors to fifty pupils in 1978. Secondary years six and seven (the equivalent of the British "sixth form") will have over eighty pupils and the number taking the European Baccalaureate each year will, from 1986, settle to an average of fifty. At the other end of the school, the four to six year old children are now organised in three nursery classes, each providing for two or three languages. When the new seventh year secondary classes meet in September, the reform of the curriculum which has been in progress for the last few years in all the European Schools, will be complete. Its main characteristics are greater freedom of choice of subjects and a less rigid approach to annual promotion from one class to the next. At the same time, the opportunity has been taken to examine thoroughly the syllabuses of the European Schools and to modernise them, taking into account the reform of schools in most member states of the European Community. It is already clear that the European Baccalaureate is highly acceptable for entry to higher education in the United Kingdom: the School already has former pupils of various nationalities at the universities of Oxford, Cambridge, Edinburgh, London and a number of newer foundations.

In September, the School at Culham will occupy eight new primary classrooms and some rooms in the old and original building around the quadrangle will be freed for secondary use. Adaptations will also provide two more laboratories, giving the School a total of six. This new building is being provided by the United Kingdom Government, since it is the responsibility of the host country to provide the premises of a European School. Care is being taken by the architect to enhance the appearance of the site by the provision of another court with cloisters. This considerable expenditure might be said to reflect confidence in the future of the European Schools. The European Parliament is urging the creation of more schools, even where there is no institution of the European Community but in places where the increasing mobility of labour makes one desirable. Only about half the pupils at Culham are the children of JET staff: the others come from the European Centre of Medium Range Weather Forecasting, a growing international industrial and business community along the route of the M4 Motorway, from non-British families in Oxford (many at the University) and from other families whose needs cannot be met in local English schools. Continuing pressure on the English Language Section, which contains Irish, Danes, Swedes, Finns, Jugoslavs, Greeks and Israelis as well as British, will require the maintenance of the existing policy on admissions; in other words, English mother tongue children are not accepted unless they are "entitled" through parental employment, or they have language skills which local schools cannot fully develop.

The European School has a vigorous parents' association to which it is grateful for assistance in many ways; it also benefits from a very positive and helpful co-operation from the JET Management. (JET's Associate Director for Administration represents both JET and the Commission on the Administrative Board of the School). The School had its official opening in September 1979, when Mr. Roy Jenkins, President of the European Commission, came to Culham. Now, for the official opening of the Joint European Torus Project in April 1984, the School sends its best wishes for the success of Europe's most exciting and important scientific enterprise.

Appendix I

JET Executive Committee

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

Appendix II

JET Scientific Council

Members nominated by the JET Council

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