JOINT
EUROPEAN
TORUS

JET
JOINT UNDERTAKING

ANNUAL REPORT
1979

EUR 6832 EN
(EUR-JET-AR 2)

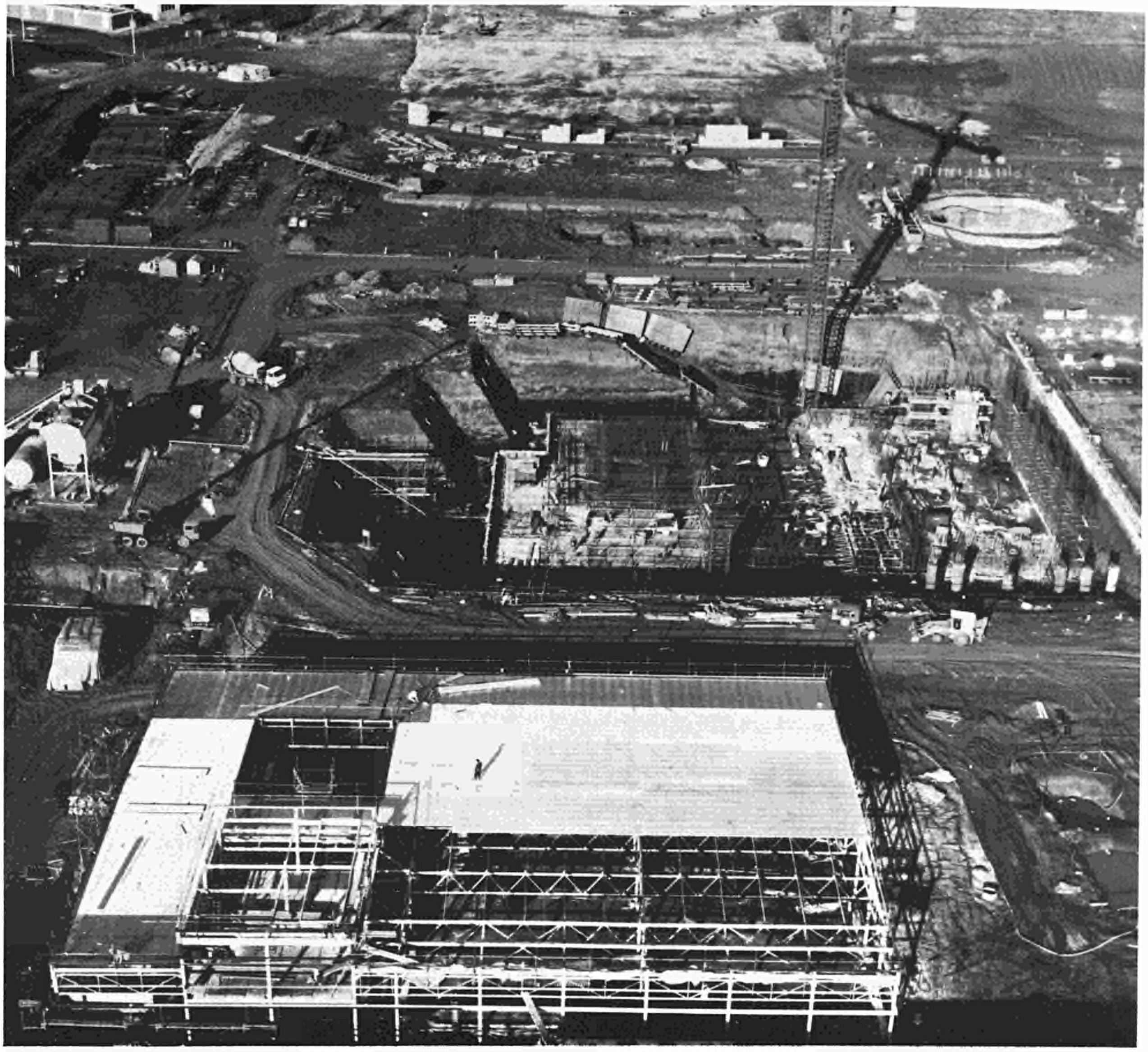
JET
JOINT UNDERTAKING

Report for the period 1 January – 31 December 1979

September 1980

EUR-6832 EN (EUR-JET-AR2) September 1980

Editorial work on this report was carried out by B.J. Green and G.W. O'Hara. The preparation for publication was undertaken by J.L. Hall, P.J. Oliver and the Documentation Service, Culham Laboratory.



Aerial view of the JET Laboratory (January 25, 1980) showing the concrete foundation for the basement of the torus hall. The control building is shown in the foreground, and in the background, preparation for the power supply buildings (note the generator pits at right) is evident.

Preface

This report shows that progress with the development of the JET site and the construction of the JET buildings and basic experimental machine was in line with the Project's programme for 1979. This progress was highlighted by the laying of the foundation stone for the JET main building on 18 May 1979 by Dr Guido Brunner, Member of the Commission of the European Communities.

A notable development was the decision by the Council of the European Communities in August 1979 to approve the modifications to the JET Statutes to allow for the accession of Switzerland to the Project which reflects a European need greater than that of the Community's to develop an independent source of energy, and a common purpose to achieve this objective.

A further significant development was the establishment by the JET Council in February 1979 of a JET Scientific Council to advise it on scientific and technical matters, including proposals involving significant changes in the design of JET, its exploitation and its long-term scientific implications. At the same time there was created in the Project Team a Scientific Department which assumed the direction of the Experimental Systems Division. The aim of this Department is to expand the collaboration with the Associations in all the areas of physics associated with JET, and in particular, to extend the involvement of the Associations in the application of current theory to JET problems.

The Project has not, of course, been free of problems and I should like to refer in particular to difficulties related to the staffing and financing of the Project. The results of the Project's endeavours to recruit suitable personnel during the year have not been fully satisfactory. Whilst an intensive recruitment programme was undertaken throughout the period, only 222 from a total of 275 approved posts could be filled at the year end. This underlines the difficulty confronting JET in being obliged to recruit all its staff through the Associations. A continuation of this trend would inevitably have adverse implications for the Project's programme.

Because of inflation during 1977 and 1978 – an average of 12% over the two years for European countries – the JET Council was obliged in March 1979 to request the Council of Ministers to increase the overall Project Cost Estimates from 184·6 MEUA (January 1977 prices) to 200 MEUA (January 1979 prices). In March 1980 an adjusted budget of 201·5 MEUA (January 1979 prices) was approved by the Council of Ministers.

The continuing support provided by the United Kingdom Atomic Energy Authority and in particular by its Culham Laboratory, with operational and advisory services and the assignment of staff has helped the Project greatly in meeting its programme targets. The high level of cooperation which exists at all levels between JET and Culham Laboratory staff augurs well for the future. A similar degree of cooperation has also been established by JET with various sections of the Commission of the European Communities both at Brussels and Luxembourg and their advice and guidance are highly valued. Much attention has been devoted to establishing good working relationships with the Associated Laboratories whose support will become increasingly important as the Project progresses.

I should like to record my appreciation of the commitment and support of my colleagues on the JET Council which met three times during the years; and to express my gratitude to the members of the JET Executive Committee, which met six times, for the thoroughness of their deliberations and their assistance to the JET Council and to the management of the Project. Although the JET Scientific Council had the opportunity to meet only twice before the year end I look forward with confidence to their assistance in developing the experimental programme.

I wish also to thank the Director and his colleagues on the Project for their continuing diligence and industry and for their success in achieving the targets of the work programmes.

J. Teillac
Chairman of the JET Council

Organs of the JET Joint Undertaking

(1) The JET Council

Member	**Representatives**
The European Atomic Energy Community (EURATOM)	D. Palumbo, G. Schuster
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)	M. Frérotte, P.E.M. Vandenplas
The Commissariat à l'Énergie Atomique, France (CEA)	J. Horowitz, J. Teillac (Chairman)
The Comitato Nazionale per l'Energia Nucleare, Italy (CNEN) The Consiglio Nazionale delle Ricerche, Italy (CNR)	P. Longo, C. Salvetti
The Forsøgsanlaeg Risø, Denmark (Risø)	N.E. Busch, H. von Bülow
The Grand Duchy of Luxembourg (Luxembourg)	J. Alex, J. Hoffmann
Ireland	S. Collins, C. Cunningham
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)	G. von Klitzing, R. Wienecke
The National Swedish Board for Energy Source Development	G. Holte, L. Rey
The Swiss Confederation	C. Risch, E.S. Weibel
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 FUSION PROGRAMME

Research and Training Programme for Euratom in the Field of Controlled Thermonuclear Fusion (Euratom Fusion Programme)

The co-ordination of controlled nuclear fusion research in Europe began in 1959 after the creation of the European Atomic Energy Community (Euratom). At that time, fusion research in the six countries of the Community was not very advanced, although work had begun in parts of Europe in the early 1950s. Euratom and the national centres chose to conclude contracts of association in order to promote and co-ordinate research. Euratom is represented on each of the steering committees responsible for the programmes covered by these contracts of association and makes available to the centres both financial aid and manpower.

The present situation in the enlarged Community is shown in Fig.1. It is significant that two non-member countries, Sweden and Switzerland, are now associated with the Euratom fusion programme. This programme is designed to lead, in due course, to the production by industry of fusion power systems which will generate enough electricity to meet a significant fraction of the European demand.

Community and International Tokamak Research

The Euratom fusion programme is concentrated on the magnetic confinement of plasma (the state of matter in which nuclear fusion reactions will be exploited) using tokamak-type, toroidal machines. This concentration of effort on the tokamak confinement system (first developed in the USSR) is due to the fact that, at present, such systems show the most promise for meeting the requirements of a thermonuclear fusion power reactor.

At present, there are several small to medium sized tokamaks operating in the Associated Laboratories. The tokamak TFR-600 (in its previous form TFR-400, it was for some time the most powerful tokamak in the world) at the CEA Fontenay-aux-Roses Laboratory is involved in plasma heating studies with significant ion-cyclotron frequency power, and very encouraging results have been obtained. The same method is also being studied on ERASMUS (École Royale Militaire, Brussels). Lower hybrid frequency plasma heating is being studied at the CEA Grenoble Laboratory on PETULA and WEGA in collaboration with the Max-Planck Institut für

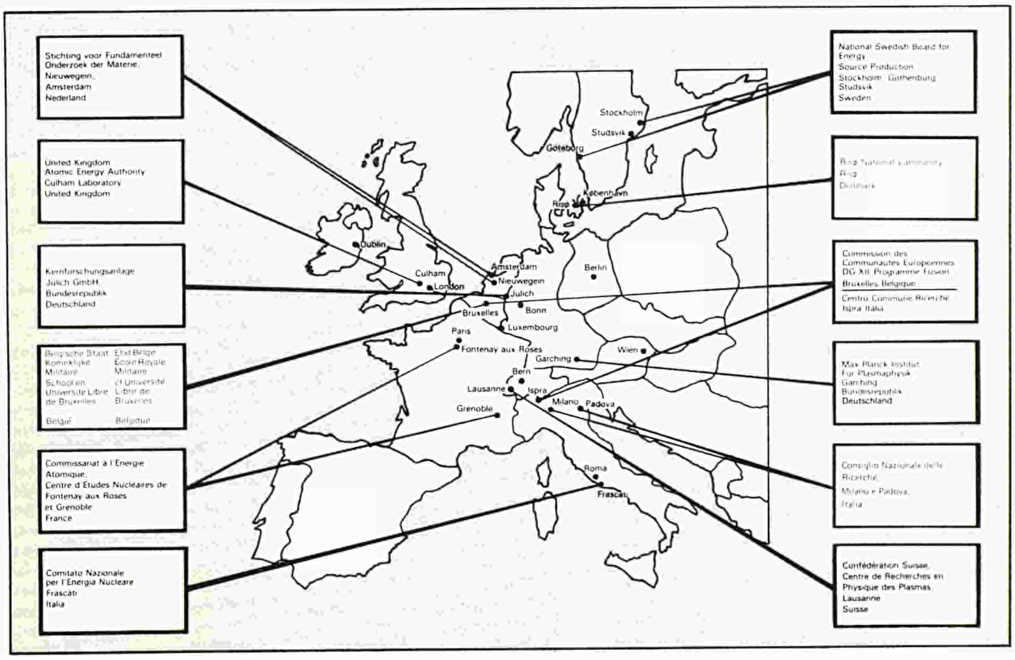


Fig.1 Location of the organisations associated with the Euratom fusion research programme.

Plasmaphysik (IPP). Investigations of the control of impurity (non-hydrogenic) material in hydrogen plasmas are being performed on DITE (Culham Laboratory, UKAEA) and have just begun on ASDEX (IPP). The control and reduction of impurities in tokamak plasmas is of fundamental importance to the achievement of thermonuclear plasma conditions. Related studies are being carried out in RINGBOOG II (FOM-Nieuwegein).

The Frascati Tokamak (CNEN) with its high magnetic fields (8 – 10 T) is capable of high plasma density operation, and this has resulted in the achievement of density-confinement time products ($n\tau_E$) of about $1{\cdot}5 \times 10^{19}$ m^{-3} s, comparable with the best tokamak performance in the world. Basic studies have been performed on PULSATOR (IPP) concerning current disruptions, at present the chief barrier to high-density tokamak operation. Fuelling studies on DANTE (Risφ) and plasma cross-section shaping on TOSCA (Culham Laboratory, UKAEA) also support the general tokamak programme as do the very important neutral injection heating experiments on TFR and DITE. Studies of the basic plasma-wall interaction will be performed on TEXTOR (KFA-Jülich) which is at present under construction.

Overseas tokamak research has continued to progress since the ALCATOR (USA) high density results ($n\tau_E \sim 10^{19}$ m^{-3} s) and the PLT (USA) high temperature results, (e.g. 5·5 keV at $n\tau_E \sim 7 \times 10^{17}$ m^{-3} s). The subsequent advances have been less spectacular but have resulted in a more detailed understanding of plasma behaviour and the containment of higher plasma pressure than before (4·3% peak β value with 1 MW of neutral beam 40 keV H^+ on ISX-B (USA)). These results serve to support the growing number of theoretical predictions of maximum beta values in the range 5–10% for stably-confined tokamak plasmas. For JET, it appears that an average stable beta value of at least 4% will be attainable. A reasonably high plasma beta value will be necessary for efficient fusion power production in a reactor.

Further work on additional heating has been concentrated not only on neutral beam injection, where significant power levels (2·4 MW on PLT, 1·8 MW on ISX-B and 1·2 MW on DITE) have been achieved, but also on radiofrequency plasma heating methods. Basic studies in Japan, the USSR and USA support, and in some cases (viz., electron-cyclotron frequency heating) extend the European work. Perhaps the most notable result is that of the ion-cyclotron frequency heating in PLT and TFR-600 where, in the two-ion regime (deuterium containing a small concentration of hydrogen), significant deuterium plasma heating was observed (2 eV/kW).

An important feature of the work on additional heating (both neutral beam and radiofrequency) is that, at the high power levels achieved so far and under appropriate conditions, there are no apparent deleterious effects on plasma confinement.

It is important to note that only a few "high performance" tokamaks will be operating in the last three years before JET commences operation (1983) and thus only a limited number of tokamaks will be able to provide relevant data to be considered in the formulation of the JET experimental programme. This implies that the future programmes of existing machines should be planned with exceptional care to ensure that they can efficiently accommodate the studies required to support large tokamak research.

The JET Project

The complex physical and technical problems and the substantial investment involved mean that the development of a tokamak fusion reactor can best be undertaken by international co-operation. The Council of Ministers of the European Communities therefore decided to build the Joint European Torus (JET) as the principal experiment of the Euratom fusion programme.

The JET Joint Undertaking (see Appendices 1 and 2) was formally established for a duration of 12 years beginning on 1 June 1978. The decision of the Council of Ministers of the European Communities of 30 May 1978 on the establishment of the Joint European Torus (JET) Joint Undertaking stated: "The implementation of the JET Project will constitute an important stage in the aim of the fusion programme to reach the status of controlled thermonuclear fusion applications from which the Community could derive benefit, in particular in the more general context of the security of its long-term energy supply.

"The scale and scientific and technological complexity of the Project as well as its dimensions and cost render necessary a joint effort in the form of an organisation able to guarantee the maintenance of the Community character of the Project and permit on the one hand, effective interaction and co-operation between the Project and the laboratories associated with the Fusion Programme and on the other hand the concentration of the financial and personnel resources under one management which shall be entirely responsible for the execution of the Project."

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" (Article 2 of the JET Statutes, see Appendix 2).

It was 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.

JET will have a stabilising magnetic field of up to 3·5 T, dimensions (minor radii 1·25 m x 2·1 m D-shaped, major radius 2·96 m) within a factor 2 or 3 of those expected in a future reactor and should be able to carry currents of up to 4·8 MA (see Table I). On completion,

Table I
Main JET parameters

Plasma minor radius (horizontal)	a	1·25m
Plasma minor radius (vertical)	b	2·10m
Plasma major radius	R_0	2·96m
Flat top pulse length		20s
Weight of the vacuum vessel		108t
Weight of the toroidal field coils		384t
Weight of the iron core		2567t

	Basic*	Extended*
Toroidal field coil power (peak on 13s rise)	250MW	380MW
Total magnetic field at plasma centre	2·8T	3·5T
Plasma current:		
– circular plasma	2·6MA	3·2MA
– D-shape plasma	3·8MA	4·8MA
Volt-seconds available to drive plasma current	25Vs	34Vs
Additional heating power	10MW	25MW

*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 extended performance. Additional funds will be required for the extended performance.

JET will have a greater performance capability than any other tokamak in the world. Recent experimental results indicate that by exploiting the full performance capability of JET, plasma conditions approaching those of thermonuclear ignition could be obtained. Such plasma conditions are necessary for fusion reactor operation. Successful completion of the JET programme should give a realistic assessment of the reactor potential of the tokamak system and the design parameters for the next stage of reactor development.

The development of the Euratom fusion programme with JET as its principal component and of other nuclear fusion programmes being undertaken simultaneously elsewhere in the world, particularly in the USA, Japan and the USSR, offers the possibility of realising a prototype nuclear reactor by about the turn of the century. The success of these development programmes would introduce a source of energy which, relative to foreseeable world needs, would be practically without limit.

JET JOINT UNDERTAKING

Members

The 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 Royale Militaire) and on behalf of the Université Libre de Bruxelles (Service de Chimie-Physique II of the ULB)
- the Commissariat à l'Énergie Atomique, France (CEA)
- The Comitato Nazionale per l'Energia Nucleare, Italy (CNEN)
- the Consiglio Nazionale delle Ricerche, Italy (CNR)
- 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 Wissenschaft e.V. – Institut für Plasmaphysik, Federal Republic of Germany (IPP)
- the National Swedish Board for Energy Source Development
- the Swiss Confederation*
- the Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)
- the United Kingdom Atomic Energy Authority (Host Organisation)

Management

The JET Joint Undertaking is governed by Statutes which were adopted by the Council of the European Communities on 30 May 1978.

The organs of the Joint Undertaking are the JET Council and the Director of the Project (page vii). The JET Council is assisted by a JET Executive Committee and is advised by a JET Scientific Council (see Fig.2).

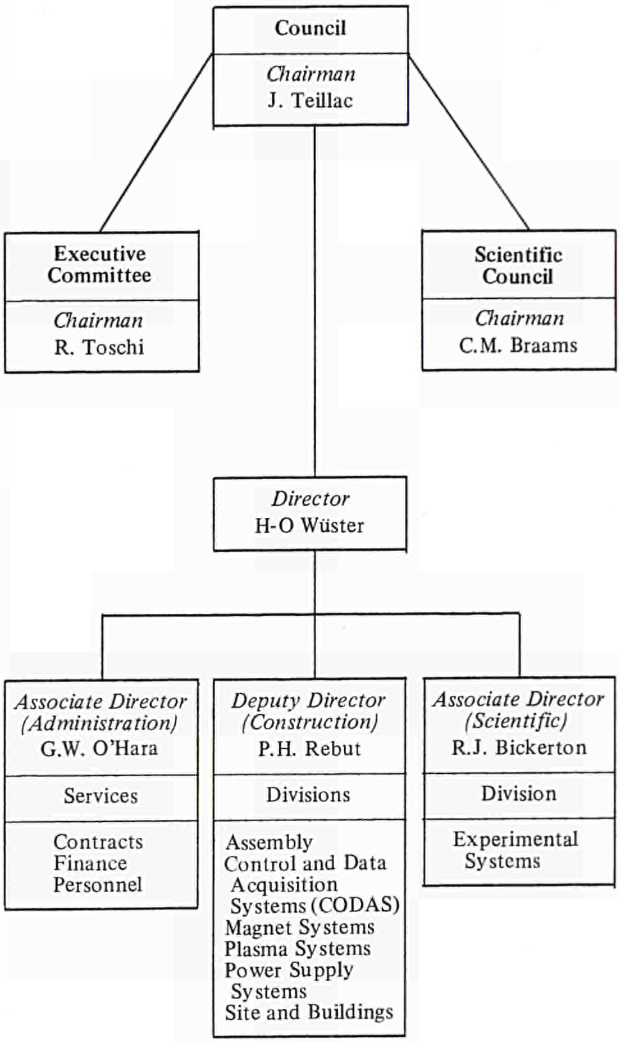


Fig.2 Organisation of the JET Joint Undertaking

JET Council

Each member of the Joint Undertaking is represented on the JET Council (see page vii). The JET Council is required to meet at least twice yearly and elects its chairman from among its members. The Council is responsible for the management of the Joint Undertaking and also responsible inter alia for:

(i) 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;

(ii) The approval of the annual budget, including staffing, as well as the Project Development Plan and the Project Cost Estimates;

(iii) Ensuring the collaboration between the Associated

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*In August 1979 the Council of the European Communities approved the modifications to the JET Statutes to allow for the accession of Switzerland to the JET Joint Undertaking from 22 August 1979.

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.

The JET Council met four times during 1979 on the following dates: 8/9 February, 23 March, 17 May and 18/19 October.

JET Executive Committee

The provisions which apply to the representation of the members in the JET Executive Committee (see Appendix 3) and its voting arrangements are the same as those which apply to the JET Council. The JET Executive Committee is required to meet at least six times a year. Its functions include:

(i) Advising the JET Council and the Director of the Project on the status of the Project on the basis of regular reports;

(ii) 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;

(iii) Approving, in accordance with the rules on the award of contracts established by the JET Council (Annex II, JET Financial Regulations, see Appendix 2), the tendering procedure and the award of contracts;

(iv) Promoting and developing collaboration between the Associated Laboratories and the Joint Undertaking in the execution of the Project.

The JET Executive Committee met six times during 1979 on the following dates: 8/9 March, 8 May, 28/29 June, 13/14 September, 25/26 October, 6/7 December.

JET Scientific Council

In accordance with Articles 3 and 6 of the JET Statutes the JET Council, at its meeting on 8/9 February 1979, established a JET Scientific Council and appointed the members (see Appendix 4), including C.M. Braams as its Chairman for a four-year term. The JET Statutes (Article 6) confer the following functions on the JET Scientific Council:

(i) 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;

(ii) To perform such other tasks as the JET Council may request it to undertake.

The JET Scientific Council held two meetings in 1979, the first on 21/22 June and the second on 24/25 September.

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 will be 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.

The Host Organisation

The United Kingdom Atomic Energy Authority is the Host Organisation (JET Statutes, Article 15) for the JET Joint Undertaking. The Host Organisation is obliged to make 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 of 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". The requirements for the "standard condition" are summarized in an Annex to the JET Statutes.

Furthermore, the Host Organisation is required to supply at proven cost such technical, administrative and general services as are required by the Joint Undertaking.

In addition to providing staff in accordance with Article 8 of the JET Statutes the Host Organisation shall provide support staff, at proven cost, to meet the requirements of the JET Project. Such staff shall be under the management authority of the Director of the Project.

Project Team Structure

A Scientific Department was established in February 1979, incorporating the Experimental Systems Division, and an Associate Director was appointed as its Head. At the same time the Scientific and Technical Department changed its name to Construction Department.

The JET Project Team is now divided into three Departments:

(i) Construction Department
(ii) Scientific Department
(iii) Administration Department.

The Departments are further sub-divided as follows:

(i) Construction Department:
  Assembly Division
  Control and Data Acquisition Systems (CODAS) Division
  Magnet Systems Division
  Plasma Systems Division
  Power Supply Systems Division
  Site and Buildings Division

(ii) Scientific Department:
  Experimental Systems Division
(iii) Administration Department:
  Contracts Service
  Finance Service
  Personnel Service.

The Heads of Departments report to the Director of the Project and together with the Director they form the Directorate.

In addition, various special functions are carried out within Directorate services, the organisation being shown in Fig.3.

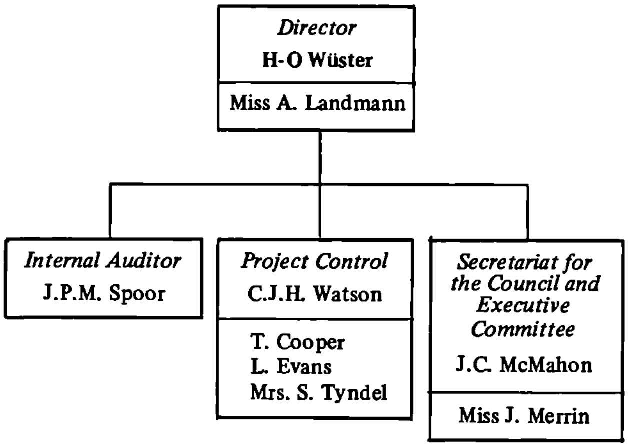


Fig.3 Directorate services staff (December 1979).

JET – ADMINISTRATION

Introduction

During the year most of the posts in the three administrative services, i.e. Contracts, Finance and Personnel, were filled (Fig.4). The build up of staff, particularly in the Finance Service, was slow, due mainly to lack of applications from suitable candidates. The deputy head of that service, for example, was not expected to take up duty before 1 April 1980. Each service, however, managed to establish effective systems and procedures to cater for the particular requirements of each of the technical divisions while at the same time meeting the daily demands of the Project as a whole.

Contracts

The Contracts Service continued to concentrate its efforts on the negotiation of contracts greater than 150 000 EUA in value, for which calls for tender were sent to firms nominated by members of the JET Joint Undertaking and for which final selection was approved by the JET Executive Committee. During the year contract conditions were formulated for supplies and services of types not previously obtained by the Project, including tenders and contracts for computer hardware and software, for large scale use of inspection services and for method feasibility studies for the assembly of the device. Prominent amongst large contracts let were prime contracts and nominated sub-contracts for the Building and Civil Works, contracts for an All Risks Contract Works Insurance Policy and for a number of large power supply items.

A controlled ordering procedure was introduced in order to have a flexible and efficient procurement service to cope with the increasing demand for smaller value items of experimental equipment. At peak demand periods the Culham Laboratory procurement service assisted the JET service.

JET also relied on the Culham Laboratory procurement service to place orders locally and it participated in contracts, arranged competitively by Culham Laboratory, for rapid delivery of standard items and local services.

The Project used the Culham Laboratory store (which itself was stocked from the Harwell main store) for the supply of items in the UKAEA's range of catalogued stores and also for physical receipt and checking of goods ordered on JET's own contracts.

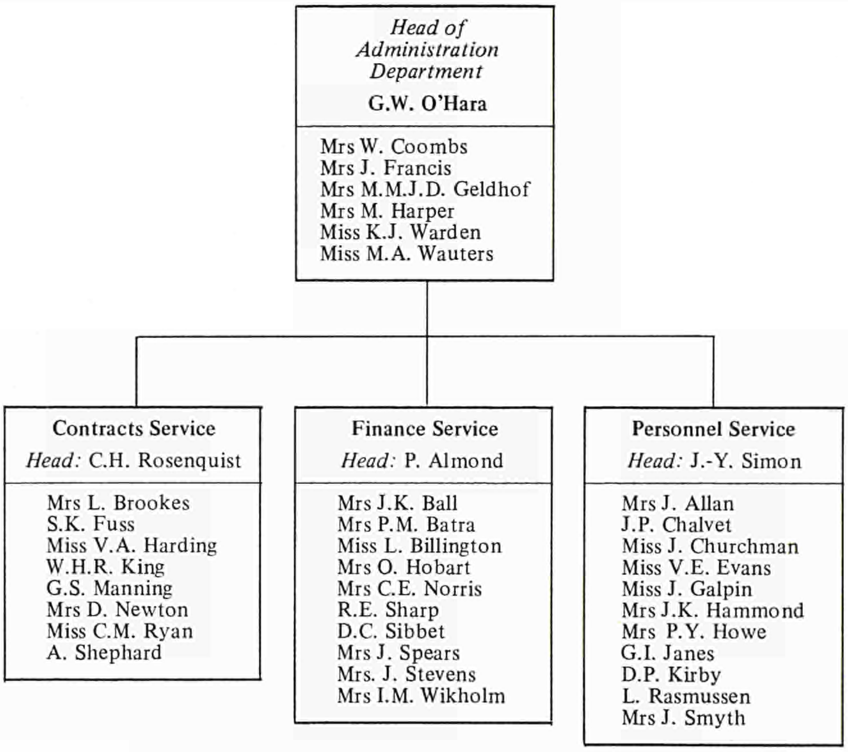


Fig.4 Administration Department staff (December 1979)

The distribution by country of contracts with a value of over 10 000 EUA each let from the start of the JET Design Phase to the end of 1979 is shown in Table II.

Table II
Analysis of contract values as at end 1979

Country	*Values in EUAs	% of Total
U.K.	42 605 340	54·88
Germany	15 777 728	20·32
Italy	6 929 600	8·93
France	5 907 638	7·61
Switzerland	1 819 395	2·34
Netherlands	1 324 498	1·71
Belgium	1 316 000	1·70
USA Finland	752 325	0·97
Denmark	659 000	0·85
Sweden	548 240	0·71
	77 639 764	(100·0)

*Values are at dates of letting of contracts and do not include subsequent adjustments due to escalation provisions.

Finance

Total Estimated Cost

The estimated cost for the Construction Phase of the Project was agreed at a total of 184·6 million European Units of Account (MEUA) at January 1977 price levels, the profile for commitment and payment of this sum over the construction period being initially forecast as shown in Table III.

During 1979 discussions took place within the JET Council on the revision of this profile with two objectives – to adjust the commitment profile in order to permit an acceleration of the construction programme, and to adjust both the commitment and payment profiles for the effects of inflation during 1977 and 1978. As a result of these discussions a submission was prepared for the Council of the European Communities (Council of Ministers) which contained the revised commitment profile shown in Table IV.

On 13 March 1980 the Council of Ministers approved a revised total budget (marginally adjusted) for the Project of 201·25 MEUA at January 1979 prices.

Annual Budget

The annual budget of the Project contains statements of income and commitment and payment appropriations.

Table III
Original commitment and payment profile: 1978–1983

Years	1978	1979	1980	1981	1982	1983	Total
Commitments (MEUA)	20	60	48	35	17	4·6	184·6
Payments (MEUA)	12	35	50	43	30	14·6	184·6

Table IV
Revised commitment and payment profile: 1976–1983

<table>
<tr><th colspan="8">New Commitment Profile (in MEUA at January 1977 Prices)</th></tr>
<tr><td></td><td>1976/8</td><td>1979</td><td>1980</td><td>1981</td><td>1982</td><td>1983</td><td>Total</td></tr>
<tr><td></td><td>20</td><td>60</td><td>58</td><td>31</td><td>11</td><td>4·6</td><td>184·6</td></tr>
<tr><th colspan="8">New Commitment and Payment Profile (in MEUA at January 1979 prices)</th></tr>
<tr><td></td><td>1976/8</td><td>1979</td><td>1980</td><td>1981</td><td>1982</td><td>1983</td><td>Total</td></tr>
<tr><td>Commitments</td><td>20</td><td>68</td><td>62·1</td><td>33·2</td><td>11·7</td><td>5·0</td><td>200</td></tr>
<tr><td>Payments</td><td>11·85</td><td>40</td><td>54·6</td><td>46·8</td><td>32·7</td><td>14·05</td><td>200</td></tr>
</table>

Income consists of contributions of Members augmented by miscellaneous income from other sources. Commitment appropriations represent the upper limit of the legal obligations which can be met from the budget, and payment appropriations represent the upper limit of expenditure to be incurred to cover commitments entered in the budget year or previous years. The budget is divided into main headings – Titles – for income, project investments, operating costs, and personnel costs. Each Title is sub-divided into a number of Chapters, which show the nature of the income or expenditure.

The budget for 1979 was approved by the JET Council on 10 November 1978 at 40 MEUA for income, 68 MEUA for commitments and 40 MEUA for payments, each sum being allocated to Titles and Chapters. The JET Executive Committee subsequently approved transfers between Titles and Chapters of the commitments and payments appropriations, within the totals approved by the JET Council.

Financial transactions during the year are shown in Table V and are summarised below.

Income Contributions from Members

The Project cost is funded as follows:

80% from the general budget of the European Communities.

10% from the United Kingdom Atomic Energy Authority as Host Member.

10% from the Members having Contracts of Association with Euratom, in proportion to the previous year's contribution from Euratom towards the cost of their Association contracts.

The 10% contribution from Members other than Euratom would normally be allocated in proportion to the Euratom contribution to the cost of Members' Euratom Association contracts for the previous year. When the allocation of the 1979 contributions was being

Table V
Extract from the 1979 annual accounts

Budget Heading	Commitments		Expenditure	
	Budget	Out-Turn	Budget	Out-Turn
Title 1 – Project Investments				
Chapter 1 JET Device	14 700 000	14 686 938	16 831 241	11 330 403
2 Power supplies	15 100 000	15 098 738	6 902 763	6 167 670
3 Diagnostics	–	–	–	–
4 Buildings	27 018 725	27 002 438	11 600 489	4 941 914
5 Auxiliary systems	1 350 000	1 317 644	800 000	574 212
6 Control, monitoring and data acquisition	1 600 000	1 538 443	1 000 000	978 696
Title 1 Total	59 768 725	59 644 201	37 134 493	23 992 895
Title 2 – Operating Costs				
Chapter 1 Consumable materials and services	170 000	166 138	170 000	157 323
2 Inventory items	180 000	179 885	180 000	153 410
3 Rentals	40 000	25 608	40 000	24 563
4 Repairs and maintenance	110 000	71 297	110 000	67 688
5 Usage of services	160 000	127 018	160 000	127 018
6 Administration costs	670 000	669 284	920 000	877 998
7 General services	500 000	486 260	500 000	485 589
Title 2 Total	1 830 000	1 725 490	2 080 000	1 893 589
Title 3 – Personnel Costs				
Chapter 1 Euratom staff	3 850 000	3 101 665	3 850 000	3 101 665
2 Overseas consultants	150 000	129 763	150 000	129 763
3 UKAEA staff	1 320 000	704 607	1 320 000	704 607
4 UK consultants and services	700 000	693 051	700 000	693 051
5 Travel and subsistence	300 000	208 078	300 000	208 078
6 Social infrastructure	100 000	1 099	100 000	1 099
Title 3 Total	6 420 000	4 838 263	6 420 000	4 838 263
Budget Total	68 018 725	66 207 954	45 634 493	30 724 747

calculated, these costs were not known for 1978. Consequently the 1979 contributions were based on the proposed contribution to the whole of the 1976–80 programme. With the accession of Switzerland to the Joint Undertaking during 1979, the original allocations were recalculated and contributions from the original Members were adjusted.

The allocations to all Members before and after the accession of Switzerland were as shown in Table VI.

Taking account of amounts owing at the beginning and end of the year, income from contributions equalled the budget of 40 MEUA.

Table VI
Original and revised allocation of budget funding to Members

	Original Allocation %	Revised Allocation %
Euratom	80·0000	80·0000
Belgium	0·1830	0·1804
CEA, France	2·0610	2·0363
CNEN, Italy	0·7340	0·7249
CNR, Italy	0·0640	0·0640
Risø, Denmark	0·0720	0·0707
KFA, FRG	0·8060	0·7956
IPP, FRG	3·8490	3·8035
Sweden	0·1980	0·1954
FOM, Netherlands	0·5780	0·5702
UKAEA	11·4550	11·4381
Switzerland	–	0·1209
	100·0000	100·0000

Income: Miscellaneous

The Project keeps funds not required for immediate use on short or medium term deposit. During the year to 31 December 1979 a total of 1 215 997 EUA was earned on these deposits. Other miscellaneous income brought the total for the year to 1 469 359 EUA which was carried forward to be set off against future contributions from Members.

Commitments

The commitments budget for the year was 68 MEUA, to which was added 18 725 EUA available as uncommitted from the 1978 budget. Commitments during the year, excluding accrued escalation on the cost of major contracts, amounted to 62 132 862 EUA, leaving a balance available of 5 885 863 EUA. The cost of escalation accruing on contracts with a value greater than 150 000 EUA (the level of JET Executive Committee financial approval) since these contracts were let, has now been calculated. The total value of this escalation, taken up to the date nearest to 31 December 1979 for which relevant information was available on each contract, amounted to 10 741 498 EUA. The JET Council has approved a proposal that 4 075 092 EUA (being the major part of the balance available under Title 1 – Project Investments) being charged to the 1979 budget, the remaining 6 666 406 EUA being charged to the 1980 budget. A total of 1 810 771 EUA from the 1979 budget remained uncommitted at 31 December and was carried forward for commitment in 1980.

Expenditure

The expenditure budget of 40 MEUA was augmented by 5 634 493 EUA from the reserve account which was set aside at the end of 1978, for payment of commitments outstanding at 31 December 1978, giving total appropriations of 45 634 493 EUA. Total expenditure in the year amounted to 30 724 747 EUA. 17 936 EUA remained outstanding from the 1978 reserve account and 12 838 700 EUA was transferred to the reserve account at 31 December 1979. The balance of unused appropriations of 1 881 989 EUA are due for return to the Members in 1980. Most of this sum related to personnel costs, and reflected the difficulties experienced by the Project in recruiting staff during 1979.

Summary

Table VII summarises the financial transactions of the JET Joint Undertaking as at 31 December 1979.

Table VII
Summary of financial transactions as at
31 December 1979

	EUA
Cumulative commitments	86 189 229
Cumulative expenditure	37 083 518
Unpaid commitments	49 105 711
Of which carried forward on reserve account	12 856 636
Amount due to be set off against future contributions from members	3 480 062

Internal Audit

The Internal Audit service, reporting to the Director of the Project, was established in August 1979. The service examined the administrative organisation and procedures relating to the financial management of the Project. It also carried out investigations of financial transactions in order to establish that the financial controls were working effectively.

Personnel

An intensive recruitment programme was undertaken throughout 1979, but the out-turn was not as good as had been hoped. A total of 202 team posts was published internationally, 37 ancillary posts were circulated within the UKAEA only, and 59 contract posts were published. During the year 110 new staff took up duty. These included 11 UKAEA, 31 non-professional staff (13 Euratom and 18 UKAEA), 19 ancillary staff and 27 contract staff. At the year end, therefore, 103 professional staff (66 Euratom and 37 UKAEA) and 60 non-professional staff (28 Euratom and 32 UKAEA of whom 27 were ancillary) were in post. There were also 59 contract staff, many of whom were temporarily occupying ancillary and non-professional team vacancies. The total number working for the Project at the year end, therefore, was 222 against a total of 275 approved posts for all categories, leaving a shortfall of 53. Much of the shortfall resulted from the dearth of applications from technicians and computer programmers in the employ of the associated laboratories, reflecting the insufficiently attractive conditions offered by JET.

The JET Executive Committee was kept informed of the problem and each of the Members was requested to advertise in their national press during 1980.

A detailed breakdown of the staff employed at 31 December 1979, is given in Fig.5. Most of these were recruited at various stages throughout the year and Table VIII shows in terms of man-years the gradual build-up of manpower on the Project between January and December 1979. The international nature of the team has been maintained as can be seen from Table IX.

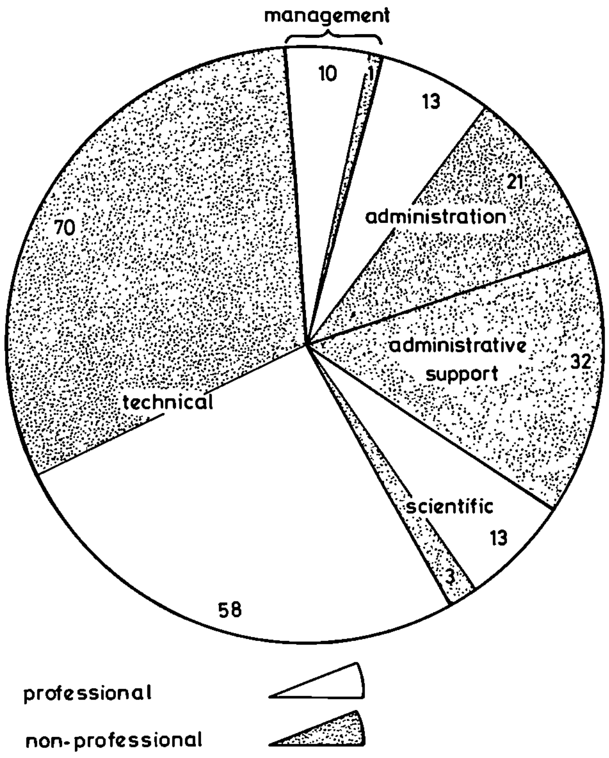


Fig.5 Breakdown of JET staff (December 1979).

The operation of two different sets of conditions of service, one for the UKAEA staff and the other for Euratom staff, resulted in some difficulties. For example, the fixing of appropriate gradings parallel to Euratom gradings for UKAEA staff assigned to the Project created some problems, while the task of implementing locally the complex rules and regulations of the European Communities governing the payment of salaries made additional, unexpected demands on the Personnel Service. However, these problems were gradually being resolved as experience was gained in working with both employers and as mutually acceptable policies were developed to meet the particular needs of the Project.

During the year a scheme was introduced to provide tuition for staff in English and other Community languages. This has been operating satisfactorily.

Table VIII
JET man-year statistics

1979	EURATOM	UKAEA (including Ancillaries & Contract Staff)		
January	3·6	5·5	0·5	2·2
February	3·6	5·6	0·8	3·0
March	4·0	6·6	0·8	3·3
April	4·0	7·0	1·0	3·7
May	4·4	8·0	1·0	4·2
June	4·7	8·0	1·1	4·0
July	4·7	8·7	1·6	3·9
August	5·0	9·0	1·7	4·0
September	5·5	9·6	1·6	4·0
October	6·0	11·7	1·9	5·5
November	6·4	12·1	2·1	5·3
December	6·5	12·1	2·0	4·9
Total	58·4	103·9	including 16·1	+ 48·0
Grand Total 162·3 man-years				

Table IX
Numbers of selected staff by nationality
(31 December 1979)

Belgium	5
Denmark	2
France	26
Germany	19
Ireland	6
Italy	15
Luxembourg	1
Netherlands	6
Sweden	11
United Kingdom	69
Others	3
Total	163

Considerable effort was also devoted to dealing with the various problems experienced by newly appointed staff. The UKAEA has given every assistance to those whom they assigned to JET from elsewhere in the United Kingdom, and this has helped greatly to assimilate them into the Project. The Personnel Service assisted non-British staff and their families in many matters relating to entry into and settlement in the United Kingdom. In this connection the Project has established good working relations with the various United Kingdom authorities dealing with expatriate staff, e.g. the Foreign and Commonwealth Office, Customs and Excise and local organisations.

The Personnel Service, with assistance from estate agents in the area, and the Housing Department of Harwell, helped overseas staff to find suitable accommodation. While it has proved difficult to rent unfurnished accommodation in the area, and there appeared to be a scarcity of good quality houses on the market, the housing of staff has not as yet become a major problem. The UKAEA has helped by making some of its houses in the area available to JET personnel and at its instigation, the South Oxfordshire District Council decided to take over a number of Ministry of Defence houses early in 1980 and to offer them on lease to JET staff.

The European School, which was established in 1978 in former Teachers' Training College premises adjacent to the Project, had at year end more than 250 pupils in five language sections, spanning all academic age groups up to pre-Baccalaureat level. The UKAEA, in accordance with the Support Agreement, provided at Culham Laboratory the agreed amount of office and laboratory space for JET staff both in its own buildings and in temporary accommodation. At the year end it had provided 217 units of accommodation (excluding drawing offices) and undertook to make a further 14 units available by the end of March 1980. While the geography and layout of the Culham Laboratory site and buildings has made it difficult to accommodate all divisions in the most efficient way, the satisfactory progress on the construction of the JET non-specific buildings should allow most of the staff to move into permanent accommodation in the JET Laboratory by the end of 1980.

External Relations

The JET Project Team engages not only in the normal exchange of information with the international scientific research community but is also involved in satisfying a large, general demand for information on fusion research and the JET Project itself.

During 1979 the JET Project Team was called upon to present the Project to several audiences. H-O Wüster presented the Edwards Memorial Lecture at the City University, London; P.H. Rebut presented an invited paper on JET to the European Nuclear Conference in Hamburg; and R.J. Bickerton also presented an invited paper on JET to the 9th European Conference on Controlled Fusion and Plasma Physics in Oxford. D.L. Smart and M. Huguet presented the James Clayton Lecture to the Institution of Mechanical Engineers in London.

Members of the Project Team also presented the Project to university groups (both in the UK and Italy), UK government research establishments, industrial firms (Liechtenstein and Germany) and professional groups (civil, electrical and mechanical engineering institutions in the UK and the Royal Aeronautical Society). Staff assisted at various international schools on plasma physics (Varenna, Italy and Culham Laboratory).

The main function which brought many visitors to the JET site was the foundation-stone-laying ceremony (18 May) for the main experimental building (Fig.6), which was held during the 1979 "Open Days" at Culham. This ceremony, which was performed by Dr G. Brunner (member of the Commission of the European Communities responsible for energy, science, research and education), and the Open Days were attended by many representatives of the media and the Project received considerable coverage in the press, on radio and television. At this time many local and national government officials, representatives from the embassies of the participating nations and representatives from industrial firms and from the Commission of the European Communities, local dignitaries, and families and friends of staff working at the Culham site, visited the Project.

At the request of the Commission, JET participated in a presentation of the Community fusion research programme at the Hannover Fair. In October a group of European science journalists visited JET under the auspices of the Commission of the European Communities. These activities resulted in considerable television, radio and press coverage of the Project.

Firms involved in work related to the JET Project requested material for press releases and such material was also exhibited in Denmark and China as well as in the UK. Several general articles on JET were published

Fig.6 The Director of the Project (H-O Wüster) presents a silver trowel to Dr. G. Brunner (Member of the Commission of the European Communities responsible for energy, research, education and science) after the latter had laid the foundation stone of the main building of the JET Laboratory.

in Europe and further afield (Australia). Requests for information from within the Community and beyond (Canada, Finland, and Spain) have increased in number. In particular, local interest has grown significantly with the appearance of buildings on the JET site.

Visits to JET also increased and included not only groups from schools, colleges and universities but also scientists and journalists from overseas (Australia, China, Kuwait and Poland), government officials from the UK and Germany. In September, participants at the 9th European Conference on Controlled Fusion and Plasma Physics (which was held in Oxford) visited the site.

JET – CONSTRUCTION

Introduction

Organisation

In April 1979 the Scientific and Technical Department became the Construction Department and the Experimental Systems Division was transferred to the newly-formed Scientific Department. The Construction Department retains responsibility for the construction of JET and comprises the following divisions: Assembly, Control and Data Acquisition Systems (CODAS), Magnet Systems, Plasma Systems, Power Supply Systems and Site and Buildings.

This year saw a rapid growth in the size of the Department as new staff were recruited. Leaders of most groups have now been appointed and in all groups staff numbers have grown. Newly-appointed staff reporting directly to the Head of the Department (a technical assistant and a quality control executive officer) took up their posts. The status of the divisional and group structure at December 1979 is shown in Figs.7 and 8. Several positions have however proved difficult to fill. The sometimes lengthy period between appointment of staff and their commencing duty also makes it difficult to meet programme targets. Several small laboratories have been established (vacuum, magnets, CODAS and remote handling) and finding appropriate space for these and related activities has been a problem.

Placing of Contracts

In the period covered by this report further contracts for the basic JET machine itself have been let so that at year end their total value (in all their stages) amounted to more than 90% of the total cost of the machine.

Among these new contracts were those for the poloidal field coils nos.2, 3 and 4, the inner cylinder and outer shell of the mechanical structure, and the magnetic circuit. Contracts have also been placed for external items, e.g. the main (400 kV/300 kV) step-down transformer, the 132 kV/11 kV distribution system, AC/DC power conversion unit, CODAS computers, CAMAC crates, assembly jigs, and the main and auxiliary cranes.

The construction of the JET Laboratory involved the placing of contracts covering the preparation of the site, foundation piling and installation of diaphragm walls, manufacture and erection of the steelwork for the JET specific buildings and the main civil engineering contract which subsequently involved a number of subcontractors. Design of the neutral beam injectors involved study contracts as a part of a joint effort by JET, Culham Laboratory (UKAEA) and CEA-Fontenay.

Programme

During 1979 the work of the Department developed to the stage where a regular review of the implications of technical modifications was required. This was achieved through weekly co-ordination meetings, the introduction of a technical control document system and regular planning and progress meetings. Planning permission for the JET Laboratory buildings was obtained in March and preliminary work began on the site immediately.

The first machine-related hardware arrived in September, namely, four computers for CODAS and in November the first four toroidal field coils were delivered.

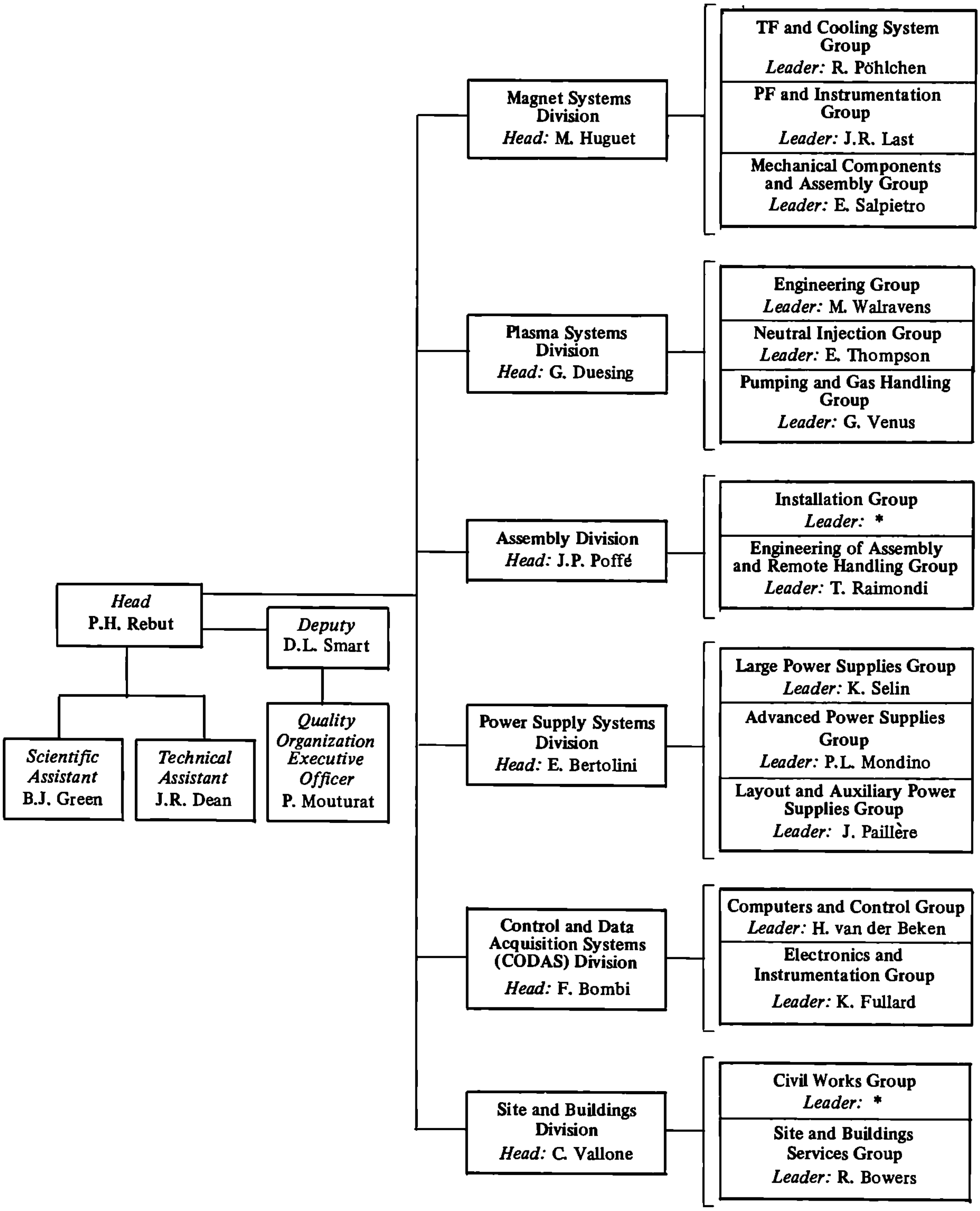
During 1979 technical features of the JET Project were discussed at several meetings; in particular the International Atomic Energy Agency's Technical Committee Meeting on the Intense Neutral Beam Heating of Tokamak Plasmas, the International Energy Agency's Workshop on Computer Control and Data Acquisition, the 8th Symposium on Engineering Problems of Fusion Research and the 9th European Conference on Plasma Physics and Controlled Fusion. Some staff also participated in more specialised meetings as well as maintaining close contacts with the Associated Laboratories.

The construction schedules foresee the completion of the machine assembly and commissioning in time for operation at the beginning of 1983. Nevertheless this depends on the avoidance of delays and the strict control of Project development.

Magnet Systems

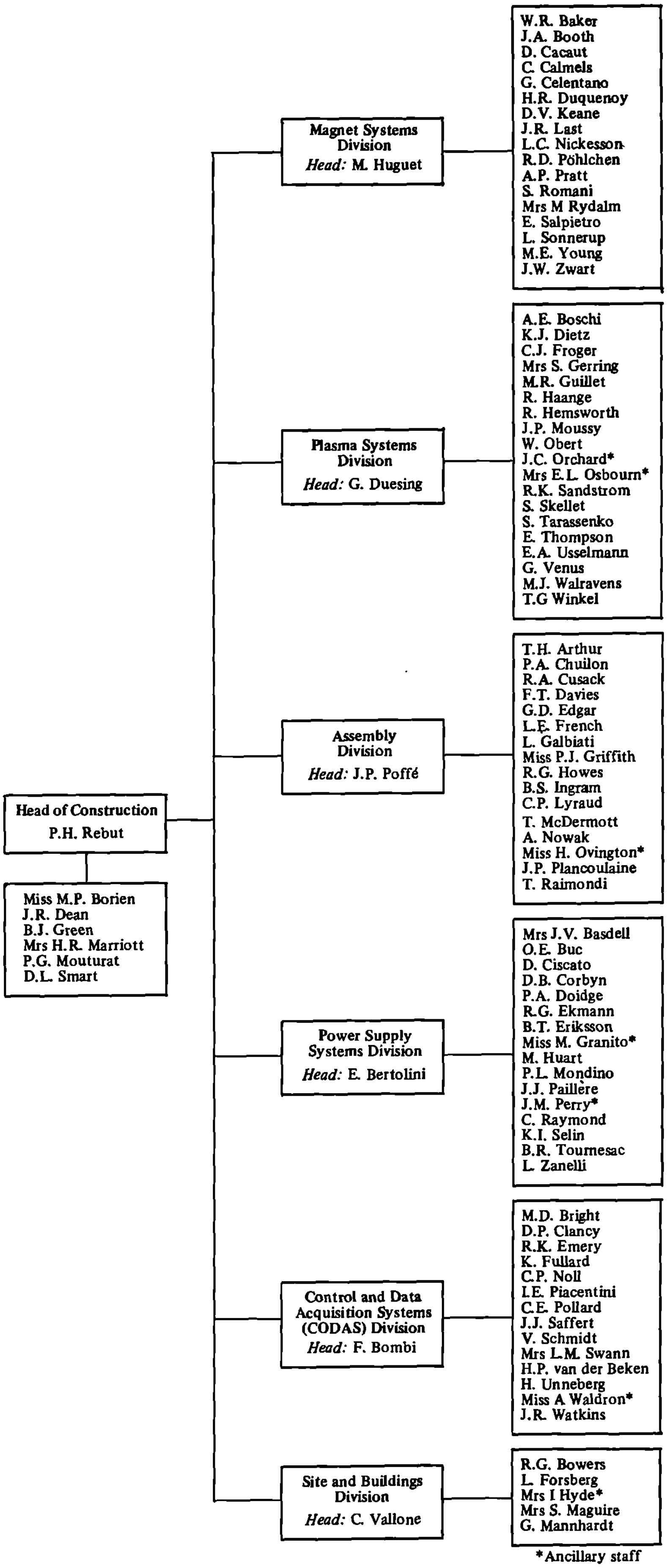
Introduction

The activities of the Division during 1979 can be split into four major categories.



*Appointment pending

Fig.7 Construction Department: group structure (December 1979).



Head of Construction
P.H. Rebut

Miss M.P. Borien
J.R. Dean
B.J. Green
Mrs H.R. Marriott
P.G. Mouturat
D.L. Smart

Magnet Systems Division
Head: M. Huguet

W.R. Baker
J.A. Booth
D. Cacaut
C. Calmels
G. Celentano
H.R. Duquenoy
D.V. Keane
J.R. Last
L.C. Nickesson
R.D. Pöhlchen
A.P. Pratt
S. Romani
Mrs M Rydalm
E. Salpietro
L. Sonnerup
M.E. Young
J.W. Zwart

Plasma Systems Division
Head: G. Duesing

A.E. Boschi
K.J. Dietz
C.J. Froger
Mrs S. Gerring
M.R. Guillet
R. Haange
R. Hemsworth
J.P. Moussy
W. Obert
J.C. Orchard*
Mrs E.L. Osbourn*
R.K. Sandstrom
S. Skellet
S. Tarassenko
E. Thompson
E.A. Usselmann
G. Venus
M.J. Walravens
T.G Winkel

Assembly Division
Head: J.P. Poffé

T.H. Arthur
P.A. Chuilon
R.A. Cusack
F.T. Davies
G.D. Edgar
L.E. French
L. Galbiati
Miss P.J. Griffith
R.G. Howes
B.S. Ingram
C.P. Lyraud
T. McDermott
A. Nowak
Miss H. Ovington*
J.P. Plancoulaine
T. Raimondi

Power Supply Systems Division
Head: E. Bertolini

Mrs J.V. Basdell
O.E. Buc
D. Ciscato
D.B. Corbyn
P.A. Doidge
R.G. Ekmann
B.T. Eriksson
Miss M. Granito*
M. Huart
P.L. Mondino
J.J. Paillère
J.M. Perry*
C. Raymond
K.I. Selin
B.R. Tournesac
L. Zanelli

Control and Data Acquisition Systems (CODAS) Division
Head: F. Bombi

M.D. Bright
D.P. Clancy
R.K. Emery
K. Fullard
C.P. Noll
I.E. Piacentini
C.E. Pollard
J.J. Saffert
V. Schmidt
Mrs L.M. Swann
H.P. van der Beken
H. Unneberg
Miss A Waldron*
J.R. Watkins

Site and Buildings Division
Head: C. Vallone

R.G. Bowers
L. Forsberg
Mrs I Hyde*
Mrs S. Maguire
G. Mannhardt

*Ancillary staff

Fig.8 Construction Department staff (December 1979).

Continuation of Manufacturing Contracts already Placed

An important milestone for the Division and indeed for the whole Project was the delivery of the first four toroidal field coils in November 1979. Other major contracts in progress were those for the poloidal field coils no.1 and the mechanical structure.

Placing of New Major Manufacturing Contracts

Contracts have been placed for the manufacture of the poloidal field coils nos.2, 3 and 4, for the magnetic circuit and for the inner cylinder of the mechanical structure.

Start of New Activities

Design work has been initiated for busbar instrumentation and water cooling systems. For all these activities, progress has been somewhat slower than expected because of interface problems with other systems. However, by the end of 1979 work had progressed sufficiently to allow calls for tender to be prepared and some to be issued.

Interfacing with other Divisions

The increasing importance of interface activities demonstrates that 1979 has been a year of transition with the whole Project moving swiftly towards the assembly phase. A considerable fraction of the working time has been devoted to identifying and solving interface problems with other systems but more particularly with those for which Assembly Division and Site and Buildings Division are responsible. There have also been interactions with the Experimental Systems Division for the layout of the diagnostics.

All these activities have necessitated a rapid build up of staff. Although the recruitment of JET staff has proved more difficult than expected, three additional professional engineers, four technicians and a secretary took up duty with the Division in 1979. Two further technicians have been appointed and commenced work early in 1980. Furthermore, there has been a significant increase in the number of staff working under contract. While the Division continues to use mechanical designers under contract, more contracts have been placed for the supply of personnel to cover activities such as inspection at factories, design work for piping and instrumentation systems.

By the end of 1979 there were 30 staff in the Division, 12 being employed by firms under contract to JET.

The following paragraphs give a brief account of the work performed on each main item.

Toroidal Field (TF) System

The prototype toroidal field coil was tested early in 1979. The test programme which included severe mechanical and thermal cycling was completed without any sign of deterioration of the coil insulation system.

For the production coils, a new schedule – one coil every 3 weeks – was agreed with the manufacturer, in the light of the experience gained during the manufacture of the prototype. The original production rate of one coil every 2 weeks could not be achieved, partly because of the additional inspection work with X-rays for the brazed joints. The production is now well under way (Fig.9) and has been reorganised to allow for its acceleration without jeopardising quality. A resident inspector has been appointed to ensure the strict adherence to the quality control plan during production.

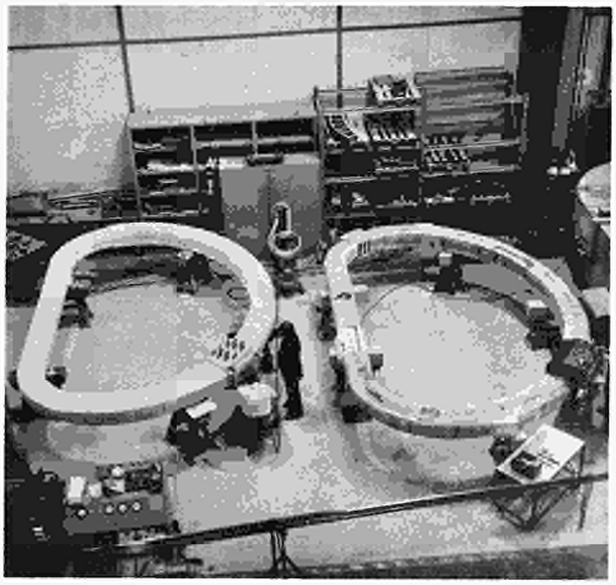


Fig.9 Toroidal field coils in the course of manufacture at the factory.

The prototype coil and the first 3 production coils were delivered to JET in November (see Figs.10 and 11)

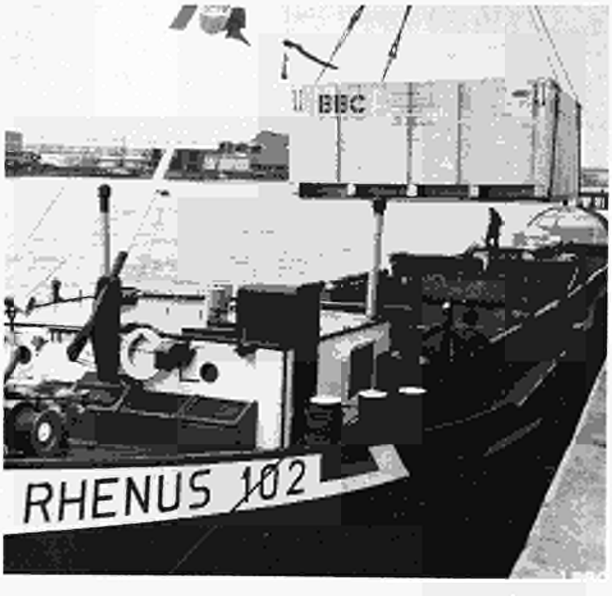


Fig.10 Loading a box containing two toroidal field coils onto a Rhine barge at Mannheim (FRG).

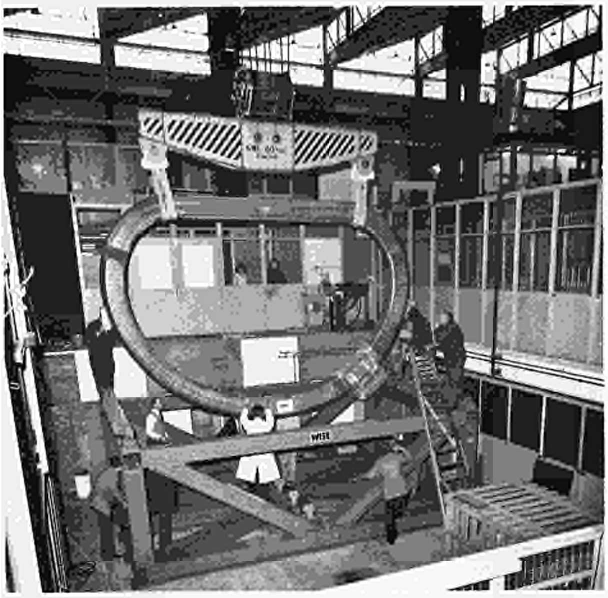


Fig.11 Delivery of the first toroidal field coil to the JET site.

and the second batch of 4 coils was ready for delivery early in January 1980. The production of the TF coils will continue until June 1981.

For the busbar system of the TF magnet, a detailed design and a specification were prepared, enabling the issue in November of a call for tender. Bids from industry will be received in January 1980.

Poloidal Field (PF) System (Fig.12)

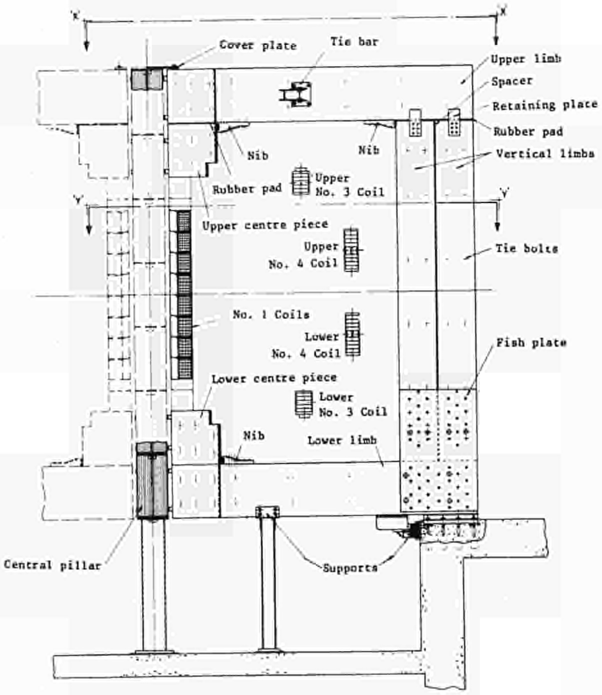


Fig.12 Layout of the poloidal field system.

Coils No.1

The contract was placed in 1978 and was running slightly behind schedule but significant progress was made. Initial tests on insulation systems have produced good results. For the external rubber layer, more tests will shortly be carried out for the final selection of an adequate material. The prototype coil was wound (Fig.13) without any problems being encountered and was prepared for impregnation. If no unforeseen difficulties arise the production of coils should start in March 1980 and the delivery of the coil stack, complete with steel accessories and busbars, should take place early in 1981.

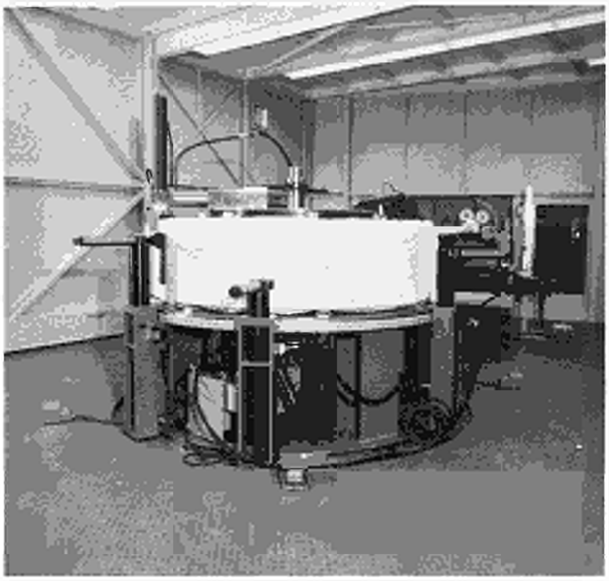


Fig.13 Winding the prototype poloidal field coil No.1.

Coils No.2

Following the call for tender, a manufacturing contract was placed in August 1979 but a period of industrial action at the factory delayed the programme. The projected delivery schedule was, however, still compatible with overall JET planning.

Coils No.3 and No.4

A contract was placed but the work was somewhat delayed by the installation of the manufacturing tools at the factory. The assembly of prototype pancakes will start in 1980. Efforts were being made to establish an efficient factory organisation for production. The delivery of the lower coils which are the most critical in terms of planning was expected by the beginning of 1981.

Busbar Systems for the PF Coils

Due to their various functions, the outer coils nos.2, 3 and 4 include several independent circuits and for each circuit, many tappings are provided to ensure the required operational flexibility. The busbar system for the PF coils is therefore necessarily complex. This complexity is increased by remote handling requirements which forbid routine circuit changes to be made on the machine itself.

Basically the system includes a large number of bars running from the coil terminals to a shielded interconnection board in the basement.

Detailed designs of these busbars, which are part of the coils, were prepared. The complete busbar system was expected to be fully designed by March 1980.

Magnetic Circuit

Steady progress was made in preparation for the manufacture of the magnetic circuit. Magnetic steel laminations were procured, the cutting, stamping and stacking tools were operational, and the assembly of vertical and horizontal limbs started. Delivery was still expected in the first months of 1981.

Mechanical Structure

Design Work

A more detailed stress analysis of the outer shell revealed some weaknesses and certain critical areas were redesigned in order to reduce peak stresses. Mechanical tests of various mechanisms such as shear keys and support teeth led to several design improvements.

Production of Castings

1979 was devoted to solving and settling all the details of the production of the castings. Maintaining the high quality level required has proved difficult in such large and complex castings (Fig.14). Pre-prototype pieces were made and cut up in order to fully assess the quality achievable. Acceptance procedures were finally agreed with the firm responsible for the machining of the castings.

For the collar, ring and tray, prototype pieces and production pieces were produced. For the outer shell, the pre-prototype piece was tested and it was expected that the first shell segment would be available for final machining by May 1980.

Machining of Castings

The contractor produced all the final drawings for manufacture and carried out all the preparatory work for machining and assembly. Machining of the first collar pieces was expected to start in January 1980.

Inner Cylinder

Following the call for tender early in 1979, a contract was placed. The initial work for design, weld qualifications and manufacturing procedures progressed according to schedule and the material was procured. Delivery was expected by the beginning of 1981.

Instrumentation Systems

The first task was to identify instrumentation requirements for each subsystem. In a second phase, instrumentation channels were defined and specifications drawn up for the transducers and the associated cable runs and electronics. Great attention was paid in the design to the very hostile environment with high radiation levels and severe electromagnetic interference.

Detection of electrical faults in the coils will be made by voltage comparison, either directly from the coil terminals for the TF coils, or by means of Rogowski

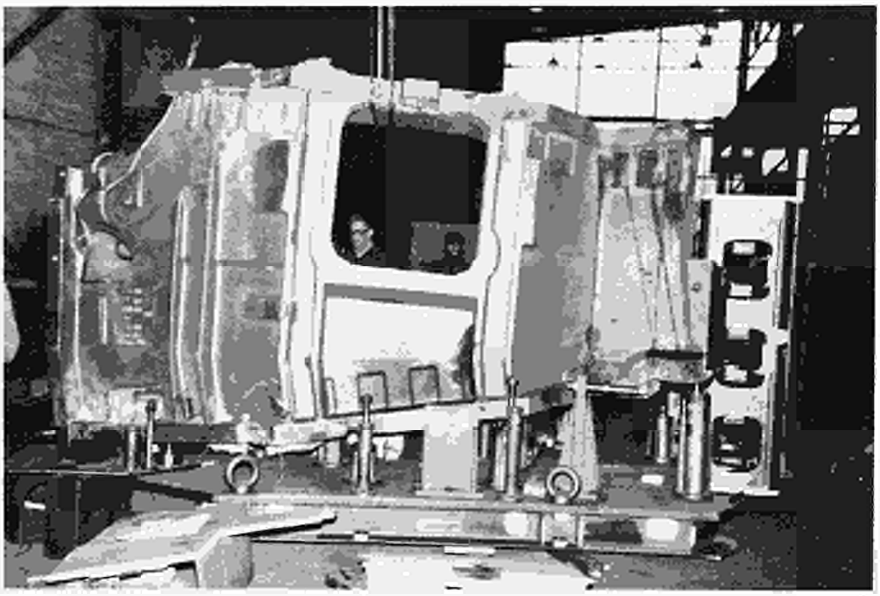


Fig.14 Casting of an external shell for the mechanical structure.

loops around the PF coils. Development work was carried out in collaboration with Culham Laboratory for special measurements involving Rogowski coils and optical methods for the measurement of absolute displacements. The complete system includes approximately 1000 channels mostly for temperature, displacement, strain and water flow measurements and electrical fault detection.

The design work was sufficiently advanced in November to enable the issue of a call for tender for the detailed design and installation of transducers and cable runs on the machine components. The supply and installation of marshalling boxes, electronic racks and cable runs in the basement was planned to be the subject of a separate call for tender to be issued by mid-1980.

Water Cooling System

The Division is responsible for the supply of water cooling for the entire JET experiment.

In 1979, cooling water requirements both for site water and de-mineralized water were fully identified. The most significant development was the large increase in water flow required for the neutral injectors and limiters.

Pipe routings and sizes were decided and the water plant for de-mineralized water was fully specified and laid out. The plant now includes the following loops:

Loop 1 = TF coils
Loop 2 = PF coils nos.1 and 2
Limiters
Neutral injectors
Loop 3 = PF coils nos.3 and 4
Loop 4 = Water supply for small equipment running day and night (vacuum pumps).

All documents, specifications and drawings were completed and it was expected that a call for tender would be issued in February 1980 for the supply and installation of the site water pipework from the cooling towers to the various JET buildings (J1, J3, J4) and for the supply and installation of the de-mineralized water plant in J1.

Future Work

The placing of a large number of major contracts was planned for 1980, including;

- TF and PF busbar systems (at least 2 contracts)
- Complete instrumentation system (split into 2 contracts)
- Water cooling system
- Thermal shield for the mechanical structure
- Neutron shield to be inserted in the box sections of the mechanical structure
- Various mechanical supports for the coils and the mechanical structure.

It was expected that preparation for the assembly phase would become increasingly important as assembly would start before the end of 1980. More technical staff would be recruited for this work.

Plasma Systems

Introduction

The Plasma Systems Division is responsible for the design, manufacture and commissioning of the toroidal vacuum vessel including components for impurity control and for baking and cooling the vessel, the neutral beam injectors and the corresponding pumping and gas handling systems.

During 1979, a major activity in the Division was the breakdown of these responsibilities into individual tasks and the recruitment of appropriate staff to undertake these tasks. For the sub-systems different stages of realisation were reached.

For the prototype octant of the vacuum vessel the bellows assemblies were delivered and the rigid sectors were machined. The assembly was almost ready to begin.

In the area of impurity control, an Inconel limiter system with active cooling was defined. Work on the definition of compound materials for the limiters and of corresponding test programmes continued. Cleaning procedures were defined and study contracts on glow discharge cleaning and on aspects of tokamak discharge cleaning were prepared. Impurity diagnostics devices were defined.

The manufacturing specification for the baking and cooling plant was being finalised. Air flow measurements in the shell of a full-scale half-octant of the vacuum vessel and corresponding heat transfer calculations were performed in order to optimise the vessel baking, and were to be continued.

The neutral injection system was defined in close co-operation with the Culham and Fontenay-aux-Roses Laboratories under various contractual arrangements. The design work on the PINI (plug-in neutral injector) led to the preparation of a contract for the supervision of the manufacture and assembly of two prototype PINIs by Culham Laboratory. The definition and design of the other components of the beam line were delayed due to major difficulties in recruiting experienced staff.

The pumping system for the vacuum vessel was specified. The very high gas flow in the neutral injection beam line led to the layout of unconventional open-structure cryo-pumps. The layout of the cryogenic supply and transfer system has been finalised. The tenders for the manufacturer of the large rotary gate valves were being evaluated. A vacuum laboratory was being prepared for the extensive future test work.

Toroidal Vacuum Vessel

Prototype Octant

All five of the rigid sectors for this octant were fabricated and were being machined and tested (Fig.15). The programme was six months behind schedule due to delays in the building programme for the special clean area required, and to industrial disputes at the manufacturer's. After incorporating the bellows units with the rigid sectors, the prototype octant assembly was due to be delivered to JET in June 1980.

It was decided that the 600°C bake-out, which would be applied to prototype and series octants, would take place at the JET Laboratory. A large oven capable of baking an octant while performing final vacuum tests, was ordered for installation in August 1980.

Series Octants

The contract stage to manufacture the series octants was released in April 1979. Manufacture was slow to get under way because of the previously mentioned building delay. The fabrication of the first rigid sectors was started and it was expected that the first octant would be delivered in September 1980.

Bellows Units for Prototype Octant

As a result of experience in building the prototype bellows units, certain dimensional changes were made which allowed wider manufacturing tolerances. A vacuum leak test procedure allowing testing while the units are being baked to 200°C was introduced. The four units for the prototype octant were completed to these revised requirements and have been delivered (Fig.16).

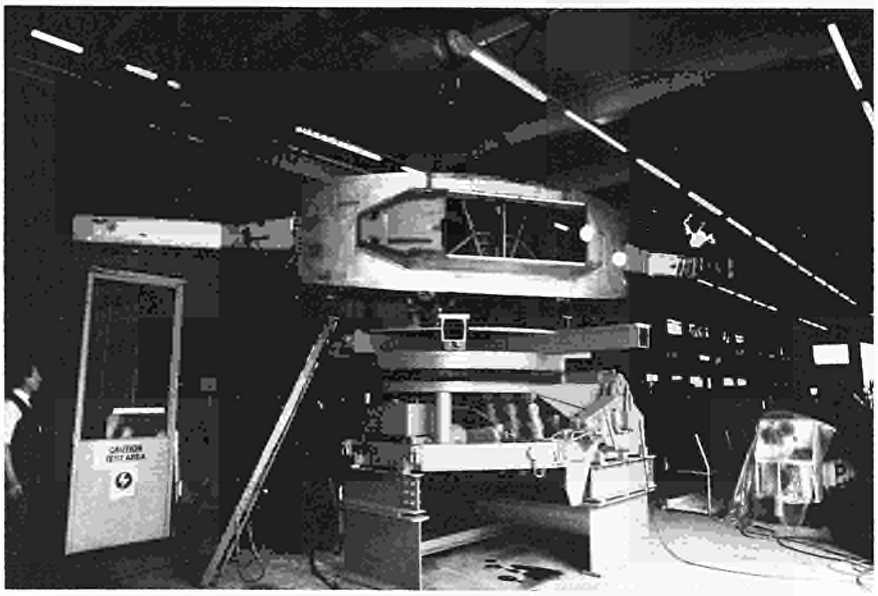


Fig.15 Fabrication of a rigid sector for the prototype octant.

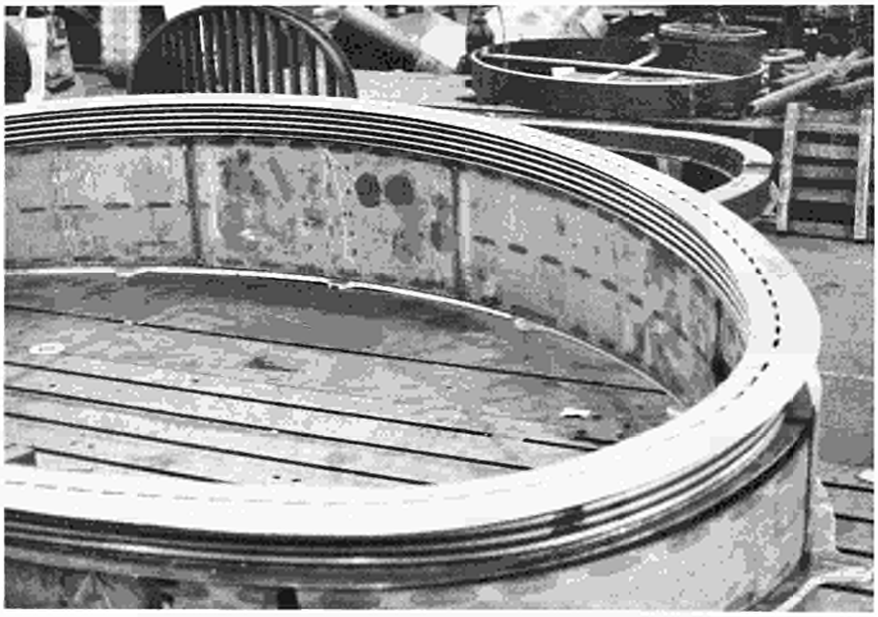


Fig.16 Bellows unit sitting on top of a rigid sector.

Main Series Bellows Units

Following consideration of the problems of assembling the prototype octant, the arrangements for fitting the bellows units to the rigid sectors were modified. It was decided that the mating flanges of the bellows units would be made oversize and would be trimmed to suit assembly. The tooling for manufacturing these flanges was being modified and production of the series bellows units was due to start in February 1980.

Vacuum Vessel Instrumentation

The basic requirements (transducers and signal conditioning) were laid down in conjunction with the CODAS requirements and the interfaces with the Magnet Systems instrumentation. A technical specification was drawn up.

Baking/Cooling Plant

The calculations regarding the rate of heating and cooling were completed, as well as the power versus time variation in all configurations. A cost estimate of the complete baking plant was worked out and a technical specification was drawn up.

Air Flow Tests

A full scale half octant of the vacuum vessel was delivered to the Cranfield Institute of Technology in June 1979. The air flow tests performed there showed a discrepancy with the results obtained on the flat ¼ scale model. Windows had to be cut into the outer wall in order to have access to the baffles. A manufacturing fault was thus discovered and remedied.

Due to labour troubles, the tests could not restart before the end of November 1979. These showed that there is much more gas diverted into the bellows sections than predicted from tests carried out to assess the effects on the heating of the side sectors (port and octant joints).

Impurity Control

The passive impurity control of JET comprises the following design tasks:

- layout and material selection for the limiters;
- establishment of cleaning procedures for the vessel including bake-out, glow discharge and tokamak discharge cleaning;
- specification of diagnostics for impurity control, i.e. surface and bulk temperature measurement of limiter and walls, residual gas analysis, and surface analysis with respect to cleaning procedures.

Limiters

A status report on the available data on low-Z materials was carried out and preparations for the design were made. This resulted in identifying design features as:

- active cooling for power loads up to 2 kW/cm^2;
- copper as a structural material;
- control of thermal expansion;
- thickness of coatings of the order of 10 μm.

As the thermal expansion of copper does not match those of the ceramics, a study contract with Harwell was placed to study the behaviour of ceramic coatings on copper under thermal cycling.

Cleaning Procedures

The cleaning procedures on the assembled vacuum vessel were defined as follows:

- final cleaning with a high pressure water jet to simulate ultrasonic cleaning;
- bake-out to 500°C for twelve hours. A study contract on the outgassing rates of Inconel 625 as a function of temperature has been issued;
- glow discharge cleaning with wall temperatures of 200–500°C in hydrogen at $p \sim 10^{-2}$ torr at current densities up to 10 μA/cm^2. A study contract to specify this system was prepared;
- tokamak discharge cleaning with electron temperatures of about 3 eV. The definition of this system was completed and details concerning the technical realisation were being considered. As the breakdown of a low power discharge might cause some difficulties, a study contract on pre-ionisation using electron-cyclotron resonance was issued.

Diagnostics

The data required are:

- surface temperature of limiter and wall;
- bulk temperature of the limiters;
- impurity concentration on the vessel wall;
- electron density and temperature as well as neutral hydrogen and impurity (C, O) density during discharge cleaning;
- amount of impurities removed from the vessel.

The definition of the necessary devices was started in co-operation with the Experimental Systems Division.

Neutral Injection

For the period under review, staff limitations imposed severe restrictions and it was only during the last quarter of 1979 that the JET Neutral Injection Group increased from one to five professionals.

Design Work

Early in 1979 it was confirmed that the JET neutral injection systems should be capable of delivering 10 MW of 80 keV H^0 with a pulse length of 10 s and capable of extension to 120 keV and ultimately 160 keV D^0. Efforts within JET have concentrated on the design of the PINI, the injector proper consisting of the plasma source, the accelerating and beam forming grid system and the first part of the neutraliser. Because it appeared that direct energy recovery systems capable of long pulse operation would not be available, the system design has considered exclusively the use of conventional beam dumps and magnetic deflection/reflection of the ion beam not converted to neutral atoms.

In an effort to minimise the overall cost of the neutral injection hardware, it is intended to supply the 10 MW, 80 keV neutral power to JET using only two large vacuum tanks, each of which houses several beam lines.

Various conceptual designs were being investigated and optimised for gas flow and beam trajectories, using codes. It was intended to finalise the design by mid-1980.

At the end of 1979 it was decided to place a contract on the supervision of the manufacture of two prototype PINIs with Culham Laboratory.

Development Programme

Another major activity during 1979 was the very intensive interaction between JET and the neutral injection development groups at the Culham (CUL) and Fontenay-aux-Roses (FAR) Laboratories. The programmes in these laboratories were oriented more directly towards meeting the JET requirements. A division of tasks was agreed, with FAR assuming responsibility for the technology required for voltages above 80 kV and CUL concentrating on the technology necessary for long pulse operation and the development of diagnostics.

Contracts fully funded by JET were placed and completed by CUL and FAR. These contracts covered several areas of neutral injection development required for JET, the most notable of which was the optimisation of the ion optics for beam formation and acceleration consistent with active cooling of the grids and the successful demonstration of an HV protection circuit suggested by JET, which utilises two tetrodes in a novel series connection. Other areas included the design of bucket and periplasmatron sources capable of illuminating large area extraction systems, measurements of the ion species produced in existing sources, and the development of technology required to manufacture actively cooled grids.

In addition to these JET funded programmes, the development of the megawatt beam lines continued. Operation at 80 keV, 36 A, 200 mA/cm^2 was achieved by FAR and at 71 keV, 9 A, 138 mA/cm^2 by CUL, both with pulse lengths of 0·1 s. The first preliminary results of measurements of beam transmission and grid power loading gave a basis for the design of the JET injectors.

Gas Handling and Vacuum Systems

Torus Pumping

The design of the torus pumping system was pursued in more detail. The torus will be pumped by eight turbomolecular pumps of 3000–5000 ℓ/s pumping speed each. Four of these will be attached directly to the torus, the other four to the rotary valves so that they act on the torus when these valves are open. The turbomolecular pumps will be backed by a centralised 'roughing' system which is located outside the torus hall and will consist of three separate roots-rotary vane pump combinations in parallel.

Cryo-pumps at 70 K are of advantage for the conditioning of the torus prior to the tritium experiments. They will pump all impurities (except He and Ne) and will not pump the hydrogen isotopes, thus keeping down the throughput of tritium. Two such pumps, giving a pumping speed of 10 000–20 000 ℓ/s, are foreseen.

Beam Line Cryo-Pumping

Cryo-condensation pumps for the neutral injection beam lines working at 3·7 K were laid out based on an "open structure" principle. In this case the liquid-helium-cooled surfaces were arranged so as to be screened by large liquid nitrogen panels from any direct sight of bodies at room temperature without the use of the complicated and costly chevron baffles of conventional cryo-pumps. The performance of such pumps was analysed with regard to specific pumping speed, pulsed heat loads under beam operation and to the interaction with neutrons and γ-radiation. Gas flow calculations showed that with these open structure cryo-pumps a pressure distribution would be maintained in the beam line such that reionisation losses are lower than 10%. An open structure model cryo-pump was ordered which would be tested during 1980.

The basic layout of the cryogenic supply and transfer system was finalised. This incorporated a central distribution unit with separate transfer lines to each cryogenic consumer to best meet the requirements for remote handling, flexibility and possible extension. The central distribution unit is compatible with the supply of cryoliquids from refrigerators or from local suppliers.

Rotary Valves

The rotary valves, which are isolation valves between the neutral injection tanks and the torus, were completely designed and specified. Offers from six firms were received by the end of 1979. The manufacture of the valves was due to be completed in August 1982.

Gas Introduction

Systems have to be provided for the introduction of gases into the torus. The filling pressure will range from 10^{-5} to 10^{-3} torr. The gases will be "conventional" gases; hydrogen, deuterium, and helium on the one hand and tritium on the other. The filling method and the quantities involved as well as a preliminary layout were assessed.

For conventional gases both continuous flow and fixed quantity filling will be provided. In the first case, the pressure of discharge gas in the torus will be determined by the continuous gas introduction and the pumping speed. In the second case single defined charges of gas will be introduced immediately (0·1 – 1 s) before the experiment starts. In addition, for both cases a programmed fast gas introduction during the experiment has been foreseen. The problems lie in ensuring the high purity of the introduced gases and in the development of fast valves.

Tritium Handling

In 1979 only minor effort was devoted to the design of the JET tritium system. Based on the tritium handling system proposed previously, some minor aspects such as the permeation of T_2 through the bellows section of the torus were analysed.

Vacuum Laboratory

The ¼ scale rotary valve tests continued. Due to several technical problems they could not be finished in 1979.

A prototype bellows assembly of the vacuum vessel was delivered to JET. Helium leak tests, also at elevated temperatures, were carried out. They proved very satisfactory showing an overall leak tightness of smaller than 10^{-9} torr ℓs^{-1}, as specified contractually.

The vacuum laboratory was being prepared for the extensive test work scheduled to begin mid-1980. The appropriate equipment was being ordered and staff recruited.

Planning and Organisation of Assembly

Introduction

The tasks undertaken in 1979 by the Assembly Division fell into three categories: (a) Assembly and remote handling, (b) Technical planning and project control, and (c) Service tasks.

Assembly and Remote Handling

A comprehensive study of the assembly of the device was undertaken in collaboration with industry. This study involved a review of the assembly procedure and the facilities required, together with a careful investigation of the resources needed to carry out the work on schedule. The study highlighted areas where additional work was required in order to allow work in the assembly hall to commence by the end of 1980. The study defined the work brief for the future assembly contractor and enabled the corresponding specification to be written.

A 1/10 scale working model of the device was being continuously up-dated by the configuration control unit (Fig.17). This unit provides a checking and co-ordinating service for the designers involved in conflicting interface problems (e.g. tolerances and positioning of equipment).

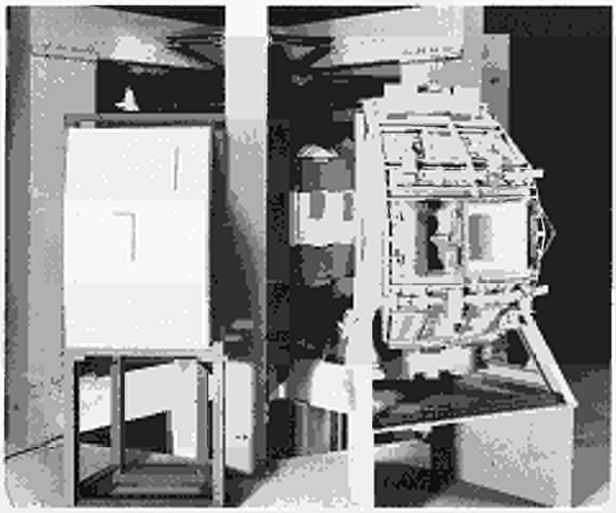


Fig.17 1:10 scale model used by the configuration control unit.

Large jigs and tools were specifically designed to facilitate the erection of the machine. Those required to assemble an octant were ordered for delivery in September 1980 when the assembly hall should be ready for occupation. Those required to put the eight octants in the torus hall were designed and a call for tender was prepared. Short-delivery assembly tools were being designed.

An experimental unit was set up to finalise procedures and carry out tests in relation to the remote maintenance of the device (with the help of a telemanipulator (Fig.18)). This programme involves the study of welding, cutting, electrical and mechanical connections and inspection techniques.

Technical Planning and Project Control

During 1979 the Project evolved an integrated system for the technical and budgetary control of its construction phase. This system was based on a hierarchical coding system known as the "Project Code" which was introduced both for the recording and budgetary control

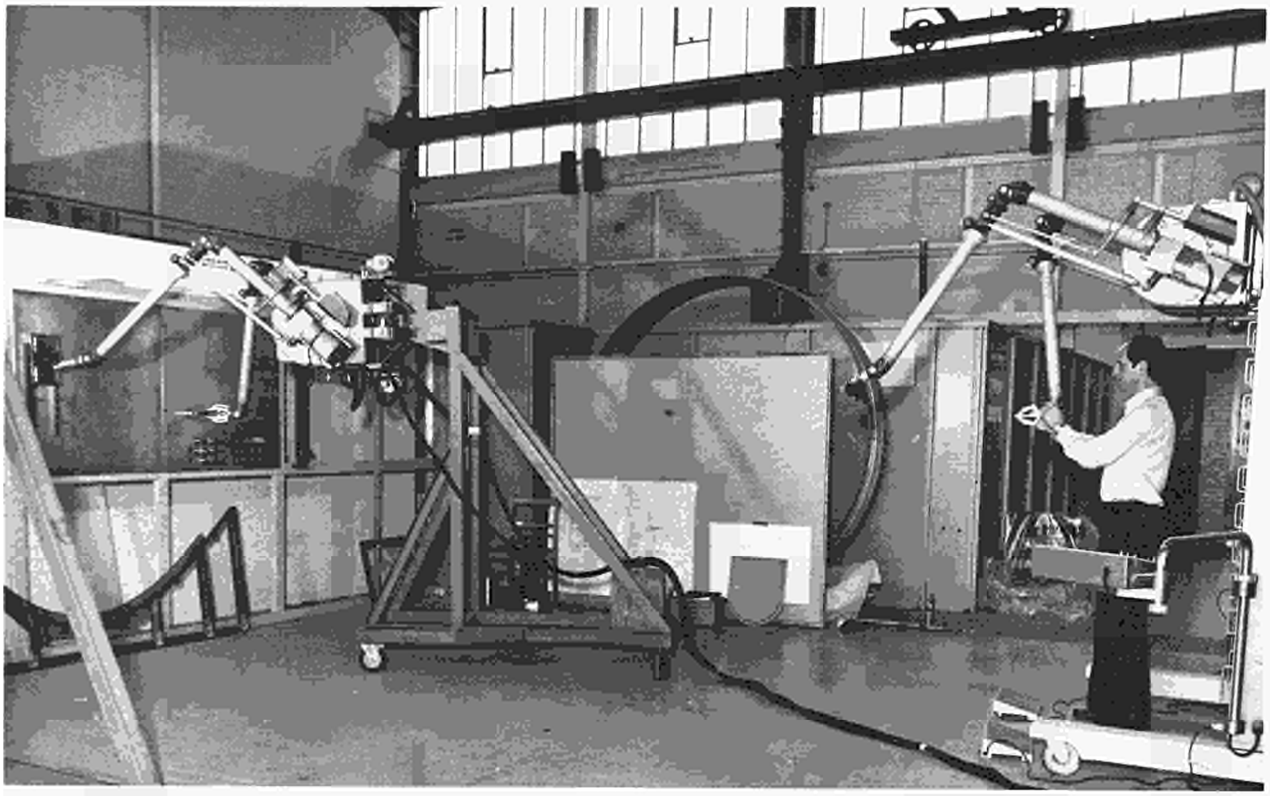


Fig.18 MASCOT servomanipulator.

of all financial transactions (requisitions, commitments and payments) and also for the planning and monitoring of all technical activities. The code defines a 4 level hierarchy. At the top level there is a broad classification into three "Titles" (Project Investments, Operating Costs and Personnel Costs). At the next level, the "Project Investments" Title (for example) is divided into 23 sub-projects, such as "Vacuum Vessel", "Additional Heating Power Supplies", "Computers and Peripherals", etc. Each sub-project is broken down into 15–30 "Super-activities" (roughly at the level of a major procurement contract or significant construction task) and each super-activity is further divided into a maximum of 99 "activities", which are the basic units of the Planning Network. This network defines the logical relationships between all the activities, and is used to compute time-tables and monitor progress on a monthly basis. The network contains about 2000 activities, and computer software has been developed to process the data, to identify the critical path and to produce monthly reports showing the earliest and latest possible start- and end-dates for each activity, and to highlight critical and near-critical activities. These reports are produced at each level in the Project Code hierarchy, and are accompanied by graphical output showing the whole (or selected parts) of the network on a real timescale, with colour coding to highlight activities which have been started or completed or have become critical.

A functional code plan was established. This concerns the identification, location and records of technical specifications of all equipment involved in the project including pipes and cables.

Within the framework of a specialised study contract, the routing of all pipes and cables within the basement and pit under the device were finalised, together with all corresponding penetrations through walls, floors and ceiling of the torus hall with due attention to radiological protection. All those routes and penetrations were incorporated in the 1/25 scale model of the basement. Flow sheets corresponding to the systems involved in the routing (water cooling, CO_2 bake-out, vacuum pumping, cryogenic, gas introduction, ventilation, building services) were integrated in a consistent way.

Service Tasks

An organisation was set up to provide drawing office staff and facilities to the various JET Divisions. Similar organisations with respect to workshop, storage and transport services were specified.

The preparation of the JET assembly phase, which was started in 1979, will be completed in 1980 when the assembly contractor will be chosen. A joint "assembly task force" comprising JET and contractor's staff will then prepare the device for commissioning.

Power Supplies

Introduction

The main tasks of the Division during 1979 were the following:

- Finalising the design of a number of power supply subsystems and preparing the technical specifications for the calls for tender, i.e. starting the procurement process.
- Placing manufacturing contracts as a follow-up of the tendering procedures and supervising the contracts placed so far.
- Continuing staff recruitment, optimising the divisional organisation structure and defining more precisely the responsibilities of the staff.

Although these tasks were distributed among the three Groups of the Division (Large Power Supplies, Advanced Power Supplies, Layout and Auxiliary Power Supplies), each task was carried out by the responsible engineer in close co-operation with colleagues having experience in the field.

System Layout and Performance

With the progress made in the definition of the requirements of the various loads, the power supplies were more accurately defined, thereby allowing the design of the various subsystems to be finalised.

The JET overall power supply scheme makes use of two incoming HV lines, the new 400 kV line dedicated to the pulsed loads and the existing 132 kV line dedicated to the auxiliary loads (Figs.19, 20, 21). Consequently, there will be a 600 MVA pulsed 400 kV/33 kV substation where power will be supplied by the Central Electricity Generating Board (CEGB) at 400 kV and a 132 kV/11 kV substation where power will be supplied by the Southern Electricity Board (SEB) at 11 kV. The two incoming supplies must of course be completely segregated, but various features for commissioning and emergency have been built in to allow the JET 11 kV ("quiet") busbar to be supplied by a (6·5 – 13 MVA) cable from the Culham Laboratory 11 kV busbar. In addition, there is a 20 MVA 33 kV/11 kV transformer with associated busbar, which is part of the 800 MW pulsed flywheel generator convertor (FGC) system. This busbar can be supplied by the JET "quiet" 11 kV busbar, if required, during generator commissioning. Furthermore, the "quiet" 11 kV busbar supplies the 11 kV/415 V (FGC) auxiliary transformer. These connections require, of course, appropriate and fail-safe interlocking.

Such a complex system had to be split into a convenient number of self-consistent subsystems, each one to be designed in detail according to the loads and system interface requirements. Each one of these subsystems has been (or will be) part of a separate procurement procedure.

Status of Main Components

Considerable progress was made in 1979 in issuing calls for tender and in placing major contracts. Table X shows the procurement position of the main power supply subsystems. In the following, the status of each subsystem is briefly reviewed in sequence according to the logic of the power flow.

400 kV/33 kV Substation

Work began on the CEGB 400 kV compound. Civil engineering was planned to be finished in August 1980 and the spur line should be erected in November 1980. The electrical equipment will be installed not later than March 1981. According to the Support Agreement, the switch station is funded by the UKAEA.

The access road in the JET compound will be constructed in November 1980 and the JET 400 kV/33 kV transformers will be erected between January and May 1981.

There were further evaluations in order to assess the network capability to exceed the 50 MW limit in the power step-up (neutral injector system power requirements).

Step-down Transformers – 400 kV/33 kV

These two transformers, of 300 MW pulsed capability (90 MVA continuous rating) each, were expected to be commissioned on site during 1981. The detailed design continued and some options (e.g. value of impedance between secondary neutral and ground, arrangement of the neutral terminals, signal electrical insulation up to 5 kV) were still open.

33 kV Distribution System

The call for tender was prepared and will be issued in February 1980 and the installation will take place during late Spring 1981. The option to choose either an indoor or an outdoor substation was left open, although the indoor option is preferable for space and maintenance reasons.

All the JET main pulsed loads (toroidal magnetic field, poloidal magnetic field, neutral injectors, plasma position control system) are supplied either directly or through the FGC, by this distribution system.

Flywheel Generator Convertor Units

The contract was placed in May 1978 (stage 1) and May 1979 (stages 2 and 3, for two identical generators) and was still proceeding according to schedule. The first (FGC) unit should be ready for commissioning beginning October 1981. During a five-month commissioning period it may also be used for the commissioning of the poloidal field circuit. The installation of the second unit was planned for three months later.

In terms of hardware the two shafts were forged and roughly machined, the main subcontracts were placed (motors, convertors, etc.) and all material was ordered.

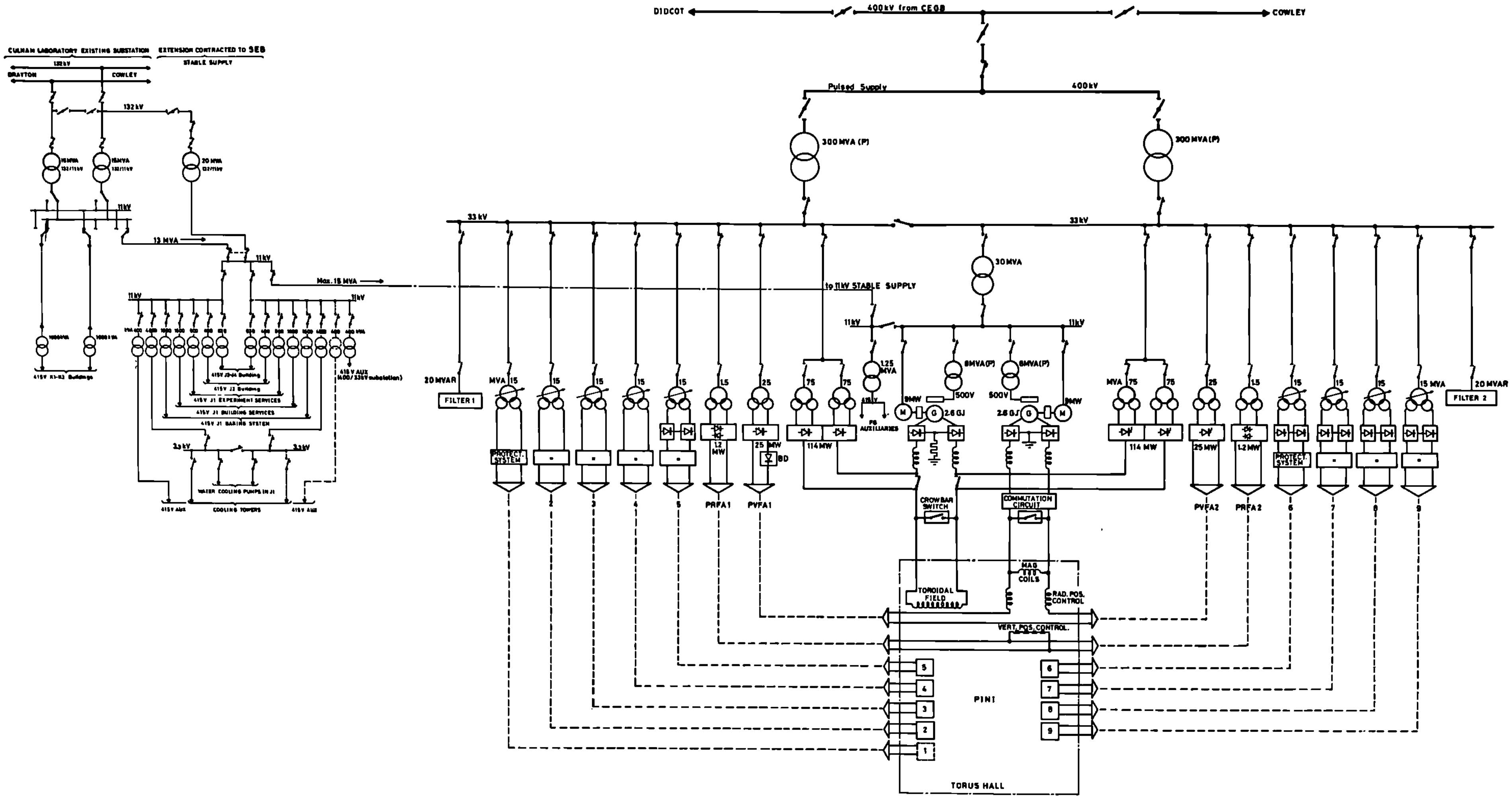


Fig.19 JET power supply — overall system.

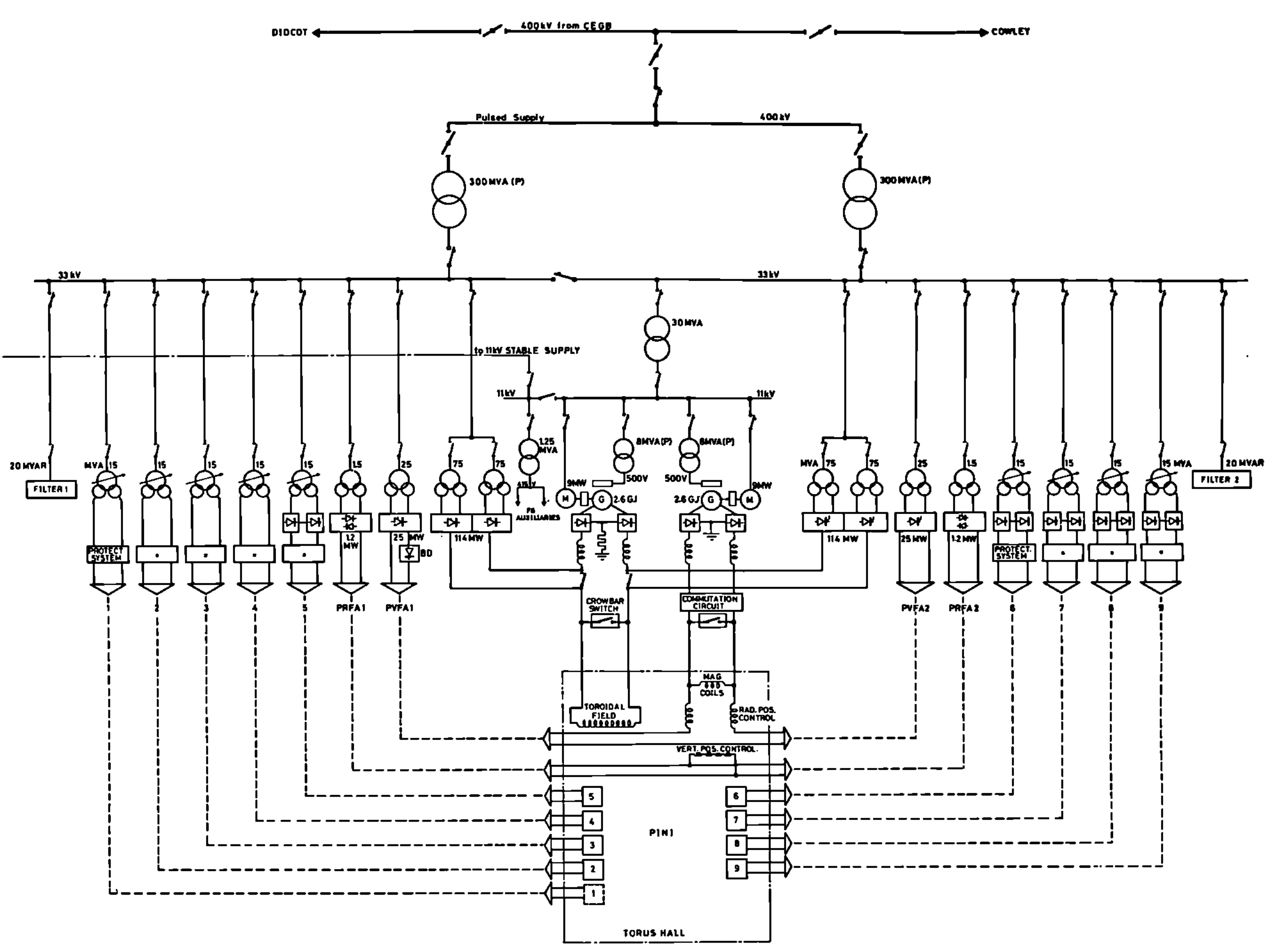


Fig.20 The 33kV distribution system supplied by the 400kV incoming line.

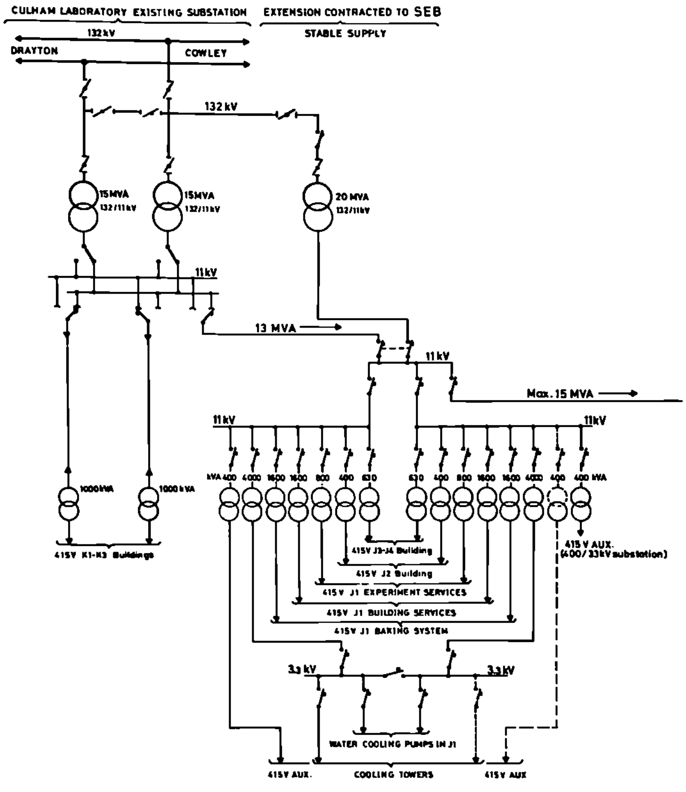


Fig.21 The 11 kV distribution system supplied by the 132kV incoming line.

Table X
Status of procurements for major subsystems

	Subsystem
Contracts Placed	Flywheel Generator Convertors
	AC/DC Convertors
	Step-Down Transformers
	DC Circuit Breakers
	11 kV Distribution
	132 kV/11 kV Substation
	Supply of Electricity of 11 kV
	400 kV Distribution
Contract Negotiations	Supply of Electricity of 400kV
	415 V Distribution
Out for Tender	Capacitor Banks for DC Breakers
	Poloidal Vertical Field Amplifiers
	33 kV Distribution
	PINI Power Supplies and Protection
Under Final Design Revision	Poloidal Horizontal Field Amplifiers
	Poloidal Field Switching Network
	Poloidal Field Protective Network
	PINI Auxiliary Power Supplies

In particular, there was a change in subcontractor for the 11 kV switchboard, for standardisation purposes.

AC/DC Convertors for the Toroidal Magnetic Field

The contract was placed and was signed in October 1979. The detailed design review was due to take place in May 1980 (based on a design report stage 1) and the ordered unit (stage 2) was expected to be ready by July 1981. A second unit (stage 3) may be ordered later.

A number of problems remained to be considered, such as the interfacing with the toroidal field (FGC) unit, the transmission of firing pulses and the work load at the factory during manufacturing.

Plasma Horizontal Position Control

The call for tender for the plasma vertical field amplifiers (PVFA) was sent out and it was expected that the contract would be placed in July 1980 while the supply should be commissioned by the end of 1981. A number of problems were still under consideration such as the possibility of increasing the current rating at a later stage (25 to 35 kA), the analysis (including fault conditions) of the combined operation of the PF ohmic heating network and amplifiers, the possible addition of capacitor banks and/or switched resistors, and the analysis of plasma current control and plasma position control interaction.

Plasma Vertical Position Control

The final design of the PRFA (plasma radial field amplifiers) was in progress based on the study performed during the design phase. Due to the fact that the hardware is similar to that of the PVFA with smaller power required (~ 3 MVA), no delivery problems affecting the planning were expected.

Power Supplies for Neutral Injectors

A preliminary inquiry based on the JET reference design was sent to a number of European manufacturers during the autumn of 1979, in order to assess their interest and capability and to encourage tenders in collaboration with some USA firms already involved in manufacturing large amounts of neutral injector power supplies for the USA experiments. The response to this inquiry was good and 14 companies expressed interest in tendering either individually or jointly.

The technical specifications were prepared for the PINI power supply and protection system (excluding the required PINI auxiliary supplies which were planned to form part of another tender). The call for tender was expected to be issued early in 1980 and the contracts will be placed towards the end of the year. It was expected that the first two units (60 A, 80 kV each) part of stage 1 (total of 10 units) will be installed and commissioned early in 1982.

The key option still open was whether or not to use a parallel tube (in addition to the series one) in the protection system: although slightly more expensive this solution would ease the power supply operation.

Poloidal Field Circuit

Major components of the circuit were ordered (e.g. DC switchgear) or are in the tendering phase (capacitor banks for the above). The contract for the breakers was signed in early November. The supply was expected to be ready during March 1981. It was envisaged that the remaining components of the poloidal field circuit (cross-switches, non-linear inductors, RF filters) would go out for tender one after the other before June 1980, in such a way that commissioning work with the assembled poloidal field circuit could start as soon as the first (FGC) unit could be made available (early 1982). There were however, some additional problems to be solved, such as the evaluation of the requirement for JET pulse run-down, vacuum vessel wall conditioning, adiabatic compression scheme, and computational analysis of the poloidal field circuit behaviour during a complete JET pulse.

132 kV/11 kV Substation

Contract work was initiated in July 1979.

11 kV Distribution System

The contract was signed in November. The work was expected to be completed by January 1981, or possibly somewhat earlier. Delivery and installation on site should start during July 1980. The switchgear had to be redesigned in such a way as to meet the British code of practice (and therefore fulfill the technical requirements of the SEB and of the FGCs) and JET standards.

415 V Distribution System

The call for tender was sent out towards the end of November and it was expected that the contract would be placed in March 1980, which would allow completion of the work by the end of 1980. Certain loads required more exact definition and therefore the system may have to be extended. This should be provided for in the contract.

Supply of Electricity and Tariff for the CEGB Supply at 400 kV

Technical discussions and negotiations were conducted between JET and the CEGB. The main issues which needed to be considered were:

- The step-load: the limit was now set at 50 MW. This figure may have to be increased to 100 or more in relation to the amount of neutral injection power. A trade-off must be found between the line pulse capability and the neutral injector operating mode.
- An alternative mode of operation should be studied (as a fall-back position), i.e. making use of the large time constant of the toroidal field coils for pulse shaping.

The tariff "logic" was that agreed at the time of the Site Committee Report.

Earthing System

The earthing system was under construction as part of the Buildings and Civil Works contract. The design work was undertaken by the Power Supply Systems Division and the installation was proceeding satisfactorily. The installation on site of 400 kV power complicated the normal earthing procedure in terms of safety and earthing effectiveness. A careful analysis will be made to ascertain whether it is possible to separate the 400 kV and the 33 kV earthings.

Overall Power Supply Control

Since each power supply subsystem was specified (in the manufacturing contract) with the local control unit included, the extra hardware required to complete the overall power supply local control was expected to be limited. In addition, there was close co-operation with CODAS.

However, because power supply control meant controlling the mode of operation of the JET machine, a major problem area was the relationship between the built-in capability of the power supply control and all the JET operations.

Fault Conditions and Pre-operational Tests

Each power supply subsystem was specified for tests which would reproduce or simulate fault conditions. Due to the particular nature of the JET loads the real tests of the power supplies can be performed only with the actual JET loads. However, most of the power supply equipment was expected to be ready before the assembly of the JET machine. This implied that acceptance tests for the various subsystems would have to be performed as simulation tests, which could not cover all of the actual performance. This required a study to prepare a plan of "pre-operational" tests as soon as the loads would be available.

Staff

The success of such a large and complex undertaking as the JET power supply system relies heavily on the availability of a sufficient number of engineers, who are highly competent and experienced in specific areas, so as to allow design and procurement work to be done expeditiously. Staff numbers in 1979 will be insufficient to cope with the twenty-two major contracts placed or foreseen for 1980–81. Three high-quality engineers were selected during 1979, but they declined to join the team. As this represented 20% of the professional staff of the Division it highlighted the problem of attracting suitable staff.

Future Work

Seven major contracts were placed during 1979 and three major calls for tender issued. It was planned to issue all the remaining major calls for tender during 1980 and to place at least six additional large contracts before the end of the year.

Installation on site was expected to begin during the second part of 1980 for: the 400 kV and the 132 kV/11 kV substations, the 11 kV and the 415 V distribution systems, the poloidal field circuit DC breakers, and the flywheel generators.

Control and Data Acquisition System (CODAS)

Introduction

The CODAS Division is responsible for the design and implementation of the computerised control and data acquisition system (CODAS) of JET. CODAS is a centralised system, based on the use of a network of mini-computers, which allows the experiment's operation sequence to be carried out entirely from the two control rooms. The system is implemented with a modular structure in order to allow independent operation of separate parts of the apparatus or of individual diagnostics during construction, commissioning or maintenance.

During the JET design phase and the second half of 1978 the conceptual design of the system evolved. Some detailed design and specification of major components were carried out and some procurement was also started. These included:

- The computers and the basic software;
- The structure of the computer interface (CAMAC serial highway) (Fig.22);
- Some of the CAMAC components (the powered crate and serial crate controller).

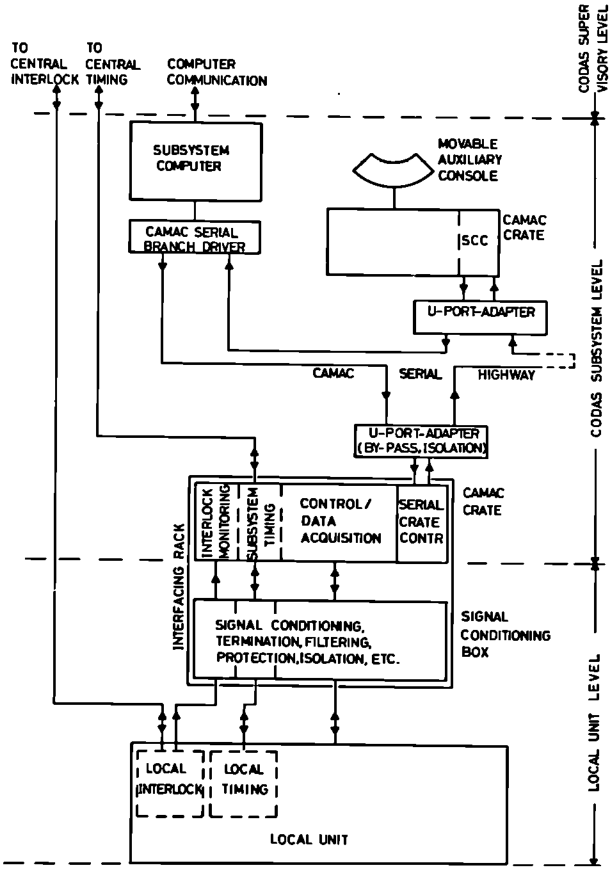


Fig.22 CODAS subsystem level — typical structure.

Definition of the Control Building (J2) and its associated services, the Central Timing System and the man/machine interface (main and movable consoles) progressed.

During the period under review the work of the Division was concentrated in three main areas, namely, subsystem integration, computers and control, and electronics and instrumentation. The following paragraphs outline the progress in each area.

During 1979 a considerable effort was placed in recruitment, with the aim of building up a team of sufficient strength. In spite of some difficulties encountered in attracting staff expert in the areas of computers, control and electronics, the Division strength grew from 5 people at the beginning of the year to 18 people at the end, and a further 6 appointed who had not taken up duty by the year end.

Subsystem Integration

The major effort in this area was in the co-ordination of activities of other Divisions concerning control instrumentation and data acquisition and in particular results were achieved on the following topics:

- The consequences of the radiation levels estimated in the vicinity of the JET device for the use of electronic equipment were considered. Further investigations will be required as soon as more accurate values for the radiation levels become available.
- The final design of the plasma position and shape control feedback system was undertaken. The system involves components under the responsibility of various divisions and an interdivisional working group was established. To complete the design, the major contributions in this field to date were the conceptual design of the magnetic field measuring system for plasma control and the initial design of internal pick-up coils and external flux loops (with some support from Culham Laboratory); further magnetic field computations (including iron effects); study of the radial position control during the current rise phase; and consideration of the effects of stray magnetic fields on signal transmission lines with an indication of the measures needed to reduce common mode signals.
- Active participation in the Working Group on Operating Scenarios offered an opportunity to contribute to the definition of the JET operation with special regard to the discharge cleaning modes (AC and pulsed).

Computers and Control

At the beginning of 1979 the computers were selected and a contract was concluded with a firm to supply them. All the computers used in the CODAS are NORD 100 with the exception of the Storage and Analysis Computer which will be a NORD 500. The computers are integrated in a network supplied by the manufacturer as an extension of the standard NORDNET software. A first machine (of the old NORD 10 type) was temporarily delivered and installed in May and was replaced in October with four of the final NORD 100 which are presently used for program development and tests of interface electronics (Fig.23). They are interconnected using temporary hardware and software while the final products are under development in accordance with JET specification.

Fig.23 CODAS computers.

Work has progressed on the detailed design of the control and data acquisition software with the outline specification of its organisation, with the analysis of the data to be handled and with the definition of the various JET subsystems as seen from CODAS. In this area more detailed information is becoming available from the other JET Divisions as a result of progress in the procurement of power supplies, instrumentation, auxiliary equipment, etc.

In the man/machine interface area a final design of the console frames was produced and the outline specification for the console electronics was prepared.

A good working relationship has been established with various CERN Divisions and thanks to their assistance the NORDAL interpreter and other software facilities were installed in the CODAS computers for trial runs in the new environment.

Two firms were selected for the development of part of the CODAS software.

Electronics and Instrumentation

Main responsibilities in this area are the design, specification and procurement of all the computer interface equipment for both control and diagnostics purposes and to provide JET with a centralised electronic workshop. In 1979 the main work involved the definition of the principal components of the CAMAC serial systems:

- A Serial Highway Driver was specified. This is to be driven directly from the NORD 100 computer bus and will incorporate various block transfer modes. A contract was established for the development of hardware and software.
- A specification was issued for powered CAMAC crates and samples were thoroughly tested with the support of the Culham Laboratory Electronics Section which will perform much of the acceptance testing programme for CODAS equipment.
- A Serial Crate Controller of the standard ESONE L2 design was specified and samples were evaluated. In crates where LAM handling is required, LAM grading will conform to the ESONE recommendations, though the LAM grader will incorporate additional auxiliary functions.
- An Auxiliary Crate-Controller (Type ACC 2099) was selected for use in those crates where the speed of the Serial Highway is a limitation. It incorporates a 16-bit microprocessor for which programs are prepared and stored in the NORD 100 computers and loaded into the microprocessor's memory via the Serial Highway.

Work progressed also on the following items:

- The Central Timing System (CTS) was specified in detail. It comprises an interconnected network of CAMAC modules. The main module type will produce computer-controlled delays of 1 μs minimum resolution and 1-in-65 000 range. Timing pulses will be available both as electrical (15 V) and optical signals for local and long distance (200 m) use respectively.
- Tests performed to select the signal standard for the site's computer terminals have shown that a 20 mA current loop should be used at speeds up to 9600 baud.
- A start was made on the selection of laboratory instruments for use throughout JET.

Future Work

During 1980 the completion of the detailed design of all the components involved in the Division's activities was expected to lead to a phase of procurement and/or implementation. This will involve a continuous interaction with the other JET Divisions in order to identify and analyse all the control, monitoring and data-gathering needs.

The initial work will entail:

- Establishing policies for a coherent instrumentation and electronics layout in the torus hall and in the basement of J1.

- Finalising the magnetic measurement probes and the electronics for the plasma control feedback loops.
- Defining, from the physics scenarios data, the modes of operation of the various subsystems.
- Completing the definition of the subsystems control modes as soon as the relevant information concerning the actual components is made available from the various suppliers.

In the area of computers the complete network will be installed in the Control Building J2 in September/October 1980 and the commissioning of the final communication software will begin. The console frames will be delivered and the detailed design of console electronics will be produced leading to the procurement of most of the hardware required. The design of the major components of software will be completed and the implementation will start with the real-time data base for control and with the filing system for the experimental results.

In the area of electronics the major activity will be centered on the specification and procurement of the CAMAC modules already identified. Design of the interface between CAMAC and local units will progress with the identification of standard structures for the termination, isolation and signal conditioning racks. The procurement of the central timing system modules will continue and the specification of the U-port adaptors and the associated fibre optic links will be produced.

Site and Buildings

Introduction

The Site and Buildings Division is responsible for the development of the building and service facilities required for the JET Laboratory. In particular the Division is concerned with:

(i) superintending the design, construction, operation, and maintenance of the specific experimental buildings, of the distribution of the related site services, of lifting facilities around the site and of the major items of conventional mechanical plant.
(ii) liaison activities with Culham Laboratory in relation to the provision by it on the JET site of general offices, laboratories, JET non-specific buildings and site roads together with services networks external to the JET site boundary.

The JET programme requires the completion of buildings and services facilities by the end of 1981. The construction programme was planned to permit phased occupation to allow the assembly of experimental equipment and installation to commence in 1980.

Design of Building and Plant

During the year the preliminary design of all the JET buildings was completed with the exception of civil works for the 33 kV substation and neutral injection power supply areas, which require more precise identification of specific equipment. There are several features of the main experimental building which were included in the design to facilitate its disassembly. Because this disassembly will be carried out by the UKAEA, such design provisions were agreed with them. The detailed design for calls for tender was carried out in parallel with the preparation of the preliminary design.

In order to accelerate the programme, the tender documents were prepared on a "notional" basis. This meant that quantities were specified in sufficient detail to allow the formulation of unit prices but the cost of some plant and equipment could only be estimated as not all information relating to it was available. The calls for tender on this basis were issued during the year.

During the period of each call for tender a revision of the relevant drawings and specifications was carried out in order to update the documents, and contracts were let on the basis of the updated documents. Sufficient working drawings for construction were produced so that the contractors could start work. Further construction drawings were being produced in advance of the progress of works.

Therefore the three stages of preliminary, detail and construction design were overlapping and were carried on in parallel. This method of operation allowed a satisfactory acceleration of the works and made it possible to keep to an extremely tight time schedule. Nevertheless it is clear that this procedure is not satisfactory.

Calls for Tender

The calls for tender were completed within the year with the exception of that for the works related to the 33 kV substation and power supply outdoor areas. To achieve the sought-for acceleration of the work programme the design and tender stages were planned in line with the following contract priority strategy:

(a) First, placing orders for long delivery components as prime contracts, in order to accelerate the fabrication of components before the nomination of the main contractor.
(b) Second, placing contracts related to the preliminary site works, and the foundations as prime contracts with specialised contractors, again before the selection of the main contractor.
(c) Third, selecting the main contractor and in parallel nominating the principal sub-contractors connected with the structures.
(d) Fourth, nominating the sub-contractors for finishes, plant and services.

Some logistic and organisational problems resulted from the very high number of tenders handled. No less than 542 enquiries were issued in the year 1979. Never-the-less, the assessment and adjudication of tenders were satisfactorily undertaken in line with the set time schedule.

Placing of Contracts

The placing of almost all contracts and the nomination of the major sub-contractors to the main contractor were completed at year end. The last sub-contract (for heating, ventilation and mechanical services) was assessed at the end of the year, and the approval of the proposed contractor was prepared for submission to the first meeting of the JET Executive Committee in 1980.

The value of contracts placed (including heating, ventilation and mechanical services) amounted to 28·804 MEUA. This represented an increase of 3% over the budget estimate for the year which, viewed against the overall high level of inflation during the year, cannot be regarded as excessive. In any case this increase falls within the contingency allowance.

Early in the year the UKAEA placed the contract for construction of the offices and small laboratory buildings (non-specific buildings) and services external to the JET site. These are the responsibility of the host organisation and the design was completed and the call for tender was issued in the year 1978.

Progress of Works on Site

Planning permission was granted by the Local Authority in March. Ground was broken the same month, but the persistent bad weather, after an exceptionally severe winter, slowed down the earth-moving work. However, with improving weather conditions it was possible to speed up the work, which included road construction, drainage and road-crossing ducts for cables and pipes. Eventually the time lost initially was recovered and the works of this contract were terminated satisfactorily on time.

The foundation works were undertaken simultaneously with the preliminary site works (Fig.24). These included the drilling and casting of over 20 piles, necessary because of the low load-bearing capacity of the soil, the construction of two large underground pits to accommodate the generators and the laying down of a slurry diaphragm about 450 metres long and between 8 to 10 metres deep. This latter water-proofed the excavation area and was necessary because of the exceptionally high water table (between 1·0 and 1·5 metres below ground level) on the site.

Both the preliminary site works and the foundation works were completed during August, which was reasonably on schedule and satisfactory from the financial point of view, since in both contracts the final costs were expected to be within the contract values.

In August the main contractor took possession of the site and commenced the main civil works. Because it was planned to occupy the control building and the assembly hall first, the initial effort was therefore concentrated on completing the foundations of these buildings. A strike of engineering workers in the UK delayed the procurement of the steel sections and fabrication of the structure. Therefore a significant delay was incurred in the erection of the steel structures, such that although the control building structures were eventually erected within the year, there was no progress on the assembly hall. The effort was therefore diverted to the other buildings. The state of the site in October 1979 is shown in Fig.25.

Progress in the major areas is summarised below.

External Works

The site network of roads, drains etc. was completed with the exception of the few links which would interfere with the building construction, which therefore had to be left for a later phase. Construction of the main services tunnels commenced, starting from the connection to the existing Culham Laboratory tunnels.

Torus Hall

The excavation for the basement of the main experimental building was completed and the construction of the massive foundation raft (3 metres thick) was begun.

Assembly Hall

The workplan was revised in order to minimise the delay in delivery of the structural steel. The casting of the ground floor slab, initially scheduled to follow erection of the steel, was brought forward. The first strip of floor was cast before the year end.

Control Building

The foundations and the ground floor slab were completed and all the steel structures erected. The painting of the structures was commenced.

Generator Building

The generator pits, the pile caps and plinths for the foundations were completed. Preparation for the construction of ground floor and cable trenches was made.

Static Conversion Building

Work on the construction of this building, last in the building schedule, did not advance beyond the foundation piles.

Non-specific Buildings

These buildings, which include offices and small laboratories, are the responsibility of the UKAEA. By the end of the year they were all erected and roofed, and the brickwork for external walling and internal partitioning was well advanced.

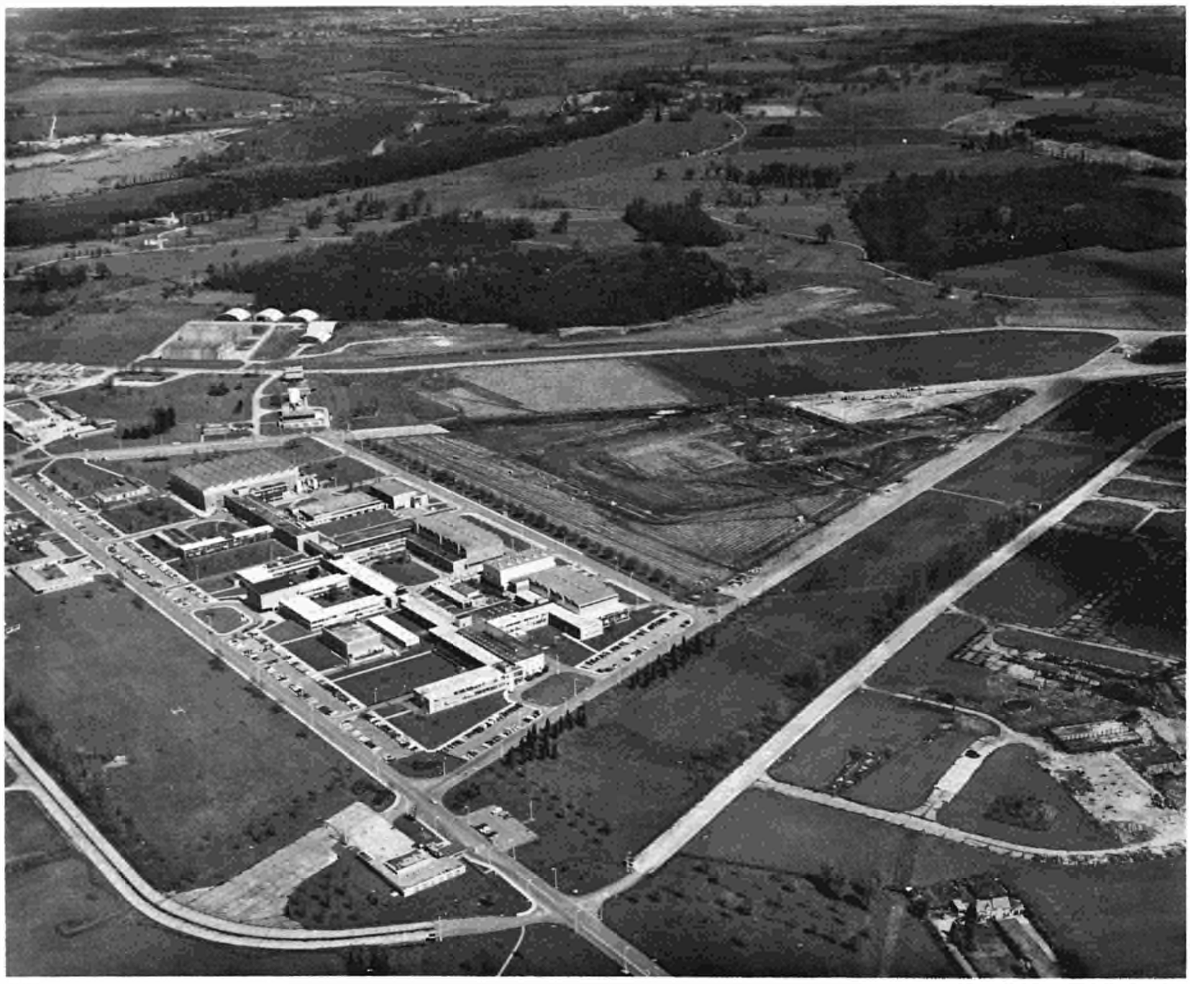


Fig.24 JET site: preliminary work (May 3, 1979).

Fig.25 JET site: status October 25, 1979.

Landscaping

In the winter the first phase of tree planting commenced in accordance with the conditions of the planning permission. The first phase of planting is concentrated around the Culham Laboratory site entrance and to the north-east and east of the JET Laboratory site. By reinforcing existing tree groups and by block planting, a series of natural groups of trees has been formed to provide more substantial screening between the JET buildings and the main road, and in the north-east between the JET buildings and the village of Clifton Hampden.

Standard trees up to 3 metres in height including Norway maple, horse chestnut, ash and lime and smaller feathered trees of Italian alder, oak, and white willow with various screening shrubs have been placed so as to reflect local site conditions and to achieve different landscaping effects.

JET – SCIENTIFIC

The Department (see Fig.26), established in April 1979, contains only the Experimental Systems Division. The work of the Department is therefore synonymous with that of the Division and is fully described below.

Head of
Scientific
Department
R.J. Bickerton

Mrs. J. Culm

Experimental Systems Division
Head: A. Gibson

M.R. Barnes
W. Core
J.J. Davis
L.C. de Kock
G. Magyar
P. Millward
P.P. Lallia
M. Profant

G.J. Sadler
F.C. Schüller
P. Stott
T.E. Stringer
M.L. Watkins
Miss J.E. Watson
Mrs. J.R. Woodage

Fig.26 Scientific Department staff (December 1979).

Experimental Systems

The work of the Division is to prepare for the experimental programme of JET. This involves planning the programme, investigating various scenarios of operation, collaborating with the Associations to produce the necessary diagnostic apparatus, studying the application of radio-frequency (rf) heating techniques, developing interpretation methods, predicting the performance of JET, and reviewing world tokamak research. The work in these areas performed during 1979 is reported in the following sections. The Division also has a responsibility for co-ordinating scientific computing services and for radiological protection studies; this work is carried out in collaboration with the UKAEA.

During 1980 collaboration with the Associations in all the areas of physics associated with JET will be continued and expanded. In particular, reports will be made to extend the involvement of the Associations in the application of current theory to JET problems. The contribution of the Associations to the JET diagnostics and rf heating programmes is also expected to grow.

Operations

A Working Group on Operating Scenarios (WOGOS), consisting of representatives of the various divisions, was formed in order to establish modes of operation for each of the various types of experiment planned for JET. Each mode of operation report will include: objectives, general description, theoretical predictions of plasma behaviour, schedules of machine parameters and conditions, necessary diagnostics, time sequences and logical schemes for switching the various subsystems. These reports will be used by CODAS as the basis for development of software programs for controlling the experimental equipment as well as by other Divisions as guidelines for their work.

Three different categories of scenarios are envisaged:

- Machine-oriented types of operation dedicated to conditioning the device or checking its proper functioning: bake-out, glow-discharge cleaning, pulse-discharge cleaning, magnetic field systems test experiment.
- Standard types of experiment featuring ohmic heating, neutral beam injection, rf-heating, expanding aperture and combinations thereof. All these types of experiment will yield less than 10^{19} neutrons/discharge.
- Fusion reaction experiments aimed at reaching as much alpha-particle heating power as possible. These experiments may include: increasing density scenarios, increasing aperture scenarios and "hot-ion" mode scenarios. Back-up scenarios to cope with particular difficulties will make use of adiabatic compression, colliding beams and cool plasma mantle concepts.

Studies towards the development of these scenarios were undertaken on the following subjects:

(a) Pulse-discharge cleaning (PDC).
(b) The high density limit for ohmically- and injection-heated plasmas.
(c) Theory of neutral beam injection (work carried out under an Article 14 contract with Culham Laboratory).

(d) RF-heating.

A short survey of the results on (a) to (d) is given below.

In 1980 similar studies will be made which include the following topics:

(e) Pre-ionisation methods.

(f) Assessment of the possibilities for the prevention of current disruptions.

(g) Active discharge termination.

(h) Glow discharge cleaning.

(i) Methods for impurity control: Ohkawa-Burrel scheme, edge plasma temperature control, sheath-potential control.

(a) Pulse-Discharge Cleaning (PDC)

In order to assess the power necessary to maintain an efficient discharge-cleaning plasma by inducing a 50 Hz CW toroidal plasma current in JET, a study was made of the various processes determining a similar plasma in D–III at 60 Hz. Of all the present-day tokamaks this comes closest to the dimensions of JET. The basic procedure is to cause a flux of low energy hydrogen neutral particles to hit the torus wall, which ultimately leads to the removal of oxygen embedded in the wall in the form of metal oxides. Analysis of D–III showed that for the demolition of hydrogen molecules into atoms there were two main processes: direct dissociation by electron collisions and more complex processes involving intermediate products such as H_2^+ and H_3^+. The atomic hydrogen either recombines at the wall to molecular hydrogen (entering the plasma or reducing metal oxides to hydroxides) or to water molecules (which enter the plasma). This latter process is the "cleaning" action of PDC. An efficient PDC plasma of JET size needs 0·5 to 1 kW/m^3 as an average power dissipation at the following plasma parameters:

$$\langle T_e \rangle = 3\,\text{eV},\ \langle n_e \rangle \sim \langle n_{H^+} \rangle \sim 3 \times 10^{11}\ \text{cm}^{-3},$$

$$\langle n_{H_2} \rangle \sim 10^{12}\ \text{cm}^{-3},\ \langle n_H \rangle \sim\ 4 \times 10^{10}\ \text{cm}^{-3}.$$

This leads to a total JET power requirement of 100–200 kW which seems to be just feasible by coupling the primary OH-coils of JET to the main grid within the technical constraints imposed by coil insulation.

(b) High Density Limit

Ohmic Heated Plasma

One theory of current disruption developed at the Oak Ridge National Laboratory (USA) suggests that current disruptions occur when magnetic islands due to m = 2, n = 1 and m = 3, n = 2 modes overlap. The magnetic island widths are proportional to the radial gradient of current density dj/dr at the critical q-surfaces, and these two neighbouring islands modify dj/dr so that they mutually amplify each other. Overlap and disruption will occur when a critical value for dj/dr at the m = 2 surface is exceeded. In ohmically-heated discharges with low contamination by high-Z impurities the energy balance will be dominated by anomalous electron heat conduction if the density is low enough. Due to the radial dependence of anomalous electron heat conductivity these discharges will have a sharply peaked temperature and current-density profile and the q = 2 surface will be outside the main bulk of the current; activity of m = 1 instabilities will be large and that of m = 2 will be low, therefore no disruptions will occur. When the density is increased by gas injection the temperature and current density will flatten due to a combination of three possible causes:

(i) The increase of the radiation from high-Z impurities in the plasma core compared to anomalous electron heat conduction.

(ii) The increase of neo-classical inward impurity transport over the anomalous outward transport (Pulsator-explanation).

(iii) The increase of neo-classical ion heat conduction compared to anomalous electron heat conduction.

Therefore with increasing density the q = 2 surface will shrink and dj/dr at q = 2 will increase until at a critical density the disruption will occur. This explains why the critical density for disruption is higher for a lower degree of contamination by high-Z impurities.

A study of the latest experimental results on the high density limit of very clean ohmically-heated tokamak discharges confirmed that the critical density increases proportional to the central current density with a proportionality factor in agreement with the take-over of ion heat conduction as the main loss mechanism in the centre of the plasma (cause iii). The scaling for the critical central electron density: $n_e(0)$ with magnetic field B is found to be: $n_e(0)_{crit} = 5 \times 10^{13}$ B (Tesla)/ R(m) cm^{-3}.

The proportionality factor is about twice that found by Murakami several years ago when tokamak plasmas could not reach such low impurity contents. The limit for pure plasmas can be exceeded if, due to elongation, the central current density is higher at the same value of $q(0) \sim 1$(ISX-B) or if strong re-cycling cools the edges and establishes a peaked profile counteracting the flattening influence of neo-classical ion heat conduction (Alcator) in the centre. Another way to prevent current disruptions is to operate at $q(a) < 2$, i.e. pushing the q = 2 magnetic surface outside the plasma boundary (r = a) as was done in some Japanese experiments, but this has the disadvantage that the energy confinement is spoiled by strong m = 1 activity.

Neutral Injection Heated Plasma

Provided that the injected power exceeds the ohmic heating power ($P_{inj} > P_\Omega$) the temperature-profile and the current-density profile will be determined by the balance between the beam specific energy deposition profile H(r) and the various loss mechanisms. At low density the penetration length λ of the beam particles will be larger or equal to minor radius a and H(r) will be mainly determined by geometrical effects leading to very peaked H(r) profiles and therefore to peaked temperature and current-density profiles. Experiments show that for $P_{inj} > P_\Omega$ and $\lambda > a$ there is indeed a strong temperature peaking increase of $m = 1$ activity and a decrease of $m = 2$ activity.

At higher densities for which $\lambda < a$, the H(r) profile will broaden and with it the T_e and j profile. This means that there will also be a high density limit for current disruptions in the case of injection-heated plasmas. Experimental data on high density, injection-heated plasmas are scarce. A discharge in ISX-B is described with $n_e(0) = 1{\cdot}1 \times 10^{14}$ cm^{-3} and $\langle n_e \rangle = 5{\cdot}1 \times 10^{13}$ cm^{-3} before injection. During injection with 40 keV H° at $P_{inj} = 3P_{\Omega}$ (which means $a = 1{\cdot}5\ \lambda$) it was noticed that the radius where $T_e = e^{-1}\ T_e(0)$ increased from 12 cm to 15 cm (a = 26 cm). This means that q(0) increased by 50%. The central density dropped to 9×10^{13} cm^{-3} with the same $\langle n_e \rangle$. These ISX-B results can be explained by a higher $m = 2$ activity due to the broader profile which could lead to a higher re-cycling around the $q = 2$ surface. At higher injection power this phenomenon was even more marked, the so-called "density clamping".

"density clamping".

In DITE the results are not completely reproducible but it is sometimes observed that with injection the density can be brought up to a higher value with pronounced $m = 1$ activity. After switching off the beam the losses in the centre are much larger than the ohmic input, the profile flattens and a current-disruption destroys the discharge. From PLT no information on high density, injection-heated plasmas is available.

The consequence of this theory for $m = 2$ activity and current disruptions are serious for JET. The highest density for ohmic heating just before injection will be $n_e(0) = 5 \times 10^{13}$ cm^{-3} with $\langle n_e \rangle = 3 \times 10^{13}$ cm^{-3}. The penetration of the 80 keV H°, 160 keV D° will be good and will lead to considerable, undesirable "shine-through" of the more perpendicularly aimed beams. This necessitates a staging of the initial injection phase by first switching on the more tangentially aimed beams, then raising the density by gas injection until the more perpendicularly aimed beams can be switched on. Subsequently the density can be brought up until a new limit is encountered. It depends on the n_e profile when this limit will be reached. At the peaked density profiles used in (c) below for the calculation of H(r), the maximum central density may be expected to be around $n_e(0) \sim 10^{14}$ cm^{-3}. The rather flat n_e profile of ISX-B could, if applicable to JET, lead to a lower maximum $n_e(0)$ value around 7×10^{13} cm^{-3} but with the same $\langle n_e \rangle$ value $\sim 5 \times 10^{13}$ cm^{-3}.

This serious theoretical limitation to the maximum density for neutral injection in JET will be investigated more extensively in the near future.

(c) Theory of Neutral Beam Injection

A JET study contract was placed with Culham Laboratory in order to get a more complete survey of various theoretical aspects of neutral beam injection in JET. In the framework of this contract studies were made and will be made of:

(i) Beam deposition profiles in the envisaged JET-geometry.

(ii) Slowing down of the fast ions taking into account: electron and ion drag, pitch-angle scattering, charge-exchange losses, loss orbits including ripple-trapping and electric field effects.

(iii) Momentum effects leading to an assessment of the Ohkawa-current and reduction of the loop voltage.

(iv) Steady-state ignition calculations with an emphasis on beam-generated, alpha-particle heating.

Part (i) of this study was carried out by means of a Monte Carlo code NFREYA developed at Princeton and Oak Ridge. This code takes fully into account the D-shape and the radial displacement of the flux surfaces as calculated by the JET equilibrium code TOPE. The actual beam injection configuration was used. The differences between the results of this sophisticated but time-consuming computer code and those of the simpler multi-pencil beam code HOFR were small enough that with some appropriate bench-marking a pencil beam calculation could be used for further calculations for parts (ii) and (iii) of the study contract.

A first result on part (iv) indicated that the "hot ion mode", i.e. the lowest $n\tau$ point on the ignition curves $n\tau$-T_e, T_i for pure plasmas would mean for JET an average ion temperature of 23 keV and an average electron temperature of 14·5 keV at an average density of 6×10^{13} cm^{-3}.

(d) RF-Heating

The potential advantages of plasma rf-heating have been acknowledged for a long time and the use of rf waves to heat plasma was considered from the beginning of the JET Design Phase. In 1979 new and promising experimental results were obtained in the PLT and TFR tokamaks, which have further increased the interest in rf-heating. A decision to build an rf-heating system for JET requires that the feasibility can be ensured, namely, (i) the physics must be sufficiently well understood to be confident that the predicted plasma heating will occur, and (ii) the techniques must be sufficiently mastered to be sure that the system can be built to an acceptable time scale and cost.

At present the two following methods are under consideration for JET:

(i) Ion-Cyclotron Resonance Heating (ICRH) at an operating frequency in the range 20–55 MHz, namely between $f \sim \sqrt{f_{cT}\, f_{cD}}$ and $f \sim f_{cH}$.

(ii) Lower Hybrid Resonance Heating (LHRH) at an operating frequency around 1·5 GHz, namely

$$f \sim \sqrt{f_{cD}\, f_{ce}}$$

where f_{ce}, f_{cH}, f_{cD}, and f_{cT} are the cyclotron frequencies for electrons, protons, deuterons and tritons respectively at a magnetic field value of 3·5 T.

Low frequency heating schemes such as Transit Time Magnetic Pumping (TTMP) suffer from high rf-power losses requiring a significant distance between the rf-coil and vessel wall which strongly reduces the plasma cross-section.

Use of Electron-Cyclotron Resonance Heating (ECRH) (f ~ 95 GHz) in JET depends on the availability of powerful and efficient rf-power sources (gyrotrons) and for the present seems incompatible with the JET time schedule. However, especially when considering the "ordinary" wave, the physics look simple and direct, and experiments in progress on T–10 and ISX show successful preliminary results. ECRH is attractive for JET and it is regrettable that no development is in progress in Europe. JET has an active interest in encouraging such work within the European programme in the coming year.

Study contracts were being negotiated with the EUR-CEA Association to propose ICRH and LHRH systems compatible with the JET design. The requirements are to transfer 15 MW of power for more than 5 s to the bulk of the plasma and to limit power deposition in the outer part of the plasma. The primary task of the specific studies in progress for JET is to specify a conceptual design of the rf-launching structure. In order to fulfil the power requirements it is assumed that a minimum value of 5 MW rf-power per JET octant should be coupled to the plasma. The second task is to include rf-heating in the numerical codes simulating the JET discharge. That has already been done for LHRH by using a simple model evaluating the interaction between the power spectrum escited by the rf-launcher (the "Grill") and the local values of the plasma parameters. The third task of the studies is to define the main parts of the system which would be directly ordered from industry, namely the high voltage power supplies, the rf-generators and the rf-power transmission line. The results of these study contracts will be available in the first part of 1980 and will be discussed in a JET workshop.

Since the main uncertainties of plasma rf-heating lie in the plasma physics, the results of the forthcoming experiments in tokamaks are expected to give crucial information concerning the validity and the feasibility of an rf-heating system for JET.

Diagnostics

During the past nine months a serious start was made to identify and define the diagnostic systems which will be needed for the experimental physics programme on JET. It is intended that the diagnostics for JET will be developed in close collaboration with other fusion laboratories in Europe, both in order to make use of their expertise in the various specialised techniques and to involve them at an early stage in work which will naturally lead into the main experimental physics programme of JET. The work of the JET Diagnostics Group is therefore both to co-ordinate the work which is being carried out in other laboratories and to design and develop certain diagnostics which are the direct responsibility of JET.

At the start of the year a list of diagnostic systems which are suitable for development by the Associated Laboratories was drawn up. Following discussions with each laboratory which identified its particular areas of interest, 26 contracts for design studies of JET diagnostics were placed under Article 14 of the JET Statutes (see Table XI). The aims of the design studies are:

- to prepare a specification for each diagnostic system on JET with realistic estimates of costs and construction schedules.
- to identify any development work which may be needed before the detailed design of the diagnostics system can commence.
- to identify any interface problems and to contribute design information to other JET sub-systems (e.g. vacuum vessel, data processing, remote handling, etc.).

Work on these design studies started in mid-1979 and the majority of them are scheduled for completion at the end of the year. Close collaboration has been maintained throughout this period between the JET Diagnostics Group and the Groups in the various Associated Laboratories which are carrying out this work. Regular meetings have been organised to exchange information and to discuss points of difficulty with the result that by the end of the year a much clearer picture of the diagnostic requirements of JET emerged. Most of the proposed diagnostics appeared to be scientifically feasible for JET although the large size of the apparatus together with the expected high fluxes of gamma rays and neutrons presents many technical difficulties which are not experienced on smaller tokamaks. It is also necessary to design the JET diagnostics to operate with a much higher degree of reliability than is normally the case in fusion research. These factors together with the generally high level of inflation for scientific apparatus indicated that the cost of the proposed JET diagnostics will be quite high. Final reports and cost estimates from the diagnostic design studies were scheduled for the end of 1979 and this information will be used to prepare a paper for the JET Scientific Council describing a diagnostic package for the JET machine.

In addition to the diagnostics which have been discussed above there are a number of systems such as flux measuring coils, and Rogowski coils, which are very closely integrated with the design and construction of the torus and which will therefore be developed within JET. Some work on these diagnostics was started earlier in the year in the CODAS Division but serious design work within the Diagnostic Group was unable to start until the last few weeks of 1979 due to a shortage of staff.

Interpretation

The One-Dimensional Transport Code

This code solves the 1–D transport equations to follow the time evolution of the radial profiles of temperature, plasma and impurity densities and the

Table XI
Summary of diagnostic design studies

Diagnostic System No.	Diagnostic	Purpose	Brief Description
2 3 4	Rogowski coils Flux loops Poloidal field pick-up coils.	Plasma current, loop volts, plasma shape and position, fluctuations.	Standard sets of electromagnetic coils will be used for control and diagnostics.
6	Hard X-ray monitors	Runaway electrons	To measure hard X-rays as a monitor and diagnostic of runaway electrons.
8.1	Single-point Thomson scattering	Reliable measurements of electron temperatures and densities.	A "conventional" ruby laser system for 90° scattering which can be scanned along the major radius between discharges to build up a profile.
8.2	Spatial-scan Thomson scattering	Complete radial profiles of electron temperatures and densities within a single discharge.	This system is required to measure a complete profile of electron temperature and density along a vertical chord of the discharge. A neodymium laser will be used with radiation at 1·06 μm for the central hot plasma and a 0·53 μm for the cooler edge plasma. Fibre optics will be used to relay the scattered light outside the neutron shield.
8.3	Quasi-continuous Thomson scattering	The time dependence of the electron temperature with a 10 ms time resolution throughout the discharge.	The application of JET of a repetitively pulsed Nd-YAG laser which is being developed for ASDEX is being considered.
9	Far infra-red interferometer	Line-of-sight electron densities and density profiles.	DCN laser (195 μm) is proposed with seven vertical transmission channels and a number of horizontal channels which would use reflectors on the inside wall of the torus.
10	Neutron diagnostics	Measurement of the neutron yield and energy spectrum to determine ion energy distributions and temperatures.	A range of techniques including counters, activation foils, time of flight and proton recoil spectrometers are proposed.
11	Scanning bolometer	Radial profile of the total radiated power.	Arrays of resistive bolometers scanning the JET discharge in both the horizontal and vertical directions are proposed in order to determine the radiated power density in discharges with non-circular cross sections.
12.1 12.2 12.4	Visible spectroscopy Normal incidence UV spectroscopy XUV spectroscopy	Space and time resolved measurements of impurity ion concentrations.	A comprehensive range of spectrometers covering visible and ultra-violet regions of the spectrum down to 10 Å is proposed.
12.3	Grazing incidence UV spectroscopy		
12.5	X-ray crystal spectrometer	Ion temperatures by line broadening measurements of metal impurity lines.	A crystal spectrometer with both the crystal and the detector (a multi-wire proportional counter) mounted outside the torus hall.
13.1	Charge-exchange neutral particle analyser	Ion temperatures and energy distribution of neutral atom fluxes.	An array of neutral particle detectors each with simultaneous mass and energy dispersion viewing different chords of the JET discharge is proposed.
13.2	Neutral particle scattering	Ion temperatures	A study is being conducted of a system to measure ion temperatures from the inelastic scattering of an energetic neutral beam.
14.1	Impurity fluorescence	The density and flux of neutral atoms or singly ionized ions of metallic impurities at the plasma boundary.	Excitation by a tunable dye laser and observation at a convenient angle of the isotropically-emitted fluorescence.
14.2	Hydrogen α fluorescence	To measure neutral hydrogen densities and fluxes near the wall and limiter.	Two methods are being considered: (1) Excitation by a dye laser at 6563 Å from the naturally populated $n = 2$ excited state; (2) Two stage excitation from the $n = 1$ ground state using a UV source at 1215 Å (see study 14.3) together with a dye laser at 6563 Å.

Diagnostic System No.	Diagnostic	Purpose	Brief Description
14.3	Lyman-α fluorescence	Neutral hydrogen densities in the interior of the JET discharge.	A high power laser at 1216 Å is needed. Two promising systems being developed are: (1) Frequency multiplication of a tunable dye laser from 6 × Lyman-α; (2) An electron beam excited Argon Eximer laser.
15.1	Infra-red scattering	Ion temperatures and the spectra of fluctuations by collective scattering in the infra-red.	Collective scattering promises a method of measuring the ion temperature of plasmas directly in plasmas where the fluctuation level is sufficiently low. For the 10·6 μm line of a CO_2 laser, forward scattering at an angle of about 1° would probably be employed.
15.2	Far infra-red scattering	Ion temperatures and fluctuation spectra.	Collective scattering at wavelengths of 66,114 or 385 μm from a single mode FIR laser pumped by a powerful CO_2 laser.
16	Limiter surface temperature	Measurement of the power flux to the limiters and observation of local hot spots due to runaways and disruptions.	A scanning detector array sensitive to thermal emission in the infra-red part of the spectrum.
17.1	X-ray pulse height spectrometer	Electron temperatures and impurity distributions.	An array of cooled Si(Li) detectors viewing different chords of the JET discharge and connected to a pulse height analyser system.
17.2	Soft X-ray diode array	The localisation of integral-q surfaces and the mode structure of MHD oscillations.	An array of silicon diodes or similar detectors arranged behind a collimator.
18	Plasma surface interactions	Diagnostics of the limiter and wall surfaces exposed to the plasma and for the plasma boundary region.	A sample handling system which will expose probes and sample surfaces in the shadow of the JET limiters and then transport them to a surface analysis laboratory where they can be analysed by a variety of surface analytical techniques.
19.1	Electron cyclotron emission	Two dimensional profiles of electron temperature with 5 – 10 ms time resolution.	Rapid scan Fourier spectroscopy with a number of Fabry-Perot or Michelson interferometers viewing different chords.
19.2	Electron cyclotron emission using reflecting echelon gratings	Electron temperatures with fast time resolution.	A rapid scan system to measure the electron temperature in JET at a number of selected points with fast time resolution by means of a spectrometer using reflecting echelon gratings.
26.1	Microwave scattering	To study the frequency and wave vector spectra of micro instabilities	A study of scattering diagnostics at short microwave wavelengths (i.e. 2 or 1 mm).
27	Microwave reflectometer	Profiles of electron density	A swept frequency microwave reflectometer to measure the plasma density profile.

poloidal magnetic field. The performance of JET was compared for neutral beams of various power levels and particle energies injected into plasmas with different starting densities and for different scalings of the transport coefficients. Including the radiated energy loss from iron sputtered from the walls by charge-exchanged neutrals and escaping protons, and using Alcator scaling for the transport coefficients, the predicted central ion temperature reached 6 keV with 10 MW injected power and more than 20 keV with 25 MW. In the latter condition, α-particle heating was dominant in the central region. The central temperature, and the ratio (Y) of α-power production to total energy loss plus the rate of change of internal energy, are shown in Fig.27 as a function of starting density for different neutral beam parameters.

The proximity to ignition of the central plasma is indicated in Fig.28 by those conditions which approach the theoretical curve for central ignition. The best performance was achieved for a narrow range of starting densities near 4 x 10^{13} cm^{-3} for which ignition of the central plasma is predicted to occur.

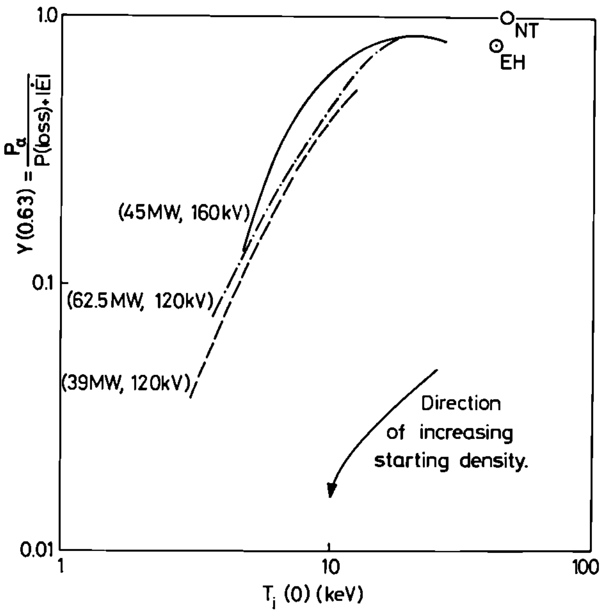


Fig.27 Variation with starting density of optimum conditions reached (measured in terms of $T_i(0)$ and Y(0·63) for different heating specifications and transport models.

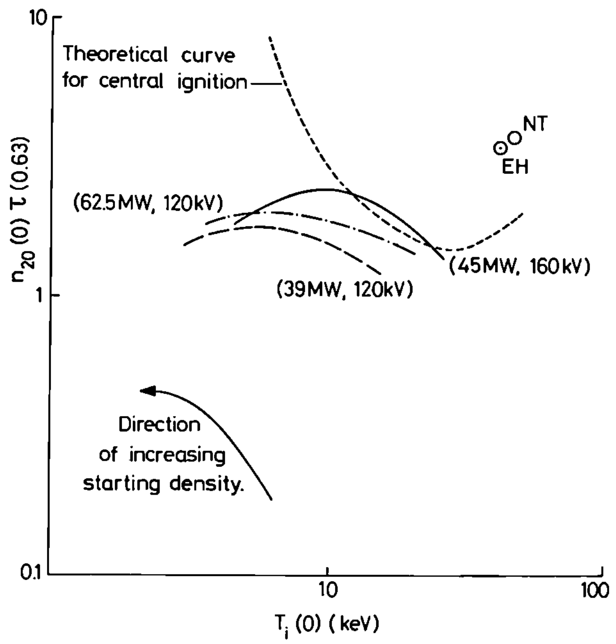


Fig.28 Variation with starting density of optimum conditions reached (measured in terms of $T_i(0)$ and $n_{20}(0)\tau(0{\cdot}63)$) for different heating specifications and transport models.

The calculations confirm the choice of 160 keV injection energy, even allowing for the lower neutralisation efficiency. Assuming the more favourable PLT scaling (D ~ 1/nT) and including the effect of sputtered iron, temperature escalation of the central plasma is reached with 25 MW injected power (point NT in Figs.27 and 28). Similar central plasma conditions are achieved with modest amounts ($\lesssim$ 12 MW) of a yet unspecified heating source that couples efficiently to the central plasma (points EH in Figs.27 and 28).

Appendix 1

A Joint Undertaking – Legal Entity

Article 49 of the Euratom Treaty states:

"Joint Undertakings shall be established by Council decision. Each Joint Undertaking shall have legal personality. In each of the Member States it shall enjoy the most extensive legal capacity accorded to legal persons under their respective national laws; it may, in particular, acquire or dispose of movable or immovable property and may be a party to legal proceedings.

"Save as otherwise provided in this Treaty or in its own statutes, each Joint Undertaking shall be governed by the rules applying to industrial or commercial undertakings; its statutes may make subsidiary reference to the national laws of the Member States.

"Save where jurisdiction is conferred upon the Court of Justice by this Treaty, disputes in which Joint Undertakings are concerned shall be determined by the appropriate national courts or tribunals".

Article 22.2 of the statutes of the JET Joint Undertaking states:

"Without prejudice to the provisions of the third paragraph of Article 49 of the Euratom Treaty, for the avoidance of doubt the Joint Undertaking shall not be regarded as a company within the meaning of the Companies Act 1948 and 1967 of the United Kingdom".

Appendix 2

The JET Joint Undertaking — Relevant Documents

1. **Decisions of the Council of the European Communities**

   1.1 Council decision of 30 May 1978 amending decision 76/345/Euratom adopting a research related programme (1976–80) of the European Atomic Energy Community in the field of fusion and plasma physics. 78/470/Euratom

   1.2 Council decision of 30 May 1978 on the establishment of the Joint European Torus (JET) Joint Undertaking. 78/471/Euratom

   1.3 Council decision of 30 May 1978 on the conferment of advantages on the Joint European Torus (JET) Joint Undertaking. 78/472/Euratom

   1.4 Council decision of 3 August 1979 approving amendments to the Statutes of the Joint European Torus (JET) Joint Undertaking (consequent upon the accession of Switzerland to the Joint Undertaking). 79/720/Euratom

   1.5 Council decision of 13 March 1980 adopting a research and training programme (1979–83) for the European Atomic Energy Community in the field of controlled thermonuclear fusion. 80/318/Euratom

2. **Statutes of the Joint European Torus (JET) Joint Undertaking.**

3. **Agreement between the participating organisations.**

4. **The support agreement between the Joint European Torus (JET) Joint Undertaking and the United Kingdom Atomic Energy Authority.**

5. **Financial regulations of the Joint European Torus (JET) Joint Undertaking.**

Appendix 3

JET Executive Committee

Member	**Representatives**
The European Atomic Energy Community (EURATOM)	K. Melchinger, 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 Chimi-Physique II of the ULB)	R. Vanhaelewyn
The Commissariat à l'Énergie Atomique, France (CEA)	J.M. Fabre, F. Prevot
The Comitato Nazionale per l'Energia Nucleare, Italy (CNEN) The Consiglio Nazionale delle Ricerche, Italy (CNR)	R. Toschi, R. Andreani
The Forsϕgsanlaeg Risϕ, Denmark (Risϕ)	V.O. Jensen, I. Rasmussen
The Grand Duchy of Luxembourg (Luxembourg)	R. Becker
Ireland	C. Cunningham, M. Manahan
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)	V. Hertling, G. von Gierke
The National Swedish Board for Energy Source Development	G. Holte
The Swiss Confederation	F. Troyon, C. Risch
The Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)	L. Ornstein, M.F. van Donselaar
The United Kingdom Atomic Energy Authority	F. Chadwick, R.S. Pease

Appendix 4

JET Scientific Council

Members Nominated by the JET Council

C.M. Braams (Chairman)
FOM-Instituut voor Plasmafysica
Postbus 7
Overeindseweg 2
NL-3430 AA Nieuwegein
Netherlands

G. Briffod
Commissariat à l'Énergie Atomique
DPH PFC-SCP
GP85, Centre di Tri
F-38041 Grenoble Cedex
France

F. Engelmann
FOM-Instituut voor Plasmafysica
Postbus 7
Overeindseweg 2
NL-3430 AA Nieuwegein
Netherlands

A. Messiaen
Laboratorie de Physique des Plasmas
École Royal Militaire
Avenue de la Renaissance 30
B-1040 Brussels
Belgium

A. Samain
Commissariat à l'Énergie Atomique
DPH PFC-SCP
BP6
F-92260 Fontenay-aux-Roses
France

A. Schlüter
Max-Planck Institut für Plasmaphysik
D-8046 Garching/München
Federal Republic of Germany

S. Segre
CNEN/Frascati
Casella Postale No.65
I-00044 Frascati (Roma)
Italy

D.R. Sweetman
Culham Laboratory
UKAEA
Abingdon
United Kingdom

J.B. Taylor
Culham Laboratory
UKAEA
Abingdon
United Kingdom

F. Troyon
CRPP
Avenue des Bains 21
CH-1007 Lausanne
Switzerland

F. Valckx
Commissariat à l'Énergie Atomique
DPH PFC-SCP
BP6
F-92260 Fontenay-aux-Roses
France

F. Waelbroeck
Kernforschungsanlage Jülich GmbH
Institut für Plasmaphysik
Postfach 1913
D-5170 Jülich 1
Federal Republic of Germany

H. Wilhelmsson
Institute of Electromagnetic Field Theory and Plasmaphysics
Chalmers University of Technology
Fack
S-412.96 Göteborg 5
Sweden

G. Wolf
Kernforschungsanlage Jülich GmbH
Institut für Plasmaphysik
Postfach 1913
D-5170 Jülich 1
Federal Republic of Germany

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Page numbers in **bold** indicate main descriptions