JOINT
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JET
JOINT UNDERTAKING

ANNUAL REPORT
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JET
JOINT UNDERTAKING

Report for the period 1 June – 31 December 1978

February 1979

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

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Preface

THE establishment of the JET Joint Undertaking on 1 June 1978 is a major step in the coordinated nuclear fusion programme of the European Atomic Energy Community. It is at the same time a confident exercise in European cooperation, calling for the pooling of substantial resources of finance and skills in an experimental project on which a significant degree of management autonomy has been bestowed. It primarily reflects the economic and political need felt among European countries to lessen their dependence on traditional sources of fuel; the development of nuclear fusion reactors promises a viable long-term alternative source of energy, the realisation of which will be brought closer by the successful exploitation of the JET experiment.

The JET Joint Undertaking is the largest single joint project yet to be undertaken by the European Communities; it represents approximately 25% of the total current budget for the five year European Fusion Programme. It has been established for a duration of twelve years, divided into two phases, the Construction Phase and the Operation Phase. A budget of 184·6 MEUA (at January 1977 prices) has been approved for the Construction Phase, together with a staff establishment of 320, mostly scientists and technologists recruited on temporary contracts from the Associated Laboratories of the member countries.

The inaugural meeting of the Council of the JET Joint Undertaking was held on 13 June 1978, at which the management structure for the organisation was agreed. The JET Council held two further meetings during the period under review. The JET Executive Committee met 4 times during the same period.

While the establishment of the JET Joint Undertaking has not been without its difficulties, progress during the period under review (1 June – 31 December 1978) can be regarded as satisfactory. At the year end, two department heads, six of the seven technical division heads and two of the three administrative services' heads had taken up duty. The general recruitment programme, however, has fallen short of its target due to the inevitable delays inherent in the recruitment procedures. A maximum number of 180 staff was planned for the period; however only 105 posts were advertised and 100 filled by the year's end. In spite of the delay in staff intake most of the Project's work programmes were on target for the period. The lack of staff resources was greatly alleviated, particularly in the administrative areas, by the continuing support provided by Culham Laboratory by way of operational and advisory services and the temporary assignment of specialist staff to the Project.

While much of this assistance has been in accordance with the terms of the Support Agreement between the United Kingdom Atomic Energy Authority and the JET Joint Undertaking, the wealth of goodwill and cooperation reflected by Culham management and staff has been a welcome support to the newly established Project Team and augers well for the future development of the Project. In this context the Commission has also been of assistance in recognising the particular needs of JET, especially with respect to personnel, finance and administrative matters, and has made specialist personnel available as needed to assist in the setting up of appropriate procedures and systems.

The Associated Laboratories have continued to support the Project through the provision of staff and the completion of work under study contracts. Such scientific and technical assistance is essential to the JET Joint Undertaking, and the continued commitment of the Associated Laboratories is crucial to the success of the Project.

The JET Project Team is now housed in temporary accommodation provided by Culham Laboratory under the Support Agreement. Planning permission for the erection of some JET non-specific buildings (offices, workshops and laboratories) has been received by Culham Laboratory and it is expected that these buildings will be ready for occupation by the JET Project Team on schedule in 1981. An application for planning approval for the JET specific buildings was lodged with the South Oxfordshire District Council in November, and a decision is expected early in 1979.

Certain contracts relating to the Project, which had been placed by the Commission during the Design Phase, have since been assigned to the JET Joint Undertaking. Several other large contracts have been awarded during the period, while calls for tender have been issued for further contracts. The Construction Phase of the Project will intensify the close collaboration between the JET Joint Undertaking and European industry as the various stages of existing contracts are released and new contracts are placed, thereby giving such industry the opportunity to gain further experience in the area of fusion power development.

A European School has been established near the JET Laboratory to cater for the educational needs of the children of the multi-national Project staff. The efficiency with which the school was established and is being run has been an important factor in attracting overseas staff and in assisting them and their families in settling into their new environment.

The year ahead is a challenging one for the Project Team. Most of the major contracts must be awarded and construction of the JET buildings, specific and non-specific, will hopefully commence at an early date. A maximum of 275 persons will have been recruited to the Team by the end of 1979. The future, however, can be viewed with optimism. The spirit of enthusiasm, commitment and dedication which characterised the Design Team has been transmitted to the existing team. This provides the foundation on which future success can be built.

H.-O. Wüster
The Director of the Project

The JET Council

European Atomic Energy Community:
Bruxelles, — G. Schuster
Belgium. — D. Palumbo
R. Saison (Secretary)

Belgium:
Service du Commissariat à l'Énergie Atomique, — M. Frérotte
Bruxelles,
Belgium.

École Royale Militaire, — P.E.M. Vandenplas
Bruxelles,
Belgium.

Denmark:
Danish Energy Agency, — H. von Bülow
Copenhagen,
Denmark.

Research Establishment Risø, — N.E. Busch
Roskilde,
Denmark.

Federal Republic of Germany:
Bundesministerium für Forschung und Technologie, — G. von Klitzing
Bonn,
Federal Republic of Germany.

Max-Planck-Institut für Plasmaphysik, — R. Wienecke
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Federal Republic of Germany.

France:
Commissariat à l'Énergie Atomique, — J. Teillac (Chairman)
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France.

CEN de Saclay, — J. Horowitz
Gif-sur-Yvette,
France.

Ireland:
Department of Industry, Commerce and Energy, — S. Collins
Dublin,
Ireland.

Nuclear Energy Board, — C. Cunningham
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Ireland.

Italy:
Comitato Nazionale per l'Energia Nucleare, — C. Salvetti
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Italy.

CNEN, — R. Toschi
Centro di Frascati,
Frascati,
Italy.

Luxembourg:
Ministère de l'Énergie, — J. Hoffman
Luxembourg.

Ministère des Affaires Étrangères, — J. Alex
Luxembourg.

Netherlands:
FOM-Instituut voor Plasmafysica, — C.M. Braams
Nieuwegein,
Netherlands.

Sweden:
National Swedish Board for Energy Source Development, — L. Rey
Stockholm,
Sweden.

AB Atomenergi, — G. Holte
Nykoeping,
Sweden.

United Kingdom:
United Kingdom Atomic Energy Authority, — A.M. Allen
London,
England.

Culham Laboratory, — R.S. Pease
Abingdon,
England.

The Director of The Project

H.-O. Wüster

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CONTROLLED NUCLEAR FUSION RESEARCH

The concept of controlling nuclear fusion reactions to provide power was considered independently in America, the Soviet Union and Europe in the 1940's. Since then research into controlled nuclear fusion has been pursued on a world scale in the expectation that it might make an essential contribution to man's energy requirements in the coming century.

The nuclear fusion process involves the release of nuclear energy which occurs when the nuclei of atoms of light elements combine on collision. The fusion reactions which are easiest to initiate take place between two different atomic forms (isotopes) of hydrogen, namely, deuterium and tritium. Deuterium occurs naturally in water, but tritium must be generated as an intermediate product in a series of nuclear reactions involving the naturally-occurring element, lithium. Lithium (a soft metal in its refined elemental state) is found in mineral form. It is also present in sea-water. Thus the basic fuel of a first-generation fusion reactor would be deuterium and lithium, which are both plentiful and widespread.

In order that thermal collisions between the reacting deuterium and tritium nuclei can overcome their mutual electrostatic repulsion very high temperatures of the deuterium and tritium mixture are necessary (thermonuclear fusion). The ultimate products of the reactions are α-particles (the nuclei of helium, an inert gas), neutrons (neutral constituents of nuclei) and energy. The controlled release of this energy requires that the very hot ionized gases (called plasma) of hydrogen isotopes are isolated long enough for a significant number of reacting collisions to occur between the nuclei.

The plasma container must thermally insulate the plasma effectively to keep it hot and must prevent contact with material walls which would otherwise lead to contamination of the plasma and consequent severe cooling by radiation. One method of providing this thermal insulation is by the use of magnetic fields which can exert a confining pressure on the electrically conducting plasma.

Fusion research involving plasma confinement by magnetic fields has focussed on three main programmes:

(a) The development of techniques for the creation of plasma and for heating it, and the study of its behaviour under relevant conditions;

(b) The study of possible magnetic field configurations to confine the plasma and the construction of experimental assemblies to study the behaviour of plasma in these fields;

(c) The development of the technology for transforming these configurations into realistic power-producing fusion reactors.

In a magnetic confinement reactor burning deuterium and tritium, the product of the energy confinement time (τ_E) and the plasma density (n) is required to be of the order of $2 \times 10^{20}\,m^{-3}s$ at temperatures in excess of 10 keV or 100 million degrees Kelvin*. Under these conditions the fusion reaction is self-sustaining in that energetic α-particles, which are reaction products, give up sufficient energy to the deuterium-tritium plasma to maintain its temperature even in the face of unavoidable energy losses, e.g. radiation. This condition is often referred to as plasma "ignition", for the fusion reactions themselves keep the "burn" going and external energy sources are not required to maintain the plasma.

The tokamak magnetic confinement configuration at present shows most promise for meeting the requirements of a thermonuclear fusion power reactor. A tokamak plasma has the form of a torus and the large electric current flowing through the plasma not only heats the plasma itself (ohmic heating) but also provides part of the confining magnetic field. The tokamak configuration as a reactor would contain a toroidal plasma which might have a minor radius of 2 m and a major radius of 6 m, carrying a current of about 10 million amperes (MA), stabilised by a magnetic field of about 50 000 gauss. By comparison, experiments now operating have minor and major radii of about 0·5 m and 1·5 m, currents of 1 MA and fields of up to 50 000 gauss. Over the past decade remarkable progress has taken place in the plasma parameters achieved by experimental tokamak devices, principally in Europe, the U.S.A. and the U.S.S.R. The temperature obtained has been increased by a factor of 20 and the $n\tau_E$ value by a factor of 1000. Typical values now are ion temperatures of 1·5 keV at an $n\tau_E$ of $10^{19}\,m^{-3}s$. Higher temperatures (5·5 keV) have been obtained at lower $n\tau_E$ values ($7 \times 10^{17}\,m^{-3}s$) and higher $n\tau_E$ values ($3 \times 10^{19}\,m^{-3}s$) at lower temperatures (0·9 keV). Thus, to reach reactor values a further increase in the product $n\tau_E$ by about a factor of 100 is required. To achieve this a significantly more powerful tokamak experimental system than at present exists is necessary.

*The temperature of a gas or plasma can be expressed in terms of the kinetic energy of the constituent particles. A convenient scale is to express temperature in keV with 1 keV equal to 11·6 million degrees.

THE JET PROJECT

The complex physical and technical problems and the substantial investment involved in the development of a tokamak fusion reactor means that it can best be undertaken by international co-operation. The Council of the European Communities therefore decided to build the Joint European Torus (JET) as the principal experiment of the fusion research programme co-ordinated by Euratom, the European Atomic Energy Community (see Appendix 1).

Participation in the European fusion research programme is not restricted to Community member states. The Community and Sweden concluded an agreement in May 1976 for co-operation in the field of controlled thermonuclear fusion and plasma physics research as a consequence of which a Swedish organisation is participating in the JET Project. It is expected that in the near future Switzerland will also participate.

The JET Joint Undertaking (see Appendix 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 this 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 cooperation 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 4 of the JET Statutes, see Appendix 3).

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 35 000 gauss, dimensions (minor radii 1·25 m × 2·1 m D-shaped, major radius 2·96m) within a factor 2 or 3 of those expected in a future reactor and should be able to carry currents of up to 4·8MA. Recent experimental results indicate that by exploiting the full performance capability of JET, plasma conditions approaching those of ignition could be obtained. 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 JET and of other nuclear fusion programmes being undertaken simultaneously elsewhere in the world, particularly in the U.S.A. and the U.S.S.R., 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 – AN HISTORICAL SURVEY

The tokamak confinement system was first developed in the U.S.S.R. in the 1960's. Measurements made on the tokamak T3 in Moscow indicated that relatively hot, well-confined plasma* could be produced in such a device. These results were confirmed at Moscow in 1969 on T3-A by a team of British scientists who used a new technique, the Thomson scattering of laser light, to measure the plasma temperature. This led to a considerable expansion in the world tokamak research programme, so that in 1970–71 construction and operation of a number of small tokamaks took place in Europe and the U.S.A. The results from these machines verified those of the Russians and extended them to even hotter and better confined plasmas.

The first discussions on the construction of a large tokamak in Europe took place in 1971 (see Table 1). At that time construction of the Princeton Large Tokamak (PLT) had been approved in the U.S.A. The PLT machine, with a minor radius of 0·45 m and a design plasma current of 1 MA, is a medium-sized device which came into operation in 1976. (It recently produced plasma ion temperatures of 5·5 keV corresponding to an

Table I. Significant dates in the progress of JET.

	1960	Soviet TOKAMAK programme begins.	1960 → 1969 INTERNATIONAL PRELIMINARIES
	1969	Culham Laser Diagnostics Group confirms high performance of Soviet TOKAMAK T3. Rapid expansions in world TOKAMAK programme.	
Early	1971	TOKAMAK ADVISORY GROUP: first discussions of a European Large Tokamak.	1971 → 1973 EUROPEAN DISCUSSIONS
February	1972	EUROPEAN TORUS WORKING GROUP (E.T.W.G.) meets.	
March	1973	E.T.W.G. proposes a 3 MA TOKAMAK for Europe.	
July	1973	Agreement to set up a DESIGN TEAM.	
September	1973	DESIGN TEAM assembles at Culham.	1973 → 1975 JET DESIGN EVOLVED
January	1974	OUTLINE DESIGN and first set of dimensions.	
April	1974	FIRST PROPOSAL (EUR-JET-R2) available.	
July	1974	COST ESTIMATE available.	
September	1974	JET parameters approved by EURATOM LIAISON GROUP.	
February	1975	Site Committee Report available.	
May	1975	DESIGN PROPOSAL (EUR-JET-R5) submitted to JET SUPERVISORY BOARD and to PARTNERS. DESIGN PROPOSAL approved.	
May	1975	Funds for certain long delivery items released (Total 3 MUC).	
January	1976	Orders for certain preproduction coils and bellows approved.	
February	1976	COUNCIL OF MINISTERS first discuss site for JET.	
October	1977	SITE DECISION reached.	INTERIM PHASE
June	1978	JOINT UNDERTAKING established.	
June	1978	Main funds released.	
Years 1–3		Main components to be manufactured.	CONSTRUCTION SCHEDULE
Year 1		Building construction to begin.	
Year 3		On-site assembly to begin.	
Year 5		Construction and commissioning to be completed.	
Year 6		EXPERIMENTAL PROGRAMME to begin.	

*Electron temperatures of up to 2 keV and energy confinement times of about 5 ms were achieved.

energy confinement time of 20ms.)

The Tokamak Advisory Group, a group of scientists selected from the Associated Laboratories, which advises the Liaison Group on tokamak-related aspects of the European fusion programme (for a description of this programme and the various related groups and committees see Appendix 1), considered that it would be wise for Europe to construct a device large enough to bridge the gap between PLT and a future experimental reactor. A Joint European Torus Working Group (see Appendix 4) was therefore established (October 1971) and it outlined the characteristics of such a large tokamak device. This group recommended (March 1973) that a detailed design be prepared and an outline plan for carrying out the design work was prepared by an Ad Hoc Group (see Appendix 4).

In July 1973 the Liaison Group and Committee of Directors approved the recommendations of the Working Group and agreed to establish a multinational project team to design a tokamak as outlined by the Working Group. This machine was named the Joint European Torus (JET). On the basis of optimistic extrapolations of the experimental results of that time, the plasma performance in JET was predicted to approach the plasma ignition conditions necessary for thermonuclear reactor operation. In view of the experimental results obtained since then the extrapolation necessary to reach such conditions is now much reduced.

A Design Team composed of staff seconded from the Associated Laboratories was established and started work (September 1973) as guests of the UKAEA at its Culham Laboratory near Oxford in the United Kingdom. P.H. Rebut headed this Design Team and was assisted by a Project Board (see Appendix 4).

The Design Team issued an outline design and first set of dimensions in the "Preliminary Description" (EUR-JET-R1) November 1973 and the "First Project Proposal" (EUR-JET-R2) in April 1974. The first cost estimate for the Project (EUR-JET-R4) was issued in July 1974. Seven "workshops" were held during 1974 and 1975 at which the physical and technical bases of the Project were discussed with members of the Associated Laboratories (EUR-JET-R6). In this way (and also through the expertise of their staff in the Design Team) the Associated Laboratories were able to make available to the Project their skills in the areas of technical design, diagnostics and additional heating and their wide experience in plasma systems and behaviour.

On the basis of the advice of the JET Supervisory Board [later the JET Management Committee (see Appendix 4)], the Liaison Group at its meeting in September 1974 accepted the parameters (EUR-JET-R2) and the cost estimates (EUR-JET-R4) as a basis for continuing design. The Design Proposal (EUR-JET-R5, made widely available as a CEC report, EUR 5516e) required by the JET Design Agreement* was issued in May 1975 and was reviewed by the JET Scientific and Technical Committee (see Appendix 4) and accepted by the Partners to this Agreement. Euratom made funds available (September 1975) so that staged contracts could be placed for some major system components with long delivery schedules. In May 1977 the scientific and technical developments of the project for 1976 were presented in EUR 5791e (EUR-JET-R8). Related administrative matters were considered by the JET Administration Committee (see Appendix 4).

In April 1974 the Commission formed a Site Committee (see Appendix 4) to consider the merits of various sites proposed for JET. On the basis of the work of this Committee, which produced its final report in February 1975, a first discussion of the choice of site for JET took place at a meeting of the Council of Research Ministers of the European Communities in February 1976. Following a series of meetings at all levels, including the Council of Foreign Ministers of the European Communities, a decision was reached on 30 October 1977 to site the JET Project on land adjacent to the Culham Laboratory.

An Interim JET Council† was formed (November 1977) to establish the conditions and statutes of a Joint Undertaking which was chosen as the form of organisation for the execution of the Project. The Director of the Project, H.-O. Wüster and the Deputy-Director, P.H. Rebut (Head of the Project Team in the Design Phase) were nominated in December 1977. The Director took up his position on a full-time basis in June 1978 when the Joint Undertaking officially came into existence and funds for the project were allocated by the Council of Ministers. Some senior staff of the Project Team were nominated by the JET Council in July 1978 and progressively other staff members took up appointments with the Project.

*The JET Design Agreement was an agreement between the European Atomic Energy Community (Euratom), represented by the Commission of the European Communities (CEC) and the Associated Laboratories (see Appendix 1).

†Prior to the establishment of the Interim JET Council (see Appendix 4) JET-related matters were the responsibility of the Consultative Committee for Fusion (see Appendix 1).

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 Forsøgsanlæg Risø, Denmark (Risø)
the Grand Duchy of Luxembourg (Luxembourg)
Ireland
the Kernforschungsanlage Jülich GmbH, Federal Republic of Germany (KFA)
the Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. – Institut für Plasmaphysik, Federal Republic of Germany (IPP)
the National Swedish Board for Energy Source Development
the Stichting voor Fundamenteel Onderzoek der Materie, the Netherlands (FOM)
the United Kingdom Atomic Energy Authority (Host Organisation)

Switzerland is shortly expected to become a member.

Management

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

The organs of the Joint Undertaking are the JET Council and the Director of the Project. The JET Council is assisted by a JET Executive Committee and may seek the advice of a JET Scientific Council. (See Fig.1)

JET Council

The members of the Joint Undertaking each have two representatives on the JET Council (see page v), which 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 is 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 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.

JET Executive Committee

The provisions which apply to the representation of the members in the JET Executive Committee (see Appendix 5) 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;

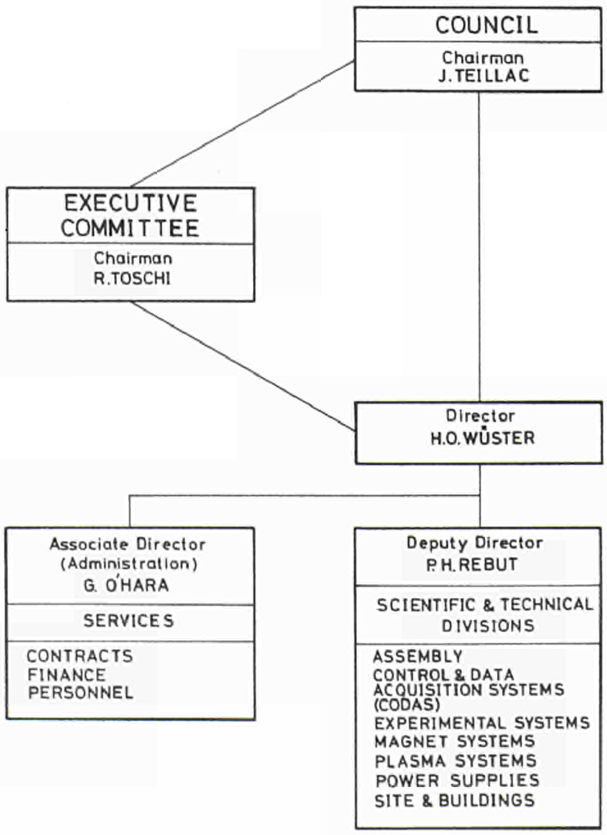

Fig. 1 Organisation of the JET Joint Undertaking

(iii) Approving, in accordance with the rules on the award of contracts established by the JET Council (Annex II, JET Financial Regulations, see Appendix 3), 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.

JET Scientific Council

The JET Scientific Council has not yet been established but its members and chairman will be appointed by the JET Council in 1979. The Scientific Council's primary function will be, upon the request of the JET Council, to advise it on scientific and technical matters, including proposals involving a significant change in the design of JET, its exploitation and its long-term scientific implications.

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

At present the JET Project Team is divided into:

(a) the Administration Department, and
(b) the Scientific and Technical Department.

The Departments are further sub-divided as follows:

(a) Administration Department:
- Contracts Service
- Finance Service
- Personnel Service

(b) Scientific and Technical Department:
- Experimental Systems Division
- Magnet Systems Division
- Plasma Systems Division
- Assembly Division
- Power Supplies Division
- Control and Data Acquisition Systems (CODAS) Division
- Site and Buildings Division

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

In addition, the following report directly to the Director; the Secretariat (which is responsible for providing all secretarial services to the JET Council and JET Executive Committee), the Project Control Section, and the Internal Audit Section (when established).

JET — ADMINISTRATION

Introduction

During the period under review the primary activity of the Administration Department has been to recruit the staff necessary to provide the three services: Contracts, Finance and Personnel. Most of the staff for the Personnel Service were recruited and have taken up their appointments; the Head of the Finance Service has also taken up office; the Head of the Contracts Service is expected to join the team early in 1979. The filling of other key posts in both Contracts and Finance Services has begun.

In spite of some delay in recruitment it was possible to provide the basic services essential to meet the initial requirements of JET with the assistance of several staff assigned temporarily by the UKAEA to JET and by making use of appropriate Culham Laboratory services.

Contracts

In the placing of contracts the JET Statutes require the Director of the Project, in collaboration with the JET Executive Committee and the members, to strive to achieve as wide a distribution as possible, taking into account the Community nature of the Project. At the same time, the selection of tenders for contracts must be based on cost competitiveness and technical efficiency. The rules governing the awarding of contracts are as set out in the Financial Regulations (Annex II). They include, inter alia, the following provisions:-

(a) Each contract and order shall be governed by general terms and conditions as similar as circumstances permit to those applied by the Commission and shall contain conditions safe-guarding the rights conferred on the members of the Joint Undertaking by the Statutes and the rights to make available the results of all relevant study contracts to firms tendering for manufacturing orders.

(b) At the proposal of the Director of the Project the JET Executive Committee shall establish for each area of work or for each major contract a list of firms to which the invitation to tender shall be directed. The list shall ensure competition between the competent firms in the countries of the members of the Joint Undertaking and, if necessary, in non-member countries. In major contracts the criteria for evaluation of tenders shall be established

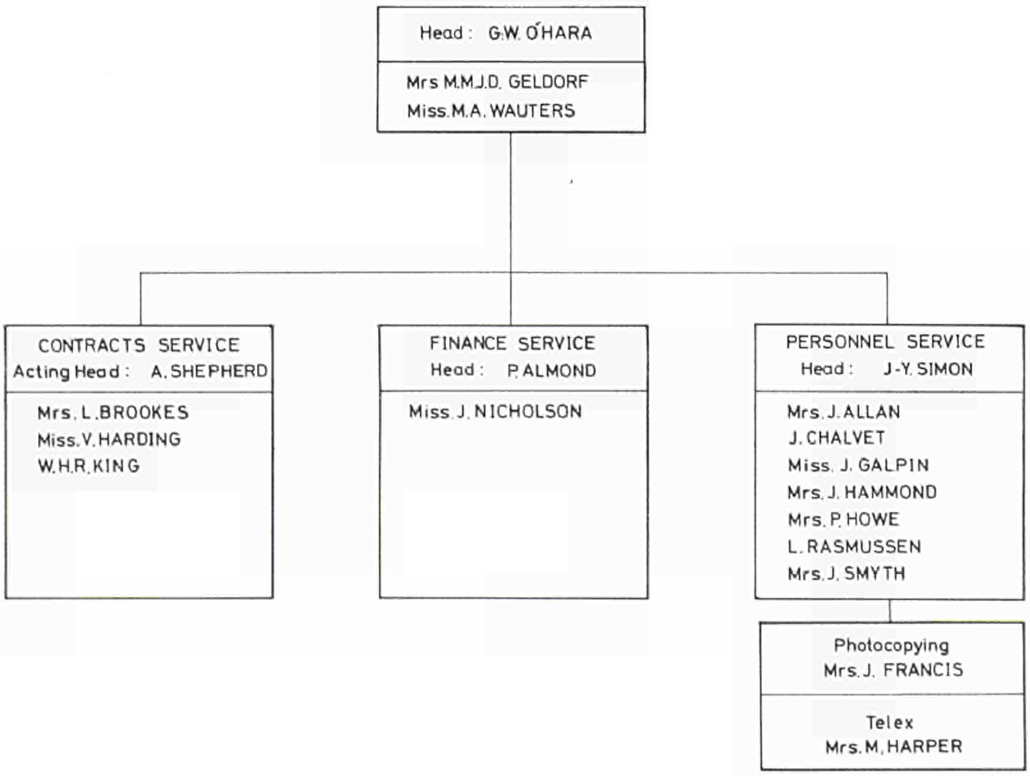

Fig.2 Administration Department staff (December 1978).

by the Director of the Project in conjunction with the JET Executive Committee before tender invitations are dispatched.

In particular, the list of possible tenderers in each member's country is checked with the members through their representatives on the JET Executive Committee. In relation to important contracts for services which may be of an advanced technical or scientific nature, preliminary enquiries may be made with proposed firms in order to assess their competence in the particular area, before issuing invitations to tender.

Status of Contracts

A number of important contracts for long delivery components were placed by the Commission during the Design Phase. Those have now been assigned by the Commission to the Joint Undertaking. In the meantime the "production" stages of most of these contracts have been released. A considerable number of study contracts related to the JET Design, which were let in the Design Phase, have been concluded, while others, not yet concluded, have been assigned by the Commission to the Joint Undertaking. Since September 1978 contracts for the mechanical structure, the magnetic circuit and the poloidal field coils (Nos.1, 3 and 4) have been awarded.

The calls for tender for the torus hall cranes, for some parts of the civil engineering and building works and for the CODAS computers have required the formulation of new special supplementary terms and conditions. This has been done and the calls for tender for the cranes, the preliminary works, the piling and structural steel, the CODAS computers and some power supply equipment have been issued. The boards for the acceptance and evaluation of tenders are organised by this service.

A programme of future calls for tender for contracts with a value of more than 0·15 MEUA each has been prepared. This programme entails a considerable workload in the placement and negotiation of contracts for 1979.

The existing large contracts, many of which will be passing through critical stages in the near future, will need to be carefully administered. In addition, contract conditions will have to be aligned with whatever policy for corporate insurance will be approved for the Joint Undertaking, and standard conditions and pro-forma orders for contracts of medium and small value will need to be prepared. There is likely to be an increase in the procurement on contract of skilled assistance to the Project Team, particularly for the drawing office and for quality assurance inspection. There will also be study contract work with the Associated Laboratories.

The Contracts Service is also responsible for the provision of stores services to the Project. While it will be necessary to establish JET specific stores, it is envisaged that the UKAEA will arrange to provide local stores and related services. The establishment of these facilities will be initiated during the coming year.

Finance

Funding

The Joint Undertaking is funded as follows:-

80% from the budget of the Commission of the European Communities.

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

10% from the members having Contracts of Association with Euratom, in proportion to the contributions from Euratom towards the cost of their Association Contracts.

Financial Regulations

The financial activities of the Project are governed by the Financial Regulations which have been adopted by the JET Council in accordance with the Statutes of the Joint Undertaking. These regulations cover all aspects of budgeting, commitment and authorisation of payments and letting of contracts. In particular, they provide that the financial year shall correspond to the calendar year, and that the budget shall be drawn up in European Units of Account (EUA) and consist of commitment appropriations and payment appropriations.

The estimated cost for the Construction Phase of the Project is 184·6MEUA at January 1977 price levels. The forecast for the profile of commitment and payment of this sum over the Construction Phase is shown in Table II.

As the Construction Phase progresses this profile will be regularly updated to reflect the current cost estimate, and to include the increases due to changes in economic conditions since 1 January 1977.

1978 Budget

The 1978 Budget was approved at 20 MEUA for commitments and 12 MEUA for payments, agreeing with the 1978 figures in the original profile. In

Table II. 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 III. Associations' 1978 contributions to the Joint Undertaking.

Member	EUA	%
European Atomic Energy Community	9 600 000	80·000
Belgian State	21 960	0·183
Commissariat à l'Énergie Atomique, France	247 320	2·061
Comitato Nazionale per l'Energia Nucleare, Italy	88 080	0·734
Consiglio Nazionale della Ricerche, Italy	7 680	0·064
Forsøgsanlæg Risø, Denmark	8 640	0·072
Kernforschungsanlage Jülich GmbH, Federal Republic of Germany	96 720	0·806
Institut für Plasmaphysik, Federal Republic of Germany	461 880	3·849
National Swedish Board for Energy Source Development, Sweden	23 760	0·198
Stichting voor Fundamenteel Onderzoek der Materie, Netherlands	69 360	0·578
United Kingdom Atomic Energy Authority	1 374 600	11·455
	12 000 000	100·000

Table IV. Estimated expenditure (in MEUA) for commitments and payments under the JET budget for 1978.

Budget Heading			Commitments		Payments	
			Budget	Estimated Expenditure	Budget	Estimated Expenditure
Title	**1**	**Investment**				
Chapter	1.01	JET Device	11·6	12·75	5·5	6·3
	1.02	Auxiliary Systems	0·3	0·2	0·2	0·15
	1.03	Power Supplies	1·2	1·1	0·5	0·35
	1.04	Control, Monitoring, Data Acquisition	0·2	-	0·1	-
	1.05	Diagnostics	0·1	-	-	-
	1.06	Buildings	1·1	1·5	0·2	0·6
Title	**1**	**Total**	14·5	15·55	6·5	7·4
Title	**2**	**Operating Costs**	1·0	0·85	1·0	0·85
Title	**3**	**Personnel Costs**				
Chapter	3.01	Euratom Staff	0·8	0·5	0·8	0·5
	3.02	UKAEA Staff	0·7	0·4	0·7	0·4
	3.03	Contracts for Consultants and Services	0·7	0·7	0·7	0·7
	3.04	Seconded Staff – Others	2·0	1·8	2·0	1·8
	3.05	Travel and Subsistence	0·3	0·2	0·3	0·2
	3.06	Social Infrastructure	-	-	-	-
Title	**3**	**Total**	4·5	3·6	4·5	3·6
		Budget Total	20·0	20·0	12·0	11·85

accordance with the funding arrangements shown above, the amounts shown in Table III were requested.

After allowance is made for outstanding commitments due for payment from the 1978 budget, but not actually paid at the end of the financial year, the provisional outturn for the year is as shown in Table IV.

Financial Arrangements

In the early part of 1978 payments were made on behalf of the Project either by the Commission of the European Communities or by the Culham Laboratory. A Finance Service has now been established within the Project Team. Following a selection procedure Sal.

Oppenheim Jr. & Cie., Cologne were appointed to handle the JET EUA bank account for major receipts and payments. In addition, Sterling and Deutschemark operating accounts have also been opened for small transactions at Lloyds Bank and Sal. Oppenheim Jr. & Cie., respectively. The Project now makes its own payments and no further payments are made from Brussels. However, because of the slow build-up of staff in the Finance Service the bill-payment service provided by the Culham Laboratory will continue to be used to some extent.

1978 Annual Accounts and Balance Sheet

The Financial Regulations require that the Annual Accounts and Balance Sheet of the Joint Undertaking be prepared for audit within two months of the end of the financial year. Accordingly, these will be presented for audit at the end of February 1979 to the Court of Auditors of the European Communities, Luxembourg. The Financial Regulations also provide for the establishment of an internal audit service to report directly to the Director of the Project. This service will be established in the near future.

Personnel

The JET Statutes (Article 8) stipulate the principles for the recruitment of staff for the Project.

The composition of the Project Team must strike a reasonable balance between the need to guarantee the Community nature of the Project, especially in the case of posts for which qualifications and experience of a certain level are required (physicists, engineers, administrative staff at an equivalent level), and the need to give the Director of the Project the widest possible authority in the matter of staff selection in the interests of efficient management. In applying this principle, account must be taken of the interests of the non-Community members of the Joint Undertaking. The Project Team is composed of staff made available by the members of the Joint Undertaking. Staff coming from the Host Organisation remain in the employment of the Host Organisation on the terms and conditions of service of that organisation and are assigned to the Joint Undertaking. Staff made available by the other members of the Joint Undertaking are recruited by the Commission for temporary posts in accordance with the "Conditions of Employment of other Servants of the European Communities" and assigned by the Commission to the Joint Undertaking. All staff expenditure, including that related to staff assigned to the Joint Undertaking by the Commission and the Host Organisation, is borne by the Joint Undertaking. Each member having a Contract of Association with Euratom shall undertake to re-employ the staff whom it places at the disposal of the Project and who were recruited by the Commission for temporary posts, as soon as the the work of such staff on the Project has been completed.

On the formal establishment of the Joint Undertaking the recruitment of a team for the Construction Phase of the Project commenced. Up to 320 team members will be recruited in the next few years.

A large proportion of the staff who had been seconded on "mobility" contracts from the Associated Laboratories for the Design Phase were immediately available to the Joint Undertaking. Most of these staff continued on "mobility" contracts until 1 November 1978 when the Director was delegated the authority by the Commission to sign contracts of employment for the duration of the Construction Phase on behalf of Euratom. All such staff will have been employed on Euratom contracts by 1 January 1979.

The selection of staff is governed by the "Supplementary Rules concerning the Assignment and Management of the Staff of the JET Joint Undertaking" (see Appendix 3). In accordance with these Rules all vacancies are normally notified initially to the Members and to the staff of the Joint Undertaking. These posts are graded only within the European Communities' categories A, B or C and have an equivalent UKAEA grading. The grade level(s) and the likely period of assignment are included in the vacancy notice for each post. Members are required to circulate vacancy notices at least within their own organisations. They may, if they wish, also seek candidates from external sources. Members are required to send to the Director any nominations which they may wish to make and to forward all applications within 25 working days from the date on which the vacancy notice was issued.

Because of the time scale implied in these recruitment procedures and also because candidates are normally required to give three months notice to their employers, an interval of six months on average arises between the preparation of a job description and the commencement of duty by a successful candidate.

The delays inherent in the procedures laid down for the publishing and filling of posts have resulted in a slower than anticipated recruitment of the Project Team. At the end of December 1978, 105 staff vacancy notices had been published and 27 others were being prepared for publication early in 1979. The 1978 budget, however, provided for 180 posts.

Of the staff who will be recruited for the Construction Phase, up to 150 will be employed under Euratom contracts; the remainder will be assigned to the Project by the Host Organisation. A satisfactory formula has now been agreed between the UKAEA and JET governing the procedures for the assignment, employment and continued assessment of such staff in conformity with the requirements of the UKAEA as the long term employers.

With the assistance of Commission staff in Brussels, systems and procedures have been established for the payment of salaries and allowances and the maintenance of personnel records consistent with the UKAEA and the Commission rules and regulations.

The initial task confronting the Personnel service has been to recruit an effective team to successfully undertake and complete the tasks of the Construction Phase. The subsequent task will be to effect the necessary changes in the composition of the team to meet the needs of the Operation Phase. This will entail a change in emphasis from engineering staff needed for the Construction Phase to scientific staff for the Operation Phase. In the coming year the future recruitment programmes must be planned so that the transition from one phase to the next can be made smoothly and efficiently.

External Relations

The JET Project Team has been engaged not only in the normal exchange of information with the international fusion research community but also with a rapidly growing demand for information from other groups.

In the past year the JET reports EUR-JET-R5 ("The JET Design Proposal") and an updated EUR-JET-R7 ("The JET Project") were reprinted, and several journal articles on JET written by JET staff have appeared both in English and German. The Project has been presented by staff members to a variety of audiences in Europe and overseas (USA and Australia); branches of the UK Institute of Physics, institutes of engineers, physics societies (German and Danish), industrial research organisations, schools (including the staff of the European School at Culham), universities, colleges, political organisations, UK government research establishments and various societies and clubs for professional engineers. A presentation of JET was made to members of interested Irish industrial firms.

Interviews have been arranged for radio programmes which were transmitted locally and on the world service of the BBC. JET staff were also involved in interviews for German and Austrian radio programmes. Television producers have been highly interested in JET and the BBC has included JET in one of its science programmes. WGBH (Boston, USA) has included JET as part of a programme on fusion to be shown on public television in the USA. Discussions concerning other television coverage and the possibility of a documentary film have been initiated.

A steady stream of mail and telephone enquiries comes from students, scientists, industrial firms, political organisations and environmental conservation groups. These requests for information are often supplemented by requests for pictorial material, in particular from industrial firms which have been engaged in work for JET. Requests for information leading to the publication of articles in many countries, including the USA, Poland, South Africa, Sweden and Finland, have been processed. Display material (including models) has been made available for various exhibitions (e.g. the Achema Exhibition, the Hannover Fair, and a Science Festival Service at the local Harwell church).

The many visits to JET in 1978 included schools (among them groups from Denmark and Sweden), representatives from industry (e.g. from Japan), the Commission, local authorities, press, governments (e.g. UK and Canada) and leading scientists (Australia, China, USA and the USSR).

JET – SCIENTIFIC AND TECHNICAL

Introduction

Organisation

Urgent tasks to be performed on the establishment of the JET Joint Undertaking were the organisation of the Scientific and Technical Department responsible for the construction of JET, and the recruitment of the necessary staff. The department is made up of seven divisions and some staff reporting directly to the department head. Each division consists of several groups. The status of the divisions and of the group structure at December 1978 is shown in Figs.3 and 4. This structure has evolved from that of the Design Phase but the present divisions have, in general, broader responsibilities than the corresponding groups of that phase. Indeed, two essentially new tasks have now to be undertaken, namely quality control and assembly.

Placing of Contracts

In the period covered by this report further contracts for the basic JET machine itself have been placed, so that they now cover (in all their stages) more than 70% of the total cost. Specifications have also been prepared for external items, e.g. the main step-down transformers and the rectifier units for the static power supply. An application for planning permission for the JET specific buildings* was lodged with the Local Authority in November 1978. A call for tender procedure was initiated for the diaphragm wall, the main cranes and for the computers of the CODAS systems.

Programme

During 1978 the JET Project was presented to several scientific and technical meetings; in particular the International Energy Agency Workshops on Operations and Maintenance and Power Supplies, the 3rd Topical Meeting on the Technology of Controlled Nuclear Fusion (American Nuclear Society), and the 10th Symposium on Fusion Technology (Euratom). In addition Project team staff participated in more specialised meetings as well as maintaining close contacts with the Associated Laboratories.

In September 1978 JET assisted in hosting the 3rd IAEA Technical Committee Meeting on Large Tokamak Experiments held in Paris. This series of meetings provides a forum for the exchange of information between the large tokamak project teams [JET (EUR), JT-60 (Japan), TFTR (USA) and T-10M (USSR)]. The recent tokamak experimental results reported at the 7th International Conference on Plasma Physics and Controlled Nuclear Fusion Research in Innsbruck and their implications for the large tokamak programmes were fully discussed.

One important result of these discussions is the awareness that the temperature of well-confined plasma can be increased beyond the ideal ignition value with suitable amounts of neutral beam heating power provided that adequate care is taken to ensure a high level of plasma purity. These results are extremely favourable for JET in the sense that the attainment of near-ignition conditions in JET no longer represents such a large extrapolation from present experimental achievements. In order to take advantage of these results a proposal has been made to bring forward the implementation of the extended performance of the device, in particular to install 25MW of additional heating power in the first experimental phase rather than the 10MW originally foreseen. TFTR has reacted similarly by seeking approval for an increase in initial additional heating power from ·24MW to 45MW. Encouraging results from rf heating experiments indicate that rf will become a realistic option for additional heating power.

The JET planning schedules have been revised to enable the Operation Phase to commence prior to mid-1983, the date originally planned. It is now proposed to accelerate construction and thus to shorten the construction period by six months to four and a half years. Operation could then begin at the end of 1982. This should be achievable by strict control of the project development at the beginning of the Construction Phase. The TFTR and JT-60 experimental programmes are scheduled to start in late 1981 and in late 1982 respectively.

Experimental Systems

The task of the Experimental Systems Division is to prepare and, in the Operation Phase, to execute the experimental programme of the JET Project. The division will therefore prepare, implement and analyse a programme of measurements on the JET plasma designed to establish a reliable basis for predicting the behaviour of plasma in a future reactor. The division will continually review world tokamak research and will

*The JET specific buildings are those to be provided by the Joint Undertaking itself. The non-specific buildings will be provided by the UKAEA under the terms of the Support Agreement. Planning permission for some of the non-specific building was obtained in October 1978.

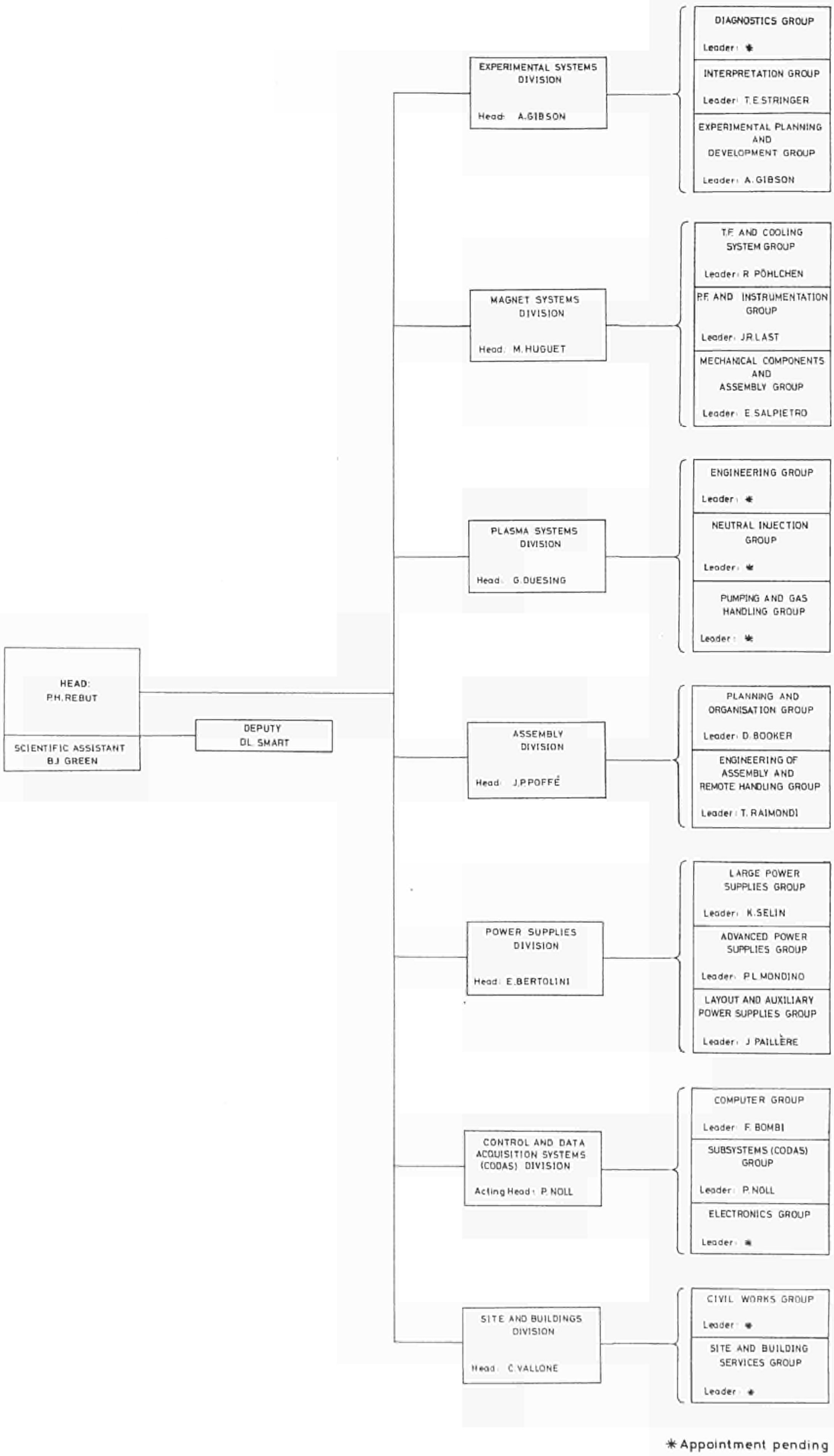

Fig.3 Scientific and Technical Department: group structure — December 1978.

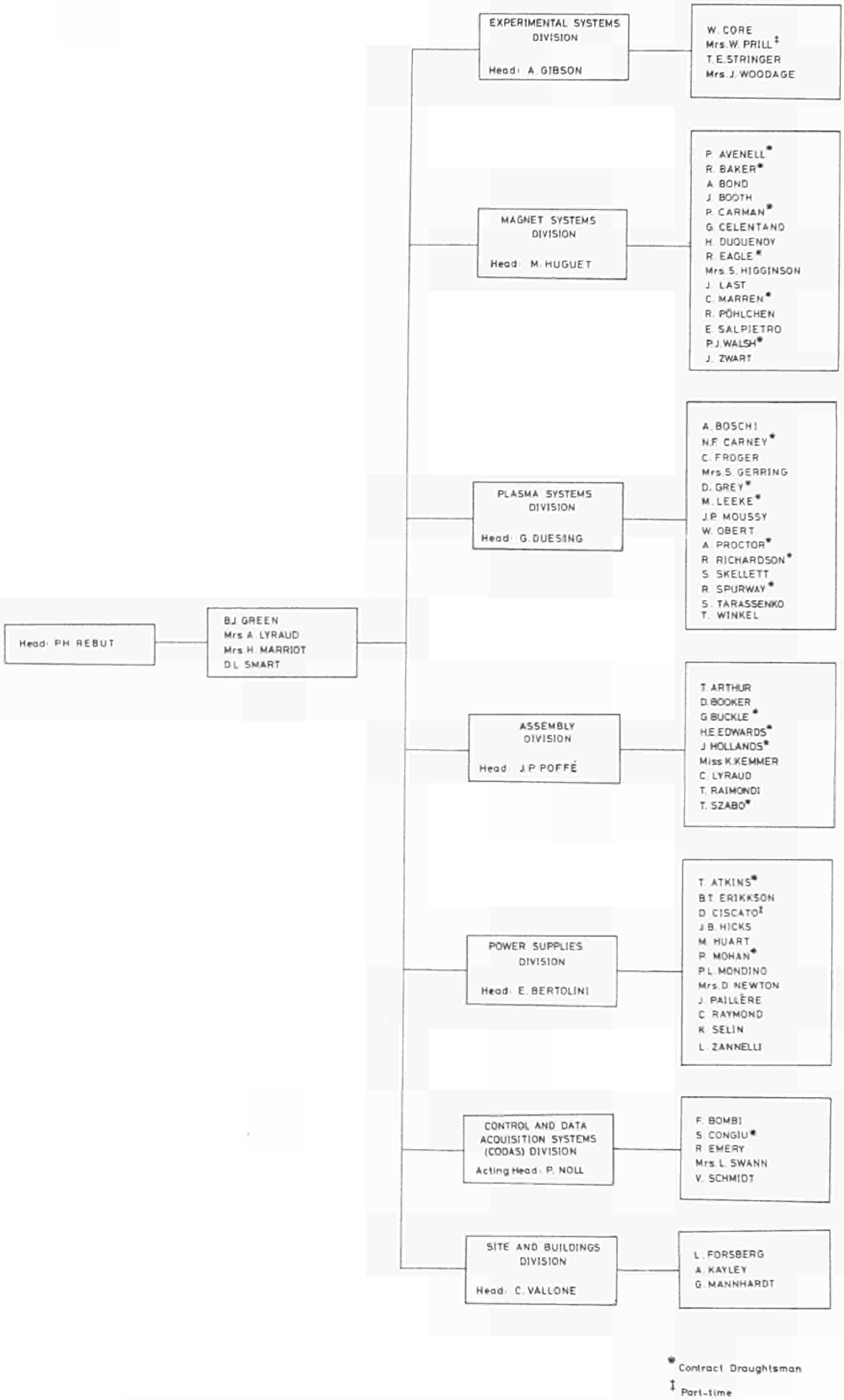

Fig.4 Scientific and Technical Department: staff — December 1978.

propose such modes of operation or apparatus enhancements as may be necessary to enable JET to attain its objective.

The Experimental Systems Division was formed from the Physics Group of the JET Design Team on the establishment of the JET Joint Undertaking in June 1978. The work and staff of the division will increase significantly as the Project approaches the Operation Phase and it is expected that some functions will separate into other divisions at that time.

Tokamak Research Developments and Implications for JET

During the period under review a notable advance has occurred in tokamak research with the production of high ion temperatures (~6keV) by the neutral injection heating of a low density plasma (mean particle number density $\bar{n} \sim 2 \times 10^{19}$ m^{-3}) in the US Tokamak PLT. This demonstration of high temperatures in PLT has the following three important implications for JET:

(i) The trapped-ion mode does not impose unacceptably short τ_E values at these plasma conditions of high temperatures and low particle collisionality. Sufficient heating leads to high plasma temperatures (in the case of PLT, 2MW heating gave 6keV temperatures in the face of an overall plasma energy confinement time of about 20 ms).

(ii) In order to control high Z impurities in PLT it was necessary to remove all high Z material from the system and in particular to use low Z limiters. The development of long-life, low Z limiters for large tokamaks is a challenging problem.

(iii) Control of low Z impurities was obtained by titanium gettering of the walls. Such methods may be difficult for a tritium experiment. Thus the DITE group (Peacock et al., 1978)* have reported measurements of hydrogen build-up on gettered and ungettered surfaces. They obtain $0{\cdot}5 \rightarrow 1 \times 10^{17}$ H atoms cm^{-2} after a few thousand discharges for ungettered surfaces and $2 \rightarrow 5 \times 10^{18}$ H atoms cm^{-2} after a few hundred shots for gettered surfaces. If these are taken to be saturation levels the total inventory of tritium on the JET wall would be:

$0{\cdot}3 \rightarrow 0{\cdot}6$ g T_2 for ungettered surfaces
and $12 \rightarrow 30$ g T_2 for gettered surfaces.

These values are large compared with the quantity of tritium typically used to fuel one discharge, i.e. 0·1 g.

The large tokamak projects responded to the favourable PLT results by initiating requests for the provision of more heating power. TFTR has announced an "Improvement Project" involving an increase in injected power from the initial implementation of 24MW to 45MW in the "Improvement". JET is seeking the implementation of extended performance (toroidal field 35kG, additional heating power 25MW and provision for operation with D–T plasma) during the Construction Phase. The reason for this request is that with the demonstration of successful low collisional plasma operation at Princeton there is good reason to expect that it will be possible to operate JET with plasma parameters close to the threshold of ignition.

As an illustration of this point, it is worth considering global extrapolations from PLT to JET made on the optimistic assumptions that impurities can be kept out of JET and that limiter problems can be solved. Then energy confinement time scalings of the type† $\tau_E \propto a^2$ or $\tau_E \propto I n_e^{1/2}$ (Mirnov, 1978)‡ give τ_E values for JET in the range of a half to a few seconds, and ~2s is a plausible value. In these conditions ignition would be obtained in JET by introducing about 25MW of additional heating power to the core of the plasma (up to 50MW overall). The corresponding mean plasma beta ($\bar{\beta}$) of about 5% might well be possible within the constraints of MHD stability.

Thus it is clear that high temperatures will only be obtained if sufficient additional heating power is provided. Furthermore, progress in the areas of impurity control and stable operation is such that there is a good possibility that the application of a technically and financially feasible amount of additional power will permit a close approach to the ignition condition. These considerations have clear consequences for JET: sufficient heating power should be provided to obtain near-ignition conditions in the initial hydrogen operation; provision should be made for early D–T operation; and steps should be taken to ensure that the programme can continue should there be a major machine failure in active conditions.

Specific Investigations

Cool Plasma Mantle: The work which was initiated in the Design Phase on methods of modifying the plasma edge profile to limit impurity influx, continues. The general principle of controlling impurity influx by controlling the power and mass deposition in the outer layers of the plasma remains promising. The computer models used are being refined to describe more realistically the low energy neutral influx and to simulate the effects of the presence of both high Z and low Z impurities.

Magnetohydrodynamic (MHD) Studies: A comprehensive study of JET MHD equilibria has been undertaken at the Culham Laboratory under a series of JET contracts initiated during the Design Phase. Reports on the individual contract investigations have been issued and a comprehensive report on the full series of investigations has been completed. Discussions are in progress with the CRPP§ (Lausanne) to install the ERATO MHD stability code on the Harwell computer for JET use. The division has also been successful in interesting other groups in JET configurations to the extent that they have used JET parameters as a basis for their stability studies. In particular, the group at the General Atomic Corporation

*Paper CN-37/N5-2, 7th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Innsbruck 1978.
†a is the plasma minor radius, I the plasma current and n_e the number density of electrons.
‡Paper CN-37/F1-2, 7th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Innsbruck 1978.
§Centre de Recherches en Physique des Plasmas.

(USA) have found fully MHD stable configurations with $\bar{\beta}$ values in excess of 5%.

Ripple Trapping: An investigation has been conducted into the effect on injected neutral beams of the magnetic field ripple at the outside edge of the JET plasma. Analytic assessments have been made of the fraction of an injected beam which is lost by the ripple trapping process. It is found that the beam power lost in this way is small and that the introduction of impurities sputtered by the lost beam particles is less than the introduction of impurities sputtered by other processes.

Horizontal Position Control: Previous calculations have been extended to use more realistic models of the coils and external structure of JET. They confirm that adequate position control is possible in the current build-up phase provided that momentary peak displacements of the order of 20–30 cm are acceptable.

Additional Heating: JET will require powerful heating techniques in addition to ohmic heating in order to reach temperatures of thermonuclear interest. Accordingly, 10MW of neutral injection heating will be installed for initial operation and this power level will be increased to 25MW or beyond if necessary by the addition of further neutral injection or radiofrequency (rf) heating. Provision is also made in the design for adiabatic major radius compression of the plasma. The neutral injection will initially have an acceleration voltage up to 80kV in hydrogen with about a 1s pulse length. This will later be extended to 160kV in deuterium with a pulse length of several seconds. Radiofrequency techniques are still under development in the Associated Laboratories and a number of frequency ranges are possible as follows; Ion Cyclotron Resonance (ICR) range (~ 50MHz in JET); Lower Hybrid Resonance (LHR) range (~ 1 GHz in JET); Transit Time Magnetic Pumping (TTMP) range (~ 50kHz in JET); and possibly, as suitable sources are developed, the Electron Cyclotron Resonance (ECR) range (~ 80GHz in JET).

Neutral Injection: During the Design Phase responsibility for neutral injection development rested with the Physics Group which co-ordinated the neutral injection development programmes in the Fontenay-aux-Roses (FAR) and UKAEA Culham laboratories. This responsibility has now been transferred to the Plasma Systems Division. The test bed lines in the two Associations which were constructed as part of the collaborative programme are now operating and are being tested at voltages up to their design value of 80kV. The power level for the next 6 months of operation will probably be around 0·5 MW neutrals for 80kV operation rather than the 1MW in the design. These test bed lines are expected to provide the basis for the design decisions now required on the JET injectors.

Direct recovery of the energy in the un-neutralised ions becomes very important for energies in excess of 60keV per nucleon. The first direct recovery system has now been operated at FAR using peripheral grids in a geometry that might be adapted to JET. The system has operated up to an extraction voltage of 70kV; at 50kV extraction voltage 80% recovery of the power of the un-neutralised energy of the full energy protons has been demonstrated. The test was made on a 14cm diameter source and required recovery grids around the system which were 80cm in diameter. A JET source might be 16cm x 40cm and would require correspondingly larger peripheral grids. Such a system, inertially cooled, might have a 1s pulse length and might raise the efficiency of a JET injector from ~20% to ~40% in addition to offering an attractive solution to the beam dump problem. However, the problems of incorporating such a large system in a JET line and of extending the pulse length are formidable.

RF Heating: Certain developments in rf heating which occurred during the period under review appear promising for JET. An rf loop antenna only 20cm in radius and a few cm wide has been used to inject 190kW of ICR (66MHz) heating power into a 500eV TFR plasma yielding temperature increases of 200→400eV, i.e. of 40% to 80%. Provisional measurements suggest a coupling efficiency from generator to plasma approaching 70%, giving the possibility of an overall efficiency of say 40%. Four such antennae mounted through 8cm diameter holes are planned to inject 3MW of power into TFR.

Success has also been obtained at other frequencies. Thus LHR experiments have shown bulk heating on a number of devices with increments in ion temperature $\Delta T_i \sim 150$eV, and electron temperature $\Delta T_e \sim 300$eV. This type of power could be introduced through the smaller auxiliary ports of JET.

TTMP has been demonstrated on PETULA where $\Delta T_i/T_i = 40\%$ from an initial $T_i = 200$eV has been reported. It is felt that overall efficiencies of 12% could be obtained on JET for an initial T_i of 3keV.

RF heating systems offer advantages of compactness and efficiency, and furthermore they permit the heating of high density plasmas. It is very important that the systems be developed to a stage where a decision can be taken as to which one can most effectively be applied to JET. This decision will have to be taken in 1980 in order that a construction programme can be started with the aim of applying, say, 15MW of rf heating to JET in the early stages of its operation.

A report "Physics and Technology Developments required for the RF Heating of the JET Plasma" (EUR-CEA-FC-982) has been produced as a result of a JET study contract placed with the CEA Grenoble Laboratory.

Radiological Protection: During the period under review a considerable amount of work has been undertaken to assess the radiological protection provisions for JET so that the JET building design can be finalised. This work involves the specification of radiation emission for various operating regimes, the limitation of air activation and the specification of the shielding walls. It has been performed in conjunction with study contracts placed at the UKAEA Winfrith Laboratory.

Computer Studies: Arrangements under the Support Agreement between JET and the UKAEA have been made for the bulk of JET computing in the period up to and including 1980 to be carried out on the Harwell computer (presently an IBM 370/168 to be replaced by an IBM 3033 in April 1979). Considerable effort has been necessary to bring into operation a remote TSO Cluster and to initiate the use of the Culham PRIME Satellite computer as an RJE station for the Harwell computer. This work has been undertaken in conjunction with the Culham Computer Group who have provided advice, procurement and installation. The first demonstration system is now in operation and has a number of JET users.

Magnet Systems

The Magnet Systems Division is responsible for the design, manufacture and commissioning of the magnets and their mechanical supports. The main components are:-

(i) the toroidal field (TF) magnet;
(ii) the poloidal field (PF) coils, No.1 or ohmic heating coils;
(iii) the poloidal field (PF) coils, Nos. 2, 3 and 4 or equilibrium field coils;
(iv) the transformer core;
(v) the mechanical structure.

The division is furthermore charged with providing the overall water cooling system for the experiment. The design, procurement and installation of auxiliary equipment, such as busbars and the instrumentation related to magnets and structural components are also the responsibility of the division.

During the JET Design Phase the activities of the Magnet Systems Division were conducted by two groups, i.e. the Toroidal Field Group (toroidal field magnet and mechanical structure) and a section of the Poloidal Field Group (poloidal field coils and transformer core). Design and development work was needed to prepare detailed technical specifications and sets of drawings for the call for tender for the main components. Most of the technological development work has been done in collaboration with European industry through study contracts and this collaboration has continued in the preliminary phases (development and prototype phases) of manufacturing contracts.

Toroidal Field Magnet

The manufacturing contract for the TF coils (32 coils plus spares) is well advanced. The prototype coil was completed by the end of 1978 and the testing programme, which includes thermal cycling and mechanical tests, will be completed in April 1979. The main difficulties which have had to be overcome during the manufacture of the prototype were:-

(i) winding D-shaped coils with a thick conductor of half-hard copper;
(ii) ensuring a high quality standard for the brazed joints.

Figs.5 to 7 show the prototype coil at various stages of manufacture. Preparations are already in train for the manufacture of the production coils. The delivery schedule which has now been agreed is longer than originally expected, but is compatible with the overall JET plan.

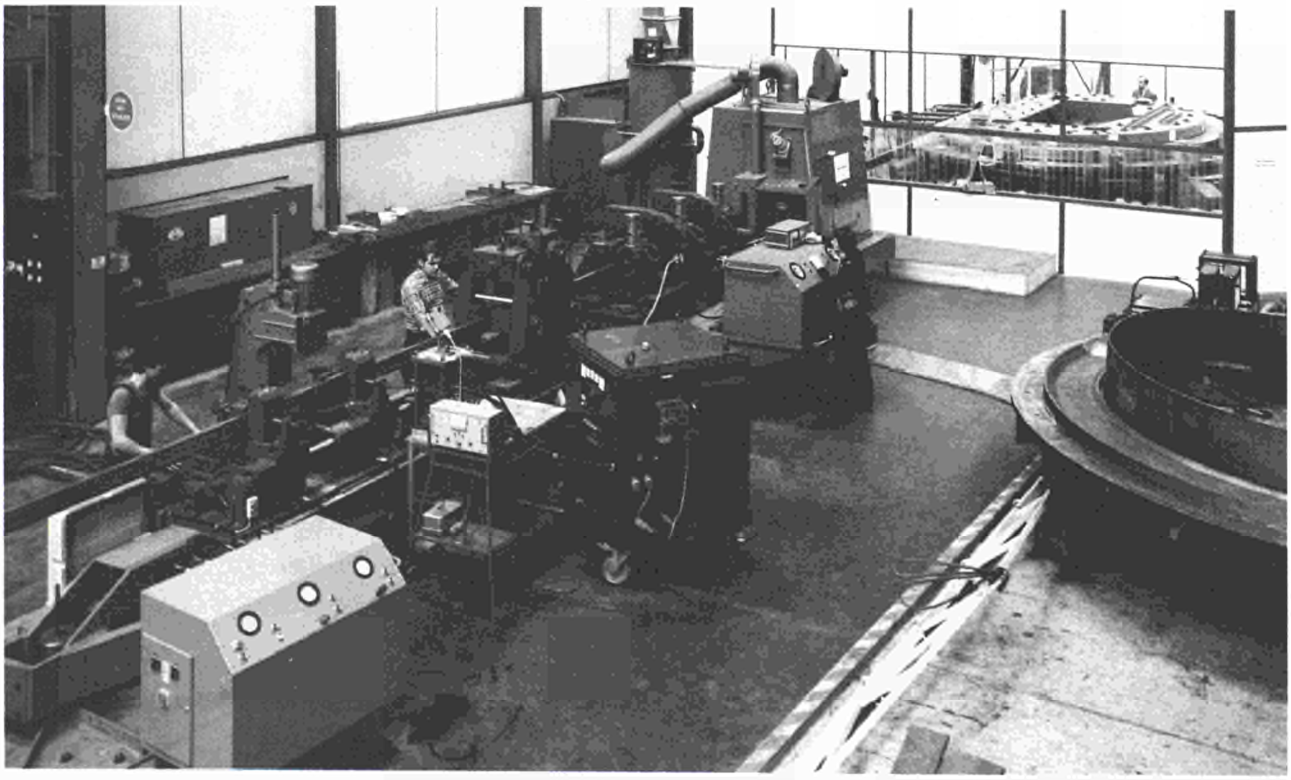

Fig. 5 The production line for the winding of the toroidal field coils.

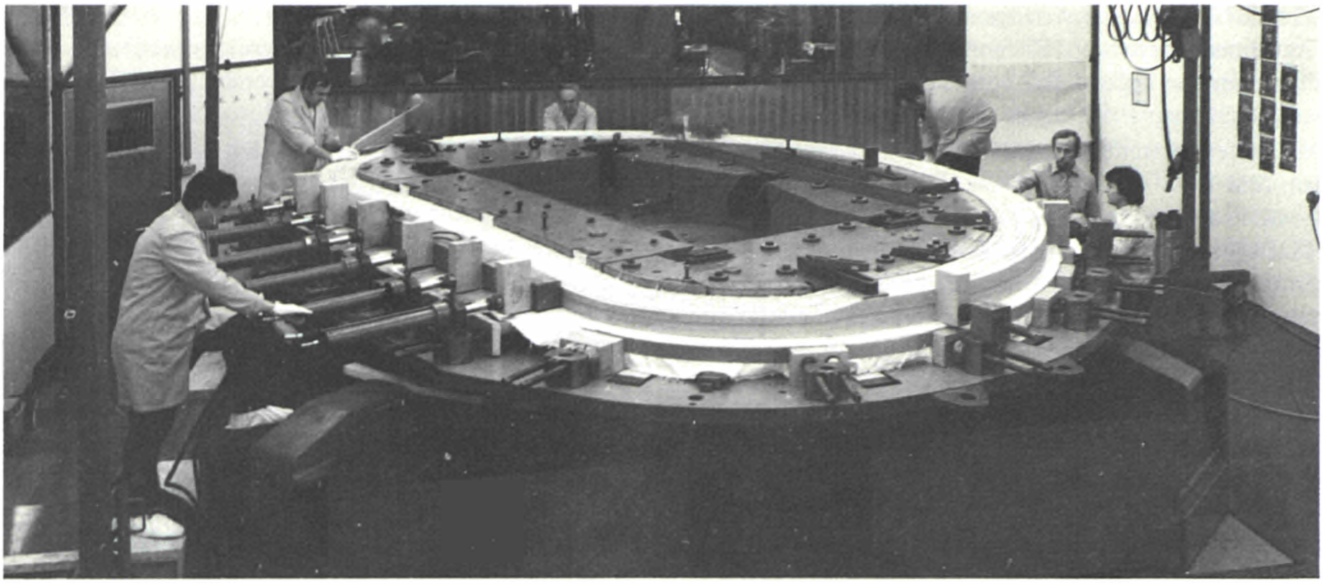

Fig. 6 Winding of the prototype toroidal field coil.

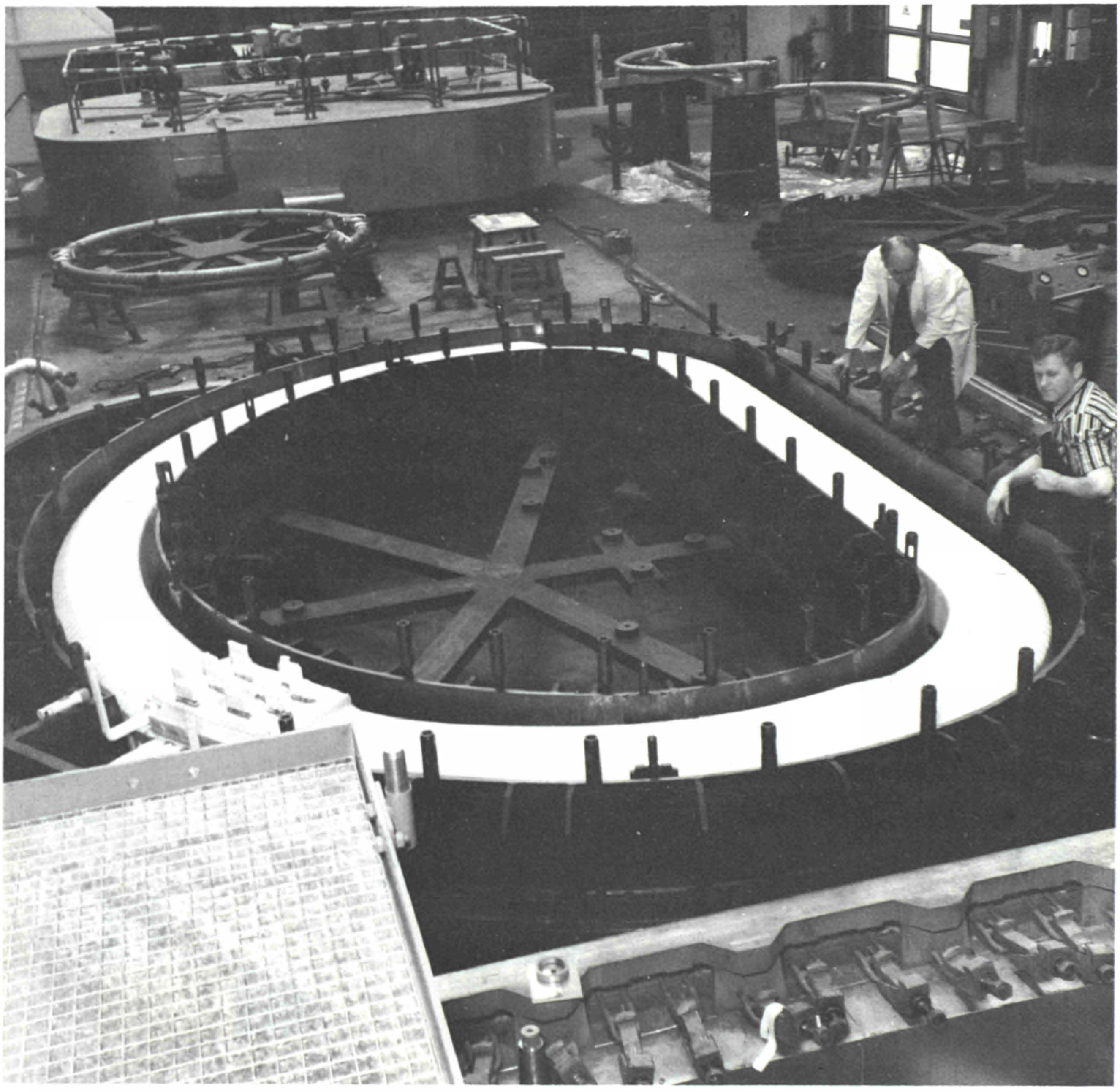

Fig. 7 The prototype field coil in the mould ready for vacuum impregnation.

Poloidal Field Coils No. 1

The design of these coils is now complete. A manufacturing contract was placed in September 1978 the first stage of which includes basic tests of the new insulation system (glass – kapton – epoxy) which will be used for these coils. The testing of the prototype coils, which include features such as an inner supporting ring and an outer rubber layer, should be completed within 12–14 months. The entire magnet should be delivered and assembled at the JET site in October 1980.

Poloidal Field Coils No. 2

An outline design has been agreed for these coils which have to provide radial and vertical equilibrium fields as well as field curvature control. Technical specifications and drawings are being prepared for the call to tender which is expected to take place early in 1979. Manufacture should be complete early in 1981.

Poloidal Field Coils Nos. 3 & 4

These coils, which provide most of the vertical equilibrium field, are of an unusual design because of their large size. In order to make them transportable they are composed of a large number of individual pancakes, each of which is split into two halves which are electrically connected by external straps. The manufacturing contract for these coils will be placed early in 1979 and the total manufacturing time will be 26 months.

The Transformer Core

The transformer core is unusual only in its overall size and weight. The design has been reviewed and finalised. Manufacture should commence early in 1979. Erection at the JET site is also part of the manufacturing contract and will take place in July–September 1981.

The Mechanical Structure

The material selected for the manufacture of the mechanical structure is an austenitic nodular cast iron. This was chosen following an extensive test programme which assessed not only the conventional mechanical properties but also the fracture mechanical properties. A prototype of the most difficult casting has now been made and its quality is being assessed. A full manufacturing contract for the production of all castings and another contract for the machining of the castings were placed at the end of 1978. The entire mechanical structure should be complete by June 1981.

The inner part of the mechanical structure (inner cylinder) will be the object of a separate manufacturing contract. Technical specifications and drawings were prepared for a call for tender which will be issued in early 1979.

Future Work

Due to limited staff numbers during the Design and Interim Phases the divisional effort has been concentrated on the major components of the machine, because these involve long delivery items. However, a much wider range of activities will be undertaken during the Construction Phase, the following of which are typical:-

(i) *Busbar Systems*

- Final designs must be established and manufacturing contracts placed;
- Tests must be carried out on flexible power connections.

(ii) *Cooling System*

The most recent development in this area is the large increase in the cooling power requirements for the neutral injectors. The system now includes three de-ionised water loops:

Loop 1 – for the TF coils and PF coils Nos.3 and 4,
Loop 2 – for the PF coils Nos. 1 and 2,
Loop 3 – for the neutral injectors.

These three loops have a common heat exchanger and a common water tank. A call for tender for detailed design, manufacture and installation is expected to be issued during the second half of 1979.

(iii) *Instrumentation*

Little work has been done so far in this area. The parameters to be measured will be:- strains, displacements, water flows, pressures and temperatures. The detailed design and development of the fault detection systems for the TF and PF coils remain to be done.

Plasma Systems

The Plasma Systems Division is responsible for the design and manufacture of the vacuum vessel, the neutral beam injectors and the corresponding pumping and gas handling systems.

The manufacture of the vacuum vessel proper involves four major industrial contracts: VDM (Germany) and Henry Wiggin (England) for the materials; Flexider (Italy) for the bellows; and Morfax (England) for the rigid sectors and assembly. The following tasks for the vessel periphery have yet to be completed: the design of and choice of materials for the limiters; the choice of the first wall cleaning methods; tests and calculations to specify the vessel baking and cooling loop; and the specification for vessel control and monitoring.

The design of the neutral beam injection lines is still in a preliminary phase awaiting the evaluation of the results of two 1 MW test lines. These have been developed at the Culham and Fontenay-aux-Roses Laboratories as part of a collaborative neutral injection development programme.

The pumping and gas handling systems are at different stages of design. The pumping systems are being modified to use mainly turbomolecular pumps for the torus and shell pumping, and cryo-pumps for the injector boxes. The development of the new bakeable gate valves is continuing. A major design effort is still needed for the cryogenic supply with its transfer lines and refrigerator. The tritium handling concept, which involves the initial installation of pumping and gas handling systems needing only minor modification to be tritium-compatible, will be reviewed.

Vacuum Vessel

Approximately 80% of the prototype limiter rigid sector has been completed (Fig.8). The manufacture of the prototype bellows assembly is proceeding and will be ready in early 1979. A full-scale half octant with dummy end plates is being assembled for air flow tests to determine the vessel baking characteristics.

Stage 1B of the Morfax contract (prototype octant manufacture) and Stage 2 of the Flexider contract (bellows units manufacture) have been released. Production schedules for both these stages have been shortened in order to regain lost time and attempts are also being made to reduce the overall vessel manufacturing time-scale.

Work is continuing on the procedures for cleaning, leak testing and baking at the manufacturers. The operational surface treatment of the first wall, its outgassing, cleaning and baking are being discussed. Assessments of the results of various study contracts concerning the sputtering yields of construction materials and the first wall potential of low Z materials have been completed.

The calculations of stress associated with the loading of the vacuum vessel when subjected to magnetic forces have been successfully concluded.

The heating gas for vessel bake-out has been selected as CO_2 and the flow rate will be optimised to enable a suitable and reasonably inexpensive gas driver to be chosen.

The cooling of the vacuum vessel between discharges imposes particular constraints on the vessel and is being investigated as a matter of high priority. The results of the study could strongly influence the design of the heating-cooling subsystem. Studies are being carried out to select the gas driver to operate under vacuum conditions. The use of removable heaters and cooling by air blast is also being investigated.

The TAFEST code is being used extensively as it is the main computational tool for a vast series of calculations in the setting up of the bake-out system. A call for tender is being circulated in respect of a study contract for the investigation of thermally-induced stresses in the vessel.

Neutral Injectors

The injector box designed to suit various ion source types has been modified and now includes the positioning of the deflection magnet, the ion dumps and the ion source back cover.

The development programme for the neutral beam injectors for JET is now the responsibility of the Plasma Systems Division. Contracts for specific work will be placed with the two Associated Laboratories concerned, namely those at Culham and Fontenay-aux-Roses. The results of the previous programme will be evaluated by a Joint Design Group early in 1979 and the group will define the prototype injector and a programme for its production.

The design for the full size rotary valve has been completed. A version with a planar seal face is being

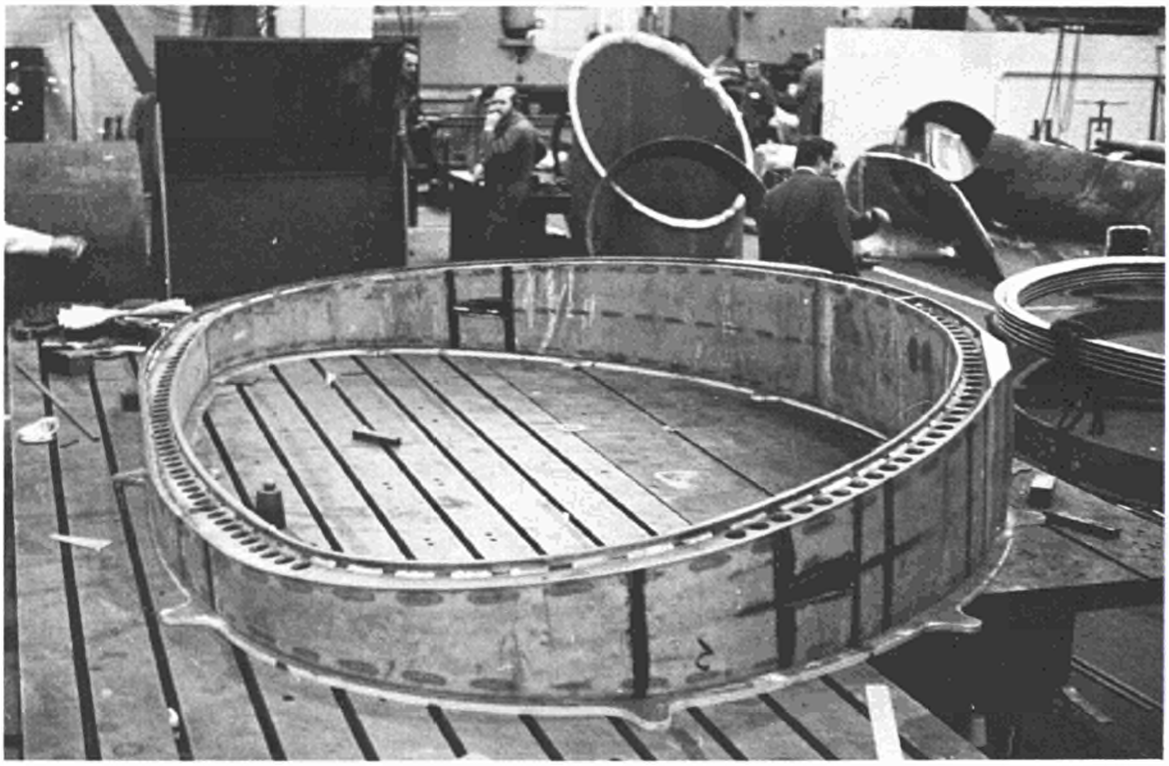

Fig.8 Prototype rigid sector in manufacture.

studied. Tests with the 1/4 scale model are being prepared. Industrial firms have expressed interest in and demonstrated the capability for the manufacture of a full scale rotary valve. Its manufacturing specification is being prepared.

Vacuum Pumping System

Torus pumping by turbomolecular pumps (TMP) through two radial ports is being studied. A novel system for a bakeable valve to isolate the pumps from the port has been designed.

JET vacuum pumping requirements are being discussed with potential suppliers. These discussions have included: pumping methods and hardware equipment design (base pressure, tritium considerations, bake-out temperature implications, specifications, testing methods, layout and installation requirements, TMP operating modes), leak detection procedures and equipment requirements.

The Princeton Laboratory's Vacuum System Transient Simulator program is being adapted for the solution of JET pumping problems. The transfer to the Harwell and Culham computers has been completed and the work on transient simulation of the shell interspace has started.

Planning and Organisation of Assembly

The Assembly Division is responsible for:

- The study and development of assembly and remote handling methods;
- The provision of general engineering services; and
- The planning and organisation of the assembly, and the installation and maintenance of the JET experimental device.

While the other technical divisions have broad "vertical" responsibilities the Assembly Division concentrates on an overall coordinating and matching function aimed at successfully completing the assembly of the device on schedule and at establishing a convenient maintenance and repair system for the Operation Phase.

The division was established in the Spring of 1978. Its work done so far is a continuation of that undertaken by various groups of the JET Design Team, which primarily consisted of the following:

- Preparation of the assembly and maintenance procedures, in particular the design of the assembly

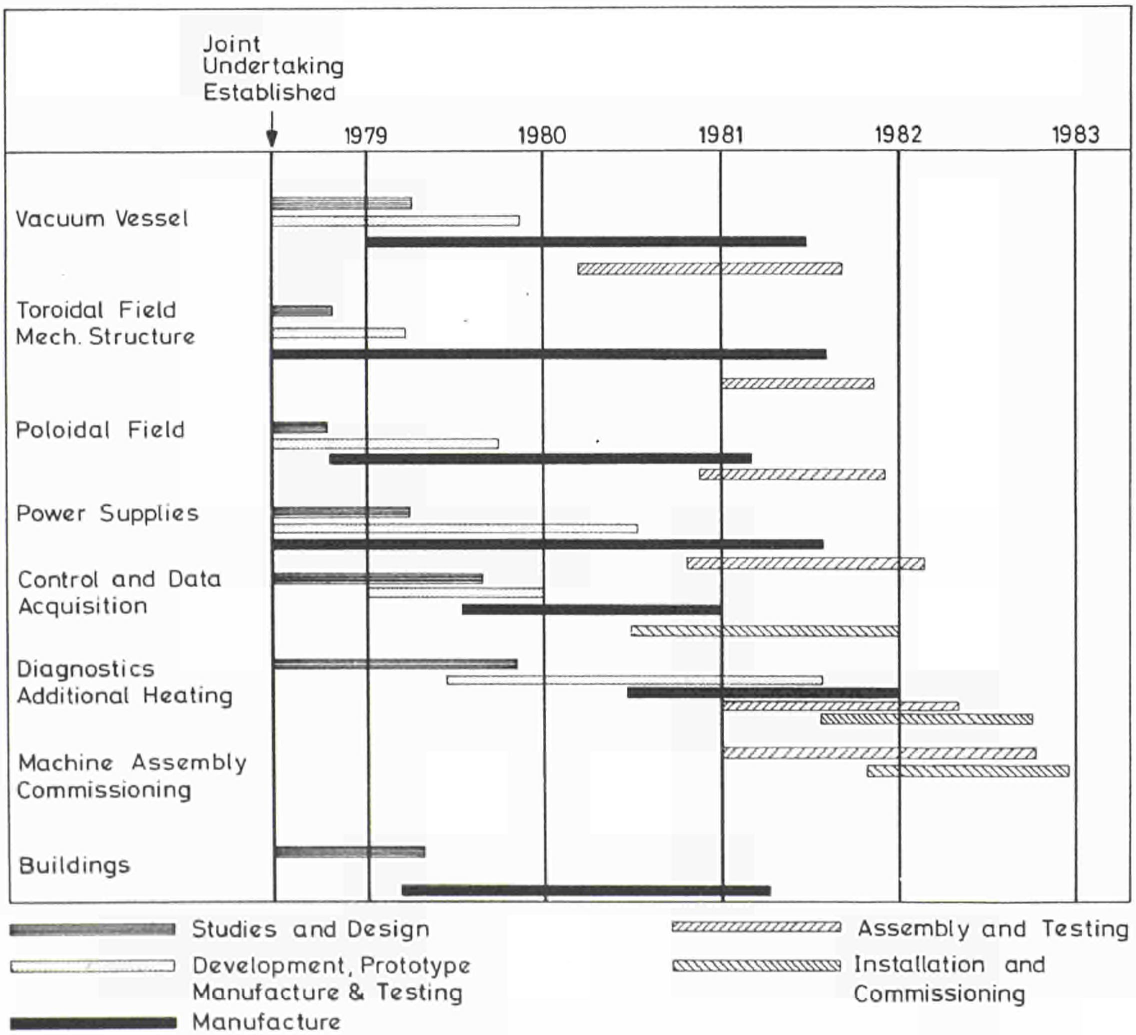

Fig.9 Construction Phase time bar chart.

jigs and tools;
and

- Assessment of the overall time planning with continuing emphasis on the cost estimates. The time-scales involved for the various components are shown in the time bar-chart (Fig.9).

The current work involves two main activities:

(i) The preparation of the calls for tender for the octant assembly rigs. With a vacuum vessel octant, four toroidal field coils and the outer mechanical structure, these rigs will permit the assembly of fully equipped machine octants in the assembly hall prior to final positioning and welding in the torus hall (this last operation will require another main rig, the octant sliding gear equipment). Enquiries are due to be sent out by March 1979.

(ii) The completion of the work breakdown for the whole project.

Future Work

During 1979 the Assembly Division will undertake the following programme of work:

(i) Implementation of the computerised planning and control system by June 1979;

(ii) Preparation of the assembly of the JET device (i.e. preparation of temporary storage and organisation of assembly stores, writing the specifications for a technical assistance contract and undertaking the tendering procedures);

(iii) Provision of information which will allow Culham Laboratory to organise workshops, stores and close assembly support for JET;

(iv) Completion of the tender action for the octant sliding gear equipment by September 1979 and commencement of tests on conventional maintenance using a telemanipulator; and

(v) Commencement of procurement of conventional assembly equipment (i.e. handling, precise positioning).

Power Supplies

The Power Supplies Division was formed by merging the former Toroidal Field Power Supply Group and the Poloidal Field Power Supply Section of the Poloidal Field Group.

The division is responsible for the design, construction and commissioning of all power supplies required by JET and the power distribution system from 400kV down to 415V.

During 1978 the activities in the division have been two-fold:

(i) The deployment of staff, together with the definition of the main tasks, responsibilities and boundaries with other divisions, the Culham Laboratory, the CEGB (Central Electricity Generating Board) and the SEB (Southern Electricity Board).

(ii) The completion of subsystem designs, preparation of technical specifications, tender actions and the placing of contracts.

A brief account of the work performed on main items and indications of work to be done are given in the following paragraphs.

Large Power Supplies

The flywheel-generator-convertor (FGC) contract has been placed with GEC Machines Ltd (UK). The contract signed in June 1978 is for two identical generators with the same kinetic energy of 2600MJ. The AC/DC diode convertors are also identical and rated for a 67kA pulse current for 20s or 100kA for 5s. The peak power available from each machine is 400MW.

Stage 1 of the contract is the detailed design of all the equipment in the generator house including pony motors, liquid resistor starters, exciters, auxiliary power supply and control equipment with data logger and interface with CODAS. Stage 1 is expected to be finished in February 1979. An important part of the work done during Stage 1 is the fatigue testing of sheet material and of machined end plate material. The work has been performed by GEC Machines Ltd in the Mechanical Engineering Laboratory of GEC Power Engineering Ltd at Whetstone. The fastening of the generator poles to the rotor rim has been improved and the safety factor against fatigue failure has been raised relative to the conditions of the tender without influencing the contract price.

A tender enquiry for the large 400/33kV step-down transformers to be connected to the supergrid network of the CEGB was sent out in December 1978. Arresters for overvoltage protection may be ordered at the same time as the transformer. One transformer is required for JET Basic Performance. The call for tender makes provision for ordering a second transformer (required for Extended Performance) two years after the first one. Each transformer will be rated to supply a pulse load of 300MVA. Taking the duty factor to be about 0·04 the continuous rating will be much less. The JET Joint Undertaking will be the only customer in England purchasing power at this very high voltage and it is therefore foreseen that it will have a special electricity supply contract directly with CEGB.

The major load for the 400/33kV transformers will be the "static" power supply to be connected with one of the flywheel-generator-convertors to form a combined power supply for the TF magnet. A number of thyristor AC/DC convertors or combinations of diode rectifiers and thyristor convertors are foreseen. The technical specifications have been prepared and a number of such options remain open, to be decided upon after the tender has been received. The call for tender for the static power supply was issued in December 1978.

The main technical specifications for each TF unit are: DC output voltage exceeding 1700V with 67kA DC current and with an AC input voltage of 33kV; current capability of 67kA for 20s, 53kA for 32s, 75kA for 16s every 10 minutes (corresponding to various power pulse scenarios); a continuous operation at 18kA is specified; the maximum amount of reactive power drawn from the 33kV line shall not exceed 60MVAR for each unit. 24 pulse operation is required.

Advanced Power Supplies

There are basically two systems involved:
(i) Additional heating power supply and protection.
(ii) The ohmic heating circuit.

Additional Heating Power Supply and Protection

Up to the end of September 1978 progress has been very slow due to the lack of staff. However, there was a study contract with Siemens (FRG) and a final discussion of the results will take place in February 1979.

Contacts were re-established with BBC Baden and JET was invited to attend the tests performed at Mannheim (Forschungsgemeinschaft für Hochspannungs- und Hochstromtechnik) on the BBC tetrode CQS-200-3. The tests were organised mainly to assess the tetrode capability at the request of Aydin Corporation (USA) who had obtained the contract to build the neutral injection power supply and protection system for the Livermore MFTF (Mirror Fusion Test Facility). Since then Aydin has decided to use BBC tetrodes CQS-200-4 and the contract is being prepared. The first tetrode will be ready in April 1979 for testing at Baden. JET has been invited to attend the tests.

Various meetings were held with companies which already have some experience from involvement in the US programme: RCA, Aydin, System Science and Software, Mullard and Phillips.

Ohmic Heating Circuit

Now that the generator design is fixed the various proposed solutions for the ohmic heating circuit are being analysed so as to finalise the circuit details. Specifications have been drafted for circuit breakers, their capacitor banks, commutating resistors, saturable inductors, nonlinear resistors, and for a large reversing switch.

Space Requirements, Ducts and Busbar Runs

The area requirements for the advanced switching components, the control amplifiers and the equipment for adiabatic compression and discharge cleaning are now complete. Decisions on duct routings and sizes are underway.

Control – Interlocks and Protection

The basic items for interlock, protection and control have been identified and preliminary requirements will be specified for the CODAS Division. Detailed work remains to be done on the procedure control and continuous monitoring requirements.

Progress on Vertical Position Control of Plasma

Further analysis and specification has been undertaken for the power supplies required for the field circuit controlling vertical movement of the plasma. A study of the thyristor amplifier requirements has been completed by the Technical University of Braunschweig.

Adiabatic Compression

All items necessary for the adiabatic compression have been identified. Detailed specifications must now be written before tender action is taken.

Discharge Cleaning Requirement

Some analysis of the power supply requirements needed to provide the discharge cleaning of the vacuum vessel has been done. Space and power have been allocated accordingly. A more detailed analysis is to be undertaken. The circuit breaker capacitors have been specified in order that they may be used for this duty. Additional switching arrangements and charging are being provided in the ohmic heating circuit design to allow for discharge cleaning.

Auxiliary Power Supplies, Layout and Services

The amount of work performed in this area during the JET Design Phase was limited. Moreover, the technical and administrative boundaries of the JET supply have had to be defined in conjunction with the UKAEA and the CEGB.

The JET power supply and distribution system is shown in Fig.10. Detailed estimates have been made for the auxiliary power requirements, and call for tender specifications are being prepared for the 132kV/11kV/415V distribution system.

A detailed electrical and mechanical design of the toroidal field load busbar system is now complete with a proposal for the 400kV/33kV substation, cabling and busbar routing, auxiliary power transformer location, and layout of the power supplies in the J3 and J4 buildings.

Control and Data Acquisition System (CODAS)

The JET computerised control and data acquisition system, CODAS, has been designed and is now being implemented. CODAS will provide:
(i) Centralised control and monitoring of JET using two main consoles; and
(ii) The independent operation of the different subsystems for commissioning and maintenance using auxiliary movable consoles.

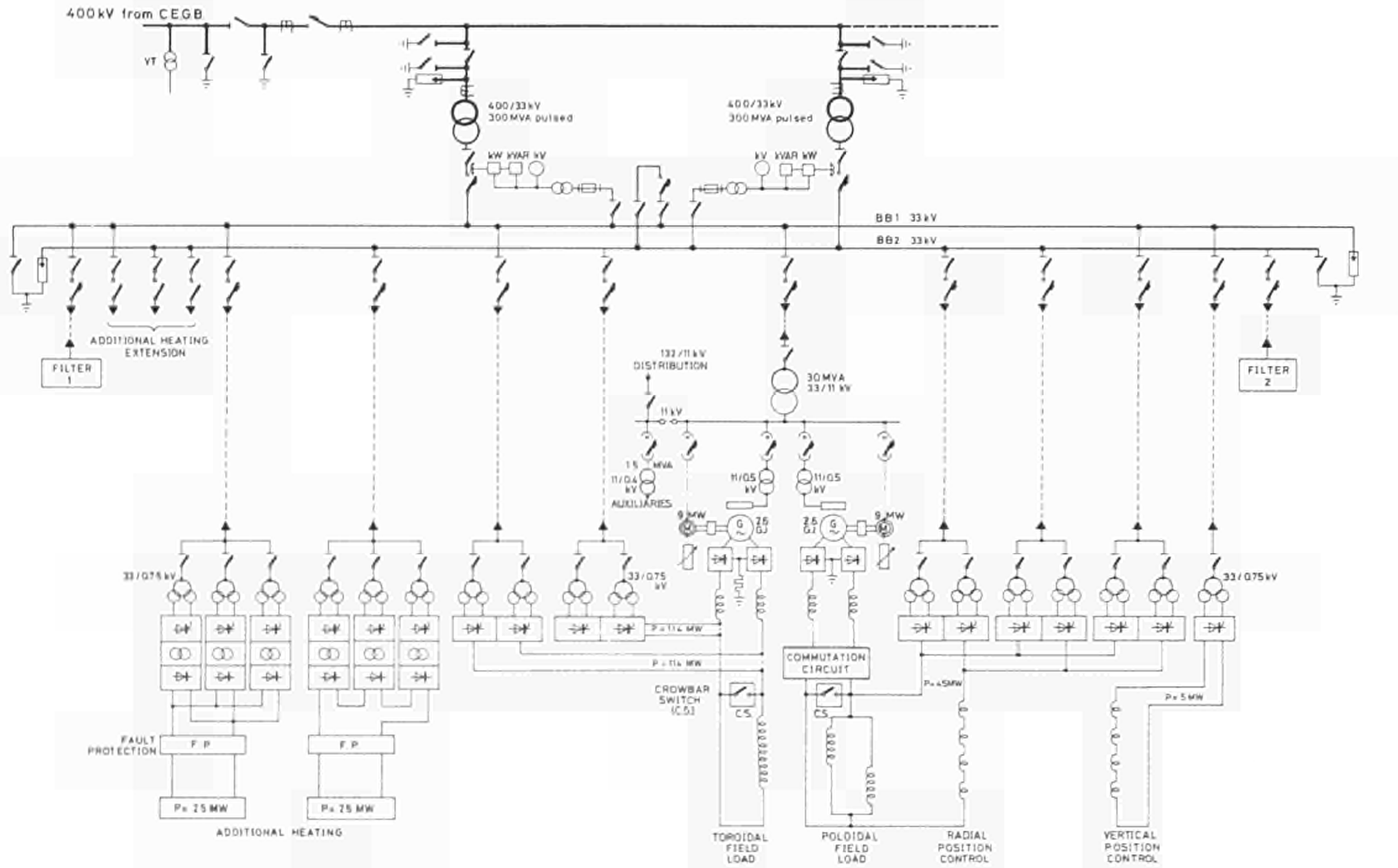

Fig. 10 Power supply and distribution system.

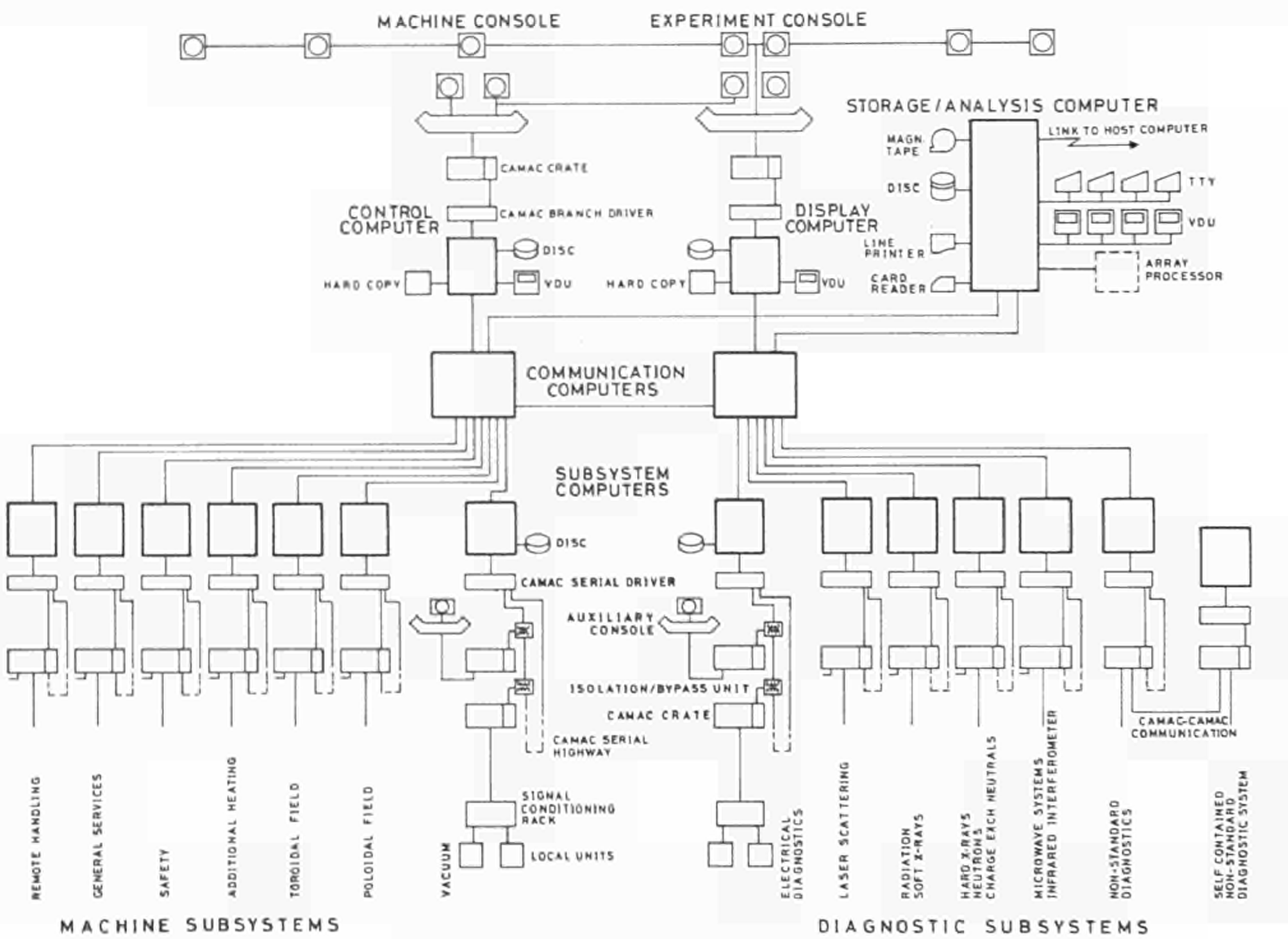

Fig. 11 CODAS multicomputer system.

CODAS will also provide a computer-controlled Central Timing System (CTS) and a computer-independent Central Interlock and Safety System (CISS). The system can acquire and store up to 10^6 plasma data and 10^5 engineering data per pulse; experimental results can be analysed on-line after each pulse in the CODAS computers or sent to a larger computer facility linked to JET for off-line computations.

The basic structure of the computer system is shown in Fig.11.

During the period under review the following tasks were completed by the CODAS Division:

- The control building (J2), including the service requirements, has been specified.
- Benchmark tests have been prepared to be used for the evaluation of tenders for the computers.
- The call for tender for the supply of all CODAS computers has been issued, based upon the evaluation of replies of computer manufacturers to a preliminary enquiry.
- The CAMAC Serial Highway and its use in CODAS has been investigated as a basis for the preparation of detailed specifications.
- The techniques which can be used for the interlock and safety system have been investigated.
- Basic interface standards for signals have been established, starting from the interface of CODAS with the flywheel-generator-motor set.
- Further studies have been performed on the plasma position and shape control and the associated electrical measurements for feedback-control.

Current Work

The current work programme of the division includes the following activities:

- Specifications are being prepared for powered CAMAC crates and the CAMAC Serial Crate Controller to be used for CODAS.
- Provisions are being made to establish an outline specification of the CAMAC Serial Driver for CODAS.
- The Central Timing System (CTS) is being defined, based upon the use of CAMAC modules.
- The final design of the man/machine interface (main and auxiliary consoles) has begun.
- The requirements for control, monitoring and data acquisition in the various JET systems are being updated in collaboration with other JET divisions.

Future Work

- Early in 1979 the computers will be selected and the order for the computers will be placed. The first computers delivered will be temporarily installed and tested. The standard software for control will be planned.
- Calls for tender will be issued for the supply of the first set of CAMAC equipment.
- The design of the Central Timing System will be finalised and prototype CAMAC modules for the CTS will be procured.
- A detailed design of the central interlock and safety system will be performed.
- The man/machine interface will be specified and tender action for the supply of the associated hardware and software will be initiated.

The CODAS Division coordinates its activities with those of other divisions so as to ensure that the JET equipment will be appropriately connected to CODAS. For example the planning of the plasma diagnostic subsystems of CODAS is done in collaboration with the Experimental Systems Division. It is proposed to use CODAS in the commissioning and testing phase of JET systems.

Site and Buildings

The Site and Building 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 directly the design, construction, operation and maintenance of the specific experimental buildings, distribution of the related site services, transport facilities around the site and major items of conventional mechanical plant.

(ii) Liaison activities with Culham Laboratory in relation to the provision on the JET site of general offices, laboratories and site roads as well as the provision of services networks external to the JET site boundary. The provision of the site and these buildings and facilities are the responsibility of Culham Laboratory as Host Organisation.

The JET programme requires the completion of buildings and services facilities by the end of 1980. The construction programme has been planned to permit sequential occupation in order to allow the start of the assembly of experimental equipment and installation early in 1980.

During the first half of 1978 the site soil investigations were completed, and a detailed report was issued, containing all significant parameters. Furthermore a contract was placed with a consulting engineering organisation for the design of the buildings. The first stage of this contract covered preliminary evaluation, collection of data and analysis of early studies, with the definition of the overall features of construction. This stage was completed by June 1978, and since then the second stage involving scheme design work has been carried out. This work has included:-

(i) Definition of the overall architectural layout of the site (see Fig.12) including landscaping requirements. The application for the planning permission of the JET specific buildings was lodged with the Local Authority in November 1978;

(ii) Design of the buildings, service facilities and related equipment to the level of definition necessary to

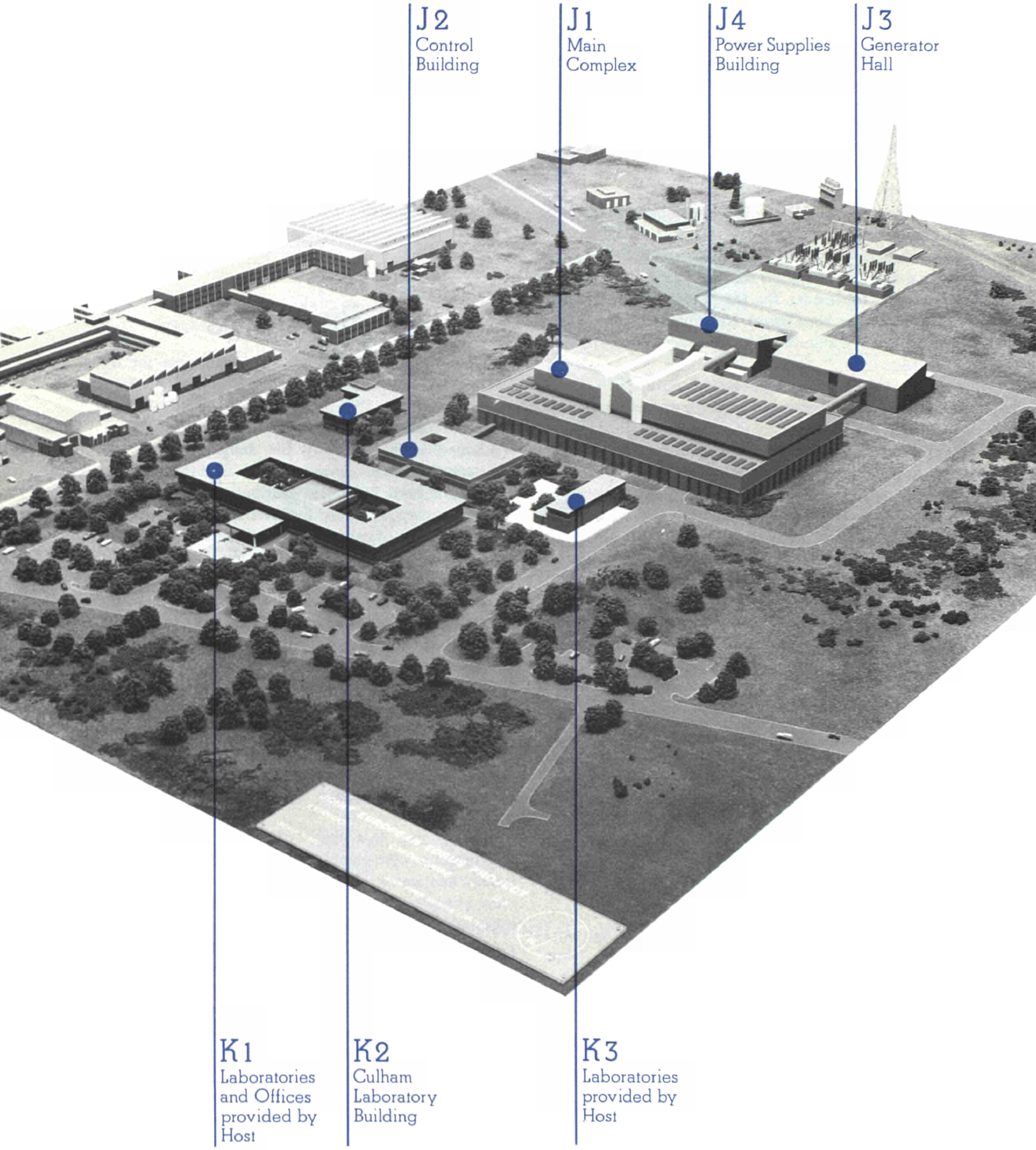

Fig. 12 Model showing the new JET Laboratory relative to part of the Culham Laboratory shown at top left.

form the basis of detailed design and specification for tendering action;

(iii) Preparation of a detailed cost estimate.

In parallel with this activity, and in order to ensure building completions within the construction target dates, tender enquiries have been prepared based on the notional requirements as currently defined.

In December 1978 tender enquiries were issued for:-

- Main cranes (150 tonne and 80 tonne cranes) in the main experimental building J1 (see Fig.12).
- Site preliminary works.

At the end of 1978 the scheme design was being finalized and evaluated.

Future Work

Tender documents have been drafted for:-

- Foundation piling work.
- Excavation diaphragm wall.
- Steel structures.
- Auxiliary cranes.

The enquiries for these works will be issued early in 1979. All the tendering activities for the principal construction works will be completed with contracts placed during the first half of 1979.

Breaking ground on the site of the JET specific buildings is expected in the first half of 1979.

Appendix 1

The Euratom Fusion Research Programme

Fusion research started about 1950 in a number of European countries. Cooperation between these countries was initiated first through exchanges of information. As the work progressed the advantages to be gained from sharing the effort became so apparent that a closer collaboration on a European scale was sought.

The first European five year programme for Plasma Physics and Fusion Research was part of the initial programme when in 1957 the European Atomic Energy Community (Euratom) was established. This has since been followed by a number of pluriannual programmes adopted by the Council of the European Communities on the proposal of the Commission of the European Communities.

According to the Euratom Treaty the Commission is responsible for the implementation of the programme. The Commission decided that, given the existence of the national programmes, the goal of a united European Fusion Programme could most readily be achieved through Contracts of Association with the laboratories which already existed or were being established.

Finally, the Council decisions repeatedly state that each pluriannual programme be part of a long term collaboration embracing all work carried out in the member states in the fields of fusion and plasma physics. This collaboration 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.

Up to now, Euratom (EUR) has concluded agreements with:

CEA – Commissariat à l'Énergie Atomique (Laboratories at Fontenay-aux-Roses and Grenoble).

CNEN – Comitato Nazionale per l'Energia Nucleare (Laboratory at Frascati).

CNR – Consiglio Nazionale delle Ricerche (Laboratories at Milan and Padua).

DEA – Danish Energy Agency (Laboratory at Risø).

EB – État Belge (Laboratories of the École Royale Militaire and the Université Libre de Bruxelles).

FOM – Stichting voor Fundamenteel Onderzoek der Materie (Laboratories at Jutphaas, Amsterdam and Eindhoven).

IPP – Max-Planck-Institut für Plasmaphysik (Laboratory at Garching near Munich).

KFA – Kernforschungsanlage Jülich GmbH (Laboratory at Jülich).

NE – National Swedish Board for Energy Source Development (Laboratories at Stockholm, Göteborg and Studsvik).

UKAEA – United Kingdom Atomic Energy Authority (Laboratory at Culham near Oxford).

The subject matter of each individual Contract of Association, a pluriannual programme, is agreed after discussion in the Committee of Directors (consisting of the Directors of the Associated Laboratories and the Commission's Director of the Fusion Programme) and a recommendation of the Liaison Group to the contracting parties. (The Liaison Group is composed of the Directors and scientific heads of the Associated Laboratories and of the Commission, and has the responsibility of giving scientific and technical advice to the Commission and Associations.) These programmes form part of a Community-wide long-term collaboration having as an aim the joint construction of large experimental facilities.

The execution of each of these programmes is supervised by the Steering Committee of the individual Association; each Steering Committee consists of a small number of Association and Commission representatives. In the framework of these Contracts of Association the Commission contributes to the expenditure of each Association by about 24% (or about 44% for certain experiments of priority interest*), and participates through representatives in the different management boards in the preparation and execution of the programmes.

A contract concerning the exchange of personnel (Mobility Contract) allows national laboratories to second their staff to other national laboratories, the cost of these secondments being reimbursed by the Commission.

The fusion programme is open to cooperation with

*The Liaison Group advises on the allocation of this preferential support. This Group is assisted by Advisory Groups composed of experts from the Associated Laboratories.

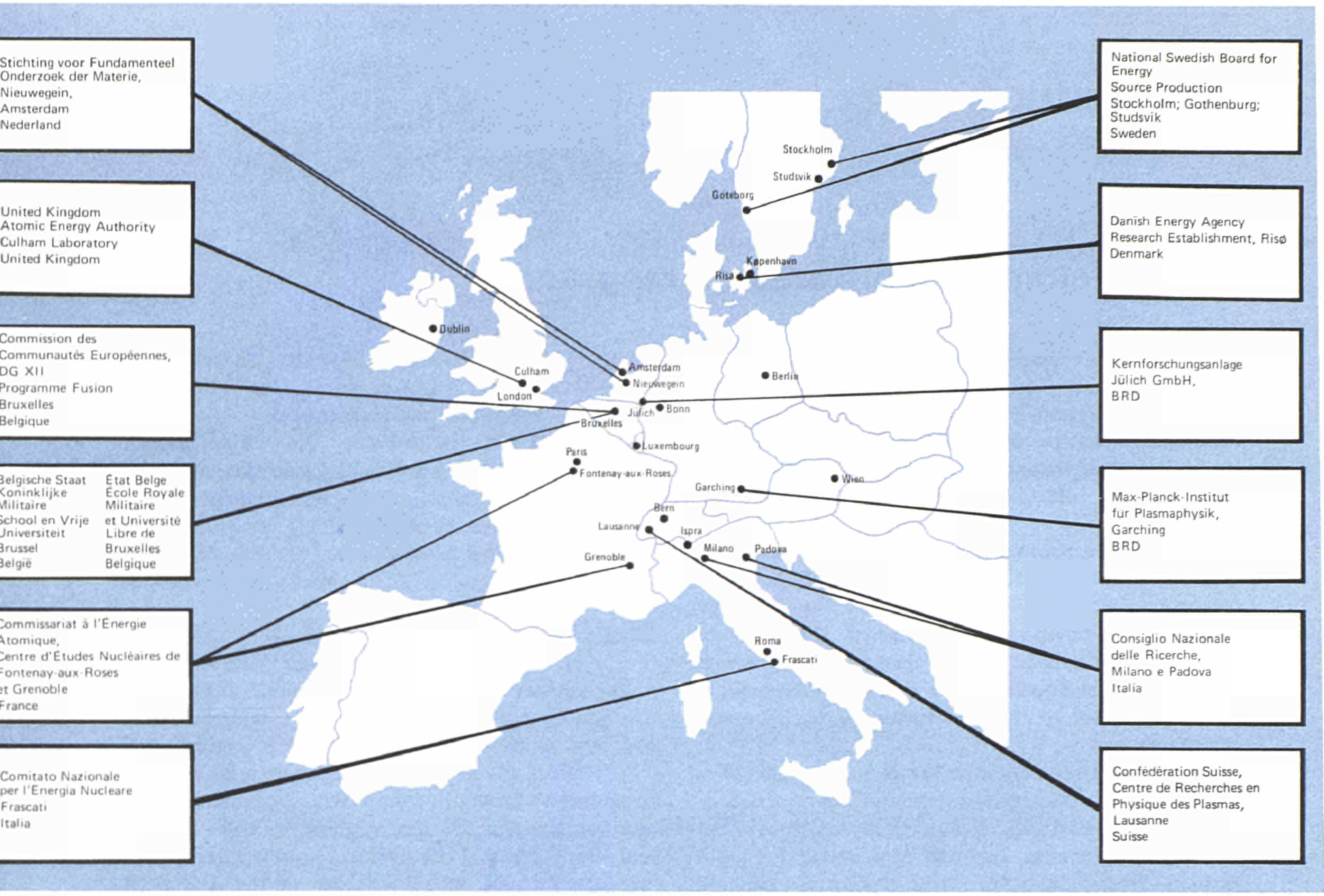

Fig. 13 Organisations associated with the Euratom fusion research programme.

countries outside the Community, in particular other European countries, e.g. Sweden. Switzerland, with a research laboratory at Lausanne (Centre de Recherches en Physique des Plasmas), is expected to join in 1979. The location of the Associated Laboratories is shown in Fig.13.

A Consultative Committee for Fusion (CCF) was created by the Commission (March 1976) and is composed of representatives of European Community Member States and Sweden (see Appendix 4). During 1976 and 1977 the CCF advised the Commission and informed the Council of Ministers on problems of the implementation and development of the fusion research programme including JET. The CCF continues to exist although the responsibility for the support and supervision of the JET Joint Undertaking was transferred in November 1977 to the Interim Jet Council (see Appendix 4), and now belongs to the JET Council (see page v).

Appendix 2

A Joint Undertaking – Legal Entity

Article 49 of the Euratom Treaty (1957) 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 3

The JET Joint Undertaking – Relevant Documents

The Official Journal of the European Communities No. L151 of 7 June 1978 includes:

1. The "Council Decision of 30 May 1978 amending Decision 76/345/Euratom adopting a research and training programme (1976 to 1980) of the European Atomic Energy Community in the field of fusion and plasma physics", (78/470/Euratom), pp.8–9. This describes the implications of the introduction of JET into the 1976–1980 Euratom fusion programme.
2. The "Council Decision of 30 May 1978 on the establishment of the 'Joint European Torus (JET), Joint Undertaking'", (78/471/Euratom), p.10.
3. "The Statutes of the 'Joint European Torus (JET), Joint Undertaking'" (referred to in this Annual Report as the JET Statutes), pp.11–20.
4. The "Annex to the Statutes of the 'Joint European Torus (JET), Joint Undertaking', Support from the Host Organisation", pp.21–22.
5. The "Council Decision of 30 May 1978 on the conferment of advantages on the 'Joint European Torus (JET), Joint Undertaking'", (78/472/Euratom), pp.23–24. This describes the consideration of taxes, duties and charges on the property, assets and revenue of the JET Joint Undertaking.

The "Financial Regulations of the 'Joint European Torus (JET), Joint Undertaking'" are specified in the Commission of the European Communities document XII/488/78 final. These are referred to in this Annual Report as the JET Financial Regulations.

Staffing procedures are defined in the "Supplementary Rules concerning the assignment and management of the staff of the JET Joint Undertaking", EUR FU 78/IJC 4/SR.

Appendix 4

JET-Related Committees Prior to the Establishment of the JET Joint Undertaking

Partners to the JET Design Agreement

The JET Design Agreement was an agreement between the European Atomic Energy Community (Euratom), represented by the Commission of the European Communities (EUR) and the Associates listed below. The agreement initially covered the period 1 October 1973 – 31 December 1975 but was subject to various extensions:

(i) to 30 June 1976
(ii) to 31 December 1976
(iii) to 30 June 1977
(iv) to 31 October 1977.

The partners were:

CEA – Commissariat à l'Énergie Atomique (Laboratories at Fontenay-aux-Roses and Grenoble).
CNEN – Comitato Nazionale per l'Energia Nucleare (Laboratory at Frascati).
CNR – Consiglio Nazionale delle Ricerche (Laboratories at Milan and Padua).
DEA – Danish Energy Agency (Laboratory at Risø).
EB – Belgian State (Laboratories of the École Royale Militaire and the Université Libre de Bruxelles).
FOM – Stichting voor Fundamenteel Onderzoek der Materie (Laboratories at Nieuwegein, Amsterdam and Eindhoven).
IPP – Max-Planck-Institut für Plasmaphysik (Laboratory at Garching).
KFA – Kernforschungsanlage Jülich GmbH (Laboratory at Jülich).
NE – National Swedish Board for Energy Source Development (Laboratories at Stockholm, Göteborg, and Studsvik)*
UKAEA – United Kingdom Atomic Energy Authority (Laboratory at Culham).

JET Working Group (February 1972 – March 1973)
Chairman : H. Luc (CEA) (deceased 24 March 1972)
L. Enriques (CNEN)
Secretary : C. Lafleur (EUR)
R. Andreani (CNEN), G. Briffod (CEA), B. Brandt (FOM), L. Enriques (CNEN), C.G. Fairclough (EUR), A. Gibson (UKAEA), M. Huguet (CEA), F. Karger (IPP), A. Knobloch (IPP), P. Komarek (KFA), P. Noll (KFA), P.H. Rebut (CEA), A. van Ingen (FOM).

Ad Hoc Group (May/June 1973)
R. Andreani (CNEN), D. Eckhartt (IPP), A. Gibson (UKAEA), M. Huguet (CEA), P.H. Rebut (CEA), D.L. Smart (UKAEA).

JET Project Board (September 1973 – May 1978)
Chairman : P.H. Rebut (CEA)
E. Bertolini (CNEN), D. Eckhartt (IPP), A. Gibson (UKAEA), J.P. Poffé (EUR), D.L. Smart (UKAEA).

*Participation from 1 July 1976

JET Supervisory Board (July 1973 – June 1976)
Chairman : R. Toschi (CNEN-CNR)
Secretary : C. Lafleur (EUR) (deceased 22 January 1976)
B. Brandt (EUR)
R.J. Bickerton (UKAEA), C.M. Braams (FOM), G. von Gierke (IPP), D. Palumbo (EUR), F. Prevot (CEA), F. Waelbroeck (EUR).

JET Scientific and Technical Committee (June 1974 – June 1975)
Chairman : R.J. Bickerton (UKAEA)
Secretary : B. Brandt (EUR)
J.B. Adams (CERN), B. Coppi (MIT, Cambridge, USA), L. Enriques (CNEN-CNR), G. Grieger (IPP), D. Kind (Institut für Hochspannungstechnik und Elektrische Anlagen), G. Laval (École Polytechnique), C. Mercier (CEA), D. Pfirsch (IPP), D.C. Robinson (UKAEA), H.G. van Bueren (Sterrewacht Sonneborgh, Utrecht), P.E.M. Vandenplas (EB).

JET Site Committee (April 1974 – February 1975)
Chairmen : G. Grieger (IPP), G. Stoecklin (KFA)
Secretary : C. Lafleur (EUR)
N.A. Gadegaard (DEA), C. Gourdon (CEA), M. Longo (CNEN-CNR), M. Neve de Mevergnies (EB), D. Palumbo (EUR), A. van Ingen (FOM), D.R. Willson (UKAEA).

JET Administrative Committee (November 1974 – July 1975)
Chairman : K. Melchinger (EUR)
Secretary : M. Bauer (JET-IPP)
Miss L. Buyse (EB), N.A. Gadegaard (DEA), J. Hoverstreydt (FOM), M. Longo (CNEN-CNR), E.J. Meusel (IPP), P.G. Oates (UKAEA), J. Pellerin (CEA), W. Schroeck-Vietor (KFA).

Consultative Committee on Fusion (April 1976 – November 1977*)†
Chairman : H. von Bülow (Denmark)
Secretary : U. Finzi (EUR)
M. Frérotte (Belgium), J.W. Graham (Ireland), J.D. de Haan (Netherlands), A. Larsson (Sweden), W. Marshall (UK), C. Salvetti (Italy), W.J. Schmidt-Küster (Federal Republic of Germany), G. Schuster (EUR), J. Teillac (France).

JET Management Committee (July 1976 – June 1978)
Chairman : R.S. Pease (UKAEA)
Secretary : R. Saison (EUR)
C. Cunningham (Ireland), Mrs. Elbaek-Jorgensen (Denmark), H. Kofoed-Hansen (Denmark), G. von Gierke (IPP), G. Holte (NE), L. Ornstein (FOM), D. Palumbo (EUR), F. Prevot (CEA), D.I. Rasmussen (DEA), R. Toschi (CNEN), R. Vanhaelewijn (EB).

*Special responsibility for JET-related matters ceased.
†Membership in May 1976.

Interim JET Council (November 1977 – May 1978)
Chairman : J. Teillac (France)
Secretary : R. Saison (EUR)

Belgium:	M. Frérotte, P.E.M. Vandenplas*
Denmark:	H. von Bülow, C.F. Jacobsen*
Federal Republic of Germany:	G. von Klitzing, R. Wienecke*
France:	J. Teillac, J. Horowitz*
Ireland:	S. Collins, C. Cunningham*
Italy:	C. Salvetti, R. Toschi*
Luxembourg:	Permanent Brussels representative
Netherlands:	J.D. de Haan, C.M. Braams*
Sweden:	L. Rey, G. Holte*
UK:	C. Herzig, A.M. Allen
EUR:	G. Schuster, D. Palumbo*

IJC Working Group on Statutes (November 1977 – March 1978)
Chairman : G. von Klitzing (Federal Republic of Germany)
Secretary : Miss C.U. Roedig (EUR)

C. Cunningham (Ireland), Mrs. Elbaek-Jorgensen (Denmark), A. Gibson (JET-UKAEA), C. Gourdon (CEA), B. Brands (Netherlands), V. Hertling (KFA), M. Longo (CNEN-CNR), C. Mallman (IPP), K. Melchinger (EUR), P.G. Oates (UKAEA), L. Procope (CEA), P.J. Svenningsson (NE).

IJC Working Group on Finance (November 1977 – February 1978)
Chairman : A.M. Allan (UKAEA)
Secretary : C.M. Vandenavont (EUR)

B. Brand (Federal Republic of Germany), Miss L. Buyse (EB), D. Eckhartt (JET-IPP), J. Fabre (France), G. von Gierke (IPP), H. Kofoed-Hansen (Denmark), K. Lundgren (NE), K. Melchinger (EUR), L. Procope (CEA), M. Purificato (Italy), K. Salow (IPP), P.J. Svenningsson (NE), J. Wright (UKAEA).

IJC Working Group on Host Support (December 1977 – February 1978)
Chairman : C.M. Braams (FOM)
Secretary : D.R. Willson (EUR)

E. Bertolini (JET-CNEN), V.G. Birchall (UKAEA), M. de Cort (EB), M. Ferrini (CNEN), G. Giacchetti (EUR), V. Hertling (KFA), A. Ilse (IPP), K. Melchinger (EUR), P. O'Brien (Ireland), R.S. Pease (UKAEA), J. Pellerin (CEA), J.P. Poffé (JET-EUR), F. Prevot (CEA), A. Verhaegen (EUR), C.J.H. Watson (UKAEA).

IJC Working Group on Staff (January 1978 – April 1978)
Chairman : D. Palumbo (EUR)
Secretary : A. Malein (EUR)

J. Baxter (EUR), T. Brand (Federal Republic of Germany), Miss L. Buyse (EB), Mrs. L. Fox (UKAEA), R. Grunwald (IPP), E. Hollis (UKAEA), H. Lammers (FOM), K. Lundgren (NE), T. Nielsen (DEA), P. O'Brien (Ireland), J. O'Connor (Ireland), L. Peek (FOM), A. Ricci (Italy), D. Rogalla (EUR), D.L. Smart (JET-UKAEA), P. Toublanc (France), D.R. Willson (EUR).

*Scientific expert

Appendix 5

The JET Executive Committee

European Atomic Energy Community:	
Bruxelles, Belgium.	D. Palumbo K. Melchinger R. Saison (Secretary)
Belgium:	
CEN/SCK, Mol, Belgium.	R. Vanhaelewijn
Denmark:	
Research Establishment Risø, Roskilde, Denmark.	V. O. Jensen I. Rasmussen
Federal Republic of Germany:	
Max-Planck-Institut für Plasmaphysik, Garching/München, Federal Republic of Germany.	G. von Gierke
Kernforschungsanlage Jülich GmbH, Jülich, Federal Republic of Germany.	V. Hertling
France:	
Association EUR-CEA, Fontenay-aux-Roses, France.	F. Prevot
Ministère du Budget Paris, France.	J. M. Fabre
Ireland:	
Nuclear Energy Board, Dublin, Ireland.	C. Cunningham
Department of Economic Planning and Development, Dublin, Ireland.	M. Manahan
Italy:	
Comitato Nazionale per l'Energia Nucleare, Centro di Frascati, Frascati, Italy.	R. Toschi (Chairman)
Luxembourg:	
Ministère de l'Énergie, Luxembourg.	R. Becker
Netherlands:	
FOM-Instituut voor Plasmafysica, Nieuwegein, Netherlands.	L. Ornstein
FOM, Utrecht, Netherlands.	B. J. M. Staffhorst
Sweden:	
AB Atomenergi, Nykoeping, Sweden.	G. Holte
United Kingdom:	
Culham Laboratory, Abingdon, England.	R. S. Pease
United Kingdom Atomic Energy Authority, London, England.	F. Chadwick

Technical Terms, Symbols and Units

A *torus* is the mathematical name given to the shape commonly encountered as a life-belt, tyre-tube or doughnut.

The standard units are sometimes inconveniently large (small) and it is common practice to use a prefix to define a smaller (larger) unit, for example:

1 ms (millisecond) is 1/1 000 of a second or 10^{-3} s
1 kG (kilogauss) is 1 000 gauss or 10^{3} G
1 MW (megawatt) is 1000000 watts or 10^{6} W
1 GJ (gigajoule) is 1 000 million joules or 10^{9} J

Quantity	*Unit*	*Symbol*	*Comment*
Atomic number	–	Z	Z is the number of protons in the nucleus and characterises an element. Z = 1 for hydrogen and 92 for uranium.
Beta	–	β	β is a dimensionless number given by a characteristic ratio of plasma pressure to the pressure of the confining magnetic field. Present tokamak experimental values are of the order of 0·01. For fusion-reactor economic reasons it is desirable to increase β to the range 0·1 – 1.
Current	ampere	A	The current flowing in the filament of an ordinary one bar electric radiator is typically several amperes.
Density	number of particles per cubic centimetre (or metre)	cm^{-3} (or m^{-3})	10^{14} cm^{-3} means 100000000000000 particles per cubic centimetre (or 10^{20} m^{-3}).
Dimensions	metre centimetre	m cm	
Energy	joule	J	1 million joules (1 MJ) will raise about 3 litres of water from room temperature to boiling point.
	electron volt	eV	1 electron volt (1 eV) is the energy gained by an electron when accelerated from rest through a potential of 1 volt.
Frequency	hertz	Hz	Electromagnetic radiations, including the radio waves which can be used for heating JET are characterised by their frequency, e.g. 1 MHz corresponds to one million wave repetitions per second.
Magnetic field	gauss	G	The very weak magnetic field of earth has a maximum value of about 0·4 G. A typical bar magnet has a field near the end of about 5 000 G = 5 kG.
Mass	gramme	g	1 tonne equals 10^{6} g.

Quantity	*Unit*	*Symbol*	*Comment*
Money	unit of account	UC	1 Unit of Account was defined by reference to a given weight of gold with fixed parities (1 UC = 50 Belgian francs). It has been superseded by the EUA.
	European unit of account	EUA	1 European Unit of Account is made up of different national currencies and reflects the aggregate movement in those currencies as well as the day-to-day fluctuations between them. The value of the EUA in various national currencies is published daily, e.g. 1 EUA = 39·907 Belgian francs, 27 April 1978.
Power	watt	W	1 watt equals 1 joule of energy used per second. A community of about 1 million people in an industrialised country uses an average power of about 100 MW. To produce 1000 MW for one day we must burn about 10000 tonnes of coal or 6600 tonnes of oil, or in a fusion reactor about 2·4 kilogrammes of lithium. An electric heating element supplied at 100V and carrying a current of 10 A provides 1000 watts (1 kW) of heating.
	volt-ampere-reactive	VAR	The volt-ampere-reactive figure is the product of the voltage and the reactive current in an AC (alternating current) circuit.
	volt-ampere	VA	The volt-ampere figure is the product of the voltage and the current in an AC circuit.
Pressure	torr	Torr	Atmospheric pressure is 760 Torr. At room temperature a pressure of 1 Torr corresponds to a particle density of about $3{\cdot}5 \times 10^{16}$ particles per cubic centimetre. At 10^{-10} Torr there are $3{\cdot}5 \times 10^{6}$ particles cm^{-3}.
Temperature	degree kelvin (or electron volt)	K (eV)	The temperature of a gas is usually given in degrees kelvin, but it can be expressed in terms of the kinetic energy of the constituent particles. A convenient scale for plasma is to express temperature in keV where 1 keV (10^3 eV) is equivalent to $11{\cdot}6 \times 10^6$ degrees kelvin. Ion temperatures are usually denoted as T_i and electron temperatures as T_e.
Time	second	s	
Voltage	volt	V	A dry cell battery for a transistor radio typically has a voltage rating of 1·5 volts.
Weight	tonne	t	1 tonne weight is the force exerted on a mass of 10^6 g due to gravity.

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JET
JOINT UNDERTAKING

Report for the period 1 June – 31 December 1978

Errata

Page v This page should be headed "**Organs of the JET JOINT UNDERTAKING.**" The addresses of the members of the JET Council are ***not*** in every instance the addresses of the member organisations of the JET JOINT UNDERTAKING (see page 5) but ***are*** the addresses of the members of the JET Council as shown.

Under Denmark, the address for N.E. Busch should read: "**Risø National Laboratory, Denmark.**"

Under Netherlands, a second member should be added:

Foundation-FOM, **C. le Pair**
Utrecht,
Netherlands.

Page 4 Column 2, lines 30/31 should read:
"**. . . . , a decision was reached on 25 October 1977 . . . .**"

Page 4 Comment to the footnote (see also the footnote on page 34 and the text on page 30):
The CCF continues to be responsible for advising the Commission on the implementation and development of the entire Euratom fusion research programme.

Page 29 Column 1, 4 lines up:
DEA (Danish Energy Agency (Laboratory at Risø) should be replaced by:
RNL – Risø National Laboratory.

Page 29 Column 2, lines 19/20 should read:
"**The Liaison Group is composed of the scientific heads of the . . . .**"

Page 30 The second box down on the right should read:
"**Risø National Laboratory**
Denmark."

Page 33 Line 16:
DEA – Danish Energy Agency (Laboratory at Risø) should be replaced by:
RNL – Risø National Laboratory.

Page 34 Under JET Management Committee, replace H. Kofoed-Hansen (Denmark) by:
O. Kofoed-Hansen (Risø) and delete: **D.I. Rasmussen (DEA).**

Page 35 Under IJC Working Group on Finance, replace H. Kofoed-Hansen (Denmark) by:
T. Nielsen (Denmark).

Page 35 Under IJC Working Group on Staff, T. Nielsen (DEA) should read:
T. Nielsen (Denmark).

Page 36 The address of the Danish Members should read:
"**Risø National Laboratory**
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