# COMMISSION OF THE EUROPEAN COMMUNITIES

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PROPOSAL

FOR A

RESEARCH AND TRAINING PROGRAMME (1979-1983)

FOR THE EUROPEAN ATOMIC ENERGY COMMUNITY

IN THE FIELD OF CONTROLLED THERMONUCLEAR FUSION

(presented to the Council by the Commission)

The programme proposed by the Commission covers practically the overall European programme on fusion. It has been established on the basis of the recommendations issued by the "Liaison Group" (assisted by "Advisory Groups" and "Experts"), taking into account the preliminary advice formulated by the "Consultative Committee for Fusion". Consultations with the associated organizations have been ensured also through the "Committee of Directors".

The Commission expresses its gratitude to the members of these bodies for their help in defining a compromise between ambitious technical proposals and realistic financial constraints.

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# CHAPTER I

# INTRODUCTION

## I.1 FUSION AS AN ENERGY SOURCE

The problem of energy sources at the world level in the long term is far from being solved. Thermonuclear fusion is one of the very few sources which might solve this problem or give a substantial contribution to its solution. The seriousness of the energy problem for Europe does not need to be stressed here. The potential benefits that Europe might draw from fusion energy are particularly important on account of its high level of energy consumption per unit area and of its latitude and climate.

The development of fusion power reactors is a long, complex and expensive venture and its success, in the light of the present state of knowledge, is not guaranteed. But in view of the importance of the final goal, the costs and the risks are not disproportionate. The yearly cost of the present fusion programme is comparable to that of 1 day's present oil consumption in the Community.

Based on such considerations, in 1958, the European Community started a programme on "Controlled Thermonuclear Fusion and Plasma Physics" whose aim is to establish the possibility of producing, at competitive cost, useful energy from the reactions between light nuclei. This programme is designed to lead in due course to the joint construction of prototype reactors with a view to their industrialisation and marketing. There must be continuous assessment of the potential of fusion power and the resources required to achieve it, in order to provide a basis for planning decisions in the more general frame of energy research and development.

Considering the progress made in recent years one can reasonably expect that scientific feasibility should be demonstrated within the next decade. The continuation and a moderate extension of the present effort should be sufficient to reach this first goal. The next steps should be the demonstration first of technical feasibility and then of economic power production. Planning studies carried out independently by various groups of experts in the world indicate that a demonstration reactor could be built at the turn of the century. But in order to do this, it is essential to start making progress now on the problems of technical feasibility and this requires an increased effort in fusion technology.

## I.2 COMMUNITY NATURE OF THE PROGRAMME

The programme is, by decision of the Council, a long term collaborative project embracing all work carried out within the Member States on fusion and plasma physics, and is partly financed by the Community. In the past, the Community was able to overcome the difficulties in setting up a common European programme in the field of physics. Now, the progress made implies the launching of a substantial programme of fusion technology for which European integration, although difficult, is even more necessary than for the physics part of the programme. The original decision of the Council to proceed on a European basis to the R. and D. leading to fusion reactors was the result of far-reaching negotiations; specific national interests in the field of fusion should still be considered in this context. The Community aspect of the whole programme must be accentuated to ensure an efficient and economical development leading to the reactor. Such a trend is well illustrated by the recent creation of the Joint Undertaking JET, which will be the focal point of the European programme in the coming years. The ability of Europe to design an advanced project of the importance of JET in only a few years has been the consequence of the patient effort of integration previously realised with the Associations.

## I.3 MOTIVATION FOR THE INITIATIVE OF THE COMMISSION

Since its creation, Euratom has contributed funds and manpower to promote activities in the laboratories of the member States and their integration in a common programme within the Associations.

The principal motivations for such an initiative of the Commission are :

- the scale of human and financial resources required, which suggests not carrying such a development on a national basis;
- the existence of a collective need, common to all member States;
- the long time scale of the effort (extending towards the end of the century) necessary to arrive at the reactor;
- the opening of a wide community market for the European reactor, when success is achieved.

## I.4 MOTIVATION OF THE PRESENT PROGRAMME PROPOSAL

The principle of the "sliding programme" (adoption of a new five-year programme after three years of implementation of the preceding one) was proposed by the Commission in 1975 in order to ensure the continuity of the programme and to re-orient it if necessary, taking into account the evolution of the scientific and technical situation.

The Council of Ministers on 25 March 1976 decided that "The Commission will submit to the Council in 1978 a review proposal designed to replace the present programme with a new five-year programme as from 1 January 1979"(1).

The Scientific and Technical Committee (STC) in its opinion on the proposed five-year fusion programme 1976-80 "regarded as positive the Commission's intention to provide for a review of the situation at mid-programme and for a rolling programme" and "asked the Commission to pay special attention, when the revision is undertaken, to fusion by inertial confinement and to technological problems".

The Commission deems it necessary to propose the present programme for the following reasons :

a) the progress achieved in Tokamak physics makes it possible to undertake new specific experiments necessary for further progress;

b) heating methods recently developed and successfully tested can now be applied to confining devices already built or under construction : a quantitative step in the effort on plasma heating is necessary;

c) since the decision on the construction of JET has been taken, it seems wise to start pre-definition work for the next step in order to be able to undertake its design during the following five-year programme : this implies an adjustment of the short term aims of the programme and of its contents;

d) the key fusion technology problems for the Tokamak line have been identified and international collaboration is starting on two of these problems (large supraconducting coils and effects of neutron bombardment on materials) : the setting up of a technology programme aiming at the solution of the problems relevant to the next step is now possible and desirable.

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(1) O.J. N° L 90 of 3 April 1976.-

# CHAPTER II

# PRESENT SITUATION OF THERMONUCLEAR FUSION RESEARCH

## II.1 TERMS OF REFERENCE

### II.1.1 Physics

To achieve a positive energy balance by fusion processes, the plasma temperature (more precisely the ion temperature) must exceed a typical value of 10 keV and the quality of the plasma confinement must also exceed a certain limit. A figure of merit measuring the quality of plasma confinement is the product $n\tau$ of the plasma density "n" and the confinement time "$\tau$". A fusion reactor will require $n\tau$ larger than $10^{14}$ ions per $cm^3$ seconds. The problem in fusion research is then first to reach these minimum values (physical feasibility), then to build a machine which faces all the technical problems that will be met in a reactor (technical feasibility), and finally to arrive at a reactor which produces energy at a competitive cost (economic feasibility).
In fact, these 3 steps are not independent : for instance, in planning experiments aiming at demonstrating physical feasibility, it is clearly of the utmost interest to consider the possibility of eventual extrapolations to future reactors.

### II.1.2 Magnetic and inertial confinements

In reaching the required value of $n\tau$, two extreme methods are conceivable :

- One can take a relatively low value for the density and maintain this for "long" confinement times (of the order of one minute); this is the route chosen by the magnetic confinement in which a plasma of large dimensions (many $m^3$) is maintained within a fixed volume (often of toroidal shape) by the action of magnetic fields created both by large currents circulating in external coils and, in the case of Tokamaks, in the plasma itself;
- One can use very high plasma densities for short periods (shorter than a millionth of a second). This is the inertial confinement route, in which the fuel (deuterium and tritium) initially

contained in a small (less than 1 cm) hollow sphere is compressed and heated very rapidly by intense beams of light (lasers), electrons or ions. The fuel subsequently undergoes fusion reactions during the free explosion of the "pellet". The duration is limited only by inertia, hence the name "inertial confinement";

- Past research has indicated that intermediate solutions do not seem to be very promising.

## II.2 SCIENTIFIC AND TECHNICAL SITUATION

### II.2.1 Magnetic Confinement

The situation is illustrated (figure 1 - A, B, C) through the evolution during the last few years of some major fundamental plasma parameters in Tokamaks (a particular type of toroidal device). The figures indicate also the minimum values (already mentioned) necessary to reach the reactor domain. It should be underlined that impressive progress has been reported recently in the Tokamak line :

1. An ion temperature of 60 millions degrees (rather close to what will be necessary in a reactor), at a density of $2.10^{13}$ ions per $cm^3$, has been obtained at Princeton in the PLT device. This major result shows that the fear of adverse effects due to high ion temperatures (see paragraph III.3.1.3) is likely to be unfounded.

2. The favourable scaling law (see paragraph III.3.1.1) of the confinement time $\tau$ ($\tau$ proportional to plasma density and to the square of the minor plasma radius) has been confirmed to be valid in a wider range of paramaters, mostly by FT (Frascati) working at 600 kamp and 80 kGauss, and PLT (Princeton) working at high temperature.

3. Beta values (see paragraph III.3.1.2) have reached mean values of 2 %, in the devices T 11 (USSR) and Tosca (Culham). Moreover, for a given toroidal magnetic field, it has been possible to increase noticeably the plasma current in several devices : Diva (Japan), Alcator (USA), TFR (Fontenay-aux-Roses) and T 11 (USSR).

Most of this progress results directly from the use of powerful auxiliary heating.

A simple extrapolation of the rate of progress gives confidence for entering the reactor domain shortly after the end of the five-year programme, relying on the next generation of machine. This is not to say that any of these machines will be a reactor itself, they will give access to new plasma regimes at higher temperatures which could possibly modify the expected scaling laws. The unknown behaviour of plasmas containing tritium and producing a large amount of thermonuclear energy will certainly require extensive investigation. Moreover, associated technologies will have to be fully developed before demonstrating technical feasibility.

### II.2.2 Inertial Confinement

Recent results are very promising : symmetrical implosions of pellets have been obtained, which led to high compression ratios (about 1000) of the plasma, and appreciable rates of thermonuclear reactions ($10^9$ per shot). Considerable progress in laser fusion technology (see figure 1 - D) and in electron beam generators is likely to lead to a rapid improvement in the performance of these systems. More specifically :

1. Laser fusion. Two multibeam systems are operating now at a power level above 10 TW : Shiva (neodimium) at Livermore and Helios ($CO_2$) at Los Alamos. Pellet implosions at full power will be performed systematically in the near future. Antares, a 100 TW $CO_2$ laser system, is under construction at Los Alamos ; completion is scheduled for 1982.

2. Electron beams. Significant progress has been made on beam-transport techniques, allowing the design of multibeam systems. EBFA, a 20 beam 30 TW device, is scheduled to be operational at Sandia (USA) in 1980. A 100 TW device is under construction at the Kurchatov Institute (Moscow).

Very important results should then be obtained in the coming years. "Breakeven" experiments, demonstrating physical feasibility, are foreseen in the mid eighties.

## II.3 WORLD CONTEXT

### II.3.1 Budgets

In three years (75-78) the annual American fusion budget has more than doubled, crossing the 400 million dollars line in 1978 (for both magnetic and inertial confinement). The Japanese effort has increased considerably (by a factor of 12 between 1970 and 1976) now reaching nearly half the European effort. In the USSR, where absolute figures are difficult to obtain, it appears that the effort remains comparable with that of the USA.

### II.3.2 Large Tokamaks

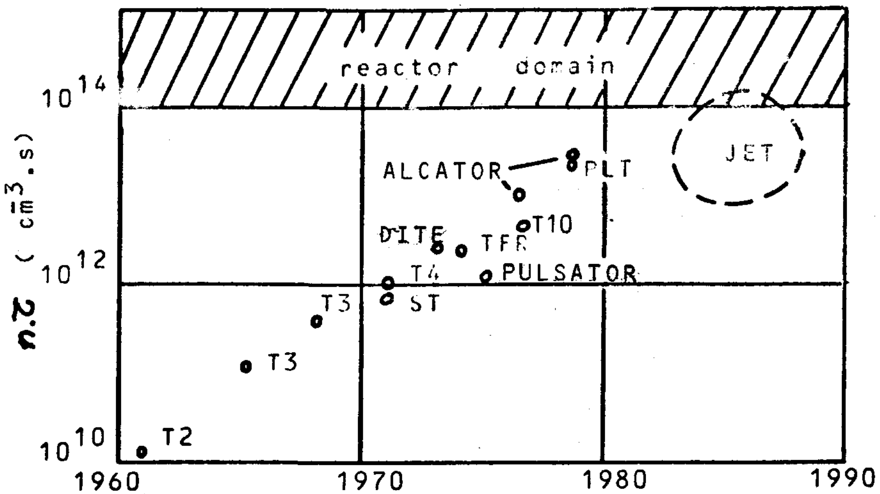
Given the progress of Tokamaks, an example of magnetic confinement device, the expansion of this line has been much faster than the others. Each programme includes, in addition to projects of intermediate size, the preparation and the construction of a large Tokamak to be ready at the beginning of next decade (JET in Europe, TFTR in the USA, JT-60 in Japan, T-10 M in USSR). Moreover, it is predominantly on the Tokamak scheme that technological problems associated with future reactors are analysed.

### II.3.3 Other magnetic approaches

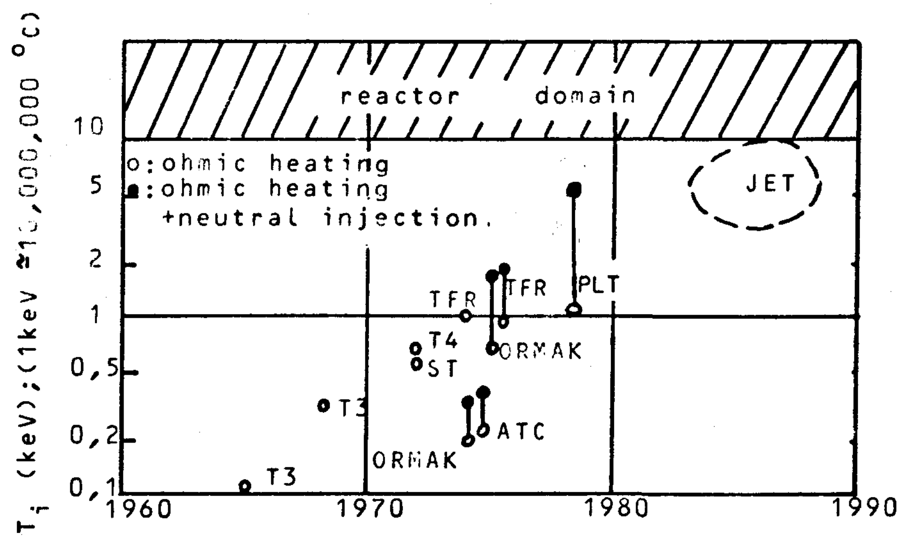
In relative terms, the activities on magnetic mirrors, Stellarators and high-beta configurations have decreased during the last few years. However, the Americans have obtained appreciable success with mirrors and are maintaining a substantial effort in this field whereas they have ceased major work on Stellarators. Europe has done the opposite, abandoning the mirrors to concentrate on Stellarators (Wendelstein VII A, at Garching, is the largest existing Stellarator) and high-beta configurations, so that the programmes are complementary for these auxiliary lines.

### II.3.4 Inertial confinement

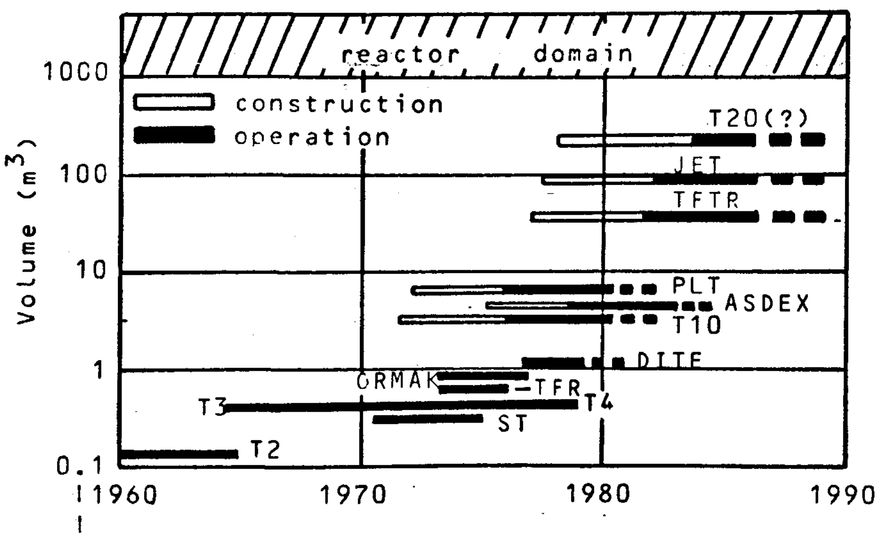
This line of research represents a true alternative to Tokamaks. Although new (large scale activity started only in 1971), it is rapidly expanding in the USA, the USSR and in Japan (from a negligible fraction of the whole American effort in 1972, it climbed to roughly 30 % of the USA fusion budget in 1978). In this line, many problems are still open (e.g. the choice between laser and



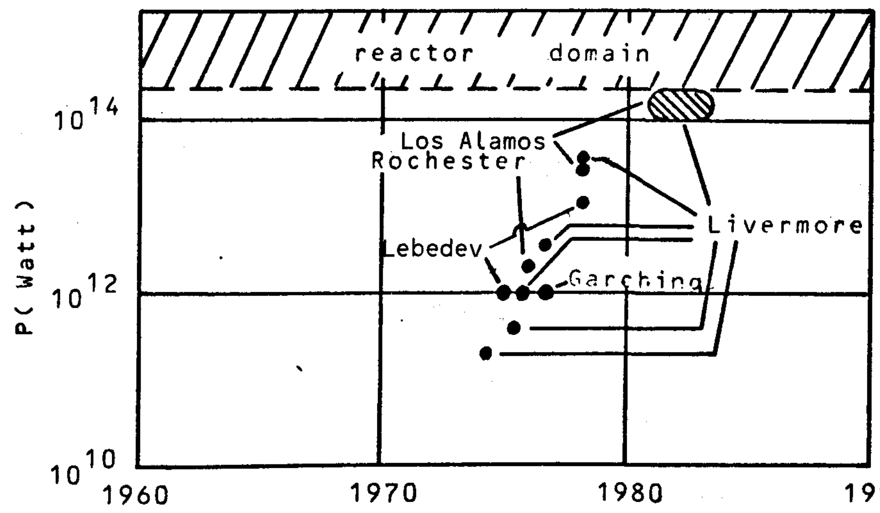

A - QUALITY OF CONFINEMENT IN TOKAMAKS.




B - ION TEMPERATURE IN TOKAMAKS.




C - PLASMA VOLUME IN TOKAMAKS.




D - LASER POWER OUTPUT.

FIG.1. EVOLUTION OF IMPORTANT PARAMETERS SINCE 1960

electron or ion beams). Nevertheless, crucial experiments are programmed for the early eighties; for instance SHIVA-NOVA, a $10^{14}$ watt laser beam experiment at Livermore should become operational before JET and could lead to break-even conditions.

### II.3.5 International collaboration

- World-wide, informal exchange of information has taken place for many years in a very satisfactory way, particularly in the field of magnetic confinement. It should be stressed that the associated laboratories can participate in this exchange of information only as long as the Community fusion programme contributes substantially to the world results. The imbalance due to the increased US effort during the last few years is already noticeable. Official cooperation is in progress in the frame of two organisations : the International Atomic Energy Agency (IAEA) and the International Energy Agency (IEA).
- The Commission is represented in the International Fusion Research Council of the IAEA, through which it contributes to the organisation of the World Conferences on Plasma Physics and Controlled Nuclear Fusion Research, to the publication of the review "Nuclear Fusion", and to other specific cooperative ventures, e.g. an annual conference on large Tokamaks.
- In the frame of the IEA, the Commission is "lead organisation" in the field of thermonuclear fusion research and acts on behalf of its partners in the Community fusion programme, for the conclusion of specific agreements. Three implementing agreements prepared by the Fusion Power Coordinating Committee of the IEA have been concluded in the last two years : on the Intense Neutron Source, on the Large Coil Project and on plasma-wall interaction (Textor). Moreover, a periodic exchange of information on Very Large Experimental Devices (TFTR in the USA, JET in the Community and JT-60 in Japan) completed by a series of workshops on specific construction problems, has been in progress for three years.

## II.4 SITUATION IN EUROPE

### II.4.1 Introduction

- This five-year plan is the fifth to be proposed to the Council.

For the first time, a further plan is produced while the previous one has only been running for less than three years, in agreement with the decision of the Council of 25 March 1976. Even though three years may be a short time in research, a number of subjects have shown significant progress since the presentation of the last plan, as reported below, which justifies "a posteriori" the usefulness of the "sliding programme" concept.

- The main aim of the last 2 plans has been to develop Tokamak research in Europe to an internationally competitive level. This aim has been fully reached : the construction of JET has effectively started, and a complementary set of medium-size devices has allowed Europe to play a leading role in Tokamak world research during the last few years. Other devices are under construction or in the phase of definition.
- Within the magnetic confinement approach, alternatives to Tokamaks (Stellarators, high-beta configurations,...) are being studied at an appropriate level. Their relative weight in the overall effort is decreasing.
- Methods for heating the plasma have been developed with great success. Heating developments absorb a large, and increasing, fraction of the fusion programme.
- Inertial confinement represents a small part of the total effort.
- A relatively small technological programme exists, devoted both to the present type of machine and to the next generation of experiments, with the fusion reactor as the final goal. This programme is expanding at the moment due mainly to the increased interest in the field of superconductivity.

II.4.2 JET

The preparation of the "Joint Undertaking JET" has been concluded in 1977 with the choice of Culham as a site. At the end of the interim phase (June 1978) the construction phase has started. The machine is planned to be operational for basic performance in 1983 or even earlier (see paragraph III.3.2.1). At the end of the interim phase of the Project, the JET staff amounts to about 50 and the internal management structure of the team has been established. About 150 contracts for specific work for the implementation of the programme have been placed with the Associations. For work to be performed by third parties (mostly industry), about 100 contracts have been placed which mainly concern tests and manufacture of components for the machine. In particular, the vacuum vessel, the toroidal coils and the power supplies (flywheel-generator-convertor systems) have been ordered. Finally, a consultancy contract has been placed for the JET specific buildings and associated services.

### II.4.3 Other Tokamaks

A Tokamak device can be basically characterized by its dimensions and its confining magnetic fields. The plasma it contains should ideally be dense, hot, clean, confined for a long time $\tau$, and have a high "$\beta$" ($\beta$ is the ratio between the plasma pressure and the pressure exerted by the magnetic field, and is a measure of the efficiency of the device). JET alone is neither sufficient nor is it designed to tackle all the problems which should be solved before Tokamaks of the next generation can be launched. The major Tokamaks already in full exploitation in the Community, TFR (Fontenay), Pulsator (Garching) and Dite (Culham) have contributed very substantially to the general progress. TFR remained the most powerful Tokamak (I = 400 kA) in the world until 1976, when T-10 and PLT started to operate; recently, temperatures of 2 keV have been obtained. Pulsator produced an excellent contribution to the study of plasma instabilities and, despite its relatively small size and low magnetic field, produced plasma of high density $\underline{n}$ and of large product $\underline{n.\tau}$. Dite has been the first Tokamak to incorporate a divertor (or magnetic system to extract plasma impurities) and is being used for important experiments on plasma heating by injection of fast neutral particles. Tosca (Culham) is a small Tokamak studying shaped cross-sections and adiabatic compression. Erasmus (Brussels) which is a small but very compact device and Petula and Wega (Grenoble) are devoted mainly to the study of plasma heating by RF schemes. FT (Frascati), a high magnetic field device, is the most ambitious technological undertaking decided in Europe during the third programme; it came into operation late in 1977 and could be among the first Tokamaks in the world to reach one mega-ampere current in the plasma. Besides the modification of TFR recently achieved to allow higher performance, some quite large new devices are near completion : Asdex (Garching) will be a Tokamak with a poloidal divertor and powerful heating by neutral injection, and Textor (Jülich), which is the object of an international implementing agreement for cooperation with the Americans, will be mostly devoted to the important problem of plasma-wall interaction.

II.4.4 Heating

- As a Tokamak configuration is essentially defined as the combination of a toroidal current carried by the plasma and a super imposed toroidal field, Ohmic heating is intrinsically present in a Tokamak. But it can be demonstrated that, with the possible exception of very high field devices, Ohmic heating will never lead to fusion temperatures. Moreover, for a given toroidal field, the influence of ohmic heating decreases when the size of the machine increases. Therefore, in the larger devices presently completed or in construction, auxiliary heating is required to achieve high performances. The importance of powerful auxiliary heating has been fully realized during the last years : it is thought that, in most future Tokamaks, auxiliary heating systems could cost as much as the machine itself.
- Two methods are under active development : the injection of high intensity beams of neutral particles, a system which is already operational at appreciable power levels (one megawatt), and radio-frequency methods, which, although less advanced seem to be more promising for future large machines and reactors. The Commission has tried successfully to coordinate the R and D efforts on heating : the laboratories of Culham and Fontenay-aux-Roses are responsible for the development of neutral injection, whereas Grenoble and Brussels are specializing in RF. In addition, fundamental studies are carried out on turbulent heating and electron-beam heating.
- Power levels comparable to that of ohmic heating have been reached recently with neutral injection heating on TFR (600 KW) and Dite without disturbing the quality of the confinement. At the same time, 1 MW injector units are being developed at Culham and Fontenay-aux-Roses under JET contract. These injectors will also be available for devices like Textor, Asdex or TFR-604. Recent success in the development of neutral injection heating can be considered as one of the best achievements of the associated laboratories.

- Concerning the RF-heating schemes, high-level expertise has also been developed. Europe is truly competitive in this domain and possesses some toroidal devices especially devoted to study the application of this type of heating. Promising results have been obtained with Petula and Wega at the Grenoble Laboratory which has the major responsibility in this field and collaborates with E.R.M. (Brussels) where Erasmus is expected to contribute.

### II.4.5 Stellarators

These are toroidal systems in which the magnetic field is essentially produced by coils located outside the plasma chamber. Although being conceptually more complicated than Tokamaks, they should be more flexible and could in principle work continuously. Up to now the present devices, Wendelstein VII-A and Cleo, were operated with ohmic heating current. Ion temperatures of 300 eV and $n.\tau$ of $10^{12}$ were reached. With respect to comparable Tokamaks they show no disruption, a higher density limit and confinement properties increasing with decreasing ohmic heating current. Technical difficulties have up to now hindered the installation of the large chamber foreseen for W VII-A. Isar T-1, a "high-beta" Stellarator, has been terminated after showing the possibility of obtaining equilibrium in such configurations.

### II.4.6 High-beta configurations

Tokamaks have so far not reached values of $\beta$ that are required for an economic reactor. Moreover, theoretical predictions on the maximum $\beta$ are uncertain and still have not been checked experimentally. The behaviour of high $\beta$ plasmas is now being investigated in a number of devices : pulsed high $\beta$ Tokamaks, such as Spica (Jutphaas), Belt Pinch (Garching, discontinued) and Tenq (Jülich, discontinued), High $\beta$ Stellarators, and reversed field pinches. Most of the high $\beta$-activity in the Community is concentrated on the reversed field pinch in a collaborative programme between Culham (HBTX) and Padua (Eta-Beta). According to ideal fluid theory, reversed field pinches can be stable for $\beta$ up to 40 %. $\beta$ values between 10 % and 40 % have been observed experimentally although at low temperatures. The design of the large RFX experiment at Culham is now completed in a parameter range comparable with present day Tokamaks.

II.4.7 Inertial confinement

The general situation in Europe is unsatisfactory. Because of the possible military interest in certain aspects of inertial confinement, the Commission has not been able to co-ordinate the whole fusion activity in this field. Nor is it yet possible to promote the expansion of work on inertial confinement which seems to be justified both by recent published results from other countries, and also by the current policies of the USA, USSR and Japan.

- In the field of laser fusion, the Association Euratom- IPP and at a somewhat lower level the Association Euratom-CNEN are conducting limited experimental investigations, with some theoretical support from the Euratom-Etat Belge and Euratom-NSBESD (Sweden) Associations. These efforts are too modest to be competitive with those outside Europe. A few years ago, some new national programmes (Rutherford Laboratory, Ecole Polytechnique) appeared outside the Euratom fusion Programme and these are developing rapidly. Finally, in laboratories which are more or less classified it is known that a substantial effort is being made at Limeil and that some work is also going on at Aldermaston.
- In the field of electron or ion beam fusion, there is practically no activity in Europe.
- In the field of Plasma Focus, which is less sensitive, coordination is more satisfactory. Euratom-UKAEA and Euratom-CNEN Associations are working in close contact with several German Universities (Stuttgart in particular). An independent activity goes on at Limeil. High densities and thermonuclear temperatures are obtained for short times in these devices, resulting in a large number of fusion reactions. The performance of the one-Megajoule Frascati device is at present limited to $10^{12}$ neutrons per pulse ($10^{13}$ are expected from scaling laws) due to plasma-wall interactions which are at present under investigation.

II.4.8 Diagnostics

In spite of remarkable progress, Tokamak research is still in a situation where the accumulation of experimental observations is the main task of the physicists working in this field. Plasma diagnostics are then of vital importance and a large effort is being made, in all laboratories, to apply known techniques to specific machines or to develop new diagnostic methods. The local measurements of electron density and temperature are now made by well established methods, the determination of ion temperature and "chemical" composition of the plasma (impurity content) is less well developed while the measurements of the plasma-current distribution and of plasma-wall interactions are in an early stage of development.

In the field of inertial confinement, even the application of known diagnostics to the specific situation requires substantial efforts because of the very high space and time resolution involved (typically one thousandth of a millimeter, and one billionth of a second).

II.4.9 Theory and computing

The recent development of theoretical studies was characterised by a steadily growing interaction with the experimental programme on one hand and by a rapid increase in the numerical calculations on the other hand. The main theoretical effort has been centred on the understanding of Tokamak limitations (disruptive phenomena, anomalous thermal diffusion and dynamics of impurities) and on the successful application of the theory of electromagnetic wave propagation to the study of RF-heating. Powerful computer codes have been formulated for dealing with both plasma behaviour and Tokamak engineering, and are at present of common use in the different laboratories. The interpretation of experimental results (data acquisition systems) is another domain in which the use of computers is expanding rapidly.

II.4.10 Fusion technology

The technology programme was established in order to assess the possibility of implementing a strong task-oriented technology programme during the next five year plan.

The present activities in fusion technology are essentially the following :

1) In the area of the IEA-collaboration three implementing agreements are running :
   - Intense neutron sources : there is a large uncertainty in

the choice of project proposal, directed towards the construction of a 14 MeV neutron generator.

- Plasma-wall interaction : TEXTOR-Jülich (see II.4.3)
- Large Coil Project : LCP - Oak Ridge (USA). The European contribution consists of the construction of at least one NbTi coil, to be tested at the US test facility in a large toroidal magnetic configuration.

2) In July 1977, the Council of Ministers(1) allocated, in the framework of the Joint Research Centre multiannual activity (1977-80) a programme on thermonuclear fusion technology with the following guidelines(2) :
   - to pursue and extend the JRC participation in European conceptual design studies on fusion reactors, already running for some years in cooperation with Frascati and Naples (FINTOR-group)
   - to contribute to the analysis of problems related to the safety and environmental aspects of fusion,
   - to participate in the study of materials for fusion, in particular radiation damage effects and the evaluation of the techniques and equipment needed for such investigations.

3) In almost all associated laboratories, system studies were carried out, not only on Tokamaks but also on RFX (Culham), Internal Ring (Jülich, Stockholm), Belt/Screw Pinch (Petten, Jutphaas). A Garching based group leads in the setting up and implementation of a modular computer code for the study of different fusion concepts.

4) Pellet injection as a refuelling method is studied in Risø and Garching.

5) In addition to the main effort on conventional superconducting magnet development in Karlsruhe in connection with the Large

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(1) O.J. n° L 200 of 8 July 1977.

(2) Concerning administration and budget, this work is carried out under the responsibility of the JRC-Ispra. In order to ensure the unity of Community activity in the field of fusion, this work is co-ordinated by the Director of the Fusion Programme; the Liaison Group - of which the JRC is a member - plays the role of Advisory Committee on Programme Management for the research work carried out at the JRC.

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Coil Project, some initial work on advanced superconducting A-15 materials is carried out in Frascati, Petten and Saclay, the latter also involved in the testing of the superfluid-helium cooled conductors for the TORUS-II-Supra.

6) At Jülich, experimental work on the thermodynamics of Li-T systems is carried out.

7) At Jülich and Harwell, investigations on bulk neutron damage (simulation) are proceeding.

8) In Garching and Culham, surface damage by energetic particles is being investigated.

9) Neutronic studies are carried out at Harwell, Jülich and Karlsruhe.

II.4.11 Implementation

The importance of research on thermonuclear fusion justifies, more than ever, a coordinated action by the Community. What has already been done has been sufficiently attractive to induce countries not belonging to the Community to apply for association with the European fusion programme : a first agreement was concluded with Sweden in 1976, and one with Switzerland is likely to follow in 1978. Such agreements lead to contracts of Association.

During the former five-year plan the contract for mobility of personnel allowed about 40 physicists and engineers to move from their home laboratory to another associated laboratory for periods of several months, and a comparable number of exchanges has already taken place during the first half of the present plan. A transfer of material (e.g. diagnostic equipment) is often involved on such occasions. The study of plasma-wall interactions on TFR (Garching and Jülich teams at Fontenay) and the collaborative programme on Wega (Garching team at Grenoble) have been among the most significant activities of recent years. This close cooperation across national boundaries bears comparison with the best attainable even within member States.

For the implementation of its fusion programme, the Community relies upon :

1) a staff of 860 professionals (mid-1978) including the JET team. The total staff, including technical and administrative support, amounts to slightly over 3,000 people. This ensemble is not merely the sum of sub-groups geographically dispersed, but represents a well integrated complex of specialists able to work together on a European scale, as has been shown during the design phase of JET.

2) 19 specialized laboratories, with modern equipment. The names and the corresponding associations are given in table I.

3) management structures created on the initiative of the Commission, and through which the work of each laboratory is integrated in a true European framework. Because of these structures, the member States of the Community find themselves in a competitive position compared with other world fusion programmes.

TABLE I

| Associations & Organizations | Countries | Dates | Laboratories |
|---|---|---|---|
| EUR-CEA | France | 1959 | Fontenay-aux-Roses<br>Grenoble |
| EUR-CNEN/CNR | Italy | 1960 | Frascati and (later)<br>Padua and Milan |
| EUR-IPP | Germany | 1961 | Garching |
| EUR-FOM | Holland | 1962 | Jutphaas, Amsterdam |
| EUR-KFA | Germany | 1962 | Jülich |
| EUR-EB | Belgium | 1968 | ERM and ULB |
| EUR-UKAEA | U.K. | 1973 | Culham |
| EUR-Risø | Denmark | 1973 | Risø |
| EUR-NSBESD | Sweden | 1976 | Stockholm, Göteborg, Studsvik |
| EUR-CH | Switzerland | 1978 (?) | Lausanne |
| JET | | 1977 | adjacent to Culham |
| JRC | | 1977 | Ispra |

## II.5 SUMMARY OF THE MAIN ACHIEVEMENTS DURING THE FIRST THREE YEARS OF THE PRESENT PROGRAMME

### II.5.1 Tokamaks

From the point of view of the quality of confinement the most recent advances have been made in the USA where the $n\tau$ values of ALCATOR ($3.10^{13}$ $cm^{-3}$ s on axis) are now confirmed by PLT which has, in addition, reached ion temperatures of 5.5 keV. These results are short, by just an order of magnitude of the Lawson criterion in $n\tau$ and by less than a factor 2 in ion temperature. Ion temperatures exceeding 2 keV were reached in Europe in 1976 in TFR where, for the first time, the ion temperature exceeded the electron temperature.

Outstanding progress has recently been achieved in the Community concerning plasma purity. At the beginning of the 1976-80 programme this was a very serious problem ($Z_{eff} \gtrsim 3$). Clean plasmas ($Z_{eff} \simeq 1$) are now currently produced particularly in TFR, DITE and FT due to new discharge cleaning techniques and to a rapid advance in the diagnostics of impurity production and diffusion as well as in their understanding and control. A bundle divertor has been applied for the first time (DITE) and the "cold mantle" concept has become clearer (Jutphaas, Stockholm).

Recently developed feedback techniques for the control of plasma equilibrium are now available (CLEO-Tok, TFR 600, TOSCA). The ability to programme the time evolution of the mean plasma density first tested on ALCATOR and PULSATOR, is now achieved on almost all experiments.

All the understanding of Tokamak physics has advanced substantially in particular as a result of the detailed energy balance studies performed on TFR and DITE.

### II.5.2 Other devices

The operation of Stellarators (CLEO, W VII A) with ohmic heating current has shown that such mixed configurations exhibit better confinement properties than equivalent Tokamaks.

A substantial improvement in the understanding of the reversed field pinch, on which the high beta line is concentrating, has led to the construction of two medium size devices (ETA-BETA, HBTX-1A) now nearing completion.

II.5.3 Heating

In the field of neutral injection the achievements of the present programme are already remarkable. The first application to a Tokamak (CLEO), only four years ago, was at the 50 KW power level, well below that of the ohmic heating. The 1 MW level has now been reached, substantially exceeding the ohmic heating without affecting the plasma confinement (TFR, DITE). The development of 1 MW units for JET is in an advanced stage. Multi-MW systems are under construction (DITE, ASDEX, TFR 604).

Concerning the high frequency heating an outstanding contribution to the testing and the understanding of Lower Hybrid Resonance heating has been provided by the Community (Grenoble). The Transit Time Magnetic Pumping experiment on PETULA was the first successful application (without pump-out) of this method. Encouraging preliminary results on Ion Cyclotron Resonance Heating have recently been obtained on TFR.

II.5.4 Inertial Confinement

The very rapid world progress in this field has not been matched by the modest European effort which has led to the development of a 1 TW iodine laser (Garching), some progress in the understanding of plasma light interaction, and the launching of an experimental activity at Frascati.

II.5.5 Fusion technology

The main problems in this field have been identified. Moreover :

- in the areas of safety and system studies, and of materials, following the inclusion of these subjects in the JRC programme (1977-1980) new work has started at Ispra where a conceptual design activity in cooperation with Frascati (FINTOR group) was already being carried out. Preparatory work on radiation damage simulation is also in progress.
- in the area of supraconducting magnet technology following the conclusion of an IEA implementing agreement for the contribution from the Community (IPP-Karlsruhe) of a supraconducting coil for the Large Coil Project (Oak Ridge),

the design of such a coil has reached the stage where construction by industry is being considered. Tests on cooling with superfluid helium are in progress (CEA-Saclay).

### II.5.6 Conclusion

The above-mentioned progress shows that in comparison with the situation three years ago, Tokamak plasmas are better confined, better heated, and have much lower impurity concentration. Thus, we are substantially closer to the criterion needed for a fusion reactor, and there is correspondingly more confidence that the physical feasibility of a fusion reactor can be demonstrated.

# CHAPTER III

# PROPOSED PROGRAMME

## III.1 INFORMATION FROM LONG TERM PLANNING STUDIES

Exploratory long term planning studies, conducted in the framework of the Community programme as well as in other parts of the world, and based on the assumption that a future reactor would be of the Tokamak type, have indicated a choice of possible strategies to reach the goal of a demonstration reactor. These strategies lead to different time schedules and different total expenditures depending mainly upon the amount of risk they accept (to give an order of magnitude, about 25 years and 10.000 MEUA could be necessary to reach a demonstration reactor). But all strategies, even if they diverge at later times, have a common trunk : the machine(s) to be built after JET (or its foreign equivalents) should be deuterium-tritium burner(s), that is to say machines in which the fusion reactions will be sustained for long times. Thus, the European Community is in a position to fix clearly the aims of its fusion programme for the next few years, both in physics and in technology.

Long term planning studies will continuously re-assess the potential advantages of the various long-term strategies, in the light of fresh experimental results. Their conclusions will be formulated on the occasion of each programme revision, and will help to define new intermediate-term objectives.

## III.2 OBJECTIVES OF THE FIVE-YEAR PLAN

### III.2.1 Magnetic confinement

The steady progress made with Tokamaks has already led to a progressive concentration of effort in this direction, and this concentration will continue during the 79-83 plan. Research on low-beta Stellarators and on high-beta configurations which could possibly lead to alternative solutions, will be carried out in a few laboratories and will represent about 10 % of the total effort. For mirror machines, no experimental activity is foreseen.

The main objectives of the programme are :

- to complete the construction of JET and to begin its operation. The Commission has already sent to the Council several documents+) which have led to the approval of the construction phase of the JET project and the decision to include the project in the fusion programme. This priority action will, therefore, not be described again in detail in the present programme proposal ;

- to accumulate enough knowledge, both in physics and in technology, to be able to define the Post-JET machine(s) during the five-year period so that construction could start during the following plan. In particular, the research should determine the optimum field and size of the Post-JET machine(s), and allow an assessment of whether it should produce tritium and generate electricity. It should also provide experimental information on the advisability of using superconducting coils.

  This implies :

  - the construction of JET, scheduled to be operational in the year 1983, or earlier (see paragraph III.3.2.1) and the preparation of its experimental programme ;
  - the obtaining of much physical key information from intermediate size toroidal devices, of Tokamak type or of other types ;
  - the development of powerful auxiliary heating systems, in particular in view of their application to JET ;
  - the implementation of a more substantial technology programme, in particular in the field of materials, superconductivity, tritium handling, remote handling, and system studies ;
  - if preliminary test on superfluid helium cooled coils give positive results, the construction of a medium size supra-conducting Tokamak devoted to profile shaping studies and plasma heating ;

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+) In particular : R/820/78 (ATO 17) of 10 April 1978.

- if preliminary studies demonstrate a reasonable balance between risk and cost, the construction of a medium-size Very High Field Tokamak (V.H.F.T.), to study for the first time some specific problems of a "burning" plasma ;

- the initiation of design studies of Post-JET machines.

Another objective of the programme is to assess up to which point other magnetic confinement schemes (Stellarator, reversed field pinch) are real alternatives to Tokamaks.

### III.2.2 Inertial confinement

The European situation is unsatisfactory, and is likely to remain so for some time. Whereas the results already obtained abroad have led to a rapid acceleration of the American, Russian and Japanese programmes, political sensitivity due to the closeness of some civilian and military interests in this domain has caused the Commission to present, against its own wishes, a minimum programme which is sufficient :

- to enable a critical evaluation of results obtained elsewhere;

- to make significant contributions to some key problems, which is a basic condition for a fruitful exchange of information with foreign laboratories;

- to maintain a nucleus of competent scientists, to serve as a focal point for the remaining European efforts scattered in various civilian laboratories, and to permit during the next plan the construction of a large fusion feasibility experiment if the necessary political decisions were taken.

A change in the European policy will be essential if the crucial experiments planned abroad produce the expected results, such as a break-even in 1983.

Anyhow, even with its very limited effort, the Commission will endeavour to secure effective collaboration with other civilian laboratories, as has already been done in the past for the Plasma Focus.

## III.3 MAGNETIC CONFINEMENT

### III.3.1 Main problems

1) Quality of confinement. It has been seen that the important parameter here is the product of the density and the confinement time ($n.\tau$). One of the aims of the programme will be to improve the understanding and the quality of the confinement and in particular :

- to ascertain the empirical laws governing $\tau$ , especially its dependence upon "n" which is not yet clearly understood ;
- to explore the limitations imposed by the violent instabilities called "disruptive".

With the generation of experiments to be completed during this plan (including JET), the aim is the achievement of values close to $10^{14}$ $cm^{-3}$ s, i.e. one order of magnitude higher than obtained at present.

2) $\beta$-values. To be economically viable, a Tokamak-like reactor requires $\beta$ -values of about 5-10 %, (mean $\beta$ -values of 2 % have already been obtained in specific devices). This point is of importance, as the quality of containment could be greatly modified when pressure becomes appreciable compared to the magnetic pressure. During this plan it is hoped to attain regimes where $\beta$ could reach a few per cent in large devices, testing the effect of non circular cross sections and of plasma profile shaping.

3) Temperature. Ignition (the situation where nuclear heating exceeds the energy losses of the plasma) requires ion temperatures higher than presently achieved. Such temperatures appear to be attainable with the technology already available, provided

the confinement properties are not too much lessened by high ion temperature effects. The minimum temperature to be reached depends on the quality of the confinement and the purity of the plasma and is higher than 5 keV.

4) Impurities were recently considered as one of the more serious problems because of the increased radiation losses they generate. At present, the situation has improved, although many questions remain open. The acceptably low impurity content recently achieved has to be confirmed for longer operating times and when powerful neutral injection is applied. Sources of impurities as well as their dynamics and control have to be further investigated. This problem is closely connected with plasma wall interaction and in the case of a reactor, with refuelling and exhaust.

5) Exhaust and refuelling. In long-pulse (or D.C) operation, means of exhausting the reaction products and of refuelling are needed. Exhaust studies by means of "divertors" will continue in DITE and will be a major task of ASDEX (which has a different type of divertor). Means of pumping helium (the chief reaction product) and of handling large amount of hot exhaust gas will be studied. The studies of the cold mantle proposal, an alternative solution, will continue. Refuelling by means of pellets, clusters and gas inlet (via the above-mentioned cold mantle) will be necessary and will be intensively studied during the plan.

6) Alpha-particles. The problem of helium is not only connected with the question of impurities but also with heating and confinement. The presence of many energetic alpha-particles (helium ions) will be an important new feature of a DT burner. This question will be tackled when JET comes into active operation and, possibly, on another device, now in the phase of definition, which is temporarily referred to as "V.H.F.T" (Very High Field Tokamak).

III.3.2 Experimental devices (cf. table II)

1) JET. The main effort of the programme is clearly carried out on JET, in physics as well as financial and manpower commitment. In the initial proposal (1), two steps were considered for the operating phase of JET and referred to as basic performance and extended performance.
The basic performance corresponds to the exploratory studies using a hydrogen plasma in a magnetic field of 27.7 kG ; the flat top of the magnetic field is 20 seconds long, the plasma current reaches 3.8 MA (in a D-shaped plasma) and the neutral injection heating amounts to 10 MW.
From the beginning, the structures are designed in such a way as to ensure the possibility of proceeding later to an extended performance stage. In this regime the magnetic field will be increased to 34.5 kG having a flat top reduced to 10 seconds, and the plasma current increased to 4.8 MA. For this second phase new power supplies will be necessary, both for the toroidal magnetic field and for the auxiliary heating, the power of which is to be brought up to 25 MW. The working gas will be Deuterium. If this phase is successful, the later utilisation of a D-T mixture should provide a large amount of thermonuclear self-heating, of the order of 10 MW.

- So far, the following schedule has been considered : the period 1979-1983 corresponds approximately to the estimated five year construction time, the manufacture of all major components of the machine being completed by mid-1981. At that time, the assembly hall should be ready while the torus hall should be ready at the beginning of 1982, the full installation being completed about one year later. Another six months will then be needed for tests and commissioning, before starting the experimental programme in mid 1983, towards the end of the present plan. The main objectives of this first phase of the exploitation are the study of the evolution of plasma behaviour with parameters close to those of a reactor, the study of plasma-wall interaction under these conditions, and the study of plasma heating. In the frame of this timetable, the second phase

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1) EUR-JET-R5, September 1975.

TABLE II - MAIN DEVICES IN MAGNETIC CONFINEMENT

| Experiments | | Site | Main objectives and Characteristics |
|---|---|---|---|
| JET (2) | | Culham | Scaling, plasma-wall interaction,<br>Plasma heating, alpha-particles |
| Medium size Tokamaks | | | |
| TFR | (1) | Fontenay | Scaling, plasma profiles, heating |
| DITE | (1) | Culham | Bundle divertor, neutral injection, impurities |
| FT | (1) | Frascati | High field, high plasma density, high current |
| Asdex | (2) | Garching | Poloidal divertor, high ion temperature |
| Textor | (2) | Jülich | Plasma wall interaction, impurities |
| Torus II | (3) | (CEA) | Plasma profiles, heating, superconducting magnets (?) |
| V.H.F.T. | (3) | Garching | Very high field, adiabatic compression, ignition (?) |
| Other Tokamaks | | | |
| Petula | (1) | Grenoble | RF heating |
| Erasmus | (1) | Brussels | RF heating |
| TCA | (2) | Lausanne | RF heating |
| Wega | (1) | Grenoble | RF heating |
| Torture | (1) | Jutphaas | Turbulent heating |
| Thor | (1) | Milano | Run away electrons, RF heating |
| Ringboog | (1) | Jutphaas | Cold mantle |
| Dante | (1) | Risø | Pellet ablation |
| Spica | (1) | Jutphaas | High beta behaviour |
| Tosca | (1) | Culham | High beta (non circular cross-section) |
| Other toroidal devices | | | |
| W-VII A | (1) | Garching | Stellarator with NI heating |
| Cleo | (1) | Culham | " with RF heating |
| HBTX-1A | (2) | Culham | Reversed field pinch |
| ETA-BETA | (1) | Padua | " |
| RFX | (3) | Culham | " of extended performances |
| F-IV | (2) | Stockholm | Cold mantle |

(1) In operation (2) in construction (3) in preparation

would be started around 1985.

- However, several very encouraging results have been obtained recently in the field of Tokamaks (II.2.1) : good behaviour of high temperature plasmas (Ti > 5 keV) in the collisionless regime ; satisfactory scaling of the plasma energy confinement time with dimensions (it varies as the square of the small plasma radius), increase of the electron-energy confinement time with Te and ne; insensitivity of energy confinement time to magnetic field and plasma current ; success in obtaining clean plasmas ; positive results, both experimental and theoretical, on the maximum attainable $\beta$-value. These facts, as well as a consideration of the timetable for other large devices - TFTR (USA) should come into operation at the beginning of 1982 and could be equipped with 45 MW neutral injection heating in 1983 ; JT 60 (Japan) is scheduled for operation at the end of 1982 - led the JET team to reconsider their timetable. A proposal is being prepared aiming at a possible acceleration of the construction phase (JET to be ready for operation in basic performance at the end of 1982).

Moreover, the JET team is considering the possibility of proceeding, at an earlier stage than previously foreseen, to the implementation of the extended performance, even during the construction phase. This could imply :

1. To have 25 MW of additional heating available at the start of the operation phase and therefore to install 125 MW of power supply (suitable for both methods of heating).
2. To experiment actively on the major method of RF Heating on the largest Tokamaks available, in order to be able to take a decision for JET in due time.
3. To install complementary power supplies to generate the increased magnetic field.
4. To make an increased effort on the development of remote handling and tritium equipment.

- Extrapolation from the results which have become available recently, the extended performance, when achieved, could lead to the following plasma parameters : $T_i \simeq 15$ keV, $n \simeq 10^{14}$ $cm^{-3}$, $\beta \simeq 6$ %. The energy confinement time should lie between 0.5 and 5 s, and when using D-T mixture, 100 MW of fusion power could be produced.

2) Other Tokamaks in operation or construction. JET alone could not give all the necessary information to proceed with the fusion programme. It is integrated in a programme of smaller complementary experiments better suited to study specific points. Some devices concerned are already in operation; others will be completed during this plan (those especially designed for heating studies will be considered in paragraph III.3.3). This coherent system is organized to cover as accurately as possible the field of problems to be tackled on the Tokamak line. It is centred on some major devices : Dite (Culham), FT (Frascati), TFR (FAR), Asdex (Garching) and Textor (Jülich, after 1981), each being specialized in the study of several of the main questions mentioned under III.3.1. In each case, adequate heating power allows the plasma to be brought to a higher performance regime. Smaller Tokamaks have specific tasks : Ringboog (Jutphaas) is dedicated to cold mantle studies in collaboration with the Stockholm Laboratory (model experiments), Dante (Risø) to pellet ablation studies in conjunction with Garching and Culham. Tosca (Culham) and a Tokamak-like experiment Spica (Jutphaas), are devoted to assess the high-beta capability of Tokamak configurations.

3) New Tokamaks. Depending upon the outcome of conceptual and experimental preliminary studies now in progress, the construction of two new devices (Torus II and V.H.F.T.) could be launched. These machines will aim specifically at demonstrating two processes essential for the step after JET but which cannot be tackled on the existing machines :

- the applicability of supraconducting coils to a real Tokamak ;
- the self heating of a DT plasma and the effect of alpha particles on plasma confinement.

Torus II, a medium-size superconducting Tokamak, is in the final phase of design in the Association Euratom-CEA. Tests on magnet cooling by superfluid helium are in progress. A final decision on construction should be taken in 1979. This device, apart from presenting a high technological interest, would be devoted to the study of high power supplementary heating (possibly with radio-frequency) and to investigations on the important question of plasma profile shaping.

V.H.F.T., a Very High Field Tokamak, is presently under preliminary study, and would extend the progress recently obtained with high density and high magnetic field operation. The definition phase should be concluded at the end of 1978 and a concrete design could start in 1979. The extrapolation of the empirical confinement time to higher densities and the use of strong ohmic heating (high current density), possibly in combination with other heating methods (neutral injection, adiabatic compression) should lead to ignition for a deuterium-tritium mixture. Such an ignition experiment would be built at Garching with the help of Frascati. This collaboration could be extended at the international level.

4) Other toroidal devices. Some activity has been maintained on lines which can be regarded both as alternative and contributory to the Tokamak line, namely : Stellarators and reversed field pinches. The Stellarators are represented by two devices : W-VII A (Garching) and Cleo (Culham). Low beta Stellarators can help the understanding of transport properties of Tokamaks. The reported positive effect caused by the external helical fields on plasma stability is of interest but its origin and its potential for reactor applications are not yet clear. A serious effort will be made to reach net current-free operation. Configurations different from classical Stellarators (i.e. toroidal main field plus field of helical windings) are studied in fast compression experiments. They may also be employed in a new load assembly for W-VII. No new Stellarator device is planned at present. The activity on reversed field pinches is developed with two devices : HBTX 1A (Culham) and Eta Beta (Padua) in the frame of a close collaboration between both laboratories. The next stage would be the large RFX experiment proposed at Culham, as part of a cooperative programme with Padua.

5) Planning groups. A definition group should start working in 1979 to define the step beyond JET and in particular whether there should be one or two post JET devices and whether or not the device immediately following JET should produce net electric power.

Definition work for the DEMO reactor will be intensified starting in 1979 with the Fintor Group (common working group Frascati-Ispra-Naples) as a nucleus.
These two groups will maintain a close contact with each other and with the Long Term Planning activity which will be continued, with its nucleus in Brussels.

### III.3.3 Heating methods

From the beginning of the Euratom fusion programme, plasma heating has been identified as one of the major problems in thermonuclear fusion research. In the light of recent results, this problem appears more and more important : in order to reach their maximum performances, JET and the medium-size devices need powerful complementary heating. As efficient heating methods begin to be available, it is both necessary and reasonable to propose a considerable expansion of the heating programme.
Up to JET size, neutral injection based on positive ion sources is a suitable solution, but it is of difficult application to larger machines. Two alternative solutions are under investigation : radio-frequency heating and neutral injection based on negative ion sources. Efforts will be made during these years to assess the relative potentialities of these two solutions.
Scientific and technological developments are being progressively concentrated in selected laboratories which also act as consultants and possible suppliers for the other laboratories in the Community. This is the case with neutral injection which has been attributed jointly to Fontenay and Culham. For radio-frequency heating, most of the expertise is concentrated in the CEA (and the ERM).

1) Neutral injection heating. It consists of the injection of a beam of high velocity neutral atoms obtained by neutralisation

of accelerated ions. The sources presently used provide positive ions which are well adapted for the present level of energy. For the higher level of energy required in larger machines, however, the neutralisation efficiency for positive ions becomes so low that it seems necessary to turn to negative ion sources which are much less developed at present. Therefore an effort should be made in the course of this 5-year programme to study sources and accelerators of negative ions, in order to be ready at the beginning of the next programme to develop an injection line using negative ions at a power level of 1 MW. Shielding of the injectors after the ignition of the plasma could make this method applicable to a reactor. Further studies are required. For the time being, the collaboration between Culham and Fontenay-aux-Roses is oriented towards the production of 1 MW 80 keV $H^\circ$ units with positive ion sources. Such a development is required for JET, which will necessitate 10 MW of neutral injection for operation in basic performances, and some 25 MW in extended performances, but also for the other intermediate size machines : Dite, TFR 604, Torus II, Asdex, Textor and Wendelstein VII A. Contracts for the delivery of neutral injection systems have already been signed between Associations. A considerable enhancement of the total efficiency of these systems will be obtained if the development of recovery systems presently in progress is sucessful. It is intended to extend the present techniques to the realisation of 1 MW 160 keV $D^\circ$ units.

2) Radio-frequency heating. It is not yet as advanced as neutral injection. The physics of the heating interaction between electromagnetic waves and plasmas is the object of active investigations. Research is going on in a variety of possible schemes, characterized by the frequency at which they operate. During this plan, it is intended to concentrate progressively on the most promising, and to develop them to a level of power comparable to what is currently reached by neutral injection (about 1 MW). It should then be possible, before the end of the plan, to select the method best suited for JET and Post-JET, and to compare its merits with those of neutral injection.

The main lines of the proposed programme are the following :

- In the low frequency range ($\sim$ 100 kHz), Petula (Grenoble), and possibly its upgraded version, should give the necessary information for a possible extrapolation to Torus II and JET.
- In the middle frequency range (1 - 100 MHz), significant tests will be made on TFR. Erasmus and TCA (Lausanne) will contribute complementary information.
- The high frequency range ($\sim$ 1 GHz) will be covered by Wega (Grenoble), a common experiment Garching-Grenoble with collaboration of ERM. FT and perhaps Asdex will also contribute. A later test on JET is envisaged. The industrial development of powerful klystrons is required.
- For the very high frequency range ($\gtrsim$ 30 GHz), a strong effort has to be made to develop the necessary technology. The first tests are planned at Culham and Milan (50 GHz gyrotrons for Cleo, 28 GHz gyrotrons for Thor and Tosca). If the development is successful, this method could be applied to the present Tokamaks (Dite, TFR).

3) Ohmic heating and other methods. The good results obtained on Alcator (USA), a compact experiment at high field, provoked the interest in checking the limits of ohmic heating when very high fields are applied. A study group has been set up at Garching with the collaboration of Frascati to assess the potential and the risks of such an experiment known under the name of Very High Field Tokamak (V.H.F.T. - see § III.3.1)

Another efficient heating method, Adiabatic Compression which has been thoroughly experimented in the past, is intrinsically limited in duration. It may be applied to JET. The application of such a method to V.H.F.T. could help to reach ignition temperatures where alpha-particles heating could take over.

Other heating methods as shock heating, turbulent heating (Jutphaas) imploding liners, laser heating or relativistic electron beams (Amsterdam), will be investigated at an exploratory level.

### III.3.4 Theoretical and computational studies

All the areas of work mentioned above involved both experimental and theoretical studies. Theoretical work is essential to provide the understanding of confinement and heating observations, so that correct assessments may be made of experimental results obtained both in Europe and abroad. They will enable sound extrapolations to be made for the new conditions encountered as reactors are approached.

Because much more detail in understanding and prediction is now needed, there will be increasing use of computational methods. Technical discussions are taking place to improve the co-ordination of fusion computing in Europe which should lead to easier exchange of computed programmes and interchangeable access to computing facilities in the different laboratories. A study has been requested to finalize proposals in this matter.

### III.3.5 Other activities

Theoretical and experimental fundamental plasma physics investigations are largely shifted to Universities. Such collaborations would have the additional benefit of creating a reserve of young scientists and engineers who might be required by an expanding programme.

## III.4 FUSION TECHNOLOGY

### III.4.1 Introduction

The main objectives of the technology part of the five-year programme àre the definition and provision of the necessary technological support for the Post-JET phase. The proposed programme is related to the following major areas :

- System Studies
- Safety and environmental impact
- Superconducting magnet technology
- Tritium and blanket technology
- Materials technology.

The technology programme originally proposed by the 'expert groups' was substantially larger and more ambitious than the one presented here. In spite of the great interest in such an extensive programme, the Commission had to make a drastic cut in the related budget in order to curtail the overall cost. This has been done by limitation to the most urgent problems and in particular those of direct interest to the design and construction of the Post-JET machines. Because of this, areas of research such as the Intense 14 MeV Neutron Source, superconducting magnet design for time varying currents or a test loop for tritium breeding blanket modules had to be postponed for re-consideration at the time of the 1981 programme revision or earlier as part of the programme of the JRC if extended. On the other hand, research programmes presently performed outside the fusion area, but with similar objectives (e.g. materials development in the fast fission breeders) could be directed in collaborative programmes towards the needs of fusion technology.

It should be noted that this five-year programme does not include development work on such items as cryogenic or water cooled high field magnets, nor large electrical power generators, since at present these are being developed within device-related projects, for example JET.

III.4.2 System Studies

The function of system studies is to develop conceptual designs of fusion reactor stations, indicate targets or optimum engineering features and perform the associated parameter sensitivity analysis. System studies will also be useful to outline the parameters for intermediate steps. In assessing the list of systems to which studies have to be directed, it is necessary to consider the basic options of the European programme. Thus no studies on mirrors and inertial confinement systems are foreseen at present. On the other hand, the main effort will be directed towards the Tokamak concept (pulsed or quasi steady state) ; some attention will be paid to other systems, such as fission-fusion hybrid systems, the reversed field pinch and belt-screw pinch reactors, and to process heat application of fusion reactors.

The conceptual studies for Demo in which the JRC will play a leading role will incorporate the findings of the Association Laboratories in a continuous updated definition of the power reactor. It is important that fusion reactor conceptual designs inherently include remote handling capability for all necessary direct servicing and repair functions. An active programme on the application of manipulators is being developed in the JET Project. A limited additional effort for the development of general purpose manipulators is included in the technology programme.

III.4.3 Safety and Environmental Impact Studies

The main studies concerning safety and the environmental impact of fusion energy will concentrate on the establishment and the continuous assessment of the safety concepts related to the main reactor stations being investigated in the definition and conceptual design groups, on the assessment of environmental impact and implication of licensing requirements. In particular these studies will include the evaluation of tritium inventory and release under normal operation the evaluation of events related to possible accidents and the disposal of active components. It will be necessary to evaluate, for each design concept, the significant accident scenarios which can cause loss of containment and resultant radioactive release to the environment.

III.4.4 Superconducting Magnet Technology

The concentrated effort foreseen in this area should place the Community in a competitive position when major decisions concerning future large superconducting devices are taken during the five-year plan. In addition, the demonstration of the operation of a superconducting magnet system, possibly in connection with a fusion-plasma experiment, is considered of great importance, because of the very high probability that future large fusion devices (based on toroidal confinement) will be equipped with superconducting magnet systems.

1) Large Coil Project (LCP). The LCP is a test facility to be built in Oak Ridge involving a toroidal set of six D-shaped field coils. The coil dimensions (4.7 x 2.5 m) will allow the results to be extrapolated to the requirements of the large post-JET devices. The first European coil from KFK (Karlsruhe) with NbTi superconducting material is expected to be delivered to Oak Ridge by the end of 1981. Three other coils are provided by the USA, one by Japan and another one (pending final approval) by Switzerland.

2) A15 Superconductors. The use of A15 compounds allows the operation of magnets with higher magnetic fields (typically 5 to 8 T on the plasma axis) and/or increased stability and temperature safety margin in realistic operation conditions. Both properties are of relevance to the most probable evolution of the magnetic fusion programme. For this reason, it is proposed that a dynamic, goal oriented programme be started. Specifically, the proposal is to build a second Community coil for the LCP test device with A15 conductors.
The most promising A15 compound, but not yet available in sufficient quantities in Europe for large coil construction, is $Nb_3Sn$. A considerable increase in effort is required to develop coils incorporating its use in a second test coil for LCP. This should be a major aim, with a completion date about three years later than the delivery of the NbTi coil.

3) Superfluid Helium Cooling (Torus II). The two main advantages of superfluid helium cooling (He II at 1.8°K) are the enhancement of the critical values of the superconductor and a substantially increased heat transfer rate for short pulses. These are clearly of value for the relatively small coils proposed for Torus II (major radius 2.15 m, field on axis 4.5 T). Preliminary experiments on a model coil in Saclay show promising results with regard to Torus II construction.

In addition, there are other activities in support of superconducting magnet systems needed in future devices. In particular, this programme proposal includes the following two areas :

4) Poloidal Field Coils. The poloidal field coils, carrying essentially variable currents in present machines, have not yet been considered for superconductors. Before the use of such coils can be envisaged, the difficulties connected with time varying currents in superconducting coils are to be overcome. Because of the priority given to the other superconducting activities, no large scale tests are foreseen before programme revision.

5) Support for the Superconducting Programme. Underlying the final fabrication of the superconducting coil systems is the

need for extensive development work, such as the methods of stabilization, heat transfer, cooling and the effects of thermal cycling on electrical and thermal insulation.

III.4.5 Tritium and Blanket Technology

The tritium technology required to operate a post-JET fusion device safely will depend upon the fuel flow and the overall radiological safety system. To demonstrate the capability of handling safely and reliably the amounts of tritium in such a device, i.e about 10g/day with about 100-2C g in the system at any time, a European tritium laboratory is proposed. This will require access to the technological know-how existing outside the fusion laboratories of the Community.

The inclusion in the DT-burner of a neutron absorbing blanket having at least a partial breeding capability would require prior demonstration of the safe and reliable operation of a blanket module. Therefore, and in conjunction with the materials programme, the need exists to perform, towards the end of the plan, blanket module technology tests including irradiation tests. In particular, the following components or systems need to be developed and tested for post-JET application :

1) Tritium Storage and Delivery System. Tritium may be stored either as some metal hydride or as a gas. Present storage techniques are probably adequate, but testing and operational experience will be required prior to operation of the DT fusion device.

2) Tritium Transfer and Exhaust Systems. Valves will in general require all metallic seals and for the pressure range $10^{-6}$ to $10^{-8}$ torr both cryogenic and turbomolecular pumps are compatible with tritium, but some development work is needed to solve specific problems related to this application, for instance helium pumping.

3) Exhaust Gas Treatment. The DT exhaust will need purification from chemical impurities like O, N and He and readjustment of the hydrogen isotope composition, this having been altered by the various fusion reactions and by injection. There are

several methods available for each of these two stages of treatment but it will be necessary to test and optimise equipment design for the method finally selected.

4) Containment and Decontamination. Containment and accidental release of tritium are properly the subject of regulations and licensing procedures in all countries of the Community. The definition of these is closely related to the other problems of reactor safety and must be considered together. The practical evaluation of the chosen method is a proper topic for the experimental programme of the tritium laboratory. Current concepts envisage enclosing the entire installation in a casing continuously flushed with inert gas that is subsequently treated to extract the tritium. In addition, the whole building containing the fusion device will itself be sealed and vented to a circulation and tritium treatment plant, providing secondary containment. The technology involved is considered to be available in principle. However, it will be essential to demonstrate the reliability of the containment system, even if on a somewhat reduced scale. This is one of the major objectives of operating the tritium laboratory.

5) Tritium Recovery from Blanket. Tritium recovery techniques will depend on the choice of the breeding material : liquid lithium metal or solid or liquid lithium compounds. In the liquid Li case, several tritium separation methods are being discussed. Encouraging experimental results on distillation have been reported, which need confirmation in a laboratory scale pilot experiment. Recovery from solid Li compounds suffers from the difficulty of preventing tritium from leaking into the primary coolant.

### III.4.6 Material Technology

The materials programme should strongly interact with the design of the post-JET device(s) for selection of materials, identification of specifications and investigation of special problems.
In addition, however, due to long lead times, significant exploratory work for the needs of the Demonstration reactor has to start now.

The main problem areas for materials in a fusion environment derive from : mechanical stresses, both continuous and cycled; corrosion in presence of lithium or lithium compounds and impurities; radiation damage in bulk material and on surface. The most serious problems are, however, the combination of these effects, which are difficult to evaluate on the basis of present day knowledge.

The main items for inclusion in the technology programme in this area should be the following :

1) Selection and Standardisation of Materials. A short term preference is given to well-developed materials such as austenitic steels and nickel-based alloys. Due to the long time needed to prove new materials, some exploratory work on alternative (chosen among those already industrially available) is needed. An important criterion is the minimisation of the activation of material.

2) Mechanical Properties of Unirradiated Materials (Creep and fatigue; embrittlement and fracture; metallurgical problems in fabrication). Some of the conditions the fusion reactor materials are going to face are very unfamiliar to engineers, for instance, pulsed stress and heat loading, with about $10^6$ cycles/yr. Creep and fatigue behaviour of even the most common materials under these conditions should receive attention.

3) Compatibility (Corrosion in liquid Li and Li compounds, corrosion by He contamination, permeability to hydrogen isotopes). Corrosion is likely to occur in all structural materials. The presence of unconventional materials (Li or Li compounds) and of impurities (like He and hydrogen isotopes) make this problem largely speculative although experimental results are becoming available. The knowledge of permeability is important to predict hydrogen-isotope concentration throughout the reactor both for its effects on materials (embrittlement) and for safety.

4) Radiation damage (Simulation through bombardment with electrons; light and heavy ions; irradiation in fission reactors; irradiation with 14 MeV neutrons; irradiation of insulating materials).
The radiation damage in fusion reactor materials induces swelling, creep, embrittlement and other changes of the mechanical and electrical properties. The damage is produced by the high energy neutrons both through displacements and through transmutations, and depends on the conditions in which the material is irradiated. Two main simulation tools are available today : irradiation with charged particles and fast neutron irradiation in fission reactors. The former can be used to simulate the effects of both displacements induced by neutrons and gas production, whereby high dose rates can be obtained. Intense neutron sources of special design, particularly those based on the DT-reaction, may provide a radiation environment which most closely resembles the one predicted in a fusion reactor; they can thus provide calibration and verification for the simulation methods. It could represent a significant subject for international collaboration. It is thus proposed to develop a European contribution (to this collaboration) by starting exploratory work so as to compare the various approaches to an intense neutron source, and to make conceptual designs of the most attractive ones.

5) Surface Damage. Plasma-wall interaction is important both from the point of view of plasma physics and from the point of view of its effects on material properties. As far as materials are concerned, the areas of surface damage to be investigated include : modification of mechanical properties of first wall materials due to surface erosion and fuel implantation; testing of appropriate materials in order to minimize impurity radiation losses; trapping and release of fuel at the first wall (see also III-3-1).

## III.5 INERTIAL CONFINEMENT

### III.5.1 Laser fusion

The problems of laser fusion can be classified as follows :

- High-power laser development;
- Studies of light-plasma interaction and energy transport;
- Compression hydrodynamics and thermonuclear burn;
- Pellet design and fabrication;
- Basic theory;
- Reactor studies.

Within the next few years, the European programme on inertial confinement will amount only to a few percent of the Soviet or U.S. programmes. To meet the purposes expressed in § III.2.2 it should then consist of a very limited number of topics in which it should try to have some impact on the world scene. Moreover, for a small overall effort, it is important for the programmes of individual laboratories to be complementary and close enough for mutual help through efficient collaboration. Finally the programmes of the various Associations should tend to converge in order to prepare the basis for the future realization (if opportune) of a large joint compression experiment (at least $5.10^{13}$ watts, minimum cost 50 MEUA).

Taking into account the expertise and equipment available in the various Associations, the proposed programme is the following :

1) High-power laser development
   - optimisation of the 1 TW iodine laser already developed and transfer of the know-how to industry, with the aim to produce in the near future modules of 1 TW - .3 nsec (Garching). Possible extension to modules of higher power.
   - Development of a $CO_2$ laser line of 250 J - 1 nsec and realization of 4 of these modules so that a 1 TW system would be available (Frascati).
   - Investigations on new high efficiency lasers (Garching).

2) Light-plasma interaction and energy transport
   - Experimental investigations using both neodimium and iodine laser beams focussed mostly on plane targets (Garching);
   - Theoretical and computational studies (Garching, Brussels, Göteborg).

3) Compression studies

- Study of the hydrodynamic stability of the implosion of pellets of large aspect ratio, at two different wavelengths (1 and 10 microns) using first a 2 x 100 J - 2 nsec neodimium system and later a 4 x 250 J - 1 nsec $CO_2$ system. Such experiments will use DT filled pellets but are not aimed at producing the maximum number of neutrons (Frascati).
- Realization of a medium size compression experiment using 2 iodine laser modules of 1 TW in order to get experience with the relevant techniques, diagnostics and computations (Garching).

4) Basic studies

Continuation of present theoretical studies (Brussels, Göteborg) on transport coefficients and non-linear phenomena, in order to apply them to specific situations met in the experimental programme.

5) Collaboration

Need for efficient collaboration is particularly felt in the following areas : computation, pellet fabrication (pellets will be bought abroad at the beginning, but this situation is highly unsatisfactory), diagnostics and reactor studies. It will be attempted to increase as much as possible the contacts between the Associations and other civilian laboratories (Rutherford, Polytechnique, Universities), for instance by including those laboratories in the area accessible through the mobility fund.

III.5.2 Other approaches

- In spite of its potentialities and of its fast development abroad, electron and ion beam fusion research cannot be initiated in the Associations within the very limited programme proposed for inertial confinement.
- Activity on Plasma Focus will remain limited for the time being to the exploitation of the large 1 Megajoule device existing at Frascati, in collaboration with Culham and in close contact with several German Universities. A general assessment of this line of research is planned for 1980.

## III.6 SUMMARY OF THE PROPOSED PROGRAMME

The proposed programme consists for a large part in the continuation of the present effort. In addition, it includes an extension of this effort and some new activities.

### III.6.1 Continuation of present activity

This means essentially the construction of JET and the start of its operation in the basic performance stage as well as the exploitation of the already existing devices and those under construction. Most of these devices are Tokamaks designed to answer specific questions (see Table II) which are of primary importance for the next step. The necessity of obtaining a maximum of information from them is evident. A few other toroidal devices belonging to the alternative lines should produce information necessary to the decision whether to carry on the development of these lines or to discontinue it. In addition they should allow the study of some problems concerning the Tokamak line : the decoupling of heating from confinement (Stellarators) and the investigation of the properties of high-beta plasmas (high beta devices).

In the field of neutral injection, the development of intermediate voltage hydrogen injection lines with positive ion sources can be considered as achieved : their extensive application to confining devices has started. The development of higher voltage lines, deuterium injectors, recovery systems and negative ion sources is concentrated in two Associations and must continue in order to meet the requirements of JET and of the next step.

In the field of radio-frequency heating the development of the Lower Hybrid Resonance heating is the most advanced : it is now entering in the application phase. Concerning other methods, their number has been reduced during the last programmes and the continuation of their development to higher power levels is necessary in order to prepare the selection of the best suited ones to meet the requirements of JET and of the next steps.

A few activities in the fusion technology area have been started recently and there is no doubt of the necessity for their continuation. These are the Large Coil Project, test on supra-conductivity with superfluid helium cooled materials, conceptual design, safety and environmental studies, radiation damage simulation.

In the field of inertial confinement the work performed until now in the associated laboratories consisted essentially for the technological part in the development of a 1 TW iodine laser and the pre-development of a 250 Joule CO2 laser and for the physics in the study of light-plasma interaction. Both the progress and the increase of effort outside the Community are so rapid that in order not to loose contact in an irreversible way an extension of the present activity is essential.

III.6.2 Extension

- Depending upon the outcome of investigations which have been triggered recently by the very positive results obtained in 1978 on the Tokamak line, it could be proposed to shorten the construction phase of JET and to implement the extended performance during the construction phase. The technical feasibility and scientific advisability of such an operation has not yet been assessed by the competent bodies of the Joint Undertaking.
- Depending upon the outcome of conceptual and experimental preliminary studies now in progress, the programme might include the construction of two new Tokamaks : a very high field device (VHFT) aiming at the ignition of a deuterium-tritium plasma and a supraconducting Tokamak (Torus II) devoted to plasma profile shaping and heating studies. For the preparation of the next step, the importance of an early ignition experiment and of the application of supraconductivity to a real Tokamak does not need to be emphasized. The possibility of building each of the two new experiments outlined above has not yet been assessed. It is "a fortiori" not certain that both will have to be built.
- In the field of plasma heating, on the contrary, an extension of effort is both possible and necessary. Most of the existing

devices have been, or will be quite soon, operated in their basic performances. In order to reach their maximum performances, they need substantial additional auxiliary heating power. Several neutral injection units for an overall power of the order of at least 25 MW will have to be produced and applied to JET and to other Tokamaks such as ASDEX, TFR 604, Dite, Textor and Torus II. Substantial radio frequency heating power at the lower hybrid resonance will have to be applied in particular to FT.

- In the fusion technology area, activity on system studies should be intensified and the development of an A15 supraconducting coil for LCP should be undertaken.
- The proposed extension in the field of inertial confinement, which is necessary in order to achieve the minimum objectives of the programme in this field, includes the industrial production of 1 TW iodine laser modules, the development and construction of four 250 Joule $CO_2$ lasers, and the initiation of compression tests.

### III.6.3 New activities

To prepare for the Post-JET machine, knowledge is required of the tritium technology needed for fusion. Tritium technology already existing in member States should be made available to the fusion programme, but there will remain a need for a European laboratory specifically devoted to the tritium technology of fusion devices. This has already been recognized in USA, where a Tritium System Test Assembly is to be built at Los Alamos. If Europe is to collaborate effectively with the USA in this field, an adequate expertise must be created within the Community. Allowing for the time needed to meet the stringent licensing requirements in the Community, action should start as soon as possible. Moreover, tests on blanket modules should start towards the end of the 5-year programme.

The problem of materials, already significant for JET, is of primary importance for the next step and crucial for the reactor. The present state of knowledge is just sufficient to identify the areas in which work is necessary. Due to long lead times involved in some testing procedures, significant exploratory work should start now, particularly with regard to radiation damage.

# CHAPTER IV

# IMPLEMENTATION

## IV.1 FINANCIAL SITUATION OF THE 1976-1980 PROGRAMME OF THE ASSOCIATIONS

The appropriation of the Commission for the financing of the programme of the Associations for the period 1976-1980, decided by the Council on 25 March 1976, was of 120 MUA[(1)]. This would correspond to a total volume of this programme of about 410 MUA (applying the 25 % rate for general support and the 45 % for preferential support) if the entire sum given by the Council as a ceiling for the financing of priority actions (39 MUA) were devoted to preferential support to these actions.

When this programme decision was adopted, the Commission pointed out[(2)] that its appropriation resulted from a substantial reduction of its initial proposal and that consequently difficulties would be encountered in the steering of the programme. Moreover the Commission pointed out that if necessary, it would submit to the Council during the execution of the programme a proposal intended to adapt its appropriation to the economic conditions.

In July 1977, in order to cope at least in part with difficulties in the financing of the general budgets of the Associations, and in view of the programme revision to be undertaken in 1978, it was agreed with the positive advice of the Consultative Committee for Fusion[(3)], to reduce the funds devoted to preferential support from 39 to 27 MUA and to increase by 12 MUA the funds devoted to general support. This would allow the Commission to finance, at the rates decided by the Council, a programme with a total volume of about 430 MUA. The Consultative Committee for Fusion approved also[(3)] the proposal of the Commission to ask the Council, on the occasion of the review to be undertaken in 1978, to revalue its financial allocation, taking into account the change in economic conditions since 1st January 1976. The final release of the appropriation of the Commission for the financing of the whole five-year programme was decided by the Council in November 1976[(4)] and the Association contracts for the period

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(1) O.J. N° L 90 of 3 April 1976 : 120 MUA = 124 MUA (total appropriation) - 4 MUA (management + mobility)

(2) Doc. R.781/76 (ATO 42) 1976-80

(3) Doc. R 1980/77 (ATO 89)

(4) Doc. T/919/76 (ATO)

1976-80 could not be concluded until 1977. The changes in the economic conditions between January 1976 and mid 1977 (about 17 % of average inflation) led the Commission to conclude these contracts for an overall financial volume of about 500 MUA, with the usual rate of 25 % of participation in general support. The increase by 70 MUA of the total financial volume from 430 to 500 MUA results in an increase in the Commission's participation of 17.5 MUA (= 25 % of 70 MUA) for the whole period 1976-1980. It must be underlined that this sum represents only the complement necessary for the Commission to honour the obligations taken towards the Associations (25 % of general expenditures) in 1977. The part of this sum actually needed for the first three years of the 1976-1980 programme, which are not covered by the new five-year programme 1979-1983, is about 10 MUA (3/5 of 17.5 MUA). Therefore the commitment of the Commission for the three years 1976, 1977 and 1978 amounts to about 84 MUA (= 10 MUA + 3/5 of the total appropriation of 124 MUA). The balance of 40 MUA (= 124-84 MUA) remaining from the 1976-80 programme is therefore available for the partial support of the 1979-83 programme.

## IV.2 PROGRAMME PROPOSAL FOR 1979-1983

### IV.2.1 Staff

The total professional manpower involved in the fusion programme including the staff seconded to JET and the Euratom staff working in the Associations and the JRC was about 860 at mid 1978. An approximate breakdown of these 860 professionals is the following :

| | |
|---|---|
| – qualified research scientists working in the Associations of the Member States (including 60 EURATOM officials) | 700 |
| – general support (direction, administration, technical services, etc...) (including 9 EURATOM officials) | 75 |
| – JET Team | 48 |
| – Association EURATOM-NSBESD (Sweden) | 25 |
| – J.R.C. (Ispra) | 12 |
| Total | 860 |

The overall manpower (including all the non-professionals) is more difficult to evaluate since in some of the Associations supporting services are shared with other laboratories, not concerned with fusion. An approximate estimate leads to a total of at least 3000 people.

Concerning the composition of the professional staff two remarks should be made :

- since experimental devices are becoming larger and technically more sophisticated, a shortage of engineers and specialized technicians for the design and construction is generally felt, although the number of physicists for the conception, the operation and the interpretation of results of the machines is sufficient;
- since the recruitment of junior professionals has been reduced nearly to zero in recent years, the average age of the staff is increasing at a rate which approaches one year per year. For a programme which should last a few more decades this ageing of the staff is a dangerous phenomenon.

For the implementation of that part of the technology programme developed outside the associated laboratories, it is intended to set up a number of subcontracts between the associated laboratories and other laboratories external to the fusion programme, most of them in the fission field. Therefore, an extensive recruitment of technology experts in the fusion laboratories for this purpose does not seem necessary at present, although the Associations will need a small number of specialists to supervise the abovementioned subcontracts.

No appreciable increase of staff is foreseen in the Associations during the five-year period 1979-83. The total manpower involved in the fusion programme will increase slightly due mostly to the build-up of the JET Team and also to the possible extension of fusion activities at the J.R.C.

In spite of the proposed extension of the programme, the Commission does not ask any increase of the number of its own staff for the implementation of this five-year programme. This will remain 113 Community employees as decided by the Council on 25 March 1976. The part of this staff working in Brussels at the fusion programme directorate has been recently increased to 20 people and should remain at this level during the execution of the proposed programme. All the other Euratom personnel will remain in the associated laboratories or will be seconded to JET.

IV.2.2 Overall expenditure of the associated laboratories

The programme proposed here is the result of a compromise between the need to intensify the activity to the extent justified by the importance of the final goal for the Community, and the awareness that the financial effort that can be asked for is limited.

A broader front of research such as the one of the fusion programme of the Soviet Union, or a more ambitious programme with tighter timing such as the American one, would be desirable but would require a much larger financial effort. In this sense, the desirable ceiling of expenditure for research in this field is well above the proposed figure. The lower limit on the contrary is well defined since it is strictly related to the manpower of the associated laboratories. If no new investment was made, the progress of research would be stopped quite soon but the level of expenditure could not be substantially reduced unless the staff itself were reduced.

The overall financial volume discussed hereafter corresponds to the programme described in Chapter III. and summarized in paragraph III.6 under the headings : Continuation of present activity, extension, new activities. It does not include the part of the programme to be carried out at the J.R.C., in Sweden and possibly in Switzerland.

1) Continuation of present activity
The sum of the provisional budgets of the associated laboratories for the year 1978 (expressed in the respective national currencies and then converted into EUA at the rates of the beginning of 1978) amounts to about 104 MEUA. This figure multiplied by 5 would lead to a total of 520 MEUA for

1979-83 programme, at the economic conditions of January 1978. The rate of inflation in the Community is at present of about 7,5 % per year (more precisely, it was 7,5 % between April 77 and April 78). This leads to a 5-year budget of about 560 MEUA at the economic conditions of January 1979. Moreover, at constant manpower, the cost of personnel is estimated from past experience to increase by at least 6 % per year in the Community ; this unavoidable increase affects about 40 % of the total fusion budget and leads to an additional requirement of 28 MEUA for the years 1980 to 1983. The continuation of work at the present level requires therefore a five-year budget of 588 MEUA. This sum includes the extrapolation of the investments made in 1978, which were moderate as most of the investments had been committed at the beginning of the 1976-1980 programme. This extrapolation gives room therefore to limited new investments corresponding to the continuation of present activity, but cannot allow the launching of any significant new action.

| | |
|---|---|
| - Volume (at economic conditions January 78) | 520 MEUA |
| - Inflation January 78-January 79 (7,5 %) | 40 MEUA |
| - Increase cost personnel (at constant manpower) | 28 MEUA |
| Continuation at present level | 588 MEUA |

2) Extension of present activity. The programme summarized in paragraph III.6.2 corresponds to the following financial commitments :

| | |
|---|---|
| - Investments for new Tokamaks : Torus II and VHFT. The cost of each of these machines will be of the order of 20 to 30 MEUA | 50 MEUA |
| - Additional heating (JET excluded) | 23 MEUA |
| - Inertial confinement | 10 MEUA |
| - Fusion technology :<br>. System and environmental studies, planning and definition groups : 5 MEUA<br>. Supraconductivity (mostly A 15 coil for LCP) : 15 MEUA | 20 MEUA |
| Total : | 103 MEUA |

3) New activities (see paragraph III.6.3)

| | |
|---|---|
| - Tritium technology | 15 MEUA |
| - Materials | 30 MEUA |
| Total : | 45 MEUA |

It should be clearly pointed out that these figures correspond to the programme described in Chapter III except for materials. In this latter case, the implementation of the programme defined by the Experts and outlined in paragraph III.4.6 would require a much larger financial commitment. With the funding indicated hereabove the initiation of this programme is possible but the speed of its development will be severely limited.

In conclusion, the general expenditure of the associated laboratories (including sub-contracts for technology) for the five-year period 1979-1983 is estimated as follows :

| | |
|---|---|
| Continuation of present activity | 588 MEUA |
| Extension of present activity | 103 MEUA |
| New activities | 45 MEUA |
| Grand Total : | 736 MEUA |

IV.2.3 Preferential support

On the basis of the technical description given in Chapter III and within the framework of the overall expenditure proposed in paragraph IV.2.2, the investments required for the implementation of the 1979-83 programme are estimated at 120 MEUA, in the economic conditions of the beginning of 1979.

The proposed partial ceilings for the investments of the associated laboratories which should be financed by the Community at the preferential support rate of 45 % are the following :

| | MEUA |
|---|---|
| Tokamaks and support to JET | 64 |
| Other toroidal devices | 15 |
| Heating and injection | 35 |
| Fusion technology | 30 |
| Inertial confinement | 6 |

In the Tokamak line, about 10 MEUA have been included for work (e.g. development of diagnostics, heating methods, study contracts, etc.) to be executed for JET by the associated laboratories. In the same line provision is made (50 MEUA) for the possible construction of Torus II and V.H.F.T.

It should be pointed out that the sum of these ceilings (150 MEUA) is higher than the proposed overall ceiling for priority actions (120 MEUA). This means that the ceilings shown cannot be reached simultaneously in all the lines.

As in the preceding five-year programmes, preferential support will be granted by the Commission only to actions which are attributed priority status by the Groupe de Liaison.

### IV.2.4 Mobility

The "Mobility contract" for the exchange of staff among the various laboratories engaged in or contributing to the implementation of the programme has been extensively used during the last two five-year programmes with good effects. This exchange has proved to be the best method for the transfer of scientific and technical know-how and an excellent means of improving the utilization of the available staff and expertise. The funds devoted to the mobility of staff should therefore be at least kept constant. A maximum amount of 2 MUA was set aside for this purpose in the 1976-80 programme and the same amount (2 MEUA) is proposed for the 1979-83 programme.

### IV.2.5 Management and administration

The staff of the fusion directorate in Brussels was increased in the last two years in accordance with the 1976-80 plan, and has reached a total of 20 people. This figure should be maintained in the course of the 79-83 programme. The average staff number during this period will therefore be higher than in the period 76-80. An increase of the cost of this personnel has been introduced by the inclusion of Community taxes on salaries in the tariff rates for staff charged to the budget of the European Community and by the transition from UA to EUA.

The expansion of the fusion programme, in particular with the inclusion of new fusion technology activity, is resulting in an increase of expenditure for the organization of meetings, workshops etc. and for expert contracts.

An appreciable increase of the expenditure for management and administration, mainly due to the cost of personnel, must then be provided for in the 79-83 programme. The appropriation of the Commission should therefore include a ceiling of about 7 MEUA for this item.

IV.2.6 JET

Present situation

As approved by the Council (R/2404/77 - ATO 116), the cost of the JET project in the construction phase (ending mid-1983) has been calculated in Belgian francs and put at 7500 million Belgian francs at January 1977 prices. This sum represents 184,6 MEUA at the rate of the EUA of 3 January 1977 (1 EUA = 40,6207 BF).

In accordance with the Statutes of the JET Joint Undertaking adopted by the Council of 30 May 1978 (1) the expenditure of the Joint Undertaking shall be borne at the 80 % rate by EURATOM.

The part of the total cost of the project in the construction phase to be borne by EURATOM is therefore 147.7 MEUA ( = 80 % of 184.6 MEUA).

The funds necessary for the participation of EURATOM in the expenditure for the project during 1976-1978 amount to 16 MEUA (=80 % of 20 MEUA). These funds have been taken out of the appropriation of 102.4 MEUA allocated by the Council decision of 30 May 1978 (2). The Commission proposes repealing repeal this decision as from the 1st January 1979 when the new programme 1979-1983 should come into force. The funds necessary for the participation of EURATOM in the expenditure of the Joint Undertaking for the period from 1979 to mid-1983 are estimated at 131.7 MEUA (= 147.7 - 16 MEUA). This sum has therefore to be included in the appropriation of the Commission for the 1979/83 fusion programme.

During the second half of 1983, JET will be in the operation phase. It has been estimated that the average annual budget of JET should not vary appreciably going from the construction of

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(1) O.J. N° L 151 of the 7.6.1978, p. 11
(2) O.J. N° L 151 of the 7.6.1978, p. 8

to the operation phase. On this basis, about 18 MEUA will be required by JET during the last semester of 1983. The funds necessary for the participation of Euratom will then amount to about 14.5 MEUA ( 80 % of 18 MEUA). These are not included in the appropriation of the Commission requested in the present document.

With the decision of 30 May 1978 (1) the Council has allocated to the fusion programme 1976/80, for the implementation of the JET project, 150 temporary staff in the sense of Article 2(a) of the Conditions of Engagement of Other Servants of the European Communities. This allocation should be confirmed in the Council Decision concerning the 1979/83 fusion programme and possibly revised on the occasion of revision to be undertaken in 1981.

Possible evolution.

The Commission has already pointed out that part of the expenditure necessary to allow the device to reach its extended performance will probably have to be committed during the second half of the construction phase(2). This commitment was of the order of 50 MEUA, for 80 % of which the Commission intended submitting a request to the Council on the occasion of the revision to be undertaken in 1981. In view of recent scientific progress, an acceleration of the construction of JET and an earlier implementation of the extended performance would appear desirable (III.3.2.1). If this turned out to be feasible, according to a preliminary estimate made by the JET team, the additional commitments could be evaluated at 62 MEUA (in July 1978 money and including contingency and additional personnel) and part of it could be committed in 1980. The main items would be the power supplies needed to bring the magnetic field up to 35 kGauss, the supplementary heating power needed to reach a total of 25 MW and the remote handling and Tritium equipment for D-T operation.
This question is to be examined by the organs of the JET Joint Undertaking. The Commission will inform the Council of Ministers, in due time and if appropriate, submit a proposal accordingly.

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(1) O.J. N° L 151 of the 7.6.1978, p. 8
(2) R/820/78 (ATO 17)

## IV.2.7 Appropriation of the Commission for 1979-1983.

1) Programme of the Associations.

The breakdown of the appropriation of the Commission requested for the 1979-83 programme, without JET, at the economic conditions of January 1979, is the following :

| | Overall volume | % | Commission participation |
|---|---|---|---|
| General support | 616 | 25 | 154 |
| Preferential support | 120 | 45 | 54 |
| Mobility of Personnel | 2 | 100 | 2 |
| Management & Administration | 7 | 100 | 7 |
| Total : | 745 MEUA | | 217 MEUA |

From the budget point of view, the new appropriation necessary to finance the 1979-83 programme of the Associations, is estimated at 177 MEUA (217 - 40 MUA), taking into account the 40 MUA which remained available from the 1976-80 programme.

A reduction of this appropriation would result in new difficulties in the steering of the programme. As agreed by the CCF, it should be avoided that the appropriation of the Commission be insufficient to cover, at the 25 % and 45 % rates, the expenditure incurred by the Associations.

2) JET

The funds necessary for the participation of EURATOM in the expenditure for the construction phase of JET during the 1979-83 programme amount to 131.7 MEUA at the economic conditions of January 1977. This sum does not include :

- the funds necessary for the participation of EURATOM in the expenditure during the operation phase of the project in 1983, estimated at about 18 MEUA, or more if the operation phase were to start before mid-1983.
- the funds necessary for the participation of EURATOM in the expenditure resulting from a possible speeding up of the project aimed at bringing forward access to the extended performance (see § IV.2.6).

3) Overall appropriation

The new requested appropriation is therefore :

| | MEUA | |
|---|---|---|
| For the participation in the programme of the Associations | 217 | at the economic conditions of January 1979 |
| For the participation in JET | 131.7 | at the economic conditions of January 1977 |
| Total : | 348.7 MEUA | |

One should point out that the appropriation for the participation in JET has already been agreed by the Council.

## IV.3 ORGANIZATION

The organization of the Community fusion programme is based on the the bilateral association contracts between EURATOM and the Institutions in the member States and in Sweden which are active in fusion research. Each Association has a Steering Committee consisting of a small number of representatives of the Commission and of the partner Institution. These meet two or three times a year and are responsible essentially for the programmes and the budgets of the Associations.

For the Community fusion programme as a whole, three committees play a consultative and coordinating role at different levels :

1) The Liaision Group, composed of leading scientists of the associated bodies and of the Commission, has the responsibility of giving scientific and technical advice to the Commission and to the Associations on new programmes and of advising the Commission on the allocation of preferential support funding at the 45 % level.

According to the Council decision of 25 March 1976 (1) this preferential support can be accorded by the Commission only to

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(1) O.J. N° L 90 of 3.4.1976, p. 13.

operations which are accorded priority status by the Liaison Group. Moreover the Liaison Group plays the role of an "Advisory Committee for Programme Management" for the fusion part of the JRC programme (1). The Liaison Group meets about three times a year. This body is assisted at present by six Advisory Groups, one for each of the main lines of the programme - Tokamaks, Screw pinches and High-beta Stellarators, Low-beta Stellarators, Heating and injection, Very high density, and Technology. The Advisory Groups are composed of experts from all the associated laboratories and meet about four times a year.

2) The Committee of Directors (C of D), composed of the Directors of the associated laboratories and JET and the Commission's Director of the fusion programme, is responsible for the preparation of the decisions concerning the programmes, the conditions of interventions by the Commission, the mobility and exchange of personnel, and for various problems concerning collaboration also outside the associated laboratories and outside the Community. Furthermore, the C of D may be requested to act as a technical committee for the CCF ; it meets in general, every other month.

Ad hoc Groups and Coordinating Committees are set up by the C of D when necessary in specialized areas (Data acquisition, computing, etc.). For the preparation of the new part of the fusion technology programme, four expert groups have been set up in January 1978 by the C of D : on "Material Development for Fusion", on "Magnet Development", on "Tritium and Blanket Technology" and on "Safety and System Studies". The proposed programmes prepared by these groups in the respective areas of competence were submitted for advice to the Advisory Group on Fusion Technology and to the GdL.

3) The Consultative Committee for Fusion (CCF), created by a decision of the Commission on 26 March 1976 and composed of officials of the member States and Sweden at the level of respon-

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(1) OJ N° C192 of 11.8.1977, p.1

sibility for nuclear and energy research, is responsible for advising the Commission (its opinions are also transmitted to the Council) on problems concerning :

- the implementation and development of the programme, including the JET project
- changes of direction which might appear necessary
- the preparation of the future programme
- determination of the total volume of the fusion research activities in the European framework
- the increasing concentration and integration of the work carried out in member States

Concerning the JET project, its management structure is defined in the Statutes of the JET Joint Undertaking. It consists essentially of the JET Council, the JET Executive Committee, and the Project Director.

The organisation of the Community fusion programme has constantly evolved in the past, according to the needs of the programme. Two improvements could be introduced in the near future :

- a possible reduction of the number of the Advisory Groups of the GdL and a redefinition of their terms of reference, taking into account the evolution of the programme, should be decided by the Groupe de Liaison after the adoption by the Council of a 1979-83 programme;

- for the coordination and implementation of the technology programme a subcommittee of the C of D should be created. According to the needs, this body could seek the advice of expert groups similar to those which have been set up for the preparation of the new part of the technology programme.

B. PROPOSAL FOR A COUNCIL DECISION

of ....

adopting a research and training programme (1979-83)
for the European Atomic Energy Community
in the field of controlled thermonuclear fusion

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THE COUNCIL OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Atomic Energy Community, and in particular Article 7 thereof,

Having regard to the proposal from the Commission submitted after consultation with the Scientific and Technical Committee,

Having regard to the opinion of the European Parliament[1)],

Having regard to the opinion of the Economic and Social Committee[2)],

Whereas in its Decision 76/345/Euratom[3)], as amended by Decision 78/470/Euratom[4)], the Council adopted a research and training programme (1976-80) in the field of fusion and plasma physics ; whereas Article 3 of that Decision provides that the Commission will submit to the Council in 1978 a review proposal designed to replace the 1976-80 programme with a new five-year programme as from 1 January 1979 ; whereas in view of the considerable efforts needed to reach the application stage of controlled thermonuclear fusion, which could be of benefit to the Community, particularly in the wider context of the security of its long-term energy supplies, the various stages of development of the work hitherto undertaken in this field should continue on a joint basis ;

Whereas the scientific progress achieved in this field in recent years in the Community and the rest of the world illustrates the need, particularly for Tokamak systems, to construct larger and more complex devices and to concentrate in particular on the development of plasma heating techniques and the study of certain technological problems with the collaboration of the JRC ;

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(1) O.J. N°
(2) O.J. N°
(3) O.J. N° L 90, 3.4. 1976, p. 12
(4) O.J. N° L 151, 7.6.1978, p. 8

Whereas it is necessary to equip the Community with a large Tokamak machine (JET : Joint European Torus) ;

Whereas the research proposed by the Commission constitutes an appropriate means of pursuing such actions and it is, consequently, in the common interest to adopt a multiannual programme in the field of controlled thermonuclear fusion, the existence of which is also a necessary condition for the Community to participate in strengthening cooperation at world level in this field ;

Whereas it is important that the Community should continue to encourage both the construction of certain equipment concerned with projects accorded priority status, by granting a preferential rate of participation in the expenditure on such equipment, and the implementation of major projects carried out jointly by all or some of the associated laboratories ;

Whereas, furthermore, the mobility of staff between organizations cooperating in the execution of the programme should be promoted,

HAS DECIDED AS FOLLOWS :

## Article 1

A research and training programme in the field of controlled thermonuclear fusion as defined in the Annex is hereby adopted for a five-year period beginning 1 January 1979.

## Article 2

The global needs for the entire duration of the programme without JET are estimated at 217 MEUA and 113 Community employees.

The global needs for the construction phase of JET during the duration of the programme are estimated at 131.7 MEUA and 150 temporary staff within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities.

These figures are only indicative.

The European unit of account is defined in Article 10 of the Financial Regulation of 21 December 1977 applicable to the general budget of the European Communities[5].

Article 3

The Commission shall submit to the Council in 1981 a review proposal designed to replace the present programme with a new five-year programme with effect from 1 January 1982.

Article 4

Decisions 76/345/Euratom and 78/470/Euratom are repealed. This Decision shall enter into force on 1 January 1979.

Done at Brussels,

For the Council

The President

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5) O.J. N° L 356, 31.12.1977, p. 1.

# ANNEX

## CONTROLLED THERMONUCLEAR FUSION

1. The subject matter of the programme to be executed shall be :

   (a) plasma physics in the sector concerned, in particular studies of a basic character relating to confinement with suitable devices and to methods for producing and heating plasma,

   (b) research into the confinement, in closed configurations, of plasma of widely varying density and temperature, if possible attaining ignition conditions ;

   (c) production of and research into plasma of high and very high density and in particular the study of laser fusion ;

   (d) the development and application to confinement devices of sufficient powerful plasma heating methods ;

   (e) improvement of diagnostic methods ;

   (f) investigation into technological problems connected with current research and problems relating to the use of thermonuclear reactions ;

   (g) implementation of the JET project.

The work referred to under (a), (b), (c), (d), (e) and (f) shall be carried out by means of association or limited duration contracts designed to yield the results necessary for the implementation of the programme and taking into consideration the work carried out by the JRC, in particular in relation to the technology referred to under (f).

The implementation of the JET project referred to under (g) has been entrusted to the "Joint European Torus (JET), Joint Undertaking", established by Decision 78/471/Euratom.[6)]

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6) O.J. N° L 151 of 7.6.1978, p. 10.

2. The programme set out in point 1 shall be part of a long-term cooperative project embracing all work carried out in the Member States in the field of controlled thermonuclear fusion. It is designed to lead in due course to the joint construction of prototypes with a view to their industrial-scale production and marketing.

3. The global needs for the duration of the programme without JET are estimated at 217 MEUA and 113 Community employees. The amount in question is intended to cover :

- expenditure on equipment for operations accorded priority status and some expenditure in support of JET ;

- the cost of staff mobility ;

- other expenditure relating to operations to be carried out under the programme excluding JET.

4. The appropriation allocated to the programme without JET can be broken down as follows :

(a) about 25 % for the financing at a preferential rate of projects, as specified in paragraph 5.

(b) about 4 % for administration costs and for expenditure intended to ensure the mobility of staff to enable them to work in organizations cooperating in the implementation of the programme ;

(c) the amount not set aside for the operations and expenditure referred to in (a) and (b) shall be devoted to the financial participation by the Community in other expenditure incurred by the associations. This participation shall be at a uniform rate of about 25 %.

5. After conducting a technical examination the Liaison Group may accord priority status to projects belonging to one of the following areas :

Tokamak systems and support for JET
Other toroidal machines
Heating and injection
Fusion technology
Inertial confinement.

The Commission may finance these projects at a uniform preferential rate of about 45 %.

In return, all partner associations shall have the right to take part in the experiments carried out with this equipment.

6. The global needs for the construction phase of the JET Project during the programme period are estimated at 131.7 million European units of account and 150 temporary staff. The amount in question is intended to finance the construction phase of the JET project with a rate of participation of 80 %.

## C) OPINION OF THE SCIENTIFIC AND TECHNICAL COMMITTEE (STC) ON THE DRAFT PROPOSAL FOR A FIVE-YEAR PROGRAMME 1979-83 ON CONTROLLED THERMONUCLEAR FUSION

- The STC has examined, at the meeting of 16 October 1978, the proposal for a five-year programme 1979-83 presented by the Commission.

- The Committee has noted with satisfaction the recent progress made in the area of magnetic confinement. These advances increase the confidence of seeing JET reach its stated objectives and make likely a demonstration of the "scientific feasibility" (1) of fusion by Tokamaks in the mid-80's ; these advances justify an increase in the effort devoted to fusion. In consequence, the Committee considers that the proposed general programme (2) is justified.

- The Committee observes that, in accordance with its previous advice, the Commission is continuing to concentrate its efforts on two well defined objectives : the Tokamak and plasma heating. As far as alternative lines are concerned in the area of magnetic confinement, the STC recommends moving towards a concentration of effort in a single line which should be given approrpriate support. Dispersion of effort must be avoided and the possibility of international collaboration exploited instead.

- The STC recalls that in its previous advice it had asked the Commission to pay special attention, when the revision was undertaken, to fusion by inertial confinement and to technological problems. Consequently,

  . The STC would like to see the basic problems associated with inertial confinement clarified as soon as possible in order to allow some position to be adopted on the subject. Meanwhile, it seems appropriate to proceed with the proposed minimum programme.

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(1) Scientific feasibility : conditions in which energy derived from the reacting plasma is greater than that expended in heating the plasma.

(2) General programme : the programme proposed by the Commission excluding the real realization and the exploitation of JET.

- The Committee, recognizing the need for a strong effort in technology in preparing for the post JET phase, regards as positive the Commission's proposals for work in the technology field, but it asks that they should be carried out prudently. It recommends that work on System Studies should be increased, thereby providing guidelines for the build up of the whole technology programme.

- The Committee insists that JET is an integral part of the fusion programme. It underlines, as does the Commission in its programme proposal, the obligation of the Associations to make an effective contribution to the success of JET. It has been informed that, following the recent advances, ways are being considered to speed up the construction of JET and preparation for its exploitation phase. The necessary financial means for doing this have not yet been worked out in detail and are not included in the programme proposal presented by the Commission. A part of these funds could be needed from 1981.

- The STC reaffirms the advantages of the sliding programme concept : the ability to review periodically the objectives and the means, assuring a continuity in the steering of the programme, and the possibility of taking into account the variations in economic conditions.

# O P I N I O N

## of the Consultative Committee for Fusion on the draft Proposal for a five-year Programme 1979-1983 on controlled thermonuclear fusion adopted at its meeting on 25 October 1978

- The CCF has examined the draft proposal for a five-year programme 1979-83 presented by the Commission.

- The Committee wishes to emphasize the importance and necessity of the sliding programme concept.

- The Committee unanimously agrees that a final decision by the Council on the programme is needed rapidly (mid 1979 at the latest). The document presented by the Commission represents a good basis for the general part of the five-year programme (1).

- The CCF is aware that, due to recent scientific progress, a proposal is being prepared aimed at speeding up the construction of JET and bringing forward access to the extended performances. It recommends the Commission to include in its programme proposal all available information on this subject, with an estimate of the extra funding which will be required.

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(1) The programme proposed by the Commission excluding the realization and the exploitation of JET.

# D) FINANCIAL RECORD SHEET

## I. FUSION PROGRAMME EXCLUDING JET

1. RELEVANT BUDGET HEADING : 3351

2. TITLE OF BUDGET HEADING : Controlled thermonuclear fusion including the JET project. This part of the record relates only the fusion programme excluding JET.

3. LEGAL BASIS : Article 7 of the EAEC Treaty
   Council Decision 76/345/Euratom (1) and decision expected before April 1979.

4. DESCRIPTION, OBJECTIVE(S), JUSTIFICATION OF THE PROJECT :

4.1 Description

The project is designed to continue the research programme in the field of controlled thermonuclear fusion and covers all activities in the Member States in this field. Sweden and Switzerland are associated with the programme. It relates in particular to the study of magnetic and inertial confinement of plasma and of fusion technology.

4.2 Objective

(a) The short term objectives of the programme are :

- to accumulate enough knowledge, both in physics and in technology, to be able to define the post-JET machine(s) during the five-year period so that construction could start during the following plan. In particular, the research should determine the optimum field and size of the post-JET machine(s), and allow an assessment of whether it should produce tritium and generate electricity. It should also provide experimental information on the advisability of using super-conducting or normal coils ;

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(1) O.J. N° L 90 of 3 April 1976.

- to assess up to what point other magnetic confinement systems (Stellarators, reversed field pinch) may be regarded as real alternatives to Tokamak ;
- to carry out a minimum programme on inertial confinement.

(b) the final aim of this programme is to determine whether energy can be produced at competitive prices from nuclear fusion reactions between light atomic nuclei and, if so, jointly to construct prototypes with a view to industrial-scale production and marketing.

4.3 Justification

The problem of energy sources at world level in the long term is far from being solved. Thermonuclear fusion is one of the very few sources which might solve this problem or at least make a substantial contribution to its solution, in a way which would be particularly beneficial to Europe. The main reasons for conducting research in this field on a Community basis are as follows :

- the scale of the human and financial resources required, which suggests that such a development could hardly be carried out on a national basis ;
- the existence of a collective need, common to all Member States ;
- the long time-scale of the effort (extending towards to end of the century) needed to arrive at the construciton of the reactor ;
- in the event of success, the opening-up of a wide Community market for the European reactor.

5. OVERALL FINANCIAL IMPLICATIONS OF THE PROJECT FOR THE WHOLE OF ITS EXPECTED DURATION (EUA)

5.0 Implications in respect of expenditure (period 1979-83)

5.0.0 Costs incurred by :

| | |
|---|---|
| - The budget of the Communities : | 217.000.000 EUA (1) |
| - National administrations and other sectors at national level : | 528.000.000 EUA |
| Total cost : | 745.000.000 EUA |

(1) The amount of 217.000.000 EUA is broken down as follows :

| | |
|---|---|
| 31.463.000 EUA | already committed from appropriations for the 1976-80 programme |
| 8.537.000 EUA | balance of appropriations for commitment 1976-80 |
| 177.000.000 EUA | new funds required for the 1979-83 programme |
| 217.000.000 EUA | |

5.5.1 Multiannual timetable

To allow for the rolling nature of the fusion programme, the timetable below relates to the period 1976-83 covering the current programme (76-80) and the proposed programme (1979-83). For the 1976-83 period there is a total allocation of 301 M EUA, consisting of 84 M EUA for the period 1976-1978 plus 217 M EUA for the period 1979-1983.

5.1.1 Appropriations for commitment (UA 1976-77, EUA - 1978-83) (rounded off to thousand EUA)

| Category of expenditure | 1976 (final execution) | 1977 (provisional execution | 1978 (1978 budget + appropriations remaining from 1977) | 1979 | 1980 | 1981 | 1982 | 1983 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Staff | 3 240 000 | 3 782 000 | 6 157 000 | 6 127 000 | 6 561 000 | 6 955 000 | 7 372 000 | 7 815 000 | 48 009 000 |
| Administrative & technical operating expenditure | 135 000 | 170 000 | 171 000 | 231 000 | 247 000 | 264 000 | 282 000 | 302 000 | 1 802 000 |
| Contracts | 10 658 000 | 82 773 000 | 8 377 000 | 20 054 000 | 113 327 000 | 8 000 000 | 8 000 000 | - | 251 189 000 |
| Total | 14 033 000 | 86 725 000 | 14 705 000 | 26 412 000 (6 412 000 AP + 20 000 000 NP) | 120 135 000 (2 125 000 AP + 118 010 000 NP) | 15 219 000 | 5 654 000 | 8 117 000 | 301 000 000 (1) |

(1) Commitments contracted in 1976-78 total 115 463 000 EUA, of which 84 000 000 EUA for work done in 1976-78 and 31 463 000 EUA for work to be carried out in 1979 and after.

(2) Appropriations for commitments requested for 1979-83 total 185 537 000 EUA, of which 8 537 000 EUA are still available in appropriations for commitment from the 1976-80 programme ; consequently new appropriations amount to 185 537 000 - 8 537 000 = 177 000 000 EUA. To the amount of 185 537 000 must be added 31 463 000 EUA committed before 1979 for work to be carried out in 1979 and after : 185 537 000 + 31 463 000 = 217 000 000 EUA.

AP = ancient programme 1976-80

NP = new programme 1979-83

5.1.2 **Appropriations for payment (UA 1976-77, EUA 1978-83, rounded off to thousand EUA)**

| Category of expenditure | 1976 (final execution) | 1977 (including appropriations for payment carried over to 1978) | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Staff | 3 240 000 | 3 782 000 | 6 157 000 | 6 127 000 | 6 561 000 | 6 955 000 | 7 372 000 | 7 815 000 | - | 48 009 000 |
| Administration & technical operating expenditure | 135 000 | 170 000 | 171 000 | 231 000 | 247 000 | 264 000 | 282 000 | 302 000 | - | 1 802 000 |
| Contracts | 17 908 000 | 16 787 000 | 19 525 000 | 30 454 000 | 33 000 000 | 36 000 000 | 40 000 000 | 44 000 000 | 13 515 000 | 251 189 000 |
| Total | 21 283 000 | 20 739 000 | 25 853 000 | AP 26 812 000<br>NP 10 000 000<br>Tot36 812 000 | AP 29 313 000<br>NP 10 495 000<br>Tot39 808 000 | 43 219 000 | 47 654 000 | 52 117 000 | 13 515 000 | 301 000 000 (1) |

(1) payments 1976-78 : 67 875 000
payments 1979-84 : 233 125 000

Total : 301 000 000 EUA

**The amount of 233 125 000 EUA for the period 1979-84 includes an amount of 16 125 000 EUA for work carried out prior to that period :**

233 125 000
- 16 125 000

217 000 000

5.2 Method of calculation

(a) Staff costs

The staff proposed for this programme consists of the following :

| Year | A | B | C | Total |
|---|---|---|---|---|
| 1979 | 74 | 35 | 3 | 112 |
| 1980-1983 | 75 | 35 | 3 | 113 |

The calculations take into account the parameters laid down for the preparation of the preliminary draft budget for the 1979 financial year. For the period 1980-83, staff costs have been increased by 6 % per annum.

(b) Administrative and technical operating expenditure

This covers the costs of travel, missions, experts and the organizatio of meetings together with the use of administrative and technical support.

(c) Contract expenditure

For the period 1979-83, the cost of carrying out the fusion programme in the laboratories associated with the Community is estimated at 736 M EUA, including Commission staff seconded to those laboratories. The Community would participate in the financing of this expenditure at a rate of about 25 %. This rate could be increased to approximatel 45 % for some operations accorded priority status by the Liaison Group. Most of this expenditure would have to be committed at the start of the new programme for 1979-83.

Costs involved in the mobility of staff other than Commission staff are estimated at 2 M EUA for the period 1979-83.

5.3 Implications in respect of revenue

- Community taxes on the salaries of Commission staff.
- Contribution of this staff to pension scheme.

6. TYPE OF CONTROL TO BE APPLIED

Scientific control :

- Steering committees set up by association contracts to be concluded with the national laboratories.
- Committee of Directors set up by the association contracts.
- Liaison Group recognized by the Council as an ACPM (O.J. C 192 of 11 August 1972, page 1).
- Consultative Committee for Fusion set up by the Commission pursuant to Article 135 of the Euratom Treaty.

Administrative and Financial Control :

- Steering Committees
- Financial Control and Contracts Department of DG XII of the Commission.
- Court of Auditors.

7. FINANCING OF THE PROJECT

Appropriations to be entered in future budgets (1979-84).

## II) JET PROJECT

1. RELEVANT BUDGET HEADING CODE : 3351

2. TITLE OF BUDGET HEADING : Controlled thermonuclear fusion including the JET Project. This part of the record relates only to the JET Project.

3. LEGAL BASIS : Article 7 of the EAEC Treaty,
Council Decision 78/470/Euratom of 30 May 1978
(O.J. L 151 of 7 June 1978, page 8) and Council Decision
expected before April 1979.

4. DESCRIPTION, OBJECTIVES AND JUSTIFICATION OF THE PROJECT :

4.1 Description

Construction, operation and exploitation, as part of the Community fusion programme and for the benefit of the participants therein, of a large torus facility of the Tokamak type and its auxiliary facilities (Joint European Torus - JET) in order to extend the parameter range applicable to controlled thermonuclear fusion experiments up to conditions close to those needed in a thermonuclear reactor.

4.2 Objectives

To obtain and study a plasma in conditions and dimensions approaching those needed in a thermonuclear reactor. Four main areas of work are required to achieve this aim :

(i) the scaling of plasma behaviour as parameters approach the reactor range ;

(ii) the plasma-wall interaction in these conditions ;

(iii) the study of plasma heating ;

(iv) the study of $\alpha$-particle production and confinement and consequen resultant plasma heating.

4.3 Justification

Execution of the JET Project is an essential stage in the development of the Community's fusion programme. With regard to the final aim of this programme and its justification, please refer to Part I, Section 4.3 of the record sheet.

5. OVERALL FINANCIAL IMPLICATIONS OF THE PROJECT FOR THE WHOLE OF ITS EXPECTED DURATION (EUA)

5.1 Implications in respect of expenditure (period 1976-83)

5.1.1 Costs incurred by :

| | |
|---|---|
| The budget of the European Communities (80 %) | 147 700 000 EUA |
| National administrations and other sectors at national level (20 %) | 36 900 000 EUA |
| Total cost : | 184 600 000 EUA |

This cost has been estimated at constant January 1977 prices.

5.1.2 Multiannual timetable

| Years | 1976/77/78 | 1979 | 1980 | 1981 | 1982 | 1983 1st half | Total |
|---|---|---|---|---|---|---|---|
| Commitments (M EUA) | 16 | 54.4 | 35.2 | 25.6 | 12.8 | 3.7 | 147.7 (1) |
| Payments (M EUA) | 9.6 | 32 | 38.4 | 32.8 | 23.2 | 11.7 | 147.7 |

5.2 Method of calculation

The cost of the JET Project in the construction phase has been estimated at 184.6 M EUA at January 1977 prices and at the conversion rate for the EUA at 3 January 1977 (1 EUA = Bfrs 40.6207). The appropriations required to cover the Community's participation of 80 % in the financing of the project amount to 147.7 M EUA.

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(1) The sum of commitments for 1979-1983 amounts to 137.7 MEUA (= 147.7 - 16) and corresponds to the JET appropriation proposed in the new programme 1979-1983.

The amount of 184.6 M EUA does not take into account :

(a) Variations in economic conditions since January 1977. It is pointed out that the JET Project consists essentially of hardware. The JET Joint Undertaking for the first time is now updating the cost estimate for the project. The Commission will inform the budget authority.

(b) The cost of operating the facility during 1983.

(c) The cost of the necessary capital investment for extended performance. The promising results obtained recently in Tokamak installations appea to justify some speeding up of the programme. It is therefore probabl that much of the expenditure for extended performance will have to be committed during the construction phase. It is understood that this additional expenditure can be committed only on the basis of a new Council Decision on this programme. The preparatory work on the establishment of this programme has already started.

5.3 Implications in respect of revenue

Community taxes on the salaries of temporary staff.

6. PROJECT FINANCED FROM :

Appropriations entered in the budgets of the European Communities for 1976, 1977 and 1978.

Appropriations to be entered in future budgets.

7. TYPE OF CONTROL TO BE APPLIED

(a) Scientific control : JET Council
Consultative Committee for Fusion

(b) Administrative and Financial Control : JET Council
Court of Auditors.