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DOCUMENT 581/78

Report

drawn up on behalf of the Committee on Energy and Research

on the proposal from the Commission of the European Communities to the Council (Doc. 508/78) for the research and training programme (1979 – 1983) for the European Atomic Energy Community in the field of controlled thermonuclear fusion

Rapporteur: Mr L. NOE'

1.2.1

PE 55.734/fin.

English Edition

By letter of 6 December 1978 the Council of the European Communities requested the European Parliament to deliver an opinion on the proposal from the Commission of the European Communities to the Council for a research and training programme (1979-1983) for the European Atomic Energy Community in the field of controlled thermonuclear fusion.

The President of the European Parliament referred this proposal to the Committee on Energy and Research as the committee responsible and to the Committee on Budgets for its opinion.

On 18 September 1978 the Committee on Energy and Research appointed Mr Noè rapporteur.

It considered the proposal at its meetings of 24 November 1978, 20 December 1978 and 25 January 1979, and at the last meeting unanimously adopted the motion for a resolution and the explanatory statement.

Present: Mrs Walz, chairman; Mr Flämig, vice-chairman; Mr Veronesi, vice-chairman; Mr Noè, rapporteur; Mr Bertrand (deputizing for Mr Verhaegen), Lord Bessborough, Mr Fioret, Mr Fuchs, Mr Lezzi, Mr Mitchell, Mr Osborn and Mr Vergeer.

The opinion of the Committee on Budgets is attached.

C O N T E N T S

A

The Committee on Energy and Research hereby submits to the European Parliament the following motion for a resolution, together with explanatory statement:

MOTION FOR A RESOLUTION

embodying the opinion of the European Parliament on the proposal from the Commission of the European Communities to the Council for a research and training programme (1979-1983) for the European Atomic Energy Community in the field of controlled thermonuclear fusion

The European Parliament,

- having regard to the proposal from the Commission of the European Communities to the Council[1],

- having been consulted by the Council (Doc. 508/78),

- having regard to the report of the Committee on Energy and Research and the opinion of the Committee on Budgets (Doc. 581/78),

- conscious of the gravity of the long-term energy supplies problem and the limited number of means available to resolve it (breeder reactors, thermonuclear fusion, solar energy),

- aware of the potential advantages which thermonuclear fusion might present for the Community, having regard to the high level of energy consumption per unit area, the latitude and the climate,

- aware of the constant progress being made in research into thermonuclear fusion and the significant results recently obtained with Tokamak devices,

- conscious of the difficulty of the scientific and technological problems which have to be solved in order to develop a new energy source based on thermonuclear fusion and the scale of the financial and human resources necessary for this development,

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[1] OJ No. C 299, 13.12.1978, p.2

1. Welcomes the high degree of Community integration achieved in this field by the Commission in conjunction with the Institutions associated with it;

2. While deploring the unjustifiable delay brought about by the Council, causing the Community to lose the lead which it had in this field in spite of repeated exhortations by Parliament, welcomes the fact that an agreement on the site and a decision to go ahead with the JET programme have been reached;

3. Stresses the value of the 'sliding programme' principle (adoption of a new five-year programme after three years'implementation of the preceding one) making it possible to adapt the programme to take account of scientific and technical progress in this field,and recognizes the need, in the present situation, to adopt a new five-year programme;

4. Notes with satisfaction that the general programme proposed by the Commission is being coordinated with the JET project, to which very high priority is being given, and is oriented towards the implementation of the next stage;

5. Welcomes the intensification of research into the Tokamak line and auxiliary heating systems and recommends that activities should be concentrated as far as alternative lines are concerned;

6. Recommends that particular attention be given to high-field Tokamak devices as they may provide a short cut to ignition;

7. Welcomes the setting up of a more substantial fusion technology programme in the five sectors proposed: superconducting coils, tritium, materials, environmental impact and reactor design and, on this last point, approves the continuation of studies into the possible applications of fusion not directly connected with generating electricity (hybrid fusion-fission reactors);

8. Finds that in the field of inertial confinement, in which the Commission has so far been unable to undertake any Community coordination or integration for reasons outside its control, research in the Member States is lagging behind that in the field of magnetic confinement, whilst outside the Community significant technological progress is being made which may lead to a scientific breakthrough;

9. Hopes, therefore, that the Commission's efforts to set up a substantial programme in this field will meet with success;

10. Stressing the fundamental importance of international cooperation in this field, particularly in view of the scale of the financial and human resources necessary to attain the final objective:

- Welcomes the fact that two European non-Member States have associated themselves with the fusion project and that various international initiatives within the framework of the IEA and the IAEA are under way,
- Recommends that the maximum effort be made to increase international cooperation in this field, with a view to achieving the final objective with the utmost speed and efficiency;

11. Finding it impossible to describe as anything other than irresponsible, after the delays in taking decisions on the JET project, any attempt under any pretext to delay further the implementation of the proposed general programme on which the success of JET depends, urges the Council to approve the Commission's proposal forthwith.

B

EXPLANATORY STATEMENT

I. Introduction

1. In 1958 the European Community set up a programme on 'controlled thermonuclear fusion and plasma physics' which was to lead to the joint construction of prototype reactors suitable for production and marketing on an industrial scale. The annual cost of this existing fusion programme is comparable to that of one day's oil consumption in the Community.

2. The Council decided that this long-term collaborative project should embrace all the work on fusion and plasma physics being carried out in the Member States and that it should be partly financed by the Commission.

3. The Community's programme on plasma physics is now functioning well and early experiments on fusion have yielded satisfactory results.

The time has now come to set up a joint programme on fusion technology, although it will probably be more difficult to prevent national initiatives being taken in this area particularly once it becomes possible to build fusion reactors for commercial use at some point in the future.

4. The Community nature of the programme has been confirmed by the creation of the joint undertaking JET which will be the focal point of the European programme over the years to come.

5. The justification for the Community nature of this programme lies in:

- the scale of human and financial resources required;
- the long time scale of the effort necessary (at least until the end of the century);
- the great interest shown in this potential source of energy in all Member States;
- the opening of a wide Community market for the European reactor when success is achieved.

II. Sliding programme

6. Since 1975 the Commission has been in favour of the principle of a 'sliding programme', i.e. the adoption of a new five-year programme after three years' implementation of the preceding one, so as to maintain the continuity of the programme while at the same time having the opportunity to adapt it, if necessary, to take account of changes in the scientific and technical situation.

7. The Council Decision of 25 March 1976 lays down 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'.

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

(a) the progress made in Tokamak physics makes it essential to undertake new specific experiments if further progress is to be achieved;

(b) Recently developed heating methods can be applied to confining devices already built or under construction, including JET; other heating methods must be developed, which are more suited to future applications;

(c) the key fusion technology problems for the Tokamak line have been identified and international collaboration has begun on two of them (large supraconducting coils and the effects of neutron bombardment on materials); it is now desirable to set up a comprehensive technological programme;

(d) there is an awareness in all the Member States of the need to make progress in the field of nuclear fusion and a desire to take appropriate action.

III. International cooperation

9. World-wide exchanges of information have been proceeding satisfactorily, particularly in the field of magnetic confinement.

An increased US effort has become noticeable on the international scene over the past few years.

Official cooperation is dealt with by two organizations: the International Atomic Energy Agency (IAEA) and the International Energy Agency (IEA).

10. In the last two years three implementing agreements have been concluded within the framework of the IEA: on the intense neutron source, the large coil project and plasma-wall interaction (Textor).

11. Moreover, a periodic exchange of information on very large experimental devices (TFTR in the USA, JET in the Community and JT-60 in Japan), accompanied by a series of workshops on specific construction problems, has been in progress for three years.

12. The present programme is the fifth to be proposed to the Council and, for the first time, it is one being presented while the previous programme has been running for less than three years, thereby complying with the Council Decision of 25 March 1976.

13. While three years may be a short time in research, sufficient progress has been made in a number of subjects to justify 'a posteriori' the use of the 'sliding programme' concept. The principal aim of the last two programmes has been to develop Tokamak research in Europe and this objective has been fulfilled: construction of JET has begun 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 course of definition.

IV. JET

14. Preparations for the 'Joint Undertaking JET' were concluded in 1977 when Culham was chosen as its site.

At the end of the interim phase (June 1978), the construction phase was begun.

The machine is planned to be operational for basic performance in 1983. About 100 contracts have been placed for work to be performed by third parties, which are mainly concerned with tests and the manufacture of components for the machine.

15. In particular, the vacuum vessel, the toroidal coils and the power supplies (flywheel-generator-converter systems) have been ordered.

Finally, a consultancy contract has been placed for the JET buildings and associated services.

16. JET alone is neither sufficient nor is it designed to tackle all the problems which have to be solved before the next generation of Tokamaks can be launched.

17. The major Tokamaks already operating in the Community, TFR (Fontenay), Pulsator (Garching), and Dite (Culham), have contributed very substantially to the general progress. Tosca (Culham) is a small Tokamak on which shaped cross-sections and adiabatic compression can be studied. FT (Frascati) is a high magnetic field device and is the most ambitious technological undertaking carried out in Europe.

18. Finally, Asdex (Garching) will be a Tokamak with a 'poloidal divertor' and powerful heating by neutron injection and Textor (Jülich) is the subject of an international implementing agreement on cooperation with the Americans and will be mostly devoted to the important problem of plasma-wall interaction.

V. Implementation of the programme

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

(a) a staff of 860 professionals, including the JET team.

The total staff, including technical and administrative support, comprises more than 3,000 people. They are a well-integrated group of specialists able to work together on a European scale.

(b) 19 specialized laboratories with modern equipment;

(c) management structures created on the Commission's initiative through which the work of each laboratory is integrated in a true European framework and thereby acquires greater importance.

A cooperation agreement was concluded with Sweden in 1976 and a similar one with Switzerland is likely to follow in 1978.

VI. Objectives of the programme

(A) Magnetic confinement

20. The main objective is to acquire sufficient knowledge to be able to define the post-JET machine.

This implies:

- construction of JET and preparation of its experimental programme;

- obtaining key physical information from intermediate size toroidal devices, of tokamak type or of other types;

- development of powerful auxiliary heating systems;

- implementation of a technological programme, particularly in the field of materials, supraconductivity, tritium handling, remote handling and reactor design studies;

- construction of a medium size supraconducting Tokamak for profile shaping and plasma stability studies;

- construction of a medium size very high field Tokamak designed to achieve ignition[1].

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

(B) Inertial confinement

21. The European situation in this field is unsatisfactory.

The Commission has prepared a minimum programme:

- to make a critical evaluation of results obtained elsewhere,

- to facilitate as far as possible an exchange of information with foreign laboratories

- to maintain a nucleus of competent scientists to monitor and assess European research efforts scattered over various civilian laboratories.

VII. Programme proposal for 1979-1983

(a) Staff

22. As of mid-1978 the professional labour force stood at about 860 persons broken down as follows:

- qualified research scientists working in the Associations of the Member States (including 60 EURATOM officials)	700
- general support (including 9 EURATOM officials)	75
- JET team	48
- Association EURATOM-NSBESD (Sweden)	25
- JRC (Ispra)	12
	860

[1] Small high-field devices may provide a short cut for obtaining ignition in a shorter time and at lower cost.

23. It is difficult to evaluate the overall manpower since, in some of the Associations, supporting services are shared with other laboratories. An approximate estimate would be a total of at least 3,000 people.

24. As to the composition of the professional staff, it appears that the number of physicists is sufficient but that there is a shortage of engineers for the design and construction of the devices. Furthermore, since there has been no recruitment of young professionals in recent years, the average age of the staff is rising at an alarming rate.

(b) Expenditure

25. Continuation of research work at the present level (1978), taking account only of inflation and the increased cost of personnel, would require a forecast expenditure of 588m EUA over the five-year period. An extension of present activity will lead to an increase in expenditure of 103m EUA and the new activities envisaged (tritium technology and tests on materials) will require additional expenditure of 45m EUA. Thus the total expenditure forecast for the five-year period is 736m EUA.

26. The investment required for implementation of the 1979-1983 programme is estimated at 120m EUA, in the economic conditions at the beginning of 1979.

27. 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:

	Millions EUA
Tokamaks and support to JET	64
Other toroidal devices	15
Heating and injection	35
Fusion technology	30
Inertial confinement	6

28. The sum of these ceilings (150m EUA) is higher than the proposed overall ceiling for priority actions (120m EUA) as the ceilings shown cannot be reached simultaneously in all the lines.

29. The cost of the JET project in the construction phase has been calculated to be 184.6m EUA at January 1977 prices and with the rate of exchange for the EUA of 3 January 1977 (1 EUA = Bfrs 40.6207). 80% of the Joint Undertaking's expenditure will be borne by EURATOM.

VIII. Conclusions

30. In view of the progress being made towards controlled thermonuclear fusion, Parliament considers that the Community should concentrate its future action in the following areas:

I. In the field of magnetic confinement, which is the only one in which the Community is making a large-scale investment, every effort will have to be made in order not to lose the lead gained over the last ten years but now jeopardized by the delay in taking decisions on the JET. Particular attention will be required in order to save time, for the final test on the use of tritium which will be carried out under the next five-year programme which should be adopted - without delay - during the initial phase of the JET programme.

31. Furthermore, it would be extremely desirable for Community activities to include the building of a small-scale Tokamak with a high magnetic field and hence ohmic heating to enable it to reach a high fusion rate in a short time and at low cost which would make possible a study of plasma behaviour in a state of near ignition and, if possible, ignition.

32. Also very important are the tests now being made at the Fontenay aux Roses Centre which will lead to the construction of a Tokamak with superconducting magnets with the aim of prolonging the duration of the fusion experiments.

33. Finally, it would be useful to intensify studies and experiments using high-frequency heating as an auxiliary plasma heating system in addition to the injection of neutrons obtained from positive ions, since this holds out better prospects for application in fusion reactors when taken together with the possible development of a technology using negative ions to inject neutrons which will penetrate deeper into the plasma.

II.

34. Though research within the Community into inertial confinement is limited largely to national actions, praise seems due to the Commission's initiative to set up a nucleus of specialists at Community level to follow closely the progress being made elsewhere, particularly in the United States.

35. This is because the fully comprehensive programme being conducted there, particularly on the use of lasers, may lead to results comparable with those obtained with magnetic confinement and it is therefore vital that the Community should also be prepared for this eventuality.

36. Finally, work going on outside the Community on hybrid fusion-fission reactors will have to be followed by design and documentation studies. This will concern both the at present and more advanced field of magnetic confinement reactors (particularly of the mirror type) and the possible use of lasers for the same purpose.

Working document
on
guidelines for research into
nuclear fusion as a source of energy

INTRODUCTION

Nuclear fusion as a source of energy for peaceful purposes is, of course, not yet a reality and will not become one for several decades.

Nevertheless it has the potential to become one of the three main primary energy sources able to meet the demand for energy over a long period and in very great quantities.

This role will be shared with breeder fission and solar energy. Fusion can be employed in a very similar way to breeder fission, particularly since it offers the benefit of continuous production.

Nuclear fusion is thus potentially an interesting alternative source of energy and the advantages which it offers over breeder fission have attracted particular attention from politicians.

Notwithstanding the fact that breeder fission is already on the point of entering commercial use and will be impossible to replace for several decades at least, given the present state of the art, the advantages of fusion over breeder fission are :

I. no radioactive fuel wastes to be reprocessed or stored;

II. a complete fuel cycle in situ;

III. no danger in the case of accidental loss of control;

IV. shorter monitoring time for irradiated structural materials (the first wall enclosing the chamber in which fusion takes place will have to be replaced periodically and the irradiated metal must then be stored);

V. less strategic importance of the fuel;

VI. short fuel doubling time;

VII. wide availability of fuel.

This list shows that nuclear fusion will be better able than breeder fission to answer objections raised on the grounds of safety and impact on the environment.

This is extremely important in view of the incontrovertible need to continue to build nuclear power stations on a large scale, initially of the types already in commercial use and subsequently breeder fission stations which are their logical development.

The positive attitude which our committee has always taken on this matter will appear even more justified if it is accompanied by firm support for the complex, long and costly research work needed into nuclear fusion which will one day make it possible to discontinue plutonium production (which is at present indispensable) with all the accompanying control and safety measures.

These arguments are even more cogent in the European context.

No other industrialized area of the world, apart from Japan, is at present so dependent on imported fuels as Europe; consequently a new energy source such as fusion, which could free the Community from this liability, would have great political advantages.

Furthermore, the high energy consumption per unit of area linked to high population density makes the problems of environmental impact particularly acute. This factor may set a limit on the development of both solar energy, because of the vast areas needed for the collector equipment, and energy production from fast-breeder reactors, because of certain problems connected with the fuel cycle.

<u>What is fusion?</u>

Thermonuclear fusion is the main source of energy in the sun and the stars and has been effected on earth by exploding the hydrogen bomb.

Research into the physical conditions necessary to obtain and maintain a controlled supply of thermonuclear energy began almost thirty years ago. While fission, or the division of heavy atoms into light atoms, is produced by the impact of neutrons on certain fissile atoms (usually isotopes of uranium and plutonium), fusion involves the creation of heavy atoms through the colliding of light atoms.

In both cases usable energy is obtained when the surplus binding energy possessed by the atoms after the process, is released.

Naturally the fusion process will become usable once the quantity of electrical energy generated by the reaction is greater than the amount needed to produce and maintain it. Fusion resembles the normal process of chemical combustion : a considerable quantity of energy is needed to 'reach ignition' or to start the fusion reaction which is not the case with fission.

To keep the reaction going, a delicate balance is required between the input and output of energy.

From this it may be deduced that, in order for the reactive mass to start to burn, it must be brought to a certain temperature and that, as in any combustion process, for the combustion to be self sustaining, the mass must be held at this temperature for a minimum period.

This minimum period is called the confinement time since, during this time, the reactive mass must be . firmly insulated from the environment to the fullest possible extent.

The confinement time may also be understood as the time which the reactive mass would take to cool, i.e. to lose its energy to the walls of the container. The minimum confinement time becomes shorter as the density of the reactive mass increases.

Reference is usually made to two types of energy equations to define the physical conditions necessary to obtain fusion. In the first a comparison is made between the electrical enegy produced and the energy needed to heat the reactive mass and to compensate for radiation losses : this is the Lawson criterion. In the second, a comparison is drawn between that fraction of the energy produced which remains confined within the reactive mass and the energy lost: this is the ignition criterion.

Both of these criteria require specific values for the temperature and the product of density and confinement time.

Where the density of the reactive mass is equal to or greater than that of the solid state, the confinement time may be so short that the combustion process produces an explosion. This is the principle of the hydrogen bomb.

The only way to control the reaction at these densities is drastically to reduce the energy released, i.e. to provoke micro-explosions and this requires densities much higher than those of the solid state. This approach to fusion is also called inertial confinement because the inertia of the particles themselves is sufficient to limit the expansion time, and hence the plasma cooling time, to values greater than the confinement time needed.

When, however, the density of the reactive mass is very low, i.e. that of a gas (ten or more orders of magnitude less than in the case of inertial confinement), the confinement time increases to one or more seconds. The walls needed to contain a gas at very high temperature and hence very high pressure for such a long time obviously cannot be material ones. This high temperature gas is ionized and thus an excellent conductor of electricity.

An ionized gas[1] is usually called plasma and since one of its properties is that it does not readily cross a magnetic field, it is possible to use non-material walls formed of magnetic fields to confine it.

The reactive mass therefore assumes the shape imposed on it by the magnetic field.

FUSION FUELS

A variety of fusion reactions can be used to produce energy.

The most interesting of these involve light nuclei.

The greatest attention has been given to two isotopes of hydrogen: deuterium (D) and tritium (T).

Deuterium is present in water to the extent of one gram in approximately thirty litres of water.

Since the fusion of the deuterium contained in a liter of water would yield the same amount of energy as the combustion of 300 litres of oil, the enormous energy potential of this process is apparent.

There is no difficulty in obtaining fuel for the D-D reaction, given the large quantities of deuterium present in water.

[1] A gas is ionized when the electrons are separated from the nuclei of atoms as a result of collisions due to thermal agitation.

In addition, reactor design and safety problems would be considerably simplified since there is no fuel to breed and a much smaller quantity of tritium present in the plant.

However, the two rigorous conditions which this fusion would pose with regard to plasma physics (temperatures five times higher and much longer confinement times than those required by the deuterium-tritium reaction) mean that no work on the D-D reaction is being carried out for the present. On the other hand, tritium has to be produced from lithium by bombarding the neutrons produced by the fusion reaction and to this extent the fusion reactor can be regarded as another type of breeder reactor.

The known reserves of lithium in the earth's crust are equal, in energy terms, to those of fertile materials (U_{238} and Th_{232}) for fast reactors; hence D-T fusion has a practically unlimited energy potential similar to that of fast reactors.

Means of realizing controlled fusion

As mentioned above, the two ways of resolving the problem of controlled fusion now being investigated are:

a - magnetic confinement
b - inertial confinement

Various means of magnetic confinement are being studied at present. They may be divided into open and closed configurations.

The former is roughly cylindrical in form and thus has a potential advantage over the more complex closed configuration; it also offers the advantage of stationary operation. Unfortunately there are serious losses of plasma from the ends of this configuration and a large part of the power produced in a reactor based on this design would have to be fed back in to sustain the thermonuclear reaction.

This line is being followed in the United States (the mirror reactor) and is considered to be the main alternative to the Tokamak system. Many scientists feel that if it were necessary to build hybrid fusion-fission reactors (see below), they could be supported by this type of fusion.

To eliminate losses from the end of an open configuration, the most obvious modification is to close it to form a torus.

The unevenness inherent in a toroidal magnetic field causes the particles to drift and, to overcome this phenomenon, a helicoidal winding would be inserted within the toroidal magnet (Stellarator, see Fig. 1) or a current induced through the ring of plasma which, as mentioned above, is a very good conductor (Tokamak, see Fig. 2).

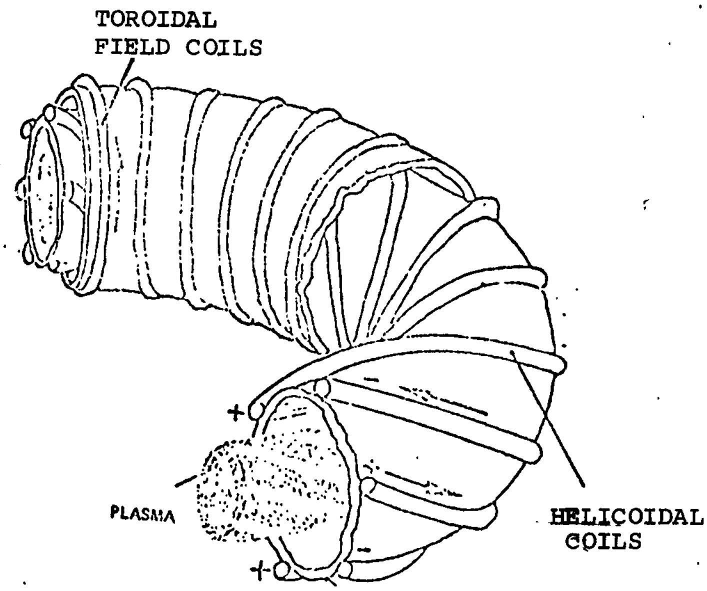

Fig.1 STELLARATOR

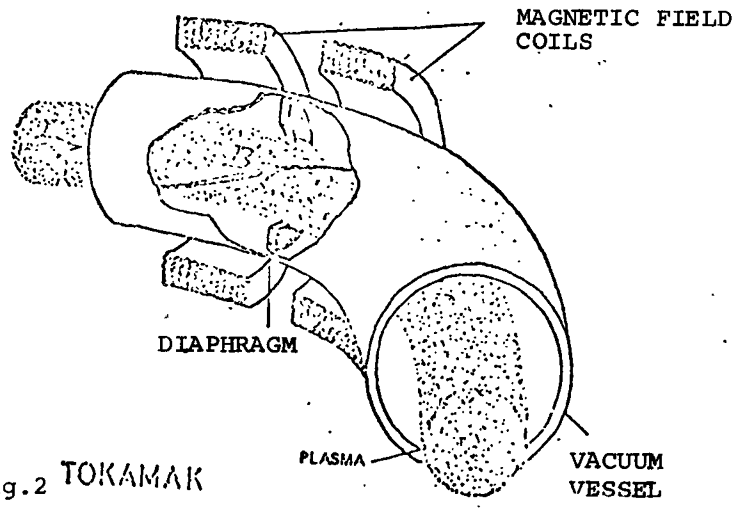

Fig.2 TOKAMAK

The Tokamak has the advantage over the Stellarator that the system for producing the magnetic field is simpler and the current in the plasma also serves to heat the latter by means of an ohmic effect.

As we shall see below, the greatest effort has been put into the Tokamak in the search for a means of obtaining controlled thermonuclear fusion.

Inertial confinement

Research into fusion using inertial confinement does suggest that it is scientifically feasible to heat and compress small spheres of a suitable fuel for very short periods so as to obtain fusion with a net output of energy.

These small spheres of fuel may be brought to the required conditions of temperature and pressure by means of lasers or beams of electrons or ions.

Most research into inertial confinement is at present directed towards heating a pellet of a diameter of approximately 1 mm containing a mixture of deuterium and tritium to provoke micro-explosions with a frequency of one or more explosions per second.

The energy and power of the beam must reach a threshold value in order to trigger off the explosion and the higher the density of the target, the lower this value can be.

It is therefore necessary to precompress the target to a density greater than that of a solid; this is possible using the same laser beam provided that its intensity, together with the geometry of the target, are suitably arranged.

Over the past ten years, rapid progress has been made in this field in the United States thanks to the integration of

- physical experiments
- the drawing up of computer programmes
- component design
- systems development.

Computer programmes make it possible to calculate the interaction and transport of laser beams, electrons, ions, X-rays and fusion products, the magnetic and electrical fields associated with these interactions and target movement.

By using the laser propagation model, it is possible to calculate the refraction and absorption caused by the incidence of laser beams on the plasma and hence the acceleration of the plasma itself boosted by the laser beams.

Special studies and experiments are under way to determine the characteristics of these targets and it appears that the best type is a hollow sphere of deuterium and tritium.

This shows the complexity of the phenomena which have to be understood and mastered. It is, however, clear that this approach is the right one to employ for this difficult job.

It is expected that, in or around the year 1982, one of the leading laboratories in this field (Livermore, USA) will carry out a crucial experiment in which the thermonuclear energy may equal the energy of the laser beam.

Success in these experiments or similar ones being carried out at Los Alamos and the Lebedev Institute in Moscow may prompt a new wave of optimism about laser fusion which at present is the subject of some doubts even though intensive research is being carried out.

It should also be remembered that some countries, particularly the USA and the USSR, are conducting large-scale classified programmes for military purposes on power lasers and their applications. These programmes may have already tackled problems of crucial interest for controlled fusion.

The existence of classified programmes, far from helping civil programmes, may in fact hinder the development in the European Community of a coordinated programme to be partly financed by EURATOM because of the danger of a proliferation of information of some probable military interest.

Some of the technical advantages and disadvantages of inertial confinement with respect to magnetic confinement can be noted in passing:

Advantages of inertial confinement:

- no magnetic fields;
- no insulating materials;
- smaller unitary power;
- simpler design for maintenance.
- less critical vacuum seals;
- smaller quantities of tritium.

Disadvantages of inertial confinement:

- more intricate preparation of the fuel;
- steering of the target;
- greater circulating power;
- laser technology still to be developed;
- very high frequency impulses;
- materials liable to thermal shock;
- radioactive fragments of the target.

The Tokamak s

As stated above, most research into controlled thermonuclear fusion is devoted to the Tokamak system.

Table I lists the main Tokamaks which are now in operation or under construction throughout the world:

TABLE I

Main Tokamaks in operation or under construction:

Plant	Location	Field (tesla)	Curr. (MA)	a (m)	R (m)	Year of completion
TFTR	Princeton	5.20	2.50	1.10	2.65	1980
PLT	Princeton	5.00	1.60	0.45	1.32	1975
ALCATOR	M.I.T.	3.2	0.16	0.095	0.54	1973
DOUBLET III	La Jolla	2.60	5.00	0.54/1.35	1.50	1978
T-7	Moscow	3.00	0.50	0.33	1.22	1977
T-10	Moscow	5.00	1.00	0.37	1.50	1975
T-4	Moscow	4.50	0.30	0.17	0.90	1970
JT-60	Jaeri, Japan	5.00	3.30	1.00	3.00	1980
JT-4	Jaeri, Japan	3.00	1.00	0.45	1.40	1980
JET	Culham	3.45	4.80	1.25/1.95	2.96	1982
ASDEX	Garching	2.8	0.50	0.40	1.64	1978
TEXTOR	Jülich	2.00	0.50	0.50	1.75	1981
FT	Frascati	10.00	1.00	0.21	0.83	1977
DITE	Culham	2.80	0.28	0.23	1.12	1976
TFR-600	Fontenay	6.00	0.60	0.24	0.98	1977

The generation of large devices which will be in use in the 1980's will, as can be seen, include JET in the European Community, TFTR in the United States and JT-60 in Japan.

Notable [illegible] smaller operational [illegible] [illegible]cati Tokamak (FT), the PLT in Princeton (USA) and the T10 in Kurchacov near Moscow.

The Princeton laboratory established a record during an experiment in the first half of August 1978 by reaching a temperature of 60 million degrees centigrade.

JET [illegible] a gigantic project, as are the other two Tokamaks of similar size.

A vertical section of the torus has a width of [illegible] 15m and a height of about 12m

The costs of constructing and operating a device of this type for the five or six years necessary for it to be properly adjusted and to carry out experiments, is estimated at approximately Lit 250 million.

The Tokamaks which should be undergoing [illegible] 1980's will probably make it possible to attain longer confinement [illegible] for the plasma at a higher temperature which would be another step forward towards the commercial use of this machine.

ENERGY FROM FUSION

Following the results obtained at Princeton University in August 1978, a new machine [illegible] under construction there and [illegible] into service in 1981 may reach ignition during the early 1980's.

The FT Tokamak which has already begun operating in Frascati (Italy) as part of the Community programme and Doublet III [illegible] construction of which by General Atomic at La Jolla is now nearing completion, should also produce some interesting results during the next few years

There are also plans under the Community programme to carry out the VHFT ignition experiment in Garching (Bavaria) in cooperation with the Frascati centre and the Americans, in which a machine of rather small dimensions with a very strong magnetic field may produce an advance in the physics of fusion over relatively short periods.

An ambitious experiment to find all the answers to these physical problems using a single machine would require expenditure of the order of eight hundred thousand million lire.

Investment of this scale can only be envisaged if a high degree of reliance can be placed on the scientific and technical results obtained.

It therefore seems more sensible to continue with the present step by step approach being followed throughout the world so that each step will create greater confidence in the outcome of this research and increase knowledge of these phenomena under gradually more rigorous conditions.

For example, some caution is advisable as to the results of the JET project since this machine is designed to operate with the plasma at temperatures above those so far recorded; this means that new phenomena may occur presenting fresh problems although results obtained at Princeton are somewhat reassuring on this point.

The most urgent problems to be tackled in order to assess the feasibility of fusion with a Tokamak system are:

in physics:
- a study of the confinement of reactive plasmas at a temperature in excess of 100 million degrees;
- additional heating methods with radio frequencies and neutron injection;
- study of the interaction of the walls with a reacting plasma (D-T) and its effect on plasma purity;

in technology:
- study of materials for the first wall resistant to high neutron flux;
- materials with a low activation index to reduce the impact on the environment;
- remote control systems for changing the first wall;
- breeding and cooling without the use of metals or liquids to increase the safety of the plant;
- techniques for the use of tritium in accordance with acceptable safety criteria;
- large superconducting magnets;
- studies of plant management and maintenance.

Impact of fusion reactors on the environment

As stated earlier, the operation of a fusion reactor does not leave any long-lived radioactive waste to be stored since the stable by-products of the fusion reaction (helium) are not radioactive.

This is the great advantage of fusion over fission. The fuel contains a radioactive component, tritium, but this is produced on the site.

One subject which demands the maximum attention is the risk of a leak of tritium into the biosphere (tritium emits beta rays and has a physical half-life of 12.3 years and a biological half-life of 12 days). The design of the reactor at present envisaged is such as to hold tritium leakage within acceptable limits.

The materials used in the construction of the reactor and particularly its most exposed part, the first wall, must be stored and held under surveillance for a certain time if they are changed during the life of the reactor and, in any case, after its decommissioning. If suitable alloys of valadium and titanium are used, it has been calculated that after some decades in storage the structural waste will have a residual radioactivity equal to that of natural uranium and will thereafter no longer require particular surveillance.

It is nevertheless clear that the most difficult problems for the Tokamaks relate to the life of the first wall. This will depend on the materials used for it in the experiments and the consequent frequency of replacement operations which in turn will be decided by the remote-control arrangements adopted.

It is obvious that a reactor cannot be operated economically if there are too frequent or too long interruptions.

<u>Hybrid fusion-fission reactors</u>

These reactors may constitute an intermediate step towards pure fusion.

The idea is as old as that of fusion and is derived from the ability to amplify the power of a fusion reactor by using its neutrons not to heat a fluid but to produce fissile material and to increase total power by a factor of 10.

Fusion systems with which it will be difficult to meet the economic target of a pure fusion reactor may lead to hybrid reactors.

Even if a hybrid solution is adopted, this will not free us from the need to reprocess irradiated fuel and store the waste because of the fission element involved. Hybrids have not aroused much interest in Europe or Japan, but have attracted slightly more attention in the USA and USSR.

A reactor of this type is very safe since the quantity of thermonuclear energy in the plasma is smaller and because the uranium fuel is always held under the critical point which is an advantage if any difficulties should arise. The process stops of its own accord without special techniques having to be used.

Some scientists studying the use of lasers in thermonuclear fusion are designing hybrid reactors to produce fissile fuel suitable for fission reactors.

Studies have also begun into the production of hydrogen by means of nuclear fusion in association with thermochemical, electronic or radiolitic processes. Of these studies, the thermochemical method, i.e. the method that the Ispra Centre has been testing for some years, seems to be the most promising.

OPINION OF THE COMMITTEE ON BUDGETS

Draftsman: The Earl of Bessborough

On 31 January 1979 the Committee on Budgets appointed the Earl of Bessborough draftsman of the opinion.

It considered the draft opinion at its meeting on 28 February and 1st March 1979 and adopted it unanimously.

Present: Mr Lange, chairman; the Earl of Bessborough, draftsman; Mr Alber; Lord Bruce of Donington; Mrs Dahlerup; Mr Schreiber; Mr Scott-Hopkins; Mr Shaw and Mr Würtz.

Attitude of the Committee on Budgets to expenditure in the sphere of research and energy

1. In drawing up this opinion, the Committee on Budgets considers it appropriate to recall its position in regard to Community expenditure on research which it had formulated in the past. This view was set out clearly and concisely in the resolution[1] on the 1978 draft budget which stated the following:

"(The European Parliament)

40. Recognizes that some steps relating to the development of European industry, in particular the strengthening of advanced technology, can best be effected at the Community level;

41. Believes that there is an obligation on the Community (a) to assist, through the budget, the financing of research and coordination in regard to some of the advanced technology sectors, the securing of some energy and raw materials, research and investment actions,... and (b) to develop a Community energy policy;

42. Acknowledges that this implies an effort on the budgetary plane which, though not inconsiderable, would represent an overall saving since there would be greater economy in total outlay than would be the case if these measures were undertaken by Member States themselves."

2. This position was reiterated in the draft resolution[2] on the 1979 draft budget which stated that:

"(The European Parliament)

27. Considers it urgent that, on the basis of the outcome of the summit conferences, the common energy policy should pursue three general aims:

(a) to reduce dependence on energy imports partly by creating a European reserve of primary energy stocks,

(b) to encourage alternative sources of energy,

(c) to push through energy conservation programmes."

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(1) O.J. Vol.20 C.280 21.11.1977

(2) Doc. 400/78

3. Therefore, against this background, the present opinion can be confined to (i) an examination of the budgetary, financial and control aspects of the Commission's proposal relating to the research and training programme (1979-1983) for the European Atomic Energy Community in the field of controlled thermonuclear fusion[1] and (ii) a consideration of the justification advanced for committing the expenditure involved.

Background of the proposal

4. The application of controlled thermonuclear fusion could be expected to be of benefit to the Community, in the longer term, because it would help to replace other diminishing sources of energy. As well, it would - if successful - add to the security of supply. However, a considerable effort will be needed if this potential source of energy is to be made a reality through operational fusion reactors.

Reasons for the proposal

5. The Commission gave the following reasons for putting forward the proposal - and these justifications fit in with the criteria formulated in the past by the Committee on Budgets, endorsed by Parliament in plenary session and which are set out at paragraphs 1 and 2 above. These are:

- the scale of the effort is such that it would be most effectively carried out on a multi-national basis;
- the need for new sources of energy is common to all Member States;
- a long-term effort is involved in developing the fusion reactor; and
- operating through a joint effort should result in a larger market for the reactor, once it is developed.

Expenditure involved

- on present activity

6. The Commission's presentation of the sums involved in its proposal is somewhat unclear. However, the following tables show the results that arise from the outline programme for the years 1979-1983. The amount of the estimates for 1978[2] (104 million EUA) is taken as a starting point; multiplying by five, a figure of 520 million EUA is obtained. To this is added 40 million EUA to cover the allowance for inflation at the rate of 7½% (the estimate for the twelve months to January 1979). Then, a sum of 28 million EUA is added to cover the cost of manpower at an unchanged numerical level but growing at the rate of 6% a year because of normal

[1] Doc. 508/78
[2] For details, see attached table.

incremental creep and allied factors.

- extension of the effort

7. At point III 6.2 of the proposal, the Commission draws attention to "the very positive results obtained in 1978 on the Tokamak line". Investigations into this aspect have not yet been completed but it could lead to a shortening of "the construction phase of JET". Further, the possibility of building two new Tokamaks is referred to - although it is pointed out that "the possibility of building each of the two new experiments ... has not yet been assessed". A more convincing case can be made for action in regard to plasma heating, fusion technology and inertial confinement. The total cost of this package of activities would be 103 million EUA.

- mobility

8. The setting aside of a maximum amount of 2 million EUA, to cover the cost of staff and information mobility, is also proposed. This would make it possible to exchange staff among the various laboratories thus helping to spread specialised knowledge within the Community. It would be in line with the wishes expressed in the report on the discharge for the 1976 financial year[1] which stated at paragraph 27 that Parliament

> "is of the view that a degree of mobility for researchers should constitute an integral part of the overall Community approach to research".[2]

- management and administration

9. A ceiling of about 7 million EUA is proposed to cover management and administration costs - staff of the fusion directorate in Brussels, the organisation of meetings, expert contracts and so on. The Committee on Budgets has frequently urged that a tight check be held on this aspect of research work - note, for example, that, in the report on the discharge for the 1975 financial year[3], it was pointed out that Parliament

> "believes that the Commission should seek to ensure that ... an optimum balance is maintained between operational research costs and staff expenditure."[4]

and again in the report on the discharge 1976 for the financial year

> "draws attention to the need for maintaining the appropriate balance between staff costs and expenditure on operational research."[5]

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(1) Doc. 489/79
(2) O.J. C.6, 8/1/1979
(3) Doc. 165/77
(4) O.J. C.183.1.8.1977
(5) O.J. C.6, 8/1/1979

Recapitulative Table (million EUA)

Continuation of present activity		
- unchanged volume	520)	
- allowance for inflation	40)	
- incremental creep	28)	588
extension of present activity		
- new Tokamaks	50)	
- additional heating	23)	
- inertial confinement	10)	
- fusion technology	20)	103
new activities		45
cost of "mobility"		2
management and administration		7
Total		745

10. However, the Commission indicates that the Community participation is estimated at 217 million EUA made up as follows:

	(million EUA)
General support	154
Preferential support	54
"Mobility"	2
Management and administration	7
	217

11. In addition to this amount for the research and training programme, a sum of 131.7 million EUA is estimated for the construction phase of JET during 1979-1983.

JET project estimates (commitments)

12. The Commission has estimated that the cost of the JET project in the phase 1979-1983 will amount to 131.7 million EUA. This was arrived at as follows:

	(million EUA)
Estimated cost 1976-1983 at constant January 1977 prices	184.6
Share to be borne by the budget of the Communities (80%)	147.7
Commitments entered into in 1976-1978	- 16.0
	131.7

It is proposed that these figures be replaced by the figures shown in the amended text which have now been supplied by the Commission and which reflect the impact of inflation since January 1977.

13. It is to be noted that this estimate of 131.7 million EUA is based on January 1977 prices. The estimate does not include (i) the cost of operating the facility during 1983 nor (ii) the cost of the necessary capital investment for an extended programme.

Breakdown of the estimate of the 217 million EUA

14. The following table sets out the estimates of appropriations for commitment:

appropriations for commitment

,000 EUA

year	contracts	staff	administration etc.	total
1979	20,054	6,127	231	26,412
1980	113,327	6,561	247	120,135
1981	8,000	6,955	264	15,219
1982	8,000	7,372	282	15,654
1983	-	7,815	302	8,117
Total	149,381	34,830	1,326	185,537*
Add:	Pre - 1979 commitments			31,463
Grand Total				217,000

* of the amount of 185,537,000 EUA, 8,537,000 EUA are still available in appropriations for commitment from the 1976-1980 programme: therefore, the new appropriations for commitment being sought amount to 177,000,000 EUA.

Manpower involved

15. The Commission estimates that the total manpower involved in the programme is of the order of 3,000 people while the total professional manpower is put at about 860; however, only a fraction (about 10 per cent) of this total will be employed by the Community. No additional staff is sought for the five years for either the JET or the non-JET parts. Figures for staff do not include those under contract in industry.

Reference to control

16. At pages 76 and 79 of the proposal, it is stated that administrative and financial control will be applied by

" - steering committees
- financial control and contracts department of D.G. XII of the Commission
- Court of Auditors".

It is surprising that no mention is made of the control responsibility exercised by the Parliament

(i) as a partner in the budgetary authority;

(ii) when examining the quarterly statements furnished in accordance with Article 29 of the Financial Regulation; and

(iii) in the context of the preparation of the discharge.

The Committee on Budgets felt that the attention of the Commission should be drawn to this aspect.

Aspects of the JET estimates

17. As is indicated at paragraph 13 above, the Committee on Budgets noted certain aspects of the way in which multiannual estimates were prepared. It is of the utmost importance that the data on which budgetary decisions must be based should represent a careful and accurate presentation of likely costs over the years ahead. Out-of-date statistics are not particularly helpful.

Comments of the Court of Auditors

18. In its report on the 1977 financial year, the Court of Auditors made a series of thought-provoking comments on various aspects of Commission activity in relation to research, investment and energy. These include "The Court is of the opinion that the Commission should have taken more effective steps to ensure their probable rate of usage of this facility before embarking on the expenditure involved." ..."The Court does not accept that such delays, which can lead to expensive equipment standing idle for long periods, can be considered as normal." ..."The financial and legal consequences of these developments, which could be considerable, have not yet been clarified."[1] These and many other issues will be gone into in the report on the discharge for 1977[2]. However, they justify a certain unease concerning the calculations (and use) of appropriations for research and investment activities. Despite this, the Committee on Budgets decided to endorse the proposal, mainly because of the considerations set out in paragraphs 1 and 2 above.

Amendments to the proposal for a Council decision

19. The Committee on Budgets considered it necessary to amend the articles of the proposed decision. These amendments, which add to the clarity of the text, are set out in the annex to this opinion. The amendment to Article 1 takes account of the fact that 1 January 1979 has now passed; the important

[1] O.J. Vol. 21 No. C.313
30.12.1978 pages 67 and 70.- these concern the JRC and not the fusion programme

[2] Now being prepared by Lord Bruce of Donington

date is that at the end of the period, i.e. 31.12.1983. Article 2 is amended (i) to bring it into line with the new agreed presentation and (ii) to show the figure for the programme (without JET) at million and the JET figure at 145 million in view of (a) the general basis of the estimates which, in any event, will be revised during future budgetary procedures and (b) the tentative nature of the proposal in regard to the second new Tokamak. Article 3 is amended to include both Parliament and Council in the budgetary authority. The change to Article 4 is in line with that to Article 1.

Conclusions

20. The Committee on Budgets

(a) recalls its positive attitude towards the financing, through the general budget of the Community, of research particularly in regard to the securing of future sources of energy;

(b) takes account of Parliament's clearly expressed support for the fusion programme and its unwillingness to tolerate further delays in getting it underway;

(c) notes the Energy and Research Committee's endorsement of the proposals now under consideration;

(d) considers it appropriate to round up the figures for the programme without JET and to modify the figures concerning the construction of JET so as to take account of the changes in economic conditions since January 1977;

(e) accepts that the budgetary authority will be informed when the results of the updating of the cost estimates for the programme are to hand;

(f) regrets that this proposal came forward so late in 1978;

(g) will pay special attention in the consideration of the discharge 1977 report to the comments made by the Court of Auditors in the research and energy spheres;

(h) asks the Court of Auditors to examine in due course the staff aspect of the JRC at Ispra insofar as its work concerns thermonuclear fusion research;

(i) reminds the Commission of Parliament's responsibility in regard to the control of Community expenditure which it exercises when examining (i) the draft budget, (ii) the quarterly returns submitted under Article 29 of the Financial Regulation and (iii) the discharge report;

(j) believes that, during the annual budgetary procedure, the estimates for the JET and non-JET parts of the programme should be reviewed in the light of scientific progress, economic development and new data supplied by the Commission;

(k) feels that the amendments indicated in the attached annex should be effected to the proposal for a Council decision;

(l) approves the Commission's proposal subject to the observations set out in this paragraph.

TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	AMENDED TEXT

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

Preamble and recitals unchanged

Article 1	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.	A research and training programme in the field of controlled thermonuclear fusion as defined in the Annex is hereby adopted for the period ending on 31 December 1983.
Article 2	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 entire duration of the programme without JET are estimated at 220 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.	The global needs for the construction phase of JET during the duration of the programme are estimated at 145 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.	These figures are of an indicative nature only.
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[1].	Unchanged.

(1) O.J. No. L356, 31.12.1977, p.1.

TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	AMENDED TEXT
Article 3	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.	The Commission shall submit to the European Parliament and the Council, not later than 1 July 1981, a review proposal designed to replace the present programme with a new five-year programme with effect from 1 January 1982.
Article 4	Article 4
Decisions 76/345/Euratom and 78/470/Euratom are repealed. This Decision shall enter into force on 1 January 1979.	Decisions 76/345/Euratom and 78/470/Euratom are repealed. This Decision shall enter into force immediately.

Annex: consequential changes to be effected

ANNEX 1

Fusion Association Budgets 1978

	National Currency	EUA (11.10.78)	UA	Laboratories
Belgium	77,911,400	1,955,715	1,558,228	ERM and ULB
France (CEA)	124,549,000	21,653,654	22,425,099	Fontenay-aux-Roses, Grenoble
Italy (CNEN)	8,710,000	7,943,022	13,936,000)	Frascati, Padua
" (CNR)	1,519,566	1,385,757	2,431,306)	and Milan
Denmark (RISØ)	5,771,000	822,273	769,467	Risø
Germany (KFA)	25,997,000	10,284,925	7,103,005	Julich
" (IPP)	95,931,400	37,952,352	26,210,765	Garching
Netherlands (FOM)	17,460,000	6,367,499	4,823,204	Jutphaas
United Kingdom (UKAEA)	10,500,000	15,567,271	25,200,000	Culham
		103,932,468	104,457,074	

Note: Sweden and Switzerland not included