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5 February 1979 **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

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 [illegible] 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.

Annex

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, rot 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.

What is fusion?

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 <u>Lawson criterion</u>. 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 <u>ignition criterion</u>.

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).

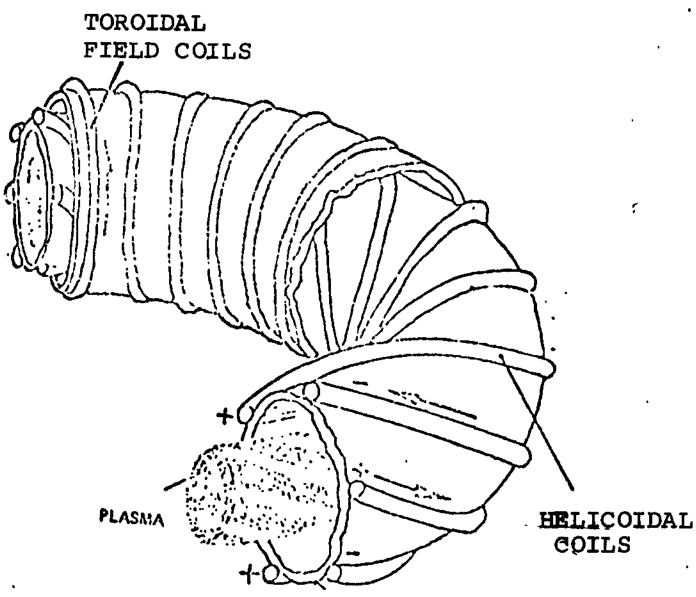

Fig.1 STELLARATOR

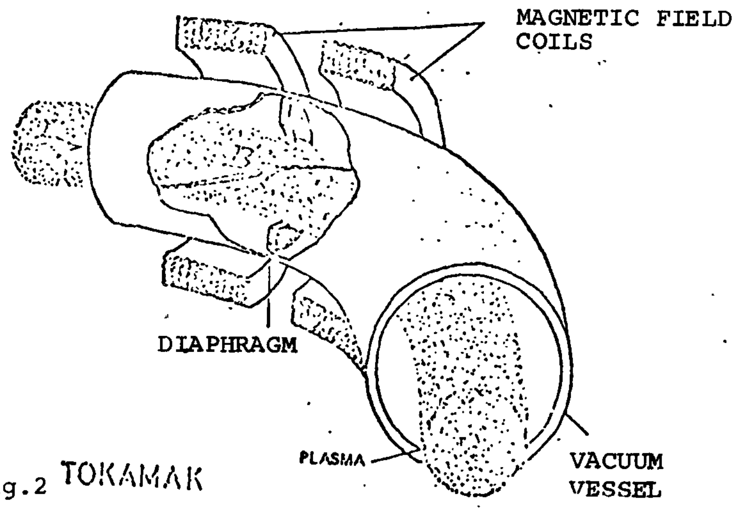

Fig.2 TOKAMAK

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.