EUROPEAN PARLIAMENT

Luxembourg L-2929

SCIENTIFIC AND TECHNOLOGICAL OPTIONS ASSESSMENT · EUROPEAN PARLIAMENT

CRITERIA FOR THE ASSESSMENT OF EUROPEAN FUSION RESEARCH

(STOA FUSION PROJECT)

VOL. II

MAY 1988

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C O N T E N T S

Each numbered section of this document is numbered internally

Section I

THE STOA PROJECT

The STOA Project (Scientific and Technological Options Assessment) is the Technology Assessment unit of the European Parliament. Set up in 1987, its function is to provide background information to the European Parliament on the scientific and technological aspects of political issues and to facilitate access to technical expertise outside the European Community institutions.

STOA is run by a Supervisory Panel of Members of the European Parliament assisted by a Project Team of officials from the Secretariat-General of the Parliament. It maintains a Network of contacts with outside experts and publishes a Newsletter. Requests for further information are welcome and should be sent to: The STOA Project, European Parliament, Room II-5/58, Luxembourg L-2929 (Telephone Luxembourg 4300-2511).

Section II

European Parliament Resolution on the Fusion Programme adopted in Strasbourg on Thursday, 10 March 1988

This resolution represents the opinion of the European Parliament. At the time of the compilation of the present document the Council had not yet taken a decision on the Fusion Programme.

The first part of what follows is the series of amendments proposed by the Parliament to the original text put forward by the Commission. The second part is a formal Legislative Resolution. The debate and resolution were based on a report by Mr Alman Metten, MEP drawn up for the European Parliament's Committee on Energy, Research and Technology. The Metten report is printed in the present document after the Resolution of 10 March 1988.

10. Controlled thermonuclear fusion - JET

Proposal for a regulation COM(87) 320 final

Council regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion

TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	TEXT AMENDED BY THE EUROPEAN PARLIAMENT
Preamble unchanged	
First two recitals unchanged	
Whereas thermonuclear fusion is a potential new source of energy using fuel which is virtually inexhaustible and universally accessible; whereas magnetic fusion reactors will have inherent safety features and hold the promise of a low impact on the enivronment; thermonuclear fusion forms therefore an important objective within the framework programme;	Whereas thermonuclear fusion is a potential new source of energy using fuel which is virtually inexhaustible and universally accessible; whereas nuclear fusion is potentially a safe and environmentally benign energy source in a number of respects; whereas one of the principal objectives of the framework programme is therefore to achieve controlled thermonuclear fusion and realize this potential in the process;
Fourth to seventh recitals unchanged	
Whereas the strategy on which the continuation of the programme is based should remain unchanged, namely:	Whereas the strategy on which the continuation of the programme is based should remain largely unchanged, namely:
3 indents unchanged	
	Whereas this strategy must be modified to ensure that a central objective will be to secure the environmental and safety-related advantages of fusion over other sources of energy;

(+) OJ No. C 247, 15.9.1987, p.2

TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	TEXT AMENDED BY THE EUROPEAN PARLIAMENT

Ninth recital unchanged

	Whereas the next review of the programme must be preceded by an independent evaluation of those components of the programme already being implemented and an appraisal of the potential environmental, safety-related and economic attractiveness of fusion;

Tenth to fourteenth recitals unchanged

Article 1 unchanged

Article 2	Article 2
The funds estimated as being necessary for the execution of the programme exclusive of JET amount to 533 Mio ECU, including expenditure on a work force of 105 staff. The funds estimated as being necessary for JET during the duration of the programme amount to 378 Mio ECU, including expenditure on a work force of 191 temporary employees within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities.	1. The funds estimated as being necessary for the execution of the programme exclusive of JET amount to 533 Mio ECU, including expenditure on a work force of 105 staff.
	2. The funds estimated as being necessary for JET during the duration of the programme amount to 378 Mio ECU including expenditure on a workforce of 191 temporary employees within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities.
	3. The final amount of appropriations and the number of staff shall be determined on the basis of decisions taken annually by the budgetary authority in accordance with real needs.

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TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	TEXT AMENDED BY THE EUROPEAN PARLIAMENT
Article 3	Article 3
During the course of its third year, the Commission shall proceed to the evaluation of the programme having regard to its objectives set out in the Annex. Following this evaluation, the Commission shall submit to the Council in 1989 a revision proposal designed to replace the present programme with a five-year programme with effect from 1 January 1990.	The Commission shall arrange for an independent evaluation of the programme, having regard to its objectives set out in the Annex, and for an appraisal to be conducted of the potential environmental, safety-related and economic attractiveness of fusion. On the basis of this evaluation and appraisal, of which the report will be forwarded to Parliament and Council, the Commission shall submit to Parliament and Council a revision proposal designed to replace the present programme with a five-year programme with effect from 1 January 1990.

Articles 4 and 5 unchanged

ANNEX	ANNEX
CONTROLLED THERMONUCLEAR FUSION	CONTROLLED THERMONUCLEAR FUSION
1. The programme to be executed will cover :	1. The programme to be executed will cover :

Indents (a) to (g) unchanged

	(ga) a fusion feasibility study covering environmental impact, safety and economic viability.
The work referred to in (a), (b), (c), (d), (e) and (f) will be carried out by means of associations or limited duration contracts which are designed to yield the results necessary for the implementation of the programme and which take into consideration the work carried out by the Joint Research Centre, in particular in relation to NET and technology referred to in (f).	The work referred to in (a), (b), (c), (d), (e), (f) and (ga) will be carried out by means of associations or limited duration contracts which are designed to yield the results necessary for the implementation of the programme and which take into consideration the work carried out by the Joint Research Centre, in particular in relation to NET and technology referred to in (f), and also to the matters referred to in (ga).

Last subparagraph unchanged

Point 2 unchanged

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TEXT PROPOSED BY THE COMMISSION OF THE EUROPEAN COMMUNITIES	TEXT AMENDED BY THE EUROPEAN PARLIAMENT
3. The amount of 533 m ECU estimated as being necessary for the execution of the programme exclusive of JET is intended to finance:	3. The amount of 533 m ECU estimated as being necessary for the execution of the programme exclusive of JET is intended to finance :

Indents (a) to (e) unchanged

	(ea) an independent evaluation of the programme and an appraisal of the potential environmental, safety-related and economic attractiveness of fusion.
	(eb) After consulting the Consultative Committee for the Fusion Programme, shared cost contracts with groups in Member States that do not possess an Association, to cover specific items of research at a rate of about 25% for running expenditure and of about 45% for capital expenditure specific to the research.

Last subparagraph unchanged

Points 4 and 5 unchanged

Doc. A2-320/87

LEGISLATIVE RESOLUTION

embodying the opinion of the European Parliament on the proposal from the Commission of the European Communities to the Council for a Regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion

The European Parliament,

- having regard to the proposal from the Commission to the Council(1),

- having been consulted by the Council pursuant to Article 7 of the EAEC Treaty (Doc. C 2-146/87),

- considering the proposed legal basis to be appropriate,

- having regard to the report of the Committee on Energy, Research and Technology and the opinions of the Committee on Budgets, Committee on Legal Affairs and Citizens' Rights and the Committee on the Environment, Public Health and Consumer Protection (Doc. A 2-320/87),

- having regard to the Commission's position on the amendments adopted by Parliament,

1. Approves the Commission's proposal subject to Parliament's amendments and in accordance with the vote thereon;

2. Calls on the Commission to notify Parliament should it intend to depart from the text approved by Parliament;

3. Reserves the right to open the conciliation procedure should the Council intend to depart from the text approved by Parliament;

4. Asks to be consulted again should the Council intend to make substantial modifications to the Commission's proposal;

5. Instructs its President to forward this opinion to the Council and the Commission.

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Section V

EN

European Communities

EUROPEAN PARLIAMENT

SESSION DOCUMENTS

English Edition 1987-88

29 February 1988 SERIES A DOCUMENT A 2-320/87

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REPORT

drawn up on behalf of the Committee on Energy, Research and Technology

on the proposal from the Commission of the European Communities to the Council (COM(87) 302 final - C 2-146/87) for a regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion

Rapporteur: Mr Alman METTEN

EN(88)0156E/0157E

PE 116.137/fin.
Or. En.

By letter of 18 September 1987, the President of the Council of the European Communities requested the European Parliament to deliver an opinion on the proposal from the Commission of the European Communities for a Council regulation adopting a research and training programme (1987 - 1991) in the field of controlled thermonuclear fusion.

On October 1987, the President of the European Parliament referred this proposal to the Committee on Energy, Research and Technology as the committee responsible and to the Committee on Budgets, and the Committee on the Environment, Public Health and Consumer Protection for an opinion.

The Council of the European Communities announced that it would request a debate by urgent procedure on the proposal pursuant to Rule 75 of the Rules of Procedure.

The Committee considered the Commission proposal and the draft report at its meetings of 22 and 23 September 1987, 25 and 26 November 1987, 25 and 26 January 1988. During the latter meeting, the Committee decided unanimously to recommend to Parliament that it approve the Commission proposal, subject to the following amendments.

The Committee then adopted the draft legislative resolution with 6 votes in favour and 5 against, with no abstentions.

The following took part in the vote Mr Poniatowski, Chairman; Mr Adam and Mr Kolokotronis, Vice-Chairmen, Mr Metten, rapporteur; Mrs Bloch von Blottnitz (deputizing for Mr Harlin), Mr O'Donnell (deputizing for Mr Rinsche), Mrs Peus, Mr Robles Piquer, Mr Seligman, Mr Smith, Mr Staes and Mr Viehoff.

The report was tabled on 29 February 1988.

The deadline for tabling amendments to this report will appear on the draft agenda for the part-session at which it is to be considered.

10

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CONTENTS

//

Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology

The Committee on Energy, Research and Technology hereby submits to the European Parliament the following amendments to the Commission's proposal and draft legislative resolution together with explanatory statement:

Proposal for a Council regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion

Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology

Citations unchanged

First two recitals unchanged

Third recital

	Amendment No. 1
	Replace the second and third clauses of this recital by the following:
Whereas thermonuclear fusion is a potential new source of energy using fuel which is virtually inexhaustible and universally accessible; whereas magnetic fusion reactors will have inherent safety features and hold the promise of a low impact on the enivronment; thermonuclear fusion forms therefore an important objective within the framework programme;	whereas nuclear fusion is potentially a safe and environmentally benign energy source in a number of respects; whereas one of the principal objectives of the framework programme is therefore to achieve controlled thermonuclear fusion and realize this potential in the process;

Fourth to seventh recitals unchanged

Eighth recital

	Amendment No. 2
	The introductory phrase to read as follows:
Whereas the strategy on which the continuation of the programme is based should remain unchanged, namely: ...	Whereas the strategy on which the continuation of the programme is based should remain largely unchanged, namely: ....
	Amendment No. 3
	After the eighth recital, insert a NEW recital:
	Whereas this strategy must be modified to ensure that a central objective will be to secure the environmental and safety-related advantages of fusion over other sources of energy;

Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology

Ninth recital unchanged

	Amendment No. 4 After the ninth recital, insert a NEW recital: Whereas the next review of the programme must be preceded by an independent evaluation of those components of the programme already being implemented and an appraisal of the potential environmental, safety-related and economic attractiveness of fusion;

Tenth to fourteenth recitals unchanged

Article 1 unchanged

Article 2

	Amendment No. 5
The funds estimated as being necessary for the execution of the programme exclusive of JET amount to 533 Mio ECU, including expenditure on a work force of 105 staff. The funds estimated as being necessary for JET during the duration of the programme amount to 378 Mio ECU, including expenditure on a work force of 191 temporary employees within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities.	1. The funds estimated as being necessary for the execution of the programme exclusive of JET amount to 533 Mio ECU, including expenditure on a work force of 105 staff. 2. The funds estimated as being necessary for JET during the duration of the programme amount to 378 Mio ECU including expenditure on a workforce of 191 temporary employees within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities. 3. The final amount of appropriations and the number of staff shall be determined on the basis of decisions taken annually by the budgetary authority in accordance with real needs.

Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology

Article 3

	Amendment No. 6
	Replace Article 3 by the following:
During the course of its third year, the Commission shall proceed to the evaluation of the programme having regard to its objectives set out in the Annex. Following this evaluation, the Commission shall submit to the Council in 1989 a revision proposal designed to replace the present programme with a five-year programme with effect from 1 January 1990.	The Commission shall arrange for an independent evaluation of the programme, having regard to its objectives set out in the Annex, and for an appraisal to be conducted of the potential environmental, safety-related and economic attractiveness of fusion. On the basis of this evaluation and appraisal, <u>of which the report will be forwarded to Parliament and Council</u>, the Commission shall submit to Parliament and Council a revision proposal designed to replace the present programme with a five-year programme with effect from 1 January 1990.

Articles 4 and 5 unchanged

ANNEX

CONTROLLED THERMONUCLEAR FUSION

Paragraph 1

	Amendment No. 7
	Add a new paragraph 1(h).
1. The programme to be executed will cover:	Paragraphs 1(a) to (g) unchanged
(a) plasma physics in the sector concerned, in particular studies of a basic character relating to confinement with suitable devices and to methods for producing and heating plasma;	
(b) research into the confinement, in closed configurations, of hydrogen, deuterium and tritium plasmas of widely varying density and temperature;	
(c) research into light-matter interactions and transport phenomena and the development of high-power lasers;	
(d) the development and application to confinement devices of sufficiently powerful plasma heating methods;	

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Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology
(e) improvement of diagnostic methods;	
(f) predesign and possibly commencement of the detailed engineering design of NET (Next European Torus) and technological developments required for its design and construction as well as those needed in the longer term for the fusion reactor;	
(g) extension of the JET device to full performance; operation and exploitation of JET.	
	(h) a fusion feasibility study covering environmental impact, safety and economic viability.
	The introductory phrase of this paragraph to read as follows:
The work referred to in (a), (b), (c), (d), (e) and (f) will be carried out by means of associations or limited duration contracts which are designed to yield the results necessary for the implementation of the programme and which take into consideration the work carried out by the Joint Research Centre, in particular in relation to NET and technology referred to in (f).	The work referred to in (a), (b), (c), (d), (e), (f) and (h) will be carried out ... (rest unchanged, but with the addition of the following phrase at the end of the subparagraph:) ... referred to in (f), <u>and also to the matters referred to in (h)</u>.
The implementation of the JET project referred to in (g) has been entrusted to the 'Joint European Torus (JET), Joint Undertaking', established by Decision 78/471/EURATOM(1).	Unchanged

<u>Paragraph 2 unchanged</u>

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Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology
	Paragraph 3
	Amendment No. 8
	Add new subparagraphs 3(f) and 3(g).
3. The amount of 533 m ECU estimated as being necessary for the execution of the programme exclusive of JET is intended to finance:	Paragraphs 3(a) to (e) unchanged.
(a) priority projects at a uniform rate of approximately 45%, as specified in paragraph 4;	
(b) running expenditure of the associations at a uniform rate of approximately 25%;	
(c) certain industrial contracts in the fields of 'NET/fusion technology' and the development of advanced plasma heating methods at a rate of 100%, as defined in paragraph 4;	
(d) administration costs and expenditure intended to ensure the mobility of staff to enable them to work in organizations cooperating in the implementation of the programme and in the NET Team;	
(e) operational costs of the NET Team at a rate of approximately 75%;	
	(f) an independent evaluation of the programme and an appraisal of the potential environmental, safety-related and economic attractiveness of fusion.
	(g) After consulting the Consultative Committee for the Fusion Programme, shared cost contracts with groups in Member States that do not possess an Association, to cover specific items of research at a rate of about 25% for running expenditure and of about 45% for capital expenditure specific to the research.

Text proposed by the Commission of the European Communities	Amendments tabled by the Committee on Energy, Research and Technology
Any positive balance from the contributions of associated third countries (Sweden and Switzerland) under the programme exclusive of JET, shall be devoted to the financial participation by the Community in the expenditure referred to in paragraph 3.	Unchanged

Rest unchanged

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DRAFT LEGISLATIVE RESOLUTION

embodying the opinion of the European Parliament in first reading on the proposal from the Commission of the European Communities to the Council for a Regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion

The European Parliament,

- having regard to the proposal from the Commission to the Council(1),
- having been consulted by the Council pursuant to Article 7 of the EAEC Treaty (Doc. C 2-146/87),
- considering the proposed legal basis to be appropriate,
- having regard to the report of the Committee on Energy, Research and Technology and the opinions of the Committee on Budgets, Committee on Legal Affairs and Citizens' Rights and the Committee on the Environment, Public Health and Consumer Protection (Doc. A 2-320/87),
- having regard to the Commission's position on the amendments adopted by Parliament,

1. Approves the Commission's proposal subject to Parliament's amendments and in accordance with the vote thereon;
2. Calls on the Commission to notify Parliament should it intend to depart from the text approved by Parliament;
3. Reserves the right to open the conciliation procedure should the Council intend to depart from the text approved by Parliament;
4. Asks to be consulted again should the Council intend to make substantial modifications to the Commission's proposal;
5. Instructs its President to forward this opinion to the Council and the Commission.

(1) OJ C 247, 15.9 87, p.2

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B

EXPLANATORY STATEMENT

Controlled nuclear fusion

1. Matter - in either solid, liquid or gaseous state - consists of very small particles called atoms. Protons and neutrons form the nucleus of these atoms, with electrons in orbit around them. Nuclear fusion is a process whereby light hydrogen nuclei are fused to form a heavier helium nucleus. Energy is released during this process.

2. Nuclear fusion occurs between the nuclei of the hydrogen isotopes deuterium and tritium. Deuterium is obtained from water, in particular sea water, from which it is recovered using filter and centrifuge techniques. Tritium can be obtained from the reaction between neutrons and lithium. Lithium is found in a variety of minerals and mineral waters. These fuels, or base materials, for the nuclear fusion process are readily available and virtually inexhaustible.

3. Nuclear fusion for the purpose of generating energy is known as controlled nuclear fusion. There is also a form of non-controlled nuclear fusion: the hydrogen bomb, or H-bomb. This type of fusion is possible because of a preceding nuclear-fission reaction and is practicable if the sole purpose of the fusion reaction is an explosion.

4. The process of controlled nuclear fusion takes place in a special fusion reactor. The fusion of deuterium and tritium produces helium gas and a neutron and releases energy. The helium gas, which is neither toxic nor radioactive, is removed. The release of neutrons is used to produce a reaction with the lithium present in the reactor blanket, and this produces tritium. Tritium is used in the fusion process. The neutrons also carry the energy which is released; they transfer it to the blanket around the reactor. Steam turbines use this heat to generate electricity.

5. The main fusion reactor studied in the European Community is the Tokamak design, which is Russian in origin. Tokamak stands for toroidal magnetic chamber. The Tokamak reactor has produced the best results so far and it is the most promising. However, for the sake of clarity, it should be pointed out that experiments are being carried out in the Community on other designs: the Reversed Field Pinch reactor and the Stellarator. The advantages of the Reversed Field Pinch reactor are lower energy and material requirements and easier replacement and maintenance because it is a smaller reactor of simpler design with better facilities for spontaneous ignition of the plasma. The Stellarator is also smaller, with the same advantages, and is more energy-economical; it also affords other, specific advantages, the most significant being that it operates in a natural steady-state environment rather than on the basis of energy pulses, in respect of which mechanical and materials-related requirements are considerable.

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6. In the Tokamak fusion reactor the aim is to create the conditions for a nuclear-fusion process. These conditions are:

(a) An extremely high temperature (circa 100 000 000°C) to heat the fuels to such a level that the electrons and the nuclei are separated and collide with each other at high speed. Without this heat, and hence this speed (several thousand kilometres per second), the nuclei would repel each other and fusion would not take place. However, nuclear fusion occurs only once in every 10 000 collisions. The moving mass of nuclei and electrons is known as a plasma.

(b) The heating process must be maintained for a relatively long period and be capable of being applied regularly.

(c) The plasma must be sufficiently dense to enable the fusion process to take place and must be kept away from the reactor wall by magnetic confinement to prevent temperature loss.

7. Experiments are being carried out on various forms of heating:

(a) Ohmic Heating, - whereby the plasma is heated by electricity. The temperature reached is not high enough, however.

(b) Neutral Beam Injection, whereby neutral hydrogen atoms are injected to heat the plasma. However, this is a low-yield method.

(c) 'High-Power Radio Frequency Heating', whereby electromagnetic energy is injected into and absorbed by the plasma. This is an encreasingly popular method.

8. The fusion process is initiated by heating. The process must be sustained for a certain period by its own heat, and if that fails, must be restarted by external heating. A specific rhythm (pulses) must be used for this. The balance of energy input and energy output must be positive. The break-even point is the point when this balance is in equilibrium. The moment when the process sustains itself is known as ignition.

9. The plasma has to be prevented from colliding with the wall, since this would involve an excess loss of heat and damage to the wall. To prevent this, a magnetic field is created by using toroidal and poloidal magnetic rings and limiters are inserted in the reactor. These come into contact with the plasma before the plasma can reach the wall. The two forms of magnetism - vertical and horizontal - move the plasma as close as possible to the centre of the reactor. The shape of the reactor is designed to accommodate this process: it is a torus - an annular, hollow tube.

10. The fusion process is not possible at present because:

(a) it is not yet possible to heat to beyond 100 000 000°C without negative effects on energy confinement time;

(b)it has not yet been possible to reach break-even point and achieve ignition.

11. European nuclear-fusion research is carried out in Community laboratories such as Culham and Ispra and in national research institutes with which research contracts have been signed (the Association partners). The main Community programme is JET stands for Joint European Torus.

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12. The main purpose of JET is to demonstrate the scientific feasibility of nuclear fusion, i.e. to demonstrate that nuclear fusion is possible and that experimenting will have to continue until it is clear how the process can be achieved.

JET research is concerned principally with the following:

(a) plasma density, plasma behaviour, plasma heating and plasma-wall interaction;

(b) the method of magnetic confinement;

(c) the use of tritium;

(d) the use of different materials for the wall;

(e) the use of robots for repair, maintenance and replacement work;

(f) the environment and safety.

JET started in 1978 after a few years of preparatory work. In 1971 a Euratom working party came out in favour of designing a large Tokamak. In 1973 a design team for this reactor was appointed. In 1975 a design was presented and approved. The JET construction phase started in 1978. The operational phase started in 1983 and experiments began with the torus. The original intention was to complete this phase, and hence the entire JET programme, in 1990. However, because additional heating of the plasma meant that higher temperatures were achieved but that the confinement time was reduced, additional equipment must be installed and the operational phase of JET extended to 31 December 1992 in order to achieve the original objectives.

13. The next phase in achieving controlled nuclear fusion is the Next European Torus (NET), which is intended to confirm the scientific feasibility of nuclear fusion and to demonstrate technological and constructional feasibility. A preparatory team has been operating since 1983 on design phase, which will last until 1990. Following a further technical-design phase, construction of NET could start in 1993, lasting until approximately 2000.

The objectives of NET are: to achieve the controlled ignition and long-term combustion of the deuterium-tritium mixture, to demonstrate the reliability and stability of the system and to demonstrate safe and environmentally compatible operations. In addition, NET must demonstrate the viability of design concepts, test materials and test tritium and energy withdrawal systems for the demonstration reactor.

14. After the year 2000, the DEMO project is to start - the demonstration reactor which will have to be built on the basis of NET research findings. The DEMO reactor will be used to investigate the industrial and commercial feasibility of nuclear fusion. According to current plans, results are expected between 2030 and 2040. The most optimistic appraisal is that nuclear fusion could play a role in Europe's energy supplies after 2030.

15. In addition to JET and the groundwork for NET, considerable research has been conducted into fusion technology in Community research centres and associated national laboratories. Together these make up the total Community nuclear-fusion research effort. Research costs are borne by the Community and the Member States. From 1976 to 1986, fusion research outlay exceeded 2.3 billion ECU, including some 1 billion ECU from the Community. Between 1987 and 1991, costs will total some 2.2 billion ECU, with the Community again contributing about 1 billion ECU.

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The following table sets out total cost between 1976 and 1991:

Table 1: Cost of the Community's fusion programme 1976 - 1991 (in ECU)

Funding Source	General Programme	JET	Total
European Community	1181	868.4	2049.4*
Member States	2146.7	353.3	2500
Total	3327.7	1221.7	4549.4*

Proposed spending on fusion for the next five years is on a scale comparable with outlay in the first 11 years, revealing a rising-cost trend likely to continue.

The Commission's proposal for a fusion programme for the period 1987 - 1991 would require the following commitment appropriations (including carry-overs from 1986):

Table 2: Cost of the Community's fusion programme 1987 - 1991 (in m ECU)

Funding source	General Programme	JET	Total
European Community	G16	397.2	1013.2*
Member States	1117.7	112.4	1230.1
Total	1733.7	509.6	2243.3*

An initial appraisal

16. Controlled nuclear fusion has not yet been achieved; nor has there been any scientific proof that it is at all possible (JET and similar experiments in Japan, the USSR and the US are intended to provide that proof). Consequently, considerable caution is needed in evaluating nuclear fusion as a possible future energy source.

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*Exclusive of research conducted by the JRC (75m ECU for period 1987 - 1991)

17. The claims made for nuclear fusion are quite considerable:

(a) It is an inexhaustible source of energy.

(b) It is clean.

(c) It is safe.

(d) It is cheap.

These claims can be justified:

(a) The fuels used in nuclear fusion are indeed virtually inexhaustible. Very little sea water is required to provide a considerable volume of deuterium, and there is a superabundance of sea water. Lithium will be readily available for several thousand years. The fuel production costs are low in comparison with the other cost components in the nuclear-fusion process.

(b) The claim that nuclear fusion is a clean source of energy, with low radiation and virtually no radioactive waste, is not entirely true.

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Highly radioactive tritium is a very volatile substance which easily penetrates walls, valves and coolant ducts etc. There is a correspondingly high risk of the substance escaping. Checking for possible sources of leaks is a major technical problem in nuclear fusion research. Once it has escaped it disperses very rapidly in air and water. Absorption into the human body is also very rapid. The estimates of the amount of tritium present in a fusion reactor differ.

There is also some controversy as to the claim that there is little nuclear waste. The fuels themselves do indeed produce no nuclear waste.

The radioactive waste - probably for the most part low- or medium-level - originates in the wall and blanket. If these have to be replaced prematurely or if the power station is decommissioned after 30 years or so, there is a waste problem widely believed to be at least comparable to the waste problem in connection with fission power stations. Replacing the mantel and the wall depends on the materials used. Estimates indicate a replacement rate of once every two to ten years for the wall and no replacements at all for the blanket. Research into different wall materials (vanadium and various types of stainless steel) has not yet produced satisfactory results to enable a final choice to be made. The properties, price, scarcity and other factors are not yet sufficiently researched. Hence it would certainly be wrong to minimise the waste problem in connection with nuclear fusion.

(c) There is also considerable controversy about the safety of the nuclear-fusion process. Safety is defined as inherent safety. Plasma expands as it is heated. Hence it is not possible to increase the density to a level at which the plasma can explode. An additional advantage is that the pressure in the reactor is virtually equivalent to normal pressure.

However, there are the following risks:

- If there are faults in the control system either the plasma can become too dense or the temperature too high;under a worst-case scenario, the wall may melt or crack.

- The plasma, if suddenly cooled, may form a deposit on the wall , in which holes may form as a result.

- If liquid lithium is used in the blanket and the lithium comes in to contact with water or air, there may be explosions with severe lithium fires.

- Radioactive tritium may be released during maintenance, replacement work or repairs; tritium leaks may occur at other times too.

- Sudden discharge of the high concentration of electricity present in the magnetic coils may cause a short circuit.

If these risks materialize, the fusion process as such will stop but the damage can be considerable and the consequences serious. Effective troubleshooting facilities and technical innovations (e.g. in tritium treatment and keeping lithium separate from air and waterand ensuring that metallic lithium is not used) may serve to minimize the risks. However, it would be an exaggeration, in pointing to the inherent safety of the nuclear-fusion process, to claim that it is a virtually risk-free source of energy. Much technical research is needed to minimise the risks of the fusion process and to maximise reactor safety.

18. There is some controversy about two other aspects of nuclear fusion.

(a) Two alternative approaches - laser fusion and fusion-fission hybrid reactor - can be used for military purposes.

The laser fusion process is initiated by the concentrated heat of laser beams. Successful experiments have been carried out in Japan in particular. The Community is endeavouring merely to keep abreast of this development. If laser fusion becomes routinely workable, hydrogen bombs could in theory be exploded by using lasers. In what are known as hybrid power stations the fusion process is used not so much as an independent energy source but as part of the enrichment technology for fission power stations. Uranium is placed in the blanket and the neutrons released in the fusion process produce plutonium. This is how fuel is produced for nuclear power stations, but also the raw material for atomic weapons, is produced. At present only the Soviet Union is still considering utilizing this technology; there, it is regarded as an alternative if the economic practicability of nuclear fusion as such cannot be demonstrated. Because it would be a straightforward process for hybrid power stations to produce plutonium, the proliferation risk involved in developing such power stations is obvious.

(b) There are doubts about the technical and economic feasibility of fusion based on the deuterium-tritium reaction. This reaction would always involve a large quantity of fast neutrons and hence a radioactive risk. Overcoming this risk requires a technical effort which is problematic and in any case extremely expensive. A more acceptable form of fusion would be fusion based on a reaction in which neutrons of a far lower velocity are released, e.g. a deuterium-deuterium reaction.

Advocates of this approach acknowledge that it will take longer to derive such result from fusion research because it is much harder to achieve this type of reaction and, in theory, it releases less energy. However, they believe that it was premature to opt for the deuterium-tritium reaction. Proponents of the deuterium-tritium reaction point out that it is much more important first to demonstrate the scientific and technical feasibility of the fusion process as such, and hence to opt for the most promising type of reaction, before considering more acceptable alternatives, technically and economically, which can be undertaken subsequently.

19. The last point to be considered is the economic feasibility of nuclear fusion. It is claimed to be a cheap energy source, particularly because of the low-cost fuels used. However, this claim must be qualified. It is obvsious that the main costs involved will be capital expenditure; an estimate of the costs of a power station which is to operate on the basis of a process the functioning of which has not yet been demonstrated in practice is indeed bound to be highly tentative. It is just as difficult to claim that fusion energy is cheap as it is to claim the opposite.

It is striking, however, that most recent articles about the price of fusion energy have adopted a defensive tone. According to the Commission's study, which also looked at the economic propsects of fusion, 'the overall generating cost of electricity from a fusion power station is within the wide range of costs expected from existing or other alternative energy sources. Fusion can therefore not be dismissed purely on economic grounds.' (rapporteur's emphasis). Although the technological and industrial spin-off from

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nuclear-fusion research benefits European industry, this is no justification for an extremely costly programme such as the nuclear-fusion programme. What might go a long way towards justifying this would be if nuclear-fusion energy - if it were feasible - were to make Europe less dependent on imports. We must of course bear in mind the time scale. Should nuclear fusion prove technically feasible, and initial contribution in energy consumption cannot be expected until 2030 at the earliest, i.e. nuclear fusion is a potential energy source for the long term and, in the intervening years, will have no role to play in energy supply.

The future of nuclear-fusion research

20. The excellent quality of European nuclear-fusion research has been established beyond doubt. It is a form of cooperation which can be taken as an excellent example for research at European or even world level. Although the research has been slowed up somewhat by physical problems (confinement degradation - the reason for the request to extend JET), there is nothing in the way the research is actually being carried out to suggest doubts about further progress. Since nuclear-fusion research is financed to a large extent from the Community research budget, external appraisal criteria must also be applied.

21. The European Parliament faces an immense problem whenever it is obliged to judge whether the outlay on fusion research is money well spent; moreover, the Commission and Council face more or less the same problem. By consulting specialist literature and experts, politicans can indeed reach sound conclusions on the quality of nuclear-fusion research. However, neither the question of whether research will yield results nor the question of acceptability of results can be answered with absolute certainty. In view of the considerable and rising cost of fusion research, these questions are nevertheless crucial.

22. The first basic question which Parliament, the Council and the Commission need to answer is: how long are they prepared to provide funding for this research when the results are uncertain? It may be 2020 before it is established that nuclear fusion is economically viable (assuming it is actually feasible). Are all the parties concerned prepared, in principle, to continue injecting funds into the project until then? This will depend partly on the importance attached to the research per se, the energy supply pattern expected in the next century and the alternatives.

23. The second basic question which the politicians have to answer is: under what conditions do they consider nuclear fusion acceptable? What is now the acceptable level of pollution, of likely risk and of costs compared with alternative sources?

24. The rapporteur believes that these questions cannot be answered at this stage in the research programme. The technical feasibility of fusion will have to be demonstrated by the experimental reactors now in operation. If it can be demonstrated, the decision on the next phase - the design and construction of NET (Next European Torus) - can be taken. When the initial decision is due, in about 1990, Parliament, the Commission and the Council will need to have at their disposal all the relevant information: not only a thorough evaluation of what has been achieved, but also realistic prognoses for economic viability, reactor risk and environmental impact. This means that work should start forthwith on a thorough and independent evaluation relevant to the policy-making process so that the political decision-takers have the information they require in good time. The report by the Office of Technology Assessment for the US Congress ('Starpower: the US and the International Quest for Fusion Energy') is an example of what Parliament, the Commission and the Council require.

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The recently published Heldren report ('Exploring the competitive potential of magnetic fusion energy: the interaction of economics with safety and environmental characteristics') also contains more reliable information than the Commission's 'Environmental Impact and Economic Prospects of Fusion', which reads too much like propaganda.

An evaluation of this type should be the sine qua non for Parliament to discuss any proposal concerning NET (or any international equivalent).

25. The US, Japan, the USSR and the European Community are cooperating on defining the next step to be taken. For the Community, this is proceeding in tandem with the NET definition phase.

When a specific NET design has to be defined, there will need to be international agreement on whether the four partners in ITER (International Thermonuclear Experimental Reactor) should also cooperate in designing and building a second reactor. Since Parliament, the Commission and the Council will have to debate this in due course, the implications of such cooperation will need to be considered in the evaluations and forecasts. Attention will have to focus on the political implications: high-investment, and valuable cooperation between the USSR and the US in what is a sensitive high-tech area may have far-reaching consequences for international political relations.

26. Conclusions

(a) The legal basis of the Commission's proposal for a Council regulation on the nuclear-fusion programme should be amended so that the proposal is subject to the procedure laid down in Article 130 Q(2) of the Single European Act. See the relevant note.

(b) The strategy underlying the present programme can remain largely unchanged, though one important modification is required: the programme must be explicitly biased towards securing the potential environmental and safety-related advantages of fusion over fission. These advantages can only be secured if designs are tailored to this purpose and if the usability of low-activation materials for fusion can be demonstrated.

Postponing consideration of major environmental and safety-related problems until the technical problems have been ironed out is the wrong approach, and it would jeopardise the long-term feasibility of the fusion programme itself. In plain English: the programme will come unstuck, sooner or later, without convincing guarantees on safety and environmental impact; the sources of funding will dry up because society will no longer support it.

(c) There must be an independent assessment of the programme, involving forecasts of the potential environmental, safety-related and economic attractiveness of fusion.

Parliament needs to have an input in this evaluation process, and the evaluation itself will have to be made available to Parliament before it considers the programme review.

(d) In keeping with Article 130 N of the Single European Act, Parliament must be involved at an early stage in the decision-making process in respect of the next phase of ITER.

(e) JET, though still based on the Euratom Treaty and not Article 130 (o) of the Single European Act, is covered by the framework programme and the decision-making procedures provided for in that programme. Extending JET will have financial implications; but this is a necessary step, otherwise it will be quite impossible to take a decision on the construction of NET. Parliament therefore approves the proposal to extend JET.

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THE LEGAL BASIS FOR THE NUCLEAR-FUSION PROGRAMME (COM(87) 302 final)

In his Draft Report, the Rapporteur proposed draft amendments which would have changed the Legal Base. These draft amendments were not adopted by the Committee. However, the arguments in favour of them are set out below.

1. The legal basis is the framework programme. On 28 September 1987, the Council adopted the framework research programme 1987-1991, the legal basis for which was Article 130 Q(1) of the EEC Treaty and Article 7 of the EURATOM Treaty. The Council's unanimous decision to adopt the framework programme therefore implies that decisions have been taken on EURATOM research and training programmes and on relevant EEC activities. The annexes, which are an integral part of the framework programme, are moreover entirely unambiguous in this respect.

2. The framework programme is binding on Euratom services too and comprises research activities to be carried out by both EEC and EURATOM. Although there is no reference to 'framework programme' in the EURATOM Treaty itself, framework will obviously be legally binding as regards EURATOM's research and training programmes too, since part of its legal basis is to be found in the EURATOM Treaty.

3. Framework lays down the decision-taking procedure in respect of specific programmes. The EURATOM Treaty does not lay down what further action is to be taken, once the Council has unanimously adopted EURATOM research and training programmes, unlike framework, which does, however, specify how to proceed further, referring to activities (Article 1) to be implemented by means of specific programmes (Article 2). The breakdown of the amount deemed necessary between the activities concerned, the broad thrust of the activities and their scientific and technical objectives are set out in highly detailed annexes which, as referred to above, are an integral part of the Framework programme.

4. The nuclear-fusion programme is a specific programme. Annexes I and II of Framework establish beyond doubt that the nuclear-fusion programme is also regarded as a specific programme under the terms of Framework. No reference is made to specific programmes in the EURATOM Treaty; however, this treaty forms part of the basis of the framework programme, adopted by the Council, in which considerable importance is attached to the term. It is therefore difficult to contend that specific programmes are irrelevant to the EURATOM Treaty: because of Framework, which is partly based on the EURATOM Treaty, such programmes are relevant.

5. There is only one decision-taking procedure for specific programmes. Is there uncertainty in this regard? Could, for example, decision-taking procedures vary with the type of specific programme concerned? Such a distinction, if possible, ought to be indicated in the Framework programme itself; however, neither the recitals nor the annexes, which are highly detailed, contain any indication to that effect. Indeed, the implication is that the distinction between, for example, nuclear and non-nuclear specific programmes has been abandoned. According to Article 1(3), the total amount deemed necessary for Community participation (Community in the singular), i.e. the sum earmarked for the specific programmes to be adopted during this period, has been fixed at 5396 m ECU. It can hardly be claimed that 'Community' refers only to one of the two Communities concerned, since the annexed breakdown of the total amount covers all specific programmes, irrespective of whether they principally relate to nuclear or non-nuclear fields. For this reason, the distinction between the EEC and EURATOM has been abandoned in the Framework programme itself.

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6. Under the framework programme, there is only one type of specific programme. Because part of the basis for Framework is to be found in Article 130 Q(1) of the EEC Treaty, decision-taking in respect of specific programmes must be based on the cooperation procedure involving the European Parliament. The Council would have had every opportunity to lay down, in the framework programme itself, a different decision-taking procedure for certain components of the programme if it had wished to do so. Not only did it not do so; it even refrained from making any distinction between specific programmes by, for example, designating separate activities or referring to the different Communities.

7. The legal basis for the nuclear-fusion programme should be amended. The basis proposed by the Commission - the EURATOM Treaty alone, in particular Article 7 thereof - is erroneous. This must be regarded as a reprehensible and short-sighted attempt to short-circuit the European Parliament's influence over a programme accounting for 15% of Framework and costing 1 bn ECU over five years: reprehensible in that it seeks to nullify one of Parliament's powers established by the Single European Act even before the ink on that document has dried; and short-sighted in that the support of Parliament, as one arm of the budgetary authority, is obviously required if the programme is to be implemented, nor, since this is a high-cost programme to be financed from a permanently strained overall budget, is there any strategic rationale in seeking to debar Parliament from influencing the programme.

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O P I N I O N

(Rule 120 of the Rules of Procedure)

of the Committee on Budgets

Draftsman: Mr PAPOUTSIS

At its meeting of 23 September 1987, the Committee on Budgets appointed Mr PAPOUTSIS draftsman for all the proposals concerning the framework programme for research and technological development in the Community.

The committee considered the draft opinion at its meeting of 27 January 1988 and adopted the conclusions unanimously.

The following were present: Mr COT, chairman; Mr PAPOUTSIS, rapporteur; Mr ADAM (deputizing for Mr STEVENSON), Mrs BARBARELLA, Mr CAAMANO BERNAL, Mr CALVO ORTEGA, Mr CHRISTODOULOU, Mr COLOM I NAVAL, Mr DANKERT, Mr HACKEL, Mr d'ORMESSON and Mr PRICE.

1. In document COM(87) 302 final, the Commission put forward two proposals and a report on:

(a) a review of the current controlled thermonuclear fusion programme (1985-1989) and the adoption of a new five-year programme for 1987-1991 and,

(b) extending the JET (JOINT EUROPEAN TORUS) Joint Undertaking until the end of 1992,

(c) the environmental impact and economic prospects of fusion.

2. As regards the legal framework, the regulation relating to the specific nuclear fusion programme will have to be approved in accordance with Article 7 of the EAEC Treaty, which stipulates that 'Community research and training programmes shall be determined by the Council, acting unanimously on a proposal from the Commission, which shall consult the Scientific and Technical Committee'. To extend JET, the decision will have to be taken in accordance with Article 50 of the EAEC Treaty, which requires the unanimous approval of the Council.

Although it is not obligatory, the Commission called on the Council to seek Parliament's opinion.

3. The European thermonuclear fusion programme which enabled the JET Joint Undertaking (1978) and the NET team (1983) to be set up has proved exceptionally successful. Not only have the technological and scientific results achieved placed Europe in the forefront as regards magnetic fusion, since the JET programme was an important step in demonstrating that fusion can be achieved from a scientific point of view, but, in addition, the fusion programme made a substantial contribution to the building-up of a genuine scientific and technological community of small and large-scale laboratories.

4. From a strategic point of view, the objects of continuing the fusion programme are:

- the completion of the first phase, which consists of the JET programme with its various spin-offs and includes fully exploiting the existing mechanical equipment and equipment being constructed by the various companies,

- the preliminary plan for the second stage of the programme, the setting-up of a demonstration reactor (DEMO), to be based on the tokamak, in other words the Next European Torus (NET),

- widening the field of alternative possibilities which could lead to the construction of a fusion reactor.

5. Against this background, if the objectives of the JET programme are to be achieved, and particularly if its final stage, the tritium stage, is to be put into effect, additional equipment will be required; this cannot be constructed, commissioned and operated within the lifetime of the Joint Undertaking as laid down in the JET Regulation. The Commission therefore proposes that the Council extend the Joint Undertaking for two years and seven months from 31 May 1990 to 31 December 1992.

6. As far as the financial implications are concerned, the following table shows the total level of Community participation and the relationship between the General Programme, JET and JRC (Joint Research Centre), the new appropriations to be earmarked for fusion within the 1987-1991 framework programme and the appropriations which have been transferred from current programmes.

Mio ECU	New appropriations corresponding to the 1987-1991 framework programme	Transferred appropriations from 1985-1989	Total financing for the 1987-1991 period
General programme	362	171	533
Participation in the JET Joint Undertaking	169	209	378 (1)
Fusion programme total	531	380	911
JRC (not included in this proposal)	60	15	75
Total for fusion activities	591	395	986

(1) Including additional expenditure occasioned by extending JET.

The above table demonstrates that the Commission's two proposals do not relate exclusively to the General Programme and JET. The work being done by the JRC in the field of fusion, although, from a technological and scientific point of view, they fall under the overall fusion programme, is governed by a different decision relating to special research programmes 1988-1991 which the JRC is required to carry out on behalf of the European Atomic Energy Community.

As far as the effects which extending JET will have on the budget, the additional expenditure will amount to 188 m ECU and is included in the table above.

7. Where objectives are concerned, the fusion programme is at the stage of demonstrating scientific feasibility and, building on the progress achieved so far, one of the main objectives is to set up the physical substructure needed for JET, especially creating and studying a plasma of a size and in conditions close to those which will be required in a thermonuclear reactor.

   Since in the course of 1990-1991 the NET project will be moving into the detailed project stage and component prototypes will consequently have to be ordered from industry, the rapporteur considers that the Community should provide a minimum guaranteed level of funding towards the expenditure associated with partnership contracts with universities and research centres.

8. In conclusion, the rapporteur proposes that the Committee on Budgets reiterate the views which it expressed on the budget, to the effect that:

   (a) the appropriations required for implementing the proposed programme shall be determined annually, according to actual requirements, during the annual budget procedure, although it will not be possible to establish an absolute figure for the overall financing of the framework programme, with the result that the budgetary authority is not tied down by any limit,

   (b) the manpower levels required for carrying out the programme will have to be considered in the context of approving the general budget for the financial year in which it falls and not by means of a proposal for a regulation to that effect.

9. <u>CONCLUSIONS</u>

   In view of the above, the Committee on Budgets proposes the following amendments to the Commission's proposal for a regulation:

   <u>AMENDMENT No. 1</u>
   <u>Article 2</u>

   to read:

   '1. The funds estimated as being necessary for the execution of the programme exclusive of JET amount to 533 Mio ECU, including expenditure on staff.

   2. The funds estimated as being necessary for JET during the duration of the programme amount to 378 Mio ECU including expenditure on temporary employees within the meaning of Article 2(a) of the conditions of employment of other servants of the European Communities.

   '<u>The final amount of appropriations and the number of staff shall be determined on the basis of decisions taken annually by the budgetary authority in accordance with real needs.</u>'

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3. The overall amount of appropriations shall be determined on the basis of the appropriations approved annually by the budgetary authority in the light of actual expenditure.

4. A proportion of the order of 4% of total financing shall be set aside for basic research in the field of plasma, in which universities and research institutions from all the Community countries may participate.'

AMENDMENT No. 2
Article 3

to read:

'During the course of its third year, the Commission shall proceed to the evaluation of the programme having regard to its objectives set out in the Annex. Following this evaluation, the Commission shall submit to the Council, and to the European Parliament for the purpose of consultation, a revision proposal designed to replace the present programme with a five-year programme with effect from 1 January 1990.'

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COMMITTEE ON LEGAL AFFAIRS AND CITIZENS' RIGHTS

OPINION

pursuant to Rule 36(3) of the Rules of Procedure
on the legal basis for the Commission proposals

- for a Council regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion (Doc. C 2-146/87, COM(87) 302 final)

and

- for a Council decision revising the multiannual research and training programme for the European Atomic Energy Community in the field of radiation protection (1985-1989) (Doc. C 2-131/87, COM(87) 332 final).

Draftsman: Mr W. ROTHLEY

3 December 1987

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By letter of 30 October 1987 the President of the European Parliament, Lord PLUMB, referred the request for examination of the legal basis for two Commission proposals by Mr Gordon ADAM, acting chairman of the Committee on Energy, Research and Technology, pursuant to Rule 36(3) in conjunction with Rule 120 of the Rules of Procedure to the Committee on Legal Affairs and Citizens' Rights.

At its meeting of 30 September/1 October 1987 the Committee on Legal Affairs and Citizens' Rights appointed Mr ROTHLEY draftsman of opinions on all requests for the examination of legal bases until 31 January 1988.

The Committee considered the draft opinion at its meeting of 2 December 1987 and adopted the conclusions unanimously.

The following took part in the vote: Lady ELLES, chairman; Mrs VAYSSADE, vice-chairman; Mr ROTHLEY, draftsman; Mr ALBER, Mr BARZANTI, Mr DE WINTER, Mrs FONTAINE, Mr GARCIA AMIGO, Mr GAZIS and Mr LAFUENTE LOPEZ.

A. The Commission's proposals and the views of the Committee on Energy, Research and Technology

1. The Commission bases these two proposals on Article 7 of the EURATOM Treaty. This article requires the Council to act by unanimity on a proposal from the Commission. The European Parliament does not have to be consulted.

The committee responsible considers that in both cases the procedure under Article 130 K and 130 Q(2) of the EEC Treaty might apply, i.e. cooperation with the European Parliament. The Council could then act by qualified majority (see Article 149(2) of the EEC Treaty).

B. The correct legal basis

2. The decision-making procedure depends on the legal basis. The committee responsible considers the framework programme[1] to be the correct legal basis. According to Article 130 I of the EEC Treaty, the Community shall adopt a multiannual framework programme setting out all its activities and laying down objectives and priorities. Article 130 K states that the framework programme shall be implemented through specific programmes developed within each activity. Article 130 Q requires the Council to adopt the provisions required for this purpose by a qualified majority in cooperation with the European Parliament.

3. The statement that the framework programme is the correct legal basis can mean one of two things: the empowering provision could be the basis for the framework programme (a) or the framework programme itself (b).

4. (a) The framework programme is based on both Article 130 Q(1) of the EEC Treaty and on Article 7 of the EURATOM Treaty. The only respect in which this does not coincide with the Commission proposal is that the Articles 43 and 75 of the EEC Treaty which it also cited, no longer appear[2]. The reasons for their disappearance are not relevant to our enquiry. In its opinion[3] the European Parliament made no comments on the legal basis proposed.

5. The procedure under Article 130 Q(2) of the EEC Treaty might be applied to these proposals if Article 130 F et seq. of the EEC Treaty were the independent legal basis for all research activities. Article 130 F and I of the EEC Treaty mention 'the Community'. This means the European Economic Community by distinction from the ECSC and the EAEC. This is perfectly clear in respect of the ECSC Treaty, as research activities under that Treaty are

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[1] Council Decision of 28 September 1987 concerning the framework programme for Community activities in the field of research and technological development (1987-1991), OJ No. L 302, 24.10.1987, p. 1 et seq.
[2] OJ No. C 275, 31.10.1986, p. 4; see in particular footnote 1
[3] Resolution of 8 December 1986, OJ No. C 7, 12.1.1987, p. 19 et seq.

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not included in the framework programme because of a lack of institutional comparability (see the preamble to the Council decision). The same is also true as regards the EAEC, with which the EEC shares a budget. The term 'European Community' is politically attractive, and internationally has even received a degree of recognition, but the situation remains that there are three Communities with three separate legal personalities, established by Article 6 of the ECSC Treaty, Article 210 of the EEC Treaty and Article 184 of the EURATOM Treaty. Article 32 of the merger Treaty has not changed this situation; it may forecast the establishment of a single European Community, but this has not yet occurred.

6. The Community mentioned in Article 130 F and I of the EEC Treaty is therefore the Economic Community alone, which does not include the EAEC. Article 130 F et seq. of the EEC Treaty therefore governs only research covered by the EEC Treaty. Radiation protection programmes pursuant to Article 4(2) of the EURATOM Treaty in conjunction with Annex I, Chapter VI, and fusion programmes pursuant to Article 4(2) of the EEC Treaty in conjunction with Annex I, Chapter II(1)(e) fall within the sphere of the EURATOM Treaty.

7. The Single European Act came into force on 1 July 1987. On the general principle of the subsequent measure and taking into account the 'spirit of the Single European Act' it might be thought to have superseded the procedures under Article 7 of the EURATOM Treaty. Even matters falling within the sphere of the EURATOM Treaty would then be governed by the new procedures under the Single European Act. Article 232(2) of the EEC Treaty is the first stumbling block to this theory, stating that the EEC Treaty, of which Article 130f et seq. is a part, shall not derogate from the provisions of the EURATOM Treaty. It is true that Article 232(1) of the EEC Treaty sets out the relationship with the ECSC Treaty in different terms; but the difference is simply the result of the different background: the EEC Treaty and the EURATOM Treaty came into force at the same time, when the ECSC Treaty had been in existence for years.

8. The conclusion to be drawn is clearly set out in Article 32 of the Single European Act. These provisions simply express the outcome of the intergovernmental conference, to the effect that the Single European Act would amend the EURATOM Treaty and the ECSC Treaty only in respect of the Court of Justice and the establishment of one institution (the European Council) and the appointment of one other (the European Parliament). Article 7 of the EURATOM Treaty is therefore unaffected and in relation to the EEC Treaty is the specific provision governing research programmes in the fields of fusion and radiation protection.

9. (b) The framework programme itself could provide the legal basis. Article 2(1) of the framework programme states that that programme shall be implemented through specific programmes. Radiation protection and controlled thermonuclear fusion are in fact included in Annex II of the framework programme. The present proposals therefore represent specific programmes for the purposes of the framework programme. They are also included in the planned budget estimates.

10. If the framework programme and the related specific programmes were to be finally governed by Article 130 F et seq. of the EEC Treaty, this would amount to a derogation from Article 7 of the EURATOM Treaty.

Article 7 of the EURATOM Treaty in fact speaks of 'research and training programmes' and makes no mention of the terms 'framework programme' or 'specific programmes'. Article 130 I, K, L, M and P of the EEC Treaty

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expressly use the term 'the framework programme' and Article 130 K and p of the EEC Treaty mention 'specific programmes'. However, from this we cannot draw the conclusion that Article 130 F et seq. of the EEC Treaty alone govern these programmes and that the procedures under Article 130 Q of the EEC Treaty should then apply:

11. For one thing the framework programme which has now been adopted is expressly based on Article 7 of the EURATOM Treaty as well and not simply on Article 130 Q(1) of the EEC Treaty, to which the European Parliament has clearly agreed.

For another, historical considerations also make it clear that the terms framework programme and specific programmes cannot simply be regarded as legal terms. The present framework programme had a predecessor which also included the words framework programme in its title, was implemented through specific programmes, and was based on both the EEC and the EURATOM Treaties. The term then had an exclusively political significance: its purpose was to provide a conspectus of all research activity in the fields covered by the EEC and the EAEC, to provide information on the anticipated financial burden and to achieve a proper balance between nuclear and non-nuclear research. With the Single European Act, what had been exclusively political terms were established as legal terms within the sphere of the EEC. However, this does not change anything within the sphere of the EAEC, in which the political significance remains, and both terms are to be subsumed within the wording of Article 7 of the EURATOM Treaty. The framework programme thus contains two separate components: the EEC part, in which it is a legal term, and the EAEC part, in which the political meaning still applies.

12. 'Framework programme' and 'specific programmes' are therefore terms which may be used in the EEC Treaty and in the EURATOM Treaty, but with different meanings.

C. CONCLUSION

13. The Committee on Legal Affairs and Citizens' Rights recommends the Committee on Energy, Research and Technology to accept the legal bases proposed by the Commission in the research programmes under consideration.

OPINION

(Rule 120 of the Rules of Procedure)

of the Committee on the Environment, Public Health and Consumer Protection

Draftsman: Mrs BLOCH von BLOTTNITZ

At its meeting of 4 December 1987, the Committee on the Environment, Public Health and Consumer Protection appointed Mrs Undine BLOCH von BLOTTNITZ draftsman of its opinion.

The Committee considered the draft opinion at its meeting of Thursday 25 February 1988, and adopted it unanimously.

The following took part in the vote: Mrs WEBER (Chairman), Mrs SCHLEICHER (Vice-President, Mr PEREIRA (Vice-President), Mrs BLOCH von BLOTTNITZ (Draftsman), Mrs BANOTTI, Mr BONINO, Mr DEVEZE (deputizing for Mr LE PEN), Mr FIGUEIREDO LOPES, Mr FITZSIMONS (deputizing for Mr VERNIER), Mrs LENZ-CORNETTE; Mrs LLORCA VILAPLANA, Mrs MARTIN, Mrs SQUARCIALUPI, Ms TONGUE and Mr WEDEKIND (deputizing for Mr ALBER).

Introduction

Nuclear fusion is the process whereby extremely light nuclei, usually those of the isotopes of hydrogen known as tritium (^{3}H) and deuterium (^{2}H), fuse together to produce a heavier nucleus such as helium ($^{4}_{2}He$), with a considerable release of energy. The energy release occurs because the heavier nucleus sits at a lower energy level than the lighter ones, and energy has to be given out to get down to this level. Unfortunately, electrostatic repulsion between the protons in the nuclei has to be overcome before fusion (involving the enormously powerful, but very short range "strong nuclear force") can occur. The way to do this (that is, force more violent collisions to occur) is to heat and compress the mixture.

The hydrogen bomb does this by using an 'ordinary' fission bomb as the trigger. For controlled thermonuclear fusion, however, a way must be found to heat and hold a plasma (in which all the orbiting electrons have been ripped away from the nuclei) at a temperature approaching 100 million degrees centigrade. Since no material substance can do this, the favoured device at present is a tokamak, a doughnut shaped toroidal vacuum chamber in which the heated plasma is contained without touching the walls by a powerful magnetic field produced by huge electromagnets. The world's leading tokamak experiment is the European Fusion Research Programme's JET, situated at Culham in the UK. (A more familiar fusion device is the sun, which actually runs at a lower temperature because of its higher density).

The Commission Proposals

According to COM(87)302, "the Community Fusion Programme is a long-term cooperative project embracing all the work carried out in the Member States in the field of controlled thermonuclear fusion. It is designed to lead in due course to the joint construction of prototype reactors with a view to their industrial production and marketing" (p.4). The Commission has chosen Article 7 of the Euratom Treaty as the legal base for the proposal. This is commented on separately in the Conclusions and Recommendations of this opinion.

The present strategy is to extend the JET experiment to 1992, to decide on the construction of NET (the Next European Torus) by 1994, with completion around the year 2000, and to proceed early next century to the construction of DEMO. At the same time, research will also be carried out on specialist devices in national laboratories associated with the programme.

JET is designed to partly establish the scientific feasibility of fusion; NET phase I will complete this stage; NET phase 2 will demonstrate technological

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feasibility; and DEMO will demonstrate that a working fusion reactor can be built. After this stage, commercial exploitation is expected to follow, probably not before 2030.

The overall fusion programme has so far cost in the order of 2.600 Mio ECU. The proposed expenditure in the new 1987-91 proposal is 986 Mio ECU. As for the likely overall costs of the programme up to the stage where commercial feasibility can be demonstrated, a figure of 20 billion ECU would seem to be a rough approximation. (Source: US Congress OTA report on fusion: "Starpower" October 1987). The present proposal from the Commission concerns only the next five year "rolling programme", plus the necessary change to the JET statutes to permit the experiment to run until 1992 instead of closing down in 1990.

There are similar fusion research programmes in Japan, the USA, and the USSR. There is also a project known as ITER (International Thermonuclear Experimental Reactor) which proposes to combine all 4 of the world's leading programmes to design, and possibly build, a sort of World-NET machine. This project is organised under the auspices of the IAEA in Vienna, but the site for the meetings of the Conceptual Design Team has been fixed at Garching, near Munich, the headquarters of the NET team.

Comments

The basic case for the development of fusion power is that it offers the only environmentally and politically acceptable alternative to fast breeder reactors for the future long term centralised production of electricity, assuming finite reserves of coal and oil, and a limited contribution from renewable energy sources and conservation. The basic assumption is thus that energy production and consumption patterns will continue more or less as they are at present, and that therefore an energy source which uses deuterium as its base fuel (with enormous quantities present in sea water) and which breeds its second fuel, tritium, from a blanket containing lithium (large resources in the earth's crust) is a very attractive proposition. Low fuel costsalone, however, may not be enough to make fusion commercially attractive, since the capital costs of construction will be very large indeed. Moreover, the environmentally clean image of fusion is not entirely accurate, a point considered further below.

Fusion as an energy research programme

It is impossible to do fusion research on the cheap: experimental and prototype reactors have to be built on virtually the same scale as a final commercial reactor. This means that the costs of fusion research are high in relation to all other energy technology research programmes including the fast breeder reactor. It is therefore essential that fusion be evaluated across the board in comparison with competing long-term energy resources. The basic question here is what is the opportunity cost of the fusion research programme? What are we foregoing in terms of research into renewable energy resources (including perhaps expensive high technology space-based photo-voltaic systems) and conservation techniques if we commit so much money and so much scientific and technological expertise to this one energy source? Furthermore the case for the development of fusion rests on certain future energy scenarios; but your draftsman is not convinced that adequate attention has been paid to other equally credible energy scenarios which involve roughly steady state energy production and consumption. During consideration of the working document produced by its rapporteur, Members of the Committee on Energy, Research and Technology referred to the growing energy demand in the developing world as reinforcing the case for fusion. Your draftsman is of the opinion that fusion, because of its extraordinary technological sophistication and capital costs, is only a possible option for the most advanced industrialised countries in the world.

Uncertainties facing the fusion research programme

(1) Scientific and technolgical

It is clear that major uncertainties are still present here, and include the likely behaviour of an ignited plasma; the problems of running supercooled superconducting magnets close to an extraordinarily hot plasma; problems deriving from the impact of 14 MeV neutrons with the first wall and blanket materials (these "carry" the heat from the reactor, but also cause radiological damage); problems associated with the choice of coolant; problems relating to the design and construction of an extensive range of remote handling facilities; problems of tritium handling, and so on.

(2) Economic

It seems to your draftsman that the above factors, plus the ones mentioned below, mean that a working fusion reactor will be an extremely costly and complicated device; at least as complicated and costly as a fission reactor. There is no consensus on the likely costs of fusion generated electricity. The Commission's expert study of the likely costs, published as a separate "Statement" in COM(87)302 final, concludes that fusion costs should be within a factor of 2 to 3 of fission costs, and maybe lower still. On the other hand, Colin Sweet (Centre for Energy Studies, London) in his interim report presented to the STOA Fusion Workshop (JET, 12-13 Nov.1987) noted with reference to the Commission study that

"We find the approach to the long term resource costs and the possible benefits to be seriously defective. We can only take the view that the economic study is not so much inadequate as misconstrued and ought to be put to one side and new efforts made to assess economic feasibility which are consistent with mainstream energy investment appraisal techniques and resource evaluation". (p.4). Even more provocatively, Dr K-H Schmitter and Dr D. Pfirsch of the Max Planck Institut für Plasmaphysik, in a communication to the EP STOA project dated 21/12/87, state that "a tokamak power plant would be at least 10 times, but more likely 20 times as expensive as a PWR of equal net power."

(3) Safety Aspects

A fusion reactor would be intrinsically much safer than a fission reactor. It does not contain a large amount of heavy radionucleides, and it cannot suffer from a runaway 'nuclear excursion' of the Chernobyl type, since there is only a relatively small amount of fuel present at any one time, and in any case disturbances to the plasma lead to collapse of the confinement, and the reaction stops. Nonetheless accident scenarios can be imagined which would result, for example, in a release of 200 gm of tritium to the environment (COM(87)302 final).

Routine production of radioactive substances

The most significant environmental problem, which may prove to be the most significant political problem facing the development of fusion, is that of the routine generation of substantial quantities of radioactive material. Most of this is produced by the intense neutron bombardment of the first wall and blanket materials by the 14 MeV neutrons produced in the plasma by the fusion reaction. These materials are likely to be special steels which have been developed to have a low activation potential. Even so, the total amount of radioactivity present in such materials at the end of a fusion reactor working life would be nearly as high as those in a fission reactor. It would be present in the more benign form of structural steels rather than in liquids or gases, and thus will pose less of a biological hazard, but this material is radioactive waste, and each working 1GW fusion reactor might be expected to produce several hundred tonnes of such waste material per year. Clearly, then, if a country adopted fusion on a large scale, then perhaps 10,000 tonnes of the material will be produced each year due to regular replacement of first wall and blanket segments.

Precisely how problematic these wastes would be remains uncertain. COM(87) 302 concludes that "deep geological disposal would not be required" (annex "statement p.8). The ESECOM report produced by the Lawrence Livermore Laboratory, USA, under the chairmanship of Dr John Holdren (1987, in print) states that "In some of the reference designs examined by ESECOM, all of the radioactive wastes would qualify for shallow burial under the logic of current regulations" (Summary, p.75).

Your draftsman would draw your attention, however, to a report published by the UK National Radiological Protection Board in December 1987, entitled "Radiological Aspects of the Management of Solid Wastes from the Operation of D-T Fusion Reactors" (J.P. Davis & G.M. Smith, NRBB - R.210), which appears to be an extremely thorough investigation of this problem, and which concludes that:

"1. None of the candidates for first wall and breeder blanket materials appear to give rise to wastes suitable for direct disposal to shallow land burial facilities (....) .... the activity levels in the wastes are significantly above the upper limit for low-level waste"....

The report concludes that deep geological or deep ocean disposal probably would be possible, but presumably this will add considerable costs to fusion power generation. The report also concludes, in contrast to COM(87)302 and the ESECOM report, that there is little long-term advantage from the use of special low-activation steels or vanadium alloys, because of the problematic generation of carbon-14 and/or rhenium-186. Indeed "^{14}C is unusual in that, once released, it is both sufficiently long-lived and mobile in the environment to become dispersed over the entire globe before it decays substantially" (NRPB 210, op cit, p.11).

Lastly there is the problem of the routine production of tritium, which, being the third isotope of hydrogen, is the third smallest atom in the known universe, and hence extremely difficult to contain. It is so small that it diffuses gradually through containment materials. It is radioactive (β^-), and presents a serious radiological hazard. Whether the estimated 800 TBq (= 8×10^{14} Bq) per annum routine release from a commercial fusion reactor is a hazard is a matter of debate (COM(87) 302, annex p.33)

Conclusions and recommendations

Defined in its own terms, which are largely so far those of science, the European Fusion Research Programme can be seen as a very successful example of European collaborative strategic research. Defined as a programme aimed at the competitive production of electricity, there is still a very long way to go. It is clear that major decisions about the future stages of the fusion research programme will have to be taken in the early 1990's, but the current proposal from the Commission does not pre-empt these decisions: indeed, the Commission argues that necessary information will have to be provided from the next five-year programme to ensure that informed decisions are made for the next phase, and that before these decisions are made, "the Commission will undertake an in-depth evaluation of the fusion programme, including the environmental and economic aspects" (COM(87) 302 final p.82). Your draftsman strongly recommends that any such evaluation should be completely independent of the Commission Fusion Programme, since previous evaluations appear to have involved mainly the eminent members of the international fusion research community, hardly a neutral forum. The European Parliament's STOA Project Fusion Study is an excellent first step in the direction of enabling "outsiders" to contribute to the fusion debate, given the limited resources at its disposal. The STOA Fusion Workshop held at JET in November 1987 was particularly valuable in letting more daylight into a very complex subject area, and may have resulted in subtle changes of attitude amongst the participants. Consideration should be given to the possibility that the European Parliament might be the most appropriate body to organise the next external evaluation of the fusion programme.

With respect to the current five year programme proposal, it would probably be churlish to place any obstacles in its way since it is essentially work in preparation for the key decisions of the early 1990's. Moreover, during this period the ITER design team should reach the stage where it will be possible to decide which step, if any, to take next. Alternatively, the entire programme could be cancelled now, thereby saving a great deal of money. Nonetheless, the problem of the legal base remains. The Commission has chosen Article 7 of the Euratom Treaty, which covers research carried out under the aegis of the Euratom Treaty - i.e. nuclear research. But the fusion proposals "are programmatically and financially coherent with the Decision concerning the Framework Programme of Community Activity in the field of Research and Technological developments" (COM (87) 302, p3). In other words the fusion programme is being treated effectively as part of the Framework Programme, the specific programmes of which are subject to the cooperation procedure with the European Parliament according to Article 130(q)(2) of the EEC Treaty as amended by the Single Act.

It is politically indefensible to deny the use of the cooperation procedure for the single most expensive research programme in the European Community budget. It is a denial of adequate democratic control by the directly elected European Parliament. An insistance on the legal correctness of Euratom Article 7 by the Member States can only be seen as farcical when one considers that huge swathes of the Euratom Treaty have never been, and will never be properly applied by the same Member States.

Accordingly, the Committee strongly recommends that the Committee on Energy, Research and Technology should consider challenging the legal base chosen and should seek to ensure that Article 130(q)(2) is used instead.

Lastly, it is noteworthy that in its recent proposals for the reorganisation of the Joint Research Centre, the Commission makes considerable reference to the customer/contractor principle in the organisation of applied research. If this principle were to be applied to the fusion programme, then the logical conclusion would be to make DG XVII (Energy) the customer for this applied energy R & D programme, and DG XII (Science, Research & Development) the executive contractor. This would ensure that fusion had to be justified as an energy research investment, rather than as the favoured option of fusion scientists and engineers. The Committee feels that this is an essential feature of the customer/contractor principle which should be closely borne in mind by the Committee on Energy, Research and Technology.

Section IV

FUSION RESEARCH: CONTEXT AND SCALE

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1. This short paper is intended to contribute to the STOA initiative on fusion research in Europe. It is based on our knowledge of fusion research and other energy R&D, and on our attendance at the very useful workshop held at Culham Laboratory on November 12 and 13, 1987 as part of the STOA project.

2. Technology assessment of fusion (or of anything else) can be either 'internal' or 'external'. Fusion is still at a point of predominantly scientific development with the bulk of serious technological and engineering development still to be done, so internal review necessarily remains a matter of judging the scientific quality of the work and ensuring that funds allocated are used to the greatest advantage. This is an important task in itself but it does lean heavily on the expertise of scientific peer groups and science administrators; the contribution of outsiders is necessarily limited. More difficult, but equally important, is the external review of fusion. This is the attempt to evaluate its priority and success (present and future) in the context of other energy research whose products may compete with it. The problems inherent in all such external reviews are more acute in the case of fusion because of the unique character of the enterprise in terms of its time-scale, R&D costs, and scientific, technological and engineering ambitions.

3. In the context of external review, our stress on alternative lines of energy research is of fundamental importance. For the individual countries of Europe, collaboration plus the financial contribution made by the European Communities has helped to keep national annual fusion expenditures small relative to total energy R&D commitments. If fusion development continues along the lines explained at the workshop, then it seems inevitable that the sums expended must get substantially larger (we return

to this point later), and therefore that this situation must change. Nonetheless, in 1986, the leading IEA nations in the European fusion programme were already spending more on fusion research than on all renewable sources of energy put together, and (with the exception of Britain) than on energy conservation, while fusion has commanded the largest slice of the CEC energy R&D budget (varying between 33 and 49 per cent) since 1981.

4. The larger sums spent on fusion reflect the inherently more costly nature of fusion research compared to renewables or conservation research. It is also important to note that the present sums expended on fusion are, for the stage of development reached, large in relation to all other energy technology research, including the fast breeder reactor. By stage of development we refer to the spectrum of activities along a continuum from research, through development and demonstration, to commercially sustainable diffusion. Fusion research - in the era of JET - is squarely in the reserch category; it is hardly possible to argue that a significant amount of development work has yet taken place. This makes JET broadly comparable to the laboratory reactor stage of fast breeder research, or testing to confirm the principle of a wave power device. The JET project itself amounts to more than just the construction of a large machine, and in turn is complemented by a larger Community fusion programme, the costs of which are shown in Table 1 (1986 prices and January 1986 exchange rates). The cost of fusion research may be compared with those for wave power, an equally novel technology; the UK government has spent about £27.5 million (44.6 MioECU) to reach the equivalent of the end of the JET stage of fusion. The 108kW experimental wave power station being constructed on the Isle of Islay is expected to cost £0.23 million to build (0.37 MioECU); as this should produce electricity it can be considered at least equivalent to the NET stage of fusion (which will not). Fusion research costs may also usefully be compared to those for the fast breeder, as the energy technology most nearly approaching it in complexity. Fast breeder research in the UK (1954-1982) is estimated to have cost some £2700m of public money (4360 MioECU) (1986 prices) to take the technology to the stage of an electricity-producing 250MWe prototype reactor; that is, to the equivalent of the most successful possible outcome of the DEMO ('demonstration' - see below) stage with fusion.

Table 1

European expenditures on fusion research : 1976-86 and forecasts for 1987-91

(1986 prices and January 1986 exchange rates)

		MioECU	(£m)
1. 1976-1986			
(a)	General Programme (Community expenditure only)	648	(400)
(b)	General Programme (Member States' expenditure)	1350*	(833)
(c)	JET project (Community + Member States' expenditure)	634	(390)

[JET construction cost : 630 mioECU (£388m)]

2. Estimates 1987-91			
(a)	General Programme (Community expenditure)	533	(328)
(b)	General Programme (Member States)	1117	(688)
(c)	JET Project (Community + Member States)	531	(327)
(d)	Construction of NET	not included	
		2181	

[NET construction cost, preliminary estimate : 2760 mioECU (£1700m)]

Note: * It is difficult to obtain accurate figures for this item. The estimate made is conservative : that is, actual expenditures are almost certainly under-estimated rather than over-estimated.

5. There is a crude rule of thumb that ratio of expenditures on the successive stages of research, development and demonstration commonly amounts to 1:10:100. It may well be that the two later stages of fusion development will entirely defy this admittedly mechanistic (but empirically based) rule, and prove to be comparatively cheaper. However, Dr Epstein of the US Congress Office of Technology Assessment told us at the workshop that the US fusion community will probably need to spend a further $20 billion (roughly, 22.5 BioECU), alone or in collaboration, before it will be possible to sensibly assess fusion's economic potential. This does not suggest that fusion will prove radically different, in terms of successive stages of cost increase, from other technologies.

6. All this points clearly to the fact that, before many years have passed, continued fusion development along the lines of current thinking will lead to a situation in which expenditure on the European programme become noticeable on a national scale (unless the Community allocation to fushion increases very substantially). In either case, expenditures will become even larger in relation to existing energy research alternatives. To argue that this is not yet so is to ignore that imminent decisions, for example, on NET, will bring such a day much closer. We therefore regard it as essential that, in principle, fusion be evaluated across the board in relation to competing long-term energy sources. In other words, there is an important element of opportunity cost - other research opportunities foregone and the alternative employment of valuable scientific and engineering skills - in pursuing the current and proposed form of the European fusion programme.

7. This raises the question of what alternatives exist to fusion power. Excluding fast breeder reactors, the representatives of the fusion community at the workshop identified only coal, to which other participants rightly added renewable energy sources. (To be fair, members of the fusion community have elsewhere identified solar photovoltaic power stations as possible competitors). We suggest the further addition of research on energy conservation and energy efficiency. This is related to the important question of the general shape of the energy future into which a commercial fusion reactor would be implanted. There is a need for extremely long term speculation here because of the extended time-scale

over which fusion could possibly become a commercial proposition. The current vision within the fusion programme, as reported as the workshop, seems to assume an inevitable high energy future - a scenario in which energy demand has grown inexorably and seemingly without obvious limit or saturation. This is clearly one possibility and should be considered. However, other possibilities also exist, no less implausible, including scenarios with much lower energy demand. These futures could result partly from the application of generic new technologies like micro-electronics (for example, to control systems) and new materials (for example, lighter materials replacing heavier ones) but also partly from deliberate energy R&D strategies which emphasise conservation and efficiency. After all, technology can only become available if the R&D is performed. There is therefore an element of circularity and the self-fulfilling prophecy here. If a high energy future is expected, and fusion is reckoned to be essential to its achievement, the consequence may be increasingly heavy spending on fusion R&D, and (the opportunity cost point) a consequent neglect of the possibilities of research aimed at enabling lower energy futures via conservation and more efficient energy use. A similar argument applies to a second aspect of the energy future implicitly projected within the fusion programme - that it will be one in which electricity is the overwhelmingly dominant energy carrier and economies of scale turn out to favour high capacity generating plant.

8. But whatever may be true about the opportunity cost of fusion research, low energy futures are at least a serious possibility and a minimal condition for the evaluation of fusion research would be to test the robustness of fusion against low, as well as high, energy futures.

9. In the context of alternatives and opportunity costs, it is important to remember that while fusion is <u>scientifically</u> unique, it is far form exceptional in <u>energy</u> terms. This is because fusion is a route to the production of electricity, and there are many other routes, including fission (thermal and fast), coal (including combined heat and power and combined cycle gasifiers), and many renewables. A failure on fusion's part would not deprive us of the availability of electricity: merely of one possible way of obtaining it. In other words, fusion power is not an example of an economically revolutionary technology; it would not allow

us to do something new or different that we cannot do already. The analogy made by a member of the CEC team at the workshop between fusion and aerospace technology is therefore not, in energy or economic terms valid. Without aerospace technology we cannot fly; without fusion we can still have electricity. In this very important energy and economic sense, fusion power is therefore very different to recently-developed areas of science and technology such as microelectronics, which is radical both in that it has applications over the whole spectrum of technological tasks and in that it admits us to entirely new activities.

10. Of course, it may be that the economic benefits of fusion would turn out to be very large if the technology can be commercialised. It is of course exceptionally difficult to evaluate any benefits because of the long time horizon before they could become apparent. It is however, important to note that the idea of 'inexhaustibilty' of fusion power (<u>not</u> one, it must be said, claimed by participants in the workshop, but one that commonly characterises fusion PR) is <u>not</u> the same thing as large economic benefits. Inexhaustibility can only possibly refer to the availability over time of 'fuel' <u>inputs</u> to fusion and this notion therefore applies equally to the renewable sources of power. What is more important is the availability of power at any particular time and in this context what are not inexhaustible are the capital investment resources needed to get useful energy <u>out of</u> 'inexhaustible' inputs. If current research trends are followed, it seems virtually inevitable that fusion reactors will be large, complex, and expensive to build. For fusion's benefits to be large, either substantial improvements will be needed here, or (and herein lies the importance of energy futures and scenarios), competing sources of energy will need to become extremely scarce and expensive.

11. Our final issue concerns the stages of future development of fusion. Fusion community representatives at Culham suggested that there might be only two further stages - NET and a 'demonstration' machine (DEMO) - before utilities might order fusion reactors on a fully commercial basis. All earlier experience with comparable technologies, for example, fast breeder reactors, suggests that this is optimistic to the point of unreality. It is of paramount importance to remember that in the JET - NET - DEMO sequence, only DEMO is, conceptually, a fully engineered power producing

reactor. (JET is a plasma physics experiment; NET is essentially a test-bed device which will not produce electricity and research with it will in fact begin with a plasma physics phase, although to succeed, NET will need to produce ignition or something approaching it). The idea that in so complex a technology as fusion there need be only one power-producing device before full commercialisation is achieved contradicts all earlier experience. For instance, in British development of fast breeder reactors the sequence of pilot reactor (DFR) followed by prototype reactor (PFR) has not been enough to persuade utilities to take a serious interest in them; the building of a commercial demonstration reactor is awaited. Given, then, that a commercial fusion reactor would, according to the fusion scientists at the workshop, need to embody substantial technical changes compared to DEMO, we suggest that, realistically, at least one, and possibly two further pre-commercial large devices would be needed prior to real commercialisation. This, if accepted, has major implications for the timescale and cost of fusion RD&D.

12. Adequate external review of a technology so unique, complex and long-term as fusion is an exceptionally difficult task. We have sought, in this brief paper, to outline some of the major issues that we believe such an external review should consider, not in the belief they admit of easy resolution, but in the conviction that they do need to be drawn out as fully as possible.

Section V

EUROPEAN PARLIAMENT
Committee on Energy, Research and Technology

Luxembourg L-2929

SCIENTIFIC AND TECHNOLOGICAL OPTIONS ASSESSMENT · EUROPEAN PARLIAMENT

STOA BACKGROUND BRIEFING

ON

CONTROLLED THERMONUCLEAR FUSION

7 March 1988

PE 121.237

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Friday, 13 November 1987

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STOA BACKGROUND BRIEFING ON CONTROLLED THERMONUCLEAR FUSION

Fusion is one of the first three areas of investigation chosen by the European Parliament's experimental project in technology assessment - the STOA Project - which was launched earlier in 1987. The European Parliament has always taken a close interest in the European Fusion Programme in general and the JET (Joint European Torus) Joint Undertaking in particular. The reason for looking at fusion at this stage is to help to clarify the various issues - scientific, technical, economic, political and environmental - which are likely to be relevant as a number of key decisions of the future of European research in controlled thermonuclear fusion come up on the horizon.

It is not STOA's job to make political decisions, and the current investigation, including the Workshop, is not intended to replace the normal system for consulting the European Parliament on Commission proposals.

There are two distinct aspects to STOA's work on fusion. The main STOA Report on the European Fusion Research Programme will be published in the summer of 1988 and will concentrate on the long-term issues and questions of interest to the European Parliament, in particular those that relate to the key decisions to be taken in the early 1990's and the possible consequencies of these decisions. As part of the process of preparing this report, the STOA Fusion Project organised a two-day Workshop at the JET Joint Undertaking in the UK on 12 and 13 November 1987, where experts and officials from the European Fusion Research Programme exchanged views with independent experts in the presence of MEPs. The revised views of the independent experts present at the STOA Fusion Workshop will be incorporated into the final STOA Fusion Project Report, but STOA believes that the contributions made by the participants at the Workshop may help to inform the debate to be held in the European Parliament on the report prepared by Mr Alman METTEN for the Committee on Energy, Research and Technology (Doc A2-320/87)) on the proposal from the Commission for a Council Regulation adopting a research and training programme (1987-1991) in the field of controlled thermonuclear fusion, and the proposal for a Council Decision approving amendments to the Statutes of the Joint European Torus (JET) Joint Undertaking (COM(87)302 final).

The speakers and participants at the STOA Fusion Workshop included Dr Gerald Epstein, author of the recent fusion report by the Office of Technology Assessment of the US Congress in Washington, Professor Jochen Benecke of the Sollner Institut in Munich, Professor José Campos of the University of Madrid, Dr John Davies and Dr John Lawson of Rurtherford Appleton Laboratory, Mr Robert Carruthers, retired technology director of Culham, Dr Gordon MacKerron and Ms Judy Clarke of the Science Policy Research Unit, University of Sussex, and Mr Colin Sweet of the Centre for Energy Studies, South Bank Polytechnic.

The presentations on behalf of the European Fusion Programme and JET were made by Dr Paul-Henri Rebut, Director of JET, Dr Charles Maisonnier, Director of the European Fusion Programme, Professor Pinkau, Director of the Max Planck Institute of Plasma Physics, Garching, near Munich, Dr Romano Toschi, Head of the NET Team and Mr RS Pease, Director of the UKAEA Fusion Programme.

The Workshop was chaired by Rolf Linkohr, MEP (D, Soc)*. The other Members of the European Parliament attending were Amédée Tuner (UK, EDG) - he, like Mr Linkohr, is a member of the STOA Supervisory Panel - Alman Metten (NL, Soc), who is rapporteur on fusion for the Committee on Energy, Research and Technology, James Elles (UK, EDG), MEP for Oxford and Buckinghamshre, Otto Bardong (D, EPP), a Member of the European Parliament's Committee on Budgetary Control and two other Members of the Committee on Energy, Research and Technology: Undine Bloch von Blottnitz (D, Arc), and Madron Seligman (UK, EDG).

In addition, the Workshop was attended by a number of observers, including specialist journalists.

This Background Briefing is a compilation of the main presentations made at the Workshop, edited where necessary to avoid unnecessary duplication. In addition, the STOA Fusion Project has provided an introduction to the basic scientific and technological aspects of fusion research.

* NOTE:

D=W. Germany , UK=United Kingdom, NL=The Netherlands. As regards political group affiliation, Soc=Socialist Group, EDG=European democratic Group (including Conservatives), EPP=Group of the European Pople's Party (Christian Democratic Group) and ARC=Rainbow Group (including Greens).

THE STOA PROJECT - BACKGROUND INFORMATION

The STOA Project came into existence as the result of a report adopted by the European Parliament on 18 October 1985. That report, which was drawn up for the Committee on Energy, Research and Technology (CERT) by one of its Members, Rolf Linkohr, recommended that the European Parliament should equip itself with a facility modelled on the Office of Technology Assessment fo the US Congress, albeit on a smaller scale. After this proposal had received the endorsement of the plenary session, it was studied during 1986 and plans were drawn up for an experimental project in 'Scientific and Technological Options Assessment' which would begin work early in 1987 and operate for a trial period of 18 months.

On 6 February 1987, the Supervisory Panel of STOA met in Brussels and decided on three initial topics for investigation:

1. The re-organisation of telecommunications in Europe,
2. Problems of transfrontier chemical pollution, and
3. Controlled thermonuclear fusion.

The Supervisory Panel consists of five Members of CERT, although the Project is being fun for the benefit of all the Committees of Parliament. Ideally, the functioning of STOA would be demand-led: that is, it would respond to requests for information or assistance by the various Parliamentary Committees arising from their normal work. To get the Project off to a start, however, the decision was taken to commence with three areas of investigation likely to be of more than short-term relevance to such Committees of the European

Parliament as CERT, the Committee on Economic and Monetary Affairs and Industrial Policy and the Committee on the Environment, Public Health and Consumer Protection.

The Members of the Supervisory Panel of STOA are Michel Poniatowski (F, LDR)* the Chairman of CERT, Bernhard Sälzer (D, EPP) Vice-chairman, Felice Ippolito (I, LDR), Amédéé Turner (UK, EDG) and Rolf Linkohr (D, Soc).

There is also a STOA Project Team of EP officials, who also continue to have other duties in the EP Secretariat- General. The STOA Adminstrator is Dick Holdsworth of the CERT Secretariat. The STOA Fusion Project Leader is Gordon Lake, of the Secretariat of the Committee on the Environment, Public Health and Consumer Protection. From the Directorate-General for Research, there are John Wittenberg (Pollution Project Leader), Anton Lensen (Telecommunications Project Leader), Peter Palinkas (Indicators/statistics) and Ralph Spencer (Librarian and documentalist). The Team is advised by Pietro Bianchessi, of the Informatics Directorate.

STOA is building up a Network of individuals and organizations interested in keeping abreast of developments in European parliamentary technology assessment. Members of the Network receive the STOA Newsletter. STOA maintians contacts with other specialised TA bodies.

* NOTE:
F=France, D=Germany, I=Italy and UK=United Kingdom,
Political Groups: LDR=Liberal and Democratic Reformist Group, EPP=Group of the European People's Party (Christian Democratic Group), EDG=European Democratic Group (including Conservatives), Soc=Socialist Group.

WHAT IS CONTROLLED THERMONUCLEAR FUSION?

Information Paper prepared by Mr Gordon Lake
of the Directorate-General for Committees and Delegations,
STOA Fusion Project Leader

Atoms are the basic building blocks of the universe, but atoms themselves are composed of smaller particles. In a simple model, an atom consists of a nucleus or central core, surrounded (at a considerable distance) by orbiting electrons, rather like a miniature model of the solar system. The nucleus itself, although only occupying a minute space within the centre of an atom, accounts for over 99.9% of a total atomic mass. It consists of a mixture of protons (carrying a positive electric charge) and neutrons (which have no charge), and is thus positively charged. The orbiting electrons are negatively charged, resulting in overall electrical neutrality for the atom.

Since like charges repel, the positively charged protons in the nucleus would repel each other, if this force were not overcome by an even more powerful, but extremely short-range force which 'glues' the mixture of protons and neutrons (collectively known as nucleons) together. Just how tightly a nucleus can be 'glued' together will depend on the particular numbers of protons and neutrons which constitute a particular nucleus.

The simplest atom of all, hydrogen, has a nucleus consisting simply of a single proton, around which orbits a single electron. Hydrogen can, however, exist in two other forms. The second variety, deuterium, has a nucleus consisting of one proton and one neutron. The third variety, tritium, has one proton and two neutrons in its nucleus. All three variations are still forms of hydrogen: they all have just one orbiting electron, and are thus chemically identical. (Chemical behaviour is governed by the orbiting electrons, not by the nucleus). These varieties of the same chemical element thus have the same atomic number (number of protons), but different atomic masses, because of the different numbers of neutrons present. They are known as isotopes of the element.

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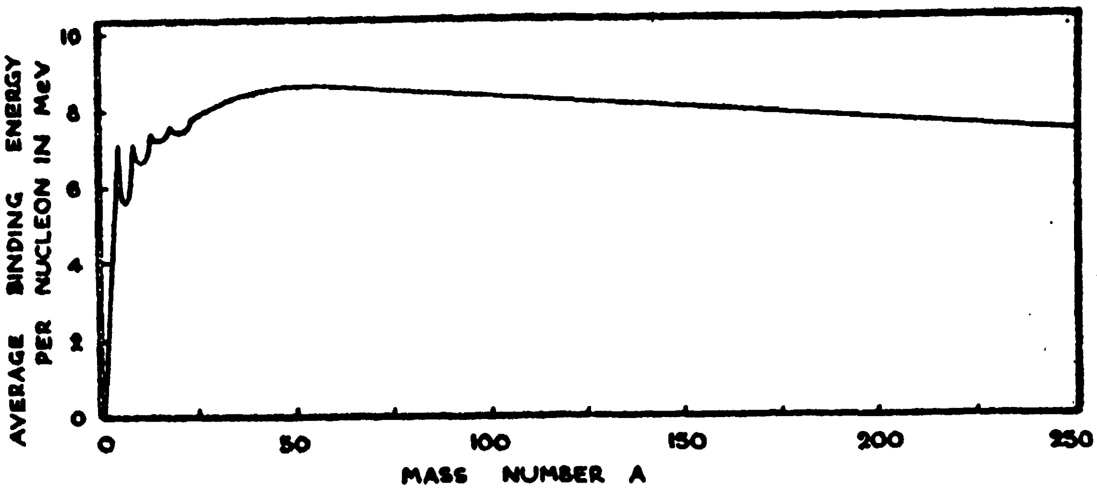
One measure of how effective the nuclear glue is in holding a particlar nucleus together is the binding energy per nucleon. The total mass of a nucleus is always less than the sum of the masses of its constituent nucleons - the missing mass represents the binding energy of the nucleus, according to Einstein's famous mass-energy equation $E=MC^2$.



—Average binding energy per nucleon as a function of mass number

Since the binding energy is 'given out' as you move to the centre of this graph from either end, then in a sense the most stable nuclei, those of similar atomic numbers to silver (47), can be seen to be sitting at the bottom of the deepest energy valleys, and thus in principle light nuclei could be made to combine together (undergo fusion); or heavy nuclei could be made to split apart (undergo fission), so as to produce more energetically stable nuclei, together with a considerable release of energy. The problem is that high 'energy mountains' separate the deep 'energy valleys', and energy has to be expended to push the nuclei over these barriers.

In the case of nuclear fission, certain heavy nuclei, in particular those of certain isotopes of uranium and plutonium, are so unstable that they only need the energetic imput from an incoming neutron to persuade them to fall apart, and since the neutron is neutral, it doesn't meet any electrical resistance en route.

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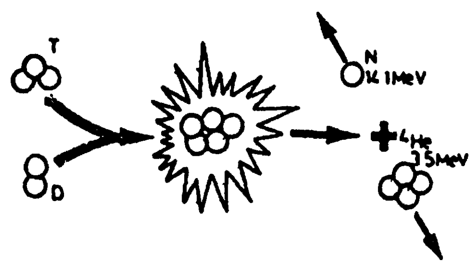
At the opposite end of the scale, where the energy rewards are much greater, things are much more difficult. The most promising fusion reaction at present for use in a fusion reactor is that between deuterium and tritium, which fuse together to form a helium nucleus plus a high energy neutron.

${}_1H^2$	+	${}_1H^3$	->	${}_2He^4$	+	${}_0n^1$	+	17.59 MeV
(deuterium)		(tritium)		(helium)		(neutron)		(energy)

(MeV=million electron volts)

(the energy output is distributed approximately 14.1MeV for the neutron, and 3.5MeV for the helium nucleus (alpha particle))



As can be seen, this reaction liberates (relatively) enormous amounts of energy. Burning a single atom of coal (ie carbon), would, for example, only liberate about 4eV of energy: the fusion reaction is more than 4 million times as energetic.

The problem is that in order for such a fusion reaction to occur, the repulsive forces which act between positively charged nuclei have first to be overcome before the powerful nuclear glue can come into play. Thus the nuclei have to be made to collide with each other with sufficient force, and the basic way to do this is by heating the mixture to over a hundred million degrees centigrade, at the same time as somehow keeping it contained.

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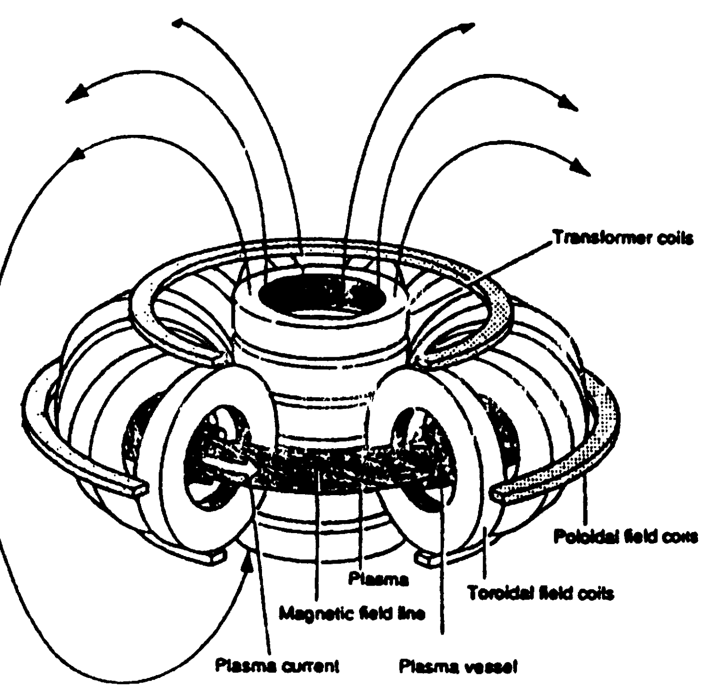
The hydrogen bomb demonstrates that fusion works - it uses the heat energy and compressive power generated by an 'ordinary' fission bomb as a trigger for an uncontrolled fusion reaction - a thermonuclear explosion. The sun, like all other stars, is a very complex fusion system, but again is not very useful as a model of controlled thermonuclear fusion in a power station on earth.

There are a variety of ways of 'containing' an extremely hot plasma. (At these temperatures, atoms become ionised: their orbiting electrons are stripped away leaving positively charged nuclei and negatively charged electrons in highly energetic random motion. This is a plasma.)

Since no material substance can withstand temperatures of 100 million°C or more, the most popular concept has been to use powerful magnetic fields to create a magnetic 'bottle' in which to trap the plasma. The most successful configuration so far is the tokamak (from the Russian acronym taken from the words for 'toroidal chamber with magnetic coil'), announced by the Soviet Union in 1968.

A tokamak is designed to trap a doughnut shaped ring of plasma by combining a powerful externally generated toroidal magnetic field with a poloidal magnetic field generated by driving an electrical current around the ring of plasma. The resultant field lines twist around the plasma as they extend around the ring.



It takes a complex array of magnetic fields to create the confinement configuration known as a tokamak: Transformer Coils create a current in the plasma, and keep it flowing: Toroidal Field Coils and Poloidal Field Coils combine with the field produced by the current flowing through the plasma to create magnetic forces that keep the plasma away from the walls of the Plasma Vessel. The ultimate aim of magnetic containment systems is to produce a set of Magnetic Field Lines that spiral around the toroidal plasma

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Source: New Scientist, 26 November 1987 (from an article by Bill Spears: 'Fusion through the NET')

Other Confinement Systems

Other confinement systems are regarded as possible alternatives to the tokamak. A stellarator is a toroidal device which uses magnetic coils arranged in a kind of double helix shape around the vacuum chamber containing the plasma, coupled with inner and outer annular coils. These result in a confining field which does not depend on a current flowing through the plasma itself. This in turn means that the stellarator is designed to operate in a steady state mode rather than using pulses as in the tokamak system.

The stellarator design concept predates the tokamak, but interest in helical designs has revived recently in several fusion laboratories.

Design variants on the original stellarator concept are sometimes known as 'heliotrons'.

Another alternative system is that known as Reversed Field Pinch, which as in a tokamak combines an externally generated toroidal field with a plasma current generated poloidal field. The difference is that the toroidal field reverses direction near the outside of the plasma. In this system, the plasma current driven poloidal field plays a more important role than the toroidal field, and consequently the external magnets can be smaller and simpler. The large heating effect provided by the plasma current also reduces the need for other forms of external heating.

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Inertial confinement

A completely different approach to controlled thermonuclear fusion involves focussing a series of high power lasers onto a pellet containing deuterium and/or tritium, and then repeating this process many times per second. In theory, a spherical pellet can be made to implode, with the temperature and pressure increasing dramatically as the implosion moves in towards the centre of the pellet. Indeed the density which can be achieved is thought to be of the order of 10 billion times that of magnetically confined plasma, and this only needs to be confined for maybe one billionth of a second for the fusion reaction to take place.

Unfortunately much of the mathematics and physics which describes this implosion process is the same as that used in the design of thermonuclear weapons and, therefore, great deal of intertial confinedment work is therefore still classified. There are also rather substantial engineering problems in designing a reactor using a range of highly sophisticated and sensitive lasers which have to cope with an explosion maybe equivalent to 100kg of TNT several times a second, the energy from which must be successfully transferred to an electricity generation system.

There is no doubt that the tokamak is the most highly developed confinement concept, but the possibility remains open that fundamental problems with it may one day lead to a change to another preferred system. The difficulty is that resources are not large enough to permit equal development of all possible systems. The situation is somewhat analagous to the early development of the motor car engine. The reciprocating internal combustion engine eventually emerged as the most popular design, (despite the eccentricity of using up and down linear displacements to generate rotational energy), because it works. If the tokamak works, there will not be a great incentive to develop an alternative.

Plasma heating

Since the fusion reaction occurs only at extremely high temperatures, the plasma has to be heated in order to start the reaction off. A range of different techniques have been developed to do this.

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Ohmic heating

Passing an electrical current throught the plasma causes it to get hotter, just as passing an electric current through the bars of an electric fire causes them to become hotter. The higher the resistance in the conductors, the more heat is produced. Unfortunately as a plasma gets hotter, the better it conducts electricity, and therefore the heating effect of the plasma current diminishes.

Radio frequency heating (RFH)

This operates in a similar manner to a microwave oven. Electromagnetic radiation will resonate with particle vibration/energy levels at specific frequencies, increase the vibration/energy, and thereby heat the plasma via collisions. The JET experiment is making increasing use of RFH.

Neutral beam injection (NBI)

This technique relies upon transferring the kinetic energy of high speed neutral particles, usually hydrogen or deuterium atoms, to the plasma. Neutral particles have to be used because charged particles would be blocked/deflected by the powerful magnetic fields confining the plasma. Since, however, it is only possible to accelerate charged particles, the neutral beam injection device first accelerates hydrogen or deuterium ions (nuclei) and then electrons are added to produce the neutral atoms which collide with the plasma particles.

Compression heating

Higher plasma pressures created by more powerful magnetic confinement also increase plasma temperatures. The Reversed Field Pinch device would attempt to make the most of this characteristic.

Heating by alpha particles

The D-T fusion reaction produces a 3.5MeV alpha particle (helium nucleus) as well as a 14.1MeV neutron. The neutron, carrying no charge, usually escapes from the plasma and transfers its energy to the first wall/blanket. The alpha particles, four times heavier and positively charged, will usually collide with other particles in the plasma, thereby heating it. In order for a fusion reactor to 'work', ie to generate much more power than it consumes, the plasma will have to become ignited. That is to say the fusion reaction must be self-sustaining via the plasma self-heating through alpha particle collisions. Once this stage is reached, as with an ordinary domestic fire, there should be no need for further external heating, just the provision of more fuel.

Demonstrating the scientific feasibility of fusion: breakdown and ignition

In order for fusion reactions to take place, the plasma must be as hot as possible, as dense as possible, and be confined for as long as possible. The so called Fusion Product is a mathematical device for measuring the success of fusion devices in reaching reactor relevant conditions. If the Central Ion Temperature, Ti, is measured in keV (1keV = 11.6million°C); the Central Ion Density, ni in ions per cubic metre; the Global Energy Confinement Time, $T\mathcal{E}$, in seconds, then the Fusion Product is expressed in units of m^{-3} skeV.

Reactor relevant conditions need a Fusion Product of $5x10^{21} m^{-3}$skeV. This would be achieved, for example, by Ti=10keV

ni=$2.5x10^{20} m^{-3}$

$T\mathcal{E}$=2s.

The fundamental problem in reaching these figures is that all three factors: temperature, density and confinement time, tend to be inversely related. The hotter a plasma is, the lower its density tends to be, and the harder it is to confine. The most successful experiments so far at JET have reached a Fusion Product of $2x10^{20} m^{-3}$skeV.

Another way of measuring success in fusion experiments is to look at the energy gain in the system. Energy gain, Q, is the ratio of the fusion power output from a given device to the input power injected into the plasma. No large experimental device in the world yet uses tritium, so no fusion power output has yet been achieved. Consequently an 'equivalent' Q is measured, which is defined as the Q that would have been resulted from the particular plasma parameters achieved, if the plasma had been fueled equally by tritium and deuterium. When Q=1 the condition is described as "breakeven": the output power equals the input power. It must be stressed, however, that this measurement only relates to the internal energy balance within the plasma. It thus assumes that all the fusion power is retained in the plasma, rather than being transmitted to the first wall and blanket, and it also measures energy input as the energy finally delivered to the plasma, and thus takes no account of the energy losses incurred in generating the heating power and in delivering it to the plasma, nor does it allow for the energy needed to maintain the magnetic fields, or the vacuum, or other support systems.

"In present-generation experiments, the power excluded from the definition of Q is as much as 35 times greater than the power accounted for by this ratio" (OTA 'Starpower' Report, p68).

'Breakeven' is thus essentially a scientific concept rather than a technological one. Achieving it will be a significant milepost en route to the demonstration of the scientific feasibility of controlled thermonuclear fusion, but it must not be regarded as a measure of technological feasibility: it does not represent an overall energy balance in the system.

As values of Q higher than unity are reached, the reaction will eventually reach the stage of ignition, when Q essentially should become infinite, since no further external energy should need to be added to maintain the fusion reaction. Before this stage is reached, the reaction may achieve conditions which have been described as those of a 'wet wood burner'. In other words energy output from fusion reactions will be significantly higher than energy input from heating systems, but the latter will still be needed to keep the fusion reaction going - just as a wet wood burning stove needs the addition of a constant source of additional energy such as burning oil or gas.

None of the world's existing fusion experiments will achieve ignition. NET is designed to do so, and so is the more modest CIT (Compact Ignition Torus) being designed in the USA. It is generally agreed that ignition will represent the final demonstration of the scientific feasibility of controlled fusion.

Tritium breeding

As well as transmitting the heat energy of the fusion reaction the intense neutron flux would also be used to produce tritium in the breeder blanket which surrounds the vacuum chamber. The favoured element for breeding purposes is lithium, and there are two possible routes to tritium from lithium, depending upon which isotope is involved.

1.	n	+	^{6}Li	->	^{3}H	+	^{4}He	+	3.8MeV
	(neutron)		(lithium)		(tritium)		(helium)		(energy)

2. n + ^{7}Li + 2.5MeV -> ^{3}H + ^{4}He + n

(^{6}Li constitutes only 7% of natural lithium, but most of the tritium would be generated by the ^{6}Li reaction, since it has a much higher individual probablility of occurring.)

Judicious use of neutron multipliers such as beryllium, which can react with one neutron to produce two, would improve the prospects for tritium production.

Clearly if one tritium nucleus is generated in the blanket for every tritium nucleus 'lost' by fusion in the plasma, then the reactor will 'produce' the same amount of tritium that it consumes, and the overall breeding ratio will be 1. To allow for losses and other uncertainties, a breeding ratio of 1.1 or 1.2 would probably be needed to guarantee tritium replacement in the reactor system.

Heat extraction

In some fusion reactor designs, a liquid metal coolant containing liquid lithium would act simultaneously as coolant and breeding material. The ESECOM study referred to in 'Fusion As A Source of Energy: Its Economics And The Environment' refers to a reference case fusion reactor using a pure liquid lithium coolant, but in fact the European Fusion Research Programme has decided that such a coolant is too problematic because of the fire risk associated with the extreme reactivity of liquid lithium.

Whichever material is finally selected for the coolant, its final purpose is exactly the same as in a fission reactor; that is to transfer the heat from the nuclear reaction via a heat exchanger to a water/steam system used to drive conventional steam turbines to provide electricity. As will be appreciated, the engineering problems still to be faced in the development of the tritium breeding and heat transfer systems in a working fusion reactor are at least as significant as the scientific problems which have faced the development of a controlled ignited plasma.

STOA FUSION WORKSHOP

SUMMARY REPORT OF PROCEEDINGS

Thursday, 12 November 1987, 15.00 - Afternoon session

THE EUROPEAN FUSION PROGRAMME AND THE JET JOINT UNDERTAKING

The afternoon session opened with welcoming remarks by the Director of JET, Dr P-H Rebut.

The Chairman of the Workshop, Mr Linkohr, MEP, thanked Dr Rebut and spoke on the nature and purpose of STOA and the Workshop.

Dr C Maisonnier, Director of the EC Fusion Programme then addressed the Workshop on EUROPEAN FUSION PROGRAMME STRATEGY. The following written summary of his remarks was supplied after the Workshop by the Commission. (Note: the same procedure has been followed here in respect of the Speeches by Dr Rebut, Professor Toschi, Professor Pinkau and Dr RS Pease)

EUROPEAN FUSION PROGRAMME STRATEGY

1. Future energy sources. Dr Maisonnier started with the fundamental question which is: What are the energy sources having the potential to supply a substantial fraction of the electrical energy needs in the long-term? In his view these are coal, fission, fusion and perhaps solar. their large scale deployments have to be considered to be strongly dependent on many factors, technical, environmental and economic. At the end, these sources might well turn out to be more complementary than competitive.

2. The Community Fusion Programme. Dr Maisonnier pointed out that by decision of the Council of Ministers of the European Communities all efforts in the field of thermonuclear fusion are coordinated in one European programme, which has as its single aim to design a demonstration reactor.

3. Fusion as an Energy Source. The principle of a fusion reactor, the fact that its primary fuels (deuterium and lithium) and its reaction products are non-radioactive were illustrated by Dr Maisonnier. He stressed, however, that "inside the box" fusion is not altogether "clean" due to activation of the mechanical structure by neutrons. Overall, fusion has the potential for a moderate impact on the environment, for inherent safety and for using practically inexhaustible fuels. As the fuel will be consumed in very small quantities in a future fusion eactor, the electricity generating costs of a commerical fusion reactor will be dominated by capital investment. It is too early to make definite statements on fusion as an economically competitive energy source; preliminary studies show that the order of magnitude of the cost of fusion energy is right. Given the timescale for the development of thermonuclear fusion, fusion plants should not be expected to be making a substantial contribution to energy supply before the middle of the next century.

4. European Fusion Programme Strategy. The path to a fusion reactor, Dr Maisonnier said, could in a very simplified picture, be viewed as a series of steps involving the demonstration of the scientific, then the technical and finally the economic feasibilities. Of course, in practice these steps are not independent from each other and overlap in many aspects. JET, now

scheduled to end 1992, and the medium-size machines of the Associations tackle essentially the scientific matters while NET which could start operation around 2000 will largely be devoted to demonstrate the technical feasibility. The economic feasibility has to be demonstrated later by a DEMO device. In particular, Dr Maisonnier emphasized the merits of the sliding nature of the European Fusion Programme. He also noted that experience with high-level assessment panels in 1981 and 1984, chaired by Professor KH Beckurts, shows such panels being extremely useful in times when important decisions have to be taken. According to the 1987-91 programme which is on the Parliament's desk and in view of the possibility of launching a detailed NET design at the beginning of the 1990s the Commission foresees a further independent high-level assessment around 1990.

5. The 1987-91 Programme. The main objectives of the programme are to establish the physics and technical basis for NET, to embark on its detailed design before the end of the programme period and to explore the reactor potential of some alternative lines; they have been explained by Dr Maisonnier in detail. In particular, he mentioned that the overall volume of the programme, which occupies 1300 professionals in Europe as a whole, is about 2300 MECU for 5 years, about 42% of it being financed by the Commission. The implementation of the programme is mostly devoted to magnetic confinement in toroidal devices through JET, NET, the Associations, the JRC and European industry (which received about 120 MECU of contracts in 1987). A substantial increase of the involvement of European industry is expected when a decision is taken on the start of the engineering design of NET.

6. Amendments to the Statutes of JET. Concerning the document (COM(87)302 final) containing three proposals - a Council regulation adopting a fusion research and training programme (1987-91), a statement of environmental impact and economic prospects of fusion, and an admendment to the Statutes of JET - which has been transmitted by the Commission to Council and Parliament, Dr Maisonnier explicitly pointed out the need to prolong JET by the end of 1992. He expressed and underlined the scientific conviction of the European fusion community to have extremely good chances to meet fully the initially stated JET objectives by introducing into JET some additional equipment, the virtues of which have been highlighted by recent experiments. This requires an extension of 2.5 years of the life of the project.

7. International Cooperation. Dr Maisonnier illustrated that today (1987) all four large fusion programmes (Europe, USA, Japan, USSR) are comparable in overall volume. He stressed the importance of international cooperation which the Commission realizes by having bilateral framework agreements with the USA, Canada and Japan (in preparation) and several implementing agreements in the framework of the IEA (OECD). In particular, Dr Maisonnier emphasized the quadripartite cooperation initiative of Europe, USA, USSR and Japan on an International Thermonuclear Experimental Reactor (ITER) under the IAEA auspices. The conceptual design phase of ITER is scheduled to start in April 1988 with Garching, where the NET team is located, acting as a technical site for joint work. This, and the work of NET as well, demonstrates, as Dr Maisonnier was pleased to note, the recognized outstanding position and leadership of Europe within the ITER initiative.

The Chairman asked for questions. These were put by Mr Lake, STOA Fusion Project Leader, and Mrs Bloch von Blottnitz, MEP. Mr Maisonnier replied. (Details of this discussion will be given in a later, fuller version of this Report of Proceedings.)

Dr PH Rebut then addressed the Workshop on PRINCIPLES OF FUSION AND THE JET PROJECT.

PRINCIPLES OF FUSION AND THE JET PROJECT

1. Dr Rebut reminded the Workshop that fusion is the main source of energy in the universe. Nuclear fusion takes place in stars but at lower temperatures and reaction rates than to be envisaged on earth to produce the required fusion power in a reactor.

2. Basics of Fusion. Dr Rebut described the basic processes of nuclear fusion, considering deuterium and tritium as the reacting elements. The primary fuels of a reactor are deuterium and lithium, which are abundant in the sea water and in the earth. Tritium which does not occur naturally is

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formed in a blanket of lithium surrounding the reacting plasma. At a later stage, Dr Rebut said, other possible reactions with advanced fuels requiring much higher temperatures, but without using tritium and not producing neutrons, might be considered.

3. Problems of Fusion. The problems in fusion experiments are essentially twofold: first, the need to heat the fuel to about 100 Mio°C, and second, the need for a container for the hot fuel. Dr Rebut mentioned that the three essential heating mehtods (the ohmic heating based on a strong plasma current, the heating by radio-frequency waves that the injection of fast, high-energy atoms) have all been applied and studied on JET. Studies on plasma containment have been, of course, concentrated on magnetic confinement.

4. Advantages of Fusion. A summary of the principal advantages of nuclear fusion was given by Dr Rebut: the basic fuels are cheap, and abundant; they are not radioactive; a reactor is inherently safe and cannot runaway; and, the environmental impact is low.

5. JET. JET is the largest nuclear fusion experiment inside the Community and, indeed, in the world, as pointed out by Dr Rebut. Its aims are to provide the information necessary to define the parameters for NET and eventually of a reactor by studying the plasma in conditions close to those needed for a fusion reactor.

6. Status of JET Experiments. Dr Rebut described the way to be followed in order to advance towards ignition conditions. In 1986, JET was about 25 times away from the ignition point in terms of the fusion product "density times temperature times confinement time". In JET each of these parameters can separately be produced at the value required for a reactor. Future developments are aimed at increasing their combined value in the fusion product.

7. JET Programme and Costs. It is planned that JET, Dr Rebut said, should be in its final configuration in 1990 and that operation with tritium would start soon after in ordr to study a burning core plasma and a significant

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alpha-particle production. The overall capital costs including investments to be planned in future, will be about 520 MECU (1987 prices). The annual budget is about 110 MECU with a staff of about 250 professionals.

8. JET Achievements. Dr Rebut emphasized that JET is recognized as the leading fusion experiment in the world. It has been built on time and broadly to cost. The design performance has been achieved or exceeded. JET is an excellent example of successful scientific collaboration in Europe and an attractive and successful partner of European industry.

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The Chairman called for questions. These were asked by Mrs Bloch von Blottnitz, the Chairman, Dr Benecke and Mr Sweet. Dr Rebut replied.

Professor Toschi, Leader of the NET Team, then addressed the Workshop on NET, TECHNOLOGY, PROJECTIONS TOWARDS A DEMONSTRATION REACTOR.

NET, TECHNOLOGY, PROJECTIONS TOWARDS A DEMONSTRATION REACTOR

1. Professor Toschi reminded the Workshop that, in the agreed strategy for the European Fusion Programme, there would be only one step (NET) between JET and a demonstration reactor (DEMO). Therefore, the design solutions for NET need to be directly extrapolable to reactor conditions.

2. Objectives of NET. Professor Toschi said that the main objective of NET is to demonstrate fusion energy production in an apparatus that meets the basic design and operating requirements of a reactor and, in particular:

- To demonstrate a self-sustainin D-T thermonuclear reaction;
- To extend the burn time up to steady state;
- To qualify components in reactor-like conditions;
- To demonstrate the breeding of tritium;
- To demonstrate the extraction of energy at a sufficiently high-grade for electricity generation.

To achieve these objectives the NET machine will need to operate at a relatively high availability. Professor Toschi considered a 25% availability to be an interesting design target for NET.

3. Operation of NET. As it will be the only machine between JET and DEMO, NET will have both a physics phase and a technology phase. Professor Toschi considered, however, that this division into two phases was rather arbitrary as the physics, which would have an integrated burn time of about 300 hours, would include a significant technology programme such as the assessment of plasma facing components, the assessment of machine relability, and

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preliminary blanket module testing. The technology phase of about 7000 hours integrated burn time would likewise contain a strong physics element in the programme.

4. Parameters of NET. Professor Toschi described the current thinking on the NET design, in particular the desire to have a flexible machine, that would allow for improvements during operation and which, wherever possible, would use reactor-relevant technologies. Among its main parameters would be a plasma current of about 15 MA. He described the design as a prudent one in which the confinement capability of the machine should allow an ignition margin up to about three depending on the scaling law used, but he emphasized that the uncertainty on the scaling law to be adopted was still rather large. The ignition margin needs to be unity in order to reach ignition).

5. Timetable for NET. The NET design activity was launched in 1983. This activity has provided a sound basis for the Community's technology programme, much of which is directly geared to the requirements of NET. In 1990, the NET Team will present a case for moving into the detailed engineering design and prototype testing of NET. Professor Toschi siad that, to succeed, the case will need to show that there is an adequatee scientific bases for the extrapolation to NET and that it is feasible to build a machine with a sufficient reliability and availability to perform the required programme. It will also need to give details of schedule and costs. Construction could start about 1994 and be completed by about 2000.

6. ITER. Turning to ITER, the quadripartite initiative (Europe, USA, USSR, Japan) to produce a conceptual design for the Next Device, Professor Toschi remarked that Europe had succeeded in convincing its partners that the main parameters of NET should act as the starting point for the conceptual design phase of ITER, which is scheduled to end in 1990. The total effort of the ITER partners on this phase of ITER is estimated at about 400 man-years over two and one half years and about $120 million of supporting R&D over the same period.

7. DEMO. The purpose of DEMO will be to provide the basis for assessing the potential of fusion. Professor Toschi emphasized that DEMO will not necessarily itself be economic. In terms of the extrapolation from NET, the

neutron fluence of DEMO will be a factor of five greater, the availability a factor of three and the breeding ratio a factor two. Studies have shown that the critical extrapolation factor is the plant availability and in particular the lifetime of in-vessel components. It is to these critical factors that the NET Programme would be especially addressed.

Questions were put by Dr Benecke, the Chairman, Mr Carruthers and Mr Sweet.

Professor K Pinkau, Director of the Institute for Plasma Physics, Garching, then addressed the Workshop on FUSION AS A SOURCE OF ENERGY: ITS ECONOMICS AND THE ENVIRONMENT

FUSION AS A SOURCE OF ENERGY: ITS ECONOMICS AND THE ENVIRONMENT

1. Introducing his talk, Professor Pinkau explained that he was not personally involved in studying the economics and environmental impact of fusion. He saw his role as one of explaining why the findings of recent studies, in particular the Commission's publication on the Environmental Impact and Economic Prospects of Nuclear Fusion and the ESECOM (Holdren) Report on the Competitive Potential of Magnetic Fusion Energy, are what they are.

2. Professor Pinkau first asked how many different energy systems do we need to develop. At present and for the immediate future, there appears to be sufficient energy. But perceptions of this can and have changed rapidly. R&D policy regarding future energy systems must have a longer time-frame and, to ensure continuity, must act as a buffer against these shorter term changes of attitude. In the distant future, only thermal fission and fission breeders, solar energy and fusion have the scope to provide energy on the required scale. As each has its own special features and drawbacks, all need to be developed.

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3. The path to a fusion power station will be long. Professor Pinkau explained why, in order to minimize the R&D resources required, the scientific and political communities had agreed on a sequential strategy to achieve their goal. In this strategy, the results of each successive step, for example JET, NET, DEMO, need to be evaluated before proceeding to the next. Each step requires about 20 years. The alternative, a crash programme, would be much more expensive and would carry higher risks of failure.

4. Professor Pinkau considered that the European Parliament had a very special responsibility to support fusion, which will require a continuity of political and financial support for each step once it is underway. He also pointed out that, unlike other R&D programmes, the fusion programme exists only on the European scale. Without support at the European level, the development of fusion would cease. It could not continue on a national scale.

The Environmental Impact of Fusion

5. Professor Pinkau considered there to be two fundamental reasons why fusion plants should have only a moderate impact on the environment:

- First, because fusion energy is produced in an oven, not in a reactor. In a fusion plant, the "oven" contains only that quantity of fuel that is required for immediate use (say 1-2 seconds). The energy content of the oven is therefore very small. By contrast, a fission reactor needs to contain the fuel needed for a large part of the life of the system (say 1-2 years).

- Second, the reaction products of fission, ie those derived from the splitting of the nuclear fuel in the fission process and from its irradiation by the fissionneutrons, are radioactive because of the laws of nature. The reaction products of fusion are not radioactive. The radioactivity in a tritium plant arises from the intermediate tritium fuel and from the interaction between neturons and the strucutral materials of the plant. The development of an environmentally benign fusion reactor is, therefore, a question of engineering and materials development aimed at keeping the activiation of structural materials to a low level, and at maintaining a low tritium inventory.

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6. Materials Development. Professor Pinkau illustrated how few of the constituent isotopes of present-day structural materials actually produce long-lived radioactive products as a result of neutron bombardment. The aim of materials development is, therefore, to "tailor" new structural materials, which do not contain such constituents, and whose radioactivity woud decay to such manageabe levels after say 50 years, perhaps even 30 years, that a fusion plant could then be dismantled like any other non-nucear plant.

7. Safety. Professor Pinkau referred to the four levels of safety assulrance defined in the Holdren Report, moving from Level 1, the most desirable to Level 4, the least desirable:

- In a Level 1 power plant, material properties suffice to prevent fatal release.
- In a Level 2 plant, material properties and passive design features are sufficient to make off-site fatalities incredible.
- In a Level 3 plant, passive design features alone are sufficient to make off-site fatalities incredible provided that, for example, the coolant boundary is substantially intact.
- In a Level 4 plant, there events that, if they occur, require active systems to preclude an off-site fatality, and that cannot be made incredible by design measures alone.

The Holdren Report demonstrated that sevel concepts of a fusion pwer plant could fall in Levels 1 or 2. A fission plant, for example, a PWR, is, by its very nature, Level 4.

8. Intruder Dose. Professor Pinkau explained the concept of an "Intruder Dose", as used in the Holdren Report. This is the dose received by a person excavating and living at the site where the waste materials of a fusion reactor had been buried between 100 and 1000 years ago in a "shallow" fashion. The "Intruder Dose" for a fusion reactor would be of the order of 0.22 rem, or even less.

9. Tritium. To prevent the possibility of large-scale impact on the environment of a D-T fusion plant, the active inventory of tritium will be kept as low as possibel and the tritium that is being stored for future use

will be kept separate in a safe vault. In the longer-term, of course, future generations of fusion plant may employ systems that do not require tritium fuel.

The Economics of Fusion

10. Professor Pinkau noted that it had been said by critics of fusion that, as fusion plants will be much more complicated than, for example, PWR fission plants, they will produce electricity at a much higher cost. He referred to the Holdren Report, which had concluded that fusion plants had the potential to generate electricity at costs comparable to those of present and future fission systems, perhaps within a factor of two or three or so.

11. Summing up, Professor Pinkau concluded that it is too early to say whether or not fusion plants would be economically attractive. There are two reasons for this uncertainty: first, fusion will finally have to be costed in the technological and economic world of the more distant future and, second, we do not know now which price we will wish to pay then for which type of energy generation.

There was another round of questions.

Dr RS Pease, Programme Director of the UKAEA addressed the Workshop on MUON-CATALYSED FUSION (sometimes referred to colloquially as 'Cold Fusion').

MUON-CATALYSED FUSION

1. The UKAEA's Culham Laboratory has been working for many years in fusion. Dr Pease explained that, although the laboratory's programme is based essentially on the magnetic confinement route to a fusion reactor, it has always been part of the programme to see whether there are other options that deserve to be examined. Muon catalysed fusion could be one of these alternatives.

2. Dr Pease illustrated the principles of muon-catalysed fusion or "cold" fusion as it is often called. Its chief advantage is that D-T fusion takes place at more-or-less ambient temperatures but otherwise it would have many of the features of hot D-T fusion. He pointed out one of the immediate problems as there is to find a means to increase the low number of fusion reactions catalysed by each muon which would result in a low overall efficiency. The prospects based on today's theory of obtaining sufficiently high catalysis rates are not considered to be very promising. In addition, there is, at present, no reason to suppose that muonic fusion could have significant advantages with respect to costs and environment compared with magnetic confinement systems.

3. The UKAEA Euratom Fusion Association is contributing to an international experiment on muon-catalysed fusion conducted at the Rutherford Laboratory. Dr Pease recommended to keep an eye on research in this field but not to make any substantial investments at the time being. Dr Pease underlined the fact that, at the moment, magnetic confinement research as demonstrated by the JET machine is much more promising.

This was followed by questions.

At 18.30 Hrs the Afternoon Session closed, and the Members of the Workshop proceeded on a visit to the JET laboratories.

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Friday, 13 November 1987, 09.15 Hrs - Morning Session

Presentations by invited experts other than representatives of the European Fusion Programme

The Chairman opened the Session and gave the floor to Mr Colin Sweet of the Centre for Energy Studies, South Bank Polytechnic, London.

Mr Sweet addressed the Workshop (Note: Mr Sweet has been commissioned by STOA to present a study on fusion. An interim version of the study was available at the Workshop. For reasons of length, it cannot be reproduced here. The full study will be published later in the year in the STOA series of documents on fusion).

Mr Sweet emphasized the importance of making an integrated approach to the question of fusion energy. Stating that "fusion is emerging from the laboratory", he said this integrated approach meant taking all the various aspects together: scientific, technological, economic and environmental. He detailed especially the economic questions and the feasibility of estimates based on 'scaling-up' from the experimental to the commercial stages. Commenting that it was a mistake to believe that variable costs would be negligable, he said that at the end of the day it would be the marginal cost of fusion energy which would determine its fate in the energy market place. He noted the argument that in the long run there would only be 3 significant energy sources: fission, fusion and solar, but he thought this was too rigid. Any technology could be uneconomic: it was only economic by comparison with alternatives. This meant that more emphasis should be given to the economic and the management aspects of the question.

Mr Sweet said that before a decision was taken on NET there was a need for a major feasibility study on an inter-disciplinary basis.

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The Chairman called for questions, and there was a discussion involving Dr Maisonnier, Dr Rebut, Mr Turner, MEP, Dr Lawson, Dr Pease, Mr Seligman, Professor Pinkau, Mrs Bloch von Blottnitz, MEP, Mr Metten, MEP, who is the European Parliament's rapporteur on fusion, Mr Sweet and his colleague Dr Jackson.

At the end of the discussion, there was a break for coffee.

The Session resumed at 11.10 Hrs with a presentation by Dr Jochen Benecke of the Sollner Institut, Munich.

Dr Benecke addressed the Workshop (Note: Dr Benecke has also prepared a paper which is printed in the next section of the present document).

In brief summary, Dr Benecke said that in the presentations of the previous afternoon the counter arguments to fusion had not been presented, but there was a need to consider the possibility that controlled fusion energy, which was at present only in the experimental stage, might never prove to be possible or practically viable. The scientific criteria were not the only criteria of practical feasibility, but when other criteria were taken into account, the costs escalated.

Dr Benecke mentioned the view the electricity demand may decline in future with the use of enhanced techniques for energy conservation. He also discussed environmental aspects, stating that in terms of radio activity, as opposed to radio toxicity, fusion would not be very much different from fission. Other topics discussed were the viability of tailored structural materials, cost of size comparisons of fusion and fission reactors and uncertainties about the future energy market.

The Chairman opened a discussion which involved Mr Seligman, Dr Maisonnier, Dr Davies, Professor Pinkau, Professor Toschi, Mr Darvas and Dr Benecke.

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The Chairman called the next speaker.

Professor Konshin of the International Energy Agency addressed the Workshop on international cooperation and ITER. He reported on the 18-19 October meeting at the IAEA in Vienna between the USSR, the USA, Japan and the Europeans. There had been agreement to go ahead with the conceptual design of the International Experimental Reactor (ITER).

There was a discussion involving Mr Seligman, Mr Metten and Professor Pinkau. The Chairman called the next speaker.

Dr Gerald Epstein addressed the Workshop on 'Star Power', the fusion report recently published by the Office of Technology Assessment (OTA) at the US Congress in Washington. (Note: STOA has prepared the following summary based on the OTA report and remarks by Dr Epstein who was the author of the report).

SUMMARY OF "STARPOWER: THE US AND THE INTERNATIONAL QUEST FOR FUSION ENERGY (US CONGRESS OFFICE OF TECHNOLOGY ASSESSMENT, OCTOBER 1987) PRESENTED BY Dr GERALD EPSTEIN, PROJECT DIRECTOR, OTA

Potential Role of Fusion

If successfully developed, nuclear fusion could provide humanity with an effectively unlimited source of electricity that has environmental and safety advantages over other electric energy technologies. However, it is too early to tell whether these advantages, which could be significant, can be economically realized. Research aimed at developing fusion as an energy source has been vigorously pursued since the 1950s, and, despite considerable progress in recent years, it appears that at least three decades of additional research and development will be required before a prototype commercial fusion reactor can be demonstrated.

The Department of Energy (DOE) manages the U.S. fusion program, and its goal is to evaluate fusion's technological feasibility—to determine whether or not a fusion reactor can be designed and built—early in the 21st century. A positive evaluation would enable a decision to be made at that time to construct a prototype commercial reactor. However, this schedule cannot be met under existing U.S. fusion budgets. The DOE plan requires either that U.S. budgets be increased substantially or that the world fusion programs collaborate much more closely on fusion research.

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The Policy Context

The budget for fusion research increased more than tenfold in the 1970s, due largely to growing public concern about environmental protection and uncertainty in long-range energy supply. However, a much-reduced sense of public urgency in the 1980s, coupled with the mounting Federal budget deficit, halted and then reversed the growth of the fusion budget. Today, the fusion program is being funded (in 1986 dollars) at about half of its peak level of a decade agc

The change in the fusion program's status over the past 10 years has not resulted from poor technical performance or a more pessimistic evaluation of fusion's prospects. On the contrary, the program has made substantial progress. However, the disappearance of a perceived need for near-term commercialization has reduced the impetus to develop commercial fusion energy and has tightened pressure on fusion research budgets. Over the past decade, the fusion program has been unable to maintain a constant funding level, much less command the substantial funding increases required for next-generation facilities. In fact, due to funding constraints, the program has been unable to complete and operate some of its existing facilities.

EDITOR'snote :

It should be noted that in the comparative table which follows the Indépendent Path refers to a completely independent pursuit of commercial fusion power by the U.S.A; the Collaborative Path refers mainly to the prospects offered by the quadripartite ITER agreement working under the auspices of the IAEA ; the Limited Path envisages continuing research into the final demonstration of scientific feasibility, with a "not very limited path" possibly including the construction of a Compact Ignition TORUS(CIT);and the Mothballed Path is self explanatory.

Choices made over the next several years can place the U.S. fusion program on one of four fundamantally different paths:

1. The Independent Path

   With substantial funding increases, the fusion program could complete its currently mapped-out research effort domestically, permitting decisions to be made early in the next century concerning fusion's potential for commercialization.

   Advantages: Control over R & D; Energy Supply; Infrastrcture; Stature

   Disadvantages: Cost, Potential Overemphasis

2. The Collaborative Path

   At only moderate increases in U.S. funding levels, the same results as above might be attainable - although possibly somewhat delayed - if the United States can work with some or all of the world's other major fusion programmes (Western Europe, Japan, and the Soviet Union) at an unprecedented level of collaboration.

   Advantages: Cost-sharing; Energy Supply; Improved Technical Base, Foreign Policy Benefits

   Disadvantages: Share control; Obstacles to Collaboration; Cost; Potential Adverse Domestic Impact

- The Limited Path

Decreased funding levels, or current funding levels in the absence of exten sive collaboration, would require modification of the program's overall goals. At these constrained funding levels, U.S. evaluation of fusion as an energy technology would be delayed.

Advantages: Cost; Flexibility; Risk Avoidance

Disadvantages: Delaying Energy Supply; Loss of Direction and Scope; Damage to Infrastrcture, Loss of Momentum and Statutre; Difficulty in Collaboration

4. The Mothballed Path

If fusion research ceased in the United States, the possibility of domestically developing fusion as an energy technology would be foreclosed unless and until funding were restored. Work would probably continue abroad, although possibly at a reduced pace, resumption of research at a later time in the United States would be possible but difficult.

Advantages: Saving Money

Disadvantages: Unavailability of Energy Supply; Destruction of Infrastructure; Loss of Stature; Inability to Collaborate

The Main Issues Concerning Path Choices Are:

Likelihood of Success; Perceived Urgency. Attitude Towards Collaboration; Cost of Research Facilities; Near-Term Benefits; Potential for Surprise.

Findings

Here are some of the overall findings from OTA's analysis:

- Experiments now built or proposed should, over the next few years, resolve most of the major remaining scientific uncertainties regarding the fusion process. If those experiments do not uncover major surprises, it is likely—although by no means certain—that the engineering work necessary to build an electricity-producing fusion reactor can be completed successfully.
- Additional scientific understanding and technological development is required before fusion's potential can be assessed. It will take at least 20 years, under the best circumstances, to determine whether construction of a prototype commercial fusion reactor will be possible or desirable; additional time beyond then will be required to build, operate, and evaluate such a device.
- It is unlikely that major, irreversible energy shortages will occur early in the next century that could only be ameliorated by the crash development of fusion power. There is little to be gained—and a great deal to be lost—by introducing fusion before its potential economic, environmental, and safety capabilities are attained. Even if difficulties with other energy technologies are encountered that call for the urgent development of an alternative source of energy supply, that alternative must be preferable in order to be accepted. It would be unwise to emphasize one fusion feature—economics or safety or environmental advantages—over the others before we know which aspect will be most important for fusion's eventual acceptance.
- Due to the high risk and the long time before any return can be expected, private industry has not invested appreciably in fusion research and cannot be expected to do so in the near future. But, unless the govern-

- It is now too early to tell whether fusion reactors, once developed, can be economically competitive with other energy technologies.
- Demonstration and commercialization of fusion power will take several decades after completion of the research program. Even under the most favorable circumstances, it does not appear likely that fusion will be able to satisfy a significant fraction of the Nation's electricity demand before the middle of the 21st century.

- With appropriate design, fusion reactors should be environmentally superior to other energy technologies. Unlike fossil fuel combustion, fusion reactors do not produce carbon dioxide gas, whose accumulation in the atmosphere could affect world climate. Unlike nuclear fission—the process utilized in existing nuclear powerplants—fusion reactors should not produce high-level, long-lived radioactive wastes.
- One of the most attractive features of fusion is its essentially unlimited fuel supply. The only resources possibly constraining fusion's development might be the materials needed to build fusion reactors. At this stage of development, it is impossible to determine what materials will eventually be developed and selected for fusion reactor construction.
- If fusion technology is developed successfully, it should be possible to design fusion reactors with a higher degree of safety assurance than fission reactors. It may be possible to design fusion reactors that are incapable of causing any immediate off-site fatalities in the event of malfunction, natural disaster, or operator error.
- Potential problems with other major sources of electricity—fossil fuels and nuclear fission—provide incentives to develop alternate energy technologies as well as to substantially improve the efficiency of energy use. Fusion is one of several technologies being explored.

ment decides to own and operate fusion generating stations, the responsibility for fusion research, development, and commercialization must be transferred to private industry at some stage. The nature and timing of this transition are highly controversial.

- Fusion research has provided a number of near-term benefits such as development of plasma physics, education of trained researchers, contribution to "spin-off" technologies, and support of the scientific stature of the United States. However, fusion's contributions to these areas do not imply that devoting the same resources to other fields of study would not produce equivalent benefits. Therefore, while near-term benefits do provide additional justification for conducting research, it is difficult to use them to justify one field of study over another.
- Fusion research has a long history of successful and mutually beneficial international cooperation. If this tradition can be extrapolated in the future to an unprecedented level of collaboration, much of the remaining cost of developing fusion power can be shared among the world's major fusion programs.
- International collaboration cannot substitute for a strong domestic research program. If the domestic program is sacrificed to support international projects, the rationale for collaboration will be lost and the ability to conduct it successfully will be compromised.
- Agreeing to collaborate on fusion research, both within the U.S. Government and between the U.S. Government and potential partners, will require sustained support at the highest levels of government. A variety of potential difficulties associated with large-scale collaborative projects will have to be resolved, and Presidential support will be required. If these difficulties can be resolved, the benefits of successful collaboration are substantial.

There was a discussion involving Mr Seligman, Mr Turner, Mr Metten, Dr Maisonnier, Mr Carruthers and Professor Pinkau. Dr Epstein replied.

The Chairman closed the Session at 13.30 Hrs.

During the lunch break, an informal talk was given by Professor John Davies of Birmingham University on cold fusion.

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Friday, 13 November 1987, 14.30 Hrs - Afternoon Session

After lunch the Afternoon Session began at 14.30 Hrs.

Mr Carruthers, formerly Head of Applied Physics and Technology Division, Culham addressed the Workshop as the first speaker in the Afternoon Session. He considered that statements about the economic prospects for fusion energy were uncertain and premature despite the fact that fusion reactor studies had already been going on for at least 23 years. He expressed doubts about estimated pay-back times, about mass/density scaling and about capital costs+

There was a discussion involving Mr Hancox, Mr Carruthers, the Chairman and Mr MacKerron of the Science Policy Research Unit (SPRU), Sussex University.

Professor José Campos of the University of Madrid then addressed the Workshop. He spoke on areas of spin-off from the fusion programme in other sectors of science and technology, mentioning collision physics, materials science, super conductors, computers, stimulating the search for scarce elements and the quest for very pure materials, etc.

There was a discussion in which Professor Pinkau,, Mrs Bloch von Blottnitz, Dr Maisonnier, Dr Rebut and Mr MacKerron took part.

Mr Linkohr thanked the Director of JET and all the participants. The Workshop closed at 16.00 Hrs.

+An edited version of the contribution by Mr Carruthers is annexed to the present document. It has been edited for reasons of space.

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Edited version of contribution by Robert Carruthers (formerly Head of Applied Physics and Technology Division, Culham)

It is important for the Committee to remember that fusion research started in the UK some forty years ago and reactor studies have been under way for more than 23 years. We have heard about the great progress made in plasma physics, but the result of reactor studies are still given the same cautious qualifications - uncertainty, too soon, difficult to predict the economic environment fifty years hence, fusion is a high capital cost power source but with benefits for which people will pay the price.

To better understand the situation it is necessary for the Committee to appreciate the background to Reactor Studies. This has been an on-going, iterative exercise, through stages shown in Fig. 1. Since the tokamak became so favoured as a research tool for plasma physics Reactor Studies have been pressurised by the question 'Can you build an electricity generating tokamak ?'. (To be used as evidence that the Commission was bearing in mind its avowed long-term objective.) Unfortunately, it was possible to reach an answer 'Yes' after Stage 2 ; but the subjective observation that it looked to be an unattractive engineering proposition did not carry much weight. Only after completing Stage 3 and moving into Stage 4 was it possible to start to quantify the engineering and economic worries.

Fig.2 shows the overall layout of a fusion reactor which was the outcome of studies at Culham - it may be looked upon as a first attempt to meet Stage 3, but it omits several, as yet, unspecifiable features and falls short of many requirements for acceptable operation. Superimposing on this layout the outline of a similarly rated PWR and its housing shows a difference in scale which we felt could lead to a substantially higher capital cost and consequently to a higher cost for generated electricity. Many different approaches have been tried to quantify this difference and try to present it in a way which would clearly indicate the severe problems which cast grave doubts on the prospects of the tokamak ever being developed to the stage of being an economically acceptable power producer.

It was natural to think, initially in money terms - an estimate of the building costs in cash at present worth. There are two ways of approaching this. They may be regarded as 'Top Down' and 'Bottom Up'. The first is, broadly, that behind an early Culham study (1966). Using some simple geometric arguments one arrives at the hardware content of a fusion reactor and the power rating it must have to be 'economic'. There is a well established engineering technique of obtaining a rough cost from data for the

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FIGURE 1

REACTOR STUDIES

1. DEVELOP A BROAD CONCEPT

— Something which can be drawn

2. INTRODUCE SOME PRACTICAL ENGINEERING

— A design which can be built

3. CONSIDER THE LIFETIME PERFORMANCE

— A design which can be operated and maintainec

4. STAND BACK AND THINK

— Will it be economic,
acceptable to a utility operator

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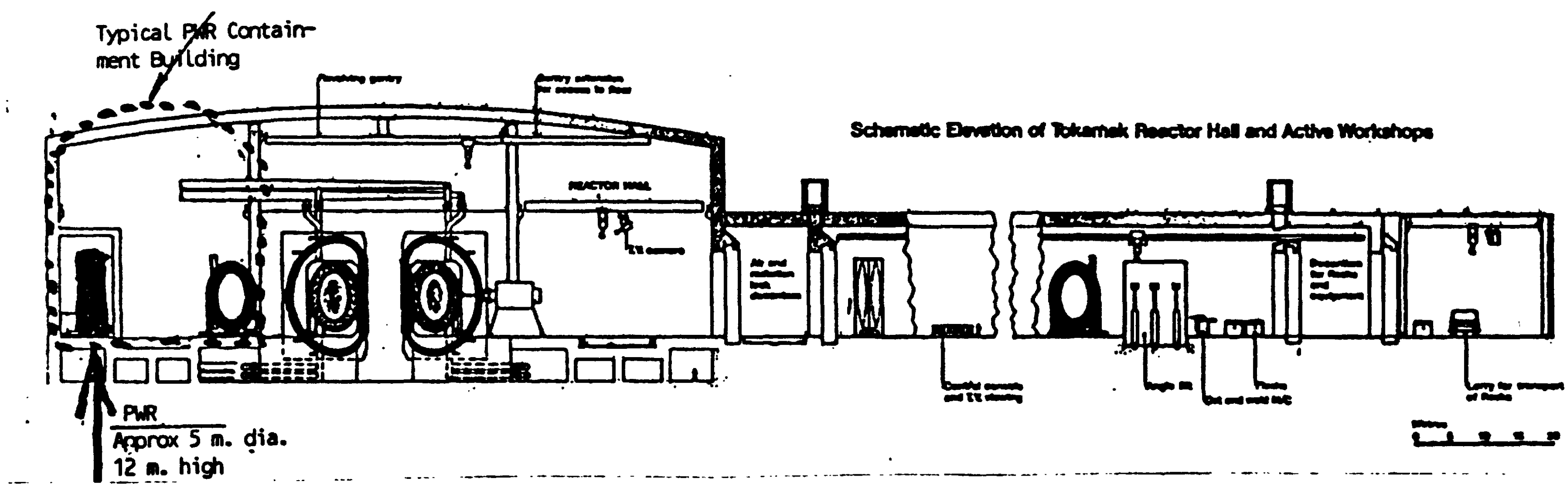
FIGURE 2


Typical PWR Contain-
ment Building
REACTOR HALL
Schematic Elevation of Tokamak Reactor Hall and Active Workshops
PWR
Approx 5 m. dia.
12 m. high

cost/tonne of different types of engineering artefacts and materials. This approach has an advantage that, to a first order, it is not confused by plasma physics: indeed it indicates targets for plasma parameters which ought to be achieved for a reactor to be economic. An important parameter in judging reactor economics is the 'wall loading' - the total nuclear power produced divided by the inner surface area of the torus - expressed in Megawatts per square metre (Mw/m^2). It is interesting to note that this early Culham study- it omitted that which we knew remained to be invented - found that a wall loading of at least 13 Mw/m^2 would be required.

Reactor Studies in the 1970's were, mostly, of the 'Bottom Up' variety. They are based on forward extrapolations based on the best interpretations of current plasma physics knowledge. This has led to reactor designs containing much more detail and so, seemingly, more appropriate for costing on the basis of comparable engineering projects. The in-built constraints - mainly determined by plasma physics assumptions - lead to 'wall loadings' of 3 - 5 Mw/m^2. The consequence is that both capital cost and the estimated cost of electricity generation are higher than 'competitors' costed by the same methodology. The Commission's report suggests '2 - 3 times' and hints that this is 'pessimistic'. It is not. Such a low figure can only be derived from the quoted US study, STARFIRE. This has long been known to be an under-priced study. It has been made so compact that the access for routine maintenance is not considered adequate to achieve the claimed, high availability. An important factor in its costing was some assumptions on the sputter erosion of the 'first wall'. The Surface Physics Group at IPP Garching drew attention to an error of a factor of 10 in an important parameter which would result in an underestimate of wall erosion.

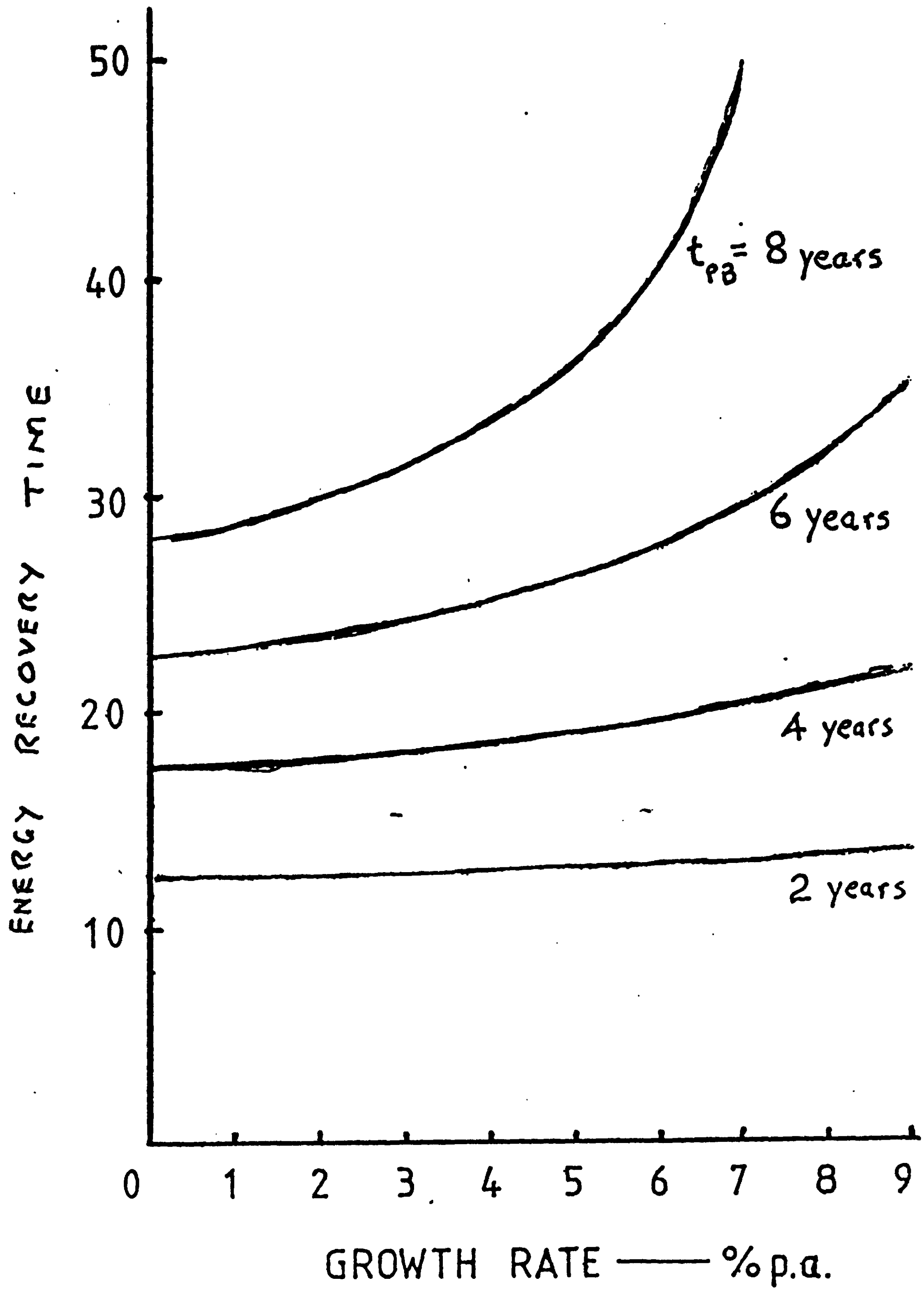
Other costing studies would suggest that the ratio of 2 - 3 is optimistic and that it would be more realistic to anticipate a figure in the range 5 - 10. We had to recognise that costing in money terms was presenting problems. It was not easy to compare different studies - money values changed with time, exchange rates added confusion and some financing conventions varied from country to country.

An alternative approach was the 'energy audit'. This was mentioned in Prof. Pinkau's presentation. He tried to dismiss the pessimistic findings of some energy audits by suggesting that there was no sound reason for scaling the energy content of comparable types of engineering hardware - in terms of Joules per Tonne or Joules per cubic metre. The examples he quoted were misleading and if the extrapolation had been done correctly (as in the studies with which I am acquainted) they would not have supported his argument. He failed to deal with one of main motivations for making the energy audits, which was to try and arrive at a much less controversial way of displaying the parlous future for a tokamak based fusion reactor. We wished to present a picture of 'energy flow' which can be much more instructive than a consideration of cash flow. The results of such a study are shown in Fig. 3. For a single reactor the energy invested in its construction is recovered after it has operated for a number of years, the 'pay-back time' t_{PB}. For a new power source to displace an existing but ageing source there must be a growing rate of installation of the new sources. (7% p.a. represents a doubling in ten years, i.e. if one had 2 working fusion reactors ten years from the start of commercialisation, then one would only have 4 after twenty years - not a rapid rate of re-placement.) As more of the new units are manufactured and installed there is an increasing use of energy devoted to this activity and therefore not available for sale. The 'Energy Recovery Time' is the period for which the system has to operate before the new technology ceases to be an energy consumer and can start to contribute to the country's power needs.

For light water reactors and coal-fired generation the t_{PB} is 2 years or less and it is clear that the 'Growth Rate' may be quite high without affecting the energy recovery time significantly - the system becomes a net energy generator well within a fraction of the design life-time of the plant. The energy investment in building a tokamak type of fusion reactor will be much greater than that for a PWR. A ratio of 3 would be an optimistic minimum, whilst a figure of 5 - 10 is likely to emerge as designs become more realistic. Hence, t_{PB} may be 10 years or more and a tokamak based fusion system would still be a net energy consumer when the first reactors to be commissioned had reached the end of their lives.

It is this consideration of ENERGY FLOW which we consider to be one of the clearest ways of highlighting the dangers of the fiction that '--- even though fusion may prove to be a high cost power source it will offer advantages which people will be prepared to pay for ----'. It is important to keep this point under regular review to be certain that the fusion programme is not at risk of leading to a situation where a progressive construction of tokamak power stations serves only to provide energy for the construction of more tokamaks !.

FIGURE 3



ENERGY RECOVERY TIME
50
40
30
20
10
t_{PB} = 8 years
6 years
4 years
2 years
0
1
2
3
4
5
6
7
8
9
GROWTH RATE —— % p.a.

ALTERNATIVES. The Commission have mentioned the 'alternatives' in the programme. It is important to understand that an 'alternative' in terms of plasma physics is not necessarily an alternative to a reactor engineer. The engineering and economic limitations to the exploitation of the 'conventional' tokamak apply almost equally to the stellarator and to the reversed field pinch

REACTOR COSTS related to COST ESTIMATES FOR EXPERIMENTS.

It has been made quite clear that there is much scope for disputation and equivocation over the cost of a possible tokamak reactor and its chances of commercial acceptability some decades hence. The next stage of experiment (NET, ITER etc.) will be seeking real money and the estimated costs must be expected to come closer to reality. It is clearly right to avoid the wasteful duplication of effort but a major motivation for the internationalisatio of the next stage is the high, anticipated cost (NET @ approx. 3.6 Billion ecu in 1986 money). If the cost of this 'experiment' is to be so high then the future plans should give some indication of the steps whereby the cost of the much larger device, producing economically acceptable power, will be brought below the costs of NET. Vague talk of 'technological progress' and 'cost reduction by replication' are not considered to be engineeringly sound. Mr Sweet, in his presentation, made reference to programme management problems. I should like to close with a quotation which is very relevant to this point.

1970 - Meeting of the APS Plasma Physics Division, Washington DC (November).

Commissioner Theos. J Thompson, "Fusion Power - An Uncertain Certainty".

' The danger in allowing ----- the engineering aspects of CTR to take a back seat to the physics on the mistaken premise that engineering should only be pursued once the physics is completely understood.'

Many engineers who have worked a long time in fusion feel that in 17 years we have striven to change this situation - but with little effect.

Section VI

On the Prospects of Power Reactors based on Nuclear Fusion

Compilation of some Critical Arguments

prepared for

The Scientific and Technological Options Assessment
(STOA) of the European Parliament

by

Jochen Benecke
Sollner Institut, München

February 1988

1. Introduction

Nuclear fusion power has long been advertised as being an unexhaustible, clean and relatively cheap source of energy. None of these assertions seems to be warranted.

It is not possible, of course, to prove that fusion reactors will cause a sizeable release of radioactivity and will exhaust its material resources and the financial resources of the European countries soon. Precise statements on these points must be based on a detailed and definite reactor design which does not exist yet. If a certain material proves to be an obstacle because of limited supply or, e.g., because of neutron-induced radiation one may want to substitute that material by another one. A particular problem may be solved this way - but other problems may aggravate as, e.g., the costs may rise or the resistivity of reactor components with respect to high temperatures may decrease.

This is to explain that there are no simple or quick solutions to the problems listed below and, in particular, there are no technically proven ones.

The problems to be discussed do not touch upon the so-called scientific feasibility. This term designates

> "the proof that, under laboratory conditions a reacting fusion plasma can be confined for a sufficiently long time, and that a positive energy balance can be obtained. It is expected that this scientific feasibility will be demonstrated during the 80s in the large Tokamak experiments now in an advanced stage of construction (JET in Culham, TFTR in Princeton, JT-60 in Tokai Mura)" [1].

Although there is little hope for demonstrating the scientific feasibility during the 80s I am supposing for the following that it will be demonstrated eventually. My criticism deals with the question whether a fusion reactor will ever be suitable for a power station, in other words, it questions the technical an the commercial feasibility.

The definitions of the latter terms, as expressed in the Report of the European Fusion Review Panel [1] are as follows:

> "Technical feasibility, i.e. the proof that the basic technical problems of the fusion reactor can be solved. Examples are: large-scale tritium handling, materials behavior under extreme irradiation stresses, remote handling of very complex machinery and converting the fusion energy, which mainly appears as neutron kinetic energy, into a useful secondary energy form. To demonstrate technological feasibility is the main objective of some very large and expensive devices now under consideration in several parts of the world (NET in Europe, FED in the USA, FER in Japan, INTOR as a joint EC-US-USSR-Japan project) with some hope that for at least one of them construction will start by the middle of the 80's."

> "Commercial feasibility, i.e. proof that fusion power reactors can be built on an industrial scale, can be operated reliably and produce usable energy at prices competitive with other energy sources. Studies have given a wide range of cost estimates which, though higher, do not differ in order of magnitude from the cost of conventional nuclear power, but it is much too early to make a definitive assessment. It appears very unlikely that commercial feasibility will be reached with the generation of devices to be built after technical feasibility has been demonstrated. Rather, at least one intermediate step of 'demonstration fusion power reactor' will be required."

With respect to the technical or commercial feasibility of a fusion reactor, L.M. Lidsky, professor of Nuclear Engineering at the Massachusetts Institute of Technology and former associate director of the Plasma Fusion Center draws the conclusion that

> "even if the fusion program produces a reactor, no one will want it" [2].

This judgment is based on the finding that

> "a chain of indesirable effects ensures that any reactor employing deuterium tritium fusion will be a large, complex, expensive, and unreliable source of power. That is hardly preferable to present-day fission reactors, much less the improved fission reactors that are almost sure to come" [2].

Two of the directors of the Max-Planck-Institut für Plasmaphysik at Garching, F.R.G., express similar views. They state:

> "Tokamaks with superconducting magnetic field coils are scarcely suitable as nuclear boilers in base-load power plants since investment costs are estimated to be high and the degree of availability low." [3]

I want to stress again that the negative judgment does not touch upon the unsettled question whether fusion will work at least in a laboratory scale. In other words, the lacking proof of scientific feasibility is not the origin of the criticism.

Some of the arguments which cast doubt on the technical and commercial prospects of fusion power plants are as follows.

2. Some Critical Arguments

2.1 Resource Limitations

In case of nuclear fusion, there are no fuel limitations. There may arise a shortness of certain materials, though, like beryllium, lead and molybdenum - depending, of course, on the specific reactor design.

In order to achieve a sufficiently high tritium breeding rate an enhancement of the neutron flux in the blanket may be indispensable. In particular, if thin blankets are to be applied for cost and unit size reasons the enhancement of the neutron flux is a necessity. Neutron multipliers like beryllium or lead may do the job - but only for a limited span of time, due to resource limitations. In the literature, a span of 50 years is mentioned [4].

Molybdenum is an ingredient of the stainless steel which is used for the reactor structures in most reactor design studies. Because of rather short lifetime of a sizeable portion of the structures, huge amounts of this steel will be needed, causing shortage of molybdenum in the foreseeable future.

Molybdenum and other ingredients of the steel have an awkward side-effect: The bombardment by fast neutrons causes the steel to become highly radioactive within a short time of reactor operation, see fig.1. The hazard indices for inhalation and ingestion, in comparison to a liquid metal fast breeder reactor (LMFBR), are shown in figs. 2 and 3, respectively. Although fusion has lower hazard indices by about one order of magnitude (i.e. a factor of ten) it is plagued, like fission, with radiation problems.

Consequently, the attempt of avoiding molybdenum shortage by reprocessing of waste steel will be a rather inconvenient, hazardous and costly enterprise.

The problems caused by neutron-induced radiation could be largely reduced by choosing a vanadium alloy instead of stainless steel, see fig.4. Vanadium, though, has the disadvantage of limited resource availability, see table 1. If titanium is used in addition to vanadium, there is only a rather narrow band of acceptable temperatures: Below 250°C, titanium is unacceptable because of a high tritium pickup rate and above 450°C, it undergoes an unfavourable phase transition.

In view of the activation problems, fusion proponents offer the option of isotopically "tailored" structural materials. Until now, however, there are no favourable candidates to substantiate the option, not to mention the problem of finding technically and economically viable routes for producing the "tailored" materials. Conseqently, stainless steel is still the prime candidate in all reactor design studies so far. Another reason for sticking to steel is the long experience and the large data base accumulated with this material.

2.2 Ecological Hazards

Although the activated structures are not volatile - in contrast to many fission products that are produced in light-water reactors and fast breeders - the activation radioactivity still poses a hazard to the public. Pointing to Nukem, Mol and Transnuclear may serve as an argument.

If fusion reactors are to come their fuel will be - at least for the foreseeable future - a mixture of deuterium and tritium. With respect to radio-ecology, tritium is of particular concern. A fusion reactor will probably contain several tens of kg of tritium [5] - not just about 3 kg as stated in the recent report of the Commission of the European Communities [6] . An amount of 10 kg of tritium corresponds to a decay activity of 10^8 Curie or 3.7×10^{18} Becquerel.Tritium is volatile and permeates metal walls easily at temperatures of a few hundred degrees centigrade. If released it forms tritiated water (HTO) which unavoidably enters the biosphere.

Tritium undergoes a rather soft beta decay, i.e., the maximum kinetic energy of the emitted electron is not very high (20 keV). Despite its softness, tritium decay causes damage to cells of a living organism if tritium is incorporated into the body. The damage may be twofold:

a) Direct breaking of chromosomes by ionizing irradiation; each damaged cell may be the germ for a cancer to develop

b) The "doppelgänger" role.

Usually the dosimetry for tritium does not take its "doppelgänger" hazard into account: When incorporated as HTO by plants and animals it is not only retained in cell fluids but will also get bound in organic molecules. A discussion paper for last year's European Conference on Radiation and Health summarizes some of the effects as follows [7]:

> "This organically bound tritium (OBT) has the capacity to cause much greater biological damage than HTO. For instance, in their tritiated forms, leucine (a protein precursor), uridine (RNA precursor) and thymidine (DNA precursor) are, respectively, approximately 10, 100 and 1000 times more toxic than HTO [8]. In the case of newly formed embryos, tritium thymidine is 5000 times as damaging as HTO [9]. This is because OBT is better biochemically 'embedded' in the organism, and because it has a far longer biological half-life* than HTO: between 400 and 600 days, as compared with 10 days for HTO (the highest value, 600 days, is for brain DNA [10]).(The) ICRP (recommendation) 30 [11] chooses to neglect the effects of OBT and bases its recommendations on a biological half-life of 10 days for all tritium."

*The biological half-life is the time elapsing before half the incorporated radionuclide has been eliminated from the body.

The ecological and the health hazards posed by tritium deserve further study. My impression is that this field of research has not been adequately dealt with in the laboratories associated with Euratom. History of technology teaches us not to just believe the following statement made by the Commission [6]:

> "... fusion would provide a safe power source with a very small environmental impact on the public during normal operation or even following a major reactor accident."

This statement is based on the most severe accident identified - there may well be others. Moreover, the asserted maximum dose of 60 to 80 mSv (6 to 6 rem) at a distance of 1 km from the plant has been estimated under the assumption that HTO is the most hazardous form of tritium - OBT has not been considered.

2.3 Economic Prospects

I will be brief here since a recent report from the Max-Planck-Institut für Plasmaphysik lists the main critical arguments[4]. This report by D. Pfirsch und K. H. Schmitter of December 1987 has been sent to the STOA Project and to the rapporteur for the European Parliament, Mrs. Undine Bloch von Blottnitz, MEP.

At first sight, an economic assessment of an installation that can only be built in about 50 or 100 years may appear bold or impudent. There is a way, however, to estimate the cost of a fusion reactor by comparing its construction principles to that of a fission reactor. This comparison yields a costing of the fusion plant relative to the known costs of present-day fission plants. The result does not speek in favour of the fusion reactor: Its cost was estimated by Pfirsch and Schmitter to exceed the one of a fission reactor of equal power output by at least a factor of ten.

This kind of cost estimate was questioned by R. Toschi, head of the NET team, at the STOA Fusion Workshop at JET last November. Toschi claimed that there exist new cost estimates for NET and the fusion reactors to come that are much more precise than the ones by Pfirsch and Schmitter and yield costs of the order of magnitude of that of a fission reactor. Unfortunately, Toschi was not willing to present the mentioned new cost estimates. A check of his group's figures was not possible, therefore.

The result of Pfirsch and Schmitter is based on the following arguments:

The volume of the nuclear boiler of a fusion reactor will roughly be a factor of 100 larger than that of a fission (pressurized water) reactor, see fig. 5. The difference in volume (packed with complex and expensive equipment) is reflected in the difference in cost of the respective nuclear boilers.

The difference in volume is caused by the much lower power density of a fusion reactor as compared to a fission reactor. This in turn is caused by a limitation in permissible temperatures and thermal stresses of the so-called first wall, and by plasma physics constraints.

Pfirsch and Schmitter also stress the point that, due to the complexity of the plant, a fusion power reactor will have a rather low availability. By sheer unit size, such a reactor will be a base-load plant; on the other hand, it must be expected to be so unreliable that it can never be used as a base-load plant.

The report by Pfirsch and Schmitter [4] also proves that the economic assessment of the Commission report [6] is without any justification. It is based on

- false logic
- false or uncheckable data
- unsuitable methods of cost estimation.

3. Conclusion

Despite the fact that it is unknown how and when a fusion reactor will function physics-wise, a cost estimation can be done already at present days. This is due to the fact that the conversion of neutron kinetic energy into a useful form of energy (heat, then steam, then electricity) will be accomplished by conventional technology. Its cost is known, at least relative to the cost of a fission reactor.

The technology needed for a fusion reactor will be highly complex. By basic principles, its complexitiy is different from, e.g., the complexity of a modern airplane to which it was compared in [6]. The difference is explained in [4]. The high complexity stipulates a low availability of the plant.

The technical and economic prospects of a fusion reactor are extremely dim. The discovery of the new high-temperature superconductors does not change the picture.

With respect to radioactivity, one would be better off with fusion than with fission, but not by much. The problems associated with tritium are far from being understood.

In view of the fact that uranium can be gained from sea water the fuel abundance of fusion is not much of an advantage over (conventional light-water reactor) fission technology.

Plasma physics is certainly a worthy field of scientific research. This does not imply that plasa physics will eventually lead to useful fusion power plants. It is always possible to question and scale down or stop the mission of producing a fusion power plant without destroying plasma physics research.

For the development of a sustainable source of energy we do not have much time to loose. It appears to be imprudent to base one's hopes on fusion power reactors. A much saver and rewarding route is the development of techniques for efficient utilisation of solar energy.

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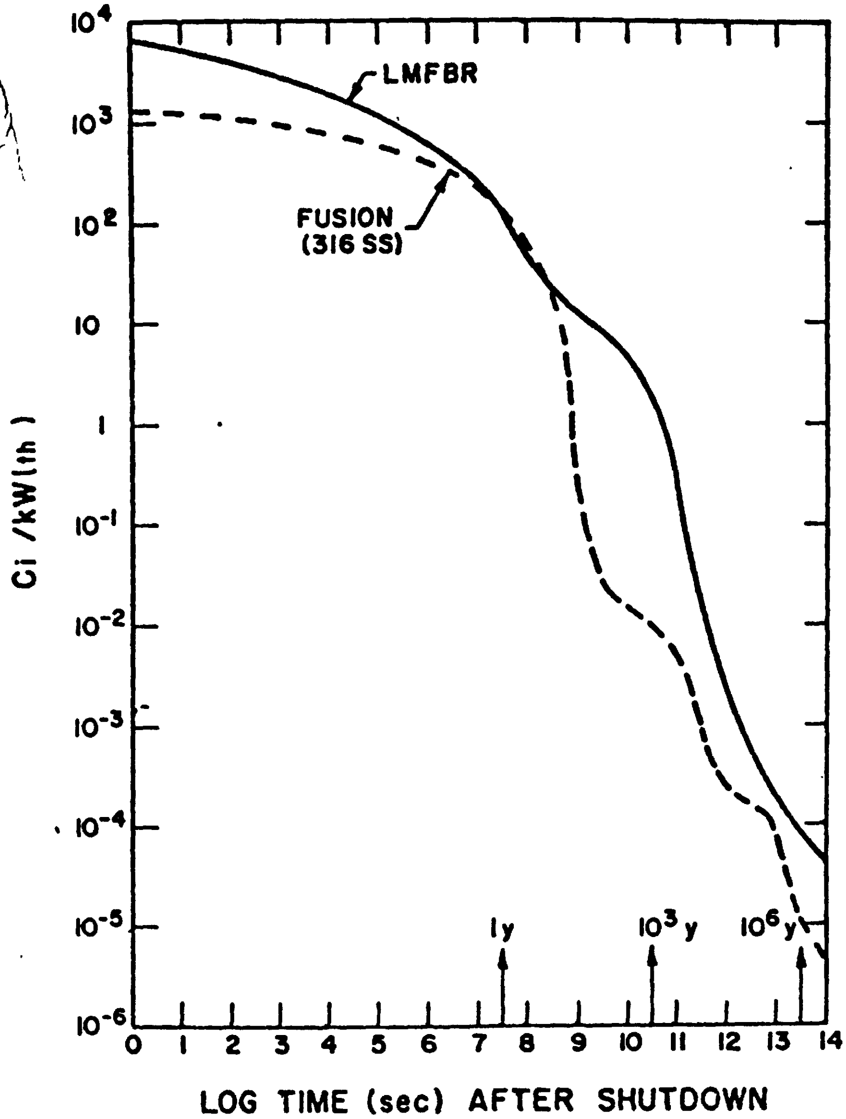
Table 1

Criteria for Selecting First Wall Materials† in Fusion Reactors in General Priority Order

Criteria	Favored Materials	Less Favored
1. Radiation Damage and Lifetime		
a. Swelling (Dim. Stability)	Ti, V, Mo, SS	Nb, Al, C
b. Embrittlement	C, Nb, V, Ti, SS	Mo, Al
c. Surface Properties	V, Ti, Al, C	SS, Nb, Mo
2. Compatibility with Coolants and Tritium		
a. Lithium	Ti, V, Nb, Mo, SS	(Al, C)*
b. Helium	SS, Ti, Mo, Al, C	(Nb, V)*
c. Water	SS, Al, Ti	(C)*
d. Tritium	Mo, Al, SS	Ti, V, Nb, C
3. Mechanical and Thermal Properties (Irradiated)		
a. Yield Strength	Mo, Nb, V, Ti, SS	Al, C
b. Fracture Toughness	SS, Ti, Al	V, Nb, Mo, C
c. Creep Strength	Mo, V, Ti, SS	C, Al, Nb
d. Thermal Stress Parameter $\left(M \equiv \frac{2\sigma_y k(1-\nu)}{\alpha E}\right)$	Mo, Al, Nb, V	Ti, SS, C
4. Fabricability and Joining	SS, Al, Ti	Nb, V, Mo, C
5. Industrial Capability and Data Base	SS, Al, Ti, C	Mo, Nb, V
6. Cost	C, Al, SS, Ti	Mo, Nb, V
7. Long Lived Induced Radioactivity	V, C, Ti, Al	SS, Nb, Mo
8. Resource Availability (U.S.A.)	C, Ti, Mo, Al, SS	Nb, V

† Alloys. Ti-6Al-4V, V-20Ti, TZM, Nb-1Zr, 316 SS, Al-6061. This is an illustrative list.

* Materials in parenthesis are unacceptable with stated coolant.

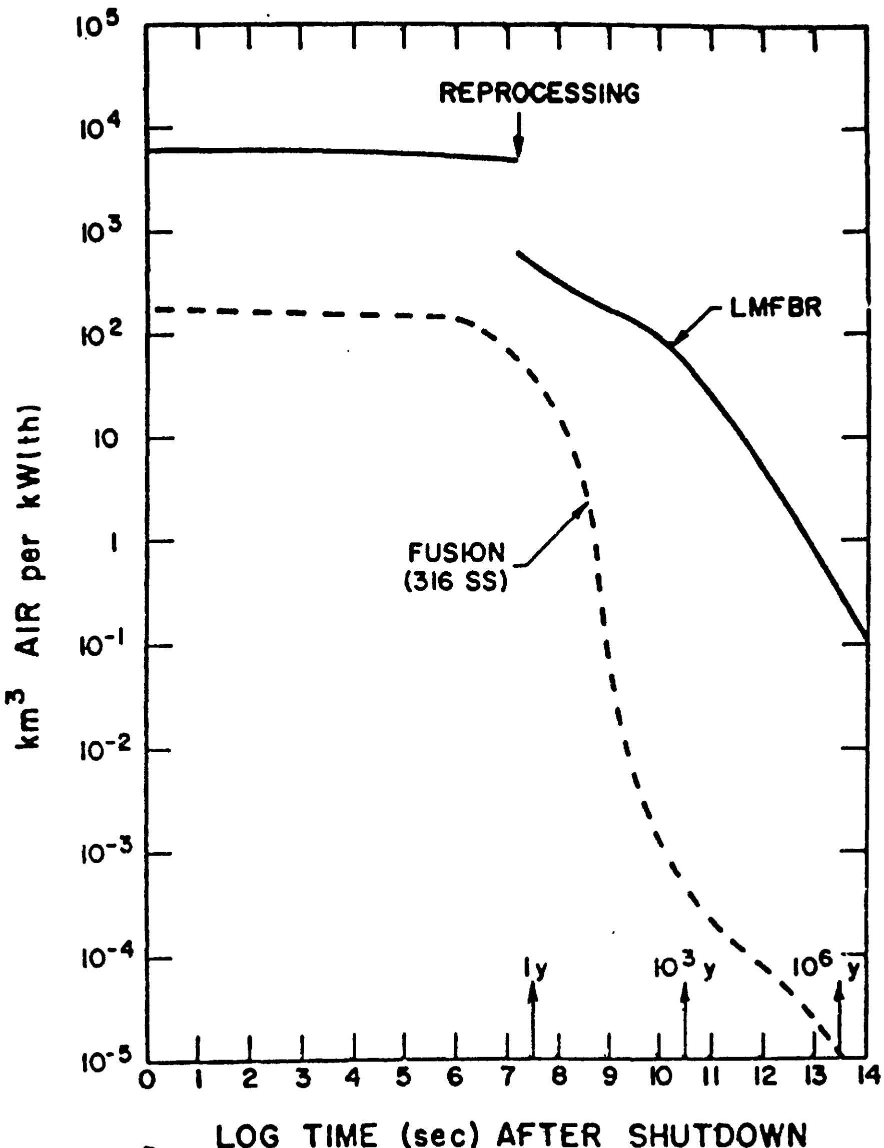


Ref. [12]

Figure V-18: Comparison of Radioactivity Inventory For Fission and Fusion Reactors With SS 316 Structure

LMFBR = Liquid Metal Fast Breeder Reactor

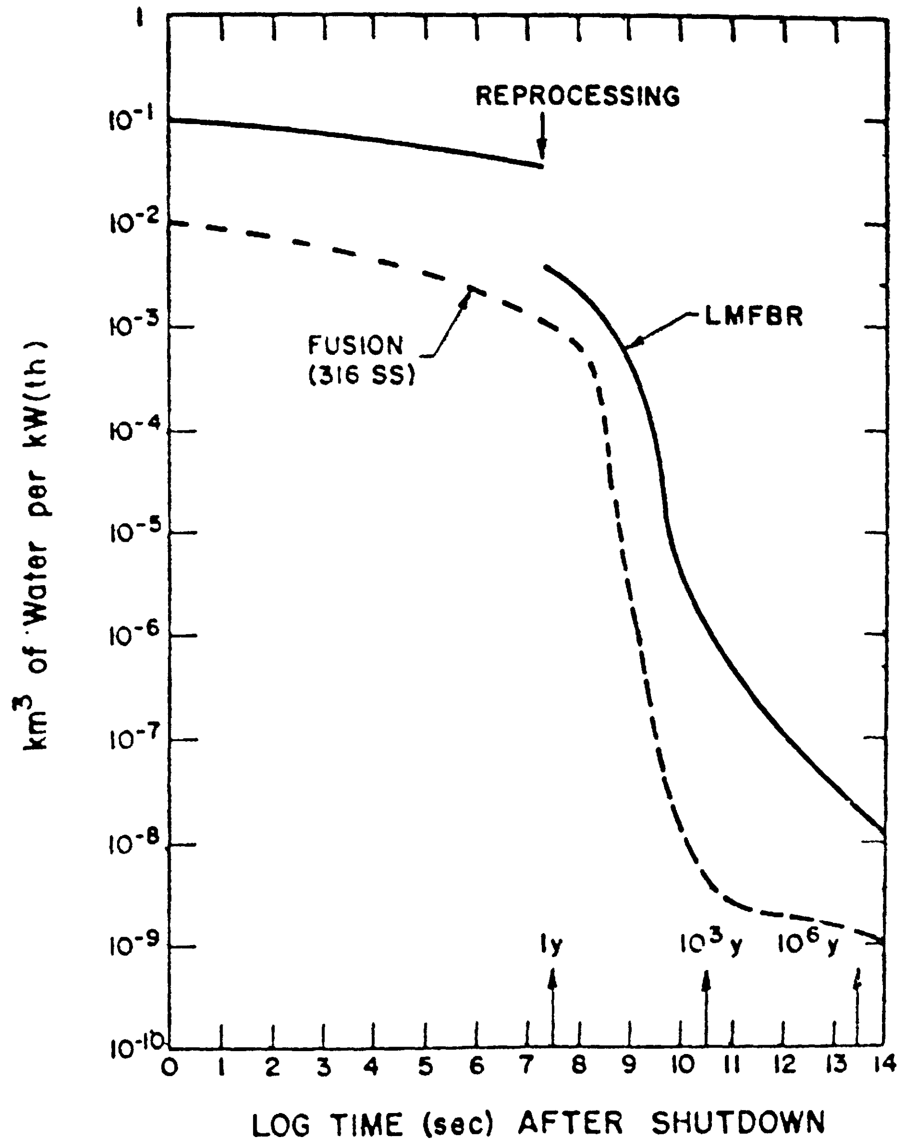
Fig. 1



Ref. [12]

Figure V-19: Comparison of Inhalation Hazard Index of an LMFBR and a D-T Fusion Reactor with SS 316 Structure

Fig. 2



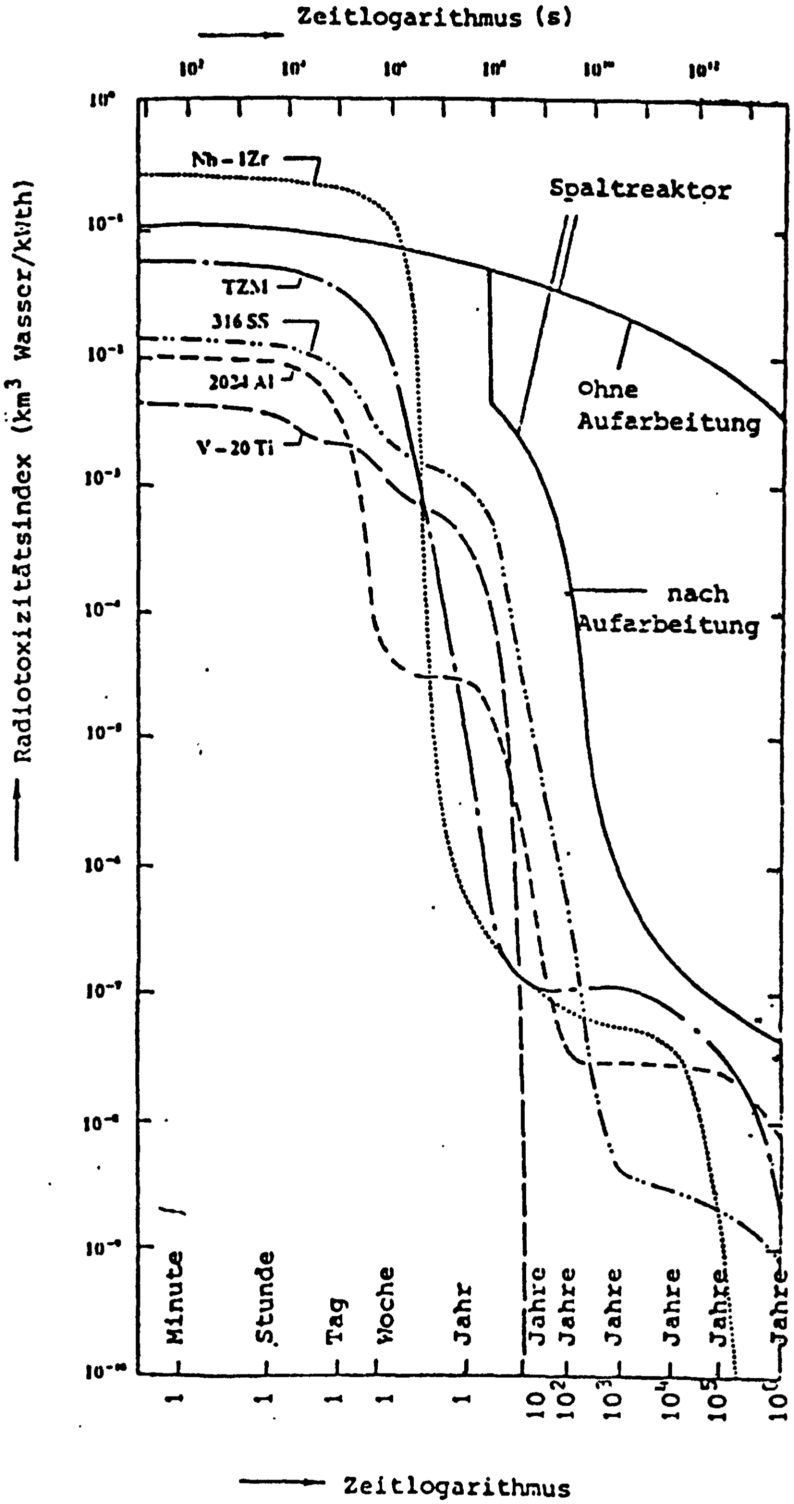
Ref. [12]

Figure V-20: Comparison of Ingestion Hazard Index of an LMFBR and a D-T Fusion Reactor with SS 316 Structure

Fig. 3

Nach: W. Häfele et al.,
IIASA RR-77-8

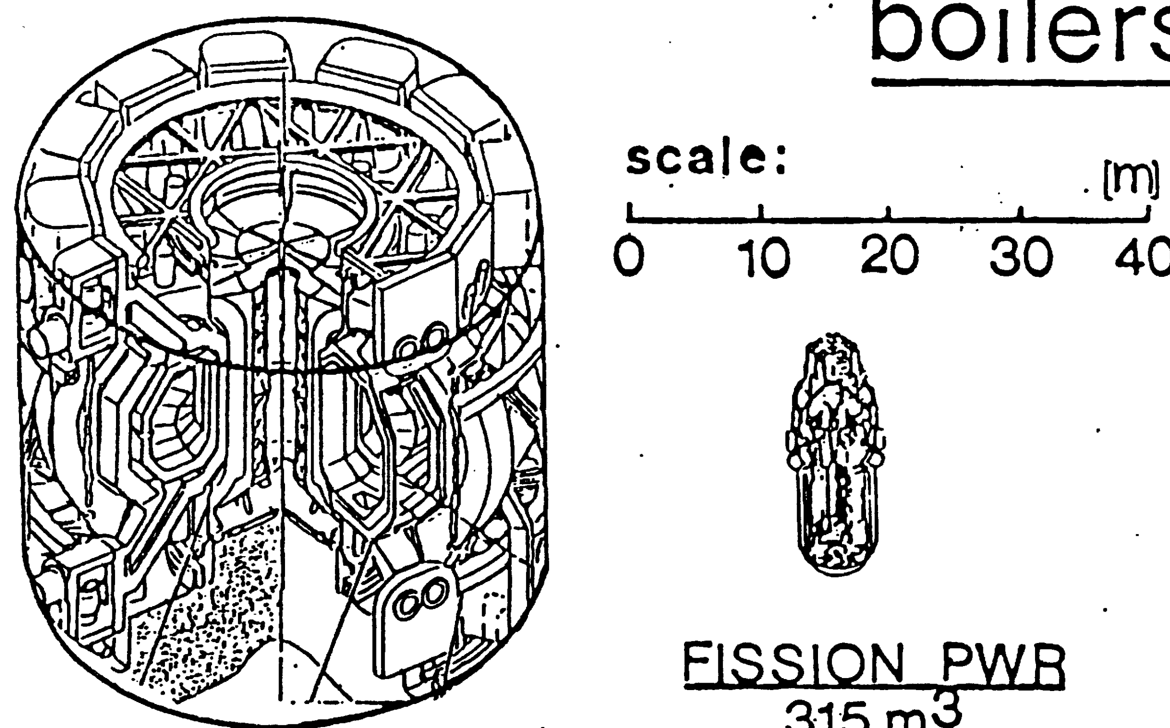
und: B. Brandt et al.,
ECN-79-126



Vergleich des Radiotoxizitätsindex des jährlichen Abfalls eines Brutreaktors (durchgezogene Linien) und verschiedener Fusionsreaktormodelle in Abhängigkeit von der Zeit nach Entnahme des Materials aus dem Reaktor.

Fig. 4

Envelopes of 3.7 GW_{th} nuclear boilers



FUSION TOKAMAK
~35.000 m^3
First Wall Life: 10 years

FISSION PWR
315 m^3

Ref. [4]

Fig. 5