The Fusion Technology Programme of the European Community

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The European Fusion Programme is essentially based on the magnetic confinement approach and is constituted by the fusion research activities in the Member States of the European Communities, the associated programmes of Sweden and Switzerland, the JET Project and the contributions made by the Community Joint Research Centre.

The Programme is adopted by Decision of the Council of Ministers of the European Community for five-year periods (with a revision every third year). The last programme Decision, covering the period 1982-1986, provides for a substantial increase of effort in the fusion technology area.

The emerging reliance on cooperative projects, brought about by the increasing investment cost of large machines and the European decision to concentrate on the Tokamak as the main line of research, has led to the focusing of attention on the Technology needs of the 'Next' device. This is taken to be a Tokamak though, as elsewhere in other world programmes, the possibility of the 'Demonstration' reactor being based on an alternative line is not ruled out. Europe's Next Step machine is to be the Tokamak, NET.

As with the other partners in the IAEA workshop on INTOR, much work has been carried out in national laboratories on INTOR-like studies and these have pointed to the long development time needed in certain areas of fusion technology, either because of technical problems 'per se' or because of the envisaged regulatory delays in establishing a working demonstration of an ignited thermonuclear plasma.

The European Fusion Technology programme, currently being implemented within the period 1982-86, will be based on the needs of the NET device as outlined by the NET Design Team recently established at the Euratom/IPP Fusion Association's Garching laboratory near Munich in south Germany.

The needs of the Programme are seen to be covered by the principal topic areas as follows :

- Superconducting Toroidal and Poloidal Field Coils
- Tritium and Refuelling Systems
- Breeding Blankets
- Remote Maintenance Operations
- Irradiation Studies on Materials
- Safety and Environment Impact Studies

The paper to the Conference seeks to give a balanced overview of the programme of research within the laboratories associated with the programme - outlining the achievements so far and the orientations for the future.

I. Introduction

The Fusion Programme of the European Atomic Energy Community (Euratom) is adopted by a Decision of the Council of Ministers of the European Community. This follows a Proposal⁽¹⁾ of the Commission for a 'Research and Training Programme in the field of Controlled Thermonuclear Fusion'. The Programme runs for five years with a revision normally being undertaken at the end of three years : it is thus a 'sliding programme'.

The Programme is implemented by the research carried out in the national laboratories, and other institutions of the member States, active in the field. Contracts of Association are drawn up between the Commission and competent bodies of the member States, and also of Sweden and Switzerland which have joined their fusion activities to the Community programme. For the construction and operation of JET, the Joint European Torus, a Joint Undertaking has been set up.

The Commission's financial appropriation is used to support the fusion programmes of the Associations, and for the funding of the JET Joint Undertaking.

The fusion programme of Euratom's own Joint Research Centre at Ispra is wholly funded by the Community.

2. The European Programme

The European fusion programme, essentially based on the magnetic confinement approach, officially started in 1959. As can be seen from the Map (Fig. 1), all the Institutions active in this field throughout Europe have joined the programme since then.

The magnetic confinement programme is concentrated on toroidal systems and particularly the Tokamak, though as in other world programmes an appropriate level of research is maintained on 'alternative lines' such as the Stellarator and Reversed Field Pinches.

The Commission receives advice on the planning, preparation and implementation of the Fusion Programme from the Consultative Committee for the Fusion Programme (CCFP), having representatives from each member State and from Sweden and Switzerland. Studies of 'Next Step' devices and principally the IAEA INTOR Workshop, have highlighted the importance of technological developments in addition to the ongoing plasma physics activities of the Associations. The Recommendations of the European Fusion Panel,⁽²⁾ published during 1981, suggested that the rather modest past efforts in technology should be strengthened in the future by identification of long term development projects. These should be decided with particular reference to the needs of the next European Tokamak, NET.

To this end the CCFP recommended the setting up of a Fusion Technology Steering Committee, to assist in the establishment of the NET design team and to plan and assist in implementation of the technology programme independently of the physics programme.

3. Fusion Technology

The Programme Plan has identified six prime areas of technology having the greatest dependence upon NET requirements. These are :

Location of fusion laboratories in Europe

Fig. 1

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- Superconducting Toroidal and Poloidal Coils (Magnetics)
- Tritium and Refuelling Systems
- Breeding Blankets
- Remote Operations and Maintenance
- Irradiation Studies and the Development of Fusion Materials
- Safety and Environmental Impact Studies.

Other important technologies, e.g. plasma heating, are by definition part of the physics programme.

The topics mentioned above constitute the basis of the programme oriented towards the needs of NET. The NET Design Team established at the German Max-Planck-Institute for Plasma Physics (IPP) at Garching near Munich, although only recently set up, has been able to benefit from the work of its predecessor, the NET organization which supported the European delegation to INTOR. The head of NET has remained unchanged.

The topics listed above are addressed in order. The discussion will deal with the programme objectives in the light of NET (and INTOR) studies and the precise components of the 1982-86 Technology Programme to which the Associated laboratories have responded by offering to undertake one or more of the listed tasks.

4. Elements of the Technology Programme being undertaken by the Associated Fusion Laboratories

4.1 Superconducting Toroidal and Poloidal Magnetic Field Coils

A toroidal field coil for a machine of the size of NET will represent an investment of the order of \$ 40 Million. A development programme leading to the provision of a number of such coils must seek to minimize the risks in final construction where this may have to be undertaken at the site itself and with no full field tests prior to installation. This difficulty has been realized by all the main world fusion programmes and the Large Coil Task (Annex to the IEA Implementing Agreement for a Programme of Research and Development on Superconducting Magnets for Fusion Power) is a significant step in the evaluation of toroidal field (TF) coils.

Two of the coils to be assembled at the US Operating Agent's site at Oak Ridge (ORNL) are coming from Europe. One of these is an independent contribution from Switzerland (started before this country became associated with the fusion programme of the European Community) and the other is the 'Euratom' Coil, supported by the European Community and now the largest single project under the auspices of the Technology part of the programme. The LCT assembly with coil size about one third of the linear dimensions foreseen for NET coils and with a maximum field of 8 Tesla (T) (instead of 12 T), will not give answers to all the problems of the toroidal field system for the next step Tokamak. Experience of operating a fully instrumented Tokamak equipped with superconducting coils will be provided only partly by the French TORE-SUPRA Tokamak now under construction at Cadarache.

Poloidal field coils pose different problems in their design and construction. The poloidal field coils although included in the one generic term actually fulfil four distinct functions; the provision of the vertical field necessary for maintaining the

plasma at constant radius, the horizontal field for stabilizing the plasma in a vertical direction, divertor action and that change of vertical flux needed to drive a plasma current.

For the provision of Tokamak fields the technology programme has decided on two intermediate objectives; the construction and test by 1991 of a NET size TF coil and the solution of the problems associated with the manufacture of poloidal field (PF) coils including the provision for them to be manufactured actually at the NET site.

The tasks for the laboratories of the Community are considered to be well defined in the toroidal field coil area; i.e. the support of the LCT project and the delivery of the coil to ORNL, a wide range of developments on superconductors and cooling methods, the building of a high field test facility and subsequently the proof of candidate materials selected for making the prototype NET coil.

For the PF coil systems the situation is not so clear and INTOR assessments find that studies even worldwide are 'inadequate'. The European programme intends to assess the two PF coil options defined by the INTOR studies, to make a choice of cable suitable both for the central Tokamak ohmic heating (OH) coil and for the large (EF) ring coils and to make a model coil for testing the chosen option.

4.2 Tritium and Refuelling Systems

The approach to problems associated with tritium handling and supply systems for the NET device has been difficult because of the existence in two member States of tritium 'know-how' which, however, was not freely available under the conditions of Euratom Association contracts. With the need to furnish a system for the later stages of JET operating with tritium, and to develop the tritium system for the Next Step, a programme of research is now being initiated in which the priority problem areas can be examined with the help of experts and with the participation of laboratories having relevant expertise.

The motivation for the programme is similar to that which led to the setting up of the tritium laboratory (TSTA) at Los Alamos (LASL) in the United States, namely, the need for a technical demonstration of the processes involved, the safety aspects of tritium handling techniques and licensing procedures.

The main features of the programme, which will be implemented in the 1982-86 period, with the needs of NET in mind, comprise : the 'fuel clean-up' system, tritium recovery, tritium accounting systems, atmospheric air clean-up and the development of tritium compatible hardware components for use in tritium fuel circuits and vacuum systems.

Each of these areas have particular problems which need experimental development of a systematic kind.

4.3 The Breeding Blanket

The inclusion of this 'multiple technology' topic in the fusion programme at an early stage was endorsed by the Fusion Review Panel on the basis of its long term importance and its three essential functions in the fusion reactor : tritium breeding, energy transfer and shielding of the magnet system.

The evaluation of the tritium breeding capacity is a key issue and a breeding ratio in excess of unity is essential in view of the prospects of having sufficient tritium only for a relatively short start-up cycle. Yet, a blanket reference design by the NET team is a first necessity in order to get a realistic evaluation.

The choice of a breeding material itself is still unresolved. All facets of the subject have common areas of interaction with parallel technologies, thus the behaviour of tritium (extraction, permeation ..) is involved, as is the materials problem involving thermal cycling (fatigue, stress corrosion etc..) and magnetics (shielding of superconductors, insulators etc..).

The laboratories concerned with this work are those of the Fusion Associations which have traditionally been connected with fission reactor and radio-chemistry processes.

4.4 Remote operations and maintenance

Remote or automated operations of a certain kind are now well advanced in those areas of industry where repetitive multiple actions have to be carried out and where reliability and cost effectiveness is of prime importance. Most of these functions have in the past been performed manually and the task had become well defined, and refined, before automation took over more or less smoothly. The tasks were of a repetitive nature; machines could 'learn' from 'operator experience'.

In fusion technology, 'hands-on' work will be specifically denied, yet the operations, even if foreseen, may never have been performed by man and are unlikely to be of the repetitive kind. They may, in fact, never have to be performed at all !

Thus the tasks in this area cannot be predetermined in advance of the machine design and remote operations and maintenance techniques will have to be devised at each stage of evolution by the appropriate division of the NET organization. In turn the design of NET itself will be strongly influenced and even determined by remote handling requirements.

The NET design team will incorporate remotely operated equipment for routine operations, (diagnostics manipulation etc..) and for special operations and maintenance. More difficult will be the provision of machines to handle accidental occurrences, repairs and finally the dismantling, deactivation and sealing of the plant at the end of its active life.

European industry has, however, been alerted to the needs of the programme and a European Industrial Seminar was held in 1982 in conjunction with the University of Milan and close cooperation with industrial interests will be maintained during the early stages of the NET design.

4.5 Fusion Materials and Irradiation Studies

This is a rapidly evolving part of the programme, of very extensive range and objectives. It has the greatest importance for, and interaction with, the design of NET. Because of its topicality this subject is given comprehensive treatment at the SMIRT Conference.

The problem of finding suitable materials for building a fusion reactor exemplifies the situation where the solutions applicable to NET will not be capable of extrapolation directly to the later needs of fusion reactors. For NET, presently existing materials will have to be used, but additional data on their properties in the fusion environment are necessary for the design. But for the long term, new alloys and insulating materials, optimized for fusion reactor requirements, will have to be specially developed.

While materials testing fusion reactors are not available, the ideal method of performing radiation damage studies appears to be by means of an intense 14 MeV source, but a large source of this kind has not yet been constructed for fusion research use and so a wider strategy has been developed by the European Community in conjunction with other nations participating in the 'Implementing Agreement for a Programme of Research and Development on Radiation Damage in Fusion Materials' - again under the auspices of the IEA. This Agreement has two main tasks :

- Annex I : 'the design, development, construction and preparation for use' of the Fusion Materials Irradiation Test Facility (FMIT) at Hanford, USA (Operating Agent, USA).
- Annex II : 'joint irradiation experiments, development of correlation procedures and establishment of a common pool of relevant data' (Operating Agent, Euratom).

During 1983 FMIT has been subject to an international assessment, the outcome of which cannot be anticipated at the time of writing this summary.

In the absence of sources providing high fluencies of fusion neutrons, added emphasis has been given to the full utilization of other radiation facilities (e.g. fission reactors) for examining materials under irradiation. The European programme embodies much work in support of this Annex to the Agreement, the range of materials considered extends from alloys for the first wall and blanket structure to graphite, ceramics and other materials specified for the NET machine.

European laboratories having experience in fission reactor materials development have extended their facilities to provide 'in pile' experiments on swelling, radiation creep, fatigue, and crack-growth. In order to standardize techniques and allow simulation experiments to be correlated a number of specimens of a specially selected reference alloy are being exchanged for assessment in European and US materials testing reactors.

Recently, accelerator based simulation techniques have improved greatly. Simultaneous radiation damage and helium implantation effects can be accomplished by dual beam systems and so accelerators are also considered valuable tools for first assessments of irradiation behaviour, particularly of alloys not containing nickel for which the appropriate He/dpa ratio cannot be obtained in fission reactors.

A part of the European programme is therefore associated with accelerator based investigations on martensitic and manganese steels, alloys of vanadium, titanium and molybdenum.

4.6 Safety and Environmental Aspects

The safety problems are mainly related to the use of tritium, to the activation of the structure of the device, to the large lithium inventory and to the stored energy in the electrical and magnetic circuits.

A serious assessment of the risks of operating fusion plant, based on accident analysis, can only be made when designs become frozen and thus much of this responsibility will fall upon the NET design team.

Europe's small programme in this area is divided between those topics which are clearly for the attention of Next Step designers and those which are less specific in nature and which can be handled without having precise design details. Of this category the following have been identified for early study : the assessment of release mechanisms and the determination of source terms for releases of tritium and activated products to the environment, dose-rate calculations and a survey of European regulations for handling and transporting tritium and activated products.

Accident analysis is considered to be a NET design responsibility, while Waste Management, being heavily dependent upon the processes being developed in the Tritium and Blanket programmes to be carried out in radiochemical laboratories and industry, should be assumed to be part of those same developments.

5. The Cost of the Fusion Technology Programme

The total appropriation of the Commission for the Technology Programme (1982-86), is about 52 Mio ECU. It represents an overall volume of activity within the Associations of about 144 Mio ECU, the level of support ranging from 25% (general support) through 45% (for special or capital projects) to 100% for some industrial developments. The total represents a considerable increase over previous programmes.

6. Conclusion

In this summary the main topics selected for priority treatment within the Fusion Technology part of the 1982-86 European Community Fusion Programme have been briefly dealt with according to their importance. With the exception of materials, this importance reflects the development needs of that particular technology for the NET design. The NET design team will continue to be the main source of information leading to the proper orientation of the overall programme of research leading to the construction of the NET device.

References

- (1) Proposal for a Council Decision adopting a research and training programme (1982 to 1986) in the field of controlled thermonuclear fusion : Commission of the European Communities, COM(81) 357 final.
- (2) Report of the European Fusion Review Panel: Commission of the European Communities, SEC(81) 1933.