The European fusion programme is clearly oriented towards the useful application of fusion energy. This objective has been declared in many Council decisions: "The long-term objective of this action, embracing all the research activities undertaken in the member states and in Switzerland aimed at harnessing fusion, is the joint creation of prototype reactors for power stations to meet the needs of society: operational safety, environmental compatibility, economic viability."[1] For the 5th Framework Programme the Commission's proposal for fusion R&D specifies that ongoing research shall be continued with the aim of developing the capacity to plan an experimental reactor, as is presently pursued in the Engineering Design Activities programme of ITER. The proposal further states that research shall continue to improve the basic concepts of fusion devices, and prepare in the longer term by research into technology the plan for the demonstration reactor DEMO

[1] European Commission's proposal for the 5th Framework programme

The EU Fusion Programme

Hardo Bruhns
DG 12, European Commission, Brussels, Belgium

A central issue for economic growth, prosperity and the quality of life in the industrialized world is the availability of secure, sustainable and financially competitive sources of energy. Given the expected growth in energy demand in the future, even with vigorous measures for energy savings, use will need to be made of all potential energy sources (*see Fells, chapter 1*). Strategic considerations favour the development of energy sources that offer greater sustainability and have less impact on health and the environment.

Nuclear fusion, for which the fuel source is virtually limitless in quantity, could in the long term be an important option in this energy mix. For developing this option, fusion R&D is a key facet of the European Commission's proposal for the Euratom Framework Programme which will last from this year until 2002 (the proposal has been presented to Council together with the 5th-Framework Programme for Community Research that covers the same period).

The proposal has been structured into four thematic programmes. The fourth theme, Preserving the Ecosystem, addresses the closely linked areas of energy and environmental research. It has been foreseen that just over 21% of the proposed 16.3 billion ecus of the entire 5th Framework Programme will be needed for this theme. This consists of about 14.2% for non-nuclear activities and 7% for fusion and fission (the final percentages and overall amount for the Framework Programmes proposed by the Commission are still subject to a decision in the coming weeks).

Development of the Programme

The creation of the European Atomic Energy Community (Euratom) in 1957 was the starting-point for the European fusion programme. The long time-scale needed and the large effort involved in the development of fusion were already apparent in the early stages of research. This led in 1958 to the declassification of world-wide magnetic confinement fusion research—it was previously to a large extent kept secret by the countries involved—and led to a strong international collaboration.

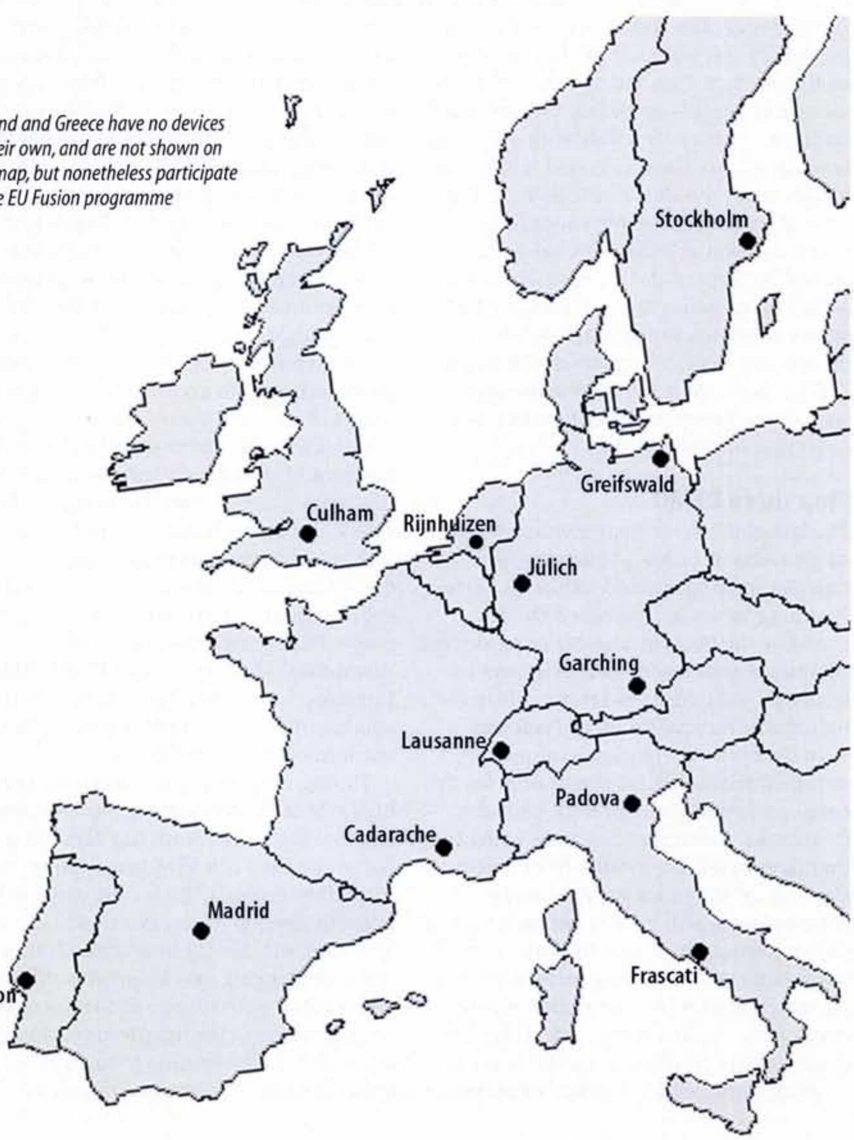
In an international situation where strong fusion programmes were existing in Russia and the United States, it was decided that the then six European countries of the European Community would join all their efforts in fusion, and collaborate on research on magnetic confinement. Contracts, known as 'association' contracts, were concluded between Euratom and national institutions in member states that were active in magnetic confinement fusion. And the Community Fusion Programme was charged with running activities to 'keep-in-touch' with other approaches to fusion, in particular inertial confinement.

Today, all EU member states have institutions actively participating in the fusion programme—all states except Greece participate through 'association' contracts. The Community's own Joint Research Centre (JRC), which has institutes in various locations, also undertakes work for the programme. Switzerland is fully associated to the programme (as Sweden was before it had become a EU Member State). Associations were established in Finland (1995) and in Austria (1996) after enlargement of the Union took in these countries.

The associations are the backbone of the fusion programme. They operate a number of fusion devices in their laboratories (*see map*). Most of these fusion devices have been built along the tokamak principle, but there are also stellarators and reversed field pinches. And there are a

EU Fusion Devices

name	location	objective	major/minor radius (m)	current (MA)	magnetic field (T)	power/ radius (MW/m)	operational from
Tokamaks							
JET	Abingdon, UK	integrated high performance operation, DT operation	2.96/1.25	7	3.45		83-
TORE SUPRA	Cadarache, F	long-pulse operation in Next Step relevant conditions	2.40/0.75	1.7	4.5	9.3	88-
TEXTOR 94	Jülich, D	plasma/wall interaction, heating and exhaust, pumped divertor	1.75/0.48	<0.8	3.0	4.6	83-
ASDEX-Upgrade	Garching, D	poloidal divertor, plasma purity control in reactor relevant topology	1.65/0.50	<1.6	3.9	<16	91-
FTU	Frascati, I	confinement at high density and high current, high power wall studies	0.93/0.31	<1.6	8.0	8.5	90-
TCV	Lausanne, CH	high-beta studies and disruption control	0.88/0.24	<1.2	1.4	5.1	92-
COMPASS-D	Culham, UK	high-beta and MHD stability studies, poloidal divertor type shaped plasma	0.56/0.21	0.35	2.1	4.5	89-
ISTTOK	Lisbon, P	MHD activity, transport	0.46/0.09	0.01	0.5		93-
MAST	Culham, UK	tight aspect ratio tokamak physics with hot plasmas, disruption avoidance	>0.6/>0.5	>1	0.5	<10	98-
Stellarators							
WENDELSTEIN 7-X	Greifswald, D	modular cryogenic coil system to study fully optimized HELIAS in hot plasmas	5.5/0.55		3.0	3-7	2006-
WENDELSTEIN 7-AS	Garching, D	modular coils, plasma behaviour in an optimized magnetic configuration	2.0/0.20		2.5	2.4	90-
TJ-II	Madrid, E	flexible stellarator, helical magnetic axis for confinement and high-beta studies	1.5/0.20		1.2	2.9	97-
Reversed Field Pinches							
RFX	Padova, I	largest RFP device, to study the reactor prospects for this concept	2.0/0.48	<2.0			91-
EXTRAP-T2	Stockholm, S	medium-sized RFP; shell, stability and transport studies	1.24/0.18	0.5			94-



Finland and Greece have no devices of their own, and are not shown on this map, but nonetheless participate in the EU Fusion programme

number of facilities for technological development such as large superconducting-magnet-testing facilities.

At the end of the seventies it was decided to build, under the name of the JET Joint Undertaking, a fusion device (a tokamak) of much larger size than any fusion experiment existing at the time. JET, the Joint European Torus, located at Abingdon in the UK, began operation in 1983 and has become the flagship of the whole EU fusion programme (*see Keilhacker and Watkins, chapter 4.4*).

Around the same time the Next European Torus team (NET) was established and given the task of enhancing the programme's activities on safety and the environment, concentrating on the preparation (in particular the engineering and technological side) of the next-step experiment beyond JET.

The NET team has become the pivotal-point for initiating and coordinating R&D in fusion technology, as well as for Europe's contribution to the Engineering Design Activities of the International Thermonuclear Experimental Reactor (ITER EDA) which was established in 1992 by the EU, Japan, Russia and the US.

Staff and Finances

Fusion research means working at the forefront of many high-technology areas—the physics of the hot plasma core, surface physics, high-power microwave equipment, materials research, the technology of high-field and high-current superconductors, to name only a few. The European programme involves the work of about 2000 physicists and engineers (including around 250 PhD students) in the associated laboratories at JET and the JRC. A large number of university groups participate in the programme and industry is involved in the construction of specific equipment and, with increasing importance, in developing new technologies relevant to fusion. The DG 12 of the European Commission in Brussels is in charge of the central management of the programme.

The activities of the programme are jointly funded by the national associates and by Euratom. Generally, activities are supported by Euratom at 25%. A system of preferential support at a rate of about 45% is used to foster investment in the construction of devices or equipment of particular Europe-wide interest to the programme. At JET about 10% of the annual budget (currently 78 million ecus) is being shared among the national partners in the associations, 10% is borne by the host, the UKAEA (United Kingdom Atomic Energy Authority), and the remaining 80% is provided by Euratom from Community funds. But since the JET Joint Undertaking will finish at the end of 1999, a possible use of the facilities by the associations during the period 2000-2002, and a new agreement, are presently being considered. Overall, the annual expenditure of the programme is close to 500 million ecus, to which Euratom contributes about 40 to 45%.

Step one JET

Three logical steps are intended to lead to the ultimate-goal of the programme. In the first step JET is the representative experiment. It is currently the largest and most powerful experiment world-wide and the only one which can operate with deuterium-tritium fuel.

The R&D strategy of the Community Fusion Programme has been successfully based on the interaction between teams working on a number of specialized devices, with JET serving as a large central device. The specialized devices, located at associated institutions, can explore solutions to specific problems, and do so more flexibly and cost-efficiently than would be possible with the large central device at JET (and furthermore they provide an excellent development and training setup). The team at JET can then integrate and validate these solutions (such as the poloidal divertor for plasma and energy exhaust recently installed at JET) at parameters close to the ones of the core of a future fusion plant.

This synergy has led JET to world-records in fusion power production, led to the development of high-performance operation scenarios, elucidated fusion physics and established reactor-relevant technologies. In return JET is giving orientation for the work on the specialized devices and is stimulating dedicated experimental and theoretical R&D.

Step two ITER

Progress with the tokamak concept, to which JET has made key contributions, has made it possible to address the next-step in fusion, which aims for a long-pulse-burning fusion plasma.

World-wide sharing of expertise and cost was agreed among the four large fusion partners—the EU, Japan, Soviet Union (now Russia) and the US—and led in 1992 to the engineering design of such a next-step device, ITER (*see Parker, chapter 4.3*).

The objective was to design a device that could demonstrate the scientific feasibility of fusion by achieving a controlled and sustained fusion burn, and to contribute to the development of technologies needed for a real fusion power station. The ITER Final Design Report was presented in January 1998. The report provides a complete, fully integrated design for the device, analyses which demonstrate that it can be safely and reliably operated, and cost studies from industry which show that the total estimated costs have remained within the targets set at the start of the EDA. At the time of writing [November 1998] a three-year extension of ITER EDA has been signed by three of the four parties (*see editorial*). In response to the tightening budgetary situation, which requires looking for less-expensive alternatives to the large ITER, a new aim is to redefine the objectives of the device in order to arrive at a reduction in cost and size.

Step three DEMO

The last of the three steps involves testing all elements of fusion physics and technologies in an integrated fashion. A corresponding future device, called DEMO, would be the first one capable of producing significant amounts of electricity and so would provide the basis for the construction of commercial prototype reactors.

In order to alleviate some of today's stringent technological constraints for the core of a fusion plant, present concepts (tokamaks, stellarators, *etc.*) are being further developed. The results from a next-step device with a long-pulse-burning fusion plasma will have significant impact on our view on how best to progress with improvements in the long term. A continual watch is kept over new and revived developments, which are undertaken for their features in physics and technology.

Work is pursued in the European programme on the tokamak concept (for advanced operation scenarios and variants like the spherical tokamak), the stellarator and also the reversed field pinch (RFP) which are sufficiently akin to the tokamak to benefit mutually from research, although the level of advancement is still lagging behind the main-line tokamak, which is the only one for which a burning plasma device can be envisioned today.

Conceptual improvements will become essential for an optimal approach to DEMO, and will provide much information on the operational range accessible to fusion devices, thereby helping to develop next-step operational aspects.

The progress of fusion physics towards a detailed, viable concept of a fusion power station has increased the importance of technological research. Fusion technology for the next-step, comprising the most basic elements of technology needed for a fusion reactor, has focused in the recent past with increasing industrial participation on superconducting magnet development and, in the field of nuclear technologies, on remote handling and tritium technology, yielding viable solutions for an experimental reactor. For the longer term, towards DEMO, essential aspects on which efforts will concentrate are blanket technology (for producing the necessary but radioactive tritium fuel from lithium in the reactor itself) and materials R&D for low-activation structural materials.

An essential aspect of the programme is to optimize R&D in view of the ultimate goal. For this purpose European fusion reference designs have been established taking into account the requirements of a fusion power station. They are being improved and updated as needed in the light of new developments. Based on this work a comprehensive study of the safety and environmental aspects of fusion has been undertaken which demonstrates the attractive safety and environmental characteristics of fusion power (*Safety and Environmental Assessment of Fusion Power* EURFUBRU 12-217/95, June 1995). This effort is being continued and is complemented by socio-economic studies on fusion.

During the past decade, there has been a high rate of progress and comprehensive engineering design work has been carried out under the ITER EDA programme. Inevitably, however, the further steps to be taken to develop fusion as a practical energy source will add up to several decades and a challenging development is still needed for making fusion one of the few energy sources which in the long-term could make a significant contribution to satisfy the growing electricity demand of society.