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Fusion Energy

Moving Forward

Spin-off benefits from Fusion R&D

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FOREWORD


Philippe Busquin

Fusion is the powerhouse of the universe. It is the energy source of the sun and other stars. For environmental reasons, the extent of the world's dependence on the burning of fossil fuels for the supply of energy now appears to be unsustainable in the medium to longer term. Fusion is one of the alternative options for the future supply of energy and harnessing the power of fusion on earth will bring benefits for all mankind.

The goal of European fusion research is to demonstrate the feasibility of fusion as a future energy option to meet the needs of a growing world population. The abundant and widespread fuel resources, the inherent safety aspects, and the environmental friendliness of fusion are all reasons why Europe and the large nations of the world are pursuing its development as a possible future energy source.

Achieving the aim of making fusion a viable energy source requires a sustained long-term research effort. Due to the scale of the undertaking and the need for expertise in a wide range of disciplines, it is being conducted as a joint effort by the EU Member States. The successes achieved to date show that we are ready to demonstrate the scientific and technical feasibility of fusion by a further major experiment that is essentially the 'core' of a fusion power station. Collaboration is now taking place on a global scale on the possible construction and operation of such an experiment. Together with its international partners, Europe is engaged in the planning of the large next-step fusion device ITER.

The underlying basic science, plasma physics, and a whole range of supporting technologies have advanced in leaps and bounds in the co-ordinated work on fusion R&D. A major benefit has been the degree of co-operation on both a European and on a world level. This has evolved to a higher degree than in any other field of scientific or technological research, providing a valuable model and a precedent for the internationalisation of R&D in other areas.

Attainment of the goal of fusion power is an exciting and stimulating challenge. Along the way many of the leading-edge technologies involved have been pushed to new limits and in many cases the innovative solutions to the challenging problems have found applications far beyond the bounds of fusion. There are already numerous examples of spin-offs with other applications in industry, providing real solutions to real and current problems. The exploitation of spin-offs from the technologies developed within the fusion programme is of significant benefit to European society. Examples of spin-off successes resulting from development work in the fusion programme, past and present are highlighted in this brochure.

A feature of the European Fusion Programme is the constant knowledge transfer between the Programme and industry. ITER, however, is an exciting new challenge promising a wealth of additional spin-off opportunities for those involved. The purpose of this brochure is to stimulate interest in the exciting challenges in fusion R&D and to provide guidance on where to obtain help and information on the exploitation of potential spin-offs. Large companies, many of which may already have experience of operating on an international stage, would be involved in ITER. Small and Medium Sized Enterprises (SME's), many of which may previously only have had experience in a more limited area of operation, would also be involved either directly or indirectly as subcontractors of larger companies. Involvement in a major international project on the scale of ITER would bring benefits from the enhancement of the international profile of the company, of particular relevance to SMEs.

Philippe Busquin
European Research Commissioner

INTRODUCTION


Alain Vallée

The long-term objective of the EU Fusion Programme is the harnessing of fusion energy leading to the construction of prototype fusion power plants. The principal focus of the fusion research is on confining and heating plasmas using strong magnetic fields. It is conducted within the European Atomic Energy Community (Euratom) multi-annual framework programmes and the work will continue in the Sixth Framework Programme.

Fusion has a number of key aspects that make it attractive for the large-scale production of electricity: no greenhouse gases are produced and the system has inherent safety features. In addition, the raw materials required for the fuel are available in abundance everywhere. These combined advantages give fusion the potential to make a substantial contribution to future world energy demand.

Fusion R&D have been part of the Community research programme since the inception of the Euratom Treaty in 1957, in which it is listed as one of the areas of research to be supported by the Community. It has also been included in all five Research and Technological Development Framework Programmes. All the EU Member States and the third states associated with

Euratom (Switzerland since 1979 and Bulgaria, the Czech Republic, Hungary, Latvia, Romania, the Slovak Republic and Slovenia since 1999), participate in the European Fusion Programme through Contracts of Association between the relevant research units and Euratom.

In 1999 a new agreement was established to accommodate the evolving requirements of fusion R&D: the European Fusion Development Agreement (EFDA), which is a framework contract between Euratom and its usual partners in fusion (the Associates). It includes three activities:

- technology activities carried out by the Associations and by European industry;
- the collective use of the Joint European Torus (JET) facilities; and
- European contributions to international collaborations such as ITER.

Since 1992, the Next Step activities have been focused on ITER. The original Engineering Design Activities (EDA) phase of ITER commenced in 1992 and was concluded in July 1998. It was followed by a three-year extension in which three of the parties (EU, Japan, Russia) participated.

The successful completion of the ITER Engineering Design Activities has made it possible to move towards the realisation of the Next Step, in line with the reactor orientation of the Community activities on fusion energy research. International negotiations are in progress on the possible joint implementation of ITER (construction, operation, exploitation and decommissioning). Subject to a positive outcome of the negotiations, a specific decision could be sought in the period 2003-2004, effectively enabling construction to start during the period 2005-2006.

Alain Vallée
Senior Vice-President Framatome – ANP
Chairman of the CFI

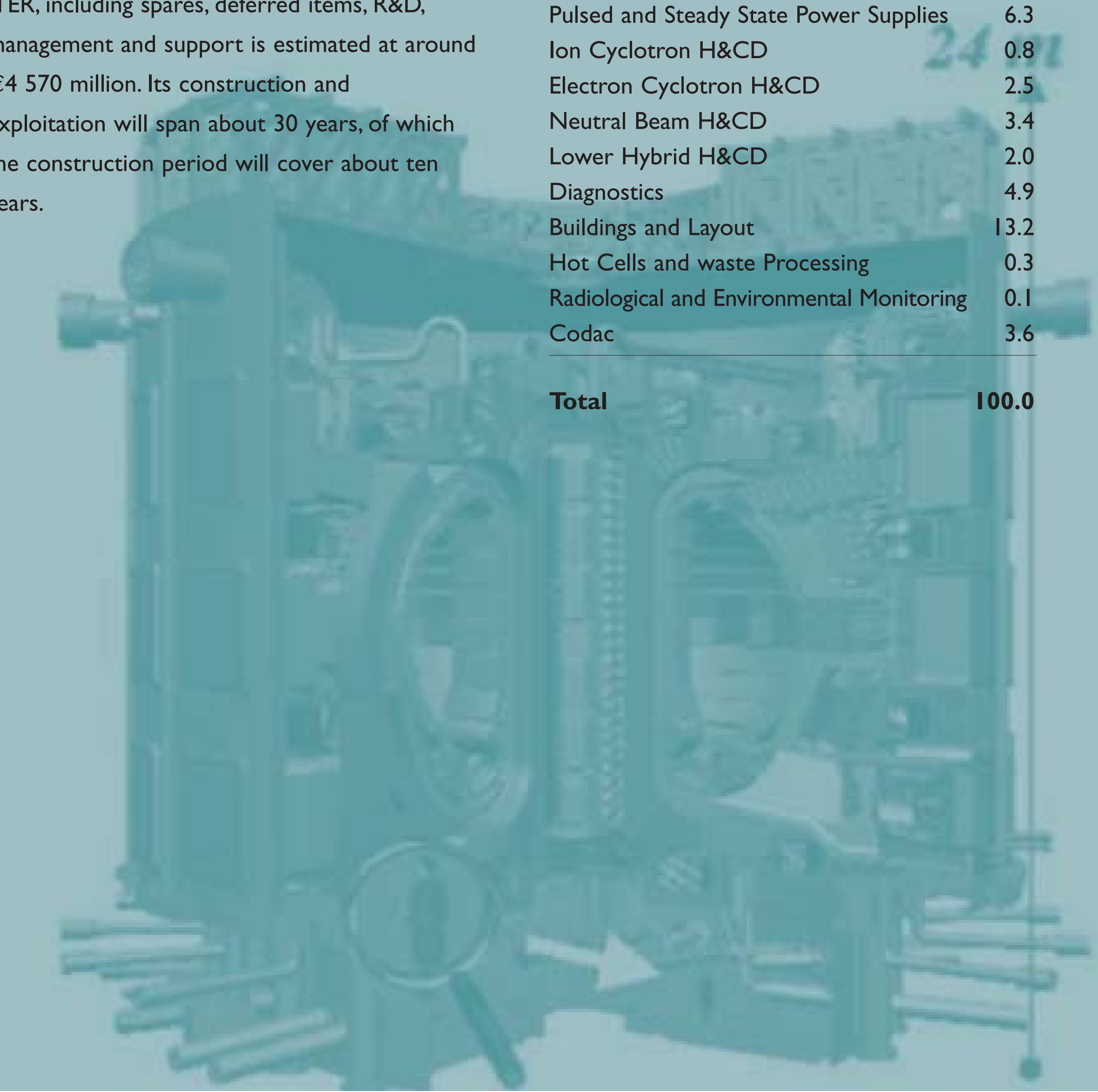
THE ITER PROJECT

ITER is an international collaborative project for a Next Step fusion device for the demonstration of the scientific and technological feasibility of fusion energy for peaceful purposes. ITER will demonstrate extended energy production, essential fusion energy technologies in an integrated system and will perform integrated testing of the key elements required to use fusion as a practical energy source. ITER, based on the "tokamak" concept, will be the first fusion device to produce 500 MW of thermal power, similar to the level of a commercial power station.

The estimated total cost for the construction of ITER, including spares, deferred items, R&D, management and support is estimated at around €4 570 million. Its construction and exploitation will span about 30 years, of which the construction period will cover about ten years.

The following table provides the breakdown (in percent) of the total cost among the various systems/components.

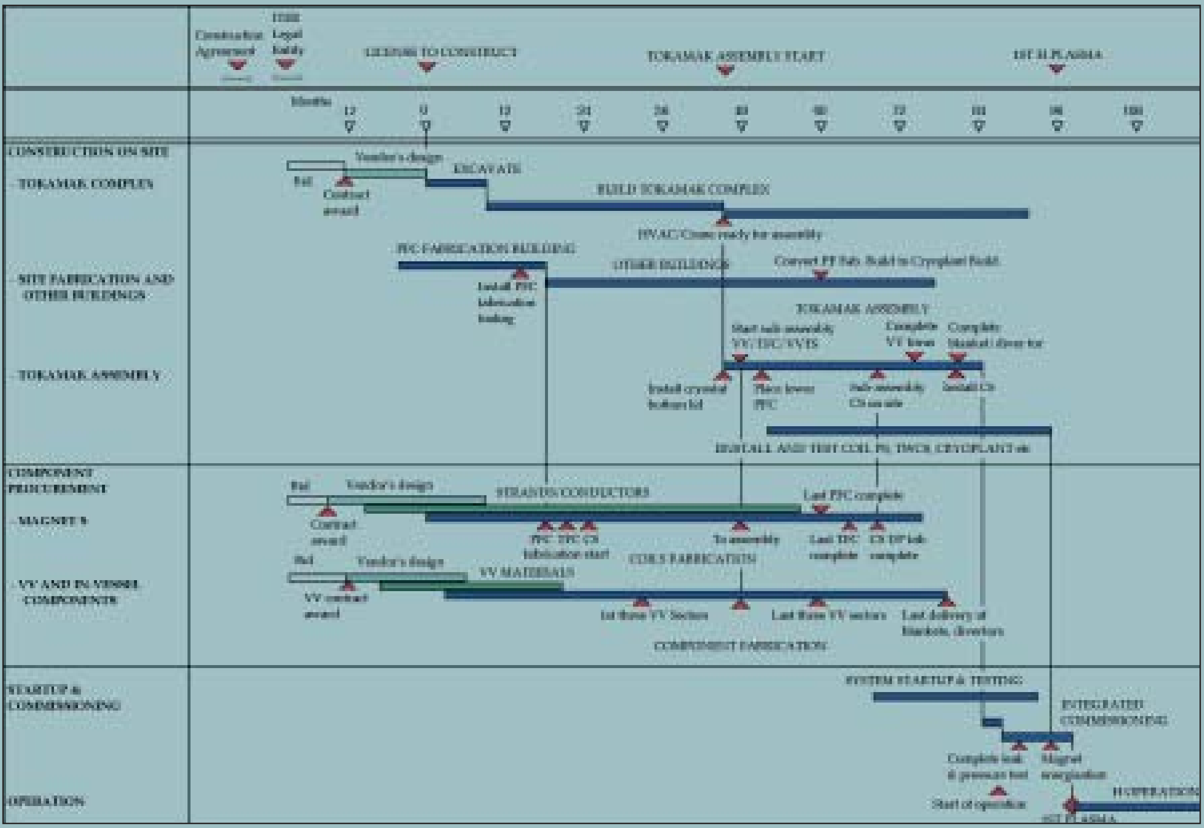
System/Component	**Percentage/Total**
Magnets	29.3
Vacuum Vessel	6.0
Blanket	4.9
Divertor	3.2
Assembly Procedure	2.7
Remote Handling	2.9
Cryostat	2.2
Cooling Water	4.3
Thermal Shields	0.8
Vacuum Pumping and Fuelling	1.2
Tritium Plant and Detritiation	2.3
Cryoplant and Cryodistribution	3.0
Pulsed and Steady State Power Supplies	6.3
Ion Cyclotron H&CD	0.8
Electron Cyclotron H&CD	2.5
Neutral Beam H&CD	3.4
Lower Hybrid H&CD	2.0
Diagnostics	4.9
Buildings and Layout	13.2
Hot Cells and waste Processing	0.3
Radiological and Environmental Monitoring	0.1
Codac	3.6
Total	**100.0**



The project time schedule depends on a number of assumptions such as site selection and the licensing procedure.

An ITER Joint Implementation Agreement (JIA) is being negotiated between Canada, Euratom, Japan and the Russian Federation. The ITER legal entity (ILE) will be established after the JIA is ratified within each Party.

The overall schedule, shown in the following figure, is given in months from the date when the actual construction work for the tokamak buildings is started.



TECHNOLOGIES ASSOCIATED WITH FUSION R&D

Fusion R&D encompasses a wide range of technologies. The ITER project will be a major engineering undertaking on the scale of the construction of a large commercial power plant. There will be large-scale industrial contributions in conventional civil, mechanical and electrical engineering. The table in the project description also gives an indication of the more specialised areas of technology involved. To meet these requirements and in anticipation of ITER construction, lists of European firms or European groupings of firms have been established in 17 technologies which are specific to fusion and essential for the possible construction of an experimental reactor. These 17 fusion specific technologies cover:

Plasma Engineering

1. High-power, high-frequency transmission lines (in the range 120-180 GHz)
2. High-power, high-frequency sources (in the range 5-8 GHz and 120-180 GHz)
3. Neutral Beam Power Supplies and High Voltage Components (of the order of 1 MV)

Plasma Facing Components

4. Tiles and Coatings
5. Plasma Facing Component Mock-ups

Vessel, Shield and Blanket

6. Vacuum Vessel, segments of Neutron Shields and of Tritium Breeding Blankets

Superconducting Magnets

7. Strand
8. Conductor
9. Model Coil Winding
10. Electrical Power Supplies

Remote Handling Equipment

11. Qualification of Standards and Tools
12. Transporters and end effectors

Fuel Cycle

13. Vacuum Cryopumps and Mechanical Pumps
14. Tritium Compatible Valves
15. Tritium Handling and Atmosphere Detritiation

Materials for fusion specific applications

16. Low activation structural materials for in-vessel components of a fusion reactor
17. Materials for tritium breeding blankets including ceramic breeder and beryllium pebbles and permeation barriers

R&D issues covering breeding blankets, materials development and the conceptual design of a fusion materials irradiation test facility are also addressed in the long-term technology component of the fusion programme with a view to the later construction of a prototype fusion power plant.

Successful spin-offs from fusion R&D

The close collaboration between the Fusion Associates and industry on resolving issues within the R&D programme has resulted in successful spin-offs in many areas.

These include:

- Remote handling systems
- Semiconductor manufacturing
- Large area plasma etching and deposition
- Extreme Ultra Violet Lithography (EUVL)
- Thin film deposition EUV masks
- Precision EUV optical elements
- X-ray micro-lithography
- Direct write e-beam array using nano-tube electron field emitters
- Ion implantation
- Plasma HDTV display panels

In some areas of technology, multiple examples of fusion spin-offs may be found:

Medical/Health

- Laser cavity drilling
- Medical isotope separation (laser/rf)
- Tissue welding
- X-ray catheter
- Continuous glucose monitor
- Photo-acoustic laser system for blood clot emulsification
- Dental imaging
- Grain sterilisation & milk pasteurisation
- Magnetic Resonance Imaging (MRI)

Pulsed power and power conversion

- IGBT power conversion units for trains, buses and earth movers
- Microwave Impulse Radar (MIR)
- Power generation, transmission, storage, conditioning, surge limiting and motors

Material processing

- Laser peening
- Ion beam surface modification
- Microwave sintering
- Enhanced Chemical Vapour Deposition (EPCVD)
- Optical material manufacturing
- Rapid crystal growth
- Laser machining

Superconductivity

- Nuclear Magnetic Resonance (NMR)
- Superconducting cyclotrons for isotope production and neutron radiography
- Superconducting synchrotrons for X-ray lithography
- Magnetic separation of materials (e.g. clay)
- Magnetic Resonance Imaging (MRI)

Space propulsion

- Magneto plasma thrusters

Waste processing

- Plasma torch
- Waste vitrification
- Cryopellet ablation
- Isotope separation
- Microwave spallation of contaminated surfaces
- Plasma-assisted catalyst

MOVING FORWARD

The technology transfer process associated with fusion R&D involves a continuous interaction between the fusion research community and industry. Both sides benefit from this and both fundamental and applied fusion R&D have led to many spin-off technologies, companies and, in some cases, to whole industries.

Ten specific examples are presented here to illustrate not only the breadth of the technologies involved but also the geographical spread across the partner states contributing to the fusion programme and the distribution between firms, both large and small.

Examples of spin-off successes involving R&D in the Associations

Associates	*Spin-off summary*	*Non-fusion application*
CEA (France)	Toroidal pump limiter of Tore Supra/CIEL, developed with Plansee AG, Reutte, Austria, using specific bonding of carbon fibre composite (CFC) to copper	Actively cooled high heat flux components in space applications
RISØ (Denmark)	Development of laser diagnostics for fusion plasmas in the ASDEX tokamak applied to CO_2 laser anemometers.	Application in laser anemometers used on wind turbines
CEA (France)	Fabrication of Tore Supra superconducting cables and model coil with Alstom, Belfort	Applications in medical device: Magnetic Resonance Imaging (MRI)
FZK (Germany)	Development of gyrotrons, together with CRPP, CEA, TEKES and NTUA, for ECRH heating of fusion plasmas	Know-how transfer to European industry for industrial applications
IPP (Germany)	Development of two computer codes, TRIM and TRIDYN for damage analysis of fast plasma ions interacting with plasma vessel wall	Applications for ion implantation in the semiconductor industry
DCU (Ireland)	Development of diagnostic techniques with Scientific Systems Ltd for investigation of RF power coupling and plasma phenomena in negative ion sources	Industrial applications, mainly in semiconductor processing
ENEA (Italy)	Diagnostics developed for the study of edge physics in RFX applied to the study of turbulence developed in a prototype magneto-plasma dynamics thruster	Thrusters for satellite applications, operating at Centro Spazia in Pisa
ENEA (Italy)	Development of multifilamentary Nb3Sn and NbTi strands for fusion applications with Europa Metalli	Development used for applications in LHC magnets (CERN) and for MRI medical systems
UKAEA (UK)	Developments on micro-actuators and on switched mode power supply units for fusion have found applications in electronic jacquard machines	Applications in electronic jacquard machines developed by the Bonas Machine Company
UKAEA (UK)	Development of carbon-carbon composites with Dunlop Aviation for first wall tiles has had beneficial spin-off in industrial applications	Spin-off benefits in applications on brakes and clutches used in aviation, trains and motor racing

HIGH HEAT FLUX COMPONENTS

Plansee AG, Reutte, Austria is a company engaged in many areas of technology including powder metallurgy, metal forming and joining technology, and refractory, ceramic and composite materials. Working together with the **CEA**, Cadarache, France they have developed methods for the specific bonding of carbon fibre composite (CFC) which are used on the pump limiter for Tore Supra/CIEL. The technology also has applications in actively cooled high heat flux components in other areas.

Electrical contacts: The first development of Active Metal Casting (AMC) for Tungsten-CuCrZr bonding has led to applications in high-duty electrical switches.

Space shuttle project (X33): Development of high heat flux material: CFC-metal bonding with AMC and laser treatment for rocket engine aerospikes.

Tore Supra Toroidal Pump Limiter (TPL):

- Specific bonding of actively cooled high heat flux components: Carbon fibre Carbon (CFC) – CuCrZr bondings using AMC and specific laser treatment.
- Power handling >10 MW/m^2 continuously

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LASER ANEMOMETRY FOR PERFORMANCE TESTING OF WIND TURBINES

Dr. René Skov Hansen and Dr. Sten Tronæs Frandsen from **Risø National Laboratory** in Denmark are using technology developed for plasma diagnostics in fusion to construct an anemometer to measure wind velocities in front of a wind turbine. The Scottish company **Ferranti Photonics Ltd**., together with Risø, are responsible for developing the laser, and two Danish companies, **NEG-Micon** and **WEA Engineering**, are working on testing and control system development.

The Optics and Fluid Dynamics Department at the Risø National Laboratory in Denmark have gained experience of using CO_2 lasers in anemometers during a fusion project aimed at measuring velocity fields in plasmas, where a clear link has been demonstrated between plasma confinement and intensity of turbulence. They are applying this experience to develop new technology for use in wind turbines.

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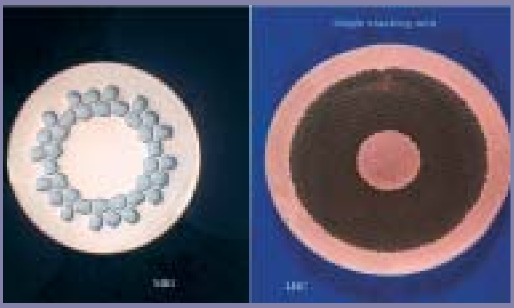
SUPERCONDUCTORS FOR MAGNETIC RESONANCE IMAGING (MRI)

Alstom in France has gained experience in superconductor R&D, working together with the **CEA** on the development of the magnet systems for the Tore Supra experiment in Cadarache. The technology, involving superconducting NbTi strands, is applied in the large-scale production of strand for the magnets used in Magnetic Resonance Imaging (MRI). MRI is now routinely employed in many large hospitals for scanning body tissue.

From Tore Supra superconductors R&D: NbTi strands (10 000 filaments – 23 microns diam.), large-scale fabrication (20 tonnes in 1984-86) with continuous control.



NbTi superconductor simple strands for MRI magnets (36 filaments – 40 microns diam.).
More sophisticated strands for LHC (5 000 filaments – 6 microns diam.).

Implementation at Alstom of large-scale production of NbTi strands for Magnetic Resonance Imaging: (MRI) magnets (2 000 p.y) and for large scientific devices such as the Large Hadron Collider (LHC) at CERN (500 tons NbTi). Improvement of quality assurance has been achieved by continuous in-line control.

Contact for further information

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INDUSTRIAL APPLICATIONS FOR HIGH POWER GYROTRONS AND MICROWAVE SOURCES

Within the European Fusion Programme, a consortium of Associations, **FZK, CRPP, CEA, TEKES** and **NTUA** has accumulated considerable know-how in the design of specific high-power microwave sources (gyrotrons) which are used to heat fusion plasmas at the electron cyclotron resonance frequency. This know-how is currently being transferred to European industry, **Thales Electron Devices**, for application in the production of gyrotron tubes for other fusion experiments including Tore Supra in Cadarache, TCV in Lausanne, Wendelstein 7X in Greifswald, Germany, and also for ITER.

In parallel with fusion activities, knowledge in the field of high-power gyrotrons and microwaves is used for research and development in the field of materials processing, and is receiving growing interest from industry. The essential advantages of this technology are that it provides a source of instantaneous, volumetric and homogeneous heating that can be exploited for various industrial processes. In particular, for materials with low thermal conductivity, such as powders, powder compacts, polymers, glass or composites, heating with microwaves may lead to a considerable reduction in processing time and energy consumption compared to conventional resistive heating or gas firing. There are several collaborative ventures between industry and the FZK internal technology transfer programme, as well as within the European Framework Programme.

Contact for further information

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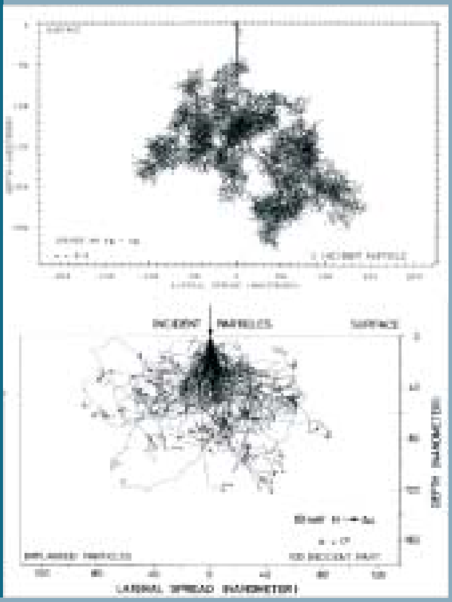
From Plasma-Wall Interactions to Semiconductor Technology



Two computer codes, TRIM and TRIDYN, have been developed at **IPP**, Garching to analyse damage that may be caused by fast plasma ions impinging on the walls of the plasma vessel of a fusion device. The purpose of the codes is to simulate the trajectories of ions penetrating the wall at a given energy and angle of incidence. This is done by tracking the collision behaviour of the projectiles and observing the atoms of the bombarded solid. The entire collision cascade can be recorded and any sputtering of the surface or reflection of the ions can be described. The penetration depth and damage inflicted on the material by any incorporated particles can thus be determined. The TRIDYN code also takes into account dynamic changes in the composition of samples resulting from ion bombardment.

Since their development in the eighties, the two codes have been used by around 90 different companies and institutions, e.g. IBM in Mainz, Fraunhofer-Institut für Siliziumtechnologie (ISIT) in Itzehoe, and Laboratoire d´Analyse des Matériaux, CRP in Luxembourg. They now enjoy world-wide application from Europe to Australia, the USA, and Japan. Their main application is in ion implantation, for example in doping during the development of semiconductors. This process is the specific tailoring of the electronic properties of a semiconductor by the incorporation of foreign atoms.

Contact for further information

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PLASMA DIAGNOSTICS DEVELOPMENTS USED IN MICROELECTRONICS INDUSTRY

Scientific Systems Ltd is a successful and substantial spin-off company that arose from the Irish Fusion Association Euratom DCU research. Dr Michael Hopkins, President, CEO and co-founder of Scientific Systems Ltd was previously the Director of the Plasma Research Laboratory working on negative ion beam sources and plasma diagnostics for fusion applications. He left to set up Scientific Systems Ltd in 1998.

Scientific Systems make high-end plasma diagnostic systems; Power and Impedance monitors, Ion flux probe and advanced Langmuir probe which are used worldwide by plasma research laboratories and plasma-based manufacturing industries including the semiconductor and thin-film coating industry sectors. The diagnostic techniques are similar to those originally developed within the Association DCU for investigation of radio-frequency power coupling and plasma phenomenon in negative ion sources being developed for application to fusion plasma heating. At Scientific Systems, the technology has been re-engineered to handle the rigours of industrial application, primarily to semiconductor processing. Their sensors are widely used in the semiconductor industry during equipment development, and are installed in advanced production lines.

Scientific Systems Ltd., now employing 60 people, was winner of the year 2000 National Innovation Award from the Irish Government's Science, Technology and Innovation Awareness Programme. Its winning entry, SmartPIM, is an on-the-production-line plasma sensor that highlights characteristics and defects to the highest resolution through the measurement of critical plasma parameters.

SmartProbeTM: The number one Langmuir Probe for accuracy, reliability and performance.

The Ion Flux Probe (IFTTM): enabling real-time plasma density monitoring.

Contact for further information

http://www.scisys.com

PLASMA PROPULSION FOR ADVANCED SPACE THRUSTERS

Diagnostics developed for studying edge physics in the **RFX** experiment in Padua are being applied to the study of turbulence developed in a prototype magneto-plasma dynamic thruster for satellite applications, operating at **Centrospazio** in Pisa.

Magneto plasma dynamic thrusters are being developed for long range space missions. At high currents a critical regime is reached, that causes a degradation of the thrust efficiency. Electron density and temperature in the plume of the thruster have been measured by an array of Langmuir probes already used in the RFX fusion experiment. The measurements have identified strong fluctuations associated with the loss of thrust. The fluctuation analysis, carried out with the same tools used for fusion plasma data, highlighted preferred frequencies and spatial structures depending on power and the external magnetic field. The information from these results provides the key to understanding the origin of the instabilities, allowing for their mitigation, and the restoration of the thrust efficiency.

Contact for further information

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STRANDS FOR SUPERCONDUCTING MAGNET SYSTEMS

Europa Metalli (EM) started the manufacture of NbTi multi-filament strands in 1977, working in close collaboration with the Applied Superconductivity Laboratory at **ENEA** Frascati. The NbTi strands resulting from the development work are found in the conductor which was used to fabricate a 2m high, 1.3m bore, 6T solenoid still operating as an Italian contribution in the European Test Facility SULTAN at CRPP Villigen, Switzerland.

Europa Metalli has participated more recently with success in international tenders for the supply of NbTi strands for particle accelerators. The superconducting dipoles and quadrupoles at the Accelerator DESY, Hamburg, Germany, are all made with NbTi EM strands manufactured in the eighties. Further applications include the superconducting magnetic system of the Large Hadron Collider (LHC), a particle accelerator under construction at CERN, Geneva, Switzerland and in the poloidal field magnets of the ITER project. A cross-section of the strand is shown in fig.1. The know-how acquired has also been used to manufacture NbTi strand for MRI medical systems, in which highly symmetric distribution of the superconducting filaments is required, as shown in fig.2.

The scale-up of the EM capability in the industrial manufacturing of Nb3Sn internal tin strand was achieved to comply with a Euratom contract for about 4000kg of a 0.81mm multi-filament strand for the ITER Model Coils Programme shown in fig 3. A further example of an application of the acquired know-how has been in the manufacture of high critical current density Nb3Sn strand for applications in high field, high frequency Nuclear Magnetic Resonance (NMR) imaging systems for biological investigations.

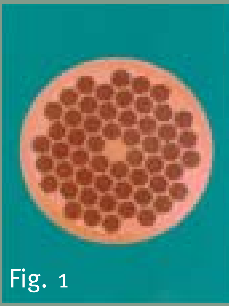
Fig. 1

NbTi multi-filamentary strand for LHC.

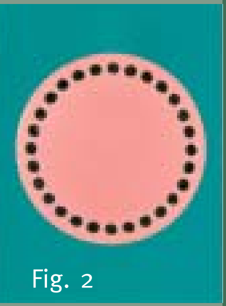
Fig. 2

NbTi strand for MRI applications.

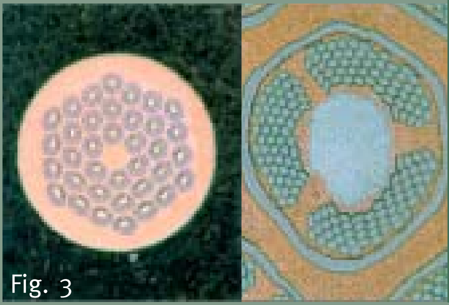
Fig. 3

Cross-section of the ITER Nb3Sn multi-filamentary strand. On the left an enlarged view of one of the 36 bundles inside the wire.

Contact for further information

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FROM FUSION R&D TO HIGH-TECH WEAVING

The **Bonas Machine Company** is one of the world's leading manufacturers of electronic jacquards which enable weavers to produce very high added-value cloth and fabrics from computer-generated designs. Ninety-five percent of the jacquards made by Bonas are exported.

Technical consultancy from **UKAEA** Fusion staff has helped the company stay ahead of the competition.

Dr Norman Waterman, Chief Executive of **Quo-Tec** – a technology transfer consultancy specialising in advanced materials – initiated the relationship between UKAEA Fusion and Bonas. Quo-Tec had been providing services to Bonas for ten years, and understood their business and their new technology needs.

While working on a feasibility study on the new materials needed for the first wall and divertor components of tokamaks, Quo-Tec, through discussion with senior UKAEA Fusion staff, became aware of their special expertise on micro-actuators, and switched mode power supply unit designs.

The design issues of a variety of actuator concepts have been discussed with a view to improving the performance of the Bonas jacquard machines further. The net result of the consultancy supplied to Bonas by UKAEA Fusion is:

- A micro-actuator which, when the price of key elements drops below a certain threshold, could be the basis of a completely new jacquard.

"The overlap in technologies between the Bonas Machine Company and fusion primarily concerns the requirements for long-life, highly stressed electro-mechanical structures".

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CARBON-CARBON COMPOSITES IN HIGH PERFORMANCE BRAKES

Dunlop Aviation is part of **Dunlop Aerospace Limited**, a company manufacturing aerospace equipment. Dunlop Aviation designs and manufactures aircraft wheels, brakes, braking systems and ice protection systems for civil, regional, business and military aircraft. Dunlop Aerospace Limited also comprises Dunlop Precision Rubber, **Dunlop Equipment and Serck Aviation**.

Dunlop Aviation has supplied approximately 6 tonnes of carbon-carbon composite (C-C) tile blanks to fusion facilities at **JET, UKAEA** and other projects worldwide. In addition, Dunlop Aviation has participated in European-funded work to develop C-C with improved thermal properties to meet the expected service requirements of next generation fusion machines. Success in this field has broadened the company's product portfolio beyond its core aerospace market.

Supplies of C-C tiles used for plasma facing components in the divertor and the first wall of fusion machines has increased production efficiency and reduced costs in core business products.

Dunlop Aviation manufactures C-C materials primarily for use as friction discs in aircraft brakes, but also for non-aviation friction applications including train brakes, brakes and clutches for Formula 1 and other racing applications.

Since the mid 1980s, Dunlop Aviation has worked closely with fusion projects in Europe and North America to develop and manufacture C-C. These have been manufactured as fusion tiles, high temperature furnace furniture, furnace heating elements and heat sinks for satellite electronics systems.

They have been supplied for plasma -facing components for first wall and divertor applications where the properties required are similar to those needed in aircraft friction materials, namely, the ability to transfer large heat fluxes, and retention of strength at elevated temperatures and low density.

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PEOPLE MOVING FORWARD

As the spin-off examples illustrate, technology transfer from fusion research to industry is a continual process. There is another element of the knowledge transfer process, which is also of significant benefit to industry. This may be described as "People Spin-off". The challenging and interdisciplinary nature of the fusion research environment involves physics, engineering, mathematics, materials science and other skills. It has proved the ideal grounding for engineering entrepreneurs and it has provided a supply of highly trained staff and students, many of whom have used it as a launch pad to successful careers in other fields.
As an example, we present two typical case studies of the "People Spin-off" phenomenon:

Professor Christopher Bishop, *Assistant Director, Microsoft European Research Centre*

It was while developing the first, real-time, closed loop control system for the fusion experiment the COMPASS-D (compact assembly) tokamak that Chris Bishop first developed an interest in neural networks. "As well as making a significant difference to the way we control the plasma, it was a defining moment in developing my own career."

"Machine intelligence represents an incredible opportunity. For example, here at Microsoft we're using it to assemble digital camera images into 3D virtual reality models," says Professor Christopher Bishop.

After eight years as a theoretical physicist at Culham, Chris moved to UKAEA Harwell to develop his interest in machine intelligence further before taking a Chair of Computer Science at Aston University's Department of Computer Science and Applied Mathematics, and setting up the Neural Computing Research Group. Following a six-month sabbatical at the Isaac Newton Institute in Cambridge he was appointed as Assistant Director at Microsoft Research. This was in the same week that Chris was also appointed Professor of Computer Science at Edinburgh University.

Chris' role at Microsoft includes managing research teams and external relations with the academic community at large, as well as conducting basic research. Communications skills are essential and Chris points to his time at Culham as providing these. "I had developed a new model for localised separatrix modes in tokamaks. This attracted considerable interest and gave me the opportunity to develop my presentation skills through giving numerous talks at international conferences and research laboratories.

You'd be forgiven for thinking that, with a background in physics, Chris Bishop might struggle with heading up research teams of computer scientists. "Culham gave me an excellent grounding in linear mathematics and calculus that has been invaluable in machine learning. By taking this less conventional route to working in computer research, I'm able to offer a breadth of vision and experience that a pure computer scientist often doesn't have."

Emanuela Ciattaglia, ***Mechanical Engineer, Oxford Instruments Superconductivity***

Emanuela completed her degree in Mechanical Engineering at the University of Rome (Tor Vergata) in October 2000. Part of her final project was spent at the Culham Science Centre during which time she worked with the team tackling a design problem on the MAST solenoid. "At the time I knew little about electromagnetic and magnet design but, as I soon discovered, you have to pick up things quickly at Culham. You're encouraged to look beyond the immediate mechanical and electromagnetic analyses if you're to stand a chance of understanding the problem." After some preparatory theoretical work, Emanuela developed a solenoid design prototype that successfully passed test trials.

The Culham experience enabled Emanuela to take a research position at Oxford Instruments Superconductivity, a world leader in the supply of superconducting magnets and low-temperature cryogenic systems to the scientific and industrial research community.

Although Emanuela spent just over a year at Culham, she believes the experience is already proving its worth. "At Culham we were able to take structural analyses to the nth degree and compare theoretical predictions with actual test results which demonstrated the reliability of our model as well as revealing ways in which we could refine it. This, coupled with the opportunity to see all aspects of a project from beginning to end, gives you an appreciation of the bigger picture, something you don't necessarily get when you're only dealing with one aspect of a much larger project in industry."

"Working on the solenoid on the Mega Amp Spherical Tokamak (MAST) at Culham has given me an insight into design, prototype development and manufacture that is unusual for recently qualified graduates," says Emanuela Ciattaglia.

REFERENCE MATERIAL AND SUPPORTING INFORMATION

The European Fusion Programme
Information related to spin-offs from the European Fusion Programme may be obtained from:

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General information on the European Fusion Programme may be obtained from the European Commission website on energy research:
http://www.europa.eu.int/comm/research/energy/index_en.html

The website includes a selection of links where more information can be found about both the European Fusion Programme and fusion research in general, for example:

CORDIS (Community Research and Development Information Service)
CORDIS is a free service provided by the European Commission's Innovation/SMEs Programme. CORDIS offers access to a wide range of information on EU research and innovation development activities.

The European Commission (EC)
EC funding of fusion research is managed by the Directorate-General for Research.

The European Fusion Development Agreement (EFDA)
EFDA is responsible for supervising fusion technology R&D, European participation in international collaborations such as ITER, and the scientific exploitation of the JET facilities. Operation of the JET facilities is the responsibility of the Association Euratom-UKAEA.

ITER
ITER is a world-wide collaboration involving Canada, the EU, Japan, and Russia in the design of the Next Step fusion experiment.

Intellectual Property Rights (IPR)
IPR is a key issue in the exploitation of potential spin-offs. An IPR Helpdesk has been set up to raise the awareness of the European research community on IPR issues. Those potentially and currently involved in community-funded research may use the Helpdesk as an initial point of contact on IPR issues on:
www.ipr-helpdesk.org

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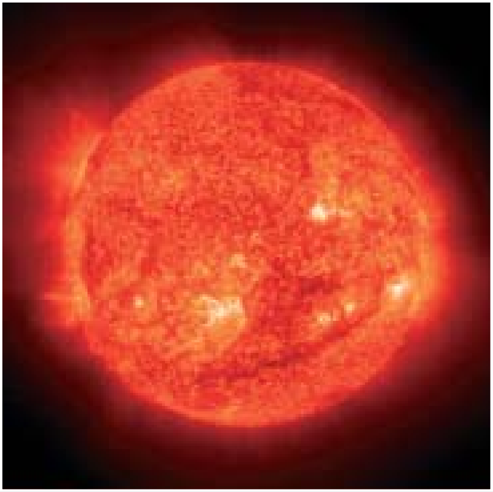

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