2 General Introduction

2.1 FUSION ENERGY RESEARCH

2.1.1 FUSION FOR ENERGY PRODUCTION

Fusion is the fundamental energy source of the universe, the process that powers the sun and the stars. In a fusion reaction, light atoms fuse together at extremely high temperatures, releasing huge amounts of energy. Fusion research aims to reproduce this process here on earth, and to use fusion as a safe way of producing large-scale energy, without the emission of greenhouse gases.

The fusion reaction that is easiest to accomplish on earth is the reaction between deuterium and tritium, two isotopes of hydrogen. As shown in Figure 2.1, a deuterium and a tritium nucleus can combine to form a helium nucleus, and a neutron. The helium and particularly the neutron carry a large amount of energy, and it is this energy that would be used to heat water and drive turbines in a fusion power station.

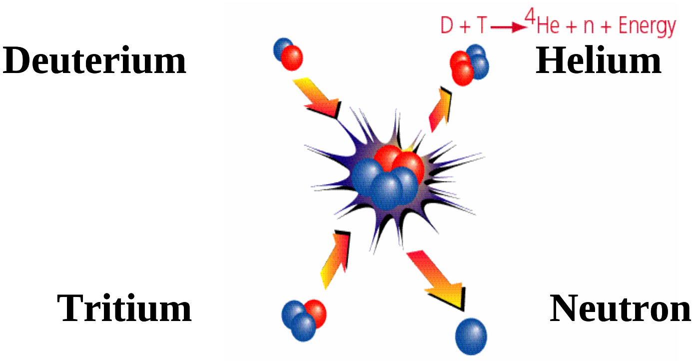

Figure 2.1: *Schematic of the deuterium-tritium fusion reaction*

Deuterium is readily extracted from seawater and tritium would be made in a fusion power plant from neutrons striking lithium, which is widely available in the earth's crust. In a fusion reaction, the amount of energy released is about ten million times as high as the amount of energy released in an ordinary chemical reaction, such as the burning of coal. That enormous difference means that a fusion power plant only needs a very small quantity of fuel. The lithium from one laptop battery, combined with half a bath of water, would provide the fuel for 200,000kW-hours of electricity – the same as 70 tonnes of coal, and equal to the UK's per capita electricity consumption for 30 years.

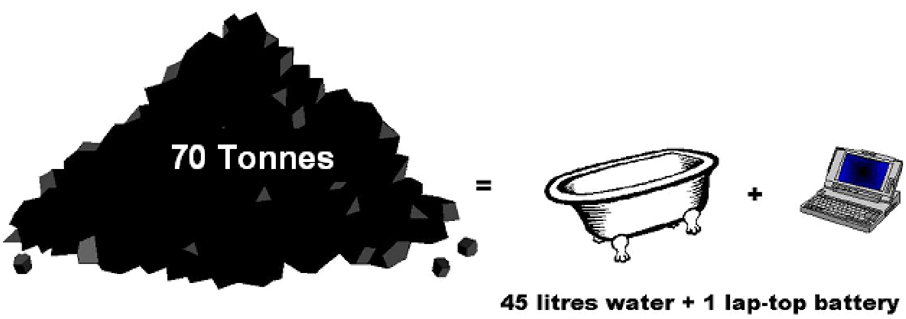

Figure 2.2: *Half a bath of water plus the lithium in one laptop battery would provide the fuel needed for the same amount of electricity as 70 tonnes of coal*

Fusion reactions occur naturally at the middle of the sun (Figure 2.3) at temperatures of 15 million °C. The sun keeps the hot plasma together by gravity, which causes a very high pressure in the centre of the sun. On earth gravity is much too weak, so a different technique needs to be used. One practical approach on earth is *magnetic confinement,* where strong magnetic fields are used to control and confine a much lower density plasma, which is heated to a higher temperature (over 100 million °C).

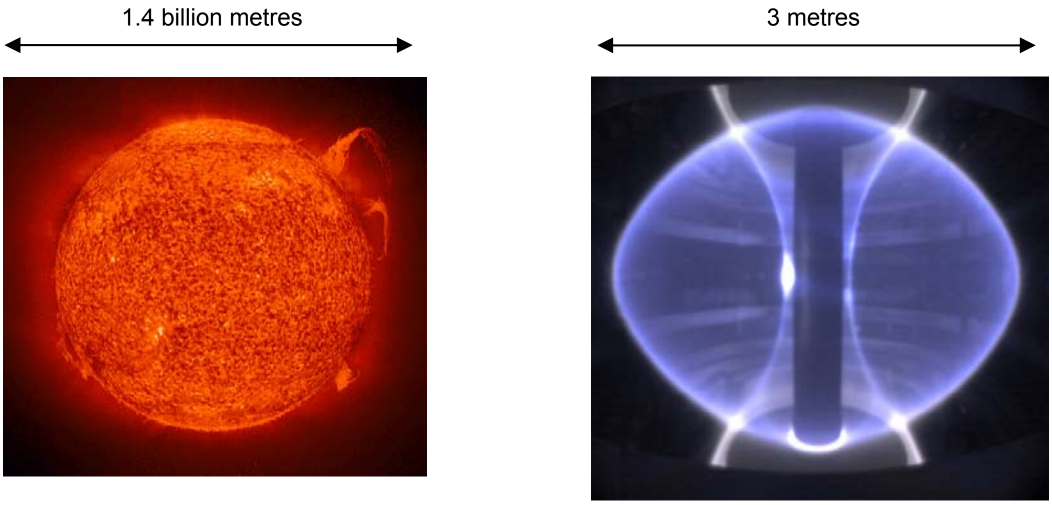

Figure 2.3: *Hot plasmas with copious fusion reactions occur naturally in the sun (left) and at Culham we create plasmas just as hot in MAST (right)*

With climate change and the need for increasing energy resources moving to the top of the world's governmental agendas, fusion is one of the key options that could contribute to a solution to this global challenge, with almost unlimited supplies of fuel, produced in devices that have low levels of stored and potential energy and can therefore be operated safely. Fusion R&D programmes are carried out in about 50 member countries of the International Atomic Energy Agency.

Other information about fusion research is available on CCFE's fusion website: http://www.ccfe.ac.uk and a glossary of fusion terms is provided in Chapter 11.

2.1.2 Overview of European and UK Research

Fusion research in Europe is aimed at demonstrating that nuclear fusion is a viable future energy option. It is fully integrated at the European level, with 26 EURATOM fusion Associations in European Union Member States and Switzerland contributing to the programme. The research activities in the various Member States are co-ordinated and complementary, and make it possible to undertake projects that would be on too large a scale for any individual member.

The collective aspects of the European physics activities, the management of the research on the Joint European Torus (JET) at Culham (Section 2.1.4) and on emerging technologies and training are all organised under the European Fusion Development Agreement (EFDA, http://www.efda.org/). Fusion for Energy – F4E, http://fusionforenergy.europa.eu/ – a EURATOM Joint Undertaking situated in Spain, manages and provides Europe's contribution to the ITER project and to the Broader Approach projects agreed with Japan (Section 2.1.3).

The programme is focused on the tokamak approach to the development of magnetic confinement of fusion, whereby the plasma is confined by a magnetic field with two main components. The biggest (so-called *toroidal*) field is produced by external coils, and keeps the plasma away from the walls. However, by itself this field is not enough to confine the plasma. A second (so-called *poloidal*) field is added to reduce particle drifts and to counteract the natural pressure inside the plasma which tries to make it expand. In a tokamak, the poloidal field is generated by a strong electrical current which flows through the plasma, and which is also used to heat the plasma.

Other important ingredients are high vacuum conditions, powerful additional heating systems (using high energy beams of neutral atoms, radiofrequency waves and microwaves) and, to measure the plasma performance, a wide range of instrumentation ('diagnostics').

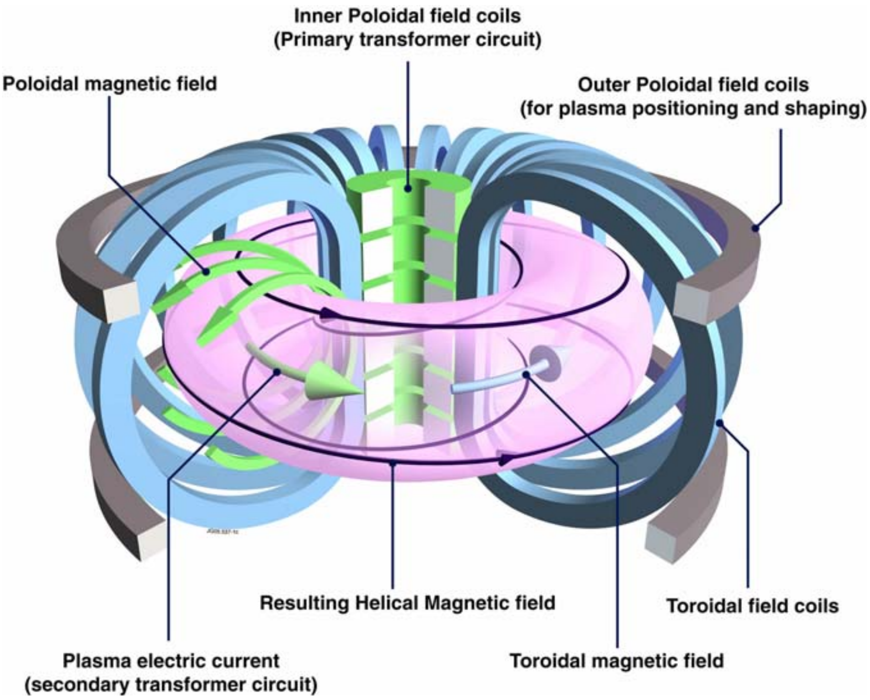

Figure 2.4: *Schematic of the tokamak approach to magnetic confinement fusion; the magnetic field is produced by a combination of external coils and the plasma current*

The EURATOM/CCFE Fusion Association is a world leader in the study of a variant of the tokamak called the spherical tokamak (ST), currently represented by the Mega Amp Spherical Tokamak (MAST) device at Culham (Chapter 5). In STs the plasma is much more compact (resembling a cored apple) than in the more conventional JET-like plasmas (which have the shape of the inner tube of a truck tyre).

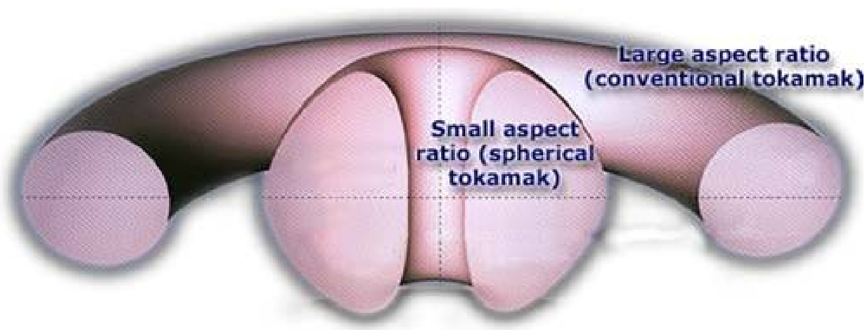

Figure 2.5: *The ST has more compact plasmas than the conventional large aspect ratio tokamak*

MAST can address key ITER-relevant issues by testing ITER physics in new regimes, checking scaling laws and makes many contributions to ITER physics results co-ordinated by the International Tokamak Physics Activities collaboration.

Experimental and theoretical evidence suggest that the ST has a number of attractive properties, which if confirmed on MAST and other machines, would position it as a promising candidate for a Component Test Facility (a machine that could test whole power station components in a proper fusion environment) and perhaps, in the longer term, for a cheaper fusion power plant. These properties include good plasma stability and confinement, high pressure capability and the potential for continuous operation.

An alternative to the magnetic confinement approach is inertial confinement, in which extremely intense laser or particle beams are used to compress and heat small fuel pellets to densities and temperatures high enough for fusion to occur for a very short time. The European programme maintains a 'keep-in-touch' watching brief on this research, some of which is carried out at the Central Laser Facility based at the Rutherford-Appleton Laboratory in the UK (Section 2.5).

The EURATOM/CCFE research programme is jointly funded by EURATOM and the UK Engineering and Physical Sciences Research Council (EPSRC, http://www.epsrc.ac.uk). EPSRC recently approved a major upgrade to MAST (See Chapter 5).

2.1.3 ITER

ITER is an international project that aims to demonstrate the scientific and technical feasibility of fusion power, and will constitute the largest international scientific project bringing together countries representing over one-half of the world's population. The partners in the project – the ITER Parties – are the People's Republic of China, the European Union (represented by EURATOM), the Republic of India, Japan, the Republic of Korea, the Russian Federation and the United States of America. ITER is being constructed in Europe, at Cadarache, in the South of France.

The heart of ITER will be a superconducting tokamak facility, similar in shape to JET, but twice its size. Its design builds on the success of a very wide range of fusion experiments around the world as well as theory and modelling of tokamak plasmas, and developments in fusion technology.

In ITER, scientists will study plasmas, with a major radius of six metres, in conditions similar to those expected in an electricity-generating fusion power plant. Its goal is to release 500MW of fusion power for extended periods of time, ten times the power input needed to keep the plasma at the right temperature. It will therefore be the first fusion experiment to produce net power. It will also test a number of key technologies for fusion power stations, including the superconducting coils, the blankets surrounding the plasma which will breed tritium and absorb the neutrons' energy, and remote maintenance.

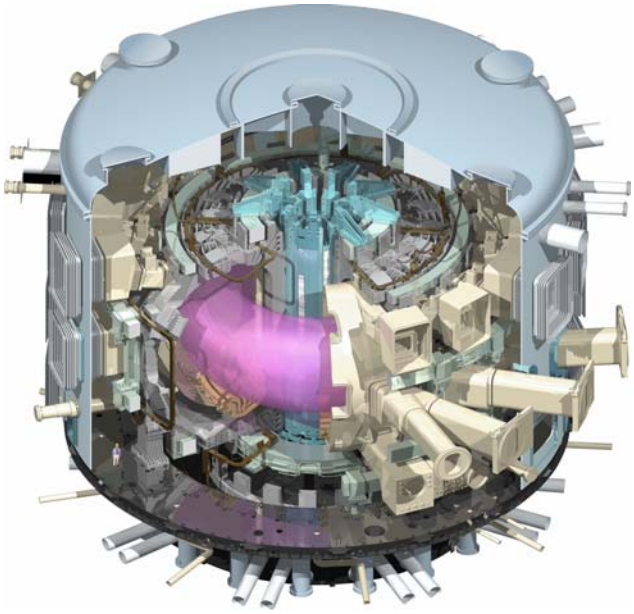

Figure 2.6: *Cutaway of the ITER machine*

CCFE has been pursuing work on ITER in a number of areas of significance to the ITER diagnostic and heating systems in particular. Work so far has mainly been funded via F4E grants, where F4E provide approximately 40% of the funding, and the remaining 60% comes from the EPSRC block grant. CCFE has also pursued 100% F4E funded contracts together with 100% funded contracts from the central ITER Organisation (IO) itself, and hopes to increase this contract work. CCFE has continued its substantial role in key ITER systems (Chapter 8):

- Ion cyclotron resonance heating (ICRH) system;
- Neutral beam injection system;
- Core LIDAR Thomson scattering to measure the electron temperature and density profiles

As part of the ITER site decision it was agreed that Europe and Japan would participate in 'Broader Approach' projects to complement the ITER project and accelerate the development of fusion energy. The projects include:

- A new fusion machine in Japan: the JT-60U tokamak is being converted to an advanced superconducting fusion machine known as JT-60SA, to act as a 'satellite' to ITER to develop operating scenarios and address key physics issues in support of ITER and the future DEMO power plant;
- Completion of the design and prototyping of IFMIF, a facility to test and qualify advanced materials for use in a future fusion power plant;
- An International Fusion Energy Research Centre in Rokkasho in the north of Japan to house the core of the Broader Approach activities, including the project team for IFMIF, supercomputing facilities and work on a demonstration power station (DEMO) to follow ITER.

In a 'fast track' approach to fusion development, ITER and IFMIF would operate in parallel and a demonstration power station could be providing electricity to the grid within thirty years.

Other information on ITER can be found on the ITER website: http://www.iter.org/ and on the Broader Approach on the Fusion for Energy website, http://fusionforenergy.europa.eu/.

2.1.4 THE JET FACILITIES

JET, the Joint European Torus, is the flagship of the EURATOM Fusion Programme and is the largest and most powerful fusion experiment in the world. It has operated for over 25 years and holds the current world record for fusion power (16MW – a value comparable to the power needed for heating one thousand households in a cold winter) and fusion energy (21MJ) released in one shot. However, JET cannot produce more energy than it consumes and can produce fusion power for only a few tens of seconds because it does not have the superconducting coils that will be used in ITER and fusion power plants.

Figure 2.7: *Interior view of the JET vacuum vessel The inside of the vessel is about three metres high*

The plasmas in JET have a very similar shape to those planned for ITER, but with half of their linear dimension. The JET facilities include plasma heating systems capable of delivering over 30MW of power, an Active Gas Handling System and a Beryllium Handling Facility providing JET with unique tritium and beryllium capability, respectively. The UK Atomic Energy Authority, through its fusion arm, CCFE, is responsible for the safety, maintenance and operation of the JET facilities for a collective European programme of experiments. The work is carried out under the auspices of EFDA and its JET Implementing Agreement, with the Authority's costs reimbursed via the JET Operation Contract (Chapter 3). The UK is responsible for the eventual dismantling of the facilities.

In addition to operating the facilities and providing support to the EFDA Close Support Unit at Culham, which co-ordinates the JET programme, CCFE plays a full role in the Scientific and Technical Task Forces (described further in Chapter 4). As well as undertaking fusion plasma physics experiments, the Task Forces examine technology issues such as the conditioning of plasma-facing materials (tritium retention and dust removal being particular concerns) and machine activation. Non-EURATOM countries (the USA, Japan, the Russian Federation and China) also participate in the exploitation of the JET facilities under International Energy Agency (IEA) and other auspices.

Other information on JET can be found on the JET website, http://www.jet.efda.org.

2.2 THE EURATOM/CCFE PROGRAMME

2.2.1 REBRANDING UKAEA CULHAM

From 2 November fusion at Culham had a new name: Culham Centre for Fusion Energy (CCFE) and an accompanying logo. The new, strong identity, which relates directly to the laboratory's aspirations for fusion research as a new energy source, was created jointly by the PR group and Culham Publication Services. The redesigned fusion website www.ccfe.ac.uk complete with the new brand was launched at the beginning of November.

CCFE
CULHAM CENTRE FOR FUSION ENERGY

Figure 2.8: *CCFE logo*

The rebranding opportunity came about as the sale of UKAEA's decommissioning activity by the UK government to Babcock International included the brand 'UKAEA' and the stylised crest.; the sale agreement actually prohibits the United Kingdom Atomic Energy Authority from using the UKAEA abbreviation. Therefore, in addition to the introduction of CCFE, it was necessary to develop a brand for the remainder of Group Services, Finance and Human Resources who will remain part of the Non-Departmental Public Body (NDPB). This will be known by our unabbreviated name: the United Kingdom Atomic Energy Authority (or 'the Authority' for short). The original Authority crest has been revived for all legal documents and certain stationery.

2.2.2 COMPONENTS OF THE PROGRAMME

The overall aim of the EURATOM/CCFE programme is to maximise the UK's contribution to the 'fast track' development of fusion power. The main themes are: (a) ITER science – improving the ITER science base through experiments on MAST and JET, and related Theory & Modelling; (b) ITER technology – developing specialist equipment for deployment on the machine; (c) developing the spherical tokamak (ST) concept which has the potential to play a key role in fusion development; and (d) work on the science of materials and other aspects of fusion power technology.

The programme benefits from collaborations with many other research organisations, including UK universities, most of the other EURATOM Associations, and fusion institutes in the rest of the world.

The main components constituting this programme are shown in Table 2.1. The substantial activity in relation to JET operations is described in Chapter 3.

Chapter	Main objectives
4. JET Studies	• Participate in the EFDA Science and Technical programme on JET to improve the physics and technology understanding for ITER and their translation to future power plants

5. Tokamak Development (MAST)	• Contribute to the optimisation of the design and operating scenarios of ITER • Explore the potential of the spherical tokamak as a basis for a Component Test Facility (CTF) and as a future fusion power plant
6. Theory	• Address key physics issues for ITER and spherical tokamaks, by developing theories and codes validated by experimental data
7. Materials & Technology	• Improve understanding of the behaviour of materials in the fusion environment, particularly their tolerance to neutron bombardment • Improve understanding of the safety, environmental and socio-economic attractiveness of fusion power • Examine the spherical tokamak route to CTF and a fusion power station • Participate in DEMO and other studies in the international Fast Track to fusion
8. ITER Projects	• Contribute to the development of specialist equipment for ITER, e.g. heating and current drive systems, diagnostics, port plugs, plasma control, plant control and data acquisition systems
9. Industry	• Encourage companies to tender for fusion procurement and consultancy contracts arising from the national and international programmes • Facilitate technology transfer from fusion research

Table 2.1: *Main components of the EURATOM/CCFE programme*

The largest component of the programme relates to the experiments for ITER and the development of the ST using the MAST facility. MAST is one of the two largest and most advanced STs in the world, the other being NSTX at Princeton Plasma Physics Laboratory in the USA. The ST is a very promising line of research, pioneered at Culham, which now features in fusion programmes around the world (USA, Japan, Brazil, the Russian Federation, Italy and China); devices of this type are the subject of an IEA Implementing Agreement.

The ST has been proposed as the basis of a Component Test Facility (CTF), which would be desirable for the development of fusion power. A CTF could provide the necessary conditions to test and develop reliable fusion reactor components and structures in an environment which combines a realistic fusion neutron spectrum and all the other relevant tokamak stress fields.

The European Fusion Facilities Review in 2008 acknowledged that MAST made important contributions to both ITER physics, by providing data in new regimes, and to the possible development of a CTF. In late 2009, the UK Research Councils reviewed fusion research in the UK and following this EPSRC agreed a revised strategy for the magnetic programme centred at CCFE. It supported the research as a long term endeavour with the UK playing a leading role in the international programme to develop fusion energy. It envisaged a gradual shift of emphasis from fusion tokamak science (i.e. plasma physics) to fusion technology, and agreed additional funding for a major upgrade of MAST; this will mean MAST makes stronger contributions to ITER physics and will allow scientists to study whether the ST approach is suitable for a CTF.

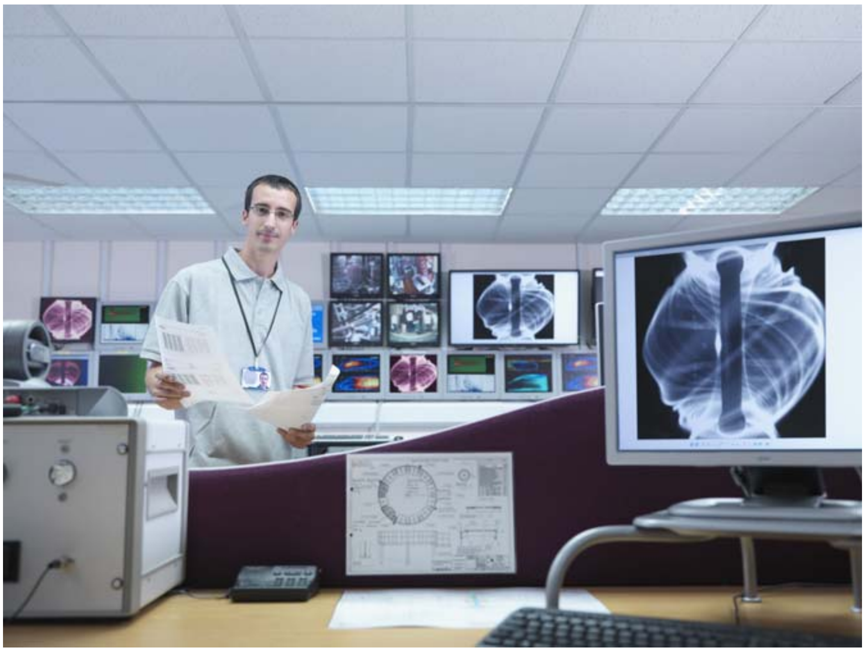

Figure 2.9: *The MAST control room*

Participation in the JET scientific and technical programme, when combined with work on MAST and other tokamaks, provides the best possible data for the development of ITER operating scenarios and their translation to a fusion power plant. In addition to the development of reacting plasmas, the exploitation of JET contributes to the performance characterisation of plasma-facing materials, tritium technology and the development of ITER equipment. The UK contributions to JET are co-ordinated with all others by the Culham-based EFDA Close Support Unit.

The MAST and JET programmes have inter-dependent links with the development of the theoretical physics understanding of plasmas and their modelling, using state-of-the art, sophisticated codes. The work in this area is targeted on the key issues for ITER and spherical tokamaks, and is evolving in response to the future development needs of these concepts. The models developed are tested where possible by comparing with results from MAST, JET and other tokamaks.

The technology work promotes the cost-effective accelerated development of fusion as a safe, environmentally benign and economically attractive source of energy. This is achieved through work on a number of ‘fast track’ and longer-term technology issues. The development of robust structural and plasma facing materials is on the critical path to fusion power, and the programme concentrates on the development and characterisation of suitable materials needed for fusion power plants and DEMO.

The programme on ITER projects focuses on securing the most appropriate ITER specialist equipment projects for the UK. Leading roles in partnerships of European fusion laboratories on certain diagnostic systems and heating and current drive projects have already been established. A related issue is the UK participation in ITER procurement and construction activities, and the Culham industry liaison programme concentrates on ITER and encourages UK companies, both big and small, to bid for contracts. UK companies have already won some important ITER contracts.

The results of the research and development work are published in journals, presented at international conferences and workshops, and at meetings of the international tokamak physics activity (ITPA) Topical Groups, which co-ordinate work on the various topics. A list of publications in 200910 is available in Chapter 10, and a Glossary in Chapter 11.

2.2.3 INTERNATIONAL COLLABORATIONS

The EURATOM/CCFE Association undertakes collaborative work with many laboratories and institutes in the framework of the European and international fusion programmes. Much of this is within EFDA-co-ordinated programmes – CCFE staff are among the EFDA Task Force Leaders – or under the auspices of the IAEA and the IEA. These include: the EFDA, F4E and ITER Teams; ERM Brussels (Belgium); IPP Hefei (China); Institute of Plasma Physics (Czech Republic); Risø (Denmark); TEKES and Helsinki University of Technology (Finland); CEA Cadarache and CEA Saclay (France); Institute of Plasma Physics (Garching, Berlin and Greifswald), FZ Jülich, FZ Karlsruhe, (Germany); Hong Kong Polytechnic University; Hungarian Academy of Sciences (Hungary); Dublin City University and University College Cork (Ireland); ENEA Frascati and Consorzio RFX (Italy); University of Toyko, NIFS and JAEA (Japan); Taegu University (Korea); FOM and University of Eindhoven (the Netherlands); Institute of Plasma Physics and Laser Microfusion (Poland), Instituto Superior Tecnico Lisbon (Portugal); MEdC (Romania); the Kurchatov and Ioffe Institutes, Moscow State University, St. Petersburg State Technical University (Russian Federation); CIEMAT, University of Alicante and University of Seville (Spain); Vetenskapsrådet (VR) (Sweden); CRPP Lausanne, University of Basle and Paul Scherrer Institute (Switzerland); General Atomics in San Diego, Princeton Plasma Physics Laboratory, Oak Ridge National Laboratory, Argonne National Laboratory, Stanford University, Massachusetts Institute of Technology, University of California (San Diego, Los Angeles and Davis), University of Wisconsin, Lawrence Livermore National Laboratory, University of Maryland (all USA).

2.2.4 UNIVERSITY COLLABORATIONS

There are collaborations and other links with UK universities, many of which have post-graduate and other students working at Culham.

Over 40 students from manyUK (and a few overseas) universities work on fusion with CCFE, with about half based at Culham and half at their universities. The topics studied span theoretical and experimental plasma physics, materials science, technology and engineering. Many are ‘EPSRC Industrial CASE’ students of which Culham has an annual quota of six. In addition to collaborations involving students, there is work with university staff on a range of research projects, many of which are featured in this report. And in some cases Culham staff contribute lectures to university courses.

Universities with which there were active collaborations in 2009/10, some of which have their own fusion-related EPSRC grants, include: Birmingham, Bristol, Brunel, Cambridge, Cranfield, Durham, Edinburgh, Glasgow, Heriot Watt, Imperial College London, Liverpool, Loughborough, Manchester, Oxford, Queens Belfast, Salford, Sheffield, St. Andrews, Strathclyde, University College London, Warwick and York.

2.3 EXTERNAL RELATIONS

2.3.1 PUBLIC UNDERSTANDING OF FUSION

The continuing interest in climate change and the need for a new baseline energy source has kept fusion in the public eye throughout the year.

A Public affairs and media

Culham made some 100 appearances in the media during 2009/10. These ranged from the extremely high-profile: Channel 4 News report on '10 ideas to save the planet' , BBC 'Bang Goes the Theory' popular science series and BBC Radio 4 'Costing the Earth' and 'Frontiers' and print articles and features in national newspapers to articles in the scientific and technical press and in the local media.

During the year, the Public Relations team continued its use of 'new media' to reach out to new audiences by developing a series of video podcasts available on YouTube, and making use of social networking websites including Facebook and Twitter, where Director Steve Cowley's talk at the prestigious TED (Technology, Entertainment, Design) Global conference held in Oxford was referenced many times.

Figure 2.10: *CCFE Director Steve Cowley speaking at the TED Global conference in Oxford*

In the Public Affairs area a briefing programme for UK Members of the European Parliament was undertaken with visits by Marina Yannakoudakis, James Elles and Catherine Bearder to Culham and dinner debates for groups of MEPs held in Strasbourg. Lord Drayson, then Minister for Science and Innovation, was also welcomed to Culham, as were local councillors who benefited from a dedicated Open Evening.

Public Relations staff, aided by willing volunteers from within the Culham programme, also gave a large number of external talks during 2009/10.

B Public outreach

To meet a growing demand, the normal series of Open Evenings through the year has been increased to nine in 2009/10. Each evening welcomes 100-120 people to learn about fusion and visit the JET and MAST experiments.

Culham also actively supported local outreach events such as the Abingdon Schools Science Fair and the opening event of the annual Oxfordshire Science Festival. Staff also took part in various local ‘Science Shop’ type activities.

C EFDA-JET CSU support

The EFDA-JET Close Support Unit is responsible for the management and co-ordination of the JET experimental programme, for analysis and dissemination of the results and for monitoring of UK Atomic Energy Authority’s implementation of the JET Operation contract.

The CCFE Public Relations team continued to provide through ‘Host Support’ strong support for EFDA-JET’s communications activities and also its EIROforum activities throughout the year. It provides one of the core members of the Outreach and Education group, which links the public and schools around Europe to the work at the EIROforum laboratories (the other members being CERN, ESRF, ILL, ESA, ESO and EMBL).

D Education outreach

The high demand from secondary schools, colleges and universities for visits to Culham continued to outstrip capacity. The Public Relations team welcomed as many groups of students as possible, with around 1,700 (primarily ‘A’ level physics) students visiting during 2009/10. The number of guides has been increased to continue to accommodate as many school requests as possible. Culham staff also went out to schools around the country, discussing fusion with around 850 students.

The Sun Dome outreach activity, aimed at primary school-age children (10-11 years old), remained in great demand following its launch in March 2007. Developed originally with the aid of an EPSRC Partnership for Public Awareness rant and EURATOM funding, the Sun Dome uses a large portable dome which is inflated at the school venue and comprises movies and interactive role-play activities. There continues to be excellent feedback from teachers and pupils and the number of Sun Dome shows (mostly at schools local to Culham) has been stepped up to build on this positive response, with 4100 children attending almost 1,000 shows in 2009/10.

In addition to being offered as a free resource to local primary schools, new shows are being developed and trialled for secondary schools.

Fig 2.11: *Report on Sun Dome on BBC local television*

2.3.2 Culham Summer School

The 46th annual Plasma Physics Summer School took place at Culham Science Centre over two weeks in July. This year's School was attended by 25 students of whom two thirds came from outside the United Kingdom. Lecturers are drawn from research and academic institutions across Europe, providing a broad-based curriculum. The Culham Plasma Physics Summer School is committed to offer training in plasma physics suitable for a wide scientific community.

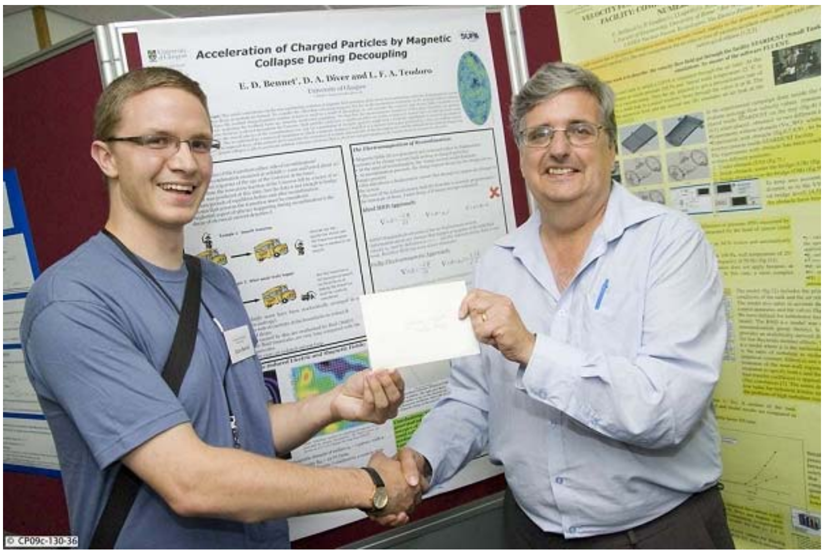

Figure 2.12: *Culham Summer School 2009 poster prize being awarded to Euan Bennet, University of Glasgow by Tim Hender*

2.3.3 Culham Thesis Prize

Each year CCFE sponsors through the UK Institute of Physics a prize for the best thesis in the field of plasma physics submitted through a UK or Irish University. The 2009 Culham Thesis Prize was awarded to Ian Chapman for his thesis entitled 'Modelling the stability of the n=1 internal kink mode in tokamak plasmas'. He received a cheque for £500 at the annual IOP plasma physics conference in Windermere.

Figure 2.13: *Ian Chapman (left) receiving a cheque from Declan Diver, Chair of the IoP Plasma Physics Group*

2.4 INTERNAL INITIATIVES AND CONTROL

2.4.1 SAFETY

The United Kingdom Atomic Energy Authority continues to maintain a low accident rate. Injury accidents have increased slightly, primarily due to both JET and MAST entering periods of shutdown where industrial risks are generally higher. All these accidents have been relatively minor in nature with few lost days and causes fully investigated.

Significant progress has been made on addressing management of the site electrical safety. A survey of all electrical cubicles and junction boxes (more than 2000) was completed and a monitored database of actions is in place. All cubicles with electrical supplies above Extra Low Voltage (ELV) are now locked with keys controlled by an appointed person.

Another full year was completed under the Occupational Health and Safety Improvement Programmes. Key achievements included:

- The implementation of a behavioural safety programme. This is a peer led programme with the training being delivered by trained personal from Authority staff and contractors. To date about 1000 people have attended the training and feedback has been overwhelmingly positive. Since the introduction of this course there has been an increase in the number of pro-active near miss reports where people have raised safety concerns;
- A new work control system was implemented following a detailed pilot. The aim was to reduce paperwork and streamline the system. The system is still bedding in but to date users have found it an improvement on the previous system;
- Work was done to improve safety communication including themed safety notice boards.

The Authority board and Senior Management team display visible, strong commitment to improving safety on the Culham site which has been key to the successes this year.

2.4.2 QUALITY AND MANAGEMENT SYSTEMS

In 2009 CCFE maintained its certification to the national and international standards ISO9001, ISO14001, and BS OHSAS18001 (for Quality, Environmental, and Occupational Health & Safety management respectively) with only two minor Corrective Actions raised by the assessors. In addition, following the successful completion of an improvement project that ran throughout 2009, CCFE Health Physics has recently been accredited to the ISO17025 standard for testing and calibration laboratories. Achieving this accreditation ensures the quality of the analysis of beryllium Personal Air Sampling undertaken at CCFE for staff working on JET.

During the year the revised work control system (the system for ensuring on-site work – installation, maintenance etc – is defined and undertaken safely while meeting the necessary quality standards) has been rolled out across CCFE. This system is now in operation for all the work undertaken as part of the major JET Shutdown that started in October 2009. The new system unifies and simplifies the arrangements for the pre-planning and approval of systems of work for the many complex and, in some cases, high hazard tasks being undertaken.

As part of the normal process of continual improvement a range of procedures and specifications related to the technical control system, which ensures equipment designed and procured for use on the JET and MAST devices meets the required standards, have been reviewed, revised, and reissued. Also in relation to ensuring appropriate quality standards for design, a project has been successfully undertaken to implement the SmarTeam product lifecycle software across the CCFE Design Office. This software provides a step change in the management of engineering models and drawings and provides a platform for collaboration with other fusion organisations, particularly with regard to ITER related tasks for Fusion for Energy (F4E), the European agency responsible for ITER procurement.

2.4.3 ENVIRONMENT

2009/2010 has seen significant change for environmental management at Culham. The Environment Section has been relocated into Safety Group (now the Safety, Health and Environment Group), allowing integration of these related fields to progress.

The Authority's Environmental Management System retains certification under ISO14001:2004, and has continued with a programme of continual improvement as part of the requirements. Initiatives onsite this year have included: the installation of new water metres across site to improve accountability of use; the sending offsite for reuse or recycling of over 40 tonnes of metal waste and 26 tonnes of gravel and sand (for use as aggregate); the introduction of site waste collection and survey schedules to prevent waste from accumulating with risk to the environment and health and safety.

A project has been started to re-examine Culham's methods of disposal for radioactive material, seeking to provide confirmation that the best practicable environmental methods are being utilised. The report is due to be completed before the end of 2010/11.

2.4.4 TRAINING

A Culham Research Fellowships

The scheme offering Fellowships for outstanding researchers in an early stage of their career (typically immediately after their PhD, or after a short post doctoral position elsewhere) is in its fourth year. These two-year Culham Fusion Research Fellowships are open to anyone, to research on any topic within the research programme of the EURATOM/CCFE Association. Candidates are invited to propose their own research project, and a period working in another laboratory is encouraged to provide wider experience. One or two are selected each year. Several past fellows have also been awarded EFDA Fusion Research Fellowships, and all have been selected for posts in fusion research at Culham or elsewhere at or before the end of their fellowship.

Further details on the Culham Fusion Research Fellowships can be found at: http://www.ccfe.ac.uk/Fellowships.aspx.

B Culham Apprentice Scheme

CCFE runs an advanced apprentice scheme, in order to maintain the engineering skills base at technician level. The first apprentice intake has now successfully completed the apprenticeship, which was celebrated at a Graduation Prize Giving Ceremony in September 2009. Ross Brawn, of Formula 1 fame who is an ex - Authority Harwell Apprentice presented the prizes and told how his career had developed based on much of what he learned during his apprenticeship.

In 2009, the scheme continued to function well. Two of the fourth-years are studying at Oxford Brookes University, one at the Thames Valley University, Reading and one at Swindon College. The second-years will be commencing the new Oxford Brookes Foundation Degree, starting in September 2010, parts of this syllabus having been written by CCFE employees via employer consultation with Abingdon and Witney College. . A further four apprentices (two mechanical and two electrical) joined the scheme in 2009 and recruitment is in progress for this year's intake. More information on the scheme can be found at: www.culhamapprenticeshipscheme.com

The Apprentice Appreciation Week was a great success once again being well attended by local schools and again culminating in the popular rocket launch competition. This year's winners were from King Alfred's School in Wantage.

2.14: *CCFE apprentices competed for the Oxfordshire Science Festival 'Siege Engineer 2010' title, building a trebuchet capable of launching missiles 50 metres*

C Culham Graduate Scheme

The Culham Graduate Scheme is going from strength to strength since it was started in 2007. This year saw a very strong field of candidates from across the UK numbering more than 100 in total. These were short-listed to a final dozen who attended the annual assessment centre in March. The quality of the applicants was very high resulting in four engineering graduates and one physicist being selected, bringing the total on the two-year scheme to 12, the highest number ever at Culham. The numbers and quality of applicants reflects the efforts made under our 'engineering outreach' programme and by the graduate team to promote the work at Culham and the career opportunities available. More details on the scheme and its benefits are available at: http://www.culhamgraduatescheme.com.

D Power Academy

The Power Academy is a scheme run by the IET that supports power engineering students through their studies at one of the member universities. A total of six university, sixteen industry and two institution partners work together to further power engineering and ensure a healthy pool of talent for all power engineering needs. Culham, elected to the Academy in 2007, can sponsor up to two Power Engineering undergraduates each year. In 2009, one student was selected. Further details on the Power Academy can be found at: http://www.theiet.org/about/scholarships-awards/power-academy/partners.cfm.

E EFDA Goal Orientated Training Scheme

CCFE is taking part in a number of projects in the Goal Orientated Training Scheme, which was initiated to provide a structured programme to develop staff with particular expertise in areas identified as being of significant relevance to the future fusion programme, but where there was currently limited expertise. The projects CCFE is currently involved in are on fusion blankets, tokamak theory, neutral beams, tritium technology, tokamak operation, power supply engineering and quality assurance. CCFE both provides staff to be trained and gives some of the training courses.

2.5 KEEP-IN-TOUCH WORK ON INERTIAL FUSION ENERGY

2.5.1 INTRODUCTION

The work that is undertaken in the UK on Inertial Fusion Energy takes place at the Central Laser Facility at the STFC Rutherford Appleton Laboratory (RAL, http://www.clf.rl.ac.uk). This work receives some EURATOM funding as part of its keep-in-touch inertial fusion programme.

In last year's report, experiments were described that examined the possibility of control the divergence of the fast electron beam. For cone-guided fast ignition, the leading candidate for the realisation of inertial fusion energy, this is a very important parameter in minimising the required petawatt laser energy for ignition. If the divergence is too large, then the beam energy becomes simply too big for a practical facility. Successful experiments were reported which showed that control over the divergence of the fast electron beam was possible in one-dimension using large magnetic fields generated in the target material resistivity mismatch concept. A tin-layer was sandwiched between two layers of aluminium and then irradiated by the petawatt laser pulse delivered by the Vulcan PW laser facility. The experiment was led by physicists based at Queens University Belfast and the collaboration was between physicists based there and at the Rutherford Appleton Laboratory, the University of Strathclyde and Imperial College London.

This year, the team extended their study to two dimensions, using a core/cladding structure, analogous to an optical waveguide. Collimation was achieved by self-generated magnetic fields (of MGauss magnitude) at the boundary of a high resistivity core with a low resistivity cladding. The relativistic electron beam was confined to an area of the order of the core diameter (50 μm), which has the potential to substantially enhance the coupling efficiency of electrons to the compressed fusion fuel in the Fast Ignitor fusion in full-scale fusion experiments.

2.5.2 EXPERIMENT

Computational modelling indicates that the propagation of an intense electron beam, generated by a petawatt laser-plasma interaction with solid targets, is accompanied a magnetic field that is formed inside the dense plasma on the edge of the beam. The field arises from Faraday's law for magnetic field ($\underline{B}$) growth

$$\frac{\partial \underline{B}}{\partial t} = \eta \underline{\nabla} \times \underline{j} + (\underline{\nabla}\eta) \times \underline{j} \qquad (1)$$

where $\underline{j}$ is the fast electron current and η is the plasma resistivity. The first term in equation (1) generates a $\underline{B}$ field that acts to push electrons into regions of higher current density and causes focusing, pinching and collimation of the beam. It can also lead to beam filamentation. The second term in equation (1) indicates that the B-field will grow at resistivity gradients such that fast electrons are pushed into regions of higher resistivity. Initially, the first term dominates. As the temperature rises, the resistivity falls faster than linearly with temperature and the magnetic field eventually changes sign and hollows rather than focuses the beam.

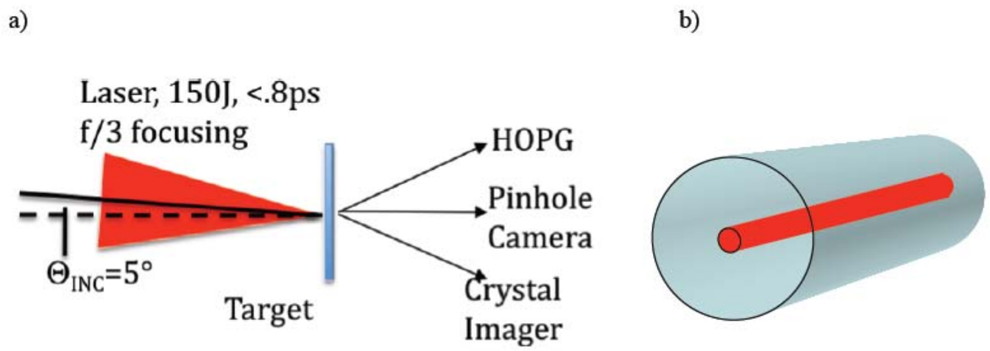

Figure 2.15: *(a) schematic of the experimental and diagnostic arrangement; (b) schematic of the structured collimator target that was irradiated by the Vulcan PW laser pulse*

Equation (1) indicates that a target that has a central region of higher (lower) resistivity surrounded material that has a lower (higher) resistivity will act to collimate (hollow) the fast electron beam. This concept has been extensively investigated both analytically and by numerical simulations by Robinson and Sherlock. They showed that the employment of structured targets comprising different material layers can use this effect to control the beam pattern. The first proof-of-principle experiment used the Vulcan PW laser facility to irradiate a one-dimensional 'sandwich' target. Observations of optical transition radiation and X-ray bremsstrahlung radiation confirmed that the electron beam was restricted in the plane between the layers due to B field growth. Those observations have been published recently in Physical Review Letters.

These measurements were extended to two dimensions with the use of a structured core/cladding target illustrated schematically in Figure 2.15. X-ray images of the rear surface of plane aluminium targets with increasing thickness confirm that the beam diverges with a given angle. However, when the structure core is added, the beam is restricted to 60□m Full Width at Half Maximum.

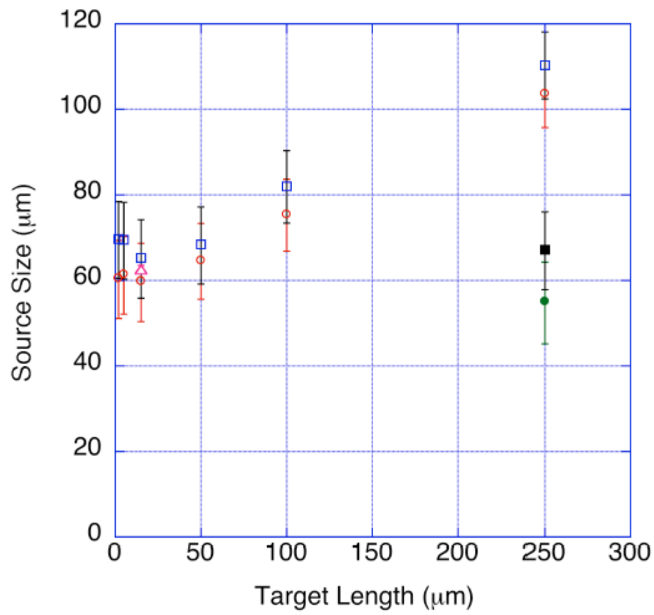

Figure 2.16: *X-ray spot sizes of plane targets (open symbols) and core / cladding targets (filled symbols) as a function of target thickness*

This is encouraging because it shows that this method to control fast electron beam is robust (i.e. extends to two dimensions) and opens the design space for fast ignition.