Large Research Facilities

UK TRADE & INVESTMENT

Business opportunities from Large Research Facilities

UK industrial and research capability serving the world

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The number of Large Research Facilities, commonly referred to as "Research Infrastructures", has risen sharply in the last few decades both in Europe and further afield. Many of these facilities undertake cutting-edge, and increasingly international, scientific research. Crucially, they also offer a wide range of business opportunities.

Cover image: *Planck during its final cleaning. The spacecraft's surface was inspected under UV light to detect dust particles that fluoresce after illumination with UV (Credit: ESA)*

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About this publication

The aim of this publication is to make UK organisations (especially companies) aware of major business opportunities from Large Research Facilities (LRFs) on a worldwide basis. It highlights the factors they need to consider when seeking to exploit such opportunities, and how UK Trade & Investment (UKTI) can offer targeted support to bid for and win contracts from these facilities.

Another important purpose is to provide UK missions abroad with a comprehensive picture of the UK's world-leading academic/industrial capability in selected technology areas and the types of LRFs that exist in this country. This is done to help in the identification of commercial opportunities arising from LRFs in overseas markets that would be relevant to UK organisations.

This publication is divided into three sections: **Section A** highlights the breadth of business opportunities presented by LRFs and offers practical guidance on what factors to consider when applying for tenders from these facilities.

Section B showcases UK capability in selected technology areas such as cryogenics, fusion energy, high-performance computing, neutron scattering and muon spectroscopy, precision engineering and synchrotrons. This is supplemented by a series of case studies of UK companies, which have won contracts from LRFs (some with UKTI support).

Section C presents an overview of LRFs in the UK, focusing particularly on Research Councils, and other facilities such as the National Nuclear Laboratory, the Integrated Vehicle Health Management Centre and the Catapult centres.

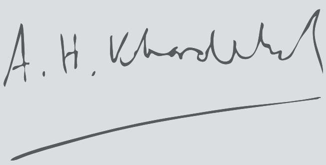
A series of Annexes lists abbreviations, glossary of technical terms, selected websites, bibliography and contact detail in UKTI. The glossary provides general descriptions of selected technical terms used in this document. These descriptors have been found using a variety of sources, including Wikipedia.

The reader should also note that this publication does not include every LRF in the UK or provide a detailed analysis of all the country's Research Councils and academic/industrial capability. Nor does it present a comprehensive list of overseas LRFs. There are simply too many of them.

What it does do, though, is present a thorough overview of selected UK industrial and research capability and how it can support LRFs around the world.

Dr Amit Khandelwal

UKTI



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Zeeko Ltd

Foreword

Steve O'Leary
Director – Infrastructure and Low Carbon, UKTI

Visible and Infrared Survey Telescope for Astronomy (VISTA) is a 4-m class wide field survey telescope for the southern hemisphere, equipped with a near infrared camera and has an azimuth-altitude mount. It is located at the ESO's Cerro Paranal Observatory in Chile (Credit: VISTA).

Right: Wide-field view of the Orion Nebula (Messier 42), lying about 1350 light-years from Earth taken with the VISTA infrared survey telescope. The new telescope's huge field of view allows the whole nebula and its surroundings to be imaged in a single picture and its infrared vision also means that it can peer deep into the normally hidden dusty regions and reveal the curious antics of the very active young stars buried there. This image was created from images taken through Z, J and Ks filters in the near-infrared part of the spectrum. The exposure times were ten minutes per filter. The image covers a region of sky about one degree by 1.5 degrees.(Credit: ESO/J. Emerson/VISTA. Acknowledgment: Cambridge Astronomical Survey Unit)

It is my pleasure to present this publication, *Business Opportunities from Large Research Facilities – UK Industrial and Research Capability Serving the World*.

The UK is home to some of the biggest and best LRFs anywhere in the world, catering for many different disciplines ranging from astronomy and engineering through to molecular biology, medical research and the natural sciences.

Funded by the UK Government, facilities such as the British Antarctic Survey, Diamond Light Source, ISIS Pulsed Neutron and Muon Source, and the Culham Centre for Fusion Energy, have not only secured the UK the premier position as one of the best places to undertake research but also support a vibrant high-technology industrial manufacturing base.

The UK also contributes to several international LRFs through direct subscription fees to overseas facilities such as CERN, home to the world's largest particle accelerator and the European Southern Observatory (ESO) or through the EU, for example, ITER (the International Tokamak Experimental Reactor). This investment is focused on ensuring that the UK's research community remains at the forefront of science, technology and innovation through scientific collaboration.

Crucially, LRFs offer diverse and attractive procurement opportunities for UK organisations. For example, the European Southern Observatory has budgeted €1 billion for the construction of Europe's Extremely Large Telescope, while CERN's annual procurement budget is over £200 million.

As part of the UK Government's agenda of growth through trade, UKTI is keen to ensure that UK organisations are:

- Aware of major business opportunities from LRFs on a worldwide basis, and
- Offered targeted support through UKTI's extensive global network so that they are able to make contact with senior LRF decision makers, and bid for/win contracts from these facilities.

UKTI is also keen to help overseas organisations bring their high-quality investment to the UK, and ideally to set up in science and innovation hubs such as the Harwell Oxford Science and Innovation Campus and the Daresbury Science and Innovation Campus, or in one of the many science parks that exist in this country.

“The UK supports some of the biggest and best LRFs anywhere in the world, embracing many different disciplines ranging from astronomy and engineering through to the natural sciences. These LRFs offer significant and challenging business opportunities for UK Industry globally”

The aim of this publication is threefold. First, to help highlight the breadth of business opportunities offered by LRFs, and which UK organisations should consider applying for. Practical guidance gleaned from companies, the UK’s Research Councils and procurement officials at LRFs is also provided. This outlines the factors to consider when applying for tenders to win contracts from these facilities.

Second, to showcase the UK’s academic and industrial capability in a range of technology areas such as cryogenics, nuclear fusion, precision engineering and synchrotrons. This is supplemented by a series of case studies of UK organisations which have engaged with LRFs and subsequently won contracts from them.

Third, to provide an overview of the diverse range and capabilities of LRFs currently based in the UK. They are playing an increasing role in undertaking contract research and providing solutions to academic and industrial challenges throughout the world, especially through research-based partnerships.

Whether you are venturing into selling to an overseas LRF for the first time, or are an experienced exporter trying to break into an existing or new facility, UKTI offers a range of trade support services that can help you in doing business internationally.

I would encourage you to contact us (see Annex 5) to explore the business opportunities that arise from LRFs all over the world, and we wish you luck in winning contracts.

Artist’s impression of the European Extremely Large Telescope (E-ELT) on Cerro Armazones, a 3060-metre mountaintop in Chile’s Atacama Desert. The E-ELT, a LRF in development, will be the largest optical/ infrared telescope in the world — the world’s biggest eye on the sky. (Credit: ESO)

UKTI

UK TRADE & INVESTMENT

UK Trade & Investment (UKTI) is the Government Department that helps UK-based companies to succeed in the global economy. We also help overseas companies bring their high-quality investment to the UK's dynamic economy, acknowledged as Europe's best place from which to succeed in global business.

UKTI offers expertise and contacts through its extensive network of specialists both in the UK and in British embassies and other diplomatic offices around the world. We provide companies with the tools they require to be competitive on the world stage.

UK TRADE & INVESTMENT

UKTI supports a wide range of British businesses through events and specialist workshops

Investment

UKTI's comprehensive range of services assists overseas companies, whatever their size and experience, to bring high-quality investment to the UK. They are delivered in partnership with teams in London and the devolved administrations of Scotland, Wales and Northern Ireland.

Our services include providing bespoke information about important commercial matters, such as company registration, immigration, incentives, labour, real estate, transport and legal issues.

Deciding where to locate your international business is often a long and involved process. It is UKTI's job to know the UK's strengths and where investment opportunities exist and to help businesses coming to the UK get up and running with speed and confidence.

Trade

UKTI staff are experts in helping your business grow internationally. We provide expert trade advice and practical support to UK-based companies wishing to grow their business overseas. Whatever stage of development your business is at, we can give you the support that you need to expand and prosper, assisting you on every step of the exporting journey.

Through a range of unique services, including participation at selected trade fairs, outward missions and providing bespoke market intelligence, we can help you crack foreign markets and get to grips quickly with overseas regulations and business practice.

In October 2010, UKTI was awarded the accolade of **Best Trade Promotion Organisation** (Developed Country) at the International Trade Centre's Trade Promotion Organisation Network Awards. The awards recognise excellence in export development initiatives and the ability of UKTI to meet the challenges ahead.

For further information please visit ***www.ukti.gov.uk***

“The diversity of Large Research Facilities around the world is truly astonishing, ranging from medical research hospitals and ground-based telescopes through to nuclear fusion experimental reactors, neutron sources and particle accelerators. Crucially, they have a diverse range of needs, such as architectural design, civil engineering, cryogenics, instrumentation and sensor systems among many others, which the UK can help meet. UK business should seize upon these requirements and, with support from UKTI, build long-term profitable partnerships on what are exciting business opportunities.”

Dr Amit Khandelwal
UKTI

Section A

Large Research Facilities

Large Research Facilities

Aerial view of Diamond Synchrotron. (Image courtesy of Diamond Light Source)

1.1 Introduction

The number of Large Research Facilities (LRFs), commonly referred to as "Research Infrastructures", has risen sharply in the last few decades both in Europe and further afield. Many of these facilities undertake cutting-edge, and increasingly international, scientific research to provide answers to questions such as:

- Why is there a universe? Was there ever life on Mars?
- How are the chemical elements created?
- How can we design better treatments for cancer, malaria and diabetes?
- How do the oceans regulate the Earth's climate?
- Can we create new materials to store energy?

In essence, LRFs serve to solve challenges facing the world on energy, living with environmental change, ageing and health, digital economy and nanoscience, through engineering to applications.

Yet, despite this growth, there is no one universal definition of what constitutes an LRF as they can vary so much – from oceanographic ships to particle accelerators and synchrotrons, and from research hospitals to nuclear fusion reactors, space-based sensors and ground-based telescopes and large data sets.

Two specific examples are the Diamond Light Source – the UK's national synchrotron facility – which has helped to solve commercial concerns such as speeding up the drug discovery process for the pharmaceutical industry, and CERN's Large Hadron Collider (LHC), a particle accelerator which is currently being used to elucidate the existence of the Higgs boson.

1.2 Types of Large Research Facility

LRFs can be simplistically divided into the following categories: (i) UK – national facility, (ii) intergovernmental and (iii) overseas, as outlined in *Table 1.1*.

A key feature of an LRF is its substantial procurement budget, either for upgrades to existing infrastructure or for new builds. As a result, LRFs can offer diverse, lucrative and often high-end business opportunities for UK companies.

Table 1.1: Selected examples of LRFs – UK national facility, intergovernmental and overseas

Type of LRF	Funding	Selected examples	Additional details
UK – national facility	Principally funded by the UK Government through the Research Councils such as the Natural Environment Research Council (NERC) and the Science and Technology Facilities Council (STFC).	**Culham Centre for Fusion Energy (CCFE)** **NERC** • British Antarctic Survey • National Oceanography Centre • National Centre for Atmospheric Science **STFC** • Diamond Light Source (with 14% from the Wellcome Trust) • ISIS Pulsed Neutron and Muon Source • UK Astronomy Technology Centre	Procurement rules in these facilities are subject to OJEU rules established by the European Commission.
Intergovernmental	Funded by a series of nations. This could be jointly with European partners, or with other global partners such as the USA. These facilities can be located in the UK or elsewhere around the world.	• Extreme Light Infrastructure (ELI), Czech Republic, Hungary, Romania • European Organization for Nuclear Research (CERN), Switzerland and France • European Southern Observatory (ESO), Germany and Chile • European Synchrotron Radiation Facility (ESRF), France • Institut Laue-Langevin (ILL), France • International Tokamak Experimental Reactor (ITER), France (originally called the International Thermonuclear Experimental Reactor)	These tend to have either unique procurement rules or rules based on the EU system. They often aim to buy from their funding countries.
Overseas	These national facilities are principally funded by overseas governments.	• National Laboratory for Particle and Nuclear Physics, Canada • Tata Institute of Fundamental Research, India • Korea Aerospace Research Institute, South Korea • National Space Organization, Taiwan • New Karolinska Solna University Hospital Project (including Research Centre), Sweden • Oak Ridge National Laboratory, USA • Los Alamos National Laboratory, USA	These have unique procurement rules. The facilities often prefer procurement from organisations based in the funding country.

Concomitantly, there are opportunities for innovative UK-based and overseas companies to use LRFs at national science and innovation campuses such as at Harwell and Daresbury, and to draw on the diverse range of technical capabilities within this specialist environment.

Another important characteristic of LRFs is their considerable size and the fact that they are expensive to build, maintain and operate. For example, in 2011 CERN's overall budget was 1.16 billion Swiss francs, which is spent on the running costs of the facility such as salaries and energy, and on procuring a wide range of products and services.

Not surprisingly, LRFs have a life span of between 10 and 20 years (or more), are often multidisciplinary and serve many different users. Yet another defining feature is that the facilities have strong academic and increasingly business links, often across nations.

Given that research is being pursued on an international basis, reflecting the nature of global challenges such as climate change and in areas such as particle physics, many national LRFs are being replaced by next-generation international facilities such as the European Southern Observatory and ITER. These are now being viewed as a research resource for both academia and industry.

LRFs often fall outside the funding remit or capability of any individual organisation, and are potentially jointly funded or suitable subjects for international collaboration, in some cases distributed across a number of different countries. For example, the Extreme Light Infrastructure (ELI) is located in the Czech Republic, Hungary and Romania.

Crucially, these large infrastructures also have ongoing procurement needs, which can present attractive business opportunities to UK organisations. This is discussed below.

1.3 Business opportunities from Large Research Facilities

LRFs offer both volume-based and value-added opportunities for UK organisations, and there are plenty of worthwhile ones to pursue. For example, these can range from accelerator technology, advanced materials (such as beryllium-coated vacuum vessels and metal matrix composites), construction and cryogenics through to project management, design studies and remote handling *(see Table 1.2)*.

For example, when constructing the LHC, CERN had a materials budget of almost 5 billion Swiss francs, while the ESO has budgeted €1 billion for the construction of Europe's Extremely Large Telescope.

Contracts worth millions of euros are regularly awarded to European suppliers in high-technology areas, including detectors, optics and precision motion systems. Furthermore, there is the opportunity to develop cutting-edge technologies or products in association with LRFs.

When planning the next generation of science facilities, LRFs will often encounter areas where their scientific requirements cannot be met by today's products and technologies. To address this issue, LRFs regularly initiate multi-million-euro development programmes in partnership with organisations such as universities. For example, in 2011 CERN entered into collaboration with five UK universities, as well as the Accelerator Science and Technology Centre (ASTeC) at the Science and Technology Facilities Council's Daresbury Laboratory for the design of key components of the beam delivery system for the Compact Linear Collider (CLIC).

The aim of CLIC is to develop a machine to collide electrons and positrons (anti-electrons) head on at energies up to several teraelectronvolts (TeV). This energy range is similar to the LHC, but by using electrons and their antiparticles rather than protons, physicists will gain a different perspective on the underlying physics.

Table 1.2: *Examples of areas in which LRFs procure*

- Accelerator technology, magnets and superconductivity
- Advanced materials
- Architecture, civil engineering, buildings and construction
- Biological material
- Chemicals
- Cryogenics, vacuum systems and gas
- Computing and IT services/support
- Design studies
- Electrical/electronic systems
- Fluid systems
- Instrumentation and sensor systems
- Mechanical handling and structures
- Particle detectors
- Project management
- Remote handling
- Support services
- Synchrotron beamlines
- System integration services
- Welded structures

For a UK company, such programmes represent a potential opportunity to advise on engineering and design challenges, as well as to participate in the manufacture of component parts for the machine itself.

Most LRFs also actively promote the commercial exploitation of intellectual property that has been generated through their technology development programmes. In some cases they may even provide funding to support the application of these technologies to other fields. Not surprisingly this can prove to be an attractive proposition for many UK cutting-edge technology companies.

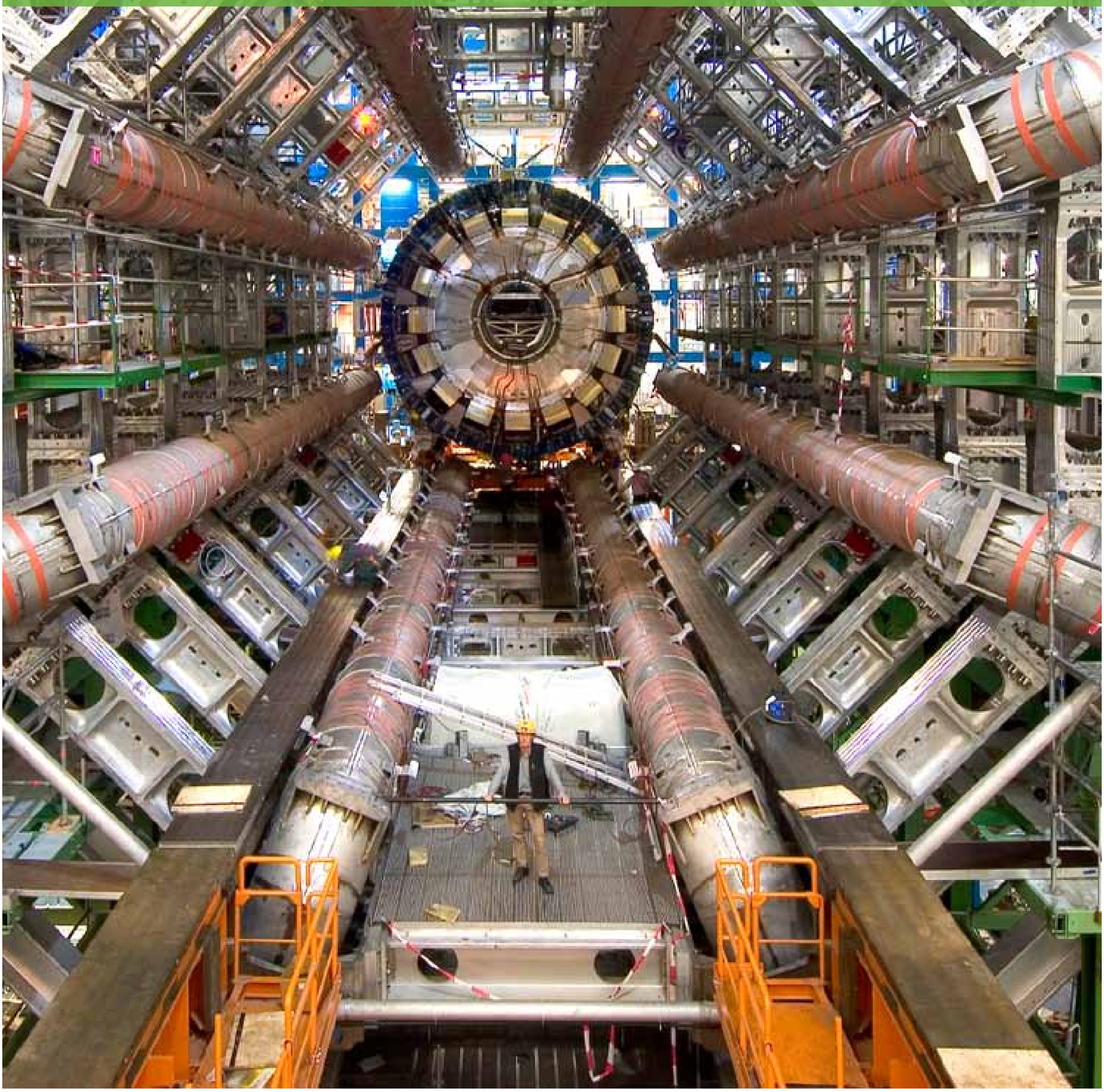
But it's not just technology companies that can benefit from working with LRFs. Contracts for architectural design, large steel structure fabrication or tunnel excavation are also awarded by LRFs. For example, a UK architectural firm, BFLS, won the contract to design the building for ELI in the Czech Republic.

Many LRFs, such as Diamond Light Source, CERN and ITER, are also prominent national and international brands, and a case study showing how a product and/or service from the UK has been used by them is a compelling endorsement and a powerful marketing tool to gain new business from other LRFs around the world.

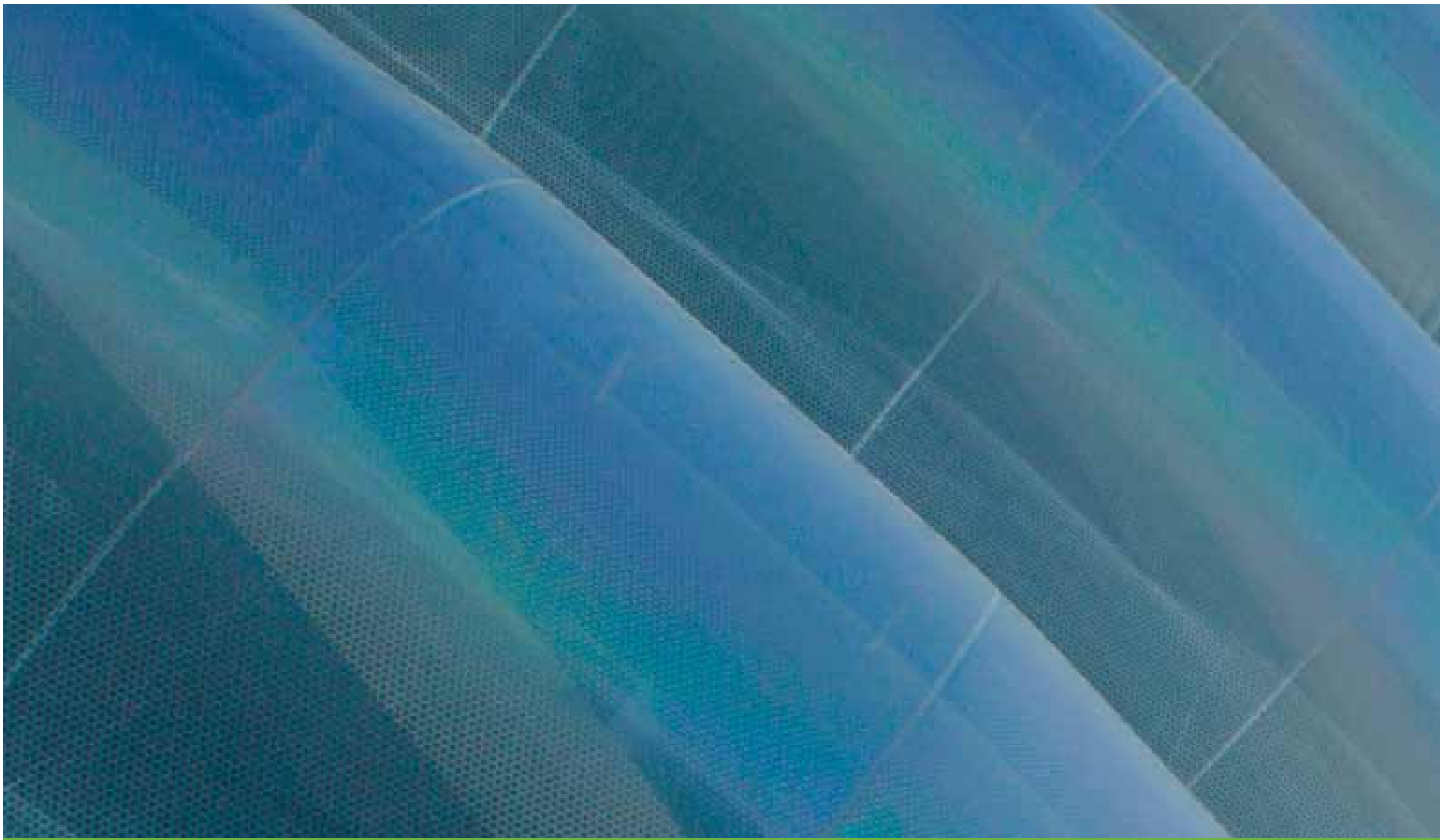
There is no doubt that LRFs are an attractive customer for UK organisations from the perspective of business opportunities. Winning a contract from an LRF can not only generate revenue but also enhance your reputation. This in turn can lead to repeat or new business by opening doors to procurements from other LRFs.

In short, there is a lot that UK businesses can do to increase their chances of winning an LRF contract and hence add to their profitability. The next chapter identifies some of the key factors of success in order to win business from LRFs around the world.

Many LRFs, such as Diamond Light Source, CERN and ITER, are also prominent national and international brands, and a case study showing how your product has been used by them is a compelling endorsement and a powerful marketing tool to gain new business from other LRFs around the world.



ATLAS particle detector at the LHC during installation © CERN



"Industry is vital in keeping CERN's research facilities running, supplying us with everything from off-the-shelf products to highly technical components. This provides the opportunity to small, medium and large enterprises to participate in and benefit from technological advancements in our quest for scientific discoveries."

Dante Gregorio
Section Head – Contracts for supplies and IT, Procurement Service at CERN

Winning business from Large Research Facilities

Winning business from Large Research Facilities

The LRF zone at Technology World 2010 and specialist one2one meetings at Technology World 2011.

2.1 Introduction

A wide variety of factors should be considered in order to enhance a UK organisation's chances of successfully applying for, and winning, tenders from LRFs. This includes networking and establishing personal contact within an LRF; keeping abreast of developments in LRFs both in the UK and abroad; getting involved in technical development; and understanding procurement rules. These factors, together with the type of support that UKTI offers, are discussed below.

2.2 Key factors of success

Networking and establishing personal contact

Personal contacts at LRFs can help with understanding the requirements of upcoming projects and can also make the industry aware of lower-value contracts that do not need to go through formal procedures.

The UK has an industry representative for many of the intergovernmental research facilities funded by this country. For example, the UK has industry liaison officers for CERN, the European Synchrotron Radiation Facility (ESRF), Institut Laue-Langevin (ILL), the European Southern Observatory (ESO) and the International Tokamak Experimental Reactor (ITER). Their work is designed to improve the flow of information from the facilities to UK industry and can be valuable in helping business to make contacts as well as providing information on procurement rules. UKTI can also help in this regard *(see Section 2.3)*.

Learning about future research infrastructures

A number of roadmaps on LRFs have been published. For example, the Research Council UK (RCUK) Large Facilities Roadmap provides a comprehensive picture of current facilities, and their renewals and upgrades. It also identifies emerging facilities that are of the highest strategic importance for the UK.

Similarly, the European Strategy Forum on Research Infrastructures (ESFRI) roadmap identified new and potential LRFs of pan-European interest. They correspond to the long-term needs of European research communities, covering all scientific areas, regardless of location. In essence, this activity aims to promote the European research area concept which will be delivered through a host of LRFs.

Several European countries are now using the ESFRI Roadmap as a blueprint for the development of national roadmaps and for the setting of national priorities, including existing and new research facilities.

Such resources can be invaluable for businesses by giving them significant notice about existing upgrades and upcoming developments in research infrastructures.

Getting involved in technical development

Facilities often require cutting-edge technologies which are not "off-the-shelf" products. Development of these technologies often involves large teams of researchers from the facilities, academia and industry working together

For further information on the RCUK and ESFRI roadmaps please visit:

Research Councils UK Large Facilities Roadmap:

www.rcuk.ac.uk/research/Infrastructure/Pages/lfr.aspx

European Strategy Forum on Research Infrastructures (ESFRI) Roadmap:

www.ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri-roadmap

with funds coming from several routes, such as the facilities and industries themselves or funding agencies.

Industry involvement at a development stage positions a company to receive contracts in that sector. It also allows them to supply similar facilities that may use similar technologies.

Understanding the procurement rules

Understanding the procurement rules of each LRF is key to bidding for, and winning, tenders. Many have different rules depending on their governance, the country they are located in and the local laws that apply. For example, research infrastructures in the EU will follow the European procurement rules. These include UK research infrastructures such as the High-End Computing Terascale Resource (HECToR) and the Science and Technology Facilities Council's (STFC's) Central Laser Facility and ISIS.

Other research facilities, like CERN, are funded by several countries and have the status of intergovernmental organisation. Others, like ILL and ESRF in France, are established as private companies governed by civil law.

Such facilities can establish their own internal governance procedures, including the rules under which they purchase equipment and services, and are not subject to EU procurement requirements. Their internal rules are usually decided upon and agreed by representatives of the funding member states or partner country and are intended to ensure a high level of cost efficiency, transparency and fairness to the member states.

For example, CERN's basis of adjudication for supply contracts is that a contract will be awarded to the bidder with the lowest offer ((Free Carrier (FCA) price)), which complies with the technical specification and delivery requirements. This is applied even if a bid offers a technically superior product. If, however, suppliers in a member state cannot provide the equipment required at a reasonable cost or if no technical alternative exists, then as an exceptional circumstance contracts can be placed with non-member states.

It is noteworthy that some intergovernmental organisations, like CERN, aim to achieve *"juste retour,"* which represents a quantitative linkage between the contributions that a partner country makes to an LRF collaboration, and the benefits that it obtains in terms of contracts awarded and nationals hired.

Juste retour can be a formal requirement, with strict accounting to ensure that money contributed returns to each partner as the infrastructure is built and operated. More often, it is a "soft" requirement, where benefits, averaged over several years, are in some kind of approximate proportion to investments made.

Overall, understanding which process will be applied during the assessment of any bids is crucial for winning tenders. *Table 2.1* presents a comprehensive list of factors to consider when identifying and applying for business opportunities from LRFs.

The next section looks at the types of support UKTI offers in assisting UK organisations to engage with LRFs around the world.

Table 2.1

Factors to consider when identifying and applying for business opportunities from LRFs

Theme	Area(s)	Details
Networking and communication	"Opening the door" "Making personal contact" and "Gaining traction"	Identify and make contact with key decision makers in the LRF (e.g., in procurement and technical functions) to: • Build your relationship and establish your business credentials on your skills base and industrial capability, • Gain general information/intelligence on doing business with that particular LRF, • Understand and discuss with LRF officials aspects such as how the LRF operates, the requirements of a specific tender and the intricacies of the procurement process. Once your relationship is established, it ought to be easier to get responses to emails on specific questions you may have regarding an existing or future business opportunity. If in doubt, ask. Do not make any assumptions and do learn more about the LRF. This will help increase your confidence about the LRF, its focus and what it is trying to achieve. This should help you construct any bid and reduce risk in terms of time and cost.
	UKTI and Industry Liaison Officers (ILOs)	Make contact with UKTI's LRF Unit and Research Councils such as STFC and the Culham Centre for Fusion Energy (CCFE) to explore what help they can provide to your organisation. This could include participating in overseas trade missions to LRFs or "meet-the-buyer" type events where key decision makers from LRFs are going to be present. Note: STFC has ILOs for CERN, ESRF, ILL and ESO, while CCFE has one for ITER.
	Communications strategy/flow	Maintain an open communication style which engenders trust and builds relationships with officials in the LRF. Always reply to requests for information (for example, related to specific tendering opportunities/bids) even if it is only to say thank -you. This will help maintain a healthy profile with LRF officials.
Marketing	Marketing strategy, brand management	• Prominently position your brand when you approach LRFs and at the same time ensure that your marketing is fit for purpose and clearly linked to the business opportunity. For example, it is crucial to understand the technical components of the tender, and how your organisation can deliver to the tender requirement. This will help to present your case on technically challenging opportunities given the high risk content in some of these projects. • Emphasise quality standards, past and present customer base, key differentiators of your product/service/technical capability from competitor organisations, and the ability to undertake the work and deliver it on time/to cost.
	Market research	Most LRFs have procurement teams that undertake "market research" to ascertain what suppliers exist nationally and globally. This activity is also referred to as "market survey", a term used at CERN. Some LRFs may restrict this search in the first instance to countries that provide funding to their organisation. Market research can become part of the pre-qualification stage within the overall LRF procurement process.
Tendering opportunities, procurement, pricing, foreign exchange, over-gilding	Accessing tenders	Regularly consult LRF websites for tender opportunities. For example, ITER opportunities can be found at http://fusionforenergy.europa.eu/procurementsgrants/industryportal.aspx while the STFC tender alert service can be found at www.stfc.ac.uk/forms/tenderreg.aspx. Register your details with UKTI to receive notifications about business opportunities from LRFs.
	Procurement	• Understand the procurement rules, and seek clarity where needed from the procuring organisation. These rules can be bureaucratic and stringent, irrespective of the organisation's size. • Timescales for applying for tenders vary and, at times, the window of opportunity can be limited. • Do not over-step the mark in terms of capacity, capability and expertise when considering applying for a tender. • If you have never undertaken business with LRFs or do not have the experience of undertaking large contracts, focus on the smaller contracts which can be successfully delivered. A small contract may seed a larger one in due course.
	Pricing	• The lowest bid or "offer" which complies with the technical specification/delivery requirements can be the basis of an adjudication for LRFs' procurements in contrast to the best technical tender or other extra "value add" considerations such as quality and longevity of products or service delivered. For example, CERN awards contracts for industrial services to be executed on its site on a best-value-for-money basis. • There is likely to be inflexibility from the LRF in the negotiation of the final contract in terms of price. Hence it is important to seek clarification from the LRF about the scope for negotiation on this matter. • Present a clear breakdown of prices (e.g. costs for design, specialised tooling, raw materials, testing/quality assurance, transport) and factor in price increases to cover unforeseen changes in raw material and/or labour costs
	Exchange rate fluctuations	• Be aware of the price sensitivities of the procuring LRF, in particular due to fluctuating foreign exchange rates which can impact on your profit stream. In essence, never speculate in a currency in which you do not have major exposure or conduct business.
	Over-gilding	• Don't "over-gild" (give the buyer more than requested in the tender document and associated technical specification).

Table 2.1 continued

Theme	Area(s)	Details
Business arrangements/ processes	Local distributors	Consider establishing your presence in a foreign market through a local distributor, especially in countries such as South Korea and Taiwan where market access can be difficult because of language barriers. A local distributor can help in identifying tenders before they are formally released into the open marketplace, thereby giving you more time to consider the opportunity as well as for the application process. UKTI can help find local agents through its Overseas Market Introduction Service.
	Contractual conditions	• Commercial conditions in contracts from LRFs can be rigid (with almost no negotiation). For example: • Consequential and indirect losses might be unacceptable and unlimited liabilities are imposed on companies delivering the contract by the LRF procuring the product or service. Some LRFs, such as CERN, do not impose the condition that a contractor is liable for any indirect or consequential losses, except in cases of gross negligence or wilful misconduct. • The cap on contractor liabilities is high (e.g. twice the contract value for technical liabilities) or is ruled out by UK corporate governance rules. For example, CERN normally caps the liability to the highest of (i) the contract price or (ii) 1 million Swiss francs or (iii) the insured amount of the liable party's applicable insurance policy (except for personal injury or death and cases of gross negligence or wilful misconduct). • There may be caps on what contractors can claim. For example, there might be an unrealistic ceiling on living expenses. • Contract negotiations tend to be legalistic and led by the legal team. The technical team may be sidelined and there may seem to be no independent exercise to establish the best technical tender. • Technical officials often do not foresee contractual problems. • Payment terms might be unhelpful, especially for small and medium-sized enterprises. Do note that once contracts are placed by LRFs, they generally tend to run smoothly.
	Contract termination	Be clear about the impact and implication of contract termination. LRFs are likely to stipulate that they are not liable for costs incurred by the contractor for raw materials, specific investments and tooling.
	Sub-contractor	If you are planning to sub-contract any work, be prepared to specify the nature of the sub-contracting, the names of the proposed sub-contractors and the estimated value of the work to be performed by them. In order to minimise risk, some LRFs might impose restrictions at the tendering phase as to the extent of sub-contracting.
	Contract performance	• Companies will be judged not only on the offer price but also on the performance of the contract. Be prepared for the monitoring of contract performance on a regular basis. If a contract has been awarded by an LRF, continually inform its officials about progress, execution plans and delivery schedules, including any difficulties. • Some LRFs might insist on detailed monitoring for non-standard products where the industry has no experience in manufacturing specific products.
Scientific/ technological development	Partnerships	• Proactively network and consider partnering in the technical arena. This may help realise future business opportunities. Do note that LRFs might include contractual clauses which sufficiently protect themselves against possible risks, especially where collaborative/joint development work is undertaken. • Clarify the ownership and use of any intellectual property to be generated before any partnering arrangement commences.
	Market intelligence	Keep abreast of developments in new or existing research infrastructures through roadmaps and LRF Industrial Advisory Boards. Also liaise with UKTI, as well as with ILOs at STFC and CCFE.
Intellectual property rights (IPR)	Technical capability, know-how, licensing	• Protect your technical capability and know-how by thoroughly reviewing issues surrounding the ownership of IPR, especially when developed in a consortium arrangement or between a company and the LRF. • Keep a clear inventory of background and foreground intellectual property. • Consider licensing your technology, especially if you are concerned about IPR protection, enforcement and access within a specific geographical market.
Relationship development	Cultures	Be sensitive to cultural differences in doing business. For example, relationship-building and networking in Asia are key components to success. In contrast, in North America the business approach is more transactional.
	Language	Some tenders will be released only in a local language rather than in English. Therefore, pay particular attention to the accurate translation of documents to ensure clarity in what an LRF requires. Also check which language the bid needs to be submitted in, and thoroughly proofread the bid prior to submission. Always keep a copy of the bid itself and any supporting documents.
	Procurement and technical officials	• Forge a robust relationship with procurement officials and technical researchers. The former will help to explain the procurement rules/procedures and identify technical officials. The latter will be able to talk in detail about the specification of the tender. • Building good relationships in the long term will prove indispensable for future tendering needs/opportunities. • Be prepared to share your CV (and that of your team, including sub-contractors) if requested to do so. These actions will help to establish your credibility and technical competency.
Consortia and accessing supply chains	Consortia formation	Consider consortium formation with organisations in the host country where the LRF is located. This is likely to be viewed favourably by the procuring organisation. But be clear about the ownership of any IPR that is generated as a consequence of the consortium's work.
	Supply chains	Identifying and accessing supply chains can help win work from LRFs. This is especially true where a UK company is not a primary contractor or the UK does not have sole expertise in a specific area of need. A local distribution agent can also assist in accessing supply chains.

Table 2.2: Winning LRF contracts – how UKTI can help

UKTI Trade Support Services	
• Undertaking the Overseas Market Introduction Service (OMIS) – a chargeable but heavily subsidised activity which focuses on generating bespoke research and business intelligence on existing and upcoming overseas LRFs; it highlights partners for creating consortia and identifies key areas of overseas industrial and academic strength. • Delivering a range of events and missions in the UK and abroad, for example: • Information days in the UK on partnering and business opportunities from the Extreme Light Infrastructure (ELI) project – Czech Republic, Hungary. • UK mission to a conference on business opportunities from ITER in Barcelona, Spain and Cadarache, France. • "Meet- the- buyer" event through outward and inward missions. For example: • Outward mission to CERN (Switzerland), ESRF (France) and ILL (France) • Inward missions to the UK from CERN (Switzerland), ESO (Germany), ELI (Czech Republic and Hungary), New Karolinska Solna Hospital Project (Sweden) and the National Aerospace Laboratories (India).	• Arranging and facilitating general/bespoke networking activities between UK organisations and senior officials at LRFs, such as with India's NAL. This activity focused on on partnering opportunities in airframe structures work, research and technology collaborations in areas such as impact, crashworthiness, structural health monitoring, structural dynamics and aero elasticity, computational mechanics and simulation, fatigue and structural integrity and up gradation of facilities at NAL's Structural Technologies Division. • Monitoring of LRF tenders and alerting relevant companies to the opportunities through an industrial database of UK firms. • Engaging with officials in the Department for Business, Innovation and Skills on issues such as industry opportunities and concerns with procurement processes in LRFs where the UK provides funding support directly or indirectly, such as at CERN and ITER.

2.3 How can UKTI help UK organisations succeed with Large Research Facilities to win contracts?

UKTI can provide UK organisations with a wealth of assistance ranging from market intelligence through to making contacts at the right decision-making level in LRFs around the world.

We do this through our overseas networks in British embassies and high commission's around the world, and by working closely with the Science and Innovation Network (jointly funded by the Department for Business, Innovation and Skills and the Foreign & Commonwealth Office), to identify overseas LRFs, to understand their procurement requirements and to pursue relevant tendering opportunities.

In addition, UKTI partners with CCFE, the Technology Strategy Board's Knowledge Transfer Networks and the UK Research Councils (such as Science and Technology Facilities Council) to highlight LRF opportunities to UK organisations.

While the focus of this publication is on supporting UK organisations to win contracts from LRFs worldwide, UKTI helps to attract inward investors to bring their high-quality investment to the UK and, ideally, to set up in "science and innovation hubs" like the Harwell Oxford Science and Innovation Campus or in one of the many science parks that exist in this country. A list of science parks can be found at the United Kingdom Science Park Association website, www.ukspa.org.uk.

The types of trade support that UKTI provides are summarised in *Table 2.2*, while Annex 5 provides contact details within UKTI.

Whether you are venturing into selling to LRFs overseas for the first time, or are an experienced exporter trying to break into existing and/or new facilities such as ELI, ESO, CERN or ITER, UKTI's dedicated team offers a range of trade support services that can make doing business internationally as easy as doing business in the UK.

We can also provide budding and established exporters with tailored packages of support in the form of local market research, covering cultural, political and business issues, and access to key contacts.

A good way of promoting your expertise to international buyers and meeting useful contacts is by attending UKTI-sponsored information days on specific business opportunities offered by overseas LRFs. UKTI regularly brings senior decision makers and technical staff from these research facilities to meet UK companies at these events.

This publication now shifts its focus to highlight capability in selected technology areas where the UK has world-leading industrial and academic expertise. This is supplemented by a series of case studies of UK organisations which have won contracts from LRFs.

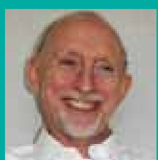
"Building the world's best telescopes and instruments presents significant commercial opportunities for UK industry, working in partnership with the UK Astronomy Technology Centre, ESO and the University instrumentation groups, especially as we move toward construction of the European Extremely Large Telescope."

Professor Colin Cunningham
UK Extremely Large Telescope Programme Director

Section B

UK capability in selected technology areas

“We feel privileged to have been able to develop products in close collaboration with world-leading neutron scientists from ISIS. Their knowledge and expertise was crucial to the development of a range of helium recondensing magnet products particularly well suited to neutron scattering facilities. Delivering innovative systems to a prestigious facility like ISIS also enhanced Oxford Instruments’ reputation and credibility as world leaders in superconducting magnet systems. We have since been able to offer similar systems to other key neutron scattering facilities in Europe, USA, Australia, Japan and more recently China. This application area accounts for around 10 per cent of our overall business, so it played a significant part in the growth of Oxford Instruments NanoScience over the last few years”



Dr Jim Hutchins
Managing Director
Oxford Instruments NanoScience

UK capability in selected technology areas

Table 3.1: Selected examples of UK organisations possessing cryogenic capability (indicating scope of supply)

Organisation	Description	Field/area of operation
Cryoconnect	Cryoconnect is a specialist division of Tekdata's Interconnect Systems, and deals solely with cabling and interconnection solutions in cryogenic systems. Its cables are used in dilution refrigerators, cryogenic systems, superconducting magnet systems, low-temperature detector systems, infrared array systems, and general housekeeping on cryogenic systems of all scales. Cryoconnect has supplied a range of LRFs such as ESO, CERN, CCFE and the James Webb Space Telescope (which will be a large infrared- optimized space telescope with a 6.5-meter primary mirror, and is an international collaboration between NASA, the European Space Agency and the Canadian Space Agency).	Cryogenic wiring and interconnections
CVT Ltd (see Case Study 3.1)	CVT Ltd manufactures ultra-high vacuum (UHV) chambers, systems and components for different application areas. The company's facility is made up of computer numerical control (CNC) machining, welding, UHV cleaning and electrical/electronics wiring, assembly and test for integrated systems.	Manufacturing UHV chambers, high vacuum systems and components, related assembling, fabrication and computer-aided design (CAD) services
Herose UK	Herose develops and manufactures innovative valves for use in extreme temperatures between -270°C and +400°C, special valves for air separation and valves for liquefied natural gas (LNG). Herose also develops its range of cryogenic shut-off valves by using unique features that have resulted in improvements to the sealing characteristics and also substantially reduced wear during service life.	Cryogenic valves
ICEoxford	ICEoxford designs, manufactures and refurbishes specialist ultra-low temperature equipment for the cryogenic research community. This includes wet systems, dry systems and recondensing systems.	Instruments, cryogenic thermometry and sensors
Monroe Brothers Ltd	Monroe Brothers provides consultancy in the field of low-temperature engineering. It specialises in technologies using liquid nitrogen at -196°C to provide fast and effective cooling for industrial and scientific applications, and also liquid helium down to 1.4K for scientific applications. Examples include pollution control with liquid nitrogen and superconducting magnet design with liquid helium.	Design, consultancy and custom-built systems
Oxford Cryosystems Ltd	Oxford Cryosystems manufactures a range of coolers designed specifically for sample cooling in X-ray diffraction experiments. These include the Cobra, Desktop Cooler and Cryostream, the latter of which was first developed over 25 years ago in the Clarendon Laboratory at the University of Oxford. Software has also been a traditional strength of the company, from the firmware used to control low-temperature systems to specialist crystallographic software. The company also manufactures the Coolstar range of Gifford McMahon coolers, and is branching out into new applications for its cryocoolers such as high-temperature superconductivity and astrophysics.	Coolers for Diffraction and Cryocoolers
Oxford Instruments NanoScience (OINS) (see Case Study 3.2)	OINS creates high-performance cryogenic and cryogen-free environments for ultra-low temperature and high magnetic field applications, including nanoscale characterisation, materials science and quantum computing. It provides the most advanced experimental equipment and scientific instrumentation, from "best in class" standard products to custom-built systems and tailored consultancy services. The product range includes dilution refrigerators, superconducting magnets, optical and spectroscopy cryostats and cryogenic spares and accessories, including a new range of cryogenic temperature controllers and magnet power supplies.	Design, consultancy and custom-built systems

3.1 Introduction

The UK possesses a strong and vibrant academic and industrial base in a diverse range of high-technology areas, such as cryogenics, fusion energy, high-performance computing, neutron scattering, muon spectroscopy, precision engineering and synchrotron beamlines.

This capability plays a critical role in ensuring that the UK remains at the forefront in terms of technology advancement and supplying toLRFs around the world. A capability analysis of these areas now follows, supported by a series of case studies of UK organisations that have won contracts from LRFs. The reader is asked to note that the organisations listed in Section B are purely to illustrate the UK's capability in the high-technology areas where they are mentioned.

Table 3.1 continued

Organisation	Description	Field/area of operation
Peco Cryogenics	Peco Cryogenics is a specialist provider of vacuum-insulated technologies for cryogenic handling. Their systems are suited to liquid nitrogen, helium and oxygen and provide the highest quality of liquid delivery with minimal transfer losses.	Vacuum-insulated cryogenic handling solutions
Scientific Magnetics	Scientific Magnetics offers standard and tailor-made superconducting magnet and cryogenic solutions. It also (i) develops a superconducting magnet system from the initial geometry of the coils, through design to assembly, test and commissioning, (ii) manufactures superconducting magnets for both low temperature and high-temperature superconductors, in circular and non-circular geometries, (iii) designs and builds cryostats operating at temperatures down to 0.3K, including normal and superfluid helium systems, zero boil-off (recondensing) and cryogen-free superconducting magnet systems, and (iv) designs and builds cryogenic valve boxes and special cryostats for a wide variety of applications.	Superconducting magnets
Temati	Temati is a specialist in cryogenic thermometry and a worldwide distributor of carbon ceramic cryogenic temperature sensors. These sensors offer excellent performance and stability in the harshest environments, coping well with magnetic fields, high-dose radiation, large mechanical forces and vibration. They are also thermally very responsive as their relatively large ceramic body has low thermal capacitance and absorbs and transmits heat faster than normal sensors. Temati has supplied to a range of LRFs overseas such as CERN, ITER and SRON Netherlands Institute for Space Research.	Instruments, cryogenic thermometry and sensors
Tesla Engineering Ltd	Tesla Engineering Ltd manufactures resistive and superconducting electromagnets for particle accelerators of all types, and produces specialised gradient coils for magnetic resonance imaging scanners. Tesla also supplies electromagnets for emerging applications, such as fusion research and the semiconductor industry.	Superconducting magnets
Thames Cryogenics Ltd	Thames Cryogenics manufactures, installs and services cryogenic storage and distribution equipment. It has supported the food industry, from fish freezing to breweries, but in the last 10 years its business has shifted over significantly to the life sciences sector. For example, it worked with the UK Biobank to supply and install vacuum-insulated pipework from two large liquid nitrogen storage tanks to feed over 40 of the largest, most efficient cryogenic freezers available in the UK. Thames Cryogenics and UK Biobank have now established a successful, long-term partnership for the establishment and maintenance of this LRF. Following on from its success with UK Biobank, Thames Cryogenics teamed up with Biomedica, a Saudi Arabia-based specialist equipment supplier to bid for and win contracts in the cryogenic field for the Biobank planned in the country by its health authority, National Guard Affairs.	Cryogenic piping
Wessington Cryogenics Ltd	Wessington Cryogenics is a worldwide manufacturer of cryogenic pressure vessels used for the transport and storage of cryogenic gases, including carbon dioxide, oxygen, nitrogen, argon, helium and LNG, and has supplied to numerous customers across a diverse range of sectors. These include LRFs such as CERN, NASA and RAL. A particularly strong area for Wessington has been the design of custom-built and very large liquid helium dewars as well as bespoke products such as mobile purge units designed and developed at the request of Air Products.	Cryogenic vessels

3.2 Cryogenics

The UK has exceptional strength in cryogenic technology, catalysed by R&D work undertaken by organisations such as the University of Oxford, Oxford Brookes University, the Universities of Sheffield and Southampton, the Science and Technology Facilities Council's (STFC's) RAL Space, the Culham Centre for Fusion Energy (CCFE) and Oxford Instruments.

In fact, many commercial organisations in this field can trace their origins to, or have links with, Oxford Instruments. One such entity is Siemens Magnet Technology, which is responsible for almost half the world's production of magnetic resonance imaging scanner magnets.

The infrastructure of industrial gas companies (such as Air Products, which supplies "coolant" gases such as liquid nitrogen) and specialist tiers of service and component suppliers has also evolved around these organisations. This concentration of cryogenic capability has resulted in the creation of the British Cryogenics Cluster. Its membership is illustrated in *Figure 3.1*.

In fact, almost "anything cryogenic" can be sourced in this country, be it temperature sensors from Temati to giant superconducting magnets from STFC, as illustrated in *Table 3.1*. As

continued on page 30

Figure 3.1

Member organisations of the British Cryogenics Cluster

kT kelvin Technology, Ltd.	LTi METAL TECH	M1 ENGINEERING
Monroe Brothers Ltd +44 (0)1386 701777 Cryogenic Consultants www.monroebrothers.co.uk	MRC Harwell	McNaughton Dynamics
OXFORD INSTRUMENTS The Business of Science®	Oxeta ENGINEERING THE FUTURE	OxfordCryosystems
OXFORD BROOKES UNIVERSITY	PECO cryogenics	Quantum
SAFETY GAS DETECTION	Science & Technology Facilities Council	SCIENTIFIC MAGNETICS
SIEMENS	STRATOX	Sumitomo (SHI) CRYOGENICS OF EUROPE LIMITED
TAMO	TCL THAMES CRYOGENICS LTD. Total Cryogenic Solutions	temati
tesla	The University Of Sheffield.	University of Leicester
UNIVERSITY OF OXFORD	UNIVERSITY OF Southampton Research Institute for Industry	wessington cryogenics

Table 3.2: Overview of British cryogenic equipment at LRFs (source: British Cryogenics Cluster)

UK supplier	LRF – name	LRF – location	British cryogenic equipment at the LRF
Cryoconnect	European Southern Obervatory Atacama Large Millimetre Array	Chile	Assemblies for the cryostats and detectors
	CERN (the ATLAS Detector at the Large Hadron Collider)	Switzerland	Assemblies for the cryostats and detectors
	Joint European Torus at CCFE	UK	Assemblies for the cryostats and detectors
	James Webb Space Telescope	Outer Space (anticipated launch date 2018)	Spacecraft harnesses
CVT Ltd + Scientific Magnetics	Diamond Light Source	UK	3D superconducting magnet in UHV
	CELLS ALBA Synchrotron	Spain	3D superconducting magnet in UHV
	Swiss Light Source	Switzerland	3D superconducting magnet in UHV
Oxford Instruments	ISIS	UK	Recondensing superconducting magnets
Peco Cryogenics	Diamond Light Source	UK	Cryogenic transfer lines and system engineering
STFC	CERN	Switzerland	ATLAS end-cap superconducting magnets
Temati	Academy of Sciences	China	Cryogenic temperature sensors
	CEA (French government technological research organisation) and ITER	France	Cryogenic temperature sensors
	GSI Helmholtzzentrum für Schwerionenforschung	Germany	Cryogenic temperature sensors
	Max Planck Institute for Plasma Physics	Germany	Cryogenic temperature sensors
	SRON Netherlands Institute for Space Research	Netherlands	Cryogenic temperature sensors
	CERN	Switzerland	Cryogenic temperature sensors
	Jefferson Laboratory, NASA	USA	Cryogenic temperature sensors
Thames Cryogenics Ltd	National Guard Health Affairs Biobank	Saudi Arabia	Cryogenic piping, biofreezers and alarms
	UK Biobank	UK	Cryogenic piping, alarms, storage tanks and biofreezers
Wessington Cryogenics	CCFE Joint European Torus (JET)	UK	Liquid helium tank

a consequence of this strength, UK cryogenic equipment can be found in a large number of LRFs around the world. This is shown in *Table 3.2*.

Case studies focusing on CVT Ltd and Oxford Instruments *(Case Studies 3.1 and 3.2 respectively)* are also presented to demonstrate the vital role that industrial and academic partnerships have played to continually strengthen cryogenic capability in the UK and allow this sector to deliver bespoke cryogenic solutions to LRFs worldwide.

3.3 Fusion energy

The UK has played a key role globally in the development of fusion energy. Initiatives in this regard include operating the JET fusion facility at CCFE and contributing to the spherical tokamak approach, from the Small Tight Aspect Ratio Tokamak up to the Mega Amp Spherical Tokamak (MAST).

CCFE is also playing a major role in the world's largest fusion energy experiment, ITER, which is based on the principles of magnetic confinement fusion (MCF) as opposed to inertial confinement fusion (ICF).

CCFE's role in supporting ITER can be highly attributed to the UK's expertise in tokamak operations, engineering and fusion physics, developed under JET. In addition to the strong facility operations is a sound experimental and theory programme, which is being carried out in collaboration with national universities and international partners. The focus of MCF is expected to shift to ITER with the impending closure of the JET in five to 10 years. Case Study 3.3 portrays CCFE's role in supporting UK businesses to win contracts from ITER.

A number of UK companies, both small and large, have won contracts from ITER, JET and MAST, covering a wide range of fields from architectural design and nuclear site management to remote-handling applications and production of heavy tungsten alloys *(see Table 3.3)*.

Their expertise and capability in the fusion energy arena have allowed them to win contracts from other LRFs such as CERN and UK's Diamond Light Source, as exemplified by MG Sanders Ltd *(see Case Study 3.4)*.

3.4 High-performance computing

The UK is a major global centre for high-performance computing (HPC). Its key national facility supporting the academic base is the High-End Computing Terascale Resource (HECToR), funded by the UK Research Councils and operated by Edinburgh University's Parallel Computing Centre. It is available for use by academia and industry in the UK and Europe. In addition to this, there are numerous dispersed HPC facilities, for example:

- STFC's Daresbury Science and Innovation Campus, which provides high-performance and distributed computing and data services, for both small and large organisations.
- Oxford Supercomputing Centre at the University of Oxford, which provides researchers with services such as training, application support, access to powerful computer clusters and

Table 3.3: Selected examples of UK organisations which have expertise in fusion energy (indicating scope of supply)

Organisation	Description	Field/area of operation
AMEC plc	One of the largest UK private-sector suppliers to the nuclear sector of programme management and engineering services. AMEC has been a pioneer in the development of fusion technology, working with the UK Atomic Energy Authority Culham (now CCFE). It is a founding member of the European Fusion Engineering and Technology consortium, a European Economic Interest Grouping which brings together major systems engineering companies from seven European countries . AMEC has undertaken many projects on JET, design and safety activities for ITER and studies for fusion power plants. It continues to provide R&D support, and prototype manufacture and development of mock-ups of key ITER components. "We have successfully developed a new low-temperature hot isostatic pressing diffusion bonding technique that will be used in the manufacture of fusion-related components. "This new technique has benefited other aspects of nuclear generation, including the design and development of a copper-bonded steam generator for use in future sodium-cooled fast reactors. "As the next generation of reactors is developed, both fission and fusion, we will remain at the forefront of delivering nuclear solutions both in the UK and internationally." – Alain Chevalier, Business Manager, International and Reactor Development, AMEC plc.	AMEC is a focused supplier of consultancy, engineering and project management services to its customers in the world's oil and gas, minerals and metals, clean energy, environment and infrastructure markets. With annual revenues of some £3.3 billion, AMEC designs, delivers and maintains strategic and complex assets and employs over 27,000 people in around 40 countries worldwide.
Atkins UK	Atkins is one of the world's leading engineering and design consultancies and the largest engineering consultancy in the UK, employing some 17,700 people across the UK, North America, Middle East, Asia Pacific and Europe. Atkins is leading the design and overseeing the procurement and construction of the 39 buildings and associated infrastructure that will make up the ITER research facility in Cadarache, France. As project director and design manager of the Engage consortium, appointed as architect engineer on the project, Atkins is at the forefront of design optimisation of the infrastructure and the co-ordination of all of the technological components that will make up the facility ready for scientific experiments to begin in 2019. With over 40 years' experience in the UK's nuclear sector, delivering engineering services from new build through to decommissioning, Atkins is now rapidly growing its presence in the international market place; expanding its services into the US and, through its ntriplea alliance with French engineering giant, Asysstem, in Europe, South Africa and the Middle East.	Design and engineering services and related technical consultancy
Babcock International Group	Babcock provides site management services at nuclear sites and operates a nuclear services consultancy business, providing a range of specialist, knowledge-based, outsourced solutions to customers in both the UK and abroad. The company's services include programme management, decommissioning, waste management, environmental services and technical consulting. It has won contracts/sub-contracts with the ITER project, including providing five project control specialities to the Central Programme Control Office.	Nuclear site management, operations, decommissioning and advisory
Jacobs	Jacobs is one of the world's largest and most diverse providers of professional technical services, covering a range of primary markets including energy, infrastructure and technology. For example, Jacobs has been involved in the ITER project for six years, having undertaken the preliminary design of all the buildings, including the Tokamak Complex for the European Fusion Development Agreement. It is now providing support to ITER's Building and Site Infrastructure Department and to the Machine Assembly and Installation Department.	Provider of scientific and specialty consulting, as well as all aspects of engineering and construction, and operations and maintenance.
Meggitt Aerospace Braking Systems (part of Meggitt plc)	Meggitt Aerospace is involved in the design and manufacture of wheels, brakes and braking systems, heat exchangers and bleed valves. Key clients include airline operators, aircraft constructors, private aircraft owners and charter operators, governments and military operations, distributors and repair stations. The company has worked on fusion projects with clients across Europe and North America, helping them develop the carbon–carbon (C–C) materials with the ability to transfer large heat fluxes (with retention of strength at elevated temperatures and low density). It provided C–C composite tiles to clad the plasma-facing metallic parts of the JET vessel wall. The tiles help to thwart plasma contact with the vessel wall and other devices extending from the wall such as antenna structures. For the ITER project, Meggitt supplies C–C tiles for trials of a divertor design that is being piloted in the JET vessel. "The divertor located at the base of the tokamak vessel is exposed to the highest heat fluxes during operation, and in order to meet the heat flux demands, the C–C tile blanks contain carbon fibres on a matrix of carbon. To optimise thermal properties for use in fusion applications the C–C is heat-treated at temperatures in excess of 2,400°C. "ITER is an exciting project that is at the forefront of materials development and a key strategic business project. Our experience of fusion has been very positive. So far it has led to changes in production engineering practice resulting in increased efficiency and reduced costs that have been transferred across to core business products." – Ben van Sleeuwen, Head of Aftermarket and Advanced Material Programmes, Meggitt Aerospace Braking Systems	Aircraft braking systems and wheels, C–C heat-resistant tiles
MG Sanders Ltd (see Case Study 3.4)	Established in 1971, MG Sanders has expertise in the production of heavy tungsten alloys, which are widely used in the aerospace, defence, automotive, motorsport, nuclear energy and nuclear medicine sectors.	CNC turning, EDM wire erosion, abrasive water jet cutting, assembly, DENSAMET® heavy tungsten alloys, industrial power, quality and materials laboratory and military antennas

Table 3.3 continued

Organisation	Description	Field/area of operation
Oxford Instruments	Involved in the R&D, manufacture and sale of high-technology tools and systems for the analysis and manipulation of matter at the smallest scale. It caters to sectors such as industrial analysis, research, education, space and energy. The company's tools are being used for the development of alternative energy, climate change research and environmental pollution. Recently won contracts with ITER include: • A £30 million contract for supplying 58 tonnes of superconducting wire from Fusion for Energy, the European procurement agency for ITER. • A £5 million contract for supplying nine tonnes of superconducting wire through a deal agreed with Oak Ridge National Laboratory/UT-Battelle on behalf of the US ITER Project Office, the procurement agency in the USA for ITER.	Nanotechnology tools, industrial products and services
Oxford Technologies	Involved in the development of technologies and expertise for the implementation of cost-effective solutions to remote-handling applications.	Remote-handling applications
Phoenix Inspection Systems Ltd	A developer and manufacturer of automated non-destructive testing equipment using ultrasonic techniques, serving sectors such as energy, aerospace, process industries and rail. The company's assignment with the ITER vacuum vessel consists of developing phased array ultrasonic techniques for inspecting the vessel's splice plate welds that join the nine sections of the vessel together. Narrow gap welding of the nine sections using tungsten inert gas welding reduces the risk of distortion over the length of the weld. The confined space makes inspection difficult as narrow gap welds are not conveniently oriented for inspection. In order to overcome this issue, Phoenix has developed a special ultrasonic probe mounted on a probe pan and carried by the welding robot to perform automated ultrasonic inspection. "The technique for inspecting these welds uses phased array along with other advanced ultrasonic methods. The ITER vacuum vessel work has broadened our capability in inspecting similar welds throughout the nuclear and energy sectors." – Karl Quirk, Managing Director, Phoenix Inspection Systems Ltd	Ultrasonic non-destructive testing solutions

***Table 3.4**: Selected examples of UK companies with HPC expertise (indicating scope of supply)*

Organisation	Description	Field/area of operation
Allinea	Allinea Software is the leader in development tools for parallel programming. World-leading institutions, such as the Oak Ridge National Laboratory in USA, rely on this company, as do partners like Cray and IBM. Allinea DDT (distributed debugging tool) easily handles classic bugs and those arising from execution on up to 200,000 cores simultaneously. It's the most scalable debugger for scalar, threaded and parallel codes on central processing unit and graphics processing units. Allinea OPT (optimisation and profiling tool) helps to identify bottlenecks in code to help increase performance.	High Performance Computing
ClusterVision	Specialists in the design, implementation and support of large-scale computer clusters	Computer clusters, high-availability clusters, fast networking (Myrinet, Quadrics, SCI and Infiniband), storage (>3TB), database clusters (Oracle 10g), servers (AMD/Intel)
Eurotech Computer Services Ltd	Develops and implements HPC and storage clusters and specialises in providing information and data management solutions and services.	Specialists in all aspects of processing, protecting, managing and analysis of data. Creates and integrates large-scale HPC solutions with a specific focus on the oil and gas, life sciences and research sectors.
OCF plc	High-performance server and storage cluster integrator, cluster services and support team, and Compute on Demand provider	Largest HPC delivery team in the UK; provides tailored solutions utilising innovative HPC and storage systems
Viglen Ltd (see Case Study 3.5)	Supplies IT hardware, software and technical support to two-thirds of UK's universities, including Oxford and Cambridge, as well as CERN	Designing and installation of custom-built HPC solutions; provision of products that cover storage, high-performance, software, servers, learning platforms and training
Xyratex Ltd	Provider of modular solutions for the enterprise data storage and hard disk drive capital equipment industry.	Advanced, scalable data storage solutions for Original Equipment Manufacturers and HPC communities

Table 3.5: Example of a UK company working in the field of neutron scattering and muon spectroscopy (indicating scope of supply)

Organisation	Description	Field/area of operation
Prototech Engineering Ltd (see Case Study 3.6)	Prototech offers a range of in-house engineering services, including CAD drawing, procurement of materials, machining of components, mechanical and electrical assembly, and welding and testing of finished products. Its equipment and services could be used by the gases, chemicals, furnace and smelting industries, as well as by atomic energy authorities and LRFs.	Diversified field of operation which includes manufacturing of prototype and small batch precision-engineered components and equipment; process control systems; cryogenic and ultra-high vacuum equipment; and specialised welding services

Table 3.6: Examples of UK academic centres of excellence that support precision engineering (PE)

PE centres of excellence	Detail
Cranfield University Precision Engineering (CUPE)	CUPE focuses on the design and development of precision production systems, ultra-precision machining, metrology and micro-engineering. It has supplied precision machines and systems to organisations such as NASA, ESA, ESO, NPL, RAL and high-technology manufacturing companies. CUPE operates ultra-precision laboratories of over 1,000m2 at Cranfield and OpTIC.
University of Huddersfield's Centre for Precision Technologies (CPT)	CPT focuses on areas such as advanced machining technology, engineering control, machine tool performance and micro nano metrology. The University of Huddersfield and the National Physical Laboratory have entered into a Memorandum of Understanding to co-operate in engineering measurement research. The CPT is now the EPSRC Centre for Innovative Manufacturing in Advanced Metrology.
Ultra-Precision Structured Surfaces Integrated Knowledge Centre (UPS2)	UPS2 is a partnership combining the ultra-precision expertise of Cranfield University with PE facilities and resources held by Glyndŵr Innovations Ltd at OpTIC in North Wales. Other partner institutions include UCL and the University of Cambridge. Specific capabilities are based around a world-class diamond machining system for large area surface structuring and large-sized optics fabrication facilities at OpTIC and Cranfield. This offers a full suite of surface metrology equipment, including measurement interferometers, high stability for form measurement, miniature high accuracy, and white-light for small-scale surface profiling.

shared memory machines, and a large storage facility.

- UK's Atomic Weapons Establishment (AWE), which has one of the most advanced and powerful supercomputing facilities in the world, undertakes three-dimensional modelling, simulation and visualisations studies using its HPC capabilities. For example, computer codes used in the mathematical modelling of nuclear weapons performance are refined using information from hydrodynamics and laser experiments, data from studies on how materials age, and results from previous actual nuclear tests.

Supporting this HPC capability are numerous UK companies (some of them are listed in Table 3.4). They include Viglen Ltd, which has supplied HPC equipment to CERN (see Case Study 3.5), whilst Xyrates Ltd has recently supplied its ClusterStor 3000 – a new optimal scale-out storage platform – to the University of Cambridge.

In October 2011, the UK Government announced £145 million in aid to support the development of HPC and associated e-infrastructure in order to maintain the UK as a world leader in supercomputing. Improving computing infrastructure is considered key to driving growth and giving businesses confidence to invest in the country.

3.5 Neutron scattering and muon spectroscopy

The UK's neutron scattering and muon spectroscopy capabilities are amply supported by the ISIS Pulsed Neutron and Muon Source, based at STFC's RAL, and through the UK's subscription to ILL in Grenoble, France, one of the most intense neutron sources globally.

Furthermore, the UK has a number of leading companies which work in this area. These are listed in Tables 3.1 and 3.5. Case Study 3.6 provides an example of how Prototech Engineering Ltd, a UK SME, has successfully won contracts from an LRF.

3.6 Precision engineering

The UK possesses strong academic and industrial capabilities in precision engineering (PE), ranging from machining, materials handling, metrology and micro-engineering to optics. Table 3.6 outlines a number of UK academic centres of excellence that support PE, while Table 3.7 provides a list of companies that deliver PE solutions.

Two case studies are also presented. Case Study 3.7 focuses on Zeeko Ltd, which offers ultra-precision polishing services for optics used, for example, as telescopic mirrors. Case Study 3.8 concentrates on OpTIC, a company which specialises in precision optical design and manufacturing.

These cases studies demonstrate how two small yet highly specialist UK companies can engage successfully with LRFs such as NASA and the European Southern Observatory.

Table 3.7: Selected examples of UK organisations that have expertise in precision engineering (PE) (indicating scope of supply)

Organisation	Description	Field/area of operation
Claro Precision Engineering Ltd	Established in 1978, Claro specialises in precision machining and precision machined parts, sub-contract machining design and manufacture of parts for key areas such as medical instrumentation, lasers, aerospace, sub-sea and electronics housing.	CNC milling and turning, material supply, design, assembly, packaging, labelling and managing the anodising, plating, painting and heat treatment of components
FGP Precision Engineering Ltd	Established in 1970, FGP offers a complete sub-contract machining facility to its clients representing the aircraft, automotive, hydraulic and nuclear industries.	CNC milling and turning, manual milling and turning, grinding, honing, lapping, spark erosion, inspection equipment
Genesis Precision Engineering Ltd	Genesis provides precision machined components for varied industries such as medical, optical, laboratory, instrument, electronic, scientific, machinery and component manufacturers.	CNC manufacture of components from varied materials
GOM UK Ltd	The company's capabilities include the development and distribution of optical measuring systems with a focus on applications such as 3D digitising, 3D co-ordinate measurements, deformation measurements and quality control. GOM systems are used by the automotive, aerospace and consumer goods industry, and by LRFs.	Optical measurement systems
Hutton Engineering (Precision) Ltd	Hutton Engineering, part of the KAS Technologies Group, specialises in precision machining and precision machined parts, prototyping, production and packaging of materials across sectors such as medical, Formula One, semiconductor and aerospace.	CNC milling and turning, water jet cutting, design for manufacture advice, assembly, material supply, packing, labelling of components, anodising, plating, painting and heat treatment of materials
Merc Engineering UK Ltd	Merc Engineering has expertise in producing customised, high-quality precision parts and sub-assemblies for the defence, aerospace, railway, nuclear, power generation and commercial sectors.	CNC milling and turning, sliding-head CNC turning, multi-axis mill turning, EDM wire erosion, EDM spark erosion, EDM fast hole drilling, welding and fabrication
OpTIC (see Case Study 3.9)	An offshoot of Glyndŵr Innovations, OpTIC designs and develops prototypes, new processes and products for various industries.	Micro-precision engineering: nano-scale polishing, micro-precision engineering-structured pattern drums, solar energy research, holography, lasers, polymerisation reaction engineering and optical systems consultancy
Pace Precision	Pace Precision is a light engineering company involved in the design, prototyping, engineering and production of components for a broad range of industries, including packaging, defence, aerospace, electronics and medical.	Precision CNC machining, milling and turning, maintenance and repair, sheet metal and fabrication, CAD and prototyping
Scitech Precision Ltd	Scitech Precision mainly provides bespoke micro-targets for use in high-energy photon science experiments.	Micro-assembly, thin film coating, characterisation, micro-engineering and micro-manufacture based upon micro-electro-mechanical systems (MEMS) fabrication techniques
Taylor Hobson	A high-precision engineering company providing contact and non-contact metrology solutions for various applications.	Optic applications, automotive applications, Aerospect stack prediction for alignment and measurement of gas turbine and jet engines in the aerospace industry, bearings applications, hard disk, MEMS and semiconductor applications, nano-scale metrology for medical applications and thin film analysis
Zeeko Ltd (see Case Study 3.7)	Established in 2000, Zeeko is a technology company that provides ultra-precision polishing solutions for optics and other complex surfaces such as telescopic surfaces for the aerospace, healthcare, optics, moulded optics, semi-conductor and display industries.	Ultra-precision polishing solutions for optics and complex surfaces, manufacture of ultra-specific polishing machines, manufacture of corrective polishing machines for fabricating high-precision optics, orthopaedic joints, semi-conductor applications and precision moulds in a variety of materials

AMEC operates the NIRAS laboratory, which provides independent radioactivity testing. Photo by courtesy of AMEC

Table 3.8: Select examples of UK organisations with expertise to supply, build and maintain synchrotron facilities (indicating scope of supply)

Organisation	Description	Field/area of operation
FMB Oxford	FMB Oxford supplies instrumentation to the scientific community. The company is also involved in providing synchrotron beamline components and systems. Their core competencies include project management, design, assembly, testing and installation of beamline systems and components. It has delivered key components for three macromolecular crystallography beamlines to Diamond Light Source, two bending magnet beamlines and two insertion device beamlines for the Australian Synchrotron Project, and one beamline for Indus-1 in India. They are currently working on a nano-beamline for ANKA at the Karlsruhe Institute of Technology and an X-ray absorption spectroscopy beamline for the CELLS ALBA Synchrotron.	Beamlines and beamline components, monochromators, mirror systems, slits, controls, ancillary components, detectors and diagnostics
Genvolt	Genvolt is involved in the design, development and manufacture of DC stabilised high-voltage power supplies. It has recently won contracts from CERN. and RAL.	High-voltage power supplies
Instrument Design Technology (IDT) (see Case Study 3.9)	IDT provides a range of components for the synchrotron beamline market. The company has supplied to most synchrotron radiation sources worldwide, including the High Pressure Collaborative Access Team at the Advanced Photon Source (Chicago, USA), the Hard X-ray Microanalysis at the Canadian Light Source (Saskatoon, Canada) and the Micro-spectroscopy Beamline ID5 at the Australian Synchrotron Project (Melbourne, Australia).	Designing and building beamlines and beamline components
Kurt J Lesker Company	Established in 1954, Kurt J Lesker is long considered a global market leader in the manufacture and distribution of high-quality vacuum parts and systems. The company's four divisions include; Vacuum Mart, Process Equipment, Materials and Manufacturing.	Customised vacuum systems and support, deposition materials, design and engineering services. The most complete line of vacuum products in the world.
Observatory Sciences Ltd (see Case Study 3.10)	Observatory Sciences is a leading developer and supplier of software for the control of "big science" systems and instruments, including large telescopes and synchrotrons. They provide a range of bespoke systems development, consultancy and project management services tailored to the needs of individual clients, and employ a wide range of software technologies for producing control systems, including the EPICS toolkit and the LabVIEW graphical programming language from National Instruments, as well as Java and C/C++ programming. Projects include the Advanced Technology Solar Telescope, the Gemini Observatory, the Magdalena Ridge Observatory Interferometer, the European Extremely Large Telescope, the Discovery Channel Telescope, Diamond Light Source and ITER.	Developing and supplying software for the control of "big science" systems and instruments, and consultancy
Q-par Angus Ltd	Q-par Angus's expertise includes microwave design and manufacture. The company focuses on R&D and manufacture of microwave components and antenna systems for the entire breath of radio frequency spectrum.	Antenna positioners, the entire range of antennas comprising horn, omni, sinuous and spiral antennas, sub-systems and bespoke components
VG Scienta	VG Scienta was formed by merging the businesses of Vacuum Generators and Gammadata Scienta. It is considered as a worldwide premier supplier of quality products in the area of surface physics, and UHV and vacuum components.	Vacuum components, surface science instruments such as spectrometers, and VG Scienta Systems (special vacuum systems for scientific use)

3.7 Synchrotrons

The UK's principal synchrotron light source capability resides in Diamond at the Harwell Oxford Science and Innovation Campus. Diamond is a not-for-profit limited company funded as a joint venture by the UK Government through the Science & Technology Facilities Council (STFC) in partnership with the Wellcome Trust.

Diamond and the ESRF serve the light source community, providing an advanced research tool for both applied and fundamental science. STFC's Particle Physics Department at RAL actively supports the particle physics research programme; its work includes construction of large detector systems, computing, data analysis and accelerator expertise. Some of the global projects and experiments that use its expertise include CERN's Large Hadron Collider and international grid computing.

Other UK centres for particle physics include the Accelerator Science and Technology Centre (ASTeC) located at Daresbury Science and Innovation Campus.

The UK also has many prominent companies that help to build, supply and maintain synchrotron research facilities. A select number are listed in Tables 3.1 and 3.8. Case Studies 3.9 and 3.10 focus on highlighting two SMEs, namely Instrument Design Technology (IDT) and Observatory Sciences Ltd, which have successfully supplied to synchrotron facilities worldwide.

"As an SME specialising in manufacturing tungsten and other exotic materials, the EFDA contract award for divertor modules in the JET-ITER like wall project was a major milestone in our company's evolution. It has allowed us to invest and innovate in new manufacturing processes and techniques which have provided the foundation for current and future supply opportunities to all of the Large Research Facilities"

Ian Warrington
MG Sanders, Project Manager

Case studies

Section B

Case studies

Case study 3.1

Scientific Magnetics and CVT Ltd

Two members of the British Cryogenics Cluster, Scientific Magnetics and CVT Ltd, have been collaborating on the design and manufacture of 3D superconducting vector magnets operating in UHV in order to deliver sophisticated instruments that would not be possible if they were operating as individual companies.

“Having LRFs as customers is essential for our business development as their requirements often lead us to new technologies or materials that we use to our commercial advantage elsewhere”

Richard Davies
Managing Director, CVT Ltd

Scientific Magnetics, world leaders in the design and manufacture of superconducting vector magnets, coupled its skills with CVT Ltd, which has over 30 years’ experience in the design and manufacture of UHV systems, particularly sample handling in UHV conditions.

The challenges included maintaining the 10mm diameter sample at any temperature between <5K and 370K while applying three orthogonal magnetic fields, centred on the sample, at up to 6 tesla (T). The sample had to be easily transferred into and out of the system while maintaining a pressure of $<7 \times 10^{-10}$mbar. In-situ facilities to prepare the sample surface were essential and included cleaving, abrasion, ion beam cleaning and thin-film deposition.

To date, three custom instruments have been installed at Diamond Light Source UK, Swiss Light Source and the CELLS ALBA Synchrotron in Spain.

For further information please visit
www.scientificmagnetics.com
www.cvt.ltd.uk

A 3-Axis superconducting magnet and UHV cryostat installed at the Diamond Light Source

Case study 3.2

Oxford Instruments and its partnership with ISIS

Oxford Instruments provides high-technology tools and systems for industrial and research markets, based on its ability to analyse and manipulate matter at the smallest scale.

*Top: 14 Tesla neutron scattering magnet with sample access +10°/-5° in the vertical and 340° in the horizontal directions. **Right:** The ISIS Neutron source Target Station 2 Experimental Hall*

It partnered with the ISIS Pulsed Neutron and Muon Source at STFC RAL in Oxfordshire to develop superconducting magnets that would allow a cost-effective reduction in the amount of liquid helium needed to keep the magnets cold, especially in ISIS's Second Target Station's instruments.

Traditional superconducting magnets operate at very low temperatures (4.2K; -269°C) and generate enormous magnetic fields of up to 14T. Keeping similar magnets cold traditionally requires large amounts of liquid helium, an increasingly expensive and scarce resource.

ISIS scientist Oleg Kirichek said: "This was a difficult problem that required a bespoke solution. It presented a huge investment risk for the supplier as nothing like it had been achieved before.".

Oxford Instruments has supplied equipment to ISIS for many years and was prepared to meet the challenge. It not only provided ISIS with two state-of-the-art magnets, but also collaborated with ISIS scientists to design a system to reduce significantly the consumption of liquid helium used when cooling them.

In traditional devices, liquid helium evaporates into helium gas, which is vented from the system. The device from Oxford Instruments captures the evaporated gas and turns it back into liquid helium. This reduces costs and the frequency of manual refills, which can be hazardous if not done properly.

John Burgoyne, Manager of the Magnets Business Group at Oxford Instruments said: "Working with ISIS gave us access to some of the world's leading neutron scientists. Their knowledge and expertise in neutron scattering was crucial to the successful delivery of these innovative systems. It has also enabled us to expand our knowledge and develop a new system that we have since been able to offer to other facilities – giving us a competitive edge over other instrument suppliers."

"ISIS is a well-known and prestigious facility so delivering these innovative systems on time has enhanced Oxford Instruments' reputation and credibility as world leaders in superconducting magnet systems."

The technology developed on the two ISIS high-field superconducting magnet systems has since been further exploited on other magnet systems delivered to LRFs in the UK, mainland Europe, the USA and Australia, continuing to provide leading-edge sample environments to neutron, muon and X-ray synchrotron beamlines.

For further information please visit
www.oxford-instruments.com
www.isis.stfc.ac.uk

Above: *9 Tesla and 13.8 Tesla neutron scattering magnet systems with liquid helium recondensing cryostats, installed at the ISIS Neutron Source, UK (ISIS staff and facility images courtesy of ISIS).*
Right: *9 Tesla, wide-angle neutron scattering magnet system with liquid helium recondensing cryostat*

"Advanced superconducting magnets, cryostats and ultra-low temperature refrigerators developed by Oxford Instruments in collaboration with ISIS open up extraordinary new opportunities across broad areas of science"

Dr. Oleg Kirichek
Sample Enviroment, The ISIS Facility

Case study 3.3

Culham Centre for Fusion Energy

In southern France, an area the size of 60 football pitches has been cleared for the site of the world's largest fusion energy experiment. A global partnership including Europe, USA, China and Russia is undertaking the €14 billion ITER project which they believe will be a key stepping stone to commercial fusion power stations.

Culham Centre for Fusion Energy is the UK's national fusion laboratory and is recognised for its major contribution to the worldwide research and development of this emerging energy source. Already Culham has already successfully bid with a number of consortia for funding to design key parts of the ITER's systems, including the LIDAR diagnostic, which uses lasers to measure the plasma temperature, and the ion cyclotron resonance and neutral beam heating systems.

Culham is also using its considerable knowledge and expertise to encourage UK businesses to apply for forthcoming ITER contracts. UK firms have already won €150 million of ITER contracts, many in consortia with companies from other countries, but there are more opportunities for the taking.

UK fusion capabilities

"There has never been a better time for British companies to get involved in fusion," says Dan Mistry, Fusion and Industry Manager at Culham. "Investment is increasing with the advent of ITER – the next construction phase alone is worth at least €2 billion. We are playing our part by alerting firms to opportunities and helping them form consortia to bid for contracts. Our first aim is for the UK to be number one in winning European contracts on ITER and then to establish this country as a leading player in the future fusion power economy."

He adds: "The ITER project faces significant engineering and project management challenges where UK companies can compete effectively – either on their own or as part of a consortium. The opportunities for involvement are wide-ranging, from civil, mechanical and electrical engineering, design consultancy and project management, through to instrumentation, advanced materials, magnets, vacuum systems, nuclear technologies and precision engineering."

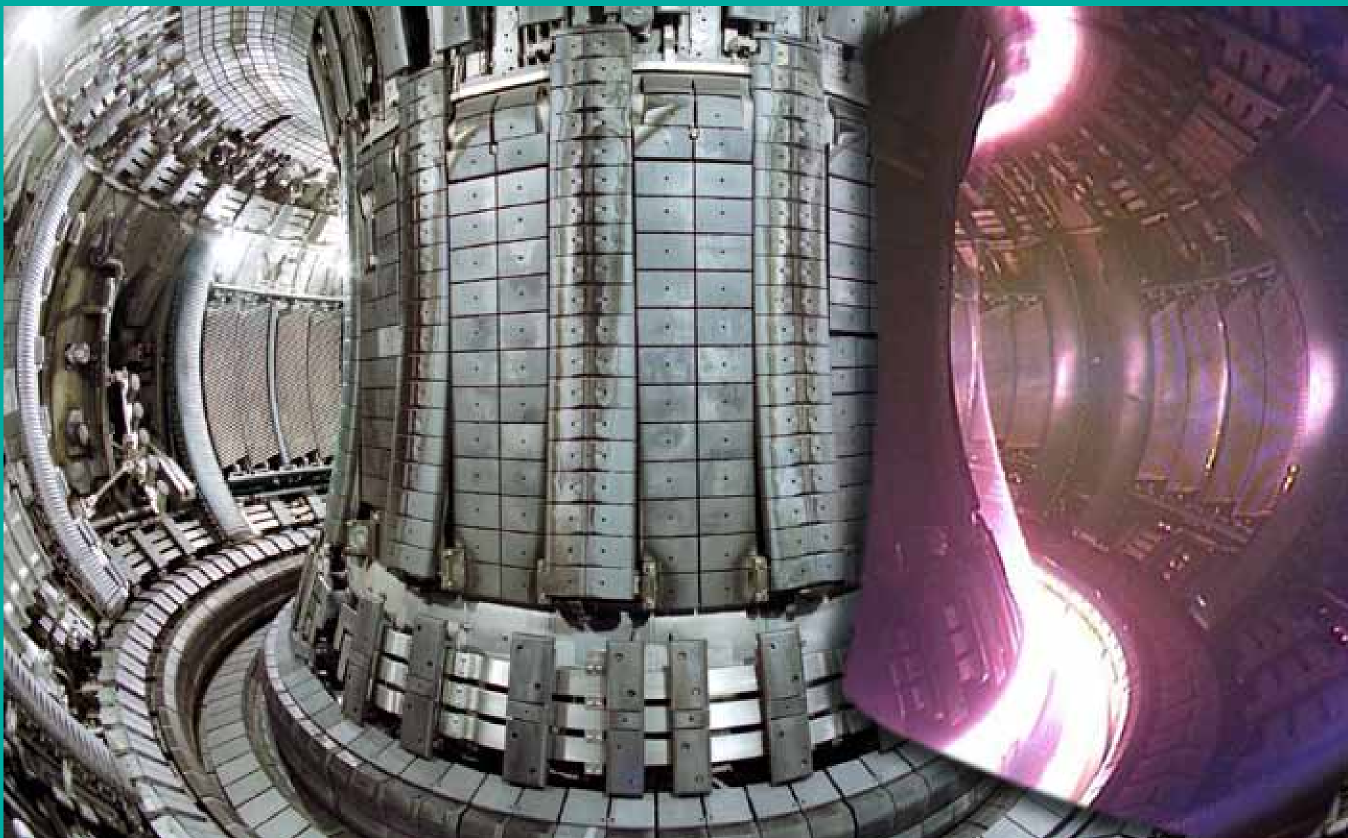
£30 million upgrade

Culham Centre for Fusion Energy hosts the Europe-wide research collaboration JET - Joint European Torus – which is currently the largest fusion device in the

For further information please visit
www.ccfe.ac.uk

Left: *The Mega Amp Spherical Tokamak at Culham*

The inside of the Joint European Torus at Culham with a fusion plasma superimposed (Image courtesy of EFDA-JET)



world. Culham also operates the UK's fusion experiment MAST - the Mega Amp Spherical Tokamak - which is pioneering a promising design concept for compact fusion reactors. A major £30 million upgrade to MAST, to be completed in 2015, will enable it to test technology for future power reactors, including an innovative heat exhaust system which may be adopted in the prototype fusion power station that will follow ITER.

Thanks to JET and MAST there are opportunities for UK business to get direct experience of fusion. "If UK companies apply and win contracts here it will be a really good opportunity for them to gain valuable experience if they later bid for ITER," says Mistry. Involvement in big science projects is shown to have knock-on benefits to suppliers, worth up to three times the value of the original project, through new business."

Looking further ahead, Professor Steve Cowley, Chief Executive of Culham Centre for Fusion Energy, sees the UK becoming a major centre for fusion technology, with industry playing an integral role. "Although most of our current programme is focused on ensuring the success of ITER," he says, "we are also increasingly addressing the additional technical challenges for commercial fusion – the end game. With leading experts in plasma physics, materials research and power plant design, we are well placed to make this transition."

"There has never been a better time for British companies to get involved in fusion. Investment is increasing with the advent of ITER – the next construction phase alone is worth at least €2 billion"

Dan Mistry
Fusion and Industry Manager at Culham

Case study 3.4

MG Sanders Ltd

MG Sanders, an alloy manufacturing and precision engineering company, has gained an international reputation for manufacturing high-quality tungsten alloys and applying them to a wide range of applications, from fusion reactors to Formula One cars.

The company is based in Stone, between Manchester and Birmingham, and started out in the early 1970s as a small family precision engineering firm. It has since developed into a thriving small to medium-sized enterprise (SME) which employs over 60 people.

Today, its DENSAMET® alloys are in great demand worldwide and are used in a wide range of sectors, including defence, aerospace, automotive, motorsport, nuclear energy and nuclear medicine.

Ian Warrington, Project Manager for MG Sanders, says: "We produce a unique product by processing in-house tungsten powder through consolidation, sintering and heat treatment in vacuum furnaces to a fully machined component. When enhanced mechanical properties are required, our in-house swaging capability can give up to a 25 per cent improvement."

He adds: "There aren't many companies globally that manufacture components from tungsten grades they have produced themselves. It means that we have been able to innovate in this area because of our control over the manufacturing of the alloys."

In addition to tungsten alloys, the company also produces components from other engineering materials, including refractory metals such as molybdenum, niobium, zirconium and tantalum. Turnover has been growing steadily in recent years and is expected to be well over £10 million in 2012 thanks in part to the demand from large scientific projects.

"We knew our work with tungsten and heavy metal alloys would be very relevant for fusion research given the high temperatures they could withstand," says Warrington. "Apart from carbon, tungsten has the highest melting point of all the elements, so we decided to tender for a contract on the European JET reactor based in the UK."

€5 million contract

At the time, the tender was a big commitment for MG Sanders as it took over six months of preparation to submit the final bid and the same time again before they found out the result. Yet the hard work paid off. In 2006, the company successfully won a €5 million contract to supply 50 tungsten tile modules for the central part of the JET divertor, which has to withstand the highest heat loads of any component. In operation, the tungsten lamellae may have to reach temperatures of up to 2,200°C, so each one had to be individually shaped to maximise their

For further information please visit
www.mgsanders.co.uk

***Left:** A CAD image of the ITER like wall installed in JET. **Above:** Tungsten –LBSRP test array with Langmuir probes. **Above right:** MGS Vacuum Sinter facility. **Right:** Single Tungsten-LBSRP showing Inconel 625 wedge carrier and spring assembly. (Images courtesy of EFDA/CCFE and FZ Juelich)*

power-handling capabilities.

"The experience of JET has been absolutely invaluable and has placed us in a good position to win similar contracts for other big science projects," says Warrington. "A few years ago we were taken over by the Rubicon Partners Industries LLP Group, which has invested a lot in our facilities, including new CNC five-axis machine tools, clean room assembly facilities, electrical discharge machining (EDM) capability and additional metallurgical management resources."

New business opportunities

Soon after completing JET, MG Sanders was successful in winning two new contracts with one of the world's leading science experiments at CERN. "I am sure we got the work at CERN because of our experience of JET," states Warrington.

"One leads to the other. At CERN we again used our experience of tungsten, but this time to produce absorber plates for the Compact Linear Collider study."

The company also has its sights on supplying the world market for synchrotrons. It has already carried out work for the UK's Diamond Light Source and, with support from UKTI, is hoping to win contracts with the French synchrotron at Grenoble.

"This year we have been on a UKTI trade mission to the European Synchrotron Radiation Facility at Grenoble," says Warrington. "It was really helpful as UKTI arranged a lot of interviews for us as well as formal and informal gatherings. It has opened up a lot of contacts for the company and given us a lot of opportunities, so it was a really worthwhile trip."

"We produce a unique product by processing in-house tungsten powder through consolidation, sintering and heat treatment in vacuum furnaces to a fully machined component. When enhanced mechanical properties are required, our in-house swaging capability can give up to a 25 per cent improvement"

Ian Warrington
Project Manager for MG Sanders

Case study 3.5

For further information please visit
www.viglen.co.uk
www.cern.ch

Viglen Ltd – CERN collaboration

Viglen is a major solutions supplier to the UK's corporate and public sectors. It supplies IT hardware, software and technical support to the majority of the UK's universities, including Oxford and Cambridge.

Viglen's first delivery of equipment to CERN. (Image courtesy of CERN)

In 2010, Viglen received a portion of two contracts worth £1.8 million awarded by CERN. STFC's subscription to CERN on behalf of the UK helped Viglen bid for the contracts, which were to provide the HPC and storage equipment needed to handle about 15 petabytes (10^{15} B = 1 million gigabytes) of data annually.

Bordan Tkachuk, Viglen CEO, said: "We are delighted to announce this agreement with CERN. Having already worked on some innovative projects with other contributing GridPP UK-based sites, we are honoured to be the leading UK-based company to supply HPC solutions to CERN in this way in recent years. Like CERN, we maintain the same desire for excellence and this agreement will mean that CERN will possess all the storage capacity and processing power for it to remain at the forefront of scientific research."

Dr Olof Bärring, Head of Computer Facility Planning and Procurement at CERN, stated: "Viglen was one of the firms awarded large contracts for expanding our processing and storage capacity. This expansion, which represents almost a doubling of the total capacity, is required for meeting the scientific computing needs of the experiments at CERN's LHC, the world's highest-energy particle accelerator commissioned at the end of 2009. Our strong requirements on performance, cost and power efficiency were readily met by Viglen's solutions and we have been impressed by their experience in dealing with large-scale computing and storage projects as well as the timely and reliable delivery."

> "Viglen was one of the firms awarded large contracts for expanding our processing and storage capacity"
>
> ***Dr Olof Bärring***
> *Head of Computer Facility Planning and Procurement at CERN*

Case study 3.6

For further information please visit
www.prototech.co.uk
www.isis.stfc.ac.uk

Prototech Engineering Ltd – ISIS collaboration

The performance of the ISIS Pulsed Neutron and Muon Source is highly dependent on the performance of its moderators. Costing nearly £50,000 each and replaced approximately every six months, these moderators are made up of a complex system of layers containing cryogenically cooled methane and helium.

Inspection of a moderator for ISIS's new research facility, Target Station 2

Being extremely detailed in their design, these moderators require precision engineering. Prototech Engineering Ltd won the contract to supply moderators for neutron scattering and muon spectroscopy for Target Station 2, ISIS's new research facility.

Sean Higgins, a lead engineer from ISIS, said "These components are incredibly complicated to manufacture. Being able to drive down the road to Prototech to discuss progress and solve problems has reduced the cost of the project. Sometimes you can't solve problems on the phone – you need to sit next to each other and work it out. This was an incredibly complex piece of manufacturing and we are very lucky to have such skills available in the UK. But it is up to facilities such as ISIS to identify, and put them to good use. If we don't, we may lose them."

Such tendering opportunities offer small UK companies a chance to supply to world-class LRFs and also support local business. John Greenaway, Managing Director of Prototech, said: "The idea that small companies cannot work with big research facilities is wrong. Small businesses can see huge benefits from the long-term contracts on offer. Winning work from large world-class facilities such as ISIS gives us the confidence to pitch for other large contracts. And because our formal relationship with ISIS is set for four years, we can enjoy valuable long-term stability at a time when the future of the UK economy is so uncertain."

"The UK is full of small, highly skilled and specialised engineering companies, with a lot to offer. Prototech supplies complex assemblies for moderating cold neutrons. It's great to see a small UK company step up to the challenge of manufacturing complex assemblies for a world-class scientific research facility."

Sean Higgins
Project Engineer, ISIS Design Division

Case study 3.7

Zeeko Ltd

Zeeko Ltd has used British ingenuity to take the technology it developed for “big science” telescopes and apply it to a completely different sector. Its robotic polisher is able to make a replica of a knee joint by scanning its surface and turning it into a highly sophisticated prosthetic. And the key to making such a precise replica of a knee joint is the high degree of accuracy.

“We produce ultra-precise surfaces where the overall shape is a few hundred atoms and their roughness is a few tens of atoms,” says Dr David Walker, Research Director of Zeeko, as well as Research Professor at UCL and Professor of Optics at Glyndŵr.

Today, Zeeko is a world leader in the development and manufacture of computer-controlled, ultra-high-precision polishing machines that can produce freeform artifacts from 1.5mm to 2m in diameter.

While the company’s first products served the optics industry, it has adapted the technology not only for prosthetics but also for semi-conductors, display technology, mould making, aerospace and the healthcare market, including endoscope lenses, contact lenses and intra-ocular lenses. The list could go on. “We are constantly finding new uses for the technology, whether it’s plastic injection moulds, a semi-conductor wafer or a compact camera lens,” says Richard Freeman, Zeeko’s Managing Director.

Big science projects

Today, Zeeko has an annual turnover in excess of £6 million and machines in use all over the world. While the applications for the Zeeko machines are vast, the company has also stayed true to its roots. “The larger Zeeko machines are focused on the astronomical optics market and their demand for segmented telescopes that comprise large numbers of off-axis segments,” explaind Walker “This is a market that we are well placed to satisfy as we are leaders in the processing of off-axis components, as well as developing the technology to polish to the edge without rolling and degrading it.”

Perhaps Zeeko’s greatest success to date has been its involvement in the NASA 2009 satellite that was launched to remap the moon’s surface. The optics used in the two on-board cameras were entirely produced on Zeeko machines operating in California. Zeeko is also involved in the European Extremely Large Telescope with its 42m primary mirror and the equivalent US Thirty Meter Telescope.

Large Research Facilities

From its early days Zeeko has worked with many of the leading research institutes throughout the world. “Large Research Facilities are always trying to push the boundaries and as a result they often want to use our machines in ways that we never originally envisaged,” says Freeman. “For example, while they were originally designed to polish glass, you may get an academic researcher wanting to use it for tungsten carbide or, at the other

For further information please visit *www.zeeko.co.uk*

Left: *Zeeko IRP1600 Machine at OpTIC, St Asaph; currently polishing the Sample Segments for the ESO 42 Metre Telescope.* ***Below:*** *The Queen's Award being awarded by Lady Gretton to Richard Freeman (MD), with the Zeeko Team*

Below: *High-Precision Glass Shell used for making X-Ray Telescopes, being measured on Ultra-Precision Metrology Equipment.* ***Bottom:*** *A view of the Zeeko Production Floor*

extreme, plutonium. This is really helpful for us as it is a further opportunity to test our machines to the limits and ensure we have robust products."

Zeeko also offers many other benefits. "Leading-edge scientists have bright ideas and we like collaborating with them," says Freeman. "It helps us to keep moving the company forward and developing new applications. More than 20 per cent of our annual revenue is spent on research and development, which is the lifeblood of the business."

Freeman is in no doubt that UKTI has been key to helping them grow over the years. "UKTI has been tremendously helpful in all sorts of ways," he states. "Last year, I went to NASA with them and made a lot of useful connections. This year I was at Farnborough with UKTI and got to meet space- and aerospace-based companies. While I am sure I would eventually have found a way of meeting these people, UKTI made it a lot easier and quicker. Also, when working overseas they have been very helpful at market introductions as well as cutting through red tape. I have a rather special place in my heart for UKTI because I really think they make a difference."

A Zeeko IRP 1200 Machine

"We produce ultra-precise surfaces where the overall shape is a few hundred atoms and their roughness is a few tens of atoms"

Dr David Walker
Research Director of Zeeko

Case study 3.8

OpTIC

A pioneering Welsh company that specialises in precision optical design and manufacturing has developed a new technology that greatly enhances the energy uptake for commercial use photovoltaic cells. In just 12 months, OpTIC has increased sales from £50,000 to £500,000 for its specialist copper moulds that are used to produce a fine film for concentrating ultraviolet (UV) light through a Fresnel lens.

John Oliver, Marketing Director of OpTIC, says “We have the world’s most advanced CNC optical machines and as a result have become leaders in the production of high-precision film moulds. Our specialist staff and unique drum diamond turning machine give clients the opportunity to replicate patterns to tolerances and designs unparalleled in the world.”

As well as solar power, the company also predicts that there is a similar fast-growing market for moulds to produce film for light-emitting diode luminaires, which are significantly more energy efficient than traditional lighting systems. Film produced from its moulds is also being used to diffuse light in computer and television screens.

Academic collaboration

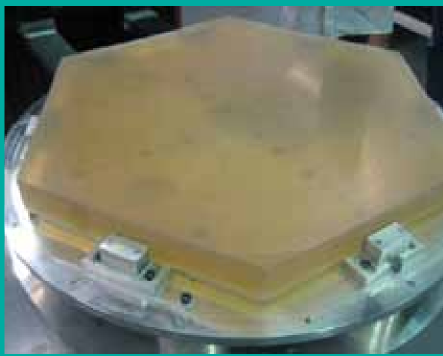
However, mould making is just one arm of this company that specialises in designing, developing and manufacturing customised precision optical and opto-mechanical components and systems. It has a capability that has worldwide demand – the past two years have seen OpTIC increase its exports fivefold.

“We’re competing against large global organisations, so collaborating with other UK organisations to enhance our international reputation has been key,” says Oliver. “In particular, we’ve partnered with leading academic organisations to help develop new processes and products – such as Cranfield, UCL and nearby Glyndŵr University. However, what is critical is that they are based on-site here and regarded as part of our team as well as being customer facing.”

OpTIC is based within one of Europe’s largest purpose-built industrial-scale facilities. The laboratory space has an unparalleled array of highly specialist manufacturing and testing equipment.

“When we are micro-cutting a precision drum – which could take up to 15 days at a time – the environment needs to be highly controlled and vibration resistant 24 hours a day,” says Olive. “We specifically chose this peaceful rural location in North Wales because of our highly specialised manufacturing requirements, but also because of the transport links to international airports such as Manchester.”

For further information please visit
www.opticinnovations.co.uk



***Opposite:** Programming a CNC polishing machine. **Top left:** Two of OpTIC's large glass polishing machines. **Top right:** 1.5m diameter mirror segment prepared for polishing. **Bottom left:** R&D tests on smaller mirror. **Bottom right:** Polishing one of the world's largest telescope mirrors*

€5 million telescope contract

One of OpTIC's recent major successes has been securing a €5 million contract to make the first seven prototype mirror segments for the world's largest telescope – the European Extremely Large Telescope – in Chile. When completed, the telescope will require 931 hexagon-shaped mirrors. The mirrors are 0.24nm in accuracy and 1.5m in diameter and polished on the largest CNC machine of its type in the world.

"The success we have had with this machine means that there is a real opportunity for moving into other sectors as the technologies are similar," says Oliver. "So, for example, we can make optics for fusion reactors, which have an even greater potential future growth market. The aerospace market also demands mirrors that are equally precise, but are much lighter in weight – typically 70-80 per cent lighter than normal – and we now have a new machine that can produce for this specification as well."

As well as manufacturing, the company also offers a precision engineering design and testing service for optical systems. This enables clients to go rapidly from concept design through to product verification and prototyping.

"We're competing against large global organisations, so collaborating with other UK organisations to enhance our international reputation has been key"

John Oliver
Marketing Director of OpTIC,

Case study 3.9

Instrument Design Technology

IDT, a Cheshire-based UK company that specialises in designing and building beamlines for synchrotrons, is doubling its laboratory space following a continual growth in orders.

In the first six months of 2011, IDT won well over £500,000-worth of contracts to supply beamlines for synchrotron facilities around the world. These include contracts with some of the most prestigious global research facilities, including Diamond Light Source, the Australian Synchrotron Project and the Advanced Photon Source in Chicago.

Synchrotrons produce very bright beams of light – sometimes substantially brighter than the sun. The result is an extremely powerful tool to study samples at a molecular level, and therefore synchrotrons are in great demand by a worldwide community of scientists.

Paul Murray, Managing Director of IDT, has considerable expertise and experience in the world of synchrotron beamlines, having worked since the early 1980s on some of the world's leading research facilities.

"My partner at IDT and I met while working as engineers at Daresbury during the 1980s," he states. "It meant we gained first-hand experience of developing beamlines for the world's first dedicated synchrotron radiation source."

It proved valuable experience and led Murray to further work at other major synchrotron facilities around the world: the Advanced Photon Source in Chicago and the European Synchrotron Radiation Facility in Grenoble. On his return to the UK in 2000, he and others set up IDT.

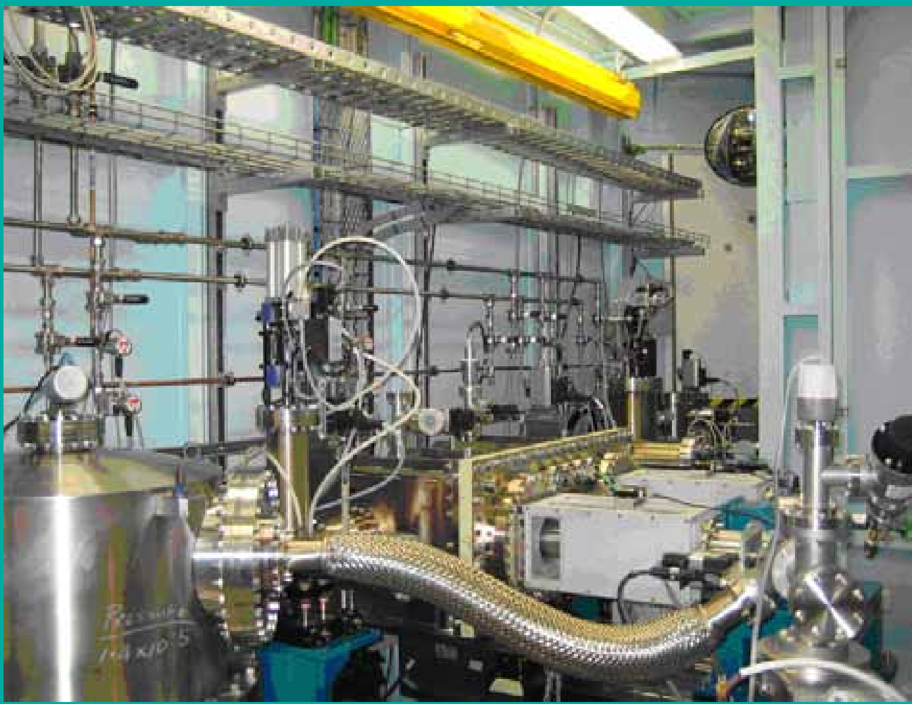
"It was a good time to start such a specialist company as governments around the world had started to invest heavily in synchrotron facilities and our skills were in big demand," he recalls.

Early in the development of the company, Murray realised that if they were to continue to grow they needed to add new skills to the team. "We were getting plenty of work but were also finding that synchrotron facilities were asking suppliers not only to design and build the beamlines but also to provide control software to complement their hardware instruments," he explains. "As we hadn't got this skill in-house, we relied on external consultants. By 2004, we decided that if we were to continue to build the company, we needed to have this capacity in-house."

IDT secured funding from a government scheme to send one of its staff with a PhD in physics on a six-month secondment to the GeoSoilEnviro Center for Advanced Radiation Sources at the University of Chicago.

"This was a great opportunity as our member of staff got to work with a leading research team and learn how to apply EPICS instrument control software to our beamline work. It was

For further information please visit
www.idtnet.co.uk



Micro-spectroscopy Beamline @ Australian Synchrotron –Melbourne. Designed, built and commissioned by IDT

a real success and has made a big difference to our ability to tender for much larger contracts," says Murray.

Today, the company, which has Total Quality Management System ISO 9001:2008 accreditation, is one of only a small handful in the world that can offer a complete design and build service for synchrotron beamlines. It employs 12 people, has a turnover in excess of £1.5 million and is regarded as a world leader in beamline instrumentation.

"The staff of IDT have decades of combined experience in professional engineering and the design, planning and construction of innovative instrumentation at the very highest level of scientific facility development," says Murray. "They include mechanical engineers, PhD physicists and highly skilled technicians."

IDT is involved in all stages of designing, building and testing precision opto-mechanical systems for synchrotron beamlines and other related scientific instruments.

"IDT has core competencies in the design and build of complex multi-axis instruments, often working in an ultra-high vacuum environment under high heat loads," states Murray. "The complex optical engineering focusing systems for X-rays often have novel concepts incorporated." He adds, "We have a growing reputation for novel monochromators with exceptional proven performance in the field. Our Small Mirror Kirkpatrick-Baez X-ray focusing systems are the market lead."

"My partner at IDT and I met while working as engineers at Daresbury during the 1980s. It meant we gained first-hand experience of developing beamlines for the world's first dedicated synchrotron radiation source"

Paul Murray
Managing Director of IDT

Case study 3.10

Observatory Sciences Ltd

Observatory Sciences Ltd is one of the world's leading developers of software for the control of "big science" systems and instruments, in particular large telescopes. The company, which is based in Sussex and Cambridge, has a core team of six specialists, who all have a background in astronomy and computer science.

"We use a wide range of software technologies for producing control systems, including the EPICS toolkit and the LabVIEW graphical programming language from National Instruments, as well as Java and C/C++ programming," says Philip Taylor, who helped set up the company 13 years ago. "We not only develop control systems, but also carry out feasibility and technology studies and training for clients, as well as placing our scientists on the ground to see projects through from concept to completion."

He adds, "We also give software support to providers of equipment used in scientific facilities, particularly in the area of motion control. We have worked with a number of companies in Europe, including Micromech, Delta Tau and Heason Technology in the UK, Danfysik in Denmark and ACCEL and attocube in Germany."

Astronomy and astrophysics projects

Observatory Sciences has worked with many of the world's LRFs on astronomy and astrophysics projects. They include the Gemini Observatory in Chile and Hawaii, the Magdalena Ridge Observatory Interferometer, the European Extremely Large Telescope and the Discovery Channel Telescope.

The company recently won a contract to produce the software that will control the world's largest solar telescope. The US$298 million Advanced Technology Solar Telescope (ATST) will have a 4m-diameter primary mirror and will be sited at an altitude of 3,048m on the Hawaiian island of Maui. It will have unprecedented abilities to view solar detail and allow scientists to learn even more about the sun and solar–terrestrial interactions. The ATST project is a collaboration of nearly all the American institutions involved with solar physics and is run by the US National Solar Observatory based in Arizona.

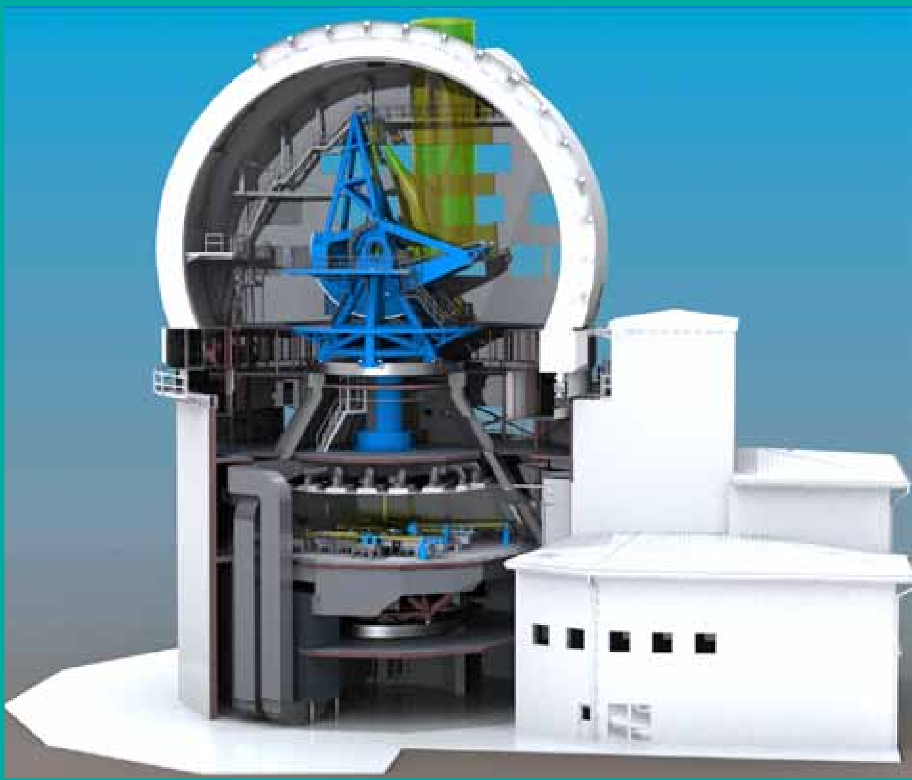
Benefits of working with LRFs

There are many benefits of working with LRFs, both directly and indirectly as a sub-contractor for other companies. "Working for LRFs means that we get a lot of variety as well as getting to work with some of the world's best scientists on cutting-edge projects. It is extremely rewarding," says Dr Chris Mayer, a Director of Observatory Sciences.

There are also real practical benefits of working with a large institution.

For further information please visit
www.observatorysciences.co.uk

Rendering of ATST looking south.
(Image courtesy of KC Environmental Inc)



Cutaway view of the ATST observatory facility. (Image courtesy of AURA/NSO/ATST)

"LRFs are big organisations and are not going to go bust, which is good news in a difficult world economic climate," states Mayer. "It also means that you get paid on time, which for a small company is really important. Additionally, while there are no guarantees, you often get the opportunity to work on these projects for many years because they are so large and have long time scales. And of course, success on one LRF project means it is much easier to win future ones."

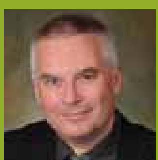
The future looks bright for the company. While it continues to specialise in astronomy, it is also branching out into new areas. In recent years, it has applied its considerable specialist skills to the development of control systems for projects such as the UK's Diamond Light Source synchrotron.

"Our consultants have been responsible for the production of Diamond software systems, as well as writing and commissioning software used to control beamline equipment and carrying out training courses," explains Mayer. "We have also been involved in the Australian Synchrotron Project in Melbourne. We will continue to look for other opportunities with LRFs to use and apply our skills, for example in the field of medicine or fusion energy projects. It's an exciting time."

"We use a wide range of software technologies for producing control systems, including the EPICS toolkit and the LabVIEW graphical programming language from National Instruments, as well as Java and C/C++ programming"

Philip Taylor
Director of Observatory Sciences Ltd

“The UK has invested significantly in Large Research Facilities over the past decade, ensuring that our scientists have access to the world-leading capabilities they need to remain at the forefront of research and to address the pressing problems faced by society and the economy”



John Womersley
Chief Executive, STFC

Section C

Large Research Facilities in the UK

Large Research Facilities in the UK

This chapter concentrates on providing an overview of the LRFs currently based in the UK. This has been included not only to increase the reader's understanding of the diverse range and capabilities of UK LRFs, but also in recognition that many LRFs are increasingly undertaking contract research in order to provide solutions to academic and industrial challenges around the world.

***Right:** Professor Fred Mosselmans loading a sample of wood from the Tudor warship the Mary Rose on the Microfocus Spectroscopy beamline. Diamond is helping with the design of a new treatment to ensure that the Mary Rose can be on public display for years to come. (Image courtesy of Diamond Light Source)*

4.1 Introduction

The UK has some of the world's most prestigious LRFs, which conduct leading-edge R&D in a wide variety of disciplines such as the medical and biological sciences, astronomy, chemistry, geology, environmental and materials sciences, physics and engineering.

The majority of these facilities are funded by the UK Government through organisations such as the United Kingdom Atomic Energy Authority's Culham Centre for Fusion Energy (CCFE), the National Nuclear Laboratory and the Research Councils (for example, the Science and Technology Facilities Council (STFC), the Natural Environment Research Council (NERC), the Biotechnology and Biological Sciences Research Council (BBSRC) and the Medical Research Council (MRC)). UK charities such as the Wellcome Trust also play a leading role in supporting LRFs, including Diamond Light Source, the UK's national synchrotron science facility.

The UK also has a number of research centres embedded within universities, such as the Dalton Nuclear Institute at the University of Manchester. Some of these centres, such as the Integrated Vehicle Health Management (IVHM) Centre based at Cranfield University, the Advanced Manufacturing Research Centre (AMRC) at Sheffield University and the Nuclear AMRC, a collaboration between the Universities of Sheffield and Manchester, have been funded through a public–private partnership with commercial organisations such as BAE Systems, Boeing and Rolls-Royce.

All these facilities are increasingly taking the form of distributed, networked resources that exploit advances in information and communications technology to underpin new modes of collaborative research, rather than operating as large physical installations.

In 2010, the Government also announced the creation of a series of Catapult centres to help drive the commercialisation of technologies from the research base and to support business-driven innovation.

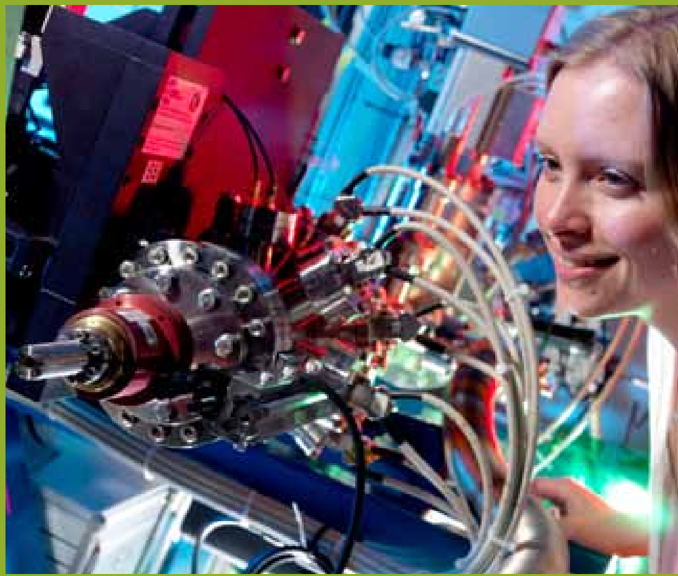
An overview of a selection of the UK's LRFs is presented below.

4.2 Science and Technology Facilities Council

STFC, one of the UK's seven Research Councils, is keeping the country at the forefront of international science and tackling some of the most significant challenges facing society. These include meeting our future energy needs, monitoring and understanding climate change and ensuring global security.

It has a broad science portfolio and works with the academic and industrial communities to share its expertise in materials science, space and ground-based astronomy technologies, laser science, microelectronics, wafer-scale manufacturing, particle and nuclear physics, alternative energy production, radio communications and radar.

STFC operates and hosts world-class experimental facilities in the UK and overseas. It also enables UK researchers to access leading international science facilities by funding membership of international bodies including CERN, the Institut Laue-Langevin (ILL), the European Synchrotron Radiation Facility (ESRF) and



__Above:__ Dr Claire Pizzey on Diamond's Small Angle Scattering & Diffraction beamline. This experimental station is used for a wide range of studies; from protecting historic parchment to improving corneal surgery. (Image courtesy of Diamond Light Source)

the European Southern Observatory (ESO). The following are some of the key UK facilities funded by STFC.

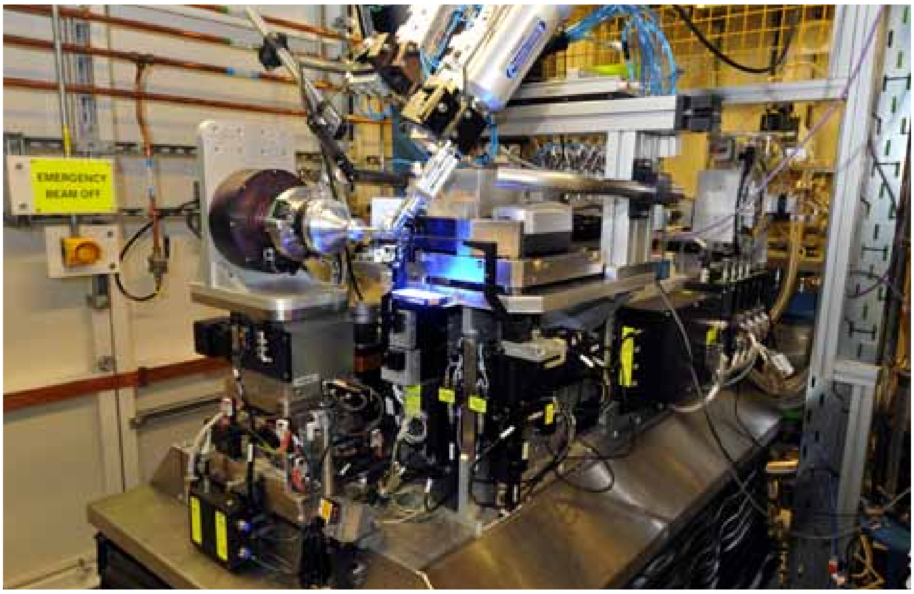
4.2.1 Diamond Light Source

Diamond Light Source is the UK's national synchrotron facility, located at Harwell Oxford, the national science and innovation campus in Oxfordshire. Construction of this research facility began in early 2003, and Diamond became operational on schedule in early 2007.

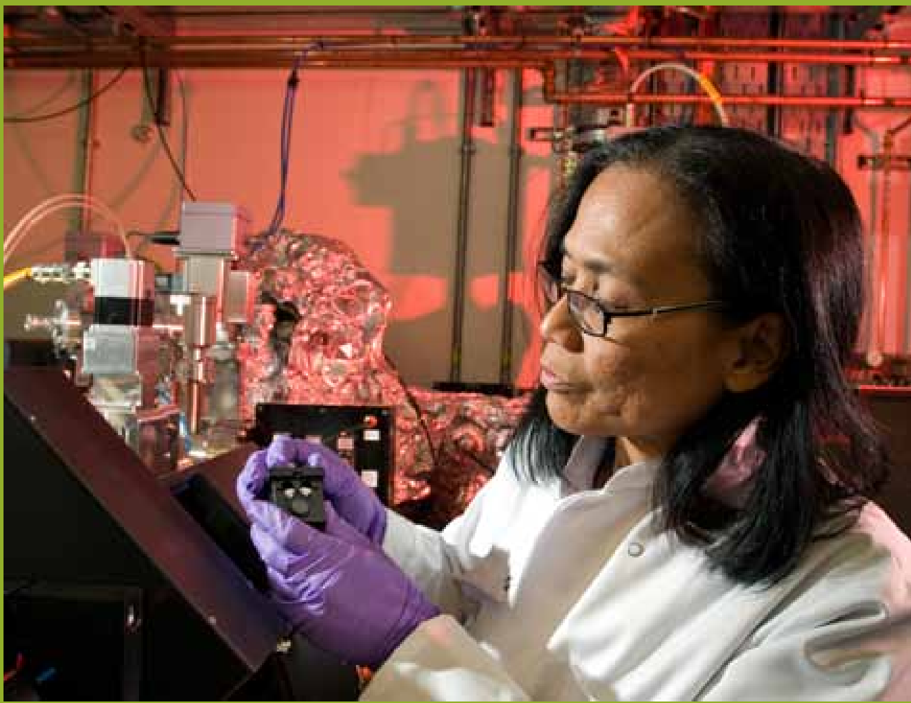
It is run by Diamond Light Source Ltd, a joint venture limited company funded by the UK Government via STFC and the Wellcome Trust. These organisations own 86 per cent and 14per cent of the shares respectively in the limited company, which is operated as a public–private partnership. This type of funding model is groundbreaking and has been set up to encourage industry not only to utilise the synchrotron facility but also to spread the cost of maintaining and running it. Diamond is the largest scientific facility to be built in the UK for over 40 years.

A third-generation synchrotron, Diamond accelerates electrons to near light-speed to generate brilliant beams of light from infrared to X-rays, which are used for academic and industrial R&D across a range of scientific disciplines including structural biology, physics, chemistry, materials science, engineering, and earth and environmental sciences.

Diamond is being developed in three phases. A total of 20 beamlines are now operational, with two more due to

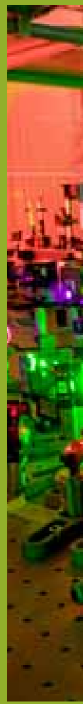


One of the five macromolecular crystallography (MX) beamlines at Diamond, I04 is used to carry out research in the life sciences, helping to determine the 3D structures of proteins and other large biological molecules. Previous studies using structural data from Diamond's MX beamlines include gaining a better understanding of hypertension in the pre-natal condition pre-eclampsia, learning how a key tuberculosis drug is activated, understanding how bird flu can affect humans, and revealing the mechanism used by HIV to attack the body.. See page 12 for an aerial view of the Diamond Synchrotron.



PhD student Teresa Buenavista on Diamond's Circular Dichroism (CD) beamline. CD is a technique that can help us understand the structure-function relationship in proteins, an essential step in identifying new targets for novel drug therapeutics

Central Laser Facility – Right: *Adjusting mirrors in the front end pump laser for the Vulcan 1 PW Petawatt Laser Facility, one of the most powerful lasers in the world. With the potential to upgrade to 10 PW, enabling the further advancement of extreme physics, giving the ability to investigate pulsar magnetospheres - the science of stars.* ***Far Right:*** *The lasers are being collimated and aligned before entering a TIRF microscope. The microscope was set up for either wavelength (an adjustment to a filter ring enabled the changeover). (Credit: James Berridge)*



come online in 2012. Each beamline is optimised for a specific technique and ranges from macromolecular crystallography to angle-resolved photoemission spectroscopy. In March 2011, Phase III was launched, which involves building an additional 10 advanced beamlines between 2011 and 2018, bringing the total to 32.

Over 3,000 researchers from the UK and worldwide currently use Diamond, and this work generates several hundred research papers in leading scientific journals every year. Diamond increasingly supports industrial R&D, technology and innovation in areas ranging from drug discovery and design through catalysts and energy applications to aerospace engineering.

4.2.2 ISIS

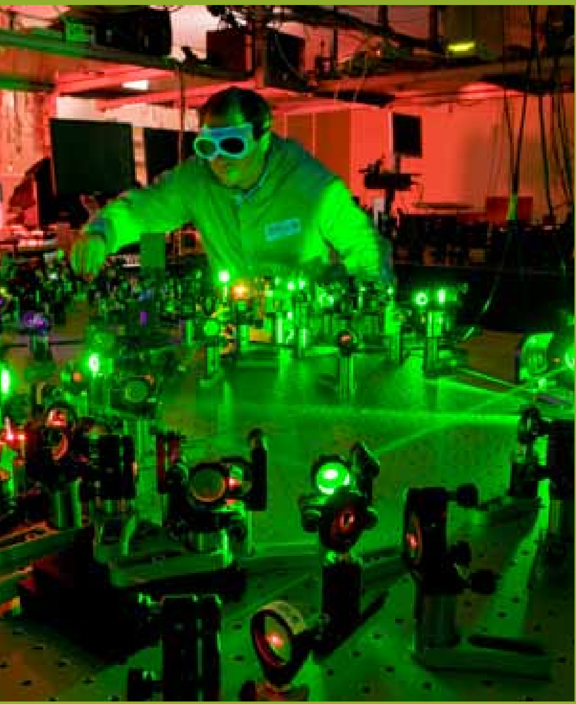
The ISIS Pulsed Neutron and Muon Source at RAL Space, located in Harwell, Oxford is a world-leading research centre in the physical and life sciences. At the heart of ISIS is a proton accelerator that produces intense pulses of protons 50 times per second.

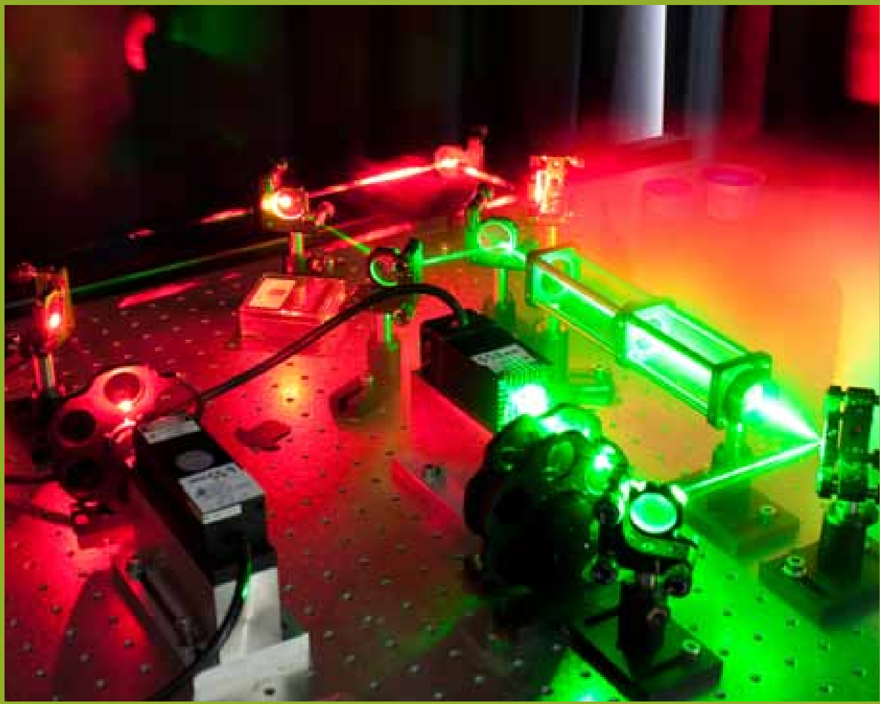
Muons are produced when the proton beam passes through a carbon target. The protons then go on to collide with a tungsten target and produce neutron pulses.

Neutron scattering and muon spectroscopy can then be used to probe the structure and dynamics of condensed matter on a microscopic scale ranging from the subatomic to the macromolecular. Neutrons and muons can easily penetrate matter and, by pinpointing the location of atoms and molecules, it is possible to determine the structure of materials and how this relates to their possible use.

ISIS research has been used to improve the performance of aircraft and power stations; develop bio-compatible materials, including a new method for cleft-palate treatment and plastic surgery; identify solutions for waste water treatment, such as determining the fate of nanoparticles or characterising the breakdown of environmental contamination by natural enzymes; and

The ISIS Neutron source Target Station 2 Experimental Hall.





in the discovery of new materials for hydrogen storage and clean energy.

During 2009, ISIS completed a £145 million expansion by building a second target station to increase scientific capability and add capacity for the key research areas of soft matter, advanced materials and bioscience. There is capacity for at least 18 new instruments on the second target station.

Seven instruments have been built during Phase One and all are operational. The Phase Two Instruments Project will build the next four instruments together with the necessary advanced detectors, electronics and software. The four new instruments, listed below, will give ISIS scientific capability that is in short supply worldwide:

- Chipir – Facility for the aerospace and electronics industries to examine how microchips respond to cosmic radiation, thereby ensuring that computer systems for cars, communications and medical equipment operate reliably, and keeping aircraft safe.
- Imat – Neutron imaging and materials testing for power generation, civil engineering, transportation and aerospace.
- Larmor – Advanced techniques instrument for polymer science, biomaterials and food science.
- Zoom – Small-angle scattering instrument for advanced materials, biological and environmental science, pharmacy and magnetism.

Overall, the neutron and muon beams produced at ISIS are used in research areas ranging from clean energy and the environment to pharmaceuticals, nanotechnology and information technology.

4.2.3 Central Laser Facility

The Central Laser Facility (CLF) at STFC's RAL is a world leader in its field. Its wide-ranging applications include experiments in physics, chemistry and biology, accelerating subatomic particles to higher energies and probing chemical reactions on the shortest timescales.

***Table 4.1**: STFC CLF laser systems*

Laser facilities	Details
Vulcan	This petawatt laser can deliver a focused beam, which for 1 picosecond is 10,000 times more powerful than the National Grid. Vulcan plays a key role in laser plasma research in the UK, especially the role of inertial fusion in the UK fusion programme.
OCTOPUS	Optics Clustered to OutPut Unique Solutions comprises a central core of lasers coupled to multiple advanced microscopy stations that can be used to image samples from single molecules to whole cells and tissues.
Artemis	This aims to bring together femtosecond laser and synchrotron technologies to enable new science in the emerging field of ultra-fast time-resolved X-ray techniques.
Astra	This is a high-power, ultra-short pulse, high repetition rate laser using titanium-doped sapphire as its active material, and works in the near infrared part of the spectrum.
Astra Gemini	This is an extension of Astra, which can deliver 30 times as much energy. The extreme concentration of energy possible with Gemini makes it one of the most intense lasers in the world.

Central Laser Facility *– Targets with the dimensions in microns act as "samples" for investigations into the physics of extreme conditions comparable to temperatures and pressures at the centre of the sun; they are at the forefront of research into laser-induced fusion as a potential energy source and particle beam therapies for cancer treatment.*

The CLF provides access to large-scale laser systems for researchers from the UK and other EU countries. The facility operates high-power glass and Ti:sapphire laser installations and a number of smaller-scale, tuneable lasers. Its laser facilities are listed in Table 4.1.

The CLF also has a Target Fabrication Group, who possess extensive experience in micro-assembly, thin-film coating, characterisation of micro-targets and micro-machining.

They work closely with the user community to provide advice, delivery and characterisation of high-specification micro-targets. They are also actively involved in R&D projects into novel target designs and micro-assembly techniques to be able to deliver targets for the high-power lasers of the future.

4.2.4 Computational Science and Engineering

The International Centre of Excellence in Computational Science and Engineering (ICE-CSE) is located at STFC's Daresbury Laboratory. ICE-CSE is a new kind of computational science institute for the UK. It brings together academic, government and industry communities and focuses on multidisciplinary, multi-scale, efficient and effective simulation by creating next-generation simulation software.

The aim of ICE-CSE is to provide a step-change in simulation and modelling capabilities that will address key societal challenges such as environmental monitoring, more accurate weather and climate prediction, developing cleaner and more efficient energy sources and modelling new medicines.

In 2011, the UK Government announced an investment of £37.5 million in computational science at Daresbury Laboratory. This will see the existing infrastructure upgraded to enable the ICE-CSE to host the next generation of high-performance computing systems (Blue Gene/Q, iDataplex, Data Intensive Systems and large disc and tape storage systems).

These improvements will put the ICE-CSE at the forefront of the development of new software applications and services, which in turn should enhance the UK's ability to address key challenges and deliver new breakthroughs in science in the next few years.

Left: The view shows the first LOFAR station to be built, located at STFC's Chilbolton Observatory. Unlike conventional radio telescopes, there are no moving parts, but steering of the telescope is done in software. When completed, LOFAR will consist of over 5,000 separate antennas spread in "stations" all over Europe. The project is based in the Netherlands where the core of the array is located.
Below left: *One of the LOFAR Low-Band Array (LBA) aerials at Chilbolton*

4.2.5 Chilbolton Facility for Atmospheric and Radio Research

The Chilbolton Facility for Atmospheric and Radio Research (CFARR) is one of the most advanced meteorological radar experimental facilities in the world, and is home to the world's largest fully steerable meteorological radar, the Chilbolton Advanced Meteorological Radar.

In January 2006, Chilbolton received the first signals from the new GIOVE-A satellite, launched for the European Space Agency's Galileo navigation system.

The main research tool at the Chilbolton Observatory is a 25m, fully steerable antenna. The pioneering 3GHz Doppler-polarisation radar is installed on this antenna, along with the 1275MHz clear air radar.

Other facilities at the site include 35GHz and 94GHz cloud radar systems, meteorological sensors and a high-power UV Light Detection and Ranging (LIDAR) that measures clouds and water-vapour profiles.

The Isaac Newton Group of Telescopes situated on the island of La Palma, one of the Canary Islands

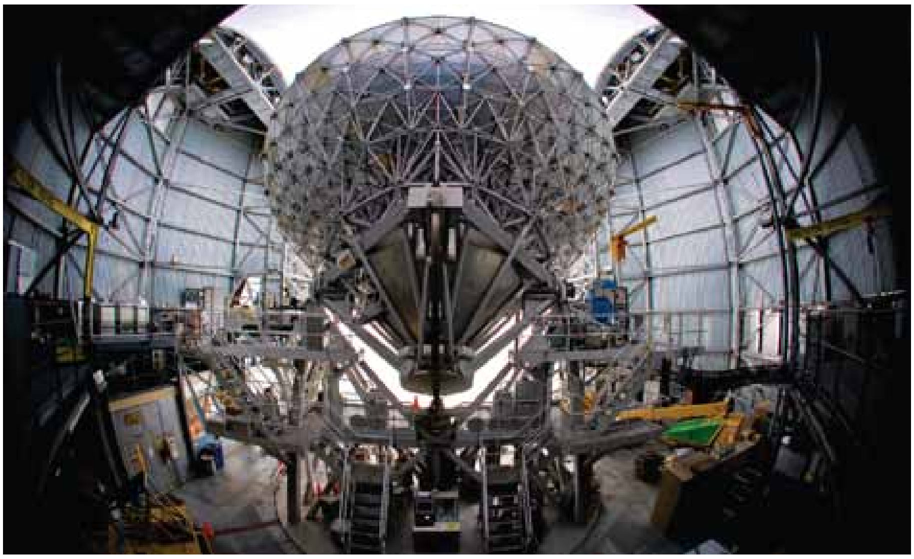
4.2.6 Isaac Newton Group of Telescopes

The Isaac Newton Group of Telescopes consists of the 4.2m William Herschel Telescope, the 2.5m Isaac Newton Telescope and the 1m Jacobus Kapteyn Telescope, operating on the island of La Palma in the Canary Islands, Spain.

These facilities have allowed researchers to undertake a wide range of astronomical observations, from the optical wavelengths to the infrared, covering both imaging and spectroscopy. In turn, these observations have helped in discovering the accelerated expansion of the universe and have contributed to developments in the fields of observational cosmology, gamma-ray bursts, galaxy dynamics and star evolution.

The William Herschel Telescope remains at the forefront of astronomical research, aided by continued development of instrumentation, particularly in the field of adaptive optics.

***Below**: The James Clerk Maxwell Telecsope with its gortex covering is able to observe during the daytime. **Below right**: A view from inside JCMT. The backing structure provides support for the 15m dish.*



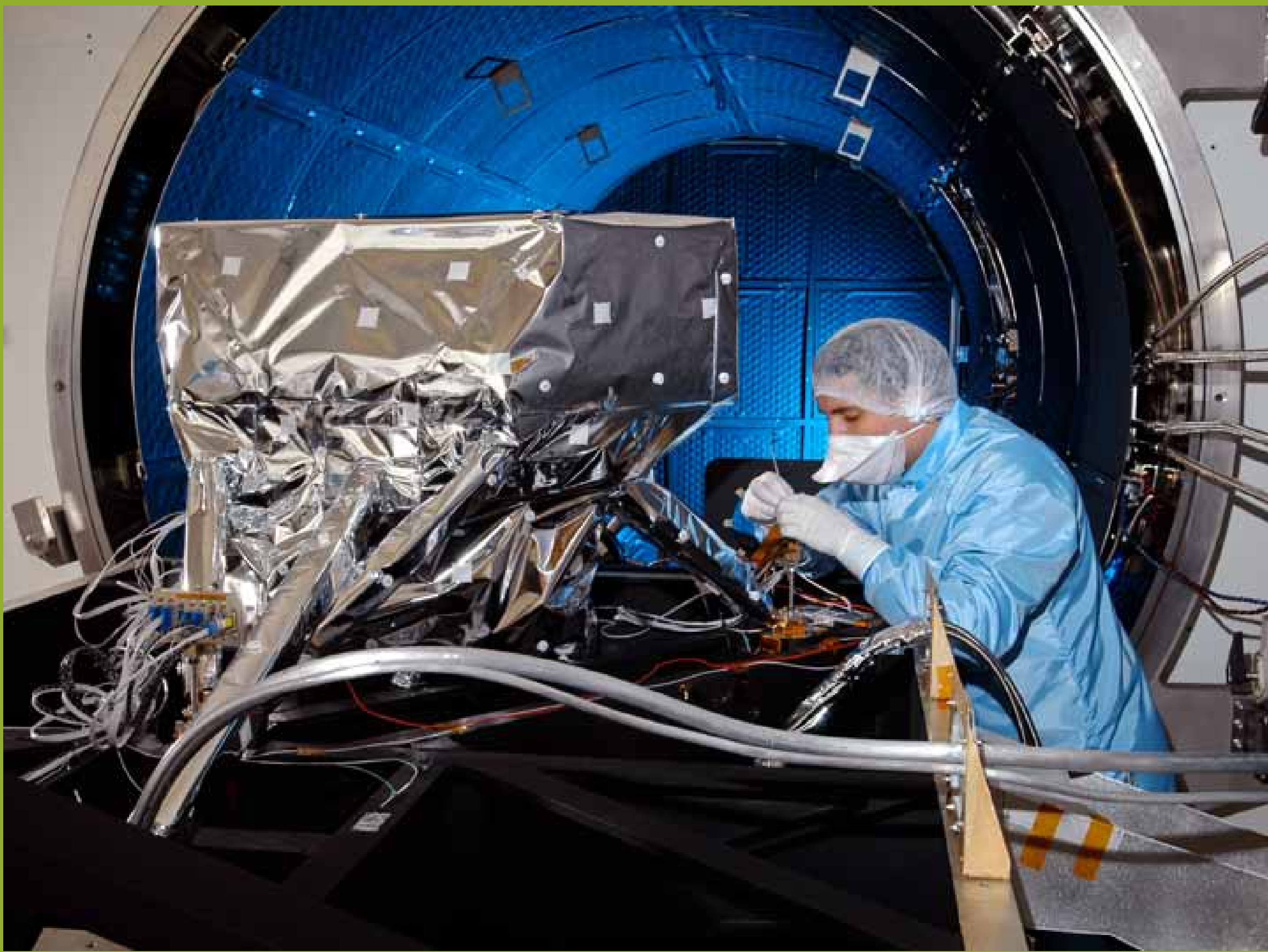
__Left:__ Aerial view of the Royal Observatory Edinburgh, including the UK ATC, from the South East. __Below left:__ KMOS is a state-of-the art multi-object spectrograph working at near-infrared wavelengths, which will be installed on the Very Large Telescope at Cerro Paranal in Chile in Autumn 2012. This new instrument, built by a British-German consortium, will be an invaluable tool to investigate the physical, chemical and dynamical processes which shape the evolution of galaxies over the entire history of the Universe. In fact, its ability to carry out spatially-resolved 3D spectroscopy for 24 sources simultaneously by using deployable Integral Field Units, will be essential to trace the star-formation and mass assembly history of galaxies from the local Universe up to very early epochs, just a few hundred million years after the Big Bang

4.2.7 UK Astronomy Technology Centre

The UK Astronomy Technology Centre (UK ATC) is the national centre for astronomical technology. Based at the Royal Observatory in Edinburgh and operated by STFC, its technology can be found in telescopes both on the ground and in space.

The UK ATC designs and builds state-of-the-art instruments for many of the world's major telescopes, including the James Clerk Maxwell Telescope (JCMT) the James Webb Space Telescope and the European Extremely Large Telescope, as well as conducting observational astronomical research. It also manages UK and international astronomy collaborations with universities, research centres, national institutes and industry.

The expertise it has built-up over many years of designing and building such world-class astronomy instruments and telescopes is now being exploited in other areas of scientific research, including particle physics and synchrotrons, and in performing cutting-edge industrial work for both UK and international customers.



4.2.8 Joint Astronomy Centre

The Joint Astronomy Centre (JAC) is located in Hilo, on the east coast of the Big Island of Hawaii. The Centre houses the James Clerk Maxwell Telescope, which is the largest astronomical telescope in the world designed specifically to operate in the submillimetre wavelength region of the spectrum. It also operates the United Kingdom Infrared Telescope, the world's largest telescope dedicated solely to infrared astronomy.

These telescopes are used to study the chemistry of interstellar gas and its temperature, density and motion and to enhance our understanding of how the planets, stars and galaxies were born and evolved into the universe we see today.

4.2.9 RAL Space

RAL Space, STFC's space science department, has been at the forefront of UK space research for 50 years, possessing a unique combination of science and engineering expertise, laboratories and testing facilities. It undertakes world-leading space research and technology development, provides space test and ground-based facilities, designs and builds instruments, analyses and processes data and operates S-band and X-band ground-station facilities, as well as leading conceptual studies for future missions.

For example, the assembly and testing of products and instruments designed for use in space missions is essential in order to ensure that these products and instruments will withstand the rigours of a space mission. Hence, equipment and materials need to be tested for resilience to extreme temperatures, vibrations and pressure. RAL Space's Environmental Test Facility undertakes this task and consists of a vibration test facility; the UK's largest thermal vacuum chamber; vacuum bakeout facilities; and large, clean rooms for assembly and integration of sensitive flight hardware.

The facility produces work to the strict quality standards imposed by the European Space Agency and NASA. These high standards have nurtured an outlook which ensures that testing remains within timescales and is of consistent quality. In recognition of its space product assurance system, the facility has been

__RAL Space – Left:__ Paul Eccleston prepares the Mid-Infrared Instrument (MIRI) for cryogenic testing in the thermal vacuum in RAL Space's space test chamber. __Below:__ The Precision Development Facility, RAL Space and Millimetre Wave Technology is a comprehensive and well-equipped facility providing expertise in precision machining and novel component prototyping associated with the manufacture of miniature detectors. Using specialised techniques, components as small as 100 x 26 microns can be produced. __Right:__ One of the RAL Space's CNC (Computer Numerical Control) machine tools in the Precision Development Facility; providing precision machining and novel component prototyping. __Below right:__ Paul Eccleston and Dave Rippington of RAL Space, test the Mid-Infrared Instrument (MIRI) in the vibration test facility within the space test facilities.

awarded ISO 9000:2000 accreditation.

Overall, the capabilities of RAL Space have allowed it to work with space and ground-based groups around the world.

4.2.10 Accelerator Science and Technology Centre

The Accelerator Science and Technology Centre (ASTeC) studies all aspects of the science and technology of charged particle accelerators, ranging from large-scale international and national research facilities, such as Diamond Light Source and ISIS, through to specialised industrial and medical applications. The ASTeC record includes:

- Initial design of Diamond, the UK's advanced third-generation light source on the Harwell Oxford Campus,
- Conceptual studies of fourth-generation light sources, including the 4GLS project (based on energy recovery technology) and New Light Source (a state-of-the-art, high-performance superconducting linear accelerator-based proposal),
- Concept, construction and commissioning of ALICE (Accelerators and Lasers In Combined Experiments), an accelerator test facility at STFC's Daresbury Laboratory, based around Europe's first operational energy recovery system.

The pioneering EMMA (Electron Model for Many Applications) accelerator is a prototype for a brand new type of particle accelerator that will massively impact fundamental science by changing the way such accelerators across the world are designed and built in the future

- Design and build of EMMA, a revolutionary fixed-field alternating gradient accelerator at the Daresbury Laboratory, which will contribute to advances in cancer therapy, energy generation and industrial processing,
- Leading roles in the two latest international studies into future particle physics accelerators (an electron linear collider and a neutrino factory),
- Preliminary studies on next-generation spallation neutron source options.

Together with additional R&D facilities and expertise in all aspects of enabling technologies such as beam simulation, radio-frequency design, diagnostics and vacuum science, ASTeC contributes to world-leading advances in electron, neutron and muon accelerator development and in maximising their scientific and societal impact.

ASTeC has recently secured £2.5 million of Government funding to establish a novel Electron Beam Test Facility in partnership with sector-leading businesses, the primary focus of which will be to develop the next generation of more compact, efficient and cost-effective accelerators.

4.3 Natural Environment Research Council

NERC is the UK's main agency for funding and undertaking research, training and knowledge exchange in the environmental sciences. It tackles some of the world's most important issues, such as climate change, environmental influences on human health, sustainable use of natural resources, biodiversity, earth system science and the genetic make-up of life on earth.

NERC works internationally and has bases in the most inhospitable parts of the planet, including the Antarctic. It also runs a number of research ships and aircraft and invests in satellite technology to monitor gradual environmental change on a global scale.

NERC currently operates six research centres: the British Antarctic Survey (BAS), the British Geological Survey (BGS), the Centre for Ecology & Hydrology (CEH), the

*British Antarctic Survey – **Left:** Halley VI. **Above:** A BAS Twin Otter with a halo behind during a refuel stop near Bluefields depot, on the way to Halley Research Station. **Right:** Dr Liz Thomas of the British Antarctic Survey conducts initial analysis of the Gomez ice core*

National Centre for Atmospheric Science (NCAS), the National Centre for Earth Observation (NCEO) and the National Oceanography Centre (NOC).

They provide key national capability and leadership to the UK environmental science community and play an influential role in international science collaborations. These research centres are briefly described below.

4.3.1 British Antarctic Survey

BAS has, for over 60 years, undertaken and enabled the majority of Britain's scientific research on and around Antarctica.

Polar science, the principal focus of BAS, extends from the outer limits of the Earth's atmosphere to the depths of oceanic trenches. Its timespan encompasses a billion years of geological history and it is crucial for understanding how the Earth operates as a global system.

Current BAS projects include a multinational collaborative study of the Gamburtsev mountains (the size of the Alps, under the Antarctic ice sheet) and a leading role in the NERC consortium to explore the sub-glacial Lake Ellsworth. Without such fundamental research, our ability to predict and safeguard the future of Antarctica and Earth's complex ecosystem would be greatly diminished.

NERC invests around £37 million every year in BAS, which, among other activities, runs three Antarctic stations, Rothera, Halley and Signy, and two stations on South Georgia at King Edward Point and Bird Island. These stations are supported by:

- Two ice-strengthened ships: the James Clark Ross, which has facilities for oceanographic research, and the Ernest Shackleton, primarily a logistics ship used for the re-supply of stations,
- Five aircraft: four Twin Otter aircraft, fitted with wheels and skis and operated from Rothera and Halley, and a wheels-only Dash-7 aircraft which provides the inter-continental air-link from Rothera to the Falkland Islands, and flies inland to ice runways.

At Halley, where BAS scientists discovered the ozone hole, a new state-

As part of the development of the International Space Innovation Centre (ISIC) at Harwell, staff at NCEO and the Centre for Environmental Data Archival have developed and deployed a new data visualisation service for Earth Observation. This is a web based application to allow users to visualise and make use of Earth Observation data and climate model simulations and display them. The images and animations can be exported for viewing and manipulation on the ISIC videowall, on Google Earth or other viewing software. This image is of the ISIC videowall showing NCEO Earth Observation images of significant ocean wave heights produced by Susanne Fangohn and David Woolf, using data from the TOPEX satellite. The images are shown on multiple globes, one for each month.

NCAS – The Atmospheric Research Aircraft is a modified BAe 146-301, owned by BAE SYSTEMS and operated as a collaboration between NERC and the Met Office. The Atmospheric Research Aircraft is managed by the Facility for Airborne Atmospheric Measurement (FAAM) as an airborne measurement platform for use by the atmospheric science community. The aircraft is used globally to conduct research in areas such as radiative transfer studies in clear and cloudy air, tropospheric chemistry measurements, cloud physics and dynamic studies, dynamics of mesoscale weather systems, boundary layer and turbulence studies, remote sensing, verification of ground based instruments and as a satellite instrument test-bed. (Credit: FAAM)

Lee Jones of the British Geological Survey prepares to survey the lava dome using ground-based LiDAR, Montserrat.

***Right**: NOC – The latest addition to the Autosub fleet Autosub Long Range is an underwater robot being developed at the National Oceanography Centre. It is intended that Autosub LR will have a range of 6000km and be capable of working at depths of 6000m. This will enable it to cross an ocean or traverse the Arctic Ocean under the ice.*

of-the-art ski-mounted research station called Halley VI has been recently constructed and is now operational.

The ships, aircraft and research stations allow BAS to operate in a harsh and remote environment in order to:

- Provide a national capability for Antarctic science and logistics,
- Carry out scientific research, long-term observations and surveys that cannot be done by anyone else in the UK,
- Act as a focus for international co-operation (in Antarctica) and for its conservation,
- Co-ordinate international research programmes to enhance understanding of the polar sciences.

4.3.2 British Geological Survey

BGS, founded in 1835 and based at Keyworth just outside Nottingham, is the world's longest-established national geological survey and the UK's premier centre for earth science information and expertise.

BGS's annual budget is in the region of £52 million, half of which is contributed by NERC. The remainder is obtained from research commissioned by the public and private sectors. In addition to geological work in the UK, BGS has an extensive programme of overseas research, surveying and monitoring, including major programmes in the developing world. Much of this work is now won through competitive tendering.

Examples of BGS' research focus, capability and expertise are presented in Table 4.2.

4.3.3 Centre for Ecology & Hydrology

CEH is the UK's centre of excellence for integrated research in terrestrial and freshwater ecosystems and their interaction with the atmosphere. The centre carries out innovative, independent and interdisciplinary science and long-term environmental monitoring.

CEH works in partnership with the research community, policymakers, industry and society, delivering world-class solutions to the most complex environmental challenges facing humankind. CEH's skills and expertise range from the smallest scale (the gene) to the largest scale (whole-Earth systems).

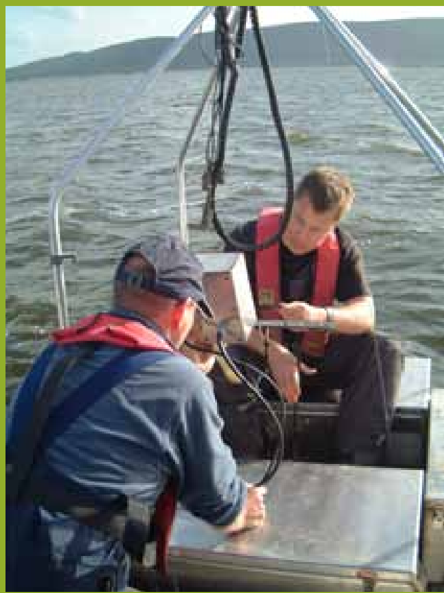
The organisation is a major custodian of environmental data, and contributes to major international networks, such as the Partnership for European Environmental Research (PEER), as well as leading European and global research efforts in the areas of water science, biogeochemistry and biodiversity.

NERC provides over £20 million of CEH's £35 million budget; the rest comes from external funding. CEH has four research sites located at Bangor, Edinburgh, Lancaster and Wallingford (CEH headquarters).

4.3.4 National Centre for Atmospheric Science

NCAS provides a national capability in atmospheric science research. With

NOC – Isis is the UK's deepest diving remotely operated vehicle, working at depths of 6000m. It has provided footage of hydrothermal vents and the animals that inhabit them.



***Above**: Scientists installing a water quality monitoring bouy on Loch Leven in Scotland. The bouy is part of a UK network that CEH maintain. (Photography by Dr Bryan Spears/CEH). **Right**: Taking water samples in the ocean using a CTD (conductivity, temperature and pressure) device.*

an annual budget of £9 million, the centre increases knowledge of key environmental issues, including:

- Climate change, including modelling and predictions,
- Weather processes,
- Atmospheric composition, including air quality.

It uses state-of-the-art technologies for observing and modelling the atmosphere, for example, a world-leading research aircraft, a ground-based instrumentation pool, access to computer models and facilities for storing and accessing data. Its research is used by policymakers and the wider UK science base.

NCAS is a collaborative centre made up of three science directorates (climate, weather and atmospheric composition) and four services and facilities distributed across many UK universities and related institutions.

***Table 4.2**: Research focus and selected areas of expertise at the British Geological Survey*

Research focus and expertise	Detail
UK geology and and geoscience technologies	Performing multidisciplinary surveys and research into British geology, producing 2D and 3D geological maps and models, thereby assisting geodiversity and geoconservation studies. Using geoscience technologies such as satellite and airborne remote sensing and ground-based geophysical measurements. The 3D modelling of the Earth's subsurface helps to improve knowledge for research into water, mineral and energy resources, carbon storage, natural hazards prediction and environmental prediction.
Climate change	Observing past and present climates, and predicting future climates and the environmental responses to those climates. This is done through modelling, assessing carbon concentration in the soil and organic chemistry research into pollution and climate in several UK and international estuaries.
Earth hazards	Understanding the dynamic processes in the Earth's core, mantle and crust, and the space environment surrounding our planet to enable better forecasts to be made of earthquake occurrence and volcanic eruptions, and of related hazards including tsunamis.
Energy	Understanding and maximising the recovery of dwindling fossil fuel reserves, and helping the development of renewable energy such as geothermal power. BGS is a world leader in capture and storage science and geophysical research into the structure of underground reservoirs, as well as a centre for research into unconventional hydrocarbon and coal resource development.
Groundwater science	Developing expertise in the hydrosciences including groundwater-related monitoring and surveys; undertaking integrated catchment studies through the development of field sites and novel monitoring technologies; developing groundwater models and the providing supporting services and analytical facilities. This capability allows BGS to focus on areas such as the sustainability of water resources and quality; the impacts of environmental change on the water cycle; natural hazards in the context of groundwater; and groundwater and human health.

Above: Researchers in the glasshouses of the John Innes Centre (Credit Oliver Smith). ***Right****:* Assessing of biogenic greenhouse gases from agricultural soils at Rothamsted Research – North Wyke (Credit: Rothamsted Research). ***Far right:*** *The broadbalk experiment at Rothamsted Research examines the effects of inorganic fertilisers and organic manures on the nutrition and yield of a number of important crops. It has been ongoing for more than 150 years (Credit: Rothamsted Research).*

4.3.5 National Centre for Earth Observation

NCEO provides NERC with national capability in Earth observation science.

NCEO uses data from Earth observation satellites to monitor global and regional changes in the environment in order to predict future environmental conditions. The centre has already highlighted significant environmental changes in, for example, ozone depletion, atmospheric pollution and melting sea ice.

The Norwich Research Park, including the John Innes Centre, The Institute of Food Research and The Genome Analysis Centre. (Credit: Norwich BioScience Institutes)

4.3.6 National Oceanography Centre

NOC is a national research organisation delivering integrated marine science and technology from the coast to the deep ocean. It works with institutions across the UK's marine science community, addressing key science challenges including sea-level change, the oceans' role in climate change, the future of the Arctic Ocean and long-term monitoring technologies.

Working with its partners, the centre focuses on providing capability to meet the needs of the whole of the country's marine research community, including Royal Research Ships, deep submersibles, advanced ocean sensors and instruments.

NOC is home to the global mean sea-level data archive, the UK's sea-level monitoring system for flood warning and climate change, the national archive of sub-sea sediment cores, which is key to the understanding of historic climate change, and the British Oceanographic Data Centre.

4.4 Biotechnology and Biological Sciences Research Council

BBSRC invests in world-class bioscience research and training on behalf of the UK public. Its aim is to further scientific knowledge, to promote economic growth, wealth and job creation and to improve quality of life in the UK and beyond.

Funded by Government, and with an annual budget of around £445million, BBSRC supports research and training in universities and strategically funded institutes such as the Institute for Animal Health (IAH), the Babraham Institute, the Institute of Biological, Environmental and Rural Sciences (IBERS), the Institute of Food Research (IFR), the John Innes Centre (JIC), The Genome Analysis Centre (TGAC), the Roslin Institute and Rothamsted Research.

These institutes deliver innovative, world-class bioscience research and training, leading to wealth and job creation and generating high returns

Table 4.3: List of BBSRC research institutes

Research institute	Detail
Institute for Animal Health (IAH)	IAH, principally based at Pirbright, is a world-leading centre of excellence for research into infectious diseases of farm animals. It aims to advance the knowledge of veterinary and medical science, and to enhance the sustainability of livestock farming. The institute is a unique national capability for the UK, providing high bio-containment level (CL) 4 laboratories, CL3 and CL4 animal experimentation facilities, and an insectary to combat newly emerging and re-emerging insect-transmitted viruses. Furthermore, a new £100M+ state-of-the-art laboratory complex is under construction at Pirbright to secure IAH's place at the forefront of research on animal diseases.
The Babraham Institute	The Babraham Institute undertakes innovative biomedical research to discover the molecular mechanisms that underlie normal cellular processes and functions, and how, over lifetime, their failure or abnormality may lead to disease.
Institute of Biological, Environmental and Rural Sciences (IBERS)	IBERS provides a unique research base that supports food security, bioenergy and sustainable land use – all of which face a range of conflicting demands, both now and in a future of predicted climate change. Specific research focus is on genome diversity and plant breeding, bio-renewables and environmental change and animal and microbial biology.
Institute of Food Research (IFR)	IFR is a world leader in research into harnessing food for health and controlling food-related diseases. It is developing intervention strategies based on an increased understanding of the biology of bacterial foodborne pathogens and the requirements for establishing and maintaining a healthy gut. IFR has strong research infrastructure. It has a purpose-built laboratory for work on foodborne pathogens, together with access to several joint technology platforms, a state-of-the-art disease modelling unit with gnotobiotic animals and excellent facilities for human dietary intervention studies. IFR also houses the National Collection of Yeast Cultures, which is strategically important to the UK in relation to the food production chain.
John Innes Centre (JIC)	JIC is an independent, internationally renowned bioscience research centre in plant science and microbiology. JIC's research focuses on the growth underpinning yield in plants, biotic interactions of plants, wheat improvement, and the metabolism of plants and microbes through the use of genetics. It also applies modern biotechnology to agriculture in an environmentally sustainable context.
The Genome Analysis Centre (TGAC)	TGAC is a national genomics and bioinformatics centre which addresses problems in agriculture, sustainable energy and food and nutrition, through novel approaches in genomics and specialising in genomics technology, high-throughput data analysis, advanced bioinformatics and innovation. TGAC has already established itself as an expert partner in high throughput sequencing, with projects including de novo sequencing of a rubber tree genome, and as a member of the international wheat genome project consortium.
Roslin Institute	The Roslin Institute undertakes research focused on the health and welfare of animals (livestock and companion animals), and the application of basic animal sciences in human and veterinary medicine, the livestock industry and food security. The Institute's research is supported by a number of unique resources, including the ARK-Genomics Centre for Comparative and Functional Genomics which utilises the latest genomics technologies for research into genome structure, genetic variation, gene expression and function with a focus on systems of relevance to animal health and food security. Similarly, the avian research facility, a national resource centre for experimental science of poultry and model avian species (including transgenic avian lines), provides specialist resources for avian biology research. In addition, the Roslin Institute holds the UK natural scrapie resource, a Cheviot sheep flock with endemic natural scrapie but which also has cases of atypical scrapie. The flock represents the only controlled TSE (transmissible spongiform encephalopathy) flock worldwide in which the progeny of each sheep is known in detail; research data from this flock was key to the development of the UK's National Scrapie Plan.
Rothamsted Research	Rothamsted Research is the largest agricultural research centre in the UK and almost certainly the longest-running agricultural research station in the world. Founded in 1843, Rothamsted Research has built an international reputation as a centre of excellence for science in support of sustainable land management and its environmental impacts. For example, inventing synthetic pyrethroid insecticides which now comprise a quarter of chemical pest control agents used worldwide, and creating permethrin, cypermethrin and deltamethrin – the second-generation pyrethroids. Currently, work at Rothamsted Research focuses on the following areas: • 20:20 wheat: increasing wheat productivity to yield 20 tonnes per hectare in 20 years, • Cropping carbon: optimising carbon capture by grasslands and perennial energy crops, such as willow, to help underpin the UK's transition to a low carbon economy, • Designing seeds: harnessing expertise in seed biology and biochemistry to deliver improved health and nutrition through seeds, • Delivering sustainable systems: designing, modelling and assessing sustainable agricultural systems that increase productivity while minimising environmental impact.

for the UK economy. They have strong links with business, industry and the wider community and support policy development. More details are outlined in Table 4.3.

BBSRC also funds the Sustainable Bioenergy Centre, which is an innovative academic–industry research partnership to underpin development in the bioenergy sector from growing biomass to fermentation for biofuels. In addition, it supports six Systems Biology centres and six Structural Biology centres based at UK universities, including Imperial College London, Cambridge, York and Manchester.

BBSRC also supports basic research that is directly relevant to important new technologies and to addressing major challenges such as animal welfare, environmental change, food security, nanotechnology, obesity, research on ageing and stem cell research.

__Left:__ MRC Laboratory of Molecular Biology (Neil Grant, LMB Visual Aids, Cambridge (2011).
__Below left:__ MRC Human Immunology Unit, University of Oxford (photography by Noel Murphy). Researchers at the MRC Human Immunology Unit, University of Oxford. The unit undertakes vital research into diseases involving the immune system including flu, arthritis and multiple sclerosis.
__Below:__ MRC National Institute for Medical Research, London (photography by Noel Murphy). Researchers at the MRC National Institute for Medical Research, London preparing vials for experiments to study the genetics of growth and metabolism in fruit flies to gain insights into human disease

The research that BBSRC funds underpins key sectors of the UK economy, such as farming, food, industrial biotechnology and pharmaceuticals, and the people it funds are helping society to meet major challenges, including food security, green energy and healthier, longer lives.

4.5 Medical Research Council

For almost 100 years, the MRC has been improving the health of people in the UK and around the world by supporting the highest-quality research into the medical sciences, making significant discoveries such as the link between smoking and cancer and the invention of therapeutic antibodies.

The MRC contributes strongly to economic growth through its commercial success. It funds research with more than 80 companies worldwide, including pharmaceutical, bioscience and healthcare companies. One notable success is that of Heptares, a London-based drug-discovery company formed in 2007 and based on the pioneering work of scientists at the MRC Laboratory of Molecular Biology and the MRC National Institute for Medical Research. The company now employs 46 people and had raised £26 million in venture capital by 2010 for its work to produce new medicines that target a family of proteins in cell membranes.

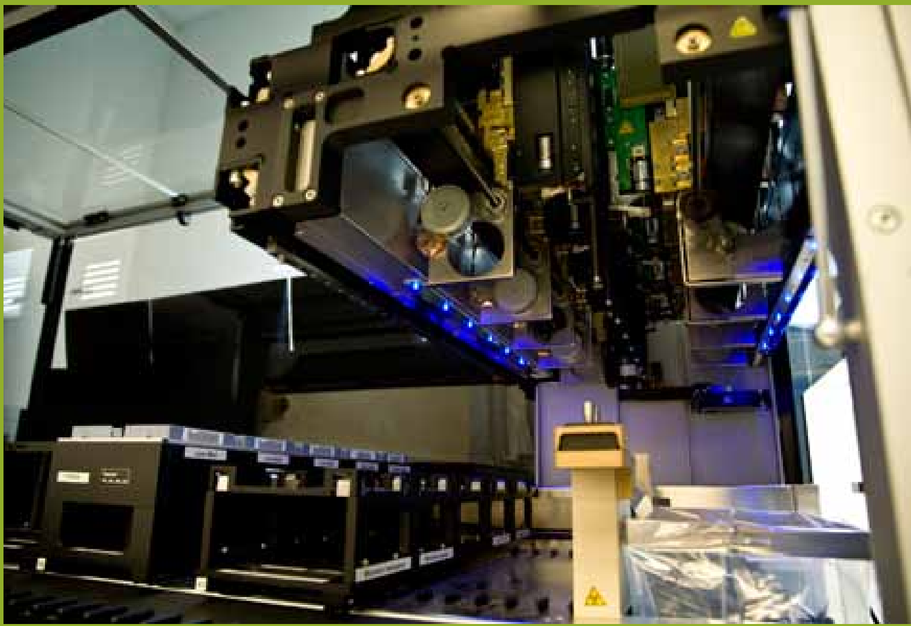
In 2009-10, the MRC spent £758 million on research, which it supports in three main ways, namely:

- Through research institutes and research units,
- By funding research centres in partnership with universities (www.mrc.ac.uk/ourresearch/unitscentresinstitutes/unitalphalist/index.htm),
- By providing research grants and career awards to scientists in UK universities and hospitals (www.mrc.ac.uk/ourresearch/index.htm).

Research institutes (Table 4.4), are very long-term flexible investments adopting broad multidisciplinary approaches to address major challenges in health-related research. They are provided with sustained support and state-of-the-art facilities over a long period of time, and offer scientists maximum flexibility to engage in innovative "risky" research, avoiding traditional university-style departmental boundaries.

In contrast, research units (Table 4.5) are set up to meet specific needs or to tackle important research questions where the need cannot easily be addressed through grant funding. They are fully funded by the MRC and there is no set limit on the lifespan of a unit.

The MRC has recently embarked on a programme of building the 'laboratories of tomorrow' in order to ensure that the UK maintains its premier position in medical research. For example, the MRC is constructing a new building for the Laboratory of Molecular Biology. The



MRC Epidemiology Unit, Cambridge (photography by Noel Murphy). Automated liquid handling robot used for quality checking and preparing thousands of DNA samples for genetic analysis work

MRC Protein Phosphorylation Unit, Dundee (photography by Noel Murphy). DNA sequencing and DNA fragment size analysis (like "DNA fingerprinting")/Anode buffer and polymer assembly in Applied Biosystems model 3730 Genetic Analyzer

facility, being built by BAM Construction Ltd, will cost around £200 million, and is being paid for in part from the royalties derived from antibody-related work at this laboratory.

The soon-to-be-opened building will provide an environment that fosters innovation and collaboration, and will be home to some of the world's leading scientists.

Elsewhere, the MRC is working with partners to establish a unique international centre for scientific excellence in medical research in the heart of London: The Francis Crick Institute. This is a consortium of six of the UK's most successful scientific and academic organisations — the MRC, Cancer Research UK, the Wellcome Trust, UCL, Imperial College London and King's College London. It will bring together scientists from across disciplines who will conduct groundbreaking medical research to understand why disease develops and find new ways to prevent and treat illnesses.

The centre is scheduled to be completed in 2015, and when fully operational will employ 1,500 staff, including 1,250 scientists, and have an operating budget of more than £100 million.

This is one of the most significant developments in UK biomedical science for a generation as the institute will

Table 4.4: *MRC research institutes*

Name	Detail
National Institute for Medical Research (NIMR), including the Biomedical NMR Centre	NIMR is the MRC's largest research establishment and has four major research areas: genetics and development; infections and immunity; neurosciences and structural biology. The World Health Organization Influenza Centre is located here. The Biomedical NMR Centre is a multi-user facility for biomedical nuclear magnetic resonance, and has well-supported facilities for liquid-state NMR studies of biological macromolecules.
Laboratory of Molecular Biology (LMB)	LMB's goal is the understanding of biological processes at the molecular level to help tackle problems in human health and disease. LMB helped unravel the structure of DNA, and it has played an important role in the development of new techniques, including X-ray crystallography of proteins, DNA sequencing and monoclonal antibodies. The LMB has four scientific divisions: structural studies, protein and nucleic acid chemistry, cell biology and neurobiology.
Clinical Sciences Centre (CSC)	CSC uses modern biological approaches and patient-derived information to gain an understanding of the molecular and physiological basis of health and disease. CSC has three sections – epigenetics; brain repair and dysfunction; and genes and metabolism – providing unique opportunities for scientific discovery and healthcare benefit.

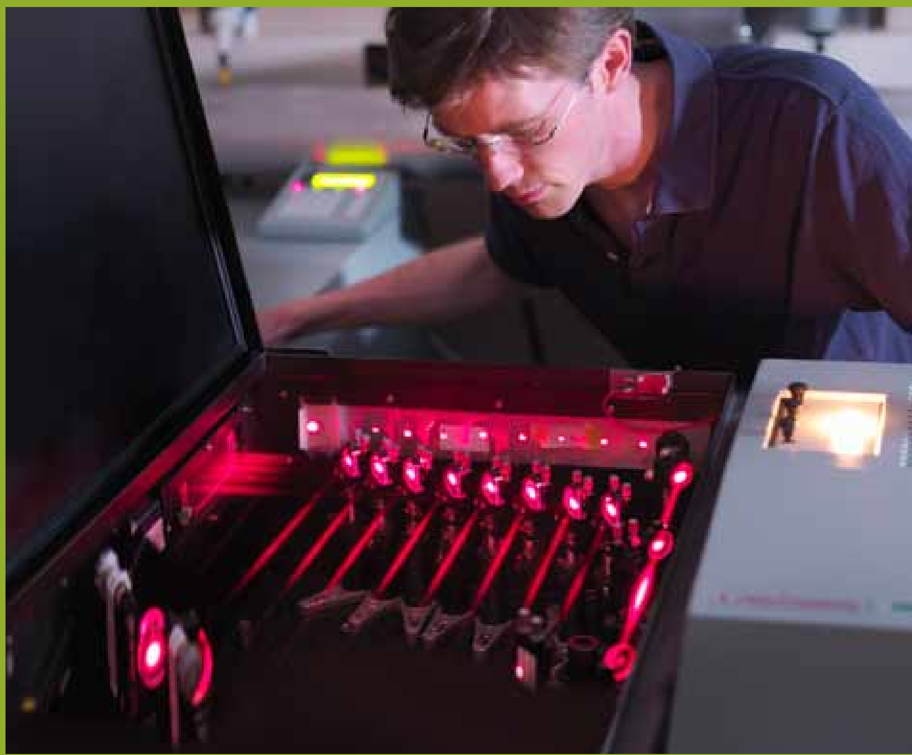
Table 4.5: MRC research units

Name	Detail
MRC Biostatistics Unit, Cambridge	The Biostatistics Unit is an internationally leading centre for the development, application and dissemination of statistical methods
MRC Cancer Cell Unit Cambridge	The MRC Cancer Cell Unit undertakes research into understanding how cancers develop (with a focus on discovering the early steps in epithelial carcinogenesis to improve the care and survival of patients with epithelial malignancies such as pancreatic, oesophageal, lung, breast and skin cancers.
MRC Cognition and Brain Sciences Unit, Cambridge	The mission of the Cognition and Brain Sciences Unit is to understand and enhance cognition and behaviour in health, disease, and disorder by developing integrated explanations of human behaviour and its disorders that link cognition with the brain and other biological systems.
MRC Epidemiology Unit, Cambridge	The MRC Epidemiology Unit research is focussed on the genetic, developmental and environmental determinants of obesity, type 2 diabetes and related metabolic disorders and to contribute to the prevention of these disorders.
MRC Mitochondrial Biology Unit, Cambridge	The Mitochondrial Biology Unit aims are to understand the fundamental processes taking place in mitochondria and their involvement in human diseases and to exploit knowledge of these fundamental processes for the development of new therapies to treat human diseases.
MRC Human Nutrition Research, Cambridge	The Human Nutrition Research centre conducts nutrition research and surveillance to improve the health of the population with a focus on obesity and metabolic risk, musculoskeletal health, intestinal health and nutritional inequalities.
MRC Protein Phosphorylation Unit, Dundee	The Protein Phosphorylation Unit uses biochemistry, cell and molecular biology and mouse genetics to investigate the role of protein phosphorylation and dephosphorylation in cell regulation and human disease.
MRC-University of Edinburgh Human Genetics Unit	The Human Genetics Unit's research focuses on the understanding of genetic factors implicated in human disease and normal and abnormal development and physiology (including developmental genetics, common disease genetics, chromosome biology and models for human genetic diseases).
MRC-University of Glasgow Centre for Virus Research/	The Centre for Virus Research carries out multidisciplinary research on viruses and viral diseases of humans and animals, translating the knowledge gained for the improvement of human and animal health.
MRC Social and Public Health Sciences Unit, Glasgow	The Social and Public Health Sciences Unit research focuses on social and environmental influences on health including studies on social position, social and physical environments, the influence on physical and mental health and capacity to lead healthy lives, designing and evaluating interventions aiming to improve public health and reduce social inequalities in health.
Mammalian Genetics Unit, Harwell and The Mary Lyon Centre, Harwell	The Mammalian Genetics Unit undertakes studies in mouse genetics and functional genomics, investigating a wide variety of disease models to enhancing understanding of the molecular and genetic bases of disease (including Diabetes and Obesity, Metabolism, Liver and Bone disease, Sensory Dysfunction (Vision and Deafness), Neuromuscular, Neurodegenerative and Behavioural disorders, Developmental Defects). The Mary Lyon Centre Mary Lyon Centre offers academic and industry research programs access to specialist infrastructure dedicated to mouse breeding, transgenics, mutagenesis, phenotypic analysis (imaging, pathology, clinical chemistry, and drug validation and testing. They also operate a national bioarchive of mouse lines allowing access to existing and novel models being developed in the UK and internationally through our distribution network in the EU, North America, China and Japan.
MRC Toxicology Unit, Leicester	The Toxicology Unit researches the effects that occur following cellular exposure to chemicals, radiation and external biological agents to facilitate the development of new models that are better able to predict adverse drug reactions and to elucidate the molecular mechanisms of diseases that are associated with toxic exposure.
MRC Cell Biology Unit, London	Research at the Cell Biology Unit focuses on fundamental questions in molecular cell biology. Using model organisms and the latest molecular and imaging technologies, this unit explores some of the key processes underlying cell function and behaviour including the control of cell number, the determination of cell and tissue architecture, the regulation of communication within and between cells and the control of cell movement.
MRC Clinical Trials Unit, London	The Clinical Trials Unit designs, conducts, analyses and publishes clinical trials, observational studies, meta-analyses and other systematic reviews which are of clinical or public health importance
MRC Prion Unit, London	The Prion Unit undertakes studies, which address the fundamental aspects of prion biology with a view to understand the wider relevance of these processes in human disease including in "protein-misfolding diseases" such as Alzheimer's disease. The Unit also provides a specialist centre to safely handle and characterise existing and emerging human and zoonotic prion pathogens with appropriate biosecurity and expertise.

Table 4.5 continued

Name	Detail
MRC Unit for Lifelong Health and Ageing, London	The recently established MRC Unit for Lifelong Health and Ageing is the new home of the MRC National Survey of Health and Development which is the oldest of the British birth cohort studies, is unique in having data from birth to age 60 years on the health and social circumstances of a representative sample (N=5362) of men and women born in England, Scotland or Wales in March 1946.
MRC Institute of Hearing Research, Nottingham	The Institute of Hearing Research also receives funding from the Chief Scientist Office and the Department of Health. Its objective is to conduct research into hearing and hearing disorders, and translate this research from scientific discovery to clinical practice
MRC Anatomical Neuropharmacology Unit, Oxford	The mission of the Unit is to define the molecular, spatial and temporal organisational principles of networks in the brain at the synaptic and cellular level by analysing a variety of brain regions affected in disease.
MRC/Cancer Research UK/BHF Clinical Trial Service Unit & Epidemiological Studies Unit	The Clinical Trial Service Unit's work involves studies of the causes and treatment of "chronic" diseases such as cancer, heart attack or stroke (which, collectively, account for most adult deaths worldwide), although it does also involve some studies of other major conditions in developed and developing countries.
MRC Functional Genomics Unit, Oxford	The mission of the Functional Genomics Unit is to use genomic information to determine mechanisms of disease in order to develop novel therapeutic approaches. Their approach combines computational analyses and the latest experimental technologies in model organisms to reveal the roles of genes and genomes in health and disease.
MRC/Cancer Research UK Gray Institute for Radiation Oncology and Biology, University of Oxford	The Gray Institute has been created to be the world's largest and most comprehensive centre for research and training in radiation oncology and biology. The work at the Institute includes DNA damage signalling, tissue signal transduction, tumour microenvironment, imaging, radiation physics, signal transduction and the development of radiopharmaceuticals for systemic use that target the cytotoxicity of radiation directly to tumour cells. The Institute is supported by two core facilities Radiation Biophysics and Imaging.
MRC/ University of Oxford Human Immunology Unit (within the Weatherall Institute of Molecular Medicine)	The Human Immunology Unit aims to increase the understanding of the human immune response. Ongoing work encompasses attempts to understand, at a molecular and cellular level, how immune responses protect against, and in some cases cause, disease. In addition, the development of novel vaccines and immunotherapies is a priority.
MRC/ University of Oxford Molecular Haematology Unit (within the Weatherall Institute of Molecular Medicine)	The Molecular Haematology Unit applies molecular and cell biology approaches to haematological and related diseases. In addition, the unit's research interests include regulation of the developmental changes of human haemoglobin and the way in which these are modified in patients with inherited disorders of haemoglobin synthesis.
MRC Lifecourse Epidemiology Unit, Southampton	The Lifecourse Epidemiology Unit is a centre of excellence which utilises epidemiological methods to delineate the environmental causes throughout the lifecourse of chronic musculoskeletal disorders; diabetes mellitus and the metabolic syndrome; and cardiovascular disease. The EEU maintains and develops long-term cohort studies assembled in Southampton as national and international resources to explore the developmental origins of health lifecourse.
MRC Unit, The Gambia	The MRC Unit in The Gambia is the UK's single largest investment in medical research in a developing country and is internationally recognised for its track record of research into tropical infectious diseases. Its success is based on innovative lab-based research, clinical studies and field-oriented science, and the translation of research into clinical and public health practice. The Units three major research themes are Child Survival, Vaccinology and Disease Elimination and Control. The close proximity of the International Nutrition Unit in The Gambia provides the opportunity to further enhance investigations of the important role of nutrition in each of the research themes.
MRC/ Uganda Virus Research Institute - Uganda Research Unit on AIDS	The Uganda Research Unit on AIDS is based at the Uganda Virus Research Institute. It was established following a request in 1988 from the Ugandan Government to the British Government for assistance regarding the research and the control of HIV and AIDS. The primary focus of the Unit's programme is to investigate HIV infection related issues of public health relevance to Uganda and other parts of sub-Saharan Africa. Activities range from virology and immunology to social science, clinical studies and intervention trials.

Top: Culham Centre for Fusion Energy, the UK's national laboratory for fusion research. Above: MAST, the UK's domestic fusion experiment, located at Culham. (Images Courtesy of CCFE)



Diagnostic equipment for collecting data from the MAST device. (Image Courtesy of CCFE)

invest in innovative, creative and collaborative scientists, working to understand the biology underlying human health.

4.6 Culham Centre for Fusion Energy

CCFE is the UK's national research laboratory for fusion energy. It is based at the Culham Science Centre in Oxfordshire and is owned and operated by the UK Atomic Energy Authority. The nuclear fusion programme is funded by the Engineering and Physical Sciences Research Council and the EU under the EURATOM treaty.

Key capabilities and competencies at CCFE include plasma physics research; computer modelling of plasma behaviour, materials research for nuclear use; robotics and remote-handling technology; engineering of fusion reactor technology, especially mechanical and electrical engineering; cryogenic systems; power plant design and power supplies; neutral beam and microwave heating systems; and diagnostic systems development.

Two principal research programmes are the Mega Amp Spherical Tokamak (MAST) experiment and the Joint European Torus (JET). These are briefly described below.

4.6.1 Mega Amp Spherical Tokamak

The UK fusion programme is centred on the MAST experiment pioneered by CCFE, which continues to lead on its development.

Experiments on MAST are important because they help determine the long-term potential of the spherical tokamak fusion concept, which may eventually be suitable as the basis for a power station. In fact, a design based on MAST may lead to a compact component test facility, which would reduce risk and accelerate the development of commercial fusion power.

CCFE is taking spherical tokamaks to the next level by implementing a major £30 million two-stage upgrade, to be completed by 2015. The main features of the upgrade include more heating power, better control and pumping necessary to contain the resulting higher temperature and longer-pulse plasmas, and the capability to test advanced "divertor" solutions to handle high exhaust powers from the plasma.

These enhancements will allow scientists to study plasmas which approach "steady-state" conditions – operating regimes that could be used for the design of future fusion machines, which must run for hours or days rather than the seconds of today's devices.

The MAST upgrade will offer possibilities for scientific collaborations from the UK and overseas and once online it will operate as a user facility to allow scientists from other fusion laboratories and universities to exploit its capabilities.

State-of-the-art remote handling technology is used to maintain and upgrade the JET facility. (Image Courtesy of EFDA-JET)

4.6.2 Joint European Torus

CCFE also hosts the world's largest magnetic fusion experiment, JET, on behalf of its European partners. The JET tokamak is the largest and most powerful ever built, and is the focal point of the European fusion research programme. Designed to study fusion in conditions approaching those needed for a power plant, it is the only device currently operating that can use the deuterium-tritium fuel mix that will be used for commercial fusion power plants.

In recent years, JET has carried out important work in assisting the design and construction of the International Tokamak Experimental Reactor (ITER), an international research and development project which aims to demonstrate that it is possible to produce commercial energy from fusion. It is based in France and is expected to demonstrate a 500 megawatt tokamak fusion power plant.

JET continues to act as a test-bed for ITER technologies. A recent 18-month upgrade has seen the installation of a new inner wall in the JET machine to test the mix of beryllium and tungsten materials that ITER will employ. The JET facilities are operated by scientists from around Europe who work together under the European Fusion Development Agreement.

4.7 Other research facilities

The UK has a number of other research facilities that have been developed as a joint venture with industry using public–private partnership models.

They include the National Nuclear Laboratory (NNL), the Dalton Nuclear Institute at the University of Manchester, the AMRC at the University of Sheffield and the IVHM centre at Cranfield University. These are briefly described below.

4.7.1 National Nuclear Laboratory

NNL is a UK government-owned company, managed by an appointed contractor (Battelle, SERCO and the University of Manchester). It is organised as a commercial business and receives no funding from government. NNL's core business is to provide experts and technologies to ensure that the UK nuclear industry operates safely and is cost-effective.

Its services cover a wide range of areas, including fuel manufacture and reactors; operating reprocessing/waste plants; decommissioning and treatment of legacy waste; environmental management; disposal, including geological, defence, chemical biological radiological and nuclear materials linked to homeland security; new nuclear build/ future nuclear systems; and research, training and academia.

NNL has access to some of the most advanced facilities in the world. Research activities span the entire nuclear fuel cycle, including fuel design, support to ongoing operations, waste immobilisation and processing, fuel disposition,

The Plutonium and Minor Actinides (PuMA) Laboratory, part of the Central Laboratory at Sellafield. Able to carry out experiments on plutonium and a range of other actinides. Current research includes work on a project to determine potential use of americium in space batteries

The Hot Isostatic Press (HIP) rig at Workington Laboratory. NNL has been working with the Australian Nuclear Science and Technology Organisation (ANSTO) to develop a process for the treatment of plutonium residues. Using the HIP process produces a stable ceramic matrix suitable for long-term storage

Table 4.6 *National Nuclear Laboratory Facilities*

Central Laboratory, Sellafield	**Windscale Laboratory, Sellafield**
Active and non-active laboratories including an active rig hall	Post-irradiation examination of nuclear fuel and irradiated materials.
Plutonium and high-active alpha/beta/gamma cells	Radioactive waste processing and management
	Handling and management of radioactive sealed sources
	Material analysis and mechanical testing
Preston Laboratory, Lancashire	**Workington Laboratory, Cumbria**
Purpose-built facility dealing with uranium-active materials	Non-radioactive engineering and rig testing facility
Low and non-active research and development	Technical assessment and solution proposition
	Design, manufacture and build of test rigs plus testing
	Operator training

plutonium management and nuclear security and non-proliferation.

NNL is also involved in more novel research, including a project with the European Space Agency to assess the use of americium in space batteries. Its facilities are listed in Table 4.6.

As a national laboratory, part of its remit is to work with a range of organisations to maximise research activities and potential benefits. It has recently become a key player in the first TIC, the High-Value Manufacturing Catapult (see Section 4.8).

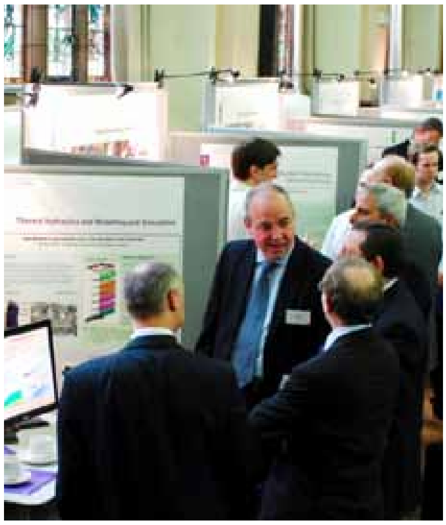
NNL collaborates with universities and other national laboratories in the UK and overseas, as well as UK and international companies. It also offers independent advice to the UK Government in the nuclear arena.

4.7.2 Dalton Nuclear Institute

The Dalton Nuclear Institute was established at the University of Manchester in 2005 as a leading national centre for nuclear research and higher learning. The Institute is delivering a sustainable programme of transformational nuclear research, targeted higher learning and effective social engagement by establishing:

__Far left:__ Postgraduate students from the Dalton Nuclear Institute's Centre for Radiochemistry Research working with radioactive materials in one of the Centre's glove boxes. __Left:__ Postdoctoral researchers using state-of-the-art X-ray facilities to investigate the surface chemistry of reactor materials in the Dalton Nuclear Institute's Materials Performance Centre. __Below:__ Dalton Cumbrian Facility.

__Below:__ School children learn the principles of nuclear reactor operation by operating The University of Manchester's reactor simulator at one of the Dalton Nuclear Institute's outreach events. __Below right:__ A postdoctoral researcher undertakes a sophisticated experiment to assess the performance of structural materials in the challenging high temperature water environment of a Pressurised Water Reactor. __Right:__ Academics at The University of Manchester engaging the nuclear industry to build strategic research partnerships, transfer new methods and understanding, and develop the next generation of skills



- The research capability needed to deliver new knowledge to underpin the UK's future nuclear energy strategy with the academic leadership and specialist facilities required to undertake world-leading nuclear research.
- A sustained programme of nuclear skills training at undergraduate and postgraduate levels that meets the requirements of growing industry.
- Strategic research partnerships with the nuclear sector, including industry, Government and academia, to maximise the impact of research and skills development.

The Dalton Nuclear Institute has established a broad range of nuclear research capabilities, including the new Dalton Cumbrian Facility for radiation science and nuclear engineering decommissioning with academic access to the NNL facilities, and the Nuclear AMRC in collaboration with Sheffield University. Research programmes address reactor technology (existing reactors, new nuclear build and nuclear fuel technology), decommissioning and radioactive waste management, as well as other nuclear technologies, including medicine, security and policy.

*IVHM Centre – **Left:** Fuel rig experiment with National Instruments LabView interface. **Top:** Test workstation for Machine Fault Simulator & Wavelet transform method. **Above:** Testing and soldering of a test printed circuit board. **Right:** Machine Fault Simulator experiment*

4.7.3 Advanced Manufacturing Research Centre

The AMRC with Boeing is a global centre of advanced machining and materials research for aerospace and other high-value manufacturing sectors.

The AMRC was established in 2001 through collaboration between the University of Sheffield and Boeing. More than 60 companies are now members, from global aerospace giants such as Rolls-Royce, BAE Systems and Messier-Bugatti-Dowty, to local SMEs.

The AMRC model of collaborative industry-focused research has been adopted by research centres worldwide, including the UK's new generation of 'Catapult centres' (see section 4.8).

Mori Seiki millturn in the AMRC with Boeing's Rolls Royce Factory of the Future shopfloor

The AMRC is a world leader in high-performance machining research. This involves designing and producing machined parts in the shortest-possible time, without compromising the structural or surface integrity of the component.

By deploying a range of innovative design, analysis and control techniques, AMRC researchers can typically improve the efficiency of a machining process by around 40 per cent. Other core research groups focus on automated systems for large complex assemblies, advanced structural testing and certification, and the production and machining of composite and metal hybrid components.

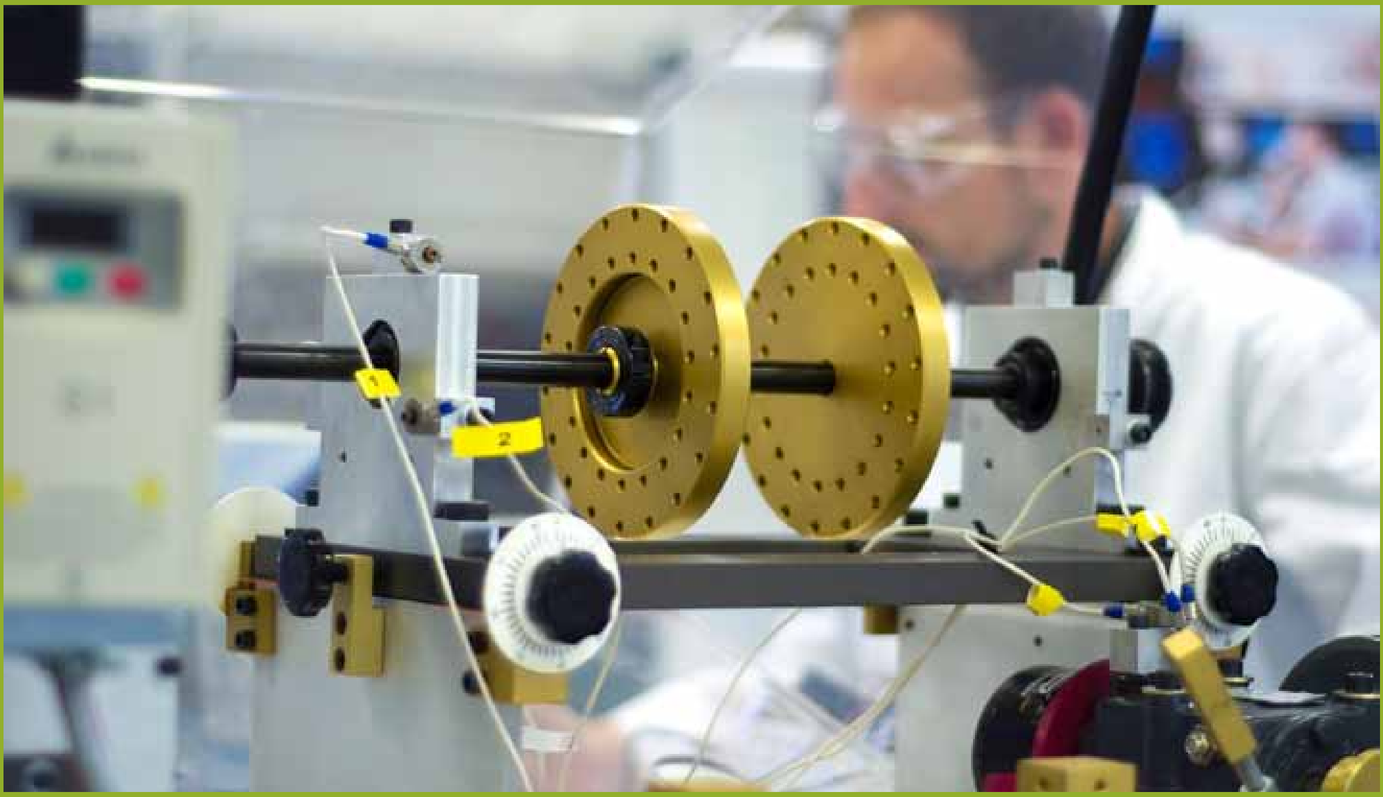
The AMRC employs around 200 researchers and engineers, from apprentices to PhDs, at the Advanced Manufacturing Park (AMP) in South Yorkshire. The AMP is also home to the new Nuclear Advanced Manufacturing Research Centre, the AMRC's sister facility, which is applying the same collaborative research model to the civil nuclear manufacturing supply chain.

4.7.4 Integrated Vehicle Health Management Centre

The IVHM Centre was established in 2008 as a joint venture between Cranfield University and industry, with involvement from companies such as Boeing, Rolls-Royce, BAE Systems, Meggitt and Thales.

It was created to develop state-of-the-art diagnostic and prognostic capabilities to enable the health of a vehicle to be monitored and assessed. This is done through the distribution of sensors throughout the vehicle in order to collect data on the condition of components and subsystems. On-board processors assess the vehicle's health and predict possible deterioration and future life.

This data and resulting information can be used to improve maintenance, extend the life of both the whole vehicle



(such as aircraft, ships, high-speed trains and high-performance cars) and individual components, improve vehicle readiness and availability, and reduce operating costs.

The IVHM Centre possesses the following core competencies, namely business modelling and simulation; business transformation and culture change; demonstration and fast prototyping; analysis and algorithm development (including. data exploitation); systems engineering /architecture; and systems integration and knowledge integration.

It also has the ability to design, build and fly complex platforms such as the advanced concept, fuel-efficient blended wing body – the 'X48B' – and to undertake end-to-end integration of technologies from diverse institutions (for example, a project, called FLAVIIR which looks at technologies for future unmanned air vehicles).

The IVHM Centre has a number of projects spanning a wide array of fields, from electronic prognostics through structural health monitoring to machine fault detection. The centre has developed new methods for detecting gear damage. This enables the detection and prediction of gear and gearbox damage that would seriously impact the performance and operational safety of machines such as jet engines or wind turbines.

Overall, the Centre offers a unique capability for advancing the field of IVHM supported by direct high-speed communication links to the testing and hardware laboratories at Cranfield with those of partner organisations and industry test partners across the globe.

4.7.5 Cockcroft Institute

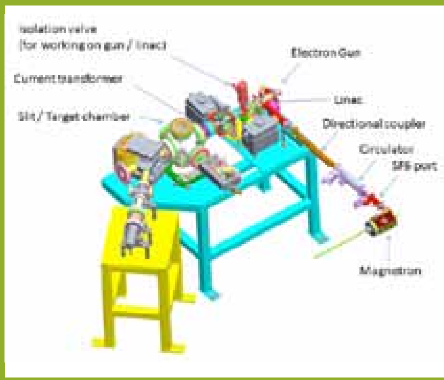
The Cockcroft Institute, located at the Daresbury Science and Innovation Campus, in the North-West of England, is an emerging international centre enabling "discovery class" science and addressing global needs in energy, environment, health and security.

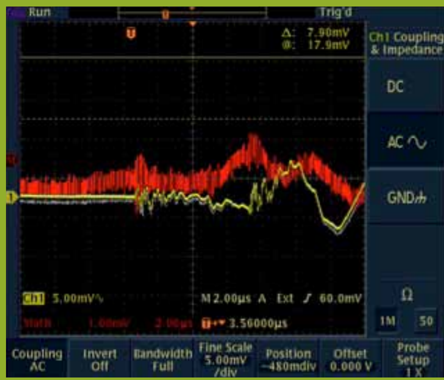
The institute, whose research focuses on innovative tools of accelerators and free electron lasers, was officially inaugurated in 2006 as a collaboration of STFC's Daresbury Laboratory (in particular its Accelerator Science and Technology Centre (ASTeC), described in section 4.2.10) with the Universities of Lancaster, Liverpool and Manchester, and the former North West Development Agency. It aims to:

- Provide the intellectual focus and R&D test facilities for research and development of particle, nuclear, photon and neutron sciences; accelerator-based skills applied to probe "anti-matter" and cosmology; particle beam-, laser- and microwave-based cancer and medical therapy; solar energy; sub-critical reactors; transmutation of radioactive waste for cleaner environment; and compact accelerator systems for security scanning;
- Develop a robust industrial collaboration framework for UK

Parts of the Cockcroft-Walton Generator that once powered protons in the ISIS facility at RAL Space – a novel voltage multiplier invented by Sir John Cockcroft in collaboration with Ernest Walton in 1932, enabling the world's first "splitting of the atom" — now housed in the building that marks the iconic Cockcroft Institute in Daresbury Campus

The Cockcroft Institute is working with CERN in spearheading the development of the next generation large particle physics facility: the Large Hadron Collider in CERN, Geneva, Switzerland





__Above__: A virtual computer-aided design of a compact microwave-driven linear electron accelerator system for X-ray scanning. __Above right:__ A waveform showing the accelerating electromagnetic waves in the operating accelerator. __Right__: The detailed precision machining of the microwave linear accelerator waveguide at a high frequency of approximately 9 Gigahertz

industry in areas such as precision magnets, electromagnetic cavities, digital electronics and photonics components, vacuum systems, metrology, diagnostics and instrumentation.
This has enabled the creation of a "CERN-UK Industrial Incubation Centre" at Daresbury with the goal of enabling UK industry to bid for the design, fabrication and delivery of sophisticated engineering and technological components for future large facilities construction projects in the European Union such as the future accelerators at CERN and the European Spallation Source in Lund, Sweden.

- Enable UK scientists and engineers to take a leading role in innovating future tools for scientific discovery via conception and design of world-leading research accelerators such as the Large Hadron Collider at CERN.
- Nurture the curiosity of emerging minds via a vibrant education, training and outreach programme.

The Cockcroft Institute also provides access to large-scale R&D test facilities such as the existing Research Council-operated accelerators. This includes ALICE ('Accelerators and Lasers In Combined Experiments' – a prototype for a next-generation energy-recovery efficient accelerator) and EMMA (Electron Machine with Many Applications); the Electron Beam Test Facility under construction at Daresbury Laboratory; the state-of-the-art laser facilities at the University of Manchester Photon Science Institute; the Terahertz Tissue Culture Facility at ALICE operated by the University of Liverpool; and state-of-the art vacuum, microwave and diagnostics laboratories supported by ASTeC and the universities of Lancaster, Manchester and Liverpool.

In summary, the institute's core competencies cover a diverse range of areas such as compact particle accelerator systems; technologies for development of radiation sources in the infrared, ultraviolet and x-rays for science and various applications in security and medical imaging and treatment; advanced computation, mathematical modelling, simulation and visualization tools; parametric optimisation of designs and value-engineering; high and low-power microwaves and their precise control; high-power microwave processing; high-speed digital electronics and signal processing; ultra-fast light and photonics; superconducting magnets and microwave cavities; ultra-high vacuum systems and surface science and engineering; sensor, diagnostics and instrumentation techniques; nuclear detection techniques of particles and radiation; novel materials e.g. structured metamaterials, photonic band-gap structures, semi-conductor photocathodes, MEG (Multiple Exciton Generation) structures for Type-III solar cells, and superconducting materials for electromagnetics.

4.8 Catapult centres

In 2010, the UK Government announced it would invest more than £200 million in four years to create a network of world-leading technology and innovation centres, called Catapults, which will transform the UK's ability to create new products and services in priority areas, and drive future economic growth. Established and overseen by the Technology Strategy Board, the UK's innovation agency, these Catapults will offer critical mass for business and research innovation by focusing on a specific technology where there is a potentially large global market and a significant UK capability.

These centres, in addition to the LRFs mentioned in this brochure, will be an important part of the UK's innovation system, making a major long-term contribution to national economic growth by:

- Allowing businesses to access equipment and expertise that would otherwise be out of reach, enabling them to conduct their own in-house R&D,
- Helping businesses to access new funding streams and pointing them towards the potential of emerging technologies,
- Bridging the gap between universities and businesses and helping to commercialise the outputs of the UK's world-class research base.

The first Catapult, in high-value manufacturing, became operational in October 2011. Seven partners are working together in this centre, bringing together their expertise in different and complementary areas of high-value manufacturing. They are the:

- Advanced Manufacturing Research Centre with Boeing at the University of Sheffield (see Section 4.7.3)
- Nuclear Advanced Manufacturing Research Centre at the Universities of Sheffield and Manchester
- Manufacturing Technology Centre, a partnership of the Universities of Loughborough, Nottingham and Birmingham TWI.
- Advanced Forming Research Centre at the University of Strathclyde
- National Composites Centre at the University of Bristol
- Centre for Process Innovation at Wilton and Sedgefield
- Warwick Manufacturing Group at the University of Warwick.

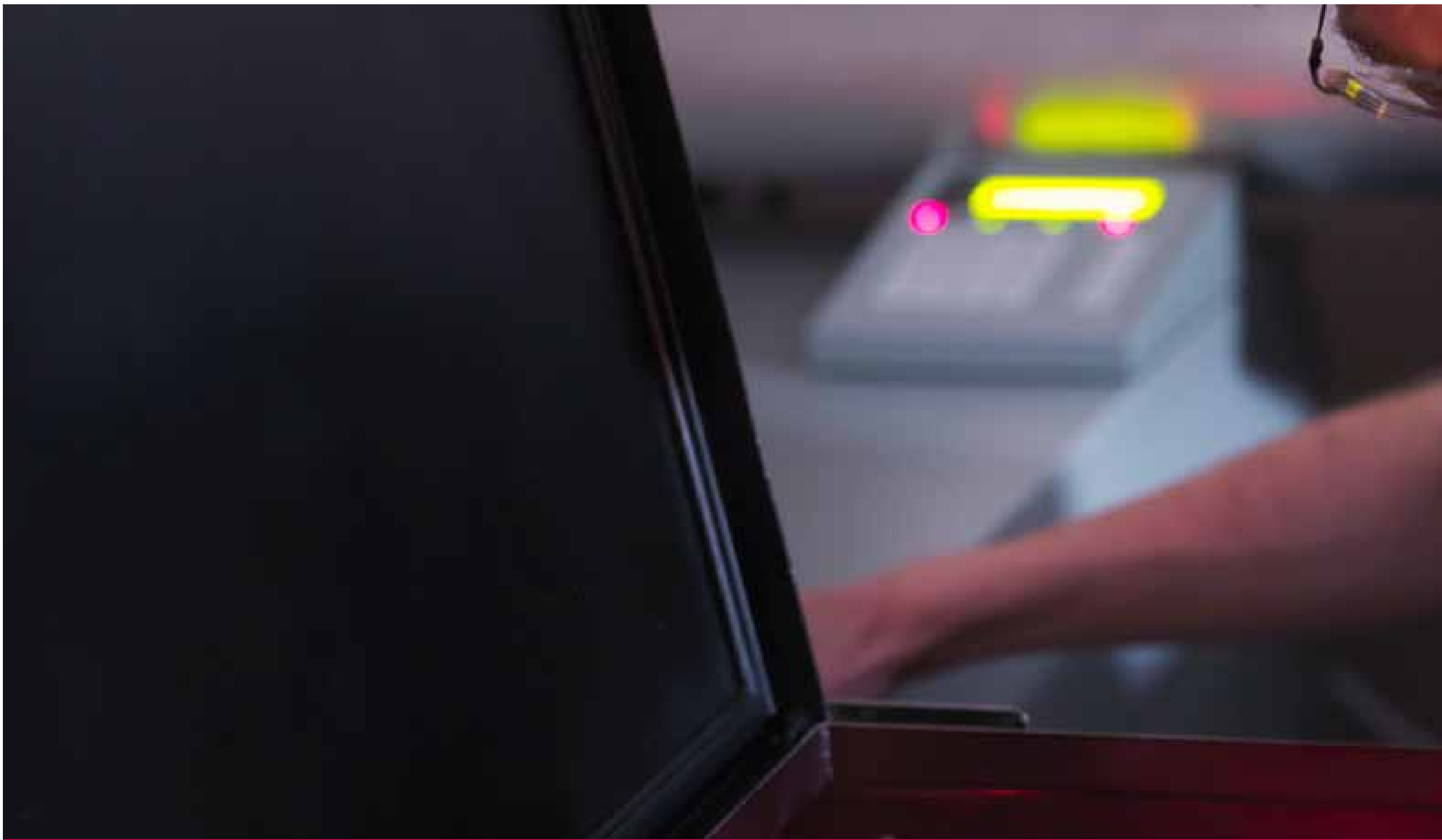
The new centre provides an integrated capability and embraces all forms of manufacture using metals and composites, in addition to process manufacturing technologies and bio-processing. It will also draw on excellent university research to accelerate the commercialisation of new and emerging manufacturing technologies.

Two more Catapults, in cell therapy and offshore renewable energy, are on schedule to open by autumn 2012, whilst the Catapults in satellite applications, connected digital economy, future cities and transport systems are due to open towards the end of 2012 or early 2013. All the Catapults are expected to be fully operational in 2013.

Overall, the Catapult centres, working in close collaboration with the diverse range of UK LRFs, will allow this country to be the best place in the world to undertake scientific research and provide solutions to the commercial challenges facing the world.

"The IVHM Centre, encompassing research, education and demonstration facilities, was set up by industry to solve industrial problems. UKTI played a pivotal role in the formation of the Centre and continues by helping us seek business opportunities in foreign markets such as with India's National Aerospace Laboratories located in Bangalore."

Ian Jennions
Director, IVHM Centre
Cranfield University



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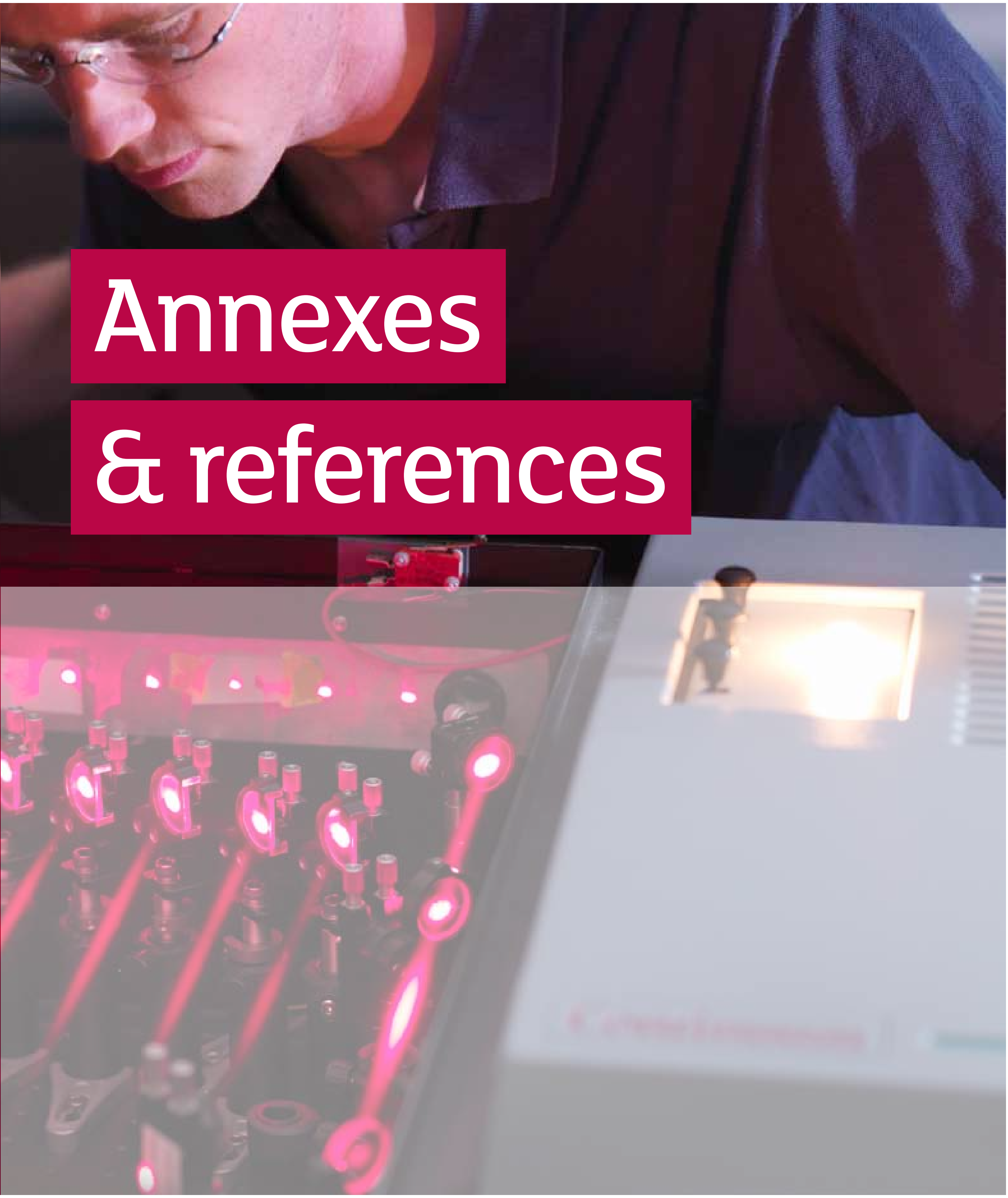

Annexes & references

Annex 1 - Abbreviations

ALICE	Accelerators and Lasers In Combined Experiments
AMRC	Advanced Manufacturing Research Centre, University of Sheffield
AMP	Advanced Manufacturing Park
ASTeC	Accelerator Science and Technology Centre, STFC
ATST	Advanced Technology Solar Telescope
BAS	British Antarctic Survey, NERC
BBSRC	Biotechnology and Biological Sciences Research Council
BGS	British Geological Survey, NERC
CAD	Computer-aided design
C–C	Carbon–carbon bond
CEH	Centre for Ecology and Hydrology, NERC
CERN	European Organization for Nuclear Research
CFARR	Chilbolton Facility for Atmospheric and Radio Research, STFC
CL	(Bio)-containment level
CLF	Central Laser Facility, STFC
CLIC	Compact Linear Collider
CNC	Computer numerical control
CPT	Centre for Precision Technologies, University of Huddersfield
CSC	Clinical Sciences Centre, MRC
CUPE	Cranfield University Precision Engineering
DNA	Deoxyribonucleic acid
EDM	Electrical discharge machining
ELI	Extreme Light Infrastructure
E-ELT	European Extremely Large Telescope
EMMA	Electron Machine with Many Applications
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
FAAM	Facility for Airborne Atmospheric Measurement
HECToR	High-End Computing Terascale Resource
HPC	High-performance computing
IAH	Institute for Animal Health, BBSRC
IBERS	Institute of Biological, Environmental and Rural Sciences, BBSRC/Aberystwyth University
ICE-CSE	International Centre of Excellence in Computational Science and Engineering, STFC
ICF	Inertial confinement fusion
IFR	Institute of Food Research, BBSRC
ILL	Institut Laue-Langevin
ILO	Industry liaison officer

ISIC	International Space Innovation Centre
ITER	International Tokamak Experimental Reactor
IVHM	Integrated Vehicle Health Management, Cranfield University
JCMT	James Clerk Maxwell Telescope
JET	Joint European Torus
JIC	John Innes Centre, BBSRC
JWST	James Webb Space Telescope
LHC	Large Hadron Collider
LMB	Laboratory for Molecular Biology, MRC
LNG	Liquefied natural gas
LRF	Large Research Facility
MAST	Mega Amp Spherical Tokamak
MEG	Multiple Excitor Generation
MCF	Magnetic confinement fusion
MEMS	Micro-electro-mechanical systems
MRC	Medical Research Council
NAL	National Aerospace Laboratories
NASA	National Aeronautics and Space Administration
NCAS	National Centre for Atmospheric Science, NERC
NCEO	National Centre for Earth Observation, NERC
NERC	Natural Environment Research Council
NIMR	National Institute for Medical Research, MRC
NNL	National Nuclear Laboratory
NOC	National Oceanography Centre, NERC
OCTOPUS	Optics Clustered to OutPut Unique Solutions
OINS	Oxford Instruments NanoScience
PE	Precision engineering
PEER	Partnership for European Environmental Research
RAL	Rutherford Appleton Laboratory
RCUK	Research Councils UK
RNA	Ribonucleic acid
STFC	Science and Technology Facilities Council
TGAC	The Genome Analysis Centre, BBSRC
UHV	Ultra-high vacuum
UK ATC	UK Astronomy Technology Centre, STFC
UPS2	Ultra-Precision Structured Surfaces Integrated Knowledge Centre
UV	Ultraviolet
VISTA	Visible and Infrared Survey Telescope for Astronomy

Annex 2 - Glossary of technical terms

Alloy	An alloy is a homogeneous mixture or metallic solid solution composed of two or more elements.
Biogeochemistry	This is the study of the processes and reactions that govern the composition of the natural environment. These processes may be chemical, physical, geological and/or biological; the definition of natural environment encompasses water, soil, air, living organisms and the Earth's crust.
Biomaterial	A biomaterial is any matter, surface or construct that interacts with biological systems.
Catalyst	A catalyst is a substance which speeds up the rate of a chemical reaction but remains unchanged chemically once the reaction has finished.
Cryogenics	Cryogenics is the study of the production of very low temperature (below -150°C, -238°F or 123K) and the behaviour of materials at those temperatures. The technology behind this field is critical to enable a spectrum of activity ranging from the preservation of stem cells to cooling detectors in order to minimise atomic vibration to capture the sharpest image from faint signals from space. In fact, a great deal of science is already conducted at low temperatures, and the growing use of superconductors is adding to the need for cryogenic technology and expertise.
Crystallography	Crystallography is the experimental science of the arrangement of atoms in solids.
Deuterium	Deuterium is a type of hydrogen, also called heavy hydrogen. It is naturally found in the Earth's oceans and is one of the elements required for fusion energy production.
Electromagnet	An electromagnet is a type of magnet in which the magnetic field is produced by the flow of electric current. The magnetic field disappears when the current is turned off.
Electron beam	Streams of electrons observed in vacuum tubes.
Femtosecond	A femtosecond is a unit of time equal to 10-15 seconds.

Fresnel lens	A Fresnel lens is a type of lens originally developed by French physicist Augustin-Jean Fresnel for lighthouses. The design allows the construction of lenses of large aperture and short focal length without the mass and volume of material that would be required by a lens of conventional design. Compared with conventional bulky lenses, the Fresnel lens is much thinner, larger and flatter, and captures more oblique light from a light source, thus allowing the light from a lighthouse to be visible over a much greater distance.
Fusion energy	Fusion energy is energy generated by nuclear fusion processes. In fusion reactions, two light atomic nuclei fuse together to form a heavier nucleus. In doing so, they release a large amount of energy which is manifested as an increase in temperature of the reactants. Major advantages for power stations using fusion energy include: • No emission of carbon through the process, thereby decreasing pollution • Abundant fuels • Energy efficiency – the energy provided by 1kg of fusion fuel is equivalent to the energy provided by 10 million kg of fossil fuel • Non long-term radioactive waste • Generation of reliable power. To create fusion energy artificially, scientists invented the process of heating gas from deuterium and tritium to a high temperature. They have been exploring two main avenues for generating fusion energy, namely: • Magnetic confinement fusion - using magnetic fields to confine the hot fusion fuel in the form of plasma, • Inertial confinement fusion - nuclear fusion reactions are initiated by heating and compressing a fuel target, usually in the form of a pellet that contains a mixture of deuterium and tritium.
Genome	The genome is the entirety of an organism's hereditary information. It is encoded either in DNA or, for many types of virus, in RNA. The genome includes both the genes and the non-coding sequences of the DNA/RNA.

Gnotobiotic animal	Gnotobiotic animals are born in aseptic conditions, removed from the mother by Caesarean section. They are reared in the laboratory, and exposed only to those microorganisms that the researchers wish to be present in the animal. They are used in research into the symbiotic relationship between an animal and the micro-organisms that inhabit its body, sometimes called its 'eco-organ'.
Heat treatment	Heat treating is a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as the hardening or softening of a material.
Higgs Boson	The Higgs Boson is a hypothetical elementary particle, the existence of which is postulated to resolve inconsistencies in theoretical physics and unfold the mystery of the creation of the universe, the Big Bang.
High-performance computing (HPC)	HPC integrates systems administration and parallel programming into a multidisciplinary field that combines digital electronics, computer architecture, system software, programming languages, algorithms and computational techniques. It is rapidly replacing traditional experimental-based methods in the delivery of scientific insights, simulation and modelling, as well as facilitating fundamental breakthroughs in fields such as engineering, medicine and entertainment. HPC is also increasingly being embraced by industrial sectors such as aerospace, electronics, energy, chemical, pharmaceutical, biomedical, life sciences and defence. For example, it is coming out into the mainstream in commercial applications such as: • Simulating galaxy creation, fusion energy and global warming • The simulation of car crashes for structural design • Molecular interaction for new drug design • Simulating airflow over motor vehicles or aeroplanes • Working to create more accurate short and long-term weather forecasts.

Infrared (IR)	IR light is electromagnetic radiation with a wavelength longer than that of visible light, measured from the nominal edge of visible red light at 0.74µm, and extending conventionally to 300µm.
Joint European Torus (JET)	JET is the world's largest and most powerful tokamak and the focal point of the European fusion research programme. Designed to study fusion in conditions approaching those needed for a power plant, it is the only device currently operating that can use the deuterium–tritium fuel mix that will be used for commercial fusion power.
Juste retour	This term represents a quantitative link between the financial contributions that a partner country makes to an LRF collaboration, and the benefits that it obtains in terms of contracts awarded and nationals hired ('the fair return agenda').
Lamella	A lamella is a gill-shaped structure: fine sheets of material held adjacent to one another, often with fluid in between though sometimes simply a set of "welded" plates.
Large Hadron Collider	This is the world's largest and highest-energy particle accelerator. It is expected to address some of the most fundamental questions of physics, advancing the understanding of the deepest laws of nature. It aims to recreate the conditions just after the Big Bang, by colliding two beams of subatomic particles at very high energy.
Laser	A laser is a device that emits light through a process of optical amplification based on the stimulated emission of photons. The term 'laser' originated as an acronym for light amplification by stimulated emission of radiation.
Market research	A study, which is often undertaken by procurement and technical officials in LRFs, to ascertain the level of industrial capability and skills with member states or partner countries.
Mega Amp Spherical Tokamak (MAST)	MAST is the UK's fusion energy experiment, based at the Culham Centre for Fusion Energy. Along with NSTX – a complementary experiment at Princeton in the USA – MAST is one of the world's two leading spherical tokamaks.

Monochromator	A monochromator is an optical device that transmits a mechanically selectable narrow band of wavelengths of light or other radiation chosen from a wider range of wavelengths available at the input.
Muon	The muon is an elementary particle similar to the electron, with a negative electric charge.
Muon scattering or muon spectroscopy	Muon scattering or muon spectroscopy is used to examine the magnetic properties of atoms as well as to determine magnetism and superconductivity properties of materials. This technique has applications in many fields such as biosciences, particle physics, materials science, nuclear physics and condensed matter physics. For example, exploring the membrane activity of plant seed defence proteins, and elucidating the solution structure of proteasome activators.
Nanotechnology	The design, characterisation, production and application of structures, devices and systems within the nano-scale, which covers the size range from approximately 1nm to 10nm.
Neutron scattering	Neutron scattering is used to study the structure and magnetic properties of materials. Like muon spectrocsopy, it has applications in many fields such as biosciences, particle physics, materials science, nuclear physics and condensed matter physics. For example: • Optimising polymer solutions for printed electronics • Advancing low temperature cryogenics based on pulse-tube technology.
Nuclear physics	Nuclear physics is the field of physics that studies the building blocks and interactions of atomic nuclei.
Particle accelerator	A particle accelerator is a device that uses electromagnetic fields to propel charged particles to high speeds and to contain them in well-defined beams.
Particle physics	Particle physics is the study of the fundamental constituents of matter and the forces of nature.
Petawatt	The petawatt is equal to one quadrillion (1015) watts and can be produced by the current generation of lasers for timescales in the order of femtoseconds (10-15 seconds).
Photovoltaic cell	Also known as a solar cell. It is a solid state electrical device that converts the energy of light directly into electricity.

Plasma	Plasma is a state of matter similar to gas in which a certain portion of the particles are ionised. Heating a gas may ionise (reduce the number of electrons in) its molecules or atoms, thus turning it into plasma, which contains charged particles: positive ions and negative electrons.
Precision engineering (PE)	PE deals with the design and manufacture of machines, fixtures or structures which possess features such as exceptionally low tolerances, and which are repeatable and stable over time. The field covers a multiplicity of areas such as optical fabrication, materials, interferometry, precision optics, materials processing, precision controls, nanotechnology, machine design, surface metrology, dimensions metrology, scanning microscopes, precision replication, semiconductor processing and ultra-precision machining. PE is critical in supplying to a range of LRFs such as the UK's Diamond Synchrotron, CERN and ESO as well as sectors with high technology requirements, for example, automotive, defence, energy, healthcare and space.
Pulsed neutron source	A scientific apparatus used for neutron scattering research.
Refractory metals	Refractory metals are a class of metals that are extraordinarily resistant to heat and wear. These include molybdenum, niobium, zirconium and tantalum.
Sintering	Sintering is a method used to create objects from powders. It is based on atomic diffusion. Diffusion occurs in any material above absolute zero, albeit much faster at higher temperatures. In most sintering processes, the powdered material is held in a mould and then heated to a temperature below the melting point. The atoms in the powder particles diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece.
Small-angle scattering	Small-angle scattering is a scattering technique based on the deflection of a beam of particles, or an electromagnetic or acoustic wave, away from the straight trajectory after it interacts with structures that are much larger than the wavelength of the radiation. The deflection is small (0.1–10°) hence the name "small-angle". Small-angle scattering techniques can give information about the size, shape and orientation of structures in a sample.

Spacecraft harness	Spacecraft harnesses describe the spacecraft structure wiring connecting the various parts of a spacecraft including the power distribution and electronic data. They tend to be large harnesses which need to meet the stringent thermal requirements for functionality at operating temperatures which will be below 50 Kelvin (-223 degree C) at L2, the second Lagrange point, approximately 1.5 million km from Earth. They are also referred to as cryogenic harnesses except that the wiring for cryogenic harnesses used in cryostats and instruments with detectors (especially for ultra low temperature applications) are miniature and generally use resistance alloys for the wiring and miniature connectors. This allows them to minimise the heat load to meet the thermal budget requirements. Cryostats are the 'fridges' that cool the systems and detectors need to be cooled to very low temperatures to be able to detect the radiative sources at or near the beginning of time, big bang, star formations, black holes in the various light frequencies. Hence on the James Webb Space Telescope (JWST), the spacecraft harnesses are connecting the spacecraft's central nervous system. which will link the spacecraft systems to the telescope, controlling its alignment and providing temperature information for health monitoring. The Cryostat and detector harnesses form part of the electronic wiring on the instruments that will be on the JWST such as the Mid InfraRed Instrument (MIRI) which will operate at a temperature of 7 Kelvin (-266° C) using a helium cryocooler system. and the Near Infrared Camera (NIRCam), Near Infrared Spectrometer (NIRSpec) and the Fine Guidance Sensor (FGS) which will operate at a temperature of 39 K (-234° C or -389° F) through a passive cooling system.
Spectroscopy	Spectroscopy is the study of the interaction between matter and radiated energy. Historically, spectroscopy originated through the study of visible light dispersed according to its wavelength, for example by a prism. Later, the concept was expanded greatly to include any interaction with radiative energy as a function of its wavelength or frequency. Spectroscopic data is often represented by a spectrum, a plot of the response of interest as a function of wavelength or frequency.

Superconductivity	Superconductivity is a phenomenon of exactly zero electrical resistance occurring in certain materials below a characteristic temperature.
Swaging	Swaging is a forging process in which the dimensions of an item are altered using a die or dies, into which the item is forced. Swaging is usually a cold working process; however, it is sometimes done as a hot working process.
Synchrotron	A synchrotron is a large machine designed to produce very intense beams of X-rays, infrared and ultraviolet light, called synchrotron light (also referred to as synchrotron radiation). It does this by accelerating particles in a cyclical fashion using an electric field and the magnetic field. Synchrotron light can be as much as 100 billion times brighter than the sun. This allows scientists to study samples in incredible detail, and is used in all types of research, from determining the structure of proteins to understanding how best to conserve historical artefacts.
Thermal vacuum chamber	A vacuum chamber in which the radiative thermal environment is controlled. They are frequently used for testing spacecraft or parts thereof under a simulated space environment.
Third-generation synchrotron	Third-generation synchrotron radiation sources were conceived and optimised from the outset to produce bright X-rays. Fourth-generation sources will include different concepts for producing ultra-bright, pulsed, time-structured X-rays for extremely demanding and also probably yet-to-be-conceived experiments.
Tokamak	The tokamak is the most developed magnetic confinement system and is the basis for the design of future fusion reactors using this method. The most successful device yet found for magnetic confinement of plasma, its magnetic field is made up from helical lines of force on toroidal surfaces, and is generated both by external field coils and by the current in the plasma.
Torus	Doughnut-shaped magnet used in JET.
Tritium	Tritium is another type of hydrogen, called hydrogen 3. Tritium does not occur naturally, because it is unstable to radioactive decay. It is also one of the elements required for fusion energy production.

Ultraviolet (UV) light	UV light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, in the range 10nm to 400nm, and energies from 3 electron volts to 124 electron volts. It is named ultraviolet because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the colour violet.

Annex 3 - List of websites

Accelerator Science and Technology Centre	*www.stfc.ac.uk/astec*
Advanced Forming Research Centre, University of Strathclyde	*www.strath.ac.uk/afrc*
Advanced Manufacturing Research Centre, University of Sheffield	*www.amrc.co.uk*
Allinea	*www.allinea.com*
AMEC plc	*www.amec.com*
Atkins UK	*www.atkinsglobal.co.uk*
Atomic Weapons Establishment	*www.awe.co.uk*
Babcock International Group	*www.babcock.co.uk*
Biotechnology and Biological Sciences Research Council	*www.bbsrc.ac.uk*
British Antarctic Survey	*www.antarctica.ac.uk*
British Cryogenics Cluster	*www.bcryo.org.uk*
British Geological Survey	*www.bgs.ac.uk*
Catapult centres	*www.catapult.org.uk*
Centre for Process Innovation	*www.uk-cpi.com*
CERN (European Organization for Nuclear Research)	*www.cern.ch*
Chilbolton Facility for Atmospheric and Radio Research	*www.stfc.ac.uk/chilbolton*
Claro Precision Engineering Limited	*www.claro.co.uk*
ClusterVision	*www.clustervision.com*
Cockcroft Institute	*www.cockcroft.ac.uk*
Compact Linear Collider	www.clic-study.org
Cranfield University Precision Engineering	www.cranfield.ac.uk/sas/precisionengineering
Cryoconnect	*www.cryoconnect.com*
Culham Centre for Fusion Energy	*www.ccfe.ac.uk*
CVT Ltd	*www.cvt.ltd.uk*
Dalton Nuclear Institute, University of Manchester	*www.dalton.manchester.ac.uk*

Daresbury Science & Innovation Campus	*www.daresburysic.co.uk*
Department for Business, Innovation and Skills	*www.bis.gov.uk*
Diamond Light Source	*www.diamond.ac.uk*
European Southern Observatory	*www.eso.org*
European Space Agency	*www.esa.int*
European Strategy Forum on Research Infrastructures roadmap	*www.ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri-roadmap*
European Synchrotron Radiation Facility	*www.esrf.eu*
Eurotech Computer Services Ltd	*www.eurotech-computers.com*
Extreme Light Infrastructure	*www.extreme-light-infrastructure.eu*
Facility for Airborne Atmospheric Measurement	*www.faam.ac.uk*
FGP Precision Engineering Limited	*www.fgpltd.com*
FLAVIIR	*www.flaviir.com/home.htm*
FMB Oxford	*www.fmb-oxford.com*
Genesis Precision Engineering Ltd	*www.genesisprecision.co.uk*
Genvolt	*www.genvolt.co.uk*
GOM UK Ltd	*www.gom.com*
Harwell Oxford (also referred to as Harwell Science and Innovation Campus)	*www.harwelloxford.com*
Herose UK	*www.herose.co.uk*
High End Computing Terascale Resource	*www.hector.ac.uk*
High Value Manufacturing Catapult	*www.catapult.org.uk/manufacturing*
Hutton Engineering (Precision) Ltd	*www.huttonengineering.co.uk*
ICE Oxford	*www.iceoxford.com*
Institute of Animal Health	*www.iah.ac.uk*
Institute of Biological, Environmental and Rural Sciences	*www.aber.ac.uk*

Institute of Food Research	*www.ifr.ac.uk*
Institut Laue-Langevin	*www.ill.eu*
Instrument Design Technology Ltd	*www.idtnet.co.uk*
Integrated Vehicle Health Management Centre, Cranfield University	*www.cranfield.ac.uk/ivhm*
Isaac Newton Group of Telecscopes	*www.ing.iac.es*
ISIS	*www.isis.stfc.ac.uk*
ITER	*www.iter.org*
Jacobs	*www.jacobs.com*
James Clerk Maxwell Telescope	*www.jach.hawaii.edu/JCMT*
James Webb Space Telescope	*www.jwst.nasa.gov*
John Innes Centre	*www.jic.ac.uk*
Joint Astronomy Centre	*www.jach.hawaii.edu*
Joint European Torus	*www.ccfe.ac.uk/JET.aspx*
Korea Aerospace Research Institute, South Korea	*www.kari.re.kr/eng/index.asp*
Kurt J Lesker Company	*www.lesker.com*
Los Alamos National Laboratory, USA	*www.lanl.gov*
Manufacturing Technology Centre	*www.the-mtc.org*
Medical Research Council	*www.mrc.ac.uk*
Mega Amp Spherical Tokamak	*www.ccfe.ac.uk/MAST.aspx*
Meggitt Aircraft Braking Systems	*www.meggitt.com*
Merc Engineering Ltd	*www.merceng.co.uk*
Met Office	*www.metoffice.gov.uk*
MG Sanders Ltd	*www.mgsanders.co.uk*
Monroe Brothers Ltd	*www.monroebrothers.co.uk*
MRC Anatomical Neuropharmacology Unit	*www.mrc.ox.ac.uk*
MRC Biomedical NMR Centre	*www.nmrcentre.mrc.ac.uk*
MRC Biostatistics Unit	*www.mrc-bsu.cam.ac.uk*
MRC Cancer Cell Unit	*www.mrc-ccu.cam.ac.uk*

MRC/Cancer Research UK/BHF Clinical Trial Service Unit & Epidemiological Studies Unit	*www.ctsu.ox.ac.uk*
MRC/Cancer Research UK Gray Institute for Radiation Oncology and Biology	*www.rob.ox.ac.uk*
MRC Cell Biology Unit	*www.ucl.ac.uk/lmcb*
MRC Clinical Sciences Centre	*www.csc.mrc.ac.uk*
MRC Clinical Trials Unit	*www.ctu.mrc.ac.uk*
MRC Cognition and Brain Sciences Unit	*www.mrc-cbu.cam.ac.uk*
MRC Epidemiology Unit	*www.mrc-epid.cam.ac.uk*
MRC Functional Genomics Unit	*www.mrcfgu.ox.ac.uk*
MRC Human Nutrition Research	*www.mrc-hnr.cam.ac.uk*
MRC Institute of Hearing Research	*www.ihr.mrc.ac.uk*
MRC Laboratory of Molecular Biology	*www2.mrc-lmb.cam.ac.uk*
MRC Lifecourse Epidemiology Unit	*www.mrc.soton.ac.uk*
MRC Mammalian Genetics Unit & The Mary Lyon Centre	*www.har.mrc.ac.uk*
MRC Mitochondrial Biology Unit	*www.mrc-mbu.cam.ac.uk*
MRC National Institute for Medical Research	*www.nimr.mrc.ac.uk*
MRC Prion Unit	*www.prion.ucl.ac.uk*
MRC Protein Phosphorylation Unit	*www.ppu.mrc.ac.uk*
MRC Social and Public Health Sciences Unit	*www.sphsu.mrc.ac.uk*
MRC Toxicology Unit	*www.mrctox.le.ac.uk*
MRC Unit, The Gambia	*www.mrc.gm*
MRC Unit for Lifelong Health and Ageing	*www.nshd.mrc.ac.uk*
MRC/University of Edinburgh Human Genetics Unit	*www.hgu.mrc.ac.uk*
MRC/University of Glasgow Centre for Virus Research	*www.gla.ac.uk/researchinstitutes/iii/cvr*

MRC/University of Oxford Human Immunology Unit (within the Weatherall Institute of Molecular Medicine)	*www.imm.ox.ac.uk*
MRC/University of Oxford Molecular Haematology Unit (within the Weatherall Institute of Molecular Medicine)	*www.imm.ox.ac.uk/wimm-research/molhaem*
MRC/UVRI Uganda Research Unit on AIDS	*www.mrcuganda.org*
National Aeronautics and Space Administration	*www.nasa.gov*
National Aerospace Laboratories	*www.nal.res.in*
National Centre for Atmospheric Science	*www.ncas.ac.uk*
National Centre for Earth Observation	*www.nceo.ac.uk*
National Composites Centre	*www.nationalcompositescentre.co.uk*
National Laboratory for Particle and Nuclear Physics, Canada	*www.triumf.ca*
National Nuclear Laboratory	*www.nnl.co.uk*
National Oceanography Centre	*www.noc.ac.uk*
National Space Organization, Taiwan	*www.nspo.org.tw/2008e*
Natural Environment Research Council	*www.nerc.ac.uk*
New Karolinska Solna University Hospital Project (including Research Centre), Sweden	*www.nyakarolinskasolna.se/en*
Nuclear Advanced Manufacturing Research Centre	*www.namrc.co.uk*
Oak Ridge National Laboratory, USA	*www.ornl.gov*
Observatory Sciences Ltd	*www.observatorysciences.co.uk*
OCF plc	*www.ocf.co.uk*
OpTIC	*www.opticinnovations.co.uk*
Oxford Cryosystems Ltd	*www.oxcryo.com*
Oxford Instruments	*www.oxford-instruments.com*

Oxford Instruments NanoScience	*www.oxford-instruments.com/businesses/nanoscience/Pages/nanoscience.aspx*
Oxford Supercomputing Centre	*www.oerc.ox.ac.uk/computing-resources/osc*
Oxford Technologies	*www.oxfordtechnologies.co.uk*
Pace Precision	*www.paceprecision.co.uk*
PECO Cyrogenics	*www.peco-europe.com/cryogenics*
Phoenix Inspection Systems Ltd	*www.phoenixisl.co.uk*
Prototech Engineering Ltd	*www.prototech.co.uk*
Q-par Angus Ltd	*www.q-par.com*
RAL Space	*www.stfc.ac.uk/RALSpace*
Research Council UK Large Research Facilities Roadmap	*www.rcuk.ac.uk/research/ Infrastructure/Pages/lfr.aspx*
Roslin Institute	*www.roslin.ed.ac.uk*
Rothamsted Research	*www.rothamsted.ac.uk*
Science and Technology Facilities Council	*www.stfc.ac.uk*
STFC Central Laser Facility	*www.clf.rl.ac.uk*
STFC Computational Science and Engineering Department	*www.stfc.ac.uk/cse/default.aspx*
Scientific Magnetics	*www.scientificmagnetics.com*
Scitech Precision Ltd	*www.scitechprecision.com*
Tata Institute of Fundamental Research, India	*www.tifr.res.in*
Taylor Hobson	*www.taylor-hobson.com*
Temati	*www.temati-uk.com*
Tesla Engineering Ltd	*www.tesla.co.uk/aboutus.htm*
Thames Cryogenics Ltd	*www.thamescryogenics.com*
The Babraham Institute	*www.babraham.ac.uk*
The Centre for Ecology & Hydrology	*www.ceh.ac.uk*
The Genome Analysis Centre	*www.tgac.ac.uk*
UK Astronomy Technology Centre	*www.roe.ac.uk/ukatc*
UK Biobank	*www.ukbiobank.ac.uk*

UK Trade & Investment	*www.ukti.gov.uk*
Ultra-Precision Structured Surfaces Integrated Knowledge Centre	*www.ups2.co.uk*
United Kingdom Science Park Association	*www.ukspa.org.uk*
University of Huddersfield's Centre for Precision Technologies	*www.hud.ac.uk/cpt*
VG Scienta	*www.vgscienta.com*
Viglen Ltd	*www.viglen.co.uk*
Warwick Manufacturing Group	*www2.warwick.ac.uk/fac/sci/wmg*
Wellcome Trust	*www.wellcome.ac.uk*
Wessington Cryogenics Ltd	*www.wessingtoncryogenics.co.uk*
Xyratex Ltd	*www.xyratex.com*
Zeeko Ltd	*www.zeeko.co.uk*

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Research Councils UK, *Large Facilities Roadmap 2010*
www.rcuk.ac.uk/documents/research/RCUKLargeFacilitiesRoadmap2010.pdf

Annex 5 - Contact UKTI

For more information about business opportunities with LRFs, please contact:

Dr Amit Khandelwal
UK Trade & Investment
Orchard 3, Level 1
1 Victoria Street
London SW1H 0ET
Tel: +44 (0)20 7215 0977
Email: amit.khandelwal@ukti.gsi.gov.uk

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