New Light on Science

The Social & Economic Impact of the Daresbury Synchrotron Radiation Source, (1981 - 2008)

Science & Technology Facilities Council

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Executive summary

Cleaner fuel, safer aircraft and new medicines, not to mention two Nobel prizes, great tasting chocolate and iPods - all of these things have been influenced or made possible by world leading scientific research carried out on the Synchrotron Radiation Source (SRS). Located at the Science and Technology Facilities Council's (STFC) Daresbury Laboratory, the SRS was the world's first 2nd generation multi user X-ray synchrotron radiation facility. The facility ceased operations in 2008 after 28 years of operation and two million hours of science which was undertaken by a wide-ranging, cross-discipline, national and international user base.

"The SRS was one of the world's most pioneering scientific inventions and Daresbury can be very proud of its outstanding achievements.[1]"

This report is the first complete study in the world which explores the social and economic impact of a large science facility over its whole lifetime. This impact has been vast and will continue years after the closure of the facility. This report highlights the many ways in which the SRS has impacted at the regional, national and international level. The SRS has not only impacted the scientific, industrial and skill base of the UK but has also produced impact on a world wide scale. Impacts from the SRS include the creation of knowledge, improved quality of life in the UK, the generation and transfer of skills, improved competitiveness of industry, the commercialisation of technology, financial effects and the creation of jobs.

Global impacts

The impact of the SRS has been felt on a number of different levels. The most significant impacts are global and long term impacts both from the research carried out at the SRS and from the proliferation of synchrotron radiation sources and their resulting impact around the world.

Fuelling the impact of the world's synchrotrons

The SRS was the world's first 2nd generation multi user X-ray synchrotron radiation facility and as such provided an exemplar for Synchrotron Radiation facilities across the globe. The SRS pioneered the way for the development of 70 similar machines; this worldwide synchrotron community is providing impact on a global scale. Staff from the SRS played a significant role in the establishment of these facilities, having formal collaborations with 40% and informal collaborations with the majority. SRS staff played a key role in training, advising and transferring key skills and technology to these facilities.

The world's synchrotron radiation facilities are used to conduct scientific research which explores the world through a detailed knowledge of the structure of matter. These facilities are used in a variety of scientific fields and science carried out on Synchrotron Radiation facilities makes a variety of contributions to society. Examples include, addressing global challenges such as research into the environment and energy. Synchrotrons around the world have ensured the development of new drugs, medicines, technologies; products and materials.

[1] *Professor Colin Whitehouse, STFC's Director of Campus Strategy, speaking at the closing ceremony of the SRS in August 2008*

One example area in which the world wide synchrotron community has had a global impact is the area of bioscience. Pharmaceutical and bioscience companies have recognised the huge commercial potential that lies behind understanding the multitude of processes that take place within living organisms at a molecular level. Advances in Structural Biology have accelerated greatly as a result of access to the synchrotron facilities that have been developed around the world.

Sophisticated analysis methods and software packages involving new scientific fields on the SRS were developed and distributed and used all over the world. For example, one of the major impacts of the facility has been the emergence of techniques to facilitate structural biology, in particular protein crystallography (PX). This technique was pioneered at the SRS, making the UK a world leader in this area. This strength has supported the skills base and R&D competitiveness of the world's pharmaceutical and biotechnology industries. This was one of many impacts which were not envisaged at the outset of the facility. This highlights the somewhat serendipitous nature of basic science meaning that certain high impact developments cannot always be predicted.

Although the overall impact of the worldwide synchrotron community is impossible to quantify it has been significant. With numbers of facilities growing every year, the impact of the SRS will continue to be felt many years into the future.

Creation of knowledge

The SRS played a key role in enabling and performing cutting edge research in many areas of UK and international science. During its lifetime, the SRS has collaborated with almost every country active in scientific research. The SRS produced beams of light so intense that they revealed the structure of atoms and molecules inside a wide range of different materials. Over the lifetime of the SRS, synchrotron light supported cutting-edge research in biology, chemistry, materials science and physics and opened up many new areas of research in fields such as medicine, earth sciences (including both geological and environmental studies) and archaeology. The SRS has contributed to the publication of over 5000 papers and solved over 1200 protein structures which have been deposited in the worldwide Protein Data Bank database repository. The contribution to the global pool of research knowledge is another example of significant, yet unquantifiable impact of the facility.

Quality of life impacts

The SRS has improved the quality of our lives in a remarkable number of ways. Examples include the development of new medicines and medical research such as control of host-graft rejection and HIV/AIDS. In addition, the SRS has facilitated the production of new materials for use in electronics and clothing and it has led to the development of new detergents. It has even played a role in improving the taste of chocolate and the safety of aircraft by looking at the crystal formations in chocolate and metal. Recent research on the SRS even paved the way for bigger iPod memories. Another famous example is the crystal structure of the Foot and Mouth Disease Virus, which created large media impact and recognition in the public domain.

Whilst these examples directly impact on people's quality of life, they also have a financial impact on the Government, industry and ultimately the tax payer. For example the Foot & Mouth outbreak in 2001 cost the Government and industry £8.4 billion[2]. The structure of the Foot & Mouth Disease Virus was solved at the SRS for the first time and this research has allowed vaccines to be developed. Foot & Mouth disease is endemic in many countries around the world and this vaccine may defray some of the negative economical and social impacts which the disease produces.

Indirect impacts

Innovation was a constant factor throughout the lifetime of the facility. This continued from the birth of the facility using a particle physics experiment to the innovative use of equipment after its closure. This produced indirect medium to long term impacts on the UK, which are continuing after the closure of the facility –

Improving the performance of UK industry

The SRS impacted UK industry in several ways, the first being usage of the facility by industry to

[2] *www.archive.cabinetoffice.gov.uk/fmd/fmd_report/report/index.htm*

investigate the properties of materials including structures of pharmaceuticals and their protein targets. Over its lifetime, the SRS had approximately 200 proprietary customers including government departments, industry, hospitals, museums, universities and other Synchrotron Radiation sources. The industry sectors which benefited the most from the use of the facility are pharmaceutical, chemical and healthcare industries. Industrial users of the facility included large multinational companies and SMEs: customers included ICI, BP, Unilever, Shell, GSK, AstraZeneca and Pfizer. Indeed 48% of the companies represented in the top 25 of the 2008 R&D Scoreboard[3] were users of the SRS. For example, the SRS was used to characterise the molecular structure of blockers to reduce the effects of drugs given during operations. This allowed Organon to develop a drug to reduce the recovery time of patients after operations; this drug has now been released and will significantly reduce post-operative care costs.

In addition to the usage of the facility there was a significant amount of knowledge exchange between the SRS staff and industry during construction and development of the facility. These projects involved the transfer of unique skills and technology to industry on several projects and the development of SRS technology by industry. The challenging nature of these projects and their high specifications meant the industrial partners' capabilities were improved, allowing them to win contracts and grow their businesses. Examples of this work include joint design and production of the Helios compact synchrotron source by SRS staff and Oxford Instruments for IBM, a contract worth £18million to Oxford Instruments. Another example included a collaboration of e2v with SRS staff which allowed the company to win £250million of sales after development of an anti-multipactor coating.

Creating new companies in the UK

Skills, technology and knowledge gained on the SRS have helped in the creation of 9 new companies and one commercial service provider. These new companies are in a range of areas which include scientific instrumentation, detectors, cholesterol monitoring, software, cryogenics, mechanical instrumentation and drug discovery. These companies are creating impact through the stimulation of the UK's economy and the impact to people's daily lives that these activities will produce.

Delivering highly skilled people to the labour market

A critical mass of highly skilled engineers, technicians and instrumentation developers was built up over the lifetime of the SRS, with staff numbers peaking at 325 in 1998/99. The skills required to design, run and support the research at the SRS was vast, requiring world class expertise in a range of technologies.

This allowed SRS staff to transfer their expertise and knowledge to industry, universities and other research establishments. Over 100 staff from the SRS transferred to academia, industry or other synchrotrons around the world, transferring the knowledge and skills learnt at the SRS.

The SRS also developed the skills of its scientific and industrial users; over 11,000 individual users used the SRS during its lifetime from over 25 countries. In addition it also played a big part in the studies of many students, 4,000 of which used the SRS as part of their degrees or doctorates, with 2,000 post-doctoral researchers using the SRS for their research. The supply of skilled graduates and researchers who are trained at large facilities such as the SRS and then transfer to industry or other public sector bodies is a key impact from research.

[3] *http://www.innovation.gov.uk/rd_scoreboard/default.asp?p=13*

Direct local impacts

The final level of impacts from the SRS are direct, short term and tangible and occurred through the location of the facility in the North West of England –

Stimulating the economy in the North West of England

There was increased economic activity in the North West through the creation of jobs and the construction and operation of the facility between 1975 and 2008. This represented a direct financial impact of £600 million, the majority of which was spent in the locality of the SRS. Due to multiplier effects, this initial investment increased to create an estimated total financial impact of nearly £1 billion to the North West.

The SRS also acted as a purchaser of goods and services in the local area and wider UK. Throughout its lifetime, the SRS has traded with over 300 local businesses. This purchase of goods or services from suppliers leads to a further chain reaction of purchases from their supply chain and also has indirect effects on employment, spend and taxation.

Future impacts

Finally, the SRS has facilitated several activities which are creating impact for many years into the future –

Shaping the future of science and innovation

The Daresbury Science and Innovation Campus was created to exploit the critical mass of expertise, facilities and industrial links that were created around SRS and the wider Daresbury Laboratory. In addition to the scientific facilities already on the site, the Campus has led to the establishment of a world class centre for accelerator science, the Cockcroft Institute and will further benefit from two other centres based on computational science and detectors systems in the near future.

In addition, 100 high tech businesses from a wide range of commercial backgrounds are now located in the Campus's Daresbury Innovation Centre. Tenants come from sectors including biomedical, energy, environmental, advanced engineering and instrumentation industries. In 2008/2009, companies in the Innovation Centre delivered £14.9M in sales, secured £20.5M in investment and had an average growth turnover of 67%. Nearly half of all Campus companies have made significant use of the facilities, services and expertise at Daresbury Laboratory. 97 new jobs have been created in these tenant companies since they located onto the Campus with many companies expanding their businesses, recruiting more staff and looking to increase the size of their operations on Campus.

The next generation of impact

Other facilities like the Diamond Light Source and ALICE all benefit from skills, knowledge and expertise generated at the SRS. For example, the SRS and its staff played a key role in the establishment of the UK's 3rd generation light source – the Diamond Light Source. Over £400 million has already been invested in the facility, which is owned and funded at the 14% level by the Welcome Trust and currently employs around 350 staff. DLS operations begun in 2007 and it has already had significant impact. UK industry has also benefited from winning major construction and high technology equipment supply contracts, with a further 2000 companies supplying other products and services to the facility.

As already highlighted, one of the most substantial legacies of the SRS was the emergence of techniques to facilitate structural biology, in particular protein crystallography. This is reflected in the £50M investment made by the Welcome Trust into the Diamond Light Source, to carry on the protein crystallography work started at the SRS.

Summary

Even after the closure of the SRS, it continues to generate economic impact both in the UK and abroad. The following report details the extensive economic impact that the SRS has created through the science and associated technology it facilitated, the assistance that the SRS has provided for industry, the knowledge and skills that have resulted from the facility and the funding of the facility.

Given the current increased emphasis on demonstrating the economic impact of public investment in large scale facilities such as the SRS, there are a growing number of studies emerging internationally which outline the potential impact of future large scale facilities. For example, the recent study of the potential regional impact of the European Spallation Source[4] in Lund. Where appropriate, the methodology of these studies has been outlined later in the report for reference.

[4] *http://www.skane.se/templates/Page.aspx?id=210747*

Chapter 2
Introduction

Chapter 2

Introduction

2.1 Background

Published in 2006, the Research Councils UK (RCUK) Economic Impact Group report "Increasing the economic impact of the Research Councils"[5] made a number of recommendations to the Government regarding how the Research Councils could deliver a major increase in the economic impact of their investments. One key recommendation of the report was that the Research Councils should report on their impact and set a baseline for future reporting –

> *"Research Councils should make strenuous efforts to demonstrate more clearly the impact they already achieve from their investments. It is difficult to measure the economic impact of innovations which may be delayed in time and indirect in consequence. It is important to measure outcomes, however difficult, rather than outputs."*

Since 2007 the Research Councils have responded with a series of reports and activities in response to this recommendation.

Given the unique nature of the STFC as a funder of large scale scientific facilities, the STFC has undertaken a project to investigate the economic impact of one such facility, the Synchrotron Radiation Source. Using the SRS to demonstrate economic impact is timely given its closure in 2008, after 28 years of operation. This report represents the only lifetime report of a large scale facility in the world.

2.2 Project aims

The main aims of the project were to illustrate the impact of the SRS over its lifetime and highlight any issues with gathering this data. This will provide the basis for the STFC to formulate a framework for future economic impact reporting on large facilities and across the rest of its projects and programmes.

2.3 Research approach

Research was both qualitative and quantitative in nature and encompassed a series of interviews with key stakeholders involved with the SRS over its lifetime. These included industrial partners, SRS users and SRS staff. The majority of the research was done via desk research and questionnaires for users were also utilised. Data sources included SRS annual reports, publications of research carried out on the SRS, the SRS user database and other economic impact studies.

2.4 Assumptions & caveats

Given the period of time over which the study has taken place, there has inevitably been information which was not recorded. For example, details of commercial companies engaged in the construction of the SRS do not exist. This is because the construction was in the 1970s when the importance of such data was not then recognised and the advent of the desk PC had not yet taken place.

[5] *http://www.berr.gov.uk/dius/science/page32834.html*

The data contained in this report is more qualitative than quantitative, with financial economic impact given wherever possible. In the cases where financial economic data has not been available, qualitative case studies have been used to illustrate the impacts. This also means that it has not been possible to put a figure on the total economic impact of the SRS, but some financial impacts have been modelled. It should also be noted that all financial figures have been indexed to reflect them at today's costs.

It should also be recognised that this method of research could never capture the full economic impact of the SRS – whatever is reported here is an underestimate due to the limitations with the data.

2.5 Report structure & content

This report sets out the impact of the SRS over its lifetime. Chapter 3 describes the economic impact methodology used in the report and chapter 4 gives an introduction to the SRS. The remaining chapters describe various outputs from the SRS and illustrate the economic impact that has resulted from these outputs in both the UK and abroad. Each chapter ends with a summary of the impacts. The report finishes with conclusions from the project and highlights issues which have arisen from the research.

2.6 Scope

This report is intended to illustrate the vast economic impact that has come from the SRS over its lifetime and continues to make after its closure. The scientific output of the SRS has been extensive and well documented; this report is not intended to explore the vast scientific or technical output of the facility. However research that has made an impact to daily lives, for example healthcare or environmental research, has been highlighted.

Chapter 3
Economic impact methodology

Chapter 3

Economic impact methodology

3.1 Measurement of economic impact

Economic impact is generally thought of as the effect on a given economy produced by a particular project, policy or activity in a given region or country.

The definition of economic impact which will be used in this report is given in the Treasury Green Book:

"An action or activity has an economic impact when it affects the welfare of consumers, the profits of firms and/or the revenue of government. Economic impacts range from those that are readily quantifiable, in terms of greater wealth, cheaper prices and more revenue, to those less easily quantifiable, such as effects on the environment, public health and quality of life.[6]"

This definition highlights the stakeholders who "receive" the impact: consumers (through greater choice and cheaper products and other welfare effects), firms (through increased profits and efficiency in production) and government (through increased revenue and better policies).

The definition also highlights some issues with economic impact measurement (which will be explored later on in the report); that is, some components of economic impact are both tangible (easy to measure) and intangible (harder to measure). It also defines economic impact as having both economic and social aspects, with measurement of the latter potentially more difficult to measure and quantify.

In 2007, the STFC's parent Government department, the Department of Innovation Universities & Skills (DIUS) (now the Department of Business Innovation & Skills) introduced an economic impact framework as a guide to the areas which should be measured and reported on by the Research Councils. These are illustrated in the diagram below –

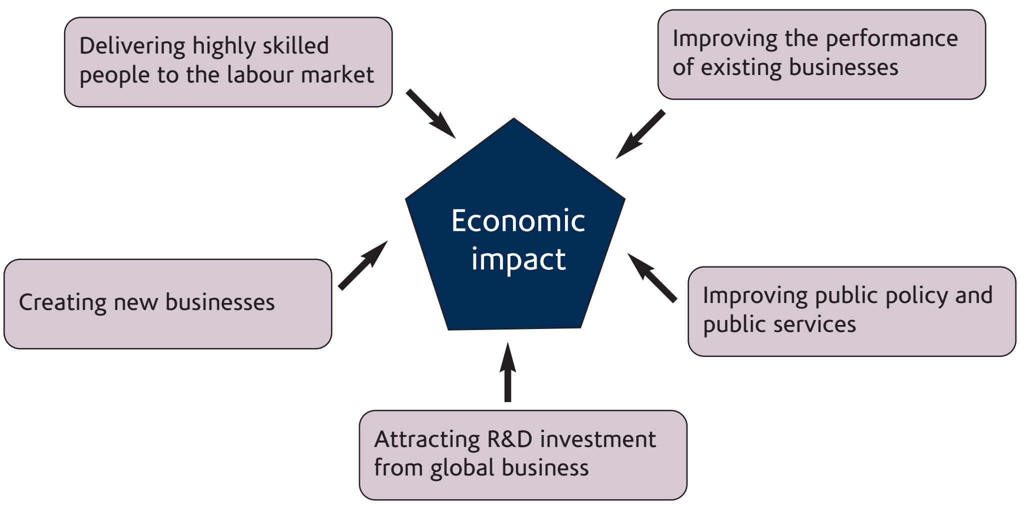


Figure 1, five key ways of generating economic impact from research, DIUS 'Economic Impact Framework' – May 2007

[6] *HM Treasury's "The Green book: Appraisal and Evaluation in Central Government" (2003) (www.hm-treasury.gov.uk/media/05553/Green_Book_03.pdf)*

3.2 SRS economic impact areas of analysis

The Research Councils report elements of their progress on economic impact to the Government through Economic Impact Baseline reports. The STFC's Economic Impact Baseline from 2007/08 is detailed in appendix 1. Utilising key themes from the baseline, the areas of economic impact which were investigated for this study are –

a) Generation of knowledge and skills

The major output of research is the generation of knowledge, both codified and tacit.

Codifiable knowledge generation

Codifiable knowledge generation comes through research. Any research information which is published or can be accessed can make an impact. The measurement of publication data, high impact publications and other data sharing schemes are all relevant here.

Tacit knowledge generation

Tacit knowledge cannot be codified, it is the knowledge that people carry with them and is gained and transferred through personal experience. Tacit knowledge comes through the provision of education, training and skills to a range of stakeholders at all levels from schools through to industry. The mechanism of transferring tacit knowledge comes through the transfer of skilled people from one organisation to another. Knowledge can also flow through the involvement of staff on panels and committees, in networks and via lecturing and teaching.

b) Improving UK business competitiveness

Improved business competitiveness for UK companies through –

Improved products and processes

This element of EI is concerned with how UK plc can be assisted to improve its products and processes, for example through process, yield or cycle time improvement. This can be done via collaborative research projects and the commercial use of facilities and technology.

Creating opportunities for UK business

This involves ensuring that UK companies are able to tender for work at major research centres and facilities. In addition, new and existing businesses that are co-located or spun-in to the Daresbury and Harwell Science and Innovation Campuses can also be assisted. This is done through providing business, facility, scientific and technological support from the STFC.

Attracting and retaining investment in the UK

This represents the ability to attract external investment into the UK. Nationally this can be from Regional Development Agencies, the other Research Councils, Universities, industry and other partners. Internationally this can be from Universities, other large scale facilities, international industry and the EU. These impacts can be directly measured via the investment from each of these partners.

Commercialisation

This area represents commercial activity through spin-outs and the generation of intellectual property. The establishment of new companies is considered to be a key route through which economic impact is achieved through research.

c) Impact to international partners

This is the contribution to the scientific and technological development of other countries both in the EU and internationally at both an academic and industrial level.

d) Welfare impacts

The contribution to health, environmental, cultural, social and national security outcomes through research programmes. For example, spin-out companies who work on home land security, cultural heritage projects such as restoration of the Mary Rose and impacts via drug discovery and disease characterisation.

3.3 Measuring the impact of R&D

There are several groups and initiatives which have attempted to capture the impact of R&D. For example, the Science Policy Research Unit (SPRU) from the University of Sussex has carried out several studies on the benefits of publicly funded research. Martin & Salter (1996)[7] and more recently Martin & Tang[8] (2007) quote –

> *"Any attempt to assess and quantify the economic and social benefits from publicly funded research is beset by problems."*

They highlight both conceptual and methodological issues but state that the benefits of publicly funded research are substantial. The same report quotes the results of several econometric studies into the EI of publicly funded R&D "all of which show a large positive contribution to economic growth". They cite studies which find that the rate of return of publicly funded research to be between 20 – 50%. Their research highlights the following impacts of research – new useful information, new instrumentation and methodologies, trained research scientists supporting other economic sectors, access to international networks of expertise and information, the provision of scientists capable of solving complex technical problems to the private sector and spin out companies.

3.4 The impacts of large scale science facilities

The economic benefits and return from public investment in large research facilities is a recognised consideration in the decision making process to host them. This was explored in the CCLRC Neutron Review of 2006[9] (one of STFC's predecessor Councils). This report states the following level of impacts from large scale facilities –

- **Direct** – through the design, construction and operation of the facility. Such impact, relatively easily quantified, is short to medium term in nature – at least for the 20-30 year life of a facility – and is primarily localised.
- **Indirect** – through the creation of campuses surrounding a facility – by definition localised – clustering high technology users/exploiters of a facility's capabilities, through spin-close, spin-in and spin-out enterprises. The impact of the campus is harder to quantify and extends beyond the actual lifetime of a facility.
- **Global** – the diffuse and very long term impact that arises from the establishment of a global hub in the knowledge economy. The impact of such a focus extends from the influence of national attitudes to an exploitation of science and innovation, and the establishment of global contact networks – to national prestige, credibility and influence.

There is a growing body of publications on the potential economic impact of future large scale facilities, reflecting the recent focus on this area. These reports include several on the future European Spallation Source project in various potential locations, [10], [11], [12], [13], [14], the Australian Light Source and the Canadian Light Source.

In addition to potential economic reports, a report was undertaken by the Cabinet Office, the Office of Science and Technology and the Office of Public Service and Science in 1993[15]. This report investigated the economic benefits of hosting large international scientific facilities, in order to develop

[7] *Martin, B.R. & Salter (1996), "The Relationship between Publicly funded basic research and Economic Performance", Prepared by the Science Policy Research Unit (SPRU), University of Sussex for HM Treasury*

[8] *Martin, B. and Tang, P. (2007), "The Benefits from Publicly Funded Research", SPRU working paper 161, (www.sussex.ac.uk/spru/1-6-1-2-1-55.html)*

[9] *http://www.neutrons.cclrc.ac.uk/home.aspx*

[10] *Science at the Cutting Edge. The Future of the Oresund Region, G. Tornqvist, Chapter 13, Copenhagen Business School Press, 2002.*

[11] *Impacts of Large-Scale Research Facilities - A Socio-Economic Analysis, O. Hallonsten, M. Benner and G. Holmberg, School of Economic and Management, Lund University, August 2004.*

[12] *"What benefits will Denmark obtain for it science, technology and competitiveness by co-hosting an advanced large-scale research facility near Lund?" F. Valentin, M.T. Larsen and N. Heineke, Copenhagen Business School, 2005.*

[13] *"Assessment of the potential to locate the European Spallation Source in Sweden - Summary, discussion and recommendations", A. Larsson, 2005.*

[14] *The economic impact of a large-scale facility on Yorkshire and the Humber region, Arthur D. Little, November, 2004.*

[15] *Economic Impacts of Hosting International Scientific Facilities, Cabinet Office, OST and Office of public service and science, April 1993*

a framework for appraising the benefits of such facilities. The analysis focused on CERN, JET, ESRF and the ILL but also considered the SRS and ISIS. A summary of the report includes –

- Benefits to the national economy come from direct employment and expenditure and industrial supply to the facility, although it does state that local and national impacts can be hard to pick apart.
- Benefits to the local economy come from the skills gained by staff that work at the facility and also include economic activity generated by visiting staff and users. Another significant local impact is the clustering of other research institutes and companies around large science facilities.
- The report states that the most direct way in which large facilities have impact to the host nation is through the national science base. The host of a large scientific facility gains scientific prestige and leadership and the ability to raise the profile of a particular science area.
- The report concludes that the benefits of hosting are difficult to quantify – qualitatively or quantitatively, especially if they displace other economic activity.

3.5 Difficulties with impact measurement

There are several difficulties which occur when measuring economic impact as illustrated in the 2007 Annual Report on the 10 year Science and Innovation Investment Framework[16] –

"The consensus in the economics literature[17] is that measuring the economic impacts of science and innovation is highly problematic, due to the following issues:

- *The time taken from an increase in R&D spend to an increase in welfare can be variable and lengthy.*
- *The global nature of science and innovation makes it particularly difficult to attribute domestic economic impacts to domestic science and innovation investment and policies.*
- *The research base having direct as well as indirect effects on economic impact also complicates the attribution of impacts to inputs of the research base."*

It also states that it can take up to 6 years for publications to result from investments in R&D. Hence it can be stated that impacts vary over time, are global in nature and are both direct and indirect.

3.6 Financial impacts & models

In addition to the impact of the R&D output of a major facility there are financial economic impacts to the locality in which large scale scientific facilities or scientific employers are located. These impacts occur through the budget of the employer being spent in the area local to the site or to the wider UK. Budgets are spent on wages, equipment and overheads etc in the area local to the employer.

In addition to direct spending, there is a multiplying effect of the repeated re-spending of this budget in the local economy. This recognises that the direct investment initiates an economic "chain reaction" of further spending, production, income, and employment. Hence, there are several levels of financial impact which are continuing to be felt as a result of the SRS –

- Direct impacts – direct employment and direct spend by the SRS.
- Indirect or "supply chain" impacts – The initial purchase of goods or services from suppliers leads to a further chain reaction of purchases from their supply chain. This also has indirect effects on employment, spend and taxation.

[16] *www.berr.gov.uk/files/file40398.doc*

[17] *SPRU (2007) provides a comprehensive literature review on the measurement of the economic impact of publicly funded research (www.sussex.ac.uk/spru/1-6-1-2-1-55.html)*

- Induced impacts - employment and spend supported by the spending of those employed directly or indirectly by the SRS.

The diagram below indicates this effect –

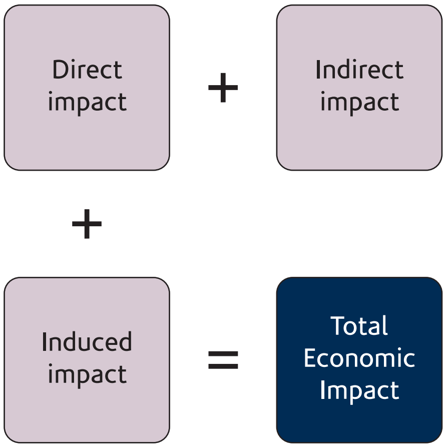


Figure 2, Illustration of total financial economic impact

These effects are illustrated by an economic impact study[18] of the Lawrence Berkeley Laboratory (LBL) in California which states –

> *"This money is re-spent again and again in the economy, creating jobs and income for businesses and other workers. Many individuals not employed by the Laboratory and numerous businesses depend to some extent upon the ripple effects of Berkeley Lab spending for their livelihoods."*

These indirect and induced impacts are calculated by using so-called economic multipliers, which vary depending on industry sector and region in the UK. This method is commonly used, see - Laurence Berkeley Laboratory[18], UK Universities[19] and potential large facilities like the Australian Synchrotron[20]. For example, the indirect economic multiplier used to calculate the economic impact of the Intermediate Sector by Oxford Economics[21] is 1.6 –

> *"This means that for every £1 million of output generated by the Intermediate Sector, another £0.6 million of output is generated indirectly in its supply chain in the UK."*

In the UK, economic multipliers are generally based on or taken directly from the "United Kingdom Input-Output Analytical Tables" produced by the Office of National Statistics (ONS) in 2001. The Input-Output framework brings together components of Gross Value Added (GVA)[22], industry inputs and outputs, product supply and demand, and the composition of uses and resources across institutional sectors for the UK economy.

Due to the fact that most impacts occur at a regional level, the Treasury Green Book recommends using Regional Development Agency multipliers or those available by English Partnerships. According to SQW[23], regional multipliers can vary between 1.2 and 2. For specific sectors in specific regions specific multipliers must be calculated, requiring information on the behaviour of supply chains, wages etc. Examples of multipliers quoted in a selection of economic impact reports are presented in table 1 overleaf –

[18] *www.berkeley.edu/econimpact/2005-2006-econimpact-report.pdf*

[19] *"The economic impact of UK higher education institutions", Universities UK, (2006), www.universitiesuk.ac.uk/Publications/Documents/economicimpact3.pdf*

[20] *Houghton, J., Rasmussen, B. and Sheehan, P. 2003, The Australian Synchrotron Project: An Economic Impact Study, Report to the Victorian Department of Innovation, Industry and Regional Development, October, CSES, Victoria University, Melbourne.*

[21] *www.oxfordeconomics.com/Free/pdfs/OxfordAIRTOFINAL%20.pdf*

[22] *Gross Value Added (GVA) can be used to measure the contribution to the economy of each individual producer, industry or sector in the United Kingdom and is used in the estimation of Gross Domestic Product (GDP).*

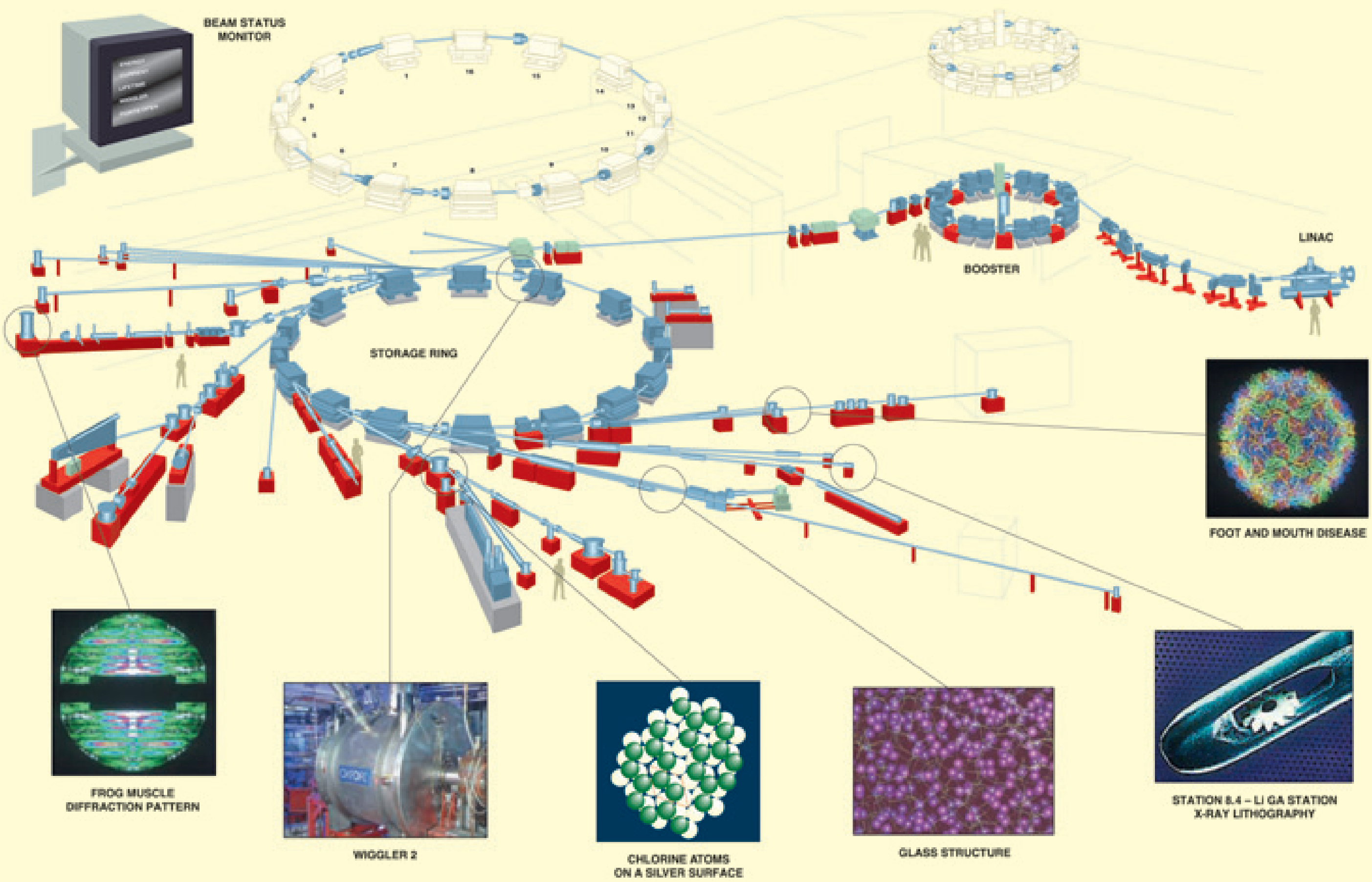
[23] *"The economic impact and potential of higher education institutions in the North West : A report to the Northwest Development Agency", April 2009, SQW Consulting*

Source	Industry	Type II multiplier output	Type II employment output
Partnerships UK (2006)	UK HEIs	2.52	1.99
ONS (2001)	Research & development	1.44	1.23
Oxford Economics (2006)	Intermediate sector	1.6	
Birmingham University (2007)	Birmingham University	1.4	1.7
SQW (2009)	North West HEIs	1.5	1.5

Table 1, comparator multipliers for various UK industries

Due to its location in the North West of England, multipliers from this region should be used for the calculation. However, the North West Development Agency has not produced any regional multipliers for the R&D sector, so an approximation must be made using existing multipliers. Hence the national multipliers for the R&D sector from the Office of National Statistics will be used.

Chapter 4
SRS introduction & background



Chapter 4

SRS introduction & background

4.1 Introduction

This chapter will describe the STFC, the background to the establishment of the SRS, its predecessor facility (the SRF) and the Daresbury Laboratory. The SRS was operated by the Science and Technology Facilities Council (STFC) between 2007 and the end of 2008 when it ceased operation.

4.2 The Science and Technology Facilities Council

The SRS was located at the Daresbury Laboratory in Cheshire which forms part of the Daresbury Science and Innovation Campus. The STFC was formed by the merger of the Council for the Central Laboratory of the Research Councils (CCLRC) and the Particle Physics and Astronomy Research Council (PPARC) in April 2007.

The STFC is one of Europe's largest multidisciplinary research organisations supporting scientists and engineers world-wide. The Council has a wide ranging science portfolio including astronomy, particle physics, particle astrophysics, nuclear physics, space science, synchrotron radiation, neutron sources and high power lasers.

The STFC has an approximate annual budget of £500M and in excess of 2000 staff across seven sites which include a further two laboratories in addition to the Daresbury Laboratory: the Rutherford Appleton Laboratory, part of the Harwell Science and Innovation Campus (HSIC) in Oxfordshire and the UK Astronomy Technology Centre (ATC) located in Edinburgh. The STFC has a wide ranging remit, more details of which can be found at the STFC's website[24].

At present, the STFC funds the provision of Synchrotron Radiation (SR) facilities in the UK through an 86% share in the Diamond Light Source and a 14% contribution to the European Synchrotron Radiation Facility in France.

4.3 The Daresbury Laboratory

The Daresbury Laboratory is one of two publicly funded national laboratories to house large-scale, international-class scientific facilities in the UK. The Laboratory has a proud tradition of scientific excellence, has achieved world renown for its pioneering developments and houses several scientific facilities, departments and support groups. The Laboratory was established in 1962 and was initially set up to house the National Institute Northern Accelerator (NINA). NINA opened in 1967 and was a 5 GeV electron synchrotron accelerator devoted to the study of particle physics. In addition to NINA, the Daresbury Laboratory housed the Nuclear Structure Facility which became the world's highest energy ion beam accelerator.

Synchrotron Radiation research at Daresbury Laboratory started in 1967 with an exploratory experiment to parasitically exploit synchrotron radiation produced by the NINA ring. A proposal for a formal user facility, the Synchrotron Radiation Facility (SRF)[25], a so-called 1st generation light source, was approved in 1969 and ran from 1972 until the closure of NINA in 1977. The SRF consisted of two beamlines feeding six experimental stations. The initial science programme included experiments on the absorption and reflection spectra of atoms and molecules and VUV molecular spectroscopy of organic solids.

[24] *www.stfc.ac.uk*
[25] *www.journals.iucr.org/s/issues/1997/06/00/hi0059/hi0059.pdf*

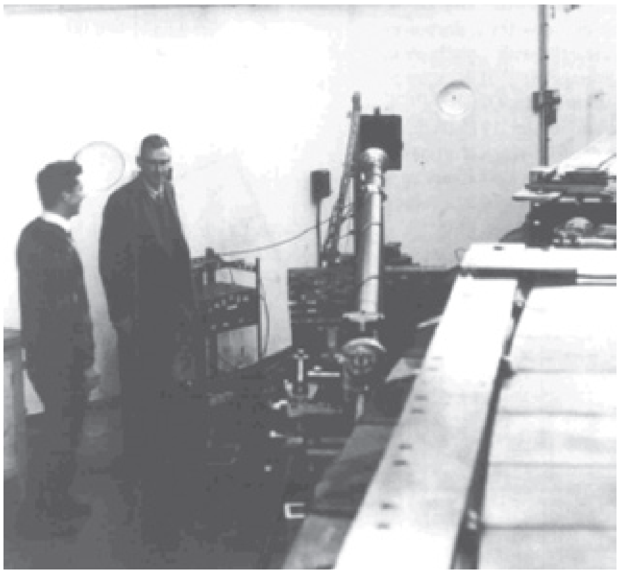


Figure 3, the first synchrotron beamline on NINA, constructed in 1966/67. (I.H. Munro & T.D.S. Hamilton)

The closure of NINA (and hence the SRF) was prompted by the UK's decision to close its national particle accelerators and concentrate particle physics research at CERN. A threefold plan emerged to replace NINA[26], which included a plan for a dedicated synchrotron radiation source which would both benefit from existing Daresbury infrastructure and expertise and meet the needs of an expanding synchrotron radiation community. Approval for the construction for the SRS was given in 1975 –

> *"The approval of this purpose-built dedicated source of X-rays in the UK led the way into a new era of dedicated synchrotron radiation sources around the globe."*
> *Professor I.H. Munro[27]*

4.4 The Synchrotron Radiation Source

In the late 1970s and early 1980s, staff at the Daresbury Laboratory designed and constructed the world's first purpose built, multi user facility dedicated to the production of X-ray synchrotron radiation - a so-called 2nd generation synchrotron radiation facility, called the Synchrotron Radiation Source (SRS)[28]. The SRS was a 2GeV electron storage ring, operated solely for the provision of synchrotron radiation for multiple simultaneous user experiments. Being the first facility of its kind brought a significant amount of influence on future facilities around the world; this is just one of the benefits that will be explored in this report.

Between the closure of NINA in 1977 and the commencement of SRS user operations in 1981, the SR users and many of the Laboratory staff worked for a significant period at other SR sources around the world. Funded by the Daresbury Laboratory, this established a strong network for the exchange of scientific and technical information in the field which was exploited throughout the lifetime of the SRS.

The SRS was a world class facility dedicated to the exploitation of SR for fundamental and applied research, which began operations in 1981. The SRS was a national research facility available on a "free at the point of use" basis to academics and via appropriate payment mechanisms to industry. The SRS offered a diverse set of experimental facilities which delivered radiation with wavelengths extending from the infrared to hard X-rays. Examples of techniques provided included protein crystallography, X-ray diffraction and infrared microscopy.

The SRS was used to study a diverse range of scientific subjects, a significant proportion of which are applicable to many different industries. Research performed on the facility included biology, engineering, environmental science, materials science, physics and chemistry. Application areas of this science include understanding the basic processes of life at the molecular level, medicine and pharmaceutical development, the development

[26] *www.iop.org/EJ/abstract/0957-0233/3/2/018*
[27] *www.journals.iucr.org/s/issues/1997/06/00/hi0059/hi0059.pdf*
[28] *www.srs.ac.uk/srs*

of new materials, the environment and nanotechnology. The multidisciplinary nature of the SRS meant that there was a huge transfer of knowledge and expertise across traditional scientific boundaries. This "blurring" of single subject boundaries enabled new areas of science to open up and contributed to a shift in attitudes of funding agencies.

The SRS served many communities and staff and interacted with many stakeholders over the lifetime of the facility. Each one of the stakeholders detailed below have experienced some level of economic impact from the existence of the SRS.

In 2005, the Minister for Science announced that the SRS would close in 2008 after a two-year overlap with the Diamond Light Source[29] which would take over as the UK's national synchrotron radiation source. This resulted in a phased run-down of the SRS until its closure in August 2008. The following report outlines the high level of economic impact that has resulted from the SRS in its lifetime and which is continuing to be felt after its closure.

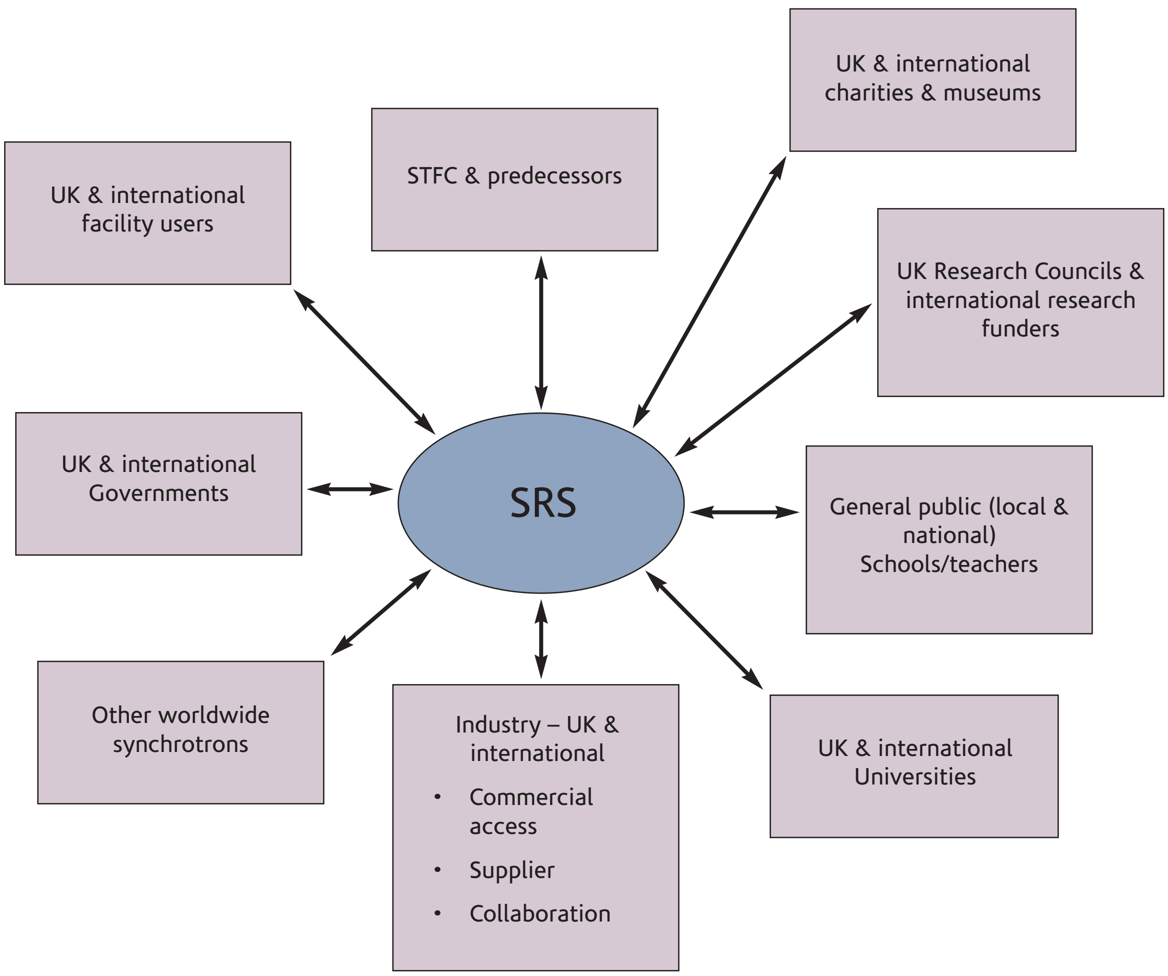
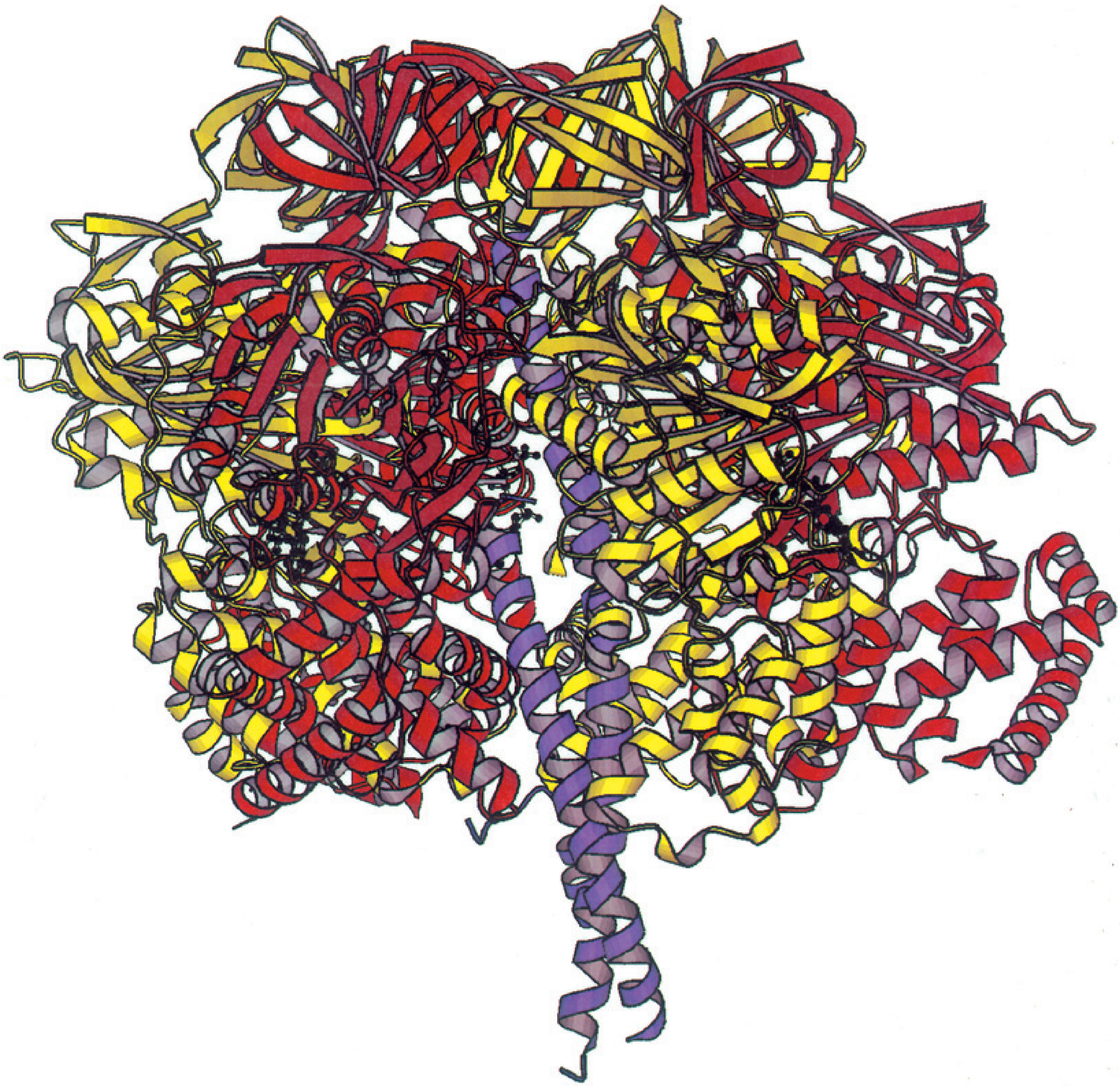


Figure 4, SRS stakeholder diagram

[29] *www.diamond.ac.uk/default.htm*

The global impact of the SRS

Chapter 5
Impacting the world's synchrotron community



Chapter 5

Impacting the world's synchrotron community

5.1 Introduction

The SRS was the world's first 2nd generation multi user X-ray synchrotron radiation facility and as such provided an exemplar for Synchrotron Radiation facilities across the globe. The SRS pioneered the way for the development of 70 similar machines[30]; this worldwide synchrotron community is providing impact on a global scale. In this chapter, the influence of the SRS on the worldwide synchrotron radiation community will be explored, along with the global impact of these facilities. The SRS not only influenced the development of a worldwide community of SR sources but also collaborated with many other scientific establishments, themselves producing impact.

> *"There is now hardly an area of science that has not benefited from the use of synchrotron radiation.[31]"*

5.2 The impact of the worldwide synchrotron community

The world's synchrotron radiation facilities are used to conduct scientific research which explores the world through a detailed knowledge of the structure of matter. These facilities are used in a variety of scientific fields and science done on Synchrotron Radiation facilities makes a variety of contributions to society. For example, research addressing global challenges such as the environment, energy and global warming. Synchrotrons around the world have ensured the development of new drugs, medicines, technologies, products and materials.

Examples[32] of the areas in which the world wide synchrotron community has had a global impact are –

- **Bioscience**
  Pharmaceutical and bioscience companies have been swift to recognise the huge commercial potential that lies behind understanding the multitude of processes that take place within living organisms at a molecular level. Advances in Structural Biology have accelerated greatly as a result of access to the synchrotron facilities that have been developed around the world in the past 25 years. Pioneered at the SRS, the technique of protein crystallography in particular has had a world wide impact in the structural biology field.

- **Aerospace**
  The aerospace industry requires in depth knowledge of the properties and behaviour of materials under extreme conditions. Synchrotron radiation enables non-destructive, high resolution stress analysis on a timescale far shorter than laboratory-based techniques. The ability to assess structural weakness of components and materials on a microscopic scale is crucial to ensuring safety, whilst boosting performance.

- **Engineering**
  The engineering industry is continually looking to advance performance and gain a lead over the competition. As the field of synchrotron research has matured and expanded from traditional sciences into applied engineering,

30 A note on terminology: the light source described in this chapter include some with storage rings and some without; many operate as x-ray sources but some are photon accelerators. The word synchrotron is used here to refer to all of these.
31 Review of SR science", EPSRC publication, 1994, hard copy
32 These examples are taken from the Diamond Light Source website - www.diamond.ac.uk

experts have developed highly innovative and specialised ways to meet the challenges presented by the different types of experiments that the growing user community wish to embark on.

- **Environmental Science**
  The complexity of current environmental issues means that companies require expertise in a combination of areas and need advanced analytical techniques to make real breakthroughs. By harnessing the technical capabilities of synchrotron radiation sources, the environmental sector can investigate solutions to drive their businesses forward, and make real, high impact changes.

- **IT Hardware**
  Faster, smaller, lighter are key drivers for the development of new IT hardware components. The ability of synchrotron radiation to penetrate through layers of material, characterise materials on an atomic scale and use time resolved studies in, for example, in situ phase transformations provide a valuable tool, supporting further research and development in the IT industry.

These are just some examples of the significant impact that the growth of the synchrotron community has had on the world. The impact of the synchrotron community is impossible to fully quantify but it has certainly provided significant impact on a world wide scale.

5.3 Pioneering developments

The numbers of synchrotron radiation facilities are growing every year, but how has the SRS impacted on this worldwide community? Many of the operational features now considered standard in the operation of user-focused SR facilities were pioneered at the SRS. As other dedicated sources were developed, the SRS model of operation was generally followed. Its key features were:

- The synchrotrons were used as storage rings at constant energy.

- The synchrotrons were designed such that scientists could operate without special radiation protection i.e. they did not have to be registered as radiation workers during normal operation. (This was not followed fully in some later sources, to their detriment).

- Ancillary laboratories, for example specialist biology facilities, were located alongside the source.

- Station scientists were appointed and developed, so that they fully understood all aspects of particular techniques and beamlines.

- User support scientists were appointed to help users to make the best use of their beamtime.

- A commercial office was set up to provide clients with a 'one-stop-shop' for enquiries, scientific solutions, scheduling and reporting.

- Industrial access was offered for a fee, with non-publication as the standard option.

- A range of services, from full data acquisition and analysis to the provision of beam-time exclusively to experienced commercial clients; this pattern was later adopted by a number of new sources[33].

- Partnerships could be set up in which external organisations could design and build a beamline largely for their own use, but also with time made available through the hosting organisation for general users.

- Operation on a 24 hours a day 7 days a week basis for scheduled periods. This was unique amongst SR facilities and pushed the technology required to support the scientists working for such long hours on experiments, for example automation via robotics to change samples.

Due to the attraction of the outstanding science that could be performed on the facility and with a workable model evident, user-demand growing and an ever-widening range of techniques becoming available, it was inevitable that the number of working synchrotrons would increase rapidly worldwide.

[33] *For example, the new synchrotron source ANKA, (http://ankaweb.fzk.de/)*

5.4 The growth in numbers

Whilst the SRS was the first purpose-built synchrotron, others followed soon after. It can be seen from the graph below that after the establishment of the SRS in 1980, approximately 70 additional synchrotron radiation sources followed in the next 30 years.

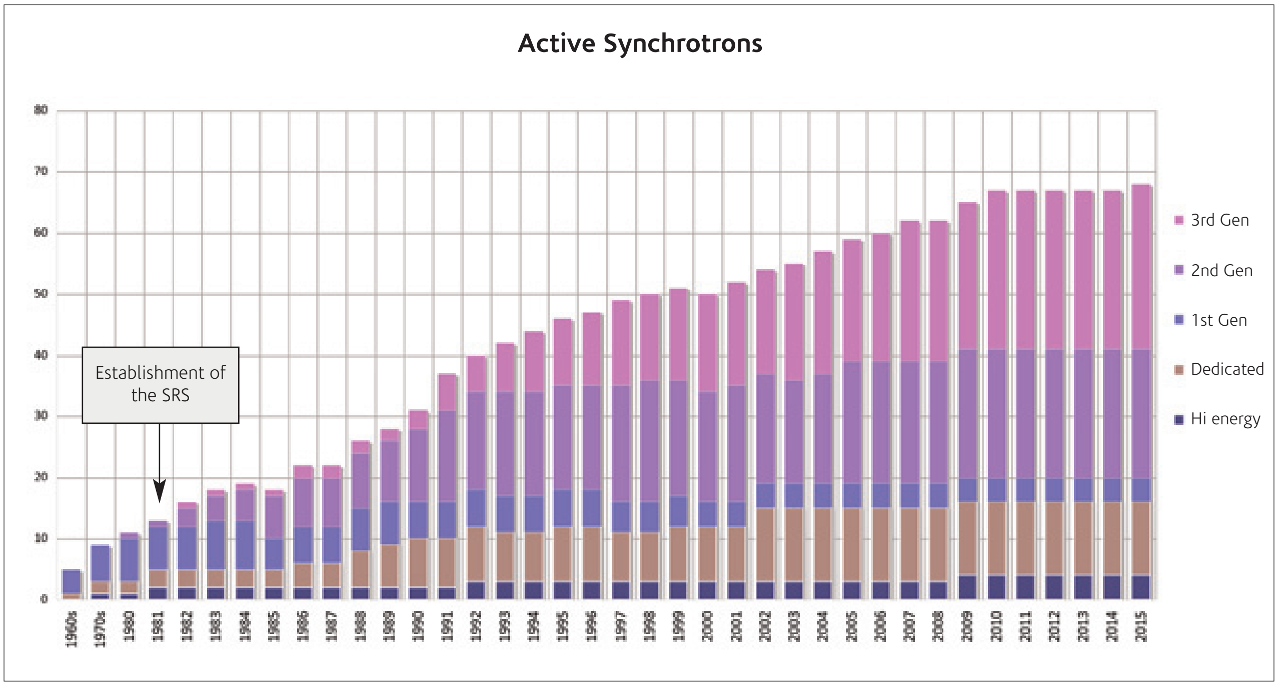


Figure 5, the growth and number of synchrotrons worldwide

As can be seen from figure 5, there are currently approximately 68 first to third generation synchrotron facilities currently operating worldwide[34]. The definitions of first to third generation synchrotrons are given in Appendix 2.

Of particular note is the fact that some of the newer synchrotrons are being built in developing countries for example Jordan[35], China, Brazil[36], Korea, Taiwan and Thailand[37]. The science establishment in such countries has recognised the capability of synchrotron sources to support the emerging science base, and to drive through developments in associated fields such as precision engineering. For example, in addition to SESAME as detailed in chapter 13, the Brazilian Light Source was established to act as a catalyst to build a local and national skill base.

34 Start-up dates have been chosen, as far as possible, to be the date when the SR sources were made available to users for experiments.
35 www.sesame.org.jo/
36 www.lnls.br
37 www.nsrc.or.th

5.5 Collaboration with other SR sources

Staff from the SRS played a significant role in the establishment of other SR facilities around the world. Staff from the SRS had informal collaborations with the majority of the world's synchrotrons and had formal collaborations such as agreements and memoranda of understanding with nearly half.

As the first of the major national light source facilities, the SRS and its staff had a large impact on new projects worldwide, including direct personal involvement in many cases. SRS staff played a key role in training, advising and transferring key skills and technology to these facilities. Staff from the SRS collaborated extensively, addressing topics including fundamental science, synchrotron design and operation, detector development and applied research for industrial processes. In addition to working with many of the synchrotrons across the world, many of the SRS staff later went on to actually work at these other synchrotrons, further disseminating their expertise. Some 63 SRS staff transferred to other synchrotrons around the world, transferring their skills to these sources.

SRS staff had formal collaborations with at least 27 synchrotrons around the world (around 40% of the current total) and had informal collaborations with the majority. An excerpt from the CCLRC's Quinquenial Review in 2000 states –

> *"The SRS is well integrated into the world-wide fellowship of synchrotron radiation sources, and every synchrotron radiation source in the world has had Daresbury Laboratory involvement during its development. For many facilities there have been formal links, usually through membership of international advisory panels, while for others the connections have been informal. For instance, in the last three years, the SRS has hosted visits from staff from 12 overseas synchrotron radiation centres, and Daresbury senior staff have visited 17 sources."*

In addition, SRS staff were on the Scientific or Advisory Boards of the Australian Light Source, the Canadian Light Source, the Spanish Light source ALBA and SESAME. One of the major interactions was with the ESRF, with leading roles for UK personnel in its conception, design and construction. Ex-SRS staff also led synchrotron projects in the USA, Australia and Spain.

Figure 6, artist's impression of the Australian Synchrotron by night. (Courtesy: Australian Synchrotron)

Finally, SRS staff were active and influential in several networks at regional, national and international levels. Significant international networks included the Integrated Infrastructure Initiative (I3)[38] which seeks to integrate activity and promote joint research activities on synchrotron and free electron laser research throughout Europe. SRS staff were important contributors to this initiative which is the largest such organisation in the world. Additionally, two SRS staff were founding Editors of the Journal of Synchrotron Radiation[39], an international publication which celebrated its 15th year in 2008. The impact of the Journal and associated Editorial work on academic and industrial research has been significant.

5.6 The strength of collaboration

The following examples of collaboration between the SRS and other countries SR programmes were particularly substantive in their influence –

- The Spanish science research council had an interest in synchrotron radiation, largely driven by its intention to have a facility in Spain. In preparation for a future facility, the council funded researchers at the SRS, seeing them as "scouts" who were developing skills for future deployment in Spain. From 1987 to 1992, 7 PhD and post-doctoral students joined the SRS from Spanish Universities to study biological systems. The knowledge they gained meant that the Spanish Government could make the decision to invest in a beam-line at ESRF which ultimately led to the establishment of the ALBA[40] light source in Barcelona. Some of these researchers have gone on to be influential in the worldwide synchrotron community, including the current director of the ALBA light source, Professor Joan Bordas.

- INTAS[41], the International Association for the promotion of co-operation with scientists from the New Independent States (NIS) of the former Soviet Union, was established in 1993. INTAS was set up to promote scientific research activities and scientific co-operation between NIS scientists and the international scientific community. Funded by INTAS, Russian scientists visited the SRS to garner knowledge on the operation of synchrotrons, in particular computing, data management and instrument control. At least fifty publications resulted from this collaboration and the Siberia 1 and Siberia 2 designs for Russian synchrotrons included elements learned from the exchanges at the SRS. In later years, X-ray monochromators were purchased for the SRS from Russia, where the sole suppliers were located at the time.

- There was a major collaboration on synchrotron research between the UK and Japanese research bodies, starting with a Memorandum of Understanding in 1987, and a collaboration between staff from the SRS and the Japan Synchrotron Radiation Research Institute (JASRI) starting in 1991[42]. This collaboration resulted in a substantial amount of knowledge and staff exchange which benefited both parties and was perceived as a great success, generating a substantial publication list. In addition, from 1996[43] onwards, there was an important collaboration between the Japanese research institute RIKEN and the SRS in the area of structural biology. The collaboration was seen to be of great importance in strengthening Japanese-Anglo co-operation in science and technology. This enabled progress to be made in the understanding of neurodegenerative diseases in both organisations.

- One of the legacies of the SRS is the re-cycling of equipment from the facility. As part of the SRS decommissioning process, equipment from the SRS has been released in brokering deals with overseas sources to provide access for UK users. For example, a detector has recently been bought by a Swedish University for a beamline at ELETTRA and an X-ray mirror was donated to the Brazilian Light Source. Most recently a gift of high-tech decommissioned

38 *www.elettra.trieste.it/i3/*
39 *http://journals.iucr.org/s/journalhomepage.html*
40 *http://www.cells.es/*
41 *http://www.intas.be/*
42 *www.srs.ac.uk/srs/agreements.html*
43 *www.srs.ac.uk/srs/news_extras/RIKEN_Symposium_May04.htm*

components has been made to the SESAME synchrotron. The high-tech components will be used to construct experimental beamlines for research into materials and life sciences. The UK observer on the SESAME Council and former SRS group leader, Professor Samar Hasnain, Max Perutz Professor of Biological Sciences at the University of Liverpool, stated –

"I am delighted that this equipment will go to a project that unites the participating nations, enabling them to work together. It will allow the next generation of scientists from member countries to carry out world-class fundamental scientific research."

5.7 Impact summary

- *Being an exemplar first 2nd generation multi user machine, the transfer of skills and technology through both formal and informal collaborations was vast. SRS staff had collaborations with most of the world's synchrotron facilities.*
- *The SRS facilitated the growth of the worldwide synchrotron community, themselves producing extensive impact.*
- *Although the overall impact of the worldwide synchrotron community is impossible to quantify it has been significant with impacts in fields such as engineering, bioscience and environmental science. With numbers of facilities growing every year, the impact of the SRS will continue to be felt many years into the future.*

Chapter 6

Addressing global challenges

Chapter 6

Addressing global challenges

"The opening of the dedicated radiation source at SRS, Daresbury, in 1981 gave rise to a new chapter for research.[44]"

6.1 Introduction

The SRS was a world class facility dedicated to the exploitation of Synchrotron Radiation for fundamental and applied research. As such it played a key role in the creation of new scientific knowledge and the development of technology that had a global impact. A key aspect of the success of the facility was the interdisciplinary nature of the facility which pushed the boundaries of science in the UK at that time.

The SRS was used by around 1500 scientists per year to study the basic structure of matter. Hence, the SRS has made a major impact on many areas of science, with a truly interdisciplinary programme in physics, chemistry, materials science, biology, engineering and environmental science. Towards the end of its life cycle the SRS was used increasingly by new communities such as medical imaging, geological studies, structural genomics and archaeology.

The award of Nobel Prizes in Chemistry (1997 and 2009) to two SRS users highlight the significant scientific output of the SRS. Sir John Walker for his elucidation of the mechanism of the ATP cycle and Professor Venkatraman Ramakrishnan for work on the structure and function of the ribosome, the cell's protein factory. Information on the research volume and dissemination from the facility can be found in appendix 3.

6.2 Collaboration and interdisciplinary research in the UK

The success of the SRS was in part due to the interdisciplinary nature of the science it facilitated, a feature that was apparent from the late 1970s onwards. The experimental area of the SRS was perhaps the only place in the country where one could find experimental physicists, chemists, biologists, earth scientists, materials scientists, theoreticians, software scientists and engineers working alongside each other every day. This interdisciplinary approach and 'skills blending' was a key aspect of the national importance of SR research in the UK and of its impact in the rest of the world.

Since its inception in the early 1980s, the SRS had a significant impact on the scientific research of UK scientists. At this time, aside from elementary particle physics studies, the great majority of research studies in the physical sciences was undertaken in comparatively small university groups and at relatively low cost. The orders of magnitude advantage in brilliance offered by synchrotron radiation sources to photon scientists generated a substantial movement from academic departments to work at large scale scientific facilities. This meant that facilities such as the SRS became both customer driven and customer led. It also compelled the individual university groups to work closely together within the constraints of a large facility striving to serve the needs of a great many groups.

During the early 1980s this circumstance stimulated the growth of a host of new ideas and novel technologies in which traditional single subject science boundaries became of reduced importance. The interaction, in particular between physicists &

[44] *Johnson, L.N. & Blundell, T.L., The Journal of Synchrotron Radiation (1999), issue 6, P.813 - 815*

biologists and chemists & geologists, enabled the original single discipline research areas to grow much more rapidly than could have occurred had the researchers remained isolated within their host Departments. This collaborative and multidisciplinary approach continued throughout the lifetime of the SRS. A recent example was the collaboration between in-house physicists and university colleagues in the manipulation of nanomagnets produced by bacteria which have potential applications in cancer therapy[45].

6.3 Issues with research impacts

In addition to research dissemination and the tacit technical knowledge which facilitated research on the SRS, the research itself had an economic impact. The main economic impacts from the scientific output of the SRS occur via the applicability of the research to many industrial markets and areas of everyday life and welfare. For example, samples as diverse as viruses, archaeological objects, corneas, pharmaceuticals and familiar every day products such as chocolate, shampoos and crisp wrappers have all been studied at the SRS.

The issues of time lag and attributability of research data were highlighted as issues when considering economic impact in chapter 3. However, despite these issues, SPRU cite studies which find that the rate of return of publicly funded research varies between 20 – 50%.

The SRS was part of a much larger research effort, typically involving university scientists, companies and R&D programmes over a great many years. Disentangling the SRS contribution, and coming up with an impact figure attributable to it, is not possible. In the absence of an accepted model to appropriately capture the economic impact of research, qualitative examples are given in the rest of this chapter which highlight the impact of the research output from the SRS with quantitative figures given where available.

6.4 Research examples

These examples, from diverse areas of science, represent a few of the tremendous achievements of the SRS that have had lasting impact on daily life[46]. It should be noted that all of these research projects have been carried out with funding from the other Research Councils, without their support this research would not have been possible.

6.4.1 Combating global warming

Water in our seas and oceans accounts for only about 10% of the total - the remainder is stored inside rocks deep within the Earth. This is a highly dynamic system: water is sucked down into the Earth in regions known as subduction zones, and returned to the surface at mid-ocean ridges and in volcanic eruptions. A key question for environmentalists is – are the oceans rising or falling? This is a vital question when considering the issue of global warming.

Figure 7, artists illustration of global warming (Copyright: Ian Tragen @ Shutterstock)

[45] Staniland S. et al, (2008), "Controlled cobalt doping of magnetosomes in vivo", Nature Nanotechnology 3, P.158-162. (see also www.news.bbc.co.uk/2/hi/health/7270913.stm)

[46] The science examples have been taken from various SRS annual reports, CCLRC Research Highlights, SRS website, review websites and other internal documents and websites and contributions from ex SRS users.

A comprehensive water audit is severely hampered by a lack of understanding of the mechanisms by which rocks store water. Facilities were utilised at the SRS to address this important problem. Hydrous minerals were subjected to pressures and temperatures equivalent to those found hundreds of kilometres below the surface of the earth, whilst their composition and thermodynamic properties were monitored by X-ray diffraction. A notable success showed that at high pressure and temperature the mineral talc converts into a new material known colloquially as the "10Å phase". The 10Å phase carries the water deep into the Earth rather than returning it to the surface, as previously thought[1]. These findings will eventually help to produce a detailed understanding of the role of water inside the Earth, and with it an improved understanding of our environment.

Figure 8, Illustration of the move from CD to MP3 player

6.4.2 Increasing the memory of the iPod

Research on all types of magnetic material was performed on the SRS, from magnetic quantum dots to the large blocks of magnets used in modern particle accelerators. Soft X-ray Magnetic Scattering has proved an especially powerful technique in this area as it allows the study of thin films and multilayers, both scientifically and technologically important magnetic materials.

An example of the technique in action is a collaboration between researchers at Durham and York Universities and SRS staff, to study cobalt-copper multilayers known to exhibit Giant Magneto Resistance (GMR)[47&48]. A detailed analysis of multilayer diffraction profiles from the magnetic and chemical periodicities provided crucial information about the structure of magnetic domains and the relationship between magnetic and chemical 'roughness' at the interfaces. The latter is known to play a crucial role in determining the size of the GMR effect and, ultimately, the applicability of these materials to the magnetic read-heads of the future.

In addition, studies of GMR on the SRS have played a key role in the development of new electronic memory devices that use spintronics, a new form of electronics that uses the spin of particles to record information. This is used in devices such as the iPod, helping to fit more information on them.

This research has helped enable the development of the huge magnetic memory of MP3 players. MP3 players have a significant worldwide market with over 220 million iPods sold globally since 2002, generating billions of pounds worth of revenue every year.

6.4.3 Combating engineering stress

Two different types of engineering research were carried out on the SRS. The first is generic work investigating the basic principles of residual stresses that are deliberately or accidentally included in the material even when there are no stresses applied, and are incorporated into engineering design. This is important because they can lead to unexpected failure if not accounted for.

[47] *T.P.A. Hase et al. (2000), "Soft x-ray resonant magnetic diffuse scattering from strongly coupled Cu/Co multilayers.", Physics Review Letters, Vol. 61, P.3792-3795*

[48] *H.A. Dürr et al. (2000) "Magnetization profile of ultrathin FePd films", Journal of Synchrotron Radiation, Vol. 7, P.178-181*

The second aspect is the direct use of synchrotron X-ray diffraction measurements for improving our knowledge of particular engineering processes or the effect of particular surface cycles on residual stress development. The following examples illustrate this work –

- Work with Airbus looking at the stresses introduced into aerospace components by peening processes. These processes are used either to correct the shape of the component or to introduce protective residual stresses to prolong the life of the component. This enabled scientists, led by the University of Manchester, to identify the depth and magnitude of these residual stresses as a function of the peening process parameters.
- Residual stresses in nuclear engineering plants, working with British Energy.
- The examination of the processing of aero-engine components for Rolls Royce. Rolls Royce used this data to refine their heat treatments for the control of stress in their new generation of superalloys.

In all these cases the work has led to a better understanding of the manufacturing processes and better incorporation of those residual stresses into engineering structural integrity assessment. Work is continuing on stresses in materials at the Diamond Light Source, the European Synchrotron Research Facility (ESRF) and the Institut Laue Langevin (ILL).

Figure 9, airplane turbine, one target of stress research, Copyright: Steve Mann @ Shutterstock

6.4.4 Solving the world's ancient mysteries

Figure 10, samples from this Atacameño mummy examined using the SRS reveals that the indigenous people in the Atacama desert were exposed to extremely high levels of arsenic in the diet

From 1999, SRS and Daresbury Laboratory scientists were at the forefront of the exploitation of synchrotron radiation in support of heritage science.

The first international conference on synchrotron radiation in art and archaeology was held at the Daresbury Laboratory in that year and has subsequently been followed by others at Stanford, Grenoble and Berlin. The SRS was used to study historic objects and processes, covering a wide range of ancient materials including parchment, paper, textiles, masonry, ceramics, glass, glazes, metals, timber, bone, paintings and pigments.

Synchrotron radiation proved to be a powerful new tool for archaeologists, conservators and art historians. Primary areas addressed were the identification of states of degradation, corrosion pathways and insights in the historic production technologies. The methods employed included detailed chemical quantification of the current state of historic artefacts and the development of experiments to reproduce production methods, conservation strategies and degradation processes.

These investigations help in the preservation of our cultural heritage and in our understanding and appreciation of the societies which created them. Specific examples include –

- Preservation of the Mary Rose and other historic timber vessels. Working in collaboration with the Mary Rose Trust conservators, studies using synchrotron radiation are playing an important part in understanding the role sulphur compounds play in the degradation of marine timbers. The findings from this work have helped to inform the conservation strategy of this important artefact and other similar vessels worldwide[49].

Figure 11, the hull of The Mary Rose undergoing active conservation, on display in Portsmouth

- Metal corrosion, especially of ancient bronzes. This involved a combination of a detailed study of historic bronzes, an investigation of the chemical processes affecting bronze and the effectiveness of electrochemical treatments under controlled laboratory conditions. Work at both the SRS and ESRF used a novel electrochemistry cell, and data collection in real-time mode improved our understanding of treating corroded bronze objects. The procedure is also aimed at corroded lead and silver objects, thus aiding their preservation and their enjoyment by future generations[50].

- Investigations into the historic development of ceramic lusterware and the evolution of production technologies used at different places and times since its invention in 9th century Iraq. This includes a combination of studies of historic artefacts with reproductions of the production process under laboratory conditions. These studies help explain the transfer of technology around the Mediterranean region and the technological developments underpinning specific changes in finish, thus adding to our knowledge of the historic societies responsible for these works of art and our appreciation of the artefacts themselves[51].

6.4.5 Battling viruses

In the 1980s, a leading virus researcher from Purdue University, brought crystals of human rhinovirus-14 to the SRS, which were the cause of the common cold. This defined the early methods for tackling such samples, which were very radiation sensitive, using the first SRS protein crystallography station. After this, research on the Simian Virus by scientists from Harvard University was undertaken - an even bigger virus which remains one of the biggest virus structures solved to date. Following this, work led by Oxford University revealed the Foot and Mouth Disease Virus (FMDV) crystal structure, being reported on the BBC Evening News. The FMDV, HIV/AIDS and the Avian Flu viruses are illustrated as case studies below.

a) Foot and mouth disease virus

The research to determine the 3D structure of FMDV was carried out by researchers in a collaboration between Porton Down, Oxford University and Wellcome Biotech. At the time this was one of the largest structures to be characterised at the atomic level and the first animal virus structure to be determined in Europe[52].

The challenges faced in the characterisation were not merely scientific. The samples had to be handled

[49] Work undertaken by the Mary Rose Trust, Kent and Portsmouth Universities
[50] Work undertaken at Ghent and Warwick Universities
[51] Work undertaken by Barcelona and Catalunya Universities
[52] Work undertaken by Barcelona and Catalunya Universities

according to strict bio-hazard protocols, with the crystals being made available for a limited 24 hour period. Technical challenges included working with crystals as small as 50 micron and the radiation damage caused by the short wavelengths used to analyse the sample. The expertise gained led to usage of the ESRF for yet larger viruses including the Blue Tongue Virus, also investigated by the Oxford University team.

Figure 12, Nature 1989; the structure of Foot and Mouth Disease Virus

Knowledge of the structure of this virus, which would not have been possible without the SRS, suggested that the design and development of more effective vaccines against FMDV would be the most appropriate approach to tackle the disease. This has led to the development of a vaccine, providing hope for controlling the virus in countries where it is potentially endemic in the longer term and may cause severe economic loss.

It is not possible to give an accurate estimate of the potential savings resulting from FMDV vaccines. However, the magnitude of the opportunity can be assessed by examining the costs of the 2001 outbreak in the UK.

The costs of the 2001 outbreak are estimated by DEFRA[53] at £8.4 billion, with the following split:

- Agricultural producers (£355 million).
- Food industry (£170 million).
- Tourism (£3,000 million (average)).
- Indirect costs for supply companies (£2,100 million).
- Expenditure on FMDV by Government (£2,800 million).

The figures given relate to those which are easily measurable, human and other costs have not been measured. It should be noted that the vaccine was available in the 2001 outbreak but the policy at the time was not to use vaccines as it affected export opportunities. However, if vaccines were used to avoid any future outbreak, the contribution of the SRS, while hard to quantify, would be significant. If the knowledge gained through SRS and associated work could contribute even 1% to the costs presented above, this would represent a financial impact of £84million. In contrast, the work undertaken to determine the X-ray crystal structure using SRS was estimated to take some hundreds of scientist days, valued at tens of thousands of pounds.

Figure 13, Cow carcasses are readied for burning during the 2001 outbreak (David Cheskin/Associated Press/PA)[54]

[53] www.archive.cabinetoffice.gov.uk/fmd/fmd_report/report/index.htm (see economic impact of FMDV, section14)
[54] http://www.cbc.ca/world/story/2007/08/03/cattle-disease.html

b) HIV\AIDS

The structure of the first of the 14 proteins encoded by the HIV1 virus was published in 1989, based on data collected at the SRS. Soon afterwards, many pharmaceutical companies, including GlaxoSmithKline, were able to use that structure as a template to hone the fit of their inhibitory drugs. Other HIV1 protein structures followed, most notably the Reverse Transcriptase, which was difficult to solve but eventually succumbed to the determined efforts of the SRS users.

Figure 14, Retroviral capsid domain solved on the SRS and featured on the cover of Nature[55]

It is estimated that the AIDS pandemic killed more than 2 million people in 2007, with 33.2 million people living with the disease worldwide[56]. Over three-quarters of these deaths occurred in sub-Saharan Africa[57], affecting economic growth and reducing human capital. It is expected that this reduction in human capital will cause the breakdown of economies and societies in countries with a significant AIDS population[58].

The majority of anti-AIDS drugs target Reverse Transcriptase (solved on the SRS) and will form the basis for the next generation of drugs. GlaxoSmithKline now manufacture antiretrovirals which are recommended by the World Health Organisation[59].

c) Avian flu

Human influenza pandemics are nothing new. In the last century there were three major flu outbreaks; the most serious being the 1918 'Spanish flu' which is thought to have killed around 20 million people worldwide. The virus responsible is thought to have originated from an avian virus that was introduced into the human population. The ability to be passed from human to human was a crucial factor in this virus being able to cause such devastation. This explains scientists' current concern with the potentially rapid spread of the avian and swine flu viruses amongst humans.

Using X-ray crystallography at the SRS, scientists were able to study the structure of flu virus molecules to better understand how the viruses might transfer from animals to humans. To be infectious, the influenza A virus binds to cells using a series of peaks protruding from its surface. Each of these peaks is made from a protein called Haemaglutinin (HA). Mutation of a few amino acids in this protein can give it the ability to bind to human cells rather than bird cells. In 2005 a team from the Medical Research Council worked with scientists at the SRS to characterise HA from the 1918 influenza virus to gain insight into why this virus was so devastating for humans.

The UK government has recently published its strategy for dealing with national risks[60]. A conclusion of the strategy is that both an influenza pandemic and the outbreak of an animal disease such as avian flu are both considered to be a serious threat to the UK. Avian flu, or a similar illness, can cause serious harm to a major part of the UK agricultural industry. Additionally, the effect of a human flu pandemic has been estimated at 50,000 to 750,000 fatalities, with substantial disruption to normal life in the UK.

[55] *Nature, Sep 2004: Murine Leukaemia virus capsid structure. Insights into retroviral assembly. Steven Gamblin, NIMR Mill Hill*
[56] *http://www3.interscience.wiley.com/journal/119410005/abstract?CRETRY=1&SRETRY=0*
[57] *http://www.data.unaids.org/pub/EPISlides/2007/2007_epiupdate_en.pdf*
[58] *http://en.wikipedia.org/wiki/AIDS*
[59] *http://www.gsk.com/press_archive/press2003/press_10162003.htm*
[60] *www.interactive.cabinetoffice.gov.uk/documents/security/national_security_strategy.pdf*

Oxford Economics[61] have carried out a study of the potential impact of a flu pandemic developed from avian flu –

"Clearly, the threat of a human flu variant developing from Avian flu is now serious and such a flu virus could pose a severe risk to human life. Even compared to previous scenario experience, the potential impact of a pandemic flu appears massive, should it occur in a virulent form."

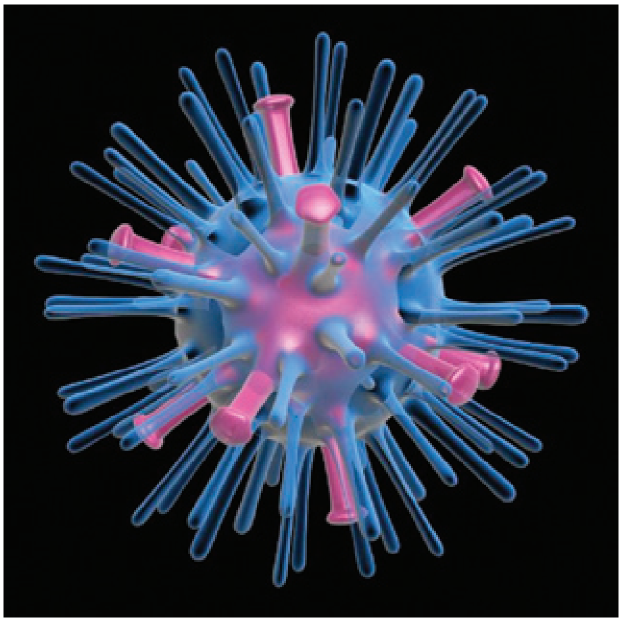


Figure 15, the Avian Flu virus, photo from sgame @ Shutterstock.com

They estimate that even the limited avian flu outbreak in 2003 caused economic loss to Asia of around $20billion. The report also suggests that the minimum cost of a global avian flu pandemic would be $400 billion of lost GDP. However, the report states that under reasonable assumptions over the duration, attack rates and mortality rates of a flu pandemic, the annual cost could easily rise to more than 5% of world GDP - representing losses of about $2 trillion per annum.

Fundamental research carried out at the SRS on the causes of such epidemics may play a crucial role in avoiding any future outbreak and transfer of the disease to humans, which could have the devastating impact outlined above.

6.4.5 Molecular machines

The F1 ATPase enzyme is the "molecular machine" by which protons are pumped across cell membranes, generating adenosine triphosphate (ATP), and storing energy within the cell. The detailed structure and mechanism of F1-ATPase were determined by Sir John Walker, Andrew Leslie and his colleagues of the MRC Laboratory for Molecular Biology in Cambridge, and resulted in Sir John Walker being awarded a share in the Nobel Prize for Chemistry in 1997.

Using X-ray crystallography at the SRS in combination with other SR sources, Walker and his team uncovered the three-dimensional structure of F1-ATPase, the key enzyme involved in cellular energy production[62]. The structure determination, at atomic resolution, took Walker twelve years of continuous effort, pushing back the boundaries of biochemistry and crystallography. The molecule was so complex that new methods of data analysis had to be developed to determine the final protein structure. The structure was eventually published in 1994 and the structure provided firm evidence to support the model for ATP synthesis proposed by Paul Boyer, co-winner of the Nobel Prize.

Figure 16, protein structure of F1 ATPase

[61] *www.oxfordeconomics.com/*

[62] *Abrahams, J. P. et al. (1993), "The structure of bovine F1-ATPase complexed with the antibiotic inhibitor aurovertin B.", Proceedings of the National Academy of Sciences, P. 6913-6917*

Scientists are finding that a malfunction in the mechanism of ATP synthesis may play an important part in a number of degenerative diseases. It is thought that the ability to convert food energy into ATP usually diminishes as people age. Such effects could be related to diseases which occur in later life, such as Alzheimer's and Parkinson's. It is hoped that the insights gained from the structural investigations will contribute towards understanding and eventually preventing these conditions.

6.4.7 The cell's protein factory

Professor Venkatraman Ramakrishnan of the Medical Research Council's Laboratory for Molecular Biology won the 2009 Nobel Prize for chemistry, shared with Thomas Steitz (Yale University, USA), and Ada Yonath (Weizmann Institute, Israel). The prize was awarded to the trio for their work on the structure and function of the ribosome, the structure within the cell that turns the information contained in DNA into the proteins that make cells function.

Professor Ramakrishnan used synchrotron light sources at Daresbury and Grenoble extensively in his work on the ribosome. The high power X-rays from synchrotron light sources provided the only way to reveal the complex 3-D structure of the ribosome at an atomic level, opening the door to understanding the way ribosomes function and the differences between ribosomes in bacterial and human cells. Knowing the differences between ribosomes in bacteria and humans has led the way to the development of new drugs to treat infections resistant to traditional antibiotics.

Professor Colin Whitehouse, STFC's Deputy CEO and Director of Daresbury Laboratory said: "Synchrotron light is an essential tool for structural biology and is being used around the world to study proteins and structures of critical biomedical importance. In order to get atomic-level information about complex proteins, researchers first have to get them to form small crystals. Daresbury Laboratory's synchrotron light source, the SRS, helped Professor Ramakrishnan identify which of his crystals were the best to study, and these were then taken to other synchrotrons including the ESRF in Grenoble to get high resolution images."

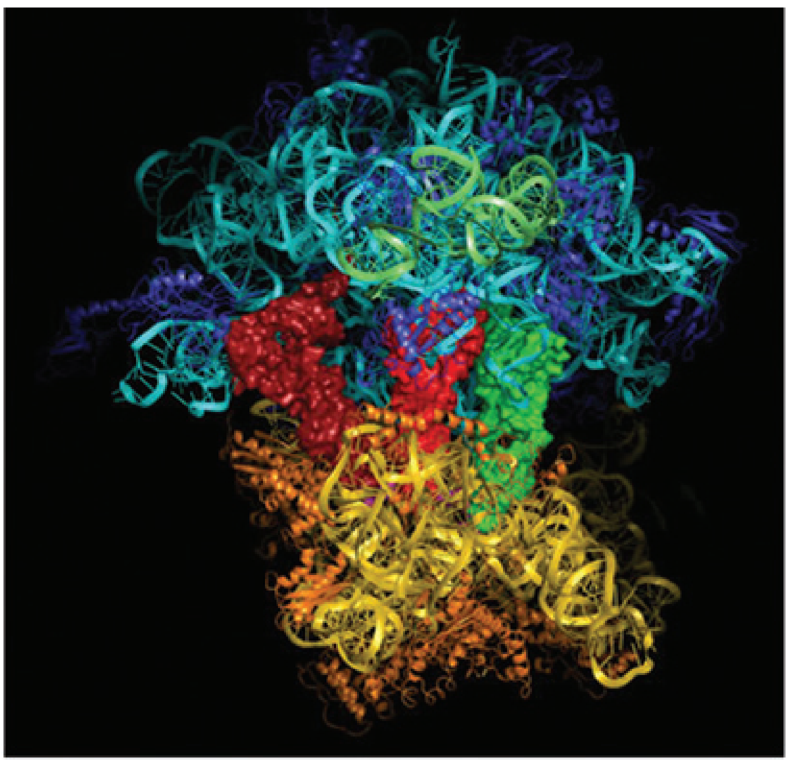


Figure 17, structure of the ribosome

6.4.8 Tackling motor neuron disease

Motor Neurone Disease (MND) is a progressive, fatal neurodegenerative disease for which there is currently no cure. The disease is characterised by weakness, muscle wasting and difficulties with breathing and swallowing. At any one time, seven in every 100,000 people are living with MND and approximately one in every 300 deaths is related to MND.

Figure 18, image of the brain, Copyright: YAKOBCHUK VASYL@ Shutterstock

A proportion of these cases are known to have a genetic basis, and the only established cause to date is the mutation of one of the body's vital antioxidant molecules, superoxide dismutase (SOD). These SOD mutations are the only known cause of MND, but it is not known precisely why the mutant proteins are toxic.

SRS staff established an international consortium with research groups in the USA and Sweden to tackle this challenging problem[63],[64],[65] They led the way in understanding the effects that different SOD mutations have on the way the SOD protein works. Results from the SRS indicated that mutant SOD proteins pair up differently to the normal protein (SOD molecules exist naturally as a pair) causing them to be less stable and that this change might give an opportunity for therapeutic intervention. Based on this research, drug discovery programmes including one funded by a UK charity (Motor Neurone Disease Association[66]) are underway.

6.4.9 Battling blindness

The SRS was used extensively by staff from Cardiff University's Department of Optometry and Vision Sciences, to study the structure of the cornea. X-ray diffraction (XRD) was used on the SRS from the early 1980s to study the structure of the cornea. Visual loss caused by abnormalities in the cornea is a widespread problem but questions about the structure of the cornea remain. Defects in the transparent window are one of the leading causes of blindness, yet hundreds of corneal grafts fail each year in the UK. Researchers try to explain corneal defects to free up health service resources –

> *"By increasing our understanding of corneal problems we can alleviate the burden of corneal disease on the NHS.[67]"*

Highlights from the work include research concluding that aspirin prevents the ageing of a protein in the cornea of the human eye. The research also indicated the possible role of aspirin in preventing some of the pathology of diabetes and Alzheimer's disease, and ageing in general. This research will ultimately help to optimise procedures for a range of corneal conditions, from treatment of corneal astigmatism, to recovery of good vision after a corneal graft or cataract surgery, and even laser surgery to correct myopia.

[63] *Hough M.A. et al. (2004), "Structures of motor neuron disease mutants", Proceedings of the National Academy of Science of the USA, 101, (16), P.5976-5981*

[64] *Ray SS & Lansbury PT Jr. (2004), "A possible therapeutic target for Lou Gehrig's disease", Proceedings of the National Academy of Science of the USA, 10, (16), P.5701-5702*

[65] *Elam J.S. et al (2003), "2Amyloid-like filaments and water-filled nanotubes formed by SOD1 mutant proteins linked to familial ALS", Nature Structural Biology, 10, P.461-467*

[66] *www.mndassociation.org*

[67] *Professor Keith Meek as quoted on - www.news.bbc.co.uk/1/hi/wales/1428841.stm*

Figure 19, eye image with test vision chart, Copyright: Ana de Sousa @ Shutterstock

6.4.10 The green catalyst mystery

Natural and synthetic zeolites are remarkably versatile materials; highly valued in chemical and related industries. Around 40 zeolites are found in nature but the prospect of greener, more efficient chemistry has led chemists to attempt to make synthetic varieties. Over 150 synthetic zeolites have now been made, and their value to the chemicals industry is undisputed. They are used as molecular sieves, as ion exchangers for softening water, and perhaps most importantly, as catalysts enabling reactions between other chemicals to happen more efficiently.

Development of unique facilities at the SRS enabled staff at the Universities of St Andrews and Portsmouth in the UK and Valencia in Spain to study a new zeolite, SSZ-23. This zeolite worked well as a catalyst but researchers were unable to determine its shape. Researchers on the SRS found that the structure of SSZ-23 is entirely different from the rest of its chemical family, even though it works just as well as a catalyst. This discovery could be the first sighting of an entirely new family of zeolites. It puts new ideas at the fingertips of synthetic chemists and could open the way for new types of 'green' catalyst with more subtle behaviour.

The team from St Andrews are now applying the same technique to investigate the atomic detail of how zeolites shrink when heated, with the research continuing at the Diamond Light Source after the closure of the SRS. They hope that this type of study will help to reveal even more about the unknown fundamentals of zeolite chemistry. The solving of the green catalyst mystery could be just the start of some unexpected developments in industrial catalysis.

Figure 20, zeolite catalysts play an important role in modern refineries, Copyright: TebNad @ Shutterstock

6.4.11 Making industrial glass stronger

Figure 21, glass structures in Canary Warf London, Copyright: StraH @ Shutterstock

Complex materials increasingly attract attention because of their industrial as well as their academic potential. Glass is a classic example. Work on glass at the SRS has resulted in a significant change in understanding its structure and properties, which enable its continued attractiveness to the building and automotive industries. Techniques like EXAFS, X-ray diffraction and small angle X-ray scattering have resulted in the determination of atomic structures.

In a unique series of synchrotron radiation experiments, structures at the local chemistry and nanostructure level were both directly observed at the SRS by a team of industrial researchers and academics from the University of Aberystwyth. For example, it is now possible to characterise the channels for ionic diffusion that determine the mechanical strength of glass and the inhibition of chemical corrosion – two of the most important functions of glass as an industrial product.

6.4.12 Reducing the devastation of malaria

Each year there are 350–500 million cases of malaria worldwide[68], with fatalities between approximately one and three million people per year, the majority of which are children[69]. It is one of the planet's deadliest killers and the leading cause of sickness and death in the developing world. Although antimalarial drugs such as quinine and chloroquinine can help to prevent the contraction of malaria, no-one knows exactly how they work. In 2005 a researcher from the SRS worked in combination with researchers from Cape Town University in South Africa to investigate how the drugs worked. The aim of the research was to produce readily available and effective drugs that will protect people in developing countries from this killer disease.

One theory about how antimalarial drugs prevent people from getting malaria is that these drugs interrupt a vital part of the malaria parasite's digestion pattern. Malaria parasites survive by eating the haemoglobin in blood cells. However, the structure around the iron in the blood cell (called the haem) is toxic to the parasite so it converts the haem to pigment which it stores in a sac inside its body. Antimalarial drugs are believed to kill the parasite by preventing the formation of the pigment and the key is to understand how drugs can control this.

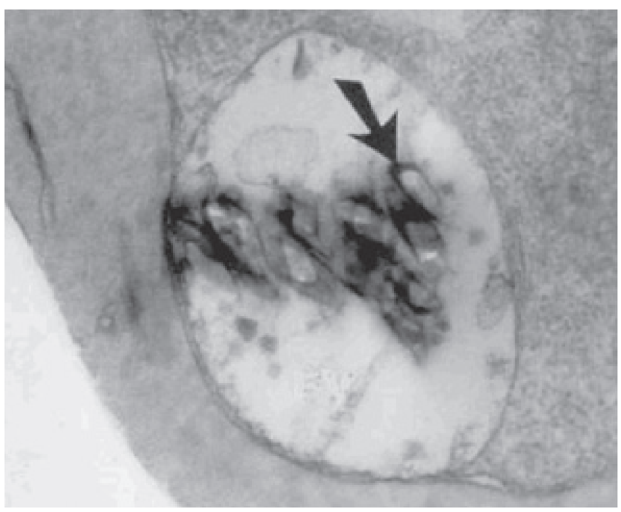


Figure 22, an electron micrograph of a malaria parasite inside a red blood cell

[68] http://www.cdc.gov/malaria/facts.htm
[69] http://www.nature.com/nature/journal/v434/n7030/full/nature03342.html

Figure 23, a mosquito drawing blood, Copyright: Gregor Buir @ Shutterstock

The SRS was used to investigate how haem can be converted into malaria pigment. A synthetic version of haem was used to confirm that the pigment was formed in the predicted manner. The current stage of the experiment involves using real haem from the parasite, which is a difficult job. The final stage of the research will be to insert inhibitors to try and stop the pigment from forming.

The researchers believe that their findings could lead to a cheap and effective drug to protect people in developing countries and reduce the devastating effect of malaria.

6.4.13 Helping the 3rd world address water pollution

In some parts of the world drinking groundwater is laced with arsenic and is poisoning those who drink it. From skin lesions to cancers, arsenic poisoning is a serious problem. Bangladesh is one of the worst affected countries, but parts of India, Nepal, Pakistan, Cambodia and Vietnam also have similar problems.

Scientists from the University of Manchester headed a team which investigated how arsenic gets into the groundwater. Using the SRS in 2005, they made significant progress in understanding arsenic pollution. The research included investigation of where the arsenic was in the sediment and what caused it to be stripped off and dissolved into water. The team analysed sediment samples from wells in West Bengal, India and were able to discover what kind of environment encouraged arsenic to be released into surrounding water.

The team discovered that the optimum conditions for arsenic release occurred as a result of bacterial action in low oxygen and organic carbon rich environments. The arsenic is locked up with iron oxide grain coatings in the sediment, under certain conditions bacteria dissolve the iron and this releases the arsenic.

In places like Bangladesh and West Bengal, groundwater is often pumped up which encourages the draw down of organic carbon rich water from the surface. Some scientists are worried that pumping could be exacerbating the problem by stimulating the bacteria that help to release the arsenic. The team from Manchester University are continuing to investigate arsenic release and hope that their work will contribute towards a solution for this problem which blights millions of people's lives.

Figure 24, researchers from Manchester University test a recently installed well for arsenic

6.4.14 Why does a lobster change colour on cooking?

The molecules causing the colouration properties of marine organisms such as lobsters were revealed in the crustacyanin crystal structures in work by SRS researchers[70] and received very large media and public interest. The colouration of the lobster shell, famously known from its colour change on cooking, derives from a complicated mix of astaxanthin carotenoid molecules and several proteins in complex known as "crustacyanins".

There are wider biological implications of these lobster coloration studies, including the colours of rare lobsters, where site-specific amino acid changes could be a cause. Protein engineering molecular biology for colour tuning of an artificially produced crustacyanin is also underway as a result of this work. A future application of this work is the design of a colour based heat sensor.

Public interest in the question 'Why does a lobster change colour on cooking?' was especially strong, with the work featuring as a Friday Evening Discourse at the Royal Institution in 2004, with Baroness Greenfield presiding. The Liverpool Daily Post also reported the work –


Solution cooked up to red lobster riddle

From the Liverpool Daily Post but articles also in The Times, The Guardian, The Independent also Radio, TV, Scientific American New Scientist, Physics Today etc.

Figure 25, article from the Liverpool Daily Post

The TV and newspapers reported a new method of delivering the antioxidant, which is possibly cancer preventing. Other newspapers referred to the possibility of using protein engineering and site specific mutagenesis to manipulate the colour, leading to potential applications in food colourants or flowering plants.

High school students formed a second wave of interest with emailed requests to the SRS scientists for details of the research article so as to complete their chemistry homework assignments (see Gerritsen 2002 for a summary of the work)[71]. Later came more detailed science articles, such as in Physics Today (Day 2002)[72], including a description of the molecular basis of the narrowing of the energy gap between the highest occupied and the lowest unoccupied molecular orbitals. This work highlights the role of the SRS in scientific discovery and its ability to engage members of the public and school children in pure science.

Figure 26, a fresh lobster before cooking, Copyright: Aida Ricciardiello @ Shutterstock

Figure 27, a fresh lobster after cooking, highlighting the colour change, Copyright: Alexander Raths @ Shutterstock

[70] *M Cianci, P J Rizkallah, A Olczak, J Raftery, N E Chayen, P F Zagalsky and J R Helliwell "The molecular basis of the coloration mechanism in lobster shell: ,-crustacyanin at 3.2 A resolution" (2002) PNAS USA 99, 9795-9800.*

[71] *Gerritsen, V. B. (2002). Protein Spotlight, Issue 26. Swiss-Prot/Swiss Institute of Bioinformatics.*

[72] *M Cianci, P J Rizkallah, A OlczDay, C. (2002). Physics. Today, 55, 22-23.*

6.5 Impact summary

It is clear that the economic impact of the research carried out on the SRS has been vast and the impact straddles all of the economic impact areas detailed in chapter 3. Hence the impact from the science has come in many forms –

- *A significant amount of codified knowledge in the form of publications and the solution of many protein crystal structures.*
- *The multidisciplinary and collaborative nature of science on the SRS has facilitated a great number of new scientific and technical developments.*
- *The requirement of cutting edge technology has additionally facilitated leading edge science on the SRS and the technology itself has led to further economic impact by its usage by other large scale facilities and industry.*
- *The development of new scientific techniques on the SRS is a significant impact; the example of PX development on the SRS was a major contributing factor for the need for 3rd generation light sources and was responsible for the private sector investment in the Diamond Light Source, with an initial investment of approximately £50M from the Wellcome Trust.*
- *The impact to society and our everyday lives has been vast - research into drug discovery, the prevention of diseases, cancer diagnosis and even the assistance of archaeology and marine animal colouration have or will have an impact on our lives and affect other organisations such as the NHS. Using the FMDV example, if research at the SRS saves just 1% of the cost of a potential future outbreak, it could save the UK over £80million.*
- *It is also clear that a significant amount of this research has directly benefited industry and underpinned commercial advances in areas such as magnetic recording media, drug design and catalyst development. Research on the SRS has also benefited developing countries in the fight against malaria and the search for clean drinking water.*

However, as illustrated in the chapter, it is extremely difficult to put a value on some of these groundbreaking research activities. Even if one only takes the examples that have figures attributed to them, this runs into the hundreds of millions of pounds. It is also worth noting that the examples presented above are a very small fraction of the research which took place on the SRS.

Chapter 7
Pushing the boundaries of technology

Chapter 7

Pushing the boundaries of technology

7.1 Introduction

The success of the SRS has had a major impact on the UK science base. This included continual development of new technology and instrumentation that was demanded by such a high tech facility. This chapter will describe just some of the breakthroughs in science, technology and technique development that occurred over the lifetime of the SRS.

7.2 How the SRS pushed the barriers of research

In the 1970s, synchrotron radiation research was focused on the areas of atomic, molecular and condensed matter physics. This changed in the mid 1980s when the SRS programme was dominated by biology and then chemistry. The development of new techniques and instrumentation which were made available to the wider science community enabled the growth of new scientific areas and techniques, for example protein crystallography. Hence, the application to materials and biological science expanded rapidly so that by the 1990s the distribution of science areas on the SRS was approximately equal i.e. 25% each between physics, biology, chemistry and materials. The ability to enable new science was a major impact of the SRS.

It is interesting to note that biology played only a small part in the science case for the SRS in 1975 but currently constitutes one of the UK's largest user communities. In addition, a major justification for the science case of the Diamond Light Source was synchrotron protein crystallography which was pioneered at the SRS. In fact, the SRS was responsible for pioneering several techniques which in turn facilitated the science output of the facility.

7.3 Technique & technology development

A resulting benefit of the operation of the SRS as a central facility was the broad and rapid transfer of techniques, instrumentation and ideas between the diverse sciences. The users of the SRS demanded the most cutting edge instrumentation to facilitate their science, which was developed by SRS scientists and engineers in areas such as detectors, optics, metrology, robotics, data acquisition, sample environment and software.

There was an on-going programme of technical developments and upgrades throughout the lifetime of the SRS. Funding was often made available from external agencies such as the Research Councils or the Wellcome Trust for technical developments on the beamlines which in turn furthered the quality of the research output from the facility.

Protein crystallography

The technique of protein crystallography is highlighted here due to its huge significance. The economic impact of protein crystallography development at the SRS was the subject of a case study commissioned through RCUK and undertaken by PA Consulting. More information can be found in the study[73] but several quotes are highlighted here to underline its importance –

[73] *www.rcuk.ac.uk/innovation/impact/default.htm*

"Structural biology and the way it is done now would not be possible without the SRS and the subsequent development of other sources."

"Difficult proteins would not have been solved without the improvements in technology and the speed of crystallographic structure determination. The ribosome structure, viruses, membrane proteins and structural genomics projects would not have been possible."

"The impact of synchrotron radiation and PX has been vast. Imagining biological research without synchrotron radiation sources is by analogy like imagining life without the computer."

Detector development
Amongst the most significant technical developments at the SRS were detector developments, where the maximum scientific benefit from an SR facility is realised by matching the detector to the SR source. This was recognised in the 2008 Light Source Review –

"The committee applauds the UK involvement in detector development, with examples such as the new detectors planned for the XFEL.[74]"

Major improvements at the SRS included parallel electron detection for spectroscopy, large multi-wire proportional chambers (MWPC), multi-element solid state detectors and signal processing. Such detectors facilitate dynamic studies in materials processing. The most successful of these has been the MWPC based RAPID system which has been deployed at ESRF and sold to the Diamond Light Source and SPring-8.

7.4 In-house support

A specific advantage at the SRS was related to expert in-house support groups, particularly in the areas of electronics, computing and precision engineering. This support drove some world-class developments in pursuit of individual university research programmes. Collective specialised requirements of users led to the build up of world class technical support groups within the Daresbury Laboratory. This required a wide range of knowledge and skills, all of which supported the research output of the SRS.

Examples of user driven support developments are given below –

- The SRS inherited substantial and highly specialised computing and electronic facilities from the previous NINA synchrotron. The first ever report of a computer-controlled monochromator was published at the Synchrotron Radiation Facility in the 1970s. Using Daresbury based electronics, particularly the CAMAC standard interfacing system, led to the speedy growth of computer-controlled instrumentation, data acquisition and accelerator safety and control systems. Many of these ideas and some of the hardware has been exported around the world, for example to the ESRF in France and to the ALS in the USA.

- Even more striking developments have been associated with the large computing power supported at the laboratory, through IBM and Cray computers. The extensive use of the JANET academic network led to the evolution of the Daresbury Laboratory as a computational 'node' –

    - This situation stimulated the growth of collaborative computational projects or CCP's. The best-known of these is CCP4 which is a major focus for the processing of structural information concerning proteins and for the analysis of data derived from protein crystallography using synchrotron radiation. These projects assist academics and industrial organisations which in turn creates further economic impact through the transfer of knowledge and the skills development of the users. In addition to facilitating academic research and the impact that this brings, the Daresbury Laue Analysis suite also has future commercial applications in drug discovery and new materials.

[74] *www.stfc.ac.uk/About/Strat/Council/AdCom/UKLSR/Contents.aspx*

- The software and computing support developed for the SRS supported the generation of research output for the facility. This expertise and technology has now been utilised to facilitate research for many other facilities, university groups and industry across the world.

- The computational science support from the CSED has now expanded to be the UK's biggest computational science group and ran the UK's most powerful supercomputer which supports advanced scientific research.

- The e-Science Centre has contributed to the generation of codified knowledge by storing and making scientific data available to other researchers. This world leading activity has been adopted by several facilities worldwide.

Appendix 4 describes the full nature of the software development resulting from the SRS.

7.5 Impact summary

Many of the techniques and technologies developed at the SRS have had worldwide impact –

- *Protein crystallography has revolutionised drug development and the detectors developed on the SRS have been adopted by many other facilities around the world.*

- *The software and computing support developed for the SRS has now been utilised to facilitate research for many other facilities, university groups and industry in the UK and across the world.*

Again, these developments show the truly worldwide impact of the SRS.

Indirect Impacts

Chapter 8
The generation of skills from the SRS

Chapter 8

The generation of skills from the SRS

> *"...the exposure to state of the art science and instrumentation (at the SRS) provides uniquely valuable education and training.[75]"*

8.1 Introduction

In 2006, the HM Treasury published the Leitch Report[76] which highlighted the role of skills development in achieving economic growth. The skills agenda is one in which the SRS and the wider Daresbury Laboratory has had a significant role.

Major outputs of the SRS included the attraction of highly skilled scientists and engineers to the North West and the creation of skilled and qualified people, both internal staff and users. This created a critical mass of expertise at the SRS and the wider Daresbury Laboratory which continues to grow. Valentin et al (2005)[77] see this establishment of a local talent pool as the creation of a "transit labour market of highly specialized PhD students, academics and professionals" which will then be recruited into science and technology based industries.

In addition, the supply of skilled graduates and researchers who are trained at large facilities and then transfer to industry or other public sector bodies is seen as a key impact from research (McMillan & Hamilton, 2003)[78].

The development and support of the SRS required substantial technical infrastructure, requiring the

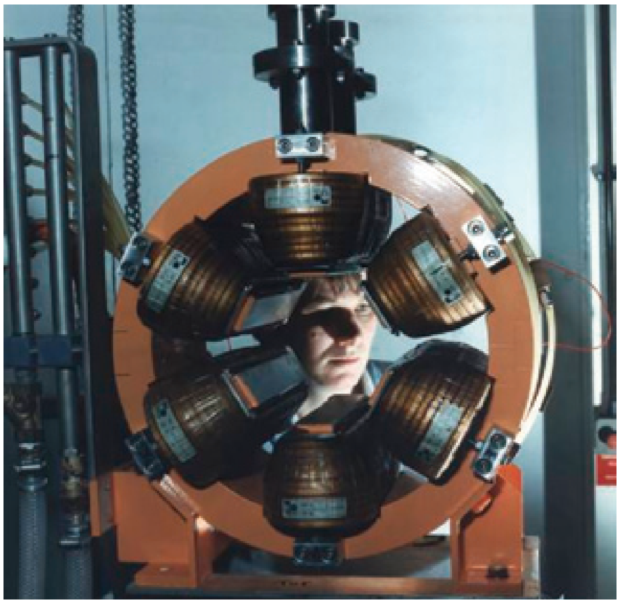


Figure 28, staff developing skills on the SRS

[75] *Excerpt from "Science and Engineering Opportunities with a MEXS", hard copy publication by EPSRC.*

[76] *http://www.hm-treasury.gov.uk/leitch_review_index.htm*

[77] *Valentin, F. Larsen, M.T. Heineke, N. (2005), "Neutrons and Innovations: What benefits will Denmark obtain for its science, technology and competitiveness by co-hosting an advanced large scale facility near Lund?", Research Centre on Boitech Business, Copenhagen Business School, www.ess-scandinavia.org – 2nd February 2009*

[78] *McMillan, S.G. & Hamilton R.D. (2003), "The impact of publically funded basic research: An integrative of Martin & Salter", IEEE Transactions on Engineering Management, Volume 50, no.2, May, p184 - 191*

support of highly skilled engineers, technicians and instrumentation developers, in addition to the scientists who carried out the research. The skill of the staff at the SRS spanned many areas of expertise which was built up due to the demands of designing and exploiting such a technically demanding facility. Much of this expertise has been exploited by other facilities and departments and continues after the closure of the SRS.

In addition to the significant knowledge that was gained from designing, building and operating the SRS, skills were also developed through the usage of the SRS. The SRS was also an important tool for the training of graduates, post graduates and apprentices. There were also several studentship programmes and training programmes which ran during the operation of the facility.

With 28 years of operation, and with a staff at times numbering in excess of 325, it is inevitable that employees from the SRS moved to other fields of work. Several staff members went on to work in different functions at other synchrotrons, in industry, academia or the public sector. The summaries later on in this chapter give some indication of the dispersion of some of those staff members, but the list is not comprehensive due to a lack of complete records.

8.2 Users

Around 1500 individual visiting scientists and engineers used the SRS each year to carry out experiments. The size of the user community peaked at around 2000 per year in the mid 1990s and at any one time there were some 100 – 200 users on site when the SRS was in operation. The majority of users came from the UK but also the EU and overseas, from over 25 countries. For example, in 2005/2006 the distribution of users included 55 UK universities, 32 non UK universities, 28 industrial or other organisations from the UK and 35 non UK industrial and government organisations - including 9 other synchrotrons.

Table 3 and figure 29 opposite illustrate the number of different users and how many visits they made to the SRS between 2000/01 to 2006/07, with each user making an average of 2-3 visits per year.

Scheduling Period	No. of Users per year
2000/01	1195
2001/02	1020
2002/03	970
2003/04	1350
2004/05	1341
2005/06	1464
2006/07	1020

Table 3, usage of the SRS from 2000 – 2007

Between 1991 (when an electronic data collection system was implemented) and 2007, 9000 individual users used the SRS over 28000 times. Of these approximately 36% were undergraduate or postgraduate students. Estimating, probably very conservatively, an additional 2000 users for the period between 1981 and 1991, this makes a total of 11000 different users of the SRS. The spread of user type is illustrated in the graph below.

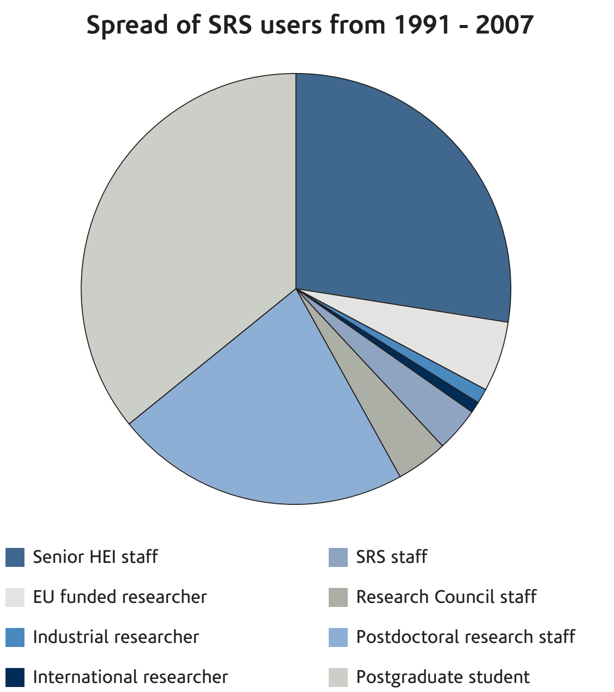


Figure 29, distribution of SRS users, 1991 - 2007

Estimates from the facility show that –

- On average more than 700 individuals (UK and EU post doctoral researchers and PhD students) used the beamlines annually.
- A total of 4000 UK students used the SRS as part of their degrees or doctorates over its lifetime.
- A further 2000 post doctoral researchers used the SRS as part of their research.

This is a substantial contribution to the UK knowledge base. As an illustration, the numbers of students trained on the SRS can be shown from the year 2006/07 alone:

- 444 PhD students.
- 14 CASE students.
- 3 Sandwich students.
- 33 Students attended SR Summer School.
- 16 student supervisors.
- 2 M.Sc. SR staff students.
- 39 active SRS staff researchers.

In addition to research knowledge and qualifications that SRS users have gained through their work on the SRS, there is a substantial amount of other training and skills development that occurs via facility usage. The SRS has been an important training ground for aspects such as experimental set up, data acquisition, calibration, data analysis, sample preparation, health & safety etc. All of the 11000 users who have used the SRS over the years will have been trained in some or all of these areas, dependant on their experience of SR sources. Such multi disciplinary R&D laboratories provide the training ground for staff who go on to be employed by R&D-intensive companies in the UK. Hence supporting the development of such skills is critically important.

An interviewee from the PA Consulting Group report on the economic impact of the Research Councils remarks that –

> *".. this is part of the ethos at the SRS: training and providing a service [to users].[79]"*

8.3 Training

Internal studentships and training courses

An SRS studentship scheme from 2002 to 2004 directly funded nine PhD studentships. The SRS has also contributed to funding industrial CASE studentships. Since the SRS became eligible for industrial partnership under the CASE studentship scheme in 2000, between two and three such studentships were awarded per year. In addition, many collaborative studentships, sandwich course and vacation students were supported by the SRS.

A variety of training courses and summer schools were also provided by the SRS and each science area of the SRS ran its own kind of training provision. From 1991, the SRS ran SR summer schools (e.g. funded by EPSRC or the EU etc) every 2-3 years for PhD students and post doctoral researchers, consisting of a seminar component and a practical component carried out on the SRS.

Another example of training associated with the SRS is the CCP4 computing project which still runs a series of summer schools and study weekend[80]. Scientists and users of the SRS contributed to the content of these courses, utilising their expertise gained on the SRS.

[79] *www.rcuk.ac.uk/cmsweb/downloads/rcuk/economicimpact/ei2.pdf*
[80] *www.ccp4.ac.uk/ccp4course.php*

Figure 30, Synchrotron Radiation Summer School in 2006

Additionally, the SRS ran several "Accelerator Schools" in which SRS staff contributed. These included –

- CERN Accelerator School[81], who collaborate with the US-CERN-JAPAN-RUSSIA Joint Accelerator School (JAS) in delivery of some courses.
- JUAS[82] – the Joint Universities Accelerator Schools, based in Geneva, supported by CERN and sponsored by several major synchrotrons.
- US Particle Accelerator School[83], which has run courses across the US from 1987 to the present day.

Apprenticeships

Since the inception of the SRS, a substantial number of apprentices completed their training at the Daresbury Laboratory. 108 apprentices were employed over the years on the SRS. The great majority of these apprentices worked directly on the SRS, with a smaller number on ancillary facilities.

Work Experience

For many years the Daresbury Laboratory has invited students for work experience. Some participated during their school years, whilst others worked at the Laboratory as part of their undergraduate or post-graduate studies. Many worked with scientists, often on the SRS or its support functions; others worked in functions such as IT or administration. Duration ranged from one week to six months and 454 students in total underwent work experience training.

A number of those who had undertaken work experience at the Daresbury Laboratory subsequently took up permanent employment on the site. Some were asked about the impact and value of the experience, and some of their points are listed below:

- Students at the Laboratory were generally given more responsibility, and more worthwhile projects, than was usual for many work experience students.

[81] *www.cas.web.cern.ch/cas/*
[82] *www.juas.in2p3.fr/*
[83] *http://uspas.fnal.gov/*

- All the former work experience students remarked that Daresbury Laboratory was able to combine real professionalism in the workplace with a warm and friendly culture.
- In one instance, a student was so impressed by the science that she switched her planned degree from law to physics.
- Several of the students had worked on the SRS at some stage in its life, and were impressed that they had been part of such a significant facility.
- One student joined for a six months placement, but subsequently studied for a PhD and joined the permanent staff.
- Above all, several had their preconceptions about science and scientists challenged - "I learned that scientists are cool and interesting!"

8.4 Skills resulting from technology development

The skills required to design, run and support the research at the SRS was vast. The SRS staff of 325 (at its maximum in 1998/99) built up world class expertise in areas such as engineering, instrumentation, detectors, electronics, power supplies, radio frequency, accelerators, cryogenics, vacuum, critical cleaning and a host of other expertise. This allowed SRS staff and support staff to transfer their expertise and knowledge to industry, universities, schools and other synchrotrons and particle physics facilities. This is highlighted in the three sections below.

8.5 SRS contribution to light sources around the world

In addition to working with many of the synchrotrons across the world, many of the SRS staff later went on to actually work at these other synchrotrons, further disseminating their expertise. The list below describes the 63 SRS staff who have moved to other synchrotrons around the world and transferred their skills to contribute to these sources. For example the Director of the Spanish synchrotron radiation source (ALBA)[84], Professor Joan Bordas, is an ex Director of the SRS.

SR Source	Scientific or Managerial Staff
ALBA	3
Diamond Light Source, UK	21
ESRF, France	9
Australian Light Source	6
Advanced Light Source, USA	7
Aarhus, Denmark	1
Okazaki, Japan	1
BESSY, Gemany	2
DESY, Germany	2
Singapore Light Source	1
ELETTRA Trieste, Italy	1
NSLS Brookhaven, USA	6
Jefferson Laboratory, USA	1
CAMD Louisiana, USA	1
Soleil, France	1
Brazilian Light Source	1

Table 4, SRS staff who have transferred to other synchrotrons around the world

8.6 Staff transferring to the academic sector

Interviews show that at least 28 staff from the SRS, covering the range from technician to director level, have transferred to academic posts in universities both in the UK and abroad. In addition, it is known that at least 5 staff have gone on to be teachers in schools and/or colleges after leaving the SRS.

[84] *www.cells.es/*

8.7 Staff transferring to the industrial sector

Over the years, many SRS staff left to take up industrial positions. Their destinations were not recorded and so a comprehensive list cannot be given here, but interviews show that at least 19 ex SRS staff have moved to industry. These staff moved to a diverse range of industries including Schlumberger, VG Scientia and BNFL and several of the STFC's own spin-out companies.

8.8 Joint appointments

Throughout the lifetime of the SRS it has been beneficial to have staff employed partly at the Daresbury Laboratory and partly in an academic institution, carrying out related work. Joint appointments were an important aspect to the skills exchange between the SRS and the host university. It additionally helped to bring science drivers and challenges to the SRS from the universities.

In the 1990s, there were around 30 joint appointments at any one time. This reduced as the SRS started its run down to closure with nine joint appointments in 2006/07. In addition, at least five SRS staff held visiting fellowships or professorial positions in academic institutions in the 1990s.

The following case study illustrates the career path of a professional associated with the SRS as an illustration of how the skills and expertise gained on the SRS helped in his career.

The Dissemination of Expertise – Professor John R. Helliwell

Professor Helliwell provides an excellent example of how SRS expertise was disseminated to academic and industrial organisations throughout the world. Whilst his experience is more widespread than most, it does indicate the breath of roles and influence displayed by many SRS staff.

Between 1974 and 1977 Professor Helliwell conducted research in the Laboratory of Molecular Biophysics at the University of Oxford culminating in the award of D Phil in 1978. The crystallographic techniques in use then were slow and primitive and led Professor Helliwell to explore the possibility of using synchrotron radiation in protein crystallography. Synchrotron radiation was seen to have potential but the idea of a centralized X-ray source was met with deep scepticism. However, in 1976 Professor Helliwell initiated the first synchrotron radiation protein crystallography experiments on NINA.

Shortly following a brief period of post-doctoral research, Professor Helliwell was given a joint appointment (50:50) between the University of Keele and the SRS to develop protein crystallography (1979-1983). With the assistance of leading engineers, this culminated in three dedicated instruments on the SRS. Numerous pioneering protein crystallographic studies resulted, including Professor Helliwell's involvement in the first PX Laue diffraction patterns ever recorded at the SRS.

During the period 1983-1985 Professor Helliwell was funded 100% by the SERC and was appointed as a Senior Scientific Officer at the SRS, in 1985 he became a Principal Scientific Officer and was made an Honorary Lecturer in Physics at Keele University. From 1985-1993 Prof Helliwell continued work on the SRS from York University and then as a Professor in Structural Chemistry at the University of Manchester (1989-present). Between 2002 and 2003 he became the CCLRC Director of SR Science and after this, continued at Manchester University.

In parallel with work at Manchester University and Daresbury, Professor Helliwell was highly influential in the design and construction of the ESRF and became a key contributor to the ESRF programme for a substantial period of *time including several ESRF Advisory Roles and Science Advisory Committee and ESRF Council. He was leader of the protein crystallography instruments definition group, the work of which resulted in submissions to the ESRF Foundation Phase Report (the 'Red Book'). Substantial knowledge transfer occurred between the SRS protein crystallography group and the ESRF, as a consequence, the European pharmaceutical expenditure at the ESRF is now substantial, of the order of 2.5 million Euros per annum. In 1992 Professor Helliwell published "Macromolecular Crystallography with Synchrotron Radiation) with Cambridge University Press; this was republished in paperback in 2005 by CUP.*

In 2001 Professor Helliwell was the UK Delegate to the G5 (France, Italy, Spain, Germany and UK) European Working Group on the future plans for synchrotron, neutron and laser facilities provision in Europe.

Additional positions include:

- *Honorary Scientist and Scientific Advisor with the SRS industrial services (now STFC Innovations Ltd).*
- *Co-Editor of the Synchrotron Radiation News.*
- *Co-Editor of the Journal of Applied Crystallography published by the IUCr.*
- *Co-Editor of Crystallography Reviews*
- *Editor of Acta Crystallographica (1996-2005).*
- *President of the European Crystallographic Association (2006-2009).*
- *Honorary Member of the National Institute of Chemistry, Ljubljana, Slovenia.*
- *Visiting Professor of Crystallography at Birkbeck College, University of London (2002-present).*

8.9 Impact summary

This chapter describes the key role and numerous routes through which the SRS has provided a training ground for highly skilled and specialised staff. The UK Government sees skills development as a key way of achieving economic growth.

- *This chapter highlights the role of the SRS in providing highly skilled people both through general usage of the SRS for research (over 11000 people) and more specifically the usage of the SRS to assist in gaining a qualification (4000 degrees or doctorates and 2000 postdoctoral researchers). These qualified students and researchers are then recruited into science and technology based industries.*
- *A major impact of the SRS has been through the transfer of skilled staff. At least 106 staff have transferred to other synchrotrons, other academic institutions and industry.*
- *This range of skilled staff is an extremely useful resource for industry (Zellner, 2002 & 2003).*
- *Publicly funded research facilities like the SRS are key training grounds for R&D intensive industries.*
- *They have the indirect effect of improving UK business, providing skills and expertise to other synchrotrons and academia, and in turn facilitating additional economic impact.*

Chapter 9
Public understanding of science

Chapter 9

Public Understanding of Science

"..central facilities like the SRS afford excellent theatre for extending the public awareness of science.[85]"

9.1 Introduction

A major role of Daresbury Laboratory has been its involvement in the public understanding of science, engineering and technology (PUSET). The Daresbury Laboratory plays a lead role in bringing science to the general public, schools and teachers and its PUSET programme forms part of an overall STFC programme[86]. Prior to 1996 there had been a relatively low but significant level of public outreach done at Daresbury Laboratory with around 100 public visits to the lab taking place each year. With the establishment of the CCLRC in 1995, more resource was committed to public outreach activities and the Laboratory's role in PUSET started in earnest.

The number of people who engaged with Daresbury Laboratory is substantial and is illustrated in the graph below.

Since its inception, the Daresbury Laboratory's PUSET programme has helped to inform and engage the public with advances in science and technology and inspire school pupils to become the next generation of scientists and engineers. Activities for the public, teachers and schools often involve local and regional partners from the education, outreach and professional sectors to maximise impact and ensure effective delivery. Although the PUSET programme comes from the whole of the Laboratory, the SRS was the main focus of the science in the programme over its lifetime – referred to as "the jewel in the crown" of the programme. Outreach activities are also carried out on behalf of the Laboratory's partners in the Daresbury Science and Innovation Campus and are continuing after the closure of the SRS. Daresbury Laboratory engages in mostly local and regional outreach and its staff are also involved in the STFC's wider public outreach programme.

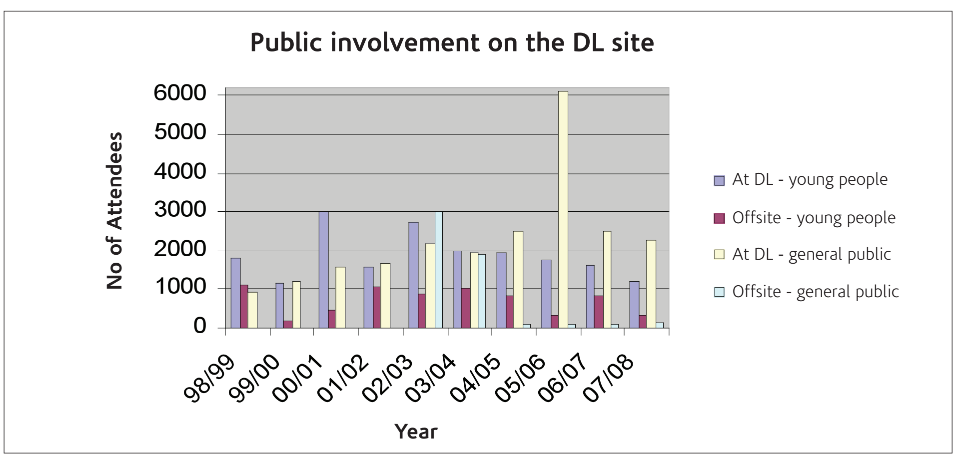


Figure 31, public visits at the Daresbury Laboratory

[85] *Extract from SERC document "Scientific & Engineering Opportunities with a Medium Energy X-ray Source", hard copy*
[86] *www.scitech.ac.uk/PandS/SinS/Contents.aspx*

9.2 Summary of activities

- Each year over 3,000 members of the public visit the Laboratory to hear about the latest developments in science and technology and see the Laboratory's world-leading facilities. Activities for the public include free monthly lectures, visits, science festivals and open days. In 2006/2007 the SRS had 33 different school groups visiting the SRS.

- In addition, 3000 school pupils per year are inspired to follow their interest in science by taking part in programmes and activities either at the Laboratory or led by the Laboratory in their school. Available activities include master classes, workshops, lectures, tours, science projects and work experience. More recently, the Laboratory has hosted a visit for children from Chernobyl.

- Daresbury Laboratory has awarded a schools science prize annually since 1996. The prize is give to a pupil from each of 32 schools. There have now been 384 prize-winners.

- The Science and Engineering Ambassadors (SEAs) Programme[87] is a flagship programme run by the Science, Technology, Engineering and Maths Network[88]. Ambassadors from the SRS and wider Daresbury Laboratory have offered their time and expertise to help inspire young people. Typical activities in which Ambassadors get involved include supporting schools in science and engineering activities and helping with school's STEM competitions, events and awards.

- In 2005 one of the STFC's predecessor Councils, the CCLRC, produced an educational CD ROM called "Seeing Science", a teaching aid for teachers of key stage 3 pupils (11 – 14 year olds). The aim of the CD ROM is to encourage more young people to study science and engineering at a higher level. The lessons allow pupils to compare the methods used in a school laboratory to those used by professional scientists working in the STFC's laboratories. Material on the CD ROM includes science from the SRS and is available via request from the Seeing Science website[89]. Since its launch, 6000 copies of the CD ROM have been distributed to schools across the country.

- 60 – 70 teachers per year visit the lab to receive training on curriculum hot topics, go on placements to understand more about the work of the Laboratory and attend master classes. For example in 1996 a group of eight vocational teachers from Germany visited Daresbury Laboratory as part of a week's programme focusing on education and training. The group were given the opportunity to shadow staff to get a taste of the work of the Laboratory. The visit was judged to be very beneficial by the teachers themselves who said their time spent had been "very useful".

A full list of PUSET activities that the Laboratory undertakes can be found in Appendix 5.

9.3 Impact summary

The PUSET programme creates economic impact through its contribution to the knowledge economy as highlighted in the previous chapter. This programme has had societal impacts by encouraging interest in science with the aim of increasing the uptake of physical sciences and maths at school level, educating and informing the general public, inspiring the next generation of scientists and educating teachers.

[87] *www.stemnet.org.uk/Ambassadors_SEAs/Who_are_SEAs.cfm*
[88] *www.stemnet.org.uk/?referred*
[89] *www.seeingscience.cclrc.ac.uk/home.aspx*

Chapter 10
Growing UK industry

Chapter 10

Growing UK industry

10.1 Introduction

The technology from the SRS has been commercially exploited through direct sales, patents, licences and spin-out companies. In recent years the commercialisation of technology from the SRS has been managed by the STFC's commercialisation company, STFC Innovations Ltd[90].

Additionally, there have been indirect spin-outs in which the SRS has played some part in educating those staff or users who have gone on to start up companies themselves.

10.2 STFC Innovations Ltd

STFC Innovations Ltd is the technology exploitation company of the Science and Technology Facilities Council. Wholly-owned by the Council, STFC Innovations Ltd manages commercial activity through spin-outs, licensing and trading. STFC Innovations Ltd has the exclusive rights to the commercial exploitation of the intellectual property of the STFC's laboratories. By working closely with the technical inventors, the team progress individual projects through various business models to the point of implementation – either as a commercial licence or spin-out company. Since its inception in 2002, STFC Innovations Ltd has spun out ten companies based on STFC technology and is currently working on spinning out a further five new ventures. STFC Innovations Ltd is also responsible for commercial access to STFC facilities and services.

10.3 SRS spin-outs

Five spin out companies have been created to commercialise technology associated with the SRS – ARES (no longer in existence), Quantum Detectors, L3T, Histone Technology and DSoFt Solutions. In addition, a sixth spin-out Cryox, has recently spun-out of the STFC as a result of cryogenic capability build up through the SRS and the STFC laboratories at the Rutherford Appleton Laboratory and the UK Astronomy Technology Centre. These spin-outs are detailed below.

Quantum Detectors
Quantum Detectors[91] was created in late 2007, to promote wider exploitation of detectors that were developed for the SRS by the STFC's Engineering and Instrumentation Department. Quantum Detectors is part owned by the STFC and Diamond Light Source, using their experience in the development of both detection technology and turnkey detector systems. Due to its success with detectors from the SRS, the STFC is a leader in the synchrotron detector market.

Quantum detectors offers technology previously unavailable to commercial customers, providing specialist solutions for research and industry. The market of large scale facilities for detectors which Quantum Detectors will initially address accounts for £20M pa, in which the products will address 25% of the market.

L3 Technology (L3T)
Established in 2003, L3T[92] is a spin-out from the SRS set up to commercialise a new method of cholesterol monitoring – making the availability of immediate, accurate tests for high cholesterol at your local GP's surgery a step closer. L3T currently

[90] *http://www.stfcinnovations.co.uk/default.aspx*
[91] *www.quantumdetectors.com*
[92] *http://www.l3technology.co.uk/*

employs four people and has recently secured a second round investment of £1.75m, enabling the company to commercialise its patented technology. The company has secured a total of £2.75M in investment to date.

Coronary heart disease, of which a major contributing factor is high cholesterol, is set to become the biggest killer disease worldwide by 2010. There are several types of cholesterol, some of which are good for you and some of which are bad. Existing over-the-counter tests do not distinguish between good and bad cholesterol so the results don't give a full picture of the patient's health. For accurate diagnosis, current tests rely on a doctor taking a blood sample from the patient and sending it to a laboratory for analysis – the results can take days. L3T's technique provides accurate results in minutes.

The L3T approach means that doctors will be able to provide a high cholesterol diagnosis with unprecedented laboratory-standard accuracy, with just a pin prick of blood from the patient – all within a minute. The system works by placing the blood into a cartridge, which is then inserted into a 'miniature lab', the size of a laptop, for immediate blood lipid and cholesterol analysis. It is expected that the immediacy and accuracy of the test could save the NHS millions of pounds, improving patients' health through enabling an immediate and precise prescription of drugs. Almost a billion cholesterol tests are carried out worldwide every year - the potential future economic benefits are obvious.

Histone Technology

Histone Technology[93] was established in 2004 to commercialise the production of DNA binding proteins known as histones. Histone Technology is commercialising a suite of biochemical techniques designed to extract high volumes of histones from the nuclei of cells. Initial work was carried out on chicken erythrocytes due to their cheapness and relative availability, resulting in a supply deal with Abcam[94] and a number of sales. Although the chick proteins have achieved some success, the market really wants human nuclear proteins and this is what the company is now concentrating on. The company has successfully isolated the human forms and are now in the process of validation after which they intend to market the human proteins.

DSoFt Solutions

DSoFt Solutions[95] was set up by two staff from the SRS computing group with expertise in the integration of electronic hardware and software. They have developed techniques to take outputs from a wide variety of equipment, and present it in an accessible and user-friendly form. This expertise can be deployed to make researchers' experience of complex systems, such as light sources, as straightforward and efficient as possible. DSoFt Solutions design, construct, test, implement and support a wide range of scientific, engineering and technology applications using a variety of platforms and languages.

Cryox

Cryox[96] is a new company formed in 2008 to commercialise cryogenic & superconducting technology - in growing demand across diverse applications in science and industry. Backed by the Science and Technology Facilities Council, and based at the Rutherford Appleton Laboratory, Cryox has exclusive access to leading edge cryogenic technology from STFC Research Laboratories. This world-class resource is now available through Cryox under licence or in products and services offered under the Cryox brand. Expertise in cryogenics from the SRS and across the STFC's facilities and programmes has allowed this new venture to be set up.

10.4 Instrument design technology

While not a direct spin-out of the SRS, Instrument Design Technology[97] (IDT) was formed in 2000 by an ex SRS engineer Paul Murray and 2 other STFC staff members and is currently located at the Daresbury Innovation Centre. Paul Murray, the Managing Director of IDT has worked at several SR sources –

93 *www.srs.ac.uk/BioMed/projects/chromatin.htm*
94 *www.abcam.com/*
95 *www.dsoft-solutions.co.uk/*
96 *www.cryox.co.uk/index.html*
97 *www.idtnet.co.uk*

the SRS, the ESRF and the APS - and used expertise developed here to exploit the opportunity to supply leading-edge instrumentation to scientific markets, principally to SR facilities. The company initially worked on beam line design and consultancy and started to build and design hardware around 2002. IDT provide the world's synchrotron community with a design and project management resource in state of the art mechanical precision instrumentation. IDT was awarded a Department of Trade & Industry SMART award for DCM Goniometer development in 2003.

IDT have designed and built two beamlines for the Advanced Photon Source (APS), one for the Canadian Light Source and one for the Australian Light Source. The company has also provided equipment for the Diamond Light Source, the Swiss Light Source and PETRA 3 at DESY.

The market in which IDT operates is very competitive; IDT is the only UK company with these capabilities. IDT currently employ 10 people (two of these staff are former SRS technicians) and was initially self funded through a consultancy project for the APS. IDT's turnover has been £1M per year for the last 3 years and is expected to rise to £1.5 – 2M over the next 3 years. IDT estimate that 30 – 40% of this turnover is spent on local companies. Their suppliers are mostly in the North West of England with all of their components (e.g. motors and X-ray and optical components) being bought in. IDT use SuperClean (see below) to clean components and find benefit from interaction and an "exchange of ideas" with Daresbury Laboratory scientists and engineers.

10.5 Indirect spin-outs

BEDE Scientific Instruments

BEDE Scientific Instruments[98] evolved from the need to cut silicon crystals for mirrors and monochromators for facilities like the SRS. The founders of Bede Scientific Instruments, Mike Hart and Keith Bowen were important users involved with the SRS since its inception and were on the 1st SR users committee. Mike Hart was also a Science Director of the SRS.

Keith Bowen (Warwick University) and Mike Hart (Bristol University) and later Brian Tanner (Durham University) worked closely together on developing some of the early stations for the facility. After this initial involvement they became major consultants for X-ray work and provided consultancy to the SRS on silicon, which was being considered as a material for the monochromators crystals at the time. Work was undertaken at the SRS investigating the crystal quality of silicon through x-ray topography work. The early engineering technology of double crystal monochromators was developed during the course of this work.

Bede Scientific was spun-out from Durham University in 1978 and by the early 1980s they were advising companies on silicon and cutting crystals. Keith Bowen developed an X-ray topography station in collaboration with the SRS for the Beijing storage ring which included a silicon monochromator. This and other work allowed them to develop their expertise in silicon monochromators, allowing them to grow their business into other areas. The company went on to manufacture semiconductor metrology tools for control of wafer quality within the semiconductor industry. Listed on the Stock Exchange from 2000, Bede Scientific became a leading supplier of High Resolution XRD metrology for the semiconductor and compound industries with revenues of $11.6M in 2007 and was acquired by Jordan Valley Semiconductors UK Ltd in April 2008[99].

Astex Therapeutics Ltd[100]

Astex Therapeutics Ltd[101] a world leader in fragment-based drug discovery, was founded in 1999. The founders included Dr Harren Jhoti, Professor Sir Tom Blundell, FRS, Professor Chris Abell, and Dr Roberto Solari. Both Professor Blundell and Professor Jhoti were users of the SRS in the 1980s. Astex was a regular user of the PX capability of the SRS and entered into a contractual agreement for access to the SRS in 2001.

Astex has established strategic collaborations with major pharmaceutical companies[102]. For example, Pfizer have taken a non-exclusive, worldwide licence of Astex's cytochrome P450 intellectual

98 www.bede.com
99 Information on Bede Ltd has not been reviewed by anyone at the former organisation as they were unavailable for comment
100 Case study adapted from PA Consulting report on the "Economic Impact of the Research Councils" and an interview with Astex Ltd
101 www.astex-therapeutics.com
102 www.astex-therapeutics.com/investorsandmedia/pressdetail.php?uid=57

property[103] which extends the bioavailability of drugs in the body. Interviewees from the PA Consulting EI case study on PX at the SRS[104] stated - "The development of compounds binding to P450 by Astex Therapeutics is a good example of the successful use of PX at the SRS for drug discovery". Additionally - “it is hard to imagine how such companies could exist without access to SR facilities such as the SRS.”

Since Astex began its operations it has raised more than £77 million in equity capital and venture loans. This example illustrates how useful the SRS has been to Astex users of the SRS, contributing to the knowledge of the founders and subsequently contributing to the capabilities of the company.

10.6 Patents and licences

A number of patents have resulted from both accelerator and experimental applications on the SRS and royalties have accrued from both the licensing of inventions and copyrighted designs. In all, twenty-five patents were registered directly from work on the SRS, twelve of which are still active. Of these, seven have been licensed to STFC spin-out companies (L3T and PETRRA[105]) and one is licensed to an external commercial customer. Royalties received for the licence of SRS technology from mid 1990s to 2008 brought in revenue of £1M from 15 different licenses. These licences were sold to 10 industrial customers and 1 other synchrotron.

10.7 SuperClean

In addition to spin-outs from the SRS, a cleaning service is offered to commercial customers. High tech industries such as aerospace, medical, defence, communications and electronics have benefited from high precision cleaning techniques developed at the SRS due to a supply chain collaboration service business. SuperClean[106] uses technology and expertise developed to clean components on the SRS to offer critical precision cleaning for a wide range of high technology applications including defence, aerospace, medical, communications, electronics and other industries. SuperClean is a trading name which represents collaboration between the SRS Vacuum Services Group and Longworth Process Technology[107] and is an established contract cleaner and manufacturer of cleaning technology.

Even the tiniest traces of contamination can cause huge problems in a manufacturing or scientific environment. Organisations are outsourcing their cleaning to SuperClean which offers ultra high specification cleaning and can provide mass spectroscopic analysis of cleaned components.

10.8 Impact summary

- *The economic impact of commercialisation of SRS technology has resulted in 6 spin-out companies and one commercial service provider. In addition, one company has been spun-out by ex SRS staff members and two have been spun-out by ex SRS users.*
- *These examples illustrate how the skills, expertise and technology from the SRS have been successfully exploited to create new businesses and hence generate impact in the economy and create jobs.*
- *In addition, some of these companies operate in industry sectors that are directly of benefit to everyday life, for example cholesterol testing or drug development.*
- *These examples show how the exploitation of cutting edge science can be translated to meet the real needs of our society, directly benefiting both the UK economy and the health and well-being of people, on an international scale.*

[103] *www.astex-therapeutics.com/partnering/cyp450.php*
[104] *www.rcuk.ac.uk/innovation/impact/default.htm*
[105] *http://www.petrra.com/index.htm*
[106] *www.superclean.dl.ac.uk*
[107] *www.bmlongworth.com*

Chapter 11

Helping to solve industrial problems

Chapter 11

Helping to solve industrial problems

11.1 Introduction

Throughout the life of the SRS, there was a conscious effort to explore the potential for the use of the facility by other organisations. The SRS was primarily focused on the academic community in the early years of its operation. However, as time and attitudes to commercial usage of academic facilities changed, it became apparent that access to the SRS also had value for proprietary customers. This chapter presents an account of the industrial usage of the facility undertaken by direct contractual engagement with commercial clients for proprietary work. As highlighted earlier in the report, the usage of the SRS by industry became significant with 48% of the 2008 R&D Scoreboard[108] using the SRS in its lifetime.

As an attempt to indicate the scale and impact of this contractual work, data of certain metrics recorded over the life of the facility is presented wherever possible in quantitative form. However, it should be appreciated that, due to the strict commercial confidentiality surrounding this work, in many cases data concerning the economic and competitive advantage gained by commercial clients was never revealed and cannot be presented. It is therefore necessary to represent the economic impact of the commercial work through the details of the data recorded in house and those cases in which permission has been granted by industrial partners.

Hence in the following chapter (and subsequent commercial chapters) it is only possible to identify those clients where explicit permission has been given. This does not exclude the use of statistical data and it is possible to present both quantitative and qualitative information relating to commercial use of the SRS, without breaking confidentialities.

11.2 Early commercial use

Early use of synchrotron radiation was initiated by an Industrial Consortium made up of Shell, BP and ICI. The funds raised by the first five years of the Industrial Consortium contract were specifically identified in the written agreement as contributing substantially to the capital necessary for the construction and commissioning of a new materials science station; this subsequently was one of the 'flag-ship' stations on the SRS, used extensively by both academics and industrialists.

Due to marketing activities aimed at widening the range of industries making use of synchrotron radiation for their R&D programmes, new contracts were written with Unilever, a Swiss academic institute (fronting for one or more industrial backers) and with a number of other UK industrial organisations who had become alerted to the potential use of synchrotron radiation for materials characterisation.

During these early activities, the use of the stations on the SRS and the acquisition of data were usually carried out by the companies' own staff, with the standard support from a station scientist. This involved a substantial degree of training for the commercial scientific staff. This meant that those staff members not only learned how to set up the SRS station and take data, but also became more aware of the details of the techniques available and the potential for the SRS to further enhance their company's research and development programmes.

[108] *http://www.innovation.gov.uk/rd_scoreboard/default.asp?p=13*

In addition, the pharmaceutical company, Glaxo, entered into contract for the provision of a protein crystal structural characterisation service. Glaxo's requirement was to submit crystals and have the SRS staff carry out data acquisition and initial analysis. The data would then be returned to the company for their own staff to fully resolve the protein structure. The SRS staff provided their expertise in data acquisition and interpretation and this model became the standard pattern for a future industrial service. Using this model, both Glaxo and Unilever also bought dedicated SRS staff time to carry out analysis of a particular problem.

An important factor in this early usage of the facility by industry was the IP ownership model adopted by the SRS. In this model, the user owned all of the IP which resulted from the sample and the Daresbury Laboratory owned any IP which arose from development of technology which had to be generated to manipulate the sample. This was a model which was different to that of overseas synchrotrons and hence made the usage of the SRS attractive to commercial customers. This also meant that the SRS was the first facility to develop standard terms and conditions associated with commercial use.

11.3 The growth in commercial use

From the commencement of marketing activities in 1988 up to the mid 1990s there was a sustained growth in the use of beams from the SRS by industrial users, measured both by the number of commercial contracts and by the number of experimental station hours allocated for such work. On a number of stations the industrial demand approached or even occasionally exceeded the 10% limit of total station time allocated for commercial use. Statistics of this development were published in a number of scientific journals[109],[110],[111], both for publicity and to provide information for other synchrotron radiation laboratories that had started to work directly with industry[112].

An internal Daresbury Laboratory report[113] of 1997 provides statistical data of the industrial use of synchrotron radiation by industry during the period 1990-96. This data indicates that over 11,000 hours was allocated to 20 individual companies with 2500 hours allocated to 13 individual academic intermediaries which were funded by industrial principals to carry out research projects. A conservative estimate for these shifts allocated (at 1996/97 prices) is £2.3M. The break-down of the commercial use by industrial type is shown in figure 32 below. As the industrial nature of the principals behind the contracting academics was undeclared, the academic clients are shown as a single group.

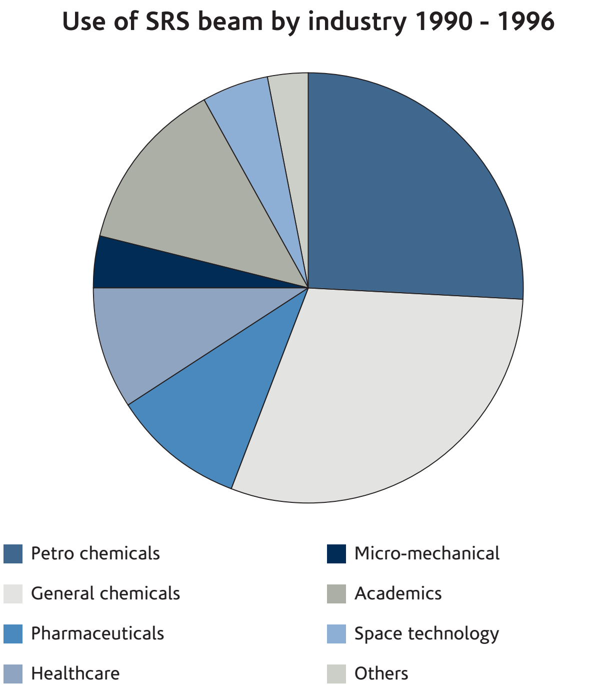


Figure 32, use of SRS beam by industry from 1990 to mid 1996; broken down according to type of industry

[109] *'Industrial Applications of Synchrotron Radiation', P. Barnes, J. Charnock and N. Marks, Nucl. Insts. and Meths., B56/57 (1991).*
[110] *'The use of Synchrotron Radiation in Industrial Research', P. Barnes and N. Marks, Nucl. Insts. and Meths., A314 (1992).*
[111] *'Industrial Applications at the Daresbury SRS', P. Barnes, J. Charnock and N. Marks, Synchrotron Radiation News, 1993, Vol 6, No 6.*
[112] *'Synchrotron Radiation Projects of Industrial Interest, N. Marks, Proc of 6th European Particle Accelerator Conference, Stockholm, 1998*
[113] *'Industrial Liaison Activities of S.R. Department 1990 -96, N. Marks, internal Daresbury Laboratory Report, Nov 1997*

11.4 Working with BP and ICI

Examples of the kind of work carried out by industry are given in this section. The STFC is indebted to BP and the current owners of ICI intellectual property for allowing some of the information relating to both company's use of the SRS for their research programmes to be made available. Also to Professors Richard Joyner and Richard Oldman, who provided the details below.

BP

The BP programme was coordinated from their research centre in Sunbury, which carried out corporate work in addition to more applied research projects for both BP Oil and BP Chemicals. BP's main topic of interest was heterogeneous catalysis, probably amounting to about 90% of the work done on the SRS. Prof. Joyner's particular area of expertise was extended X-ray absorption fine structure (EXAFS), a major spectroscopic technique which identifies the position and bond of a target element in a solid or liquid compound. Much of the work involved in-situ catalyst studies, with reagent gases including propane and nitrous oxide.

Investigations were also carried out on alkali-metal promoters for catalysts. The effect had been discovered in Japan, but BP optimised this technique, with the SRS playing some part in this work. Generally the SRS work was undertaken to improve general understanding of the catalyst and its operation, rather than to improve particular materials or processes. Other projects included studies of the degradation of zinc dithio-dihydro phosphate, an oil additive. Work was also carried out on the SRS to determine trace metal levels in oil-bearing rock cores.

ICI

Scientists within the major research departments of ICI were among the first industrialists to recognise the potential of the SRS, which they used for a breadth of applications. During the fourteen years of ICI research at Daresbury, at which time ICI was one of the largest chemical companies in the world, virtually every one of its divisions participated, using all the major techniques available on the synchrotron.

The research ranged from the short-term and tactical, to more strategic, fundamental research. Towards the end of the consortium's operations, the ICI portion was shared with Zeneca, formerly ICI Pharmaceuticals, which had separated from the parent company. Conservatively, it is estimated that ICI spent more than £1 million at the SRS, but this amount was much less than the cost of ICI manpower employed. Typically, ICI deployed a team of four or five PhD scientists to work on various techniques at the SRS. Alongside those experimentalists were several scientists whose expertise lay in modelling or data analysis. It was estimated that for much of the research, a 24-hour shift of beam-time resulted in a man-month of desk work on analysis, modelling, dissemination and publication.

Even now, more than 20 years after the experiments began their financial, scientific and operational benefits cannot be disclosed in detail; only a small proportion of the work was published externally. However, a list of topics, with a short summary for each, is given in Appendix 6, to provide an indication of the diversity of the topics studied. In summary, the details in Appendix 6 show that a very wide range of products and processes were examined. Much of the research was used to enhance the fundamental understanding rather than to lead directly to new products and processes, and consequently the exact financial benefits cannot be determined precisely. However, as an example, the safeguarding of the patent for electrode coatings, detailed in the Appendix, may well have contributed to the success of ICI's electrode coating business. This technology is now installed in many tens of cell rooms worldwide and has created a multi-million pound UK business, substantial enough to win the Queen's Award for Export.

11.5 On-going commercial access

Work carried out by the commercial office at the SRS indicated that the facility was relevant to a wider range of industries than previously thought, including major companies involved in materials, specialised chemicals, and other areas, to which synchrotron radiation would be relevant to their R&D needs. Market analysis indicated that these companies would need specialised support by SRS staff in carrying out experiments and analysis. Hence a new materials characterisation service (the "Daresbury Analytical Research and Technical Service" – DARTS) was created to offer an extended service to industry.

The new service built up a data base of 62 commercial (industrial) clients and 15 academic institutes wishing to obtain beam-time through commercial access. It is likely that much of the commercially oriented academic access was to perform work for an industrial sponsor who wished to retain the intellectual property of the results, without publication. Some degree of the nature of this work can perhaps be deduced from the station utilisation statistics.

Year	Customers per year	'Jobs' per year
1997	15	19
1998	11	20
1999	18	56
2000	19	41
2001	18	52
2002	17	49
2003	10	18
2004	18	44
2005	18	36
2006	15	19
2007	16	32
TOTAL JOBS:		**386**

Table 5, performance of the DARTS service between 1997 and 2007

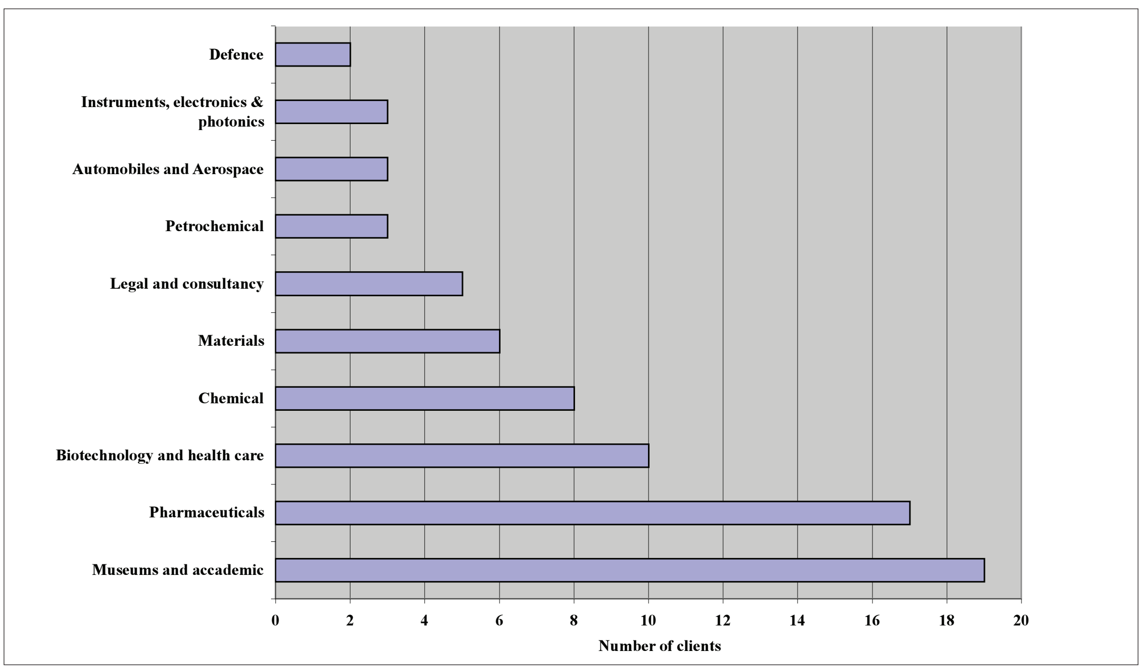


Figure 33, number of clients using the DARTS service from 1997 to 2007, according to industry type

As with the early work, the details of the performed work are confidential and hence it is not possible to provide a detailed list with the client's identities. However, statistical data is presented in the table 5, detailing the number of customers and 'jobs' performed per annum between 1997 and 2007. Figure 33 shows the number of clients, according to industry type, using the DARTS service in that decade. Figure 34 details the income during the same period expressed as a percentage of the total income.

During the period from 1997 to 2007, records indicate that total income from the industrial service amounted to nearly £2M. It is clear from figures 33 and 34 that the pharmaceutical industry was the largest single commercial sector making use of the service. Most of this work remains highly confidential, though it is possible to provide some details of the impact of work performed by some customers who have agreed to have their work published in case studies, some of which are given for reference in Appendix 7.

The area of drug discovery is highlighted below as a number of pharmaceutical and biotechnology companies use protein structures, derived from protein crystallography work at the SRS, to assist their drug discovery programmes. The information below is adapted from the PA Consulting case study on protein crystallography on the SRS[114].

11.6 Drug discovery

The knowledge of protein structure can increase the effectiveness of drug discovery, in particular the generation and optimisation of lead drug compounds. This knowledge has the potential to realise benefits in two ways: offering a completely new product to the market; and reducing development costs.

Whilst it is clear that the pharmaceutical industry's use of the SRS (and other synchrotrons) has had an impact on structure based drug discovery, it is extremely difficult to quantify the contribution of the SRS to any drug discovery. One researcher interviewed by PA Consulting states –

"...its contributions are blunted by the length of time required for drug development from target identification through to the identification of a library of compounds, clinical trials and finally regulatory approval. The costs involved reduce the perceived impact and benefit of PX in drug discovery and development."

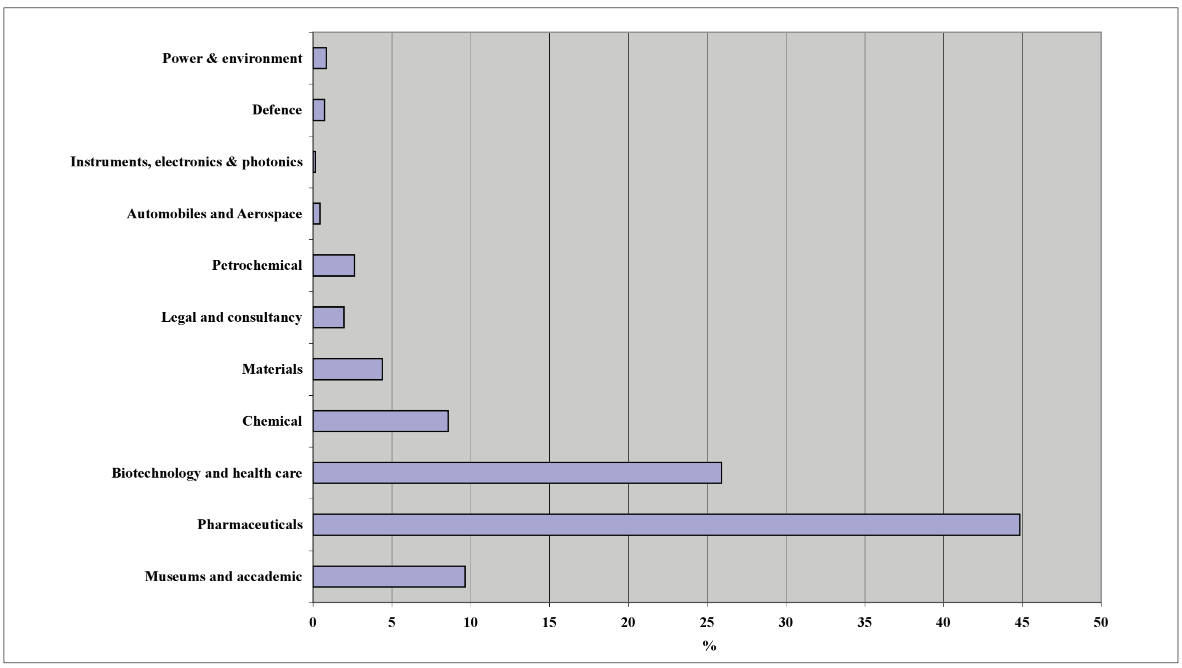


Figure 34, income from DARTS service from 1997 to 2007, expressed as a percentage of the total, according to industry type

[114] www.rcuk.ac.uk/innovation/impact/default.htm

Bearing this in mind, the following benefits have arisen from the use of the SRS –

- **Reduced development time**
  The Association of the British Pharmaceutical Industry[115] states that the cost of developing a new medicine is estimated at more than $700 million and takes between ten and twelve years, with no guarantee of commercial success. The SRS has played a role in drug discovery programmes by enabling structural insights that lead to more effective drug development. The application of high throughput PX techniques and computational methods for drug design contribute to reducing that development time. It is impossible to estimate the value of this contribution but even if it is a small fraction then the impact is still many $millions per drug.

- **Earlier market exploitation**
  A new blockbuster drug[116] will generate revenues of close to $1,000 million per annum for 10 or 12 years. The SRS could provide results inaccessible to other techniques and if the time to market could be reduced by just six months, then $500 million additional revenue can potentially be generated. This assumes that the new drug does not displace an existing product. Of this a small but significant proportion would be expected to be attributed to the PX insights.

The markets which are relevant to structure based (or guided) drug discovery are extremely significant - cancer chemotherapy[117] ($42,000 million), influenza[118] ($3,000 million), HIV[119] ($8,500 million), multiple sclerosis[120] ($5,000 million) and rheumatoid arthritis[121] ($8,000 million). If work on the SRS has contributed as much as 0.5% towards the revenues for drugs in these markets then the economic impact remains hugely significant, ranging from $15 million to $200 million of revenue in various therapeutic areas.

Examples
There are a number of examples of contributions to drug discovery from the SRS –

- BioCryst Pharmaceuticals[122] based in the USA design drug candidates using detailed knowledge of the structures of active sites of targeted enzymes. The structure of the enzyme purine nucleoside phosphorylase[123], provided a starting point to design new drugs to target diseases such as psoriasis, rheumatoid arthritis, multiple sclerosis and Crohn's disease[124],[125].

  The company was set up in 1986 to develop such inhibitors on the basis of codified knowledge gained from the use of the protein crystallography capability at the SRS. The collaboration between the company's founder and SRS station scientists was particularly strong. Quoted in Scientific American, the company stated –

"The real aggravation arose when we proceeded to the detailed structural determination. In the early years we had to depend on an X-ray source that generated relatively low-intensity waves. The resulting low-resolution diffraction patterns enabled us to discern the overall shape of the molecules, but we could not properly place the individual atoms. We eventually filled in the missing details in collaboration with John R. Helliwell of the Daresbury Laboratory Synchrotron Radiation Source in England. The synchrotron emitted the intense X-rays needed for high-resolution imaging."(Quote from reference 123)

115 *www.abpi.org.uk/statistics/intro.asp*
116 *www.en.wikipedia.org/wiki/Blockbuster_drug*
117 *Chemotherapy Market Insights, 2006-2016: A Critical Analysis of Cancer Research, Treatments, Pipelines, and Commercial Opportunities (Spectra Intelligence, 2006)*
118 *The worldwide Influenza market (Business Communications Company, 2006)*
119 *The Global Anti-Virals Market: R&D Pipelines, Market Analysis and Competitive Landscape (Arrowhead Publishers, 2006)*
120 *The Global Market and Future Outlook for Neurodegenerative Disorder Therapies (Arrowhead Publishers, 2007)*
121 *www.imshealth.com/web/content/0,3148,64576068_63872702_70261004_78677274,00.html*
122 *http://www.biocryst.com/*
123 *Three-dimensional Structure of Human Erythrocytic Purine Nucleoside Phosphorylase at 3.2Å Resolution Ealick, S.E.; Rule, S.A.; Carter, D.C.; Greenhough, T.J.; Babu, Y.S.; Cook, W.J.; Habash, J.; Helliwell, J.R.; Stoeckler, J.D.; Parks, R.E. Jr.; Chen, S.-f.; Bugg, C.E. Journal of Biolological Chemistry, 1990, 265, 1812-1820.*
124 *Bugg, C. E. et al. (1993), "Drugs by design", Scientific American 269, P.92-98*
125 *Bu, Y. S. at al. (1995), "Structure-based design of inhibitors of purine nucleoside phosphorylase", ActaCrystallographica Section D51, 529-535*

Today BioCryst has extensive research programmes and compounds in clinical trials on a range of disease targets. One inhibitor of this enzyme is in clinical trials and has been licensed to Roche[126].

- One interviewee commented that "GlaxoSmithKline did [a significant amount of] work on the influenza virus. Haemagglutinin and neuraminidase structures were completed 17 or 18 years ago from which drugs have been developed."
- As already mentioed, the SRS played a significant role in the identification of the first 14 HIV proteins. The HIV1 protease is another example of the success of structure based drug design. A number of companies investigated these structures via proprietary research or in collaboration with academic researchers using the SRS (from 1989 to 1993 and later)[127],[128]. An interviewee remarked that "a large number of structures were determined involving researchers and synchrotrons all over the world, including the SRS." The structures allowed the development of a cocktail of inhibitors (to overcome the development of resistance) as new anti-viral treatments (Abbott Laboratories and Merck Research Laboratories).
- Avidex Ltd, a biotechnology company, used the SRS to determine the structure of wild-type and mutant CD8+ T-cell receptors and their complexes with antigen-peptide complexes. The company then engineered the receptors to selectively bind oesophageal cancer cells and induce an immune response[129].
- Astex Therapeutics Ltd were regular users of the SRS until 2004 and pioneered the use of high throughput protein crystallography using chemical fragment-based screening. Their drug discovery program focuses on kinase inhibitors as anticancer agents and uses the knowledge of the structure of human cytochrome P450 enzyme isoforms (2003/04) to extend the bioavailability of drugs in the body. Pfizer have taken a non-exclusive, worldwide licence[130] of Astex's cytochrome P450 intellectual property.
- Research scientists from Organon Laboratories developed a novel method for reversing the effects of neuromuscular blockers administered during operations performed under general anaesthetic, additionally eliminating many of the commonly encountered side effects from anaesthesia, thus aiding the recovery.

  Data was collected on the SRS that allowed the structure of the blocker to be solved, confirming that the drug design process had been successful. Clinical trials have shown this new method to reverse the effects of the neuromuscular blocker twice as fast as conventional treatments and with none of the side effects. Human clinical trials have taken place and the drug has recently been released into the market. Schering-Plough and Organon have released BRIDION[131] for the reversal of neuromuscular blockers. A recent press release for the drug states –

  "Schering-Plough Corporation today announced that the European Commission has approved BRIDION injection, the first and only selective relaxant binding agent and the first major pharmaceutical advance in the field of anaesthesia in two decades."

  The impact on post operative intensive care costs through use of this drug is expected to be significant.

[126] *www.biocryst.com/bcx_4208.htm*
[127] *Wonacott, A. et al. (1993), "A series of penicillin-derived C2-symmetrical inhibitors of HIV-1 proteinase – structural and modelling studies", Journal of Medicinal Chemistry 36, P.3113-3119*
[128] *Lapatto, R. at al. (1989), "X-ray analysis of HIV-1 proteinase at 2.7 Å resolution confirms structural homology among retroviral enzymes", Nature 342, 299-302*
[129] *Chen, J. et al. (2005), Structural and kinetic basis for heightened immunogenicity of T cell vaccines", Journal of Experimental Medicine 201, P.1243-1255*
[130] *www.astex-therapeutics.com/partnering/cyp450.php*
[131] *http://www.bridion.com/hcp/index.asp*

Other structure based drug design examples include anti-tuberculosis agents, drugs for sleeping sickness and compounds targeting malarial proteins. Overall, many of the 3D structures determined at the SRS have been of human proteins or proteins from organisms that affect human well being. Knowledge of the 3D structure of such proteins can allow chemists to tailor the design of pharmaceuticals to better fit and exert an effect on the target. This has led to some drug designs that are currently bearing fruit in improving worldwide healthcare and the quality of life[132]. Hence the SRS has been a key resource for the UK bio-community and pharmaceutical companies.

11.7 Facility brokering service

In addition to providing the full analytical service, with interpretation and explanation of data, SRS staff aided their clients with pressing or demanding problems by providing a facility brokering service. One of the customers supported in this way was a Middle Eastern company which became involved in a patent dispute. The SRS was approached by a UK academic who had been contacted by the end company, having acted as an expert witness on such cases for some years. The academic and the client recognised that the SRS had the capability to determine some facts about a chemical product which could prove the validity of a key patent. However, the Daresbury SRS was unavailable within the very tight time-scale required by the client.

Staff members used their networks and connections to facilitate access to the ESRF within a few days – a much faster turnaround than is normal for ESRF. Daresbury Laboratory scientists verified the data quality and interpretation, and supplied the results to the client in a format that could be used for patent defence. The project was perceived by the client to have been a very successful exercise and he subsequently approached the SRS to undertake further sample characterisation.

11.8 Industrial access through grant-awarded academics

In addition to the academics with industrial backers who entered into commercial contracts for beam access, it was known that other academics accessing the facility through the research councils' peer review system were, in some instances, in collaboration with industrial partners. Whilst such arrangements are seldom identified on grant proposals, these liaisons were demonstrated both by the presence of the industrial company's staff on the experimental station during data acquisition and also by inclusion in the author lists of published papers. These collaborating companies chose academic liaison in preference to a direct commercial contract on the SRS. It is noteworthy that some of the most outstanding, highly cited work performed on the SRS has been supported in this way. For example, the University of Oxford's determination of the 3-D structure of the Foot and Mouth Disease virus in conjunction with the Wellcome company, before their merger with Glaxo.

In an attempt to assess the scale of such indirect industrial use, academic papers identified in the SRS Annual Report 1994/95 were examined and all instances of industrial companies' staff being included as co-authors noted. The list of companies produced by this exercise is shown in the first section of Appendix 8. Additionally, EPSRC was approached and a further group of commercial collaborators was identified from grant application data; this group is shown in the second section of Appendix 8.

This exercise demonstrates that, during a typical single year, a total of 56 organisations (34 UK based and 22 overseas), who did not pay for direct access, chose to enter into collaboration with entitled academics in order to access the SRS. The nature and scale of the resulting work was difficult to assess. However, even though there are no records of the work undertaken or the beam-time required, the evidence suggests that this access was similar in volume to the direct commercial access and is significant when considering the impact the SRS has had on industry.

[132] *Stevens, R. C. (2004), "Long live structural biology", Nature Structural & Molecular Biology 11, P.293-295*

11.9 Micro-mechanical components for the nuclear industry

LIGA (German acronym - LIthographie, Galvanoformung und Abformung)[133],[134] is a generic lithographic technology developed to produce micro-mechanical components for the nuclear industry. Synchrotron radiation is an essential part of the process, the intensity and parallelism of the X-rays allowing greater and more accurate penetration of the photo-resist than is provided by more conventional sources. In the 1990s, many synchrotron sources around the world were involved in exploration of the technique. The system was developed at the KFK Institute, Karlsruhe[135] (now the FZK). It was soon recognised as having considerable potential for many micro-mechanics applications and its use spread to a much wider range of industries.

Early work at Daresbury by staff from KFK and a spin-off company, 'Micro-parts'[136], which entered into contract for the provision of synchrotron radiation, demonstrated that the radiation in an SRS X-ray station was ideal for the technique. Hence, the SRS was one of the most suitable sources in Europe to support a LIGA industrial programme. It was clear that the radiation from the SRS was a valuable tool for this process and a major initiative, to attract and inform UK industry of the potential of the technique, commenced in 1994.

The initiative resulted in the creation of a 'LIGA Club', with full industrial membership offering the members technology advice and the production of two different micro-components based on bespoke designs specified by the member. Four organisations entered into full membership of the club, BNFL, BICC, Oxley Developments (an SME electronics component company) and De Montfort University (representing a number of automotive principals). A 'LIGA Interest Group' was also formed with 54 members, which included major multi-national industries, SMEs and academic institutions. Meetings and workshops were organised and liaison with the two German based organisations arranged. Appendix 9 gives the aims of the LIGA Interest Group and a list of the member organisations.

An example of a primary LIGA product is shown in Figure 35. The production of the LIGA devices at the SRS demonstrated a number of significant technical difficulties. In spite of these problems, marketing activities continued[137] and the use of LIGA for deep lithography is still active today. Many of the companies which had first been introduced to micro-technology as members of the LIGA Interest Group continue to benefit from the technology that they learned at that time and are currently active in this field[138].

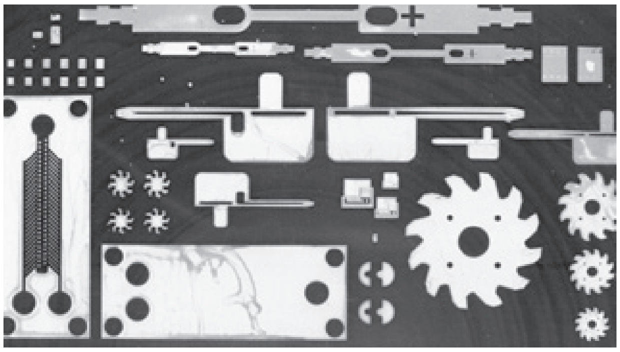


Figure 35, LIGA structures produced for DTI North West, as a market demonstrator (scale note - the smallest devices shown are the array of 12 sensors (top left) - each is less than 0.5 mm across, with detail less than an order of magnitude smaller (not resolved in this reproduction)

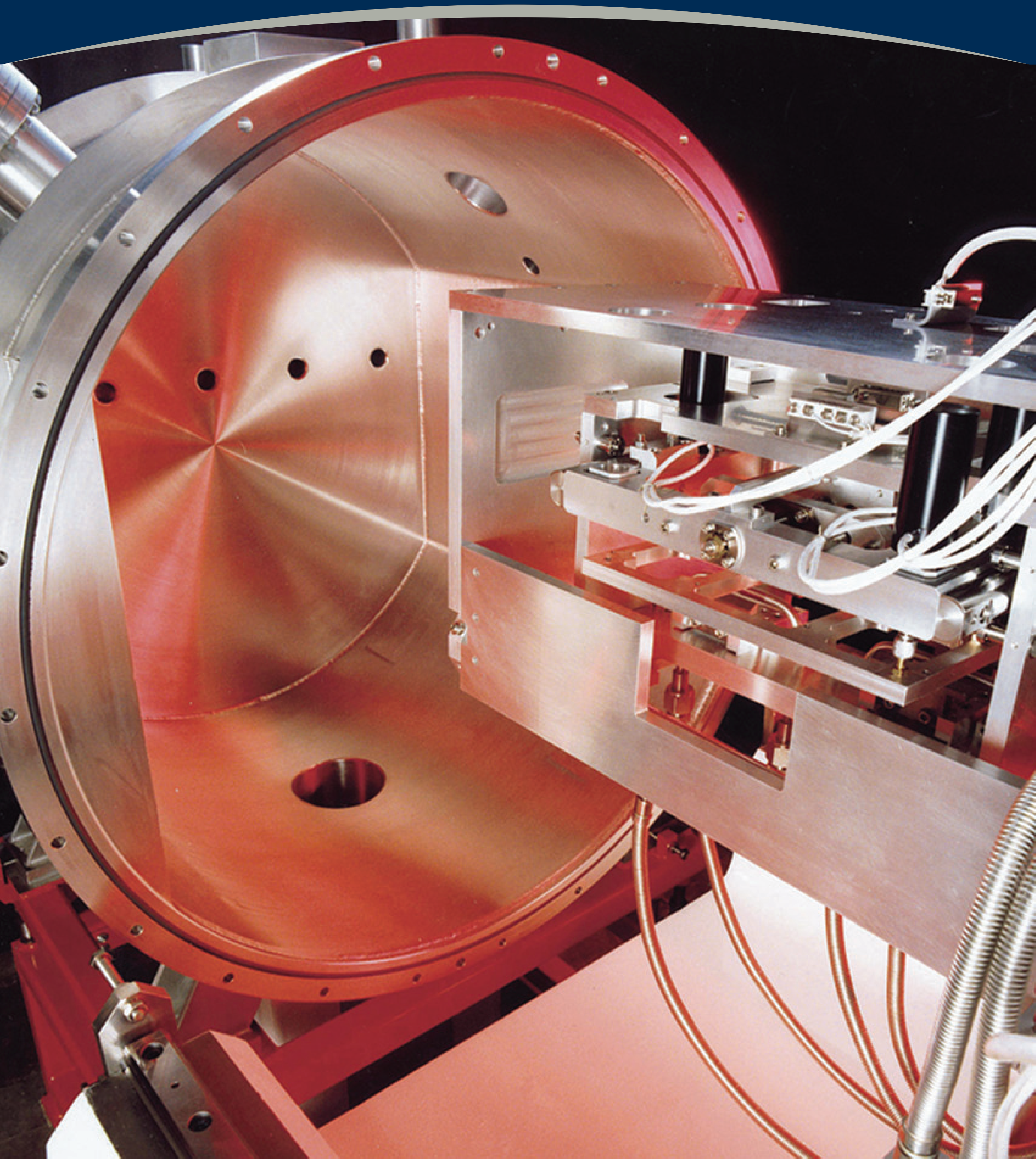
[133] *Becker, E.W. et al. (1986), "Fabrication of microstructures with high aspect ratios and great structural heights by synchrotron radiation lithography, galvanoforming, and plastic molding (LIGA process)," Microelectric Engineering, vol. 4, P.35*
[134] *W Bacher et al. (1995), "The LIGA technique and its potential for microsystems-a survey", IEEE Transactions on Industrial Electronics, Vol 42, No5*
[135] *www.fzk.de/fzk/idcplg?IdcService=FZK&node=Home&lang=en*
[136] *www.boehringeringelheim.de/produkte/mikrosystemtechnik/microtechnology*
[137] *D.W.T.Tolfree (1996), 'Infrastructure and Technology Transfer Programmes for Micro-technology in the UK', Proceedings of Commercialization of Microsystems, Kona, Hawaii.*
[138] *D.W.W.T. Tolfree & M.J. Jackson (2008) "Commercialising Micro-Nanotechnology Products", Chs 1-9, CRC Press*

11.10 Impact summary

As can be seen from this chapter there has been significant impact to industry through the usage of the SRS –

- *Hundreds of industrial partners worked with the SRS to improve their products and processes. These customers were wide ranging, including government departments, industry, hospitals, museums and universities. From 1990 to 2007, the income generated by this proprietary usage was over £4M, which was re-invested into the facility.*
- *The exact financial impact to the customers of the SRS cannot be quantified but one can assume that this work created opportunities for UK industry and would have gone some way to increase the turnover and competitiveness of the companies assisted, in addition to improving the quality of life in the UK. In particular the SRS was a key resource for the UK bio-community and pharmaceutical sectors, leading to some drug designs that are impacting worldwide healthcare.*
- *Welfare impacts will also have been felt by public sector customers such as hospitals, cancer research organisations and museums; their usage for disease prevention and cultural studies has impacted daily lives in the UK.*

Chapter 12
Exchanging knowledge with industry



Chapter 12

Exchanging knowledge with industry

"I am delighted that the SRS continues to enable excellent science to be done, and that it is used by so many researchers from a wide range of organisations. The reports show that it plays an important role in helping the transfer of technology from the science base to users – something that the Government is keen to foster.[139]"

12.1 Introduction

The majority of the commercial activities detailed in the previous chapter involved knowledge transfer between SRS staff and the commercial client. When a commercial user interacted with the facility, SRS staff support was not restricted to technical details but often included discussion and advice on measurement techniques and potential for future developments. Discussions frequently included scientific issues involved in performing data analysis and explaining conclusions of the work. Hence, knowledge transfer is inherent in all such activities detailed in the previous chapter.

However, there have also been many commercial activities where the knowledge transfer was more than just incidental to the prime activity of the collaboration. In these cases technology transfer was either the exclusive aim of the contract or it was a vital and sustained feature of the deliverables. Examples of such projects are given in this chapter.

In addition, there was a significant occurrence of knowledge exchange in those cases where technology development occurred between the SRS and a supplier of a particular technology. In order to design, build and operate such a technically demanding facility as the SRS, it was necessary for the staff involved to become expert in a range of different technologies. The construction of both the accelerator complex and the experimental beam-lines for the SRS involved major in-house design, followed by the purchase of equipment from commercial companies and subsequent assembly in the facility.

In some instances essential technologies were developed with industry, to the benefit of both the Laboratory's experience and to the industrial partners involved. Whilst in these cases there may not have been direct, intentional technology transfer, there was still a significant benefit to the company both in finances and experience. These benefits occurred both at the construction stage of the facility, and throughout its lifetime as new technical developments opened up new research methods and goals, and continued almost to the end of the facility's operation. The satisfactory operation and development of the SRS therefore required an ongoing procurement exercise, the nature of which changed with time. The success of these procurement initiatives depended on transparent, effective and willing communication between those tasked with the procurement of the capital equipment and the manufacturers. It is therefore not surprising that significant, two-way knowledge transfer occurred during the purchase of major items of equipment. There was then an on-going interplay between supplier and demander which, of necessity, resulted in the successful testing and delivery of equipment which was fit-for-purpose. This serendipitous or indirect knowledge exchange through technology development and equipment procurement is also detailed in the following chapter.

[139] *Sir John Cadogan, Director-General, Research Councils, 1995, presentation at the Daresbury Laboratory*

12.2 Direct knowledge exchange

This section details a number of contracts specifically oriented on knowledge exchange between the SRS and a commercial partner.

12.2.1 Building a compact synchrotron source

During the mid 1980s, the UK company Oxford Instruments (OI), which specialised in superconducting technology, approached the Daresbury Laboratory requesting support in the design and construction of a compact synchrotron source for use in X-ray lithography. The company had received an enquiry from IBM (USA) to design and build a superconducting storage ring for this purpose; the basic ring was to be sufficiently compact to allow transport by air and was to be designed with multiple beam-lines so as to support an active and intensive lithography programme.

The accelerator was jointly designed by Oxford Instruments and SRS staff under the terms of two contracts, one covering the provision and licensing of background intellectual property and the other covered the provision of consultancy during the contract. The SRS accelerator staff were responsible for the design and engineering of several of the major components of the source, its testing and commissioning. Oxford Instruments successfully tendered to IBM for the contract, citing the role of the SRS scientists as a major component in winning the contract.

The compact storage ring was subsequently named "Helios" and the design and construction went to plan. During testing and commissioning in Oxford, an additional contract was tendered which secured the services of the Daresbury radiation protection officer to fulfil the health and safety requirements of the contract. The Helios source was successfully delivered to IBM, and performed according to their specification. The Oxford Instrument's Helios project manager subsequently published a report on this successful collaboration[140] in which he states –

"With a 99.5% uptime in 1993, Helios I has established itself as one of the world's most reliable storage rings. None of this could have been achieved without Oxford's collaboration with Daresbury, a collaboration that continues."

A photograph of Helios I undergoing initial commissioning at Oxford Instruments is shown below.

Figure 36, Helios I undergoing initial commissioning at Oxford Instruments

After this initial success, the company was able to apply the skills and experience learned in the Helios I exercise to manage the in-house design of a second accelerator (Helios II) in a fully independent way - the hallmark of truly successful technology transfer. Helios II is fully operational at the Singapore Synchrotron Light Source[141] and is supporting a strong academic and industrial research programme, including LIGA. This work certainly pump-primed generic accelerator and photon science expertise in Oxford Instruments. The following financial figures (at 1990 price levels) are provided to indicate the size and significance of the Helios project to Oxford Instruments and their recognition of the work performed by SRS staff –

[140] *M.N.Wilson, (1994), "Technology Transfer on the Helios Project", Proc of 4th European Particle Accelerator Conference, London*

[141] *H.O.Moser et al (2004), 'Singapore Synchrotron Light Source - Helios II and Beyond', Proceedings of 9th European Particle Accelerator Conference, Lucerne*

Element	Cost
Helios I	£8750K
Royalty paid by OI to SRS relating to the sale of Helios I	£401K
Helios II	£9636K
Royalty paid by OI to SRS relating to the sale of Helios II	£215K

Table 6, royalties for Helios project

Oxford Instruments also commented on this activity when they were asked to input information into a House of Commons Science and Technology Select Committee hearing on Engineering and Physical Sciences Based Innovation in 1998[142]. An excerpt of this is given below –

> *"We would like to make it clear that the businesses which have been built on the basis of the technologies developed in these Government (or former Government) Laboratories would not exist today without the knowledge generated in those laboratories and in a number of cases the people transferred to the industrial sector."*

Another indication of the quality of the SRS staff input to this project was the fact that they won the Research Council Inventors' Awards for design and delivery of HELIOS.

12.2.2 Developing equipment for other SR sources

As part of an ongoing programme of improvements to the SRS experimental facilities, scientific and engineering staff developed an in-house design for a double silicon crystal X-ray monochromator. These instruments select a narrow band of radiation, with variable wavelength, from the broad synchrotron radiation spectrum emerging from the source and are essential equipment in any synchrotron radiation facility. The double crystal monochromator was developed principally for use in X-ray spectroscopy studies, and the design achieved a level of precision and stability equal, if not superior, to any commercial instrument then available. After a number of the instruments had been installed on SRS experimental stations and results published, international interest was stimulated by the quality of the design, and two further monochromators were assembled and sold directly by the Laboratory to overseas sources (ESRF and ELETTRA). These two direct sales were regarded as final prototyping, with the Daresbury engineers refining the design to make a commercially viable package.

The design was then offered as a licence to various manufacturers, with a tender exercise being used to determine the successful company. The exclusive licence was won by the UK vacuum specialist company, Vacuum Generators (VG), part of the Fisons conglomerate. Earlier, the Daresbury Laboratory had entered into a non-exclusive contract with VG, to provide ongoing technical help and advice. In addition to providing the manufacture of monochromators, the new contract supported further development work of the basic design and customised modification to meet the needs of the customer.

This collaboration was extremely successful with considerable interest developing as new SR sources were proposed and funded. This was substantially aided in the USA by the appointment, by VG, of a leading USA vacuum science equipment manufacturer and distributor, Kurt J. Lesker Company[143], as their agent. As a result, multiple orders were received for instruments to be installed on the USA national synchrotron source, the APS Chicago.

Subsequently, in excess of 17 monochromators were manufactured by Fisons VG and sold to new synchrotron radiation sources, many as exports to USA, Europe and elsewhere. Appendix 10 lists the sales of the SRS designed double crystal monochromator made by Vacuum Generators,

[142] *www.publications.parliament.uk/pa/cm199900/cmselect/cmsctech/195/195ap63.htm*
[143] *Pwww.lesker.com/newweb/index.cfm*

under the terms of the exploitation licence. It is recorded that the total value of the sales made by VG was £2.1M and the total royalty payment received by Daresbury Laboratory from VG was £96K.

Figure 37, the first double-crystal monochromator manufactured by Vacuum Generators in May 1995 and delivered to the new Advanced Photon source (APS)

This technology transfer resulted in a number of benefits, including exports for the UK, enhanced sales for a British company, and royalty receipts into the SRS. However, probably the most significant advantage to the synchrotron radiation sources world-wide was the further improvements and upgrades to the instrument's functionality and performance that resulted from the varied requirements of the different customers requesting specialised features on the monochromators.

12.2.3 Improving safety systems

An essential part of any accelerator complex is the personnel safety system which monitors staff access to high radiation areas and prevents the introduction of ionising beams into these areas when occupied. This system must be of the highest reliability and subject to exhaustive testing to demonstrate complete effectiveness before an operating licence can be issued to cover the commissioning of the accelerator. A system had been developed in-house for the SRS, controlling access to both the accelerator and experimental areas; the system provided complete computer monitoring so that area status and faults could be displayed to operators. The operational history of this system demonstrated no fail-to-danger incidents throughout the life of the SRS.

During the construction of the European Synchrotron Radiation Facility[144], a number of personnel safety systems were considered and the SRS design was chosen as the preferred system. SRS staff were consulted and supported the ESRF in producing a specification for construction. The contract was awarded to N.E. Technology[145] who subcontracted it to a North West company, Horwich Electronics[146] - an SME local to the SRS, which had produced the electronic crates and modules for the original SRS safety system. A second contract, for half of the experimental area system, was placed with AEA Technology, Culham, who again used Horwich Electronics as a sub-contractor. To complete the system, ESRF placed the final contract directly with Horwich with ESRF and SRS staff jointly managing the production and commissioning of the remaining electronic units.

The value of the three contracts for this system amounted to approximately £1M (1993 prices), of which an appreciable fraction was received by Horwich Electronics. Daresbury Laboratory charged a technology transfer fee and a royalty payment pro-rata to the contract values. This contract demonstrated the multiple benefits that can accrue from such commercial activity:

- The support of and supply of vital equipment to an international laboratory of which the UK was a member
- The economic and technical benefit to a small local electronics manufacturer
- Financial income to the SRS to support further development of the facility

144 *www.esrf.eu/*

145 *N.E. Technology Ltd, Bath Rd., Beenham, Reading, Berkshire. Acquired by Saint-Gobain in 1995 and eventually merged into the Bicron-NE business unit. See - www.powerhousemuseum.com/collection/database/?irn=365888*

146 *Horwich Electronic Laboratories, Longworth Road, Horwich, Bolton, BL6 7BN; (Tel: 01204 650555); no web site.*

12.3 Technology development

This section explores the nature of some of the more specialised and advanced technologies that were required for the synchrotron source and experiments and how interaction with the supply chain resulted in significant technical knowledge gain for the commercial contractor.

12.3.1 Developing magnet technologies

Tesla Engineering[147] located in West Sussex, manufacture electro-magnets for particle accelerators. This is a highly specialised market position, with Tesla having no UK competitors and with only four other accelerator magnet manufacturers trading in the whole of Western Europe. During the initial construction of the SRS storage ring, Tesla Engineering was a small company with modest production facilities but which had the benefit of a skilled work-force and a management that was highly experienced in magnet technology. Tesla successfully tendered for the production of the quadrupole magnets which were subsequently installed in the SRS and operated without problem over the life of the facility.

Later, during the significant upgrade to the magnet lattice of the SRS, Tesla again supplied the magnets which were added to the SRS ring. During the life of the SRS there was on-going contact between SRS accelerator physicists and Tesla Engineering; the contacts were both formal for magnet procurement and informal technical discussions at meetings and conferences.

A major issue that was highlighted from the on-going collaboration was that Tesla needed to obtain and operate its own precision magnet measurement equipment. This capability allowed the company to expand its supply profile, offering a complete engineering package of magnet supply, from initial design to final delivery of fully tested and measurement magnets. With advice from SRS scientists, this equipment ensured that the company's technical competence and its trading competitiveness was enhanced.

After winning a contract in excess of £2M for 240 magnets for the Diamond Light Source, Tesla commissioned and operated a measurement rig as advised by SRS staff. The Diamond procurement team included ex SRS staff who worked with Tesla to overcome initial technical problems with the system. This expertise came directly from knowledge gained on the SRS, both from interaction with other laboratories (particularly CERN) and from experience gained during the building, operation and up-grading of the SRS facility.

The result of this work is that Tesla Engineering now has fully functional and operationally proven magnet measuring equipment that it can cite in contractual quotations and use to offer an enhanced commercial service to customers, thus improving its competitiveness and expanding its market potential.

Considering the role that the SRS has played in the development of his company, Dr Michael Begg, Managing Director of Tesla Engineering wrote:

> *"It is useful to companies such as Tesla to be able to talk to people in physics laboratories and to ask questions about how various technologies work. During my time at Tesla I have often asked questions about materials, measurements, cryogenics, assembly methods as they relate to magnet building. No practical advice can be given unless there are still labs, such as the SRS, doing real projects that enable people to learn about new and interesting things.*
>
> *Also, it is challenging to companies such as Tesla to be asked to make things that are new and different. Novel and difficult requirements are often specified by physicists and engineers working in facilities such as the SRS. With challenging requirements comes high technology and with high technology comes jobs and profits."*

[147] *www.tesla.co.uk/*

The fruitful relationship with the Daresbury Laboratory scientists and Tesla Engineering continues, with Tesla recently winning the contract to provide magnets for the EMMA system (see chapter 14) at a cost of £300K.

12.3.2 Insertion device development

The introduction of specialised 'insertion devices' into the SRS allowed the generation of synchrotron radiation with higher intensity and different spectra to that which had been previously generated. Stations which received radiation from these insertion devices became the most advanced, provided the highest quality beams and contributed strongly to the outstanding success of the SRS experimental programme.

Insertion devices can, broadly, be categorised into three distinct types - undulator magnets, wiggler magnets and wavelength shifters. The principal insertion devices used on the SRS are listed in Appendix 11 together with the details of any commercial involvement. The insertion devices that were assembled at Daresbury Laboratory were built using many components purchased from commercial suppliers, either as catalogue items or bespoke according to an SRS design. The principal and most demanding items were:

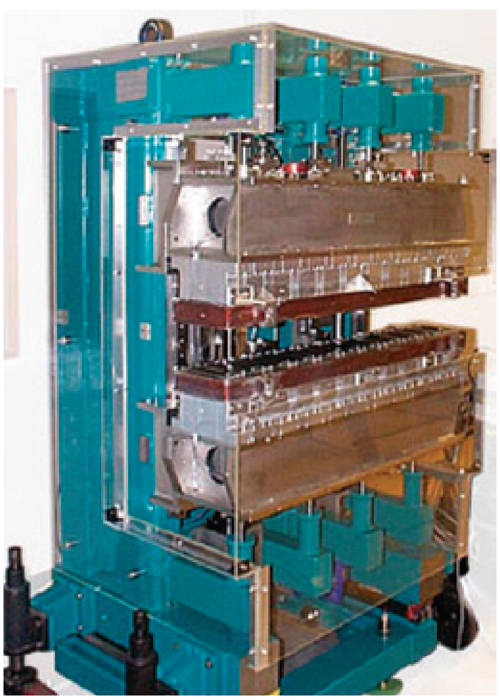


Figure 38, Multi-pole wiggler 6/14 prior to installation in the SRS

Permanent magnet blocks: A wide range of permanent magnetic materials are commercially available, with sintered rare-earth alloys having the highest energy density. The SRS wigglers used such material, specified and purchased from Vacuumschmelze GmbH & Co., a German manufacturer of specialised magnetic materials[148].

Precision motor drives: The inter-pole gaps in permanent magnet insertion devices need to be variable, with high precision and repeatability; they also have to drive against the very strong forces between the poles. All Daresbury Laboratory built variable gap insertion devices used motor drives manufactured by McLennan[149], a UK company that specialises in servo controlled motion drive systems. This company's products have also been used in other equipment and further reference is made later in the chapter.

12.3.3 Helping e2v product development

Radio-frequency (RF) power equipment has an important role in particle accelerators, providing the longitudinal electric field that is required to accelerate the particles. The design and construction of RF windows (usually a ceramic plate) is an exacting technology which is crucial for the successful operation of the accelerator. Over the life of the SRS there was strong and effective on-going communication between the SRS radio-frequency experts and the principal UK manufacturer of high power RF power sources, e2v[150]. The company has undergone several changes of ownership and throughout all these changes the company has continued to maintain a close contact with Daresbury Laboratory and SRS staff. The following information has been supplied by a retired senior member of the Company[151], with the Company's permission –

148 *www.vacuumschmelze.de/dynamic/en/*
149 *www.mclennan.co.uk*
150 *www.e2v.com/*
151 *Dr David Wilcox (ex e2v) - Private communication*

"At the time the SRS was commissioned, e2v (then EEV) was already closely involved with the engineering team at the Daresbury Laboratory. A short while later, the company was engaged by the SRS team to manufacture replacement ceramic RF windows, as there had been a number of unaccountable failures due to cracked ceramics caused by, it was thought, multipactor bombardment. Multipactoring, as its name suggests, is a phenomenon involving repeated bombardment of a surface by electrons. The solution to this problem was the development of antimultipactor coating.

At the time e2v also happened to be suffering a recurring and intractable problem of the cracking of ceramic RF output windows on its new range of wideband television klystron amplifiers. This, too, seemed to be caused by multipactoring. The solution to this was to adapt the coating method used on the SRS for application to TV klystrons. At a stroke, this reduced the problem to such a great degree that failure for this reason was no longer a matter of concern. From then onwards, the method was applied to all TV klystrons and subsequently to all TV Inductive Output Tubes (IOTs).

This was an example of the transfer of some key knowledge from the SRS project to a manufacturer, the lasting value of which was not foreseen at the time. It is also worth noting that the knowledge was not directly related to the technology of the product being manufactured but rather to an incidental problem having similarities with that on the SRS and seen to have a common cause and common solution. Were it not for the close working relations between the SRS team and the e2v's personnel, it is quite possible that the existence of this panacea would have remained hidden.

At the time immediately preceding the introduction of the coating, the ceramic cracking problem was placing the TV klystron business at e2v (then EEV) in jeopardy. Subsequent to its introduction, and quite quickly thereafter, the Company's position in this market rose from being one of three or four world suppliers to being the overwhelmingly dominant one. This huge success continued with the introduction of IOT technology and even today, some 20 years on, e2v looks forward to at least another ten years of profitable business for TV IOTs and klystrons. What is more, the products will, of necessity, continue to incorporate the anti-multipactor technique first witnessed on the SRS. As a financial measure of its worth, the sales value during the lifetime of these products incorporating the coating is estimated to reach of the order of £250 million, of which some 90% to 95% will have been exported."

12.3.4 Building the capacity of the vacuum science industry

In the late 1970s when the SRS was being designed, the major part of the vacuum industry in the UK was centred on the low to high vacuum regions, i.e. pressures of ~ 10^{-7} to 10^{8} mbar. There were a number of specialist companies which had the capability of producing vacuum systems which operated at lower pressures than this, well into the true UHV (Ultra High Vacuum) regime (i.e. <10^{-9} mbar). However, this was by and large confined to the manufacture of small scale laboratory and research systems. It was beyond the routine capacity at the time of such companies to produce the necessary vacuum vessels for the SRS, which was required to operate at a base pressure approaching 10^{-10} mbar. The large number of such vessels and the short production time scales also placed a considerable strain on the capacity of most firms willing to take on such work. It was therefore necessary for the SRS to embark on a process of education of a number of companies as to how they could fulfil the requirements of the project. It was the smaller and more specialist firms that took up the challenge, the larger vacuum companies at the time either being unwilling to diversify or seeing it as a diversion from their base markets.

The routine achievement of UHV in laboratory systems had been available since the 1960s and had been successfully implemented on a large scale in accelerators overseas, notably at CERN. However this had not impacted on UK industry significantly and CERN had carried out much of the specialist work in-house. The SRS team did not have facilities available to take this approach but were able to draw on the available knowledge to support UK industry.

It rapidly became clear that industry would not be able to make the necessary investment to provide the complete range of processes required for the construction and processing of vacuum vessels to the necessary high standard. In particular, since the SRS could not guarantee a large volume of business to individual companies, the return available to them from the installation particularly of expensive large scale cleaning and baking kit might not justify the investment required. Therefore some of these specialist facilities were provided by the SRS and made available to industry, either free of charge for SRS work or at a commercial rate for other commercial orders. Some companies concerned were prepared to adopt new manufacturing techniques, such as clean welding, and learn how to work with new materials, like specialist stainless steels to produce high-integrity vessels and assemblies. Also, skilled SRS staff were able to spend time in the companies, both carrying out work themselves and training staff in these companies to carry out the particular processing work themselves.

This cooperative approach, with the SRS providing designs, specifications and procedures which were then implemented by willing companies, resulted in a built machine which met the necessary operating criteria. Subsequently, UK industry was able to use these procedures and the experience and skills gained to win orders from accelerator laboratories and other large projects in Europe and worldwide. However, later rationalisation in the industry meant that a number of these companies either disappeared or withdrew from the market.

In addition to the vacuum vessels, the complete vacuum systems for both accelerator and experiments required a large amount of ancillary equipment. These also were required to meet UHV standards and created further specialised technical challenges for suppliers. The way that these were met for pumps, gauges, pump and gauge controllers and residual gas analysers, with fruitful interaction between the project and industry, is detailed in Appendix 12.

Although it has proved difficult to get quantitative information from UK vacuum companies regarding the effects on their business with the SRS, most are happy to acknowledge that the expertise and demands of the SRS vacuum team has put them in a position to be internationally successful and recognised as competent in the demanding field of large scale UHV. Many use the procedures, standards and methodology developed by the SRS as the basis for their own quality control systems. They also acknowledge that interaction with the highly skilled and knowledgeable SRS staff provided a stimulus to ensure that their own expertise was up to the mark.

Richard Davies, Managing Director of CVT Ltd, has kindly supplied the following statement:

"CVT Ltd was formed in the late 1970s as a breakaway from the VG Instruments Group. At that time we had four employees working in an 800 sq ft industrial unit in Milton Keynes. By contrast, our former employers and biggest competitor, VG, were turning over in excess of £50M and operating out of multiple factories in the south east and north west of England. We were aware of the potential that synchrotrons would have for our particular speciality, manufacture of UHV chambers and mechanisms, and our start up coincided with the construction of the SRS facility at Daresbury Laboratory.

Daresbury operated a policy of tendering for build to print manufacturing which was perfect for a start up company such as ours, the current industry wide practice of the contractor being totally responsible for design and functionality was introduced 20 years later. This tender process allowed us to win contracts that were within our capabilities and in this process we were very enthusiastically assisted and encouraged by Daresbury staff who were both keen to have a strong British vacuum engineering industry and unstinting in their sharing of knowledge and experience.

CVT was not the only company in this happy situation, I know of several others that were treated in the same way. As CVT grew, we won larger and more complex projects eventually being awarded a running contract for the manufacture of vacuum chambers for Daresbury (we still hold a similar contract for the Rutherford Laboratory) and enabled us to win significant contracts at other European synchrotrons (MAX Sweden £1M, ESRF France £3M, BESSY Germany £5M).

I know that Daresbury's primary function was to produce world class science and in this they have excelled but our experience shows that their active role in the development of SMEs is also very important and should be considered as a major influence in the way that all UK research facilities are structured."

12.3.5 Securing contracts for UK industry

Being an extremely important piece of kit for the SRS, there was an ongoing major initiative to improve existing monochromator designs and to take advantage of the advances in materials technology and engineering techniques to develop better, higher quality instruments. This occurred throughout the life of the SRS.

Prior to the construction of the SRS, NINA scientific and engineering staff had been involved with a UK company, Bird & Tole[152] to build and improve monochromators. The contact with the SRS was originally channelled through the University of Reading. For nearly twenty years, during the build-up of the SRS experimental area, there was a fruitful interaction that provided the facility with high quality monochromators and helped Bird & Tole establish itself in this market, helping them to generate export orders.

SRS scientific staff carried out the basic optical design and provided a detailed mechanical specification for the various necessary movements, i.e. the accuracy and tolerances required for the mechanisms. Bird & Tole would then turn the initial ideas into a mechanism that could be built as an engineering reality. Details of the on-going collaboration have been recorded in a privately published booK[153]; this provides details of 23 instruments built by Bird & Tole either for the SRS or for other overseas synchrotron facilities, with the advice and support from SRS scientists. Appendix 13 lists the instruments and the laboratory for which they were destined. The strong collaboration between different research laboratories working in

[152] *'Bird and Tole' still exist but are now part of 'Cougar Engineering Services'; they no longer manufacture monochromators; see: http://www.birdandtole.co.uk/*

[153] *'Don Tole's Monochromators', compiled by W.B.Peatman and J.B.West; private publication by Daresbury Laboratory, 1986; copy available on loan from the Laboratory's library.*

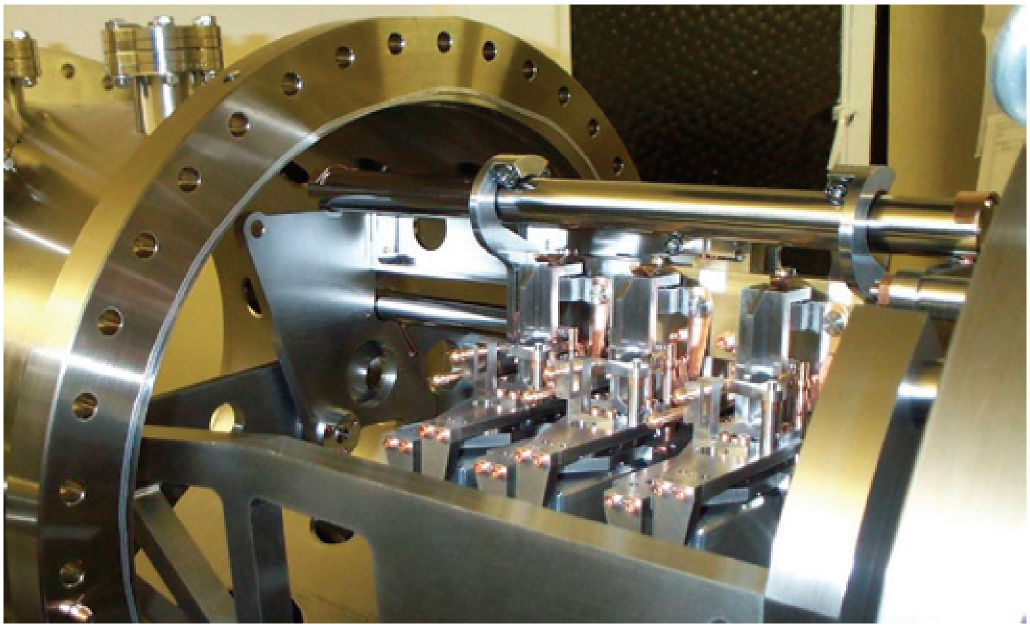


Figure 39, photograph of the high resolution grating mechanism installed in a Bird & Tole monochromator developed for an up-grade on SRS beamline 6.1

the area of VUV/soft X-ray is apparent from the number of instruments that were loaned to other light-sources either for testing or to provide temporary cover in an on-going research programme that was experiencing instrument difficulties.

It must be emphasised that the contracts with Bird & Tole were always placed after open competition via the tendering process, but no-one else could compete on the grounds of excellence in design and reasonable price. The titles of the monochromators given in Appendix 13 indicate that the original design concepts for the instruments originated at Japanese laboratories; names such as ‘Miyake’ and ‘Seya-Namioka’ indicate such origins. It is a demonstration of the prevailing spirit of the academic collaborations at that time that such designs were freely communicated between laboratories, without any thought being given to ownership of intellectual property. It was therefore in the same spirit that the SRS teams, working in this area of science, modified and improved on those basic concepts; they worked with Bird & Tole on the engineering realisation of the developments, informed sister laboratories (particularly the BESSY laboratory in Berlin) of the improvements and encouraged and helped Bird & Tole to build and sell the more advanced instruments to other research institutes.

With this free multi-way transmission of data and designs, it is difficult, after the significant lapse of time, to ‘pin-down’, who did what and who had the bright ideas that resulted in the major steps forward in instrument design, with corresponding improvements in experimental data quality. However, the situation is neatly summed up by text in the cited publication[154] relating to the BESSY[155] 1-meter Seya-Namioka monochromator (item 7 in the list of Appendix 13), which states:

> *“The very first monochromator that BESSY obtained was the 1-metre Seya-Namioka monochromator, originally built for the Fritz-Haber Institute in Berlin for use at the Bonn synchrotron and moved from there when BESSY1 started operation. It was also the first Bird & Tole monochromator to be exported from England. It is perhaps the only exact copy of a monochromator that Bird & Tole had the pleasure of building, being a copy of John West’s 1-metre Seya at Daresbury (item 6 in the list of Appendix 13). Even the drawings were unchanged............”*

[154] *www.cas.web.cern.ch/cas/CAS-Prog-2004.html*
[155] *www.bessy.de/?idcat=22&changelang=5*

Dr J.B West, the SRS staff member mentioned above, has provided much of the information in this section[156] and adds the following comment:

"In the end, the collaboration produced some of the finest VUV monochromators anywhere in the world, as was widely acknowledged at the time. The proof of the pudding was in the eating: we were able to carry out experiments that people elsewhere in the world could not do, and this contributed greatly to the Lab's high reputation internationally in VUV spectroscopy. I think it would be fair to say that Bird & Tole certainly did benefit commercially from the interaction with Daresbury Laboratory. Through our contacts they secured contracts in the USA at NSLS Brookhaven[157]. They also became well known in Grenoble (ESRF[158]) and made components for instruments there, as well as complete instruments at BESSY (and) a soft X-ray instrument at Super-ACO" (French light-source, now shut-down).

A photograph of the Bird & Tole high resolution grating mechanism developed for an up-grade on SRS beamline 6.1 is shown in Figure 39.

The above information all relates to monochromators developed for the VUV and soft X-ray programme. However, high quality monochromators were also essential for the hard X-ray experimental programme. The outstanding example of successful design for hard X-ray instruments is the double-crystal monochromator developed by SRS staff for extended X-ray absorption fine structure (EXAFS) measurements and subsequently licensed to VG for commercial exploitation as described earlier in this chapter.

12.3.6 Developing and transferring detector technology

The significance of detectors, as essential components in any experimental assembly, is obvious. For all of the many techniques available on SRS experimental stations, the radiation emerging from the experimental sample has to be 'detected' and then recorded electronically for analysis. The spatial and energy resolving power of the detector is a determining factor affecting the quality of the experimental results in addition to the time response of the detector. In many cases the SRS experimental stations were 'detector limited', as are most SR instruments. Consequently, throughout the life of the SRS, there was an active detector development programme. Investments in STFC's in-house detector innovations, along with beamline optics developments and accelerator design upgrades, kept the 2nd generation SRS competitive with newer 3rd generation SR sources in cutting-edge sciences. Appendix 14 lists the twenty world class in-house detector developments that took place over the lifetime of the SRS. These developments meant that the SRS was one of the few SR facilities which had detector system that was matched to the station's output, keeping the facility competitive until the end of its lifetime.

Examination of the data in appendix 14 demonstrates a number of particular features –

- Of the twenty different detectors that were built specifically for the SRS, twelve were developed exclusively at Daresbury Laboratory, three in collaboration with the Rutherford-Appleton Laboratory and the remainder in collaboration with academic or commercial partners;
- A number of these detectors have attracted interest from other light sources (Spring-8, Diamond Light Source, ALBA, ESRF). The STFC and Diamond Light Source spin-off company Quantum Detectors is now marketing nine of these designs and there has also been strong interest in a number of other designs from two commercial companies (Canberra[159] and EG&G Ortec[160]).

[156] *Dr J.B.West (senior SRS scientist, now retired); private communication.*
[157] *www.nsls.bnl.gov/*
[158] *www.esrf.eu/*
[159] *Scientific instrument manufacturer and distributor 'CANBERRA', an AREVA company; see - www.canberra.com/default.asp*
[160] *www.ortec-online.com/index.html*

Throughout the life of the SRS, there was sustained interaction with the companies Canberra and EG&G Ortec, to the mutual advantage of both the SRS experimental programme and the commercial collaborators. An example, detailing the ongoing development and resulting ‘spin-offs’ from one particular detector are chronicled –

“The requirement for compact, high rate, fluorescence detectors for the SRS was appreciated early in the life of the facility and a 13 element germanium detector, for use on station 8.1, was obtained in the early 1990s. The initial instrumentation for this detector made use of equipment coming from the Daresbury Nuclear Structure Facility during its rundown and gave a basic system that could be used. However, this was not very easy to operate.

The design of a more user friendly instrument was initiated by the SRS solid state detector team. Interactions with Canberra commenced and gave rise to a new specification of smaller diodes in a more compact configuration; this detector became the standard fluorescence configuration sold to several synchrotrons. The existing analogue system coupled with Canberra detectors worked well for several years but with beamline MPW16 being proposed it was clear that to handle the rates in fluorescence experiments proposed on station 16.5 a new approach was required and work began on a high rate direct digitisation system. This system, which would become XSPRESS, would overcome some of the limitations in analogue systems and give greater user flexibility; additionally a higher number of channels - at least 30 - were required for the detector for 16.5.

The quest for a new detector was won by Ortec who developed a 30 element high rate germanium detector which was matched to XSPRESS. This was a new development for Ortec and offered advantages in the front end electronics design, of which XSPRESS could take.

Once this system was completed, the requirements were seen for a more compact system for the newly refurbished focusing optics station 7.1. This resulted in the first truly monolithic germanium detector for XAFS (C-TRAIN,) which could be coupled to XSPRESS. In this development not only was the state-of-the-art detector developed by staff at Ortec but a new high rate preamplifier was developed at the Rutherford Appleton Laboratory. This system was subsequently adopted for the SRS station 9.3 and later for the Belgiun beamline, DUBBLE, at the ESRF. Upgrades to XSPRESS have now taken place and a C-TRAIN XSPRESS2 system is in place on beamline I18 at Diamond.”

12.3.7 Engineering challenges

High quality mechanical engineering is the corner stone of any facility such as the SRS and, with ongoing development of the accelerator, beamlines and experimental stations occurring throughout the life of the facility, there was a continuous development in this area supported by Daresbury Laboratory’s permanent team of engineers. The nature of the tasks varied considerably and included a major up-grade to the accelerator lattice, the ongoing assembly and addition of insertion devices into the accelerator, the ongoing addition of new beamlines and the development of existing beamlines. The latter included the complete construction of new state-of-the-art facilities, including robotics.

Major projects required high standards and mainly involved engineering that was available from quality local engineering companies who undertook precision manufacture and assembly. TSW Engineering Ltd[161] (formally Willaston Engineering Co), which is a small engineering company local to Daresbury Laboratory in Birkenhead, supplied significant quantities of machined components and light fabrications over the life of the SRS. Due to the links with Daresbury, TSW has now delivered to the overseas facilities CERN[162] and DESY[163]. Another

161 www.tswengineers.co.uk/
162 http://public.web.cern.ch/Public/Welcome.html
163 http://www-hasylab.desy.de/
164 www.senar.co.uk/

local engineering company LVW Senar[164], also based in Birkenhead, supplied precision engineering components to the SRS. As a direct result of the close links with the SRS, they now also supply a significant amount of components to the Rutherford Appleton Laboratory.

In the early years of the SRS construction, complete turnkey solutions were not available from industry and the laboratory needed to develop expertise of delivering high specification devices to meet the needs of the science. The demand was for integrated systems using multidisciplinary technology, an area of strength which had been developed within the laboratory by engineers and scientists making use of proven techniques and high quality components. Through supply and collaboration, a range of companies, which could meet such requirements, was established. A list of such competent and experienced suppliers that were used for SRS engineering requirements is given in Appendix 15, totalling 22 companies. Experience in supplying to the SRS has also enabled these companies to obtain contracts from other institutes requiring similar high specification devices.

12.4 Impact summary

This chapter highlights the impact that the SRS has made both to UK companies and other synchrotrons world wide. Significant advantages came to the synchrotron radiation sources through improvements and upgrades in functionality and performance that resulted from the varied requests for specialised features such as the monochromators.

The examples above are only a small number of case studies which illustrate the range and impact of just some of the technology and knowledge transfer activities that the SRS has been involved in with UK companies. These cases alone show the significant impact that the SRS has made to the companies involved, allowing them to develop products for sale to other companies and synchrotrons and helping them to win new contracts for business.

The 22 supplying companies identified, honed their manufacturing and measuring techniques to meet the demands of that specialised segment of the market. Over the life of the facility, this resulted in major gains to the manufacturers, creating competitive advantage in both the range and effectiveness of their technologies, products and processes and the optimisation of their designs to win competitive tender exercises. This was both to supply synchrotrons abroad and other UK companies.

One company alone, e2v, have stated that developing their antimultipactor coating in collaboration with the SRS was worth £250M in business to their company. Additionally, CVT quote gains of £8M in contracts and Tesla Engineering have benefited from at least £2.5M in new contracts. In addition, the three direct knowledge exchange examples given resulted in 22 contracts being won by the companies involved to the value of £21million shared between Oxford Instruments, Vacuum Generators and Horwich Electronics.

Hence the examples given here represent a gain of at least £300M in sales for UK companies as a direct result of technology and knowledge gained from the SRS which was leveraged by the companies to win subsequent contracts. This also created further indirect impacts in which the initial purchase of goods or services from suppliers led to a further chain reaction of purchases from their supply chain. It should also be noted that this figure is likely to be an underestimate due to the difficulty in collecting data on this kind of work.

Direct local impacts

Chapter 13
Local financial impact of the SRS

Chapter 13

Local financial impact of the SRS

13.1 Introduction

High quality research facilities are recognised as important contributors to regional development and knowledge-driven economies both in the UK and abroad. Indeed the establishment of the UNESCO-sponsored SESAME synchrotron radiation facility involving eight countries (Bahrain, Cyprus, Egypt, Israel, Jordan, Palestinian Authority, Pakistan and Turkey) recognises the significant regional economic effects that these facilities create. UNESCO calls it "a quintessential UNESCO project for capacity building through science"[165] and significant benefits to the region have already been felt. Other examples are the ESRF in Grenoble and the SOLEIL Project in Paris, both highly valued in their respective regions.

The SRS made a significant contribution directly to the economy of its local region and the wider UK over its construction and 28 year operational lifetime. In addition, the SRS has attracted a significant amount of external investment to the facility over its lifetime - not only from the Government and the Research Councils, but also from external sources such as the EU, and commercial and private funding from the UK and overseas.

A significant amount of the annual budget of the SRS was spent in the region local to the facility as well as the wider UK and abroad. In particular, the annual salaries of the staff have had a significant impact on the local economy. These direct funds paid to employees and companies are then re-spent in the local and greater economies, creating a ripple effect of financial impacts. In addition, facility users, visitors and attendees at events and conferences also brought income to the region via their expenditure in local hotels, and on taxis etc.

13.2 SRS funding & investment

The SRS was used primarily by academics and public sector scientists funded by their host institutions or via a UK Research Council or international equivalent. Over its lifetime the operation of the SRS was funded from the Science Vote by the UK Government.

From its construction in 1977 until 1994/95, the SRS was funded directly by the Science and Engineering Research Council (SERC). Between 1994/95 and 2003/04, the SRS was funded through Service Level Agreements with the other Research Councils; the majority of funds coming from the EPSRC, but also the BBSRC and MRC, and with some funds from NERC. Following the CCLRC Quinquennial[166] Review in 2004/05, the responsibility for funding the SRS changed to the CCLRC direct vote funding. This funding model continued until 2007 when the STFC took over funding responsibility for the SRS until its closure at the end of 2008. This is illustrated in the diagram below.

Including initial construction costs and decommissioning costs, the total expenditure on the

SRS funding sources over its lifetime 1975 - 2008			
SERC	Research Councils	CCLRC	STFC
1977	1994/95	2004/05	2007 — 2008

Figure 40, SRS funding timeline

[165] www.sesame.org.jo/pdf/DevCountries.pdf
[166] Pwww.berr.gov.uk/dius/science/researchcouncils/quinquennial_reviews_of_cclrc/page13198.html

SRS over its lifetime was approximately £600M. It should be noted that this figure has been indexed to reflect costs at today's prices.

The funding for the SRS came from several different sources in addition to the funding from the UK Government. The SRS attracted additional funding from the European Union through its Framework programmes (FP3 – FP6), the Wellcome Trust, UK Universities, charities and income from commercial activity. This totalled over £25M in external investment. External investment through joint work with European Universities was also prolific but cannot be quantified. An example of this type of work is given in appendix 16.

13.3 Breakdown of SRS budget

The SRS operating budget was spent on pay, recurrent items, capital equipment items and overheads. The breakdown of the budget on these items between 1994/95 and 2008/09 can be illustrated in the diagram below[167].

As can be seen from the diagram, the majority of the expenditure on the SRS was on staff costs, recurrent items and overheads.

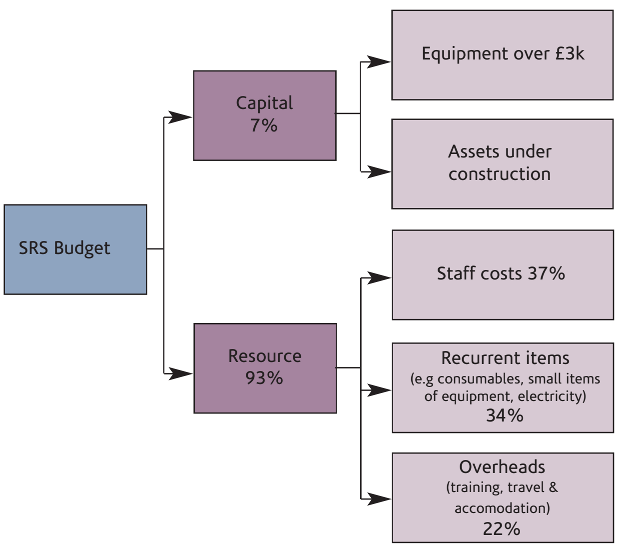


Figure 41, breakdown of spend on SRS over its lifetime

13.4 Job creation & salary

The SRS acted as a large and significant employer in the North West area over its lifetime. The staff numbers from the SRS and its associated programmes peaked at 325, with an average workforce of 229 per annum over its lifetime. This is shown in figure 42.

The vast majority of staff from the SRS resided in areas local to the Daresbury Laboratory, including Liverpool, Manchester, Warrington and Cheshire. Staff location data from 2007 indicated that 99% of staff were resident in the area local to the SRS, with the remaining staff in residence in another areas of the UK. Using staff salary data between 1989/90 and 2008/09 and extrapolating back to 1977/78, the total cost of wages paid directly to staff was £220M over the lifetime of the SRS, with a significant amount of this money going into the local economy.

13.5 Impact to local and national businesses

The SRS acted not only as an employer in the North West, but also as a purchaser of goods and services in the local area, the wider UK and abroad. Throughout its lifetime, the SRS traded with over 300 local businesses and spent money on items such as consumables, small equipment items and maintenance.

Around 90% of the total spend on the SRS was spent in the area local to the laboratory, with 37% being spent on wages, 34% on recurrent items and 22% on overheads. This totals £534M over the lifetime of the facility. The remaining 10% of the budget was spent on large capital items - some with UK companies and some with international companies.

As highlighted in chapter 3, this purchase of goods or services from suppliers leads to a further chain reaction of purchases from their supply chain and also has indirect effects on employment, spend and taxation.

[167] The data is not available to investigate years previous to this, although this spread is believed to be typical over the lifetime of the SRS.

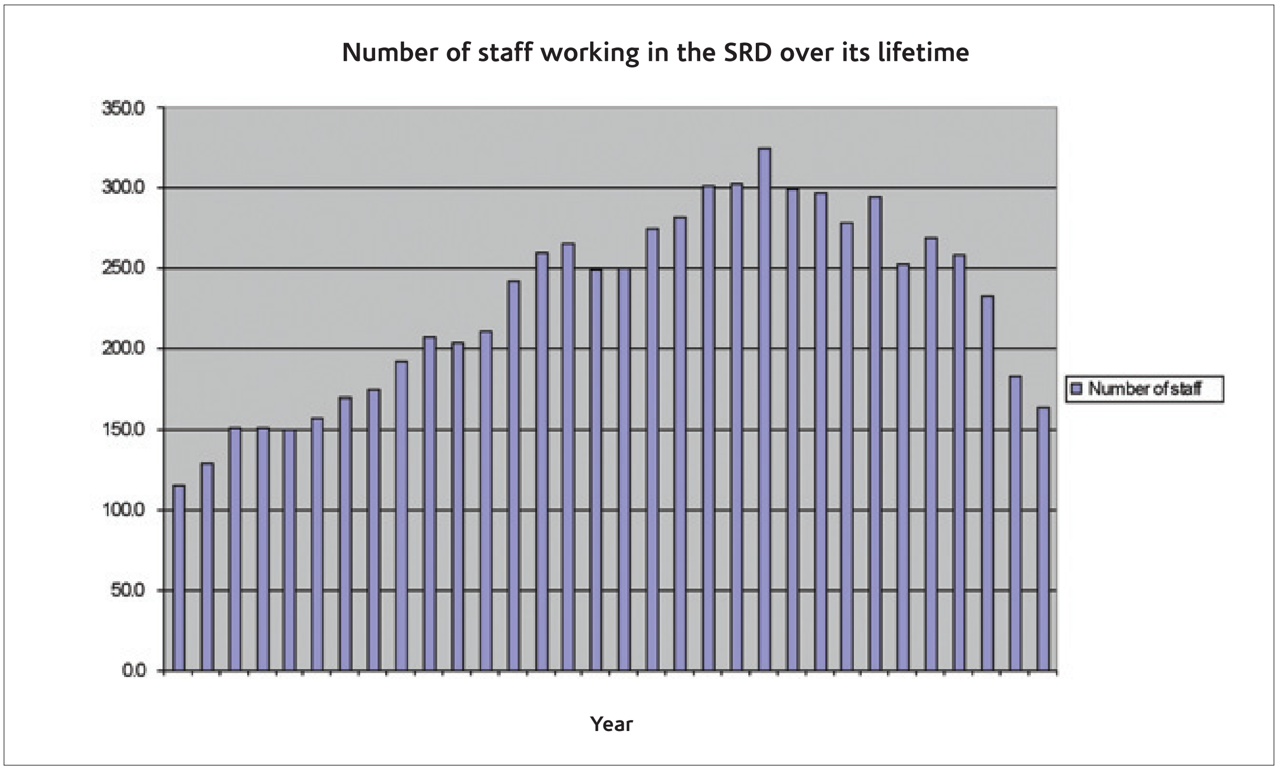


Figure 42, the number of staff working on the SRS and associated programmes over the lifetime of the facility

Specific examples of development and technology transfer projects with local and wider UK businesses were given in chapters 11 and 12. An example of a business from the North West which benefited from supplying the SRS is given below. Note that the company wished to remain anonymous.

The company is part of the £100M business of its parent company which operates in the UK, France, Germany, the Netherlands and the Republic of Ireland. The company is situated in Chester and employs around 105 staff, and specialises in lead products with key markets in building construction and applications relating to radiation shielding. This application crosses many sectors, including nuclear plants, nuclear medicine, X-ray enclosures, radiation shielding and defence.

The company have supplied shielded chambers (hutches) to large scale facilities in the UK, the first being the SRS with ISIS[168] (the STFC's neutron facility), Diamond and JET[169] following. The company have also subsequently supplied hutches to other synchrotron facilities around the world including the ESRF in France, the Swiss Light Source, the Canadian Light Source, and the National Synchrotron Light Source and Argonne National Laboratory, both in the USA. The group have recently been awarded the contract to supply the hutches to the ALBA synchrotron source in Barcelona. Competition for the supply of hutches within Europe is confined to two to three other companies based in France and Germany. The supply of hutches to large scale scientific facilities is worth approximately £2m per annum to the company.

The company stated that the location of a large scale facilities in the UK allows strong relationships to be built up. Those relationships promote close communication which is essential in finalising the design and exact requirements of the customised products to be installed. This close relationship also builds up confidence in

[168] http://www.isis.rl.ac.uk/
[169] http://www.jet.efda.org/index.html

the capabilities of the suppliers. The beamline scientists are often highly mobile, working in different international facilities within a close-knit scientific community; therefore, the existence of the UK facilities is important in sustaining an international reputation.

The association of the company as a supplier to the UK and international synchrotron markets is perceived as raising the profile of the company and their products, especially within the small scientific community which is mobile on a global scale. Similarly, the company perceive that their credibility has also been raised, with the kudos of being associated with these large-scale, high-technology facilities. The synchrotron sector is seen as a pioneering market area which allows for new market opportunities.

This example illustrates the effect the SRS had on a business in its locality. The SRS was the first UK facility that the company supplied to which developed their skills, expertise and reputation to the extent to which they could then supply to other facilities both in the UK and abroad. Therefore a ripple effect is felt by the company in which they can subsequently win more and more business and grow their company as a direct result of the first contracts with the SRS.

13.6 Modelling secondary economic effects

As detailed in the preceding sections and in chapter 3, there was a multiplying effect of the repeated re-spending of the SRS budget in the local economy; the induced economic impact through salary and the indirect impact through industry supply chain effects. This recognises that the direct investment initiates an economic "chain reaction" of further spending, production, income and employment, creating both indirect and induced economic impacts. These secondary economic effects have been approximated using multipliers taken from the ONS Input-Output Analytical Tables, last revised in 2001. Therefore using the multiplier of 0.44 for the induced economic impact and 0.23 for the indirect economic impact, the secondary financial impact of the SRS is estimated to be £398M. It should be noted that this figure is an approximation as exact multipliers for the SRS are not available. Additional negative effects such as displacement of economic impacts from other regions have not been considered.

13.7 Impact summary

As this chapter has shown, large scale research facilities are important contributors to regional development. A significant amount of the annual budget of the SRS was spent in the region local to the facility In particular, the annual salaries of the staff, equipment and maintenance costs were all locally funded, creating local economic impacts. Adding secondary effects to this initial spending effect means that the SRS created significant local regional growth.

Impact on employment

- *The SRS has supported an average of 229 direct jobs for every year of its operation.*

Direct and secondary financial impacts

- *The SRS budget had a total financial impact of £594M over its lifetime, with £534 spent in the local area over its 33 year lifetime (including construction, operation and decommissioning). 37% was spent on wages and 34% was spent on recurrent items with local businesses.*
- *The indirect and induced financial economic impact resulting from the SRS budget was £398M, with impacts mostly occurring in the area local to the SRS. This represents the financial ripple effect of the SRS budget spend over its lifetime.*

Therefore the total financial economic impact of the SRS was approximately £992M, with the majority of this impacting the local economy. (this figure presumes that the net economic impact is equal to the gross impact, in addition to the stated multiplier effects.)

Seeding future impacts

Chapter 14

Providing the next generation of impact

Chapter 14

Providing the next generation of impact

14.1 Introduction

The development of the technology, skills and instrumentation developed at the SRS led to the establishment of other scientific facilities and centres of excellence, themselves creating significant impact.

The following examples illustrate how the skills, technology and know-how built up in the UK through the construction and operation of the SRS have led to the next generation of scientific facilities in the UK.

14.2 Diamond Light Source

"The SRS has kept the UK at the forefront of scientific research and now passes its baton onto the new Diamond Light Source in Oxfordshire, the UK's direct successor to the SRS. Diamond will continue to build on the positive legacy of synchrotron light research in this country.[170]"

In 1993, the Woolfson Review[171] on synchrotron radiation provision in the UK reported that UK researchers required a new facility to replace the SRS and continue the success of the facility. To that end, scientists and engineers at the Daresbury Laboratory and elsewhere began developing plans for a new 3GeV X-ray source, subsequently called the Diamond Light Source.

In 2000, it was announced that the Diamond Light Source would be sited at the Rutherford Appleton Laboratory. The SRS users and staff had a significant impact on the establishment of the Diamond Light Source[172], with the users of the SRS helping to build and develop the science case for the Diamond Light Source. In 2002, SRS and ASTeC delivered the formal Design Study Report from which the facility was subsequently constructed. SRS and ASTeC staff thus contributed to the early conception, design and expertise for the establishment of the facility. To date, some 21 people have transferred to the Diamond Light Source, taking with them the skills and knowledge gained on the SRS. During construction, SRS staff played major technical and managerial roles in supporting the newly formed Diamond Light Source team and were also involved in the early operation of the facility. Collaboration between the facilities occurred in areas such as beamlines, detectors, accelerator physics, RF devices, magnets, vacuum, power supplies and insertion devices.

In addition, two beamlines have been transferred from the SRS to the Diamond Light Source for XAS (X-ray Absorption Spectroscopy) and SAXS (Small Angle X-ray Scattering). A team of SRS scientists, engineers and technicians used their skills and experience from the SRS to model and re-engineer the beamline components for their new roles at the Diamond Light Source.

Construction of the facility began in early 2003 and Diamond became operational in January 2007. The facility employs around 350 staff and is run by a Joint Venture funded by the UK Government through the STFC (86%) and the Wellcome Trust

170 Professor Ian Munro, one of the original founders of the concept that synchrotron light could be used to perform science, and who was responsible for the plans for building the SRS and its operation, speaking at the SRS closure ceremony, August 2008
171 EPSRC 1993
172 http://www.diamond.ac.uk/default.htm

(14%). The facility employs around 350 staff and is run by a Joint Venture funded by the UK Government through the STFC (86%) and the Wellcome Trust (14%). Phase I investment of £250 million included Diamond's buildings and the first seven experimental stations. The construction of the building and the synchrotron hall was undertaken by Costain Ltd[173], a British construction and civil engineering company.

Phase II funding of £120 million for a further 15 beamlines was confirmed in October 2004. The facility represents the largest UK scientific investment for 40 years and can ultimately host up to 40 beamlines. Building on the impact of the SRS, the Diamond Light Source is already producing impact both at the UK and international level. Examples of current research are projects on HIV, DNA, cancer and Bird Flu, some of which were started on the SRS.

14.3 Accelerator Science and Technology Centre

Knowledge of accelerator science and the associated skilled staff was an extremely important output of the SRS. To utilise and exploit this expertise, the UK's Centre of Expertise for Accelerator Science and Technology (ASTeC) was set up. Originally based at the Daresbury Laboratory but now also incorporating staff from the Rutherford Appleton Laboratory, ASTeC was formed in 2001 as a centre of excellence in the field of accelerator science and technology. The Centre carries out programmes of research and design in support of STFC's large facilities, based on the previous long experience of its staff in developing the SRS and later the design of the Diamond Light Source. The remit of ASTeC has also expanded to cover both a wider range of future accelerator based facilities (e.g. particle physics and neutron sources) and also on the development of generic

Figure 43, Diamond scientist examining a fragment of the Mary Rose, research started on the SRS. Courtesy of Diamond Light Source Ltd.

[173] *http://www.costain.com/*

underpinning technologies. This represents a significant transfer of both knowledge and skills to other scientific areas. ASTeC also continues to support upgrades of existing STFC facilities such as ISIS.

In addition to the development and design of the SRS, other related achievements of ASTeC and its staff include:

- The concept and detailed design of Diamond, the UK's 3rd Generation SR facility, and subsequent technical assistance throughout the construction process.
- Design, construction and commissioning of ALICE, an energy recovery demonstrator and a unique accelerator and photon science test bed for the UK.
- Design and construction of EMMA, the world's first non-scaling fixed-field alternating-gradient (FFAG) accelerator to be added to ALICE (see next section for more info on EMMA and ALICE).
- A major role in the UK collaborations undertaking R&D on Linear Colliders and Neutrino Factory schemes.

Hence the staff at ASTeC have expertise in all types of accelerator and participate both in design studies and construction projects. As a centre of excellence, ASTeC offers high quality advice and services to stakeholders on development and application of advanced accelerator systems. The significance of the upsurge in interest in accelerator technology is substantial –

"Until less than five years ago, the only accelerator expertise in the UK was at Daresbury and RAL. That expertise is now spreading around with a renaissance in the Higher Education Institutes. In 2001, there was just one PhD thesis on the subject of accelerator science: now there are more than 50 in progress.[174]"

14.4 ALICE

The SRS also facilitated subsequent accelerator based experiments, including the Accelerators and Lasers in Combined Experiments (ALICE) prototype system. The ALICE project, an energy recovery test facility at the Daresbury Laboratory, is the first particle accelerator of its kind in Europe.

The facility consists of a laser driven photoinjector, two super-conducting linear accelerator modules and a mid-infrared free electron laser (FEL). This is the only free electron laser in the UK.

Some of the applications for ALICE technology include cancer treatment, the development of high-efficiency solar cells and nano-fabrication. ALICE has attracted funding totalling around £20 million from the STFC, North West Science Fund, EPSRC and BBSRC.

ALICE applications - advancing cancer treatment
The British Accelerator Science and Radiation Oncology Consortium[175] (BASROC) is an umbrella group of academic, medical and industry specialists in accelerator and medical technology with the aim of promoting the use of accelerators in science, industry and medicine. BASROC has been awarded its first grant from the RCUK Basic Technology Research Programme for the project called CONFORM[176] (COnstruction of a Nonscaling FFag for Oncology, Research, and Medicine).

The project is based on fixed-field alternating gradient (FFAG) accelerator technology and is led by the University of Manchester and the Cockcroft Institute with other university and institute partners. The following 3 parts to the project are funded –

- EMMA - The Electron Model of Many Applications. This is the design and construction of a 20 MeV electron accelerator. EMMA is an entirely experimental machine used to learn how to design non-scaling (NS) FFAGs for a variety of applications. It is situated at the Daresbury Laboratory using ALICE as the electron injector. Magnets for

[174] Prof Mike Poole, Former Director of ASTeC, 2008
[175] www.basroc.org.uk/
[176] www.conform.ac.uk/

EMMA were produced by TESLA, continuing the fruitful relationship with the UK company as detailed in chapter 12.

- PAMELA - The Particle Accelerator for MEdicaL Applications.This is a design study for a prototype proton NS-FFAG to demonstrate biological experiments for usage in hadron therapy. The intention is to build a complete facility for the treatment of patients using hadron beams. It is proposed to construct PAMELA at the Churchill Hospital in Oxford for the Department of Radiation Oncology and Biology and strengthen the case for hadron therapy in UK.
- Applications – the final phase of the project will focus on exploitation of FFAG technology in a wider context than just medical applications. There is already major interest in high power capabilities of relevance to accelerator driven sub-critical reactors and the transmutation of nuclear waste.

14.4 The impact of the SRS on accelerator science and technology in the UK

The impact of the SRS on accelerator science and technology can be shown schematically in the figure 45. It can be seen that the SRS has been pivotal in supporting the development of accelerator science in a remarkably wide range of applications.

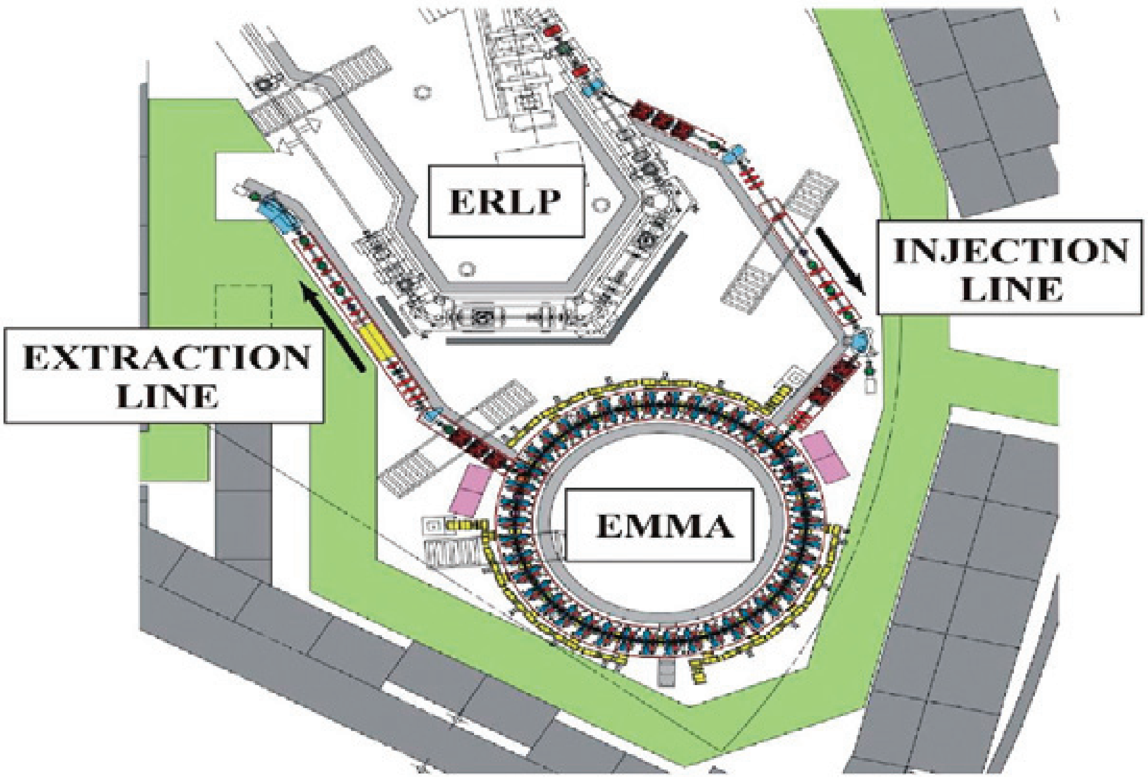


Figure 44, the ALICE & EMMA facilities

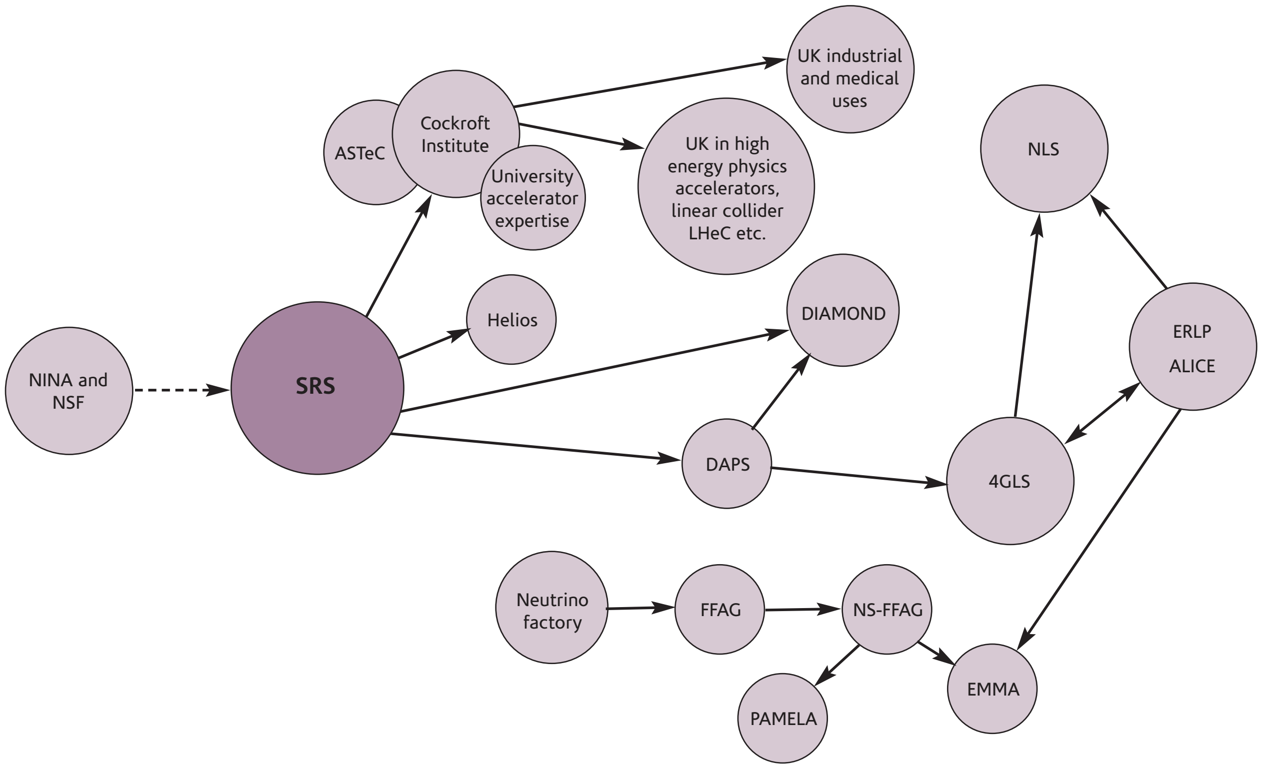


Figure 45, the SRS and its influence on Accelerator Science[177]

14.5 Impact summary

Another significant impact of the SRS has been the establishment of other large and medium scale facilities and centres of excellence which build on the skills, expertise and technology developed over the SRS lifetime.

These facilities will themselves in turn provide significant economic impact to the UK. Substantial investment has already been made in these facilities, a percentage of which has come from the private sector. In addition, these facilities will –

- *Provide fertile training grounds for the development of skills.*
- *Be significant employers.*
- *Their research will provide a huge benefit to our everyday lives.*
- *Generate financial impact through spend on equipment and wages.*
- *Provide opportunities for commercialisation and the ability for industry to both utilise the facilities and provide equipment for these facilities.*

[177] *DAPS is the Daresbury Advance Photon Source, a design study for a high brilliance soft X-ray. 4GLS (the 4th Generation Light Source) is a precursor study to the New Light Source and the Neutrino Factory is a proposed particle accelerator complex that will produce the most intense and focused beams of neutrinos ever achieved*

Chapter 15

Shaping the future of science and innovation

Chapter 15

Shaping the future of science and innovation

15.1 Introduction

The development and support of major research facilities, such as those at the Daresbury Laboratory, requires substantial technical infrastructure, including a critical mass of highly skilled engineers, technicians and instrumentation developers. Other factors such as the site neutrality and even the stability of the bedrock (which is essential for some high technology facilities), were all key factors in attracting other facilities and businesses to the Daresbury Laboratory site over the years. Appendix 17 describes the facilities and businesses that located onto the Daresbury Laboratory site and their connection to the SRS.

Building on the success of the SRS, it was recognised by many groups and organisations that the Daresbury Laboratory had a continuing role to play for science and technology, not just in the North West, but nationally and internationally as well.

In 2006, the Government formally announced the creation of the Daresbury Science and Innovation Campus (DSIC)[178] and its sister campus, the Harwell Science and Innovation Campus (HSIC) in Oxfordshire. One of the principal drivers for the formation of campuses was the recognition of the considerable untapped potential that existed for STFC laboratories housing large-scale facilities and employing a critical mass of expertise to engage much further with industry.

The main reason for the creation of the campuses was to –

> *"...generate the critical mass to achieve a step change in knowledge transfer from large facilities, maximising opportunities for business engagement and commercialising the fruits of research.[179]"*

15.2 Daresbury Science and Innovation Campus

The Daresbury Science and Innovation Campus is an internationally recognised location for high-tech businesses and leading-edge science. It represents a fundamentally new approach to driving UK competitiveness in global science and innovation.

The Campus provides a unique environment for innovation and business growth with knowledge sharing, collaboration and networking, and offers major opportunities to a wide range of sectors including: biomedical, materials chemistry, advanced engineering and manufacturing. In addition, the STFC manages a number of leading edge facilities through the Daresbury Laboratory, which are of key importance across these sectors.

Daresbury SIC was formed by the Northwest Regional Development Agency (NWDA), the Science and Technology Facilities Council (STFC), Halton Borough Council and the research intensive universities of Lancaster, Liverpool and Manchester. To date there has been a significant investment in the Campus and two flagship buildings have been established - the Daresbury Innovation Centre and the Cockcroft Institute.

[178] *http://www.daresburyinnovation.co.uk/*
[179] *http://www.hm-treasury.gov.uk/budget/budget_06/assoc_docs/bud_bud06_adscience.cfm*

One of the Campus' primary objectives is to establish strong, co-operative links with industry on a national and international basis. Daresbury SIC is already playing a significant part in engaging with industry and the high-tech SME sector in the North West by providing the ideal environment for collaboration and cross-fertilisation of ideas.

Future development on the Campus will focus on the three major scientific and technological elements, namely Daresbury Laboratory, the Technology Gateway Centres (including the Cockcroft Institute) and the Daresbury Innovation Centre (and successive units concentrating on business incubation and expansion). In addition, the Campus itself will expand as an exciting public-private partnership vehicle for science and innovation.

15.3 Business at the heart of science

The Campus' flagship accommodation facility for high-tech businesses is the Daresbury Innovation Centre. The Daresbury Innovation Centre is home to 100 high-tech businesses, ranging from small start-ups to strategic units of large multi-national corporations. Although the Daresbury Innovation Centre (DIC) acts primarily as an incubation centre for leading-edge, hi-tech SMEs, it also provides accommodation for small teams allied to larger businesses, including personnel for global, blue chip organisations such as IBM and SGI.

The vision of the enterprise is that tenants in the centre are focused around science and technology and their work should have identifiable synergies with programmes at the Daresbury Laboratory.

The Innovation Centre provides –

- A recognised research & development focused environment with an STFC account manager and links to a wide network of research-intensive universities.
- Opportunities for technological and commercial collaboration, and fast access to commercial and academic contacts through a high-tech focused ecosystem.
- Tailored business support and connections to major funding streams.

An annual survey carried out in 2009 of the DIC Companies reveals that –

In 2008-2009 -

- *Average growth rate in turnover of these companies has been 67%.*
- *There has also been very significant growth in investment at 55%.*
- *Companies delivered £14.9M in sales, and secured £20.5M in investment.*
- *The number of "Supernetworker" Companies who have collaborations with other DIC companies, STFC and the North West Universities has increased from 12 to 17. It should be noted that this specific grouping of companies realise a significantly higher sales growth than average (106% in 2008).*
- *48% of Campus companies have made significant use of the facilities, services and expertise at Daresbury Laboratory.*
- *The companies developed 137 new products, 32 already in the market place.*
- *17 companies filed new patents.*
- *55% of the companies are now using Business Link services, and 43% are using UKTI services, as a direct result of the purposeful involvement of these organisations with the DIC activities.*
- *64 new high-level FTE jobs were created in 2008 and 97 since the companies moved to the campus.*
- *The DIC "Breakfast Networking" Events, held monthly, continue to be extremely successful. Typical meetings attract in the region of 120-150 attendees, not only from DSIC and the campus partners, but also much further afield.*

Many Campus companies are expanding their businesses, recruiting more staff and looking to increase the size of their operations on Campus. The Daresbury Innovation Centre has proved to be a successful venture and many of the companies have stated unequivocally that they based themselves on the Campus to be located adjacent to Daresbury Laboratory so as to gain access to its facilities, skills and knowledge base.

Figure 46, the Daresbury Innovation Centre

15.4 Big science supporting small business

The support labs of the SRS, housing more than £3M of state-of-the-art scientific equipment, are now available at the Daresbury Laboratory for use by small high-tech start-up companies and academic researchers. The STFC Innovations Technology Access Centre (ITAC) offers flexible and affordable access to a wide range of cutting-edge scientific equipment in 16 fully-equipped biological, imaging, materials and physical science laboratories. This provides businesses and researchers with the ideal environment to carry out high-tech research and development work.

Access to high specification laboratory space at low cost and low commitment can be difficult to obtain, especially at the proof of concept stage, these facilities provide the ideal environment for both start-ups and the R&D teams of established companies. Businesses located in the Centre can make full use of the wide range of facilities including leasing their own exclusive-use, 'lock and leave' laboratories. Also provided are a number of multi-user laboratories available on an hourly basis ("hot labbing"). Analytical user facilities include a surface science and imaging laboratory which contains a suite of electron microscopes and optical microscopes. There is also an instrumentation laboratory which includes a range of spectrometers, calorimeters, chromatography facilities and two designated X-ray diffractometers.

Two companies on Campus already benefiting from the ITAC facility are Byotrol[180] and BioEden[181]. Manchester-based Byotrol is the first long-term tenant at the Centre following the recent relocation of their principle microbiology R&D operations to the North West. Byotrol has developed a patented, next generation hygiene technology, described as having the characteristics of the ideal biocide. Byotrol is using the Centre to develop specific versions of the technology for the healthcare, food production, animal welfare and consumer markets. Bioeden, based in the Daresbury Innovation Centre, is an international business with an innovative process for collecting stem cells from children's milk teeth, and is using the space within the ITAC facility for storage of their backup cell bank.

A presence in the Centre puts companies at the heart of the rapidly growing Daresbury SIC network, which, in addition to providing specialist support from STFC's own highly skilled scientists, enables companies to tap into the knowledge base of the leading North West academic institutions.

15.5 Cockcroft Institute

The Cockcroft Institute[182] was created in 2006 and is an international centre for accelerator science and technology in the UK. It is a joint venture between the Universities of Lancaster, Liverpool and Manchester, the STFC's ASTeC and the NWDA. The Institute has satellite centres in each of the participating universities.

The Institute provides an academic focus linked to existing educational infrastructure and STFC's

180 *http://www.byotrol.co.uk/home*
181 *http://www.bioeden.co.uk*
182 *http://www.cockcroft.ac.uk/*

scientific and technological facilities. This enables UK scientists and engineers to take a major role in innovating future tools for scientific discoveries and in the conception, design, construction and use of the world's leading research accelerators. The Cockcroft Institute model is a template for future research institutes at both Campuses.

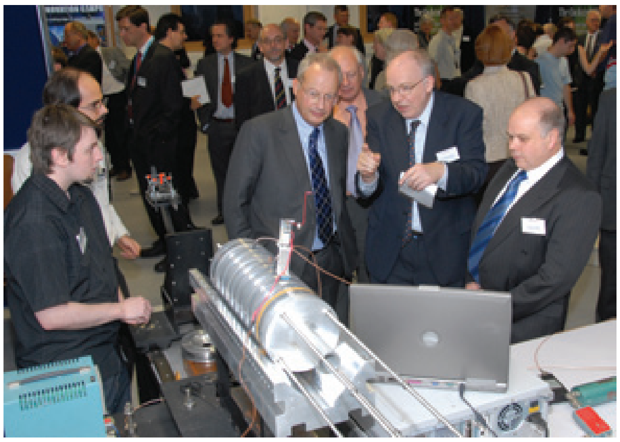


Figure 47, Lord Sainsbury with Cockcroft Institute staff at a demonstration of a prototype RF cavity at the opening of the Institute

15.6 Future development of Daresbury SIC - Technology Gateway Centres

In 2007 the STFC announced a series of research institutes at both of the STFC's Campuses based on five capability areas designed to strengthen the technology impact of their activities. The main drivers for these Technology Gateway Centres[183] are to further exploit STFC's technology base, improve connections with universities and industry and to increase the impact of the Campuses and STFC's facilities as locations for research and collaboration.

The capabilities being developed are:

- Computational Science and Engineering.
- Detectors.
- Space Technology.
- Imaging.

DSIC relevant centres are described in the next sections.

15.7 Hartree Centre

In order to make best use of the cutting edge science and discovery emerging from the early days of the SRS, a sound theoretical basis was required to substantiate the experimental results. These developments were taken up world-wide and led to the establishment of a large computational science department at Daresbury. In recognition of these skills and capabilities, the Hartree Centre will be a new kind of computational sciences institute for the UK, bringing together academic, government and industrial communities, focusing on multi-disciplinary, multi-scale, efficient and effective simulation. Its location on the campus will provide a step-change in modelling capabilities for strategic themes in energy, life sciences, the environment and materials. It is anticipated it will comprise a $1000m^2$ computer room, 150 - 200 staff, training rooms and access grid infrastructure.

15.8 Detector Systems Centre

Similarly, the cutting edge science and discovery emerging from the SRS demanded new instrumentation, notably high resolution and high count rate detector systems. This led to the formation of a world-renowned detector systems unit at Daresbury Laboratory. The new Detector Systems Centre seeks to establish a dynamic, open innovation, technology centre with a critical mass of expertise from STFC, academia and industry to deliver training and catalyse new advanced product development in the UK. Its core objective is to maximise the impact of STFC's research programme in detector technology. The Detector Systems Centre builds on STFC's world class reputation for microelectronics training and the development and delivery of specialised, high performance detector systems. The Centre will seek to maximise the impact of emerging sensor technologies on a wide range of economically important application areas. These include: energy, lifelong health and wellbeing research, climate research, environment and security.

[183] *www.scitech.ac.uk/ResFac/Gateway/GatewayCentres.aspx*

15.9 Future plans

Plans are being progressed to develop the Campus, including discussions with blue-chip companies about the potential to locate at DSIC. A Joint Venture with a private sector partner is also being pursued, following a similar model to the Harwell Science and Innovation Campus[184].

In parallel with these developments, a framework for the Campus has been developed which visualises an expansion of the Campus to reach out to and include Daresbury Park (the business park to the south of Daresbury Laboratory). In total, approximately 600 acres may be encompassed in the campus over the next 30 years and around 2000 people could be employed by 2040.

The DIC forms the kernel for the future growth of the campus, evidenced by a third building being built adjacent to the Cockcroft Institute for industrial grow on space. The plans to establish the new building and to develop the Technology Gateway Centres are ensuring that these activities continue to grow and make impact in the future, building on the legacy of the SRS.

15.10 Impact summary

The high quality specialist knowledge developed at Daresbury Laboratory as a result of the SRS has been a key contributor to the formation of the Campus. DSIC, through the DIC, has delivered a dynamic, successful, high-tech business incubator which is delivering economic impact in collaboration with STFC and HEIs.

As is evident in this chapter, one major economic impact of the Campus has been the location and support of the ~100 companies which reside in the Daresbury Innovation Centre. These companies have generated significant sales, attained investment and increased turnover since locating on the Campus. A very significant percentage of the companies have benefited from interaction with staff from the Daresbury Laboratory and a significant amount of collaborative work has taken place between the companies in the DIC and with STFC and university staff. The DIC forms the kernel for the future growth of the campus, evidenced by the commencement of a third building adjacent to the Cockcroft Institute.

[184] *www.stfc.ac.uk/PMC/PRel/STFC/JVHarwell.aspx*

Chapter 16

Conclusions

Chapter 16

Conclusions

Introduction

This report represents the first complete lifetime study of a large scale facility in the world and demonstrates the significant impacts that arise from such a facility. Demonstration of this impact is valuable impact evidence for the STFC and its stakeholders and provides a fitting legacy for the recently closed facility.

This report has provided a framework and methodology through which the impact assessment of the STFC's past and future investments can be carried out. It has also developed the STFC's in house expertise in the field of economic impact studies.

The project has also highlighted many of the methodological issues which are faced when trying to measure the economic impact of research and technology.

Due to lack of emphasis on the economic impact of research in the past, much of the relevant data from the SRS was not captured. This made researching the full impact of the SRS difficult; indeed the evidence presented in this report does not represent the full impact of the facility.

Another important conclusion that can be made from this report is that although it has provided a framework within which to estimate the future impact of projects, the full impact of future projects can never be predicted in this manner. This is due to the serendipitous nature of research. This effect is highlighted in this report by the emergence of the technique of protein crystallography which was not included in the original case for the facility.

Summary of impacts

As has been highlighted in this report, the economic and social impact of the SRS has been vast and continues to impact years after the closure of the facility. Whilst it has not been possible to put a total figure on this impact, the report highlights the great many stakeholders who have benefited from the facility. The SRS has not only impacted the science and industrial base of the UK but has had impact on a world wide scale. It has also played a significant role in the regional economy of the North West. The key areas in which the SRS has impacted are highlighted below –

The SRS has provided impact on a global scale

- The SRS was the world's first 2nd generation multi user X-ray synchrotron radiation facility and as such provided an exemplar for SR facilities. This pioneered the way for the development of 70 similar machines around the world with SRS staff having formal collaborations with 40% of these facilities and informal collaborations with many more. Staff from the SRS played a key role in training, giving advice to staff and the transfer of skills and technology. In addition, the SRS secured inward investment from other European countries to guarantee their usage of the SRS, which on many occasions meant the transfer of skills to their particular countries.

- The SRS has had a significant impact to its international partners in the worldwide scientific community through scientific collaborations. Staff from the SRS have collaborated with partners which have included universities, museums, hospitals, industry and research institutes in the UK, Europe and further a field (for example the USA, Japan and Russia), in projects to study subjects such as biological systems and various diseases. This means that the SRS has helped the UK play a major role in the global science base and has enhanced the UK's international reputation.

R&D from the SRS impacts people's daily lives

- Helping the ageing population with research into Parkinson's and Alzheimer's disease.
- Improving the health of the nation through research into Motor Neurone Disease, eye disease and the production of new medicines.
- Improving everyday products –
  - MP3 players.
  - Chocolate.
  - Electronics.
  - Clothing.
  - Detergents.
  - Aircraft.
- Helping to solve global challenges - HIV/AIDS, global warming, water pollution in the 3rd world, Foot & Mouth Disease, Bird Flu & Malaria.
- Protecting the world's history.

The scientific and technical legacy of the SRS continues to be felt

- The SRS has brought scientific prestige to the UK through the world leading science that has been done on the facility, for example its world leading structural biology programme and helping to win Nobel prizes.
- The SRS has helped to sustain and improve the UK's science base and research infrastructure and has played a key role as a central research facility, from which the UK's science base has benefited from.
- In addition to the world class R&D that has resulted from the SRS, the facility has created the knowledge and expertise that has allowed the next generation of accelerator facilities to be built in the UK. The establishment of the SRS, the world's first 2nd generation light source, paved the way for the UK's 3rd generation light source (Diamond Light Source) in addition to a potential 4th generation light source and other facilities such as ALICE. In addition, accelerator science capability was gained through the experience of developing the SRS. This was reflected in the establishment of the Accelerator Science and Technology Centre which is now a partner in the Cockcroft Institute together with the key North West universities. The Institute's remit is to research, design and develop particle accelerators.

The SRS has delivered highly skilled people to the labour market

- Staff skills – A critical mass of highly skilled engineers, technicians and instrumentation developers in addition to users of the facility was built up over the lifetime of the SRS with staff numbers peaking at 325 in 1998/99. The skills required to design, run and support the research at the SRS was vast, requiring world class expertise in areas such as engineering, instrumentation, and many technologies including; detector, power supply, radio frequency, accelerator, cryogenic, vacuum & critical cleaning and electronics. As one expert quoted – "Without the SRS the UK would have lost its electron storage ring expertise".

- Staff transfer – This has allowed SRS staff and support staff to transfer their expertise and knowledge to industry, universities synchrotrons and particle physics experiments. Over 100 staff from the SRS have transferred to academia, industry or other synchrotrons around the world, transferring the knowledge and skills learnt at the SRS to these other bodies.

- Apprentices – Since the inception of the SRS, 108 apprentices completed their training at the Daresbury Laboratory. The great majority of these apprentices worked directly on the SRS, with a smaller number on ancillary facilities.

- Developing skills of users – The SRS also developed the skills of its scientific and industrial users; over 11,000 individual users have used the SRS during its lifetime from over 25 countries. In addition it also played a big part in the studies of many students, 4,000 of which used the SRS as part of their degrees or doctorates and 2,000 post-doctoral researchers used the SRS for some aspect of their research. The supply of skilled graduates and researchers who are trained at large facilities such as the SRS and then transfer to industry or other public sector bodies is a key impact from research, whilst additionally retaining and attracting scientists to the area.

The SRS inspired young people to take up science & increased the public's awareness of science

- The SRS was the "jewel in the crown" of the Daresbury Laboratory's Public Understanding of Science programme. In order to inspire the next generation of scientists and engineers, the Laboratory hosts 3000 members of the public and 3000 school pupils per year to hear about the latest developments in science and technology and take part in programmes and activities.

- For many years, the Daresbury Laboratory has invited students for work experience. Some participated during their school years, whilst others worked at DL as part of their undergraduate or post-graduate studies. Many worked with scientists, often on the SRS or its support functions; others worked in functions such as IT or administration. A total of 454 students underwent work experience at the Laboratory.

The SRS has improved the performance of UK industry

- Over its lifetime the SRS had partnerships with 200 proprietary stakeholders including government departments, industry, hospitals, museums, universities and other SR sources. The industry sectors which benefited from the usage of the facility included pharmaceuticals, biotechnology, healthcare, oil & petroleum, aerospace & defence, energy and automotive. Industrial users of the facility included SMEs and large corporations from both the UK and abroad. 11 out of the top 25 companies in the UK R&D Scoreboard (2008) benefited from the SRS including ICI, BP, Unilever, Shell, GSK, AstraZeneca and Pfizer.

- Pharmaceutical, biotechnology and healthcare customers were the biggest users of the SRS and particularly benefited from the strengths of SRS staff in the area of structural biology. One of the major impacts of the facility has been the emergence of techniques to facilitate structural biology, in particular Protein Crystallography using synchrotron radiation. This technique was pioneered at the SRS and the UK is world class in this area. This strength has supported the skills base and R&D competitiveness of the UK's pharmaceutical and biotechnology industries. This is reflected in the £50M investment made by the Wellcome Trust into the UK's replacement for the SRS, the Diamond Light Source, to carry on the protein crystallography work started at the SRS. The following quote highlights this impact –

> *"The UK owes its leading position in Structural Biology to SRS Daresbury. The pharmaceutical industry also places high value on access to SRS Daresbury.[185]"*

It should be noted that the technique of Protein Crystallography was not in the original science case for the facility. This highlights the somewhat serendipitous nature of basic science and that certain high impact developments cannot always be predicted.

- There was a significant amount of knowledge exchange between the SRS staff and industry during the construction and development of the facility. These projects involved the transfer of unique skills and technology to industry on several projects and the technological development of some key SRS components by UK industry. The challenging nature of these projects and their high specifications meant the industrial partner's capabilities were improved, allowing them to win subsequent contracts and develop products for export. The study identified contracts worth nearly £300M which were won by UK industry as a direct result of working with the SRS.
- The SRS also acted as a purchaser of goods and services in the local area and wider UK. Throughout its lifetime, the SRS has traded with over 300 local businesses, investing on small items such as consumables, small items of equipment and maintenance. This purchase of goods or services from suppliers leads to a further chain reaction of purchases from their supply chain and also has indirect effects on employment, spend and taxation.

The SRS created new companies in the UK

Skills, technology and knowledge gained on the SRS has helped in the creation of 9 new companies and one commercial service provider. These new companies are in a range of areas which include scientific instrumentation, detectors for academic and commercial applications, cholesterol monitoring, software, cryogenics, mechanical precision instrumentation and drug discovery.

The SRS stimulated the economy in the North West of England

- There was a direct financial impact to the North West through financial investment in the facility. This impacted on UK industry with the SRS working with over 300 businesses local to the facility, creating indirect effects due to impact on the supply chain of these businesses. This financial impact has also created jobs – staff numbers peaked at 325 also creating induced economic impacts via spend of wages and creation of new jobs.
- The SRS budget was £594M overits lifetime, with £534 spent in the local area over its 33 year lifetime (including construction, operation and decommissioning). 37% was spent on wages and 34% spent on recurrent items with local businesses. The indirect and induced financial economic impact resulting from the SRS budget was £398M, with impacts mostly occurring in the area local to the SRS. This represents the financial ripple effect of the SRS budget spend over its lifetime.

[185] *BBSRC Review of UK Structural Biology, Polaris House (1996).*

- Therefore the total financial economic impact of the SRS was approximately £992M.

The SRS developed a knowledge base and skills to facilitate the realisation of the Daresbury Science and Innovation Campus

- The Daresbury Science and Innovation Campus was created to exploit the critical mass of expertise, facilities and industrial links that had been created by the SRS and the wider Daresbury Laboratory. In addition to the scientific facilities already on the site, the Campus has led to the establishment of a world class centre for accelerator science, the Cockcroft Institute and will further benefit from two other centres based on computational science and detectors systems in the near future.

- 100 high tech businesses from a wide range of commercial backgrounds are now located in the Daresbury Innovation Centre. Tenants come from sectors including biomedical, energy, environmental, advanced engineering and instrumentation industries.

- In 2008/2009 companies in the Innovation Centre delivered £14.9M in sales, and secured £20.5M in investment and the average growth rate in turnover of these companies was 67%. 48% of Campus companies have made significant use of the facilities, services and expertise at Daresbury Laboratory. 97 new jobs have been created in these tenant companies since they located onto the Campus with many companies expanding their businesses, recruiting more staff and looking to increase the size of their operations on Campus.

- The success of the companies on the Campus has generated a requirement for grow-on space for DIC tenants and new businesses.

- In 2009 there were approximately 800 people working on the Campus, which include staff in the Cockcroft Institute, tenant companies in the Daresbury Innovation Centre, Daresbury Laboratory staff and students, contractors and visiting scientists. This figure is expected to reach 2000 employees by 2040.

Chapter 17

Methodological issues

Chapter 17

Methodological issues

17.1 Introduction

This section highlights some of the methodological issues that have been raised as a result of this project.

17.2 Methodological issues

Research surrounding the limitations of economic impact measurement was highlighted in chapter 3. Several methodological difficulties were encountered when trying to convert the output data from the SRS into impact data, confirming the issues highlighted in chapter 3. These include –

- Timescales – in some instances, research and technological output from the SRS has not yet fully impacted, highlighting that research may take decades to impact. Hence, choosing the appropriate time to asses impact after the project is finished is an important issue.

- Attribution – there are always several inputs to the research process meaning that it can be difficult to attribute impact to any one source. Inputs to the SRS included funding, support and expertise from several sources including national and international universities, research councils, RDAs and industry. It has been difficult to untangle how much impact the SRS has been directly responsible for, for example, the research was generally a small part of an overall research programme and was funded in collaboration with other Research Councils.

  In addition, as projects progress through time they are also often in collaboration with other partners and funded through other routes. When impact is finally realised, deconstruction of the STFC's role and specific impact may be a complex issue.

  The project also highlighted a particular issue regarding how to track the commercial impacts of large scale facility users such as spin-outs or licenses funded by other research councils or universities. There is no doubt that the facility facilitates commercial activity but the amount of credit that the STFC should take for this is not clear.

- Confidentiality – any paid commercial access to facilities is subject to confidentiality agreements. Companies are generally reticent to make details of research or turnover available in the public domain. Hence the impact in this area is clearly an underestimate.

- Industry contacts – in addition to confidentiality issues, it was difficult to find the correct contacts, especially in large companies. Several companies had also went into administration. There were also several instances where the staff who had been involved in the original research had left the country and could not be contacted.

- Electronic records – the SRS was built in the late 1970's before the advent of the PC, making it difficult or impossible to access some data. For example, there was no record of which companies were involved in the construction of the SRS. In these instances, people's memories were the only resource.

- Quantification of impact – The quantitative and qualitative nature of the data contained in this report highlights that the quantification of impact is not possible in all cases.

Appendices

Appendix 1

STFC economic impact baseline (2007/2008)

STFC delivers economic impact throughout the whole range of its diverse programme and since 2006 has required Knowledge Transfer/Exchange plans to be included with applications for research funding. STFC plays a dual role as a funding agency supporting research in universities and major international centres as well as operating the two national Science and Innovation Campuses (SIC) at Daresbury and Harwell, the research facilities based at the two sites and the UK Astronomy Technology Centre at Edinburgh.

- Daresbury Innovation Centre (DIC) currently hosts 71 companies (compared with 55 in 2006/07) co-located alongside STFC's laboratory, with over new 50 jobs created by DIC companies since locating there.
- 50% of companies in the DIC have collaborated with each other, with 23 joint developments involving DIC companies with STFC and/or North West universities.
- 78% of DIC companies have made significant use of DL facilities, services and expertise.
- Over 4500 people work on the Harwell SIC in some 120 organisations (80 in 2006/07).
- STFC has signed the Joint Venture partnership at HSIC to take forward the delivery of the Campus initiatives.

Through our research programmes, facilities and wholly-owned exploitation vehicle CLIK, STFC has created spin outs (full list in Annex 2) and enabled companies to develop new capabilities which they can exploit commercially in wider markets;

- L3T is a spin-out from Daresbury Laboratory set up to commercialise a brand new method of Cholesterol monitoring using a highly accurate fluorescent assay. L3T have patented a novel way of measuring all of the cholesterol sub-fractions with unprecedented accuracy;
- e2v won £250m of sales after development of an antimultipactor coating in collaboration with the SRS at Daresbury.
- Constellation Technologies, a newly formed spinout from CLIK, has been awarded the 'best improver' award and is taking gLite technologies from CERN to offer commercial access to Cloud (the new internet) computing.
- Understanding the foot and mouth disease virus (FMDV) structure, which led to the development of vaccines, would not have been possible without the Daresbury SRS facilities during the 1980s. FMDV is a major killer of livestock, and the 2001 outbreak had estimated direct costs totalling £8.4b[186].

Providing highly skilled people

Through its facilities STFC plays a key role in education, training and skills provision at all levels from schools and apprentices to PhD and fellowships, both within its programmes and through the provision of courses.

- 999 people engaged with all level of training courses (2006/07).
- There was an increase of 73% for qualified scientists using facilities in 2006/07 compared to 2005/06.

186 http://archive.cabinetoffice.gov.uk/fmd/fmd_report/report/index.htm (see economic impact of FMDV, section14).

- 150 individuals from 7 SMEs have received NVQ level 3-5 training in advanced instrumentation and engineering at the Harwell SIC.

- 110 work experience placements at RAL and Daresbury in 2006/07.

Science and Technology Gateway Centres. The Science and Innovation Campuses at Daresbury and Harwell will act as important national focal points for science-based collaboration and knowledge exchange with academic and industrial researchers. The first three proposed Centres are: Detector Systems Centre, Hartree Centre, and Imaging Solutions Centre.

STFC is the funding agency for PhD studentships at a national level for key areas of physics and will maintain this to ensure a strong flow of trained researchers both to maintain the health of the research discipline and to feed out into the wider economy, where evidence shows that students are highly desirable in high technology, computing and financial industries (source: HESA data).

- Over 45% of PhD students enter university research on completion.

- 16% enter public sector/government (2003).

- There has been a steady increase in entering private sector by over the last ten years (28% in 2003).

STFC has a strong record of scientific publication by the scientists it supports and the researchers who use its facilities which can be used as an indicator on research output efficiency.

- On average there were 930 multidisciplinary publications from the large facilities for 2005-2008.

- Increase in publications from the astronomy community from 1893 in 2006/07 to 1902 in 2007/08.

STFC programme is contributing to the production of highly trained people and the knowledge base on which long term economic development will depend.

- STFC directly funds over 200 PhD students per year.

- STFC provides training for over 900 PhD students from a range of disciplines.

- 39 joint appointments with HEIs (21 in 2006/07).

- 63 visiting fellows (from and to) large facilities (56 in 2006/07).

Improving UK business competitiveness

Improved products and processes

Commercial use of the STFC facilities and technology programmes has grown:

- Over 2007/08 CLIK brought in commercial work with a total value of £347k, including £143k for access to the synchrotron.

- 14 collaborative projects with industry with a value of £15.6m (75 with a value of £11.9m in 2006/07).

- 170 facility beam days used by commercial partners in 2007/08 (across all the facilities) compared to 82 in 2006/07. The breakdown of usage was 37 individual companies, drawn from 8 industry sectors.

There are clear examples of new or enhanced products resulting from STFCs Technology and Skills base.

- CLIK records on average 20 ideas/technology prospects per year (2005-2008).

- 14 Proof of concepts are funded per year (average 2005-2008).

- There are growing numbers of partnerships between university researchers (39 joint appointments with HEIs) and our laboratory based staff (105 collaborative projects).

Creating opportunities for UK business

STFC has played an active role in ensuring that UK companies are able to tender for work at major

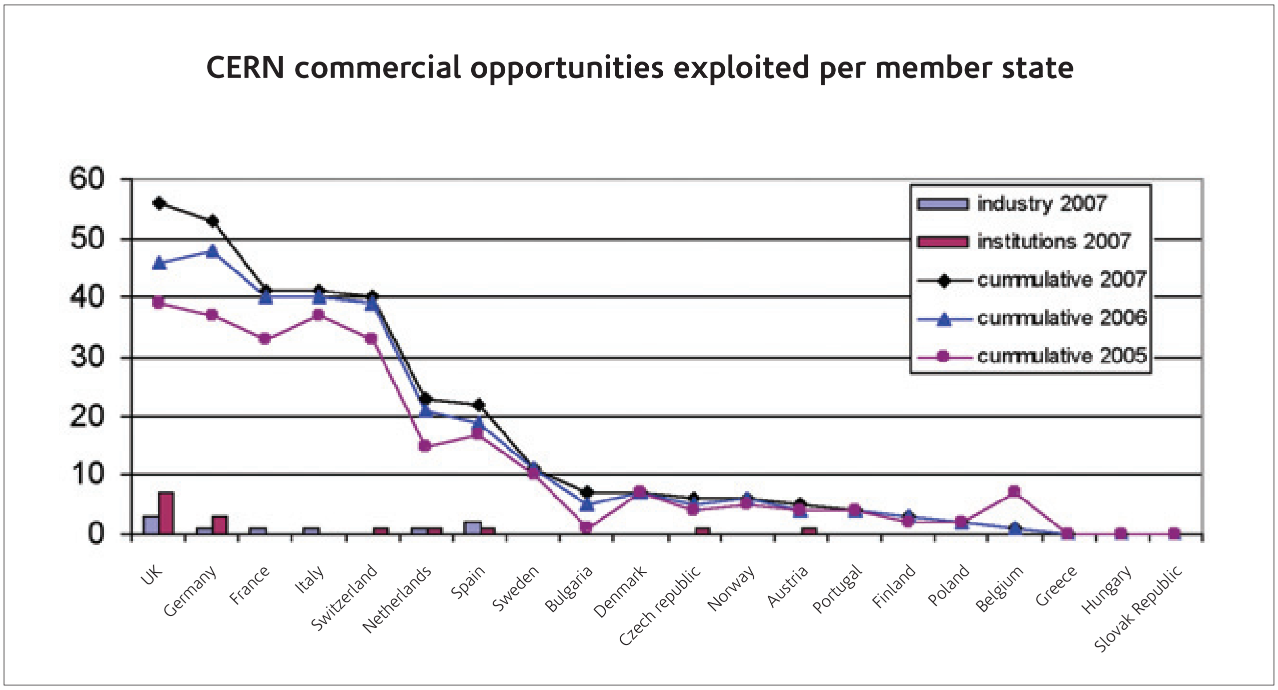


Figure 48: CERN commercial opportunities exploited per member state.

research centres. Through an initiative with UKTI and sponsorship of the SIKTN it is promoting a coherent national programme to ensure that UK companies get the widest knowledge of the opportunities open to them and early intelligence about new developments.

- Value of contracts placed with UK companies from ESA: €48.2m (€39.2m in 2006/07).
- Value of contracts placed with UK companies from ESO: €20m (€2.7m in 2006/07).
- Value of contracts placed with UK companies from CERN: CHF 11.4m (CHF 26.5m in 2006/07).

CERN/Industry interaction

The UK remains ahead of other member states for the third year running, for commercial opportunities exploited by both industry and institutions (Figure 48).

Attracting investment in the UK

Our facilities and Campuses are already attracting investment in commercial and outreach activities, and our grant-based programmes have attracted co-sponsorship from other RCs and OGDs who wish to access our knowledge base.

- The NWDA are investing over £50m in Daresbury SIC over (X) years (£8.5m in 2006/07), including approx £200k/year business support fund and a budget of £600k/year to operate the Innovation Centre.
- At Harwell SIC the new Joint Venture (JV) Partner, Goodman International, has brought inward investment to HSIC by capitalising the JV. The JV (signed August 2008) will increase overall site investment and development.

Commercialisation

STFC has a strong track record of spin out formation through CLIK, which has incubated a number of companies including L3 technology Ltd, ThruVision Ltd, Microvisk Ltd, Oxsensis Ltd, Petrra Ltd, LiteThru Ltd, Quantum Detectors Ltd and, Bi-Au Ltd. It has also worked closely with universities and international centres to encourage an entrepreneurial approach which has yielded success.

- On average seven licences created each year (2005-2008).
- Average commercial income (non-sales) from licences is £77k per year (2005-2008).

Improving public service

Research that originates from STFC can be used to improve health and security.

Health

- PETRRA, the novel positron camera, has been jointly developed by the Rutherford Appleton Laboratory and the Royal Marsden Hospital. The camera has been installed in the scanning suite at the Royal Marsden Hospital and is ideally suited to finding secondary tumours in cancer patients who need a whole-body scan.
- MeditrEn Limited is designing systems that measure how many calories a person needs. This can be used to measure people suffering from obesity and malnutrition.

Security

- ThruVision products are used to image concealed objects on moving people at a distance without any radiation and without revealing any anatomical detail. ThruVision developed its proprietary technology by adapting space imaging technology originally developed at the Rutherford Appleton Laboratory (RAL), UK which began in 1985.
- Symetrica, based at Southampton University, as developed a range of hand-held gamma ray detectors to detect terrorist activity. The detectors are capable of differentiating between dangerous materials and other, natural, substances.

STFC Economic Impact Highlights

Economic impact area	Activity and measure	
	2007/08	2006/07
Highly skilled people	• Collaboration – qualified scientists using UK facilities: 2463 • People flow – Large facility staff involved with international collaboration and visiting fellows: 523 • PhD students directly funded: 272 • CASE studentships hosted in STFC departments: 31	• Collaboration – qualified scientists using UK facilities: 4139 • People flow – Large facility staff involved with international collaboration and visiting fellows: 215 • PhD students directly funded: 207 • CASE studentships hosted in STFC departments: 40
Attracting and retaining investment in the UK	• Income from international collaboration: £12813k. • Harwell SIC: 120 companies. • Daresbury SIC: 71 companies	• Income from international collaboration: £5142k • Harwell SIC: >80# companies • Daresbury SIC: 55 companies

Table 7, STFC Economic Impact Highlights

Economic impact area	Activity and measure	
	2007/08	**2006/07**
Improved products and processes	• Major user satisfaction measure presented by academic and private sector responses for large UK facilities: 86% (target 85%) • Number and value of collaborative projects with HEIs: 105 (£40.4m) • Number and value of collaborative projects with industry: 14 (£15m) • Percentage of projects reporting successful technology output or transfer in final report (PIPSS, FoF & Faraday): 60% • Successful completion of the PRI, PIPSS or Faraday project as demonstrated through a viable proposal for industrial engagement: 4 out of 8 • 26 companies collaborating on PRI, PIPSS and Faraday covering 7 commercial sectors	• Major user satisfaction measure presented by academic and private sector responses for large UK facilities: 88% (target 85%) • Number and value of collaborative projects with HEIs: 29 (£11.0m) • Number and value of collaborative projects with industry: 75 (£11.9m)* • Percentage of projects reporting successful technology output or transfer in final report (PIPSS, FoF & Faraday): 80% • Successful completion of the PRI, PIPSS or Faraday project as demonstrated through a viable proposal for industrial engagement: 19 out of 21 • 19 companies collaborating on PRI, PIPSS and Faraday covering 6 commercial sectors
Commercialisation	• Equity investment in Spin-out Companies: £9.09m • New businesses: 11 (2005-2008) • Licences: 28 (2005-2008) • Licence revenue: £92k pa • Proof of concept funding: 52 (2005-2008)	• Equity investment in Spin-out Companies: £3.77m • New businesses: 10 (2005-2007) • Licences: 23 (2005-2007) • Licence revenue: £56k pa • Proof of concept funding: 31 (2005-2007)

Table 7 continued, STFC Economic Impact Highlights

Figure based on UKAEA estimate
* *2005/06 figure*

Appendix 2

Definitions of light sources

First generation light sources

These are synchrotron-based facilities where the SR users operate entirely 'parasitically'. Despite severe technical problems many 'ground breaking' experiments were carried out using first-generation sources in Japan (Tokyo), the UK (Daresbury), Germany (Bonn and Hamburg), France (Orsay), Italy (Frascati) and in the USA in Gaithersburg and Wisconsin.

Second generation light sources

Second-generation sources are storage-ring based facilities specifically designed and constructed for use in diffraction, scattering and spectroscopic experiments. They are normally based on electron storage rings, but some positron rings are also used. The world's first medium energy, user based X-ray facility, the SRS, offered easy, safe access to the beam at locations, called 'stations' where the photon beam was matched to the users requirements for their experiments. Specialised sample containment, sample manipulation, data collection and analysis based on local computer facilities rapidly grew around each station.

Third generation light sources

Third generation sources are electron storage rings built specifically to accommodate insertion devices. These are multipole magnet arrays, called wigglers and undulators, which are designed to generate partially coherent radiation over selected photon energy and wavelength ranges. Insertion devices yield many orders of magnitude enhancement in photon brilliance above that achievable from dipole bending magnets. The first, and one of the world's most successful third generation sources, is the ESRF constructed in 1994 in Grenoble France. There are various geometries for third generation machines but all are essentially re-circulating 'insertion device' electron accelerators which can provide partially coherent radiation across a huge range from ~10 eV to ~100 KeV, with brightness (also called brilliance) of up to 10^{19} photons/sec/mm^2/mr^{-2}/0.1% photon energy bandwidth. Higher energy machines of 5 GeV to > 7 GeV yield the greatest brightness and substantially more hard X-ray flux at ~>100 KeV, but result in a very large circumference storage ring (of the order of a kilometre). Consequently, there are significantly higher capital and running costs because of the very large size of the buildings needed, and the length of many beamlines, which can themselves be up to the order of a kilometre, but typically 60 to 80 metres.

Fourth generation sources

Fourth generation sources are effectively free-electron lasers offering coherent x-radiation radiation with immense peak brightness of up to 10^{34} units needed or more. This exceptional brightness is also manifest in the narrow (i.e. short time) pulse structure of the emitted X-rays which, in principle, might enable holograms and general structure studies of proteins and other molecules to be made in the sub picosecond time domain at an atomic level.

Fourth generation sources, none of which are currently in operation, present a considerable technical challenge in terms of photon beam manipulation and probably also of sample irradiation and survival. Linear accelerators feasible for such work are to be found in Hamburg Germany (TESLA) and Stanford USA (SLAC). Smaller lower energy machines based on Energy Recovery Linacs, have also been proposed e.g. at Daresbury Lab and these offer the great challenges and opportunities for future growth in the field. An X-ray ERLP with brightness intermediate between the 'perfect synchrotron specification' and the X-ray lasers class is being investigated e.g. at Cornell in the USA, and with which the Daresbury Laboratory's longer photon wavelengths producing ERLP has obvious links.

SRS research output & usage

SRS research output

The major output of research is the generation of knowledge, both codified and tacit. Any research information which is published or can be accessed can make an impact and is measured through publication volume and impact data. The 10 year Science and Innovation Framework[187] document recognises that –

> *"A key output from research is the volume of research articles published worldwide, as publication is a significant channel by which research findings are disseminated."*

The SRS has made a major impact to the field of research, producing over two million hours of science in its lifetime. This contribution is reflected in the great number of scientific publications and citations of these papers which resulted from the facility's usage –

- Since its inception the SRS contributed to the publication of at least 5404 papers which have been entered onto the SRS database[188].
- These papers have been cited over 80,000 times.
- The most cited SRS publication was on the Light Harvesting Protein[189], important for trapping sunlight by anaerobic bacteria. This work was carried out by Glasgow University and Daresbury Laboratory scientists and was published in 1995. This paper had amassed 1373 citations by August 2008.
- Science from the SRS has resulted in 10 high impact factor publications per year (Nature, Science & PNAS), with a further 15 per year in other high impact journals such as Cell, PRL, Angewandte Chemie and the Nature specialist journals.
- Over 1200 protein structures solved using the SRS have been placed in the Protein Data Bank.

The number of publications and high impact publications is given in the table overleaf from 2000 to 2006 shows a relatively constant high rate of publication.

These figures do not include the accelerator-related publications. Accelerator staff traditionally tend not to publish in journals and instead use the proceedings of the major conferences. For example, the biennial European Particle Accelerator Conference (EPAC), with Daresbury Laboratory staff contributing 30 papers at EPAC-96 and 29 papers at EPAC-98.

[187] *www.berr.gov.uk/files/file40398.doc*

[188] *This is known to be a significant underestimate as all of the publication data has not been collected. This data is known to be totally accurate from 2001 onwards.*

[189] *McDermott, G., S. M. Prince, A. A. Freer, A. M. Hawthornthwaite-Lawless, M. Z. Papiz, R. J. Cogdell and N. W. Isaacs. (1995) "Crystal structure of an integral membrane light-harvesting complex from photosynthetic bacteria", Nature 374, p517-521*

Calendar Year	Total (refereed) Publications	High Impact Publications (Nature, Science & PNAS)	Other high impact journals (Cell, PRL, Angewandte Chemie & the Nature specialist journals)
2000	357	3	16
2001	442	6	17
2002	427	8	11
2003	484	13	19
2004	490	8	15
2005	545	12	19
2006	434	11	9

Table 8, publications from the SRS from 2000 - 2006

SRS usage

The table below illustrates the usage of the SRS between 2000/01 to 2006/07.

Scheduling Period	No. of Operating Stations	No. of Experimental Sessions	No. of days scheduled for User Experiments	No. of Users per year	No. of User Visits
2000/01	39	1113	2754	1195	2091
2001/02	39	926	2183	1020	1762
2002/03	38	936	2242	970	1495
2003/04	35	1251	3466	1350	2293
2004/05	35	999	2827	1341	2179
2005/06	33	1313	3716	1464	2478
2006/07	28	931	2491	1020	1744

Table 9, usage of the SRS from 2000 – 2007

On average 600 experiments took place on the SRS each year varying in length from 1 day to 3 weeks. The size of the user community peaked at around 1500 per year from the late 1980s and declined in proportion to the reduction in portfolio of instruments as the SRS operations were run down.

Appendix 4

Software development

Introduction

In the early stages of the development of the SRS, it was recognised that computational science would be a very important contributor to the effective exploitation of the facility. This work was carried out by the STFC's Computational Science and Engineering Department[190] (CSED), whose work has expanded well beyond the initial SRS requirements to become the largest computational science group in the UK. The CSED currently provides world-class expertise and support for the UK theoretical and computational science communities, in both academia and industry. The major output of the CSED is the development and application of powerful simulation codes, usually in collaboration with university research groups, in core areas of quantum chemistry, molecular simulation, solid-state physics, materials simulation, engineering and environmental simulations.

In 1979, before the opening of the SRS, the first Cray supercomputer in the UK was installed at the Daresbury Laboratory, initially for nuclear research, but later for the SRS software programmes. Higher performance computers were installed over the years, and in 2002, the most high-powered computer service available to UK academic researchers (HPCx) was installed at the Laboratory as part of a consortium with Edinburgh University.

Throughout the life of the SRS, very high levels of computing capability were required to optimise its operation, and to collect as much meaningful data as possible. However, in the early 1980s, much of the envisaged hardware and software did not exist. Consequently, the software development work on the SRS was novel, demanding and emulated in other synchrotrons around the world. The SRS software generated by the team falls into four main categories as shown schematically as follows:

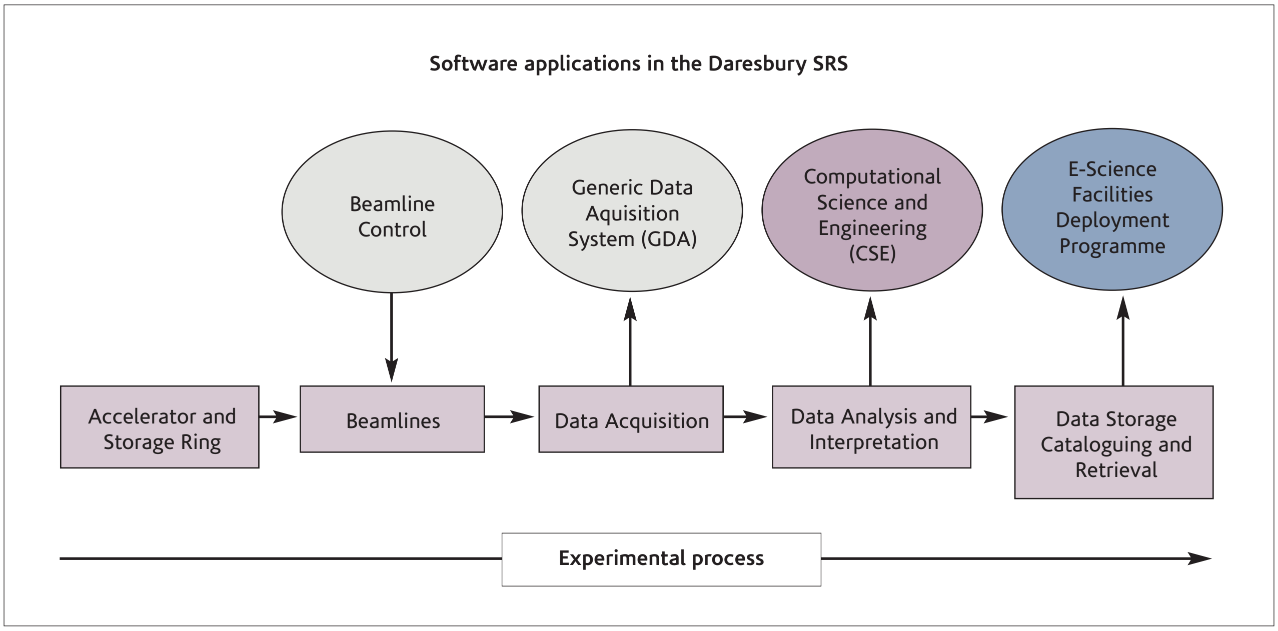


Figure 49, SRS Software Applications

190 http://www.cse.scitech.ac.uk/

There has been a significant programme of research/development on each of these software areas over the lifetime of the SRS, each of which is considered below.

Beamline control

Electronics were used to control the beamlines. The automation of beam steering and beam injection made the SRS the first computer controlled light source in the world.

Generic data acquisition system and related technologies

By the mid-90s, data acquisition systems comprised primarily of PC-based systems running Windows and LINUX operating systems driving a diverse range of hardware ranging from PC-based cards through serial RS232 to VME crate-based systems. This variety was matched by the variety of languages used e.g. FORTRAN, C and VisualBASIC.

In later years it became apparent that such diversity was unsustainable due to pressure on funding for both equipment and support effort. A solution was therefore required which would reduce the support overhead while maintaining the users' ability to perform a wide range of science. At the same time it was noted that users were becoming more sophisticated and starting to combine multiple techniques in their experiments. As a result it became much more important that data acquisition software had a consistent look and feel as well as predictable behaviour.

These requirements coincided with the building of the first multi-technique station on the SRS – MPW6.2. This utilised the newly designed RAPID2 detector and provided facilities for EXAFS, non-crystalline diffraction and X-ray diffraction techniques. The station provided an ideal platform to develop new generic software which would utilise the latest hardware and software technologies and form the basis of the Generic Data Acquisition (GDA) software.

The key features of GDA were –

- Processor and operating system independence.
- Modularity – i.e. providing the ability to reuse components as required.
- Ease of configuration.
- A scripting interface to allow experiment prototyping.
- Ability to incorporate and interact with 3rd party hardware and software – vital when users brought their own experiments which often used commercial software for data acquisition and analysis.

This philosophy was particularly powerful in the work carried out by SRS scientists to develop methods for the automation of the protein crystallography beamlines. Funded primarily through Biotechnology and Biological Sciences Research Council grants and the European Union, e-HTPX was developed as an electronic resource for high throughput protein crystallography (PX). The goal of the project was to unify the procedures of protein structure determination into a single all-encompassing interface from which users can initiate, plan, direct and document their experiment either locally or remotely from a desktop machine. This process required information handling, automation, hardware and software developments and was designed to pipeline the process of PX[191]. A core part was the automatic collection of X-ray diffraction data which uses work from the DNA project with the aim of completely automating the collection and processing of X-ray PX data. The first version of DNA was released in 2004, and its structure is shown opposite.

Another key area in generic data acquisition is the Protein Information Management System (PIMS), which began in 2003/04, funded by grants from the BBSRC. The aim was a targeted solution for realising crystals suitable for PX experiments using a laboratory information management system for protein sample preparation (which includes selection, cloning, expression, purification, characterisation, and where applicable,

[191] *www.clyde.dl.ac.uk/e-htpx/index*

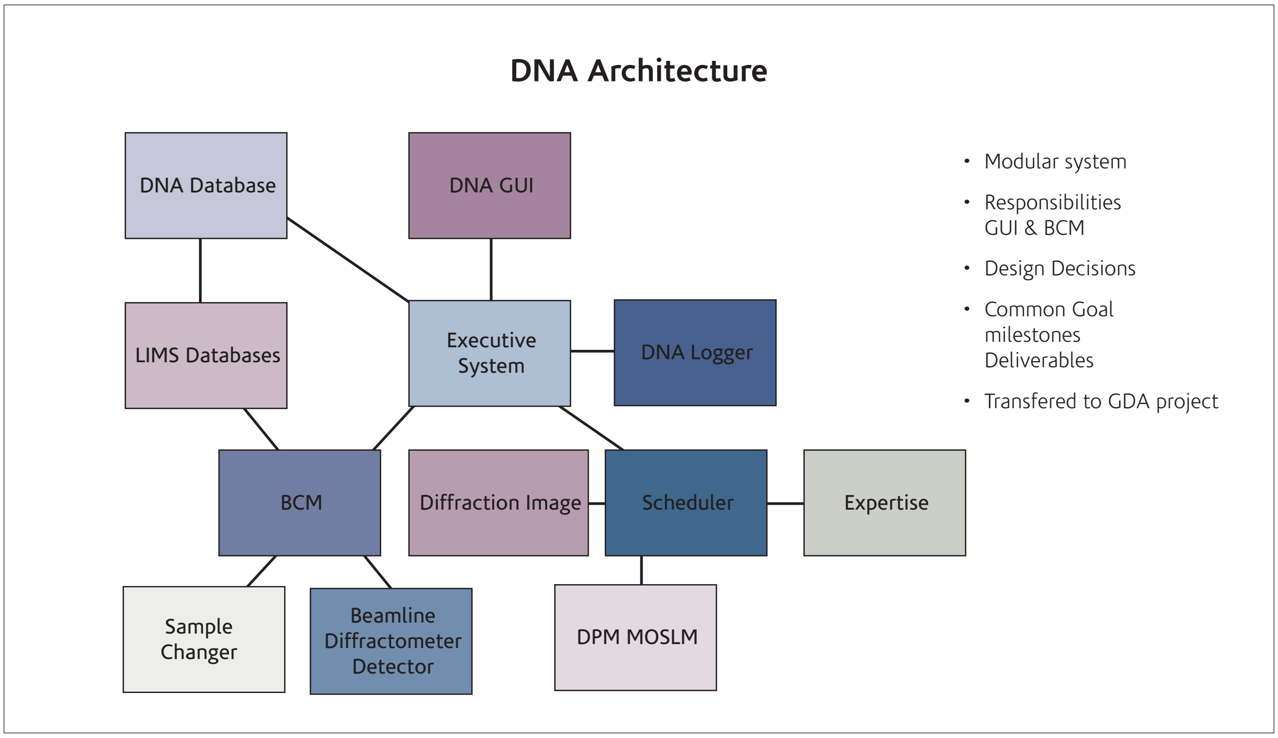


Figure 50, DNA Architecture

crystallisation) and automated data deposition in the Protein Data Bank[192]. PIMS, originally conceived by a contributor to CCP4, is one of the BBSRC Structural Proteomics of Rational Targets initiatives. This software system will contribute to the Membrane Protein Structure Initiative, a collaboration between eight leading UK academic laboratories (including the Daresbury Laboratory). The initiative co-ordinates skills, information, techniques and resources in a project to develop high throughput methods for the expression, purification, crystallisation and structure determination of integral membrane proteins, which are often of significant interest to the pharmaceutical industry as drug targets.

Indeed the software and data management systems (e-HTPX, PIMS and DNA) can be commercialised under a similar arrangement as for CCP4: free for academic use, while commercial users pay an annual subscription. Other software that has arisen from work at the SRS in PX and that is now employed by other SR Facilities, neutron facilities and by many users around the world includes the highly cited Daresbury Laue Software[193].

Computational science and engineering

In the early stages of the development of the SRS, it was recognised that computational science would be a very important contributor to the effective operation of the facility and funding was secured from the SRS for six staff to work on computational science and the associated software.

Many of the earliest experiments on the SRS were completely novel. The brightness and coherence of the source led to unprecedented levels of detail in the results – and the meaning of that detail was not always obvious. The purpose of the group was to use theoretical models to predict scientific observables. By comparing the predicted measurements with the observed data, the team were able to enhance data analysis and interpretation. The current Computational Science and Engineering Department now comprises more than 70 people, whose work has expanded well beyond the SRS requirements initially envisaged. It is the largest computational science group in the UK.

Throughout its operation, the Computational Science and Engineering Department has played a

[192] *www.mole.ac.uk/lims/project/*
[193] *Helliwell, J. R. et al. (1989) "The recording and analysis of Laue diffraction photographs", Journal of Applied Crystallography 22, P.483-497*

part in networking and distributing computing power throughout the UK academic community. In the early years, staff members supported JANET (Joint Academic NETwork) in the UK. More recently the CSED has been highly regarded for its series of Collaborative Computing Projects (CCPs), several of which are directed towards optimising the information which can be extracted from experiments carried out on synchrotrons. They are defined as follows:

> *"The Collaborative Computational Projects (CCPs) bring together leading UK expertise in key fields of computational research to tackle large-scale scientific software development, maintenance and distribution projects. Each project represents many years of intellectual and financial investment. The aim is to capitalise on this investment by encouraging widespread and long term use of the software, and by fostering new initiatives such as High End Computing consortia.[194]"*

Outputs from the CCPs are shared freely with UK academics - overseas academics pay, unless they too are collaborators and industrial organisations have to pay for access.

Whilst some of the CCPs were directed towards making best use of the outputs from the SRS (see below) others were developed to work on topics whose relationship to the SRS was more peripheral. Examples are:

- Electronic Structure of Molecules (CCP1).
- Continuum States of Atoms and Molecules (CCP2).
- The Computer Simulation of Condensed Phases (CCP5).
- Molecular Quantum Dynamics (CCP6).
- Study of the Electronic Structure of Condensed Matter (CCP9).
- High Performance Computing in Engineering (CCP12).
- Nuclear Magnetic Resonance (NMR) Spectroscopy (CCPN).
- Collaborative Computational Project for Biomolecular Simulation (CCPB).

The CCPs which were most significant in realising the potential of the SRS, and other sources world wide, are described in more detail below. These CCPs are still in operation.

CCP3 – Surface Science

Theoretical and experimental scientists work together in this CCP whose aim is to facilitate the interpretation of data from a range of surface analytical techniques such as XANES, EXAFS, X-ray absorption, and X-ray photoemission spectroscopy. (Non-synchrotron techniques such as Low Energy Electron Diffraction are also supported.)

The developed software includes codes for the analysis of experimental data, which can be used alongside software for calculation of surface properties, thereby making possible the interpretation of complex surface science data.

CCP4 – Software for macromolecular X-ray crystallography

The CCP4 project is widely recognised as a major contributor to the widespread use of macromolecular crystallography in the biological and chemical sciences. It was set up in 1979, originally by the Science and Engineering Research Council, and is now supported largely by BBSRC.

The software consists of a suite of programmes which work together to manage the data acquisition, analysis and interpretation. The software is designed so that it can be operated in the researcher's host university. Every macromolecular crystallography group in the world uses CCP4 to some extent. There is one US package which could be a serious competitor, but it has not penetrated the market to any great degree.

The packages are free to academic researchers, and industrial users are charged a fee of the order of £8k. There were around 100 commercial licences in existence in 2008,

[194] *http://www.ccp.ac.uk/*

generating ~£800k per year; overseas organisations hold about 80 – 90% of these licences. The CCP4 staff provide email and helpdesk support, and oversee the continuing development of the software. The drivers for software development are ease of use, particularly for those biologists with minimal software expertise, and the capability to tackle more complex proteins. Future developments will concentrate on enhanced automation, including methods to select the best crystals for full crystallographic study. The group also delivers training workshops, conferences and similar gatherings worldwide, with a strong presence in India and China.

CCP13 - Fibre Diffraction and Solution Scattering[195]

This project began in 1992, and was directed towards the development of software for small angle scattering and fibre diffraction. The project was considered highly successful, generating software, instigating a journal (Fibre Diffraction Review) and acting as a focus for the international community working on this topic.

The number of refereed scientific papers using this software has been recorded since 1992, and totalled 465 up to 2006[196]. However, funding ceased in 2005, but the software is currently stored at Diamond, and made available to researchers, although is not being developed further.

The e-Science Facilities Deployment Programme

By the 1990s, the SRS was generating vast amounts of data, much of it held in ad hoc fashion by station scientists, users, and others. There was no central storage facility and no formal processes or policies for data access, storage, retrieval, publication or retention.

In 1999, it was recognised that it would be desirable to find ways of making this large amount of data – much of it captured using public funds – available to a wider range of scientists. The decision was taken to set up an e-science facility, charged with capturing the wealth of information being generated not only by the SRS, but also by other major facilities.

In its early stages, the project set itself the task of capturing, cataloguing and making available the raw data generated by the SRS. It then became possible to link the raw data to the analysed and interpreted data. The facility to capture details of experimental procedures was then added, and in the fully developed phase (2008) the system was also capable of capturing all the stages of the underlying processes, from proposal, through experimental design, data collection, interpretation, publication and archiving.

Station scientists and users on the SRS assisted the early stage definition of the e-science project. They helped to test the concept and mechanisms, and thereby contributed to the definition of the required software and hardware. By linking data from different facilities, such as the SRS, ISIS[197] and the Central Laser Facility[198], scientists were able to assemble fuller information on research topics as diverse as biology and high-energy physics. The e-science project constructed access mechanisms to make it feasible for scientists to access and understand data from fields distant from their own. This has obvious implications for education, both at tertiary level and in schools and colleges, and can help young scientists to determine, more quickly than previously, what has already be done in their field of interest.

The e-science project is also still helping to extract as much value as possible from collected data. The accessibility of raw data, and the ease of finding it through the catalogues, allows researchers to go back and reinterpret historical information, by use of new techniques, or in the light of new information from other sources.

The project is world-leading: nothing similar had been achieved elsewhere, and the model has been adopted by major research facilities around the world, including:

- ISIS (STFC).
- Diamond (STFC shareholding).

195 www.small-angle.ac.uk/
196 Pwww.small-angle.ac.uk/small-angle/Publications.html
197 ISIS, The pulsed neutron and muon source at Rutherford Appleton Laboratory, www.isis.rl.ac.uk
198 http://www.clf.rl.ac.uk/

- Central Laser Facility (STFC).
- Neutron Science facility in Oakridge, USA.
- ESRF, Grenoble.
- Institute Laue Langevin, Grenoble.
- Australian Neutron Source.
- Canadian Light Source.

This activity has formed the e-Science Facilities Deployment Programme which is part of the STFC's e-Science Centre which was one of the four founding members of the Digital Curation Centre[199]. Its staff helped to write the proposal and were involved in the research work of the first phase of the centre. In 2005, they initiated a commercial assessment of the potential for a practical curation service.

In 2008, the e-Science Facilities Deployment Programme was the largest and most comprehensive Laboratory Information Management System in the world. It captures, stores and makes accessible all the stages of an experiment on a major facility – it was conceived, tested and proved on the SRS.

Highlights in software development

Over the lifetime of the SRS, there were several instances where software development at the SRS was world-leading. Some examples are given below.

Ethernet

As the amount of data being obtained from the SRS increased, it became clear that data links were comparatively slow and cumbersome. As the number of stations increased, the data transmission rates could not keep up. About this time, asynchronous Ethernet links were becoming available, and standards were emerging. SRS staff took the existing hardware and wrote the protocols for faster data transmission. Although standard protocols later emerged, the Daresbury Laboratory staff worked with their own protocols for quite some time. Indeed, Daresbury Laboratory staff helped develop those standards and still sit on the Standards Boards. The advantage to the users was that the Ethernet development took out delays in the system, and so data processing could be carried out close to the time of the experiment – with great benefits for speed and quality of experimentation.

Detector control software

Detector control software was at one stage world leading, primarily driven by demanding experiments on two-dimensional, time-resolved diffraction of muscle.

EXAFS data analysis/interpretation

The EXAFS data analysis was driven both by theoretical work and the development of the analysis code. The code was so efficient that experimentalists could get feedback in just a few minutes, allowing them to explore theoretical fits at almost the same time as they were gathering data.

LAUE crystallographic analysis

The Daresbury Laboratory Laue Software Suite[200] is a set of programs developed for the processing of Laue X-ray diffraction data. This software analysis package was established with SRS scientists in collaboration with colleagues in CSED[201].

The software has also been adopted by the Institut Laue-Langevin on both LADI (biological) and VIVALDI (chemical) neutron crystallography instruments and at the Los Alamos Neutron Facility LANSCE on its PCS (Protein Crystallography neutron Scattering) Instrument.

The Daresbury LAUE Analysis suite is mainly facilitating academic research in dynamic and time-resolved X-ray crystallography as well as neutron Laue crystallography. However, it is expected to eventually facilitate commercial applications where structural intermediates and protonation state definition would benefit applications such as drug discovery or new materials. Glaxo Smith Kline for example has already jointly supervised projects[202] in improved protein structure definition for thrombin, a key protein in blood clotting for which inhibitors can be important.

[199] *www.dcc.ac.uk/*

[200] *http://www.srs.ac.uk/px/jwc_laue/laue_top.html*

[201] *Y.P. Nieh, J. Raftery, S. Weisgerber, J. Habash, F. Schotte, T. Ursby, M. Wulff, A. Haedener, J.W. Campbell, Q. Hao and J.R. Helliwell "Accurate and highly complete synchrotron protein crystal Laue diffraction data using the ESRF CCD and the Daresbury Laue software" (1999) J. Synchrotron Rad. 6, 995–1006.)*

[202] *With Professor J. R. Heliwell of Manchester University*

Appendix 5

Daresbury Laboratory public understanding of science activities

Open days

The first Daresbury Laboratory open day took place over 5 days in June 1997 with 3,500 visitors taking part in exhibitions and events. In addition to 5 days of schools activities, lectures were given on the Laboratory, science in general and local companies. In addition, a series of events took place in 2005 to celebrate the 25th anniversary of the SRS including a tour of the SRS and other scientific facilities, a staff and family day, as well as a public open day, all attracting over 4000 people to the Lab.

Quotes from people attending included:

"Good for families and particularly children to be exposed to the wonders of science."

"All the staff were absolutely brilliant with children and us non-scientists, explaining things at a level we could understand."

"Excellent introduction to real science for young and old alike."

In all, 98% of the comments were positive and the only negative comments concerned the weather and the need for more time.

Talking Science

The “Talking Science” programme includes evening lectures and schools and special events at Daresbury Laboratory. Since its inception in 1998, Talking Science events have taken place on a near monthly basis with 10 events occurring annually. Lectures and events are on many different aspects of science (lecture titles from the current programme include “Preventing Crime”, Invisibility Cloaks” and “Science and Sport”) and are free to all members of the public.

The views of many of those who regularly attend these lectures were summarised by Dr Peter Owen, a member of staff in Daresbury, who has attended the lectures since they began. Dr Owen always found the lectures to be very worthwhile indeed. Even though the quality can vary, they are always of interest, and many of them are outstanding. A substantial proportion of the lectures are given by eminent scientists, such as Prof Robert Winston. The breadth of subjects covered is very wide, ranging from sub-atomic physics to biology. There is no other venue in the area where it is possible to hear, and indeed meet, scientists of this standing, and the lecture series is highly valued by the local community.

The lectures attract large numbers of children, even to those events which are not specifically designed for children. Whilst some lose interest over the years, others have become more and more interested, to the point where they bring their friends.

Science festival

The Daresbury Laboratory also hosts a mini science festival on an annual basis[203]. The Laboratory acts as the venue and hub for a regional showcase of outreach work. The 2008 festival has the title “STFC Daresbury Laboratory & North West British Association for the Advancement of Science Mini

[203] *www.scitech.ac.uk/PandS/SchEdu/Labs/DLscienceweek.aspx*

Science Festival". Industry is involved in these festivals and past participants have included United Utilities, AstraZeneca, Scottish Power and Greenall's Brewery. The programme illustrates the Lab's role as an open place which encourages the public to engage in science, technology and engineering.

The comments of one visitor give a flavour of the excitement engendered by the event –

> *"My eight-year-old son was delighted by the day. He found the hands-on science fascinating, and was delighted that he could handle items which flashed, burned and made smells. There is no doubt that the enthusiasm of the lecturers and demonstrators captured his attention and imagination. For weeks afterwards, he played with samples he had been given on the day."*

Support for communication of science in the North West

Staff at Daresbury Laboratory, have been particularly supportive of the work carried out by the North West Science Alliance (NWSA), a network of people from academia, industry and the public sector who aim to take science to the general public.

Staff at Daresbury, particularly Tony Buckley and his colleagues, were instrumental in starting the NWSA. They provided facilities, practical support and encouragement, and it is agreed that the network would probably not have progressed without support from Daresbury Laboratory.

NWSA also acts as a forum, disseminating information about related topics such as NWDA activities and the North West Science Strategy.

Also through the NWSA, Daresbury Laboratory staff contributed to the Manchester Science Festival and the Liverpool Science Festival in 2008. They also supported a local arts festival in Bollington, which is widening its remit to include science as well as arts.

Some quotes from Dr Lorelly Wilson, who is a member of NWSA, illustrate the distinctive contribution made by Daresbury staff:

> *"Overall, Daresbury has done a lot for science in the region. People at Daresbury are remarkable in that they 'think outside of themselves'. They have contributed to supporting science in the region because it is the right thing to do."*

Offsite activities

The PUSET programme also includes work which is carried out offsite with schools through workshops and activities. The Laboratory is involved in 4/5 such events per year and reach 400 – 500 students annually.

The laboratory also engages and assists in the events of other organisations. These include events in partnership with regional partners at the Science and Industry Museum in Manchester; this varies from 4-5 events per year reaching between 100 – 1000 attendees per year. The Laboratory also works with regional academic partners – see case study opposite.

Royal Institution Christmas lectures

Prof Tony Ryan of Sheffield, a frequent user of the SRS, was invited to present The Royal Institution Christmas Lectures in 2002. Using the theme of a spider's web, he introduced the audience to the science of polymer crystallisation and techniques of fibre spinning. In the lecture theatre, he had a ¾ size model of a beamline built, showing how it could be used to study real-time spinning of polyethylene fibres. Video screens attached to the beamline showed real outputs from the SRS experiments. As a result, a synchrotron experiment was seen by more than one million Channel 4 viewers.

Case Study – DNA Model Building and The Guinness Book of Records

Background

As part of an EPSRC grant, a Keele University academic with a strong interest in the Public Understanding of Science initiated the building of the DNA model in a shopping centre in Stoke. The project was supported by Daresbury Laboratory, and is recognised in the Guinness Book of World Records.

The Project

The academic had conceived the idea of a very large DNA model which could capture the imagination of children and the public in general. He planned to build it in The Potteries Shopping Centre, Hanley, Stoke-on-Trent, on DNA day, 9th March 2002.

Daresbury Laboratory became involved at the proposal stage, when the project was seeking funds. Daresbury hosted the meetings, helped secure grant funding from the EPSRC, brought others into the project, and, most important of all, provided engineering expertise without which the model could not be safely built.

Engineering Support

An engineer at Daresbury realised that it would not be possible to use the same design for a 10 metre high model as was used for a 1 metre high model – which could simply be a molecular model supported on a wooden rod.

He designed a metal rig with spacers, which allowed the model to be built in-situ, supporting it on a rigid system of wires. He also did the structural analysis to ensure that the model would be stable enough to be in a public area.

The design fulfilled its remit perfectly and parts of the model are still on display in the reception area of the Daresbury Laboratory and at Keele University.

Other assistance

Daresbury Laboratory's communications staff were helpful in liaising with the shopping centre to facilitate the project. They also used their media connections to ensure excellent coverage by TV, radio etc. Because of the influence of Daresbury staff, several MPs and other dignitaries were encouraged to attend.

The Event

The model was built by 3,000 school children in the Stoke-on-Trent shopping centre, with broadcast and print media present, and with local VIPs participating.

Although the shopping centre management declined to reveal attendance figures – due to commercial confidentiality – they stated that it was their busiest day of the year, on a par with a Saturday before Christmas. There were traffic jams all around the centre.

Consequences

The whole science communication community took an interest in what had been achieved. The academic has lost count of the number of reports in which his work has been described, but it has been cited by the British Association, EPSRC, NESTA, Science Year and many others. It is seen as a flagship event – the first time there had been such a high-profile event in a public place.

Even now, many years later, the academic is often asked to talk about the event, and has done so in at least 18 countries, including some as far afield as Eastern Europe and Asia. He also carried out a similar model building activity in 2008.

In 2004, the academic's work on the topic was recognised by his becoming a finalist in the EU Descartes Prize for Science Communication.

Appendix 6

Examples of research undertaken by ICI on the SRS

Films

A major product of ICI's Films Division was polyester film. The ICI /SRS team was the first to draw polyester film in situ, and anneal it at 90C, while following microstructural changes by small angle X-ray scattering (SAXS) and fibre diffraction (WAXS). The work contributed to the understanding not just of film stretching, but also of fibre spinning, and the then relatively new PET bottle blowing process. Further work on the SRS elucidated microstructural features in the walls of blown bottles.

Terephthalic acid

Studies combining single crystal diffraction and Laue diffraction at the SRS, together with optical and electron microscopy, were used to study the stability of the terephthalic acid monomer used in PET production.

The studies showed that crystal twinning was able to stabilise an otherwise metastable crystal form. The understanding was used to help optimise storage and handling of the monomer.

Polyurethanes

Rigid and flexible polyurethane foams were examined by in-situ micro-topography, leading to a deeper understanding of the three dimensional structure of the walls of the polymer cells. For the first time, foam morphology could be studied at the 20μm level, deepening understanding of the relationship between the structure and the observed physical properties.

The observed structure could be used to direct and refine finite element modelling of foam structures. Whilst some of this work was eventually carried out at the European Synchrotorn Radiation Facility (ESRF), it was stimulated directly by work at the Daresbury SRS.

In addition, SAXS studies on the SRS were used to determine relationships between formulations, particularly the hard- and soft-block components, observed structure, and physical properties.

PEEK and PEK

Polyetheretherketone (PEEK) and polyetherketone (PEK), now sold under the trade name Victrex, are high performance polymers, which can be used unfilled, or as composites containing, for example, carbon or aramid fibres. Collaborating with researchers at the University of Keele, ICI researchers used SAXS and WAXS to examine the effect of drawing and annealing of PEEK and PEK films and fibres[204]. In addition, novel high-resolution powder diffraction studies showed distinctive features of the oligomers of the etheretherketone.

BioPol

In the mid-1990s, ICI developed a polymeric material, BioPol, based on polyhydroxybutyrate (PHB). Certain micro-organisms produce PHB naturally as an energy storage medium, and it can be 'harvested' from such organisms, and then processed in conventional plastics processing facilities. The resultant polymer is similar in physical properties to polypropylene, but has the advantage that it is biodegradable. BioPol did, however, suffer from embrittlement in use, and the SRS was used to study the embrittlement process, and to characterise the micro-crystallisation which was found to occur.

[204] *Polymer, Vol 35, no 18; 1994, pp 3875-3882.*

Electrode coatings and membranes for electrolysis

Chlorine and caustic soda are manufactured in very large quantities by the electrolysis of brine. In much of the 20th century, liquid mercury was used as an electrode in the electrolysis cells, but disquiet about the use of mercury led to the processes being gradually replaced by membrane electrolysers.

ICI had large mercury cell plants, and, anticipating the need to replace them, invested heavily in the cleaner membrane cell processes. As part of this development work, ICI developed and patented novel catalytic coatings for the anode and cathode of membrane cells. A key point of the patent was that the active materials, ruthenium and titanium, formed two solid solutions. By combining several SRS techniques, the ICI researchers were able to prove that the product was indeed in the required form, and so were able to sustain the patent claims. Even before ICI – later Ineos - installed membrane cells on its own plants, it established a business supplying the proprietary electrode coatings to other producers. The business built production plants in the UK and Taiwan, and the electrodes were installed in plants as far afield as Colombia, China, Japan, Germany and the USA.
Complementing this work, research was undertaken to understand the process by which the active membranes acclimatised in a working electrolysis cell. SAXS studies on the SRS were used to follow the changes in membrane structure.

Colours & fine chemicals

ICI had a substantial pigments business, based at Blackley in the UK. Working with the University of Strathclyde and corporate researchers, high resolution XRD and Laue diffraction studies were carried out. The main focus of the research was the study of very small crystals and their growth. The output from the research, coupled with modelling work, was used in the optimisation of processing conditions.

Paints

Metal soaps are used in paints to promote drying. In the past, lead soaps were used but have more recently be replaced by less harmful alternatives such as zinc soaps. The synchrotron was used to study the morphology of the drying paint film with different additives.

Zeolites

High resolution powder diffraction studies of zeolites were carried out in studies supported by the Petrochemicals Division of ICI. The work allowed refinement of the structure of the zeolites and was supportive of patent applications.

In addition, work was carried out on the templates which were used to define the pore structure of specialised zeolites. These templates are typically quaternary ammonium salts, chosen to have dimensions close to those required in the zeolite. After formation of the zeolite, the template was removed by heating. Synchrotron studies were carried out to determine the positioning of the templates within the zeolite lattices, and thereby their "structure directing" effects.

Polypropylene catalysis

ICI's Plastics Division at Welwyn Garden City was interested in the performance of the Ziegler-Natta catalysts used in the production of polypropylene. They constructed a plastic cell containing monomer and the catalyst, $TiCl_4$. Carrying out the polymerisation at the SRS, they were able to demonstrate by EXAFS that the active species was $TiCl_4$, and not $TiCl_3$, as had been postulated by some researchers.

Naphtha reforming

ICI's Petrochemicals Division made use of naphtha reforming catalysts which were essentially mixtures of platinum and rhenium on alumina. There was a strong interest in studying the detailed structure of the platinum-rhenium catalyst to determine whether or not the metals were alloys, and what the crystallite size might be. Several lengthy studies were carried out to examine various modifications to the catalyst forms, and also to seek replacement systems.

Methanol catalysis

ICI's Catalyst Division, later named Katalco, carried out extensive studies of the copper- and zinc-based catalysts used in methanol production. The researchers were particularly interested in the preparation of the catalyst, its reduction and aging. They carried out calcination and reduction processes in a dedicated cell within the XRD and EXAFS beamlines. By combining these results with microscopy of starting and end materials, the researchers were able to elucidate the crystal structure and morphology of the active species.

Methanation catalysts

Supported nickel catalyses the methanation of unsaturated hydrocarbons. As in the case of methanol catalysts (above), the calcination step prior to reaction is crucial in achieving good performance. Studies on the Daresbury synchrotron showed correlations between the initial form of the nickel and the nature of the precursor material.

Catalytic coatings

In collaboration with the University of Keele and the University of Manchester, detailed studied were carried out to determine the orientation of small molecules such as CO2 absorbed on ZnO. The use of techniques such as NEXAFS allowed the researchers to determine the orientation of the absorbed molecules.

Other studies

- Investigation of alternative catalysts for CFC replacements.
- Studies of the structure and folding of starch molecules.
- Examination of the catalysts used in the production of Arcton.
- Studies on ammonia catalysts.
- Numerous protein crystallography studies for Zeneca, previously ICI Pharmaceuticals.

Appendix 7

Commercial case studies

Engineering molecules

Researchers within Avidex Ltd (later bought by Medigene) engineer molecules to have particular interactions with cell surface proteins. The SRS was used to ensure that the engineered molecules were binding to the target protein at the desired location and orientation. In one instance, a sulfide bond's binding site was crucial to securing a patent. The protein crystallography study demonstrated that the bond was indeed in the desired location, thereby ensuring that the patent was granted. A representative of the company explained that "If you can show a crystal structure, no-one can argue anymore."

There have now been about ten such studies, and the lead product entered into Phase 2 clinical trials. Confidence in the work meant that the company set up a new commercial venture called Immunocore which Medigene has now divested. Overall, protein crystallography using the SRS has proved to be a powerful means of confirming and demonstrating the scientific benefit - and hence the value - of the inventions.

Faith, hope and clarity

Polymer film manufacturer, UCB Films, requested evaluation of a coated polypropylene film used in food packaging, which degraded over a period of time resulting in increased opacity of the material when stored. The problem appeared to be related to the processing conditions under which the films had been manufactured. The challenge was to produce a more reliably transparent crisp packet. Rapid turnaround time from receipt of samples to results of investigation was required to allow knowledge gained to be fed back into the manufacturing process.

The SRS was used to examine the two polymer systems that the bags are manufactured from using its multidisciplinary facilities and the source of the problem was identified. This meant that UCB Films was able to alter its production conditions to eliminate hazing. The rapid solution of the problem allowed the manufacturer to demonstrate a proactive and trouble-shooting approach to its customers. Loss of production was kept to a minimum, whilst the manufacturer's reputation was enhanced.

A patent case of plagiarism

One of the world's top pharmaceutical companies was having a problem with generic manufacturers who were thought to be infringing a valuable patent on a top-selling drug. The company in question had patented a particular crystalline form of the drug and was looking to prove that the generic manufacturer was selling this form illegally. A successful challenge might increase the patent life of the product by a number of years, with a consequent substantial increase in income.

Many drug formulations only include a small amount of active ingredient with the result that detecting which crystalline form is present becomes difficult using conventional laboratory X-ray sources. The challenge in this case was to see if any of the patented crystalline form was present in the competitor's formulation - and the resulting analysis had to be rigorous enough to stand up in court. Analysis on the SRS showed that the patented form of the drug was present in the generic offering. In this case, the X-ray powder diffraction experiments carried out showed that the generic manufacturer infringing the patent and led to the successful defence of the court case. The drug manufacturer successfully retained the rights to exclusively market their patented drug for a further six years. This one experiment saved the company several millions of dollars in lost revenue.

Oiling the wheels of industry

For motor oil to operate efficiently, it has to have the correct consistency and achieving this may require the use of additives. Infineum produce specialist lubrication oils that contain inorganic chalk-like particles coated with a waxy detergent layer. Conventional analysis techniques were unable to determine the precise effect these additives were having on the formulation and so the optimum composition could not be easily determined. Infineum's own techniques had provided insufficient data to characterise the additives in detail.

A particular challenge was the response time: it had to be rapid so that modification could be made to the formulation without major loss of production time. Researchers at the SRS employed techniques to examine a large number of formulations of particles and detergent composition in the oil. This characterisation allowed quantification of process changes, control of properties and performance characteristics of the finished product and prediction of the various interactions between detergent molecules and other additives in the finished oil. The results allowed Infineum to define a narrow range of formulations that gave optimum operating performance. Loss of production time was kept to a minimum due to the rapid turnaround time between receiving the sample and reporting back the results.

Diamonds are forever

Industrial diamonds have a multitude of uses in today's market place, ranging from simple cutting tools to coatings on the windows of fighter jets. However, quality control is very important - the manufacturing process can impart strain into the synthetic diamonds which makes them less useful. A particular manufacturer of industrial diamonds approached the SRS with a large number of diamonds which required screening to identify good quality samples from poorer ones. While the method of assessing strain in crystals is well documented, the challenge for this analytical project was to find a method of screening the crystals that was fast, reliable and reproducible.

The experimental technique chosen to carry out this screening was X-ray diffraction. Additionally, by using the extensive knowledge available of the SRS staff, a novel crystal alignment procedure was devised and constructed. This allowed faster data collection, thereby making substantial savings in time which were passed on to the customer as a lower price per sample. Forty samples were turned around in 16 hours - experiments of this type on a laboratory source would be expected to take several hours each. The manufacturers were able to get a quick, straightforward result which allowed them to directly correlate growth conditions with performance and were able to change their processes accordingly.

Delivering bespoke instrumentation

The exploitation of experimental facilities to determine, for instance, structural information at the molecular level, can require specialised and novel test equipment to be designed and built. One customer required the use of an environmental cell to control temperature and humidity of their samples during data collection. It was not viable for them to develop such equipment in-house as the measurements formed only a small part of a wider R&D project. The challenge was to identify a cost-effective away to deliver the instrumentation requirements in order to achieve the project objectives.

The design and construction of instrumentation capable of the controlled variation of temperature and humidity, in conjunction with synchrotron facilities, requires specialised skills, knowledge and experience. SRS scientists have significant expertise in this field and readily undertook the development of purpose-built equipment. This was done within a short lead-time and was combined with guaranteed compatibility with the synchrotron radiation beamline on which the experiment was to be performed. The results from the experiment were vital to the successful completion of the particular project and costs and development times were significantly reduced.

Appendix 8

Commercial companies/organisations collaborating with academics entering through the peer review system 1994 – 95

i) Industrial partners/non-academics collaborating with academic users of the SRS and publishing alongside their academic collaborators:

UK	Non UK	
British Biotechnology	AMOCO Oil Co.	(US)
British Gas	CSM, Rome	(I)
Cadbury-Schweppes	Daimler Benz	(D)
Castle Cement	Deutsche Aerospace	(D)
Defence Research Agency (**)	Dow Europe, Ternuezen	NL)
Glaxo	Exxon	(US)
ICI (x 2)	BM Zurich	(CH)
Kodak	IBM	(US)
Paramins Exxon (UK)	LGIT-IRGM	(Fr)
PHLS Centre	NEC	(J)
Pilkingtons	Parke-Davies	(US)
Pirelli Cables	Philips Res	(NL)
RSSL	Schotte Glassware, Mainz	(D)
Schlumberger	Shell Lab. Amsterdam	(NL)
Unilever (x 2)	Eye Associates, Otttawa	(C)
Wellcome	Eye Res. Inst, Boston	(US)
Zeneca (Macclesfield)	Kentucky-Lions Eye Res.Inst.	(US)
Zeneca (Blackley)	NIH, Bethsada	(US)
British Museum	Univ. Hospital, Leiden	(NL)
Imp. Cancer Research Foundation		
Institute of Ophthalmology		
Manchester Eye HospitaL		
Moorefield's Eye Hospital		
Natural History Museum		
National Institute for Medical Research		
**through the MoD Research Grant Scheme		
Totals	**24 UK + 20 non-UK = 44**	

ii) IIndustrial partners collaborating with academic users of the SRS identified by EPSRC from research grant applications:

UK	Non UK
AECL Research	Pfizer Central Research Agency
Bruker (UK)	Roche Products Ltd
DTI	
Fisons	
Hirst Magnetic Instruments	
NESTEC	
Proctor & Gamble	
Rolls Royce	
Smith Kline Beecham	
VG Semiconductors	
Totals	**10 UK + 2 non-UK = 12**

Appendix 9

Aims and member organisations of the LIGA interest group

Aims:

- To encourage companies to use LIGA technology for the manufacture of microstructures.
- To bring together people with an interest in the development and application of LIGA technology and provide a forum for the exchange of ideas.
- To disseminate knowledge through the transfer of technology from Daresbury Laboratory, the German LIGA specialists and elsewhere.
- To raise companies' awareness of the development in microfabrication.
- To promote innovative projects and European collaborations.
- To seek funding support for strategic research and development.
- To publicise LIGA through promotional material, publications, seminars and training.

Member organisations:

Advanced Technical Mouldings;
Advanced Robotics Research Ltd.;
Ai Cambridge;
Amersham International plc;
Applied Microengineering Ltd.;
Armstrong Projects;
BICC Cables;
BNFL plc;
British Aerospace;
British Gas plc;
British Telecom (Development and Procurement);
Buxton Wall McPeake Ltd.;
Cambridge University (Dept. of Materials Science and Metallurgy);
Coventry University;
Crompton Plastics Ltd.;
De Montfort University;
Defence Research Agency;
DTI Northwest ;
Dundee University (Dept. of Applied Physics and Manufacturing);
Egli Research;
Europtics Ltd.;
Fisons Instruments;
Flight Refueling Ltd.;
Fluid Film Devices Ltd.;
GEC-Marconi;
Gillette UK Ltd.;
ICI Wilton Research Centre;

ICI Chemicals and Polymers;

Imperial College (Dept of Electrical Engineering);

Institute of Dental Surgery (Dept. of Bio-Materials Science);

Intravascular Research Ltd.;

ITT Cannon;

Lancaster University Dept of Engineering;

Liverpool JMU (School of Eng. & Technology Management);

Liverpool University (Dept. of Industrial Studies);

London Hospital, The (Dept. of Conservative Dentistry);

Loughborough University of Technology;

Lucas Automotive;

National Health Authority;

NIMTECH;

NIS Ltd.;

Oxford Instruments (UK) Ltd.;

Oxley Developments Ltd.;

Peter Cockshott Associates;

Phase Separations;

Polyfiltronics;

Portex Ltd;

Scapa Filtronics;

Spectra;

Strato Consulting Ltd.;

Surface Technology Systems Ltd.;

Surface Transforms Ltd.;

Videojet Systems International;

Vu-Data Ltd.;

Appendix 10

Sales of the SRS Double Crystal Monochromator by VG

To the Advanced Photon Source (APS) (USA):				
	DND-CAT	2 off	sales value	~£300K
	IMCA-CAT	2 off		~£250K
	MR-CAT	1 off		~£120K
	GSE-CARS	2 off		~£240K
To the European Synchrotron Radiation Facility (ESRF) (France):				
	UK-CRG	1 off		~£120K
	DUBBEL	2 off		~£240K
To BESSY-II Germany):				
	PTB Berlin	1 off (special twin axle)		~£260K
To CCLRC (UK):				
	SRS Daresbury	1 off		~£90K
To Oxford Instruments (UK):				
	Various	5 off		~450K
Total Value of Sales to VG:				**~£2.1M**

Appendix 11

Insertion devices used in the SRS to generate specialised radiation for particular experiments

Name	Type and location	Notes
SC Wiggler 9	Super-conducting wavelength shifter; beamline 9.	First insertion device in the SRS installed in Nov. 1982; single central high-field pole-pair; NbTi coils cooled with 4.2K liquid helium; produced 5 T at the electron beam; fed radiation to 7 separate stations; designed and built at Rutherford-Appleton Lab;
SC Wiggler 16	Super-conducting wavelength shifter; beamline 16.	Single central high-field pole-pair; NbTi coils cooled with 4.2K liquid helium; produced 6 T at the electron beam; fed radiation to 5 separate stations; designed and built by Oxford Instruments to an SRS specification.
MPW 6	Multi-pole wiggler; beamline 6.	SRS design (magnet and engineering); built by Sincrotrone di Trieste from SRS design; introduced/taught SRS staff how to accurately assemble strong PM arrays and correctly mount them; very strong 2T magnet, 200mm period; motor control/mechatronic system from Mclennan. measured at DL.
MPW 14	Multi-pole wiggler; beamline 14.	Identical to MPW 6.
MPW10	Multi-pole wiggler; beamline 14.	SRS design (magnet and engineering); components procured from industry and assembled at SRS; world record 2.4T magnet, 220mm period; magnet blocks from Vacuumschmelze; motor control system from Mclennan; measured at DL.
HU56	Undulator; beamline 5.	SRS design (magnet and engineering); replaced old in-house built undulator; advanced variable polarisation control; 56mm period, gap and phase control; magnet blocks from Vacuumschmelze; motor control system from Mclennans; measured and shimmed at DL.

Appendix 12

Industrial liaison for the procurement of vacuum equipment

Vacuum pumps

The SRS used as, its workhorse pumps, sputter ion pumps and titanium sublimation pumps (TSPs). Since these were standard items in laboratory UHV systems these were available as standard catalogue items from a number of companies, including UK companies. Ion pumps designed and built in the UK were available from Ferranti and AEI (as it was at the time) and TSPs from Vacuum Generators and Edwards High Vacuum. Subsequently Ferranti and AEI withdrew completely from this market and all ion pumps now available are manufactured outside the UK. Although the pumps themselves were standard, control units had to be modified to meet the requirements of the SRS, and this is discussed below.

Vacuum gauges

The total pressure vacuum gauges used on the SRS were standard commercially available items, although control units required modification. Some substitute materials had to be used in gauge heads for radiation resistance, e.g. in feed-throughs and cables. Residual gas analysers were, however, developed specially to meet the requirements of the SRS. These are featured below.

Pump and gauge controllers

There were two considerations that required industry to develop control units to meet the specific requirements of the SRS. The first was the high radiation environment in the ring tunnel when the machine was operating. This meant that control units had to be designed which could be separated from the controlled item by up to 100 m of cable. Secondly, all electronic units had to be interfaced to the computer control system that supervised and operated the complex machine from a remote control room. No such units were available from UK industry at the time, and indeed there were no standard control buses and interfaces such as are readily available today. Companies had to be prepared to redesign their units to provide a standard SRS interface. Although this was a proprietary system, the experience gained by companies who implemented it meant that they had the necessary skill set available to incorporate standard interfaces like IEE488 when they became available, and in particular to meet the burgeoning demand from the semiconductor industry for such facilities. UK companies like VG, Sension, Arun Electronics, AEI (by then Kratos) and Edwards High Vacuum thereby benefited.

Residual gas analysis

The SRS was one of the pioneers in the use of residual gas analysis for quality control in the vacuum field and in monitoring the "health" of large vacuum systems. For SRS use, several challenges presented themselves. In common with the other vacuum gauges, control interfaces had to be implemented and the problems of working in a high radiation environment overcome. There was one other unique requirement however. The SRS vacuum team wanted to use residual gas analysis to monitor what was happening inside vacuum systems during bakeout. By this time, industry had standardised on small radio frequency quadrupole mass filters for this class of instrument. In all cases, the Radio Frequency (RF) generator and the preamplifier electrometer were housed in a unit bolted directly on to the gauge head. This had to be removed for bakeout and was also susceptible to damaging radiation and RF and other interference from the electron beam. Designs using separated head systems were developed by companies such as VG Quadrupoles, Hiden Analytical and Spectrum Scientific. Apart from Hiden the expertise of these companies in the field was recognised by American companies who subsequently bought them out, but retain operations in the UK.

Appendix 13

Monochromators manufactured by Bird and Tole

	Monochromator	Destination
1.	Grazing incidence spectrometer	NINA parasitic beam-line
2.	Vertical Wadsworth monochromator	NINA parasitic beam-line
3.	2-metre Grazing Incidence monochromator subsequently ELSA (Bonn)	NINA parasitic beam-line
4.	Horizontal Wadsworth monochromator	NINA parasitic beam-line
5.	Daresbury Miyake MkII Grazing Incidence monochromator	NINA parasitic beam-line Tantalus, Wisconsin SRS
6.	1-metre Seya monochromator	ELSA (Bonn) SRS
7.	1-metre Seya monochromator BESSY (Berlin)	ELSA (Bonn)
8.	Daresbury SEXAFS (Grating/crystal) monochromator	SRS
9.	Grazing Incidence monochromator	NSLS, Brookhaven
10.	Miniature Toroidal Grating monochromator	NSLS, Brookhaven;
11.	6.5 metre Normal Incidence monochromator	BESSY (Berlin);
12.	Toroidal Grating 150 degree monochromator	SRS
13.	Toroidal Grating 155 degree monochromator	SRS
14.	½ -metre Seya-Namioka monochromator	SRS
15.	Soft X-ray crystal spectrometer	SRS
16.	UHV Double Crystal monochromator	BESSY
17.	2-metre Namioka monochromator	BESSY
18.	UHV Toroidal Grating monochromator	BESSY
19.	2-metre Wadsworth Grating Drive	BESSY
20.	Spherical Grating monochromator	SRS
21.	Low Energy Toroidal Grating monochromator	SRS
22.	High Energy Toroidal Grating monochromator	BESSY
23.	Toroidal Grating monochromator	BESSY

Appendix 14

Detectors systems developed over the life of the SRS

	SR Detector Systems	Science/ Applications	Development	Notes	Collaborative involvement
1	**Multiwire linear detector**	Wide Angle X-ray Scattering (WAXS) for polymer industries. Powder X-ray diffraction (XRD) for various atomic structural characterisation.	In-house at DL.	Innovation in electronics design and in data acquisition software went to underpin the RAPID detector systems and HOTWAXS development.	None or not known.
2	**Delay line Quadrant /Delay line area detector**	Millisecond time resolved Small Angle X-ray Scattering (SAXS) for polymers and bio-molecules. 10^6 photon/s detection.	In-house at DL.	Workhorse analogue systems. Used extensively on SRS.	Commercially exploitable.
3	**RAPID (v1 v2) 2D area detector**	Sub-millisecond time resolved SAXS for polymers and bio-molecules. 15x10^6 photon/s detection.	In-house at DL.	Advanced digital systems. Used on ESRF (France).	Used by SPRING8 (Japan) and Diamond (UK). Potentially ALBA (Spain).
4	**RAPID WAXS/ SAXS 1 D linear detector**	Sub-millisecond time resolved SAXS/WAXS for polymers and bio-molecules.	In-house at DL.	Advanced digital systems. Use on SRS 6.2. Will be moved to HATSAXS beamline on Diamond.	Will be marketed by Quantum Detectors.
5	**REES multi-element electron counting detector**	Electron spectroscopy for chemical and micro-electronic surface characterisation.	In-house at DL on readout. Collaboration with Univ Aberystwyth on detector.	Now in offline equipment at Univ Aberystwyth.	Some commercial interests (including NASA from US).

	SR Detector Systems	Science/ Applications	Development	Notes	Collaborative involvement
6	Ion chambers	SR beam intensity monitoring. High stability required for XAFS (X-ray spectroscopy) investigation for various chemical characterisation.	In-house at DL.	Ultra linear design for spectroscopic use on SRS 9.2/9.3/7.1 etc.	Copied globally. Marketed by Quantum Detectors.
7	MAGIC Magnetically immune gas counter	Used for X-ray magnetic diffraction and also used for non-magnetic, sub-keV measurements.	In-house at RAL/DL.	Collaboration with researchers from Bristol, York, Manchester on magnetic samples, polymers and test samples.	None, though some interest expressed by synchrotrons in China and Spain.
8	EYIELD: Electron yield detector	Used for Auger Electron XAFS. Structural studies on chemical compounds. Studies included catalysis, electrolysis, and in-situ reduction of oxides.	In-house at RAL/DL.	In-situ chemistry inside detection enclosure.	None or not known.
9	HOTWAXS High overall throughput WAXS detector	Sub-msec time resolved WAXS for polymer industries and bio-molecules. 500x10^6 photon/s global detection rate.	In-house at RAL/DL.	Prototype for sale to Diamond. Microstrip gas counter technology has made this feasible. This is again far in excess of anything possible with the latest CCD technology.	Marketed by Quantum Detectors.
10	XSPRESS: Xray Signal Processing Electronics for Solid State detectors.	High count rate X-ray fluorescence on dilute chemical and biological compounds.	In-house at DL.	Adaptive pulse processing for SR. Gave rise to XSPRESS2 used on Diamond.	Transferred to ESRF. Excellent reports and data. Marketed by Quantum Detectors.

	SR Detector Systems	Science/ Applications	Development	Notes	Collaborative involvement
11	Multi-element Ge detectors (various formats) (7 off)	High count rate X-ray fluorescence on dilute chemical and biological compounds: particularly useful for archaeological and heritage science.	Earlier versions: Interaction with Canberra. Later versions: Collaboration with Ortec (Perkin Elmer).	Worlds first 30 element Ge detector. First European use of 13 element Ge for XAFS shaped use of these on all SR sources.	Earlier versions: Marketed by Canberra[19]. Later versions: Marketed by Ortec EG&G, (now Perkin Elmer)[20].
12	CTRAIN Ge detectors (3 off)	High count rate X-ray fluorescence on dilute chemical and biological compounds: particularly useful for archaeological and heritage science.	Collaboration with Ortec (Perkin Elmer).	World's first performance SR monolithic multi-element Ge detectors	Marketed by Ortec EG&G (now Perkin Elmer)[20].
13	Ion chamber readout	A compact, low cost, high resolution and low noise charge measurement system easily interfaced to the majority of commercial ion chambers.	In-house at DL.	Ultra low noise techniques. Replicated on all SR around the world.	Marketed by Quantum Detectors.
14	Multichannel CD detector	Circular dichroism (CD) on molecular structures.	In-house at RAL.	Developed for flow cell use.	None or not known.
15	XSTRIP	Used for dispersive XAFS. Structural studies on chemical compounds (chemical industries). This detector system uncovers phenomena previously hidden within science, equally capable of providing unprecedented throughput in industrial process monitoring applications.	In-house at DL.	Worlds fastest dispersive XAFS detector. Used extensively on ID24 at ESRF.Developed using novel high speed technology to deliver superb time resolution in X-ray and associated one dimensional spectroscopic applications.	Marketed by Quantum Detectors.

	SR Detector Systems	Science/ Applications	Development	Notes	Collaborative involvement
16	XH (XSTRIP Ge)	Used for dispersive XAFS structural studies on chemical compounds.	In-house at DL in collaboration with Lawrence Berkeley National Laboratory, California, USA [20].	XSTRIP for higher energies. Built for higher X-ray energy uses on 9.3, ID24 (ESRF) and I20 (Diamond).	Commercially interesting Marketed by Quantum Detectors.
17	DAIRS (IR array) detection system	For infrared microspectroscopy allowing exploration into cancer precursors in human cells. Infrared imaging in a variety of scientific and industrial applications.	Developed under UK research funding, in-house at DL..	Built for use on BL11 at SRS. Yielding frame rates of typically 10KHz. Its parallel readout array, achieves more than two orders of magnitude performance increase.	Of interest to Soleil. Discussions underway. Great interest for ALICE (ERLP) use. Marketed by Quantum Detectors.
18	Photodiode array detector	Powder diffraction, dispersive XAFS on chemical compounds.	In-house at DL.		None or not known.
19	Beamstop intensity monitoring for NCD	SR beam intensity monitoring.	In-house at DL.	Use of photo diodes. Formed basis for many systems around the world.	None or not known.
20	ULTRA detector system	Allow the high repetition, (10kHz) ultra intense LASER pulses to be exploited in the analysis of dynamic sample phenomena.	In-house at DL.	The ULTRA system was conceived to provide the UK with a world leading photon research facility.	Marketed by Quantum Detectors.

Appendix 15

Companies which provided quality engineering systems for the SRS

Technology	Company
Vacuum chambers, bellows, accelerator components	VG scienta - http://www.thermovacgen.com/home.htm K J Lesker - http://www.lesker.com/newweb/index.cfm NTE Vacuum Technology - http://www.ntepoole.co.uk/ CVT - http://www.cvt.ltd.uk/ Palatine Precision - http://www.palatineprecision.co.uk/
Precision SR Instrumentation design and manufacture	Oxford Danfysik - http://www.oxford-danfysik.com/ Instrument Design Technology - http://www.idtnet.co.uk/
Optics Mirrors and monochromator crystals	Crystal Scientific - http://www.crystal-scientific.com/
Nanometer positioning Digital piezo translator devices	Queensgate Instruments - http://www.nanopositioning.com/
Direct drive torque motors	ETEL - http://www.etel.ch/
Precision rotary tables	Huber - http://www.xhuber.de/en Franke - http://www.franke-gmbh.de/en1/ Newport Micrcontrole - http://www.newport.com
Rotary and linear encoding	Heidenhain - http://www.heidenhain.co.uk/
Air Bearings Used as part of precision instruments monochromators, PX goniometry and high speed choppers	Fluid Film Devices - http://www.fluidfilmdevices.co.uk/
Motion Control For precision positioning devices on accelerators and beamlines	Mclennan Servo Supplies Ltd. - http://www.mclennan.co.uk/ Micromech Ltd - http://www.micromech.co.uk/

Technology	Company
Synthetic Granite base structures for optical devices. Highly rigid, self-damping and providing the most mechanically and thermally stable optical platform for mirror and monochromator systems.	Granitek Precision Granite Castings - http://www.granitek.co.uk/
Structural steelwork and precision machining. Girders for supporting magnet and vacuum chambers accelerators	Priory Engineering - http://www.prioryengineering.co.uk/
Radiation protection X-ray hutches and Pb shielding	Fabcast Engineering Ltd - www.fabcast.com
Light engineering, CNC machining and fabrication. Including custom designed and build experimental tables 1st used on the SRS and now used on other SR facilities	TSW Engineers Ltd (Formally Willaston Engineering Co) - http://www.tswengineers.co.uk/
CNC Precision machining, EDM wire eroding	LVW Senar Ltd - http://www.senar.co.uk/

Appendix 16

European Investment in SRS

An example of European investment at the SRS is illustrated in the case study below –

Dutch investment on Beamline 8

Nederlandse Organisatie voor Zuiver Wetenschappelijk Ondersoek (NWO, formerly ZWO) the Dutch Organisation for Pure Scientific Research, was early in recognising the usefulness of the Daresbury SRS. ZWO researchers had identified the need for synchrotron experiments, but had no access to a synchrotron in the Netherlands, and the ESRF was not yet running. Their own plans for a synchrotron in the Netherlands had not come to fruition, so the researchers looked to the UK for access to the desired techniques.

From the early 1980s, the ZWO researchers worked with the station manager, to design, procure and build Beamline 8. They developed 8.1 for EXAFS and 8.2 for SAXS while 8.3 (and its adjunct 8.4) was used for test and development. The arrangement was that ZWO would fund the construction and staffing of these lines, though in practice they were partly staffed by UK nationals rather than Dutch researchers. At that time there were just five beamlines in existence on the SRS, so a sixth one, funded by the Dutch, was significant.

The detailed design and construction of the beamlines was overseen by TPD, the Technical University of Delft. Line 8.1 was used by researchers for X-ray spectroscopy investigating materials as diverse as toothpaste and meteorites, for example. An important research area was the field of catalysis, investigating catalyst properties under real operating conditions. The ability to maintain a high vacuum close to the sample meant that materials containing elements with softer absorption edges such as calcium-containing materials could be studied. Other experiments were focused on dilute metallo-proteins such as transferrin. Most of the research was academic, though a portion was industrial.

Line 8.2 was initially designed for small angle scattering measurements of biological materials but in the late 1980s, researchers, including Tony Ryan (now Sheffield) and Neville Greaves (now Aberystwyth) combined Small Angle X-ray Scattering with wide angle X-ray diffraction to investigate the properties of polymers. This was a first, but the capability to combine techniques was built into subsequent designs.

Those beamlines were retained by Daresbury after the initial research finished, though they were technically owned by ZWO and could be taken back at any time. The Dutch then became involved in the ESRF through their partnership with the Belgian government in the DUBBEL CRG, and their activity moved to the ESRF. Beamlines 8 lasted for more than 20 years, closing only in 2007. The throughput on these lines was of the order of 40 research groups per year.

The X-ray monochromator used on 8.1 was designed in a collaboration between TPD, ZWO and Daresbury Laboratory. It was the first precision-engineered, UHV-compatible, 'bent crystal' double crystal monochromator in the world. The design was a predecessor of the system which became successful in commercial as well as engineering terms: over ten years, about

17 monochromators were sold worldwide, each typically selling for £120K to £150K.

The longevity and intensity of this co-operative arrangement led to considerable economic benefit to the area and to the site itself. Some of the benefits have been estimated as follows:

- *20 – 25 man years residence at Daresbury, with benefits for local economy (600 nights per year for 15 years).*
- *Funding of an electron microscope and superconducting magnet in addition to the beamline.*
- *Around 600 publications in scientific journals; citation analysis suggests that at least 60 of these are very heavily cited "super-publications" and 200 are heavily cited.*
- *Industrial work on catalysts and polymers was carried out, but its benefits are not recorded.*

Appendix 17

Co-located facilities and businesses

The following facilities and businesses located onto the Daresbury Laboratory site over the lifetime of the SRS –

Co-located facilities

HPCx

HPCx[205], the UK's national high-performance computing service until January 2010, was funded through the UK High End Computing Programme and was managed by a consortium led by the University of Edinburgh, together with the STFC and IBM. HPCx was Europe's largest academic computer, one of the world's most advanced high performance computing centres and was located within the STFC's Computational Science and Engineering Department. A terascale computer like HPCx was immensely powerful. The computing capacity provided by the HPCx service was used to examine scientific problems in ways previously unavailable. HPCx was sited at the Daresbury Laboratory due to the computational support that was centred at the Daresbury Laboratory and because of the machine room facility which now houses the computer. The experience of running HPCx has allowed the STFC's Computational Science and Engineering Department to be a key partner in the UK's next generation national supercomputing service, HECToR[206].

The National Centre for Electron Spectroscopy and Surface Science

The Research Unit in Surfaces, Transforms and Interfaces (RUSTI) was set up at the Daresbury Laboratory in 1993 as a collaboration between ICI and the SERC. Restructuring at the Daresbury Laboratory had meant that space, staff and equipment were utilised to set up the new facility –

"both space and people at Daresbury alongside the excellent Synchrotron Radiation Facility and support infrastructure including most importantly the computational modelling teams.[207]"

The facility, now called the National Centre for Electron Spectroscopy and Surface Science[208] (NCESS) utilises X-ray photoelectron spectroscopy and brings together industry and academia to address problems in materials science, surface science and engineering. Collaborative research programmes with industry and the academic community have been set up for targeted research areas, ranging from studies of polymers and composites through to ceramics, semiconductors, metals and novel materials.

The UK SuperSTEM facility

A great part of scientific and engineering progress depends on relating microscopic structure to macroscopic behaviour. The SuperSTEM[209] facility at the Daresbury Laboratory is a unique national facility allows UK scientists to do this on a hitherto impossibly fine scale. The facility houses the third aberration-corrected Scanning Transmission Electron Microscope (STEM) in the world and the first in Europe. The project was funded by the EPSRC in 2001 and the team consists of scientists from the

[205] www.hpcx.ac.uk/
[206] http://www.hector.ac.uk/
[207] www3.interscience.wiley.com/cgi-bin/abstract/109744992/ABSTRACT
[208] www.dl.ac.uk/NCESS/
[209] www.superstem.com

Universities of Liverpool, Leeds, Cambridge and Glasgow and the Daresbury Laboratory. The reasons for siting the facility at the Daresbury Laboratory were two fold – the stability of the bedrock was essential for the demands of the facility. In addition, there was a great synergy with SRS experimental techniques such as X-ray absorption spectroscopy techniques. Indeed the initial proposal for the facility was entitled "A synchrotron in a microscope" and several SRS staff developed the scientific and technology case in collaboration with the HEI community.

Medium Energy Ion Scattering Facility

The Medium Energy Ion Scattering (MEIS) Facility is operated at the Daresbury Laboratory by the STFC as a central user facility for the benefit of UK HEI researchers and industry. Although at least two universities had submitted bids to EPSRC to host the facility, the availability of relevant expertise and equipment at the Daresbury Laboratory was a major reason for locating MEIS there. Indeed, kit from the closed Nuclear Structure Facility at the Daresbury Laboratory was re-used in the building of the facility.

Tenants at Daresbury Laboratory

In addition to other scientific facilities co-locating at the Daresbury Laboratory, several SMEs also located onto the site –

Faraday Foresight NW

The first industrial tenants at the Daresbury Laboratory were Faraday Foresight NW who worked principally with regional organisations, industry and academia. The company located to the Daresbury Laboratory due to involvement with several technologies being developed at the SRS and the Computing Science and Engineering Group at the time. Staff involved in Faraday Foresight NW were pioneers of the LIGA technique on the SRS (see chapter 11).

Nimtech

Nimtech[210] was one of the early tenants on the site. The company was formed in the mid 1980s to disseminate technology from large companies, such as Pilkington and BNFL, to smaller companies in the North West region. Nimtech has now evolved into an economic development organisation, with associated skills such as marketing and consultancy. Though no longer at Daresbury Laboratory, the organisation found the site to be a most advantageous site for its launch and early years.

North West Business Leadership Team

The North West Business Leadership Team (NWBLT)[211] took up residence on the Daresbury site in August 2000. It was formed in 1989, as a group of the most influential business leaders in the North West. Their remit is to address key strategic issues affecting the well-being of the region and its people. Membership is by invitation of the Chairman and is normally restricted to senior board members of major public companies in the North West. Their approach is to act as a strategic, business-led think-tank focusing on a small number of key projects.

Atmos Technologies

"Atmos Technologies have been able to make this important breakthrough in detector technology thanks to working closely with staff at STFC Daresbury Laboratory.[212]"

Atmos Technologies[213] has developed unique radiation detectors robust enough for demanding applications. For example, the detectors can be produced in sizes large enough to be fixed to the outsides of decommissioned nuclear reactors, giving warning of leakage. Similarly they can be used to monitor radioactive waste in storage or the spread of contamination in the water. A spin-out from Salford University in the 1990s, its detectors can be used in several applications, for example anti-

[210] *www.nimtech.org.uk*
[211] *www.nwblt.com*
[212] *Prof Colin Whitehouse, Director of Campus Strategy, STFC*
[213] *www.stfc.ac.uk/PMC/PRel/STFC/Atmos.aspx*

terrorism, environmental monitoring, water testing and food testing. The detectors can also be applied to medical and food irradiation as well as the polymerisation of rubbers and plastics. Staff at the Daresbury Laboratory have worked with Atmos Technologies to develop their capabilities.

The technology is currently in an advanced stage of development and Atmos is working with partners such as Liverpool Ventures, NESTA and the Northwest Development Agency. Atmos Technologies is now seeking partners to licence the technology to manufacture the radiation detectors for commercial exploitation.

CXR Ltd

The current breed of airport scanning machines give security staff a flat, one-dimensional view of the contents of a bag. Research carried out by CXR Ltd uses multiple X-ray sources to provide more comprehensive 3D images of suitcases and baggage. Although hospital-style CT scanners have been adapted on a small-scale for baggage scanning, the system is too slow to be widely used in airports. The technology developed by CXR Ltd is faster because it uses switched multiple X-ray sources.

CXR Ltd, currently located at the Daresbury Laboratory, is a research subsidiary of Rapiscan Systems[214], a manufacturer of airport security scanners. CXR Ltd were initially attracted to the Laboratory due to their requirement for cleaning of Ultra High Vacuum components which was met by the STFC's SuperClean service (see chapter 10). The STFC and CXR Ltd have been able to expand their relationship - STFC staff from both the Daresbury Laboratory and the Rutherford Appleton Laboratory have been working with CXR Ltd on several aspects of their X-ray based security products. The relationship has proved fruitful with CXR scanners now undergoing trials at Manchester Airport.

Institute of Physics

The North West Regional Officer for the Institute of Physics moved into the Cockcroft Institute[215] in 2007 and gave the following information on why the IoP have set up an office in the Institute –

"This was due to its location near to the large community of physicists at the Daresbury Laboratory, many of whom are actively involved with the Institute through both branches and subject groups. There have always been strong links between Daresbury Laboratory and the IoP's Merseyside branch, with the Daresbury Laboratory hosting branch events each year. The relationships with all the major North West universities, especially through the establishment of the Cockcroft Institute, make the Daresbury Laboratory a focal point for physics in the region.

The Daresbury Laboratory and wider Campus is also a centre of interaction for two other important communities in the North West, and the links with these have been invaluable. Firstly, the work on public engagement is of the highest quality, and the public lectures always well attended. Through links on site, speakers from the Daresbury Laboratory have volunteered to give talks to groups around the region.

The second important area is knowledge transfer – both through the physical establishment of the Incubator, and the networks based there, including the very popular monthly breakfast meetings. This has enabled the IoP Regional Officer to meet both small businesses and other stakeholders in the region, and a number of useful discussions have resulted."

[214] *www.rapiscansystems.com/index.html*
[215] *www.cockcroft.ac.uk/*

Glossary

Glossary

Term	Meaning
ALBA	A synchrotron radiation facility in Cerdanyola del Vallès, near Barcelona, Catalonia, Spain
ALICE	Accelerators and Lasers in Combined Experiments, located in Daresbury, UK
ALS	The Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory in Berkeley, California is a synchrotron light source
ANKA	The synchrotron light source of the Forschungszentrum Karlsruhe, providing light from hard X-rays to the far-infrared for research and technology (Germany)
ASTeC	The Accelerator Science and Technology Centre (ASTeC) was created by CCLRC in 2001 as a Centre of Excellence for study of the production, acceleration and delivery of charged particle beams
ATC	The UK Astronomy Technology Centre
ATP	Adenosine triphosphate
BASROC	The British Accelerator Science and Radiation Oncology Consortium
BBSRC	Biotechnology and Biological Sciences Research Council (BBSRC) is a UK Research Council and non-departmental public bodysupporting several scientific research institutes and university research departments in the UK
BESSY	The Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m. b. H. (English: Berlin Electron Storage Ring Society for Synchrotron Radiation), abbreviated BESSY, is a research establishment in the Adlershof district of Berlin
BNFL	British Nuclear Fuels Limited (BNFL) is a private company owned by the UK Government through the Department for Business Innovation and Skills
BRIDION	BRIDION is indicated for the reversal of neuromuscular blockade in children and adolescents
CAMAC	Computer Automated Measurement And Control (CAMAC) is a standard bus for Data acquisition and control used in nuclear and particle physics experiments and in industry

Term	Meaning
CAMD	The Centre for Advanced Microstructures and Devices. CAMD is a high-tech synchrotron research centre located in Louisiana, USA
CCLRC	The Council for the Central Laboratory of the Research Councils (CCLRC) was a UK government body that carried out civil research in science and engineering
CCP's	Collaborative Computational Projects
CERN	The European Organization for Nuclear Research (French: Organisation Européenne pour la Recherche Nucléaire), known as CERN, is the world's largest particle physics laboratory, situated in the northwest suburbs of Geneva on the Franco–Swiss border, established in 1954
CONFORM	Construction of a Nonscaling FFag for Oncology, Research, and Medicine
CSED	The Computational Science and Engineering Department is a department within the Science and Technology Facilities Council
DARTS	The Daresbury Analytical Research and Technical Service
DBIS	Department of Business Innovation and Skills. STFC's parent Government Department from July 2009
DEFRA	The Department for Environment, Food and Rural Affairs (Defra) is the government department responsible for environmental protection, food production and standards, agriculture, fisheries and rural communities in the United Kingdom
DESY	The DESY (Deutsches Elektronen Synchrotron,"German Electron Synchrotron") is the biggest German research center for particle physics, with sites in Hamburg and Zeuthen
DIUS	Department for Innovation Universities and Skills STFC's parent Government Department up to July 2009
DNA	Deoxyribonucleic acid
EI	Economic Impact
ELETTRA	ELETTRA Synchrotron Light Laboratory is a national synchrotron laboratory located in Basovizza on the outskirts of Trieste, Italy
EMMA	The Electron Machine with Many Applications (EMMA) is a project at Daresbury Laboratory in the UK
EPSRC	The main UK government agency for funding research and training in engineering and the physical sciences

Term	Meaning
ESA	European Space Agency
ESRF	European Synchrotron Radiation Facility
EU	European Union
EXAFS	Extended X-Ray Absorption Fine Structure
FEL	Free electron laser
FFAG	Fixed-field alternating-gradient
FMDV	The Foot and Mouth Disease Virus
GDP	Gross Domestic Product
GeV	Giga electron volt (109 eV)
GMR	Giant magnetoresistance, (a quantum mechanical magnetoresistance effect)
HA	Haemaglutinin, a protein
HEIs	Higher Education Institutes
HSIC	The Harwell Science and Innovation Campus, located in Oxfordshire
IDT	Instrument Design Technology
ILL	The Institut Laue-Langevin, or ILL, is an internationally-financed scientific facility, situated in Grenoble, France
INTAS	The International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union (NIS)
ISIS	A pulsed neutron and muon source situated at the Rutherford Appleton Laboratory in Oxfordshire
ITAC	The STFC Innovations Technology Access Centre
JANET	The Joint Academic NETwork is a private British government-funded computer network dedicated to education and research
JASRI	Japan Synchrotron Radiation Research Institute
JET	JET, the Joint European Torus, is the largest human-made magnetic confinement plasma physics experiment currently in operation
JUAS	The Joint Universities Accelerator Schools

Term	Meaning
LIGA	Based in Geneva, LIGA is a German acronym for Lithographie, Galvanoformung, Abformug (Lithography, Electroplating, and Molding) that describes a fabrication technology used to create high-aspect-ratio microstructures
MND	Motor Neurone Disease
MRC	Medical Research Council
MWPC	Multi-wire proportional chambers
NERC	Natural Environment Research Council
NINA	National Institute Northern Accelerator
NWDA	The Northwest Regional Development Agency
NS-FFAG	Non Scaling FIxed Field Alternating Gradient
NSLS	The National Synchrotron Light Source at Brookhaven National Laboratory in New York, is a national user research facility
ONS	The Office for National Statistics (ONS) is the executive office of the UK Statistics Authority, a non-ministerial department which reports directly to the Parliament of the United Kingdom
PAMELA	The Particle Accelerator for MEdicaL Applications – proposed to be constructed at the Churchill Hospital in Oxford
PETRA	PETRA III will be a new high-brilliance synchrotron radiation source on the DESY site in Hamburg-Bahrenfeld, Germany
PPARC	The Particle Physics and Astronomy Research Council (or PPARC) was one of a number of Research Councils in the United Kingdom
PUSET	Public understanding of science, engineering and technology
PX	Protein Crystallography
RCs	The United Kingdom's Research Councils
RDAs	Research and Development Agencies
RF	Radio-frequency
RIKEN	RIKEN is a large natural sciences research institute in Japan
SAXS	Small Angle X-ray Scattering

Term	Meaning
SEAs	Science and Engineering Ambassadors Programme is a flagship programme run by the Science, Technology, Engineering and Maths Network
SERC	The Science and Engineering Research Council (SERC) used to be the UK agency in charge of publicly funded scientific and engineering research activities including astronomy, biotechnology and biological sciences, space research and particle physics
SESAME	The international Centre for Synchrotron-light for Experimental Science and Applications in the Middle East
SIC	Science and Innovation Campus
SMEs	Small and medium enterprises
SOD	Superoxide Dismutase
SPRU	Science Policy Research Unit (University of Sussex)
SR	Synchrotron Radiation
SRF	Synchrotron Radiation Facility
SRS	Synchrotron Radiation Source
STEM	The science, technology, engineering, and mathematics fields
STFC	The Science and Technology Facilities Council
UHV	Ultra high vacuum (UHV) is the vacuum regime characterised by pressures lower than about 10^7 pascal or 100 nanopascals (10^9 mbar, ~10^9 torr)
UNESCO	The United Nations Educational, Scientific and Cultural Organization (UNESCO) is a specialized agency of the United Nations
VUV	eXtreme UltraViolet radiation
XAS	X-ray Absorption Spectroscopy
XRD	X-ray diffraction

Acknowledgements

Acknowledgements

This report has been compiled after considerable input from many sources, both within the STFC and from external stakeholders including the synchrotron radiation user community and industrial partners.

Many STFC staff have been involved in this report including numerous staff from the Daresbury Laboratory, particularly former SRS and associated support staff whose knowledge of the facility was invaluable in writing this report.

A special acknowledgment goes to the following people –

Dr Liz Towns Andrews (former Director of Innovation, STFC),

Dr Pat Ridley (Former Associate Director SRS),

Professor Ian Munro (Former Director SRS),

Dr Sarah Galbraith (Galbraith Muir Consultancy),

Dr Frank Cave (Lancaster University),

Professor John Helliwell (Manchester University),

Dr Tracy Turner (STFC, Former Associate Director SRS),

Professor Neil Marks (Head of Post-graduate Education, Cockcroft Institute),

Dr Graham Bushnell-Wye (Senior Manager, STFC Photon Science Department),

Professor Mike Poole (Former Director ASTeC),

Tony Buckley (STFC Communications Department),

Stuart Eyres (Daresbury Laboratory Media Services, STFC),

Dr Elizabeth Shotton (Diamond Light Source Ltd),

Professor Richard Joyner (Former BP),

Professor Richard Oldman (Former ICI),

Dr Michael Begg (Tesla Engineering),

Dr David Wilcox (Former e2v),

Richard Davies (CVT Ltd),

Dr J.B.West (Former senior SRS scientist),

Professor Dave Stuart (University of Oxford),

Professor Tony Ryan (Sheffield University),

Professor Keith Meek (Cardiff University),

Professor Samar Hasnain (University of Liverpool),

Ian Tickle (Astex Therapeutics Ltd),

Paul Murray (IDT),

Jeffery Boardman (Atmos Technologies),

Professor Philip Withers (Manchester University),

Professor Russell Morris, (St Andrews University),

Dr Wim Bras (ESRF).

Contact details:

Claire Dougan
Innovation & Impact Manager
Science and Technology Facilities Council
The UK Astronomy Technology Centre
Royal Observatory
Blackford Hill
Edinburgh, EH9 3HJ

Tel: 0131 6688367

www.stfc.ac.uk

Published 2010 Produced by JRS Document Solutions

Science and Technology Facilities Council

Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, SN2 1SZ
T: +44(0)1793 442000 F: +(0)1793 442002 E: publications@stfc.ac.uk