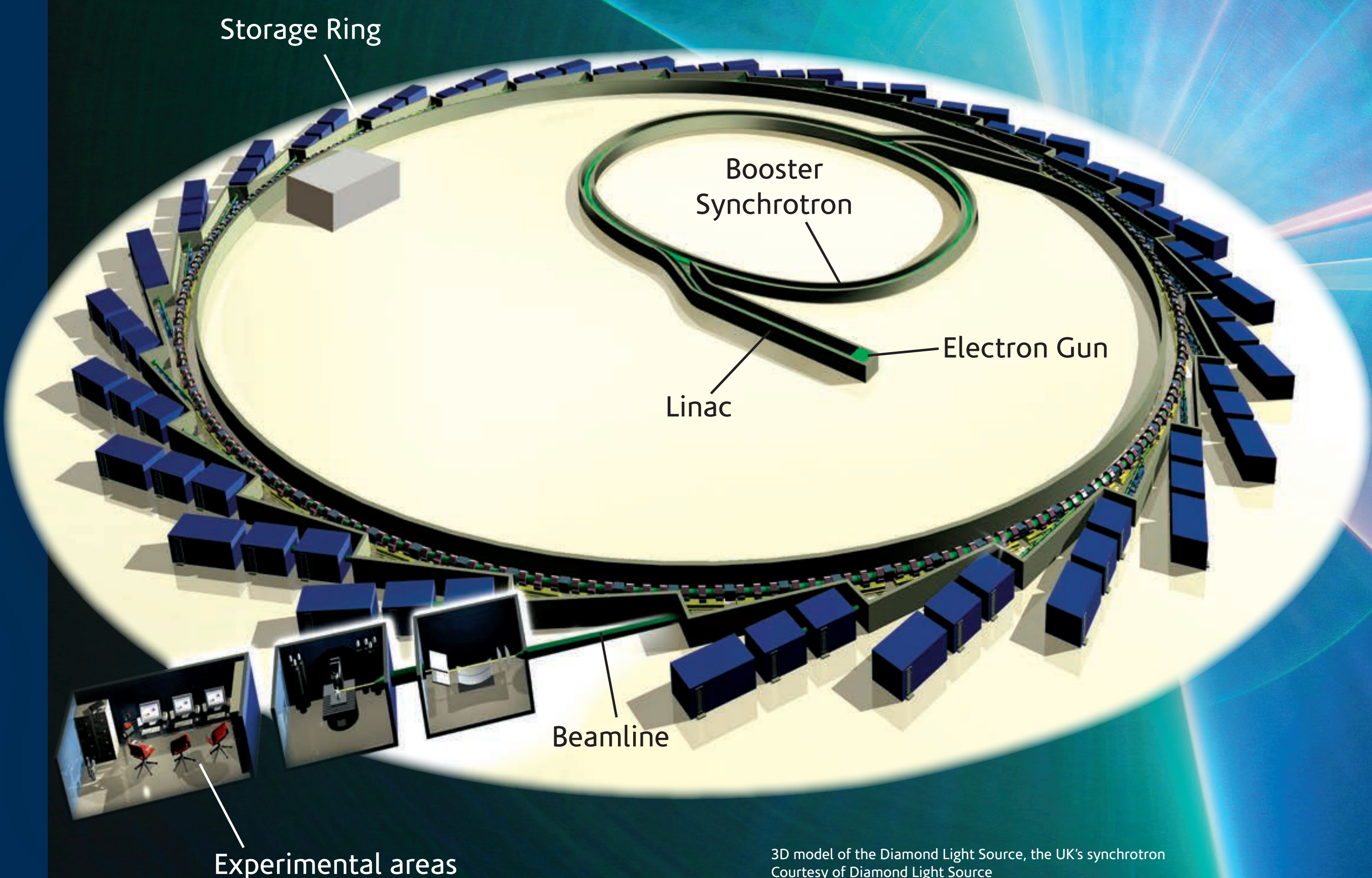
Accelerators:

powering cutting-edge research

What is a particle accelerator?



3D model of the Diamond Light Source, the UK's synchrotron
Courtesy of Diamond Light Source

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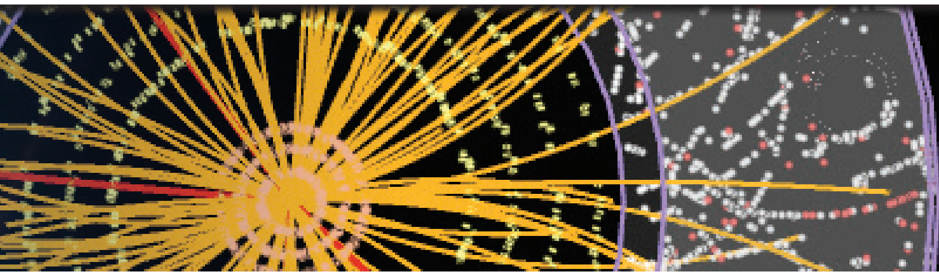
Introduction



Credit: CERN

Everything we can touch here on Earth is matter – collections of atoms made from neutrons, protons and electrons. When we look out into space, the stars and galaxies we can see are made up of matter, but the Universe wasn't always like that. In the moments after the Big Bang, the Universe was simply a ball of fundamental particles. As it expanded and cooled, these fundamental particles decayed into others that joined together to form everything we see now, including ourselves.

Particle accelerators are our attempt to turn back the clock and see into the early stages of the Universe. They accelerate everyday charged particles (electrons or protons) to close to the speed of light. Some are particle colliders, smashing particles together. Fundamental particles are formed in those collisions (depending on the energies involved), and exist for tiny fractions of a second before they decay. By studying the particles produced in these collisions (or, very often, the particles they decay into), we learn more about the Universe.

Particle accelerators aren't just used for fundamental science research. They are also very useful tools for science in general, allowing us to produce beams of particles that can be used to investigate the structure of materials – an indispensable tool for industry, medicine and science as a whole. And they have another trick up their sleeve. Many particle accelerators send their particles round in a loop – it saves on space. When the particle beams are turned around corners, they produce X-rays. Although these were once considered to be a hazardous waste product, some particle accelerators (such as the Diamond Light Source) are designed to harness this effect and produce beams of high-intensity X-rays that are another incredibly useful research tool.

Radiotherapy machines in hospitals, used to treat cancer patients, are examples of particle accelerators that are used in everyday life. A third of the word's radiotherapy machines are made in the UK, and it's a billion pound industry. Particle accelerators are also needed to produce the radioisotopes used for medical diagnosis.

The Science and Technology Facilities Council (STFC) operates the UK's large particle accelerator facilities (ISIS and Diamond Light Source), funds UK access to international research facilities (including CERN and ESRF), and develops the accelerators of the future. STFC produced this brochure in collaboration with the Cockcroft Institute and the Institute of Physics. There are thousands of particle accelerators in use around the world, and this brochure can only mention a tiny fraction, but it aims to showcase the wide range of ways they influence our everyday lives.

Contents

The information scientists gather from experiments involving particle accelerators is proving indispensable in our search for solutions to the major challenges of our time.

…from clean energy and environmental clean-up, industry and security, through to radiotherapy and other medical applications.

Energy

Meeting our energy needs without adding to our greenhouse gas emissions is one of the biggest challenges we face. The UK's nuclear power stations are one part of the strategy for keeping the lights on, and proving that they're still safe to operate allows us to extend their lifespan with confidence.

Carbon capture and storage is a technique for removing carbon dioxide from the atmosphere and preventing it from fostering climate change. Advanced materials are being developed that could make burning fossil fuels much cleaner.

Alternative energy sources have also benefitted from particle accelerator science. Read on to discover more about flexible solar cells, and liquid fuels made from carbon monoxide.

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Fighting cancer

With over 14 million new cases of cancer in the world each year, treating cancer has a huge societal and economic impact. Half of the world's particle accelerators are used for radiotherapy, and treatment technology is continually evolving. Behind the scenes, scientists are working on developing new cancer treatments, making existing treatments more efficient, and improving diagnostic tests.

PET scanners owe their existence to pioneering particle accelerator research carried out at CERN, and use radioisotopes produced in a cyclotron (a type of particle accelerator in which the charged particles accelerate outwards from the centre, in a spiral path). New research is working on early detection of oesophageal cancer, and two new proton beam therapy centres are being built in the UK to treat patients from 2018. Researchers are even investigating whether gold nanoparticles can help target radiotherapy more effectively.

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Medicine

Pharmaceutical companies were able to develop the antiretroviral drugs that are used to control HIV because the structures of key proteins in the virus were discovered using a synchrotron. More than 1200 lives are saved every year in the UK alone by retroviral drugs; worldwide, nearly 10 million HIV sufferers have access to these treatments.

Synchrotrons have also shed light on the parasite that causes malaria, moved us towards earlier detection of Parkinson's disease, and helped develop more nutritious staple crops that could help end malnutrition here and in the developing world. At ISIS, a particle accelerator is involved in producing beams of neutrons that are improving our understanding of diabetes, treatments for which cost the NHS millions every single day.

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Environment

A quarter of all carbon emissions are estimated to come from road transport. Hydrogen cars have obvious advantages – they're carbon-free and their only emission is water. With the market for fuel cells growing, researchers are using particle accelerators to investigate advanced materials that store hydrogen safely.

Emissions from a different kind of human activity – animal husbandry – can affect cloud formation. There's a link to the low-carbon economy here, too, as the same chemicals are used in the main scrubbing technique for capturing carbon dioxide emissions from power stations.

And whilst some researchers are working to clean up environments contaminated by industrial processes, or nuclear accidents, others are developing new ways to reduce the environmental impact of our buildings and infrastructure.

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Industry

At any given moment, around 200,000 people are flying on-board a plane powered by Rolls-Royce engines. Rolls-Royce makes use of particle accelerators to carry out research into new materials for engine components, and new manufacturing techniques. Such non-destructive testing reduces the cost of R&D (research and development) and contributes to the company's continuing success.

Cadbury and Unilever are just two of the food manufacturers who have used particle accelerator experiments to improve their products. If you like chocolate or ice cream, you're benefitting from their research! When Thanksgiving rolls around, millions of American families enjoy a turkey that has been packaged in shrink-wrap created by an industrial electron beam.

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Security

Security is a major challenge in the modern world, with border protection agencies constantly alert to the threat of terrorist attacks. Technology can make their job easier, and new devices can be used to reliably scan everything from single items of hand luggage to entire shipping containers and trucks.

Forensic science is also benefitting from particle accelerator experiments. New techniques can lift latent fingerprints from metal objects, increasing the likelihood of police securing a conviction. Particle accelerators have been used to identify poisons that have killed both humans and animals, and have a role to play in protecting our currency from counterfeiting.

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Natural world and heritage

State-of-the-art technology and cutting-edge science are also being put to use to preserve our cultural heritage. Synchrotron light has helped determine the effects of exposure to light on one of Turner's favourite pigments, feeding in to more effective conservation strategies. It has also been used in experiments aimed at preserving the timbers of the Mary Rose, and neutron beam experiments on coins found on the ship have told us a lot about Tudor minting methods.

It's not only artefacts that benefit from this kind of research, as synchrotron light has been used to examine the potential health hazards of exposure to museum samples preserved with mercury.

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Energy

Keeping the lights on at nuclear power stations

The UK currently has 16 nuclear reactors, generating about 18% of our electricity. 14 of these are advanced gas-cooled reactors (AGRs), and all but one is due to be decommissioned by 2023. The UK will need to build new power stations to take their place, but in the meantime, scientists are using ISIS to determine whether we can safely extend the lifetimes of our existing nuclear power stations, keeping the lights on and deferring £3 billion decommissioning costs.

A team of researchers, led by The Open University and EDF, used ISIS to look at the integrity of welded joints. Their results allowed nuclear safety regulators to grant an extension of five years to the lifespan of four AGRs at two nuclear power stations. Further work at ISIS looked at how zirconium alloys age inside nuclear reactors. Zirconium alloys are a critical material because they combine good mechanical properties, corrosion resistance in high temperature water and good neutronic properties.

ISIS has also been used to investigate how graphite changes during irradiation. AGRs have a graphite core that acts as a moderator, slowing down the neutrons produced during nuclear fission so that they are more likely to cause on-going fission reactions. The graphite bricks used can crack as they age, and currently this process is poorly understood. If the bricks were to break, or move, this could affect our control of the nuclear reaction. A clearer understanding of the processes involved, allowing us to predict the long-term effects, is therefore crucial to knowing how long we can safely run these reactors.

What we learn through these experiments also allows us to optimise the materials we'll use to build the next generation of nuclear power stations.

Taking a flexible approach to solar cells

Humanity is facing the challenge of meeting ever-increasing energy needs without using fossil fuels; the EU target is for countries to meet 15% of their energy demand from renewable sources by 2020. Solar energy is one answer, but silicon solar cells are expensive and energy-intensive to produce. Solar cells made from polymers (plastic) are cheaper and easier to produce, lighter and more easily transported – but they're not as efficient as silicon cells. Scientists from the universities of Sheffield and Cambridge have been using ISIS and Diamond Light Source to investigate how different processing steps affect the efficiency of polymer solar cells. They have discovered that when cells are made by 'painting' or 'printing' on layers of molecules in solution, the molecules spontaneously form into the most efficient configurations - a finding that could help usher in a new age of affordable, renewable energy.

Recharging modern life

Lithium-ion batteries are a major feature of modern life, appearing in everything from computers and smartphones to electric cars. The market for them is expected to expand from $1.6 billion in 2012 to $22 billion by 2020. Their advantage over lead-acid batteries is that they're lighter, and store up to six times as much energy. However, we're reaching the limits of performance of the materials currently used to make electrodes and electrolytes. The key to building better batteries is to understand them better, and Toyota have been using the muon beamline at ISIS to investigate the ion diffusion rate that determines how quickly batteries can be charged and discharged. Muons are perfect for the job, because they're excellent for probing magnetic fields. Another team of researchers, from the University of Kent, have been using ISIS's muons (and Diamond Light Source's X-rays) to investigate new materials for battery cathodes, made from nanoparticles. And US-led research has used ISIS's neutrons to look at how carbon spheres made from plastic bag waste could be used to improve long-term performance in products as diverse as batteries and car engines.

Turning carbon monoxide into fuel

The last few decades have seen a resurgence of interest in the use of the Fischer-Tropsch (F-T) process to manufacture petrol and diesel from syngas (synthetic gas) made from carbon monoxide and hydrogen. The carbon monoxide can come from any carbon source – including coal, methane and biomass, and several industrial operations have been commissioned throughout the world. The F-T process relies on an iron- or cobalt-based catalyst, and a team of researchers from the University of Glasgow and Sasol Technology UK Ltd took a sample from a working F-T reactor at Secunda in South Africa and used ISIS's neutrons to study the composition of the catalyst. More experiments are planned, with the ultimate goal of improving the efficiency of this economically significant reaction; the total combined value of the USA and European markets for syngas as an alternative fuel is over US $400 million.

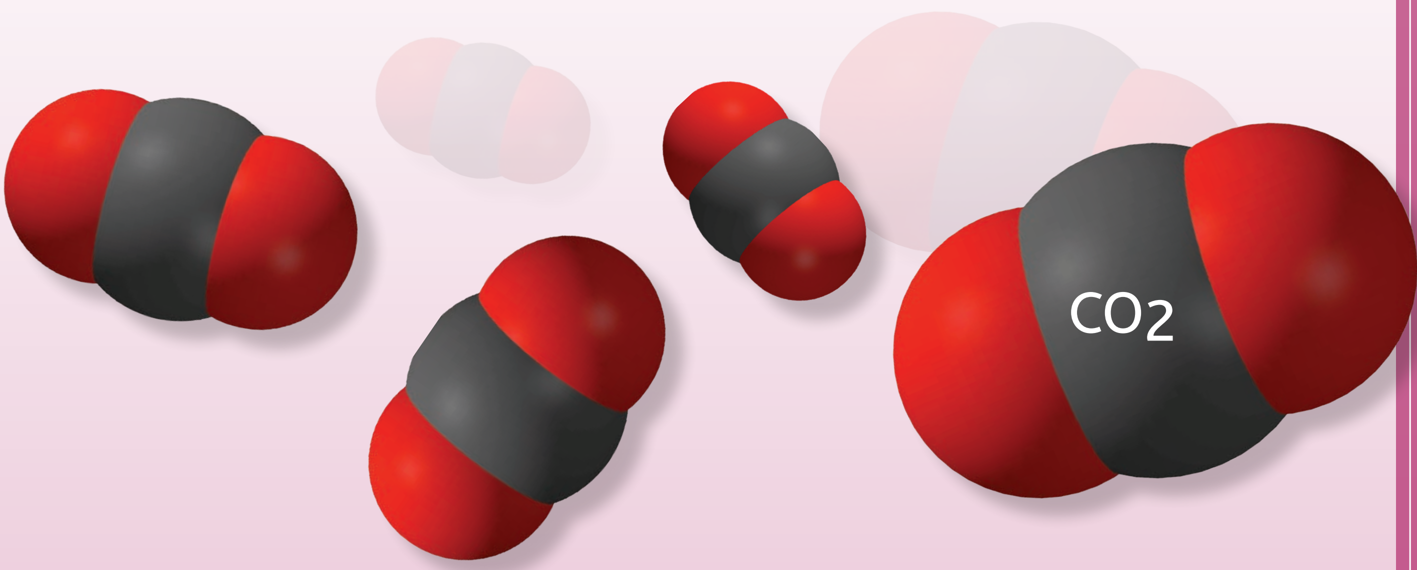
Capturing and storing carbon dioxide

Carbon capture and storage (CCS) is the only way that we can continue to use fossil fuels such as coal and gas whilst still reducing our carbon dioxide emissions. Many different CCS technologies are being investigated, and CCS could create 100,000 jobs across the UK by 2030, contributing £6.5 billion to the UK's economy. The global CCS market could be worth $5 trillion by 2050.

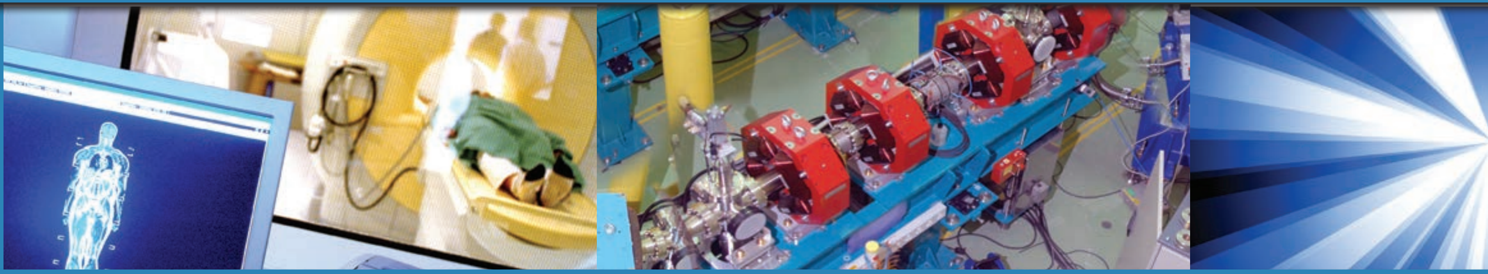
A collaboration between STFC, the universities of Nottingham and Oxford and Peking University in China has developed a low-cost, advanced material that is able to capture both carbon dioxide and sulfur dioxide, offering exciting prospects for combating global warming and atmospheric pollution. Use of ISIS and Diamond Light Source enabled the team to determine the crystal structure of the material, and to understand the mechanism by which it captures carbon dioxide and sulfur dioxide.

The new material, called NOTT-300, is cheaper than existing technologies and is more environmentally friendly. As well as being completely reusable, its production does not involve the use of any organic solvents. NOTT-300 is gas-specific, capturing only carbon dioxide and sulfur dioxide, and allowing other gases to pass through. In experiments it captures 100% of carbon dioxide, and this is expected to remain over 90% in real-world scenarios.

NOTT-300 also absorbs water vapour, and further work is needed to overcome this limitation. However, the researchers are already working with companies in the CCS industry to commercialise this product. As NOTT-300 is able to capture sulfur dioxide, it also has the potential to be used to prevent acid rain, and the considerable environmental impact it causes.



Fighting cancer



Treating cancer patients

With an estimated 14 million new cases of cancer in the world in 2012, and the annual incidence expected to rise to 17 million by 2030, treating cancer has a huge economic and societal impact. The chance of getting cancer increases with age, and one in three people will develop the disease at some point. Cancer survival rates have doubled in the past 40 years, as both our understanding of the disease, and our treatments for it, have improved. However, there were around 159,000 deaths from cancer in the UK in 2011.

Around 50% of all cancer patients undergo radiotherapy, which uses high-energy radiation to destroy cancer cells. External beam therapy is the most common form of radiation treatment, delivering radiation from a source outside the patient's body. The radiation (usually X-rays) is generated by a linear accelerator, housed in a rotating machine that can accurately target the tumour and minimise the damage to the surrounding, healthy tissue.

Half of the world's 20,000 particle accelerators are used in hospitals, with each one capable of treating up to 6500 patients each year. The global market for radiotherapy equipment is projected to reach $6.8 billion by 2018. One of the major suppliers, Elekta, produces one new digital linac (linear accelerator) machine every day in their manufacturing plant in Crawley, West Sussex and employs over 800 people in the UK. They estimate that 6000 hospitals worldwide have an Elekta digital linac radiotherapy machine.

Treatment technology is continually evolving. Four research groups around the world are working on combining a radiotherapy machine with a magnetic resonance imaging (MRI) scanner – the result of which would be to give real-time imaging of the tumour during treatment and dramatically improve the accuracy with which the necessary dosage can be applied. Greater protection for healthy tissue could mean fewer side effects – a potential benefit for patients, but also a possible economic saving for the NHS. Combining the two machines isn't an easy task, as the magnetic field produced by the MRI can be affected by the ferromagnetic components in the linac, and can also influence the treatment beam. However, an early prototype machine was produced in 2008 and two groups - one at the University of Alberta in Canada and one at the University of Utrecht in the Netherlands - in collaboration with Elekta, are each working on a new prototype.

Detecting oesophageal cancer

ALICE was the first energy recovery linear accelerator to be built in Europe, and is one of only three in the world. Built as a prototype for the next generation of particle accelerators, ALICE recovers and reuses 99.9% of the energy needed to power its high-energy beam – making it cheaper, and more environmentally friendly, to run.

But ALICE's state-of-the-art design is also being put to good use in the field of cancer research. A cutting-edge study being carried out by a collaboration between four universities (Cardiff, Lancaster, Liverpool and Manchester) and three NHS hospital trusts (Christie, Lancaster and Liverpool) is using ALICE to develop new cancer detection techniques.

One of the aims of the three-year project (funded by EPSRC) is to develop a reliable diagnostic test for oesophageal cancer, which currently affects almost half a million people worldwide each year. More than 30,000 cases were diagnosed in Europe in 2008, and the incidence of this cancer is rising. Unfortunately, early detection - the key to successful treatment of this cancer - is difficult, and the survival rate is currently low. Current diagnostic techniques can lead to both false positives (and the resulting unnecessary surgery) and false negatives that lead to delays in treatment.

This research project is also looking at ways to improve detection of cervical and prostate cancer. The UK spends around £200 million a year on the screening programme for cervical cancer alone, and the results of this work could not only reduce the costs of screening programmes, but lead to earlier and reliable cancer detection, and more successful treatment.

Improving medical diagnosis

More than 10,000 hospitals around the world use radioisotopes, with 90% of the procedures being used for diagnosis (predominantly of cancer). In Europe there are around 10 million procedures each year, and the use of radiopharmaceuticals for diagnosis is growing at more than 10% per year. Positron emission tomography (PET) is a precise and sophisticated technique that uses isotopes produced in a cyclotron. A radioactive substance that emits positrons is introduced to the body, usually via injection, and accumulates in the tissue of interest. The positrons it emits are then detected by a PET camera, and this has been proven to be the most accurate, non-invasive means of detecting and evaluating cancers.

The development of PET scanners owes a lot to early and essential work at CERN and at the Geneva Cantonal Hospital – the detectors used in PET scanners were initially developed as particle detectors for CERN experiments. More recently, combined PET/CT scanners have proved their value in oncology (CT stands for computerised tomography, and involves taking a series of X-rays to produce a detailed image). The advanced rotating tomograph, a forerunner of PET/CT scanners, was developed at CERN in 1989-1990, and has had such a major impact on medical imaging that now all of the PET scanners available from major commercial suppliers are combined PET/CT scanners.

Developing new cancer treatments

The aim of radiotherapy is to deliver the most effective dose of radiation to the tumour, whilst minimising the dose that's received by the surrounding, healthy tissue. Doing so reduces side-effects and complications, but the limitations of conventional radiotherapy (using photons) mean that some cancers - including those where the tumour is next to critical organs - can be hard to treat. One of the options to overcome these limitations is hadron therapy, which uses beams of particles (protons or light ions, such as carbon). Proton beam therapy is already used to treat some rare eye cancers in the UK (at the Clatterbridge Centre in Merseyside, the first hospital in the world to have its own cyclotron), but other patients are sent to the US for treatment. In 2013, the UK government pledged £250 million to build two new proton beam centres, at the University College London Hospitals NHS Foundation Trust and The Christie Hospital in Manchester, that will be able to treat 1500 patients a year from 2018.

There are currently around 40 hadron therapy centres worldwide, with 20 more planned or under construction. The UK is a key supplier of component parts for these modern accelerators. Research into hadron therapy is ongoing, with CERN spin-out company ADAM SA aiming to capitalise on CERN know-how and infrastructure to build innovative accelerators for both proton therapy and conventional radiotherapy.

Improving radiotherapy efficiency

Another way to improve the efficiency of radiotherapy, and to reduce side-effects, is to look for ways to make cancer cells more sensitive to radiation. One possibility involves the use of heavy-element contrast agents; their high-energy absorption coefficients increase the dose deposited in their vicinity. Gold nanoparticles (GNPs) are of particular interest, as they are apparently biocompatible as well as having a high atomic number. Two independent experiments, making use of ESRF and Diamond Light Source, suggest that the sensitising effects of GNPs may not be entirely down to their high absorption. It is hoped that these interesting results will help in the development of future cancer therapies.

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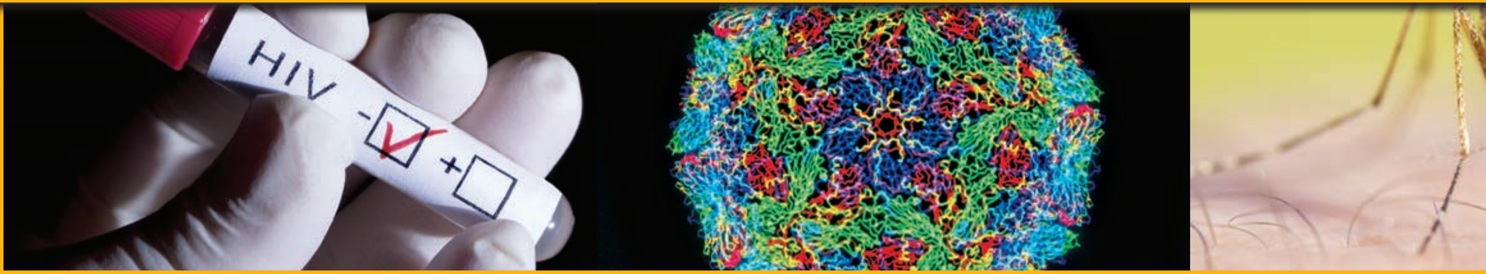
Medicine



Treating HIV

AIDS was first diagnosed in the United States in 1981, and the retrovirus that causes it (HIV), was isolated in 1986. HIV damages the human immune system, leaving sufferers increasingly vulnerable to opportunistic infections. Since the beginning of the HIV/AIDS outbreak, 36 million people are estimated to have died from AIDS-related illnesses.

In 1989, scientists published information on the structure of the first 14 proteins encoded by the HIV virus, which they discovered using the SRS (Synchrotron Radiation Source) at Daresbury. Pharmaceutical companies, such as GlaxoSmithKline, were then able to use this knowledge of the viral structure to produce antiretroviral drugs that slow down the progression of HIV to AIDS. Timely, ongoing treatment allows HIV suffers to live relatively normal lives, and greatly increases their lifespan.

In 2012, 35.3 million people worldwide were living with HIV, of whom 9.7 million had access to antiretroviral therapy. In the UK, where nearly 100,000 people are thought to be living with HIV, 77,610 (including 770 children) received specialist HIV care in 2012. Antiretroviral drugs are thought to save over 1200 lives here every year.

Ongoing research is improving our understanding of HIV and working towards better treatments. In 2010 scientists from Imperial College London and Harvard University published the results of their research at the Diamond Light Source, through which they solved the riddle of how HIV establishes itself in the body. The integrase enzyme is key to this process, allowing the virus to copy its genetic information into human DNA. The team uncovered the structure of integrase, and were able to observe how integrase inhibitors work to deactivate the virus. Antiretroviral drugs already target integrase, but the hope is that a better understanding of how the enzyme works could lead to better treatments, to which HIV is unable to develop resistance.

Controlling foot and mouth disease

Foot and mouth disease (FMD) is one of the most contagious animal diseases, and has an estimated global impact of £4 - 13 billion per year. The 2001 outbreak cost the UK alone around £8 billion, with agricultural producers, the food industry and tourism all affected. Research carried out at the SRS determined the 3D structure of the virus, which allowed the first vaccines to be developed. In 2013 researchers used the Diamond Light Source to develop a new way to produce an FMD vaccine that does not require the use of live viruses. The new synthetic vaccine is therefore much safer to produce, and is also less fragile and easier to transport. There's still a long way to go before the vaccine reaches the market, but the signs from early clinical trials are very promising. Unlike current vaccines, this new vaccine allows vaccinated animals to be differentiated from infected animals, protecting UK exports. What's more, this approach to making and stabilising vaccines could also impact on how similar viruses from the same family are fought, including the virus that causes polio in humans.

Managing malaria

Malaria is one of the world's deadliest killers, with between 350 and 500 million cases worldwide leading to one to three million deaths every year, with the majority of victims being children under five. With the aim of developing readily-available and more effective drugs to protect people in developing countries, scientists used the SRS to investigate how traditional anti-malarial drugs such as quinine work.

Malaria is caused by the *Plasmodium* parasite, which lives within red blood cells and feeds on haemoglobin. In the process it produces the toxin haematin, but locks it away within a harmless substance called the malaria pigment. Researchers studied the formation of the malaria pigment, as the development of pigment inhibitors could ultimately lead to cheap and effective malaria treatments.

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Detecting Parkinson's disease

Around four million people are thought to suffer from Parkinson's disease worldwide, with 10,000 people a year being diagnosed in the UK. Parkinson's disease is a degenerative neurological condition that causes tremors, slowness of movement and stiff muscles, making it difficult to walk, write or talk. It results from the loss of nerve cells in parts of the brain. Sufferers also have abnormally high levels of iron in the brain, and researchers were able to use the Diamond Light Source to map iron concentrations and obtain information about how iron is stored at different stages of the disease. There is currently no cure for Parkinson's disease, and the aim of this research is to develop early detection methods and therapies that can lead to improved quality of life for patients and lower care costs.

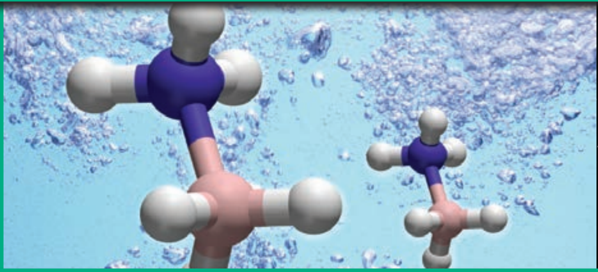
Dealing with diabetes

Treatment of diabetes and its complications costs over **£1.5m an hour** or 10% of the annual NHS budget for England and Wales, and can have a debilitating effect on the lives of sufferers. Researchers have been conducting crystallography experiments at Diamond Light Source to investigate the role that the body's 'killer' T-cells (which normally protect us from disease) play in type-1 diabetes, by destroying insulin-producing cells in the pancreas. At ISIS, small-angle neutron scattering has been used to study the early stages of insulin aggregation in real time, work that may lead to insights into how to tackle neurodegenerative diseases such as Parkinson's and Alzheimer's, as well as type-2 diabetes.

Improving nutrition through staple crops

Nearly 40% of Earth's land is used to grow agricultural crops, and the three main staples - rice, maize and wheat - provide two-thirds of our food. The focus for breeding modern wheat varieties has been on increasing their productivity, but in the process their micro-nutrient levels have declined. Many of the minerals (such as zinc and iron) in the wheat remain locked up by the chemical phytate, for which we lack a digestive enzyme. The UK has one of the highest obesity levels in Europe, with obesity often going hand-in-hand with nutrient deficiencies ('hidden hunger'), which are a global problem. A team of scientists from Rothamsted Research (and funded by BBSRC) is using Diamond Light Source's X-rays to investigate low-phytate varieties of wheat, bred using conventional methods, which could turn our morning cereal into a 'superfood'. This research could fundamentally improve the diets of people around the world and save millions of lives in the process.

Environment




Storing hydrogen

A material first conceived by scientists at ISIS, the London Centre for Nanotechnology at University College London and the University of Oxford, could make hydrogen-powered cars a reality. ISIS spin-out Cella Energy is developing the technology, which uses micro-fibres thirty times smaller than a human hair to store hydrogen safely. Conventional storage techniques for hydrogen gas require the use of either very high pressures or very low temperatures – both expensive, and hard to deliver at a garage forecourt.

Drivers expect to be able to fill their tanks quickly, and to travel as far as 400 miles before refuelling – neither of which is a possibility with current hydrogen storage technology. Cella Energy's tissue-like material means that hydrogen gas can safely be handled in air. It can also be formed into microbeads, smaller than grains of sand, which can be pumped like a liquid and used in conventional combustion engines. This means it could be used as a petrol additive, or even as a fuel in its own right.

The advantages of hydrogen as a vehicle fuel are obvious – it is carbon-free, and currently 25% of all carbon emissions are estimated to come from road transport. The only emission from burning hydrogen fuel is water, and it contains three times as much energy per unit weight as petrol. The global fuel cell and hydrogen energy market is projected to be worth over £114 m in 2050, with revenues in the fuel cell sector expected to grow by 26% per year over the next decade.

Cella Energy won the Shell Springboard Award 2011. Since then, they have opened new labs at the Rutherford Appleton Laboratory and at NASA's Kennedy Space Center. According to the Intergovernmental Panel on Climate Change (IPCC), limiting climate change will require substantial and sustained reductions of greenhouse gas emissions (such as carbon dioxide). As applicable to air travel as it is to road transport, Cella Energy's advanced material could keep us moving, carbon-free, into the future.

Studying clouds

Clouds form from tiny droplets of water, around dust particles (aerosols) in the atmosphere. The relationship between cloud formation and our climate is very complex, and not well understood. According to the IPCC, aerosol particles and their influence on clouds remain the largest uncertainty in our understanding of human-induced climate change. Scientists working on the CLOUD experiment at the Proton Synchrotron at CERN have been investigating how amines (atmospheric vapours closely related to ammonia) can combine with sulfuric acid to form aerosol particles, at rates similar to those observed in the atmosphere. Their work will improve our understanding of cloud formation, and help to inform future IPCC reports. The main source of amines in the atmosphere is human activity - primarily animal husbandry - but as amine scrubbing is likely to become the dominant technology for capturing carbon dioxide from power plants, our amine emissions are expected to increase.

Cleaning up contaminated environments

Green rust is an unstable form of iron oxide that forms in low-oxygen environments and oxidises rapidly on contact with air. That makes it hard to study in the lab, but it is of great interest to researchers because of its ability to react with toxic and radioactive environmental contaminants - such as uranium, chromium and industrial solvents - leaving them less able to affect drinking water or migrate up the food chain. Scientists from the University of Leeds used the SRS to study the growth and crystallisation of green rust particles, and have continued their work at the Diamond Light Source. Having produced more stable formulations of green rust that persist for hours or days, the team believes that using green rust remediation technology to clean-up contaminated environments may only be years away.

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Making cement greener

Cement is one of the most common building materials in use. It's cheap, because its raw materials (such as limestone, clay and sand) are abundant, and the global industry is worth $250 billion per year. However, producing cement is an energy-intensive process, and accounts for 5% of global carbon dioxide emissions. Researchers have been using the IRIS instrument at ISIS to investigate blended cements, made with additional materials that can improve their durability and reduce carbon dioxide emissions, whilst also reducing cost. Their experiment involved a blended cement, made with ash from agricultural sugar cane waste, which has enhanced resistance to water penetration and could therefore make buildings largely maintenance-free. Cement's hydration reactions are complex, and the team used neutron spectroscopy to examine what makes this particular blend more durable. Their findings could have a positive impact on a worldwide industry, the environment and our ever-expanding infrastructure.

Decontaminating Fukushima

In March 2011, an earthquake and the resulting tsunami overwhelmed the Fukushima Daiichi nuclear power plant in Japan. The subsequent power loss allowed three of the four reactors on site to melt down, resulting in the release of radioactive materials and large scale (640 km^2) contamination. Storing large volumes of contaminated soil is just one of the challenges faced by the decontamination teams, but a team of researchers from the University of Birmingham's Unit of Functional Bionanomaterials have come up with a novel way to aid the clean-up efforts.

Hydroxyapatite (HA) is a mineral similar to that found in teeth and bones, which can already be produced commercially. The team from the University of Birmingham have been investigating new techniques of using *Serratia* bacteria to produce Bio-HAP, which can absorb up to fifteen times more radionuclides than the current commercial version. Bio-HAP is particularly suited for nuclear waste remediation because it is stable over long geological periods, resistant to self-radiation, and able to incorporate radioactive metals into its structure. The scientists have been using neutron scattering at ISIS to investigate how Bio-HAP forms over a period of 48 hours; the hope is that a better understanding of the formation process will lead to production conditions that are optimised for radionuclide uptake.

The cost of decontaminating the areas surrounding the Fukushima Daiichi plant and compensating local residents (many thousands of whom are still unable to return home) is expected to exceed $80 billion dollars. The Birmingham team are working with the Japanese Atomic Energy Agency (JAEA) to determine whether Bio-HAP could be used to decontaminate Fukushima soils, and are busy planning their next experiment at ISIS.

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Testing engine components

Every 2.5 seconds an aircraft powered by Rolls-Royce engines takes off or lands. The company has over 12,500 engines in service with customers around the world, powering 5.5 million flights a year, and travelling 12 billion miles. At any given moment around 200,000 passengers are travelling in Rolls-Royce powered planes.

In collaboration with university partners such as Imperial College and the universities of Oxford, Cambridge, Birmingham and Manchester, Rolls-Royce carries out research into new materials for engine components, and new manufacturing techniques – using the particle accelerators at ESRF, ISIS and Diamond Light Source.

At ISIS, for example, research is carried out using instrumentation designed specifically for engineering applications that can accommodate full-sized components, and allows users to map stresses in 3D. Modern aircraft engines use components made from high-performance alloys (which enhance both safety and fuel economy) that can be difficult to join together using conventional welding techniques. New techniques, such as linear friction welding, can introduce weaknesses into the joint. Research into the nature of the stresses involved allows both the optimisation of welding conditions, and the development of post-weld heat treatments to relieve the stresses.

The Diamond Light Source offers another method for non-destructive testing of engine components, and has been used to collect high-resolution measurements on fan blades for the Rolls-Royce Trent 1000 turbofan engine. X-ray diffraction is less time-consuming and more accurate than laboratory methods, and allows the development of improved materials at reduced cost. As the third largest manufacturer of aircraft engines in the world, research using particle accelerators is an important factor in Rolls-Royce's continuing success.

Fuelling the economy

Scientists and engineers use purpose-built particle accelerators and detectors (such as the Large Hadron Collider) at CERN, the European Organization for Nuclear Research, to probe the fundamental structure of the Universe. The UK has played a major role in CERN since its creation in 1954. Over the last three years, STFC has doubled the UK industrial return from CERN. £20 million in industrial contracts were won in 2012, bringing the total to £68 million since 2007. In addition, contracts from CERN leverage significant additional benefits for the UK economy; with every £1 that CERN pays to an industrial contractor, £3 worth of benefit is generated for the economy. This means the £68 million in contracts since 2007 has generated over £200 million for the UK economy. It's not all high-tech: Arcade UK Ltd (a company specialising heating, ventilation and air-conditioning) have won over £1 million of contracts to upgrade the vital ventilation systems.

The number of spin-out technologies from CERN continues to rise, including more efficient solar panels and new ways of imaging cancers, and technology from CERN benefits the UK economy by over £100 billion each year. The most successful is the World Wide Web, now a fundamental part of everyday UK life. 40% of the world's population is online, and UK e-commerce is worth around £483 billion.

The first capacitive touch screen was invented at CERN, as part of the intelligent control system for the SPS (Super Proton Synchrotron) – which would otherwise have required thousands of buttons, knobs, switches and oscilloscopes. The technology was immediately transferred to industry and used elsewhere in CERN and in other large laboratories, but didn't really take off until computers became small enough, and cheap enough, to carry them around in your pocket. The original touch screens at CERN were in use for more than 20 years, until the new LHC control room was installed in 2008. In the meantime, the idea has been reinvented for many applications, including ticket and vending machines, and the smartphones we can't live without. Three-fifths of people in the UK own a smartphone. 700 million smartphones were sold globally in 2012, with the smartphone market expected to be worth $150 billion in 2014.

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Making life sweeter

In November 2011 global sales of chocolate confectionary were over $100 billion, and demand is expected to outstrip supply. Chocolate is big, high-tech business – the chocolate-making process has to be carefully controlled to allow the cocoa butter to crystallise in the most stable form possible. Errors during production, or temperature changes during the supply process, can lead to an unattractive white 'fat bloom' on the surface of the chocolate. Researchers have been investigating the crystallisation process with the aim of optimising consumer pleasure, and therefore sales. A team of scientists working with Cadbury used the SRS to follow the crystallisation of cocoa butter in real time, discovering the optimum conditions for chocolate manufacture, which could then be reproduced to ensure optimum product characteristics. Researchers also made use of the ESRF to improve our understanding of the fat bloom mechanism.

ESRF has also added to our understanding of another popular food stuff that suffers from 'temperature abuse'. The microstructure of ice cream, its ice crystals and air bubbles, are crucial to both its quality and sensory properties. Changes in temperature during transport or storage can lead to recrystallisation and a coarser structure, and understanding how the microstructure changes can lead to better products and higher profits. As you might expect, examining ice cream *in situ* is a challenging process, and a specialised sample environment was created for the Unilever experiments. Unilever spends around €1 billion on research and development, and uses particle accelerators for a wide range of experiments. Recent research includes investigating saturated fatty acids in foods such as chocolate and margarine, that can contribute to heart disease, with the aim of producing healthier products. And it's not only sweet treats that get this treatment – Unilever is also trying to understand and improve the quality of freeze-dried vegetables.

Industry

Developing new drugs

Synchrotrons are widely used to develop new drugs by the pharmaceutical industry, which contributes £8 billion to UK GDP and supports 67,000 drugs. For example, the macromolecular crystallography technique pioneered at SRS has been used to solve the structure of many proteins, including the viruses that cause foot and mouth disease, HIV, the common cold and bird flu. Improved knowledge of these viruses has led to the development of ground-breaking treatments for them.

Industrial drug development work continues at the Diamond Light Source. Heptares Therapeutics, a biotechnology company based in Hertfordshire, solved the structure of a protein receptor in the brain which controls our response to stress. By using Diamond Light Source to visualise the stress protein receptor at the atomic level, they were able to identify a 'pocket' in the structure for the first time. Scientists can now design a drug to fit precisely into this pocket, inhibiting the response of the 'stress' receptor. The same work could pave the way for a transformation in drug treatments for depression, diabetes and osteoporosis.

GlaxoSmithKline used Diamond Light Source to quantify impurities in one of their key products, which was impossible using standard laboratory equipment. The experiment showed that the manufactured products met the required specification, leading to greater product understanding and control and giving the company confidence in the reproducibility of their manufacturing process.

Making aircraft safer

The Earth is constantly being bombarded by cosmic rays, high-energy particles that come from our galaxy and beyond. Trillions arrive every second, most either deflected away by Earth's magnetic field, or greatly slowed by our atmosphere. By the time they reach the surface of the Earth, the cosmic rays that are left pose no threat to health, but they can affect silicon chips and other electronic components.

The problem is 300 times greater at 30,000 to 35,000 feet – the altitudes at which jet aircraft routinely fly. A chip can be hit by a neutron every few seconds, and when a neutron hits silicon it can cause an electrical charge shower that can damage the chip or cause it to behave in an unexpected manner. As electronic components get smaller, the risk of damage increases.

Good design and testing are needed to compensate for the potential disruption. The ISIS neutron source can facilitate testing by supplying - in a very short timeframe - the same number of neutrons that a silicon chip might encounter during thousands of hours of flight. Manufacturers such as BAE, QinetiQ and MBDA are part of a consortium that use ISIS to test their electronic components, allowing them to build in triple redundancy and reduce the risk of damage to the electronics in a timely and cost-effective manner.

The UK aerospace industry is thriving, and is the largest outside of the US. In 2006 it directly employed 124,000 people, and had a turnover of £20 billion. In 2014 it will have access to a new instrument on ISIS – CHIPIR, a dedicated instrument that will be the world's best facility for investigating how microchips respond to cosmic neutron radiation. CHIPIR will allow the UK aerospace industry to continue improving the quality of electronic systems, making aircraft safer and keeping the UK at the forefront of aviation technology.

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Keeping Thanksgiving turkeys fresh

There's an estimated 20,000 particle accelerators around the world, and many are unsung industry workhorses rather than state-of-the-art science facilities. For decades the food industry has been using particle accelerators to improve plastic shrink wrap, which is then used to package everything from fresh turkeys and baked goods to the latest CDs and DVDs. Polyethylene plastic normally melts when heated, but when exposed to an electron beam its polymer chains cross-link with each other - greatly improving the strength of the finished product, and allowing it to be heated without melting. One big customer is Butterball LLC, the largest turkey producer in the US, accounting for 20% of American turkey production. In 2012 more than 253 million turkeys were produced in the United States, with the turkey industry employing about 25,000 people. Industrial electron beams have many other applications, including curing materials and surface coatings, sterilising medical products and foodstuffs, treating sewage and welding metal.

Credit: © Irina Khomenko | Dreamstime.com

Security

Detecting terrorist threats

The military, customs and border protection agencies need to be able to detect terrorist threats, smuggled goods and prohibited substances in cargo. Heightened security for travellers often causes queues. Whilst the delays are generally thought to be a necessary evil, Rapiscan Systems - a world-leading supplier of security screening systems - are working on solutions.

With support and training from scientists at STFC's Daresbury Laboratory, they developed baggage scanning systems that use multiple X-ray sources. This technology, called Real Time Tomography (RTT), is an advanced type of computerised tomography (CT) scanning that offers security personnel real-time, 3D images of baggage, and is significantly faster than existing systems. This product is certified for use in all European Airports, and their first order (for Manchester Airport) was worth £12.4 million. The majority of Rapiscan's sales are export-based.

Rapiscan continues to grow and innovate, with a UK manufacturing base that employs 50 people. The company is now using STFC's cutting edge facilities to develop innovative security scanning technology and, in October 2013, were VELA's first users, performing proof-of-principle experiments for the next generation of 3D cargo screening. VELA, the Versatile Electron Linear Accelerator, is a high-performance accelerator capable of delivering a highly stable, highly customisable, short pulse, high-quality electron beam.

In a further development, The University of Lancaster and STFC in collaboration with UK industry are developing a compact, controllable X-ray source that will allow rapid optimisation of both energy and dose rate for each object to be scanned, for improved threat detection and operating efficiency.

Finding the evidence

The odds of two individuals having identical fingerprints are 64 billion to one, and they have been used to identify criminals for over a hundred years. The greatest source of forensic evidence comes from 'latent' prints that are not immediately visible. Visualising these latent prints with enough clarity for positive identification is difficult - only 10% of crime scene prints are good enough to use in court. Researchers from the University of Leicester have been using neutrons from ISIS and ILL to investigate a new technique that relies on the electrically-insulating properties of fingerprints, and colour-changing fluorescent films, to produce high-quality prints. This highly sensitive technique works with even low levels of fingerprint residue, and can be combined with existing powder-based approaches. It could lead to better identification of latent fingerprints on knives, guns and metal surfaces, and may dramatically improve the accuracy of crime scene forensics.

Solving mysterious deaths

Phar Lap is Australia's most famous race horse. His success made him a sporting icon, but he died under suspicious circumstances whilst touring the USA in 1932. Necropsies (animal autopsies) proved inconclusive, and there has been speculation as to the cause of his death ever since. Phar Lap's hide was preserved by taxidermy, and kept in the Museum Victoria in Melbourne. In 2010 scientists were able to take hair samples to the Advanced Photon Source (APS) at the US Department of Energy's Argonne National Laboratory. Using synchrotron X-rays they were able to differentiate between three sources of arsenic in the hair – steady, low doses from the arsenic tonics commonly used in horse racing at the time, residues from the arsenic-based compounds used during the taxidermy process, and a large dose ingested prior to death. The team have proved that Phar Lap was deliberately poisoned, although we may never know by whom.

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Uncovering a mass poisoning

Arsenic was discovered to be the cause when four people died and sixty-three others became ill after eating curry at the summer festival in the Japanese city of Wakayama. The suspect, Masumi Hiyashi, was believed to have dosed the curry with a pesticide left over from her husband's pest control business. Arsenic trioxide is usually produced as a by-product of copper mining. The trace components depend on both the mine and the refining process used. Synchroton radiation from the Spring-8 in Hyogo Prefecture and at the Photon Facility (PH) in Tsukuba City were used to show that samples of the poison and of the pesticide were the same – evidence that was instrumental in bringing about a conviction.

Fighting counterfeiters

Counterfeiting currency is a crime almost as old as money itself. In 2013, the Bank of England removed 680,000 counterfeit banknotes from circulation, with a face value of £11.5 million. Although this is a tiny fraction of the three billion notes (on average) that are in circulation, worth £55 billion, counterfeit notes are a problem for businesses and consumers as they are completely worthless. The Bank of England work very closely with De La Rue, the company that prints banknotes for the UK (and many other countries), to introduce security features that make the notes harder to counterfeit and to stay one step ahead of the forgers.

Scientists from the University of Sheffield have used the Diamond Light Source to develop a possible new solution. They have developed special polymers that produce intensely-coloured, iridescent materials. The colours are produced by the structure of the polymers themselves, rather than a pigment, in a similar way to the colours on beetle shells and peacock feathers. The researchers used Diamond Light Source's X-rays to examine the ordered polymer structures, which helped them to understand how the colours are formed and how to improve their appearance. Using just two polymers, they can produce a complete painter's palette of colours.

Not only does this technique use very complex chemistry, which would be very hard for counterfeiters to copy, but it has huge advantages over existing systems in terms of cost, processing and colour selection. An obvious application would be to use this technique to produce anti-counterfeit devices on banknotes and passports, but it could well have wider industrial potential for combatting counterfeit goods.

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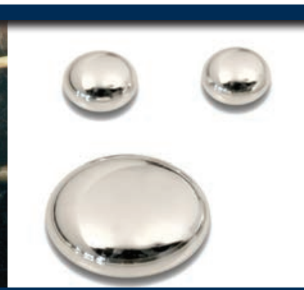
Natural world and heritage science



Conserving our heritage

In 1999 the first international conference on synchrotron radiation in art and archaeology was held at Daresbury Laboratory, where SRS scientists were at the forefront of the exploitation of synchrotron radiation in support of heritage science. 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 into historic production technologies.

These investigations help in the preservation of our cultural heritage and in our understanding and appreciation of the societies which created them, and are continuing at the Diamond Light Source. Researchers from the Technical University of Catalonia in Barcelona used an infrared microbeam to investigate the decay of the silver foil used to illustrate images of saints on medieval churches and altarpieces. Many of the images have been badly damaged by the corrosive effects of air on the organic-based glues and varnishes that hold the foils in place, or cover them. Their findings, that the decay is directly related to contact with the atmosphere, will inform future conservation efforts.

Conservation is also the goal of specialists from the Tate Gallery who are looking after 30,000 artworks by 19th century painter JMW Turner. Bequeathed to the gallery on his death, his watercolours are painted with pigments that fade with exposure to light and air. The aim of the research was to discover which gases would be best to include in air-free display cases, to conserve the paintings whilst giving the public the best possible view of the work. Working with samples of Prussian Blue, one of Turner's favourite pigments, scientists at the Diamond Light Source used a strong, artificial light to replicate 20 years' of fading in just 10 minutes. X-rays were used to show the resulting changes in the microstructure of the pigment. The ultimate goal is to convert the data gathered to useable conservation knowledge.

Protecting the Mary Rose

The raising of the Mary Rose, Henry VIII's flagship, from the bottom of the Solent gripped a generation of children, as they followed the salvage operation on television with Blue Peter. Scientists have been conserving the timbers for 30 years, using pioneering techniques, and the remains of the ship are now being carefully dried in a dedicated museum in Portsmouth. But whilst they were on the sea floor, sulfur compounds reduced by bacteria made their way into the wood. Until 2013, the ship was being continually sprayed with polyethylene glycol, which is used to replace the water in the wood, to limit shrinkage and collapse upon drying. Great care has to be taken now, as the reduced sulfur can react with oxygen to form sulfuric acid, which destroys the cellular structure of the wood. This has the potential to seriously compromise conservation efforts, and is particularly a problem near nails, bolts and shrapnel, where the presence of iron ions acts as a catalyst for the oxidation process.

Monitoring the sulfur concentrations in timber samples, and how they change over time, is a long-term project. Work began at the SRS, and is continuing using X-ray absorption spectroscopy at the Diamond Light Source. Initially, the team needed to understand the processes involved. Now that the drying process is underway, the wood needs to be monitored to ensure that it doesn't degrade (via oxidation, or the activity of bacteria) into harmful compounds over time. Access to a synchrotron is crucial for this work, which couldn't be carried out in a university laboratory.

Wood samples aren't the only artefacts from the Mary Rose to have been examined at the Rutherford Appleton Laboratory. Around thirty gold coins were recovered with the wreck, and as we know the date on which the ship sank, the coins can be accurately dated. Researchers brought the coins to the GEM instrument at ISIS to be examined using neutron diffraction. We now know that the coins were made by striking, and the research has given us a more precise understanding of the Tudor minting process.

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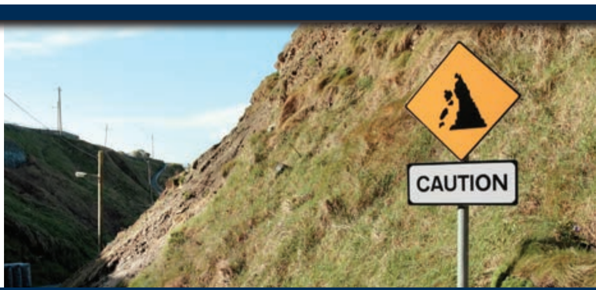


Containing mercury contamination

The University of Manchester Herbarium, founded in 1860, is home to over a million plant specimens from all over the world. Far from being a musty collection, it is a valuable resource for researchers, with specimens made available to international plant scientists. Until the 1980s, mercury salts were used to preserve the plants, which can result in volatile mercury being released – a potential hazard to herbarium staff. Scientists from the University of Manchester came to Diamond Light Source to investigate the form of mercury contamination and whether it could be safely contained via the use of selenium nanoparticles. The selenium nanoparticles they used are biogenic, produced as a by-product of treating contaminated wastewater, and the results showed that they efficiently captured mercury vapour, reducing levels by nearly 50%.

Calculating landslide risks

The Worldwide LHC Computing Grid is a computing service developed at CERN to handle the 15 petabytes the LHC produces every year, and it now links thousands of computers and storage systems in 35 different countries. Particle physicists from the University of Bristol are now using the Grid for a different purpose – solving problems in the developing world. Millions of pounds a year are lost when landslides cause disruption to commerce and communication, and damage to property and farming. The scientists aim to give engineers quick and easy access to complicated landslide risk calculations via a web portal – a vital input to their infrastructure work. Once the project is established, it can be expanded into other areas, including modelling floodplains. The Environment Agency estimates that the summer 2007 floods in the UK cost £3.2 billion.

Analysing Roman remains

Archaeologists working on the Highways Agency scheme to widen the A2 between Pepperhill and Cobham in Kent unearthed some bronze artefacts from two high-status Roman pit burials, some of the best ever seen in Britain. The artefacts, nearly 2000 years old, included jugs and vessels for mixing wine, as well as ceremonial objects. They were brought to ISIS for a non-destructive, detailed analysis of their crystal structure. At this point in history we know that Britons were beginning to take on the cultural practices of the Romans, and one of the aims of the investigations was to compare these artefacts with similar ones from Pompeii, to see if they had been imported from elsewhere in the Roman Empire, or made here.

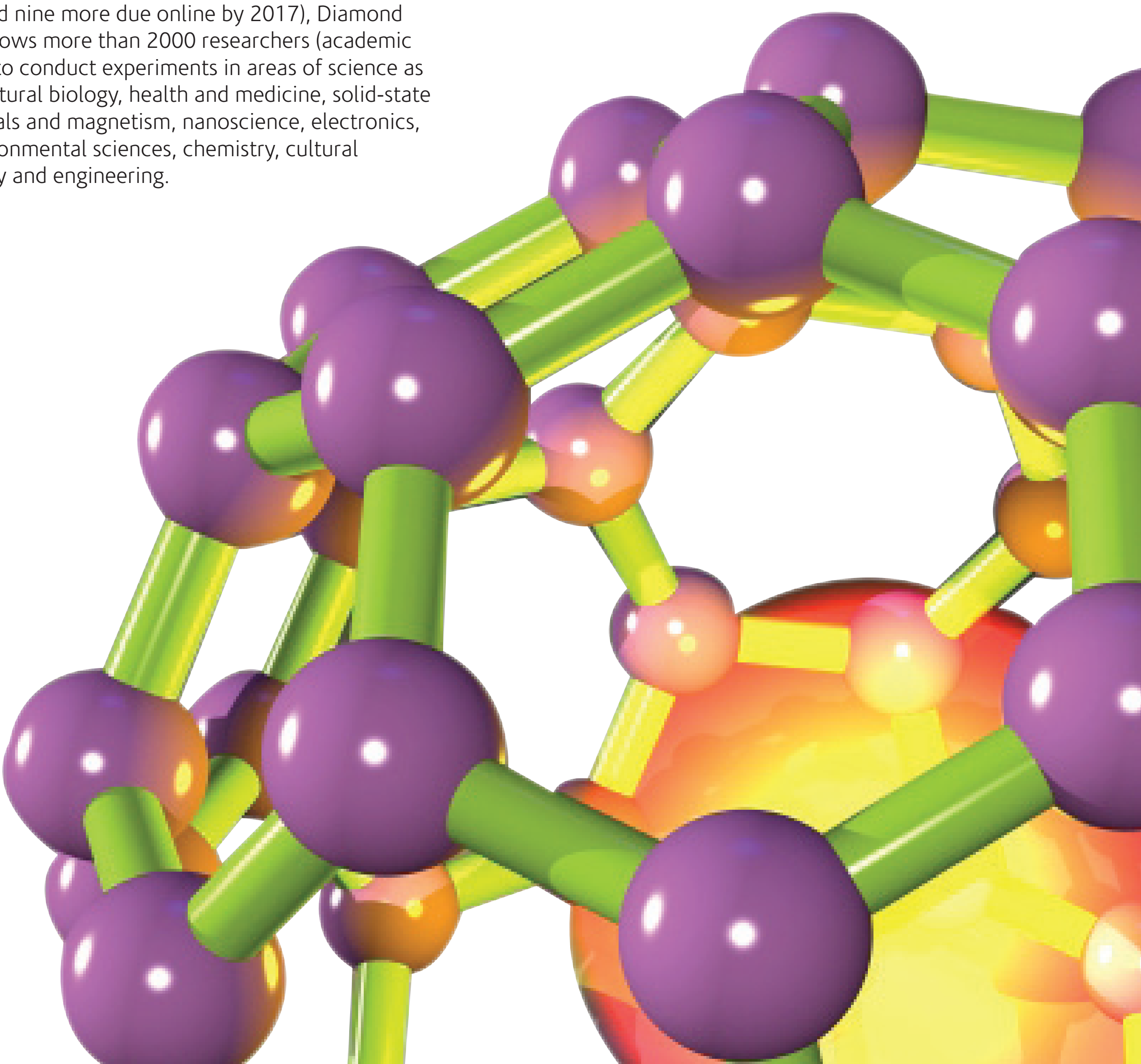
Credit: © Hennequinalain | Dreamstime.com

Particle accelerator glossary

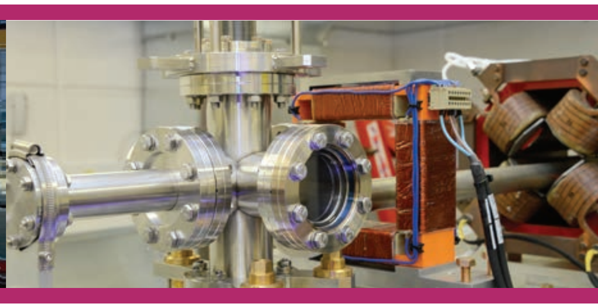
CERN is the European Organization for Nuclear Research – the largest particle physics laboratory in the world, located in Geneva on the France-Switzerland border. CERN was founded in 1954 as one of Europe's first joint ventures, and now has twenty member states. CERN is home to the Large Hadron Collider (LHC), the world's largest and most powerful particle accelerator, housed in a 27 km ring. In 2012 the Higgs boson was discovered by two experiments at the LHC, which is just the latest in a line of particle accelerators at CERN. CERN has a long track record of providing tangible benefits from the cutting-edge technology that it uses.

The **Diamond Light Source** is the UK's national synchrotron science facility, a third generation synchrotron light source, based at Harwell Oxford in the UK. Diamond Light Source uses a particle accelerator to produce highly-focused beams of X-rays, infrared and UV light – allowing scientists to probe deep inside materials. With 23 beamlines currently operational (and nine more due online by 2017), Diamond Light Source allows more than 2000 researchers (academic and industrial) to conduct experiments in areas of science as diverse as structural biology, health and medicine, solid-state physics, materials and magnetism, nanoscience, electronics, earth and environmental sciences, chemistry, cultural heritage, energy and engineering.

ESRF is the European Synchrotron Radiation Facility, based in Grenoble in France and used by scientists from 20 countries. It is the most powerful high-energy synchrotron light source in Europe - providing very intense beams of X-rays that can penetrate materials and reveal their structure down to the atomic level. ESRF runs 900 experiments a year, covering physics, chemistry, materials science, biology, medicine, geophysics and archaeology. Industrial applications include experiments in pharmaceuticals, cosmetics, petrochemicals and electronics.





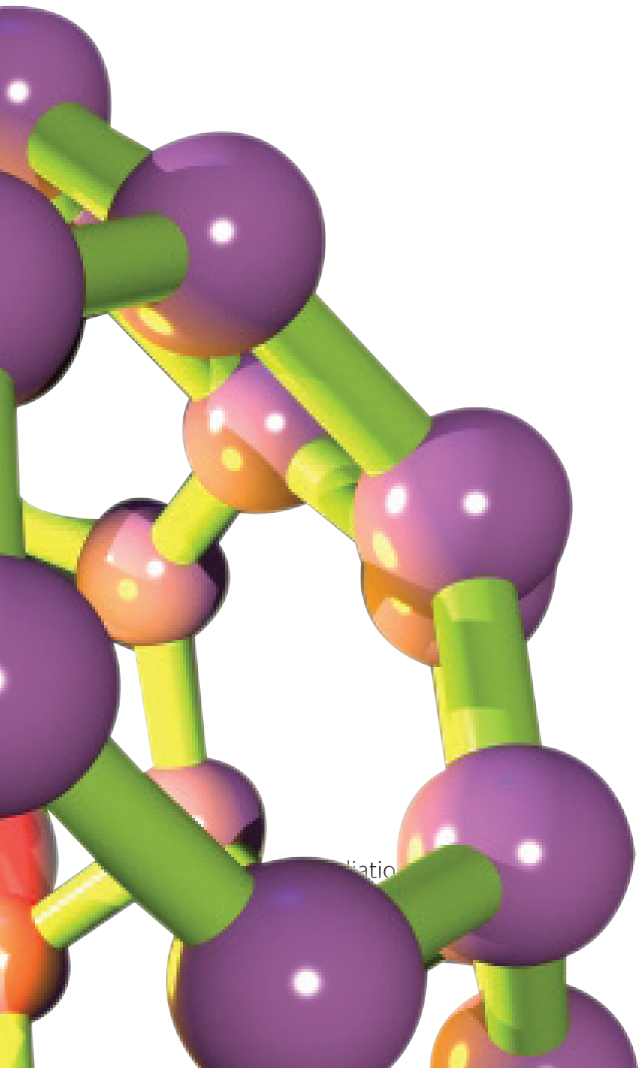


ISIS is a pulsed neutron and muon source, at Harwell Oxford. ISIS produces neutrons via spallation – it uses a particle accelerator to produce an energetic proton beam, which is fired into a target made from a heavy metal. In operation for more than 25 years, ISIS is continually upgraded to keep it a state-of-the-art facility. It allows an international community of more than 3000 scientists to do research on topics such as clean energy and the environment, pharmaceuticals and health care, nanotechnology and materials engineering, catalysis and polymers, and fundamental studies of materials. Neutron scattering allows us to study materials at the atomic level - where atoms are and how they are moving. Muons can be used in similar ways, providing additional information at the atomic level. From 2015, users will benefit from two new instruments. CHIPIR is the first dedicated facility outside of the US to examine how computer chips can be disrupted by cosmic radiation (one aspect of 'space weather'), and Larmor, a neutron super-microscope, will expand our material science research capabilities in fields such as engineering, food, health and the environment.

Laboratory in the UK was the world's first second-generation synchrotron. It operated for twenty-eight years, producing two million hours of science. The synchrotron radiation it produced was used to reveal the structure of matter and for research into new drugs and materials, cleaner fuels and safer aircraft. Experiments undertaken there improved our understanding of disease, and allowed us to conserve historical artefacts. The SRS kept the UK at the forefront of scientific research, and when it closed in 2008 it passed the baton to a worthy successor – the Diamond Light Source.

ALICE (Accelerators and Lasers in Combined Experiments) was originally designed and built as test accelerator, a prototype for an energy recovery linear accelerator. ALICE is being used to investigate and overcome the challenges faced by the scientists designing the next generation of particle accelerators and synchrotrons, but is also being used for medical research. Housed at Daresbury Laboratory in the UK, ALICE uses a free electron laser to produce short pulses of electrons, with very short bunch lengths. ALICE's energy-recovery system could halve operating costs.

Construction of **VELA**, the Versatile Electron Linear Accelerator, began in September 2011 and the facility welcomed its first users in October 2013. VELA is a high-performance accelerator capable of delivering a highly stable, highly customisable, short pulse, high-quality electron beam. VELA is primarily for industry users, but is also ideal for developing and testing the next generation of accelerator technology. VELA is based at the Daresbury Laboratory, and was able to recycle materials from the SRS during its construction.



Muonium atom trapped inside a buckyball.
Credit: STFC

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There are around 20,000 particle accelerators in use around the world. Some are large, state-of-the-art science facilities, helping us explore the world around us, uncover the properties of new materials, and investigate how our ancestors lived their lives. Particle accelerators now play an important part in our everyday lives; developing new technologies and making useful discoveries.

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