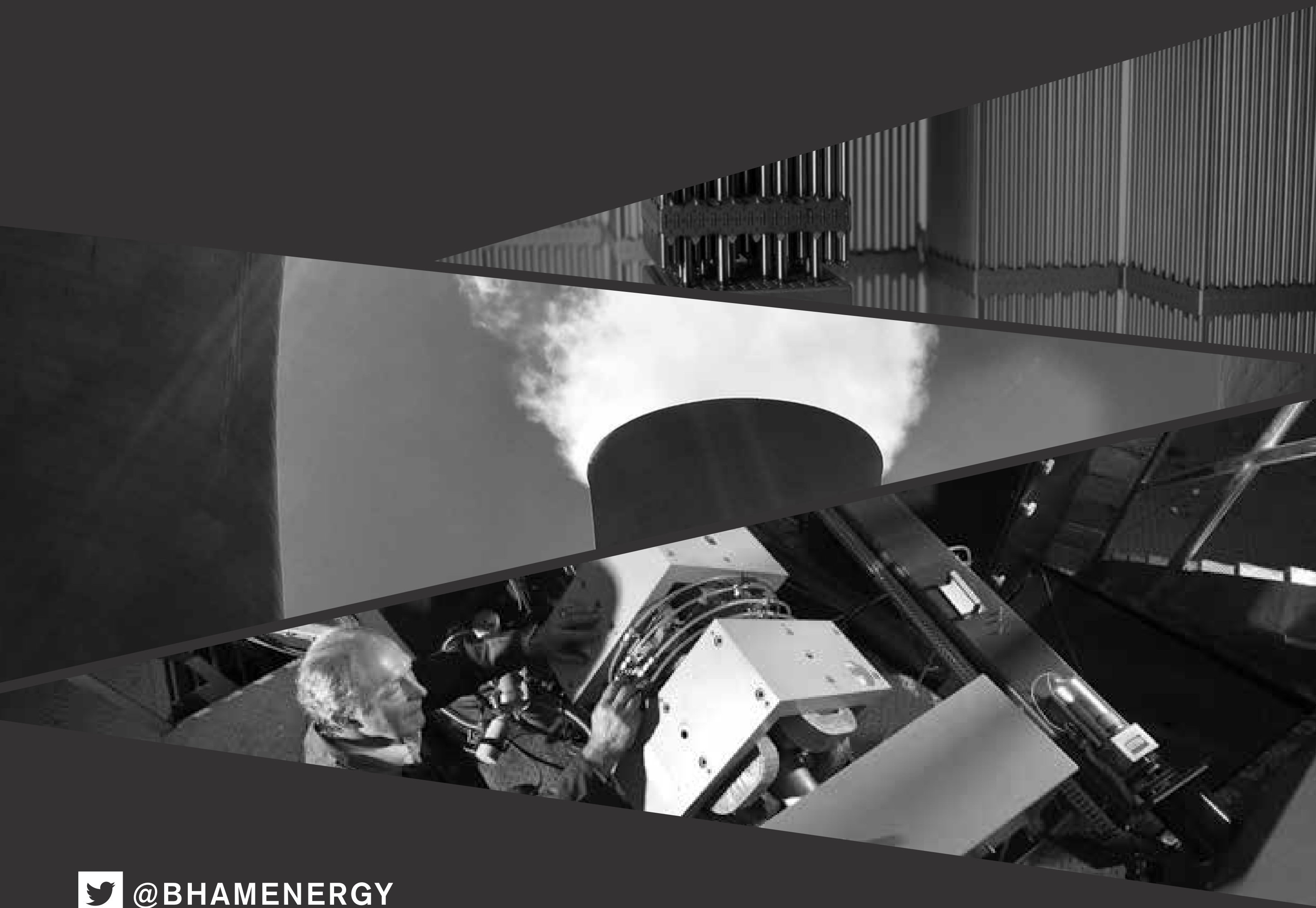
UNIVERSITY OF BIRMINGHAM

BIRMINGHAM ENERGY INSTITUTE

BIRMINGHAM CENTRE FOR NUCLEAR EDUCATION AND RESEARCH



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BIRMINGHAM CENTRE FOR NUCLEAR EDUCATION AND RESEARCH

The Birmingham Centre for Nuclear Education and Research (BCNER) was launched in 2010 and provides the investment and infrastructure to grow the nuclear expertise and capacity that has existed at Birmingham for over 50 years. The Centre brings together a multidisciplinary team from across the University to tackle fundamental nuclear industry problems.

The University of Birmingham has a long and established track record in working in areas of applied and fundamental nuclear science, nuclear data, de-commissioning, health monitoring and residual life prediction of existing nuclear power stations, dating back to the first phase of nuclear construction in the 1950s. Our work has been fundamental to the country's retention of its nuclear industry and we have led the education of nuclear engineers and scientists. Each year the Centre trains up to 100 students - many of whom go on to jobs in the nuclear industry.

Our research has ensured that nuclear power is used peacefully and safely; we are making significant contributions in the extension of the lifetime of reactor materials and in the study of effects of radiation damage to nuclear material. We are also helping develop the latest in robotic techniques for the use in safe handling of nuclear waste decommissioning. The research draws in academics from Physics, Chemistry, Computer Science, Earth and Biosciences, Electric and Mechanical Engineering and Metallurgy and Materials. This breadth provides integrated, cross-disciplinary expertise to provide the creativity to drive nuclear energy into the next generation of technology.

The University has unique facilities which include the MC40 cyclotron. This is capable of accelerating hydrogen (protons and deuterons) and helium (helium-3 and helium-4) with high intensities to energies at which it is possible to perform nuclear reactions. These reactions are typically used to create radioactive isotopes which are used in a variety of applications. In particular, the cyclotron produces radioisotopes using nationally for medical imaging.

'THE UNIVERSITY OF BIRMINGHAM HAS MADE SIGNIFICANT NEW INVESTMENTS IN THE AREA OF NUCLEAR ENGINEERING, WASTE MANAGEMENT AND DECOMMISSIONING. THIS IS TIMED TO SUPPORT THE UK'S INVESTMENT IN NEW CONSTRUCTION IN THE NUCLEAR POWER SECTOR, THE NEED TO MANAGE THE LEGACY WASTE, THE DECOMMISSIONING OF THE CURRENT GENERATION POWER STATIONS AND THE TREMENDOUS CHALLENGES IN DEVELOPING THE NEXT GENERATION NUCLEAR FACILITIES. THE DEMAND FOR HIGHLY SKILLED GRADUATES AND POSTGRADUATES IS SET TO RISE, WHICH WILL BE MET BY INCREASING PROVISION AT BOTH LEVELS. THESE ARE EXCITING TIMES FOR THE DEVELOPMENT OF NUCLEAR ENERGY IN THE UK'

PROFESSOR MARTIN FREER, DIRECTOR OF THE BIRMINGHAM ENERGY INSTITUTE

ABOUT THE BIRMINGHAM ENERGY INSTITUTE

BIRMINGHAM ENERGY INSTITUTE

The Birmingham Energy Institute is a focal point for the University and its national and international partners to create change in the way we deliver, consume and think about energy. The Institute harnesses expertise from the fundamental sciences and engineering through to business and economics to deliver co-ordinated research, education and the development of global partnerships.

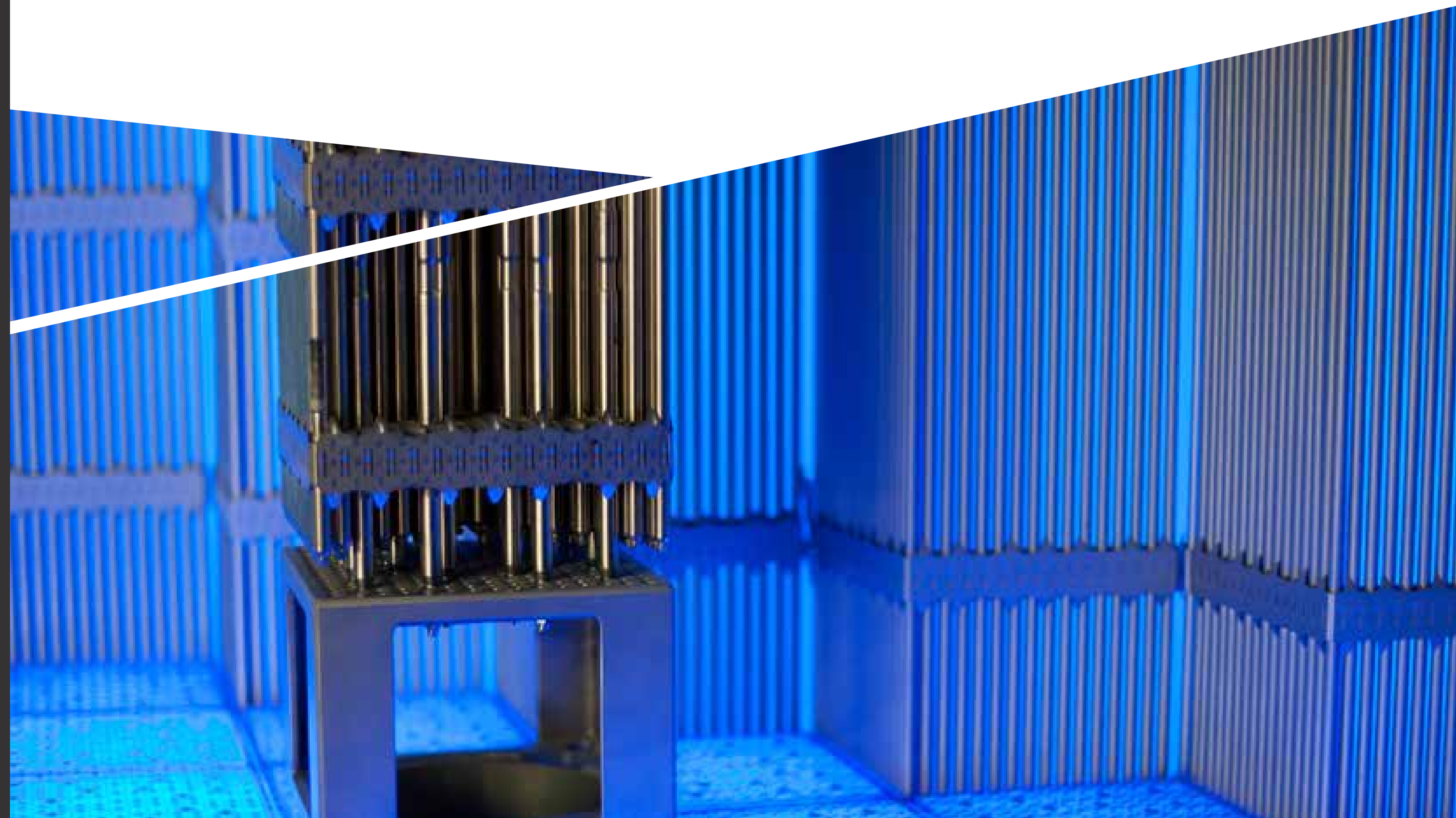
More than 140 academics from 4 colleges are engaged in energy and energy related research and development, with over £75 million external research investment. The Birmingham Energy Institute's strength comes not only from the concentration of expertise in specialised centres, but also the breadth of knowledge and facilities that it can draw upon through interdepartmental and interdisciplinary working across the University.

WE HAVE OVER 140 ACADEMICS ENGAGED IN ENERGY AND ENERGY RELATED RESEARCH AND DEVELOPMENT

£75 MILLION

AWARDED FROM EXTERNAL PROJECT FUNDING RELATED TO ENERGY

The UK has utilised nuclear power for over five decades - it is highly likely this source of energy will form an important part of the energy mix for the foreseeable future. Indeed it is possible that it could provide 40% of the UKs' electricity. The University of Birmingham focuses on the needs of the nuclear sector now and into the future, including the role of social and economic policy in shaping the landscape. The expertise that the University provides plays a significant role in training the next generation and delivering a new generation of nuclear power plants.



SCIENTIFIC RESEARCH IN NUCLEAR SCIENCE, NUCLEAR ENERGY, WASTE MANAGEMENT AND DECOMMISSIONING

ROBOTICS, VISUALISATION, SENSORS AND CONTROL

Robotics, visualisation, sensors and control are important capabilities in a range of operational activities associated with nuclear plant. The Centre utilises robotics to manipulate hazardous material, operate robotics in extreme environments, and develop novel low maintenance sensor and analysis systems for extreme environmental monitoring, such as those within a reactor.

RoMaNs

We are leading the largest robotics research project in Europe, aimed at developing the smartest robotic manipulators ever devised, for handling dangerous nuclear waste too hazardous for humans.

RoMaNS (Robotic Manipulation for Nuclear Sort and Segregation) are a three-year project is funded through a €6.4m grant from the European Commission's Horizon2020 programme and an extra €400,000 investment from UK agencies. It spans five institutions in three countries, and is coordinated by Birmingham. The project's driver is the vast, challenging job of cleaning up more than half a century of nuclear waste, which in the UK alone – mostly at the Sellafield site – represents the largest environmental remediation problem in the whole of Europe, expected to cost up to £220 billion over the next 100 years.

Millions of cubic metres of contaminated nuclear waste – including construction materials and tooling, fuel rod casing, contaminated protective clothing and radioactive sludge – are stored in large steel drums, many of which are 50 years old and have uncertain content. These must be cut open and 'sorted and segregated', so that low-level waste (80 per cent of all nuclear waste) need not be stored in extremely expensive, high-level storage facilities. This work cannot be done by humans, due to high radiation levels, which poses enormous challenges for robotics and AI – how to design autonomous or remotely operated systems with advanced cognitive and physical abilities including vision and manual dexterity. RoMaNS will focus on developing advanced robotic vision, robotic grasping and advanced interfaces between robots and their human supervisors.

Advanced autonomy

Our research will enable robots to autonomously assist human operators. An operator will be able to mouse-click on an object in a camera view. A computational vision system will reason about the object's position, size and shape, and advanced AI algorithms will plan safe trajectories to move a robot arm and hand on to the object to achieve a stable grasp. This will be a huge leap forward, as current state-of-the-art only allows human operators to slowly and painstakingly control the joints of the robots directly via joysticks, while viewing scenes through CCTV cameras with limited depth perception and situational awareness.

THE CENTRE'S RESEARCH DEVELOPS AND SUPPORTS THE UK NUCLEAR INDUSTRIES - PUSHING BACK THE FRONTIERS OF SCIENTIFIC KNOWLEDGE. THIS INCLUDES FUNDAMENTAL NUCLEAR SCIENCE - UNDERSTANDING THE NUCLEUS AND ITS STRUCTURE, AND ITS ROLE AS ONE OF THE FUNDAMENTAL BUILDING BLOCKS IN NATURE, THROUGH TO THE CHARACTERISATION OF MATERIALS USED IN THE NUCLEAR INDUSTRY AND MANAGEMENT OF NUCLEAR WASTE AND REMEDIATION OF RADIONUCLIDES IN THE ENVIRONMENT. THE CENTRE DRAWS TOGETHER SCIENTISTS ACROSS THE CAMPUS AND DISCIPLINES TO DELIVER JOINED UP SOLUTIONS TO THE CONTEMPORARY CHALLENGES OF THE SECTOR.

KAERI

We are leading a second major nuclear decommissioning robotics project – working with South Korean nuclear agency KAERI, which has a large number of nuclear reactors due for decommissioning in 20 years. This project focuses on 'mobile manipulation', i.e. robotic arms and hands mounted on a robotic vehicle. The mobile manipulator will also be used to deploy a pipe-climbing robot (developed by KAERI), which can scale the complex pipework that fills many nuclear installations. Such robots could be used to enter Fukushima or parts of old nuclear plants in order to locate, model, monitor, cut and remove contaminated legacy plant parts.

BIRMINGHAM HAS LONG BEEN KNOWN FOR ITS PIONEERING NUCLEAR RESEARCH, AND HAS THE BEST TRACK RECORD OF ANY UK UNIVERSITY FOR WINNING MAJOR EU ROBOTICS GRANTS.

ENVIRONMENTAL RESTORATION OF FUKUSHIMA

More than four years after the Fukushima Daiichi nuclear power plant disaster, a massive and assiduous clean-up of the immediate area and wider environment continues. We are leading two collaborative projects aimed at immobilising radioactive nuclides in the environment, particularly in water in and around Fukushima harbour, using novel systems devised in Birmingham.

The first of these is now being tested in Japan. This could not only help nearly a quarter of a million people return to their homes; it could also be extremely useful in the decommissioning process at Sellafield. Our research – funded by the Engineering and Physical Science Research Council – has focused on the radionuclides caesium and strontium, two of the most common fission products and a particular problem because they form water-soluble salts making them mobile in the environment and readily absorbed into the body. With radioactive half-lives of about 30 years, both pose a serious health risk: Strontium is chemically similar to calcium and can get into the bones and teeth; caesium is biologically similar to potassium and can get distributed in soft tissue throughout the body. The standard way to clean up radioactive nuclides is ion exchange, a chemical process whereby a non-radioactive, solid material containing sodium comes into contact with the polluted water and the sodium and radionuclide change places, concentrating the pollutant into the solid and, therefore, making it easier to dispose of or immobilise.

One of the most effective materials used for this is a class of absorbent minerals called zeolites. The contaminated water is pumped into a gravity flow filtration bed, through a mass of zeolites, which absorb the radioactive material, leaving the water at the bottom clean. However, there is a problem - the system requires a lot of liquid transfer, as it doesn't work very well in mobile plant. We have put our own twist on it which use the same materials and the same chemistry, but a different separation process –magnetism. By attaching nanoparticles, we have made the zeolites magnetic. Contaminated water can still be pumped, but through a tube with strong magnets around the inside, so that the radioactive particles will be caught up as they pass through. This system does work well in mobile plant, so could be of great benefit to clean-up operations spanning many square miles. The second project we're leading, in collaboration with Japan, is based around a class of materials known as hydroxyapatites (a naturally occurring mineral form of calcium apatite – the main component of bone), which are known to be particularly good for absorbing strontium into their surface. These are being used to make nanoparticles that we are trying to stabilise in liquid form, which could be injected into cracks in buildings or into ground barriers such as trenches. Cleaning up after nuclear accidents or decommissioning is important not only for those directly affected but also from a public perspective. If countries can't deal effectively with old power station problems, they won't be trusted to build new reactors.

MATERIALS, DEVELOPMENT AND PERFORMANCE

Predicting the extended lifetime, safety of existing nuclear plants and designing the next generation of nuclear plants requires a fundamental understanding of materials performance. The Centre has access to one of the largest Metallurgy and Materials Schools in the UK – facilitated with expert staff to address these issues. In addition to materials performance, the Centre has significant high-value manufacturing capability and collaborates with international companies and world leading research intensive organisations.

THE UNIVERSITY OF BIRMINGHAM **IS UNIQUE IN THE UK** FOR HAVING A MC40 CYCLOTRON

THIS PARTICLE ACCELERATOR IS USED FOR A RANGE OF NUCLEAR RELATED PROGRAMMES RANGING FROM:

- THE CHARACTERISATION OF RADIATION DAMAGE TO NUCLEAR MATERIALS
- THE PRODUCTION OF ISOTOPES USED IN HOSPITALS FOR MEDICAL IMAGING
- PRODUCTION OF POSITRON EMISSION TOMOGRAPHY (PET) ISOTOPES

The University of Birmingham's MC40 cyclotron (particle accelerator) has been used to develop a programme of irradiation of nuclear materials with beams of protons. This process is used to simulate the damage that is done by the neutrons inside a nuclear reactor. The advantage of using protons as opposed to neutrons is that the same damage that is produced inside a reactor by neutrons over many years can be achieved in several weeks. This allows the study of damage mechanisms on an accelerated timescale. The Centre's materials research spans a wide range of key areas:

1. High Temperature Materials
High operating temperature and pressures are necessary to increase the overall efficiency of power plant. In order to reach these efficiencies new materials must be developed - the next generation of nuclear plant will operate at significantly higher temperatures. We are currently investing significantly in research and development in this area.

2. Surface Engineering
Current challenges for stainless steel and other alloy components include surface degradation through wear and corrosion.

Predictive models of behaviour, developed at Birmingham from understanding underlying mechanisms of environmental interactions, fracture and fatigue, have been used to extend the certified life of high-duty components operating in complex environments within nuclear (Magnox and AGR) power stations. Such models are necessary as stations are operated beyond their original design life, to ever more onerous combinations of temperature/stress – here exemplified by dwell-fatigue and overload-dwell-fatigue cycles. This research has generated economic benefits estimated to be worth £0.5billion to EDF Energy and the Office of Nuclear Regulation.

We are investigating and developing novel surface engineering technologies that will significantly increase hardness, enhance corrosion resistance and increase wear resistance by up to two orders of magnitude.

3. Corrosion and Cracking
We have significant experience and capability in understanding and developing materials to limit corrosion and cracking both in a nuclear plant and a nuclear waste storage context. The majority of the Centre's activity in this area is in collaboration with national and international stakeholders and by its very nature is truly interdisciplinary.

4. Microstructure Characterisation and Modelling
Radiation damage can cause significant changes within an alloy and the morphology of radiation damage needs to be understood so that it can be limited. The Centre works closely with industry quantifying micro-structural development during alloy process routes, particularly determining distributions of grains and precipitates as they develop spatially and over time. There is significant collaborative work with industry in the development of non-destructive sensors that aim to monitor characteristics such as phase transformation during hot rolling processes.

5. Plant Life
The Centre's, through the experience and expertise of its materials scientists, has historically played an important role in understanding the basis for the long-term continued operation of nuclear plant. This expertise will be vital in developing the next generation of materials for reactors of the future. We also have significant chemical engineering expertise that is being utilised to understand and mitigate the development of sludge pile that can cause tube fouling and pose a threat to the safe and continuous operation of some plant.

DECOMMISSIONING AND DISPOSAL

New nuclear plants should be designed with decommissioning in mind and with a whole systems approach. Experts at the Centre have a wealth of experience in many aspects of decommissioning and disposal and have collaborated with stakeholders across the globe including the UK, US and Switzerland - often employing novel and advanced techniques to solve specific challenges related to corrosion, materials performance, ion-exchange and sub-surface remediation and monitoring.

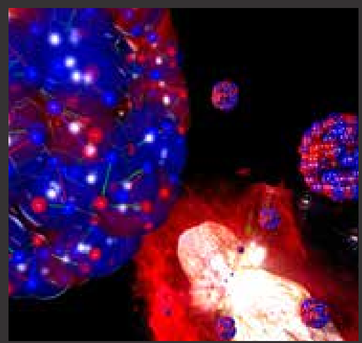
Projects have included:

- Materials synthesis - improving selectivity, rate of uptake and irreversibility of exchange for specific radionuclides; exploring new routes of production such as biomineralisation.
- Materials characterisation - determining how structures change with temperature, pressure and radiation damage; use of synchrotron X-ray and neutron facilities worldwide.
- Environmental impact - exploring how exchanged materials can be made into better (more dense, less leachable) waste forms for storage/burial.
- Corrosion - reviewing corrosion issues relating to canisters for disposal of spent fuel and high level waste in clay, and research on the reaction kinetics of pitting of stainless steels for intermediate level waste storage.
- Infrastructure - remote performance monitoring of underground structures and tunnels and the development of micro electrical mechanical sensors for smart infrastructure.

POSITRON EMISSION TOMOGRAPHY (PET)

The MC40 Cyclotron is also used for the production of medical isotopes for hospitals and to produce short-lived positron emitting isotopes for positron emission tomography (PET) and positron emission particle tracking (PEPT) studies within the Nuclear Physics Group. The Positron Imaging Centre, located at the University, allows the study of flow using positron emitting radioactive tracers. The techniques used are variants of the medical technique of positron emission tomography (PET), adapted by Birmingham for engineering applications. This technique has allowed industrial partners to optimise their mechanical processes for mixing and manufacturing of a variety of products from food to minerals.

FUNDAMENTAL NUCLEAR PHYSICS



We focus on understanding the properties of nuclei over a range of scales, from atoms, to nuclei, the protons and neutrons within all the way down to quarks. Our research is helping understand the fundamental forces at play inside the nucleus, in particular the strong interaction and the processes by which the elements in the world around us are formed through stellar nucleosynthesis. It is the delicate interplay between the forces of nature and the stellar environment which has created organic life.

With very high collisions of nuclei, our research focuses on the study of nuclear matter under extreme conditions of high temperature and high density. The important degrees of freedom are thought to be quarks and gluons, rather than hadrons. This state of matter, known as a quark-gluon plasma (or QGP), is described by Quantum Chromodynamics.

It is expected that when nuclear matter is compressed and heated in a high energy collision, a phase transition may occur. The transition marks the change of state from quark confined hadronic matter, to a plasma phase, where quarks and gluons have become liberated over a volume comparable with that of the colliding nuclei. This novel state of matter must have existed during the first fraction of a second after the Big Bang and may exist today in the core of dense stellar objects such as neutron stars. Work in this field is currently being performed at the Large Hadron Collider (LHC) at CERN using the ALICE detector.

FUSION ENERGY

In collaboration with colleagues at the UKs fusion laboratory in Culham we are working on projects relating to nuclear fusion. Led by Culham, this research has focussed on tritium breeding, primary nuclear heating, radiation damage rates, hydrogen and helium production and other parameters of interest in the design of fusion devices and their components - in particular the breading blanket surrounding the fusion reactor. Radiation damage, caused by collisions of neutrons with nuclei of the material, and swelling caused by hydrogen and helium from (n,p) and (n,a) reactions, produce materials degradation, altering thermo-physical and mechanical properties, posing critical limitations to the operational life of components. Tritium generation is crucial to achieve self-sufficiency in-situ and the group are working to provide a tool for engineering analysis of these parameters, important in the design of fusion technology.

WORKING WITH INDUSTRY

The University of Birmingham has a long history of working with the nuclear industry either through research or education and training. As the UK moves towards the construction of new nuclear power plant the need for collaboration and cooperation increases. This builds on the important work that the University has already done in the realm of life extension of the current generation of nuclear power plant. The development of nuclear energy will involve many new companies coming to the UK from Japan and China. The Centre has developed a collaboration with Hitachi-GE as part of the programme to deliver the Advanced Boiling Water Reactor (ABWR) to the UK. Similarly, the Centre has developed a relationship with the Chinese nuclear power company CGN. These form the basis for performing collaborative research, training and education.

ENERGY POLICY

The University of Birmingham has established a series of Policy Commissions to help shape the thinking of government and policy makers. The Centre led a commission which examined "The Future of Nuclear Energy in the UK". This report examined the role of nuclear energy in a low carbon energy economy, the options around the nuclear fuel cycle and the future role of fast reactors, the challenges of the disposal of nuclear waste, the potential of thorium as a fuel and understanding of public opinion when it comes to nuclear power. The report laid the foundations as the UK moves into the new nuclear age.

EDUCATION AND TRAINING

The Birmingham Centre for Nuclear Education and Research has strong active international links with industry, which directly steers the development of our teaching programmes. This collaborative environment enables us to align our research and teaching with real issues. The student experience is significantly enhanced from this exposure, resulting in high levels of recruitment opportunities for our graduates.

THE UNIVERSITY OF BIRMINGHAM HAS RAN THE MSC IN PHYSICS AND TECHNOLOGY OF NUCLEAR REACTORS FOR MORE THAN 50 YEARS. UP TO 40 STUDENT GRADUATE FROM THIS COURSE PER YEAR; 90% OF THEM GO ON TO WORK IN THE NUCLEAR SECTOR OR COMPLETE PHDS IN RELATED TOPICS

Seeking to develop future engineers that are equipped to meet the demands of future energy challenges we have developed a leading portfolio of courses, which include:

UNDERGRADUATE COURSES

- MEng: Nuclear Engineering
- BSc: Nuclear Science and Materials

NUCLEAR/RADIATION TAUGHT POSTGRADUATE COURSES

- MSc: Physics and Technology of Nuclear Reactors Masters
- MSc: Nuclear Decommissioning and Waste Management

CONTACT US

To learn more about the detail and impact of our research:

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