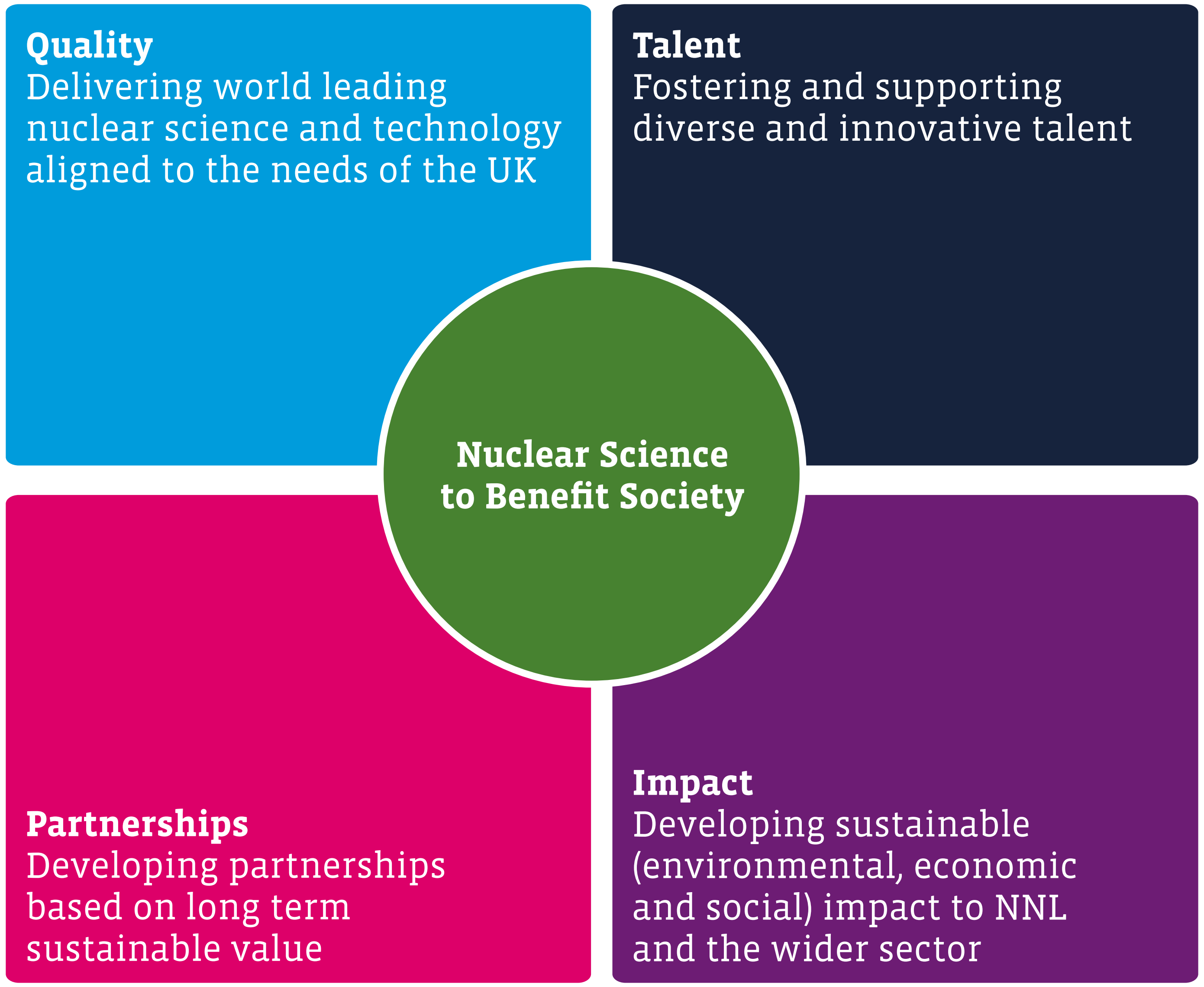
NATIONAL NUCLEAR LABORATORY

Science and Technology Agenda

Case Study Series

2022-23

NNL S&T Agenda Value Framework



Science and technology is, and always has been, the beating heart of NNL.

It is brilliant to be able to share the second case study series of our Science and Technology Agenda. Through our Agenda we invest in scientific research and unleash innovation building capability for the UK. This investment is a key part of our work as a national laboratory; allowing us to serve our customers, our partners and our nation better, and play our part in positioning the UK as a global leader in nuclear technology.

Our Science and Technology Agenda is defined by three key pillars – **Core Science, Innovation and Strategic Research** – all of which are underpinned by Collaboration. Within this publication we have selected case studies that showcase the breadth of work undertaken under the pillars over the past twelve months.

In each case study we describe the value generated against our Science and Technology Value Framework: Quality, Talent, Partnerships and Impact. It's exciting to share these case studies and the value we are delivering in partnership with a range of national and international stakeholders from across academia, industry and government.

Dr Fiona Rayment
NNL Chief Science and Technology Officer (CSTO)

Dr Paul Nevitt
NNL Science and Technology Director

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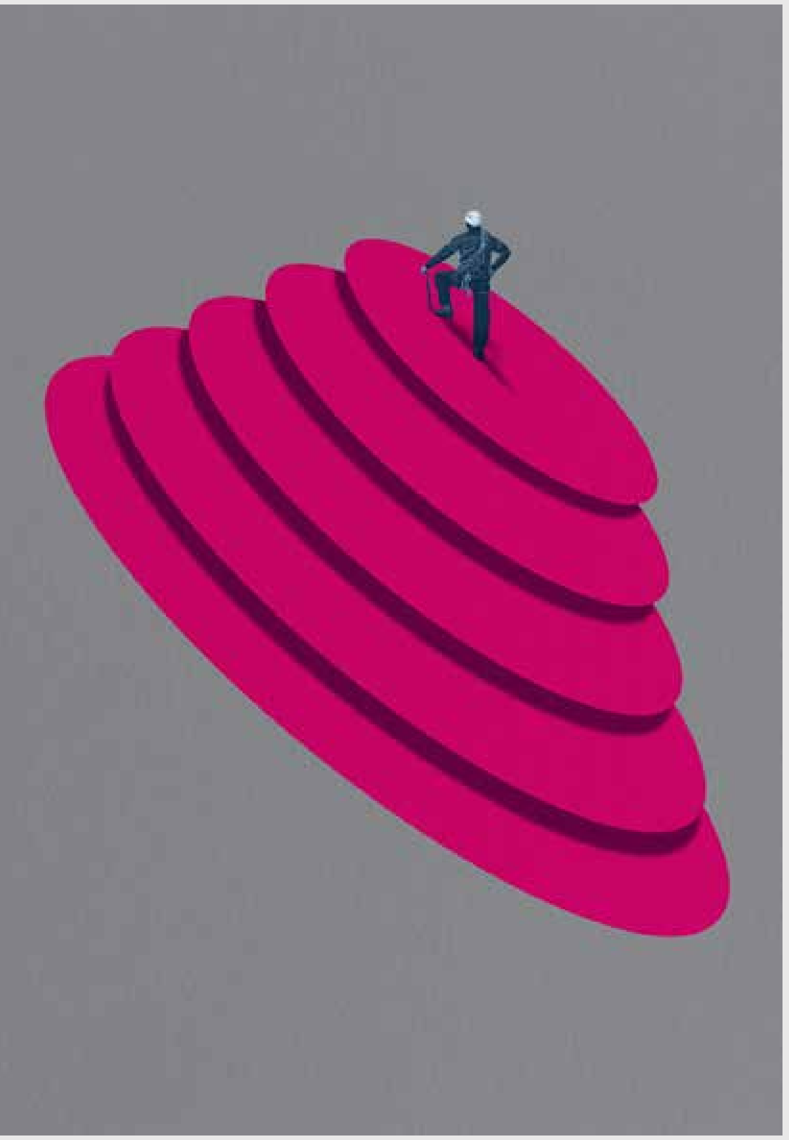
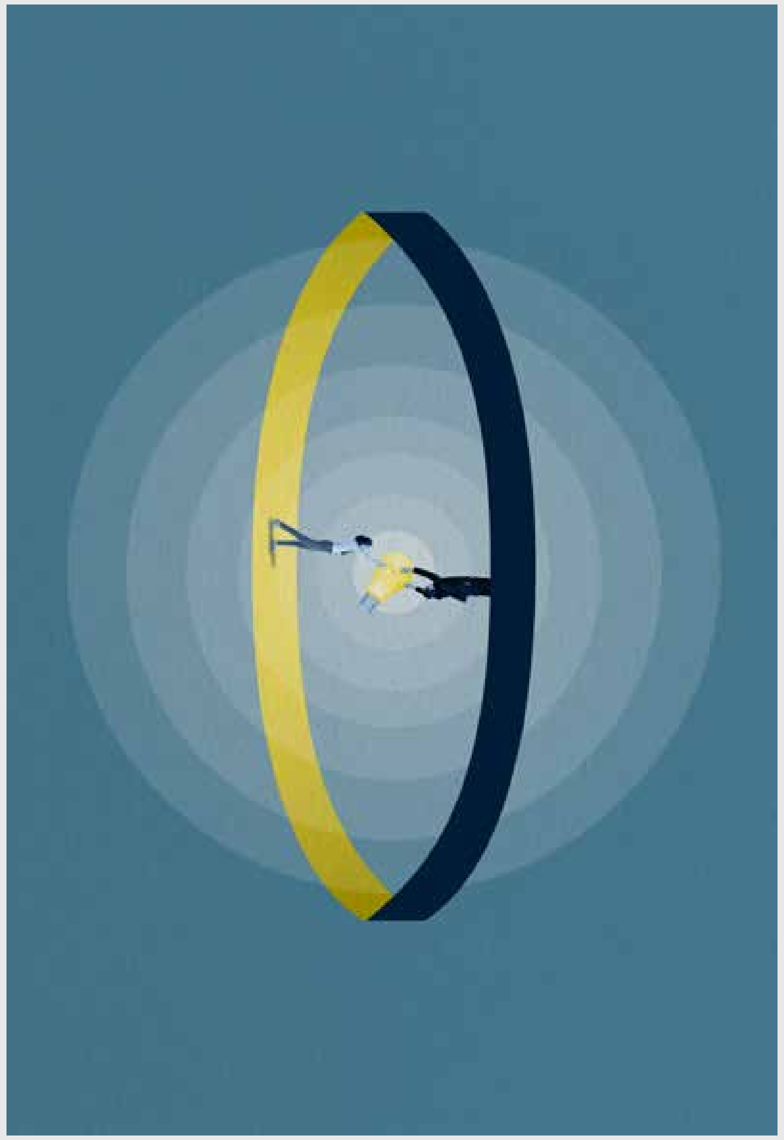
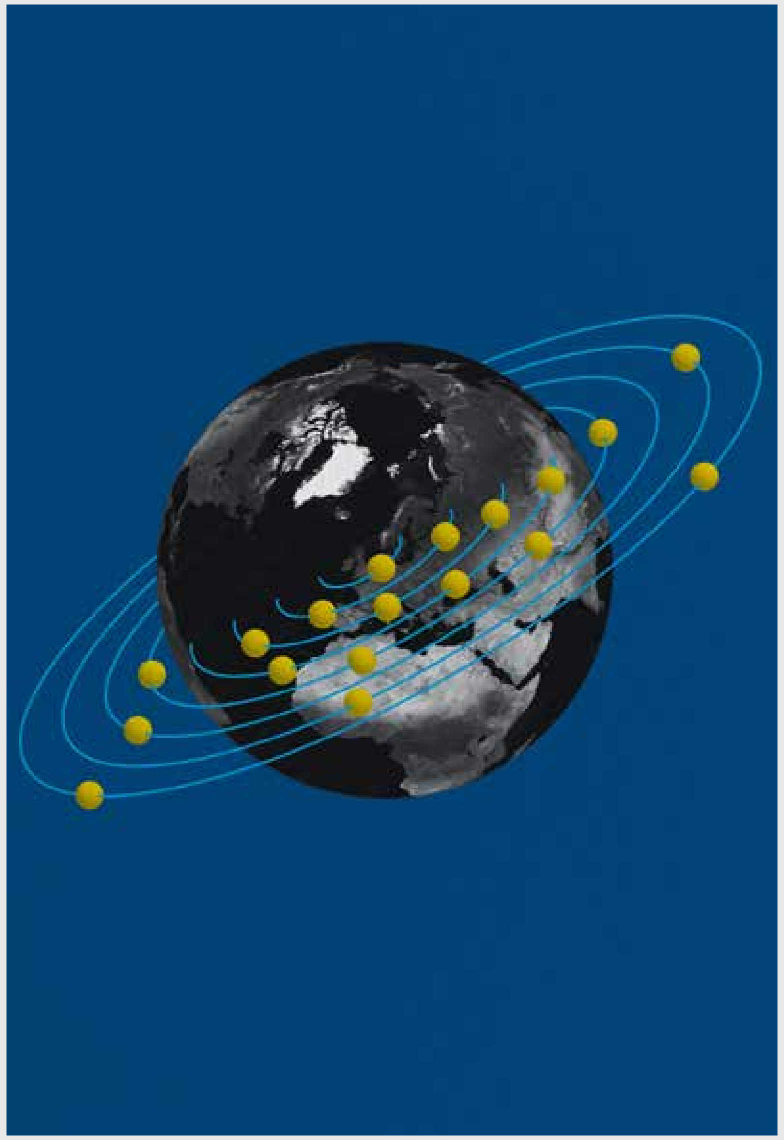
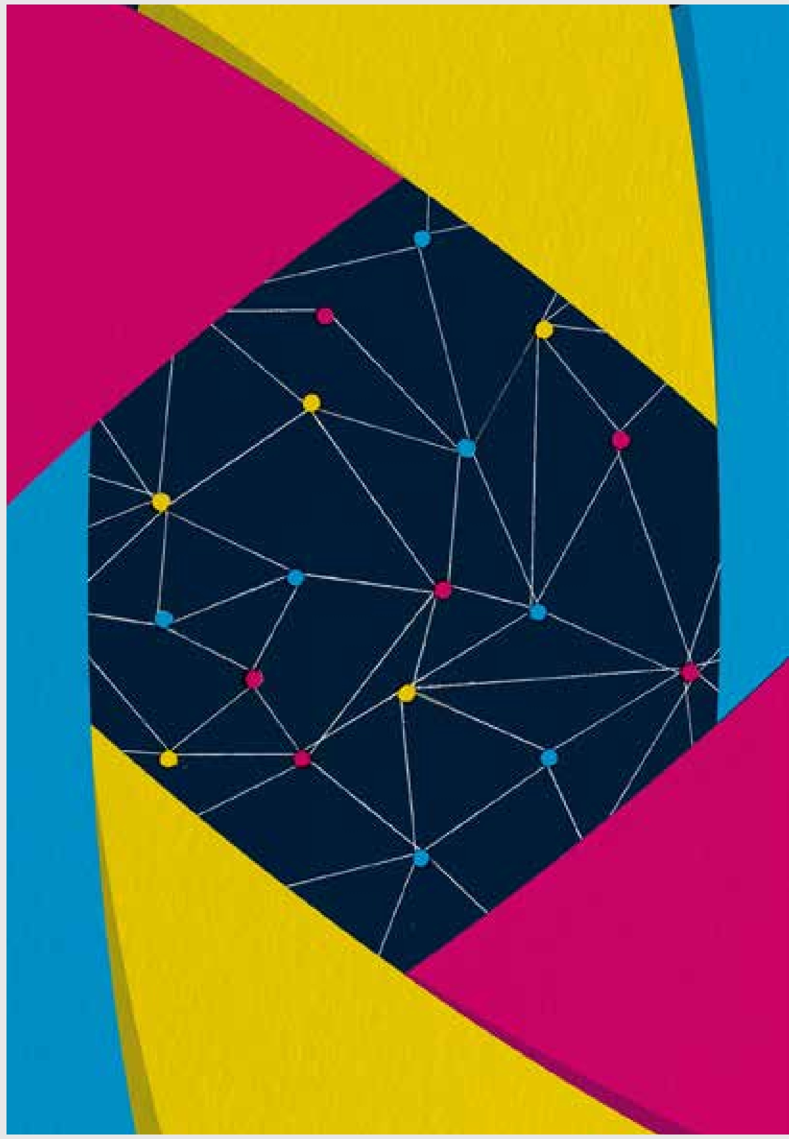





01 | Core science

Enabling **safe and efficient** operation of existing and future nuclear reactors.

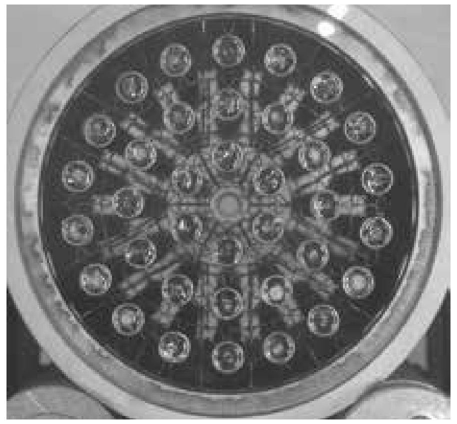
Irradiated Fuel Characterisation (IFC) is critical to the safe operation of our current fleet of nuclear reactors in the UK and a generation of new types of reactor set to begin feeding power into the grid in the 2030s.

Understanding how nuclear fuel behaves in a reactor is essential to ensuring that the operator can use the fuel safely and to maximum efficiency. Examination of irradiated fuel also gives us important insights into how spent fuel that leaves the reactor behaves under storage and how it can be securely disposed. Significantly, our work allows reactor operators and spent fuel stores to demonstrate compliance with reactor safety cases.

"Being aware of and able to predict the behaviour of spent fuels is vital to ensuring that irradiated fuel is stored and disposed of in ways that are effective and efficient. NNL's work in this area is particularly important at the moment as we look to deliver reliable and resilient options for managing spent fuels from Small Modular Reactors. Without our ongoing IFC work, it would not be possible to use nuclear fuel for energy generation in the UK and dispose of spent fuel in ways we know are safe and environmentally sustainable."

David Hambley
Fellow for
Spent Fuel at NNL

The majority of our IFC work takes place in a heavily shielded hot cell facility at NNL's Windscale Laboratory. Windscale is the UK's only facility capable of examining large quantities of irradiated fuel. The facility is run by a host of highly-skilled nuclear specialists, from scientists and technicians to engineers, fitters and electricians, with specialised techniques for handling and analysing highly radioactive irradiated fuel.



A complete element of AGR fuel. NNL conducts examination of these elements in station ponds and at Windscale to provide assurance that fuel is behaving as it should be.

Impact

Sharing science and maximising investment

Windscale receives fuel for examination from across the current fleet of reactors in the UK. Over the past decades, our scientists have been responsible for examining many thousands of nuclear fuel rods thus enabling safe generation of electricity in the UK.

Building on this legacy, work has begun this year to develop a library of irradiated fuels required for future research programmes. These fuel samples are to be linked to a database of records identifying each material, how it was manufactured and the irradiation conditions it has experienced.

Often our scientists at NNL, and our partners in industry and academia, are looking to conduct an experiment on a specific type of fuel, for example fuel that has experienced water ingress during irradiation or storage. Supported by this database, we will be able to identify useful material from within the library.

Not only does this ensure we are making best use of existing materials but, for our partners in particular, it drastically reduces their potential costs and permits work that otherwise would not be feasible. Without access to this resource, we would have to commission a programme specifically to produce fuel with the desired properties.

In the year ahead, our scientists will be making use of material in the fuel library to perform studies on high burnup structure – a feature that develops in nuclear fuel as fission products accumulate. Examining high burnup structure is important because it can affect basic properties of the fuel, such as how the fuel might fragment if released from the fuel clad. Knowledge of these properties allows us to predict how the fuel will behave, and ensure we keep the fuel within a safe operating envelope. The work expands on investigations, published by our scientists in the last year, which combined examination of high burnup structure with computer modelling of fuel behaviour.

As part of this work, we will be:

Examining a segment of Uranium Oxide base fuel using the Focused Ion Beam (FIB) technique. This technique involves focusing a high energy beam of ions which allows us to remove small sections of material so that we can analyse the inside of the material rather than the surface alone. Supporting methods also permit analysis of the composition of the structure.

Identifying a section of fuel of a contrasting fuel type, from the library, for comparison with the Uranium Oxide sample.

Spent nuclear fuel is to be held in carefully controlled storage ponds for many decades, until final geological disposal. NNL's work secures our understanding of how fuel will behave in such conditions, underpinning the decisions on how to manage fuel.

Quality

Providing a world-leading understanding of fission gas mechanics

Nuclear fuel rods consist of ceramic pellets of uranium dioxide contained in a metal alloy rod that is filled with helium. When uranium fissions it splits into two atoms, a substantial proportion of which are the noble gases xenon and krypton. As a result of their insolubility, these gases may diffuse out of the pellet matrix and grow as a fraction of the original helium fill gas, causing the pressure of the fuel rod to rise. If this pressure were to become too high, it could lead to a failure of the fuel clad – the outer jacket of the rod – resulting in radioactive fission products being released into the coolant of the reactor.

Understanding fission gas behaviour plays a key role in assuring the safe operation of fuel in both normal and off-normal reactor conditions. As part of this area of work, we have published an overview of techniques for analysing fission gas in irradiated fuel rods. This includes recommendations on how best to extract fission gas from a fuel rod and measure the internal pressure of the rod, and how to analyse the composition of the sampled gas.

Fission gas analysis has been a field of interest at NNL for many years and is one in which we have built significant expertise. Through our knowledge of fission gas mechanics, we are able to help reactor operators make informed decisions on the conditions a certain fuel is experiencing. Our work has also supported the development of the ENIGMA fuel performance code which is used for modelling and predicting the behaviour of fuel in a reactor.

"Nuclear fuel and reactor designs continue to evolve, both to improve safety and to better serve the need for a low carbon economy. The work performed by NNL on irradiated fuel ensures that the UK continues to hold a sovereign capability for assuring the safe operation of these new fuel designs.

Our expertise and facilities to provide this capability have been developed over more than four decades and are strongly aligned to our nation's current fuel needs. Our work in IFC ensures we can develop these assets further to be ready for the next four decades and beyond."

Dr Matthew Barker
Fellow for Post Irradiation Examination at NNL

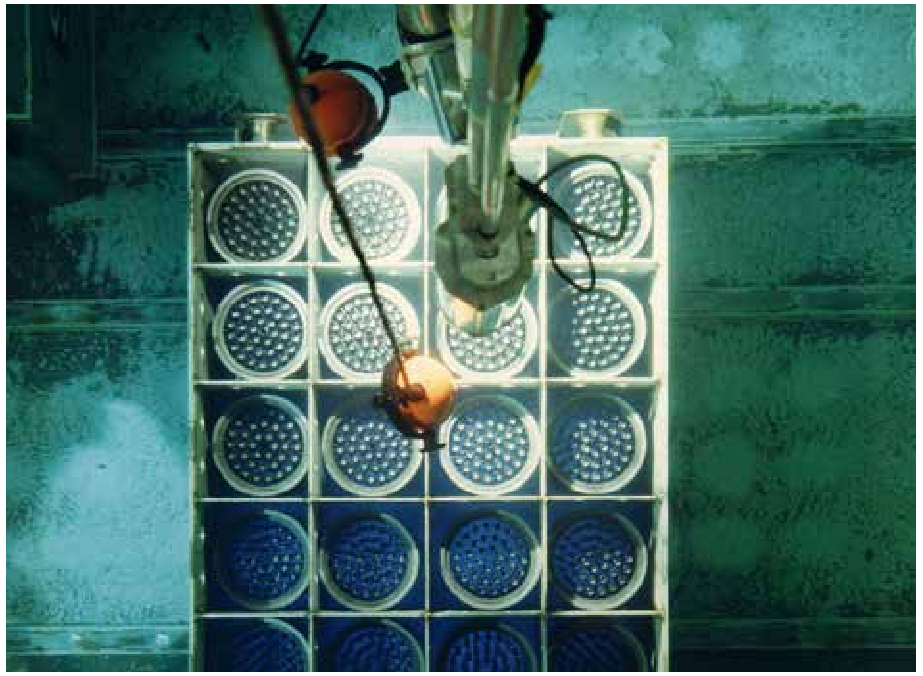
Talent

Developing the UK's next generation of materials scientists

IFC is a key area in which we engage with UK academia and our nation's next generation of materials scientists. Led by NNL Fellows Matthew Barker and David Hambley, our IFC research programme is made up of 12 scientists in the first few years of a career with us and a similar number of mid-career scientists.

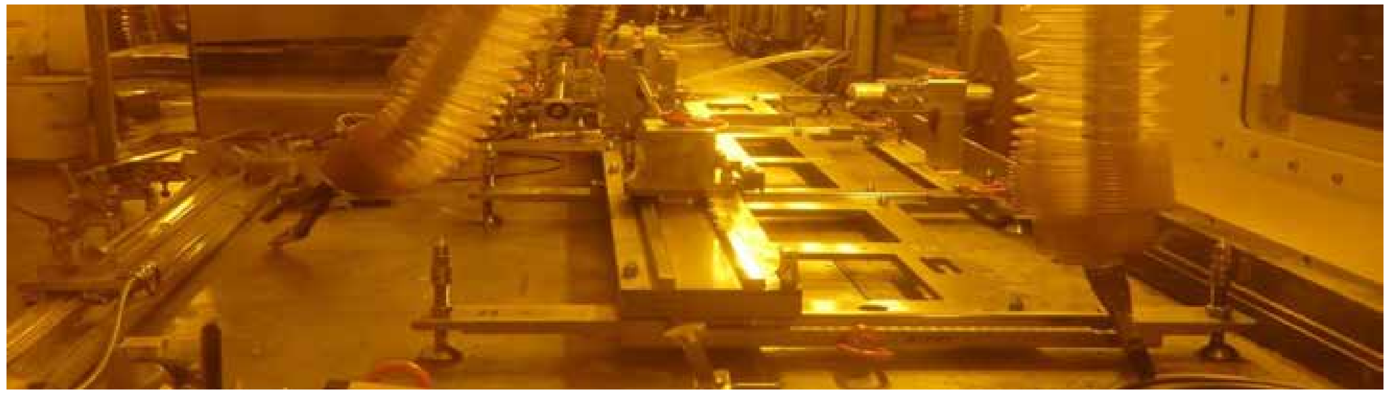
The team is closely linked to, and supports a broader capability of, over 100 scientists and technicians at NNL who are working on investigations of irradiated fuel for a range of customers and partners. These include EDF, Sellafield Ltd, the Nuclear Decommissioning Authority (NDA), Nuclear Waste Services (NWS) and Rolls-Royce.

The programme also enables PhD researchers to develop their nuclear skills through access to the irradiated fuels capabilities we uniquely offer.



Examination of fuel in a station pond demonstrating the range of techniques NNL can apply to examine irradiated fuel.

Examination of irradiated fuel takes place inside hot-cells consisting of concrete walls and lead-glass windows over a metre thick. Equipment is operated using remote manipulators and a great deal of skill.



Partnerships

Sharing best practice with partners in the UK and globally

NNL has a long and proud history of working with our partners in industry. These partnerships, including with EDF, Sellafield Ltd, the NDA, NWS and Rolls-Royce, have been instrumental in developing skills and capability within our laboratories at NNL.

IFC is a programme that benefits directly from the workstreams being pursued by our partners and customers and likewise significantly contributes to them.

Extending our expertise in IFC beyond the UK, NNL is working closely with the International Atomic Energy Agency on a variety of projects related to the management of spent fuel and the establishment of best practices.

In recent years, we have delivered a project with the IAEA to better understand how fuel behaves in reactor accidents. Using historical understanding and scientific data from events in Three Mile Island, Chernobyl and Fukushima, we chaired a collaborative research project to collate information on the three incidents, the technologies available for the retrieval and characterisation of the debris, and how to best characterise debris itself.

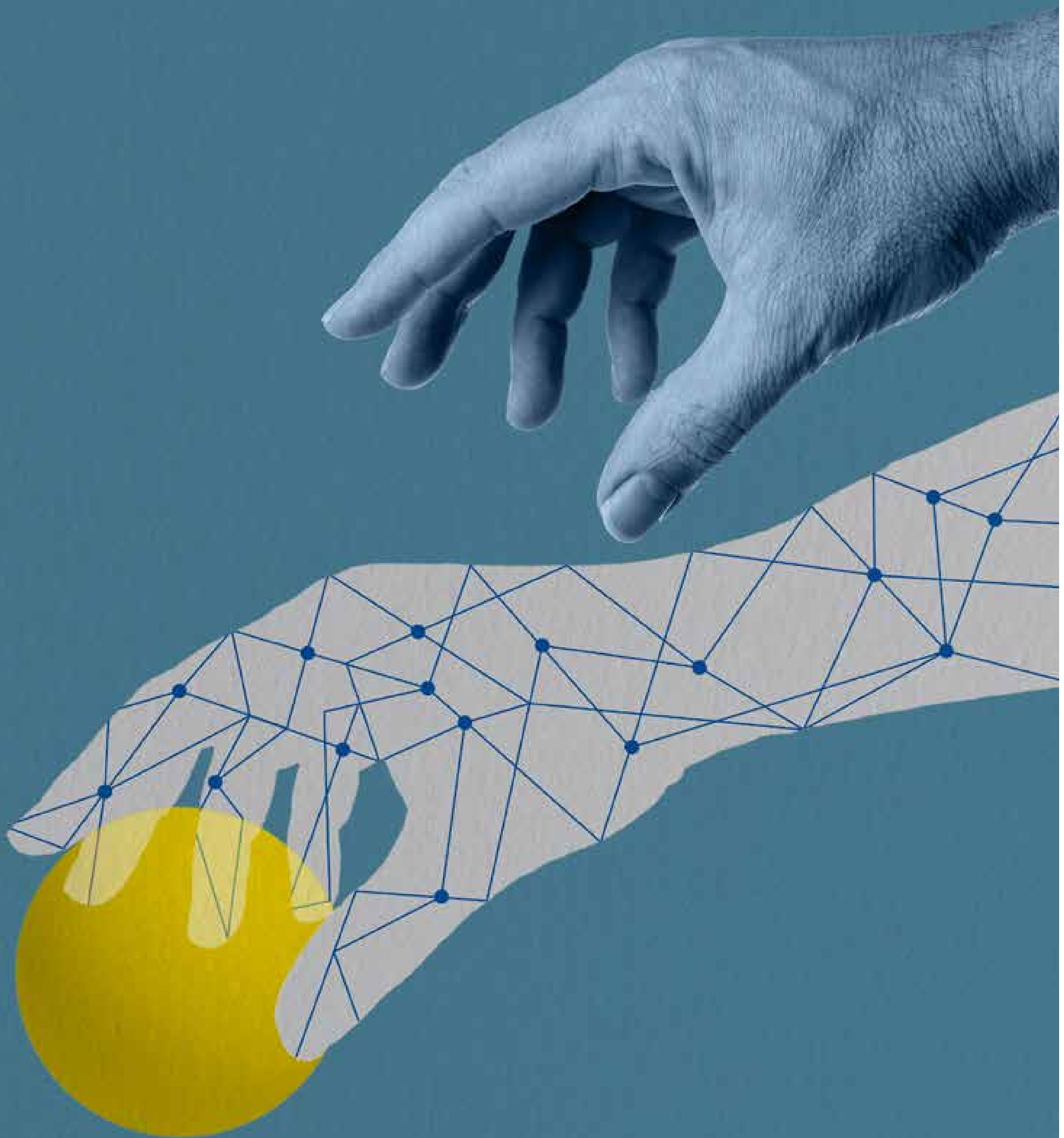
Off the back of this collaboration, our scientists are now working with international partners as part of a joint OECD-Nuclear Energy Agency project to help improve the characterisation of fuel debris at Fukushima specifically. This data can subsequently be used to enhance understanding of how the incident progressed to further strengthen reactor safety.

NNL has also been designated as the UK's first IAEA Collaborating Centre on the Advanced Fuel Cycle – the first of its kind anywhere in the world. The Centre is making an essential contribution to realising the vital role advanced nuclear technologies play in achieving net zero carbon emissions by 2050, whilst supporting the development of the next generation of global experts.

> "Maintaining understanding of the behaviour of the fuel during operation is of vital importance to the safe operation of EDF Energy's fleet of AGR reactors. Post-irradiation examination of AGR fuel is a key aspect of maintaining this understanding, and Windscale Laboratory is the only facility with this capability in the UK.
>
> The capability and expertise held at the Windscale facility has been essential to support the operation of the UK's 14 AGR reactors throughout their history. Information obtained on the fuel condition has been crucial to underpin EDF Energy's reactor operations, as well as informing improvements to operational regimes to improve safety and reliability. The facility has also developed bespoke solutions to complex issues arising with the downstream management of irradiated fuel, and is the only facility in the UK with the capability to meet EDF Energy's needs in this area."
>
> **Nick Wright**
> Fuel Engineer,
> EDF Energy

02 | Innovation

Using Artificial Intelligence
to deliver **ground-breaking science.**



At present, applications of Artificial Intelligence (AI) in the nuclear sector include robotics elements used in nuclear decommissioning as well as in day-to-day operations on nuclear sites. However, as a sector, we have only scratched the surface of its potential use and there remain many avenues where AI could have a transformative impact.

As we continue to innovate, we also need to make sure we consider how we can implement emerging AI advancements both efficiently and safely.

To support this, NNL is working closely with the Office for Nuclear Regulation (ONR) to foster conversations around how the sector can and should regulate the use of AI, both now and for the future. Representing NNL, Brendan Perry and Senior Technology Manager Gary Bolton sit on the ONR's expert panel for Artificial Intelligence. NNL is also represented in UKRI's artificial intelligence for nuclear (AI4N) group, established in 2022 to support the adoption of AI across the nuclear sector.

"Over the coming decades, AI is going to completely reshape the nuclear industry – as it will many other industries. At NNL, we are working with partners both in the UK and globally to explore how we can develop the use of AI and employ it to best effect, complementing the knowledge and work of human operators that are critical to the sector's success."

Brendan Perry
Technology Manager at NNL

Quality

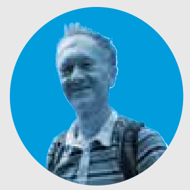
Employing AI from Silicon Valley to Sellafield

Fully functioning ventilation systems are critical to the secure and effective operation of facilities across many industries, including nuclear, manufacturing, pharma and shipping. In the UK, it is a legal requirement for ventilation systems to be regularly inspected to make sure any defects, such as perforations or loose flanges, are quickly identified. Typically, this is done via visual inspection or by using ultrasonic thickness detection. However these both involve significant cost and time and, if carried out manually, exposure to ventilation hazards.

In 2022, NNL launched an open innovation challenge to find a digital solution that would be able to conduct remote and continuous inspections. Co-funded by Safetytech Accelerator and NNL, the resulting pilot was a collaboration between NNL, Sellafield and Reality AI, a US-based SME.

At NNL's Workington Laboratory, the team constructed a test rig made of square steel ducts and a powered air filter. This in turn was connected to a series of microphones, exciters (sound creators) and a data collection device. From this, 96 acoustic samples of the ventilation in a variety of normal and defective states were collected and put through the Reality AI platform. This pilot solution was able to successfully detect a defect in the test rig within one second at almost 98% accuracy.

"Tapping into NNL expertise in designing, building and operating experimental rigs at their facilities in Cumbria once again demonstrates the strength of the collaborative relationship between Sellafield Ltd and NNL. NNL is a conduit for innovation into the UK nuclear sector, enabling innovative technologies from SMEs such as Reality AI to be developed into impactful solutions for Sellafield and beyond. We look forward to building on the excellent work undertaken in this pilot and in supporting the project towards a real-world deployment of this novel application of AI."



Andy Cooney
Innovation lead
at Sellafield

Partnerships

Sharing our pioneering robotics facilities

The National Nuclear User Facility for Hot Robotics (NNUF-HR) supports UK academia and industry to deliver ground-breaking research in robotics and AI. NNL's Workington Laboratory is home to one of four NNUF-HR facilities across the country.

With a range of full-scale industrial equipment and flexible floorspace it allows academics, SMEs and industry to develop, test, and demonstrate new and innovative robotic solutions for the nuclear industry. Importantly, having access to this shared facility means that researchers can hire the equipment they need for the length of their project, rather than invest significant sums of their own capital to purchase what is needed needed, and at the same time benefit from the knowledge and insights of our experts at NNL.

The research team from the University of Manchester at NNL's NNUF-HR.

Talent

Collaborating with academia to enable first-of-its-kind robot-human interaction

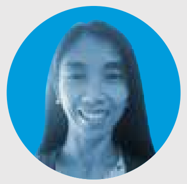
In 2022, a team of researchers from the University of Manchester were given access to Kinova Gen3 collaborative robots at Workington Laboratory. Supported by the team at NNL, the researchers used AI in several novel ways.

Firstly, they developed a Natural Language Processing (NLP) system to convert verbal instructions into commands that the robot can understand, enabling a level of human-robot interaction which did not previously exist in the nuclear sector. Alongside this, they developed a Computer Vision system which allows the robot to identify different objects in a variety of colours and shapes and their position relative to one another. The resulting system can take a verbal command, understand how this relates to the objects in front of it and implement the required action.

This project has opened up several new research paths, including further work into how we can use NLP to deploy robots in more challenging nuclear environments – helping to improve both efficiency and safety.

Building on this collaboration, NNL and the University of Manchester will continue to work closely throughout 2023 to deliver LISTENER – a collaborative project which seeks to use AI technology to better analyse health and safety data for Sellafield Ltd.

"We are grateful for having been given access to the NNUF Hot Robotics facility at Workington Laboratory. It was a really unique opportunity for us to test our research. Likewise, the support the team at NNL gave us – from guidance on system configuration and troubleshooting to other expert advice – was invaluable and enabled us to complete our experiment successfully."



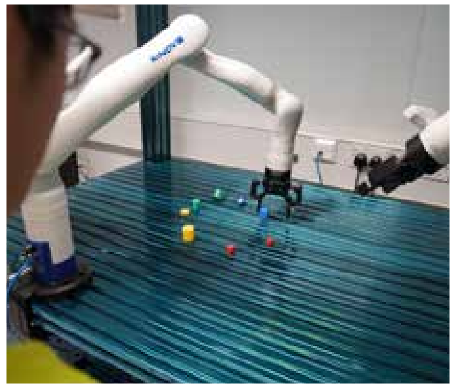
Dr Riza Batista-Navarro
Lecturer in Text Mining at the University of Manchester

Impact

Cutting-edge digital solutions to keep UK industry ahead of the curve

Through our work in this area, we are:

- **Delivering an AI-based solution to transform a critical industrial process for the benefit of UK industry as a whole;**
- **Engaging in open innovation to share our learnings from decades of work in the sector and, at the same time, benefit from the knowledge of AI experts from outside the sector;**
- **Building successful working relationships with partners in the UK and around the globe;**
- **Helping to ensure there are robust and effective processes in place to regulate the use of AI in the sector, particularly as we look to innovate for the future;**
- **Ensuring UK nuclear will benefit from pioneering developments enabled by AI, specifically the streamlining and safeguarding of day-to-day processes.**



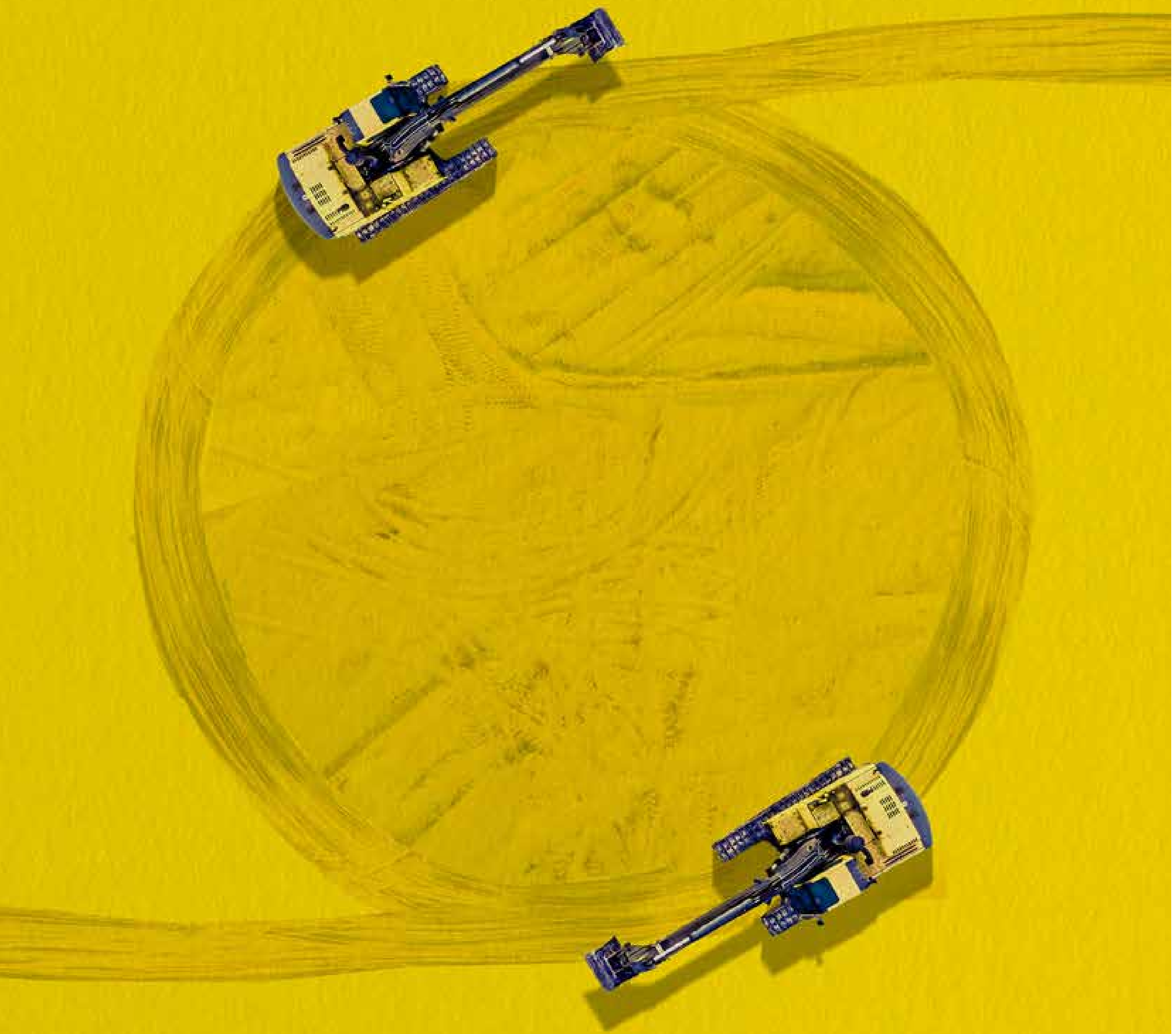
"Across the nuclear industry, experts are consistently looking at ways to integrate new and emerging digital technologies in nuclear operations – whether it's to improve the efficiency of certain processes or to enhance safeguards for human operators even further. As part of this work, at NNL we have set up a Digital Community of Practice to connect digitally-minded individuals across the organisation.

This community is a way for us to collectively discuss developments taking place across the digital landscape and for our teams to share best practice. Whether through our capabilities in robotics, AI or modelling and simulation, NNL has a proud history of delivering impactful digital solutions for the nuclear industry. It is an exciting strand of work we are looking forward to building on for the future."

Naomi Rutledge
Junior Mechanical Engineer at NNL and Chair of the Digital Community of Practice

03 | Innovation

Developing novel encapsulation formulations for a **sustainable future.**



As part of NNL's environmental restoration work, we have been investing in innovation to find sustainable alternatives to existing encapsulation formulations. This has led to a promising collaboration with Clobury Quarry Ltd, which presents an exciting opportunity not just within the nuclear sector but also beyond.

As the UK and others across the world urgently address the climate crisis, the landscape within which industries and businesses operate is evolving. Changes are being made to the way we do things to drastically reduce carbon emissions.

The UK's commitment to end the use of coal power for energy by October 2024 represents a significant step towards decarbonisation, with the phase out of coal-fired power stations now nearly complete. But the ripple effects of this also need to be addressed, such as the loss of our UK production supply of fly ash, which is most commonly derived from coal combustion.

Fly ash and Ground Granulated Blast-furnace Slag (GGBS), which is also in diminishing supply given the national and global reconfigurations in the iron and steel industry, have been key components of the cement formulations we use to encapsulate and store the UK's legacy nuclear waste on behalf of the Nuclear Decommissioning Authority (NDA), in particular Sellafield Ltd. This needs to be done safely, securely and cost-effectively for the taxpayer.

Quality

Maintaining the highest standards as we adapt and innovate

Within the UK nuclear sector, we have stringent standards across everything we do to ensure that safety for workers and the public is unquestionable. This includes the management, encapsulation and disposal of used nuclear materials. The highest quality assurance for encapsulation materials is therefore needed in order to provide products of known and predictable quality.

Currently, we rely on a high-grade mix of cement and either fly ash or GGBS. This goes beyond the robust weight-bearing formulation of concrete used by other industries and gives it the special characteristics and reliability of performance that the UK nuclear regulatory bodies demand. In identifying a new sustainable encapsulation solution, therefore, we need to satisfy these same high standards, whilst continuing to deliver efficiently for our end customers.

To meet the challenge, NNL put out a call as part of our Open Innovation programme. This asked potential collaborators to help us identify a replacement for fly ash that will retain all the existing qualities, standards and reliability of our current cement configuration.

Cloburn Quarry Company Ltd were one of the winning applicants for this work. It proposed the testing of Red Granite Dust (RGD) powder – a by-product of its rock processing activities – as an alternative material to traditional fly ash or GGBS. The powder has a chemical oxide composition similar to that of the fly ash specification for concrete and had been judged by the University of Sheffield's Chemical Engineering: Sustainable Materials and Processes Department as having the desirable qualities for further testing.

Cloburn Quarry were already looking to identify a viable long-term outlet for RGD that would have use, value and benefit to society, rather than requiring disposal. With 20,000 tonnes each year available for supply, this offers a viable long-term solution with the additional benefit of being a low-carbon footprint product across its whole life-cycle.

Our immediate focus has therefore been to progress the RGD powder from its current Technology Readiness Level of 3 to 4 for the proposed application of nuclear waste encapsulation, as a direct replacement of fly ash. This work has involved further testing to ensure the material generated by the quarry – which is initially wet – can be efficiently dried to powder form whilst retaining its low-carbon footprint properties.

Testing has proved promising so far. Once complete, the next stage of this process will be to scale up this formulation of this RGD-based conventional concrete mix and prove it at a large scale, with a view to successful implementation. Dependent on disposability acceptance by Nuclear Waste Services (NWS), and RGD being adopted by one of the UK's waste producers, this needs to be achieved within the next few years before fly ash is no longer available.

However, the RGD powder also presents a further, more pioneering opportunity. The properties of the material is such that it may prove to be a cement substitute, creating a material with the same strong qualities but with a low-carbon footprint.

Impact

Exploring sustainable solutions with far-reaching potential

This collaboration with Cloburn Quarry offers both environmental benefits and sustainability of supply for the UK. In the short term, RGD powder looks to present an almost immediate alternative to fly ash or GGBS. But the opportunity for RGD to form the basis of a novel encapsulation material would have even greater impact.

The production of cement is a highly intensive carbon generating process, yet it is a cornerstone of so many areas of our lives and industries. There is already wider work underway across the UK and globally to explore alternatives that reduce the environmental impact of conventional methods without losing the core properties of cement.

Given the scale of Cloburn Quarry's RGD supply, the nuclear sector would be a relatively niche market, should it implement either the new RGD-based conventional blended cement or novel material for nuclear waste encapsulation. However, by delivering on this research and development and proof of concept, this work will provide stronger foundations for its potential uses beyond nuclear.

For NNL, this fits within our remit as a national laboratory – not only driving innovation, skills and capabilities but benefiting society through nuclear science.

Talent

Sustaining and building UK skills and capabilities

At NNL, our world-leading expertise has been developed over decades, with environmental restoration acting as the proving ground for many of these skills and capabilities. This continues to be the case and helps us grow the next generation of nuclear specialists.

Innovation in novel encapsulation methods is the focus of a number of NNL's PhD and research programmes, allowing students and early career professionals to develop expertise in strategically important areas for the UK whilst delivering ongoing efficiencies for our customers. Longer-term programmes of research and development – such as exploring the viability of novel materials for the treatment of nuclear waste – also increase the likelihood of employees becoming Subject Matter Experts.

Partnerships

Leveraging collaboration to advance new techniques

This work is wholly underpinned by collaboration; working with another company, in another sector, to identify a solution that has a myriad of potential benefits for the UK's circular economy.

To progress this, partnership working with the University of Sheffield in particular has been vital. Harnessing NNL's world-leading specialist nuclear facilities and capabilities, we have been able to collaborate with academics to provide the fundamental underpinnings for further research and development.

As we seek to move new techniques and technologies up the Technology Readiness Level scale, it is this collaboration across academia and industry that is essential, and where national laboratories like ourselves are ideally placed to help bridge the gap.

04 | Strategic Research

Building on our **global partnerships** to accelerate the future integrated energy system.

In January 2022, as a legacy for the UK's presidency of COP26, NNL convened the first ever global summit for national laboratories working on energy research.

This summit was driven by NNL's commitment to advancing an Integrated Energy Systems approach – one which encompasses all low-carbon technologies – to accelerate the worldwide transition to net zero.

The virtual summit was a starting point for long-term international collaboration, with each delegate organisation committing to ways they would play a part. The premise was simple: by working together, we can optimise resources and investment and support global decarbonisation efforts more effectively than if we were to act alone.

Since then, the Global National Laboratories Integrated Energy Systems (GNL-IES) collaboration has begun to deliver on its ambitions. From launching an impact paper setting key recommendations on Integrated Energy Systems at the 27th United Nations Climate Change Conference (COP27), to convening a second annual summit in the UK, the forum has established strong foundations from which to deliver future impact.

GLOBAL NATIONAL LABORATORIES ENERGY SUMMIT 23

Impact

Setting the parameters for collaboration

Given the scale of the decarbonisation challenge, the forum was set up in the knowledge that greater shared working across low-carbon technologies was required to deliver a successful, holistic, integrated energy approach. With eight national laboratories across five countries represented, the first stage of the forum's work was to set the direction of travel for their collaboration, identifying what would most deliver impact in the short and longer term.

This culminated in the launch of the forum's impact paper in November 2022. Drawing together each laboratory's relevant research, this paper not only highlighted the work already being undertaken but also set out key recommendations for advancing further Integrated Energy Systems research, development and demonstration (RD&D).

These recommendations were as follows:

- **A focus on nuclear-renewable hybrid systems, with storage and flexibility, supports the decarbonisation of an increasingly electrified energy system;**
- **Beyond electricity, broaden the consideration of energy vectors to include heat, hydrogen and synthetic fuel;**
- **Deepen engagement with end users to optimise the outputs from integrated energy solutions;**
- **Take an integrated approach at multiple spatial scales and ensure consistency between national strategies and local energy planning;**
- **Take an integrated approach at each stage of system deployment, from long term planning to operational control;**
- **Ensure the integration readiness of physical system components through development and demonstration;**
- **Facilitate the economic assessment of Integrated Energy Systems to inform business planning by future owner/operators.**

These recommendations have now set the parameters within which the forum and, through it, the partner organisations will look to work collaboratively over the coming years, identifying the greatest potential areas of impact.

On panel: Jonathan Cobb, World Nuclear Association; Martin Keller, National Renewable Energy Lab (US); Paul Nevitt, NNL; Paul Kearns, Argonne National Laboratory; Chair: James Murphy, NNL.

Quality

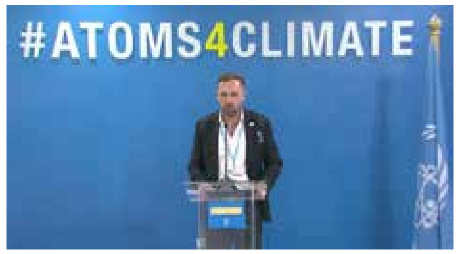
Raising our work on the global stage

The launch of the impact report was timed to coincide with COP27, which was hosted in Sharm el-Sheikh, Egypt. For NNL, we recognised this as a key opportunity not only to bring the role of nuclear to the fore within global climate discussions, but to emphasise its place as part of an Integrated Energy System. And, at a time of global energy market pressures and concerns around security of supply, this was of particular resonance.

As part of NNL's engagement in COP27, we therefore hosted a dedicated event on our international Integrated Energy Systems collaboration at the International Atomic Energy Agency (IAEA)'s Atoms4Climate Pavilion. Marking nearly a year since the initial summit, this event brought together several forum representatives – comprising both nuclear and non-nuclear national laboratories – to reflect on what the group had achieved since COP26. With the impact report providing a grounding to discussions, the panel highlighted the actions identified and once again emphasised the value of an integrated approach to the energy transition.

One of the key points of panel discussion – reflecting the impact paper – was the need to look beyond electricity if we are to achieve global decarbonisation. The event made clear the importance of broader energy vectors such as heat, hydrogen and synthetic fuel as we seek to address hard-to-decarbonise sectors, and the role of RD&D in accelerating technologies for this.

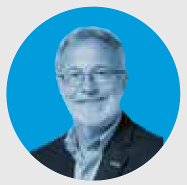
This intervention at COP27 was an important moment for raising the profile of an Integrated Energy System approach, emphasising the work of the forum and continuing the dialogue on the world stage.



NNL's Chief Strategy Officer, James Murphy, leads a panel discussion at the Atoms4Climate panel session in the IAEA pavilion at COP27

NNL at COP27 Conference (Egypt) - YouTube link

"Collaboration across laboratories and different countries is extremely important. We have historically not done too much work on the full systems integration because we had these pillars of energy use and now this is changing. Globally we are moving towards electrification but then we also have a lot of other areas of industry – like cement, steel and heavy-duty transportation – where we need to look at the whole systems approach. That's why I think this deep collaboration across borders, countries and the different laboratories is so critical."



Speaking at the COP27 panel, **Dr Martin Keller** Director, National Renewable Energy Laboratory (NREL)

NNL's Chief Science and Technology Officer, Dr Fiona Rayment at the Integrated Energy Systems Summit

Partnerships

Progressing key areas of collaboration

Following COP27, NNL was pleased to host the second annual summit in January 2023 – this time in person. National laboratories from the UK, US, Canada and France were all in attendance, with representatives from Japan joining for some virtual activities. With an additional exploratory visit to Tyseley Energy Park, meeting with the University of Birmingham and the Manufacturing Technology Centre, the second summit was an opportunity to agree an action plan for the year ahead.

In progressing the impact report's recommendations, actions agreed included the commitment to data and model sharing across countries and to engage further with end users of energy, particularly in hard-to-decarbonise sectors such as aviation and shipping. For the latter, the forum will be mapping out energy customers and identifying the laboratories interested in working with them, to allow a heat map of common interests to emerge. Another priority area of focus is around access to facilities, to ensure we make the most efficient use of specialist capabilities at our national laboratories around the world.

With a clear set of aims and tangible actions agreed for the coming year, we are now establishing working groups for delivering on the key areas of collaboration. The forum will continue to meet regularly to review progress of each working group and to maintain overall momentum.

Talent

Developing ongoing UK expertise and understanding

As we continue to develop the UK skills, research-base and relationships required for the future energy landscape, NNL announced our intention to create a UK Collaborating Centre on Integrated Energy Systems. This will act as a hub for partnership working and help to solidify links between academia, industry and other research partners to progress the RD&D the UK will need in the decades to come.

We have now set plans in place for the opening of this Collaborating Centre – which will be delivered in partnership with Energy Systems Catapult – later in 2023. Central to its mission will be developing talent, bringing in early careers researchers and modelers as well as partnering with universities for sponsored PhDs.

Summit attendees visiting Tyseley Energy Park

05 | Collaboration

Developing the next generation of experts through **innovative partnership.**

Established in 2016, the Centre for Innovative Nuclear Decommissioning (CINDe) is a pioneering PhD Hub set up by NNL in collaboration with Sellafield Ltd and based at Workington Laboratory.

CINDe is an essential component of how, at NNL, we are helping to strengthen the nuclear sector's talent pipeline and embracing fresh thinking to stay at the cutting edge of research and development. Significantly, CINDe gives researchers at our partner universities an opportunity to work closely with subject matter externs in out laboratories.

Together we provide meaningful solutions to current nuclear industry challenges, in support of our national decommissioning efforts.

Impact

Delivering real and sustainable innovation

Producing novel research that is leading to direct and on-the-ground innovation;

Contributed over £350,000 of new research and development infrastructure in West Cumbria to date;

Helping to reduce the cost of the UK's decommissioning work at Sellafield, as well as at nuclear licenced sites around the UK and internationally;

Attracting diverse and vibrant talent to the nuclear workforce, reflected in our win of the Nuclear Decommissioning Authority's (NDA) Best People Strategy Award 2022;

Offering a pathway for the UK's next generation of scientists and engineers to take up high-quality, high-skilled careers in the science and technology community;

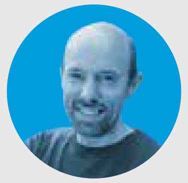
Working with local schools across the North West to engage children and young people in STEM.

Building on the success of CINDe so far, we will evolve the Hub over the coming year to involve a broader consortium of universities and, whilst decommissioning research will remain the primary focus of our researchers, to widen the scope of the Hub's work.

Partnerships

A unique partnership between industry and academia

"CINDe is great for research and for the researchers. Working together with NNL means that we are able to take our technology out of the lab and test it in the extreme and challenging environments encountered on nuclear sites such as Sellafield. The researchers themselves get exposure to the processes and practices of the nuclear industry, gaining industrial experience that is often missing on traditional PhD programmes."



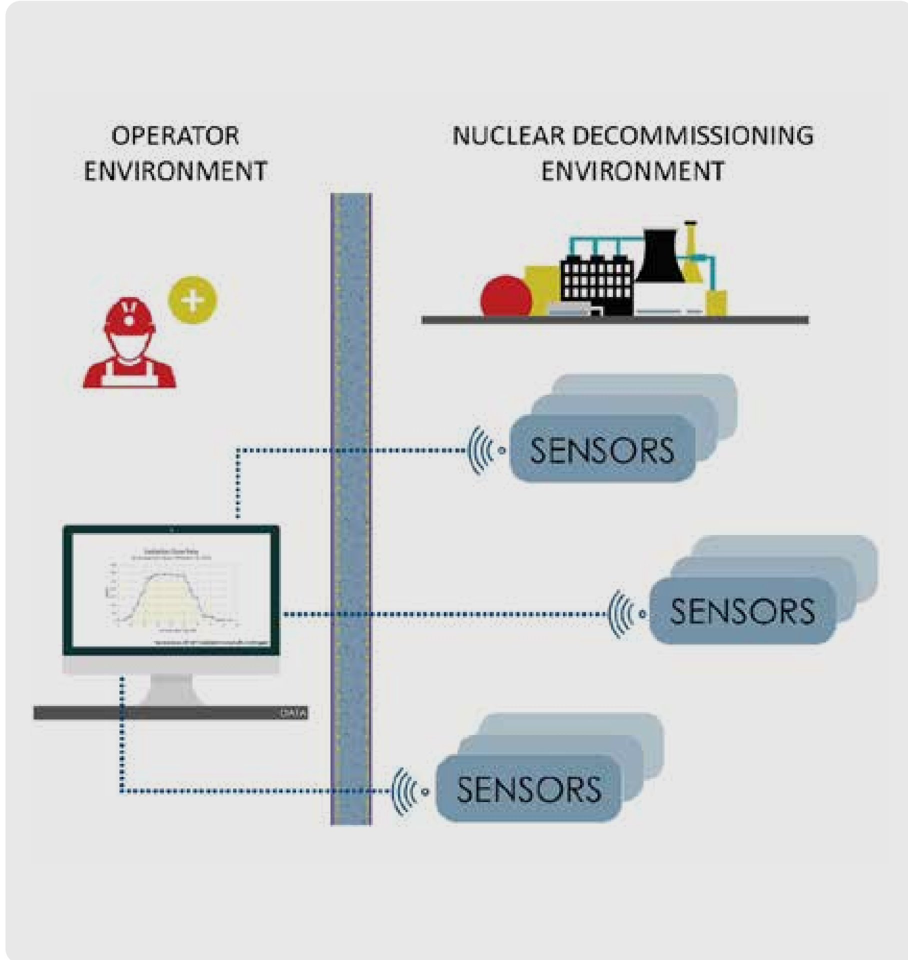
Professor Barry Lennox
The University of Manchester

To date, CINDe has welcomed 20 multi-national and multi-disciplinary researchers from across Lancaster University, the University of Liverpool and the University of Manchester. Based at NNL's Workington Laboratory, they carry out independent yet related projects that form the focal point of their PhDs throughout the four years of their studies.

As well as benefiting from the expert support of our teams at NNL, the researchers receive guidance from their university supervisors throughout their projects ensuring that their work is directly relevant to industry and meets robust academic standards.

"We have found CINDe really beneficial as it produces scientists who understand both the practical and technical challenges at nuclear sites such as Sellafield. This is reflected in the quality and value of the research that is produced and the number of researchers who then find jobs directly supporting our mission of environmental restoration."

Dr Katherine Eilbeck
Head of Technical Assurance and Governance, Sellafield Ltd.



Supporting wireless communications in nuclear decommissioning environments

Wireless Sensor Networks (WSN) are deployed across a wide range of sectors, including aerospace, agricultural science and consumer electronics, to monitor the physical conditions in their environment, such as temperature, humidity and pressure. Importantly, a WSN is scalable, flexible, reliable and does not require a human operator to access the ecosystem being monitored.

In the nuclear industry, there have been few deployments of WSN technologies for instrumentation and control due to the nature and composition of nuclear decommissioning environments. For example, the higher levels of radiation can damage the electronic equipment required and reinforced concrete wall structures commonly disrupt wireless signals.

During his time at CINDe, Antonio Di Buono, a PhD student from the University of Manchester – now a Research Technologist at NNL – carried out novel research to address this challenge.

Through his project, Antonio:

- **Designed a prototype system to remotely monitor the temperature of the Special Nuclear Material storage facility at Sellafield Ltd. in real time;**
- **Examined the behaviour of radio waves as they travel through nuclear decommissioning environments to help inform the design of an effective wireless transmitter;**
- **Explored the effect of radiation on commercial electronic components, confirming that some components are particularly sensitive to gamma radiation.**

The prototype Antonio created, as well as his wider research, are an essential step in the process to develop a WSN which can be deployed as a real industrial application at Sellafield Ltd.

Antonio Di Buono, Research Technologist, NNL

Quality

Providing the technical underpinning for our national decommissioning efforts

"The need for innovation within the nuclear and wider energy sector is greater than ever before as we work to create a clean environment for future generations and realise our national net zero ambitions. CINDe provides a unique solution to help meet this need and make sure we are continuing to push the frontiers of nuclear science.

Forming a critical link between academia and industry, CINDe is developing essential skills and experience in our next generation of nuclear scientists and researchers and, importantly, further strengthening the North West's reputation as a centre of innovation."

Lindsay Edmiston
Head of Capability for Waste Management and Decommissioning at NNL

Chris Cunliffe, Research Technologist, NNL

Improving essential Sellafield operations for future benefit

At Sellafield, one of the main priorities is the reprocessing of spent nuclear fuel. The site's Highly Active Liquid Evaporation and Storage department is responsible for safely managing and storing highly active liquid (HAL) waste – an output of reprocessing.

As Sellafield began its transition to Post Operational Clean Out operations and, with a desire to optimise the HAL transfer process, it became clear that we needed to build our understanding of how HAL flows and interacts when being transferred through partially-filled pipes at the site.

Whilst enrolled in CINDe, Chris Cunliffe, a PhD student from the University of Liverpool, carried out essential work to provide this understanding. His research ran in conjunction with existing NNL work, providing data that extended our knowledge of simulated HAL behaviours.

Significantly, Chris' project has directly influenced decisions made at Sellafield to help reduce the risk of pipe blockages and, importantly, to minimise the environmental and commercial costs of HAL transfers for the future. Alongside fellow CINDe graduate Antonio, Chris is now a Research Technologist at NNL.

Talent

Building the UK's nuclear skills pipeline

In total, 9 researchers have now completed their PhDs at CINDe, with a further 11 currently in place at the Hub.

To date, all the postgraduates who have completed the programme have gone on to start technical roles across the science and technology community. This has included at both NNL and Sellafield, as well as at top-tier companies that work in the nuclear supply chain, such as Jacobs, Orano, Mott-McDonald and WSP.

Below are some of our recent CINDe graduates and their destinations since completing the programme.

Chris Cunliffe
NNL

Jessica Hyde
WSP

Antonio Di Buono
NNL

Ed MacNeil
Sellafield Ltd

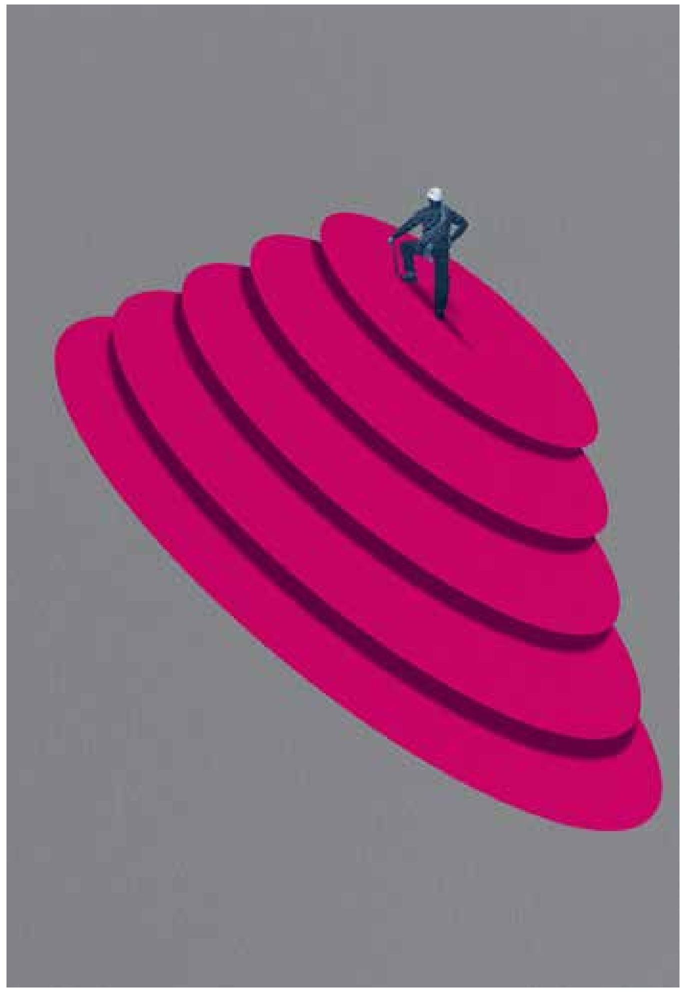
Kyriacos Hadjidemetriou
Orano

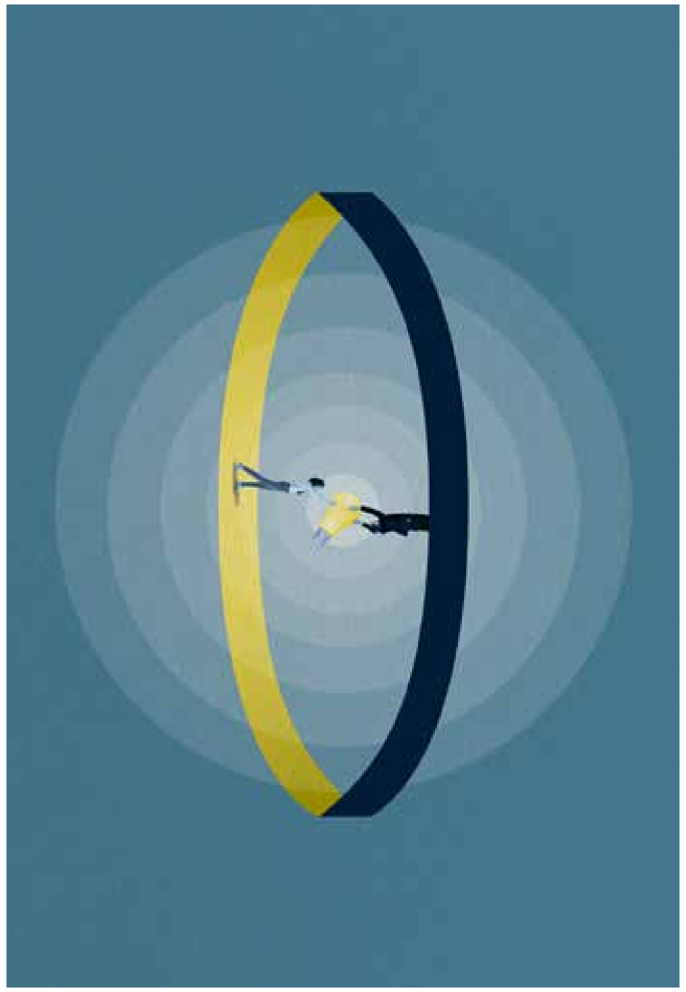
Tomas Fried
Siemens Energy

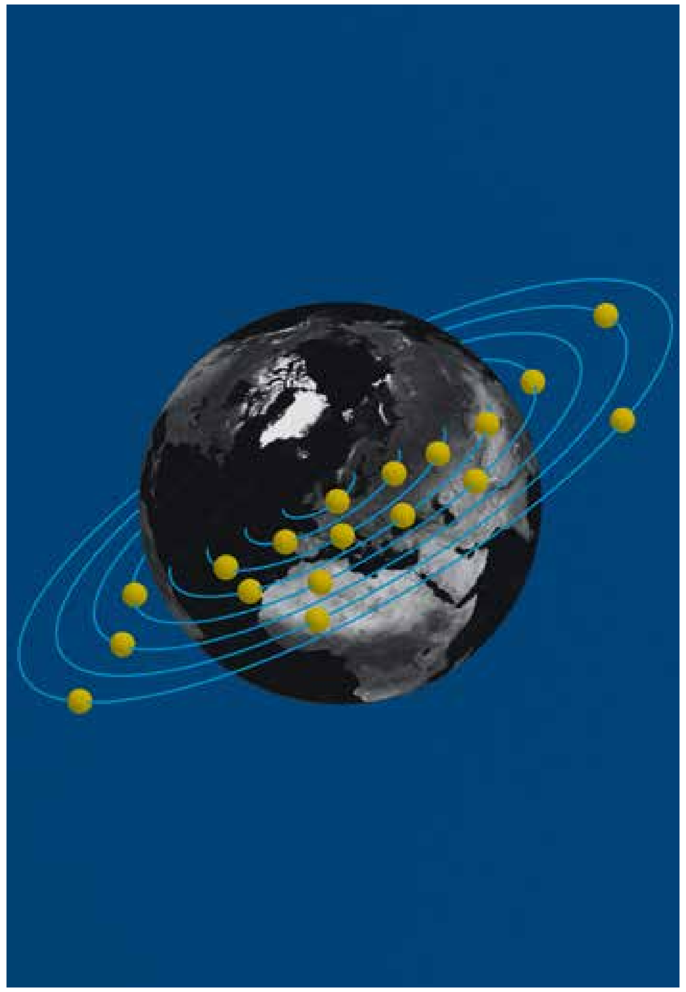
"After completing my Master's degree at the University of Manchester in Uranium Chemistry I was looking for an opportunity in the nuclear sector and came across CINDe – a programme that provides an excellent route into the industry whilst allowing you to complete a PhD at the same time. Being able to learn alongside professionals at NNL with over twenty years of experience has been invaluable throughout my studies so far and is something very few students get the opportunity to do.

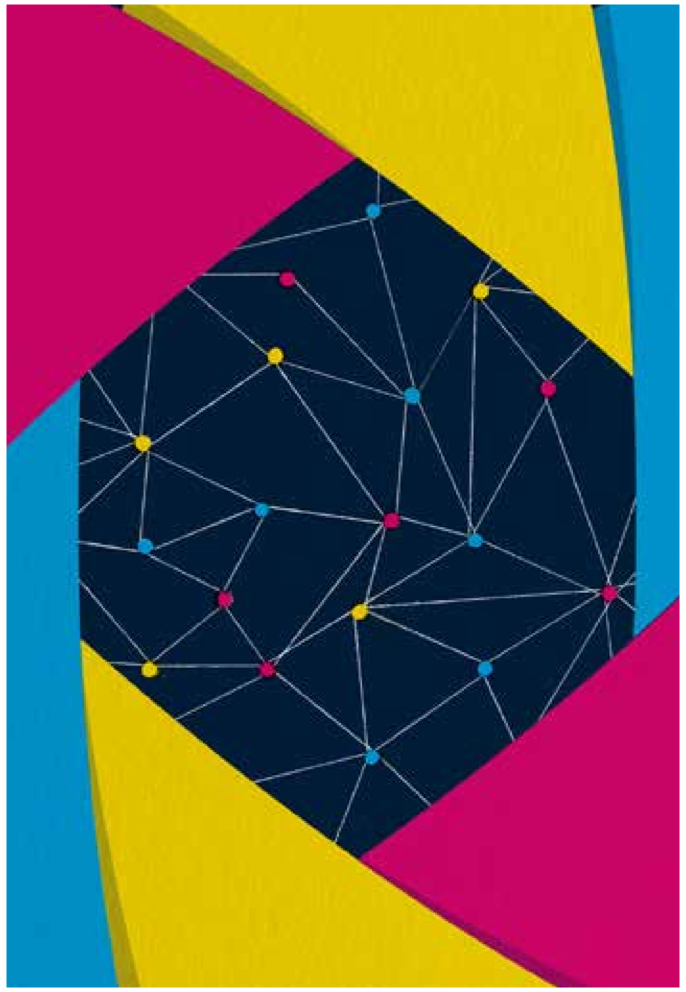
As well as providing me with insights that will be crucial to gaining employment in the sector in the future, CINDe has helped to strengthen my communication and presentation skills. From writing short technical reports to delivering elevator pitches, I am able to confidently present my work and communicate its impact to individuals from different backgrounds and with varying expertise. Working as part of the NNL team really has been a highly rewarding experience."

Thomas Mccarthy
PhD student at the University of Lancaster who is currently enrolled in CINDe









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