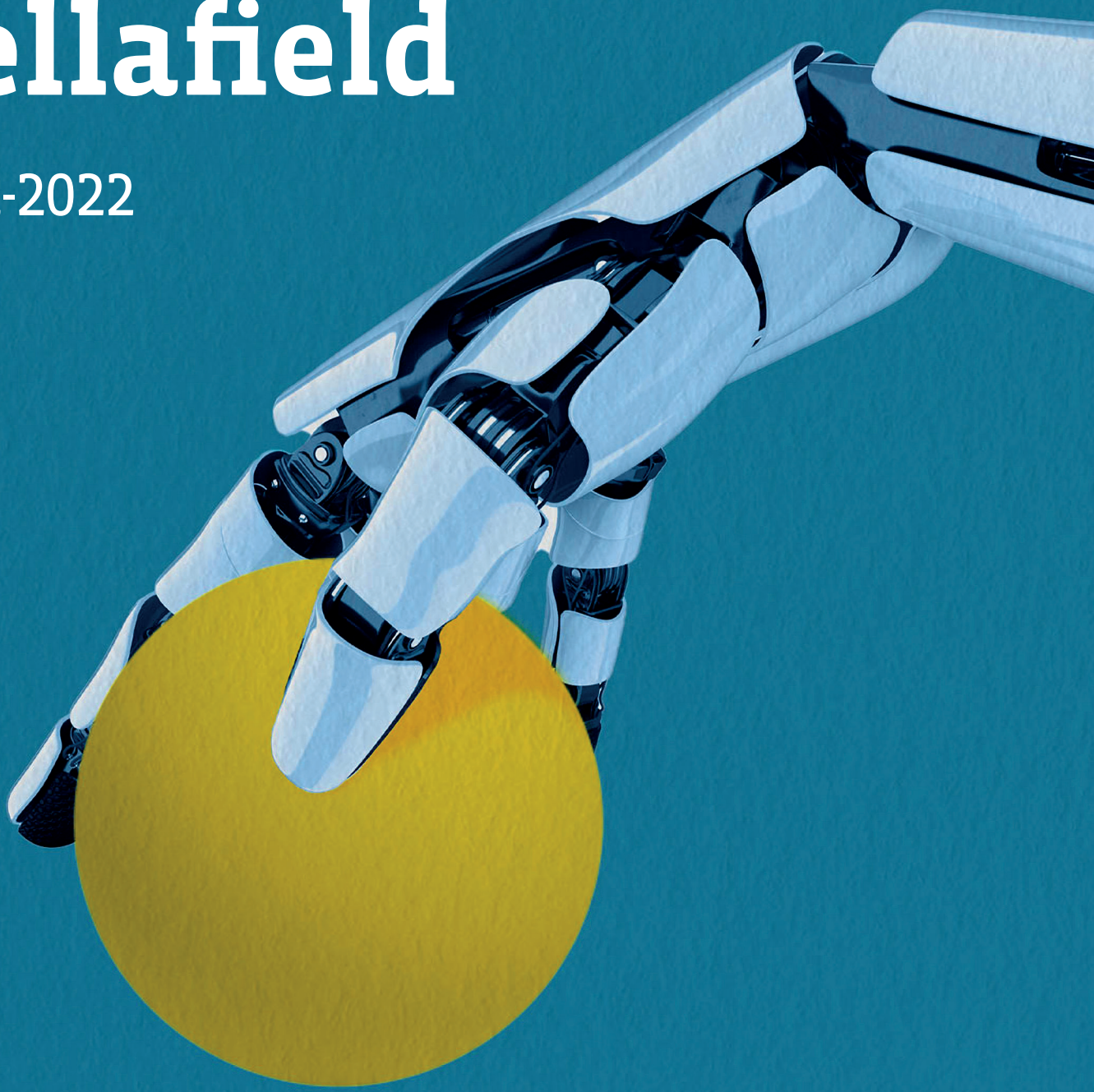
Public Interest Reinvestment Contributions to

# Environmental Restoration at Sellafield

2021-2022



NATIONAL NUCLEAR LABORATORY

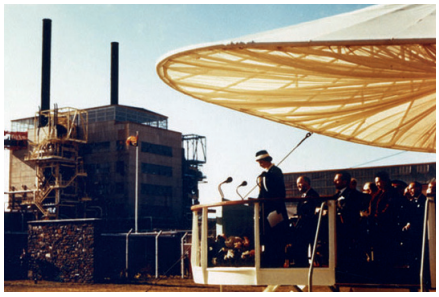
# Contents



This report has been produced as part of the technical services agreement between NNL and Sellafield Ltd. All of the examples used within this report contain support from public interest reinvestment.

# Background

Sellafield is one of the most complex nuclear sites in Europe and has been a pioneer in nuclear technology for over 70 years. The 6 km² site based in North West Cumbria has been at the heart of UK nuclear fission power generation and reprocessing, with the most diverse range of nuclear facilities in the world. With its origins in both civil and defence missions, the focus of the site today is on decommissioning the legacy of the past.



## Sellafield Ltd

From cleaning-up the country's highest nuclear risks and hazards to safeguarding nuclear fuel, materials and waste, our work is nationally important. We do this work on behalf of our owner, the Nuclear Decommissioning Authority (NDA). There are four value streams:

- **Retrievals:** we are retrieving nuclear waste, fuel and sludge that are stored inside our legacy ponds and silos, the highest risks and hazards at Sellafield.
- **Remediation:** beyond the legacy ponds and silos, we have hundreds of nuclear and non-nuclear facilities at Sellafield that need to be cleaned-up.
- **Spent nuclear fuel management:** we currently store and reprocess spent nuclear fuel. That means taking the fuel that has been used inside a nuclear power station and extracting the individual component parts of plutonium, uranium and waste. Our mission will change significantly as we come to the end of reprocessing.
- **Special nuclear materials:** we have the facilities and expertise to provide safe, secure and appropriate storage for special nuclear materials.

## NNL

As the UK's national laboratory for nuclear fission, NNL is harnessing nuclear science to help solve some of the world's biggest challenges. As a national laboratory, NNL works closely with the nuclear sector to provide critical technical support to industrial partners and to develop key technologies. NNL and Sellafield Ltd have been working together for many years to ensure that we take great steps towards creating a clean and sustainable future.

# Introduction

**Wayne Muckley**
VP Legacy Sites
NNL

As the UK's national laboratory for nuclear fission, we are proud to have a close partnership with Sellafield Ltd. We have been working to find innovative solutions through science and technology that make the task of restoring the environment at Sellafield that much easier. Over the past year, our refreshed strategy and Science and Technology Agenda showcases that commitment. It is with great pleasure that I introduce this report detailing our delivery of public interest reinvestments at Sellafield in FY21/22.

In addition, this report also takes a look at what we plan to achieve over the coming year in research and development, skills, facilities and infrastructure to support the work at Sellafield.

Since 2008 the totality of our work supporting Sellafield has been calculated to have saved the UK taxpayer in excess of £7bn, with additional savings identified to be realised in the coming years. In addition, we know that the value generated goes beyond purely financial. Our work also attracts and builds talent, delivers quality science, develops important partnerships and has real impact. The long-term collaboration agreement we have with Sellafield Ltd allows us to take a longer term view on what is required to deliver Sellafield's purpose of creating a clean and safe environment for future generations, something that is part of our own strategic focus on environmental restoration.

The report provides many great examples of the impact of the work carried out over the last year, some of the highlights include:

- The use of a specially created innovation space, enabling small and medium enterprises to demonstrate their technologies prior to active deployment on Sellafield site.
- Enabling a wider range of user access to our unique facilities, from robotics to hot cell work.
- Applying techniques developed during a PhD project to directly support facilities on Sellafield site to understand slurry transport. This potentially saves millions from blockages delaying operations.
- Developing remotely operated vehicles that have been deployed in highly radioactive environments to carry out inspections and aid the continued operations of aging facilities.

Once again, this year has involved dealing with the challenges arising from the COVID-19 pandemic. Thankfully, innovation in the medical sector through development and deploying of vaccines has enabled the UK to reduce restrictions. As the pandemic progressed, we constantly refined our response to ensure that we continued to deliver practical, innovative solutions for Sellafield Ltd. As we enter 2022, we can use the learning from this to continue to add value to the collaboration.

**Robin Ibbotson**
Chief Technology Officer
Sellafield Ltd

Our collaboration agreement with the UK's NNL is a great example of working in partnership to deliver against our vision for the site. We recognise the need to take a long-term view on Science and Technology requirements, this gives NNL the mandate to develop long-term solutions to some of our greatest challenges.

Having recently moved into the nuclear sector, it has been great to learn what has already been delivered through collaboration between NNL and Sellafield Ltd. From bringing forward innovative technologies to building the skills and capabilities that we need, it is clear what can be achieved now and in the future.

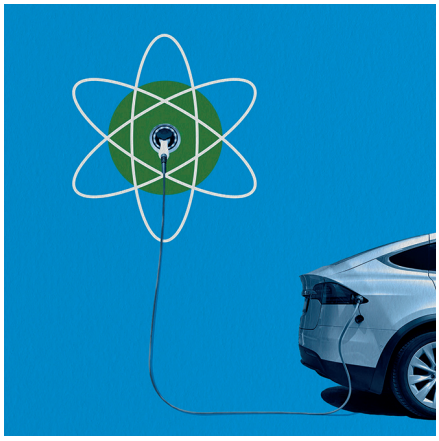
At Sellafield Ltd, we have a vision of creating a clean and safe environment for future generations. We know we can achieve that by focusing in on safe, secure and sustainable site stewardship, progressing at pace and through delivering lifetime value for money. NNL helps us in all three of these areas and it has been great to see that their own refreshed strategy maintains a strong alignment with ours.

Whilst the information contained in this report focuses in on the value that comes from NNL's public interest reinvestments, it is important to recognise the skills, capabilities and technologies that are developed to benefit the sector more widely. Whether that is in programmes such as Alpha Resilience and Capability (ARC), Game Changers or through direct commercial technical support. That is why it is really important to share the impact of these reinvestments.

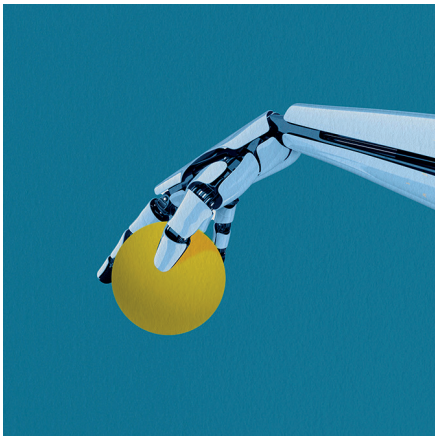
# Context

The technical services agreement between Sellafield Ltd and NNL, signed five years ago, commits NNL to using its surplus earnings from the contract over the previous financial year for use in public interest reinvestments that deliver value for Sellafield.

NNL is seeking solutions to some of today's biggest global challenges. This reinvestment approach is applied across the whole of NNL commercial work and helps NNL to deliver nuclear science to benefit society for today's nuclear sector, including Sellafield Ltd, the Department for Business, Energy and Industrial Strategy (BEIS) the NDA, Ministry of Defence (MOD) and EDF Energy. It also enables NNL: to meet its responsibility as a national laboratory and Public Sector Research Establishment (PSRE), to continually look to the future and consider the bigger picture supporting UK policy and strategic ambitions. This combined approach is reflected in our four focus areas:



**Clean Energy**



**Environmental Restoration**

**Health and Nuclear Medicine**

**Security and Non-Proliferation**

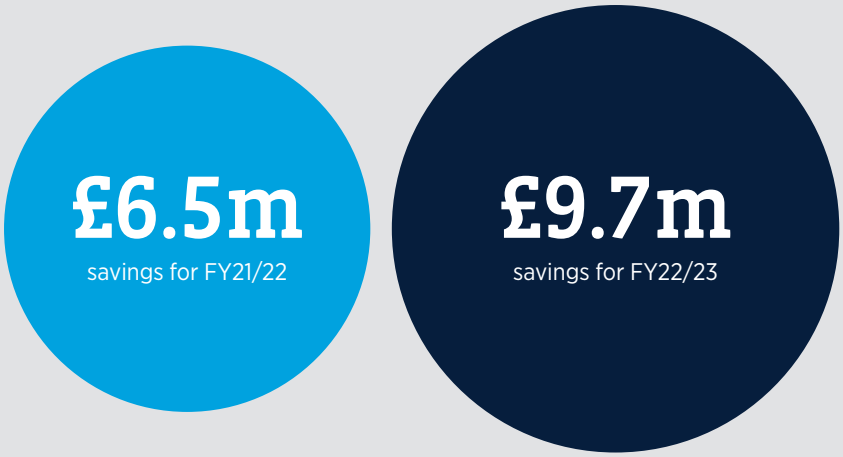
By working closely with Sellafield Ltd and other customers, NNL can deliver projects that enable the mission to progress at pace and deliver lifetime value for money, through:

- Longer-term and/or innovative research and development activities which maintain and develop key skills.
- Demonstrable investment in facilities and infrastructure.
- Strong investment in people, processes and systems to develop the skills, capabilities and facilities needed to sustain and safeguard the technical and analytical knowledge base to deliver solutions to the significant technical challenges at the site.

Not only do these investments deliver value for money, but they develop partnerships, foster the next generation of talent and provide the environment to deliver quality world-leading nuclear science and technology.

| | Actual spend in FY22 £m | Budget FY23 £m |
|---|---|---|
| Science and Technology | 2.2 | 2.6 |
| Core Science Themes | 1.5 | 1.8 |
| Innovation | 1.0 | 0.6 |
| Technical Skills and Capability | 1.3 | 2.0 |
| Facilities and Infrastructure | 1.0 | 6.2 |
| IT | 2.4 | 0.7 |
| Other* | 0.2 | 1.1 |
| **Total** | **9.7** | **15.1** |

*Other includes focus area investment in Environmental Restoration, and Security and Non-Proliferation.

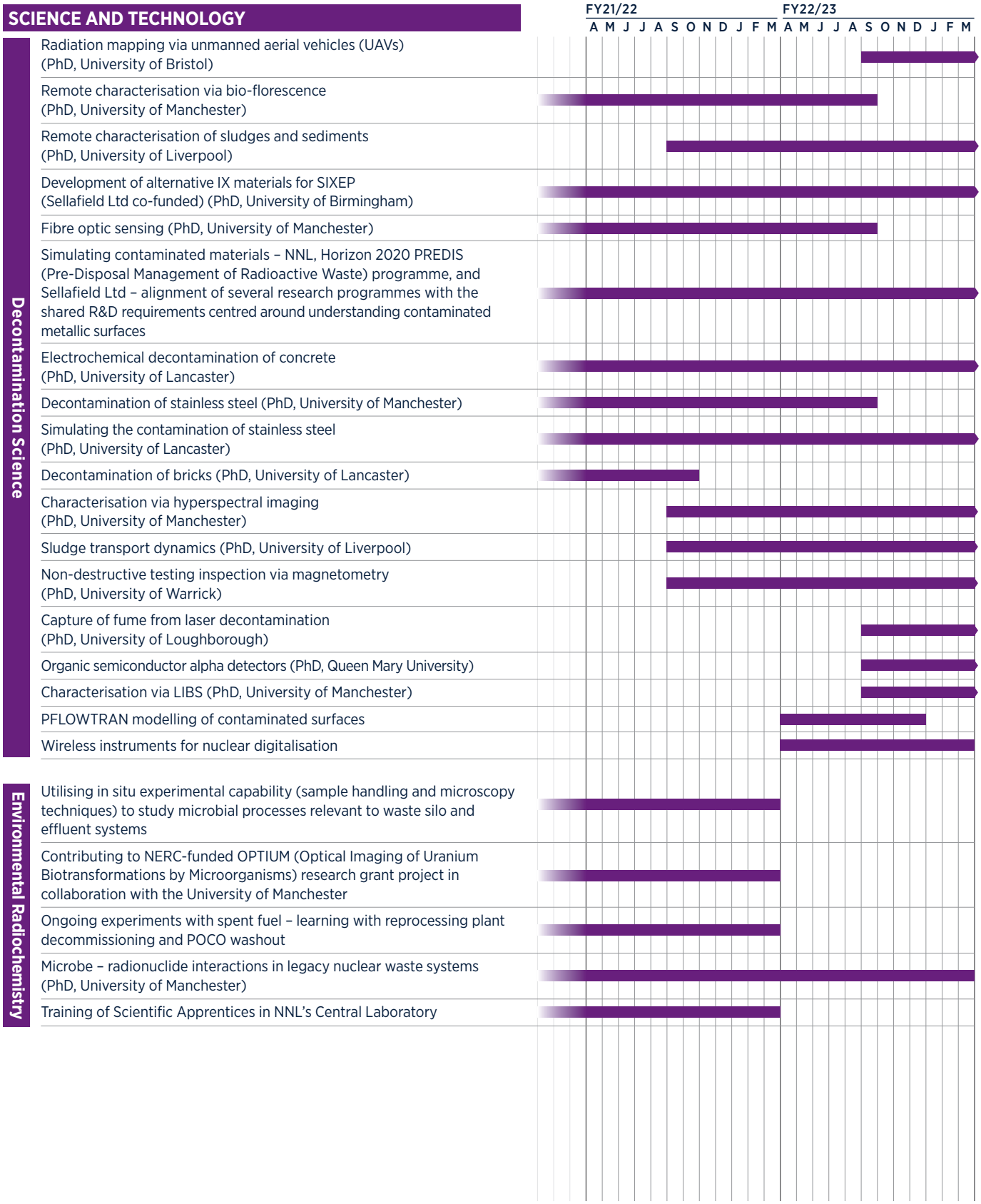



For the year FY21/22, £6.5m of savings resulting from public interest reinvestments were identified across Sellafield's business with a further £9.7m of savings expected in 22/23. Since the technical services agreement was signed, £250m worth of savings have been achieved.

# Overview

## Activity

## Timescale

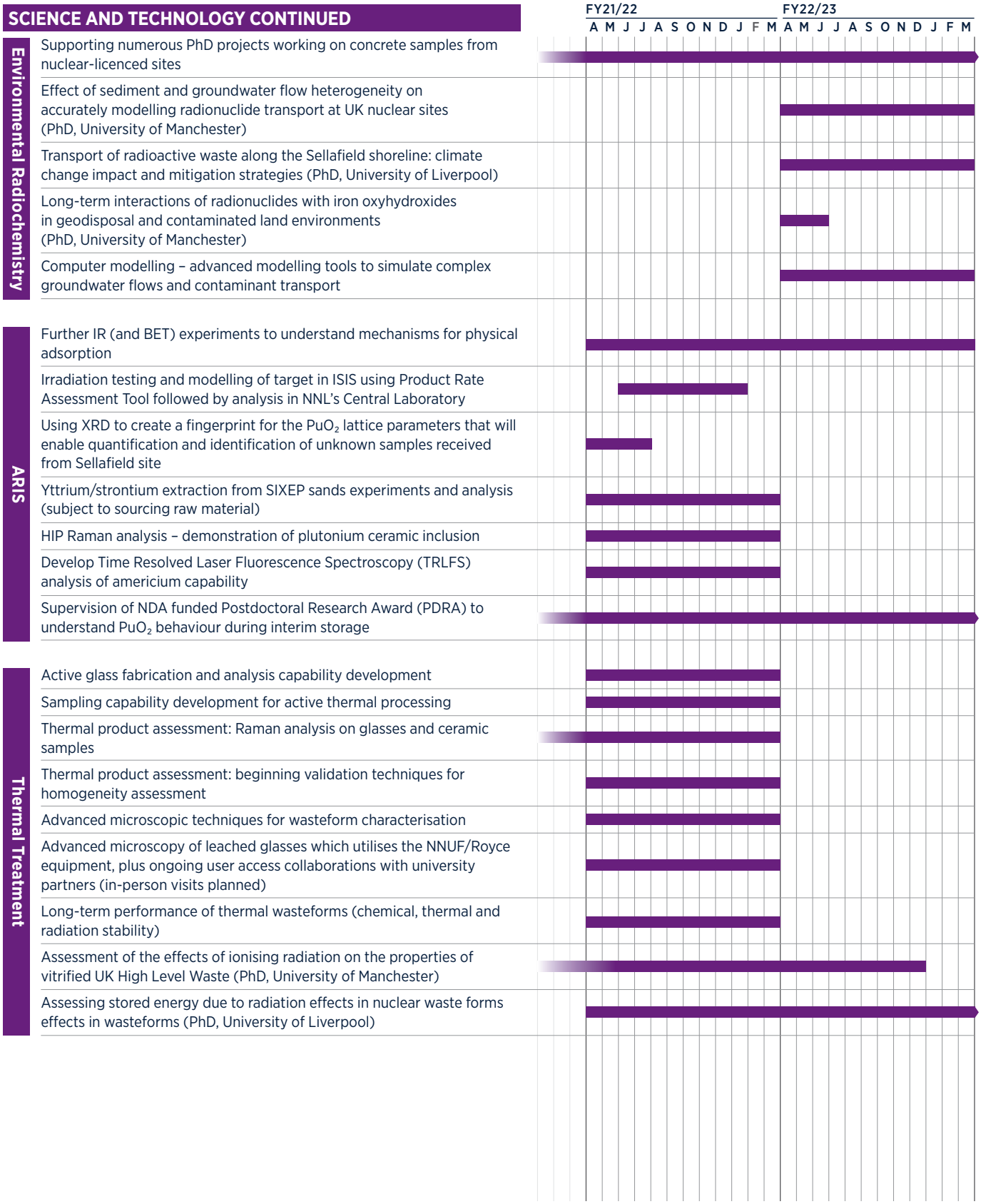



This Gantt Chart provides an approximate indication of timescales for projects. There is focus on the delivery within the FY21/22-FY22/23 time scale and as such some projects may have commenced earlier than this or are due to finish after this date. Where possible this has been indicated. Exact timings are subject to change.

## Activity

## Timescale

### SCIENCE AND TECHNOLOGY CONTINUED

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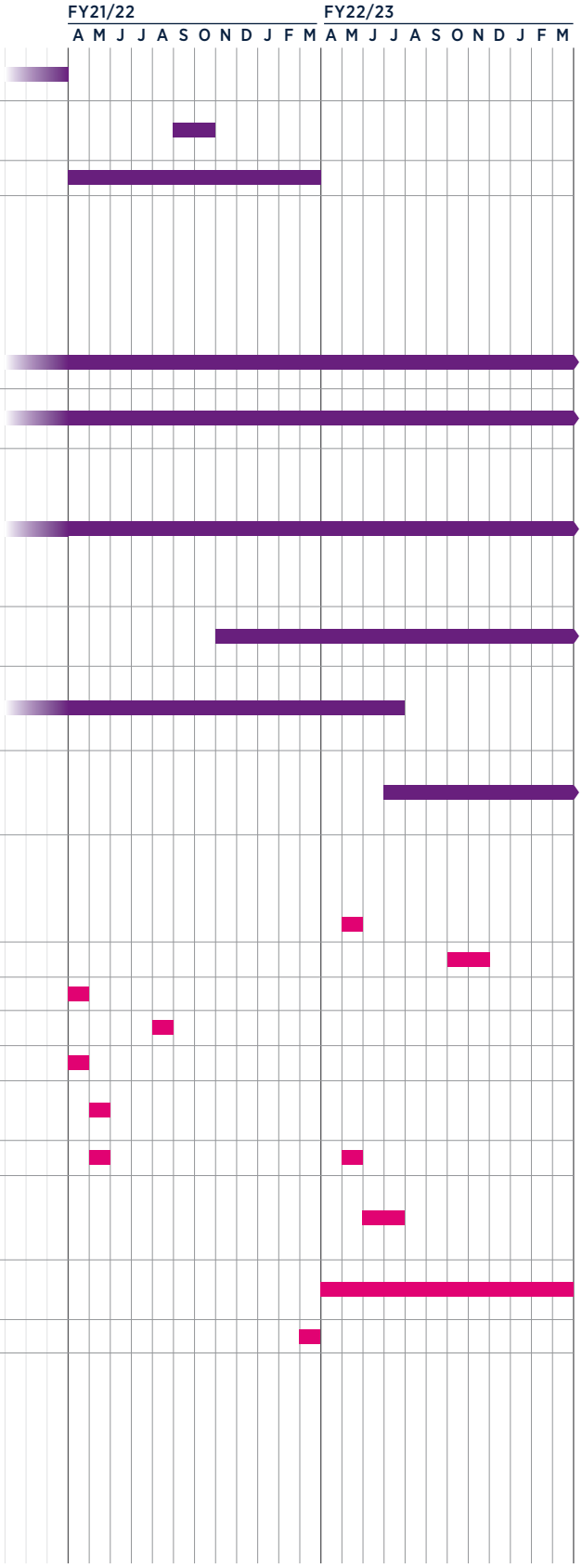


### SCIENCE AND TECHNOLOGY CONTINUED

**Materials Performance**

- Continued development of small-scale testing techniques to obtain mechanical properties from mm-scale samples
- Supervision of in-cave fuel electrochemistry work in support of Lancaster PhD student (NDA-financed)
- Chemical mapping of species in AGR fuel

**Nuclear Safety**

- Fulfilling the UK lead role on criticality-related ISO standards, facilitating appropriate input from the rest of industry
- Leading on the development of 'fit-for-purpose' solutions in chemotoxic safety
- Leading on various safety-related aspects identified of national strategic importance to the UK nuclear industry, e.g. providing the strategic industry lead on (i) criticality professional development, (ii) nuclear data awareness, (iii) driving innovative new thinking on 'As Low As Reasonably Practicable' (ALARP) solutions, and (iv) improved integration between safety and engineering
- Fulfilling the Chair role on the UK Shielding Forum, ensuring effective collaboration between organisations
- Providing thermal and criticality support to Lawrence Livermore National Laboratory on the CED-2 'Final Design' stage associated with a low temperature critical benchmark experiment
- Providing thermal and criticality support to Lawrence Livermore National Laboratory on the CED-3 'Initiate Facility Plan' stage associated with a low temperature critical benchmark experiment

### INNOVATION

- Technical demonstration of RECAP technology at NNL Workington
- Active trial of RECAP technology (Sellafield Ltd funded, NNL supervised)
- Commission Sellafield Ltd funded TED rig, ongoing support from NNL
- Technical demonstration of exogenous ultrasonics at Workington
- Technical demonstration of pipe unblocking work for Fuel Handling Plant (FHP)
- Game Changers Challenge – demonstration and testing of technologies for vertical deployment into cells and vessels
- FIRMArm (long-reach arm) – demonstration at NNL Workington TED Rig
- FIRMArm Active demonstration on the Sellafield site – this will include a visual inspection using an optical camera and also a gamma survey (Sellafield Ltd funded, NNL support)
- Developed modified Mirion camera ready for plant inspections to develop version that can fit through 6" port
- Racelogic demonstration

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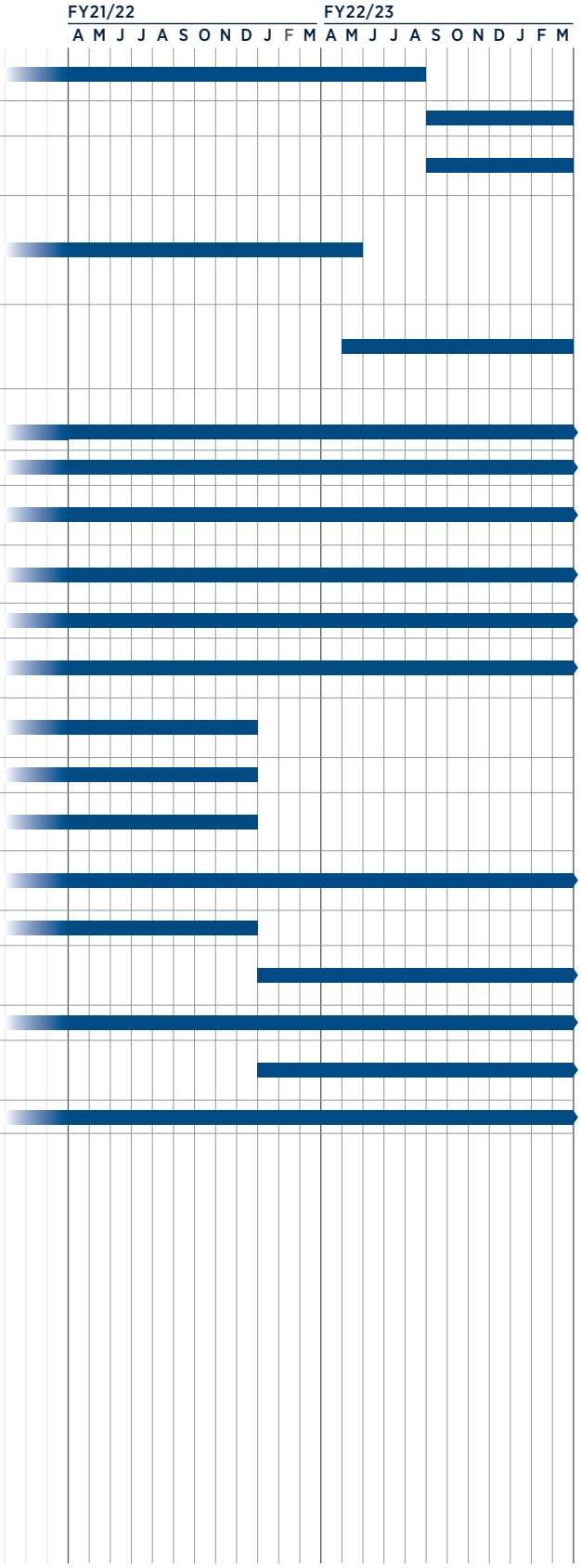


### COLLABORATIONS

**Robotics**

- Follow on development of task allocation, sequencing and coordination for robots under the Robotic Task Sequencing Programme (RTSP)
- Conducting physical trials and setting up of capability demonstration
- Understanding and developing vision-based local surface profiling and adaptive path correction for laser cutting applications
- Completion of New National Nuclear User Facility for Hot Robotics (NNUF-HR) for nuclear robotics R&D. In partnership with the University of Bristol, Manchester and the UKAEA's Remote Applications for Challenging Environments (RACE)
- Utilise the NNUF-HR to test and develop remote operations and equipment for use in sort and segregation, size reduction, laser cutting, waste management and retrieval, and glovebox operations

**International Programmes**

- PREDIS (Pre-Disposal Management of Radioactive Waste)
- JHOP 2040 (Jules Horowitz Operational Plan 2040)
- ENTENTE (European Database for Multiscale Modelling of Radiation Damage)
- PATRICIA (Partitioning and Transmuter Research Initiative in a Collaborative Innovation Action)
- PUMMA (Plutonium Management for More Agility)
- FRACTESUS (Fracture mechanics testing of irradiated RPV steels by means of sub-sized specimens)
- ESFR SMART (European Sodium Fast Reactor Safety Measures Assessment and Research Tool)
- METRODECOMM
- DISCO (Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions)
- A-CINCH (Augmented Cooperation in Education and Training in Nuclear and Radiochemistry)
- GENIORS (GEN IV Integrated Oxide Fuel Recycling Strategies)
- FREDMANS (Fuel Recycle and Experimentally Demonstrated Manufacturing of Advanced Nuclear Solutions)
- Gemini 4.0
- HARPERS (International regulatory framework in waste management and decommissioning)
- SECURE

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# Science and Technology

NNL maintains and develops world-class nuclear facilities and people so that it can deliver nuclear science for the benefit of society. In addition to directly supporting the technical needs of the nuclear industry, NNL is uniquely positioned to deliver substantial science and innovation programmes that help develop new technologies and a greater scientific understanding of complex nuclear processes.

NNL's Science and Technology Agenda has three pillars: Core Science Themes, Strategic Research and Innovation, led by knowledgeable and experienced scientists that collaborate with university partners as well as other national and international organisations. The aim of the Science and Technology Agenda is to develop capabilities and technologies that provide benefit to both the current and future nuclear sector. Within this report, focus is given to the Core Science Themes that support environmental restoration at the Sellafield site. These Themes also carry out critical work in health and nuclear medicine, clean energy and security and non-proliferation. The skills developed in these areas are applied to the work carried out in support of environmental restoration in the UK and to Sellafield Ltd.

"The work we do not only addresses the challenges of today but also looks to an exciting future for nuclear. We have structured our Science and Technology Agenda around three pillars – Core Science, Innovation, Strategic Research – which are all underpinned by collaboration and aligned to outcomes to benefit the UK. To ensure we focus on the right things we have also developed and implemented our Science and Technology Value Framework which has four key elements: Quality, Talent, Partnerships, Impact. Each one is an essential element of demonstrating value. This framework guides all our work, including in environmental restoration which has some of the most exciting science and technology challenges in the UK at the moment. It is brilliant to see us working in partnership to deliver nuclear science to benefit society."

**Paul Nevitt**
Science and Technology Director
NNL

### The 13 NNL Core Science Themes

- Advanced Fuels
- **Advanced Recycling and Isotope Separation**
- **Decontamination Science**
- **Environmental Radiochemistry**
- Health and Nuclear Medicine (NEW in 21/22)
- Irradiated Fuel Characterisation (NEW in 21/22)
- **Materials Performance**
- **Nuclear Safety**
- Reactor Chemistry and Corrosion
- Reactor Technology (NEW in 21/22)
- **Robotics and AI**
- Structural Integrity
- **Thermal Treatment**

- Total Core Science budget for FY22/23 of £1.8m
- 75 peer reviewed journal papers were published by NNL scientists in FY21/22

(Bold indicates Themes delivering work supporting the mission at Sellafield)

# Decontamination Science


## Summary

At Sellafield, there are many facilities requiring decommissioning. Each contain a wide range of different physical, chemical and radiological hazards where the use of decontamination can enhance decommissioning operations. There is a drive to develop innovative decontamination technologies to reduce the volume of all types of radioactive waste requiring disposal. A significant proportion of this Theme is dedicated to delivering environmental restoration at Sellafield. In addition, work helps support the missions of MOD, EDF Energy and the wider NDA estate.


"How much more applicable and aligned these research topics and presentations were to the problems we are faced with in the nuclear industry today."

**Liz Ostle**
Decontamination specialist
Sellafield Ltd

**Decontamination Science in focus**

Decontamination Science has the potential to unlock substantial savings both in terms of waste classification and volume, and in enabling more invasive decommissioning techniques to occur at a faster rate. To achieve this first requires an understanding of the contamination through characterisation and/or mechanistic understanding. Then, it requires that the technologies that can be used to remove that contamination are available. Finally, the treatment of any secondary waste can be considered and appropriate waste forms deployed. The remit of the Theme is flexible to adapt to the emerging needs at Sellafield.

With over half the budget supporting 13 postgraduate researchers, training and developing the next generation is key to the Theme. Furthermore, there are contributions to both the PREDIS and HARPERS European Horizon projects (see pg. 36).

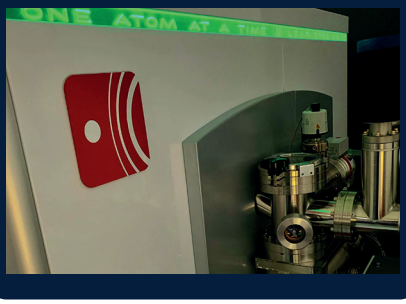
Over the last year the Theme has seen four journal articles published and several students received awards for their presentations at conferences.

In the coming year the aims are to deploy the EASD® Gel in an active plant at Sellafield (see pg. 32), publish work on the stainless steel decontamination mechanism and carry out additional work on concrete and alpha decontamination.

Each year, the Decontamination Science Theme brings researchers together to share the progress and ideas from the previous year. At this year's event Liz Ostle, a decontamination specialist at Sellafield Ltd commented "how much more applicable and aligned these research topics and presentations were to the problems we are faced with in the nuclear industry today".

**Case study update**
Artificial contamination of surfaces

- Simulating contamination on surfaces can help speed up the development of decontamination techniques and enable more efficient decommissioning.
- For the first time, Atom Probe Tomography has been used to determine the location of artificial contamination to help determine whether the simulated conditions used to produce them are similar enough to real samples.
- Work in this area is expected to continue into the future.
- This work also forms part of the PREDIS programme (see pg 36).



# Rapid testing of alternative ion-exchange materials for effluent management at Sellafield

## Challenge

At Sellafield $^{137}Cs$ and $^{90}Sr$ are removed from aqueous streams prior to discharge to minimise the environmental impact of operations. The source of the material used in the current ion exchange process, known as clinoptilolite (clino) zeolite, is known to be limited in supply. Therefore, innovative materials are required before a lack of supply impacts operations.

**Alternative clinoptilolites have been shown to be inferior in performance to the current clino sourced from Mud Hills, California with the uptake of strontium being especially impacted.**

## Solution

Through collaboration with the University of Birmingham in the TRANSCEND programme (see pg. 34), Decontamination Science has been able to demonstrate the performance of a promising material. By making a modification to the structure of a zeolite, selectivity for Cs and Sr can be increased. Over the course of the PhD project, a high degree of synthetic control has been demonstrated over the formation of the modified zeolites. Using a zeolite-based material has benefits of radiation resistance, physical durability and wasteform compatibility.

## Technology

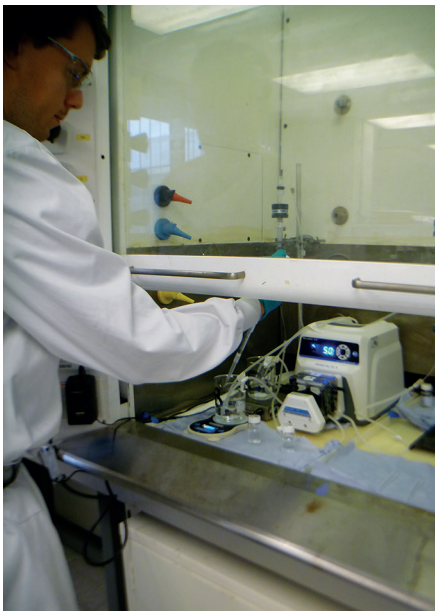
Over the last 5 years NNL has developed a method of carrying out rapid testing of ion exchange processes that simulate plant conditions. This reduces the costs involved with carrying out experiments and enables down selection of technologies.

## Outcome

The User Access team at NNL (see pg. 43) provided support to enable the PhD student to perform laboratory experiments at NNL Preston, utilising the rapid ion exchange methods already established to assess the performance of these materials under dynamic conditions. This has confirmed that the materials show promising performance, especially with respect to the troublesome $^{90}Sr$ recovery.

## Status

The work was presented at the Waste Management Symposium in Phoenix Arizona in March 2022 and is currently being written for publication in a journal. Follow on work is now being planned to scale-up and test alternative IX materials on an engineering scale. Additional work also utilising a synchrotron light source is being considered to further our mechanistic understanding of these new materials.



# Environmental Radiochemistry

## Summary

Through an increased understanding of how radionuclides behave in the environment, better decisions can be made about how to manage them. This Theme aligns with the high hazard risk reduction missions at Sellafield for legacy ponds and silos, adding substantial value.

**Core Science in focus**

This Theme works to understand the behaviour of radionuclides under a range of environmental conditions including; effluent treatment, waste storage and disposal and contaminated land. Work has helped to improve knowledge, build skills, enhance NNL's experimental and modelling capability.

The Theme has direct links to two Sellafield Integrated Research teams, Process Chemistry and Environmental Science. It has supported six postgraduate researchers with an additional two expected in the coming year.

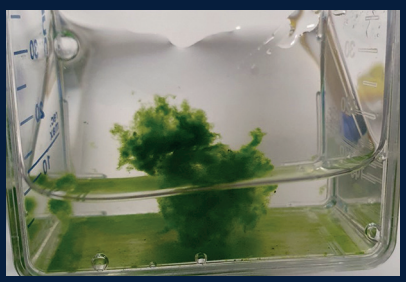
Over the past year the Theme has focused on three broad areas, biogeochemistry, contaminated land, and numerical model development, with work continuing to be carried out in these areas in the coming year.

"NNL's investment in the science Themes has been a key enabler in introducing regular DNA characterisation of legacy pond water samples, allowing plant operators to minimise the disruption caused by microbial activity. Over the last several years, the University, NNL and Sellafield Ltd have invested in building skills and capability in this area and this joined-up approach has brought significant added value."

**Professor Jon Lloyd**
University of Manchester

**Case study update**
Microorganisms in radioactive nuclear facilities

- Legacy fuel storage ponds can experience visibility issues from microbial activity causing seasonal 'blooms', leading to delays in waste retrievals.
- For several years the Environmental Radiochemistry theme has undertaken collaborative work to understand the microbiology of legacy fuel storage ponds, which has helped to secure the continued availability of a post-doctoral researcher at the University of Manchester.
- Samples from various ponds on the Sellafield site are now routinely shipped to the University for characterisation, following initial processing and DNA extractions performed by NNL colleagues in Central Laboratory.
- These established workflows provide plant operators with important data on changes to the microbial populations within their facilities, allowing them to optimise mitigation strategies and minimise delays to waste retrievals.



# Fostering talent in Environmental Radiochemistry

## Challenge

Our work at NNL requires a variety of specialised skills in order to be successfully delivered. Within Environmental Radiochemistry these range from laboratory skills utilising active fumehoods and inert atmosphere boxes, to a range of modelling approaches. Ensuring that there is sufficient strength and depth in key technical capabilities requires dedicated support.

**The Theme has been looking to enhance NNL's experimental and analytical capability to study in situ microbial processes in legacy waste and disposal environments. Improvements have also been made in NNL's modelling capability to assess the effects of microbial activity, chemical evolution and gas generation processes.**

## Solution

The Theme has been providing training in the areas of practical skills and chemical modelling, two areas requiring strength and depth in capability. The experimental work within the biogeochemistry task has allowed several NNL Scientific Apprentices to contribute, gaining experience in active fumehood and inert atmosphere work.

Training in computer modelling has focused on chemical speciation calculations and groundwater flow and contaminant transport simulations.

## Technology

The experimental team has gained experience in a range of advanced analysis and spectroscopic technologies, including mass spectrometry and ion chromatography. In previous years, user access to Central Laboratory enabled advanced microscopy techniques to be applied to legacy plant samples.

Chemical speciation modelling allows the prediction of the chemical form of numerous species, including radionuclides in solution, solubility and precipitation processes and interactions with solid phases. These calculations can help predict the behaviour of radionuclides during waste storage and effluent treatment, and often go hand in hand with experimental work with active simulants or plant samples. The Theme has delivered annual training courses in the modelling software PHREEQC, offered to NNL colleagues and PhD students for three consecutive years.


## Outcome

The contribution of Scientific Apprentices to the work of the Theme has allowed them to become fully qualified and they are now able to perform active laboratory work, including direct work for Sellafield Ltd on a range of effluents-related programmes. Remote interactive training was provided to ~30 scientists including NNL colleagues, PhD students and academics on the use of PHREEQC. This allowed the detailed experience that has been built in NNL to be shared with a wider community who can in turn utilise the software.

## Status

More than five Scientific Apprentices are now Suitably Qualified and Experienced Persons (SQEP) to carry out experimental work, with many currently deployed on experimental projects for Sellafield Ltd. More than 60 people have received training in chemical modelling, some of whom have joined NNL as staff after receiving the training during their PhD. These skills can now be utilised to support customers including Sellafield Ltd on challenges such as effluent treatment. Our contaminant transport modellers have gained experience in constructing complex models utilising geological data to understand and predict contaminant transport.

# Advanced Recycle, Plutonium and Isotope Separation (ARIS)

## Summary

Using world-leading expertise and unique facilities enables work in this Theme to address key Sellafield challenges such as managing the civil nuclear stockpile of plutonium. Using separation knowledge of nuclear separations to maximise the recovered value from nuclear materials can transform how we view wastes.

**Core Theme in focus**

Spent nuclear fuel and nuclear materials have significant potential value, but to unlock that requires an understanding of how to separate out the various elements from each other. Understanding nuclear materials and the methods that can be used to extract value from them is key. Work in this Theme cuts across multiple focus areas, including clean energy, health and nuclear medicine and environmental restoration. It requires skills in chemistry, chemical engineering, process modelling and practical alpha-active laboratory techniques. The projects supported by this Theme help to build these skills that enable the next generation to continue to support the challenges faced by both Sellafield and the wider nuclear sector.

The Theme supported four postgraduate and two post-doctoral researchers in FY21-22, with a total of five expected for FY22-23 (three new PhDs).

In support of Sellafield's mission, key activities in ARIS include those relating to understanding the behaviour of plutonium dioxide, developing analytical capabilities and improving the separation processes that enable recovery of useful materials from the waste streams present at Sellafield.

Beyond investigations into plutonium behaviour, NNL has been investing in capability to increase the ability to analyse metal concentrations in organic solution. This is key to increasing the accuracy (and decreasing uncertainty) for projects that involve separations, for example separating americium from civil nuclear stockpiles of plutonium for use as a power source in spacecraft.

In addition, methods of recovering $^{90}Y$ from spent wastes from the SIXEP treatment plant at Sellafield have been investigated. This is because $^{90}Y$ is potentially useful in radiotherapy. This last year has seen the development of the process from using inactive surrogates through active spiked tests all the way to tests on historic samples recovered from Sellafield SIXEP Bulk Storage Tanks. The information gained here is expected to allow the team to highlight the potential value of the waste stream as a source of $^{90}Y$ for medical purposes.

Over the coming year, the Theme will be extending analytical capability, continuing important work to further understand plutonium behaviour, study the decomposition of americium containing oxalates from advanced finishing process and look for further value in reprocessing wastes with platinum group metal recovery options.

# Understanding the behaviour of plutonium dioxide during storage: chloride absorption

## Challenge

Having a detailed understanding of plutonium chemistry enables safe interim storage and ultimately helps to decide on the best method of stabilising it for long-term disposal.

**Whilst species such as $Cl^-$, $CO_2$ and other volatiles are known to absorb onto Pu the process is not understood on a detailed mechanistic level. These absorbents heavily influence the physical characteristics of the Pu, so it can potentially be helpful to understand the conditions that can prevent this process. Through a better scientific understanding this special nuclear material can be more effectively stored prior to its long-term disposal.**

## Solution

NNL has used both infrared (IR) and Brunauer–Emmett–Teller (BET) to gain insight into absorption and sorption of these volatiles on $PuO_2$. Starting with $Cl^-$, work performed so far has focused on understanding the quantity of $Cl^-$ that is absorbed and the temperatures required for desorption. There have been very few investigations aimed at understanding the mechanisms of the physical adsorption of these species.

## Technology

To probe the fundamental understanding of the interaction of various species requires the use of analytical techniques, such as IR spectroscopy and BET absorption. IR can be used to provide information on chemical interactions on a molecular level. BET analysis is method of assessing the quantity of material that can absorb onto a surface, typically in a porous material.

## Outcome

By understanding the mechanism of adsorption, we can understand how storage behaviour influences Pu physical properties and therefore, ultimately, what steps could be taken to treat Pu for storage or reuse, if they are even treatable. This work also increases capability of the glovebox IR spectrometer by providing staff learning opportunities.

## Status

During the last year, new staff have been trained on the use of the IR spectrometer as work on this project continues. The results of the project will be consolidated into a journal article, communicating the science to the wider technical community and building a greater ‘body of knowledge’.

# Thermal Treatment

## Summary

Developing a 'Centre of Excellence' for thermal treatment will support the development of active thermal treatment technologies and demonstrators, key to treating challenging waste streams at Sellafield. This will be achieved by developing world-leading uranium/plutonium-active characterisation, analysis and modelling capability in thermally treated wastes.

### Core Science in focus

There will be some nuclear material which requires treatment for long-term disposal. This Theme covers the development of skills and capability that support the deployment of thermal treatment technologies, to reduce waste volumes and improve safety/stability of waste for storage and disposal.

The Theme recently realigned its focus so that it is best placed to support the deployment of active thermal treatment demonstrators at Sellafield. These projects are underway to support the disposition of problematic waste streams such as pumpable wastes, plutonium contaminated wastes and miscellaneous beta/gamma wastes.

NNL has experience operating a variety of thermal treatment technologies including Hot Isostatic Pressing (HIPing), Geomelt®, Cold-Press and Sinter (CPS), MOx fabrication, and plant scale vitrification. The skills developed from these can be used to help support the development of active demonstrators.

The Theme supported five post-graduate researchers in FY21-22, with a total of four expected for FY22-23. In addition, the Theme collaborates on the PREDIS and TRANSCEND programmes.

Over the past year, work has continued on the development of active analytical capability assessing techniques that could support thermal treatment operations and product qualification. Ongoing work to understand the chemistry of vitrification aligns with the Sellafield Integrated Research team on Process Chemistry.

Over the coming year work will focus on the development of an alpha active thermal treatment capability as well as progressing the assessment of characterisation techniques for thermal products.

# Underpinning skills to enable Pu disposition

## Challenge

There are special wastes at Sellafield for which current waste treatment routes will not be appropriate. It is important to have relevant skills ready to develop and deploy appropriate technologies that solve these challenges.

**One such challenge is the long-term disposal of civil plutonium stockpiles. As evaluations of options have progressed, Hot Isostatic Pressing (HIP) has been shown to be a useful technology for producing a durable wasteform.**

## Solution

Work in the Thermal Treatment Theme maintains HIP Glass/ceramic capability skills to ensure that almost 20 years of experience is not lost. The Theme has invested in making improvements to the process and technology, glass-ceramic formulation, characterisation and analysis.

## Technology

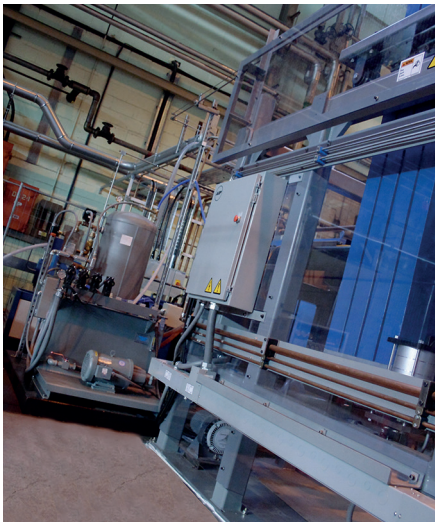
HIP is a process which uses high temperature and pressure to create wasteforms with minimised porosity and high durability. In the case of plutonium disposition, a zirconolite glass-ceramic formulation has been developed. The plutonium oxide product is first milled in the presence of wasteform pre-cursors then it is added to a HIP can. The can is then sealed and the HIP process begins. As the product experiences high temperature and pressure, it converts into the desired glass-ceramic, whilst also reducing in size as a result of the removal of porosity.

## Outcome

When it was decided that HIP might be used as a process for the disposition of Pu, the skills that had been built were able to be deployed to develop a small-scale active HIP facility, named HIP-100, to increase the Technology Readiness Level (TRL) of the process to TRL 6. The aim is to validate over 30+ years of inactive wasteform research in the area. Having a long-term waste solution for the UK's civil plutonium stockpile contributes to hazard reduction at the Sellafield site. The work supported by this Theme supports a much broader investment from Sellafield Ltd into thermal treatment options.

## Status

Experiments have been carried out using cold press and sintering to synthesise simulated wasteform in an active environment. This acts as an interim whilst development of the UK's first Pu active HIP-100 facility is ongoing. Over the last year improvements to the ceramic processing have been made. The Theme will continue to invest into the skills required to maintain this capability.



# Materials Performance


## Summary

The Material Performance team continues to develop knowledge and capabilities to improve the mechanistic understanding of long-term, safe spent fuel storage, disposal and decommissioning strategies.


"Once we were able to identify a timeframe which the experiment could be done in cave, the support and the way we got the student in and work on the cave was excellent."

**Professor Colin Boxall**
University of Lancaster

### Core Science in focus

Materials in the nuclear industry are put through a range of environments and experience varying conditions. It is important that we have a good understanding of how that material will perform, especially understanding failure conditions. This Theme is setup to allow research to understand materials in use today, but also those under development for use in future fuel cycles. This means it has relevance across the fuel cycle, from reactor operation, to interim storage and ultimately disposal.

The Theme has supported seven post-graduate researchers in FY21-22, with a total of five expected for FY22-23 (two new PhDs). In addition, the programme involves collaborations on five horizon 2020, two IAEA and one international programme.

Work over the last year has been carried out in areas such as understanding AGR fuel electrochemistry, oxidised fuel characterisation and atom probe tomography of noble metal particles in Windscale Advanced Gas Reactor (WAGR) fuel. There will be a heavy emphasis on understanding the impacts of Zircaloy corrosion caused by hydrogen that can lead to cladding failure in the coming year.

# Electrochemical studies of irradiated AGR fuel

## Challenge

After fuel leaves a reactor it can experience a range of aqueous environments from the interim storage in a fuel pond to final disposal involving a geological repository. It is important to understand how the fuel and the cladding may react to these differing environments in order for the appropriate controls to be maintained.

**Fundamental work often involves the use of simulated materials in order to avoid working with spent fuel, which requires unique capabilities to handle. However, these simulants need to be validated against data obtained on real materials in order for there to be confidence in the results.**

## Solution

A PhD student at the University of Lancaster has been investigating the electrochemical behaviour of irradiated Advanced Gas Reactor (AGR) fuel, which aims to increase understanding of material performance under different conditions. Facilitated by User Access (see pg. 43) the student was able to setup a dedicated programme of work in NNL's active handling facility to carry out the experiments on real AGR fuel.

## Outcome

This was the first time any PhD student has undertaken an independent programme of work on irradiated fuel in NNL's active handling facility. The work has provided evidence that observations from simulant studies are representative enough to support the use of these studies by end users such as Sellafield Ltd and Nuclear Waste Services. The confidence in simulated materials enables a reduction in research and development costs.

## Technology

Electrochemical analysis is a powerful technique that can be used to understand the fundamental properties of a material. For example, it can be used to understand corrosion processes by monitoring the conditions by which oxidative and reductive processes take place.

## Status

The student has gone on to complete further active tests on sample containing both fuel and cladding. Further inactive studies are also being carried out to test consistency.

# Nuclear Safety

## Summary

A high-quality safety record delivered in a cost-effective manner is an absolute priority for nuclear facilities. Innovative new ideas are essential to achieving this, but so too are As Low As Reasonably Practicable (ALARP) assessments and regulation. Through Core Science investment, NNL is leading on various initiatives nationally and internationally, helping to drive solutions that are optimal from both a cost and safety viewpoint.

"NNL utilises their national and international experience to provide valuable input to the strategic direction of the working party and positive contributions to specific activities, including integration of these into cross-industry initiatives."

**Dominic Winstanley**
Sellafield Ltd

### Core Science in focus

ALARP is the bedrock of UK health and safety law and can often drive overly conservative decision making, particularly if influenced that way by either (i) onerous standards / Good Practice Guides, (ii) compensating for significant uncertainties, or (iii) cautious judgements from inexperienced safety specialists. The projects in the Nuclear Safety Theme are all linked with initiatives that help to positively influence these three aspects. For example, some of the broad activities supported in the 2021/22 FY include:

- Shaping national and international criticality safety standards and Relevant Good Practice (RGP) which influence regulatory thinking.
- Coordinating the UK Working Party on Criticality (WPC) Continued Professional Development (CPD) webinar series which is regularly attracting ~80 national and international participants.
- Collaborating with Lawrence Livermore National Laboratory (LLNL) on a 'world-first' critical benchmark experiment designed to fill a nuclear data gap at sub-zero temperatures (which may help to reduce conservatism in transport safety cases).
- Authoring a journal article on 'fit-for-purpose' approaches to asphyxiation assessment.
- Leading an industry Good Practice Guide relating to principles to encourage the effective integration of safety case personnel and engineers during safety case production.
- Supporting a PhD student at the University of Liverpool on integrating a dose software tool with an uncertainty analysis tool to support ALARP judgements on operator dose uptake.

Whilst outside of the boundaries of nuclear safety, the Theme has also been supporting the WATer CHerenkov for Anti-Neutrinos (WATCHMAN) consortium which is developing technology and data analysis techniques to demonstrate the ability to monitor nuclear reactors from distances of tens of kilometres as part of future Nuclear Non-Proliferation Treaties. As well as aligning with NNL interests in the Security and Non-Proliferation Focus Area, this technology has spin-off benefits in terms of $^{90}Sr$ monitoring which are currently being investigated with Sellafield Ltd via the Game Changers initiative.

### Case study update
Good Practice Guide

- Twelve months ago, the case study from this Theme focused on the collaboration between NNL and Sellafield Ltd in leading a UK Good Practice Guide at the UK working party on criticality.
- The Good Practice Guide provides increased support to ensure that the combination of criticality risk and non-criticality risk is considered together such that the overall risk is ALARP.
- Progress reports at the UK working party in the last twelve months have suggested that this Good Practice Guide is already adding significant value to industry. Multimillion pound savings have already been identified for some of the end users.

# International collaboration on low temperature critical benchmark experiment

## Challenge

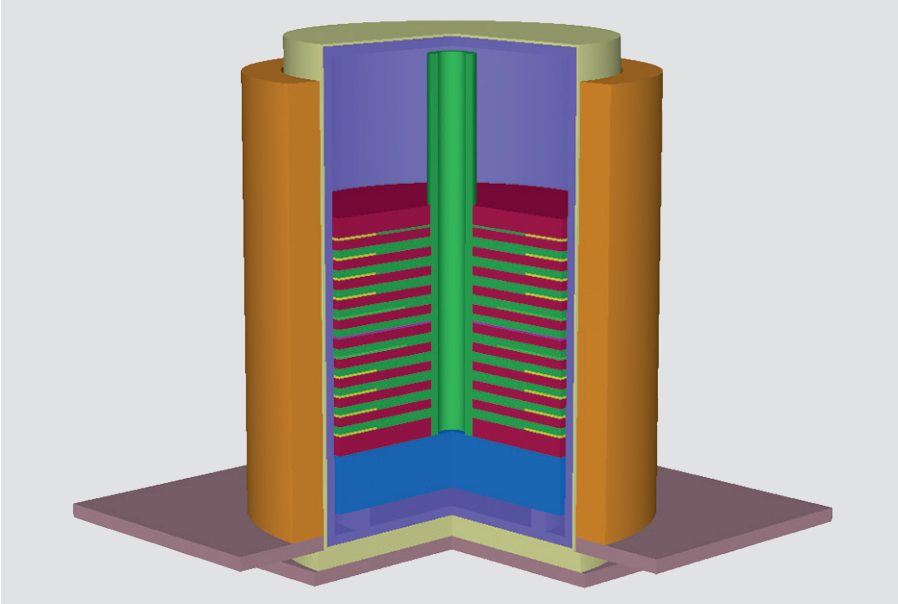
Lower temperatures can bring some systems closer to a critical chain reaction, which is an important consideration when transporting nuclear fuel (noting that the International Atomic Energy Agency (IAEA) transport regulations require criticality assessments to cover ambient temperatures of –40°C to +38°C). However, the lack of verified nuclear data relating to sub-zero conditions may potentially be leading to overly conservative safety cases with significant cost implications.

## Solution

NNL has been collaborating with LLNL in the United States on a multi-year, multimillion dollar 'world-first' critical benchmark experiment designed to fulfil this nuclear data gap, helping to develop a complex experimental rig capable of being cooled down and maintained at –40°C whilst critical experiments are performed.

## Outcome

During the 2021/22 FY, efficient cooling mechanisms under near vacuum conditions were investigated computationally by NNL to help shape the thermal design of the vacuum chamber associated with the experimental rig. The vacuum chamber is currently being engineered by a local vendor in the US with additional technical advice from NNL.



## Status

The work carried out by NNL is due to be published in July 2022 in the Critical Experiment Design 'Final Design' (CED-2) report. This report will form an important part in justifying to the US Department of Energy (USDOE) that the experiment is suitable for moving to the full build stage (currently planned for late 2022 and early 2023). NNL will continue to provide both criticality safety and thermal support to this project in the 2022/23 FY and hope to use this work as a platform to create additional collaborative links between the UK and USDOE to the benefit of UK industry.

# Innovation

Innovation is a key pillar of the NNL Science and Technology Agenda. The innovation programme at NNL uses a range of tools and strategies, including a challenge-led approach to develop solutions that address a range of internal, industrial and customer needs. The challenges at the Sellafield site form a key part of our portfolio.

Over the last few years, the Innovation team has been using a clear process to take ideas through the technology readiness levels to product delivery. This provides an optimistic environment to really assess an ideas merit for commercialisation. There are three distinct funding levels:

- Innovation Primer – Supporting early stage ideas with up to £1,000 funding to allow a review of scientific material to validate the proposed idea.
- Innovation Builder – Supporting initial proof of concept trials, with a maximum of £20,000.
- Innovation Delivery – Enabling commercialisation through product development, with awards > £20,000.

**Approved and funded Primer applications**

| FY20/21 | FY21/22 |
|---|---|
| 11 | 28 |

**Approved and funded Builder applications**

| FY20/21 | FY21/22 |
|---|---|
| 6 | 10 |

**Approved and funded Delivery applications**

| FY20/21 | FY21/22 |
|---|---|
| 2 | 4 |

**Overview of the innovation programme's funding streams**

| | Primer | Builder | Delivery |
|---|---|---|---|
| Purpose | Idea stimulation | Prototype | Commercialisation |
| Award size | < £1,000 | < £20,000 | > £20,000 |
| Duration | 2 months max | 12 months max | Unlimited |
| Review time | 1 week | 4 weeks max | 6 weeks max |

# Accelerating technologies for practical deployment at Sellafield


## Summary

Across NNL, a challenge-led approach to innovation is encouraged, embedding opportunities for out-of-the-box thinking within our everyday structures. Being able to do this quickly and in collaboration with others is crucial to driving disruptive innovation and to the benefit of the sector.


**Innovation in focus**

**Innovation Sprints... from Google to gloveboxes**

As part of the NNL Innovation team's drive to develop divergent thinking in to how we innovate; the Innovation Sprint process has been adopted, which is a novel and fast way of developing solutions.

Their first sprint focused on the application of NNL's Electrolytically Assisted Surface Decontamination (EASD®) technology (see pg. 33). This low hazard, flexible, cost effective and portable platform can be used to decontaminate metallic surfaces. The challenge presented to the sprint team was to find a way to deliver the process to remove hotspots from curved or non-uniform surfaces on the internal facing sides of a glovebox. The sprint took four days and involved input from a diverse team of colleagues across NNL and Sellafield Ltd. The results are extremely promising and are part of the ongoing innovation programme for this technology, as we develop the solution through the TRLs; to be fit for deployment.

"I thought that the 'Innovation Sprint' was a really fresh and different approach to the development of R&D. We are so used to thinking in a certain way prescribed by our roles that this sprint broke down those barriers and really got people thinking outside the box."

**Liz Ostle**
Decontamination specialist
Sellafield Ltd

"Having access to the TED Rig at the NNL Workington facility has provided FIRMA Engineering with a great opportunity to demonstrate its FIRMArm technology to potential end users. Access to experienced NNL technical staff provides valuable feedback on real working conditions faced at Sellafield."

**Lee Chapman**
FIRMA Engineering Ltd

**Case study update**
Technical Evaluation and Demonstration (TED) rig

- Last year the TED rig was constructed in our Workington facility for use as a demonstration space to thoroughly test technologies prior to their deployment on the Sellafield site.
- Its flexible design means that a multitude of deployment scenarios can be engineered to replicate 'on plant' environments.
- The TED rig has been successfully used to demonstrate a variety of technologies over the last year; in particular technologies arising from the Game Changers programme.
- Example: The FIRMArm, long-reach arm, has been demonstrated to be deployable from height for several metres, articulate at a 90° angle and extend to provide equipment or vision inside a vessel.

## Innovation in focus continued

### Collaboration with Mirion Technologies

NNL Inspection teams identified that their current camera inspection capability was reaching the end of its commercial life. Next generation products were deemed expensive options due to their frequency of contamination thus becoming unusable and ultimately resulting in a short working lifetime. Commercially available products with enhanced functionality, such as HD image capture, were too large for the deployment scenarios encountered by the team.

Based on the best available alternative technology, the NNL team worked with Mirion to co-develop a new, HD capture, camera system. This new camera is smaller than others available on the market, with dramatically improved image resolution, is small enough to be deployed through 150mm penetrations and is less expensive than other commercially available products.

The first deployable unit has been delivered to NNL colleagues in Workington and is available for demonstration and use by the Inspection team.

### Racelogic demonstration of their VBOX drone tracking technology

Demonstration of the VBOX Indoor Positioning System (VIPS), developed by Racelogic, was delivered by NNL in partnership with Racelogic at Energus in Workington. The VIPS enables highly accurate 3D position, speed and attitude (pitch/roll/yaw) tracking of drones in GNSS-denied environments.

VIPS work by utilising a network of stand-alone, battery powered beacons which communicate using ultra-wideband (UWB). The beacons are placed around the perimeter of the operation area, in known positions. A UWB receiver on the drone communicates with the beacons and uses trilateration to determine its position. This data is combined with the measurements from a highly accurate inertial measurement system, proving real-time, 3D positioning to within 2 cm and up to speeds of 270 km/hr. This industry leading accuracy is a result of Racelogic's custom hardware, software and calibration routines. Additionally, the beacons are temperature calibrated to ensure accuracy in all conditions, from -30°C to +60°C.

The demonstration informs and supports decision making on use of such technology within existing and future robotics projects at the Sellafield site.

"It was a great opportunity to meet the NNL team and to get a chance to demonstrate our indoor positioning technology on the drone. We learnt a lot from talking to potential users of our technology, and finding out more about the challenges involved in this particular industry."

**Julian Thomas**
Founder
Racelogic

# Collaboration

Collaboration is a core value for NNL. Ensuring that researchers, customers and the wider nuclear sector are connected together, developing partnerships based on long-term sustainable value.

We know that solving the challenges faced by the nuclear industry is best done together. This is why fostering strong relationships with academia, industry and the wider international community is so important.

We are committed to helping cultivate the right conditions for successful new development and promoting collaboration across academia, research bodies, government, and industry, both nationally and internationally.

"It doesn't matter who you work for, we're committed to delivering a clean and safe environment for future generations. This attitude, and the shared history of our organisations, was clear to see. I'm keen to develop that relationship and continue the level of engagement I saw."

**Robin Ibbotson**
Chief Technology Officer
Sellafield Ltd

# Robotics

## Summary

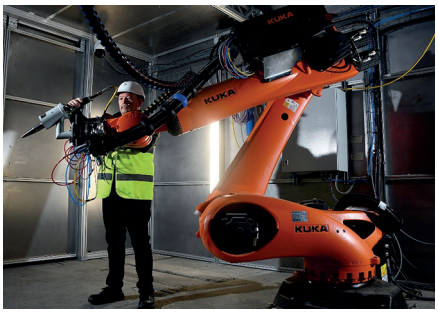
The NNL Robotics team uses collaboration to deliver key technologies of importance to both Sellafield Ltd and the wider national and international industry.

In addition to customer support, NNL invests in robotics projects with a track record of contributing to the sector and specifically to solving the challenges of the Sellafield site. This investment also ensures there is a healthy robotics capability within the laboratory.

NNL has sourced external leverage through EU/UK research councils to support capital investment, training, programme development, research and technology transfer; supporting the delivery of numerous projects including the Box Encapsulation Plant (BEP) Robotics and Simulation Programme, Robotic Laser cutting, and Alpha Decommissioning.

Testament to this capability are the organisations that NNL is involved with. Being active in these organisations means NNL is part of shaping the technological direction of robotics in the wider UK sector. NNL positions in these organisations include:

- Member of Sellafield Ltd. Central RAI Programme (C-RAI).
- Board member of National Robotics Network (NRN).
- Board member of OECD NEA Expert Group on the Application of Robotics and Remote Systems (EGRRS).
- Member of Robotics and AI Collaboration Laboratory (RAICO One) alongside Sellafield Ltd, University of Manchester, and UKAEA RACE.




### Robotics in focus

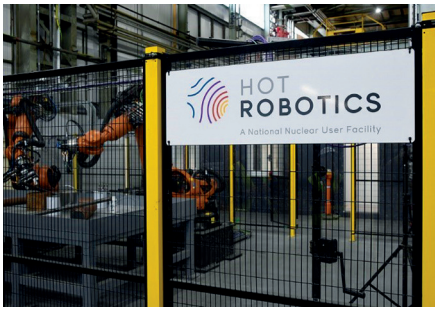
**Robotics in support of decontamination**

Supported by the Decontamination Science Theme and in collaboration with the University of Strathclyde and EDF Energy, an unmanned aerial vehicle (UAV) was developed to undergo full contact inspections of pipework. The aim is to use this to measure the impact of corrosion and determine material thickness of cylindrical pipework and vessels in hard to access locations. This has potential benefit across the nuclear sector.

**National Nuclear User Facility for Hot Robotics**

The National Nuclear User Facility for Hot Robotics (NNUF-HR) consists of four partners, each offering equipment and test spaces: NNL, University of Bristol, UK Atomic Energy Authority and The University of Manchester. NNUF-HR at NNL's Workington Laboratory provides industry-leading robotics for academic and Supply Chain users wanting to prove their robotic solutions to nuclear domain customers such as Sellafield Ltd. They also demonstrate NNL's experience with industrial robotics and our commitment to forwarding the state of the art in nuclear robotics.

NNL's facility saw its first external use in the previous year by a team from the University of Manchester. Their project on the development of a Natural Language Processing (NLP) system aims to enable robots to understand their environment and interpret instructions. For example, a user may ask the robot to pick up the yellow cylinder and the robot then correctly interprets that instruction, identifies the desired object and executes the task. The need for access comes from utilising the Kinova Gen3 robots within the NNL hosted NNUF-HR, as well as access to the expertise held within the NNL Robotics team.

# Remotely operated vehicle inspection in a highly radioactive facility, HALES

## Challenge

A requirement existed to inspect an identified quadrant of a Highly Active Liquor Evaporation and Storage (HALES) buffer storage tank, but due to the limited access to that corner of the compound, inspection by conventional means could not be carried out.

**These buffer storage tanks contain liquors of the highest activity on Sellafield site and are located in a cell, behind substantial concrete shielding. Access is only possible remotely via small diameter inspection ports which can be opened during inspection. The internal pipework and vessels within the concrete cell often prevents complete visual inspections to be carried out. The HALES facility contains some of the oldest infrastructure on Sellafield site therefore it is critical to monitor the condition of the plant thus ensuring its continued operation. This enables the high activity liquors within to ultimately be converted into a stable wasteform, vitrified glass, in another facility at Sellafield.**

## Solution

The NNL Plant Inspection, Characterisation and Development team developed a remotely operated vehicle (ROV) capable of carrying an inspection camera that could be deployed through the wall of the compound; and lowered to the tank floor to carry out the remote visual inspection. Some of the funding for this development came from public interest reinvestments.

## Technology

The ROV was developed with a stainless steel frame to provide safe deployment and retrieval through the wall access; and to facilitate lowering and raising of the vehicle into the tank using an external winch and strain wire. An inspection camera with integral lighting was attached to an ROV; along with an umbilical containing power, control and video signal cables. The design also allowed for a conventional inspection camera to be deployed after the vehicle, so that the movement through the cell could be monitored from above.

## Outcome

The use of the developed ROV for this inspection has increased the remote visual coverage of the HALES tank walls by approximately 20%. It has also increased the quality of images obtained within the cell, and also allowed more accurate identification of the tank wall condition.

## Status

Further inspection opportunities have been identified from the development and active deployment of this ROV; including inspection of the other HALES buffer tanks, sampling water from external compound sumps, and chemical analysis.

# Small and Medium Enterprises


## Summary

We work in partnership with innovative companies to deploy value adding technologies in the nuclear sector. Our expertise within the laboratory provides crucial understanding to progress technologies past the technological 'valley of death' and into the industry.


Whether providing support in-kind or direct funding, earnings to reinvest play an important role in helping small and medium enterprises (SMEs) develop their technologies for deployment. Some of the SMEs we are working with that help with Sellafield's mission include:

- FIS360, delivering the Gamechangers programme
- C-Tech, innovation on delivering EASD® and ELENDES
- FIRMA Engineering Ltd, FIRMArm technology for challenging deployments
- Racelogic, developing tracking drones in GPS denied environments
- Resolve Robotics Limited, handling hazardous materials in gloveboxes
- Mobetrics Limited, digital data capture
- Finden Ltd, NOx abatement
- Alfa Rift Oy, alpha detection solutions
- Llechi Slate Evolution Cyf, net zero encapsulation of waste
- Cloburn Quarry Company Ltd, net zero encapsulation of waste
- Mirion Technologies (IST) Ltd, HD rad tolerant inspection camera and alpha detection solutions.

# Electrochemical Assisted Surface Decontamination (EASD®)

## Challenge

Sellafield Ltd has been exploring innovative technologies to enable a significant reduction of radiological hazards within facilities during the Post Operational Clean Out (POCO) phase of a nuclear plant's life cycle. Reducing the hazard by effectively decontaminating plants in situ during POCO delivers huge cost reductions for future decommissioning operations.

**These cost reduction benefits are realized by reducing the number and complexity of remote operations as well as lowering the long-term waste disposal costs. Whilst chemical decontamination can achieve the desired level of decontamination, applying aggressive chemical reagents is hazardous, potentially difficult to control and requires there to be complimentary effluent treatment and waste routes. As innovative technologies progress up the TRLs, active testing is required to demonstrate the technologies capability. At Sellafield and across the wider nuclear sector there are metal surfaces with associated contamination (see pg. 14), during decommissioning decontamination could play an important role in reducing the volumes of higher activity wastes.**

## Solution

Electrochemical decontamination offers a possible methodology for enhancing the effectiveness of native reagents, such as nitric acid, without the complications of adding new chemical agents (i.e., no requirement to add aggressive acids or oxidizing agents). This technology could play a key role in the decommissioning of facilities at Sellafield, where remote access is required.

## Technology

The EASD® device uses an electric current to remove contaminated surface layers from metals. The activity on the surface is solubilised and can be washed away for treatment whilst the decontaminated metal that remains can be redirected to lower activity waste. This technology can be deployed in situ.

## Outcome

Several devices have now been designed that incorporate this EASD® technology and enable the decontamination process to be applied to a range of commonly contaminated items, such as pipework, tanks and hotspots of walls/floors. Recently, the EASD® technology has been demonstrated on a problematic metallic waste container (mild steel) at NNL's Preston facility which had originally been used to transport and store depleted U swarf. The container was successfully decontaminated to free-release levels in about 6-10 minutes. Analysis showed decontamination was achieved by removing 130 µm of surface material from the contaminated surface. In addition, the EASD® Gel technology was also benchmarked against other decontamination technologies currently available to Sellafield Ltd for hot spot treatment, out-performing the others when contamination had deeply penetrated into surfaces.

## Status

Engineering-scale tests have been performed on the variations of the technology, with guidance from Sellafield's system engineers and plant managers, to provide the necessary reassurance the designed devices could be successfully deployed in an on-plant scenario. The final stage of this development work is to carry out demonstrations on the Sellafield plant, two of which are currently planned.

# University Collaborations

## Summary

Working in partnership with academia allows NNL to unlock ideas, increase understanding and develop scientists of the future. NNL is well placed to connect academic ideas and understanding with industrial challenges.

### University Collaborations

**Universities**

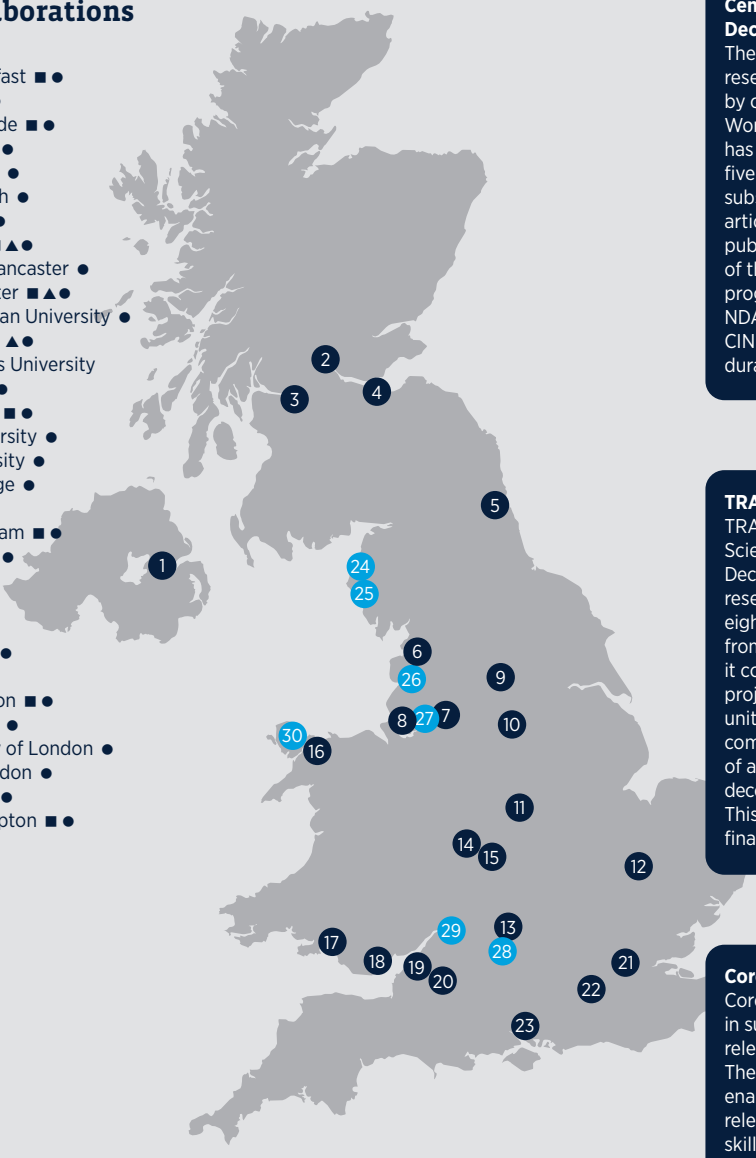
1 Queens University Belfast ■ ●
2 University of Stirling ●
3 University of Strathclyde ■ ●
3 University of Glasgow ●
4 Heriot-Watt University ●
4 University of Edinburgh ●
5 Newcastle University ●
6 Lancaster University ■ ▲ ●
6 University of Central Lancaster ●
7 University of Manchester ■ ▲ ●
7 Manchester Metropolitan University ●
8 University of Liverpool ▲ ●
8 Liverpool John Moore's University
9 University of Leeds ■ ●
10 University of Sheffield ■ ●
10 Sheffield Hallam University ●
11 Loughborough University ●
12 University of Cambridge ●
13 University of Oxford ●
14 University of Birmingham ■ ●
15 University of Warwick ●
16 Bangor University ●
17 Swansea University ●
18 Cardiff University ●
19 University of Bristol ■ ●
20 University of Bath ●
21 Imperial College London ■ ●
21 King's College London ●
21 Queen Mary University of London ●
21 University College London ●
22 University of Surrey ■ ●
23 University of Southampton ■ ●

**NNL facilities**

24 Workington
25 Sellafield
26 Preston
27 Warrington
28 Abingdon
29 Stonehouse
30 Gaerwen

**Key**

▲ CINDe
■ TRANSCEND
● Core Science R&D




**Centre for Innovation in Nuclear Decommissioning (CINDe)**
The first CINDe programme enabled researchers to work closely with industry by co-locating their workspace at NNL's Workington Laboratory. The programme has funded 16 PhD students across five cohorts in Cumbria with three subsequently joining NNL. Eleven journal articles and one book chapter have been published over the last year. The success of the joint NNL, Sellafield and NDA programme has been recognised by the NDA (see pg. 41). A second programme, CINDe 2, has an expected nine years duration.

**TRANSCEND**
TRANSCEND (Transformative Science and Engineering for Nuclear Decommissioning) is a £9.4m collaborative research consortium of 11 universities and eight industry partners (including support from public interest reinvestment), and it comprises 40 PhD and post-doctoral projects. The programme aims to unite academic and industrial research communities to enable the adoption of a comprehensive approach to decommissioning and waste management. This programme has now entered its final year.

**Core Science Theme PhDs**
Core Science Themes play a key role in supporting projects that have direct relevance to Sellafield challenges. The flexibility provided by each Theme enables projects to be created that target relevant issues and ensure that critical skills are developed and maintained.

# Understanding the transport of slurries to prevent blockages

## Challenge

Some of the liquors at the Sellafield site contain solids that can settle out and block pipelines during transportation, if the flow rate is too low, which can delay operations. Understanding the behaviour of solids settling can help determine the conditions that a plant must operate under. This helps to avoid a regime where solids settle out during transport, minimising plant downtime.

"The results to date have substantiated our baseline strategy for washout... so the value is in avoiding having to develop a new process... a cost of circa £550m is probably credible."

**Katherine Eilbeck**
Head of R&D
Sellafield Ltd

## Solution

CINDe work enabled the effective application of the latest understanding in solid settling behaviour to industrial challenges. The CINDe PhD focused on developing fundamental fluid dynamics of the flow regime and underpinning it by experimental measurements on the Slurry Transport Rig (STR). A novel flow correlation (FRESCO) was developed for this flow regime which was shown to accurately predict the bulk fluid. Sedimentation behaviour is characterised by a single dimensionless parameter. The methodology developed presents a powerful framework for the design of slurry pipeline transport operations.

## Technology

The framework allows for different settling regimes to be determined based on the fundamental parameters that govern the process. This then helps the end user to fine-tune these parameters, allowing optimisation and expansion of the operational envelope of this transport window.

## Outcome

The work on the FRESCO and settling factor correlation has been written up and published in the academic literature as well as compiled into a PhD thesis. The STR has been reconfigured to directly support various Sellafield plants to better understand how slurries will behave during transport.

## Status

The PhD was completed with the researcher subsequently joining NNL full-time, using the skills they developed during the PhD, to continue to provide slurry transport support and expertise to Sellafield Ltd.

# International Programmes


## Summary

Through investing in people, facilities and the Science and Technology Agenda, NNL is able to take on important roles in international programmes. Understanding the needs of the end user means these programmes are tailored to make best use of resources, as challenges faced by the sector are often international in nature. Funding for international programmes in 2021-2025 includes combined grants of £2m with additional funding from NNL and other parties such as Sellafield Ltd.


**International Programmes in focus**

Part of the value of being involved in these programmes comes from working in partnership with international scientists to solve a challenge more efficiently. It also provides exciting opportunities for the development of the next generation of scientists to build connections.

These programmes also receive direct contribution as part of Strategic Research or a Core Science Theme. For example, the Decontamination Science area supports work on the characterisation and decontamination of contaminated metals as part of the PREDIS programme.

**Case study update**

Pre-Disposal Management of Radioactive Waste (PREDIS), one year in

- The PREDIS programme is a large scale European project with 48 organisations across 18 EU member states.
- Its target is to develop and implement pre-disposal treatments of radioactive waste streams. NNL leads on one of the work packages, developing the European Strategic Research Agenda for PREDIS.
- The project is currently one year into a four year programme. PREDIS is in its second year, coordinated by the Finnish organisation VTT, with a total programme of €24m.
- In addition to the artificial contamination work highlighted in Decontamination Science, PREDIS is developing innovative treatment options for metallic wastes, liquid organic and solid organic wastes. Further work focuses on automation/ monitoring of waste storage.

# UK featured country at Waste Management Symposium 2022

## Challenge

It is critically important to be sharing learning with the international community about UK waste management practices and progress. This enables feedback as well as allowing the UK to bring back learning from international colleagues and businesses.

## Solution

At this year's Waste Management Symposium, the UK was the featured country. This meant many technical sessions were dedicated to UK waste challenges as well as there being a showcase of UK organisations in the exhibition hall. It was held in person for the first time in two years with NNL staff taking a leading role in organising the UK content, in partnership with the NDA, the Department for International Trade (DIT), the Nuclear Industry Association (NIA), and Sellafield Ltd. The purpose was to showcase the collaborative UK effort towards achieving the goal of remediation and environmental restoration across the NDA estate and to showcase the strength and capabilities of the UK nuclear sector.

## Outcome

Around 200 of the approximately 2,200 delegates in attendance were from the UK across site licence companies, government organisations and SMEs and included substantial contributions from NDA and Sellafield Ltd. This showed a strong united UK collaborative effort in decommissioning, with 73 of the 320 technical papers coming from UK participants. At the event a UK-US statement of intent in the area of waste management was signed between DOE, NDA, and NNL. This is beneficial for Sellafield Ltd as it means a greater sharing of learning can take place around remediation operations in both the UK and US. This should help to unlock further cost and schedule reductions.

NNL Core Science Themes supported the attendance of NNL staff to showcase work in the area of Decontamination Science, Thermal Treatment, CINDe and TRANSCEND.

# Enablers

To deliver cutting edge science requires talented people, world-class facilities and dependable digital infrastructure.

At NNL there are world-leading scientists, engineers, technologists and experts across multiple fields focused on nuclear research and championing new ideas for industry. We make sure to invest heavily in our people to continue to deliver quality science and technology that has impact.

In addition to our people, NNL operates unique nuclear facilities and cutting edge laboratories that enable our people to push the boundaries of science and innovation. We continue to make improvements and to open up access to our facilities to a wider range of potential users.

# Technologies and Digital Change

## Summary

World-leading science and technology delivery requires world-leading infrastructure. It is important to not only invest in physical assets, but digital infrastructure plays a key role in our capability.

We have been building on the remote working capability that was rapidly deployed during the COVID-19 pandemic to enable our staff to take advantage of hybrid working to deliver customer work. This ensures disruption is limited and frees up our office facilities to be utilised for more collaborative activities.

Behind the scenes substantial upgrades to our security infrastructure have been carried out along with a fundamental change in how our digital network operates. This should increase the user experience and reduce downtime. As identified last year, High-end computing is undergoing a substantial upgrade which should enable more calculations to be performed.

Over the coming months, Surface Hub technology will be rolled out enabling more collaborative hybrid meeting rooms, recognising the geographic diversity of our work and collaborators.

# Technical Skills and Capability


## Summary

People are crucial to the capabilities that NNL offer. From apprenticeships through to senior leadership training, there is substantial investment in our talented people. Without the technical skills and experience of many across the sector, the UK would not be the nuclear nation it is today. NNL contributes to the Nuclear Skills and Strategy Group (NSSG) and shares its commitment to addressing the sector's skills challenge and to bring new voices to the industry.


From apprentices, graduates and post-doctoral researchers, to mid career and senior technical leaders, NNL provides support for development and growth.

Apprenticeships play an important role, whether they are in engineering, scientific, business, IT or project management roles. NNL has candidates studying from Level 3-7. Building on the history of its graduate programme, NNL has recently adjusted its scheme allowing training to be tailored to suit individual needs.

Our post-doctoral scheme has been running for just over a year, setup in recognition of the unique skillset that is developed during a PhD. In addition to targeted training, those on the scheme have dedicated time to explore technical areas of interest and develop ideas.

One of our technical leaders was successful in their application to be part of a BEIS initiative called the Future Leaders Programme. This brings together industry, government and academia from across the technical domains to connect with technical leaders. Representation from NNL staff in this highly competitive scheme continues in the upcoming cohort, with a further two candidates involved.

"Seeing students acquire valuable nuclear skills and once they finish their PhD go onto work in industry is a key part of what CINDe was setup to achieve."

**Anthony Banford**
Chief Technologist,
Waste Management
and Decommissioning
NNL

"Completing the Scientific Apprenticeship at NNL has given me excellent opportunities to develop my career. I have been able to complete further education alongside working in active laboratories and gaining practical skills. Receiving recognition at the National Skills Academy for Nuclear Awards has given me a great sense of pride and accomplishment in my achievements so far."

**Kerry Jackson**
Scientific Apprentice
NNL

**18**

graduates,
with an additional 27 in 2022

**50**

apprentices,
with an additional 13 in 2022

**16**

post-doctoral candidates,
with an additional 13 in 2022

**8,080**

online e-learning courses,
66 virtual training events
and 13 education concessions

## Awards and recognition

National Skills Academy for Nuclear Awards 2022

**Nuclear Graduate of the Year**
Winner – James Dewar

**UK Nuclear Apprentice of the Year**
Winner – Kerry Jackson

**Inspirational Role Model**
Runner-up – Emin Vernon

**NDA 'Best People Strategy Award'**
Winner – CINDe PhD programme

"Being a graduate at NNL has opened many doors: from knowledge of the nuclear industry to working in different capability areas to advancing ED&I in its many forms – there has been a lot to get involved with."

**James Dewar**
Graduate Scientist
NNL

"I started on the Post Doc Scheme in September 2021, having been in the company for under 9 months, and thus far have found the course to be hugely beneficial. The broad range of targeted sessions have helped me hone my soft skills, understand my strengths and learn more about NNL as an organisation. For myself, the most valuable aspect of the course has been the time provided to explore other technical areas of interest."

**Ruth Davey**
Experimental Rig Operator
NNL

"I was very proud to be the first NNL representative accepted on to the Foundation for Science and Technology Future Leaders Programme. I was particularly impressed with the seniority and range of speakers on hand across the sessions."

**John-Patrick Richardson**
Future Leaders Programme,
Robotics Theme Lead
NNL

# Facilities and Infrastructure


## Summary

We are custodians of a unique set of facilities and capabilities that enable ground-breaking nuclear research and development – including four world-leading laboratories in the North West of England. Sustained investment in our facilities helps ensure we can deliver for our customers and continue to be world-leading in the services we provide, by ensuring researchers, the supply chain, academia and customers can carry out critical R&D to support UK nuclear sector missions and beyond.


In 2021/22 NNL embarked on a major programme of refurbishment and modernisation of its laboratories to ensure its ability to meet its customers' needs, as well as continue to support the R&D activities of its partners in academia, the supply chain and the nuclear sector more broadly, all of whom rely on NNL's unique capabilities to achieve their own national and organisational goals.

In 2021/22 NNL delivered around £24m of improvements to its four laboratories including:

- Physical upgrades to its facilities that further improved safety and reduced operational risk.
- Building its inventory of critical spares and replacing, refurbishing, or repairing outdated machinery, instrumentation, and equipment.
- Increasing its capacity and capability to deliver by bringing under-utilised or currently 'out of service' areas within its laboratories back into service.
- Enhancing its health, wellbeing, and safety at work facilities for the benefit of all its staff and other users of its laboratories.
- Completing the first phase of a major digitalisation programme, aimed at introducing the technologies that will underpin and increase efficiency of NNL's Asset Care and Maintenance activities in the future.

That programme will continue through to 2024/25 with investment of a further circa £80m in NNL's facilities, technology infrastructure and equipment, to ensure it is able to continue to play the critical role NNL plays for the UK, support the national programmes and to meet its customers' and partners' existing and future needs.

# Enabling scientists and companies to utilise unique capability

## Challenge

There are many researchers both in academia and industry for whom access to our facilities would accelerate their research and development. Unfamiliarity with working in these environments, and the security and safeguard requirements may mean researchers are discouraged from seeking access. It is important to ensure that those considering using our capability are empowered and encouraged.

"We are grateful for having been given access to the NNUF Hot Robotics facility at Workington... The support given by Dr Cuebong Wong, Dr Brendan Perry and Peter Sweetman – from system configuration/troubleshooting to expert advice – has been invaluable and has enabled us to complete our experiment successfully."

**Mr Shayaan Sindhoo, Dr Viktor Schlegel and Dr Riza Batista-Navarro**
University of Manchester

## Solution

In recent years, NNL worked to increase accessibility of its unique capability to other researchers whilst maintaining the level of security expected. Because of where the majority of NNL's capability is located, this has required collaboration with the site owners such as Sellafield Ltd. NNL supported a dedicated team whose role offers unfamiliar users the guidance to work in our facilities. This provides not only valuable R&D but also experiences for the early careers workforce of what it can be like to work on nuclear sites.

## Outcome

Despite the restrictions of COVID, over the last year we have still managed to host researchers in our facilities. The projects directly related to environmental restoration at Sellafield include:

- NNL Preston has been used by a PhD student to carry out hands on experimental work supported by the Decontamination Science Theme (see pg. 15).
- NNL Windscale has seen Electrochemical studies of irradiated AGR fuel, which supports the delivery of a PhD project (see pg. 23).
- Staff from the University of Manchester have utilised the NNUF-Hot Robotics facility at Workington (see pg. 30).

A dedicated User Access team produced guidance documentation to help external users to understand the specific requirements of each facility. Last year this was trialled for the Hot Robotics NNUF facility at NNL Workington, where academics used the documentation to help them successfully gain efficient access.

This closer interface between academia, NNL, industry and companies will help drive forward the goal of environmental restoration.

## Status

The User Access team continues to work closely with potential users. Since FY20/21, we have been more proactive organising specific user access calls to make it even easier to put forward proposals for use of our facilities. As COVID restrictions have lifted we expect an increase in access once more.

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