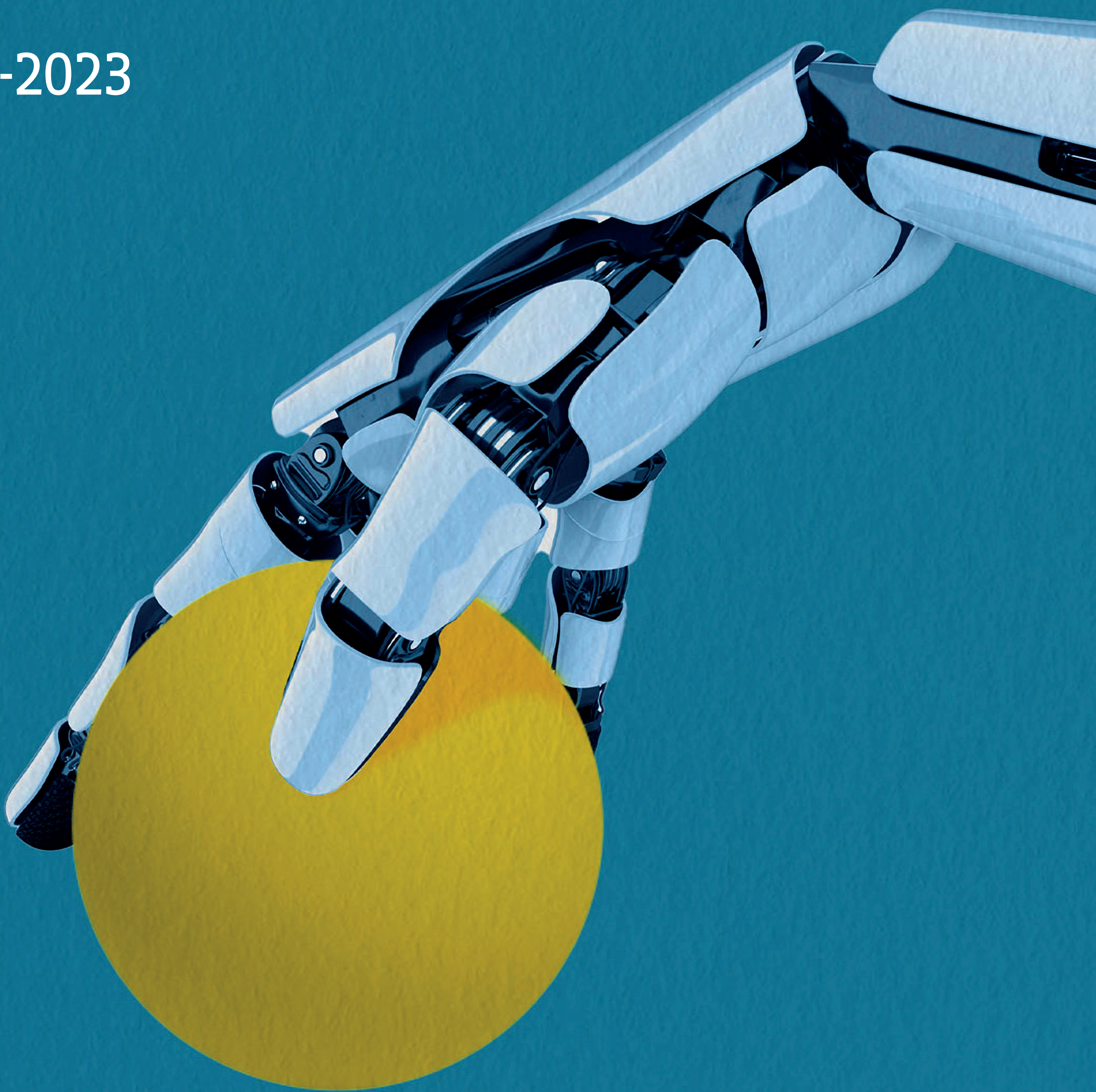
Public Interest Reinvestment Contributions to

Environmental Restoration

2022-2023



NATIONAL NUCLEAR LABORATORY

Contents

Introduction

Wayne Muckley
VP Legacy Sites
NNL

When we reflect on the thriving partnerships NNL has cultivated over the years as the UK's national laboratory for nuclear fission, one thing is abundantly clear: it is not just about what we do and how we do it, but also who we do it with. The strength of our partnerships with organisations such as Sellafield Ltd, the Nuclear Decommissioning Authority (NDA) and its operating companies is a testament to our commitment to working collaboratively, taking responsibility to deliver a step change in Environmental Restoration of the UK's nuclear legacy.

Through our Science and Technology Agenda, NNL continues to address some of the biggest challenges faced in clean-up operations of nuclear facilities. So, it is with great pleasure that I introduce this report detailing our delivery of public interest reinvestment in FY22/23 which showcases this work.

The work undertaken as part of NNL's Science and Technology Agenda is funded through earnings to reinvest. This report focuses on the science and technology we have delivered over the last year, and we plan to achieve over the coming financial year. In addition, this report will provide examples of how the work builds on prior projects and shows the development of science and technology over multiple years.

NNL's partnership with Sellafield Ltd is particularly remarkable due to the estimated more than £7bn cost saving since 2008. This has been achieved through continued optimisation and innovation of science and technology relevant to the Sellafield site. The Technical Services Agreement between NNL and Sellafield Ltd allows us to look long-term and collaborate to identify what technology, skills and people might be required for the environmental restoration of the site. We will play our part in helping to deliver this whilst also working collaboratively with the NDA, Ministry of Defence (MOD), and others to support the environmental restoration of their sites, harnessing nuclear science to benefit society.

This report provides many notable examples of work we have carried out over the last several years. Typically, this work has started with small investments from the reinvestment of earnings to progress capabilities and technologies through the Technology Readiness Levels.

Some of the highlights include:

- Participation with international partners in ASTM tests for high level waste durability testing.
- Collaboration with the US Department of Energy's national laboratories on fuel cycle technologies as part of the US-UK action plan.
- Developing and demonstrating ReCAP technology to be used for accessing vessels during Post Operation Clean out on the Sellafield site.
- Shaping subject matter experts in Decontamination and Decommissioning through sponsorship of PhD programmes, and involvement with programmes such as CINDe and TRANSCEND.

As we move forward with our vision for creating a safer and cleaner environment for future generations, I want to take the opportunity to express my gratitude to our partners and customers for their investment and support throughout the global challenges of the previous few years. The resilience shown in response to the challenges arising from the COVID-19 pandemic is evidence of the commitment, trust, and collaborative ethos in today's nuclear sector.

We are incredibly proud of the collaborative relationship we have established with NNL. Working closely to develop and share the purpose of creating a clean and safe environment for future generations aligns with the values of both organisations.

Robin Ibbotson
Chief Technology Officer
Sellafield Ltd

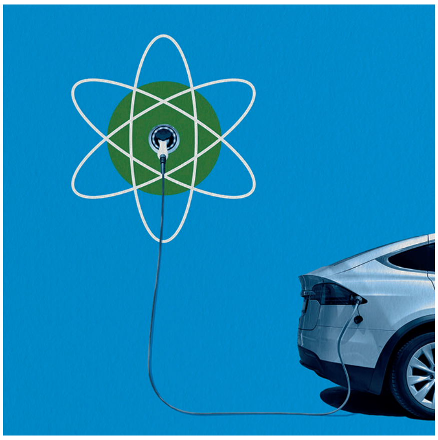
The past financial year has been another opportunity for investment into people, skills, science, and technology. Facilitated by the unique lifetime collaboration agreement Sellafield Ltd and NNL have held since 2017, we have been able to nurture the innovative ideas essential for the development of the UK nuclear industry.

To deliver our purpose of creating a clean and safe environment for future generations we first must take responsibility for the safe, secure, and sustainable stewardship of nuclear material on the Sellafield site. The technical expertise which NNL has in these areas help us greatly in our mission.

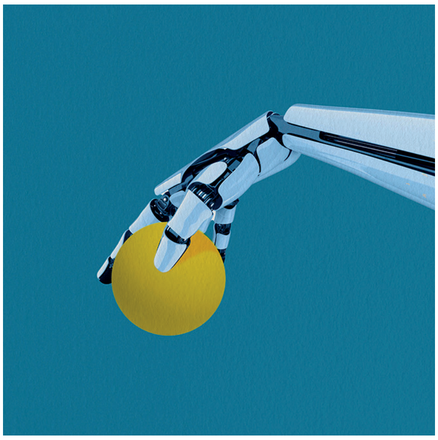
At Sellafield Ltd, we invest in understanding the aspirations of our collaborative partners, aligning their needs with our own to forge a path which benefits us all. The agreement we have with NNL shows that this is not a one-time effort; it is a continuous commitment to mutual growth. Whist we monitor and measure financial success and the benefits which a technology may bring, we also recognise that an investment can have a profound and positive impact on the unique skills and capabilities required to underpin site strategy. Growing in these areas helps us to be more prepared for the future known, and unknown challenges we have yet to face.

Context

NNL is committed to using its surplus earnings from previous financial years to reinvest in science and technology for the public interest through four focus areas. This investment delivers value for Sellafield Ltd, the NDA, the Department for Energy Security and Net Zero (DESNZ) and other customers via the development of technologies designed to tackle the nuclear industry's challenges.



Clean Energy



Environmental Restoration

Health and Nuclear Medicine

Security and Non-Proliferation

This reinvestment approach is applied across the entire portfolio of NNL commercial work and allows NNL to deliver nuclear science to benefit society for today's nuclear climate. Such reinvestment also enables NNL to meet its responsibility as a national laboratory and Public Sector Research Establishment (PSRE), supporting UK policy and strategic ambitions. NNL has defined four focus areas to develop solutions that are most relevant to nuclear.

The environmental restoration focus area is about investing in innovative, sustainable, and safe solutions to the management of hazardous waste generated from nuclear operations. All three of the other focus areas therefore evolve from environmental restoration, in terms of the science and technology and capability which has been developed. There are several core science themes associated with environmental restoration helping to deliver change in this area.

Investment in environmental restoration aims to bring 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 the technical and analytical knowledge base to deliver solutions to the significant technical challenges across nuclear licenced sites.

Overview

Activity

SCIENCE AND TECHNOLOGY

Decontamination Science

- Radiation mapping via unmanned aerial vehicles (UAVs) (PhD, University of Bristol)
- Remote characterisation via bio-fluorescence (PhD, The University of Manchester)
- Remote characterisation of sludges and sediments (PhD, University of Liverpool)
- Development of alternative IX materials for SIXEP (Sellafield Ltd co-funded) (PhD, University of Birmingham)
- Fibre optic sensing (PhD, The University of Manchester)
- Simulating contaminated materials – NNL, Horizon 2020 PREDIS (Pre-Disposal Management of Radioactive Waste) programme, and Sellafield Ltd – alignment of several research programmes with the shared R&D requirements centred around understanding contaminated metallic surfaces
- Electrochemical decontamination of concrete (PhD, University of Lancaster)
- Decontamination of stainless steel (PhD, The University of Manchester)
- Simulating the contamination of stainless steel (PhD, University of Lancaster)
- Decontamination of bricks (PhD, University of Lancaster)
- Characterisation via hyperspectral imaging (PhD, The University of Manchester)
- Sludge transport dynamics (PhD, University of Liverpool)
- Non-destructive testing inspection via magnetometry (PhD, University of Warwick)
- Capture of fume from laser decontamination (PhD, University of Loughborough)
- Organic semiconductor alpha detectors (PhD, Queen Mary University)
- Characterisation via LIBS (PhD, The University of Manchester)
- PFLOWTRAN modelling of contaminated surfaces
- Wireless instruments for nuclear digitalisation
- New composite zeolites for nuclear waste remediation (PhD, University of Birmingham and Diamond Synchrotron Light Source)
- Wireless technology HUB creation
- Non-contact pressure measurement of sealed special nuclear material containers
- Development of concrete contamination model
- Methodology development for preparing contaminated concrete coupons
- Optimisation of the preparation and characterisation of contaminated metal coupons
- Standardised monitoring of $1m^3$ waste bags

This Gantt Chart provides an approximate indication of timescales for projects. There is focus on the delivery within the FY22/23-FY23/24 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

SCIENCE AND TECHNOLOGY CONTINUED

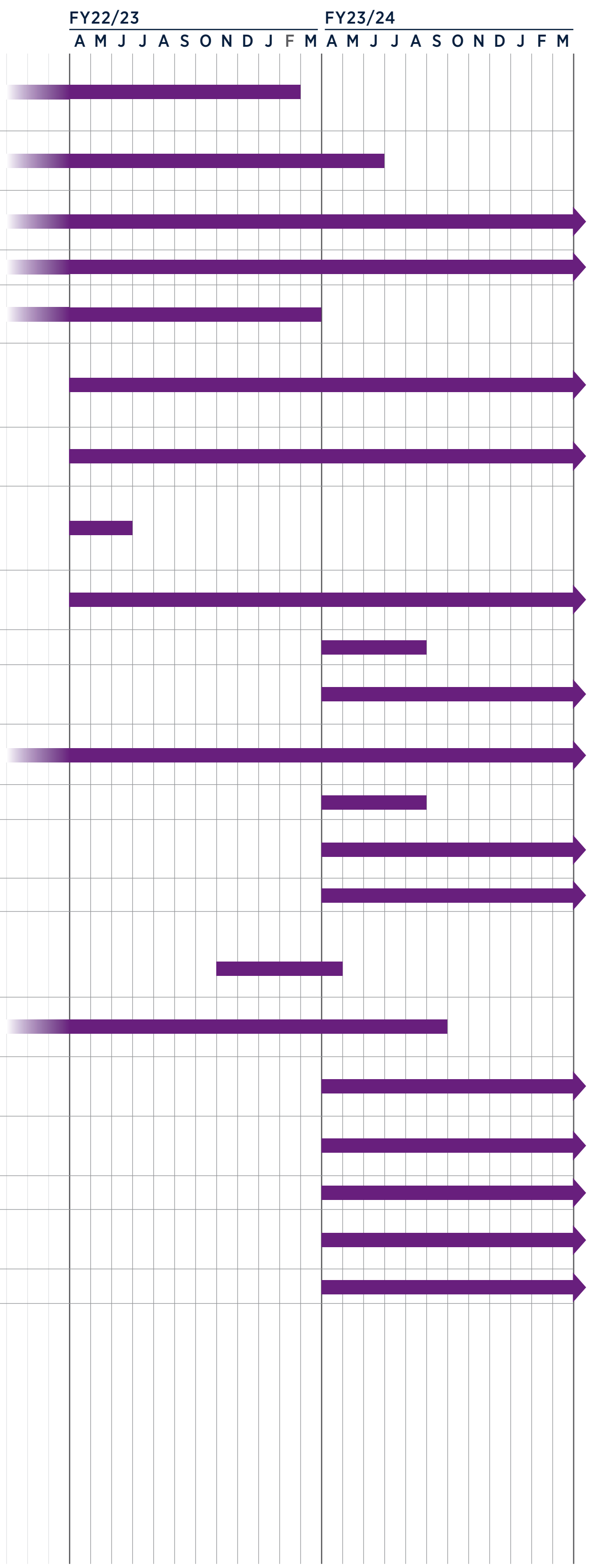
Environmental Radiochemistry

- Utilising in situ experimental capability (sample handling and microscopy techniques) to study microbial processes relevant to waste silo and effluent systems
- Ongoing experiments with spent fuel – learning with reprocessing plant decommissioning and POCO washout
- Microbe – radionuclide interactions in legacy nuclear waste systems (PhD, The University of Manchester)
- Training of Scientific Apprentices in NNL's Central Laboratory
- Supporting numerous PhD projects working on concrete samples from nuclear-licenced sites
- Effect of sediment and groundwater flow heterogeneity on accurately modelling radionuclide transport at UK nuclear sites (PhD, University of Leeds)
- Transport of radioactive waste along the Sellafield shoreline: climate change impact and mitigation strategies (PhD, University of Liverpool)
- Long-term interactions of radionuclides with iron oxyhydroxides in geodisposal and contaminated land environments (PhD, The University of Manchester)
- Computer modelling – advanced modelling tools to simulate complex groundwater flows and contaminant transport
- National Nuclear User Facility RADAR active laboratory work studying U/Tc
- Contaminated land and geological disposal of nuclear waste – new experimental work to be done eventually, starting with planning
- Modelling – linking legacy models with more modern modelling – ground water flow transport codes
- Geochemist's Workbench mibrobial model development
- Introducing uncertainty in chemical speciation modelling to facilitate probabilistic models
- Develop strategy and roadmap for contaminated land area

PARIS

- Further IR (and BET) experiments to understand mechanisms for physical adsorption
- Supervision of NDA funded Postdoctoral Research Award (PDRA) to understand PuO_2 behaviour during interim storage
- Analytical method development analytical of ICP-MS and LSC method development
- Radiolysis of actinide oxide surfaces and understanding mechanisms of radiolysis
- Literature review exploring gas phase reactions on actinide surfaces
- Development of accurate spectra of actinides in solution to support future Sellafield Ltd work
- Pu solid modelling, to include temperature in cans etc

Timescale



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Activity

SCIENCE AND TECHNOLOGY CONTINUED

Thermal Treatment

- Active glass fabrication and sampling and analysis capability development for active thermal processing
- Thermal product assessment: beginning validation techniques for homogeneity assessment
- Advanced microscopic techniques for wasteform characterisation
- Advanced microscopy of leached glasses which utilises the NNUF/Royce equipment, plus ongoing user access collaborations with university partners (in-person visits planned)
- Long-term performance of thermal wasteforms (chemical, thermal and radiation stability)
- Assessment of the effects of ionising radiation on the properties of vitrified UK High Level Waste (PhD, The University of Manchester)
- Assessing stored energy due to radiation effects in nuclear wasteforms (PhD, University of Liverpool)
- Time temperature transformation diagrams regarding thermal stability of radioactive waste glasses (PhD, University of Liverpool)
- Development of ceramic wasteform capability – Synroc

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
- Graphite waste management for the reduction of quantity of intermediate level waste

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 as 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 and emerging sensitivity/uncertainty tool application, (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-3A 'Initiate Facility Plan' stage associated with a low temperature critical benchmark experiment
- Providing thermal and criticality support to Lawrence Livermore National Laboratory on the CED-3B execution stage associated with a low temperature critical benchmark experiment
- Co-ordinate the UK Working Party on Criticality Continued Professional Development webinar series with Sellafield Ltd

Timescale

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Activity

SCIENCE AND TECHNOLOGY CONTINUED

Robotics

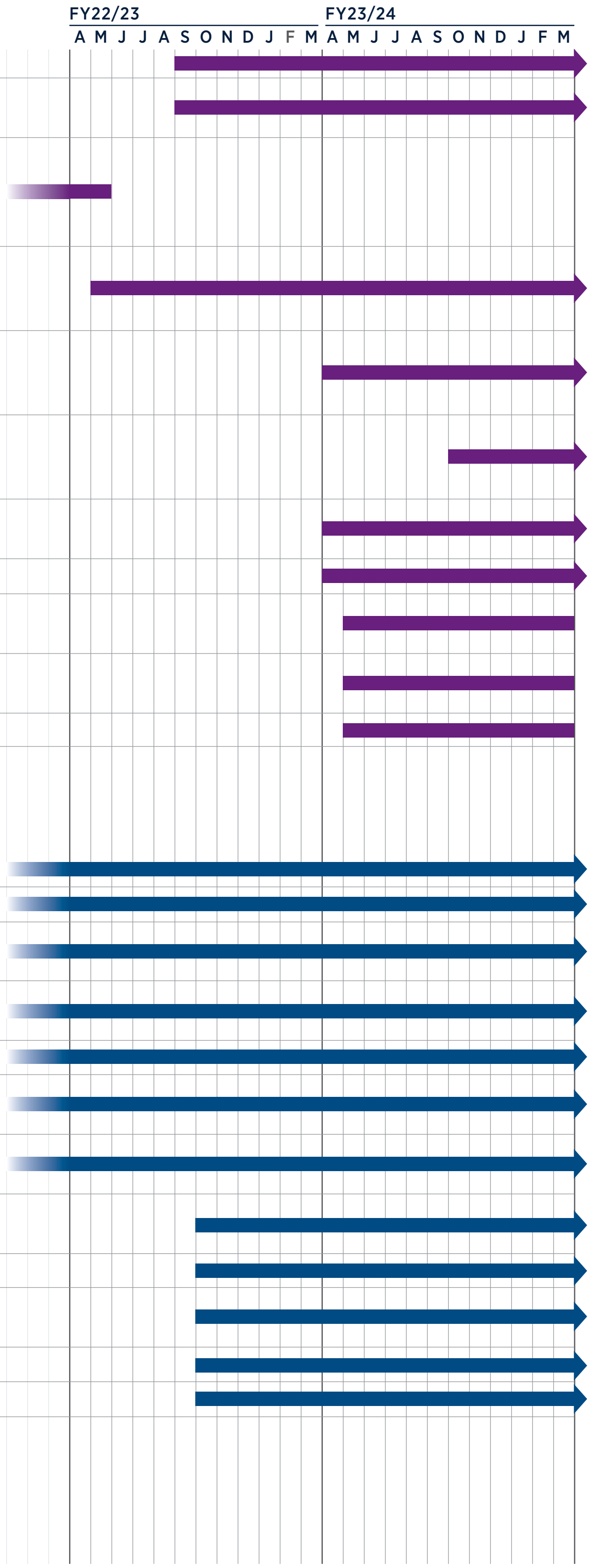
- Conducting physical trials and setting up of capability demonstration
- Understanding and developing vision-based local surface profiling and adaptive path correction for laser cutting applications
- Completion of New National Nuclear User Facility for Hot Robotics (NNUF-HR) for nuclear robotics R&D. 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
- Co-funded PhD studentship with University of Strathclyde on 'Ensuring Decommissioning Safety, Integrity and Verification through Advanced Sensor-Enabled Cutting'
- Co-funded GREEN PhD studentship with Lancaster University on advanced control system design for enhancing the situational awareness of the robotic platforms in the nuclear environment
- Proposed approach to improving reliability claims on computer-based robotic systems for safety casing
- NNL cut path planning demonstrator for laser size reduction
- Haptic controller capability development, robotic integration and demonstration
- Application of radiation detectors and data processing algorithms to size reduction and sort and segregation applications
- Robotic safety and verification framework development

COLLABORATIONS

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)
- A-CINCH (Augmented Cooperation in Education and Training in Nuclear and Radiochemistry)
- FREDMANS (Fuel Recycle and Experimentally Demonstrated Manufacturing of Advanced Nuclear Solutions)
- Gemini 4.0
- HARPERS (International regulatory framework in waste management and decommissioning)
- SECURE
- OPERA – high performance modelling of systems

Timescale



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Overview continued

Activity

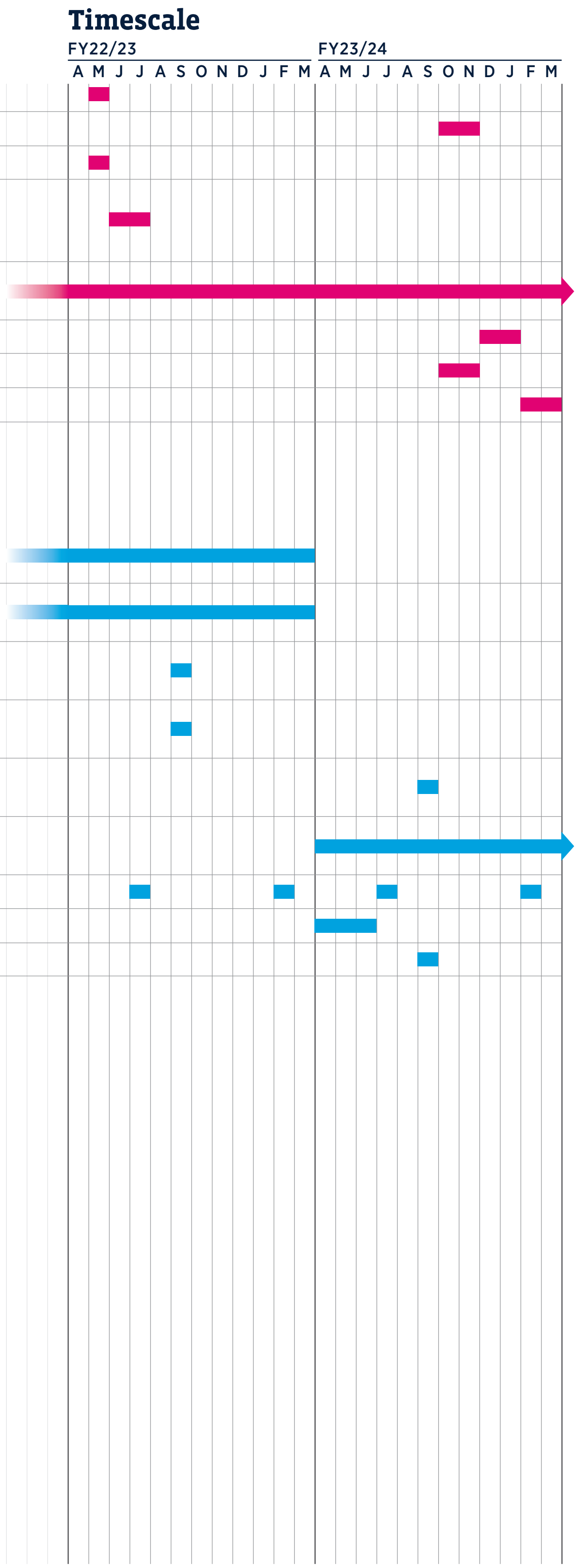
INNOVATION

- Technical demonstration of RECAP technology at NNL Workington
- Active trial of RECAP technology (Sellafield Ltd funded, NNL supervised)
- 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
- Deployment of FIRMArm in THORP Cell 306
- Deployment of SONAR probe in THORP for monitoring profile of sludge
- Combination of SONAR probe with ReCAP/Smart Plug for deployment to B212

ENABLERS

Technical Skills and Capability

- Delivered 8,080 online e-learning courses, 66 virtual training events and 13 education concessions
- Continued knowledge management development by holding 18 talks on a range of topics; three in conjunction with Sellafield Ltd
- Early careers recruitment campaign underway with 27 new graduates and 13 new apprentices expected to join NNL in 2022
- Continuing Post-Doctoral Scheme for those joining the industry at PhD level with 13 new Post-Doctoral students
- 18 graduates, 17 apprentices, 11 Post-Doctoral students to join NNL in the 23/24 cohort
- NNL outreach programme – challenging to measure but investment in future pipeline
- Dream Placement and work experience
- Bright Stars – primary school engagement
- Pan-nuclear advertisement – Destination Nuclear



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Environmental Restoration

NNL's vision for Environmental Restoration

To drive a step-change in the clean-up and management of the UK's nuclear legacy, supporting a UK approach for the export of expertise and decommissioning solutions worldwide.

NNL's ambition

- Delivering the next generation of decommissioning science and breakthrough technologies.
- The natural custodian of strategic nuclear capability on behalf of the UK.

NNL's role across the sector

- The embedded Technical Authority providing specialist services and innovating new solutions.
- A proving ground for industrialising technologies from academia and SMEs.
- Informing and underpinning government policy with technical insights.

Our Vision

To best benefit the sector by deploying expertise and capability across the waste life-cycle, from access through to end states, whilst developing the next generation of advanced tools, techniques, and science for faster, cheaper, and safer decommissioning

Our Strategic Objectives

Access and Characterisation

Decommissioning Strategy

Grow NNL's integrated offering for upfront decommissioning strategy and establish our market presence

On-Site Characterisation and Support

Develop new techniques and bespoke methods across our inspection, sampling and plant teams to provide on-site support for safe nuclear operations

Measurement, Analysis and Characterisation

Establish Analytical Services on the Sellafield site through RAP, and expand our offering across the UK

Robotics

Demonstrate and deploy robotic solutions by adapting off-the-shelf systems, leveraging our proven ability to deploy in harsh environments

Treatments and Processing

Waste Treatments

Develop and demonstrate waste treatments, including effluents, for an increasing diversity of waste-streams arising from the decommissioning agenda

Decontamination

Demonstrate and deploy novel decontamination techniques, including electro-chemical methods

Uranics

Establish the Springfields site as the UK route of choice for uranic residues treatment

Graphite

Develop graphite treatment and recycling technology ready to support demand from AGR and HTGR decommissioning

Storage, Disposal and End States

Disposal

Grow NNL's capability and understanding of long-term waste behaviour to support NWS and the Submarine Dismantling Project

Packaging and Encapsulation

Support the nuclear industry with tailored formulations to encapsulate new and emerging waste types

Land Remediation and Environmental Assessment

Develop NNL's capability and capacity to support decommissioning sites with land management and remediation plans

Thermal Treatment

Embed NNL as the trusted technical partner for the NDA estate, underpinned by active and non-active demonstrators and hosting the UK's Centre of Excellence

Special Nuclear Materials

Be the UK's technical authority on SNM and develop the skills and capabilities through ARC to help inform and carry out the UK's policy on disposition

Our Strategic Partnerships

Partnerships

To see NNL properly recognised as a collaborative national laboratory, resulting in long-term strategic partnerships across the nuclear sector

Academia and National Labs

Build NNL's academic network to continue bringing innovation through into industry and developing future skills and talent pipelines

International

Develop NNL presence in overseas markets to stimulate UK nuclear supply chain and catalyse export of UK capability

Defence

Establish NNL as a trusted and known partner with complimentary capabilities across the defence estate (including MOD, SDP, AWE)

NDA Estate

Establish the strategic partnership model with Sellafield Ltd as the exemplar standard approach and extend it across the wider NDA estate (including NWS and Magnox)

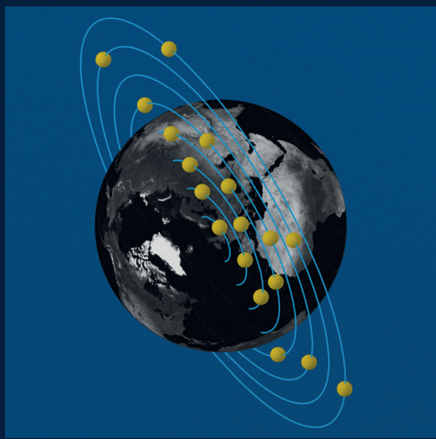
UK Industry and Supply Chain

Build long-term strategic relationships with UK industry to support their decommissioning agendas and capture of new activities

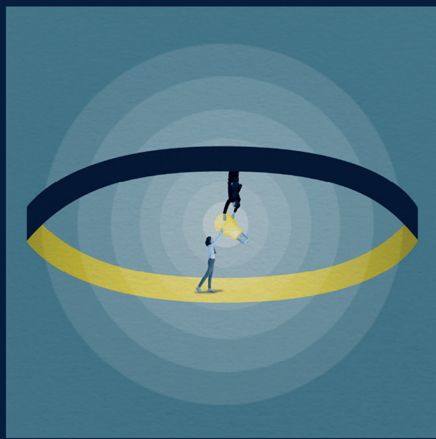
Science and Technology

Investment at NNL balances the need to push technology to address existing requirements but it also allows the market to pull our work into needed areas.

Core Science



Strategic Research



Innovation

NNL's Science and Technology Agenda has three pillars: Core Science, Strategic Research and Innovation, led by scientists that collaborate both nationally and internationally. NNL is constantly reviewing its Science and Technology Agenda to make sure it is working on topics which remain relevant to the needs of the nuclear industry today and into the future. Within this report, focus is given to the Core Science themes that support environmental restoration across the UK and beyond. The skills and capabilities developed in these areas help support organisations like Sellafield Ltd, NDA, and the MOD.

"Over the last year we've extended the breadth of our Core Science portfolio, developed our strategic relationships with academia, set out a plan to encourage user access to our facilities, published our research in the open literature and received more citations per paper than ever before. The programme inspires our scientists and facilitates collaboration for the benefit of the nuclear sector."

Jon Hyde
Head of Science and Technology NNL

The 15 NNL Core Science Themes

- Advanced Fuels
- **Plutonium and Advanced Recycle and Isotope Separation**
- **Decontamination and Decommissioning Science**
- **Environmental Radiochemistry**
- Hydrogen (NEW in 22/23)
- **Nuclear Safety**
- Reactor Chemistry and Corrosion
- Structural Integrity
- **Thermal Treatment**
- Health and Nuclear Medicine
- Irradiated Fuel Characterisation
- Reactor Technology
- Nuclear Safeguards and Security (NEW in 22/23)
- **Robotics and Artificial Intelligence**
- **Materials Performance**

(**Bold** indicates themes delivering significant environmental restoration investment)

Robotics

Summary

Robotics has been identified as a key enabler to nuclear decommissioning as it reduces hazards associated with working in nuclear such as removing humans from the vicinity of potential harm, enabling remote operation. The rapid advancement of robotic technologies introduces new ideas and solutions for their use in nuclear operations, spanning activities such as remote inspection and characterisation, waste sorting and segregation, nuclear waste management, dismantling and decommissioning.

Core Science in focus

NNL's Robotics Capability draws upon its longstanding and extensive experience to deliver robotic solutions that stretch across the full TRL domains, from fundamental research to full plant deployment, through the provision of supporting functions in safety case, engineering, modelling, software development and more.

The programme balances investment across internal research projects, collaboration with academic/industry partners, funding of PhD research projects, development of talent, and dissemination. Skills and capability development within the theme deliver direct benefit to industry stakeholders through commercial projects and wider strategic, research, and collaboration initiatives.

Over the previous year, the use of the National Nuclear User Facility (NNUF) – HOT ROBOTICS facility at NNL's Workington site to support the delivery of the Automated Stores project has been a highlight. This has been made possible through provision of rig space for a store mock-up, re-purposing of the sort and segregation rig to support feasibility trials, and engagement with stakeholders through demonstrations held in the facility.

Future robotics work will involve a focus on progressing the capability in laser cutting applications to align with the needs of our customers.

Hot Robotics

Challenge

As plants on the Sellafield site reach the end of their operational lives, the Post Operational Clean Out (POCO) of contaminated, and often complicated, infrastructure becomes necessary. For POCO where vessels must be repeatedly accessed, their contents characterised, and their surfaces decontaminated, this poses significant logistical and radiological challenges which require innovative solutions.

"The support given by the NNUF team – from system configuration/troubleshooting to expert advice – has been invaluable and has enabled us to complete our experiment successfully. The results of the experiment have opened new possible avenues for our research, e.g., the development of natural language interfaces to robots used in nuclear environments."

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

Solution

As an answer to the gap in technology development in the UK, the National Nuclear User Facility (NNUF) HOT ROBOTICS facility was established, with three regional nodes across four research partners. The facility at NNL's Workington Laboratory provides a safe testing ground for the technologies to be trialled and offers non-active industrial replicas of deployments from the Sellafield site for use by academics and supply chain members. Arriving at this point has been made possible through various networks between collaborators involved, including the University of Bristol, the University of Manchester, and UKAEA RACE.

Technology

The HOT ROBOTICS facility at NNL Workington includes robot laser cutting, sort and segregation, a flexible decommissioning cell, and a water dive tank for development and testing of Remotely Operated Vehicles (ROVs). These spaces have been used to support R&D projects with collaborators. For example, partners at the University of Manchester accessed the facility via the NNUF User Access Scheme to test a collaborative robotic manipulator solution capable of executing instructions given in natural language, investigating the application of natural language processing to support robotic operations. Other work focused on the automated management of nuclear waste and semi-autonomous laser cutting solutions have used the NNL HOT ROBOTICS facility to progress their respective TRL.

Outcome

The outcome of collaborative R&D such as the investigation of natural language processing has allowed for an exploratory demonstration of the technology that provide opportunities to engage with end users of the facility. Due to the work facilitated by the HOT ROBOTICS laboratory, work on the Automated Stores project is now on schedule to be handed over to active commissioning in 2025 which will allow for further progression of the TRL. In terms of the impact HOT ROBOTICS has had on NNL itself; the internal capability has been greatly advanced due to the integration of the rigs at Workington. The facility has also been used to progress NNL Science and Technology activities and has attracted attention internationally too with the EU PREDIS project for predisposal management of radioactive waste also benefiting from trials involving in situ inspection of 500 L waste drums at the facility.

Status

NNL's capability in the area of robotics has been greatly expanded. Currently, the HOT ROBOTICS facility is funded via the Engineering and Physical Sciences Research Council (EPSRC). However, from 2024 the facility will become an asset under NNL's capability and funding responsibility. Therefore, continued collaboration with academia and other partners will remain important to the longevity and impact of the facility. At the time of writing, PhD students from the University of Loughborough are using the facility to advance the understanding of laser cutting technology through an analysis of laser fume generation.

Development timeline

May 2020

HOT ROBOTICS early commissioning.

October 2021

HOT ROBOTICS formal launch.

November 2021 – March 2022

Completion of The University of Manchester natural language work.

May 2023

University of Warwick – testing of electromagnetic acoustic transducer (EMAT) technologies for inspection applications.

Automated Stores project – running throughout and will continue for another 2 years.

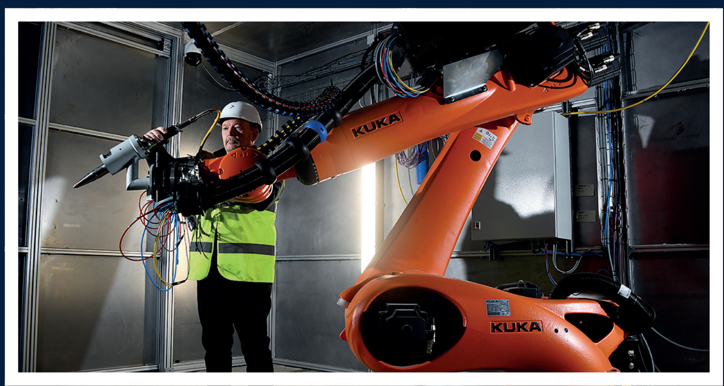
Small demonstration for EU PREDIS project involving remote inspection of 500 L waste drums in situ.

June 2023

University of Loughborough students using the robotic laser cutting facility.

Into the future

An NNL co-funded PhD student from University of Strathclyde is planned to access the robotic laser cutting facility to carry out investigations on application of ultrasonic technology.



Decontamination and Decommissioning

Summary

In Decontamination and Decommissioning, NNL is striving to develop a deeper understanding of contaminated materials and their environments to drive innovative decommissioning and waste management technologies through the TRL spectrum.

Core Science in focus

NNL's Decontamination and Decommissioning Science and Technology theme consists of a wide range of collaborative projects that are focused on the development of innovative characterisation and decontamination technologies for deployment within radioactive environments. Innovative technologies could achieve cost reductions in many ways including through improved/more informed decision making, reclassification and volume reduction of the waste generated, reutilisation of existing plant infrastructure and reagents, reduced hands-on work and dose to workers and deployment of faster and more efficient processes.

The theme aims to enable the mechanisms of contamination to be studied and to demonstrate decommissioning technologies at technology readiness level (TRL) of 7 and above. This work benefits from involvement in international research programmes (such as PREDIS), creating research communities where knowledge and experience is shared.

Decontamination and Decommissioning: Spotlight on PhDs

Challenge

Nuclear facilities undergoing decommissioning and radioactive waste disposal frequently contain a wide range of different physical, chemical, and radiological hazards which are difficult to characterise and access, and in turn are hard to decontaminate. The waste (metallic, concrete, plastic etc.) arising from the various activities worldwide is predicted to be substantial; therefore, a driver exists to develop innovative decontamination technologies to reduce the volume of all types of radioactive waste requiring disposal. This is recognised in the nuclear sector deal, targeting savings of 20% in the cost of decommissioning compared with current estimates.

"Working with NNL during my PhD project was hugely beneficial for both myself, and my career. This provided some of the most exciting and interesting research I carried out during my PhD and meant I got experience on safe handling and analysis of radioactive materials, which I have taken forward into my new role as a chemistry consultant."

Anna Denman
Former PhD student

Solution and Technology

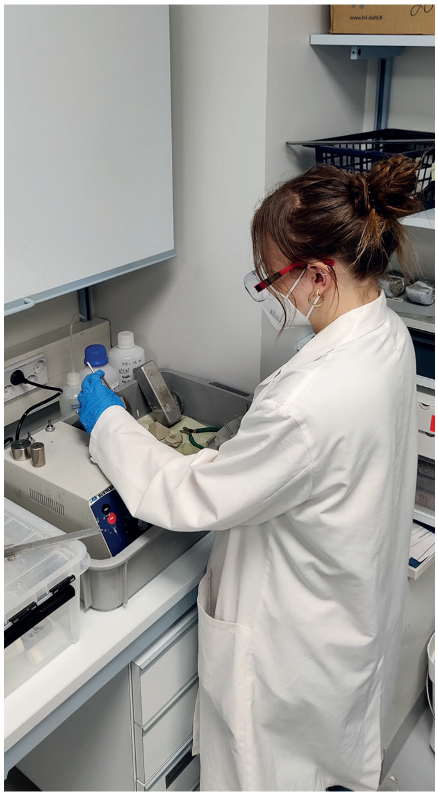
NNL continues to support a number of PhD students working on research significant to environmental restoration through the Decontamination and Decommissioning theme. Featured in this case study are three projects which have been carried out recently to help address the big challenges of decommissioning.

Outcome

PhD projects help to build knowledge and understanding in important technical fields. The research carried out helps increase the understanding of how to improve the decontamination of nuclear facilities and subsequent waste management. This has also allowed for demonstration of technologies, observations of contamination behaviours and better knowledge of characterisation profiles of nuclear facilities.

Status

As the Post Operation Clean Out (POCO) of the facilities at Sellafield is nearing, work carried out by NNL in collaboration with academic researchers will be integral to making facilities and their surrounding environments cleaner and safer for future generations.



Anna Denman
The University of Manchester

Characterisation and Decontamination of Concrete and Plastic Infrastructure from the Hunterston A Spent Nuclear Fuel Storage Pond.

Spent nuclear fuel storage ponds are both short- and long-term storage facilities which allow fuel to cool prior to processing into a final wasteform. As such, these storage facilities are typically complex environments. The leaking of Magnox fuel from storage ponds was observed during operations, thereby escalating the decommissioning challenge due the interaction of species such as Sr-90, Cs-137 and Co-60 with the surrounding structures.

Anna's PhD involved the analysis of a concrete core which was removed from a cooling pond at the Hunterston nuclear site. Anna's work showed that contamination from the radionuclides of interest (Cs, Sr, Am) was primary on the surface of the painted concrete, however some penetration up to 10 mm into the samples was also observed. Various characterisation techniques were applied during this study, including autoradiography, laser induced breakdown spectroscopy, X-ray computed tomography, gamma spectroscopy etc. This helps to develop the understanding of the contamination and characterisation profile of the structure surrounding spent fuel storage ponds.

Tom Johnson
The University of Manchester

Analysing the Swabbing Process to Improve the Accuracy of Characterisation in the Nuclear Industry.

Sending human operators into hazardous environments to take swabs essential for characterisation during decommissioning efforts may have a negative impact on safety, quality, time, and cost. Therefore, the use of robotic equipment has been identified as an alternative. However, it was thought essential to first identify characteristics of swabbing best practice to ensure that the next generation of swabbing robots can be developed with this in mind and uncertainties in the swabbing process can be reduced.

Tom's PhD project investigated factors such as how swabbing force, force application area, number of swab passes, and the contaminant mass impacted the efficiency of the swabs used for analysis and characterisation of loose contamination. This research identified that using humans to carry out swabbing operations increased the uncertainty significantly in the analysis, and that using robots is not only safer for operators but also shows more repeatability in results. Significant advancement has been made via this work into accurately controlling and predicting efficacy during swab taking.

Dan Barton
The University of Manchester

Long- and Short-Term Aqueous Contamination of Stainless Steel in Nuclear Reprocessing Environments.

Many of the structures which house radioactive material on reprocessing plants are made up of stainless-steel materials. When these stainless-steel facilities are exposed to the high acidities and temperatures associated with reprocessing activity, they themselves can become contaminated. To aid with decontamination and decommissioning, this research focused on how radionuclides interact with metallic surfaces.

In his PhD, Dan used simulated reprocessing liquors (mimicking highly active effluents at Sellafield) and immersed stainless-steel coupons in representative conditions over a period of 10,000 hours. Uptake of the contaminants by the metal was analysed and were observed to have diffused into the surface. Novel research such as this has an integral role in helping to inform appropriate decontamination strategies and decommissioning decisions.

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.

"The increases in storage capacity that will be justifiable for future geological disposal concepts through the application of the principles in the WPC Minimum Subcritical Margins GPG (led by NNL and Sellafield Ltd) could result in savings running into the many millions of pounds."

Liam Payne
Nuclear Waste Services

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 (GPGs), (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. Some of the broad activities supported in the FY2022/23 included:

- Shaping national and international 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 with Sellafield Ltd which is regularly attracting ~ 80 national and international participants.
- Collaborating with Lawrence Livermore National Laboratory (LLNL) on a multimillion dollar 'world-first' critical benchmark experiment designed to fill a nuclear data gap at sub-zero temperatures (which may help to reduce conservatism in transport cases).
- Collaborating with the US Department of Energy (DOE) Nuclear Criticality Safety Program (NCSP) and the WPC to introduce an international Learning from Experience database.
- Contributing to various WPC efforts aimed at addressing resource scarcity challenges.
- Authoring a journal article with Riskaware on a dynamic dispersion modelling tool to enable informed decision making in safety cases.
- Leading an industry GPG relating to principles to encourage the effective integration of safety case personnel and engineers during safety case production.

12-month case study update

NNL's collaboration with Lawrence Livermore National Lab on a world-first critical benchmark experiment

- Good progress has been made on the experiment in the last 12 months. The experimental rig has now been manufactured and extensive thermal testing of the equipment is currently occurring at LLNL using aluminium surrogate plates; a particular focus is being placed on improving the cooldown times and operating window.
- NNL will continue to provide both criticality safety and thermal support to this project in the FY23/24.
- Additionally collaborative opportunities between the USDOE NCSP and the UK are also emerging, e.g. there are plans for NNL to contribute to the review of a critical benchmark experiment being conducted by Los Alamos National Laboratory.

Thermal Treatment

Summary

Thermal treatment technologies will play a key role in the clean-up of nuclear waste and the long-term management and disposal of these materials. NNL plays a key role in supporting the development of thermal treatment technologies to TRL 7 through inactive development, small scale active demonstrations, product characterisation and demonstration of wasteform properties, and large-scale inactive processing.

Core Science in focus

The Thermal Treatment Core Science Theme carries out essential work involving thermal product fabrication, characterisation, and analysis to support wasteform thermal technology. This work supports the vision of the theme to become an international Centre for Excellence. A current focus of the theme has been on providing evidence of the benefits to using thermal treatment for nuclear waste management. Collaborations form an important part, both within the UK and internationally, boosting the expertise which NNL holds. In turn, this area of work significantly increases the knowledge of the capability and helps us to align our research to the needs and priorities of our key customers such as Sellafield Ltd.

Existing thermal technologies operated by NNL include hot isostatic pressing (HIPing), Geomelt®, cold-press and sinter (CPS), MOx fabrication and the vitrification test rig (VTR) in support of the Waste Vitrification Plant. Internal Research and Development supports investigations looking at additional waste feeds that may be treatable via such technologies as well as other novel thermal technologies that may be selected for future waste-streams (e.g. Sellafield demonstrators) via investment in Core Science.

A highlight of recent work includes the successful demonstration of ASTM C1308 monolith leach test using a standard reference material. Work in this area will be continued and tests on more relevant High Level Waste glasses from the vitrification test rig will be carried out.

Wasteform Durability

Challenge

In order to support the safety case for the disposal of high-level waste from nuclear fuel reprocessing at a Geological Disposal Facility (GDF), it has been recognised that improvements can be made in the modelling of wasteform durability to reduce uncertainties. Current models rely on pessimistic assumptions to demonstrate safe disposal. Improvements to the understanding of the behaviour of nuclear waste can enable a reduction in pessimism potentially unlocking substantial savings.

"The experimental work on wasteform durability undertaken by the NNL to date has been of significant benefit to Nuclear Waste Services in terms of expanding our knowledge base for underpinning the safe and secure geological disposal of the UK's higher activity waste inventory. We look forward to continuing to work with NNL on this nationally significant mission."

Jay Dunsford
Nuclear Waste Services

Solution

To accurately demonstrate how a thermally treated wasteform might behave in a GDF through laboratory experiments alone, observations would need to be made over thousands of years. The solution is to accelerate laboratory experiments using carefully designed test methodologies, data extrapolation and geochemical modelling. By exploring how the wasteform responds to a wide range of credible conditions, a mechanistic understanding of how the waste responds can be formed. This information can be used in models to predict the durability of the waste on the timeline of the repository.

Technology

Through this collaborative programme of work, tools and techniques for new leach test methodologies for thermally treated wasteforms have been produced. Staff at NNL have taken part in a series of international round robin tests to develop a new standardised method for the measurement of glass dissolution rates (ASTM C1926) and have worked commercially with partners Nuclear Waste Services (NWS) and Jacobs on confirming results for accelerated leach tests for measuring contaminant releases from solidified waste (ASTM C1308). To complement experimental techniques, initial phases of geochemical modelling will help to identify data gaps and define further experiments to drive improvements in the modelling.

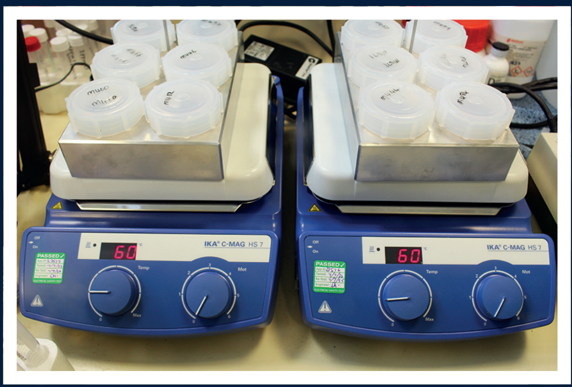
Outcome

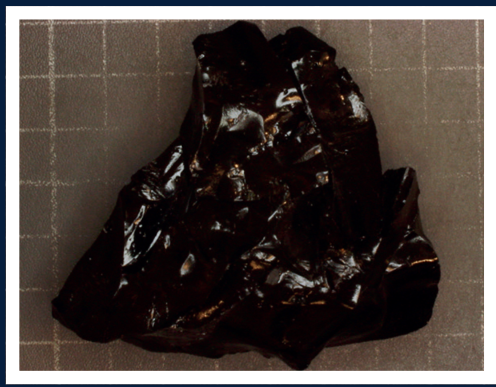
There now exists a toolkit for the UK's GDF safety case, providing a justification around the integrity of the waste resulting from improvements in mechanistic understanding of high-level waste. This work has also developed mid-career scientists as well as PhD students, ensuring there are the skills available as NWS look to build a robust UK safety case for the disposal of high-level waste from reprocessing.

Status

Following on from the demonstration of the C1308 ASTM using a standard reference glass as part of the round robin, NNL's international partners are now able to repeat the tests using active ceramic wasteforms containing uranium; these wasteforms are being considered for immobilising surplus PuO_2 from the UK's waste stockpile. Further tests are also due to be completed investigating the effect of zinc presence, as undesirable effects such as accelerated dissolution have previously been observed. Furthermore, based on some recommendations which have recently arisen from some work completed in collaboration with NWS, NNL will investigate the effect of zinc in glass during short term tests spanning 100 days. Such work will have relevance to other customers in the future as the thermal treatment of waste becomes more prescribed due to the knowledge available.

Development timeline





2006

Advance modelling, microscopy experiments.

2006-2007

Started looking at durability of wasteform.

2017

Focus within core science theme – durability.

2019

Knowledge transfer trip to CEA to learn about the kinetic and thermodynamic GRAAL model.

2022

Round robin experiments C1926 ASTM, led by PNNL.

2023

C1308 tests.

April 2023

ASTM C1926 approved.

PARIS

Summary

The Plutonium and Advanced Isotope Separations Core Science (PARIS) Theme builds internationally recognised capabilities to work on solutions to some of the nuclear industry's biggest challenges. A key area that this theme supports is the long-term storage and future use of the UK's civil plutonium stockpile.

Core Science in focus

The PARIS focus area (formerly ARIS) was renamed to recognise the plutonium research it supports to reduce the risk of activities around the safe management of the UK Pu stockpile. The key objectives of PARIS is to aid the understanding of the characteristics of Pu aging and storage under conditions relevant to the UK stockpile, analyse actinides in solution and to understand UK based options for medical radioisotope production with a focus on the practical production routes for what may be possible. This work allows NNL to support key industry challenges such as the disposition of Pu, the production of radioisotopes using non-reactor-based technologies which may be used outside of the fuel cycle, and the development of knowledgeable experts in the field.

The science underpinning Pu storage

Challenge

From the 1950s until 2022, the UK reprocessed spent nuclear fuel for both UK and overseas customers. As a result of the technology used, Pu was separated from U and the other fission products. Overall, reprocessing allows for a substantial reduction in high level waste volume compared to spent nuclear fuel disposal and it enables options for the additional recovery of value from that fuel.

Currently, the separated Pu is in storage at Sellafield and requires careful stewardship before a long-term solution is decided. One solution is to convert the Pu into a durable wasteform that is suitable for disposal. Work is still needed to best understand both how the chemistry of the stored Pu changes over time and that of the final wasteform.

Solution

NNL possess a unique skillset, situated in some of the very few facilities in the world capable of handling the material and thus tackling this challenge. Throughout recent years, computational modelling has been used to better understand the temperature evolution of stored Pu in different package types. Skill retention in this area is essential to maintain NNL's specialist capability, and has therefore been a core focus. Knowledge retention through a literature review has enabled the development of skills and improved the understanding of actinides. One area that is important to understand is the generation of hydrogen resulting from the radioactive decay of Pu. This can pressurise the storage containers if not managed correctly and has been the subject of laboratory work to better understand the mechanism.

Technology

Currently, NNL is the only organisation in the UK able to develop such capability and technology surrounding plutonium storage, with a responsibility to safeguard these skills going forward. The modelling technology established has been benchmarked against actual data from plutonium storage cans from the Magnox and THORP reprocessing plants. Furthermore, in experimental work investigating radiolysis, the humidity of the environment has been varied to understand hydrogen generation in the context of americium oxide storage; this will underpin the safe and secure storage conditions of such material.

Outcome

The fundamental science supporting Pu storage has allowed for both the maintenance and expansion of NNL's capability. In turn, this has allowed for significant improvement of the models being developed so that these can be more reliable for the future. Experimental work has also helped to gain an understanding on the behaviour of Am during storage, and to identify the differences between adjacent actinides in the periodic table in storage conditions. In the future, this work could help the models, such as gPROMS, to have predicative capability of materials' behaviour during storage.

Status

FY23/24 should see the attainment of further experimental data, and a literature review completed on the gas phase reactions for actinide – such as AmO_2 materials. Completion of this work has been made possible through the education of NNL's capability to become subject matter experts (SMEs). The work undertaken by PARIS helps support other work such as European projects, the European Space Agency (ESA) and for Sellafield Ltd.

Development timeline

2008-2016

Involvement with collaborative European research projects such as Actinide reCycling by SEParation and Transmutation (ACSEPT) and Safety of Actinide Separation Processes (SACSESS) prior to the Theme being set up at NNL.

2017

NNL's Pu area was first established after the need for such specialised capability was realised.

2017-2022

This period of time allowed for the training of staff within the area to prepare future subject matter experts. This has been carried out through familiarisation with the material and integration with other international collaborative projects such as GEN IV integrated oxide fuels recycling strategies (GENIORS).

FY22/23 and beyond

Use of gPROMS to generate 1D and 2D models of Pu in storage conditions.

FY23/24

Using experimental data generated by NNL, work will be published on the chemistry of gas phase and gas-surface reactions on plutonium oxide surfaces both internally and as part of the Can Surveillance programme.

Into the future

Development of existing tools to model a distributed system with thermal and chemical variation through the modelled system, extending the current 1D and 2D models, to look at reactions such as the radiolysis of water.

Environmental Radiochemistry

Summary

Through an increased understanding of how radionuclides behave in the environment, better decisions can be made about how to manage legacy wastes. This theme aligns with the high hazard risk reduction missions at Sellafield for legacy ponds and silos, finding methods to reduce our environmental legacy.

Core Science in focus

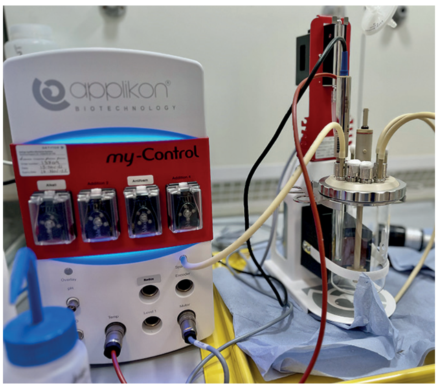
This theme focuses on understanding the behaviour of radionuclides under a range of environmental conditions, including effluent treatment, waste storage and disposal, and contaminated land. The work has helped to improve knowledge, build skills and enhance NNL's experimental and modelling capabilities.

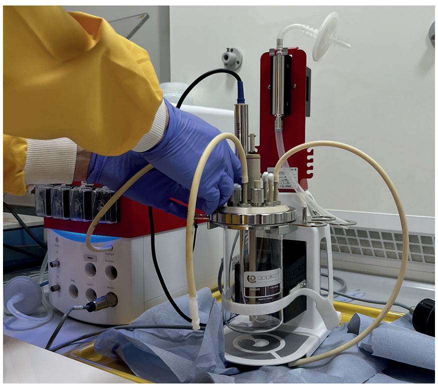
Over the past year, the experimental work of the theme has focused on improving the understanding of spent fuel and legacy wastes during retrieval and POCO operations. In addition to conducting research within our own facilities, NNL colleagues have performed collaborative work at The University of Manchester's National Nuclear User Facility (NNUF) RAdioactive waste Disposal and Environmental Remediation (RADER) facility to undertake research on the fate of Tc and U in legacy wastes during retrievals.

The theme has also developed novel computer models that simulate groundwater and contaminant migration, and team members are working closely with the newly established Disposal theme to build NNL's capability in supporting geological disposal.

"This work builds on collaborative research between the University, NNL and Sellafield Ltd including use of NNL Central Lab to characterise U colloids from legacy ponds and silos. In collaborative projects like this we benefit from the industry knowledge and appreciation of the challenges of waste retrievals while contributing to the understanding of fundamental, underpinning chemical processes."

Dr Thomas Neil
The University of Manchester





Images supplied courtesy of NWS Research Support Office

Understanding the fate of technetium in legacy wastes during retrievals

Challenge

As retrieval operations progress in the legacy ponds and silos, the contents are exposed to O_2 and CO_2 in air, which could make some elements more mobile and challenging to process.

Tc-99 is one of the most significant long-lived fission products present in nuclear wastes and its solubility increases significantly upon oxidation from Tc(IV) to Tc(VII). In the legacy ponds and silos, if this oxidation process occurred it could present challenges to downstream effluent treatment plants.

The large uranium inventory present in legacy wastes may oxidise in preference to the technetium. However, this has not been demonstrated experimentally.

"Working on this project has given me the opportunity to learn new skills, develop my understanding of Tc and U chemistry and has given me an insight into the workings of a different active laboratory. The laboratory facilities at RADER complement those of NNL, providing a unique set of capabilities to meet the complex challenges of decommissioning."

Frances Schofield
Early Career Scientist
NNL

Solution

To confirm the behaviour of reduced forms of Tc and U during exposure to air, the Environmental Radiochemistry theme has collaborated with The University of Manchester to perform a series of novel experiments, utilising the expertise and facilities of both organisations. The project has allowed for an early career NNL researcher to work at the university alongside academic researchers specialising in U and Tc chemistry.

Technology

To mimic the behaviour of waste materials exposed to air, a series of novel experiments was performed on mixtures of U and Tc under reducing conditions in aqueous media. Specialist apparatus using a sealed reaction vessel allowed for a precisely controlled supply of air to the headspace. Throughout, the system was monitored via both online measurements and regular sampling. The quantities of U and Tc present in the solution were measured over the course of several weeks of air addition.

Outcome

Results to date indicate that the mobile form of Tc is supressed by the presence of U in an oxygen-free environment. When exposed to air, however, Tc is released into solution via an apparent oxidation process. Further analysis is planned to investigate the mechanisms involved and understand the implications for legacy waste retrievals. The experimental project has provided an excellent opportunity for an early career NNL scientist to work closely with academic partners and gain new technical experience that will support their attainment of Membership of the Royal Society of Chemistry.

Status

Following completion of the experimental programme at RADER, samples have undergone solid state characterisation at the Diamond Light Source, and will soon undergo advanced microscopy at NNL's Central Laboratory. This broad array of analytical techniques will shed light on this important topic and provide greater clarity of the chemical behaviour of legacy wastes during retrievals.

Strategic Research: Recycle and Waste Management

Summary

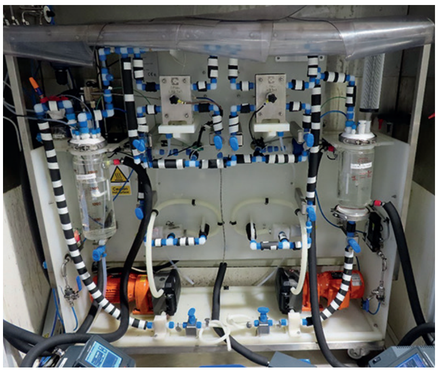
Building on the success of the Government-funded Advanced Fuel Cycle Programme (AFCP), this is an integrated research programme to develop innovative technologies and maintain the skills and capabilities for advanced recycling of spent fuels. The programme focuses on research and development of separations and waste management technologies that are also needed for the environmental restoration mission across the UK's nuclear sites.

Strategic Research in focus

Under some future energy scenarios, a closed nuclear fuel cycle may be needed to enable energy security and reduce the impacts of geological disposal, so it is prudent to keep this option open. This Strategic Research programme is designed to deliver these needs. It continues to support the broad range of skills and capabilities developed under the Government funded Advanced Fuel Cycle Programme (AFCP) in advanced recycling and waste management of materials from spent nuclear fuels. The objective is to develop credible and competitive options for the advanced reprocessing and recycling of spent nuclear fuels and the scope covers separation science and technology in both aqueous and molten salt media. The programme supports NNL's Focus Areas in Clean Energy, Security & Non-Proliferation and Environmental Restoration.

The core of the programme is based on the development and testing of advanced aqueous separations processes designed to recover potentially valuable materials for recycling. This builds on more than two decades of NNL research as well as past support to the reprocessing operations at Sellafield. In addition, the wastes generated from recycling process themselves must be minimised. There is a substantial emphasis on the waste management aspects within this research programme ensuring an integrated approach to nuclear fuel recycling. Whilst an approach based on the waste management hierarchy and life cycle assessment is adopted, with specific tasks covering off gas capture, processing of high level wastes, treatment of liquid effluents and solvents and, for molten salt based separations, the management of the salt wastes. Of particular relevance to Sellafield's mission are current studies of organics destruction using electrochemical methods (ELENDES), iodine abatement and evaluation of Joule Heated Ceramic Melters (JHCM) for thermal treatment of wastes.

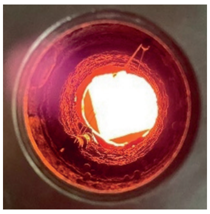
The Strategic Research programme combines experimental work, including active work with plutonium and other alpha-active materials, with modelling and simulation. It uses skills in chemistry, chemical engineering and process modelling as well as practical laboratory skills in alpha-active materials handling and on engineering-scale rigs and is supporting the development of the next generation of subject matter experts. There is a particularly strong emphasis on international collaboration to leverage investment and maintain UK impact and influence and the programme collaborates with US national laboratories, international organisations like the OECD Nuclear Energy Agency (NEA) or International Atomic Energy Agency (IAEA) and European-level projects such as PUMMA (Plutonium Management for More Agility) which is funded by the Horizon 2020 framework programme. Lastly, the programme is also championing how the recognised concepts of sustainability are applied to nuclear energy and nuclear fuel cycle options; including the application of tools and techniques such as life cycle assessment and fuel cycle models to evaluate different scenarios and technologies.

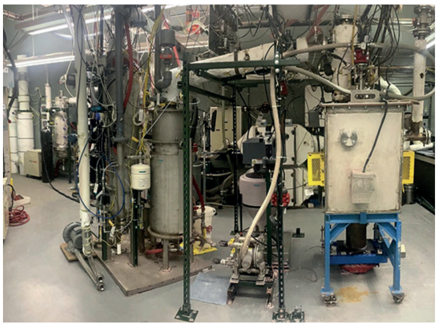


The US-UK Action Plan: collaborating with the US Department of Energy's national laboratories on fuel cycle technologies

Challenge

Development of advanced nuclear technologies for future clean energy, security or environmental restoration is a global challenge. There are, therefore, some excellent opportunities to leverage the value of UK funding, accelerate progress and influence debate by collaborating internationally.





The UK Department of Energy Security and Net Zero (DESNZ) has a bilateral agreement with the United States Department of Energy (US-DOE) to work together on specific aspects of nuclear energy and fuel cycle technologies. The agreement is supported by an 'Action Plan' that defines Fuel Cycle Technologies as one of the Working Groups. This is a key opportunity for international collaboration with a strategic partner (US-DOE) that is supported by DESNZ.

Solution

Under the US-UK Action Plan, Working Group 4 on Fuel Cycle Technologies, NNL is collaborating with various US national laboratories on a range of technical challenges. These challenges link common interests and ongoing research in the United States and in the UK to share experience, methodologies and results from respective domestic programmes enabling both partners to accelerate their R&D. Mechanisms to collaborate under the Action Plan include exchange of fundamental data, virtual and in-person meetings or workshops, secondments and joint publications.

Technology

NNL is working with Idaho, Oak Ridge and Pacific Northwestern National Laboratories on topics including:

- The development of simplified single cycle flowsheets for selective uranium separation from spent fuels; either for recovery of high assay low enriched uranium (HALEU) for advanced modular reactors or as part of a future reprocessing strategy based on Grouped Actinide Extraction (GANEX).
- The development of novel adsorbent materials for abatement of off gases; in particular capture of radioiodine from nuclear fuel or waste processing operations. The development of the novel capture materials goes hand-in-hand with the development of the immobilisation process for the waste to ensure the most efficient solution to the problem.

Additionally, the Strategic Research programme recently collaborated with Sellafield Ltd to jointly fund the secondment of an early career NNL researcher to the Vitreous State Laboratory (VSL) at the Catholic University of America in Washington DC. This enabled the researcher to observe a series of experimental trials using the Joule Heated Ceramic Melter (JHCM) technology to vitrify samples of First Generation Magnox Storage Pond simulants. There is a need to understand whether JHCM is a viable candidate in the UK for the thermal treatment of intermediate and high-level wastes either at Sellafield or for future processes. Currently the UK has little experience of JHCM whereas the VSL are acknowledged leaders in the field, supporting operations at Hanford for example.

Outcome

The secondment was very successful, providing the researcher with opportunities to be involved with nearly every aspect of the trials from preparation to running the melter and post-test activities including analysis of the samples. A detailed Visit Report has been issued and the knowledge gained is helping NNL and Sellafield define the way forward for evaluating this technology.

Status

Collaboration activities are continuing in the topics already agreed and the plans formulated under Working Group 4 to extend the collaboration in areas related to molten salts and waste technologies were recently endorsed by the US-UK Action Plan Steering Group. NNL's Strategic Research Programme is continuing to support these joint activities as a key priority for the programme.

Innovation

Innovation is a fundamental aspect of NNL's Science and Technology Agenda. The Innovation Programme has been created to build a successful, broad-ranging and balanced innovation portfolio which addresses the needs of NNL, the industry and customers.

Recently, NNL has received 'Gold accreditation' from ideasUK to certify alignment with ISO 56002 Innovation Management standards. This has been made possible through funding and demonstration of various innovation projects, for example the success of the Focus Area Challenges has allowed NNL to deliver cross-sector innovation.

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 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 of > £20,000.

Approved and funded Primer applications

28 FY21/22

27 FY22/23

Approved and funded Builder applications

10 FY21/22

14 FY22/23

Approved and funded Delivery applications

4 FY21/22

1 FY22/23

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

Tiger Teams with a spotlight on ReCAP

Summary

For the NNL Science and Technology Agenda to reach its full potential, innovation is a necessity. The use of Tiger Teams as part of the innovation programme enables solutions to challenges to be explored intensely and quickly. Tiger Teams bring together a small, technically focused team directed solely towards finding a solution against a framed challenge.

The Remote Cutting And Plugging (ReCAP) technology has been highlighted as an example of the use of Tiger Teams.

"The opportunity to remotely access High Active vessels using the ReCAP system is expected to provide significant benefits during POCO and Decommissioning of Sellafield's post reprocessing infrastructure.

The collaborative development of technologies such as ReCAP are essential in enabling hazard and risk reduction across the Sellafield site."

Chris Massey
POCO and Decontamination Lead
Sellafield Ltd

Challenge

As plants on the Sellafield site reach the end of their operational lives, the Post Operational Clean Out (POCO) of contaminated, and often complicated, infrastructure becomes necessary. One such plant is THORP which consists of novel systems and vessels that are securely shielded and largely inaccessible by human entry. For POCO where vessels must be repeatedly accessed, their contents characterised, and their surfaces decontaminated, this poses significant logistical and radiological challenges which require innovative solutions.

Solution

A Tiger Team was formed containing colleagues from the NNL Plant Inspection, Characterisation and Development team. During the project, the team collaborated with Framatome BHR to develop the Remote Cutting And Plugging (ReCAP) technology to support POCO and remediation. The solution involves the use of abrasive water jetting to penetrate a remotely accessed vessel. Then, the ReCAP technology can be deployed to line the vessel and place a resealable cap to enable access for future needs. Thus, there is now an access point to enable both characterisation and decommissioning activities to take place.

Technology

Using high-pressure abrasive water jet ablation technology engineered with Framatome BHR, a small coupon is cut and removed from a surface with minimal erosion impact on the surfaces below. A standard inspection deployment pole can then be used to lower the ReCAP technology, consisting of a liner and a tapered plug, into the hole. The technology has also been adapted so that it is appropriate for use on curved-surface vessels on the Sellafield site.

Outcome

The collaboration between NNL, Framatome BHR and Sellafield Ltd has designed and created a fully functioning ReCAP prototype ready to be deployed on active plant trials. This technology will allow for more accurate identification of vessel conditions and more straightforward decommissioning activities. While the current ReCAP system has been tested with Magnox buffer tanks as its primary application, the technology is applicable to other plant areas undergoing POCO.

Status

An active demonstration of the ReCAP technology on Magnox buffer tanks is imminent. Due to the success of trials conducted to date, and the huge potential it has for increasing the ease of entry to typically inaccessible areas of plants; further work innovating compatible accessories, including SONAR, directional water jets and cameras has been commissioned.

Development timeline

November – December 2018

NNL Tiger Team focused on investigating the feasibility of remotely cutting into vessels and then resealing them. During this period, the team collaborated with BHR to identify high pressure abrasive jetting as the most effective technology for cutting flat stainless-steel plates directly through experimental trials.

February – March 2019

Further NNL Innovation funding allowed additional work to be carried out focused on cutting curved surfaces and performing cutting from a vertical distance of 6 metres. The work was showcased in a live demonstration at NNL's Workington facility.

April 2019

NNL report issued outlining the findings from trials completed with BHR.

End of 2019

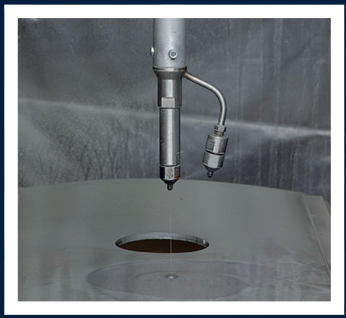
Successful live demonstrations of the cutting and plugging technology attracts Sellafield Ltd to provide funding to develop the technology further.

March 2020

Development halted due to Covid 19.

Post-covid

Developmental work continued following the re-opening of NNL facilities following the Covid 19 pandemic. During this time, a finished ReCAP prototype was developed, while BHR continued to work on post-cutting coupon removal.



April 2022

Cutting at height of vessels using the TED rig at Workington – maintain the capability and collaboration with Framatome BHR.

2023 onwards

An active demonstration is due to be carried out on the MA3 buffer tank within Magnox on the Sellafield site. In the meantime, Sellafield have commissioned further work to develop technologies compatible with ReCAP to aid with characterisation and decommissioning efforts.

Collaboration

As a core value of NNL, collaboration means being inclusive to release and maximise potential. By bringing together researchers, customers, academia and government to develop efficient partnerships to help deliver the global step change in environmental restoration.

Since April 2022, NNL has been eligible for UK Research and Innovation (UKRI) funding as a Public Sector Research Establishment. Achieving this eligibility in itself was the result of extensive internal collaboration. Since being eligible, NNL has already been successful in being awarded UKRI funding for collaborative research with universities. While this funding covers 80% of the research costs, the remaining 20% is sourced from the reinvestment of NNL's earnings.

Through funding opportunities such as UKRI, and with our network of engaged partners, we are committed developing new technologies and the people who work with them. This is one way in which NNL is demonstrating taking responsibility for ensuring the environment is safe and clean for the next generations.

University Collaborations

Summary

Collaborating with academia enables NNL to play a role in the development of new technologies and future subject matter experts. NNL's unique position as the UK's national laboratory and the geographical locations of NNL facilities promotes successful partnerships geared towards addressing some of the biggest challenges in environmental restoration.

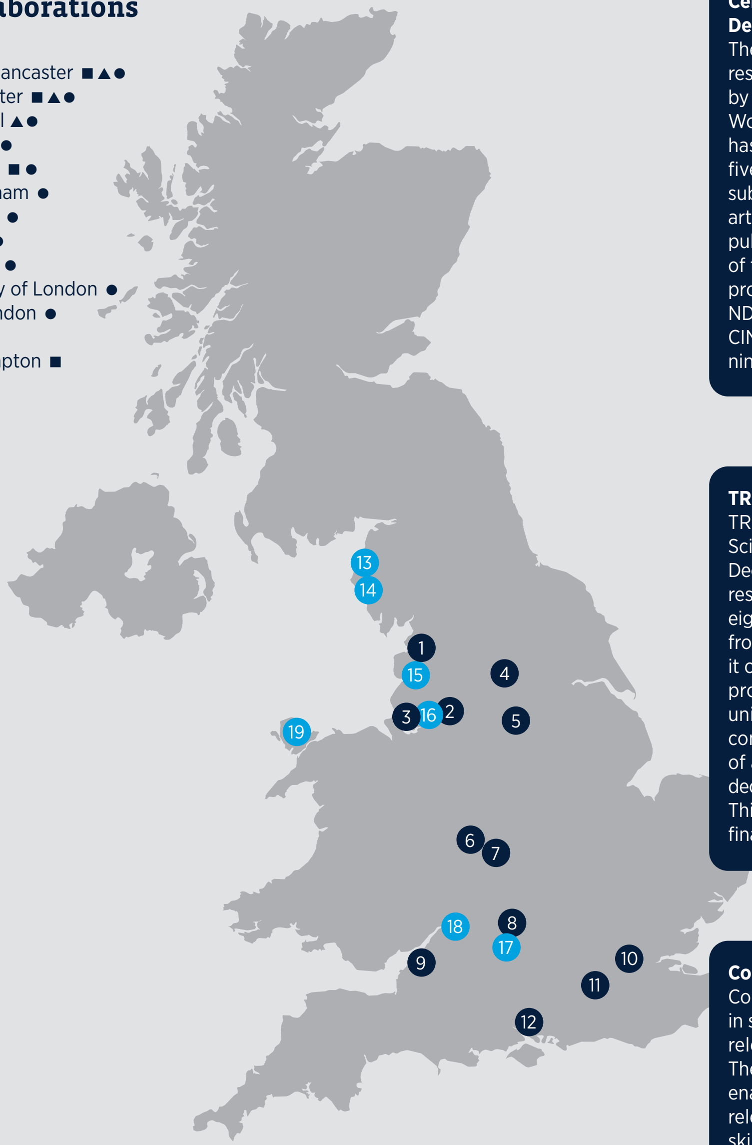
University Collaborations

● **Universities**

1 University of Central Lancaster ■▲●
2 University of Manchester ■▲●
3 University of Liverpool ▲●
4 University of Leeds ■●
5 University of Sheffield ■●
6 University of Birmingham ●
7 University of Warwick ●
8 University of Oxford ●
9 University of Bristol ■●
10 Queen Mary University of London ●
10 University College London ●
11 University of Surrey ■
12 University of Southampton ■

● **NNL facility locations**

13 Workington
14 Sellafield
15 Preston
16 Warrington
17 Abingdon
18 Stonehouse
19 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 duration of nine years.

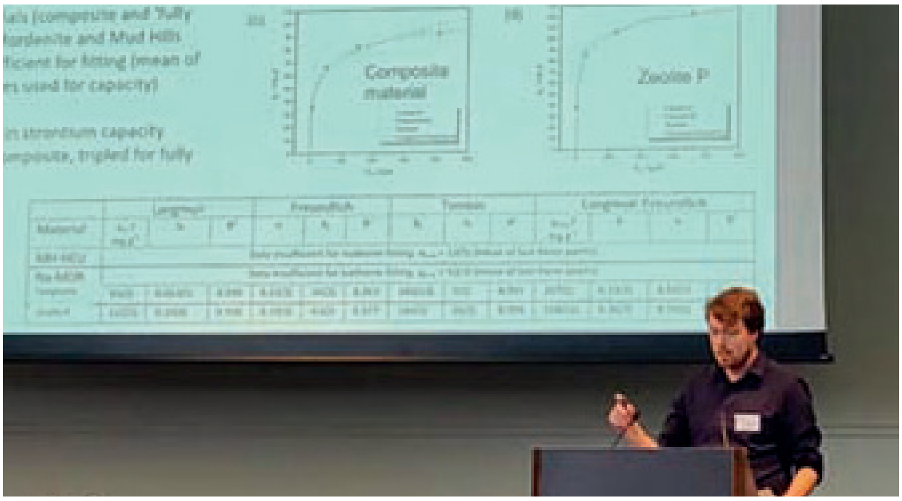
TRANSCEND
TRANSCEND (Transformative Science and Engineering for Nuclear Decommissioning) is a £9.4m collaborative research consortium of 11 universities and eight industry partners (including support from public interest reinvestment), and it comprises 40 PhD and post-doctoral projects. The programme 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.

TRANSCEND (Transformative Science and Engineering for Nuclear Decommissioning)

Challenge

There is a need for skills and capability in nuclear decommissioning for the UK to both efficiently dismantle aging nuclear facilities and to help plan for new nuclear. Nuclear energy can help the UK meet its low-carbon energy needs and through more efficient waste management and decommissioning, it can further reduce its impact.



Solution

TRANSCEND is a collaborative research consortium of which NNL is one of eight industry partners facilitating academic research at 11 universities, focusing on research relevant to big challenges in nuclear decommissioning through the TRANSCEND structure. The programme is of national importance to the UK due to its ability to bring together academia with the key stakeholders of licenced nuclear sites, developing subject matter experts through the award of PhDs directly relevant to the clean-up and geological disposal of highly active wastes.

Technology

NNL has been the primary funding organisation for 15 PhD projects via TRANSCEND since 2018. The focus of these projects has varied from topics such as the scoping of new ion exchange materials for application to the Sellafield site, the simulation of behavioural modification effects in suspension waste pipe flows, and the study of radiation effects on wasteforms. The impact that these technologies, and the people responsible for their progression, can bring is about to be realised as the UK nuclear industry undergoes its largest evolution in a generation.

Outcome

For the TRANSCEND stakeholders, the programme makes the advancement of the following possible:

- Knowledge – via conception of novel technologies relevant to management of nuclear waste and appropriate disposal, as well as development of the underlying science core to the nuclear industry.
- People – via development of the next generation of subject matter experts.
- Economy – via the commercialisation of nuclear technology, and reduction in cost of waste storage as a result of appropriate geological disposal.
- Society – via collaboration with other stakeholders to inform the UK policy on nuclear, as well as messaging to the general public.

Status

As TRANSCEND students are in the final stages of their academic research, NNL is in the process of recruiting a number of such future subject matter experts into the organisation. The TRANSCEND programme plans to be very active in areas such as communication and information dissemination, public engagement, training and development, and knowledge transfer in order to maximise the outcome which the programme can achieve. Some notable outputs facilitated through Transcend include the development of the 'Rad Dose' models for the simulation of radiation dose from radionuclides and their surrounding media, and published work detailing the use of rapid ion exchange materials for the removal of Cs-137 and Sr-90 from effluent waste.

"Over the last four years, TRANSCEND has been an amazing program for me. At the regular meetings I have developed my presenting skills, made many friends and gained understanding about the nuclear sector and its forthcoming challenges, from both industry experts and my peers. As part of the scheme, I was able to secure funding to test some of my ion-exchange materials using the NNL-developed RIX method at the Preston laboratories. This gave me invaluable experience working in an active laboratory and provided insight into the materials, which are now part of wider NNL trials. The funding also provided the opportunity to present my work at numerous domestic and international conferences, which enhanced my understanding of the industry as a whole and allowed me to develop a wide-ranging network. Attending these conferences also generated new ideas to further develop my research and the research within my group."

James Reed
NNL funded TRANSCEND student

TRANSCEND topic areas

Integrated Waste Management	**Site Decommissioning and Remediation**
Spent Fuels	**Nuclear Materials**

International Programmes

Summary

NNL has continued to use its investment in Science and Technology to play vital roles in international programmes. Recognising that the challenges of the sector are frequently international in nature and can be addressed through effective collaboration, NNL is helping to bring international best practice into the UK. Through the use of external grants and investment from NNL and other parties, we continue to develop a UK capability and our people to address the challenges of Environmental Restoration. This year, collaborations in Europe are the focus in this report.

European collaborations

Since 2017, NNL has participated in around 20 collaborative international projects, funded by the European Union, across the whole fuel cycle. In total, this has resulted in over £4m of grant funding, supplemented by investment from NNL's Strategic Research or Core Science programmes, as well as support from other parties, such as Sellafield Ltd, NDA and DESNZ. NNL continues to participate in these programmes, being part of five successful applications in 2022.

There is huge value in participation in these programmes. Working in partnership with leading scientists from across the world helps to support the development of technical capabilities, and particularly the development of our people. Through participation in European collaborative projects, we have worked with many organisations across Europe and the world. As well as our longstanding links with organisations such as CEA (France), SCK-CEN (Belgium) and VTT (Finland), we have developed strong relationships with a wide range of other organisations globally.

Case study

Harmonised Practices, Regulations and Standards in Waste Management and Decommissioning (HARPERS)

The HARPERS project began in 2022 and will run for four years. The project consists of 25 organisations across Europe. The aim of the project is to examine and clarify the benefits of more aligned and harmonised approaches to decommissioning and waste management, including the potential for increased sharing of facilities.

The project has a two-phase approach. In the first phase, a key part activity has been Stakeholder engagement, to aid in the identification of priority areas for further analysis and to assess the benefits of harmonisation.

NNL is leading the Advanced Technologies Work Package that has engaged the European stakeholder community to draw attention to the three topics that the project will take forward in the remaining 18 months of the project (Phase 2). This will see the project call upon subject matter experts external to the project partners to aid with the remaining workshops and deliverables.

NNL has engaged a large contingency of the UK waste management stakeholder group, resulting in the UK having the highest proportion of the stakeholder participation during the key Phase 1 refinement stage.

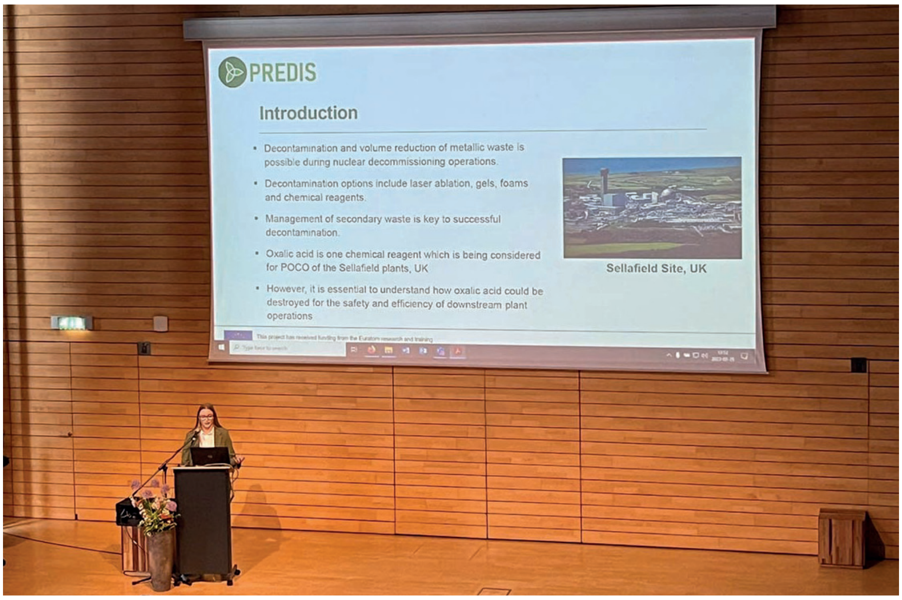
Pre-Disposal Management of Radioactive Waste (PREDIS)

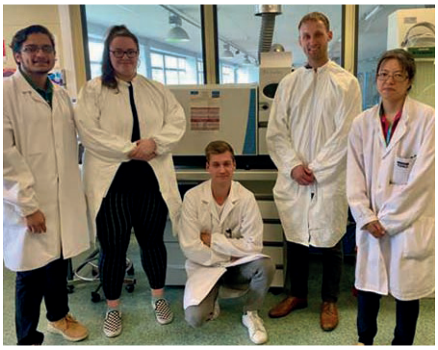
The PREDIS project is a large-scale programme, which started in 2020, consisting of 47 partners from 18 countries. With a total budget of €23.7m, the project aims to develop and demonstrate a range of waste treatment and conditioning methodologies, including for metallic wastes and solid and liquid organic waste, and to develop innovations in cemented waste handling and pre-disposal storage.

NNL is at the heart of this project, being a member of the Management Board and, as well as delivering across the whole project, is leading the development of a European Strategic Research Agenda (SRA).

Some highlights of PREDIS include:

- NNL leading the development of a geopolymer formulation for the testing of the immobilisation of problematic liquid organic wastes. This task was supported by co-investment from Sellafield Ltd and supports and informs similar programmes targeted at the Sellafield site.
- Demonstration of decontamination techniques for metallic wastes. NNL's involvement within this activity was supported by NNL's Decontamination Science Core Science theme and undertaken in parallel with work for Sellafield Ltd, allowing leverage of Sellafield Ltd funding and enabling learning from the European programme to be applied to the environmental restoration of Sellafield.
- Use of the project mobility fund to enable technical visits and training for NNL staff and associated PhD students at Institut Mines-Telecom (IMT) and Subatech (both organisations based in France), and their counterparts return visits.
- In collaboration with The University of Manchester, NNL are developing the application of Life Cycle Assessment techniques within the PREDIS project to assess the environmental impact and sustainability of the technologies developed across the PREDIS project.





Enablers

With our unique set of skills, facilities and capabilities – including four world-leading laboratories in North West England – we are harnessing nuclear science to benefit society.

We work globally at the forefront of nuclear science, providing knowledge, technology and access to cutting-edge facilities to partners and customers.

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 ensure continuous investment into our people and facilities to continue to deliver globally recognised, world leading science and technology, that has impactful benefits.

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 considering both the current and the future nuclear sectors demands.

Facilities and Infrastructure

Summary

In 2022/23 NNL embarked on a major programme of refurbishment and modernisation of its Windscale, Workington and Central Laboratory facilities to ensure our ability to meet customers' needs, as well as continue to support the R&D activities of our 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.

"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. Sustained investment in our facilities helps ensure we can deliver for our customers and continue to be world-leading in the services we provide, delivering now but evolving for the future. Our project management capability is first class leading on innovation within major projects to support the missions of NNL."

Gail Smith
CapEx Customer Workstream Lead
NNL

In 2022/23 the CapEx portfolio delivered over £20m of improvements to NNL's Windscale, Workington and Central Laboratory sites, including:

- Physical upgrades to the facility that further improved safety and reduced operational risk.
- Building defence in depth by, refurbishing, or repairing outdated machinery, and equipment.
- Increasing our capacity and capability to deliver by bringing under-utilised and new ways of operating into service.
- Enhancing the health, wellbeing, and safety at work facilities for the benefit of all its staff and other users of its sites.
- Completing the first phases of a major security enhancement project providing resilience and state of the art security enhancement for the future.

This programme will continue with further investment in NNL's facilities, 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.

CapEx project team key facts

Number of project team members – 16

Number of live projects – 45

Successes

- NSAN Nuclear Ambassador Finalist 2022
- BECBC Collaboration Award Finalist for Physical Protection Project 2023
- BECBC Rising Star Nominee 2023
- APM Nominee for PM of the future 2023

Technical Skills and Capability

Summary

People are crucial to the capabilities that NNL offer. For a robust technical skill set and capabilities crucial for ensuring the safe and efficient operation of nuclear facilities in the UK, continuous investment in people is essential. For NNL, this investment ranges from apprenticeships and other early careers programmes to senior leadership training to harbour the skills necessary for navigating the intricate landscape of nuclear energy and technology.

Skills section of the report

Data is from 1 July 2022 – 30 June 2023

E-learning completions – 7101

Training events – 120
(increase was due to NCL programme last year)

Education concessions – 20

This year, the early careers community has been highlighted to show how it is key to NNL's skills strategy.

Early careers

As a national laboratory, we are acutely aware of the increasing demand for skills across the UK nuclear sector between now and 2050 (a circa 300% increase in recruitment Nuclear Skills Strategy Group (NSSG)), and the skills challenge spans subject matter experts, nuclear, professional and trade skills. At the same time, demand for these skills has never been as high, with an overall STEM skills shortage. The close partnerships we have with organisations such as Sellafield Ltd. has enabled long-term investment in the development of skills and knowledge. Early Careers is a key part of the long-term resourcing strategy by developing the skills and leaders of the future. The UK nuclear sector is experiencing a renaissance and there has never been a better time to enter the sector or more opportunity. NNL is working to create a diverse and inclusive early careers community, who feel supported and ready to seize opportunities to grow. The NNL Skills Steering Board are tasked with identifying and delivering future skills and capability requirements and this includes directing our investment in early careers. NNL welcomes the creation of a Nuclear Skills Taskforce, chaired by Sir Simon Bollom, aimed at ensuring the UK's defence and civil nuclear sectors have the right people with the right skills. We will continue to play a part in driving the skills agenda forward and actively supporting the ongoing work of the NSSG and our sector partners in this collective endeavour.

Since 2015, 96 apprentices, 120 graduates, and 41 post-docs have been recruited and approximately 80% remain with NNL, and those that do leave tend to stay within the nuclear sector. Since 2021, NNL has had an apprenticeship, graduate and post-doctoral scheme with programmes tailored to development of each cohort. All programmes include soft-skills development as what we do is as important as how we go about our day-to-day roles. Those that are within early careers have the opportunity to take part in STEM outreach activities in primary and secondary schools and within universities. This is vitally important given the nuclear skills challenge and a rewarding experience for all involved. NNL continues to support the Cumbrian Centre for Leadership Performance Programmes and has developed a partnership with STEM Learning. During 2023/24, NNL plans to increase the level of corporate volunteering and maintain a focus on impactful STEM outreach activity.

NNL sponsor a significant number of PhD students which provides an opportunity for them to learn about NNL and whether our post-doctoral development scheme is right for them. The 2-year scheme allows recent PhD graduates colleagues to continue developing and applying their research skills through the training and resources we offer in a commercial environment. Our recent cohorts cover a wide range of capability areas including metallography, decontamination chemistry, nuclear effluent abatement, materials science, reactor chemistry, and separation science. Each person is provided with time and development funding to really focus on their technical discipline alongside their challenging role. As the scheme has matured, we have started to see our post-docs present their research on the world stage with representation at recent conferences in Vienna and South Korea.

Samantha Ree, one of NNL's radiochemists, joined our technical graduate scheme in 2017. She has been awarded the 1851 Industrial Fellowship award from the Royal Commission of the Exhibition of 1851. This Fellowship has allowed Sam to now complete her PhD whilst developing her identified research topic, which is researching separation techniques for the recovery of radionuclides suitable for cancer therapy from extant nuclear materials.

"Being awarded an Industrial Fellowship has meant that I have been able to propel my professional development whilst continuing to work at the forefront of separation science. I have been able to gain valuable insight from academia and industry which has helped me overcome research challenges linked to my PhD."

Samantha Ree
Radiochemist NNL

"Being part of the Post Doc Scheme has given me the chance to transfer my skills from academia into the nuclear industry. I have been given training opportunities alongside a cohort at a similar stage in their career, allowing me to grow professionally in a supportive environment. The variety of work that I have been involved in has enabled me to strengthen my technical skills while building knowledge of the wider nuclear sector."

Moya Hay
Chemist, Post Doc NNL

"On reflection of my first year on the graduate scheme at NNL, I have been involved in a wide range of projects with the flexibility to find work that aligns with my interests and increases my competencies. Collaboration with other companies within the industry has provided a platform to rapidly build a breadth of knowledge within nuclear and network."

Sanjay Prajapati
Graduate Chemical Engineer NNL

"Being a Scientific Apprentice has given me the opportunity to further my education (working to complete a foundation degree) whilst also understanding the application of this knowledge in industry. I have gained a wide range of new skills, from report writing to working with active material, and I am looking forward to developing these skills further."

Jasmine Sharpe
Scientific Apprentice NNL

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