Technical Services Agreement

NNL Reinvestment of Earnings Plan
April 2021

NATIONAL NUCLEAR LABORATORY

Contents

Introduction

NICK HANIGAN

Executive Leadership Team
VP Legacy Sites, Customer Executive, NNL

The National Nuclear Laboratory (NNL) and Sellafield Ltd have a long and proud history of working closely together to achieve our shared ambition of creating a clean and safe environment for future generations. I am therefore delighted to introduce this report, detailing our delivery in FY20/21 against objectives set over the previous financial year.

The report also outlines NNL's ambitions for the coming year, indicating how we will reinvest income into; research and development, skills, facilities and infrastructure, and knowledge retention to support environmental restoration work on the Sellafield site.

NNL's ambition to deliver value and benefit to the Sellafield Ltd mission, local communities and wider society is evident. Working collaboratively, we have saved the UK taxpayer in excess of £7bn since 2008, with hundreds of millions of pounds of savings identified in the next few years. We have also supported the retention and attraction of critical skills to the industry. The lifetime agreement supports the drive to invest in skills and expertise for the future, as well as nurturing the innovative ideas essential for the development of the UK nuclear industry.

The outcomes of the collaboration between NNL and Sellafield Ltd this year are significant. This strategic relationship has yielded many technological successes, innovations, and investments in our people and infrastructure. From pioneering thermal treatments to mix waste with glass or ceramics, to developing robots to remotely handle hazardous materials in radioactive environments, the Technical Services Agreement (TSA) enables NNL to deliver cutting-edge technological solutions which are significantly contributing to successful decommissioning missions. Innovative approaches towards collaboration with academia and other research organisations has also enhanced our offering. Potential solutions to key challenges can be tested and ultimately deployed on site, thus supporting our strategic decommissioning objectives.

Finally, it is important to highlight, the COVID-19 pandemic has brought significant personal and professional challenges to our colleagues, their families and friends, and society more broadly. During this time NNL and Sellafield Ltd have worked closely together and have responded quickly and appropriately to minimise the impact, with the supportive nature of colleagues coming to the fore. The ongoing relationship between NNL and Sellafield Ltd is important to us. We recognise the value derived from progressing practical, innovative solutions alongside our TSA partner and are committed to working collaboratively with Sellafield Ltd to deliver benefit and value to society for many years to come.

DUNCAN STEEL

Chief Technology Officer, Sellafield Ltd

Our lifetime collaboration agreement with NNL has put our relationship on a new footing, creating a step change in how we work together. It has allowed us to move from a transactional, project-by-project approach to one where we can take a step back and plan work strategically together over the medium and long-term.

This benefits everyone, including the UK taxpayer, by driving cost savings, greater efficiency, and exciting innovation.

Given the importance of underpinning science to the whole nuclear sector, committing to a long-term working framework has clear benefits for technical services. But beyond this, our people are also able to build diversity of thought by cross-collaboration and through increased staff secondments between NNL and Sellafield Ltd.

Perhaps the single biggest impact of this approach is on skills and capabilities. Together, we are working to address the immense workforce challenge for environmental restoration over the coming generations. There is an urgent, national imperative to grow these specialist skills and our partnership with NNL allows us to jointly tackle this.

Having a long-term partnership set up with NNL means a long-term commitment to jobs, skills and capabilities, ensuring that the UK is 'match fit' for the ongoing environmental restoration work we need to achieve our purpose of creating a clean and safe environment for future generations. Programmes like ARC and Game Changers are just two examples of the added benefits this one-team approach can bring for the UK nuclear sector and supply chain.

"Strategic advice, technical services and expert support."

Context

The TSA between Sellafield Ltd and NNL is now in its fourth year. Signed in 2017, the unique collaboration agreement states that NNL shall reinvest all its surplus earnings from the previous financial year, into Public Interest Reinvestments.

This enables NNL and Sellafield Ltd to work together to drive innovation and collaboration on a diverse portfolio of projects which support the development of the nuclear industry, the supply chain, and society more broadly. NNL reinvestments have a range of beneficiaries including but not limited to; Sellafield Ltd; the Nuclear Decommissioning Authority (NDA); and the Department for Business, Energy and Industrial Strategy (BEIS).

Importantly, the value to Sellafield Ltd delivered from such reinvestments should be equal to or greater than the financial value.

of the reinvestment (importantly, this is for Sellafield Ltd not the whole of NNL). Public Interest Reinvestments are defined as:

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

	Actual spend in FY20/21 £m	FY21/22 £m
Science and Technology	1.7	3.7
Core Science Themes	1.6	2.0
Innovation Group	0.5	0.6
Connections – CSG	0.4	0.5
Science Integrated Research Team (sIRT)	0.1	0.4
Robotics	0.8	0.3
Direct University Engagement	0.2	0.1
International Programmes	0.1	0.5
Technical Skills and Capability	0.3	2.0
Facilities and Infrastructure	7.6	6.7
Technology and Digital Change	0.9	1.6
Total	**14.1***	**18.3**

As of FY21/22, the costs for university collaborations have been diverted into other funding streams, hence the apparent decrease in reinvestment funds.

* The total actual spend in FY20/21 totalled £14.1 m, £2.08 m less than predicted in the FY19/20 report. This underspend was primarily due to COVID-19 limitations around access to resource and reduced laboratory time.

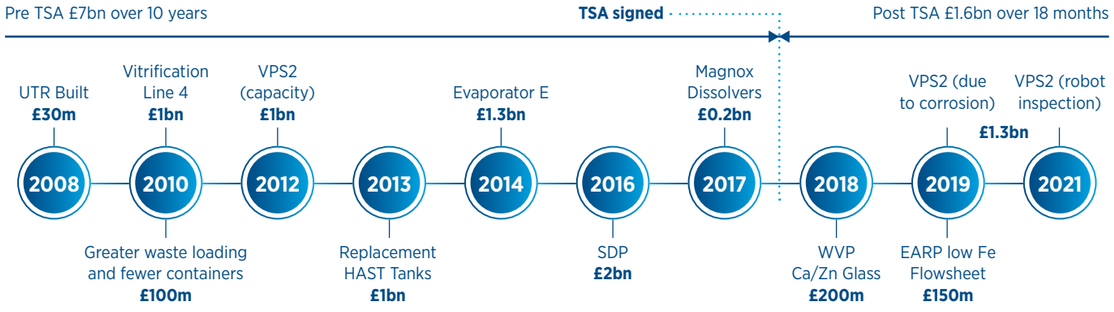
VALUE FOR PUBLIC INTEREST REINVESTMENTS

£14.1m*
FY20/21

£18.3m
FY21/22

* Subject to finalisation of Corporation Tax and research and development (R&D) tax credit following the current audits.

Jointly achieved savings through Sellafield Ltd/NNL collaboration



Overview

ACTIVITY

TIMESCALE

FY20/21 FY21/22

A M J J A S O N D J F M A M J J A S O N D J F M

SCIENCE AND TECHNOLOGY

Decontamination Science

- Radiation mapping via unmanned aerial vehicles (UAVs) (University of Bristol)
- Characterisation of contaminated materials via Laser-Induced Breakdown Spectroscopy (LIBS) (University of Manchester)
- Remote characterisation via stand-off Raman spectroscopy (University of Manchester)
- Remote characterisation of sludges and sediments (University of Liverpool)
- Remote characterisation via hyperspectral cameras (University of Manchester)
- Wireless communications in nuclear decommissioning environment (University of Manchester)
- Development of alternative IX materials for SIXEP (SL co-funded) (University of Birmingham)
- Simulating contaminated materials – NNL, Horizon 2020 PREDIS (PRE-DISposal management of radioactive waste) programme, and SL – alignment of several research programmes with the shared R&D requirements centred around understanding contaminated metallic surfaces
- EASD® (Electrolytically Assisted Surface Decontamination) – final stage active demonstration of the decontamination technology on the Sellafield plant
- Decontamination of concrete (University of Lancaster)
- Decontamination of stainless steel (University of Manchester)
- Decontamination of bricks (University of Lancaster)

Environmental Radiochemistry

Biochemistry

- Utilising in situ experimental capability (sample handling and microscopy techniques) to study microbial processes relevant to waste silo and effluent systems
- Contributing to NERC-funded OPTIUM (Optical Imaging of Uranium Biotransformations by Microorganisms) research grant project in collaboration with the University of Manchester
- Ongoing experiments with spent fuel – learning with reprocessing plant decommissioning and POCO washout
- Ongoing PhD project: Microbe – radionuclide interactions in legacy nuclear waste systems
- Training of scientific apprentices in NNL's Central Laboratory

Contaminated land

- Investigate natural attenuation processes affecting radionuclide (^{90}Sr and ^{14}C) behaviour in the subsurface
- Presentation to Goldschmidt Conference (large international geochemistry conference) on ^{90}Sr behaviour in SL sediments
- Supporting numerous PhD projects working on concrete samples from nuclear-licenced sites
- NNL contaminated land expert starting secondment into SL Land Quality Team (SL funded)

Computational modelling

- Chemical speciation modelling training module delivered to 38 PhD students at the University of Manchester to improve understanding
- Used theme to recruit hydrogeological modelling expert to team
- Theme funded NNL training in computer modelling of contaminated land and effluent treatment

This Gantt Chart provides an approximate indication of timescales for projects. There is focus on the delivery within the FY20/21-FY21/22 time scale and as such some projects may have commenced earlier than this or are due to finish after this date. Where possible this has been indicated. Exact timings are subject to change.

ACTIVITY

TIMESCALE

FY20/21 FY21/22

A M J J A S O N D J F M A M J J A S O N D J F M

SCIENCE AND TECHNOLOGY CONTINUED

ARIS

- Experimental analysis of PVC, polythene and chloride contaminated plutonium via IR spectroscopy
- Further IR (and BET) experiments to understand mechanisms for physical adsorption
- Creation of Product Rate Assessment Tool building a wrapper for the NNL-developed FISPIN to model usable isotopes from a target material
- Irradiation testing and modelling of target in ISIS using Product Rate Assessment Tool followed by analysis in NNL's Central Laboratory
- X-Ray Diffraction (XRD) analysis of annealed PuO_2 samples
- Using XRD to create a fingerprint for the PuO_2 lattice parameters that will enable quantification and identification of unknown samples received from Sellafield site
- Experimental study of ^{90}Sr recovery and ^{90}Y production from SIXEP simulants
- Strontium recovery from SIXEP simulant sands. Followed by yttrium 'milking' and analysis as a feasibility study
- Yttrium/strontium extraction from SIXEP sands experiments and analysis (subject to sourcing raw material)
- HIP Raman analysis – demonstration of theory using inactive surrogate materials and implementation of changes to safety case to allow active studies
- HIP Raman analysis – demonstration of plutonium ceramic inclusion
- Develop Time Resolved Laser Fluorescence Spectroscopy (TRLFS) analysis of americium capability

Thermal Treatment

Sub-theme 1: Thermal waste product characterisation/analysis

Centre of Excellence – active thermal processing analysis:

- Assessment of user requirements
- Glass analysis development
- Active glass fabrication and analysis capability development
- Sampling capability development

Thermal product assessment:

- Raman analysis on glasses and ceramic samples
- Beginning validation techniques for homogeneity assessment

Sub-theme 2: Thermal product assessment

- Modelling the dissolution of vitrified nuclear waste
- 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)

Sub-theme 3: Development of glass ceramics (HIP programme)

- Workington-based PhD started on powder processing for HIP

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TIMESCALE

FY20/21 FY21/22

A M J J A S O N D J F M A M J J A S O N D J F M

SCIENCE AND TECHNOLOGY CONTINUED

Materials Performance

- Roadmap outlining developmental steps for a fuel drying model
- Initial development of a methodology to demonstrate the concept of predicting drying in AGR fuel cladding has been achieved
- Chairing the IAEA Co-ordinated Research Project on Management of Corium
- Continued development of small-scale testing techniques to obtain mechanical properties from mm-scale samples. First publication accepted in Journal of Materials Engineering and Performance
- Commencing iCASE PhD on Graphite Core Dismantling for Minimising Graphite Waste Volume
- Supervision of in-cave fuel electrochemistry work in support of Lancaster PhD student (NDA-financed)
- Chemical mapping of species in AGR fuel

Nuclear Safety

- Leading the UK efforts on criticality-related ISO standards and ensuring suitable succession arrangements for the incumbent (from within NNL)
- Continue to lead efforts on criticality-related ISO standards, including developing a standard (or Industry Good Practice Guide) on Criticality Incident Detection (CID) omission cases
- Leading on various criticality-related aspects identified of national strategic importance to the UK nuclear industry (e.g. SL and NNL co-led a recently-approved Industry Good Practice Guide on Minimal Subcritical Margins)
- Leading on safety-related aspects deemed of national strategic importance to the UK nuclear industry, particularly (i) enhancing professional development opportunities, (ii) improving integration between safety and engineering, and (iii) driving innovative new thinking on As Low As Reasonably Practicable (ALARP) solutions
- In collaboration with Lawrence Livermore National Laboratory (LLNL), delivered the thermal contribution to an early design feasibility report on a critical benchmark experiment (with potential benefits to UK and international low temperature criticality assessments)
- Delivering the thermal and criticality safety support to the detailed design feasibility report for the critical benchmark experiment being developed with LLNL
- Lobbied the US criticality safety community to submit a $200k funding proposal to the US Department of Energy to expand the UK Criticality Learning from Experience database to a more powerful international tool
- Introduced a criticality-related Continued Professional Development webinar series for the UK criticality community
- Contributing to an international programme on the detection of anti-neutrinos for safeguards processes, noting that collaboration is ongoing with SL about the additional environmental benefits of the technology

INNOVATION

- Investing in Magnox Swarf Storage Silo Tiger Team outputs – Ion Selective Electrodes and Secchi disk not suitable for use in Effluent Distribution Tank CC, but alternative technologies based on fibre optic-based systems and being pursued
- Remote Capping and Plugging (RECAP) – report to address safety concerns, issued and accepted
- Technical demonstration of RECAP technology
- Developing SIXEP applications of raw water technology

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ACTIVITY

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FY20/21 FY21/22

A M J J A S O N D J F M A M J J A S O N D J F M

INNOVATION CONTINUED

- Installation of Technical Evaluation and Demonstration (TED) rig (SL funded)
- Commission SL funded TED rig
- Exogenous ultrasonics at Brunel University Innovation Centre
- Technical demonstration of exogenous ultrasonics at Workington
- Technical demonstration of pipe unblocking work for Fuel Handling Plant (FHP)
- Game Changers Challenge – demonstration and testing of technologies for vertical deployment into cells and vessels
- FirmARM (long-reach arm) – potentially suitable for non-destructive testing at SIXEP

COLLABORATIONS

sIRT

- Re-issued the Technical Memo on prioritisation outcome for four themes
- Issued updated sIRT spreadsheets in the theme areas
- Update the sIRT spreadsheets in each area and ongoing theme coordination
- Develop additional scope with the customer

Robotics

- Development of task allocation, sequencing and coordination for robots under the Robotic Task Sequencing Programme (RTSP)
- Conducting physical trials and setting up of capability demonstration
- Understanding and developing vision-based local surface profiling and adaptive path correction for laser cutting applications
- NNL named as partners in establishing a new National Nuclear User Facility for Hot Robotics (NNUF-HR) for nuclear robotics R&D in the UK; alongside the Universities of Bristol, Manchester, and the UKAEA's Remote Applications for Challenging Environments (RACE)
- Utilise the NNUF-HR facility 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

University Collaborations

- 2016-17 CINDe cohorts (first and second intake) are writing up and will be graduating in FY21/22
- Twenty TRANSCEND PhDs ongoing – these are a combination of SL, NDA and EPSRC funded positions
- Three former CINDe PhD students have joined NNL since October 2020 and are providing direct support to SL in areas related to their research (wireless data transmission, effluent treatment and Highly Active Liquor transport
- Five EPSRC iCase awards have been awarded to support CINDe PhD projects since 2016
- The future scope of the CINDe hub is being developed in conjunction with external stakeholder input, including SL
- Ongoing recruitment strategy for the next cohort of CINDe PhDs
- IChemE, international secondments and PhD student involvement with European Nuclear Young Generation Forum and High Scientific Council

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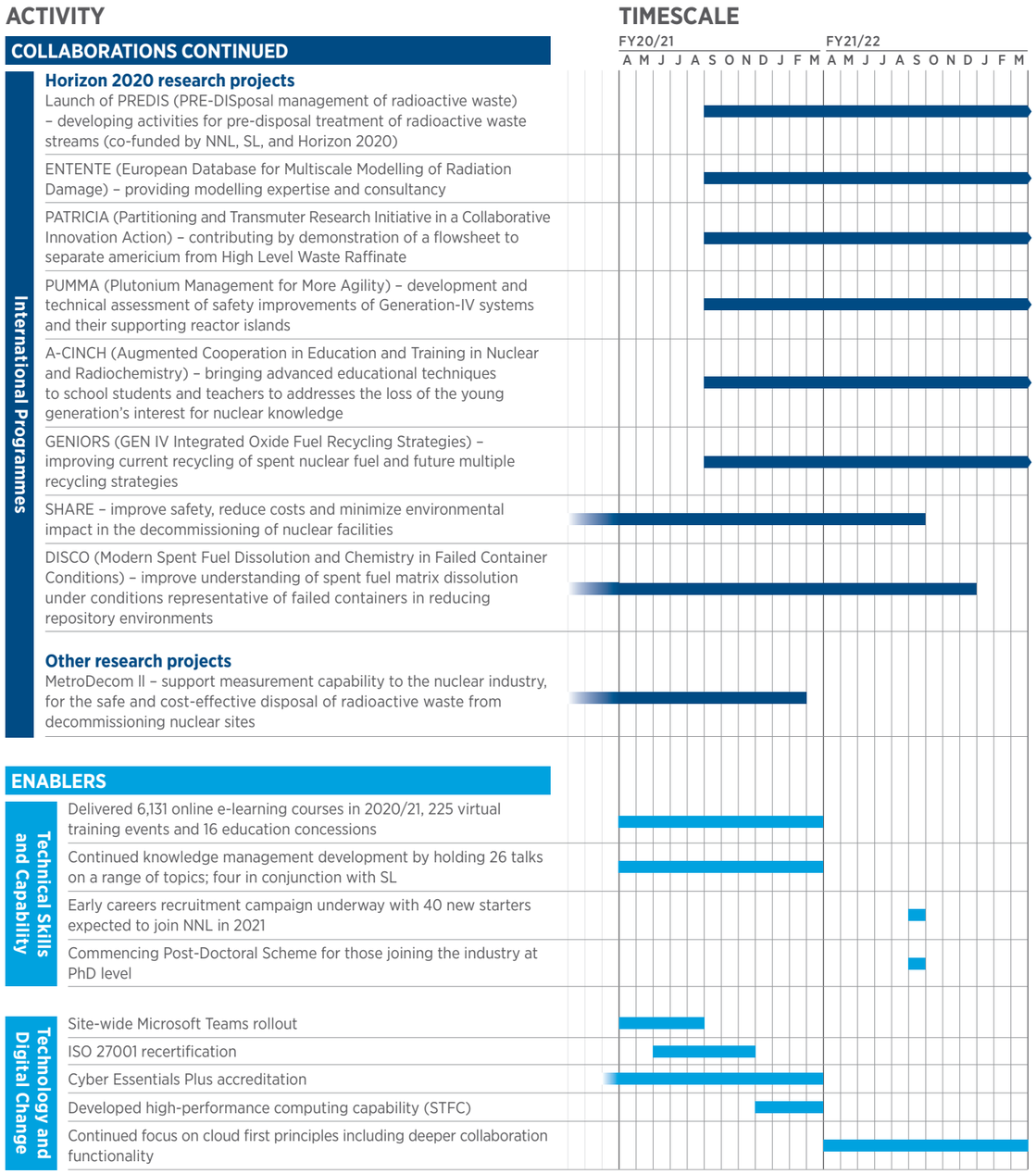

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Science and Technology

NNL is a world-class nuclear science and technology organisation delivering far-reaching societal benefit. NNL's ambition is to grow the quality and impact of our science and innovation programmes, to build resilience in our leading technical skills and develop our world-class facilities.

The Earnings to Reinvest support 12 Core Themes (three new themes added in FY21/22) and an Innovation Programme, all led by highly knowledgeable and experienced scientists with strong input from our university partners as well as other national and international collaborators.

These focused programmes use NNL investment to develop concept ideas with low technology readiness levels (TRLs) and deliver underpinning science solutions to many on-site challenges. The diverse range of new technologies being explored across Science and Technology is exciting as it enables the programme to be flexible and responsive to a changing research environment. The programmes within Science and Technology align well with Sellafield Ltd decommissioning objectives and strongly support the work of the NNL Focus Areas, principally Environmental Restoration.

There are 12 core themes for FY21/22[1] with a total budget of £2m.

"NNL's Science and Technology function enables us to invest in customer-relevant solutions which benefit industry."

1 In FY20/21 there were nine, however, three more have been added to the programme for FY21/22 reflecting the new NNL Focus Areas and purpose. These are Health and Nuclear Medicine, Reactor Technology, and Irradiated Fuel Characterisation.

Decontamination Science

Summary

By developing a deeper understanding of contaminated materials and their environments, NNL's Decontamination Science Team can help pioneer innovative decommissioning technologies and techniques with benefits for organisations across the industry.

The training and development of the next generation of scientists and engineers is essential to the theme, with over half the budget being assigned to University and PhD/PDRA funding projects.

"Decontamination Science will support 15 PhD/PDRAs in FY21/22 across a range of Sellafield Ltd-relevant research areas."

Decontamination Science in focus

The Core Science research 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. The practical technologies honed and developed through the theme support Sellafield Ltd to manage and minimise radiological hazards within facilities during the post operational clean out (POCO) phase of the nuclear plant life cycle. In addition to the development of decommissioning technologies, researchers are also studying the contamination mechanisms of materials, which in turn grows our knowledge base and facilitates more informed decisions to be made during decommissioning operations.

NNL works closely with different Sellafield Ltd teams to amplify the benefits of this work, which include the re-utilisation of existing plant infrastructure and reagents, reduced hands on work and dose to workers, the re-classification and volume reduction of the waste generated, and deployment of faster and more efficient processes. EASD® (Electrolytically Assisted Surface Decontamination) is an example of a decontamination technology that has arisen from the research theme. It is currently undergoing engineering-scale tests, with guidance from Sellafield Ltd's system engineers and plant managers, to provide the necessary reassurance the designed equipment can be successfully deployed in an on-plant scenario. The final stage of this development work has begun, in which an active demonstration of the decontamination technology on the Sellafield site is being carried out.

Artificial contamination of surfaces – bridging the gap between the laboratory and on-plant

Challenge

To develop and demonstrate decommissioning technologies to effectively reduce the hazards on the Sellafield site. The ambition is to assess technologies on 'real' contaminated components through on-plant demonstrations, however factors such as radiological hazards, limited accessibility, a lack of technical underpinning, lengthy bureaucracy and cost can often be prohibitive.

SOLUTION

Artificially contaminated samples present a useful tool in the selection, verification, and optimisation of decommissioning technologies prior to on-plant deployments. Current methodologies for preparing simulated samples are however often varied and do not accurately replicate the expected contaminated surfaces. If a set of standardised and widely accepted preparation methods were to be established, artificial samples could then be used to develop the decommissioning toolbox of techniques in a safe, timely and more cost-effective way.

OUTCOME

The requirement for representative artificial samples is not only a need for Sellafield Ltd, it is also a requirement for a wider international group of nuclear stakeholders. This field of research aligns directly with the research interests of the European Horizon 2020 PREDIS (PREDISposal management of radioactive waste) programme. Consequently, NNL has facilitated the alignment and leverage of the research programmes in this field. The ambition for this work to develop a capability for producing relevant artificial coupons which can be used as a basis for assessing innovative decommissioning technologies, including those developed by our international collaborators.

STATUS

Initial work (focusing on contaminated metallic surfaces) has shown existing preparation methods utilise relatively benign experimental conditions and shorter time durations when compared to the conditions on the Sellafield site. Experimental tests are now being performed which more closely recreate the on-plant conditions. Samples prepared from this work will then be cross compared with samples contaminating conditions, as the image below shows, that have been retrieved from the Magnox Reprocessing plant after eight years of exposure to contaminating conditions.

Environmental Radiochemistry

Summary

Working in close collaboration with our industrial and academic partners, NNL is developing state-of-the-art approaches to study the behaviour of radionuclides under a range of environments including; effluent treatment, waste storage and disposal, and contaminated land. Recent focus areas include the formation formation and transport of colloids, and the role of microbes in waste evolution.

Together we study hazardous environments that no-one else can and perform state-of-the-art analysis to probe the complex processes of biogeochemistry. In addition to experimental studies, we are building computer models of these systems, investing in code development and offering training to colleagues and students.

The work of the theme aligns well with Sellafield Ltd drivers in high hazard risk reduction for Legacy Ponds and Silos and objectives for Land Quality. NNL expertise and chosen investment channels also support two Sellafield Ltd sIRTs: Process Chemistry (spent fuel pond chemistry, effluents, and microbiology) and Environmental Science (behaviour of contamination in the subsurface, soil and groundwater remediation, and waste disposal).

Environmental Radiochemistry in focus

Over recent years we have invested in collaborative projects to understand and predict how effluent treatment plants will perform as the Sellafield site transitions from reprocessing to decommissioning activities, as well as characterise the microbial content of legacy ponds that suffer from seasonal visibility issues. The team has set up a sterile, controlled-atmosphere box within Central Laboratory, allowing the microbial transformations of active materials to be studied.

We have utilised NNL's User Access programme to facilitate the placement of two post-doctoral researchers from The University of Manchester into NNL's Central Laboratory, allowing them to study active plant samples, rather than simulants.

An important objective for the work of the theme is to build skills – both for NNL colleagues and the wider nuclear community – in areas of active fumehood work; analysis and microscopy; controlled-atmosphere work; and computer modelling (chemical speciation, reactive transport, dose assessment). Recently, several NNL Scientific Apprentices have become fully qualified by performing supervised work within the theme. By implementing these new skills to study in situ microbial processes in legacy waste and disposal environments, we are directing our research towards the needs of our partners. For example, following recent collaborations with the University of Manchester and the University of Leeds:

- A novel method for synthesising uranium colloids now takes hours, not months
- Improving the biofouling control in a Sellafield legacy pond led to a 40% increase in operational days in 2019
- Better understanding of ^{14}C contamination in Sellafield sediments saved millions of pounds in potential remediation costs.

Members of the Environmental Radiochemistry theme team work closely with Sellafield Ltd on a number of priority areas and this year a team member is seconded full-time into the Land Quality team, provided expert support to Sellafield Ltd's research needs in this area, specifically behaviour of contamination in the subsurface, soil and groundwater remediation and waste disposal.

Microorganisms in radioactive nuclear facilities

Challenge

Microorganisms can colonise the most inhospitable environments, including intensively radioactive nuclear facilities such as legacy fuel storage ponds. Here they can cause expensive plant downtime by reducing visibility in the ponds, and potentially cause 'biofouling' in downstream ion-exchange effluent treatment beds.

SOLUTION

NNL has supported several PhD and post-doctoral projects with the University of Manchester's Department of Earth and Environmental Sciences. This has allowed access to leading microbial characterisation expertise and ensures knowledge and skills retention within the area. The collaborations have established import/export routes of active pond samples for microbiological characterisation and enabled knowledge transfer and further training of staff in DNA/RNA extraction techniques.

TECHNOLOGY

A series of collaborations with the University of Manchester, Sellafield Ltd and NNL have enabled cutting edge DNA profiling techniques to be adapted and applied to identify the organisms causing 'microbial blooms' in spent fuel ponds.

OUTCOME

The investment has yielded an established, routine sample transfer route from the ponds to Central Laboratory for initial processing and analysis, then to the University for detailed characterisation. NNL staff have also been trained in handling biological samples under sterile conditions and performing DNA extractions. The skills and capabilities developed are now available to support other plants on the site. This collaborative approach between the three organisations has greatly improved the understanding of how microbial populations can affect pond visibility, underpinning the design and implementation of effective control strategies.

STATUS

Following the completion of the PhD and PDRA projects, NNL is continuing to collaborate with the academic partners by linking workflows in Manchester's new National Nuclear User Facility (NNUF) with projects in NNL's Central Laboratory, thus opening up opportunities for researchers to work across the two facilities.

Advanced Recycle, Plutonium and Isotope Separation (ARIS)

Summary

Developing internationally recognised capabilities and delivering impact by integrating internally funded and customer R&D projects, the ARIS theme makes a vital contribution to delivering Public Interest Reinvestment.

> **“Sustaining critical alpha and plutonium skills and capabilities whilst expanding our fundamental knowledge and developing novel analytical techniques and applications.”**

The theme undertakes research in multiple areas, including advanced reprocesing of spent fuel with recycling of actinides for future closed nuclear fuel cycle options and plutonium characterisation that underpins the UK’s mission of safe storage and ultimately disposition. In recent years, the theme has taken a further turn towards the separation of other isotopes of potential value for non-fuel cycle applications.

The flexibility of the theme allows scoping trials to occur, before investing further. For example, significant work is being undertaken to explore the valuable species existing in SIXEP plant wastes, which could become an asset in the future. Scoping trials are required in the first instance to establish the viability of the experimental techniques. Working closely with NNL SMEs who work closely with Sellafield plant(s) to understand the profiles of the ‘waste’ material on site, the team are hoping to open up numerous opportunities for future development, whilst also developing the next generation of skills and techniques essential for the UK industry.

Core theme in focus – Production Rate Assessment Tool

Accelerator-based systems can use an ion or energy beam to transmute elements (convert one into another). Where the target is a waste this can turn it into a commodity or more desirable material. However, there is limited experience in the UK in assessing the production rates and feasibility of such systems.

The Production Rate Assessment Tool, based on the FISPIN11 kernel, models the production of usable isotopes from a target (waste) material and will enable the investigation of particle accelerators and beamlines as a non-reactor-based production method for desired isotopes. By making use of the FISPIN kernel, this builds on the same computational techniques that are already used to calculate the nuclide inventories across Sellafield site in support of plant operations.

Experimental data gathered under ARIS using the ISIS muon and neutron source operated by the Science and Technology Facilities Council (STFC) will help to develop and validate the Production Rate Assessment Tool. Once developed, the tool will provide significant benefits to conversations and plans to produce key, target isotopes for both fuel cycle and medical applications. As well as informing which accelerators to build, this model will also be beneficial to identifying potential value in the waste streams in current and planned plants in the nuclear fuel cycles of today and tomorrow.

Exploring Raman technology for additional sample analysis

Challenge

Going forwards, one option to immobilise the highly hazardous, separated civil plutonium dioxide (PuO_2) located at Sellafield site is to thermally treat the material into a ceramic product using Hot Isostatic Pressing (HIPing).

Analysis of the subsequent zirconolite ceramic structures is essential to determine homogeneity and product quality, however, to date, the number of analytical techniques that have been applied to active products has been limited to SEM and Powder X-Ray Diffraction (XRD). Raman spectroscopy is a highly sensitive, non-destructive technique that could provide a lot of information on product quality and be applied to plutonium (Pu) active samples: this additional technique would provide further valuable insight for customers.

SOLUTION

NNL has developed various formulations of zirconolites for plutonium immobilisation and have fabricated Pu loaded samples with up to 25wt.% PuO_2 loading. These samples have been previously immobilised in epoxy resin for bench-top SEM analysis. These same samples could be used for Raman analysis; both select site probing and surface mapping. Before this can happen, it must be demonstrated on inactive surrogate samples and the Central Laboratory safety case updated to permit the use of Pu-bearing materials on the open bench. Once demonstrated inactively this will allow a library of standard spectra to be gathered for future analysis of both inactive and active samples, and become a business as usual analytical technique to demonstrate that HIP products meet the exacting criteria for acceptance as a waste form for ultimate disposal.

TECHNOLOGY

Inactive pellets were made using cerium dioxide (CeO_2) as a surrogate for PuO_2 to demonstrate the pelleting process inactively before fabrication of the PuO_2 active samples. During this phase of work the Raman equipment was upgraded and NNL colleagues were trained to perform various experiments, thus giving the opportunity for complementary analytical results to the SEM and XRD analysis already conducted on the samples.

OUTCOME

Raman spectroscopy probes the molecular fingerprint of the materials, providing spectra that can be matched with libraries to identify ceramic phases within minutes. The library of standards was also expanded with various spectra for different zirconolite polytypes, which will be beneficial when analysing future ceramic samples. This non-destructive technique will allow NNL to provide quick and efficient analysis of active HIP samples.

STATUS

The non-destructive technique will undergo further analysis and testing over FY21/22 to enable NNL to support Sellafield Ltd with future HIP sample analysis. It is hoped future Raman analysis can be conducted on the PuO_2 ceramic samples for comparison with the inactive data and to demonstrate the technique on active materials of this kind. Additional Raman capabilities have included working with the NNL Vitrification Team to analyse the structure and composition of glass samples from the Vitrification Test Rig.

Thermal Treatment

Summary

A key objective for the Thermal Treatment theme is to develop a world-leading uranium/plutonium-active characterisation, analysis and modelling capability in thermally treated waste forms.

To achieve this, the team consciously aligns its research with the needs and priorities of our customers – including Sellafield Ltd – to help realise the significant benefits in safety and cost of this transformative technology. By creating long-term and productive collaborations with academic and other strategic research partners, the team can develop SMEs who then have the skills and capability to participate in and lead international research consortia to influence the UK and global agenda.

Thermal Treatment in focus

The Thermal Treatment theme this year has refocused their project efforts directly because of NNL's participation on a Sellafield Ltd Tiger Team, held to establish the appetite for the thermal treatment of Sellafield and UK wastes and the roadmap for development and deployment of this technology. The theme is developing a 5-year roadmap to support Sellafield Ltd's understanding of active thermal demonstrators, with ambitions to develop both equipment and methodology over FY21/22.

Other highlights include:

- Theramin – series of reports produced and attended international meeting
- Compositional analysis of glass via inactive, in-house trials initially, with an aim to develop up to active trials over the next year or so
- Raman spectroscopy exploring various glasses and ceramics – these will be active trials followed by complementary SEM analysis
- Plutonium disposition – having supported the HIP and glass ceramic capability for several years, the Core Science programme has effectively enabled the current NDA-funded project on the immobilisation of surplus civil plutonium for safe long-term storage and disposal
- 'Disposability' of thermally treated products – developing modelling capability to look at dissolution models of glass for RWM currently, but potential future applications to Sellafield Ltd.

The Thermal Treatment theme currently funds seven PhDs.

"The scope delivered by NNL during the Theramin programme fed in directly to our optioneering programme providing the necessary technical underpinning to support a range of treatment decisions and has directly supported the Sellafield Ltd decision to progress to active pilot development for the thermal treatment of a range of intermediate level wastes."

Mark Dowson
Thermal Treatment Integrated Project Team (TTIPT) Lead, Sellafield Ltd

Theramin (thermal treatment for radioactive waste minimisation and reduction)

Challenge

Nuclear waste can be a significant liability to be safety managed and disposed of on account of a plethora of unique challenges. The ability to collaborate, share learnings, and demonstrate technologies 'live', is therefore invaluable to preventing opportunities being missed.

SOLUTION

Theramin was an EU supported programme under Horizon 2020 which enabled the demonstration of potentially revolutionary thermal treatment technologies. NNL played a key role in preparing scope for the Theramin programme and led the central work package covering the practical demonstrations of technologies, alongside international collaboration from; VTT Finland, CEA France, VUJE Slovakia, and the University of Sheffield.

TECHNOLOGY

An example of Theramin-supported technology is the Geomelt ICV system. Experiments using sand clinoptilolite (representing treated wastes from the Sellafield site ion exchange facility) were undertaken by using simulants and glass formers that were heated to a pre-determined temperature and allowed to cool once the vitrification process had been completed.

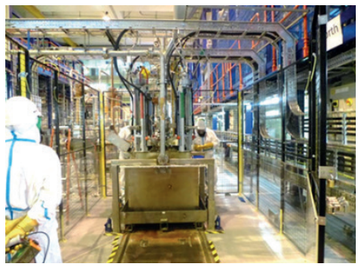
Another technology demonstration is the HIP Rig, which can immobilise radioactive wastes. NNL Workington facility processed a surrogate 5l stream, whilst the University of Sheffield's HIP facility processed a 50ml uranium sample. Sellafield Ltd could benefit from this research by gaining an improved understanding of long-term storage and disposition of civil plutonium.

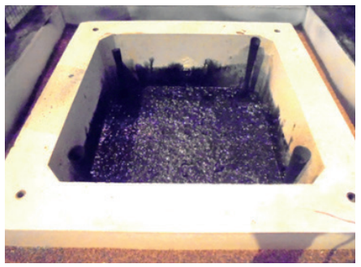
OUTCOME

Results from both technologies demonstrated that waste had been effectively vitrified with a homogenous vitrified product. NNL's participation in Theramin has shown that demonstration can have profound effects on implementing thermal technologies under the constraints of a site licence.

STATUS

The European Commission considers Theramin as an exemplar project. NNL has fed Theramin learnings into the recently commenced European PREDIS project and will continue to take part in promoting thermal treatment as a solution for radioactive waste management.





Materials Performance

Summary

The NNL Materials Performance Team is actively developing capabilities and knowledge which improve the mechanistic understanding of long-term, safe spent fuel storage, disposal and decommissioning strategies.

By working closely with Sellafield Ltd to support on-site decommissioning strategies, together we are increasing the UK's understanding of the behaviour of long-term fuel storage. The use of specific microstructural techniques to develop mechanistic insight and support the modelling of irradiated materials performance is essential here.

The Core Theme is proposed and led by a range of early careers individuals, with guidance given by more experienced professionals in the team. This opportunity to broaden knowledge and address future needs of the sector as a whole is a fundamental component of the TSA. The team are also liaising closely with academia to support a range of PhD projects thus developing the next generation of Subject Matter Experts who will continue to drive innovation and collaboration in this field.

Materials Performance in focus: Spent Fuel Storage

Experimental work in this area was delayed by the COVID-19 pandemic. However, progress was made in developing an initial model for AGR fuel drying (see case study opposite). In the coming year we expect to resume experimental work to investigate oxidised AGR fuel, including the chemical distribution of species within spent fuel.

Another activity adding value to the strategic direction of the work in the spent fuel area, is NNL's participation and chairing of the IAEA Co-ordinated Research Project on Management of Corium and severely degraded fuels research.

Development of a model of fuel drying

Challenge

The requirement to establish modelling capability to tackle AGR fuel drying fits in with the NDA mission to process and store AGR fuel as a precursor to ultimate disposal in an underground waste repository.

It is also recognised, in line with NDA's requirement to pursue mathematical model development to simulate this process, that it would be beneficial for NNL to develop a modelling approach to tackle this problem. This would complement the experimental study and fit the requirement to provide predictions of AGR drying to satisfy the demand from NDA and Sellafield Ltd.

SOLUTION

NNL is currently working on a 'roadmap' to indicate the development steps to the final product which can accommodate AGR fuel drying for a client such as Sellafield Ltd. Initial development of a methodology to demonstrate the concept of predicting drying in AGR fuel cladding has been achieved. The framework uses a 1D fluid flow/mass and heat transfer network (using the NNL INCA code) in connection with more detailed computational fluid dynamics (CFD) to begin to determine the effect of surface tension.

OUTCOME

An initial functional 1D model that captures some but not all of the key physics has been developed.

SCIENCE AND TECHNOLOGY

Nuclear Safety

Summary

A high-quality safety record is an absolute priority for nuclear facilities. Innovative new ideas are essential, but so too are as low as reasonably practicable (ALARP) assessments and regulation.

ALARP is the bedrock of UK health and safety law and can often drive overly conservative decision making, particularly if influenced that way by onerous standards/good practice guides, compensating for significant uncertainties, or cautious judgements from inexperienced safety specialists. The safety-related theme projects are therefore all linked with initiatives that help to positively influence these three aspects, and NNL is able to credibly lead these areas.

“Driving safety solutions for industry-driven challenges.”

CASE STUDY

Good Practice Guide

Challenge

The criticality safety of a fissile system is assured, in part, by providing a margin between the actual (or assumed) conditions and the conditions where criticality would occur. The smallest acceptable margin is known as the minimal subcritical margin (MSM).

There are no statutory industry requirements pertaining to the MSM, and hence expert judgement is required in determining it. Selection of an overly-conservative MSM reduces the criticality risk but can disproportionately increase the non-criticality risks and lead to an overall risk that is not ALARP, e.g. it can have a substantial effect on facility operations (e.g. reduced storage capacity/throughout) and introduce other safety hazards (e.g. conventional or radiological). There was a general consensus at the UK Working Party on Criticality (WPC) that the need to improve industry understanding around the derivation and justification of MSMs was a high priority strategic issue.

SOLUTION

Led by NNL and Sellafield Ltd, the UK WPC developed an extensive Good Practice Guide for the nuclear industry to offer guidance on deriving and justifying appropriate MSMs.

OUTCOME

The guide has been successful in explaining the purpose of an MSM, providing guidance on the setting and justification of an MSM, and outlining existing UK practices (including some examples for different applications).

STATUS

The guide was completed and endorsed by the UK WPC in June 2020 and has since been endorsed by the UK Safety Directors Forum (SDF). The guide will soon be viewable on the Nuclear Institute website.

Innovation

Technological and cultural innovation within NNL is at our core. We strive to create an environment that enables and encourages our people to innovate; to explore their ideas and interests for developing new solutions.

The innovation programme is proud to have created a successful, broad-ranging, and balanced portfolio that addresses internal innovation, as well as a multitude of industrial and customer needs. This includes a variety of cross-sector and non-nuclear opportunities for technology translation. By applying an innovative mindset, NNL delivers sectoral and societal impact by developing the technological solutions required to tackle some of the greatest challenges facing the sector.

The Innovation Team offers a creative, optimistic environment to think and provides access to funding through a clear process that takes ideas through the technology readiness levels to product delivery. There are three distinct funding levels:

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

Innovation within NNL is a continual process. The figures for comparison between the previous TSA report and the most recent financial year are opposite. Note, the reduction in the number of approved and funded applications is due to resource availability (colleagues and facilities) affected by the COVID-19 global pandemic. The figures are expected to recover to at least FY19/20 levels over the current year.

Approved and funded Primer applications

FY19/20	FY20/21
23	11

Approved and funded Builder applications

FY19/20	FY20/21
13	6

Approved and funded Delivery applications

FY19/20	FY20/21
1	2

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

Championing innovative, future technologies for practical deployment

Summary

NNL's innovation programme is a champion of collaboration and an accelerator of challenge-led technologies for deployment onto Sellafield site and into the supply chain.

The team manages an extensive portfolio of projects, many of which have direct application to the technical challenges faced on the Sellafield site and the NDA estate. Aligning projects to the NNL Focus Areas has enabled resources to link more efficiently to Sellafield Ltd priorities, especially through the Environmental Restoration and the Security and Non-Proliferation Focus Areas.

Our collaboration with Sellafield Ltd on the Game Changers programme has successfully incentivised over 100 organisations, ranging from universities to cutting-edge small and medium sized enterprises (SMEs) in the supply chain to find ways to overcome some of the most complex challenges in the nuclear industry.

Innovation in focus

Resolve Robotics

This Cumbrian SME has received Game Changers funding to develop its versatile and modular robotic deployment system CellRail, which will make it safer, easier and cheaper to carry out inspection and intervention processes in nuclear cells.

"Our relationship with Game Changers and ability to work with NNL has had a significant impact on our business, lending us credibility within the UK nuclear sector and the confidence to expand our market reach... we hope to remove barriers to decommissioning activities and minimise the overall cost and environmental impact... and provide highly specialist jobs here in the North West."

Brunel University Innovation Centre

Game Changers POCO Challenge

Sellafield Ltd requested input for technologies that remove blockages in pipes – Brunel Innovation Centre has existing technology and expertise in the oil and gas sector, but not nuclear. NNL supported the project by advising on what makes up a blockage; the types of blockages experienced on site; and the data input required to test and prove the technology. The exogenous ultrasonic technology is currently being tested at Brunel University, before being transferred to Workington for further validation and rigorous testing. This will complete the proof-of-concept phase before deployment on plant.

Technical Evaluation and Demonstration (TED) rig

Challenge

The Sellafield Ltd/NNL teams had been struggling to give 'representative demonstrations' for Game Changers technologies in Sellafield Ltd relevant environments, meaning it was difficult to thoroughly test technologies.

SOLUTION

Funded by Sellafield Ltd,NNLconstructed a TED rig for Sellafield Ltd and NNL collaborations at Workington site for use by Sellafield Ltd and supply chain partners. The rig will host various technology demonstrations once commissioned, enabling researchers to undertake non-active trials of future technology, directly relevant to Sellafield site.

TECHNOLOGY

Future technology to be tested on the rig includes:

- Remote Capping and Plugging (RECAP) technology
- Magnox Swarf Storage Silo (MSSS) containment box trials
- Pipe unblocking work for Fuel Handling Plant (FHP)
- Game Changers Challenge – demonstration and testing of technologies for vertical deployment into cells and vessels
- FirmARM (long-reach arm) – could be suitable for non-destructive testing at Site Ion Exchange Effluent Plant (SIXEP).

OUTCOME

Technologies can now be tested in a safe, non-active environment before deployment onto site. This saves costs; is easier to test and innovate on technologies; and creates an advanced technology demonstration hub for the Cumbrian supply chain partners.

STATUS

The TED rig has been installed in the NNL Workington Rig Hall facility and is being prepared for commissioning over the next few months.

Collaboration

Collaborating with others is at the heart of what NNL does. We bring together researchers, customers, and the wider nuclear industry to apply our expertise and deliver innovative solutions.

Engaging with universities and research institutes, both in the UK and internationally, adds great value to NNL and supports the numerous contributions we make to our customers. The unique relationships we form with our partners delivers sectoral and societal impact through the people, skills and ideas that we develop and the collaborations that we foster.

Our 2030 vision is to focus and stimulate cutting-edge, collaborative research with academia, nationally and internationally, and motivate the next generation of experts to address the nuclear sector's greatest challenges, through scientific discovery and proof. We will achieve this long-term vision by enriching and developing our experts, as well as working closely with outside sectors to enhance the knowledge of the industry and bring in alternative ideas and technologies to further progress the solutions we offer our customers.

Science Integrated Research Team (sIRT)

Summary

The Sellafield Ltd/NNL sIRT is an ongoing area of collaboration, supplementary to the NNL Core Themes, which seeks to develop Sellafield Ltd-relevant Science and Technology projects for site-wide deployment

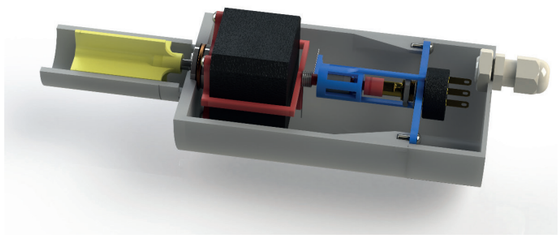
There are four themes within the sIRT; Materials Science, Process Chemistry, Particulate Behaviour and Environmental Science, and each drives a highly impactful programme of activities across the decommissioning and waste management landscape. Projects are challenge-led and applicable to the wider community of researchers and funding bodies, which therefore encourages additional research into previously unexplored areas of Science and Technology. Importantly, NNL and Sellafield Ltd are then able to disseminate critical knowledge gained through these research projects to the wider technical community. Work is ongoing in all four areas, with the ultimate aim of mapping and monitoring the work being undertaken in each technical area.

CASE STUDY

Viscometer to detect radioactive sludge

Challenge

Radioactive sludge often has unpredictable, uncertain behaviour, which coupled with restricted access to contaminated areas on site and the lack of existing equipment, heightens already tough decommissioning challenges.



SOLUTION

A CINDe PhD project was established, in conjunction with Lancaster University, to create a viscometer for remote and cheap mechanical analysis of suspensions which can deliver repeatable measurements in hazardous environments.

TECHNOLOGY

The robust prototype is made with commercial off-the-shelf components and 3D printed parts. It is inherently radiation tolerant (the device only uses two robust electronic components), is 75mm in diameter and approximately 220mm length.

OUTCOME

The analytical device will inform industry about key decommissioning challenges. The technology developed for in situ measurements will have potential future use for upcoming POCO/decommissioning activities.

STATUS

Work is currently being undertaken to further decrease the size of the prototype. Collaboration is also being undertaken with the University of Manchester on assessing the radiation tolerance of electronics. The PhD thesis was submitted in spring FY21/22, with the viva being conducted in summer of the same year. The candidate successfully passed the viva with minor corrections. Although there are no current plans to take this forward, the technology exists at a lower TRL for potential development/use in future POCO applications.

Robotics

Summary

Highly innovative and skilled, the NNL Robotics Team are pioneering a range of specialised technologies of huge importance to Sellafield Ltd, the NDA, and the wider industry both nationally and internationally.

Working closely with Sellafield Ltd through the TSA, NNL provides technical support to the Robotics and Artificial Intelligence (RAI) programmes and manages Sellafield Ltd's RAI Centre as part of the Sellafield Ltd Central RAI (C-RAI) Programme under NDA's strategic oversight.

This is undertaken in partnership with the InnovateUK Industrial Strategy Challenge Fund's (ISCF) two Harsh Environment Nuclear Hubs – RAIN (Robotics and Artificial Intelligence in Nuclear) and NCNR (National Centre for Nuclear Robotics), for which NNL also chairs the Advisory Board:

- NCNR is focused on sorting; segregating; size reducing; vision; path planning; haptic control; and grasping associated with 6/7 axis robot capabilities;
- RAIN is focused on a 'hands out of glove-boxes' mission, tetherless operations, inspection, characterisation and inspection capabilities.

Internal investment in this area has enabled NNL to enhance its robotics capability to achieve and exceed its customer expectations in being faster, cheaper, safer and more secure in its activities, thus positively contributing to the technological landscape of the UK nuclear industry. Furthermore, as well as engaging collaboratively with numerous partners in the supply chain to achieve Sellafield Ltd decommissioning objectives, NNL has also worked closely with universities to increase access to NNL expertise and facilities; as well as:

- Being active board members of the National Robotics Network (NRN) which is a network of industry end user, supply chain and academic organisations who seek to work collaboratively to increase the uptake of RAI technologies and enable UK companies to successfully compete on a global scale;
- Actioning the procurement which has initiated the development of the NRN cross sector RAI roadmaps which has become of interest to the UK Robotics Growth Partnership initiative; and
- Being members of the NEA Expert Group on the Application of Robotics and Remote Systems in the Nuclear Back-end; which advises member countries on the leading and emerging issues that focus on the development of strategic approaches to facilitate the implementation of robotic and remote systems in radioactive waste management, decommissioning and legacy management at the national and international levels.

> **"Exceed customer expectations by delivering faster, cheaper, safer and more secure decommissioning solutions through collaboration."**

Robotics in focus

The success of our RAI delivery has been due to NNL's unique ability to draw upon our extensive nuclear experience. By working collaboratively, NNL has demonstrably removed duplication of research programmes; assisted with aligning strategies; and improved efficiencies within the Robotic Hubs. The ability to stretch across the TRL domains from fundamental research to full plant deployment, from provision of supporting functions in safety case, engineering, modelling etc. is a unique attribute to NNL, ensuring technical quality and expertise for our customers.

National Nuclear User Facility for Hot Robotics

NNL alongside the University of Bristol, the University of Manchester and UKAEA's Remote Applications for Challenging Environments (RACE) have formed a consortium establishing a new National Nuclear User Facility for Hot Robotics (NNUF-HR) for nuclear robotics R&D in the UK. This investment in the Workington facility will facilitate access for researcher and academics into the NNUF facilities, as well as enhancing NNL's current in-house robotic capabilities and established networks.

The award of the NNUF-HR collaborative funding provides fantastic opportunities for Sellafield Ltd and the supply chain to use NNL's unique robotics facilities to make significant step changes in the acceleration of fundamental RAI research to meet the current and future nuclear industry challenges. The facility will also support the UK's ambitions for more cost-effective and faster decommissioning, as well as providing a range of opportunities for academia and industry to utilise cutting edge equipment and expertise.

Robotic task sequencing and motion coordination

Challenge

Currently, the planning and optimisation of task allocation for multiple robot arms is difficult due to each robot's high number of degrees of freedom and the risk of collision.

SOLUTION

The NNL Robotics Team developed an advanced modular algorithm for the allocation and sequencing of tasks and the coordination of motions between two robots for large sets of point-based tasks.

TECHNOLOGY

The algorithm is inspired by the classic 'Travelling Salesman Problem' from Computer Science and utilises a novel strategy based on clustering techniques to solve large sequencing problems efficiently. It builds on previous work that addressed the task sequencing problem for single robot arms[2]. Three different methods for motion coordination has been examined to understand and quantify the performance trade-offs between computation time and the total duration of the planned actions.

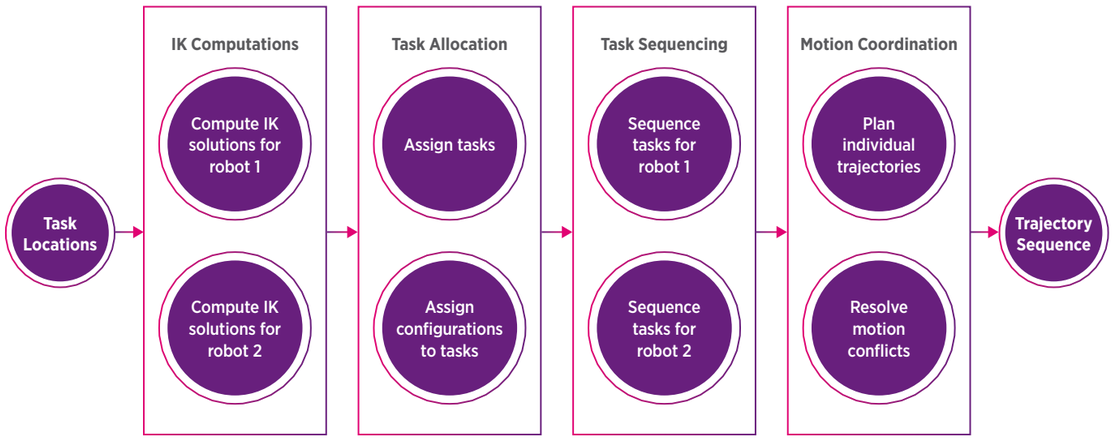
OUTCOME

Thought to be the first demonstration of a multi-robot task sequencing algorithm applied to large-scale problems involving hundreds to thousands of tasks, the modular nature of the proposed algorithm enables its components to be swapped with emerging state-of-the-art methods that better address an individual sub-problem.

STATUS

At present, the different motion coordination methods balance performance trade-off with computation time and total task duration. Future work will seek to extend the work towards physical trials and demonstration through integration with object scanning technology.

High-level overview of proposed method for multi-arm task sequencing problems



2 C. Wong, C. Mineo, E. Yang, X.-T. Yan and D. Gu, "A novel clustering-based algorithm for solving spatially-constrained robotic task sequencing problems," IEEE/ASME Transactions on Mechatronics, Early Access, 2020.

University Collaborations

Summary

Collaboration with universities at a postgraduate level is a fundamental component of NNL's work as a national laboratory.

We are safeguarding future skills through high quality development of students, with much of the talent remaining in Cumbria post-graduation. This knowledge retention and upskilling is essential to the future of the UK nuclear industry. NNL works with 22 universities and supports 144 PhDs and Post-Doctoral Research Associates. The Centre for Innovative Nuclear Decommissioning (CINDe) hub supports 16 students. The Transformative Science and Engineering for Nuclear Decommissioning (TRANSCEND) programme supports 20 PhD students, with five of these funded by Sellafield Ltd which are either direct supervised by NNL or co-supervised with Sellafield Ltd staff.

"Our university collaborations support the UK's technical talent pipeline, facilitate innovation and help steer academic research to meet the needs of industry."

CINDe

The CINDe is an idea championed jointly by Sellafield Ltd and NNL, and established at NNL's Workington Facility in 2016, in collaboration with the University of Manchester, Lancaster University, the University of Liverpool and the University of Cumbria. With the aim of contributing to the development of the next generation of nuclear scientists, the CINDe Team have established a vocational postgraduate research centre hosting industrially relevant research that supports the national decommissioning mission. Operated by NNL, the hub seeks to create scientific advances that can be easily translated through onsite demonstrations and realisation of commercial deployment opportunities. Sixteen postgraduate researchers (PGRs) joined CINDe during the first five years (cohorts 1-5), with their research spanning a range of decommissioning challenges. Many have opted to stay within West Cumbria and NNL meaning industrially relevant research skills and knowledge are maintained in the supply chain.

TRANSCEND

TRANSCEND is a £9.4m collaborative research consortium comprising eleven universities and eight industry partners. Currently in its third year, it includes 40 PhD and post-doctoral projects within four themes and seeks to unite the academic and industrial research communities to enable the adoption of a comprehensive approach to decommissioning and waste management.

NNL's TRANSCEND researchers champion innovative solutions to challenging industry problems, many with potential industrial deployment applications. Equally important is that TRANSCEND is training future subject matter experts, during their PhD and post-doctoral projects, as a key feed into the skills pipelines for all aspects of the nuclear industry.

Current TRANSCEND PGRs include:

- University of Birmingham – computational modelling of PuO_2: ageing and storage phenomena
- University of Birmingham – in situ ion exchange studies of zeolites
- Imperial College – durability of magnesium silicate cements
- University of Manchester – radiation effects on wasteforms
- University of Sheffield – encapsulation of orphan wastes using magnesium phosphate cements
- University of Southampton – electrokinetic remediation application to soils, concretes and other site and process wastes (including EDTA-containing wastes)
- University of Surrey – predicting the corrosion rate of spent nuclear fuels
- University of Bristol – building the foundations of a predictive tool for spent fuel behaviour.

The optimisation of an ultrafiltration system for nuclear decommissioning

Challenge

As the Sellafield Ltd site transitions from reprocessing to post operational clean out, activities underpinning how decontamination reagents are used could affect the operations of Enhanced Actinide Removal Plant (EARP).

SOLUTION

To further contribute to our understanding of POCO operations, a CINDe PGR (PhD) project was established to understand the behaviour of the decontamination reagents, using a non-active test rig.

TECHNOLOGY

A small-scale ultrafiltration (UF) system that mimics full-scale EARP operations and complements the existing pilot-scale EARP rig was constructed for non-active testing at NNL Workington.

OUTCOME

Using the rig, the non-active simulants of current and potential future EARP process fluids were processed, and the results have been used to validate and inform computational models of UF membrane fouling used by NNL and Sellafield Ltd.

STATUS

The rapid testing of simulants and conditions will inform future NNL EARP rig campaigns, and potentially EARP operations. The research is being collated by the post-graduate who has joined NNL full-time and is performing follow on work that is directly relevant to Sellafield Ltd. This is an excellent example of the purpose of CINDe: performing applied PhD research directly related to customer challenges and training potential future Subject Matter Experts for the nuclear industry.

International Programmes

Summary

In FY20/21 NNL received funding from Horizon 2020 and other sources to begin a variety of research projects across the areas of Waste Management and Decommissioning, Materials Science and Actinide Separation Chemistry. After being successful with each bid we submitted, we will be collaborating with multiple organisations, stakeholders, and research institutes across the world, with a combined grant value of £2m over the next four years, with additional leveraged funding from NNL and other parties such as Sellafield Ltd.

International Programmes in focus

Working in tandem with our partners and customers to spearhead innovation and collaboration within these key areas, NNL is directly enhancing the knowledge and expertise of its own colleagues, as well as supporting the nuclear industry more broadly. Sellafield Ltd is co-funding a part of the PREDIS encapsulation work package alongside NNLfor example, which will provide access and leverage to the international geopolymer community that otherwise might be difficult to achieve. This enables technology and understanding to improve and help underpin the UK's leadership in this area.

CASE STUDY

PRE-DISposal management of radioactive waste (PREDIS)

Challenge

Areas of predisposal research has often been uncoordinated and therefore difficult to collaborate with international organisations. This has made it hard to drive technologies forwards and develop innovative solutions for disposal problems.

SOLUTION

PREDIS was formed in September 2020 and is a large-scale European project with 48 organisations from across 18 EU member states, aiming to take an organised approach to fully exploring global decommissioning opportunities to deliver real benefit to research communities and society more widely. It targets the development and implementation of activities for pre-disposal treatment of radioactive waste streams. NNL is leading on work package 2 (WP2) which will develop a strategic research agenda and roadmap for pre-disposal waste management. This leadership role means NNL can steer the direction of the international community thus directly influencing the direction of the UK nuclear sector.

TECHNOLOGY

NNL is also contributing to other work packages within PREDIS:

- WP4: Performing active decontamination experiments of metallic waste on coupons in Central and Preston labs
- WP5: Undertaking non-active trials at Workington using geopolymers. Sellafield Ltd are co-funding the project meaning learning and resource can be shared for the greatest impact
- WP6: NNL will be demonstrating HIP technology at Workington.

OUTCOME

Across the workstreams, more than 30 people from within NNL are involved. We have colleagues from Waste Management and Decommissioning, Nuclear Operations, Laboratory Operations, the Project Management Authority and Commercial participating in delivering value from the international programmes.

Recently an introductory workshop was hosted with over 100 PREDIS stakeholders to foster relationship across the scientific community. Sellafield Ltd were active participants in this.

STATUS

PREDIS is a four-year programme led by Finnish organisation VTT with a total value of €14m, of which NNL's grant value is approximately £1m. Over the next four years, significant developments in collaborative predisposal programmes are expected.

Enablers

Collaboration is at the heart of what we do. We help to translate fundamental research into real-life solutions for industry. Part of this role involves providing access to our world-class facilities for others to develop their work.

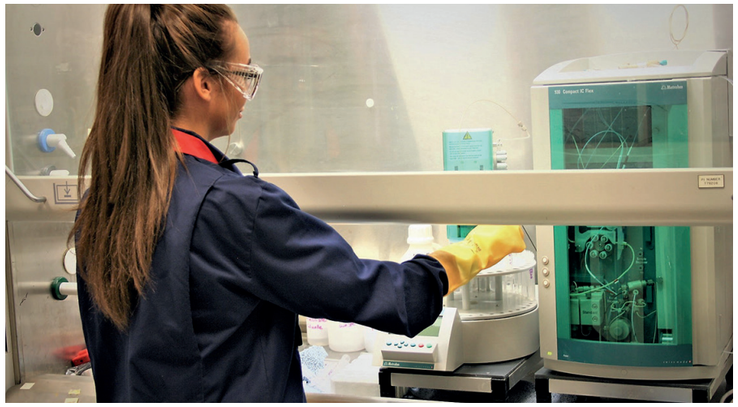
We operate some of the world's most advanced nuclear facilities and our state-of-the-art laboratories support our people in pushing the boundaries of nuclear science and innovation. NNL facilities are available to researchers and customers thus providing value to industry and contain a vast array of different laboratories and analytical capabilities suitable for addressing a range of industry challenges.

Alongside our unique infrastructure, we are proud to say that it is our people that make us unique. We have world-leading scientists, engineers, technologists, and experts in other fields who undertake focused nuclear research, championing new ideas for industry. Developing nuclear subject matter experts of the future as well as maintaining and enhancing our current skillset, NNL is at the forefront of skills and expertise in the UK nuclear industry.

Technical Skills and Capabilities

Summary

One of NNL's strongest assets is our people. The mutual investment by NNL and the passion of our colleagues to share their expertise means NNL consistently delivers value to customers. Over the last year we have developed an exciting range of behavioural courses and are currently finalising the design of our leadership framework. Furthermore, our Early Careers Team is expanding alongside our growing apprenticeship, graduate and new post-doctoral programmes.



Personal Development

The ongoing development of NNL colleagues is important. NNL is committed to supporting the upskilling and talent managements of individuals in our business to ensure colleagues are continually learning and striving to achieve their best. This supports the needs of our customers by ensuring we can deliver enhanced knowledge and capabilities on relevant projects and challenges.

Delivering high-quality technical training is a key asset for NNL and one of great importance to our customers and the industry. In total, we have delivered 6,131 online e-learning courses in 2020/21, 225 virtual training events and 16 education concessions.

Professional Development

In addition to supporting the personal development of our colleagues, we recognise the value in supporting and encouraging professional development and hence in 2020/21:

- We have expanded the number of Professional Communities of Practice to nine, each with a specific remit to help support, develop professional development from registration grade to fellow
- Over a quarter of our people are members of the Nuclear Institute and we are embedding nuclear professionalism through adoption of the Nuclear Delta across the NNL business, embedded through our leadership framework and career pathways
- We recognise that over 45% of our people hold professional membership with at least one institute and we are currently supporting all our early career's people to form associations with a relevant institute to support their professional growth.

Achievements

NNL's commitment to its employees was recognised at the National Skills Academy Nuclear awards help in March 2021:

- Winner – Sam Lyons – Nuclear Graduate of the Year
- Runner-up – Elizabeth Sunderland – Higher and Degree Apprentice of the Year
- Runner-up – NNL – Outstanding Contribution to Equality, Diversity and Inclusion.

Our commitment to diversity and inclusion was also realised at the Women in Nuclear Awards where Leah Etheridge was runner-up in the Champion of the Year awards.

Our colleagues have also won numerous other awards in FY20/21, signifying the prowess and dedication of NNL colleagues to the nuclear industry more broadly.

- YGN National Speaking Competition Winner – Allan Simpson (Cumbria). 'On Humanising Nuclear Energy'
- YGN National Speaking Competition Runner Up – Rodosthenis Charalampous (North East Region). 'Wireless Robotics and the Future of Nuclear Decommissioning'
- Nuclear Institute Pinkerton prize was awarded to Robin Taylor and Gemma Mathers for their work on the Advanced Fuel Cycle Programme.

Knowledge Management

Good knowledge and information management is essential to ensuring that knowledge is accessible to others in the organisation, but also to the industry more broadly. NNL colleagues offer a wealth of information across a diverse range of subjects so it is essential to capture and share the information as broadly as possible.

In FY20/21, there were four Knowledge Management Talks shared with Sellafield Ltd out of a total of 26. These were:

- ARMED! (Aerial Radiological Mapping of Environments by Drones)
- Collaboration Between Industry and Academia: Solving Our Decommissioning Challenges
- How can Life Cycle Assessment help us understand the environmental pros and cons of new technology?
- The N-Visage® system: products for 3D radiation characterisation.

Over the coming year, the advancements in technology and the the joint use of Microsoft Teams will enhance the relationship between NNL and Sellafield Ltd, with both companies looking to deliver more collaborative KM talks in FY21/22.

Early Careers

Developing the next generation of nuclear industry professionals is a key investment for NNL. Our graduates and apprentices have a wide range of opportunities to develop their skills both professionally and personally and get involved in numerous activities outside of their day jobs which support society more broadly. Some of these include working with schools to engage and inspire students with STEM activities; working with the Nuclear Institute Young Generation Network; and speaking at conferences, events and competitions. Expanding the horizons of NNL's early career talent is essential to creating a diverse workforce for the future.

Apprentices

Since 2016 we have employed 30 apprentices working on the Sellafield site.

- 14 are studying Engineering
- 16 are studying Scientific
- 2 are studying Health Physics

We also expect to achieve the Nuclear Sector Deal apprentice gender target this year with 50% of our apprentices identifying as female. All apprentices have remained within NNL working on the Cumbrian sites meaning skills and experience are maintained within Cumbria and the industry. This retention of critical knowledge is of paramount importance to the Sellafield Ltd decommissioning challenges of the future.

Graduates

NNL has recruited 22 graduates to the Cumbrian sites (Sellafield and Workington) since 2016, of which six identify as female. Their developing expertise will fuel the future of the industry and many are engaged on supporting Sellafield Ltd projects.

Post Doctorates

NNL is also developing a Post-Doctoral Scheme for individuals who have achieved a PhD, which is due to commence in 2021. As well as supporting researchers entering the work environment, the scheme will ensure NNL is developing a pipeline of capability to support fragile skills areas and will be one route to accelerate expertise in Sellafield Ltd-specific research areas such as special nuclear materials.

General Recruitment

Over the course of FY20/21 NNL has been active in recruiting new colleagues to various teams across our sites. New recruits (including early careers) in NNL's Cumbrian facilities total 101, of those 18 are engineers, and at our offices in Risley recruitment figures are of 57 new starters, of which four are engineers.

Facilities and Infrastructure

Summary

Facilities across all seven NNL sites are supporting innovation, technical delivery, and programme management. From our well-equipped offices to our world-leading laboratories containing inspiring equipment for use by researchers, the supply chain, and academics, NNL takes great pride in its facilities. Understanding our customers' needs and how we can improve our delivery of critical projects is a constant driver for the facilities and infrastructure team at NNL.

"Over £7.6bn of savings delivered through Sellafield Ltd/NNL partnership collaboration from 2008-2019."

NNL's reinvestment in its facilities has enabled numerous improvements to be made, ultimately enhancing the opportunities we can provide our customers, including Sellafield Ltd:

Windscale facility

- Refurbished Cave 4 including the installation of a new crane and the replacement of zinc/bromine windows
- Fully commissioned the Red Extract system for the facility and completed interim repairs on the Amber Extract system
- Refurbished the Wharton Hoist
- Continued with improving the welfare facilities e.g. replacement of building windows, upgrading of existing plus installation of additional welfare facilities
- Completed the design for the major changeroom refurbishment.

Central

- COVID-19 secure arrangements were put in place in response to pandemic enabling continued safe operations – this has enabled continued delivery of key Sellafield Ltd programmes over FY20/21
- Fire ceiling improvements installed to reduce fire risk within the facility
- Active goods lift upgrade supporting continued nuclear material movement throughout the facility
- Supporting Sellafield Ltd-funded non-active office and store improvements and installations undertaken in preparation for the Relocation of Analytical Services Project (RAP) move into Central Laboratory.

Other NNL facilities

NNL's Workington Laboratory has also benefitted from reinvestment funding to improve areas of the rig hall, as had NNL's laboratory at Springfields, Preston. These projects will continue into FY21/22 and provide benefit for our customers' needs and requirements.

Asset Management

One of NNL's key initiatives from 2021 and beyond will be to start the journey towards a new proactive approach to asset care and maintenance. Using ISO 55000 as the standards that define the desired framework and enable tracking of progress, NNL will be investing in the underlying technology, systems and processes that enable a far more proactive approach to maintaining the health of the critical national assets that it manages. That includes everything from the fabric of the buildings it operates to the capabilities that sit within them.

The overall objective is to improve the performance of our assets, create more certainty in our outcomes, make better investment decisions, and deliver better value to our customers. It's journey that will take several years to complete, but an essential one to ensure our laboratories meet the needs of our customers in the future.

Safeguarding our vital physical assets: Central Laboratory

Among NNL's unique combination of facilities is our flagship Central Laboratory, housed within the Sellafield site.
A state-of-the-art facility with significant capabilities, the laboratory is critical to the UK's plutonium stewardship programme. To permit these operations, the facility underwent a programme of security enhancements over FY20/21, and submitted a Nuclear Site Security Plan to meet necessary requirements. Working closely with a broad range of stakeholders, including Sellafield Ltd, the successful delivery of the new security plan was achieved. The capability and knowledge NNL has gained from the process has added value to our long-term management of the laboratory and to the nationally strategic capability and programmes it enables.

Furthermore, NNL has also incorporated the experience into the engineering design phase of the Sellafield Ltd funded Replacement Analytical Project (RAP) a new facility that will see the laboratory become the home of essential analytical services towards the operation of Sellafield and delivery of its legacy waste management mission. This early integration will ensure security and regulatory requirements are built in from the start saving time and money at future stages of the project. NNL has since shared learnings and best practice with UK and international industry partners, so that others across the sector can also benefit.

Technology and Digital Change

Summary

The Technical and Digital Change Team have operated flexibly and responsively throughout FY20/21, responding efficiently to the uncertainties the COVID-19 pandemic created.

Delivering a full client device refresh as part of the 2019 SmartSource programme (to insource our IT), coupled with further significant procurement activities early in 2020, have all ensured that NNL operations can continue successfully. This alongside the ongoing network upgrades and improvements, have enabled our employees to work remotely and increased our capability to respond to ongoing events more efficiently.

Customer work remained mostly undisrupted by IT improvement activities, and in fact, greater collaboration was enabled between remote teams through the successful deployment of Microsoft Teams and supporting functionality.

“Bringing digital to nuclear: solving problems, mitigating risk, and creating communities.”

Technology and Digital Change in focus

Microsoft Teams
Taking a proactive approach to digital change, the migration from Skype for Business to Microsoft Teams (telephony and video-conference) was successfully completed over a two week period, to all 1,000+ employees at NNL. Typically requiring more than six months of planning and execution, the project was expedited, and successfully delivered, in under four months.

The programme is fully accredited for all information up to Official-Sensitive (internally), of which NNL is the only nuclear authority with that capability in the UK. Because of this, NNL’s Chief IT Architect has been engaging with the Sellafield Ltd equivalent, to share our Risk Balance Case to support Sellafield Ltd in their IT infrastructure planning (conversations are also taking place with NDA about their Microsoft Teams functionality).

Numerous projects have benefitted from our investment in a more digital landscape, including the Replacement Analytical Project (RAP).

High Performance Computing
As the FY19/20 Reinvestment Report noted, NNL is significantly investing in private and public cloud-based solutions by 2025. This technology is essential for NNL’s modelling teams to expand and enhance their capabilities to support Sellafield Ltd with their decommissioning efforts. The improved capability will continue to aid safety cases and support further collaboration between Sellafield Ltd and NNL when solving complex decommissioning challenges.

PRISM is the first phase of NNL’s new high-powered computing solution, a cloud-based technology which will significantly improve NNL’s computing power across a number of customer delivery areas utilising modelling and simulation. For the first time, NNL can access national infrastructure, through the Science and Technology Facilities Council (STFC) Hartree Centre, as part of PRISM. STFC operate one of the UK’s most powerful supercomputers dedicated to support industry. This means faster, more efficient, and more cost-effective services for our customers.

“This is a significant step for NNL. Not only for those people who use this computing power on a day to day basis but for the entire business. It thrusts us to the front of the UK nuclear industry in terms of available computing power – something that is important for us as a National Laboratory.”

Mark Bankhead
Senior Technology Manager and Technical Lead for HPC in NNL

Collaboration and Microsoft Teams

Challenge

The COVID-19 pandemic stunted collaboration opportunities between internal and external teams which could have a negative effect on team morale and customer delivery, for example with the RAP project.

SOLUTION

To accelerate productive working, NNL hosted joint workshop sessions between Sellafield Ltd and internal colleagues for the RAP project with breakout rooms, live whiteboards, and additional features to create an innovative, online space.

TECHNOLOGY

Our in-house capabilities worked closely with Microsoft and other third parties to develop a comprehensive programme which can navigate official conversations, up to Official-Sensitive classification (internally).

OUTCOME

The full functionality of Microsoft Teams, improved productivity, and greater collaboration for teams across the RAP project, enabling work to continue as scheduled with minimal impact on project delivery.

STATUS

NNL rolled out the ‘Teams’ part of Microsoft Teams in March 2021, meaning easier, more efficient and effective communication, as well as real-time collaboration, internally, on documents up to, and including, Official-Sensitive.

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