Sellafield Ltd

Areas of Research Interest

2024

Contents

Introduction

Purpose of document

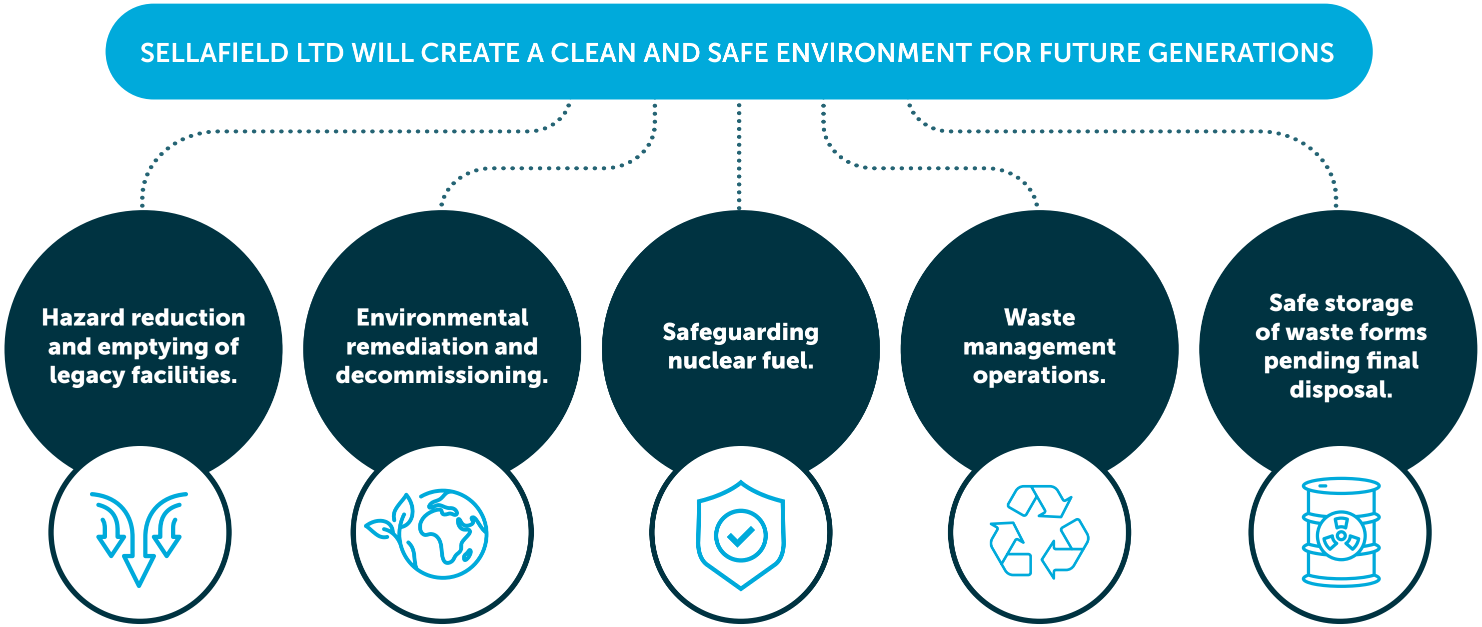
This document provides an insight into the medium to long term science and technology research needs and interests requiring Research and Development (R&D) investment at Sellafield Ltd, aligned to the Sellafield mission. This will encourage opportunities for dialogue and involvement in R&D from academia, the supply chain, and stakeholders.

This is the third publication of this document, and it is underpinned by Sellafield Ltd's science and technology research needs sheets that have been articulated in a consistent manner. These are stored centrally within the Sellafield Ltd management system and can be obtained by contacting the technical community at Sellafield Ltd.

For further information or if you want to get in touch to engage and collaborate, please contact: technical.innovation@sellafieldsites.com

Sellafield mission

Sellafield is the largest UK nuclear site with a unique and diverse range of complex challenges arising from more than 60 years of varied nuclear operations. Sellafield Ltd's mission is to safely and securely remediate the Sellafield site to benefit the industry and nation.



Background

Why Scientific Underpinning and Technology Development?

In 2020, Sellafield Ltd published its Enterprise Strategy which is driven by its purpose and manifesto. It outlines the type of organisation Sellafield Ltd wants to be whilst setting out the 2020 to 2025 objectives.

Sellafield Ltd has defined a 'technical baseline', setting out all of the processes and technologies used, or planned to be used, to deliver the mission. These processes and technologies need to be sufficiently underpinned by R&D. As the mission evolves, it is essential that the science and technology areas requiring R&D investment are aligned to the changing needs of the business. The use of innovative approaches and technologies is a key part of the Enterprise Strategy.

To ensure that the mission continues to be underpinned and to manage future risks, key areas and themes where R&D needs to be focussed in the medium to longer term have been identified. These science and technology themes form the work breakdown structure that drives the R&D programmes, shown on pages 7 and 13. In 2023-2024, Sellafield Ltd has expanded its R&D needs to explore opportunities created by using Artificial Intelligence (AI) and the increased focus on technologies which make Sellafield's activities more sustainable.

Critical to success is integration and coordination of the various R&D programmes that are delivering science and technologies; and therefore, programmes are managed by research teams with end user input.

The supply chain and academia are key to address these needs and just as important is the potential for collaboration with funding opportunities from other organisations such UK Research and Innovation.

Nuclear Decommissioning Authority Grand Challenges

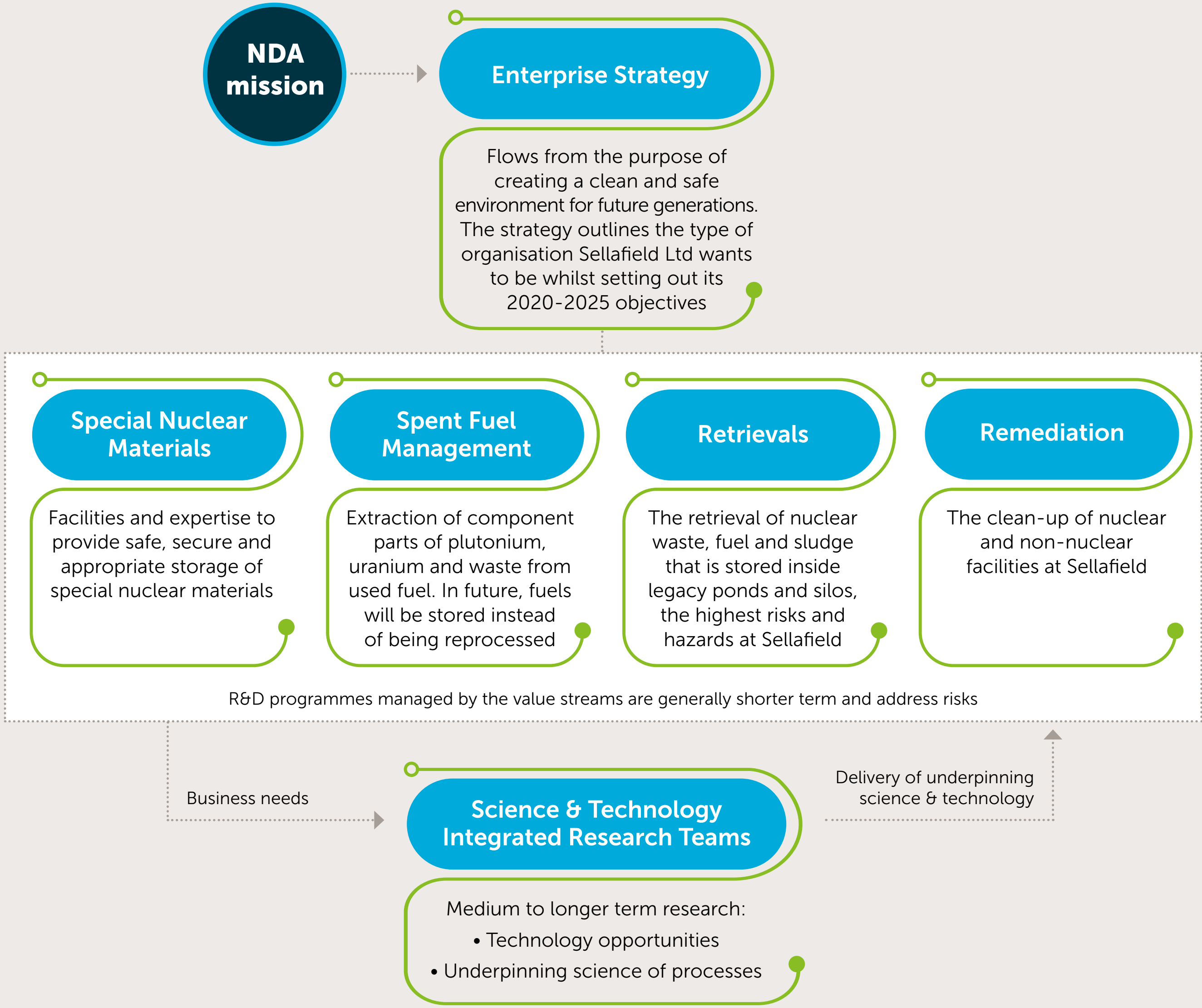
CHALLENGE THEME	CHALLENGE DETAIL
Reducing waste and reshaping the waste hierarchy	Finding new ways to drive the waste hierarchy, increasing recycling and re-use in order to reduce volumes sent for disposal
Intelligent infrastructure	Using autonomous technology to manage assets and buildings proactively and efficiently
Moving humans away from harm	Reducing the need for people to enter hazardous environments using autonomous systems, robotics and wearable technology
Digital delivery – enabling data drive decisions	Adopting digital approaches for capturing and using data, to improve planning, training and aid decision

Table 1 illustrates the Nuclear Decommissioning Authority (NDA) Grand Challenges, aspects of which are being addressed by the R&D programmes.

Sellafield Ltd Value Streams and Alignment with Longer Term R&D

Sellafield Ltd's value streams, illustrated in the figure to the right, stem from the Enterprise Strategy which is part of the overall NDA mission. Each value stream manages R&D programmes to address shorter term needs and risks.

To complement these programmes, the Central Technical function manages longer term R&D programmes. These are required to deliver underpinning science of processes and new innovative technologies, aligned to the longer term needs of the business. This R&D forms the subject matter of this document.

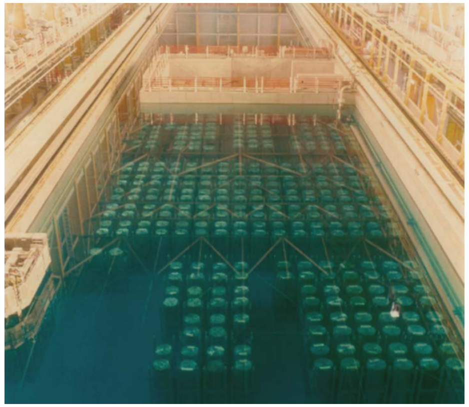


Science Themes

The scientists at Sellafield have developed the foundation of understanding needed to take on the demanding challenges of their mission. There will be first-of-a kind activities, such as dismantling the fire damaged Windscale Pile 1 reactor or undertaking the safe storage of the world's largest stock of civil plutonium.

Sellafield Ltd's science programme is a key part of their robust informed decision-making process. The decisions made will ensure that all of what is done is safe and will remain safe throughout the interim storage period.

A summary of the science themes, alongside the key areas requiring further research for each theme, is presented in this section.



THE FOUR THEMES OF THE SCIENCE PROGRAMME

Materials Science

Understanding of the chemical, physical and engineering properties of current and new materials in their relevant operational environment to facilitate decisions in support of existing operations and design of new plants.

Process Chemistry

Underpinning science of current infrastructure of treatment and storage facilities so that they can be adapted to manage future wastes. Development of new processes to assist in the delivery of the changing mission.

Particulate Behaviour

Properties and behaviour of particulate materials, including sludges, slurries and suspended particulates or liquid droplets in gases to underpin design, abatement techniques, personnel protection and flowsheets.

Environmental Science

Understanding of the long-term fate of radioactivity and its impact on the environment, as it changes.

Science Work Breakdown Structure

A work breakdown structure for the science programme has been developed to address the many risks and uncertainties that are inherent in Sellafield Ltd's future mission. For example, the evolution of many legacy uranium bearing waste forms has been examined and modelled extensively, but as with all scientific understanding, gaps in the understanding remain. Sellafield Ltd's science programme has been designed to recognise, prioritise and challenge these gaps in understanding with the aim of reducing risk and informing better decision making.

Materials science

- Improve inspection tools
- Materials performance & degradation
- Polymeric & non-metallic materials
- Container materials performance
- Waste product evolution & interactions
- Improved/new materials & manufacture
- Spend fuel integrity during storage
- Graphite disposal

Process chemistry

- Chemistry & modelling of highly active liquor systems
- Grout/encapsulation chemistry
- Understanding site-wide off-gases
- Stored plutonium
- Effluents
- Chemistry of immobilisation
- Radiolysis
- Microbiology
- Contamination/decontamination
- Hydrogen management

Particulate behaviour

- Properties of POCO sludge & slurries
- Properties of radioactive sludges & slurries
- Release of airborne particulates
- Abatement of aerial effluents

Environmental science

- Contamination of facilities maintained in a long term quiescent state
- Behaviour of contamination in the subsurface
- Locating & quantifying contamination in the environment
- Modelling & visualisation of the impact of contamination in the environment
- Soil & ground water remediation
- On site disposal of wastes
- Socio-economic modelling

Materials Science

Sellafield Ltd's materials scientists need to apply their expertise to conditions that are as unique as they are challenging. Some examples of what must be dealt with are:

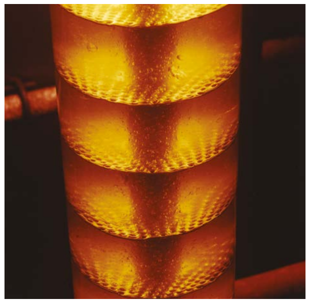
- Processing nitric acid with dissolved nuclear fission products.
- Mixing processed fuel with glass.
- Storing magnesium alloy fuel cladding and spent fuel fragments in water filled boxes for decades.

To tackle these challenges, Sellafield Ltd need to choose materials carefully and then monitor their performance. It must be ensured that materials can handle hazardous content subject to nuclear irradiation, often at high temperature, pressure, acidity and abrasion. In some cases, they will need to withstand these conditions for approximately a century.

To ensure this resilience, Sellafield Ltd's scientists are engaging with materials science experts to develop and monitor, often remotely, a wide variety of process plant and nuclear storage facilities. Sellafield Ltd's collaborators include:

TWI | FESI Forum for Engineering Structural Integrity | NPL National Physical Laboratory | RCNDE Member | National Nuclear Laboratory | Nuclear AMRC | FIND-CDT EPSRC CDT in Future Innovation in NDE

This collaboration and hard work will ensure the Sellafield site remains safe, secure and environmentally sound for decades to come.



KEY AREAS FOR SCIENTIFIC UNDERPINNING

Improved Inspection Tools

Understanding plant conditions to detect life limiting degradation before failure. This will help meet regulatory requirements.

Material performance and degradation

Underpinning science of metallic, cement-based, polymeric materials and fuel performance in current and future applications. Understanding degradation mechanisms such as corrosion and radiation damage.

Polymeric and non-metallic materials

Assessing degradation mechanisms and long-term performance. Determining the impact of material changes on performance. Inspecting polymers in-situ and assessing new materials and technologies. Managing ageing plants using modern repair technology.

Container materials performance

Predicting container performance over 100 years or more, with respect to the store environment during service (e.g., integrity of welds, lifting and closing mechanisms). Developing novel in-situ inspection capability.

Waste product evolution and interactions

Understanding waste evolution including interactions with immobilisation matrices.

Improved/new materials and manufacture

Assessing novel materials and manufacturing processes to improve performance (e.g., in high radiation environments).

Spent fuel integrity during storage

Determining condition and degradation in both wet and dry storage of fuel and cladding (e.g., short term nuclide release, environmental conditions, condition monitoring).

Graphite disposal

Managing the graphite waste streams in terms of storage and disposal. Understanding key challenges of various graphite wasteforms. Identifying optimum treatment, storage and disposal methods.

Process Chemistry

Reprocessing of nuclear fuel was the main activity on the Sellafield site for many decades. As a result, Sellafield has a very large legacy process chemistry complex. The future at Sellafield is cleaning up this legacy, and this opens a whole new set of Process Chemistry questions.

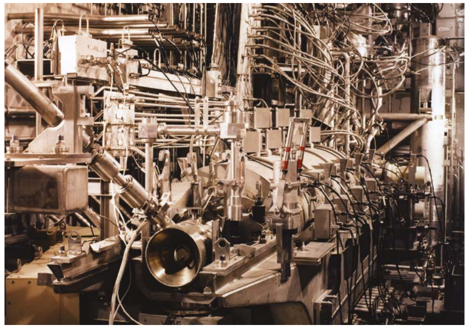
As the Sellafield site transitions away from reprocessing, it has the opportunity to repurpose many of the treatment facilities that supported the operations there for years. Existing waste plants could be used to help process the waste from the ongoing clean out of their redundant facilities. In addition, since there is no longer a requirement to reprocess fuel, an alternative approach is to store spent fuel in purpose-built facilities prior to a future decision on final disposal.

There are more than 100 tonnes of plutonium dioxide that need to be consolidated on the Sellafield site in a safe, secure environment with planned storage for more than 100 years prior to reuse or disposal. This drives the need for minimum repackaging prior to plutonium disposition being fully implemented. The underpinning science behind these activities needs to be understood so that:

- The control of operational processes can always be maintained by understanding the acceptable process parameters, the consequences of deviation from them and by monitoring them on plant.
- Plant efficiency can be improved, for instance by increasing waste loadings in encapsulation processes, by maximising separation factors in effluent treatment processes or by increasing plant throughput.

Existing processes can be adapted, and new processes can be developed to assist in the delivery of the changing mission.

This scientific understanding will also be incorporated into models to help predict the performance of existing processes and to improve the design of new ones.



KEY AREAS FOR SCIENTIFIC UNDERPINNING

Grout/encapsulation chemistry

Developing novel mixing technologies. Immobilising new wastes by existing processes (primarily in drum mixing). Developing higher waste loadings and new encapsulant formulations.

Stored plutonium

Understanding surface speciation and chemistry of solid plutonium forms. Understanding chloride contaminated plutonium in heat treatment process and storage. Improving knowledge of bulk behaviour evolution.

Radiolysis

Undergoing the radiolysis of a range of materials including those in contact with radiogenic surfaces (e.g., Post Operational Clean Out (POCO) slurries, plutonium dioxide, spent fuels, exotics, cementitious phases, metals).

Hydrogen management

Assessing potential accumulation of hydrogen in non-vented environments. Recognising ignition sources. Understanding hydrogen safe POCO states for process plants with residual inventory.

Particulate Behaviour

Much of the radioactive material on the Sellafield site takes the form of sludge, slurries, organics and other residues that may be left in vessels and pipes at the end of operations. Solid particulates or liquid droplets can also be generated from several sources, including high-pressure water jetting of radioactive surfaces, retrieval activities from open air ponds, and size reduction techniques. These sources of particulates will only become more significant during decommissioning.

Given how common this form of radioactive material is, it is essential that Sellafield Ltd understand the composition and behaviour of this material through formation, evolution, transport and disposition. There are currently knowledge gaps in radioactive airborne particulate generation that must be filled.

This understanding is essential as it will underpin the design of future plants, abatement techniques, aerial effluent flowsheets, area classifications and personnel protection needs.

KEY AREAS FOR SCIENTIFIC UNDERPINNING

Properties of POCO sludges and slurries

Understanding the sources and behaviours of residual solids that exist as mixtures. Determining potential benefits of separating components. Understanding the effects of cleaning agents on behaviour.

Properties of radioactive sludge and slurries

Determining the effect of solid surfaces on radiolysis of slurries and in-situ measurements. Predicting and monitoring gas production. Understanding bulk uranium corrosion product sludges.

Release of airborne particles

Understanding of liquid aerosol generation from processes such as high-pressure water jetting, splashing and bubble bursts. Understanding solid particulate generation and disposition.

Abatement of aerial effluents

Assessing the effectiveness of abatement techniques such as filters and scrubbers. Determining how the effectiveness changes with particle size, distribution and air velocity.

Environmental Science

As the remediation efforts on the Sellafield site progress, there will be an increasing focus on environmental remediation. In particular, there will be heightened attention paid to the remediation of ageing structures and land quality management.

Radioactive liquor is known to have leaked to ground from a number of legacy plants associated with Magnox reprocessing and associated waste management. Sellafield Ltd is committed to carrying out a clean-up programme, which will carry out appropriate remediation and groundwater monitoring.

To achieve this, Sellafield Ltd need the best possible understanding of the long-term behaviour of radioactivity in the environment, and its potential impact on a changing natural environment.

KEY AREAS FOR SCIENTIFIC UNDERPINNING

Behaviour of contamination in the subsurface

Understanding of the geology, hydrology, hydrogeology and chemistry of the Sellafield site subsurface. Assessing the evolution of the Sellafield site through climate change scenarios and the impact of contaminant distribution. Understanding the chemical and biochemical processes in a range of materials such as concrete.

Locating and quantifying contamination in the environment

Developing in-situ or in-field groundwater monitoring technologies. Measuring higher activity zones and characterising the ground and subsurface.

Modelling and visualisation of contamination in the environment

Developing predictive modelling to understand the fate and impact of radionuclides in the environment.

Soil and groundwater remediation

Removing and packaging intermediate level waste, alpha contaminated soils and trench wastes. Fixing contamination in source zones and limiting migration in plumes.

Socio-economic modelling

Determining the social value of the Sellafield site and its associated infrastructure to the linked community. Addressing remedial and end points. Assessing land use and redevelopment plans.

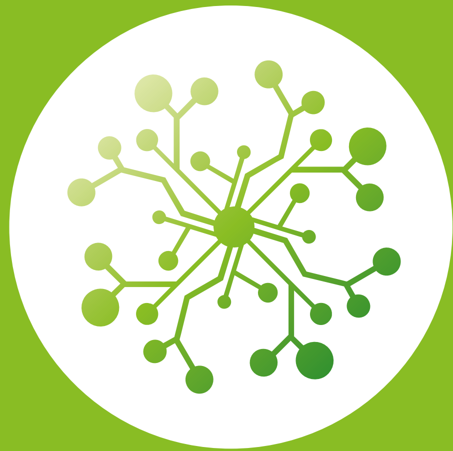
Contamination in facilities maintained in a long-term quiescent state

Maintaining some buildings in a quiescent state. Implementing asset care programmes.

On-site disposal of wastes

Developing mechanisms for the mobilisation and transport of key radioactive and non-radioactive species from managed disposal of wastes. Finding opportunities for the re-use of materials such as those used in construction.

Technology Development Themes



This section discusses the six key technology themes identified where R&D investment has the opportunity to reduce costs, improve safety and reduce timescales, alongside examples of opportunities for technology development. Each of the six technology themes mentioned below are managed by an Integrated Research Team (IRT) at Sellafield Ltd.

THE SIX TECHNOLOGY THEMES

Waste Treatment & Sustainability

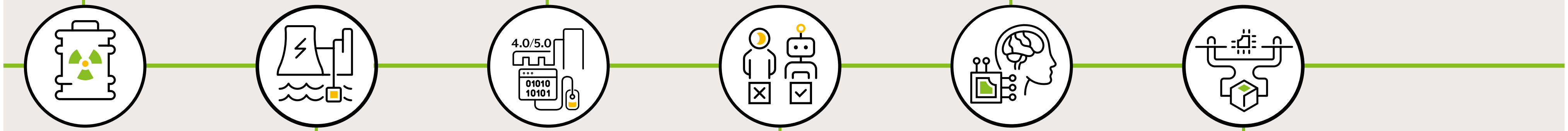
Waste immobilisation strategies, new cost-effective waste container options for decommissioning and sustainable technology development.

Digital & Data

Get greater benefits from all the data (including reports/videos etc) that are generated and explore the use of Industry 4.0 / Industry 5.0 technologies.

Artificial Intelligence

Making software and systems think like humans to enable them to carry out functions that are considered “smart”.



Measurement & Analysis

A range of measurement and deployment techniques to undertake analysis, detect signs of unexpected degradation and demonstrate control for extended storage periods.

Robotics

Broaden the use of robotics and autonomous systems, by building upon existing remote handling capability.

Manufacturing

Increased utilisation of novel manufacturing technologies and techniques that aid in the design and manufacturing of products.

Technology Work Breakdown Structure

A work breakdown structure has been developed for the six technology themes which shows the opportunities for technology development in each area.

Waste Treatment & Sustainability

- Sustainability and Carbon Management
- Alternative Encapsulants
- Other waste treatment and conditioning
- Package & store innovation

Measurement & Analysis

- Liquid Characterisation
- Particulate Characterisation
- Solid Characterisation
- Waste and Product Behaviour
- Waste and Product Package

Digital & Data

- Data Collection, Transfer and Storage
- Data Analysis, Visualisation, and Modelling
- Digital Technology
- Digitalisation of the Environment
- Communications

Robotics

- Waste Processing
- Restricted Access Decommissioning
- Aquatic Operations
- Autonomy
- Enabling Technologies

Artificial Intelligence

- Image/Video Analysis
- Virtual Assistants
- Predictive Analytics & Trends
- Machine Learning
- Natural Language Processing
- Large Language Models
- Generative Artificial Intelligence

Manufacturing

- Additive Manufacturing
- Coatings & Repair Methods
- Novel Manufacturing Techniques and Processes

Waste Treatment & Sustainability

There is a requirement for radioactive waste producers to convert waste into a passive and safe form as soon as reasonably practicable. For intermediate level wastes this has usually been achieved by encapsulation in a cement-based matrix. Ordinary Portland Cement (OPC) based encapsulants offer many advantages, such as robust products with well understood properties at a reasonable cost, and continue to be the baseline technology for a number of waste streams. However, developments in cement powder supply in response to a range of sustainability challenges present a threat to the long-term availability of current materials. Furthermore, OPCs have several disadvantages and are unlikely to be the optimal solution for all future waste immobilisation requirements.

Consequently, R&D is essential to deliver credible alternatives for encapsulation of all higher activity wastes. There are various insertion points for alternative treatment technologies into the technical baseline, depending on the retrievals timescale of each waste stream. These generally fall between 2025 and 2040. To support decisions on waste immobilisation strategies over this timescale, research is required on a range of options which have potential benefits over OPC based processes. These options include alternative low temperature processes, including geopolymers, polymers and novel inorganic cements.

Waste containers used for the disposal of waste are expensive, with current projections suggesting that over the lifetime of the Sellafield mission up to £4 billion will be spent on waste containers alone. Therefore, there is an opportunity to benefit from new manufacturing techniques in order to reduce the baseline costs. An R&D programme is required to provide an improved range of cost-effective waste container options that have been designed to facilitate decommissioning.

Supported by their sustainable technologies mission, Sellafield Ltd are also looking to develop alternative cement-based disposal container designs, which can be 'printed' on an as-required basis using a range of low carbon concrete mixes.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Sustainability

Developing sustainable technologies (e.g., sustainable concretes, concrete add mixes, alternatives to structural steel, energy recovery systems, energy efficient insulation solutions)

Encapsulants

Researching optimised mixing/deployment methods to develop a satisfactory product.

Other waste treatment

Treating or pre-treating wastes that are incompatible with current options.

Strength testing of concretene-enhanced concrete in materials lab

Spinionic technology which is a mobile effluent treatment system used to remove radioactive or other undesired species from wastewater or other aqueous solution

Thermal Treatment Case Study

Thermal treatment of legacy wastes could offer significant advantages running across the whole lifecycle of the waste, including:

- Volume reduction, leading to lifetime financial and carbon cost benefits.
- Breakdown of organics and some reactive waste constituents, leading to improved waste passivity.
- Improved waste product integrity leading to improved safety performance in storage and disposal facilities.
- May offer a treatment route for waste that currently cannot be treated.

Thermal treatment can be considered for a range of diverse wastes, from plutonium contaminated material and pumpable sludges to decommissioning solids. This leads to an array of potential technologies and wastes, all with associated technical challenges. Some of these challenges may be common across the thermal sector, whereas others will be more waste/technology specific.

In general, the operation of a thermal plant involves the import of waste, which may be via drums, or a pipe import system. For some wastes, this will be followed by a pre-treatment step which may involve the addition of glass forming chemicals, the blending of waste or the preheating of the waste. The thermal treatment could be either a batch or continuous process. Once treated, the final packages at the end of the process will range from 500 L drums to 3 m3 and 4 m3 boxes.

For the benefits of thermal treatment to be realised, all residual risks need to be identified, prioritised and addressed through a fit for purpose R&D plan. This will allow thermal treatment to reach parity with the technical maturity of other potential waste treatment options, such as encapsulation.

Additionally, undertaking R&D activities in university settings at the National Nuclear Laboratory (NNL) and within the supply chain will enable the UK to grow the breadth and depth of its skills. These skills will be necessary to fully realise the potential of an operational thermal plant.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Process

Demonstrating risks (e.g., flammable atmospheres, criticality, and corrosion) could be managed to the confidence required to fulfil safety case requirements. Understanding off-gas management needs to operate under UK regulations. Demonstrating the proposed process is insensitive to uncertainties. Determining the range of potential waste loadings from given sources. Ascertaining impacts of potential characteristics of problematic wastes. Understanding pre-sampling requirements and other operational controls.

Waste form

Understanding wasteform requirements for interim storage, transport and disposal in a future Geological Disposal Facility environment. Developing glass formulations that can increase waste loading and product quality.

Drum skid undergoing durability and structural integrity testing at high temperatures.

Close up showing drum structure failing during drum skid durability and structural integrity testing at high temperatures.

Product produced from Sellafield 2011 Geomelt Intermediate Level Waste Vitrification trials.

Measurement & Analysis

As the Sellafield mission evolves there is a fundamental change in the analytical demand on the central services function. This will result in a switch from the analysis of routine process samples to a greater proportion of characterisation of material that is more heterogeneous in nature, requiring one-off analysis or multiple analyses. This work will be labour intensive, expensive and time consuming.

Therefore, there is a significant benefit to be gained through improving how analytical information is generated. There is a driver to increase the efficiency of POCO and decommissioning decision-making through the implementation of real/near time in-situ data capture analysis for liquids, gases, particulates and solids. There are numerous different techniques which could be implemented if they can be successfully deployed.

Increased understanding of analytical requirements at source will aid decision-making on treatment options and sentencing to maximise correct application of the waste hierarchy. It is also probable that a different capability will be needed, with additional emphasis on non-radiological characterisation.

For many years both vitrified and encapsulated waste products have been stored on the Sellafield site and over the next decades, retrievals from legacy ponds and silos will generate many more waste products.

As the Sellafield site evolves into a waste management and remediation site, the range of package configurations is also expected to increase and a programme of inspection of their key properties will ensure safe storage. With many thousands of packages located in engineered stores, it would be impractical to extract and inspect all packages. Therefore, in-situ measurements are considered essential.

To address the site wide challenge of package and stores inspection, there is a need to provide a range of measurement and deployment techniques to demonstrate control and to take appropriate mitigating action where required. Additionally, there is the dose reduction to workers to consider. Using in-situ measurements can reduce dose to those who currently provide an ad-hoc condition monitoring and inspection capability.

Finally, there is also an additional driver to aggregate the many condition monitoring and inspection measurement techniques and deployment requirements to increase benefit and improve efficiency across the Sellafield site.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Liquid, Gas, Particulate and Solids Characterisation

Analysing isotopes such as tritium, strontium-90, alpha and beta contaminated liquids and hazardous compounds (e.g., asbestos, flammable and orphan solvents, hydrogen, helium).

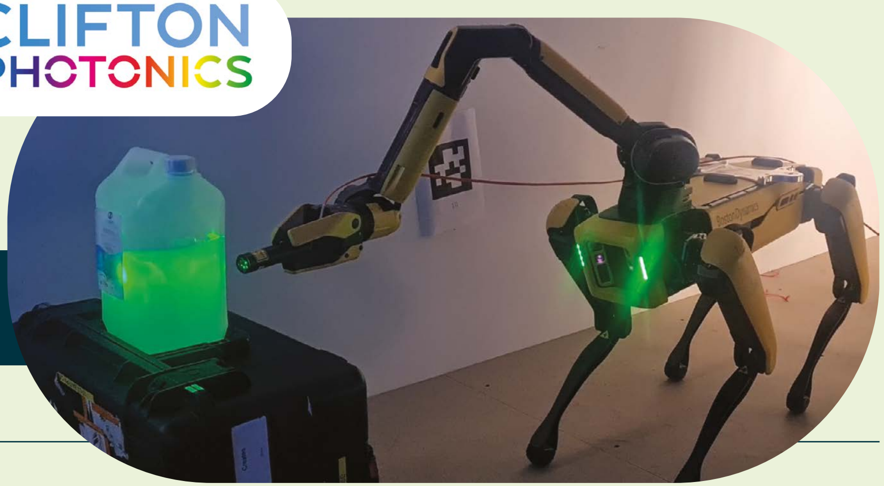
Waste and Product Behaviour

Enabling the detection of signs of unexpected degradation, including in-situ technologies requiring robotic/automated deployment.

Store Conditions

Increasing predictability by understanding how store environments can change under a range of likely scenarios. Monitoring to provide an early indication of deviation from the predicted environment. Understanding long-term optimum storage conditions for a range of products.

CLIFTON PHOTONICS



A Clifton Photonics fibre-optic Raman probe (532 nm), deployed by a Boston Dynamics Spot in an orphaned chemicals detection demonstration at the Sellafield Engineering CoE at Leconfield in December 2022, reproduced with the permission of Clifton Photonics Limited (c) 2023

Digital & Data

The Digital and Data IRT has developed in 2023 from the review of the Future Asset Management IRT, Protecting People IRT and the Data Science needs sheets. The focus of the IRT will look at how Sellafield can get greater benefits from all the data (including reports and videos) that is generated.

Sellafield Ltd would like to explore obtaining further value from their digital technology and data by exploring the use of Industry 4.0 and Industry 5.0 technologies. These technologies include immersive technology (e.g., Augmented Reality, Internet of Things), cloud computing, livestreaming, digitalisation of processes and improvements to the way operators access data. The IRT will explore how these technologies can be integrated together to bring greater value to Sellafield.

Adopting these approaches would enable Sellafield Ltd to optimise whole life operation and maintenance costs, as well as improving the performance of assets, productivity, and safety. This will increase stakeholder confidence and enable a more balanced view of the environmental impact of the facility and its operations.

There is a drive across Sellafield Ltd and various industries to adopt AI. Having high-quality data that is easily accessible, retrievable, and real-time is key to the success of these techniques. As part of this work, they will explore how a multi-disciplinary approach can improve the insights generated from data and information.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Data collection, transfer, and storage

Enabling timely and secure data transfer. Improving data collection, storage and accessibility. Improving data transfer to operators or maintainers for enhanced decision making. Facilitating traceability of packages or containers.

Data analysis, visualisation, and modelling

Providing real-time data to operators/maintainers for enhanced decision making. Modelling and visualising data. Using statistical methodologies to provide real-time cost, risk and performance data.

Digital Technology

Using digital technology to improve how training, operations and maintenance is carried out to make them more immersive to users.

Digitalisation of the environment

Improving planning pre-human entry and during tasks. Making decisions with 3D imaging and dose maps.

Communications

Transferring information in real-time to the operator and supervisor as the environment changes and the task progresses.

Personal Monitoring

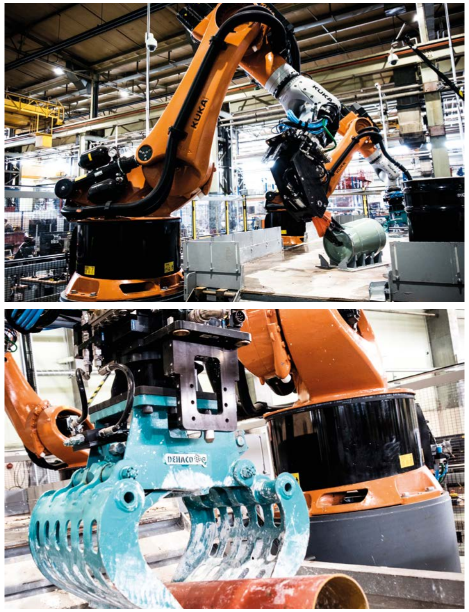
Developing techniques for real-time transfer of information to the supervisor on operator health.

Robotics

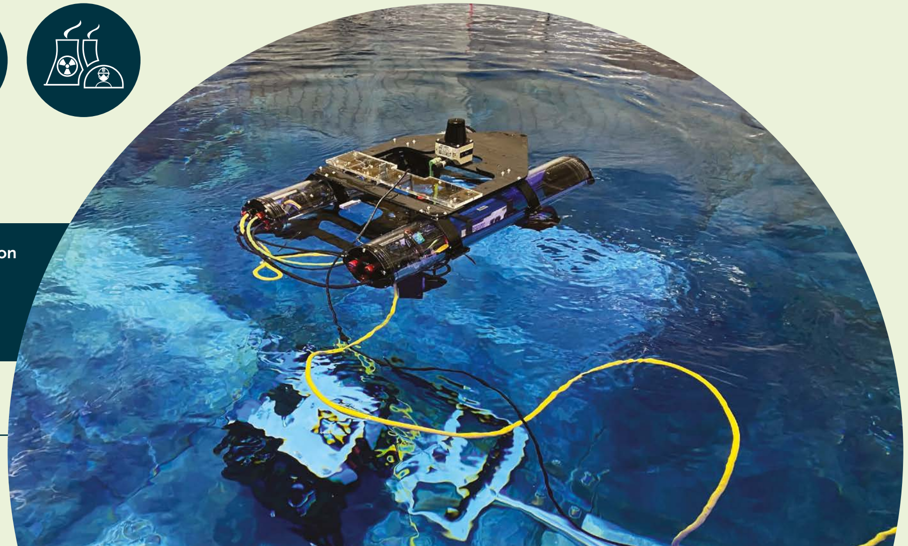
Microelectronics, data processing and robotic technologies, including autonomously operated systems, have all undergone rapid development over recent times, and will continue to do so. It has been driven by productivity and safety benefits across a range of industrial sectors, including agricultural, warehouse distribution centres, food and transport and by mass consumer markets in mobile phone, video gaming and the internet sectors.

The government, academia and industry have recognised that robotics are game changers in the way we live and work in our environment today. Increased utilisation of robotic technology has the potential to significantly increase the productivity of UK industry with resulting growth in the UK economy.

With Sellafield Ltd now embarking on a programme focused on decommissioning there is an opportunity to take advantage of these technologies to broaden its use of robotics and autonomous systems, by building upon existing remote handling capability, to increase safety for operators, improve productivity and reduce financial risk



CARMA the autonomous radiation surveying robot with alpha, beta and gamma detectors attached. Credit to Manchester University



The CORAL aquatic team. The underwater vehicle is performing an autonomous mission where the underwater vehicle is moving to predefined waypoints. The CORAL system uses only the two robots with no additional infrastructure installed around the pool.

Credit to Manchester University.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Waste processing

Developing capability for autonomous size reduction. Autonomously sorting and segregating 24 hours per day, 7 days per week. Increasing productivity with robotically enhanced waste packing.

Restricted access decommissioning

Introducing robotic capability for high hazard environments (e.g., remote devices for glove box operations).

Autonomy

Developing robotic techniques for autonomous repetitive tasks. Managing nuclear waste without operator intervention over the lifetime of the store.

Aquatic Operations

Operating in low visibility to retrieve material from ponds. Inspecting areas that are difficult to access with tether-less underwater systems.

Enabling technologies

Enhancing operatives with wearable technology. Carrying out hazardous tasks with robotic assistants. Using AI to aid in the decision-making process and complete characterisation coverage of facilities, digital environments, and autonomous sampling.

Artificial Intelligence

Artificial intelligence (AI) is the science of making software and systems think like humans to enable them to carry out functions that are considered “smart”. AI technology can process large amounts of data in ways unlike humans. The goal for AI is to be able to do things such as recognize patterns, detect anomalies, and make decisions like humans based on the data available in a more expedient and efficient way.

The Sellafield mission focuses on achieving lifetime value for money for the taxpayer, which means getting the right balance of investment in effectiveness and efficiency. Using AI allows Sellafield Ltd to gain maximum benefit from existing and new innovative data systems and create a more agile working environment for the estate.

For the lifespan of Sellafield, processes have had to be manual due to the type of information and plant systems sensitivity. Now with AI, Sellafield Ltd will be able to work more efficiently and could bring their mission end closer with the adoption of new tools and processes that will introduce automation, improve trending, and pattern identification. Also, Sellafield Ltd can improve their inspection capability with greater smart technologies that the workforce can work alongside in all aspects of the business from enterprise to plant systems.

Sellafield Ltd will gain significant benefits to the business by having real time data to analyse with the use of AI to help make critical decisions and allow the workforce to be able to solve key challenges. AI can also be used across the enterprise systems, by having a health data set that can be reviewed, analysed, and can support in document creation to make procedures run smoother. This would significantly reduce the potential for risk or downtime for operations as algorithms that support the decision-making detect and react quicker to change than humans can. Additionally, these tools have been proven to dramatically reduce any human error in linear processes.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Image/video and sensor analysis

Detecting anomalies in nuclear packages to help identify defects. Predicting lifetime of packages for the next 100 years. Identifying defects and growth of salt, corrosion and other factors managed long term. Utilising image analysis to detect vulnerabilities in civil engineering aspects of facilities.

Virtual assistants

Self-writing safety cases and Plant Modification Proposals. Helping with the substantiation of safety cases. Identifying how long a project will take to deploy based on the complexity of the task.

Predictive analysis

Reviewing the data from sources such as ATLAS (Analysing, Trending, Learning and Safety). Predicting trends that could cause issues in the future. Informing predictive maintenance and asset management for spares.

Machine learning and natural language

Tracking changes in processes and documents to automatically update the supporting documents. Supporting predictive text and dictation abilities using natural language tools. Introduction of services such as virtual assistance and chatbots.

Self-driving technologies

Utilising AI to drive both materials and the workforce around the site more safely. Introducing self-driving technologies to remove humans from harm in high hazard areas or while operating with hazardous material.

Robotics

Automating processes such as automated stores using a KUKA Mobile Robot. Increasing store productivity by speeding up processing, inspection, repackaging and manoeuvring of packages.

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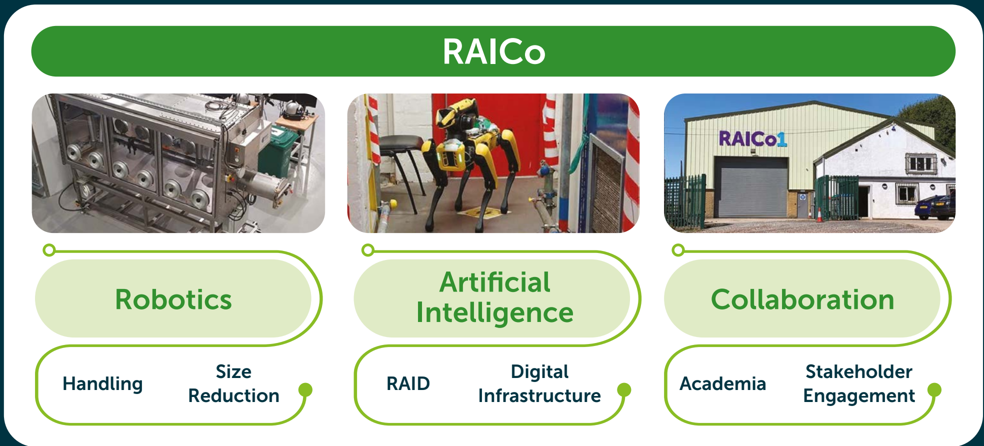
RAICo Case Study

The Robotics and Artificial Intelligence Collaboration (RAICo) is a collaboration programme set up by Sellafield Ltd, NDA, University of Manchester and the UK Atomic Energy Authority (UKAEA). The initial 3-year programme of technology development commenced in April 2022. It is focused on delivering and proving underlying robotics and AI technologies that are required for effective decommissioning, as well as providing deployment opportunities to have maximum operational impact.

Sited in Whitehaven, West Cumbria, RAICo1 is the first of a network of robotics and AI hubs across the UK. The facility will ultimately be used by Sellafield Ltd and NDA group, UKAEA, supply chain partners and academia to develop the technology needed to decommission Sellafield and other sites like it. Offering the ability to test technology in environments that mirror those on Sellafield and NDA sites, such as gloveboxes and water tanks, the facility removes some of the challenges associated with working on the nuclear sites.

The RAICo programme's strategic objectives are:

- Operationalisation of "this Generation" robotics into the nuclear sector.
- Developing remotely operated solutions for decommissioning and future fusion power.
- Developing intelligent customer and supply chain capability and capacity (viable innovation pipeline).
- Positive socio-economic impact in Cumbria (levelling up).



OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Handling, Autonomy and Control

Robotics to handle contaminated materials, enable adaptable and extensible teleoperation capabilities, reduce human intervention in hazardous areas by incorporating matured technologies into products for specific use cases, offering a testbed to assess and verify the technology developments, and de-risking robotics operations and AI integrated solutions.

Size Reduction

Size reduction tools with robotic deployment systems, size reduction harnessing quadruped robots, laser cut path planning / operator assistance, in gloveboxes utilising small robots, using Through Wall Manipulator in cells and laser ablation.

Robotics and Artificial Intelligence Data exploitation

Potential of using Building Information Modelling for nuclear decommissioning planning, deploying sensor-enhanced robotic platforms (e.g., quadrupeds, drones) for data collection and developing visualisation and inspection tools for nuclear decommissioning data.

Digital infrastructure

Digital software tools (such as Remote Handling Operations Virtual Reality for real-time 3D visualisation and simulation, and Order Management System for asset management and structured task planning) to support decision making and execution throughout the lifecycle.

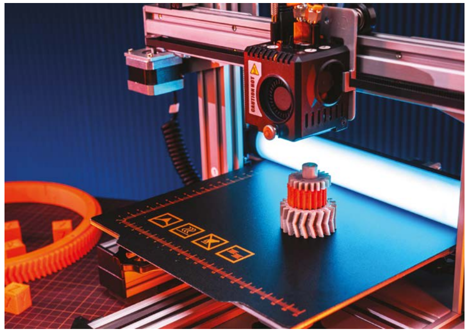
Academia

Academic research includes Continuous Autonomous Radiation Monitoring Assistant (CARMA) ground vehicle for autonomous health physics monitoring, underwater wireless optical communication system. Using robotics and AI in hazardous nuclear decommissioning environments will provide the step-change in capabilities needed to move towards a cheaper, faster, and less hazardous set of next generation decommissioning activities.

Manufacturing

As Sellafield Ltd continue retrievals from legacy facilities, and the repackaging of previously stored materials, its need for mass manufactured products, such as boxes and cans, will increase. Additionally, there is a growing number of spare parts which can no longer be obtained due to obsolescence.

The Manufacturing IRT looks to address these issues by working closely with Sellafield Ltd's manufactured products office, materials centre of expertise and engineering and maintenance teams. The R&D programme will look to de-risk activities and technologies, allowing for more novel and efficient technologies to be utilised for the products required on the Sellafield site.



Furthermore, by increasing the utilisation of novel manufacturing techniques, there is the opportunity to significantly increase productivity. This will ensure that Sellafield Ltd make the most out of every pound they get from the UK taxpayer.

OPPORTUNITIES FOR TECHNOLOGY DEVELOPMENT

Additive Manufacturing

Understanding additive manufacturing to improve performance in existing applications.

Coatings and Repair Methods

Increasing design life of products and components. Exploiting materials which have advantageous properties but poor manufacturability.

Novel Manufacturing Techniques and Processes

Utilise new technologies and processes that aid in the design and manufacturing of products.

Delivery

R&D programmes and projects that financially support technology development and underpinning science at Sellafield are funded by both Sellafield Ltd and a broad range of organisations. These organisations include the NNL, NDA, Small and Medium-sized Enterprises (SMEs) and the academic sector.

Sellafield Ltd has a long history working with NNL and in January 2017 a unique agreement was formalised between the two companies, whereby they pledged to work together to deliver value for the UK taxpayer. Since 2017, focus has been maintained on utilising science to protect and improve the environment. This relationship has continued to mature, encouraging investment in the skills and capabilities required to sustain technical knowledge, maintain facilities, and deliver high-quality solutions. As the Sellafield site drives forward its long-running decommissioning programme, it is in the public interest for the companies to continue to work closely together, ensuring that hazard reduction on the Sellafield site is delivered as safely and efficiently as possible by utilising innovative solutions.

Critical to the success of the delivery of R&D is integration and coordination of programmes to maximise efficiency, identify gaps and opportunities, and deliver value for money. This section describes the resources available to manage and deliver coordinated R&D programmes through research teams. These teams are drawn from the technical expertise, strengths, and experience available in the technical community. By clearly articulating the science and technology areas requiring investment, this document aims to encourage opportunities for dialogue and involvement in R&D from academia, the supply chain, and stakeholders.

Integrated Research Teams

The Science Integrated Research Team (sIRT) manages the underpinning science programme with an NNL coordinator for each individual topic area. Activities tend to be at the lower end of the Technology Readiness Level (TRL) scale and therefore, naturally fall within the academic environment and the scope of innovative companies.

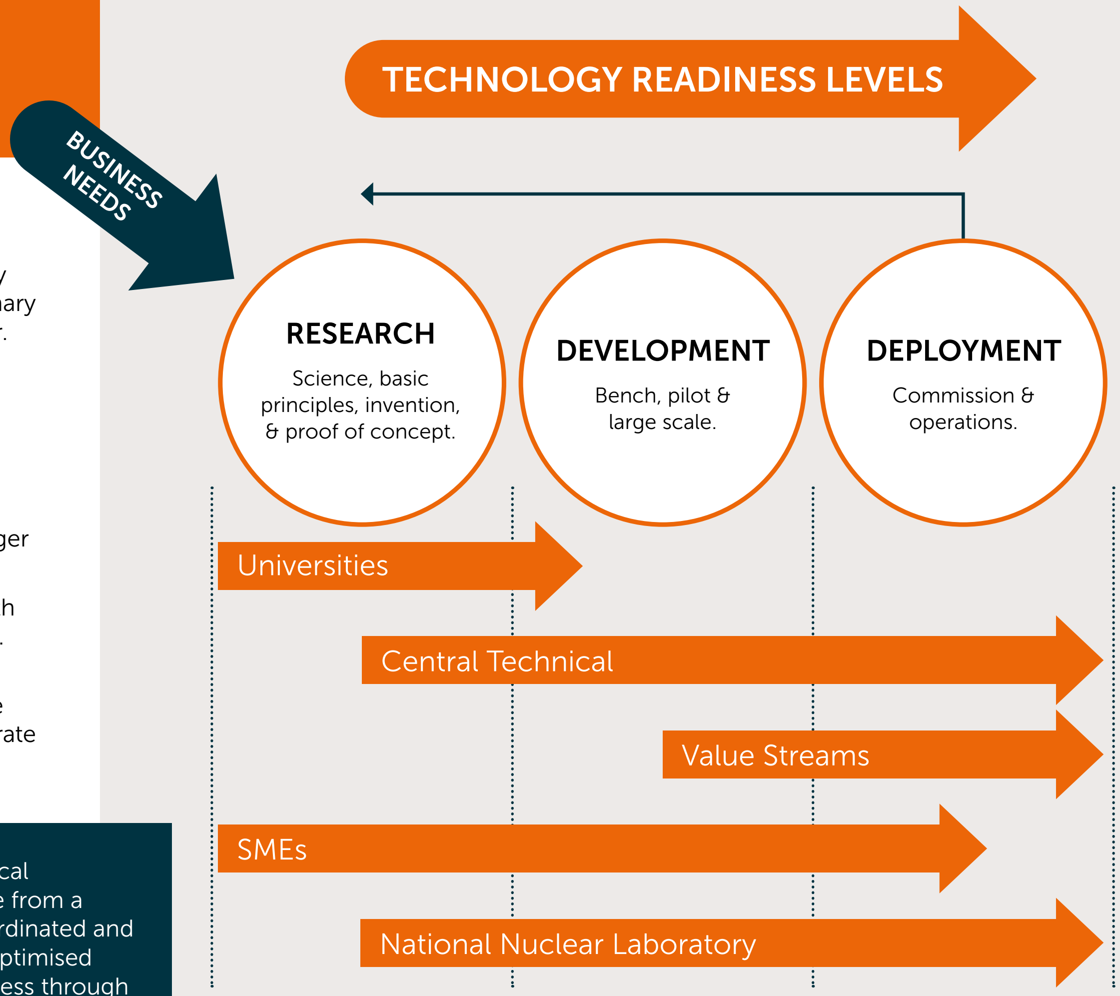
TRLs provide an indication of the readiness of a technology to be applied for a specific purpose, and are used to monitor technology readiness on projects. Sellafield Ltd has adopted the same TRL scale that is used widely across the NDA estate [1] .

Research needs are addressed by development programmes, which aim to bring forward technologies through the TRL scale. This takes them from fundamental research and early development, to laboratory and pilot scale, through to active demonstration.

Each technology theme is managed by an IRT which provides a multi-disciplinary approach with input from the end user. An IRT:

- Understands challenges and coordinates R&D.
- Delivers R&D which provides value across the enterprise.
- Is a space for more speculative longer term, high value R&D.
- Helps the value streams engage with the wider external R&D community.
- Finds technology in the supply chain that can be of use to the value streamsand helps them to demonstrate the value of this technology.

This approach draws on the technical expertise, strengths and experience from a variety of sources to provide a coordinated and well-balanced team to deliver an optimised programme. Techniques that progress through the TRL scale successfully are demonstrated in a suitable active environment on the Sellafield site, with the expectation that delivery teams on plant will assess final suitability and undertake selection.



Delivery Enablers

Interfaces and Stakeholder Engagement

There are a number of existing groups that are relevant to the research requirements for Sellafield, such as the Nuclear Waste and Decommissioning Research Forum (NWDRF). The NWDRF, and its various working groups, promote a common understanding and collaboration between relevant bodies across the UK about respective R&D requirements. Sellafield Ltd actively engage with these groups.

Sellafield Ltd have recently created the following groups which reflect the increasing appetite for the use of robotics on the Sellafield site, and which are engaged with to identify Robotics and Artificial Intelligence R&D opportunities.

These are:

- Central Robotics and Artificial Intelligence – a group aiming to support and manage consistent deployment of Robotics and Artificial Intelligence technologies across the Sellafield site through engagement with the value streams and enterprise organisations.
- Remote Handling Equipment Programme which manages the deployment and utilisation of equipment such as remotely operated vehicles and unmanned aerial vehicles.
- Engineering Design – responsible for ensuring new robotic systems and software are compatible and compliant with plant and infrastructure.

Funding opportunities

Funding for R&D is available from multiple sources, for example

- Sellafield Ltd
- National Nuclear Laboratory
- NDA Direct Research Portfolio
- UK Research and Innovation (UKRI) such as the Engineering and Physical Sciences Research Council (EPSRC) and Innovate UK

Sellafield Ltd has been involved in coordinated research programmes involving multiple universities that have attracted funding from other parts of the nuclear industry and the EPSRC.

ADDITIONAL ENABLING FUNCTIONS

There are several supporting functions and systems in place to identify the requirements and their R&D programmes:

Science and technology needs sheets

These contain the detail for each topic on the work breakdown structures on pages 7 and 13. They are live documents to allow the value streams to flexibly influence the medium to long term research programmes and are reviewed periodically to ensure that the plan remains focused, and any emerging needs are captured.

The science and technology needs sheets are stored centrally within the Sellafield management system, and they can be obtained by contacting: **technical.innovation@sellafieldsites.com**

Task sheets are prepared in response to the research needs.

Technical baseline

It is a site licence requirement to demonstrate visibility and transparency of the technical baseline to the NDA and a number of key pieces of information are required, including R&D tables which detail plans to resolve technical issues. The software system used for this also captures the detailed R&D tasks that are generated from the research needs.

Knowledge, skills and experience

These play a vital role in the efficient delivery of R&D. As part of the transformation process, Sellafield Ltd has a project in place to ensure that the resources and capabilities are available to respond to the changing site requirements and a further initiative is addressing the site wide information and knowledge management requirement.

Game Changers, The Challenge Portal and Horizon scanning

The Game Changers Programme, The Challenge Portal and Horizon Scanning initiative enables innovation development and collaboration. These are discussed in more detail on the next page.

Game Changers

Game Changers is the UK's leading nuclear innovation programme, finding solutions and developing technologies to overcome some of the most complex challenges facing the nuclear industry. Game Changers provides a platform to connect challenge owners to solution providers. The challenges are open to anyone from any sector who can offer a viable solution including SMEs, universities, research organisations and large companies.

Ideas are submitted through a simple application process and the best projects are selected for funding.

Challenge Portal

The Challenge Portal is a single centralised repository for challenges and opportunities which helps to encourage innovation collaboration across Sellafield and to avoid duplication of effort.

The Challenge Portal can be used by any Site Licence Company employee who has a challenge and needs to find a solution.

Challenges are submitted via a simple online form. They're then evaluated by a panel of relevant stakeholders within Sellafield who will suggest appropriate mechanisms for solving the challenge or addressing the opportunity. There are a variety of internal and external routes to solutions. The outcome of the panel review is communicated to challenge owners who are then guided towards solution routes by a team of innovation experts. Visit **www.thechallengeportal.com** for further information.

Horizon Scanning

Central Technical manages a horizon scanning initiative which seeks to gain early insight into new science and technologies that could have substantial benefits to delivering the Sellafield mission. This extends to trends in new areas such as digital, automation and new materials. Further information can be obtained from: **technical.innovation@sellafieldsites.com**

OPPORTUNITIES TO ENGAGE

To engage with innovation at Sellafield, email (technical.innovation@sellafieldsites.com)

If you have an idea, there are a number of ways of engaging:

01 Game Changers, Sellafield issue a number of innovation calls and are open to other offers via www.gamechangers.technology

02 Knowledge Transfer Network (KTN), Sellafield sometimes work with the KTN iX to publish challenges www.iuk.ktn-uk.org/programme/innovation-exchange/

03 For other routes check 'How to do business with Sellafield' www.gov.uk/guidance/how-to-do-business-with-sellafield-ltd

Sellafield Ltd works with others across the oneNDA estate and other sectors via, such as, I3P. www.i3p.org.uk

Abbreviations, Acronyms and References

AI................**Artificial Intelligence**

CARMA.......**Continuous Autonomous Radiation Monitoring Assistant**

EPSRC........**Engineering and Physical Sciences Research Council**

IRT..............**Integrated Research Team**

KTN............**Knowledge Transfer Network**

NDA............**Nuclear Decommissioning Authority**

NNL............**National Nuclear Laboratory**

NWDRF......**Nuclear Waste and Decommissioning Research Forum**

OPC............**Ordinary Portland Cement**

POCO.........**Post Operational Clean Out**

R&D............**Research and Development**

RAICo.........**Robotics and Artificial Intelligence Collaboration**

sIRT............**Science Integrated Research Team**

SME............**Small and Medium-sized Enterprise**

TRL.............**Technology Readiness Level**

UKAEA........**United Kingdom Atomic Energy Authority**

RAID...........**Robotics and Artificial Intelligence Data**

References:

[1] - Technical Baseline and underpinning Research and Development Requirements, Version 8, October 2019. Available at:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/842927/EGG10_Technical_Baseline_and_underpinning_research_and_development_requirements_Rev8.pdf

Sellafield Ltd

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